

# DETERMINATION AND CHARACTERISATION OF FAULT SYSTEMS AND GEOMORPHOLOGICAL FEATURES BY RS AND GIS TECHNIQUES IN THE WSW PART OF TURKEY

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**ABSTRACT:**

This article is aimed to give the first results of the project studying the faults and tectonic style of the southwestern part of Turkey based on remote sensing techniques. LANDSAT-TM and ASTER satellite data have been used in visual interpretation. The several techniques based on DEM have been applying to interpret in the determining of the tectonic features. The anaglyph image produced from LANDSAT-TM and DEM data has been found as the most suitable method in the visual interpretation of the structural elements. The results are being checked by the ground-truth studies. It is possible identify clearly the effects of the extensional tectonic on the satellite images by visual interpretations based on knowledge. The faults of the neotectonic period of the region can be distinguished clearly, and it is perceived that the motion to the SW direction in general forms the active tectonics in the region.

## 1. INTRODUCTION

The study area is located in the western part of Anatolia lying between the 38° - 40° N latitudes and 26° - 30° E longitudes (Figure 1). The area is covered approximately by three LANDSAT-TM images that have path 181 / raw 033, path 180 / raw 033 and path 179 / raw 033 numbers. There are 14 Aster images available in western and eastern sides however the central part contains the cloudy images. DEM image was produced by the contour maps of The General Command of Mapping in scale 1:250 000 (100 m contour interval).

DEM applications are considered to carry out on the DEM data that have resolution 10 to 30 m contour interval. It is possible to produce DEM from ASTER data that may be possible to get approximately 30 m contour interval. Mainly ERDAS-IMAGINE 8.5, ARC-GIS 8.2, ARC-INFO 7.2

software, and partly PCI-GEOMATICA 8.1.2, TNT 6.6 and ENVI 3.5 software have been using. The data having the location, date and magnitude of the earthquakes happened in the region was downloaded from the Kandilli Observatory web site and processed to suit the aim of the study.

The superiority of the satellite data according to the aerial photographs to study geology and geomorphology of extensive areas has been accepted by the most of the researchers. Rapid increasing of satellite data, development of hardware, software vehicles and new image processing techniques therefore, become easy to use these techniques for usual researchers, and of course, lowering the prices have been getting some new opportunities in investigations and studies in earth sciences. GIS techniques have been getting more capability in integration and interpretation of the data provided from several branches of knowledge on different formats.

