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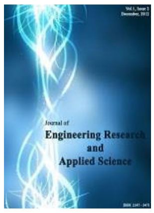

Determination of lithological differences and hydrothermal alteration areas by remote sensing studies: Kısacık (Ayvacık-Çanakkale, Biga Peninsula, Turkey)

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Abstract

Within the scope of the study, it was attempted to determine the lithological differences of Kısacık and its surroundings (Ayvacık, Çanakkale/Turkey) and to determine the hydrothermal alteration areas in the area by remote sensing studies backed by Geographic Information Systems (GIS). At the beginning of the study, aerial photographs and Landsat 7 TM + satellite image of the area were obtained and photogeology studies were conducted on aerial photographs. Subsequently, all the general geology and geochemistry data obtained during field studies were transferred to the digital environment with the help of GIS software, thus creating a comprehensive database for the area. Within the scope of remote sensing studies, after atmospheric noises of Landsat 7 TM+ satellite image was filtered and necessary geometric corrections were made, the image was then enhanced using various contrast applications, filtering and color band combinations. The last stage was the process of extracting information from the image by using techniques such as band proportion, principal component analysis (PCA) and image classification methods. As a result of GIS backed remote sensing studies, it was observed that the lithological differences determined by classical field studies in the area were also confirmed by remote sensing studies, so that the remote sensing studies to be performed before the classical geological studies can contribute significantly to reducing the workload to be performed in the field. It has also been found that remote sensing studies allow some details that are overlooked during field studies to be noticed and to focus on these details. When potential hydrothermal alteration areas were determined with the help of remote sensing studies, it was seen that it made satisfactory contributions to classical field studies. The use of GIS backed remote sensing techniques in determining hydrothermal alteration areas, which are of great importance in mineral exploration, has shown that especially land-based workload can be reduced. The transfer of all data to digital environment with the help of GIS software enables very detailed and different sized analyzes. It is an invaluable contribution to field studies both by examining the hydrothermal alteration and lithological differences with the aerial photographs used since the past, and by determining the lithological differences, and determining the potential tectonic lines and potential hydrothermal alteration areas by remote sensing studies. The complex database created from all these data allows analysis in many dimensions at every stage of the geological study. With this study carried out in Kısacık and its surroundings, it has been observed that alteration-tectonism and mineralization are associated with each other in the epithermal gold enrichments in the area, especially the remote sensing technique made using the principal component analysis gives accurate results in the determination of hydrothermal alteration areas associated with gold mineralization in the area.

Keywords: Biga Peninsula, Ayvacık, Çanakkale, mapping of lithological differences, hydrothermal alteration, remote sensing, geographic information systems.

1. Introduction

The study area is located in the Northwestern Anatolia, on the Biga Peninsula, in the north east of Ayvacık, Kısacık village and its near surroundings (Fig. 1). The south of the study area is limited by Kazdağları. Further south of the area is Edremit Bay/Aegean Sea.

When the general geological features of the study area are taken into consideration, magmatic rocks and ultramafic rocks that are in contact with these rocks are seen in the area. As the region where the study area is located has been subject to many mining activities in the past, today there are metallic mineral deposits such as Cu, Pb, Zn and precious/base metal mineralizations that are operated and waiting to be operated. Considering both the originality of the geology and the potential of the mineral deposits, the region has been the subject of

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many studies. Some of these studies are for general geological purposes and some are for mineral exploration purposes. General geological studies on the Biga Peninsula are very old, but the first serious studies started in the 1950s.

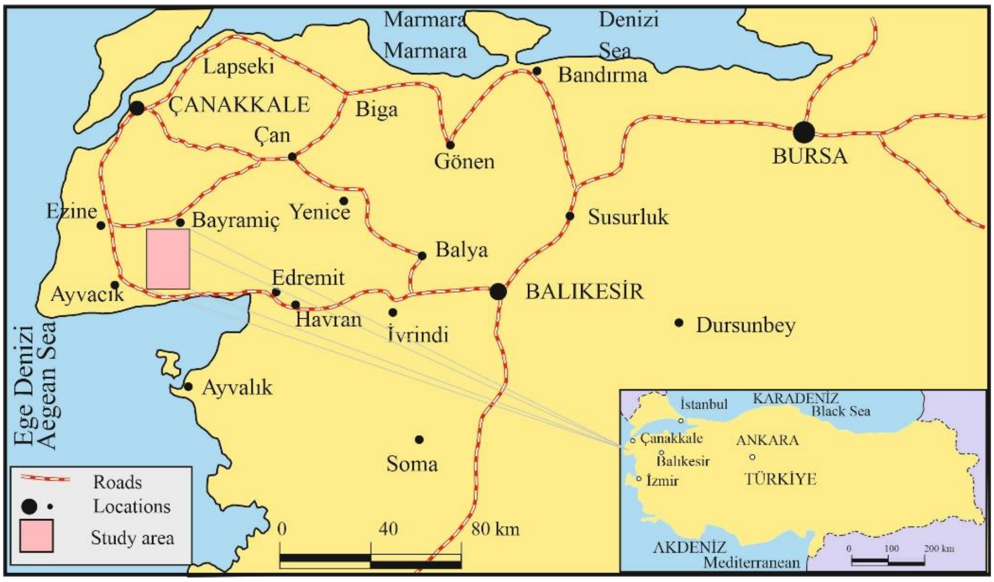

Figure 1. Location map of the study area

1/500 000 scale geological map of Turkey with the aim of making the first regional studies have been carried out by [1]. Later, [2, 3] made detailed studies. In the works of [4], the term "Karakaya" was brought to the literature. In the study conducted by [5], it was stated that the metamorphic rocks in the region consist of green schists and high metamorphic micaschists, gneisses and marbles in the albite-epidote schist facies. Researcher [2] considered the metamorphic rocks as Silurian-Devonian aged and stated that Triassic came transgressively on Paleozoic. Researcher [6], and researchers [7] stated that the Kazdag massif contains amphibolites in intermediate levels, predominantly composed of biotite amphibole gneisses, and orthoamfibolites, marbles, diabases and serpentinites overlapped these rocks and according to them, this sequence ended with epimetamorphic schists. Researchers [3], claimed that the Kazdağ massif continued in the middle pressure amphibolite and green schist facies with metadunite, metagabro and pyroxenite, amphibolite, paragneiss, marble and epimetamorphic schists and explained that the massif is in a dom morphology. The researcher stated that Triassic consists of less metamorphic grovak, conglomerate, siltstone, radiolarite, mudstone, spilite and Paleozoic limestone blocks and this unit could develop in a collapse basin formed by tension forces affecting Tetis. Using the 1 / 25.000 scale geology maps of the Biga Peninsula, researcher [8] made the 1/100.000 scale compilation map of the region. Researchers [9–12], in their studies, they distinguished four tectonic zones in the Biga Peninsula. During their studies, they revealed an important Upper Cretaceous ophiolitic melange belt passing through the center of the Biga Peninsula and a Permo-Triassic ophiolite overlying a Permian carbonate platform in the northwest of the peninsula.

