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A Detailed Geologic Lineament Analysis Using Landsat TM Data of Gölmarmara/Manisa Region, Turkey

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Abstract: A lineament analysis using a Landsat Thematic Mapper (TM) dataset of the Gölmarmara (Manisa) region was performed to identify linear geologic features that could be attributed to paleotectonic and/or neotectonic structures. The main lithologies found in the area are metamorphic rocks of the Menderes Massif, carbonates of the Jurassic-Cretaceous, İzmir-Ankara Zone mélange of the Campanian-Danian and Neogene units. Being part of the Post Eocene-Pre Miocene Neo-Tethyan suture zone and being in a continental extensional tectonic zone since the Middle Miocene, the region exhibits many structural features. Directional edge enhancement techniques using convolution kernels were applied to band 5 of Landsat TM data to enhance these structures. Structural features enhanced with NW, N-S and E-W directional filtering were analyzed and interpreted in the light of paleotectonic and neotectonic evolution of the region. Initial results indicate that extensive NE and ENW trending lineament systems have developed in the region. Most of the ENW-SSE trending lineaments are associated with recent normal faulting connected to the extensional regime of Western Anatolia after the Middle Miocene period. On the other hand, some NE trending lineaments may be correlated with the thrust faults associated with the closing of the Izmir-Ankara ocean during the Upper Cretaceous-Late Eocene period. Moreover, the results showed that the lineaments mapped using the TM data are highly correlated with the recent geological findings of the Western Anatolia tectonics.

Key words: Lineament, geology, directional filtering, remote sensing, Turkey

INTRODUCTION

Remote sensing has been used effectively for geological applications. For example, mapping of lineaments or structural features of any region may provide useful information for mineral or oil exploration studies (Lang *et al.*, 1984; Merin and Moore, 1986; Rowan *et al.*, 1991; Rowan and Bowers, 1995). Remote sensing is used for mineral exploration studies particularly using band ratioing techniques to enhance different lithologies and hydrothermally altered areas. Similarly, lineament analysis techniques using remotely sensed data help researchers identify different structural regimes and mineralization zones.

Some factors such as season, vegetation, solar angle, spectral and spatial resolution affect the recognition of lineaments. In this study, several image processing procedures along with visual interpretations have been used to delineate geologic lineaments in the Gölmarmara region. Faults of various types and sizes, alignments of tonal features, systematic fracture patterns, rectangular and trellis drainage networks are some of the lineaments found in the study area.

The Gölmarmara (Manisa) region, which is about 85 km long and 55 km wide, lies within a continental extensional region generally known as Western Anatolia in Turkey (Fig. 1). The main objective of this study, is to delineate the distribution of the geologic lineaments in the Gölmarmara region.

The Gölmarmara region is divided into four different parts (Fig. 2):

- The wide mountain ranges of the Dibekdağ and Azimdağ Uplift trending approximately in NE-SW;
- The vast plains of northern and southern branches of Gediz (Alaşehir) Graben;
- The Bozdağ Uplift located in the south of the quadrangle and
- the antiformal Çaldağ Heights that trend NW-SE are located between the two different branches of the Gediz Graben.

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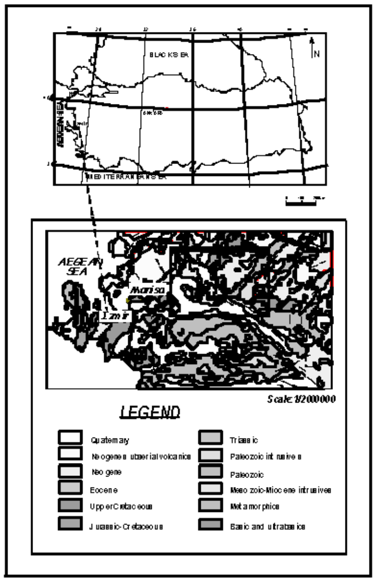

