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Determination of Tectonic and Volcanic Structures with the aid of Lineaments: Example from Çan-Etili (Canakkale) Lignite Basin

Çizgisellikler Yardımı ile Tektonik ve Volkanik Yapıların Belirlenmesi: Çan-Etili (Çanakkale) Linyit Havzası Örneği

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Abstract: In this study, the aim is to determine the volcanic and tectonic structures developed in the "Çan-Etili Lignite basin" with the aid of satellite images. The Çan-Etili lignite basin consists of Oligocene-Early Miocene volcanics (Çan Volcanics) overlying early-Middle Miocene lignite-bearing stream and lake sediments (Çan formation) occurring above an unconformity. In order to complete this study, two different satellite images (ASTER and ALOS-PALSAR) and a digital elevation model (DEM) of the region were used. Multispectral optical remote sensing data provide information about material composition, while radar data reflect surface topography and morphology better. During mapping of lineaments on satellite images, in addition to visual assessment, image processing techniques were used. A variety of orientation filters were applied to ASTER satellite images for lineament mapping. The lineaments on PALSAR images were determined with visual methods.

Using DEM data along with ASTER and PALSAR satellite images for the study area, lineaments were mapped. The results were shown that a significant portion of the lineaments had NE-SW strike. This orientation coincides with the NE-SW striking Çan-Etili fault. Additionally, some curved linear structures were obtained from satellite images and are interpreted to be associated with caldera development.

Keywords: ALOS/PALSAR, ASTER, lineament analysis, Çan-Etili basin, volcanic structures

Öz: *Bu çalışmada, Çan-Etili Linyit havzasında gelişmiş volkanik ve tektonik yapıların uydu görüntüleri yardımıyla belirlenmesi amaçlanmıştır. Çan-Etili linyit havzası, Oligosen-Erken Miyosen yaşlı volkanitler (Çan Volkanitleri) ile üzerine uyumsuz olarak gelen erken-Orta Miyosen yaşlı linyit içerikli akarsu ve göl tortullarından (Çan formasyonu) oluşur. Bu çalışmayı gerçekleştirebilmek için iki farklı uydu görüntüsü (ASTER ve ALOS-PALSAR) ve bölgenin sayısal yükseklik modeli (SYM) kullanılmıştır. Multispektral optik uzaktan algılama verileri, materyal bileşimi hakkında bilgi sağlarken radar verileri, yüzeysel engebe ve morfolojiyi daha iyi yansıtmaktadır. Uydu görüntülerinde çizgiselliklerin haritalanması sırasında görsel değerlendirmenin yanı sıra görüntü işleme teknikleri de kullanılmıştır. Çizgiselliklerin haritalanması için ASTER uydu görüntülerine çeşitli yönlü filtreler uygulanmıştır. PALSAR üzerindeki çizgisellikler görsel yöntemlerle belirlenmiştir. Çalışma alanında SYM verisi ile ASTER ve PALSAR uydu görüntüleri kullanılarak, çizgisellikler haritalanmıştır. Bu sonuçlara göre çizgiselliklerin önemli bir bölümü KD-GB doğrultusunda olduğu görülmüştür. Bu yönelim KD-GB doğrultulu Çan-Etili fayı ile uyumludur. Bunun yanında, uydu görüntülerinden elde edilen bazı kavisli çizgisel yapılar, kaldera gelişimi ile ilişkili olarak yorumlanmaktadır.*

Anahtar Kelimeler: *ALOS/PALSAR, ASTER, Çan-Etili havzası, çizgisellik analizleri, volkanik yapılar*

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INTRODUCTION

Remote sensing methods have provided great convenience for a variety of research in the earth sciences. The use of these methods in research reduces the cost and time required for field studies and increases the quality and accuracy of the results obtained. One of the topics where remote sensing is commonly applied in the earth sciences is lineament analysis. Lineament analyses have a unique and important place in mineral research and in preparations of geological maps.

Remote sensing techniques are commonly used to investigate volcanic areas of the earth (Okada and Ishii, 1993; Ramsey et al., 2004; Permenter and Oppenheimer, 2007; Saepuloh and Trianaputri, 2015). Careful analysis of spectral reflections, textures and topographic data on images provides information about paleovolcanology and lithology. Geological mapping in volcanic areas is very important to provide accurate information related to volcanic products and distribution of structures related to volcanos. Volcanic mapping does not just provide information related to volcanic activity, at the same time it provides basic information for determination of natural resources in scientific research (Saepuloh et al., 2016).

Lineament mapping, especially in construction (dams, bridges and roads), geothermal and mineral exploration and hydrological research, appears to be a very important topic in solving engineering problems with site location (Sukumar et al., 2014). Regional-scale studies and automatic mapping of linear structures like faults, fractures, folds, dykes, crustal fractures and remotely sensed lithological unit contacts have been performed in the last few decades. Faults are observed as linear or curved structures on satellite images. Structures like this with different contrast are assessed as linear structures and lengths can extend from a few meters to kilometers (Sukumar et al., 2014).

Though there are different definitions of lineaments, in a general sense they are defined as mappable linear structures on the earth's surface. Lineaments show structures like fractures, joints and faults and indicate many geological situations. One of these is volcanic structures and investigating lineaments helps to determine volcanic structures like cones, volcanic domes and calderas, etc.

The main aim of this study is to reveal the presence of correlations between paleotectonic and neotectonic lineaments in the Çan-Etili (Turkey) region in the Biga Peninsula and volcanic structure using satellite images. With this aim, two different satellite images (ASTER and ALOS-PALSAR) and the digital elevation model (DEM) of the region were used. Lineaments derived from satellite images coincided with geological units and fault lines in the study area. In this study, structures created by both volcanism and tectonism, such as lineaments caused by subsidence fractures at the edges of calderas and lineaments occurring due to fractures formed by regional tectonism were mapped and the emphasis was on the benefits of using remote sensing and geological research together.

Study Area

The study area encompasses the region north of the Kazdağ rise in the Biga Peninsula (northwest Anatolia) around the Çan-Etili lignite basin (Figure 1). The Çan-Etili lignite basin has generally smooth morphology (with elevations varying from 120-200 m). Around this plain, with roughly circular placement, there are morphological ridges constructed generally of volcanic rocks with mean elevations from 400 to 700 m.