Researchers [13] and [14], argued that the mantle, which is the source of the magmatism in the Ezine region located in the west of the study area, is a hybrid magma of cognate origin and was formed in a compression regime due to the east-west oriented graben opening. Researcher [15] has revealed that the igneous rocks in Bayramiç and its surroundings are equivalent volcanic and plutonic rocks and there is a second volcanism on these rocks. The study [16] stated that the last metamorphism of the Kazdağ Massif developed due to the detachment faults occurring in Oligocene, and that a common magmatism occurred simultaneously with metamorphism. Apart from these studies, there are many other geological studies in the region [14, 17, 26, 27, 18–25]. There are also many studies for mineral deposits in the region [28, 29]. Researcher performing the current study [30] carried out a very wide area of subject matter doctoral study, and the original features of mineralizations in the region were revealed. Apart from these, there are many current studies on mineral deposits in the region [31–40]. In the region where there are so many studies for general geology and mining geology, there are also studies for remote sensing studies backed by geographic information systems, an important auxiliary element of geological studies [41–44]. With this study, it was aimed to reveal the general geological, technical and alteration characteristics of Kısacık and its surroundings Ayvacık (Çanakkale) with GIS backed remote sensing studies by using the findings obtained with classical methods for verification purposes. Therefore, with this study, it will have been shown that remote sensing studies with geographic information system are an important part of classical geological studies.

2. Material and Methods

First, a detailed literature study was carried out regarding the study area, aerial photos and satellite images of the site were obtained and photogeology studies were conducted. A database was created with the help of GIS software (ArcGIS 8.1, 9.0 and ArcView 3.2) from the data of the regional studies on the area such as photo-geology, generel geology etc. then all the data about the area were analyzed in detail, and the field application program was prepared by determining the target sites and target sample areas before the field study. Within the scope of this study, 1/25.000 topographic maps of the area were provided and coordinated to perform remote sensing study. Nowadays, the numerical ones of these maps can also be obtained from related institutions. In our study, since our map is not digital, it was first scanned in TIF format and transferred to digital environment. Subsequently, ArcGIS 8.1, 9.0 and ArcView 3.2 were processed in GIS environment and import and rectification processes were carried out respectively. After these operations, digitization of topographic maps was carried out. The information on the map that was needed according to the purpose of the study was transferred to the computer environment in a form of a database. In the field studies, all the data obtained in coordination with the help of GPS was transferred to the digital environment and made ready for analysis with remote sensing methods and GIS software. In addition, contour lines on the topographic map of the area were digitized and Digital Elevation Model (DEM) of the field was created. All these data and Google Earth database were used analyzed effectively in the office stage of the study.

Within the scope of remote sensing study, Landsat 7 ETM + data with line-row number (181-32) and dated July 25, 2000 were used. Satellite image of the study area was obtained from the General Directorate of Mineral Research and Exploration (MTA in Turkish). Satellite images may not always produce the desired results due to sensor system errors, environmental errors. Due to the geometric structure of the world, the topography of the earth, the losses caused by the fluctuation of the wavelength or the errors that will occur, the expected quality images cannot be obtained as a result of changes in the reflection values or the inclusion of rough errors in the process. These errors cause quality drops. In this case, it is necessary to apply the pretreatments to reach the desired information from the images obtained. The improvement processes arising from the errors of satellite images are examined under two main titles as geometric improvement and radiometric improvement.

Geometric improvement/enhancement: Coordinate errors occur due to axial curvature of the world, satellite axis shifts etc. Ground control points are used to correct this. The process of placing the image on the real value on the map, that is, ensuring that the coordinates of the points in the image have the real coordinates of the earth, is called rectification. The process of matching this process at the same points of two images or correcting the coordinates of one image using another is called registering or georeferencing [45, 46].

Radiometric improvement/enhancement: may be required due to any image distortion, irregularity, or negativity during recording or storage during image acquisition. The common structure of the disorders are systematic errors and losses that occur during band-up. Radiometric errors are divided into two as sensor system errors and environmental errors [41–45, 47–49]. Environmental errors are atmospheric and topographic errors. Radiometric improvement/enhancement is useful in eliminating atmospheric errors caused by environmental effects on the image. Radiometric enhancement is generally used for comparing images with different dates or for image proportioning, for this method, two different bands belonging to the same area and with the same date are used. For the band to be improved, pixels with the smallest reflection value in the image of the related band are determined. While determining the lowest values in the image, pixel values are checked. Pixel values with the same feature are determined and selected. Because, in both images, the necessary corrections can be made by comparing the reflection values in these areas [30, 40, 41, 43–45, 50]. Commercial and open-source software are widely used in the realization of these processes.

In the process of processing remote sensing images, atmospheric noises are first filtered and the necessary geometric corrections are made and the image is made ready for processing. The image is then enhanced using various contrast applications, filtering and color band combinations. The last stage is the process of extracting information from the image by using techniques such as band proportion, principal component analysis (PCA) and image classification methods.

3. Geology of the region

The study area is located in northwest Anatolia, within the boundaries of the Biga peninsula. Units in the region were handled by researchers [9] as pre-Tertiary and post-Tertiary and Tertiary units. For pre-Tertiary period, three tectonic zones, extending in the NE-SW direction, were identified by those researchers. These are from northwest to southeast; the Ezine Zone, the Ayvacık-Karabiga Zone and the Sakarya Zone (Fig. 2). Tertiary and post-Tertiary units in the region begin with Middle Eocene neritic limestones and Upper Eocene turbidites with andesite and andesitic tuff intercalations covering them concordantly.

Then, with a unconformity, the Eocene (?) / Oligo-Miocene calcalcaline magmatism was effective in the region [9, 12, 51]. The volcanics in the area, especially dacite, andesite, rhyolite and acidic tuffs, outcrop laterally with sedimentary rocks, which also contain coal.

Ezine Zone, one of the pre-Tertiary units, is located in the southeast of the study area and consists of rocks of continental origin. In the western part, it consists of a Permo-Carboniferous sedimentary sequence (Karadağ), which has undergone metamorphism in the greenschist facies, and an ophiolite (Denizgören Ophiolite), which overlies this sequence in Permo-Triyas, and consists of high-grade metamorphic rocks (Çamlıca Mikaschists) in the east. These units are located outside the study area. In the study area, Ayvacık-Karabiga Zone and Sakarya Zone outcrops. Ayvacık-Karabiga Zone mainly consists of ophiolitic melange (Çetmi Ophiolitic Melange). Eclogite and Upper Triassic aged limestone blocks in the melange are the most typical feature of the Ayvacık-Karabiga Zone [11]. The ophiolitic melange unit consists of flysch and melange rock groups in the study area. It consists of spilitized mafic volcanic and pyroclastic rocks, Upper Triassic, Upper Jurassic, Lower and Upper Cretaceous limestone blocks, shale and grovacs. The ophiolitic melange takes place on the Kazdağ metamorphics between the villages of Alakeçi - Çaldağ after a two kilometer-thick mylonite zone. Eclogite and garnet micaschist tectonic slices are also observed in this area within the ophiolitic melange [30, 31, 52, 53]. The mylonitic zone (Alakeçi Mylonitic Zone), which lies between the melange and the Kazdağ group, consists mainly of mylonitic gneiss and metaserpentinite type rocks. Sakarya Zone is located in the southeast of Biga Peninsula, southeast of Ayvacık-Karabiga zone. It consists mainly of the Kazdag Group metamorphics, Karakaya Complex units tectonically overlying these metamorphics and post-Triassic sediments [4, 8]. The Sakarya Zone in the eastern part of the Biga Peninsula was handled by researchers [9] as pre-Jurassic three units: Pre-Karakaya units, Kazdağ Group and Karakaya Complex. Pre-Karakaya Units are metasedimentary rocks (Kalabak Formation) and intrusive metagranodiorite (Çamlık Metagranodiorite) that outcrops in the north of Edremit and Havran. Kazdağ group consists of gneiss, amphibolite and marbles that form the core of Kazdağ [4]. The Kazdag Group, which is approximately 50 km long, southwest-northeast oriented, is a complex anticlinorium cut by granodiorites at the Late Tertiary age. Kazdağ Group is tectonically covered by the metatufts of the Karakaya Complex (Nilüfer unit) and the arkosic sandstones (Hodul unit) in the east and by the Late Cretaceous ophiolitic melange in the west and north [4] (Fig. 2).

