

ALTERATION MAPPING BY REMOTE SENSING: APPLICATION TO HASANDAĞ – MELENDİZ VOLCANIC COMPLEX, CENTRAL TURKEY

E. Yetkin, V. Toprak, M. L. Süzen
RS-GIS Lab., Dept. of Geological Engineering, METU 06531 Ankara, Turkey
erdemyet@yahoo.com

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ABSTRACT:

Certain alteration minerals are used to identify the hydrothermally altered rocks. In volcanic rocks, mainly potassic, phyllic (sericitic), propylitic, argillic alteration and silicification are observed. The role of remote sensing in alteration mapping is the differentiation of the minerals that are unique for different alteration types. In this study, Landsat TM 5 images are used. General alteration trend in the area is mapped by conventional methods of color composite, band rationing, principal component analysis and multi-linear regression analysis. Detailed mineral mapping is carried on by using the United States Geological Survey (USGS) spectral library data. Spectral reflectances of selected minerals are analyzed according to the TM band intervals and appropriate band ratios are selected. TM bands 1,2,3,4,5 and 7 are used. Outputs of mineral maps are investigated for zonal distribution. Mineral maps that are obtained by the mineral separation method reveal that the youngest volcanic complex Hasandağ is poorly altered. Instead, Keçiboyduran, Melendiz and Tepeköy volcanic complexes are found to be highly altered with the pattern of clay dominant in the center and increasing oxidation towards flanks. Also the alteration along the previously mapped buried faults is a proof that the method can provide information about the alteration source.

1. INTRODUCTION

Hydrothermal alteration is defined as the reflection of response of pre-existing, rock-forming minerals to physical and chemical conditions different than those, under which they originally formed, especially by the action of hydrothermal fluids (Beane, 1982).

The nature of the alteration products depends on 1) the character of the wall rock, 2) the character of the invading fluid, which defines such factors as Eh, pH, vapor pressure of various volatile species, anion-cation composition, and degree of hydrolysis, and 3) the temperatures and pressures at which the reactions take place (Guilbert and Park, 1986).

Alteration may result from 1) diagenesis in sediments, 2) regional processes, such as metamorphism, 3) postmagmatic or post-volcanic processes associated with cooling, and 4) direct mineralization processes.

Potassic, phyllic (sericitic), propylitic, argillic alteration and silicification are main alteration types observed in volcanic rocks. Kaolinite, Illite, Montmorillonite, Pyrophyllite, Alunite, Orthoclase, Quartz, Epidote, Chlorite, Hematite, Goethite and Jarosite are alteration minerals that are mapped with techniques described in this study.

Hydrothermally altered rocks are characterized by unusually colorful rocks. The various colorful rocks are the host rocks of those mineral deposits with the colors representing the results of chemical interaction with the surrounding hydrothermal fluids. The hydrothermal fluid processes altering the mineralogy and chemistry of the host rocks can produce distinctive mineral assemblages which vary according to the location, degree and duration of those alteration processes. When these alteration products expose at the surface, it can be mapped at a zonal pattern, theoretically concentric around a core of highest grade alteration

and greatest economic interest. The importance of the recognition of such spatial patterns of alteration makes the remote sensing techniques as one of the standard procedure in exploration geology, due to its speed and price.

One of the key idea of remote sensing techniques in exploration geology is that it is applied to rocks, minerals, and structures associated with a particular ore, and not the ore itself. There are very logical reasons for this procedure. The ore is not always exposed at the surface, and it often is not as spectrally unique or as widely disseminated as the minerals and rocks that are associated with the ore body (Vincent 1997).

1.1 Geological Setting

Cappadocian Volcanic Province (CVP) extends as a belt in NE-SW direction for a length of 250-300 km situated in Central Anatolia (Fig. 1). The volcanism of the CVP has been investigated by several researchers who mainly concentrated on the chronology, petrographical and geochemical characteristics, and ignimbrite emplacement (Pasquare, 1968; Innocenti et al., 1975; Besang et al., 1977; Pasquare et al., 1988; Ercan et al., 1990, 1992; Aydar et al., 1994; Le Pennec et al., 1994; Temel et al., 1998; Schumacher and Mues-Schumacher, 1996). Accordingly, the CVP is a calc-alkaline volcanic province whose formation is attributed to the convergence between Eurasian and Afro-Arabian plates occurring in the eastern Mediterranean.

