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[Research]

Exploring Gördes zeolite sites by feature oriented principle component analysis of LANDSAT images

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ABSTRACT

Recent studies showed that remote sensing is an effective, efficient and reliable technique used in almost all the areas of earth sciences. Remote sensing as being a technique started with aerial photographs and then developed employing the multi-spectral satellite images. Nowadays, it benefits from hyper-spectral, RADAR and LIDAR data as well. This potential has widen its applicability in the various areas and professional disciplines much more efficiently as never been before. One of the areas that remote sensing has been applied well and has become one of the indispensable tools for the earth science's scientists are geologic and mineral exploration studies and especially prospection stages of these studies. In this research, it was tried to determine and to map zeolite sites in Gördes region (Turkey) which were formed as alteration products having high level of water content and developed in volcanic rock beds by the help of remote sensing and GIS. The study area is about 400 km^2 and located at the North-East of Manisa Province. The results confirmed that the zeolite areas obtained by classical exploration techniques can be determined using remote sensing techniques such as feature oriented principal component analysis. Other zeolite areas in the same scene were also determined or at least predicted by this computer learning process through the same remote sensing image analyses.

Key words: Zeolite, Feature Oriented Principal Component Analysis, Landsat images, Gordes.

INTRODUCTION

As known, objects reflect, observe and transfer electromagnetic wavelengths in different amount reaching to their surfaces due to their different spatial, structural and surface conditions with respect to one another. Contrary to other and classical techniques, remote sensing as a sole technique which is used for the determination and discrimination of natural resources and mapping their distribution on land without being on the site, uses generally reflected parts of these wavelengths by each special object or phenomenon in interest (Sabins 1999, Corumluoglu *et al.* 2015). Except these reflected Parts of electromagnetic wavelengths sent by sun to the earth, RS mainly utilizes returned part of a certain wavelengths in the microwave region produced followed by sending to RS sensors themselves and also thermal wavelengths radiated by objects on the ground (Drury 2001). These radiations can only be obtained or acquired by specially designed sensors mounted on carrying platforms. Data acquired in such ways were analyzed and processed in computers and used to produce maps of timely changes, attributes and specifications of features on an interested part of the earth. Remote sensing is a cost effective technique used in such kinds of applications when it is compared with others, it is also capable of determination of alteration areas and structural and lithological features from the space that they can never be determined while being on the earth. It then becomes so crucial data source for such resource areas with no data and no work done yet. Remote sensing makes a serious contribution to earth sciences and especially to geology by developed algorithms and methods especially for producing lithology and mineralogy maps, for determining the effect of natural disasters like floods, landslides and earthquakes and petrol leakages, for supporting coastal, change detection, structural geology and hydrology studies and exploration studies of mineral deposits, raw material resources for industry and energy (Sabins 1999). It is also currently used in the active fault studies and found as a useful tool for such studies (Tangestani & Moore 2001). Movements and some other specific parameters related to the active faults in interest can be determined and monitored very precisely by the help of images and other data from sensors mounted on satellite platforms sent to the space. Thus, it is worth to underline that RS has found wide application areas in the earth sciences, especially in geology as long as the new techniques emerge.

The use of remote sensing in mineral and raw material exploration studies

Remote sensing is exploited for mapping of geologic structures and faults where these places show up as the source of mineral deposits and other raw materials in high probability. Multi-spectral and now currently the usage of hyper-spectral images are utilized to delineate the spectral curve of any specific mineral and thus to determine rock beds which are rich in that specific minerals.

Rocks and their minerals have unique reflection values for each individual electromagnetic wavelength.

Curve formed by the reflection values of electromagnetic wavelengths reflected by each mineral or rock is called as characteristic curve of that individual mineral or rock (Sabins 1999). Rocks or minerals interact with the electromagnetic energy wavelengths in three ways when electromagnetic radiations in several wavelengths reach to their surface. So, they reflect, observe or transfer these wavelengths in different amounts.

As mentioned above, these reflected parts of incoming wavelengths delineate the curve and then characteristic parts of this curve of the individual mineral or rock help us to make our decisions on which images of wavelengths should be chosen for the determination of those minerals or the raw materials locations on earth through remote sensing image analysis. The wall rocks which are host for raw materials and mineral deposits show final products changing the chemical structure of the rock and causing settling down of ore and hydrothermal minerals in the rock as a result of hydrothermal fluid interaction with wall rock (Ruiz-Armenta & Prol-Ledesma 1998). Thus, it is known that all porphyry types of ore deposits show finely developed zones and those zones can be determined confidently by following concentration diversities of main oxides and trace elements in the zones. This elemental composition appears as a change in mineral composition of alteration zones. Secondary alterations developed in surface conditions are almost the main actor of characteristic yellowish and dark brownish and reddish colors in the altered rocks.

Those alteration products can easily be determined by RS.

Before processing remote sensing images, images are corrected for atmospheric noises by filtering and for geometrical errors. Following that corrections, some image enhancement techniques are applied to improve the visual quality of images such as contrast stretching, filtering and color composite techniques. In the final stage of image processing that can be called as information extraction stage, the techniques such as image rationing, principal component analysis (PCA) and image classification are applied to the corrected and enhanced images of remote sensing image scene.