Tertiary-Post Tertiary units in the Biga Peninsula consist of magmatic and sedimentary rocks. In the region, the Tertiary begins with the Middle Eocene neritic limestones and the Upper Eocene turbidites interlayered with andesite and andesitic tuff covering these limestones. Widespread magmatic activity in Western Anatolia started in the Eocene (?)/Oligocene period [12, 54, 55]. A common calc-alkaline magmatism prevailed in the region in the Early / Middle Miocene. Accordingly, pluton with many granodiorite composition has settled in the region and large areas are covered with volcanic rocks with andesite and dacite composition. At the end of Oligocene, there was a significant rise and continentalization in the Biga Peninsula and the

Eocene-Oligocene sequence was largely eroded. Following this phase, a very common and intense (Late) Oligo- (Early) Miocene calcalcaline magmatism affected the Biga Peninsula [15, 56–58]. Andesite, dacite, rhyolite and acidic tuffs cover large areas in Biga Peninsula in Early and Middle Miocene [13–15]. In the Late Miocene volcanism was stopped, shallow marine and fluvial clastic deposited in the Gallipoli Peninsula and north of the Biga Peninsula [30].

4. Geology of the study area

The area subject to the study includes the Kazdağ Group rocks of the Sakarya Zone and the ophiolitic melange of the Ayvacık-Karabiga Zone and the mylonitic gneisses and meta serpentinites in the developed mylonitic zone (Alakeçi Mylonite Zone) as pre-Tertiary, while Tertiary and Post Tertiary units consist of magmatic and sedimentary rocks in the study area. Igneous rocks have the Eocene (?)/Oligocene-Upper Pliocene/Quaternary (?) age range. Sedimentary rocks consist of Upper Miocene-Pliocene aged, mostly lacustrine sedimentary rocks and terrestrial clastic and Quaternary alluviums (Fig. 3). The igneous rocks in the area consist of volcanic and their pyroclastics. Volcanic rocks outcrops in the southern parts of the study area, between the villages of Küçükhüsün, Kısacık and Baharlar. Mostly; they consist of andesite, lattice, rhyolite, basaltic andesite, ignimbrite, basaltic trachyandesite lava, rhyolite, rhyolitic tuff, riodacitic tuff and pyroclastic rocks [30]. Basalts, the latest product of magmatism in the region, crops out in the creek in the south of Küçükhüsün Village in the south of the study area with a E-W extension.

5. Remote sensing studies by geographic information systems

As mentioned earlier, remote sensing studies have become an important element to assist geological, exploration ore deposit studies. These are studies that increase and facilitate the working speed, as it enables disciplined use of data with the support of GIS and allows it to be evaluated in a multidimensional way.

While choosing the satellite image of the area for remote sensing, care was taken to ensure that the image was cloudless. Satellite image of the study area was obtained from the MTA.

In the study, Landsat 7 ETM + data with line-row number (181-32) and dated July 25, 2000 were used. As the details appear in the method section, the image was rectified by importing it into ArcGIS environment, was geometrically corrected using control points on a 1:25 000 scale topographic map. Many image enhancement techniques such as decorating, filtering, band proportioning, adding, removing, etc. on the bands of the Landsat ETM$^+$ image have been applied. In addition, the principal component analyzes especially for determining the alterations in the area have been applied in detail.

The combinations of Red Green Blue (RGB) 731, RGB 754, RGB 753 and RGB 531 are known to be very useful in geological purposes. It was seen that RGB 531 composite, obtained especially from the cropped Landsat image, gives the best view in terms of determining the boundaries and textures of the rocks in the studied area. Different band composites were analyzed on the images of the area (A-land classification produced by the Self-Organizing Neural Network technique of the study area, B- land classification produced by the adaptive resonance technique of the study area, C- land classification of the study area, produced with the technique of undirected isodata classification) lithological classifications were made using different band composites, the images obtained with these classifications were compared with photogeology studies and with the geological maps made during the field studies (Fig. 4, 5). When comparing the land classifications made using different methods with the geology map made with field studies, the similarities are clearly seen. In such studies, the fact that the land is covered with dense trees and vegetation affects the study negatively. Depending on the land / plant density of the land, there are deviations from the expected ideal parallelism. There are forest areas in the study area. Although, as a result of the land being covered with forest, there are incompatibilities between the geological map produced by field studies and the images obtained by remote sensing studies, in general, the images produced as a result of remote sensing studies are observed in accordance with the geological map of the region (Fig. 4, 5).