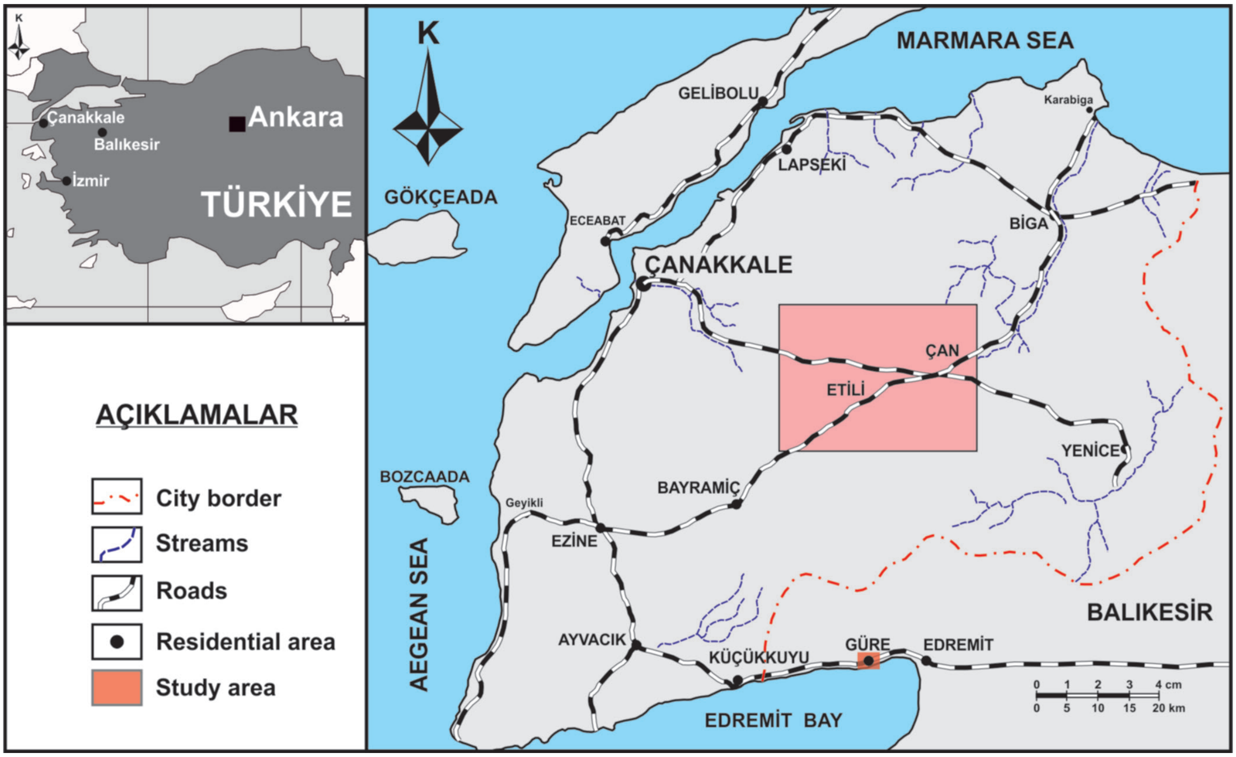

Figure 1. Location map of the study area.
Şekil 1. *Çalışma alanının yer bulduru haritası.*

Geology of the study area

The basement of the Çan-Etili basin comprises the Upper Cretaceous Çetmi ophiolitic melange containing Triassic-Jurassic and Cretaceous limestone blocks and rare serpentinite blocks and the Oligo-Miocene "Çan volcanics" containing volcanic rocks and volcanoclastics (Okay et al., 1990; Ercan et al., 1995). The Çan volcanics (Ercan et al., 1995), the Çan Formation comprising clastic and lacustrine sediments containing lignite (Hezarfen, 1976) and the Kulfa Formation (Balkış and Yazıcı, 1996) occur above the Çetmi ophiolitic melange. The Çan Formation comprises conglomerates, sandstones, bituminous shale, organic claystone, lignite, mudstone and agglomerate. It was deposited in a fluvial and lacustrine environment. All of these units are overlain by Quaternary alluvium (Figure 2).