In mineral exploration studies, various types of remote sensing images and scenes might be utilized to fulfill the study oriented requirements. Landsat scenes are the broadly used one among them. Since those scenes cover large areas, they are successful and useful for the determination and identification of regionally large objects and structures on earth. Landsat data for almost 20-30 years have been used to locate mineral deposits having iron-oxide and hydroxide origins encountered in the hydrothermally altered zones of ore deposits and in the region where arid and semi-arid climates are dominant (Abrams *et al.* 1983; Kaufman 1988; Tangestani & Moore 2001). Therefore, RS has been used especially for the determination of hydrothermally altered zones. It is known that rocky areas and soil appear in dark gray color in band 7 (2.08 -2.35 µm), since they absorb the captured wavelengths in the band.

They also appear as bright areas in band 5 (1.55 -1.75 µm), since they highly reflect the wavelengths of band 5. Furthermore, soil and rocks appear more clearly in the ratio images of these bands. Similarly, 7/1 band ratio image is preferred for the determination of hydroxide alteration zones, 5/7 ratio for clay zones and 3/2 ratio for iron-oxide alterations (Sabins 1997, 1999; Drury 2001). Thus, one can easily come to such a conclusion that 1, 3, 5 & 7 bands of LANDSAT 7 ETM+ can confidently be employed in geological studies. It is also known that RGB 731, RGB 754, RGB 753 & RGB 531 band combination images are very useful for geologic studies. Especially subset image of the study area from band 531 (RGB) combination image gives the best result image showing the boundary and texture of schist in the region.

Geological features of the study area

The study area covers the part of approximately 400 km^2 which are rich in zeolite occurrences in volcanics appeared on the land surface and located at Gördes and its near vicinity, where it is in the North-East of Manisa Province (Fig. 1).

When the study area geologically evaluated, metamorphic rocks belonged to Menderes massif which consist of gneiss, migmatites, mica-schist and quartzite, stratigraphically basement rocks.

Metamorphic rocks are unconformably overlain by Kürtköy formation which commonly consists of tufa, large conglomerates, conglomerate and sandstone. This unit is overlain by Yeniköy formation which consists of conglomerate, sandstone and algal limestone and sandstone containing lignite and lignite. Çıtak formation consisting limestone, shale, mudstone, sandstone, tuff and bituminous shale is situated on Yeniköy formastion (Göktaş, 1996) & riyolitic Gökyar tuff & Azimdağ volcanics pass upward respectively (Ercan 1983). Azimdağı volcanics are characterized by dasite, riyodasite, and riyolitic lava domes. On the Azimdağ volcanic, Tekkedere formation consisting carbonaceous shale at the bottom and limestone in upper part is situated. Balçıkdere member consisting of lacustrine limestone which belongs to Kepez formation is situated to on Tekkedere formation.

Alluviums are commonly observed in stream insides (Figs. 1-2). Depending on diagenesis and alteration, zeolite minerals occurred in different levels of volcanics in the area. These minerals occur under low temperature and pressure hydrothermal alteration conditions. In the process, minerals in feldspar mineral bearing rocks are replaced by zeolite group minerals. Generally, alkaline extrusive rocks partly or completely are transformed to zeolite group minerals. Zeolite group minerals in the area are clinoptilolite [$(Na, K, Ca)_2$-$3Al_3(Al,Si)_2Si_{13}O_{36} \cdot 12H_2O$.] and heuylandite [$(Ca,Na)_2$ - $3A_{13}(Al,Si)_2\ Si_{13}O_{36} \cdot 12H_2O$] types (Vural & Albayrak 2005). Zeolite minerals as industrial raw materials find several places in industrial production chains, especially they are used in the light concrete production processes, agricultural activities and as additive to cement. Therefore, it is a raw material which has a high commercial value.

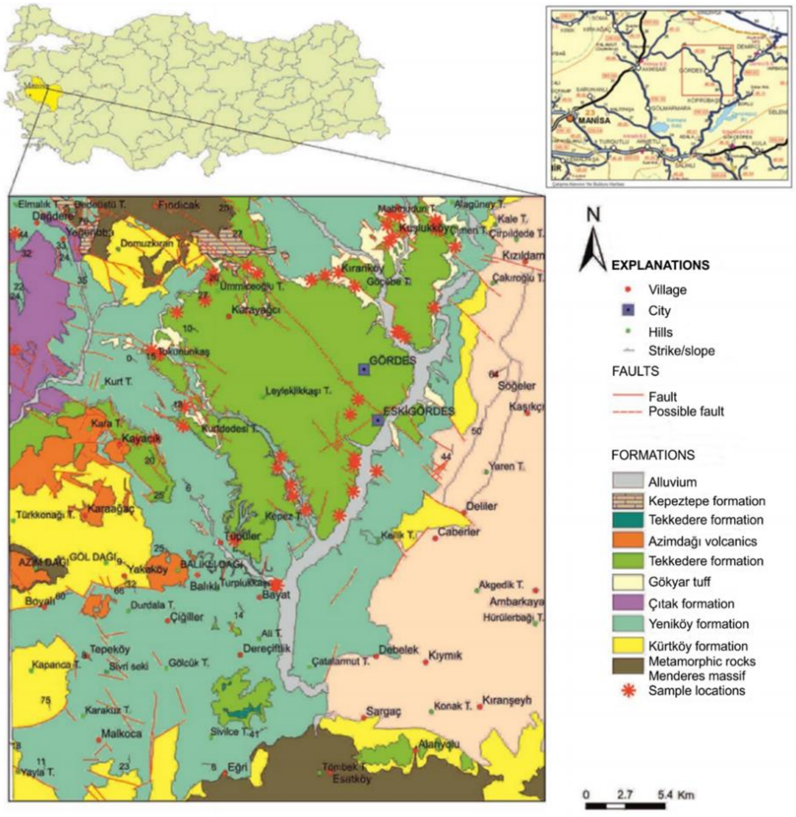

Fig. 1. Geology of the study area.