Main geological units in CVP are the Pre-Mid.-Miocene basement rocks, Lower Miocene-Pliocene continental clastics, Lower Miocene-Quaternary volcanoclastics and volcanic complexes and Quaternary fluvial deposits (Fig. 1) (Toprak, 1998). The study is mainly concentrated on Hasandağ, Keçiboyduran, Melendiz and Tepeköy volcanic complexes.

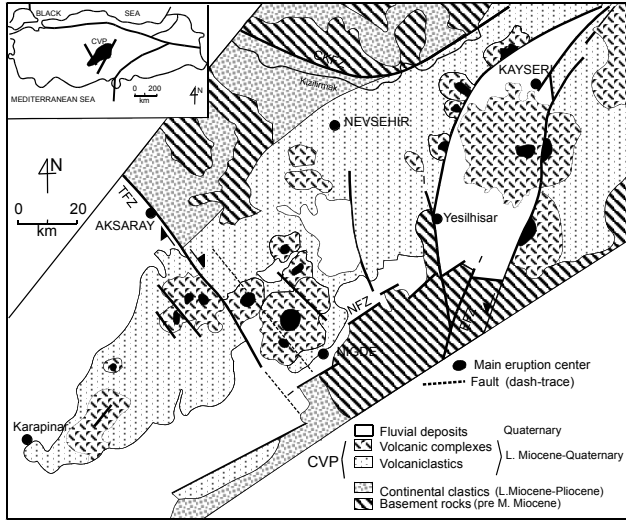


Figure 1. Geological setting of the Cappadocian Volcanic Province (Toprak, 1998).

1.2 Data and Study Area

The study area is included within the Cappadocian Volcanic Province between Niğde and Aksaray (Fig. 2). It covers the central portion of the province from Hasandağ to Melendiz Mountain, the 1:100.000 scaled map sections of L32, L33, M32 and M33.

The study area corresponds to a mountain belt that extends almost in E-W direction. Total length of the area is 45 km and the width is 30 km. The highest peak of the area is Hasandağ with an elevation of 3227 m. Average elevation of the plains surrounding the belt is about 1000 m. The relief map clearly displays that the Hasandağ, Keçiboyduran and Melendiz volcanic complexes have very high topographic relief easily distinguished from the low lying background.

Thematic Mapper (TM) images of Landsat 5 satellite are used throughout the analysis. The area of interest is included within the image 176/34.

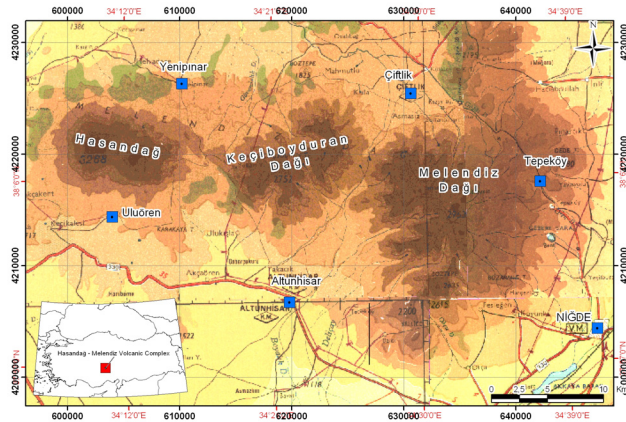


Figure 1. Location and topography map of the study area. (Coordinates in black, are Universal Transverse Mercator (UTM) zone 36 coordinates with European 1950 datum; red ones are longitude and latitude)

TM bands of 1,2,3,4,5 and 7 are used extensively in most of the processes and the Thermal Infrared band of 6 is used only in a color composite. The whole image having 2984 lines and 4320 columns of pixels is extracted to have a subscene of the study area having 1172 lines and 1996 columns; in order to minimize the disturbance of the unrelated pixels.

Furthermore, the volcanic units mapped in the area are separated from the surrounding units to better highlight the intended output maps. Geological map prepared by Toprak (1998) used as the reference guide for masking out the non-volcanic units. The boundary between the volcanics and fluvial deposits is drawn manually as a polygon. The units outside this polygon are simply cropped by using the TNT MIPS software.

The laboratory spectrum data for the minerals are gathered from USGS spectral library. As there are many spectrum data available for a specific mineral, the one which represents the other spectrums tried to be selected.

1.3 Preprocessing

Geometric corrections are performed to eliminate the systematic and non-systematic distortions related with the physical and geometric conditions of the scanning devices. The remote sensor data that is commercially available is already systematic error removed, however non-systematic error remains in the image (Jensen, 1996). The image data is accepted as free from geometric errors.