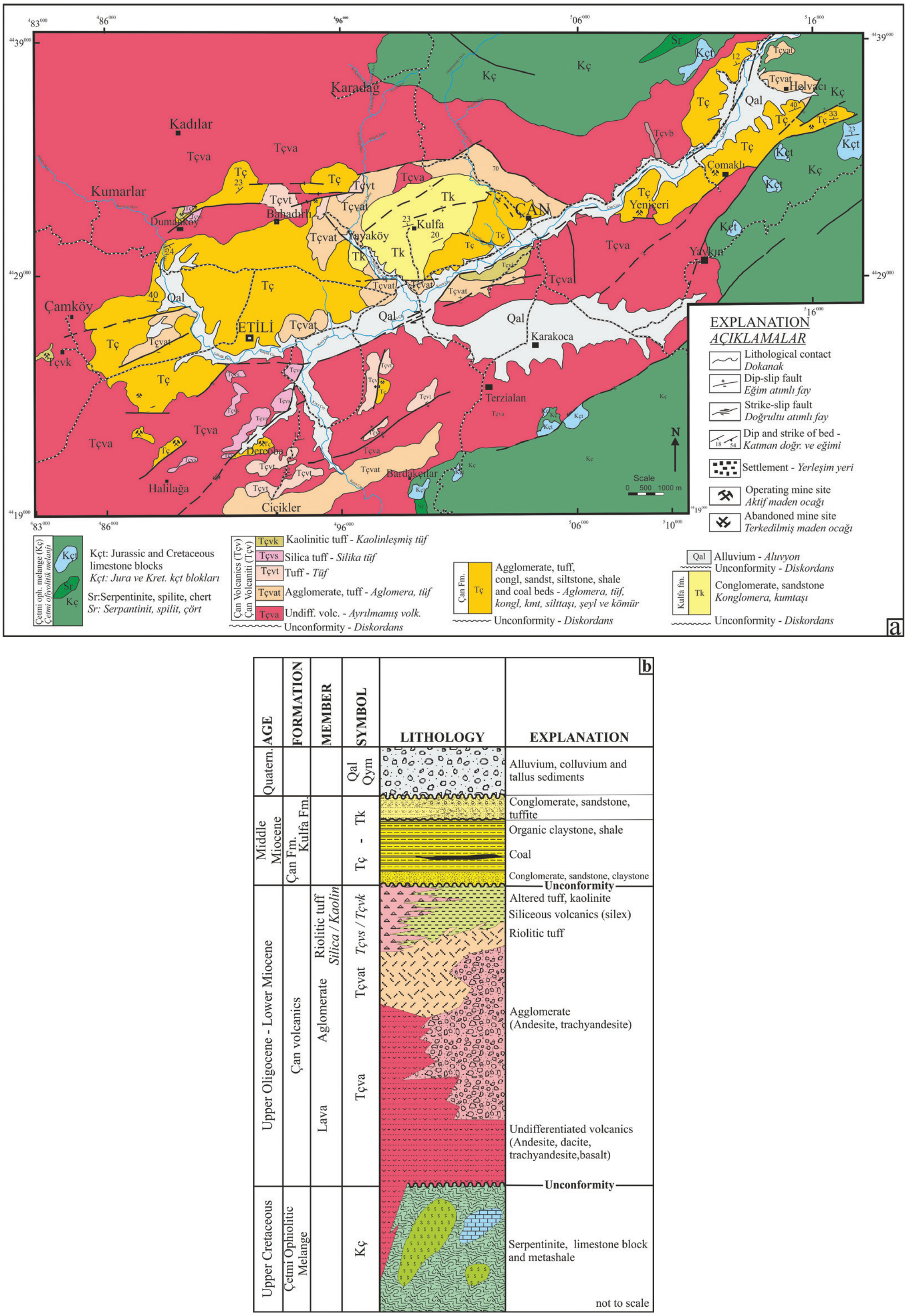

Figure 2. a) Geological map and b) Stratigraphic columnar section (Bozcu et al., 2008; Bozcu et al., 2015) for the study area.

Şekil 2. *Çalışma alanına ait a) Jeoloji haritası ve b) Stratigrafik kolon kesit (Bozcu vd., 2008; Bozcu vd., 2015).*

During field studies, two groups of faulting were identified according to source and development time in the Çan-Etili lignite basin and surroundings. These were a) synsedimentary growth faults and b) postsedimentary tectonic-sourced faults. During the geological mapping stages and during investigation of drill cores from Turkish Coal Enterprises (Türkiye Kömür İşletmeleri-TKİ), correlations showed these faults generally had NE-SW, E-W and NW-SE strike (Figure 3). With these faults, beds in the Çan formation have dips of 10-80°. Beds in sections close to the fault planes have higher dips and slump folds are commonly observed (Bozcu et al., 2008; Bozcu et al., 2015).

The Biga-Çan-Etili Fault observed in the Çan-Etili lignite basin is a member of the lateral strike system (NAFZ) affecting the region in the Plio-Quaternary period. This fault caused ground displacement and disruption in sedimentary units and coal levels in the lignite basin.

MATERIALS AND METHODS

Within the scope of this study, volcanic and tectonic structures in the Çan-Etili basin were determined using two different types of satellite images. The satellite images used with this aim were multispectral ASTER (advanced space borne thermal emission and reflection radiometer) and ALOS-PALSAR.

In addition to the satellite images, a digital elevation model (DEM) was used with the aim of determining lineaments during the study.

ASTER

ASTER was launched by NASA in 1999 on the Terra satellite and is a 14-band wavelength multispectral sensor. One frame area is 60x60 km (Abrams and Ramachadram, 2003). With high resolution multispectral ability, ASTER images have been used as a tool to reveal volcanic activity (Pieri and Abrams, 2004).

Figure 3. View of Çan-Etili fault in the field.
Şekil 3. *Çan-Etili fayının arazideki görünümü.*

The ASTER system includes three different subsystems. These are the very near infrared (VNIR), shortwave infrared (SWIR) and thermal infrared (TIR). The VNIR subsystem (0.52-0.86 mm) includes four bands with 15 m ground resolution. Other characteristics of the 3 ASTER sensor systems were tabulated in Table 1. In this study VNIR bands from ASTER images bought from Nik System Company on 09/03/2006 were used. The whole frame ASTER image used in this study is shown in Figure 4.

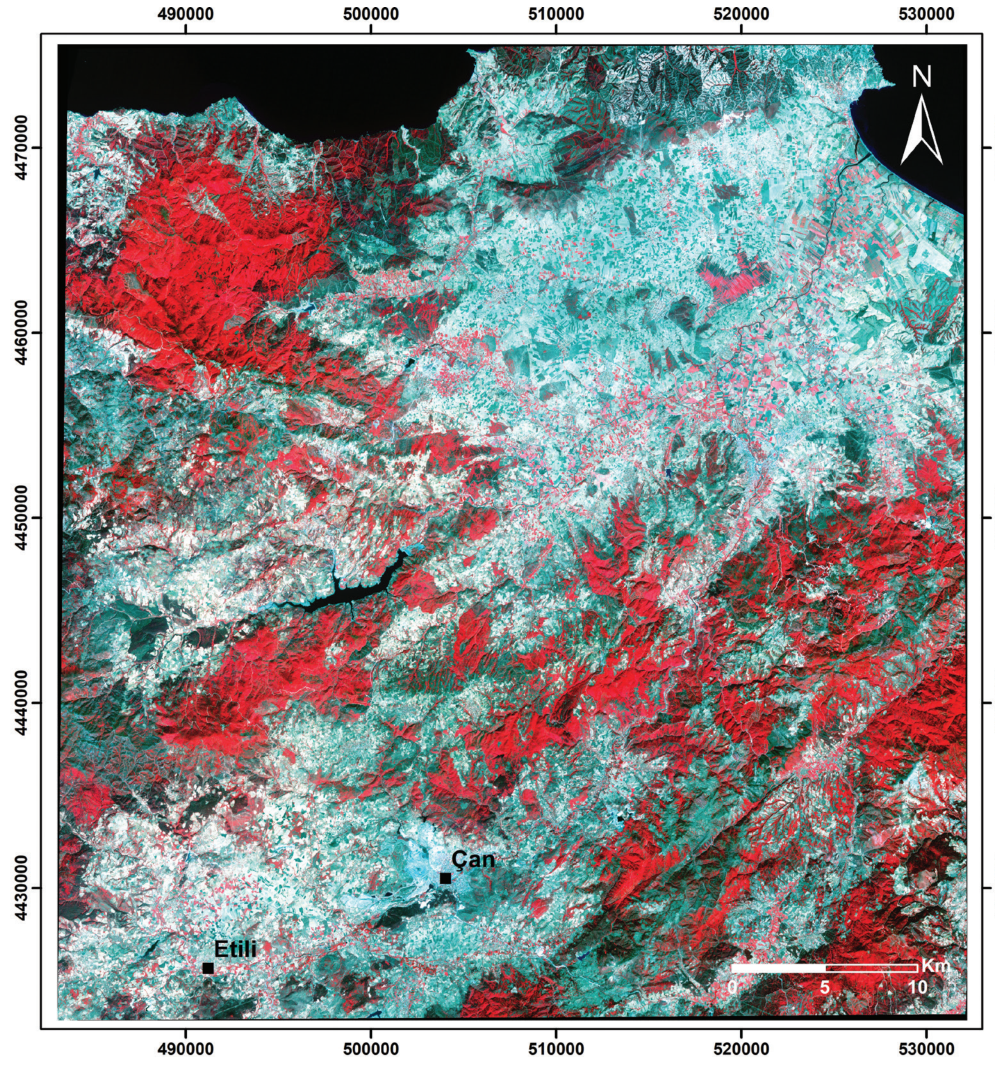

Figure 4. ASTER satellite image used in the scope of the study (321-RGB).
Şekil 4. *Çalışmada kullanılan ASTER uydu görüntüsü (321-RGB).*

Table 1. Characteristics of the three ASTER sensor systems (Abrams and Ramachadram, 2003).