Fig. 1: Location and geologic map of the study area

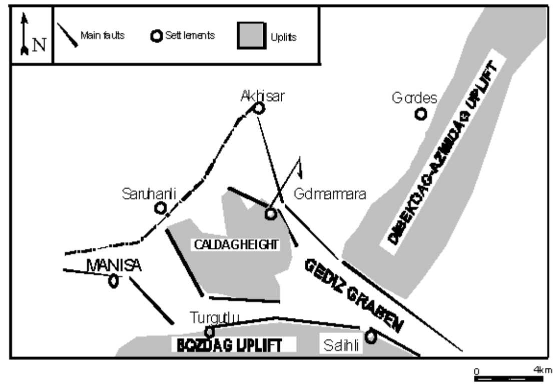

Fig. 2: Main geomorphologic components of the Gölmarmara (Manisa) region

Geological setting: Tectonically, the study area is located in a region of active continental extension in Western Anatolia, Turkey and reflects many features of a dynamic neotectonic regime. However, the area also contains the most striking realms of the Neo-Tethyan ocean and occurrences of its deformed mélange represent a paleotectonic period (Brinkmann, 1966). Main metamorphism in the Menderes Massif and movement of the Lycian nappe system of the Taurides played important roles in terms of tectonic evolution. These regional processes have produced several geological features, which include many lineament systems in the region. Therefore, superimposed lineament systems of both periods may be easily observed in the study area.

The detailed paleotectonic features of Western Anatolia have been previously studied by Dora *et al.* (1990), Erdoğan (1990, 1992) and Yılmaz (1997). Moreover, many features of the Gölmarmara (Manisa) region have also been studied by Akdeniz *et al.* (1980, 1986), Akdeniz (1985), Konak *et al.* (1980), Konak *et al.* (1980), Okay (1981) and Akman *et al.* (2001).

Neotectonic features of the region have been studied in detail by Zanchi *et al.* (1993), Seyitoğlu *et al.* (1992) and Seyitoğlu and Scott (1996). In contrast to the Basin and Range province of the USA, Koçyiğit *et al.* (1999) indicated that the Gediz graben had two different extension events during Miocene-early Pliocene and Plio-Quaternary times. The largest structural features of the region are the northern and southern branches of the Gediz Graben, which represent the best known event of the neotectonic period of Western Anatolia.

Stratigraphy of the region consists of the Upper Triassic-Maastrichtian Menderes Massif metamorphics, the Middle Eocene İzmir-Ankara Zone ophiolitic mélange, Eocene sediments and the Neogene cover (Erdoğan, 1992). The Menderes Massif metamorphics are made up of mainly micaschists, metavolcanics and metaserpentinites, marbles, metadolomites, pelagic limestones and phyllites. The remains of the Neo-Tethyan Ocean are represented by serpentinized peridotites, serpentinites, radiolarites, pelagic limestone and flysch. This mélange was cut down by internal tectonic slices. Field observations indicate that mélange rocks have not been metamorphosed. The Eocene Başlamış formation consists of limestones that cover mélange rocks in the northern part of the region. Many paleotectonic and neotectonic geological features are observed on the northern branch of Gediz Graben. In addition, it is possible to find many clues in Neogene volcanics and sediments, which indicate the closing of the Neo-Tethyan Ocean by the beginning of Middle Miocene.

MATERIALS AND METHODS

Several techniques including digital image processing and visual interpretation were used to delineate geological lineaments in the area.

Initially, visual interpretation was used to extract geologic lineaments using several false color composites of bands 1, 4, 5 and 7 of a Landsat TM dataset. These lineaments were drawn on a 1/100000 scale topographic quadrangle. Structural lineaments were interpreted attentively, excluding network of man-made lineaments such as roads, ditches and other man-made linear structures. Lineament frequency and their rose diagrams were prepared to examine lineament trends in the area.

In addition to the manual interpretation, the TM dataset of the region was evaluated using digital image processing. Several preprocessing and enhancement techniques including contrast stretching, directional filtering and ratioing have been used to enhance geological features and to extract structural lineaments in the area. Color band ratio composites, for example, enhanced a fold (axis) that could not be seen using regular image composites.