TM bands 1,2 and 3 are correlated with the band 7 and the haze amounts are decided. In the graph x-axis is the band1 and y-axis is the band7 grey levels. Band 7 values start from very near to 0 whereas band 1 values start from 52, showing that the pixels are displayed over-reflectant by this much, which known as a radiometric error caused by the atmospheric transmission. Two bands are highly correlated after the grey level of 52. This amount is subtracted from the band 1 reflectance data to remove this error.

2. METHODOLOGY

During the analysis a simple to complex step-wise path is followed. Each analysis result is compared with the previous one. Conventional methods like color composites, several band rationing techniques, principle components analysis (PCA) and least squares fitting (multilinear regression) are applied to the original unregistered raw data. Then the spectral library data used to analyze the images by means of alteration minerals. The resulting images are considered to be the potential alteration maps. If the results display any convergence with the data acquired from previous works then the final (combination) map of all techniques is registered and processed and prepared for the ground truth. The geology of the area is gathered from the published maps and mostly forms the basis of the ground truth data. Lastly according to the ground-truth study the applied techniques are criticized to have the final conclusion (Fig. 3).

2.1 Conventional Analysis

Conventional analysis techniques include the image processing techniques that are literally found to map the information

regarding the alteration of rocks. These conventional well-known methods include color composite method, band rationing method, principal component analysis and least squares fitting method.

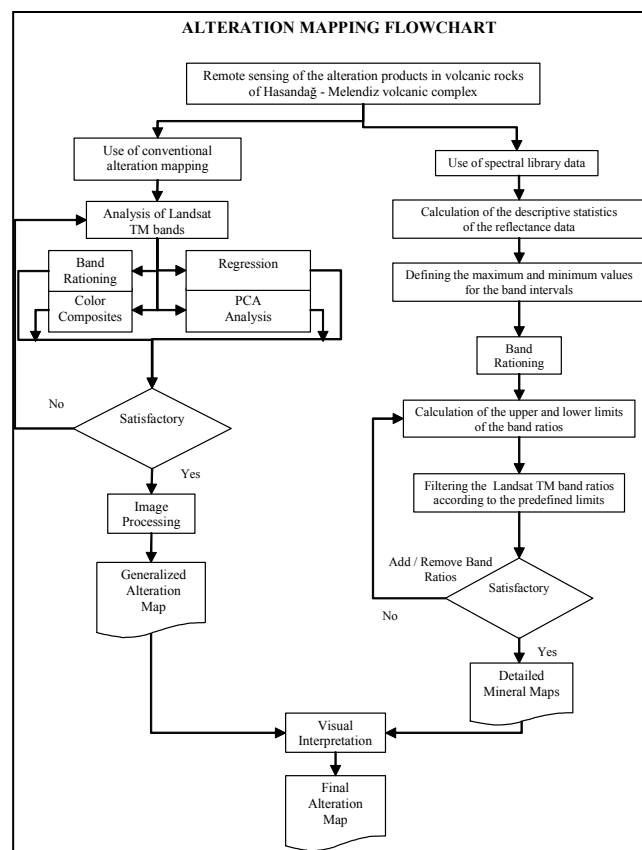


Figure 3. Flow chart of the study.

2.1.1 Color Compositing: Color composite method is simply the decision of the order of bands to be displayed in red, green and blue channels. The concept surely forms the basis of the other methods. Methods are summarized in Table 1.

No image correction has been made prior to the processes. Images that are selected to be displayed as a composite are normalize type contrast stretched. Visually, normalized contrast enhancement gives better results than linear contrast stretching. That is because the stretching transformation is performed varyingly according to the histogram density in normalizing contrast enhancement.

As it is clearly observed, the color composite method is a fast but not that detailed enough to map the certain borders for alteration types. Only general information is mapped. The procedure of assigning the bands to the display channels is the same in the other methods, changing the input bands to be displayed.