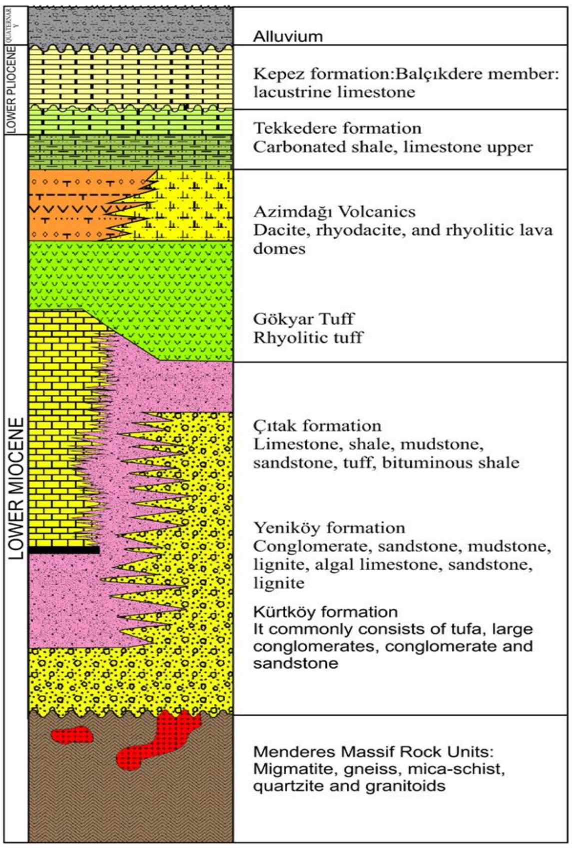

Fig. 2. Geological colon profile of Gördes and its close vicinity (taken from Göktaş 1996).

Usage of remote sensing techniques for determination of zeolite group minerals

When checking up the remote sensing studies on exploration of mineral and raw material deposits through the literature, it is found that general usage of satellite images is for the production of alteration maps using remote sensing techniques such as band rationing, supervised and unsupervised classification, and PCA (Abrams *et al.* 1983; Kaufman 1988; Loughlin 1991; Bennett *et al.* 1993; Tangestani & Moore 2001; Ranjbar 2002; Aydal *et al.* 2004, 2006a,b, 2007a,b; Vural *et al.* 2011, 2012; Corumluoglu *et al.* 2015). Among these image analysis and information extraction techniques, feature oriented PCA technique suggested by Crosta & Moore (1989) and called Crosta technique gives reasonable and fine results). Feature oriented PCA technique is then chosen as remote sensing image analysis technique in order to determine the zeolites which were developed as alterations of volcanic rocks since feldspar minerals in volcanic rocks of the study area turned into zeolite minerals by taking full amount of water in their structures. Analysis of eigenvector values in this technique assures the description of principal components having high radiometric contribution from the interested materials appeared in the original spectral bands and carrying spectral information of certain minerals. This technique depends on that the interested material or mineral appears as dark or bright pixels in the images of PCA according to the positive and negative eigenvector loads of these raw materials or minerals. As feature oriented PCA technique is one of the important image enrichment technique, it is confidentially used for the identification of ore and mineral deposit areas where are rich in iron and having hydrothermal alteration zones. When the technique is applied to images of a Landsat scene, 6 or 4 bands are used. In the use of 6 bands, the Landsat band images capturing reflected radiations are exploited except thermal bands. On the other hand, Crosta & Moore (1989) suggests a selection of 4 bands with respect to the strong and distinguishable appearance of raw material and mineral of interest in those 4 images (Ruiz-Armenta & Prol-Ledesma 1998). Since this study focuses on zeolites, it is crucial to locate hydroxide and iron-oxide zones. Therefore a set of 4 bands including bands of 5 and 7 that emphasize hydroxide and another set of 4 bands including bands of 1 and 3 emphasizing iron-oxide are suggested to be chosen. After PCA of these two sets, principal components from each sets showing highest opposite loads in + & – signs and thus a largest eigen value difference with respect to one another are used to make up final RGB composite image (Crosta & More 1989; Loughlin 1991; Tangestani & Moore 2000). To follow this procedure, two sets with 4 images were formed from 6 bands out of 8 in the Landsat scene. The obtained Landsat scene covering the study area was the Landsat 7 ETM+ scene of path 180 and row 33 acquired on 20th August 2006. This scene with bands 2, 4, & 3 assigned to RGB colors respectively can be seen as subset covering the study area in Fig. 3.

As mentioned above, both image sets include only 4 images among 6 reflection bands of the Landsat scene. The first set consists of 1st, 4th, 5th & 7th bands and the second one with 1st, 3rd, 4th & 5th bands. Following PCA of these both sets, statistics and covariance eigenvector values are generally revised to find out principal components of both sets that are showing highest differences between eigen values of both PCA individually and highest opposite loads from bands 5 & 7 in the first set and from bands 1 & 3 in the second set.

After this revision in this study, 4th principal components from both sets were found as the most appropriate principal components having highest eigen-value differences with highest opposite loads (Tables 1-2).

The second and third bands were not used intentionally to suppress iron oxide in the first set consisting of 1st, 4th, 5th & 7th bands.

Thus, PC4 came out as the PC with highest negative eigenvector load from band 7 and positive highest load from band 5, as shown in Table 1.

