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Research Article

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Determination of Faults in Gokova Region and Surrounding Area by using Steerable Filters

Ali Muhittin Albora

Istanbul University-Cerrahpasa, Engineering Faculty, Geophysical Department, 34555 Hadimkoy, Istanbul, Turkey
Email: muhittin@istanbul.edu.tr

Abstract In this study, we demonstrate the effectiveness of steerable filters as a method of delineating the boundaries of subsurface geological structures. Steerable filters, generally used for edge detection on 2-D images, have the properties of band pass filters with certain directions and are applied to many image processing problems. We first tested the method on synthetic data and then applied it to the gravity data of western Anatolian region and adjacent areas. We interpretation steerable output to this region active fault map.

Keywords Gravity, Steerable filters, western Anatolian region

Introduction

If density difference occurs in buried geological structures, discontinuity boundaries occur in gravity anomaly maps. Clearly revealing such structures and detecting discontinuities is an important issue in geophysical engineering. Thus, it is possible to have information about geological structures such as revealing the boundaries of the geological structures (mines, archaeological remains, buried fault geological structures, etc.) to be searched. For this reason, it is necessary to use filters suitable for the geological structure to be searched. According to the filter techniques to be applied, it can be understood whether the effect of the geological structures to be searched is close to the surface or deep. We can clear the data collected in the field from noise and have information about geological structures.

In this study, steerable filters are used to solve some problems in geophysics engineering. Using this method, it is aimed to determine the locations of buried fault lines from the bouguer anomaly map. The southwest Anatolia region was chosen as the field study and it was aimed to reveal the buried faults in this region.

The land of Turkey is one of the areas where the earth's crust is very active. The African plate in the south is moving towards the Eurasian plate in the north at a rate of 9 mm per year and the Arabian plate at a rate of 19 mm per year (Figure 1). The Anatolian land, which is located between these plates, is constantly compressed. Eastern Anatolia is constantly rising due to the faster movement of the Arabian plate.

Figure 1: Tectonics of the Anatolian plate and representation of the study area

Gökova province, part of the Western Anatolia-Aegean Sea region, is a regime under N-S regional expansion tectonics. Traces of this extensional regime are clearly visible in its geology and geomorphology. Although there is no doubt about the Aegean Sea in bathymetry as well as in western Anatolia, the current enlargement regime, its causes and the starting time are discussed. The most widely accepted model, proposed by [1], relates to extensional tectonism. The westward escape of the Anatolian plate as a reaction to the collision of the Arabian-African and Eurasian plates passes through the Bitlis continental collision zone. Another group of researchers argues that the posterior arc spreading of the relatively thickened Aegean crust in the eastern Mediterranean subduction is another reason for the N–S extension [2]. Gravity propagation of the relatively thickened Aegean crust has also been proposed by [3] and [4]. Submarine active tectonism in the Gökova Bay, located in the southwestern Anatolia-southeastern Aegean Sea region, was investigated with multi-channel seismic reflection data and revealed the fault lines in the Gökova basin [5].

Methods

Steerable Filters

Directional filters, which have applications in many image processing subjects such as edge detection, image compression and enhancement, and texture analysis, basically show the band-pass filter feature in a certain direction. Differently oriented edges in an image can be obtained by passing the image through basic filters with different orientations and separating them into orientation subbands. In Figure-2, the directional filter block diagram that performs this operation is given. Where

$h^{\theta_1}(x,y)$, $h^{\theta_2}(x,y)\ldots$, , $h^{\theta_M}(x,y)$ $h(x,y)$,nin θ_i, $0 \le i \le M$,–

are the impulse responses of the filters corresponding to their returned state in values. The input image is separated into the M subband using these filters, and thus the oriented edges corresponding to the orientations of the filters are determined.

A function *h(x,y)* is called a directed function if its expression at an arbitrary rotation value can be written as a linear combination of its expressions at constant rotation values. The mathematical expression of such a function is given in the following equation.

$$h^{\theta_a}(x,y)=\sum_{i=1}^{M}k_i(\theta_a)h^{\theta_i}(x,y) \tag{1}$$

$h^{\theta_a}(x,y)$, $h(x,y)$, the θ_a , corresponds to the rotated state of. $k_i(\theta_a)$, $0\le i\le M$, are interpolation functions that control filter orientations.

$$e^{jl\theta_a}=\sum_{i=1}^{M}e^{jl\theta_i}k_i(\theta_a), \qquad 0\le l\le N \tag{2}$$

If it satisfies the condition, the routing functions can be opened to the Fourier series as follows.