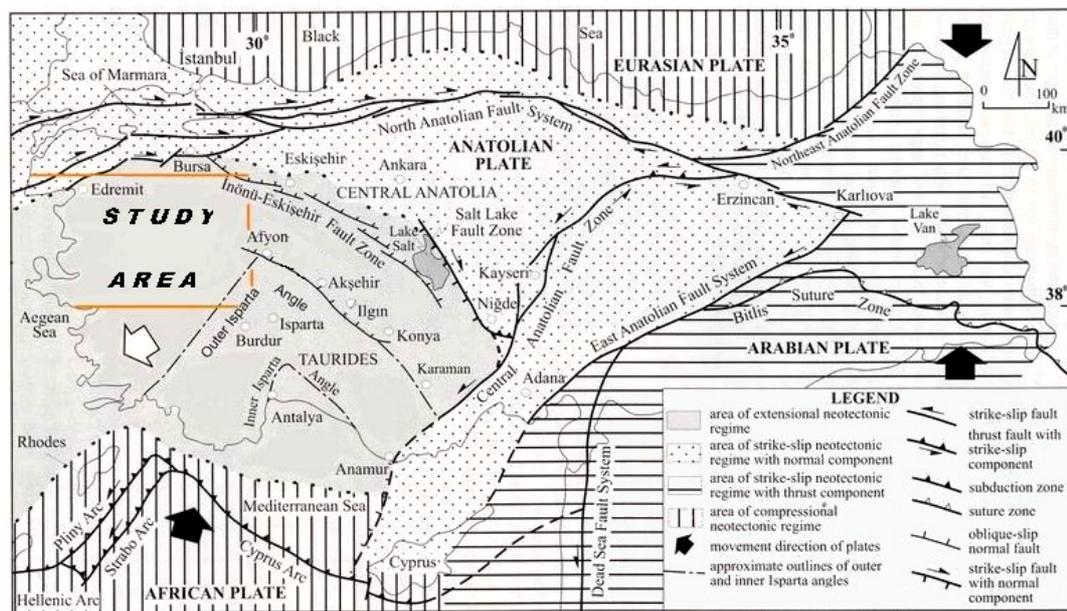


Figure 1. The study area on the simplified map of the neo-tectonic features of Turkey and surrounding areas (partly modified from Koçyiğit and Özacar, 2003 by the courtesy of Koçyiğit).

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The Anatolian Plate has been subjected to several tectonic effects between the Eurasian in the north and Gondwanaland in the south during the geological history. This effect has been continuing by the escaping Anatolian plate since the Late Pliocene time (Koçyiğit and Beyhan, 1998) in the WSW direction onto the African plate along the Hellenic-Cyprus subduction zone. This motion has been transforming by two major intra-continental transform plate boundaries, which are North Anatolian Fault System (NAFS) and East Anatolian Fault System (EAFS) (Figure 1). The other striking secondary faults are the left-lateral Central Anatolian Fault Zone (CAFZ), the right-lateral Salt Lake Fault Zone (SLFZ), and the İnönü-Eskişehir and Akşehir oblique-slip normal fault zones (Koçyiğit and Özacar, 2003). The area of neotectonic extensional tectonic regime is in effective in the southwestern part of Anatolia, partly covering the Central Anatolia region (Figure 1). The measured GPS vectors are also showing that the region moves to the WSW direction by rotating counterclockwise rotation around a pole in the Sinai (Oral et al. 1995; Altuner et al. 1997; Reilenger et al. 2002).

The study area is locating in the most active part of the region that the extensional tectonic regime is dominant. The extraction of lineaments and classifications of the faults are necessary to clarify of the complex structure of this area. This will benefit to the studies in several subjects such as seismic studies, natural hazard and risk assessment, engineering, mineral and oil exploration, researches of water and geothermal resources and the indirect usage in the cultural heritages and archaeological cite investigations and preserves.

This article aims to give the first results, methods and objectives of the project that has begun in General Directorate of Mineral Research and Exploration (MTA) of Turkey. Another intention is to introduce the project and to attract attention of the researchers in different disciplines in the international level to look for the partners. The authors have been carrying out for several years using remote sensing techniques on geological studies (Akman et al. 2000, 2001a, b; Akman and Sarı 2002; Tüfekçi et al. 2002; Tüfekçi and Akman 2004). The first objective of the project was to extract the lineaments and then interpret the quantitative of the faults. The faults will be compared with the all data such as distribution of earthquakes, hot springs, available GPS measurements and fault solutions, and some geophysical-gravimetric and magnetic-data. After the ground truth studies, the digital and printed fault maps that have the database will be prepared in regional level (in scale 1:100 000 and 1:250 000). Those will be used in the areas that given above and besides, they may be the base maps for the regional tectonic interpretations. In this article, after giving the methods used and a simplified regional geology, the first striking results of the project will be given.

## 2. METHODS

There are several techniques that have been developed for the last decade and mostly based on DEM data to determine the topographic features and the geological / geomorphologic characteristics of the terrain, and also used in Turkey. Altitudinal dispersion anomalies, standard geomorphic models, over-ground and under-ground openness, analysis of drainage and lineament patterns, denudation, dissection, aspect, slope and so on (Akman et. al. 2000, 2001a, 2001b; Sanga et al. 1999, 2001) are the methods and maps that will be used in this study. There is a difference between the actual

landform and a geomorphic model, and this difference was named "altitudinal dispersion anomaly". This altitudinal dispersion anomaly reflects the discontinuous change of the anomaly values at geologic boundaries of geologic units and tectonic movements. Information regarding geologic boundaries and faults can be extracted from these discontinuities. Akman et al. (2001a) concluded that the Simav and Alaşehir (Gediz) rift valleys have the same tectonic activity and length using this method. One of the objectives of this project is also to use the known methods above and develop a method for extracting geologic structural elements by using DEM for the western Anatolia and therefore, extracting tectonic movements such as uplift – subsidence and differential block movements.