2.1.2 Band Rationing: Band rationing is the selection of the bands, rationing to get the desired information and the meaningful order of display of these ratios. Spectral characteristics of the

RGB display of respective TM bands	Red correspondent	Green correspondent	Blue correspondent	Extra
4 : 7 : 6	Structural lineament differentiation	Hydrothermal alteration	Temperature contrast	
7 : 5 : 4	Hydrothermal alteration and intrusives	Gabbro	Vegetation	
7 : 4 : 2	Clay minerals are brighter than the others	Vegetation		Radiometric correction is important
4 : 7 : 5	Vegetation	Clay minerals are brighter	Clay minerals are brighter	Radiometric correction is important
7 : 4 : 2	Granites, FeO, MnO displayed as reddish brown areas	Monzogranite in grayish-green	Sedimentary units in bluish-grey	Sedimentary and volcanic units are separated
4 : 7 : 2	Background is pink	FeO is yellow-green		
4 : 7 : 3	Background is orange-red	FeO is yellow-green		

Table 1. Properties of some color composites.

minerals are used for deciding the pairs of bands to be rationed. Prior to the process no correction has been made to the images unless stated. Results are summarized in Table 2.

Band ratio technique is based on highlighting the spectral differences that are unique to the materials being mapped. As the resulting image will have ratios instead of grey levels, the image is normalize contrast stretched to be able to display 256 grey levels.

RGB display of respective TM band Ratios	Red correspondent	Green correspondent	Blue correspondent	Extra
5/7 : 3/2 : 4/5	Clay-rich areas	FeO rich areas		Yellow, orange areas both clay and FeO rich
7/4 : 4/3 : 5/7	Minerals containing iron ions	Vegetated zones	OH ⁻ /H ₂ O ⁻ , SO ₄ ⁻ or CO ₂ -bearing minerals	
3/4 : 5 : 5/7				FeO as apricot yellow and the background as sky-blue
5/7 : 5/4 : 3/1	Clay minerals	Iron minerals	Ferric oxides	
3/1 : 5/7 : 4/5				Highly altered zones dark-blue to violet-blue

Table 2. Summary of band ratio composites.

2.1.3 Principal Component Analysis: The Principal Components process uses the principal components transformation technique for reducing dimensionality of correlated multispectral data. The technique is used widely with a few to many correlated rasters to create a lesser number of objects.

Information from six bands of thematic mapper (TM) imagery is transformed to three processed images that contain virtually all of the variance from the set of input objects in this method. The three output bands can be displayed simultaneously as components of an RGB display, which is easier to interpret than the raw data. Also, transformation sometimes enables you to see details that were obscured in the raw data.

Reducing the number of spectral bands input for principal component analysis ensures that certain materials will not be mapped and increases the likelihood that others will be unequivocally mapped into only one of the principal component images. The methodology is called Crosta Technique. The method does not require detailed knowledge of the spectral properties of target materials; also no atmospheric or radiometric correction is needed. PCA on raw, unstretched data is found to be effective in all cases. Resulting images produced by PCA were judged and found to be accurate in delineating alteration zones (Fig. 4).

Feature Oriented Principal Components Selection is based on the examination of PCA eigenvector loadings to decide which of the principal component will extract information directly related to the theoretical spectral signatures of specific targets. The methodology relies specifically on the selective input of only four image bands for PCA. This technique performed by using four selected TM bands in order to highlight the spectral response of iron-oxide minerals (absorption in visible TM bands 1 & 2 and higher reflection in TM3) and hydroxyl-bearing (clay) minerals (absorption in TM7, higher reflectance in TM5).

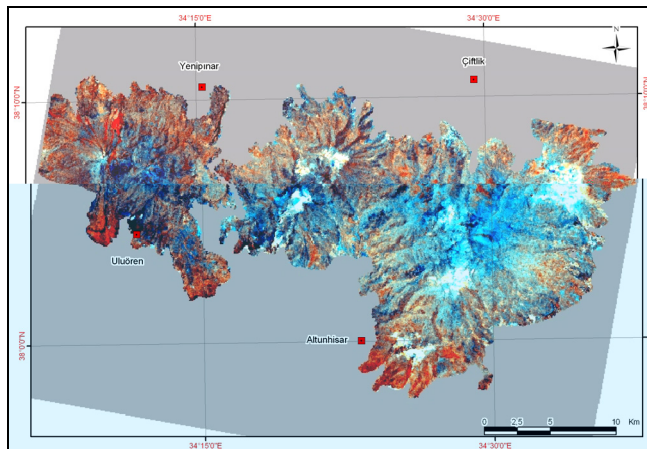


Figure 4. Color composite of Crosta H, H+F and F as RGB.