Çizelge 1. *Üç ASTER sensör sistemine ait özellikler (Abrams and Ramachadram, 2003)*

Subsystem	Band No.	Spectral Range (µm)	Spatial Resolution (m)	Quantization Levels
VNIR	1	0.52-0.60	15	8 bits
	2	0.63-0.69		
	3N	0.78-0.86		
	3B	0.78-0.86		
SWIR	4	1.60-1.70	30	8 bits
	5	2.145-2.185		
	6	2.185-2.225		
	7	2.235-2.285		
	8	2.295-2.365		
	9	2.360-2.430		
TIR	10	8.125-8.475	90	12 bits
	11	8.475-8.825		
	12	8.925-9.275		
	13	10.25-10.95		
	14	10.95-11.65		

ALOS-PALSAR

The other satellite imagery used in the study is ALOS-PALSAR (Advanced Land Observing Satellite-Phased Array type L-band Synthetic Aperture Radar). PALSAR is one of 3 sensors on ALOS (PRISM, ANVIR-2, PALSAR) and is completely different to ASTER as it produces radar images (Table 2). Radar images are formed by both the amplitude and phase values of electromagnetic waves reflected from the imaged area. PALSAR is an active microwave sensor with the ability to make observations night and day regardless of weather conditions. In this study PALSAR image obtained on 10/06/2006 was used (Figure 5).

Table 2. PALSAR characteristics (Hamazaki, 1999)

Çizelge 2. *PALSAR'ın özellikleri (Hamazaki, 1999)*

Item	Specifications
Centre frequency	1270 MHz / 23.6 cm
Chirp band width	28 MHz (single polarisation) 14 MHz (dual, quad-pol., ScanSAR)
Transmission power	2 kW (peak power)
Pulse Repetition Frequency	1500 – 2500 Hz (discrete stepping)
Image modes	Single polarization (HH or VV) Dual pol. (HH+HV or VV+VH) Quad-pol. (HH+HV+VH+VV) ScanSAR (HH or VV; 3/4/5-beam)
Bit quantisation	3 or 5 bits (5 bits standard)
Off-nadir angle	Variable: 9.9 – 50.8 deg. (inc. angle range: 7.9 - 60.0) ScanSAR: 20.1-36.5 (inc. 18.0-43.3)
Look direction	Right
Yaw steering	ON
Swath width	70 km (single/dual pol.@41.5°) 30 km (quad-pol.@21.5°) 350 km (ScanSAR 5-beam)
Ground resolution Rg (1 look) x Az (2 looks)	~ 9 m x 10 m (single pol.@41.5°) ~ 19 m x 10 m (dual pol.@41.5°) ~ 30 x 10 m (quad-pol.@21.5°) ~ 71-157m (4 look) x 100m (2 look) (ScanSAR 5-beam)
Data rates	240 Mbps (single/dual/quad-pol) 120 or 240 Mbps (ScanSAR)

Digital Elevation Model (DEM)

The importance of morphology in the determination of tectonic and volcanic structures has been known for many years. Studies related to this topic have commonly used aerial photography and satellite images together and digital elevation models are used to support these studies (Heddi et al., 1999; Jordan et al., 2005).

Most tectonic studies using digital field models have used them with shaded embossed models alone or with regional-scale satellite images (Chorowicz et al., 1999; Collet et al., 2000). The benefits of these models used to determine lineaments and tectonic structures have been proven in many studies (Jordan, 2003; Ganas et al., 2005).

Within the scope of this study, contour curves every 10 m on coordinate-transformed 1/25.000 scale topographic maps were uploaded to a computer environment using ArcGIS version 9.2. Using this prepared digital topographic map, a digital elevation model was prepared for the study area and overlaid with hillshade images (Figure 6). Here, the circular lineaments attract attention. A similar circumferential structure is seen in the drainage network map of the region in Figure 7.

Lineament analysis

This term was first used in the study by Hoobs (1904) called "Atlantic Boundary Region Lineaments". Many definitions have been made related to lineament characteristics.

Lineaments are mappable simple or complex linear surface features reflecting probable underground structures that can be clearly distinguished from surrounding features (O'Leary et al., 1976). According to Hariri (1995), linear features that are visible on aerial photographs and satellite images are called lineaments. These