### 2.1 Lineament Extraction

The lineaments of the study were extracted by visual interpretations (Figure 2). Anaglyph images, stereoscopic images and multi-angle shade images are the most suitable data to extract the lineaments of the extensive areas. The last needs DEM with the spatial resolution 10 to 30 m to extract a lineament map high in quality. The most suitable illumination angles for the study area are 0°, 60° and 120° (with light source height at 30°). The stereoscopic images have been prepared from the available ASTER data that has the stereoscopic sensor performing nadir viewing (3N) and simultaneous backward viewing (3B) in VNIR Band 3. Therefore, anaglyph images were generated and found as the most suitable method.

The visual interpretations of lineaments / faults are based the following criteria; (a) photographic characteristics such as tone and texture, (b) geomorphologic features such as; drainage patterns and density, rock resistance, landforms and development of bedding, (c) superficial cover such as vegetation and cultivation. The extraction criteria of the lineament are based on the geomorphologic features such as existence of fault-scarp, straight valley, extra-ordinary straight arrangement of river passages, existence of kerncol and kernbut, straight arrangement of the conversion points on the slope inclination, straight arrangement of the conversion points on the inclination of sedimentary rocks where the gentle inclination changes to the steep one, straight arrangement of triangular surfaces, displacement of ridge lines and river passages, drainage anomaly, straight arrangement of lakes, hot springs, volcanic vents, water wells, slope failures, landslides, alluvial fan gaps and vertical or horizontal linear displacement of river terraces.

### 2.2 Anaglyph Image Generation

Anaglyph images have been generated using LANDSAT-TM and the DEM of the region. As known, a colour anaglyph image of a region provides a 3D simulation by the image and DEM of the area. A shift is created in one band of the image by a trigonometric computing. One of the best anaglyph image results of the study area was obtained by; band 1 of LANDSAT-TM images was assigned to red band associated with the left eye and band 4 and 5 were assigned to the blue and green bands associated with the right eye. The glasses had a red colour for the left eye and cyan colour for the right eye was used to observe the 3D effect of the terrain. The relief was exaggerated by 3 times and output scale was determined as 1:100 000. Therefore, the output image was the best one of the alternative base-maps to produce in scale 1:100 000. In the case of using the 432 band combinations of LANDSAT-TM in the

process, the resultant image reflects more topographic features; however the discrimination of the rock types is lost.

different directions that also known as horst and graben system or basin and range topography.