2.1.4 Least Squares Fitting Method: The technique assumes that the bands used as input values are behaving as the variables of a linear expression. And the 'y' value of the equation, namely the predicted band information, gives us a calculated output value. This predicted band is what that band should be according to the linear equation. The problem of having vegetation responsible of some reflectance in the bands that are used to map clay minerals can therefore be omitted by using this technique. The vegetation is mapped in the predicted band with the values that are calculated just by using the reflectance information in the other bands. The minerals which are sensitive to a specific band are then differentiated from the features which are reflective to the other bands as well; just by taking the difference between the predicted values and the original values. Calling this difference, the residual, color composites are displayed with the specific anomalously reflective features and then interpreted (Fig. 5) (Clark et al., 1990).

2.2 Mineral Mapping by using Spectral Reflectance Data

The technique is purely based on the band rationing process. More than the band selection criteria, a filtering script based on the statistical calculations is developed. The technique can be summarized as in a flow chart in Figure 6.

Spectral reflectance data of the alteration minerals is statistically processed according to the TM band intervals. Descriptive statistics like the minimum, maximum, mean and standard deviation are calculated for the TM band intervals separately for every mineral.

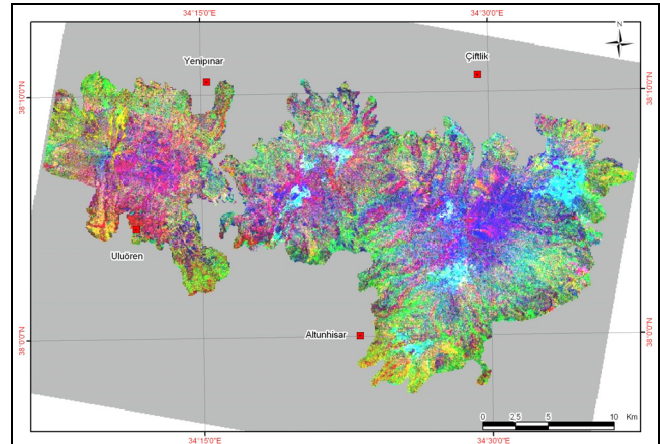


Figure 5 Color composite of LS-Fit. residual bands 3, 7 and 1 as RGB.

P-P and Q-Q plots are analyzed to obtain information about the distribution type of the data belonging to the band intervals for every mineral. Generally data is found to be normally distributed. For all of the data it is therefore assumed to be normally distributed, although it is not an accurate assumption for the whole data.

Two standard deviations are added to the mean value to have the upper limit and subtracted to have the lower limit of the mineral mask that is used to filter the band ratios.

The analysis performed in this section includes the processing and filtering of selected alteration minerals which are Kaolinite, Illite, Montmorillonite, Pyrophyllite, Alunite, Orthoclase, Quartz, Epidote, Chlorite, Hematite, Goethite and Jarosite. Basically band ratio technique is applied and filtered according to the statistically calculated ratio intervals for these minerals. Band ratios are selected according to the spectral curves, band combinations that will give distinctive ratios (very high or very low) are preferred. In Figure 7 Kaolinite pixels are mapped that have passed from the filter.

2.3 Accuracy Assessment

The pixels in the reference image and the image obtained after spectral analysis method are correlated to calculate the percentage accuracies (Table 3). Counted pixel values are shown in the table. Accordingly the (1,1) value is the pixels both mapped in the original data and in the spectral analysis result; (0,1) is the pixels displayed by original and missed by the analysis; (1,0) pixels are displayed only by analysis result and not exist in the original data and value of (0,0) are the pixels both did not displayed by original data and analysis result. Overall accuracy is calculated as % 79,7.

Correlation Matrix		Original Data		Total	Error of Commission	User Accuracy
		1	0			
Spectral Analysis Result	1	10000 px (1,1)	5814 px (1,0)	15814	36,76	63,24
	0	13428 px (0,1)	65535 px (0,0)	65535	17	83
Total		23428	71349	94777		
	Error of Omission	57,32	8,15			
	Producer Accuracy	42,68	91,85			