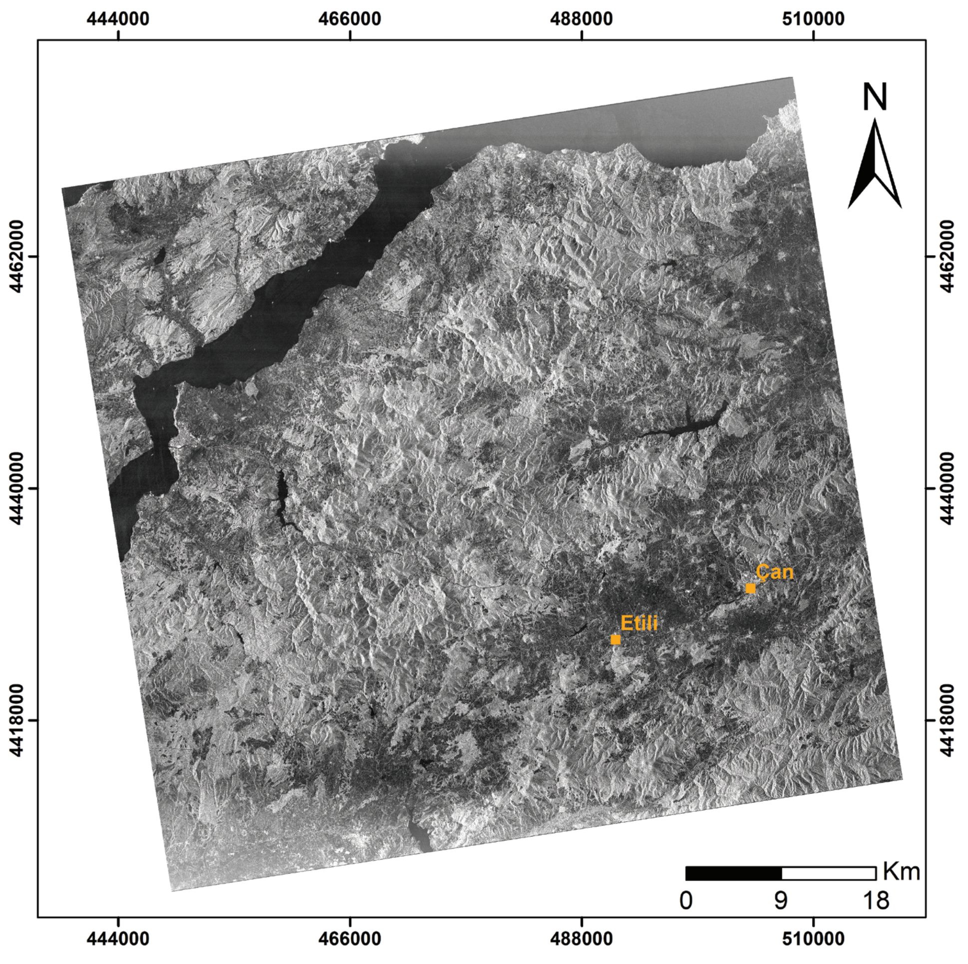

Figure 5. PALSAR satellite image used within the scope of the study.
Şekil 5. *Çalışmada kullanılan PALSAR uydu görüntüsü.*

linear features may be straight or curved and have different lengths. The majority of lineaments is associated with fractures and lithological boundaries, but may be related to relief in some situations and is distinctive on satellite images due to tone differences.

Aerial photographs have been used to identify lineaments for many years. Later, with the advances in remote sensing techniques, satellite images have become more preferable. Remote sensing techniques are commonly used to determine lineaments and provide very good results.

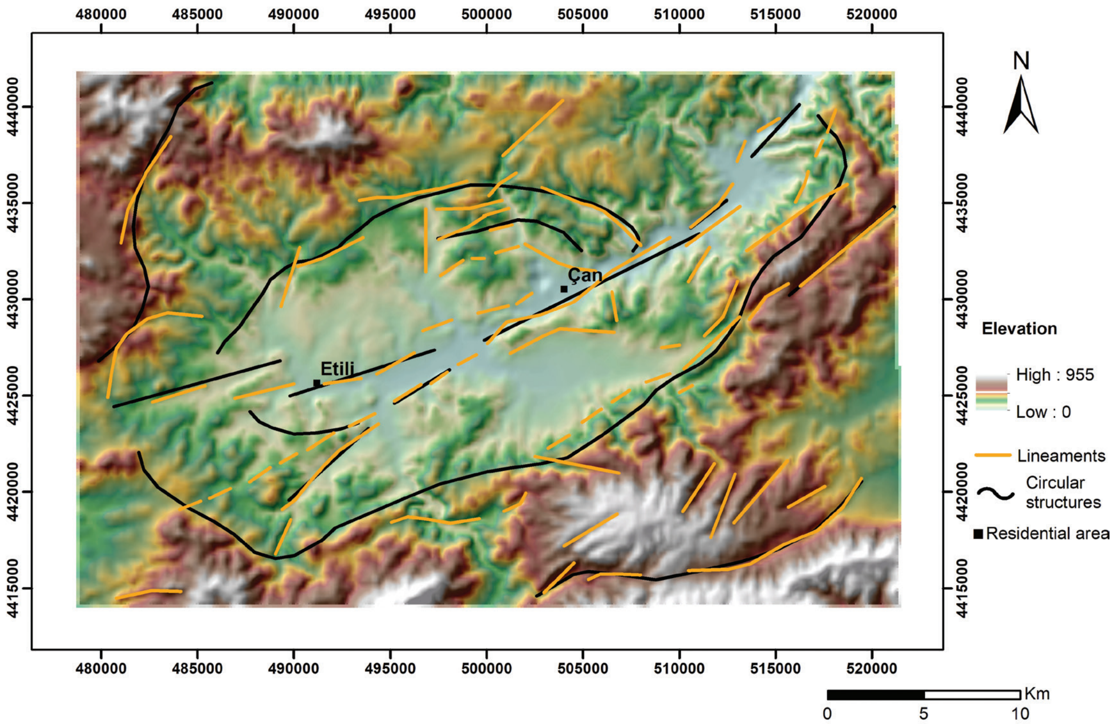

Figure 6. Appearance of circular lineaments and Çan-Etili (Çanakkale) fault with hillshade images on DEM of Çan and surroundings.

Şekil 6. *Çan-Etili (Çanakkale) ve çevresinin SYM ile hillshade görüntüsünde çembersel çizgiselliklerin ve Çan-Etili fayının görünüşü.*

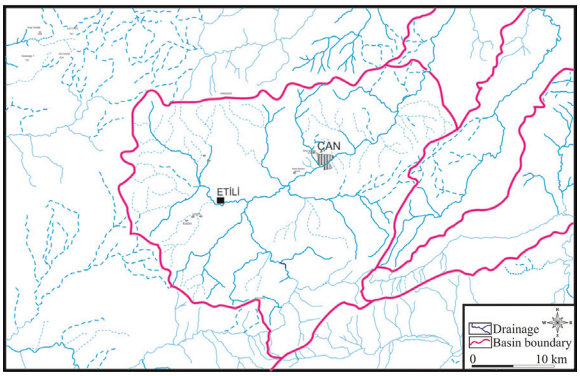

Figure 7. Drainage network map of the region.

Şekil 7. *Bölgenin drenaj ağı haritası.*

Though lineament analysis is a commonly used method in geological research (Süzen and Toprak, 1998; Över et al., 2004), lineaments do not only represent fracture lines, as valleys and ridges are also linear. Lineament analysis using satellite images can be beneficial to researchers in determining different structural elements and mineralization zones (Kavak and Çetin, 2007). They can provide ideas about groundwater assets and petroleum and mineral exploration may use satellite images. Within this context, as stated by many researchers, lineament mapping provides important information for geological studies in any region (Rowan and Bowers, 1995; Zakir et al., 1999). Lineaments may be equivalent to tectonic structures like folds and faults (Morelli and Piana, 2006; Oliveira et al., 2012). As a result, remote sensing techniques provide significant convenience and superiority for determination of active fault zones. Additionally, lineaments indicate many geological situations. Volcanic structures are one of these and investigating lineaments can be used to determine volcanic structures. For these studies volcanic geology mapping is needed to accurately determine and observe volcanic products. The study by Saepuloh et al. (2016) stated that classic problems like clouds, dense plant cover, excessive disruption and erosion in the study area generally prevented the identification and observation of volcanic products and structures. As a result, they researched the applicability of remote sensing techniques with the aim of supporting field observations in volcanic areas. For this, they used PALSAR satellite images with the aim of determining geomorphological and structural features.