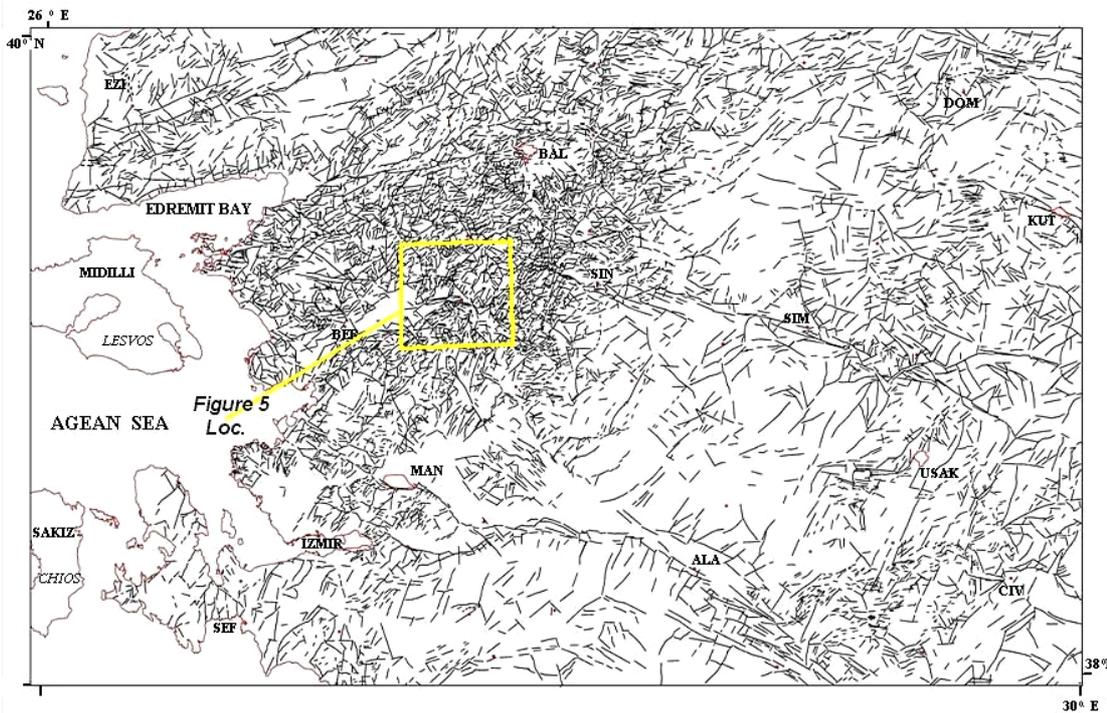


Figure 2. The lineament map of the study area. (Abbreviations of the city centres; BAL: Balıkesir, KUT: Kütahya, MAN: Manisa, ALA: Alaşehir, SIN: Sındırgı, SIM: Simav, BER: Bergama, EZI: Ezine, DOM: Domaniç, SEF: Seferihisar, CIV: Çivril.)

The lineament map produced by the LANDSAT-TM image was updated in proportion 30 percent using the anaglyph image above. Besides, there is not an important difference in the lineament maps produced by the two base-maps, the anaglyph images and ASTER stereoscopic images. However, the anaglyph image produced by the DEM that has 10 m contour interval obtained more lineaments in proportion 25 per cent in 1:25 000 map scale.

The lineament map of the western part of the study area studied in scale 1:100 000, the other area studied in scale 1:200 000. The reason of that it was focused to this area at first due to the more complex structure of that area.

### 3. THE SIMPLIFIED REGIONAL GEOLOGY

The main parts of the base geological units of the study area are the Menderes Massive (MM), the Kazdağ Massif (KM), Izmir-Ankara-Erzincan suture zone, and the granitic, volcanic and sedimentary cover rocks of the Neogene and Quaternary age. Izmir-Ankara-Erzincan suture zone continued from Late Cretaceous to Early Tertiary period passes through the central part of the study area approximately bounding the Menderes Massive (MM). The suture zone consists of oceanic crust and cover sediments, and the metamorphic rocks related to the subduction period along the suture. MM and similar the Kazdağ Massif consists of a Paleozoic crystalline schist and gneiss basement and covered by the sedimentary and metamorphic rocks of Mesozoic and Cenozoic eras. Neogene rocks consisted of the sandstone, conglomerate, clay, lignite, marl, limestone, gravel and volcanic rocks that have been deposited in terrestrial environments mainly in rift valleys and intruded by granitic rocks since Late Oligocene-Early Miocene time. Quaternary consists of volcanic, lacustrine-fan-alluvial deposits accumulated in grabens, lakes, river terraces and plains. The extensional period of western Anatolia is characterized by forming of several rift valleys with the

The first overall presentation of these horsts and grabens structurally and the naming of the most of them have been done by Koçyiğit (1984). A complete study on the active faults of Turkey has been done first time by Şaroğlu et al. (1987) and mapped some of the main active faults. There are many different views about the initiation time and the origin of the extensional tectonics in the region (Koçyiğit et al. 1999, 2000; Koçyiğit and Beyhan 1998; Koçyiğit and Özacar 2003; Dewey & Şengör 1979; Şengör, 1987; Le Pichon & Angelier 1979; Meulenkamp et al. 1988; Seyitoğlu & Scott 1992; Yılmaz et al. 2000). There are also discussions about the neotectonic period of the extension. Some of them will be discussed in the next section.

### 4. DISCUSSION AND CONCLUSION

The using of anaglyph image produced from LANDSAT-TM image in the visual interpretation of the identification of the structural elements and the geomorphic characteristic has been found the most suitable method in this study. Contour interval and quality of DEM is diagnostic in quantity of extracted elements. The using of the stereoscopic images of the ASTER data and the multi-angle shaded images produced by the DEM countered 10 m interval gives also good results.