Table 3. Accuracy assessment matrix

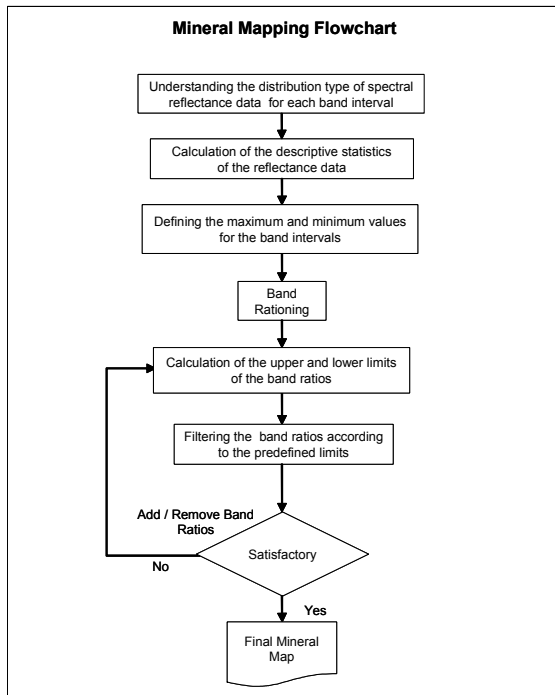


Figure 6. Flow chart of the mineral mapping technique.

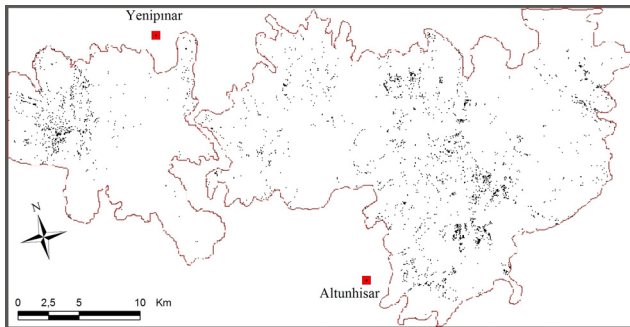


Figure 7. Band4/Band1 ; Band4/Band7 ; Band5/Band7 are filtered for Kaolinite according to the upper and lower limits. Passed values are displayed as black pixels.

3. CONCLUSION

All of the conventional methods agree that the volcanic eruption centers of Tepeköy, Keçiboyduran and Melendiz volcanic complexes are highly altered having both clay and iron oxide minerals and away from the centers, iron oxide zone is mapped in PCA and Ls-fit. techniques.

The proposed method aimed to map the alteration minerals individually. Statistical method of filtering the band ratios is tested and found to be very accurate with the vegetation data. For every mineral 30 combinations of band ratios are present. Bands that are likely to give high ratios are selected for the filtering process. Although some of the previously known clay altered areas could not be mapped, in general the results were coincident with the previously applied methods. Detailed mineral maps are obtained as outputs of this method.

The resulting mineral maps are grouped for ironoxide minerals and clay minerals separately. Main ironoxide-rich areas are mapped in Tepeköy, Melendiz and Keçiboyduran volcanic centers and along a north-south trending linear path in the west of Keçiboyduran volcanic center. This linear concentration overlaps with the buried fault in the same area (Yetkin, 2003).

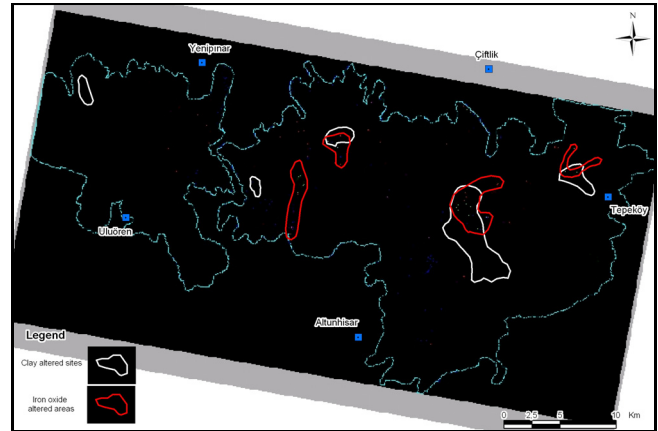


Figure 8. Areas that are both clay and iron oxide altered by mineral mapping method.

Clay-rich areas are mapped in Melendiz volcanic center, in the Tepeköy volcanic center, in the northwest flanks of Hasandağ complex and a small area between Keçiboyduran and Hasandağ volcanic complexes directed along Tuzgölü fault zone.

Melendiz volcanic center is mapped as both clay and ironoxide altered, where small areas of Tepeköy and Hasandağ volcanic complexes are mapped as ironoxide altered only.

However there are significant intersections with the conventional methods' outputs and mineral mapping method outputs, Tepeköy volcanic center, mapped as both clay and ironoxide rich in classical ways, is mapped as more fresh by the spectral analysis method (Fig. 8).

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