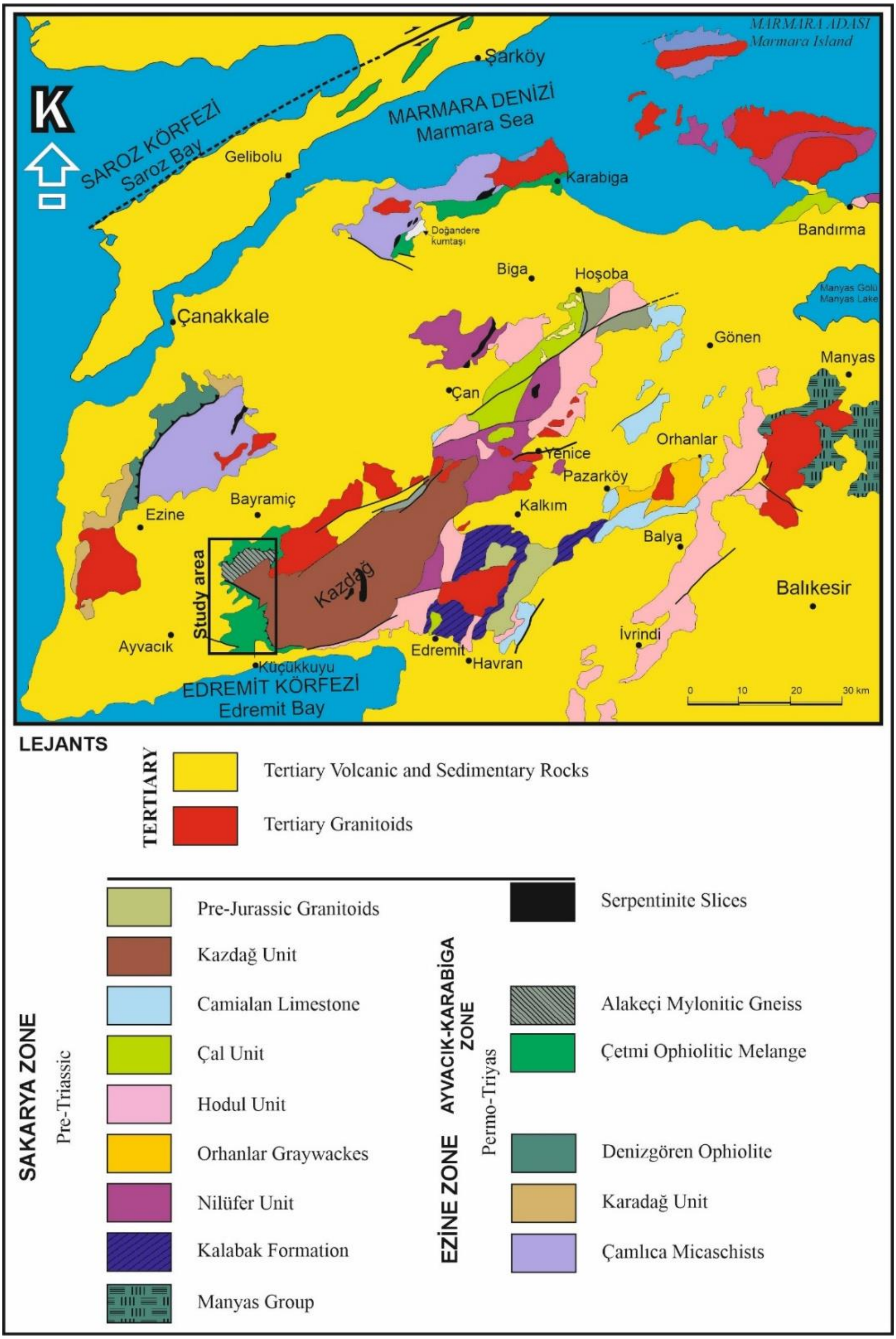

Figure 2. Regional Geology of Biga Peninsula (after [9, 30])

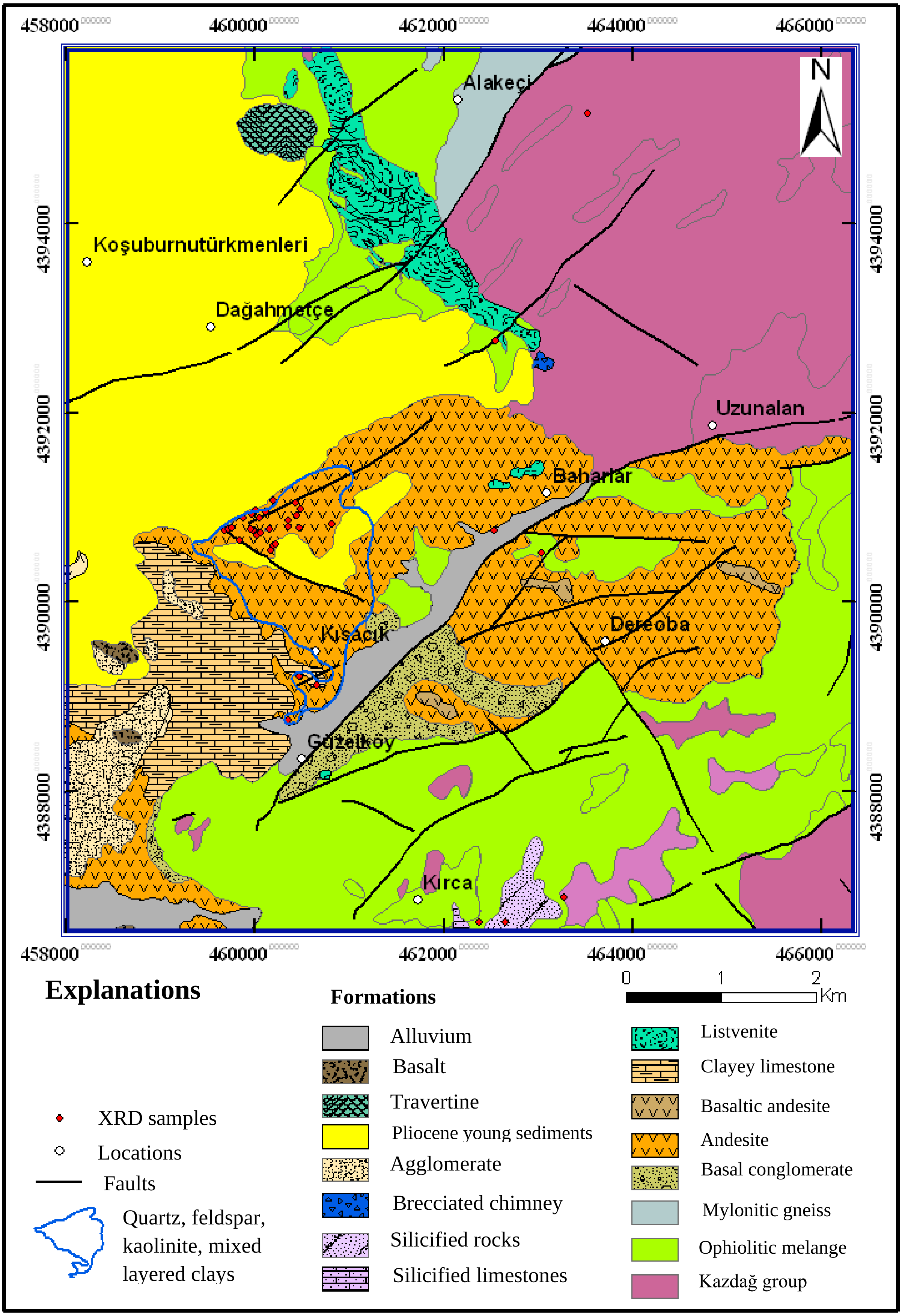

Figure 3. Geology and hydrothermal alteration map of the study area.