This PC is the principal component emphasizing hydroxide and therefore called as

"H component", while hydroxide minerals are shown as bright pixels after multiplying each pixel in the PC4 image by -1 (Fig. 4).

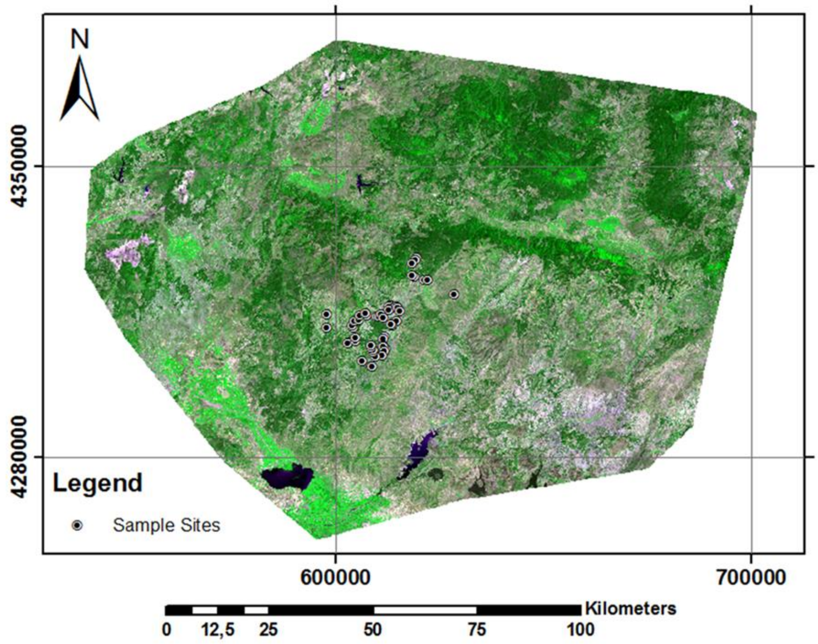

Fig. 3. LANDSAT RGB combination scene of bands respectively 2, 4 and 3 (covering sample sites).

Table 1. PC4 of 1st, 4th, 5th and 7th bands as the PC with maximum opposite load from bands 5 and 7 (for Hydroxide).

BAND 1-4-5-7				
	PC1	**PC2**	**PC3**	**PC4**
BAND 1	0.43322569	0.60685175	-0.64540360	-0.16583317
BAND 4	0.37486014	0.54516373	0.68702066	0.30046463
BAND 5	0.66248766	-0.40332686	0.21769600	-0.59249134
BAND 7	0.48260281	-0.41455386	-0.25311115	0.72881710
BAND 7-BAND 5	0.17988485	0.01122700	0.47080716	-1.32130845

Table 2. PC4 of 1st, 3th, 4th & 5th bands as the PC with maximum opposite load from bands 1 and 3 (for Ferrite oxide).

BAND 1-3-4-5				
	PC1	**PC2**	**PC3**	**PC4**
BAND 1	0.42930710	-0.60221319	-0.19080680	0.64546685
BAND 3	0.52044091	-0.00597796	-0.65663405	-0.54583628
BAND 4	0.36820298	-0.44312847	0.67680263	-0.45825966
BAND 5	0.63973685	0.66403365	0.27269523	0.27465138
BAND 1-BAND 3	0.09113381	0.59623524	-0.46582725	-1.19130313

As in the first set, in the second set consisting of 1st, 3rd, 4th & 5th bands, similar result was also obtained. Thus, as shown in Table 2, 4th principal component (PC4) came out as the PC with highest negative eigenvector load from band 1, while positive highest load from band 3. This PC is the principal component emphasizing ferrite-oxide, called as "F component" and ferrite-oxide minerals are shown as bright pixels after multiplying each pixel in the PC4 image by -1 (Fig. 5). On the next step of the image processing procedure, final PCA took place. The images put into this final analysis were those obtained on the previous step, H & F component images only. After PCA of these two images, two principal component images, PC1 & PC2 were derived. Eigenvector values of PC1 & PC2 were revised to find out which component gave the highest opposite load from these two PC4 images. It was PC1 (Fig. 6).

Thus, PC1 produced by this final PCA was added into an image stack together with these H & F components to form final RGB composite image.

It is better to pay attention while forming this final composite, thus to get a fine visual interpretation.

So that, -PC4 as H component is suggested to be assigned to Red color (R) in the false color composite, -PC4 as F component to Green color (G) and PC1 from PCA of both PC4 images to Blue color (B), as shown in Fig. 7.