In this study, lineaments in Çan (Çanakkale) and surroundings were mapped and the association between lineaments and volcanic structures in the region was determined. With this aim, ALOS-PALSAR and ASTER satellite images and DEM were used in the study area.

RESULTS AND DISCUSSION

Lineament analysis of the Çan-Etili Basin

As scientific and technological developments progress, remote sensing has made solving many geological problems easier. For geological studies, integration of optical, radar and digital elevation model data provides a large advantage.

In addition to visual assessment, automatic lineament identification techniques are used to map lineaments on satellite images. The state of the drainage provides important clues to determine the lineaments in a region. As a result, first it is important to carefully investigate drainage with visual assessment. Additionally, visual assessment of lineaments is also based on photographic features like color tone and texture and geomorphological features involving horizontal or vertical ground displacement like development of shape and layering in the field, vegetation, presence of fault surfaces, linear valleys, arrangement of triangular faces, landslides and river terraces. Lineament mapping is completed by working from this type of information.

A range of orientation filters can be used for lineament mapping. On Figure 8, color composites and lineaments are observed as a result of applying NW, E-W and N-S oriented filters to ASTER satellite images. Here, roads, field boundaries, and contacts have a linear appearance and may be confused with tectonic lineaments. As a result, it is necessary to be very careful when mapping lineaments on these images. It is always beneficial to perform controlled studies using other images and digital elevation models

Before lineament analysis on ALOS-PALSAR images, a range of image processing steps are applied. These are texture analysis, removal of parasites and edge determination/enhancement. For all these processes ERDAS-IMAGINE 9.2 software was used. After applying the Lee-sigma filter to PALSAR satellite images, the lineaments on these images were determined with visual methods (Figure 9).

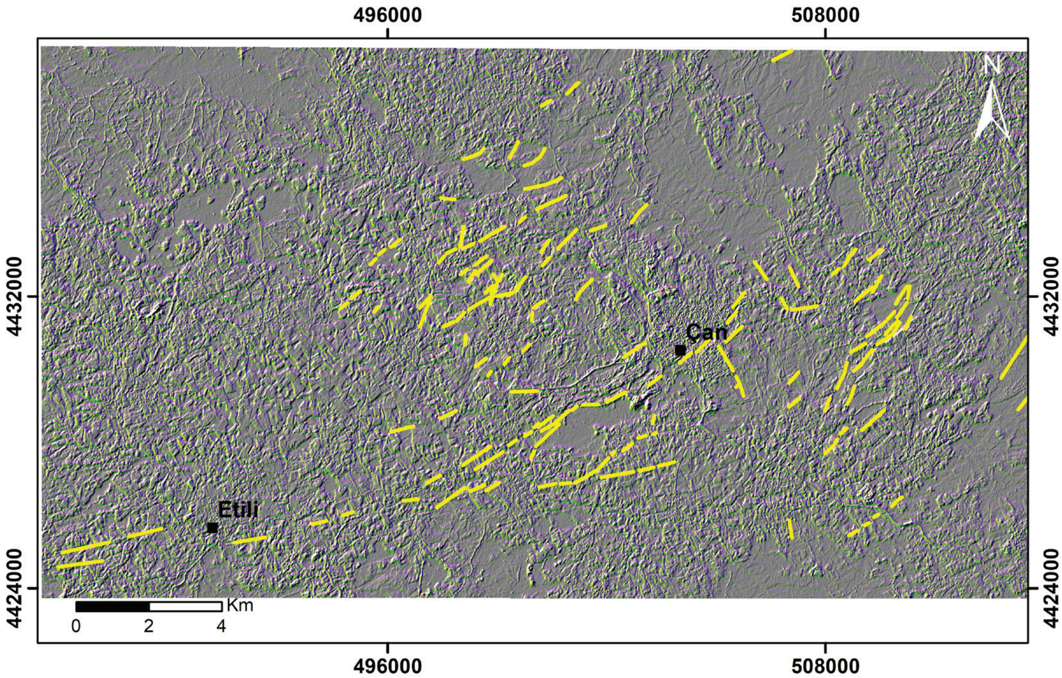

Figure 8. Color composite of NW, E-W, N-S (RGB respectively) filters applied to ASTER satellite images.
Şekil 8. *ASTER uydu görüntüsüne uygulanan KB, D-B, K-G (RGB sırasıyla) yönlü filtrelerin renkli kompoziti.*

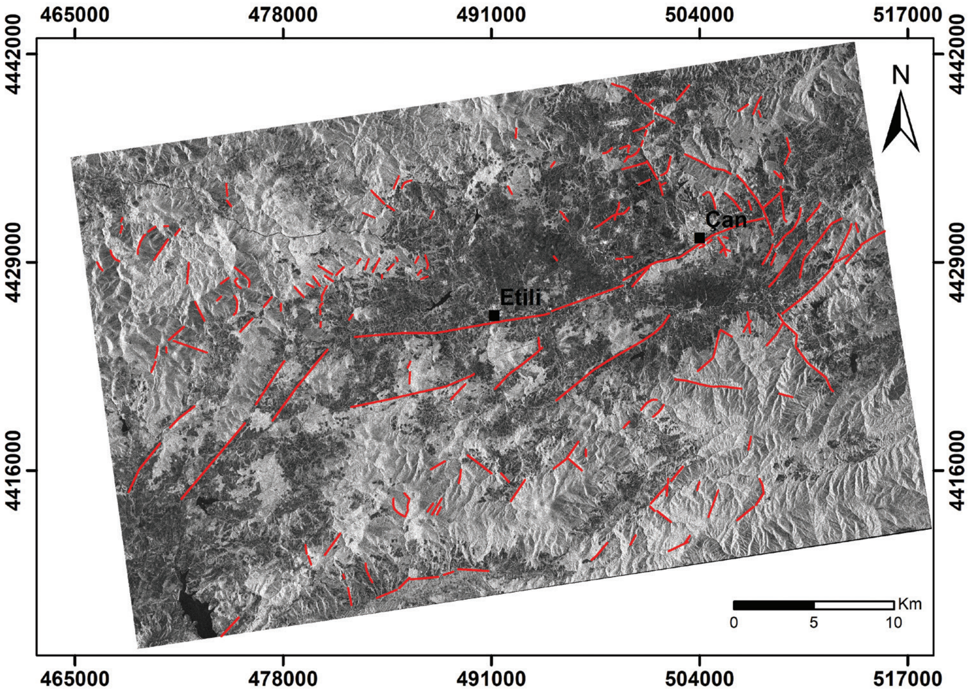

Figure 9. Lineaments drawn on PALSAR satellite images.
Şekil 9. *PALSAR uydu görüntüsü üzerine çizilmiş olan çizgisellikler.*

This study encompassing the Çan-Etili lignite basin determined two groups of faults within and around the basin based on development times. These are synsedimentary growth faults and postsedimentary tectonic faults. During field studies, the faults determined and correlated either during geological mapping stage or when investigating drill cores generally have NE-SW, E-W and NW-SE strike (Figure 10).