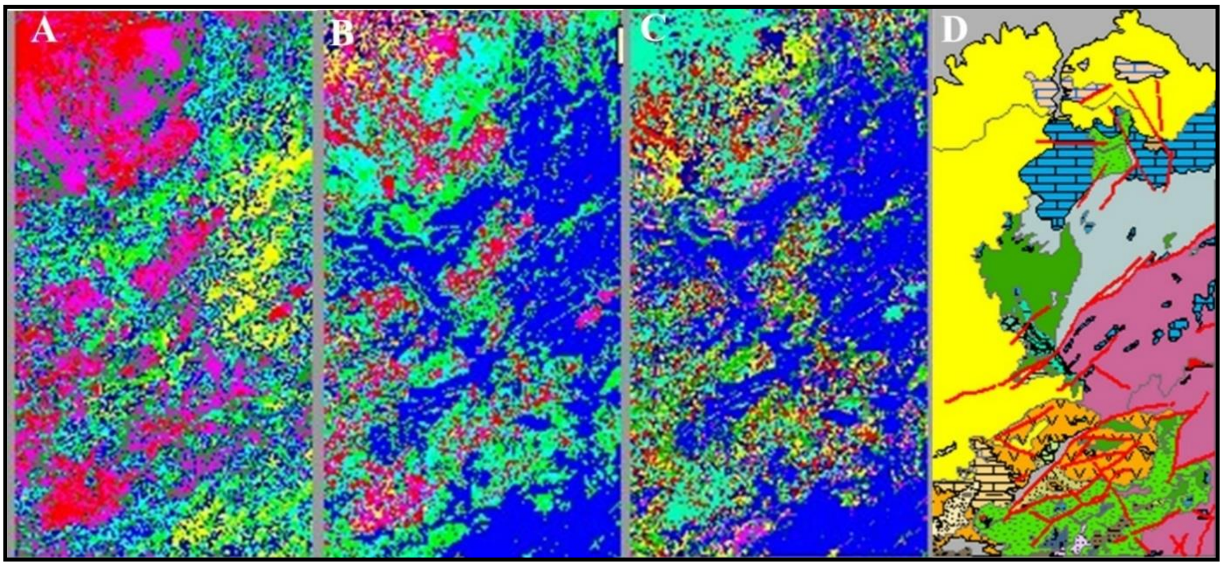

Figure 4. Within the scope of remote sensing studies, comparing the land classifications obtained with different band composites from the satellite images of the area and the geology map made in the field, A) land classification produced by the Self-Organizing Neural Network technique of the study area, B) land classification produced by the adaptive resonance technique of the study area, C) land classification of the study area, produced with the technique of undirected isodata classification, D) geology map produced by field studies

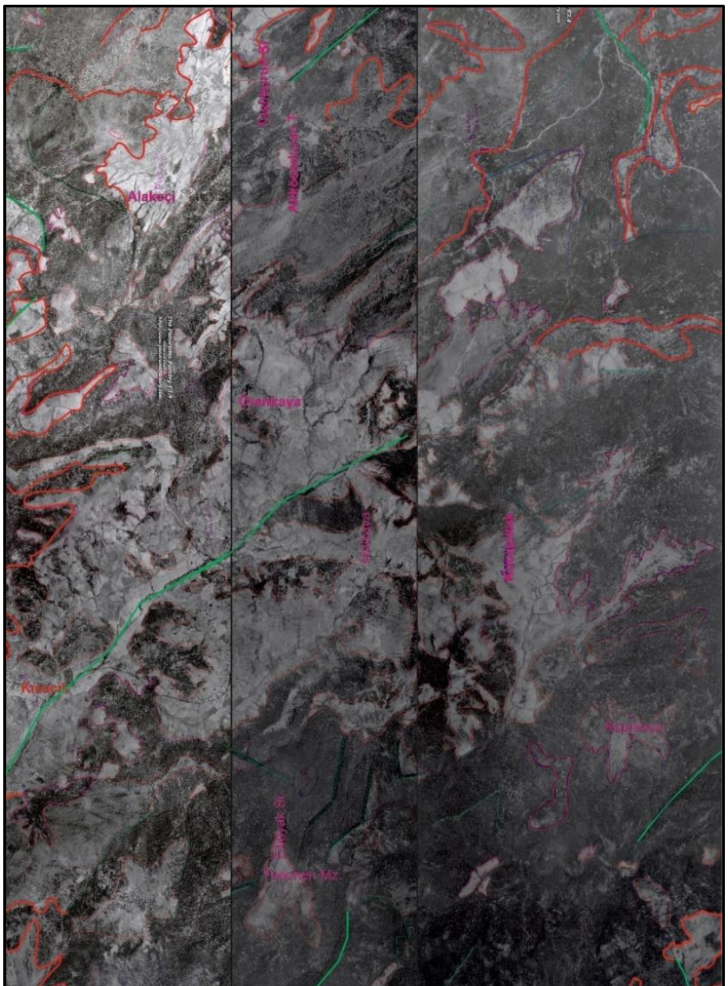

Figure 5. Photogeology study of the area

Landsat data have been used in many earth sciences applications since the mission began and are still used outdated. In geological purposes, it is used to determine the locations of minerals with iron oxide and hydroxyl roots that can be found in hydrothermally altered zones of mineral deposits, especially in regions dominated by arid and semiarid climates [41, 44, 47, 59, 60]. Therefore, it is frequently used in mine exploration studies especially in determining hydrothermal alteration zones. The hydrothermal alteration and the locations enriched by iron oxide in the study area were analyzed by principal component analysis (PCA, the method adapted to the field of remote sensing studies is also called the Crosta technique by some researchers, (e.g. [61]). There are many studies indicating that the mineralization zones previously determined by using classical methods have been determined successfully with the PCA technique [41, 44, 47, 59, 60]. Wall rocks containing mineral deposits or mineral enrichments necessarily show the end products that are formed as a result of reactions of hydrothermal fluid with the wall rock, change the chemistry of the rock and cause the settlement of ore and hydrothermal minerals [62]. All porphyry type deposits show a well-developed zone and these zones can be easily identified with the major oxides and trace element concentration differences. This elemental composition appears as a change in the mineralogical composition of altered zones. Secondary alterations that develop under surface conditions lead to significant formation of characteristic chestnut reddish, and/or yellowish colors in altered rocks. Remote sensing studies focus on detecting these alteration minerals. As mentioned before, PCA is used efficiently as an auxiliary element in the construction of alteration maps of metallogenic lands [40, 47, 48, 50, 63]. This technique (Crosta technique) is one of the feature oriented principal component analyzes. Analyzes of eigenvector values enable the identification of key components containing the spectral information of certain minerals and the contribution of the original bands associated with the spectral response of the substances of interest. This technique corresponds to the image as bright or dark pixels in key components, depending on whether the eigenvector loads are marked (+) or (-). The technique can be applied on selected 4 and 6 TM bands [30, 40, 63, 64]. This analysis method has been tried separately using 6 and 4 bands for the study area.

It is generally known that soil and rocks are highly absorbed from Landsat 7 ETM+ bands in band 7 (2.08 - 2.35 μm) and high reflectance-brightness in band 5 (1.55 - 1.75 μm). Therefore, in the image obtained by proportioning of these bands (7/5), soil and rock images become more clear. Similarly, (7/1) band ratio is preferred to determine hydroxyl alteration, (5/7) ratio clay and (3/2) ratio iron oxide alteration [40, 41, 45, 65]. Under the light of this information, it is seen that Landsat 7 ETM+ bands 1, 3, 5 and 7 bands can easily be used for geological and exploration geology studies. Principal component analysis works according to the same principles. As for the work, general statistics and correlation matrix values of Landsat 7 ETM+ bands (1,2,3,4,5 and 7) used in the study are shown in Tables 1 and 2, while PCA covariance eigenvector values are shown in Table 3.