The lineament / fault map of the study area is represented in Figure 2. The main-faults of the study area determined and compared with the seismic activity of the area (Figure 3). The seismic activity around the young grabens within the MM and in the western part is quite high. According to the fault map, it is striking that the active faults forming graben structures show three division on three dominant basement rocks (Figure 4); (1) the NE-SW and NW-SE trends in the eastern side of the study area on the mainly platform type of carbonates, (2) the ESE-WNW trends in the middle part on the metamorphic rocks of the MM and subduction zone, and (3) the different trends on the complex structure consists of granitic-volcanic-metamorphic

bodies and carbonate rocks in the western-southwestern part of the study area.

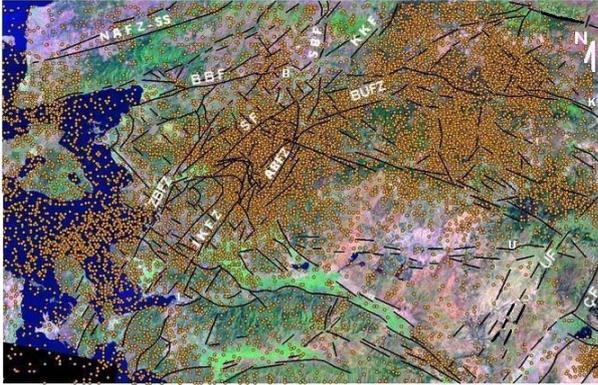


Figure 3. The main active faults of the study area were represented on the LANDSAT-TM (541) image mosaic.

The length & width and age of the active grabens in the MM increase gradually from the Kütahya Graben in the NNE to the Büyük Menderes Graben in the SSW direction, just at the south of the study area. The trends of graben and also the types of the faults of the recent tectonics show changes in the WSW part of the study area. This area is the adjacent to the NAFS and locates between two massifs, Kazdağ and Menderes. It can be concluded that the area has been moving towards the SW direction between these massifs during the neotectonic period according to the general arrangement of the faults and the visual interpretation of the overall structure of the region. The complex rock structure of the basement as mentioned above and also the NE-trend paleotectonic arrangement are forming a similar spoon-shaped structure in this area. This movement can be ascribed on a sub-horizontal detachment fault surface like a landslide movement. Akman and Sarı (2002) proposed also a similar model. It is observed in many locations that there are the NE- and NW-trending oblique-slip normal faults frequently. Also, the NW-and

WNW-trending normal faults, and some ENE-trending strike-slips on faults were observed. Nebert (1978) also determined several strike-slips on the faults in Soma coal basin.

The neotectonic stage including recent active fault development in Turkey was begun in the Pliocene time (Koçyiğit et al. 1999, 2000, Koçyiğit and Özacar, 2003). They proposed that Anatolian plate began to escape towards west-southwest direction after the sea-floor spreading of Red Sea (based on Hempton's data in 1987) in Early Pliocene time. Therefore, the neotectonic period of west Anatolia initiated around 3 million years ago.

The Neogene sedimentation in western Anatolia began in Early Miocene trending in the NE direction basins that include mostly coal beds. The graben bounding faults can be traced partly in the satellite images and also verified some of them by the ground-truth studies. However, it is not so clear that if those faults are the boundary faults of the coal basins in the Early Miocene time. The previous coal investigations (MTA reports) give in Early-Middle Miocene age to the first coal beds according to spore-morphs. But Nebert (1978) accepts the first coal sedimentation in Late Miocene age and suggests that there are three sedimentation stages in the Soma area, which can be distinguished by erosion levels; (1) Soma Formation deposited in the Late Miocene time, (2) Deniz Formation deposited in the Lower Pliocene time, and (3) the sediments deposited during Quaternary. However, the lower coal beds are assigned to Early Miocene according to the macro- and micromammalian fossils (Saraç, 2003). It is accepted that there are two main extensional periods at least in western Anatolia. It was observed (by the ground truth studies and also Koçyiğit et al. 1999, 2000; Koçyiğit and Özacar 2003) that the lower series rather folded and deformed. The basins that have been developed in the WNW-ESE trend (Figure 5 a, b) and include volcanic rocks and sedimentary deposits around Soma, Balıkesir and Kütahya corresponding to Deniz Formation of Nebert (1978). The volcanic rocks around the western parts of the area in the Figure 5 are dated Middle Miocene ages according to radiometric determinations (Ercan et al. 1997).