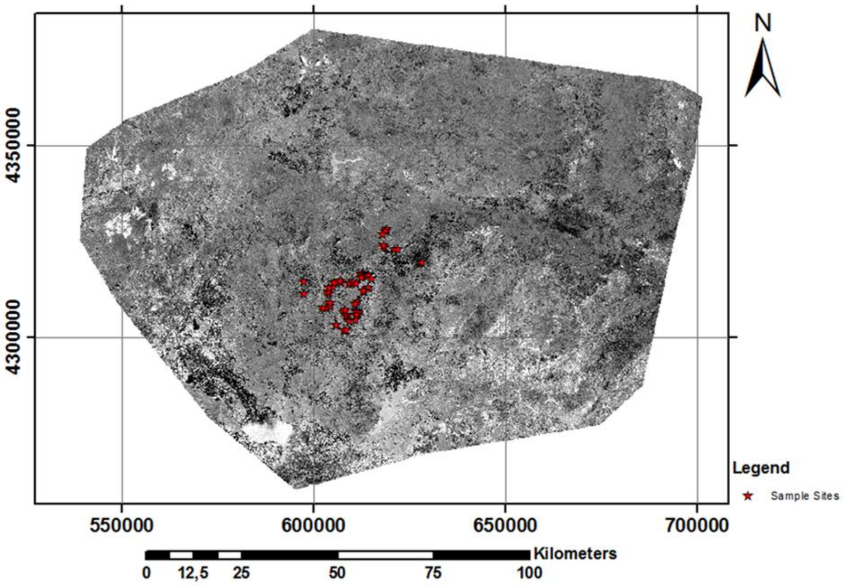

Fig. 4. Negative PC4 image of 1st, 4th, 5th and 7th bands for Hydroxide (as H component).

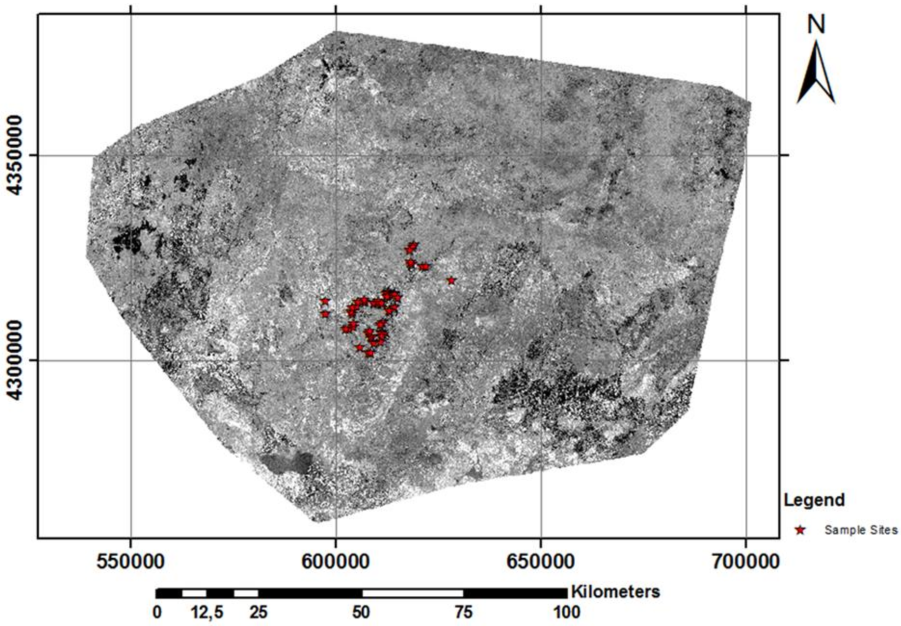

Fig. 5. Negative PC4 image of 1st, 3rd, 4th and 5th bands for Ferrite-oxide (as F component).

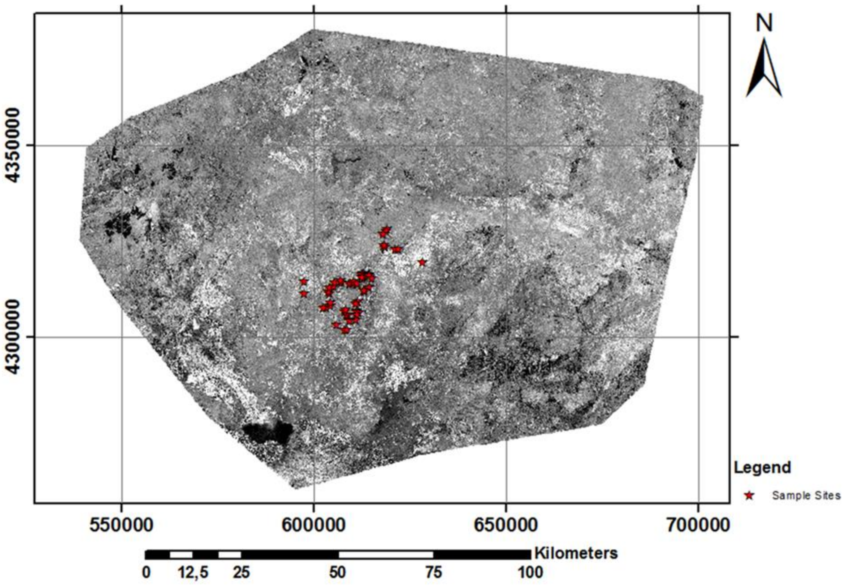

Fig. 6. PC1 from PCA of both PC4 images (H and F components).