Table 1. General statistics of the study area Landsat 7 ETM+ satellite image data for six bands

	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6
Minimum	65.00	42.00	32.00	45.00	26.00	6.00
Maximum	196.00	196.00	255.00	152.00	255.00	217.00
Mean	87.42	75.36	81.38	74.11	99.77	63.32
Median	83.93	69.67	69.46	71.75	92.20	56.28
Std. Dev.	13.37	18.48	33.92	13.32	39.60	29.54
Std. Dev. (n-1)	13.37	18.48	33.92	13.32	39.60	29.54
Corr. Eigenval.	5.54	0.28	0.13	0.03	0.01	0.01
Cov. Eigenval.	4091.82	112.33	61.39	12.34	7.95	2.80

Table 2. Correlation Matrix values of Landsat 7 ETM+ satellite image data for six bands

Correlation Matrix	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
Band 1	**1.00**	0.98	0.97	0.80	0.93	0.93
Band 2		**1.00**	0.99	0.84	0.93	0.93
Band 3			**1.00**	0.83	0.94	0.94
Band 4				**1.00**	0.84	0.77
Band 5					**1.00**	0.98
Band 7						**1.00**

Table 3. PCA values of Landsat 7 ETM+ satellite image data of the study area for six bands

Cov. Eigenval.	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
Band 1	0.20	-0.21	-0.15	0.29	-0.74	-0.52
Band 2	0.28	-0.35	-0.07	0.26	-0.28	0.81
Band 3	0.52	-0.62	-0.197	-0.35	0.38	-0.22
Band 4	0.18	-0.19	0.85	0.40	0.18	-0.13
Band 5	0.61	0.50	0.27	-0.47	-0.27	0.08
Band 7	0.45	0.42	-0.37	0.59	0.36	-0.07

One of the most important elements to be considered while performing the analysis is to choose the right PC. While obtaining the hydroxyl image, the PC with the highest but reverse marked loading of bands 5 and 7 should be selected. While obtaining the iron oxide image, the PC with the highest but reverse signs of bands 1 and 3 should be selected [30, 43, 59, 61]. In this six-band study, band 5 and band 7 were highest, and the reverse sign eigenvector loads were at PC4 (Table 3). Since band 5 has a negative (-0.47) and band 7 has a positive (0.59) maximum value, hydroxyl minerals (H component) are highlighted with this principal component and hydroxyl minerals appear as dark pixels in the image (Fig. 6a). It is possible to take negative of PC4 when it is desired to display hydroxyl rooted minerals in light color [30, 59]. Likewise, the highest and reverse sign eigenvector loads in band 1 and band 3 are on PC5. Since band 1 has a negative (-0.74) and band 3 has a positive (0.38) maximum value, this principal component and iron oxide (F component) are highlighted, and minerals containing iron oxide appear as light pixels in the resulting image (Fig. 6b) . After determining PC4 and PC5 for hydroxyl and iron oxide, an average PC is obtained by using these images. Finally, an R (PC4) G (PC5) B (average PC from PC4 and PC5) image obtained from these images is obtained as false colour image. In the resulting image, areas under hydrothermal alteration appear as bright pixels (Fig. 7a). When the figure is examined, it is seen that the pink colors correspond to the hydrothermal alteration areas. Field studies also confirm the findings obtained by remote sensing studies.

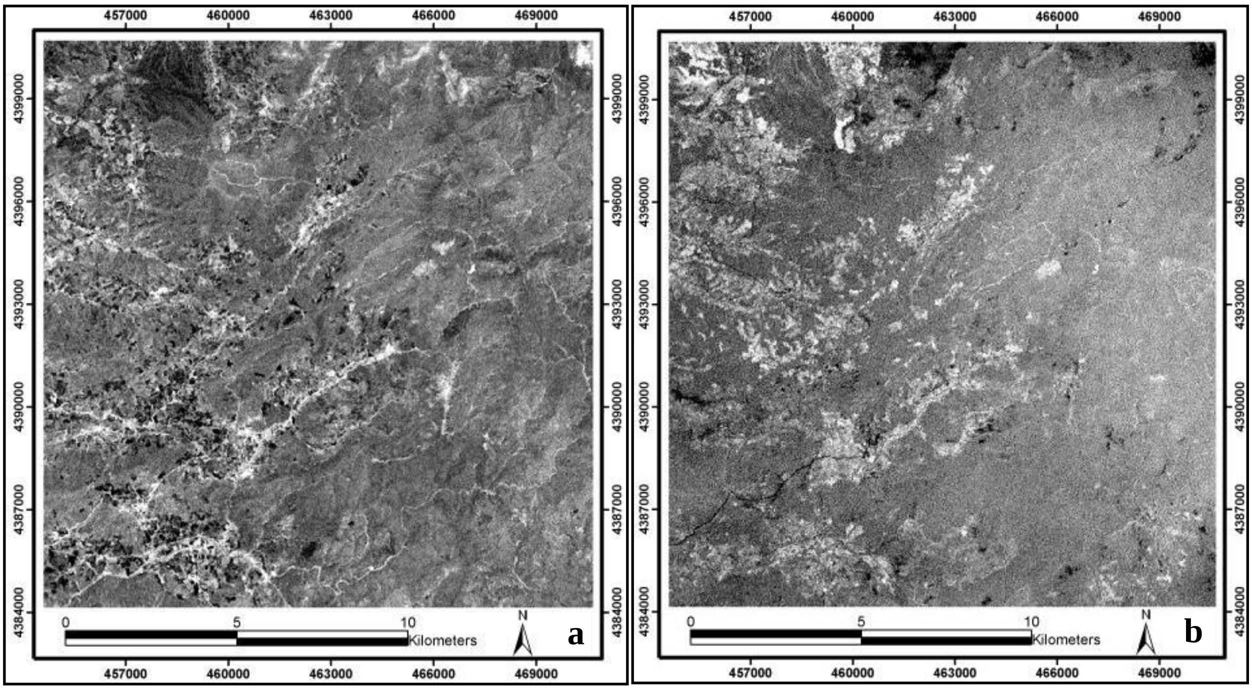

Figure 6. a) PC4 (Hydroxyl) image of the study area for Landsat 7 ETM+ six band satellite data. Dark pixels correspond to hydroxyl-rich regions (Dark pixels indicate regions rich in iron oxide). b) PC5 (iron oxide) image of the study area for Landsat 7 ETM+ six band satellite data. Light pixels indicate regions rich in iron oxide.