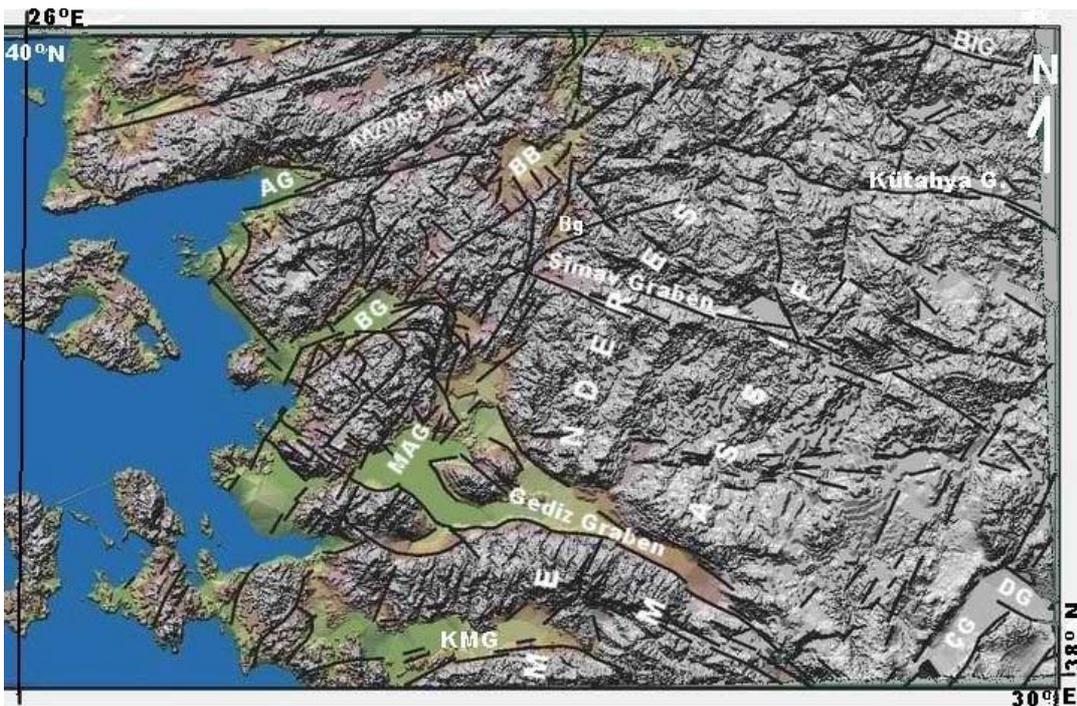


Figure 4. The distribution of grabens in the study area. The main active faults on the basemap that is the painted relief map. KMG: Küçük Menderes Graben, DG: Dinar Graben, AG: Akçay Graben, BG: Bakırçay Graben, MAG: Manisa-Akhisar Graben, Bg: Bigadiç Graben, BIG: Bozöyük-İnegöl Graben, BB: Balıkesir Basini.