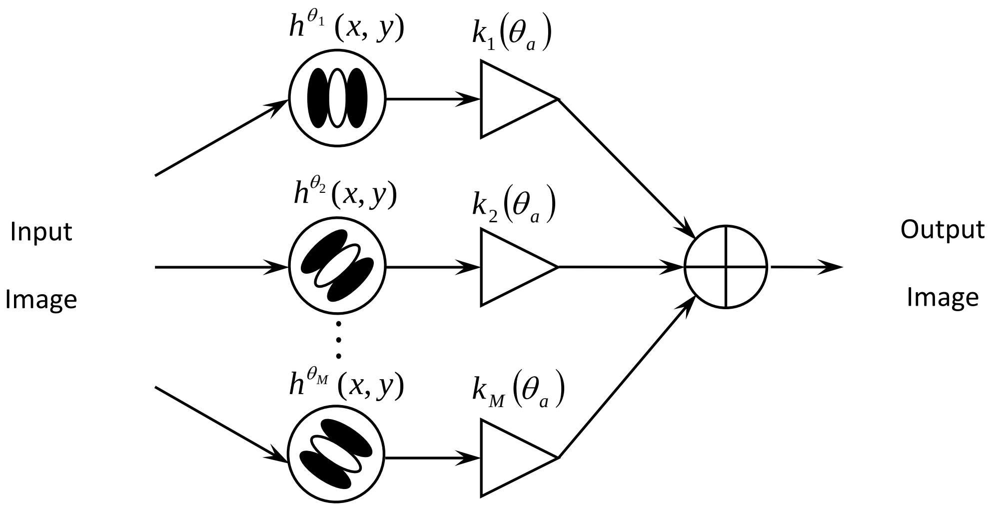


Figure 2: Block diagram of steerable filter [6]

$$h(r,\theta)=\sum_{n=-N}^{N}a_n(r)e^{jn\theta_a} \tag{3}$$

Here $r=\sqrt{x^2+y^2}$ and $\theta=\arg(x,y)$ is $x=r\cos\theta$, and $y=r\sin\theta$ can be written. After determining the basic functions and interpolation functions, m corresponding to the θ_a rotated state of $h(x,y)$ can be found using Relation-1. Thus, $h^{\theta_a}(x,y)$ the detection of edges in the θ_a direction in an image is achieved by passing this image through $h^{\theta_i}(x,y)$ filters.

The energy in the θ_a direction can be calculated by using the quadrature equivalent of band-pass filters oriented to the θ_a angle. This is called directed energy. In order to calculate the directed energy function, it is necessary to find the fundamental functions that make up the four-conjugate of $h^{\theta_a}(x,y)$ (these functions are Hilbert transformations of each other) [7]. The directed energy is calculated using the quadrature paired filters with the following expression.

$$E^{\theta_a}=\left[f(x,y)*h^{\theta_a}(x,y)\right]^2+\left[f(x,y)*g^{\theta_a}(x,y)\right]^2 \tag{4}$$

In this equation, “*” represents the convolution operation. $f(x,y)$ is the input image and $g^{\theta_a}(x,y)$ is the Hilbert transform of $h^{\theta_a}(x,y)$. The equation given by Relation-4 is expanded to the Fourier series as follows.

$$E^{\theta_a} = C_1 + C_2\cos(2\theta_a) + C_3\sin(2\theta_a) + \ldots \tag{5}$$

If the local dominant orientation is written in the θ_d direction and the strength *S*, using the low frequency terms in (Relation 5),

$$\theta_d = \frac{1}{2}\tan^{-1}\left(\frac{C_3}{C_2}\right), \quad S = \sqrt{C_2^2 + C_3^2} \tag{6}$$

If the local dominant orientation is written in the θ_d direction and the strength *S*, using the low frequency terms in (Relation 5),

After the angle showing the orientation of each pixel of an image and the corresponding energy weight coefficient maps are created, the sum of the energies corresponding to each angle value from these two maps creates the angle-energy histogram of that image.

Applications of Steerable Filters to Synthetic Data

After an image is passed through a steerable filter, the edges of the angle values on the image appear as dominant, while the orientations in the angle values away from this angle weaken or disappear completely.

Here, the first derivative of the $g(x,y) = e^{-(x^2+y^2)/2}$ shaped two-dimensional Gaussian function is used as a steerable filter.

$$g^{0^0}(x,y) = \frac{\partial}{\partial x} e^{-(x^2+y^2)/2} = -xe^{-(x^2+y^2)/2} \tag{7}$$

The same function can be written rotated by 90 degrees:

$$g^{90^0}(x,y) = \frac{\partial}{\partial y} e^{-(x^2+y^2)/2} = -ye^{-(x^2+y^2)/2} \tag{8}$$

From here, if the rotation value of this function at any angle is written by taking into account the interpolation functions:

$$g^{\theta^0}(x,y) = \cos(\theta)\cdot g^{0^0}(x,y) + \sin(\theta)\cdot g^{90^0}(x,y) \tag{9}$$

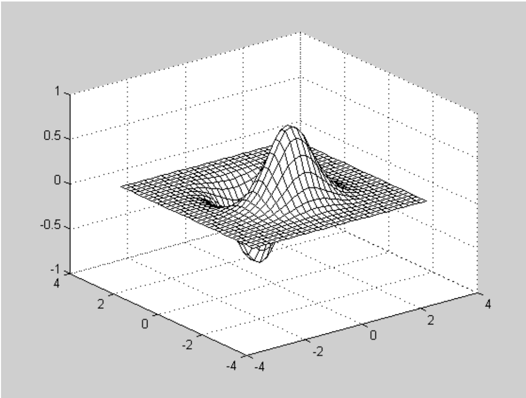
obtained.