Lineaments in the study area were interpreted and mapped using different satellite images and methods. In terms of comparing the methods, Figure 11 shows the lineaments obtained from satellite images and the field working in the common area displayed with different colors. Here it appears the PALSAR satellite image was more effective in determining lineaments. A total of 156 lineaments were mapped in the study area. Here, the dominant orientation was determined as NE-SW and these lineaments coincide with the Çan-Etili fault.

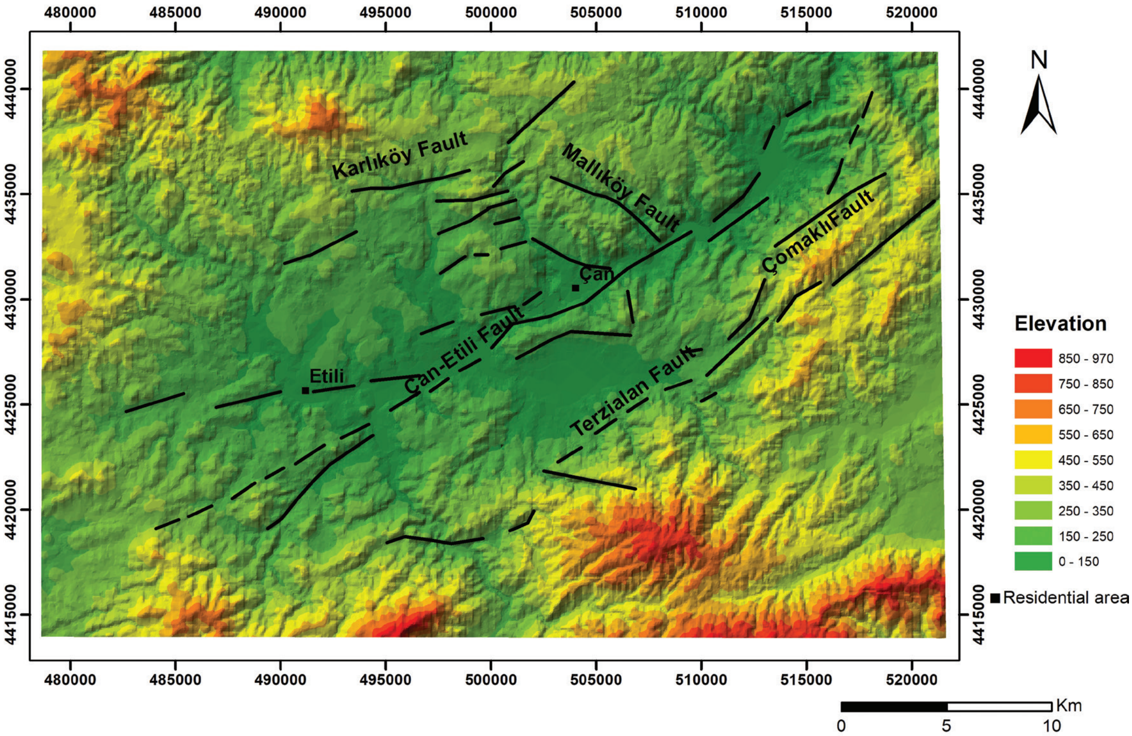

Figure 10. Location of faults drawn during field studies on a three-dimensional elevation model.
Şekil 10. *Çalışma alanında arazi çalışmaları ile çizilmiş fayların üç boyutlu yükseklik modelindeki konumu.*

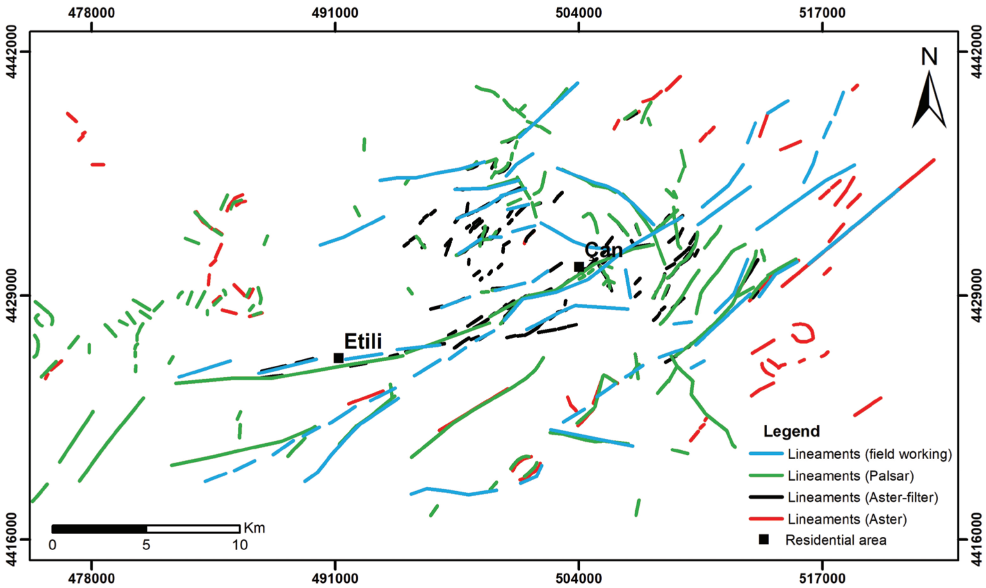

Figure 11. Lineaments in the study area.

Şekil 11. *Çalışma alanındaki çizgisellikler.*

The current morphological structure of the basin is a volcanic depression area (Figure 12). The development of this depression area has the characteristics of a caldera developing due to collapse of a volcanic output (crater).