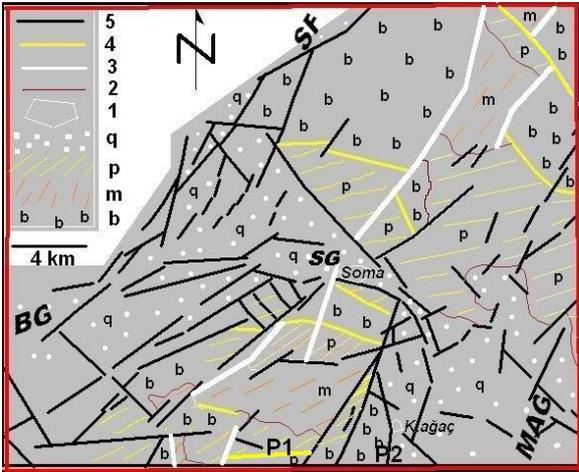
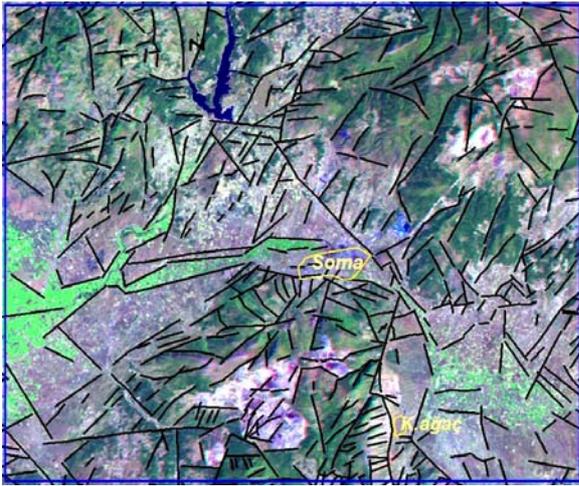


Figure 5 a, b. The lineament / fault map around Soma on the LANDSAT-TM (RGB: 541) image (in above: a) and the interpretation map integrated Nebert's map (1978) with the paleo-geographic trends and the neotectonic map of Soma area (in lower: b); b: basement, m: Soma (Sg), p: Deniř groups (Dg); q: Quaternary deposits; 1: settlement; 2: formation boundary; 3: trend of Sg; 4: trend of Dg; 5: the neotectonic faults; SF: Savařtepe fault; BG: Bakırçay, SG: Soma, MAG: Manisa-Akhisar Grabens; P1, P2: Photo locations.

It can be clearly seen from the lineament / fault map that the neotectonic faults and structures are cutting these two previous trends. The first and second group series have been rose around 700m and 400m respectively according to the recent graben deposition levels. In this case, the following result can be stated at this stage and will be explored in detail also in laboratory and field studies; (1) Deniř Formation and its equivalents were deposited in Middle Miocene in the ESE-WNW and NNE-SSW grabens, Because the NNE-SSW graben fills in the MM give Middle Miocene ages. The Early Miocene, according to the mammalian fossil findings of Saraç (2003), sediments distributed between two NE-trending positive structures; in the west, the Kozak horst was positive area according to the radiometric age (Bingöl et al. 1982) of the granitic intrusion in its center, and in the east, the MM that has no Early Miocene age findings in the deposits of the grabens in the MM. There are some Early Miocene ages in the western flank of the MM (Saraç, 2003).

Therefore, It can be concluded that the coal beds were deposited in the NE-trending trenches, probably in grabens bounded by faults (Photo 1), in Early Miocene. The striking extensional phase initiated in the Middle Miocene time in the region in two trends above. There is possibility to have been formed some of those faults during the Middle Miocene period. The boundary faults of these grabens have been covered mostly by the dense volcanic metarials in the upper levels of Deniř group. The project will try to find the answers more clearly to the discussions on the extensional period in the Neogen time.



Photo 1. One of the boundary faults in the coal beds in the western Anatolia (looking to the south in the P1 location in the Figure 5 b).

The trend of the Deniř group follows partly some neotectonic grabens (e.g. BG). This causes confusing in some areas between the basal series of the Deniř group and the Pliocene deposits that surrounding the graben flanks. The neotectonic faults and structures (in the Figure 5 a, b), which are Bakırçay, Soma and Manisa-Akhisar grabens and Savařtepe fault in the figures, cut the previous extensional structures (Photo 2 and 3).



Photo 2. One of the neotectonic faults around Kırkağaç town (looking to the NNW direction in the P2 location in the Figure 5 b). The left side has been risen almost 1000m since the Pliocene time probably. Photo 3 (left below). The oblique-slip normal fault surface of the fault in the Photo 2 can be seen after removing the slope debris materials (looking to the NW direction).

The hot spring distribution in the study area follows mostly the active flanks of the ESE-WNW trending grabens in western Anatolia and important discharge areas are located in the junctions of these faults with the NE-SW trending faults (Akman et al. 2000). In the western part, there are also hot spring successions along the NE-SW trending faults.

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