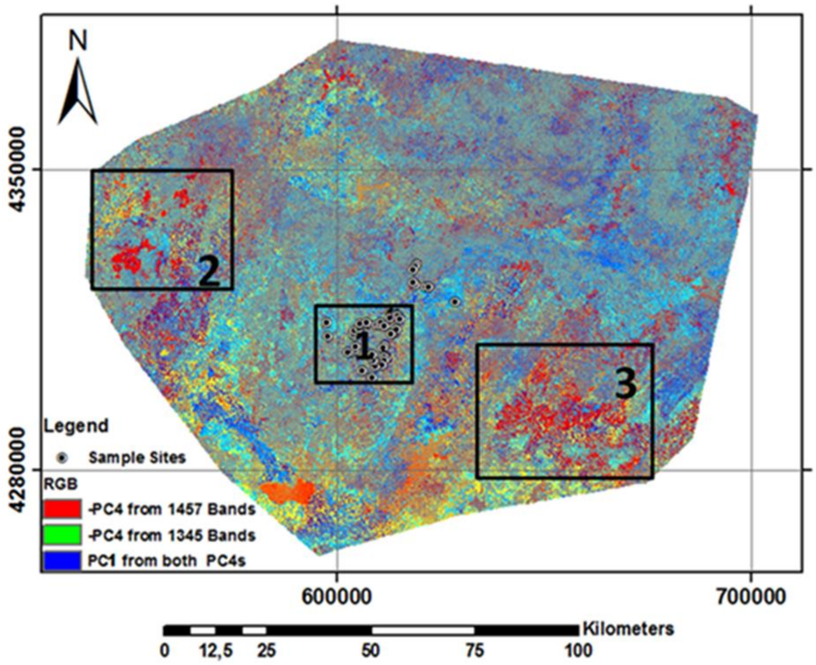

Fig. 7. Final false color composite image consisting of -PC4 from PCA of 1st, 4th, 5th and 7th bands (R), -PC4 from PCA of 1st, 3rd, 4th and 5th bands (G) and PC1 from PCA of both PC4 images (B).

In the present study, a sample data set collected by Vural & Albayrak (2005) was used for the verification of zeolite locations found by feature oriented Principal Component analysis in the way how Crosta & Moore (1989) suggested in their study. The sample locations can be seen in Fig. 7 as well. The sample data also fit into locations appearing especially as red colors in the image. Hydroxides show up as bright red pixels and iron-oxides as bright green pixels as represented in the Fig. 7. The

Locations overlapping with the sample data can be grouped as sample sites shown as region 1 within black rectangle in Fig. 7. Two other regions numbered as 2 & 3 in Fig. 7 were also found as possible zeolite sites that show the same spectral attributes with respect to those sample sites. Therefore, these locations appeared in red color as sample sites in Fig. 7. Later field check also confirmed the finding. Zeolite sample site fall in red colored locations in Fig. 7 can clearly be seen in Fig. 8 which is enlarged presentation of the sample sites, region 1. Fig. 9 shows enlarged images of possible zeolite sites found and appeared in red colors same as those sample sites.

After all, a supervised image classification was also performed to determine the other zeolite sites automatically showing the same spectral specifications as those at sample sites. General outcome of this supervised classification can be seen in Fig. 10, while detailed visualizations of sample sites and also 2nd & 3rd regions showing the zeolite locations at possible zeolite sites found after final PCA are also demonstrated in Fig. 11. Fig. 12 shows the stereo visualization of whole study area to see all three zeolite sites altogether in 3D view. Image in the Fig. includes only zeolite sites automatically found after supervised classification in red and with no other classified features, exhibiting those zeolite sites as superimposed red locations over Landsat original bands of 2, 4 & 3 as RGB composite in 3D.

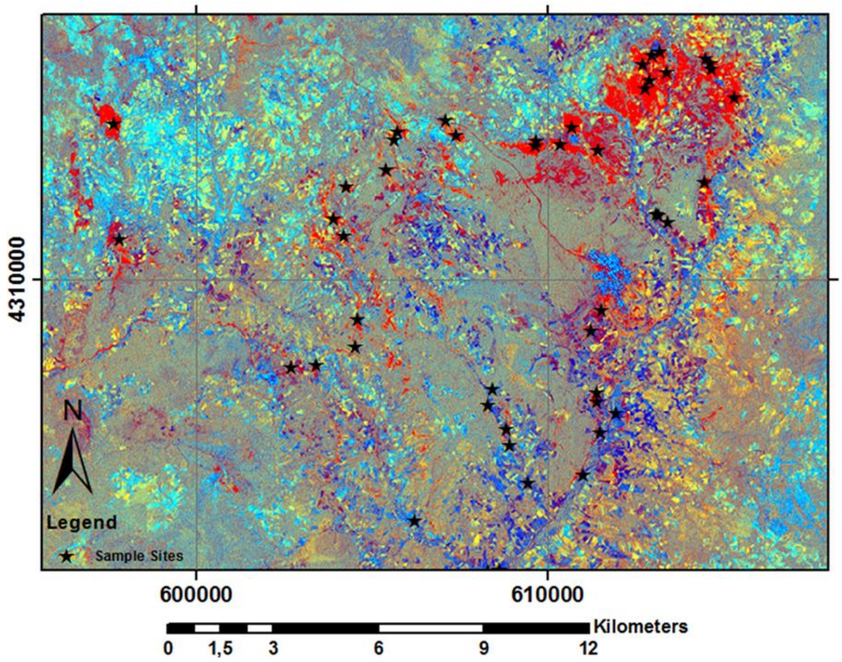

Fig.8. Sample sites shown over composite image of H and F components and PC1 from PCA of H and F components and fall in red colored areas.