RESULTS AND DISCUSSION

A Landsat TM image (Path:180, Row:33) used in this study was acquired on July 25, 1991 (Scene ID #52374-88060) and processed at the Mid-America Remote Sensing Center using ERDAS IMAGINE software. The four-band Landsat TM data were registered to the Universal Transverse Mercator (UTM) grid using a second-order polynomial, cubic convolution resampling technique and 30m pixel size. The TM image of the Golmarmara (Manisa) region covers most of the İzmir K 19 and K 20 1/100000 scale quadrangles and the area of the northern and southern part of the Gediz Graben in western Turkey (Fig. 3). This subscene covers approximately 4800 km^2 including the Gölmarmara region.

In addition to lineament analysis, a rose diagram tool from the ER Mapper V.6.2 image processing software was used to derive lineament directions in the region.

Visual lineament interpretation: A total of 238 geologic lineaments were identified and a visually interpreted lineament map was constructed using the TM image (Fig. 4). Topographic lineaments were drawn on images of the K 19 and 20 quadrangles, but are highlighted on TM images by a solar illumination azimuth of 130°, which gives a directional bias. Lineament recognition criteria such as geomorphological trends, rectangular, trellis and colinear drainage system patterns and distinct contrast differences were used in this analysis. Distribution of these lineaments was clustered particularly in the north and the NE regions of the study area, possibly due to bias caused by solar illumination from the SE. These regions are represented mainly by the Menderes Massif metamorphics, the İzmir-Ankara Zone ophiolitic melangés and Neogene formations (Fig. 1). The south and the SE regions including mostly agricultural plains did not contain as many lineaments. These plains have been formed by the younger Gediz Graben sediments. Therefore, lineaments are related to the geologic units of the test area were distributed randomly.

Figure 5 shows the azimuthal distribution of the data using a rose diagram. Most of the lineament clusters in the NE part of the region are N 20°-30° E and N 60°-70° E trending lineaments. Whereas in the NW part of the region, lineaments tend to cluster in N 50°-60° W direction.