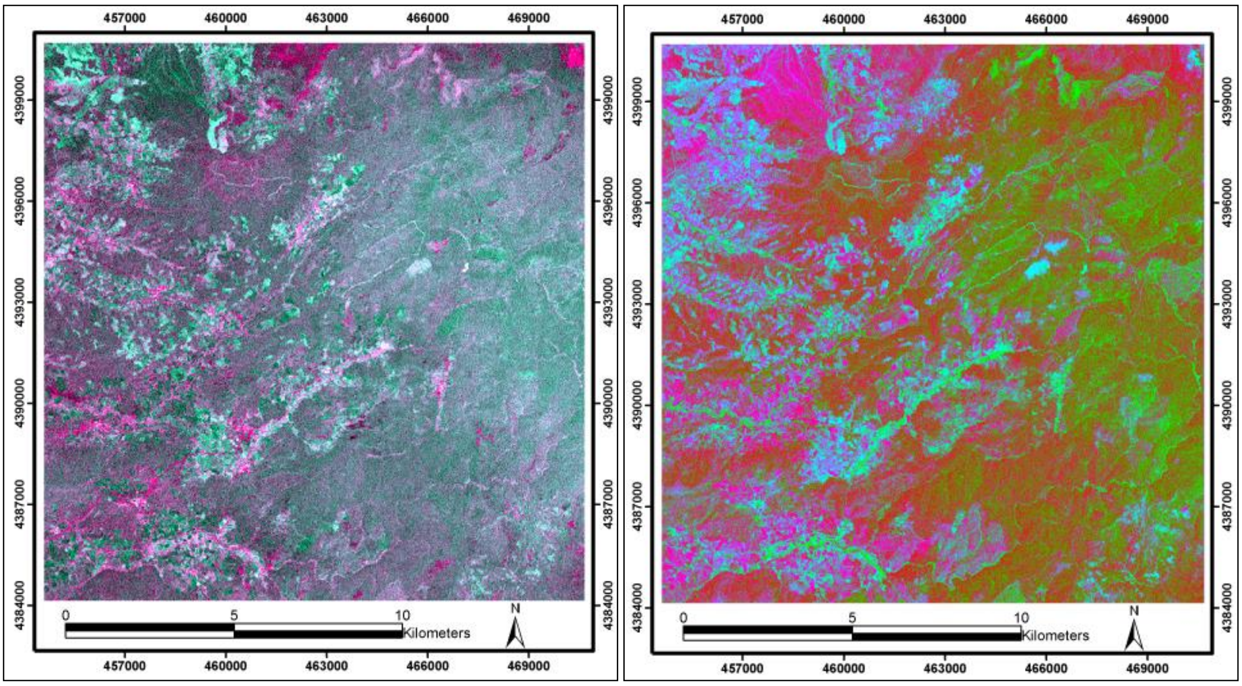

Figure 7. a) Landsat 7 ETM+ satellite image, R (PC4), G (PC5), B (average of the PC4 and PC5) composite created for six bands. Light pink pixels indicate hydrothermal alteration locations. b) R (PC4), G (PC created from PC4 and PC2), B (PC2) composite, obtained by applying PCA (Crosta technique) for Landsat 7 ETM + satellite image data for four bands. Light pink pixels indicate hydrothermal locations.

The same method was applied by creating 2 datasets of 4 bands of Landsat. To this end, two separate “virtual datasets” were created containing the (1, 4, 5 and 7) of TM bands for dataset 1 and the (1, 3, 4 and 5) of TM bands for dataset 2 second. Statistics and “Covariance Eigenvector” values for each “Virtual Datasets” were determined and examined. PC transformation values in the unstretched Landsat 7 ETM+ (1, 4, 5 and 7) bands of the region are given in Table 4. Band 2 and band 3 were not specifically used to suppress iron oxide. The PC with the highest positive eigenvector loading in band 5 (0.54) and the highest negative loading in band 7 (-0.67) is PC4. This PC is the component that shows "Hydroxyl" (component H) and appears as light pixels (Fig. 8a). PC transformation values in the region's unstretched Landsat 7 ETM + (1, 3, 4 and 5) bands are shown in Table 5. It is seen that the PC with the highest positive eigenvector loading in band 3 (0.39) and the highest negative loading in band 1 (-0.60) is PC2. This PC is the component that shows “iron oxide” (component F) (Fig. 8b).

Table 4. PC transformation values in the unstretched Landsat 7 ETM+ (1, 4, 5 and 7) bands of the region

Cov. Eigenval.	PC 1	PC 2	PC 3	PC 4
Band 1	0.48	-0.57	-0.62	0.25
Band 4	0.41	-0.52	0.60	-0.45
Band 5	0.65	0.43	0.33	0.54
Band 7	0.43	0.48	-0.37	-0.67

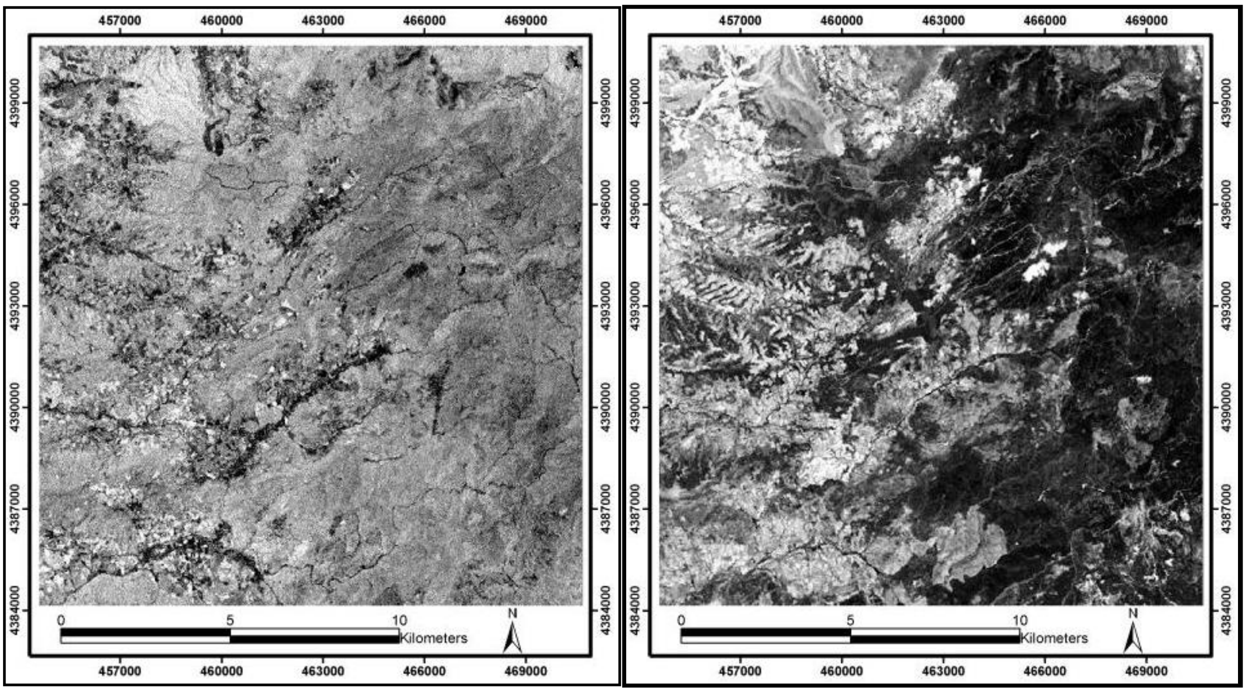

Figure 8. a) Hydroxyl (PC4) image obtained by applying Crosta technique for Landsat 7 ETM+ satellite image data for four bands (1, 4, 5 and 7). Dark pixels indicate regions rich in hydroxyl. b) The ironoxide (PC2) image obtained by applying PCA (Crosta technique) for four bands (1, 3, 4 and 5) of Landsat 7 ETM+ satellite image. Light pixels indicate regions rich in iron oxide.