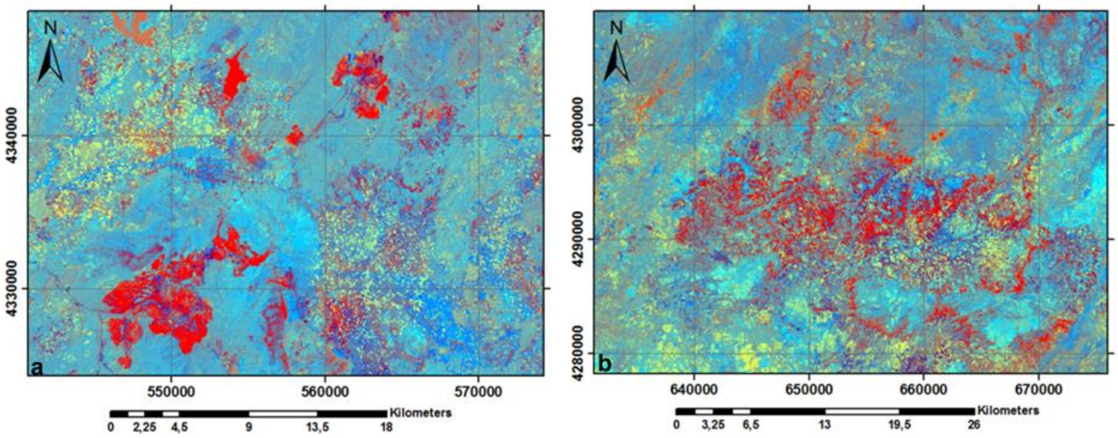

Fig. 9. Found zeolite sites and numbered as 2nd (a) and 3rd (b) in Fig. 7.

Since hydroxides and iron-oxides densely developed in the field and feldspar minerals in volcanic rocks transformed into zeolites as hydro minerals due to hydrothermal alterations, here in this study it has been being proved and shown that alterations therefore zeolites are determined apparently well by using feature of oriented PCA technique on the remote sensing multi spectral images, followed by the procedure suggested by Crosta.

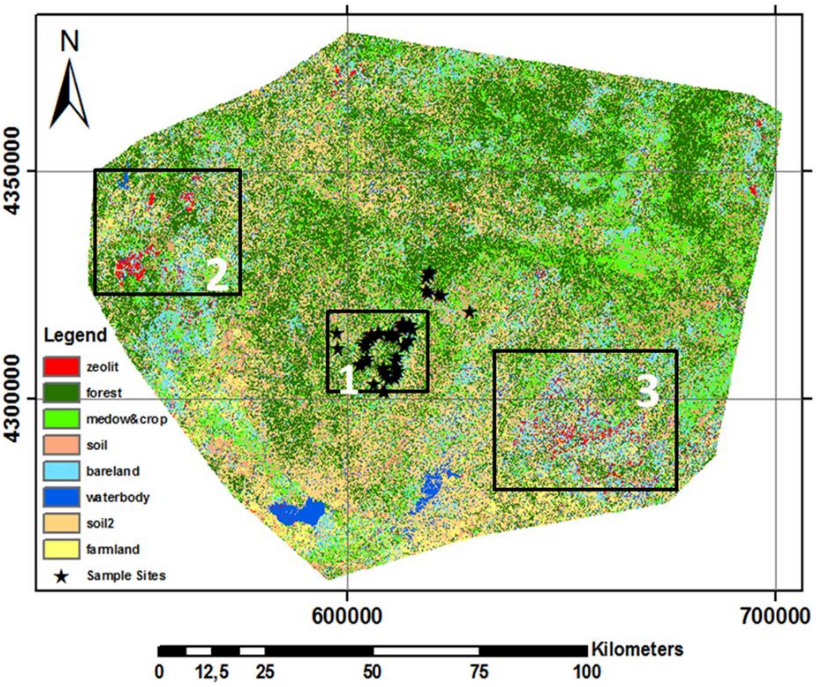

Fig. 10. General distribution of zeolites found after supervised classification over final PCA scene.

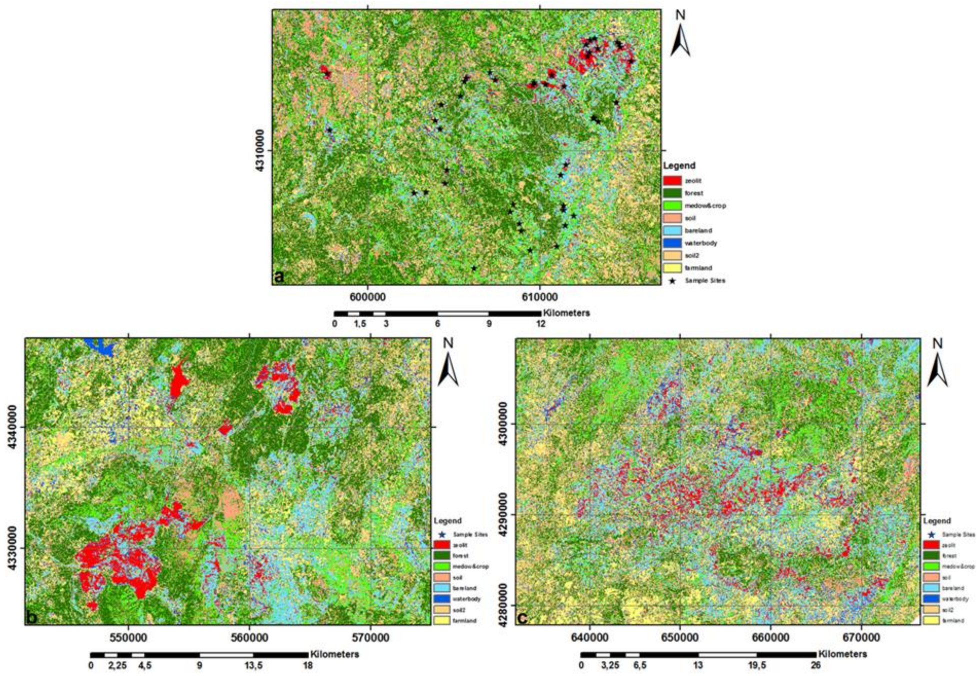

Fig. 11. Classification results of sample, 2nd and 3rd zeolite sites in detail.