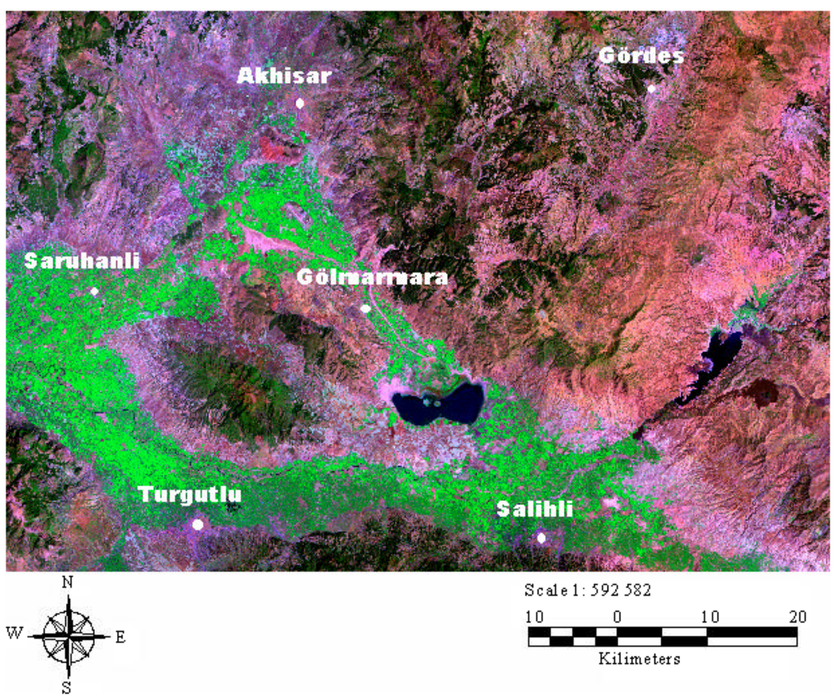

Fig. 3: Landsat 741 (RGB) false color composite image of the study area

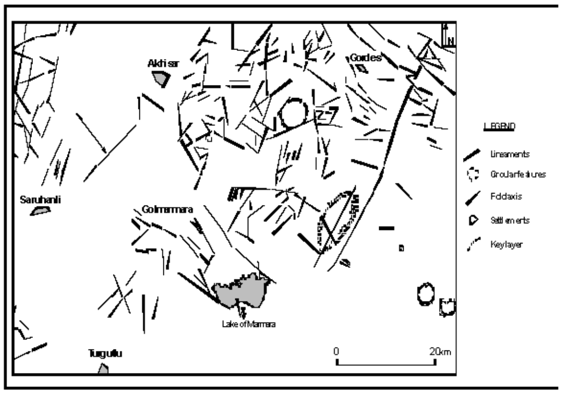

Fig. 4: Lineament map of the study area

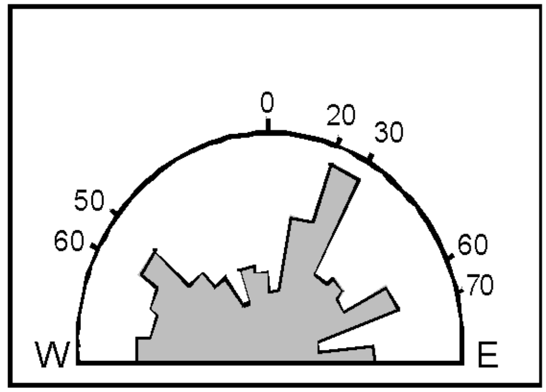

Fig. 5: Rose diagram of the lineaments in the Gölmarmara (Manisa) region

Another approach that has been used by Qari (1991) is shown using an azimuthal histogram bar in Fig. 6. Black and dotted bars represent the number of lineaments and their lengths, respectively. The number of lineaments and their length showed a high correlation. Both of them have almost same attitude in the same azimuth cell and reach almost the same level peak at 30° and 300° azimuthal measurement. Between 0°-10° and 30°-40°, it shows a relative sharp fall compared to the other cell intervals. Total lineament length in the 300°-310° range and the number of lineaments in 30°-40° range are of the highest values. The longest lineament system is about 80 km. Moreover, the total length of the lineament systems is about 809 km.

Based on previous work and the neotectonic evolution of the region, the results of this analysis showed an agreement with the dominant directions that have produced the lineament systems. The dense WNW directional lineaments may be related to the extensional regime of the Middle-Upper Miocene neotectonics in Western Anatolia. Most of these lineaments correspond to normal faults in the region.

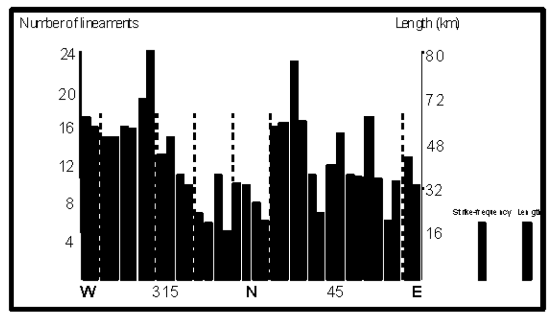

Fig. 6: Bar diagram showing the distribution of lineaments based on azimuthal direction and frequency of lineaments

Table 1: Visual and geologic features related with ratioing

Ratio	RGB color	Content	Geologic units
5/7	Red	Clay and/or İ carbonates (Beratan *et al.*, 1990)	Izmir-Ankara melangé
5/4	Green	Ferrous iron	Menderes metamorphics
4/1	Blue	Vegetation (magenta)	Agriculturalareas, pasture lands and forest

Ratioing effect to the determination of geologic lineament and structure: Figure 7 shows the individual bands, 1, 4, 5 and 7, of the Landsat TM data set of the region. The band 5 of the Landsat TM dataset is one of the best bands showing most of the features in the area.