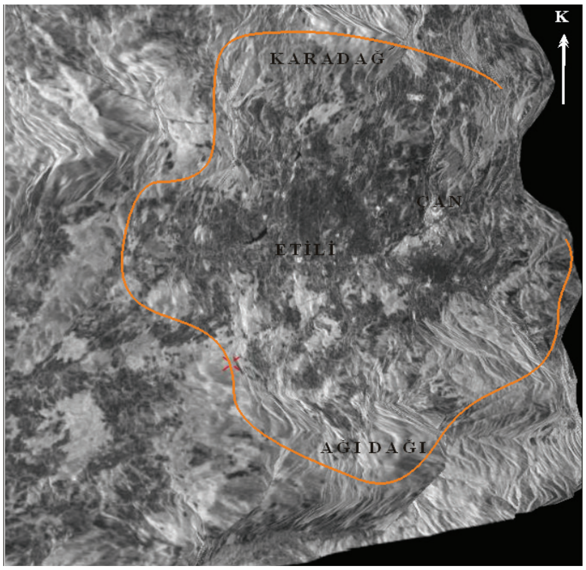

Figure 12. Three-dimensional land view of Çan Basin prepared using PALSAR satellite image.

Şekil 12. *Çan havzasının PALSAR uydu görüntüsü kullanılarak hazırlanan üç boyutlu arazi görünümü.*

CONCLUSIONS

Within the scope of this study, in addition to ASTER and PALSAR satellite images, DEM data was used to determine tectonic and volcanic structures with lineaments in the Çan-Etili region of the Biga Peninsula. With these data, 156 lineaments were mapped in the region assessed. The general orientations of lineaments are NE-SW and this coincides with the nearly NE-SW striking Çan-Etili fault. Some lineaments obtained from satellite images have NW-SE orientation and these again coincide with NE-SW striking faults found in a variety of regions in the study area. Some curved linear structures in the sediments in the Çan basin were interpreted as being associated with caldera development.

ACKNOWLEDGMENT

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GENİŞLETİLMİŞ ÖZET

Yerbilimlerinde yapılan çeşitli araştırmalarda uzaktan algılama yöntemleri büyük kolaylıklar sağlamaktadır. Bu yöntemler kullanılarak yapılan araştırmalar, arazi çalışmalarının masraflarını ve zamanını azaltırken, elde edilen sonuçların kalitesini ve doğruluğunu da artırmaktadır. Uzaktan algılamanın yerbilimlerinde sıklıkla uygulandığı konulardan birisi de çizgisellik analizleridir. Uydu görüntülerinde ve hava fotoğraflarında en göze çarpan özellikler, çizgisellikler olarak bilinen doğrusal şekillerdir. Çizgisellik analizleri, mineral araştırmalarında ve jeolojik haritaların hazırlanmasında özel ve önemli bir yer tutar.

Çizgisellikler; kırık, çatlak, fay gibi yapıları göstermekle birlikte pek çok jeolojik duruma işaret etmektedir. Volkanik yapılar da bunlardan biridir ve çizgisellikler incelenerek koni, volkanik dom, kaldera vb volkanik yapılar belirlenebilmektedir.

Dünyadaki volkanik alanların incelenmesi için uzaktan algılama teknikleri yaygın bir şekilde kullanılmaktadır (Okada ve Ishii, 1993; Ramsey ve diğ., 2004; Permenter ve Oppenheimer, 2007). Volkanik arazide jeolojik haritalama, volkanik ürünlerin ve volkanla ilgili yapıların dağılımı ile ilgili doğru bilgilerin sağlanması için çok önemlidir. Volkan haritası sadece volkanik aktiviteyle ilgili bilgi sağlamaz, aynı zamanda bilimsel araştırmalarda doğal kaynakların belirlenmesi için de temel bilgiler sağlamaktadır (Saepuloh, 2016).

Bu çalışmanın ana amacı, Biga Yarımadası'nda Çan-Etili (Türkiye) bölgesindeki paleotektonik ve neotektonik çizgisellikler ile volkanik yapılar arasındaki ilişkilerin varlığının uydu görüntüleri ile ortaya konulmasıdır. Çan-Etili linyit havzası, genellikle az engebeli bir morfolojiye sahip olmakla birlikte (yaklaşık 120-200 m arasında değişen yüksekliklere sahiptir), bu düzlük alanın etrafında yaklaşık çembersel konumlu ve ortalama yükseklikleri 400 m ile 700 m arasında değişen ve genellikle volkanik kayalardan yapılı morfolojik sırtlar bulunmaktadır.

Bölgedeki çizgisel yapıları belirlemek amacıyla iki farklı uydu görüntüsü (ASTER ve ALOS-PALSAR) ve bölgenin sayısal yükseklik modeli (SYM) kullanılmıştır. Uydu görüntülerinde çizgiselliklerin haritalanması için görsel değerlendirmenin yanı sıra filtreleme tekniklerinden de yararlanılmıştır. Çizgiselliklerin haritalanması için ayrıca çeşitli yönlü filtreler de kullanılmıştır. Bunun için ASTER uydu görüntüsü üzerine KB, D-B ve K-G yönlü filtrelemeler uygulanarak renkli kompozit elde edilmiş ve çizgisellikler belirlenmiştir (Şekil 8). ALOS-PALSAR görüntüleri üzerinde ise çizgisellik analizinden önce, birtakım görüntü işleme adımları uygulanmıştır. Bu işlemler için, ERDAS-IMAGINE 9.2 yazılımı kullanılmıştır. PALSAR uydu görüntülerine Lee-sigma filtresi uygulandıktan sonra bu görüntülerdeki çizgisellikler görsel yöntemlerle belirlenmiştir (Şekil 9).

Çan-Etili linyit havzasını kapsayan bu çalışmada havza içinde ve çevresinde köken ve gelişim zamanlarına göre iki grup fay belirlenmiştir. Bunlar, sinsedimanter büyüme fayları ve post sedimanter tektonik kökenli faylardır. Saha çalışmaları sırasında gerek jeoloji haritası yapımı aşamasında gerekse sondaj karotlarının incelenmesi ile yapılan korelasyonlarla belirlenmiş olan faylar, genel olarak KD-GB, D-B ve KB-GD doğrultularında uzanım gösterirler (Şekil 10).

Bu çalışmada kullanılan yöntemlerin karşılaştırılabilmesi açısından Şekil 11'de ortak alandaki çizgisellikler farklı renklerde gösterilmiştir. Burada, Palsar uydu görüntüsünün, çizgisellikleri belirlemede daha efektif olduğu görülmektedir. Ayrıca, Çan havzasındaki çökellerdeki bazı kavisli çizgisel yapılar, kaldera gelişimi ile ilişkili olarak yorumlanmıştır.

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