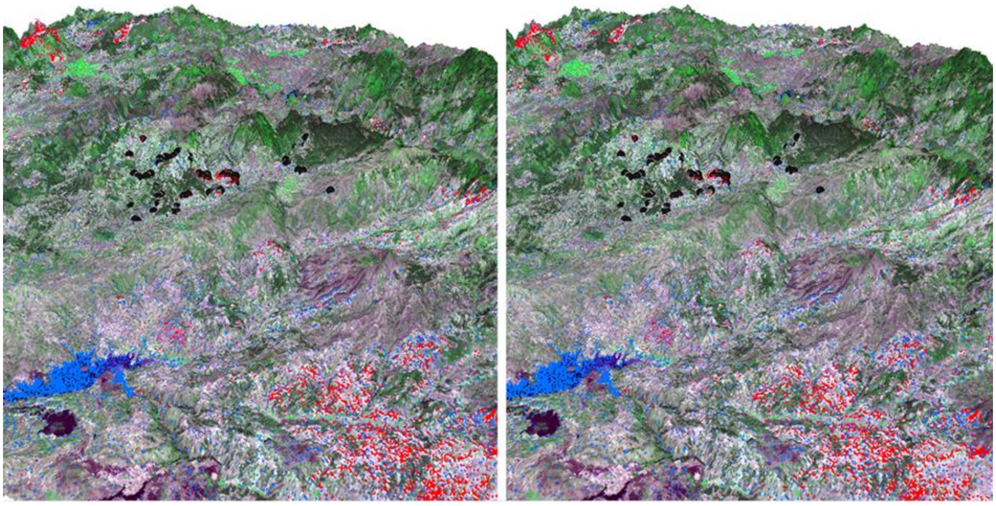

Fig. 12. Stereo visualization of sample and two other zeolite sites found after the classification.

CONCLUSION

Gördes and its near vicinity were chosen as the study area in this study, since zeolites formed after hydrothermal alterations which are rich in iron and hydro minerals are seen densely in the region. The study is then focused on determination of zeolite sites in the region by remote sensing image analysis technique depending on feature oriented PCA. To reach this scope, first of all a confirmation data was obtained. Then, this geologic data collected by previous field works run in the region was transferred into digital medium by the help of CAD and GIS software.

The other data obtained in the field was sample data from some zeolite locations collected by Vural & Albayrak and their previous work carried out in the region (Vural & Albayrak 2005).

The locations of sample data set for zeolite sites were then compared with the zeolite locations from remote sensing image analysis run in this study. According to this comparison, it can be underlined that sample data obtained using classical techniques confirmed the zeolite locations from remote sensing image analysis. In this concept, remote sensing image analysis technique was chosen as feature oriented PCA. PC4s from both PCAs showed up as PCs having highest opposite loads according to the outcomes of PCAs run for both LANDSAT image groups including 1st, 4th, 5th & 7th bands and also 1st, 3rd, 4th & 5th bands respectively.

Then negative images of these two PC4s & PC1 obtained after PCA of these two PC4s were composed as a stack image scene to form the final RGB composite image. Thus, zeolites developed in the region were successfully located red and reddish colors in this image depending on hydro and ferrite minerals on the land.

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کشف مکان‌های زئولیتی گوردس با استفاده از آنالیز مولفه‌های اصلی متمایل به وضعیت مربوط به تصاویر Landsat

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چکیده

مطالعات اخیر نشان داده است که سنجش از دور روشی موثر، کارآمد و قابل اطمینان برای استفاده در تقریباً همه علوم مربوط به کره زمین است. سنجش از دور به عنوان یک روش، ابتدا با عکس‌های هوایی شروع شد و سپس با به کارگیری تصاویر ماهواره‌ای چندطیفی توسعه پیدا کرد. امروزه این روش از دیتاهای چندطیفی، RADAR و LIDAR نیز استفاده می‌کند. این توان بالقوه، قابلیت استعمال آن را به عرصه‌های دیگر نیز گسترش داده و از دیسیپلین‌های حرفه‌ای به طور موثری استفاده کرده که تاکنون امکانپذیر نبود. یکی از این عرصه‌ها که در آن سنجش از دور به خوبی مورد استفاده قرار گرفته است، به یکی از مراحل ضروری این مطالعات تبدیل شده، مطالعات اکتشاف زمین‌شناسی و معدن‌شناسی است. در مطالعه حاضر تلاش شد تا مکان‌های زئولیت را در نواحی گوردس (ترکیه) توسط سنجش از دور و GIS تعیین کنیم. این نواحی از مواد متغیری شکل گرفته است که مقادیر زیادی آب دارد و از بسترهای صخره‌ای آتشفشانی توسعه یافته است. مساحت این نواحی ۴۰۰ کیلومتر مربع است و در شمال شرقی استان مانیسا قرار گرفته است. نتایج نشان داد که نواحی زئولیتی را که با روش‌های کلاسیک اکتشاف به دست آمده‌اند، می‌توان با استفاده از آنالیز مولفه‌های اصلی Feature Oriented یا (PCA) تعیین کرد. نواحی دیگر زئولیتی در همین عرصه را نیز می‌توان با این فرآیند آموزشی رایانه‌ای از طریق همین آنالیزهای تصاویر سنجش از دور تعیین یا حداقل پیش بینی کرد.

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