Several analysis techniques such as visual interpretation and compass gradient enhancement are routinely used for lineament studies. In this study, ratio color composite subscene images of the region were also used to enhance the lineament systems that were not clearly enhanced by other methods. Ratio images generally enhance different lithologies and features of a region. For example, various kinds of land-cover types such as rocks, vegetation and water are represented in different colors in ratio color composite images. Geological contacts can be enhanced using different colors that can help researchers interpret lineament systems easily.

Figure 8 A shows a ratio color composite image using Landsat TM 5/7 (red), 5/4 (green) and 4/1 (blue) ratios in RGB form. Clay, ferrous minerals and vegetation are represented in red green and magenta colors, respectively. Table 1 shows spectral relationships, color distributions and lithologic equivalents of the ratioing technique. Agricultural areas and natural vegetation in the region are represented by magenta hues instead of blue, because clay and vegetation spectra have similar slopes for TM5/TM7 ratio. In the literature, this combination is very

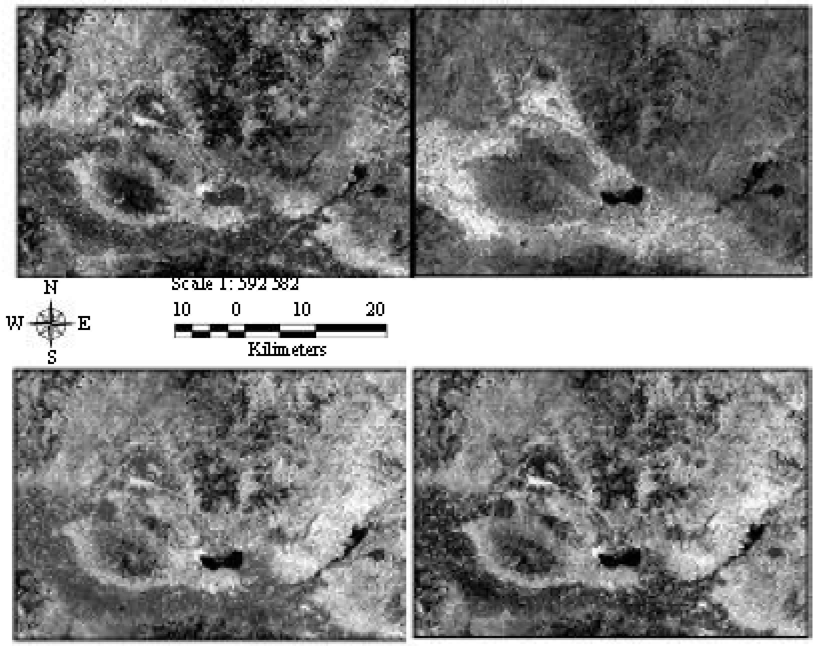

Fig. 7: Individual bands of Landsat TM (bands 1, 4, 5 and 7) of the Gölmarmara (Manisa) region. The image was acquired on July 25, 1991 with the sun azimuth of 130

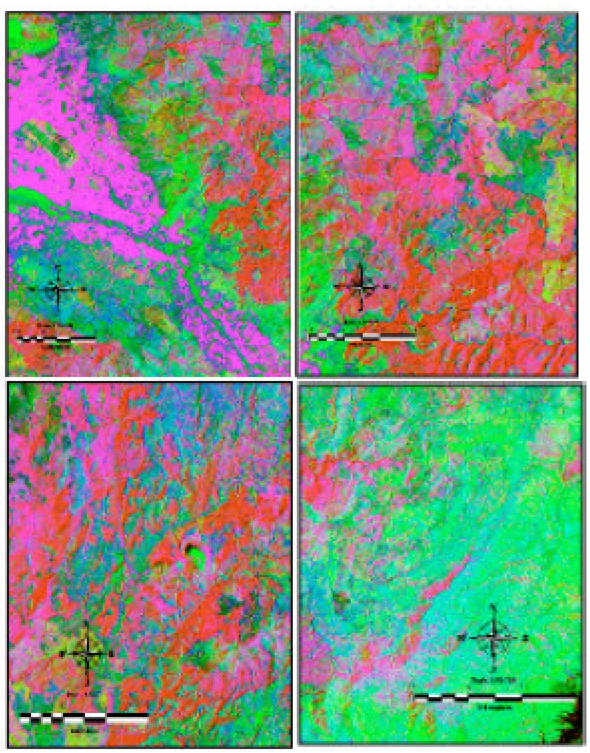

Fig. 8: Ratio color composites of the region. A, B and C show possible lineament systems. A geologic fold is clearly identifiable in D