Table 5. Principal Component Analysis values for Landsat 7 ETM + satellite data 4 bands (1, 3, 4 and 5) of the study area.

Cov. Eigenval.	PC 1	PC 2	PC 3	PC 4
Band 1	0.46	-0.60	-0.17	-0.64
Band 3	0.51	0.39	-0.74	0.20
Band 4	0.39	-0.54	0.18	0.73
Band 5	0.62	0.46	0.62	-0.15

A new two-band Virtual Dataset-PC consisting of F and H components was created and its statistic was calculated. The PC of this dataset was also obtained and finally, an RGB algorithm created by placing these values was created. PC4, from which we obtain the hydroxyl image, is assigned to **R**. PC component formed with PC4 and PC2 datasets is assigned to **G**. PC2, which we determined iron oxide, is assigned to **B**. Thus, a false color image was obtained (Fig. 7b).

General geology and geochemistry findings obtained as a result of field studies were used to confirm the obtained remote sensing findings. For this purpose, TINs (Triangulated Irregular Network) were created with the aid of GIS software using the concentrations of especially copper and zinc, which show a linear relationship with hydrothermal alteration, from the element analysis results of 193 soil samples collected from the area for geochemical purposes. In addition, the tectonic lines obtained as a result of field studies were transferred to the digital environment with the help of GIS software. The hydroxyl (PC4) image obtained by applying PCA (Crosta technique) for Landsat 7 ETM+ satellite image data for four bands (1,4,5 and 7), TIN layer for copper and zinc concentrations and tectonic lines from field studies are superimposed in digital environment (Fig. 9 a, b). When all these data are evaluated together, it is seen that the data obtained as a result of remote sensing studies coincide with the findings obtained from classical geology and geochemistry studies.

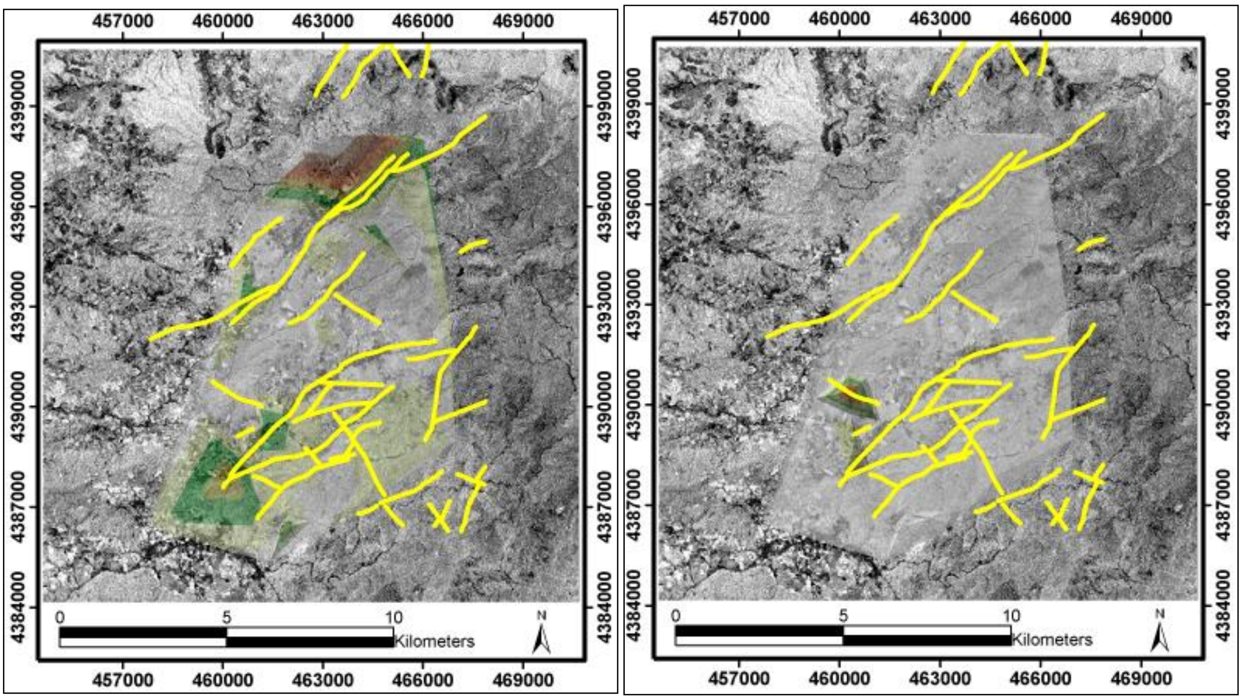

Figure 9. a) The hydroxyl (PC4) image obtained by applying PCA (Crosta technique) for Landsat 7 ETM+ satellite image data for four bands (1,4,5 and 7), TIN layer for copper concentrations and tectonic lines from field studies are superimposed in digital environment. b) The hydroxyl (PC4) image obtained by applying PCA (Crosta technique) for Landsat 7 ETM+ satellite image data for four bands (1,4,5 and 7), TIN layer for zinc concentration and tectonic lines from field studies are superimposed in digital environment

6. Conclusions

Within the scope of the study, the investigation of the lithological differences and alteration areas of Kısacık and its surroundings (Ayvacık, Çanakkale/Turkey) with remote sensing studies supported with the geographical information system. For this purpose, Landsat 7 ETM + data with line-row number (181-32) and dated July 25, 2000 were used. The image was rectified by importing it into ArcGIS environment, was geometrically corrected. In the context of remote sensing studies, many image enhancement techniques on the bands of the Landsat ETM^+ image have been applied. Also the principal component analyzes especially for determining the alterations in the area have been applied in detail. When the data of image processing methods performed to determine lithological differences are compared with field studies, it was seen that the findings obtained gave approximate results to the results obtained with field studies. Principal component analyzes were carried out in six bands (1, 2, 3, 4, 5 and 7) and in two sets as four bands (1, 3, 4 and 5; 1, 4, 5 and 7) of Landsat 7 TM+ image. Ironoxide and hydroxyl images corresponding to potential hydrothermal alteration areas were obtained by selecting the relevant principal components. When the remote sensing findings obtained were evaluated together with the general geology and geochemistry findings, it was observed that the remote sensing studies and these findings overlap.

As a result, it was once again confirmed with this study that GIS-backed remote sensing studies provide significant convenience and decrease the workload in field studies in determining the alteration areas, which are an important element in mineral exploration geochemistry studies. Especially in regions where vegetation is rare, remote sensing studies with satellite images with high spectral and spatial resolution make important contributions in terms of workload and time in the areas of difficulty in reaching and/or in the prospecting sites covering large region. Therefore, important preliminary information about very large areas is provided in a short time. Thus, it contributes to mineral exploration works.

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