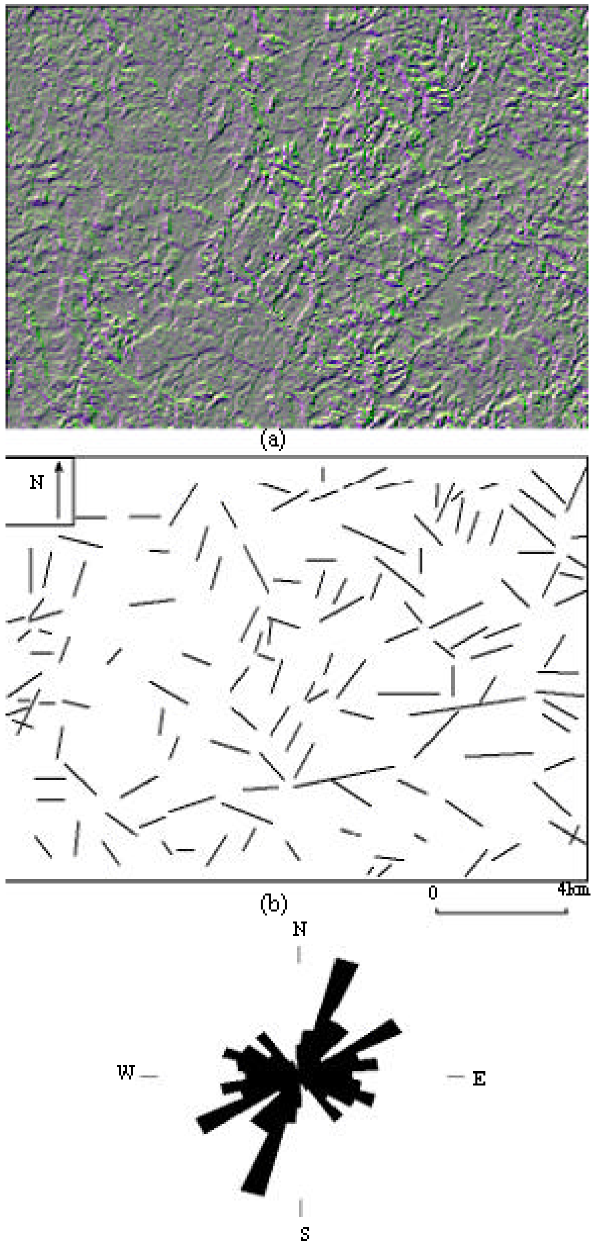

Fig. 9: RGB (NW, N-S, E-W) color composite image of directional edge detection filtering (A) and derived lineament system (B) from this. C is showing rose diagram distribution

suitable for mineral exploration (Holcomb, 1993; Erdas Field Guide, 1999).

On the other hand, some of the neotectonic features such as active faults are formed the other lineament systems in the study area. Especially, the faults that form the northern and southern flanks of the Gediz Graben represent active lineaments systems and morphologically separate broad graben plains from more rugged topographic elevations. In Fig. 8.A, magenta and green represent vegetated areas and topography that correspond with metamorphic rocks in the northeastern part of the region. Hence, it may be possible to separate these areas from topographic heights with the aid of these geomorphologic components. Similarly, some parts of the lineament network system in between different colours are seen in two different subsets as Fig. 8B and C.

In Fig. 8d, in contrast to the other subscenes, an elliptical structure, probably an anticline, is enhanced. This fold could not be seen in either single band or multiband combinations.

Table 2: Weighted kernel types used in this study

NW			N-S			E-W		
-1	-1	0	-1	-1	-1	-1	0	1
-1	0	1	0	0	0	-1	0	1
0	1	1	1	1	1	-1	0	1

Directional filtering: Edge enhancement filters are used in geological applications to highlight faults and lineaments that occur in specific azimuths (ER Mapper, Tutorial). Different filter types enhance particular spatial directions. To enhance such edges, filters are designed to map the contrast gradient orthogonal to the preferred direction (Berhe and Rothery, 1986). Some authors also prefer to use directional or directional gradient enhancement instead of compass gradient enhancement (Sabins, 1996; Vincent, 1997) terms. Richards (1986) defined filter types to detect and highlight diagonal, horizontal and vertical edges in digital images. These filters are also named as Prewitt filters (Prewitt, 1970). Another characteristic of these kernels is the distribution of nonzero weighting factors parallel to the direction. Therefore, asymmetrical filters are ideal for lineament analysis studies. Brightness is accepted as noise for these applications (Carr, 1995).

In this study, Landsat band 5 (1.55-1.75 μm) was selected for a lineament analysis (Crosta and Moore, 1989). Because, Landsat TM band 5 and/or 7 provided better rock type boundary delineation. A 414×575 pixel area has been choosen as a subscene from the Landsat TM band 5 to give a test area with higher lineament density. Directional filters are very useful for producing artificial effects suggesting tectonically controlled linear features (Drury, 1986).

For this study, several directional filters, NW, N-S and E-W compass filters, were selected. Table 2 shows the size and weight of kernels used for the test area.

The filters that have been used in this study had 3×3 kernel size. Some authors also used these filters as first derivative kernels for airborne radiometric and areomagnetic data (Fernandez and Tahon, 1991; Lee *et al.*, 1990). To provide a better visual interpretation for every filtering type, contrast enhancement procedure was also applied to three different edge detection filters. Later, filtered images taken from NW, N-S and E-W were displayed in RGB color space mode Fig. 9.

Filter direction was chosen on the structural and tectonic features of the paleo- and neotectonic episodes of the region. Regionally, Neotethyan evolutionary processes had been developed in Golmarmara parallel to the Izmir-Ankara Suture Zone, i.e. with a NE-SW direction. During the late Cretaceous-Eocene, the Tauride-Anatolide platform collided with Sakarya continent along this suture zone. The dominant expression of this compressional regime might have been parallel to this suture zone. Therefore, a NW compass filter was chosen for this feature. After the Miocene, because of changes in the Anatolian neotectonic regime, principal stress directions turned into an almost N-S direction. The tectonic regime was transformed from compressional into approximately N-S extension. Therefore, a N-S compass filter was used to extract possible E-W extensional features because of highlighting east-west trending active fault systems that characterize boundaries of Gediz Garben which was one of the most spectacular tectonic features of Western Anatolia.

A total of 116 lineaments were observed using a color composite image of the test area. Similar to the visual lineament interpretation results, the dominant directions were 20-30 (16 lineaments) and 60-70 (13 lineaments) azimuthal intervals. Similarly, 280-290 interval (9 lineaments) represents densely populated interval in the NW direction.

According to the total length of the lineaments, 20-30 and 60-70 intervals demonstrated the dominant directions values. Most of the longer lineaments are concentrated in the NW direction, which is similar to the visual interpretation results.

CONCLUSION

Visual interpretation and digital image processing methods had very high correlation in this lineament analysis based study. Filtering directions were selected according to the features of the paleo and neotectonic period. Generally, most of the lineaments were clustered in the northeastern part of the region. Furthermore, rationing method helped remove topographic effects and enhance several features in the area. In this study, NW, N-S and E-W directional filtering processes were analyzed and interpreted considering that paleotectonic and neotectonic evolution of the region. Results shows that clearly extensive NE and ENW trending lineament systems have developed in the region and most of ENW-SSE trending lineaments are associate with the recent normal faulting of the western Anatolia after the Middle Miocene period. On the other hand, some NE trending lineaments may be correlated with the thrust faults associated with the closing of the İzmir-Ankara ocean during the Upper Cretaceous-Late Eocene period.

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