The resulting function is an orientable function. Here, the $g^{\theta^0}(x,y)$ function corresponding to the rotation at any angle value consists of a linear combination of the rotation values of 00 and 900 degrees, given as $g^{0^0}(x,y)$ and $g^{90^0}(x,y)$, respectively. The three-dimensional images of this function consisting of both these two angle values and the combination of these two different angle values are shown in Figure-3.

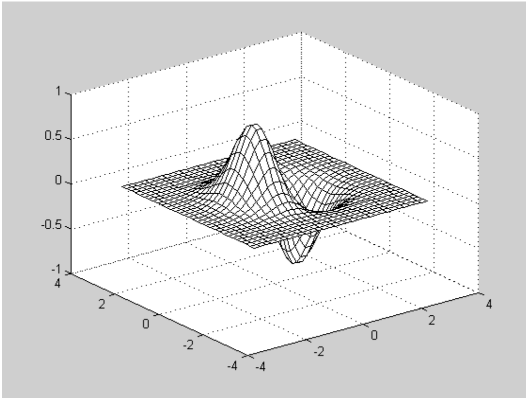
$$g^{30^0}(x,y) = \cos(30)\cdot g^{0^0}(x,y) + \sin(30)\cdot g^{90^0}(x,y) = \frac{\sqrt{3}}{2}\cdot g^{0^0}(x,y) + \frac{1}{2}\cdot g^{90^0}(x,y)$$

$$g^{135^0}(x,y) = \cos(135)\cdot g^{0^0}(x,y) + \sin(135)\cdot g^{90^0}(x,y) = -\frac{\sqrt{2}}{2}\cdot g^{0^0}(x,y) + \frac{\sqrt{2}}{2}\cdot g^{90^0}(x,y)$$

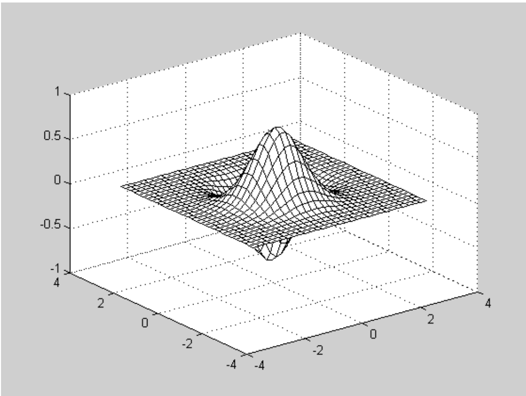
The image whose dominant edges will be determined is obtained by passing through the directional filter of that angle value at which angle value is desired to reveal the dominant edges.



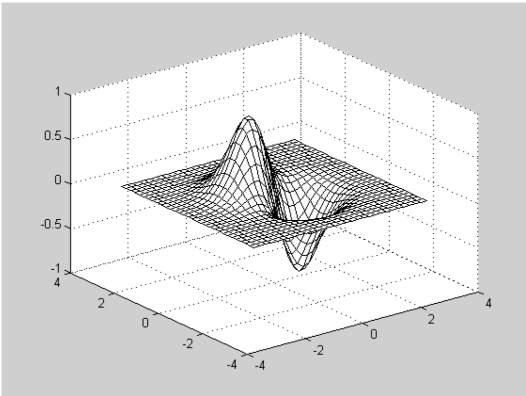
(a) $g^{0^0}(x,y)$



(b) $g^{90^0}(x,y)$



(c) $g^{45^0}(x,y)$



(d) $g^{135^0}(x,y)$

Figure 3: Rotation values at 0 and 90 degrees and rotation values at 45 and 135 degrees obtained from the linear combination of these rotation values.

Geology of the Region

When the Menderes core complex, which has wide outcrops in Western Anatolia, is considered in the massive terminology, metamorphic rocks with different metamorphism and deformation and young granitoid intrusions cutting them are observed. Among these, it has become a tradition to define metamorphites as core/Pan-African basement and cover units, taking into account the protolith stratigraphy. Accordingly, the Pan-African basement consists of Precambrian-Cambrian metasedimentary rocks and intrusive metamagmatites. In this context, the basement rocks are composed of paragneiss, schist and metamagmatite lithologies associated with them as primary intrusive. The cover units consist of Paleozoic-Mesozoic metapsamide, metapelite and metacarbonate rocks. While the lower parts of the cover units are predominantly represented by marble interbedded schist and quartzite, the upper parts contain widespread thick marble lithologies. It is possible to see metabauxite levels and rudist fossils in these areas. The uppermost section forms pelagic marble levels [8, 9, 10].

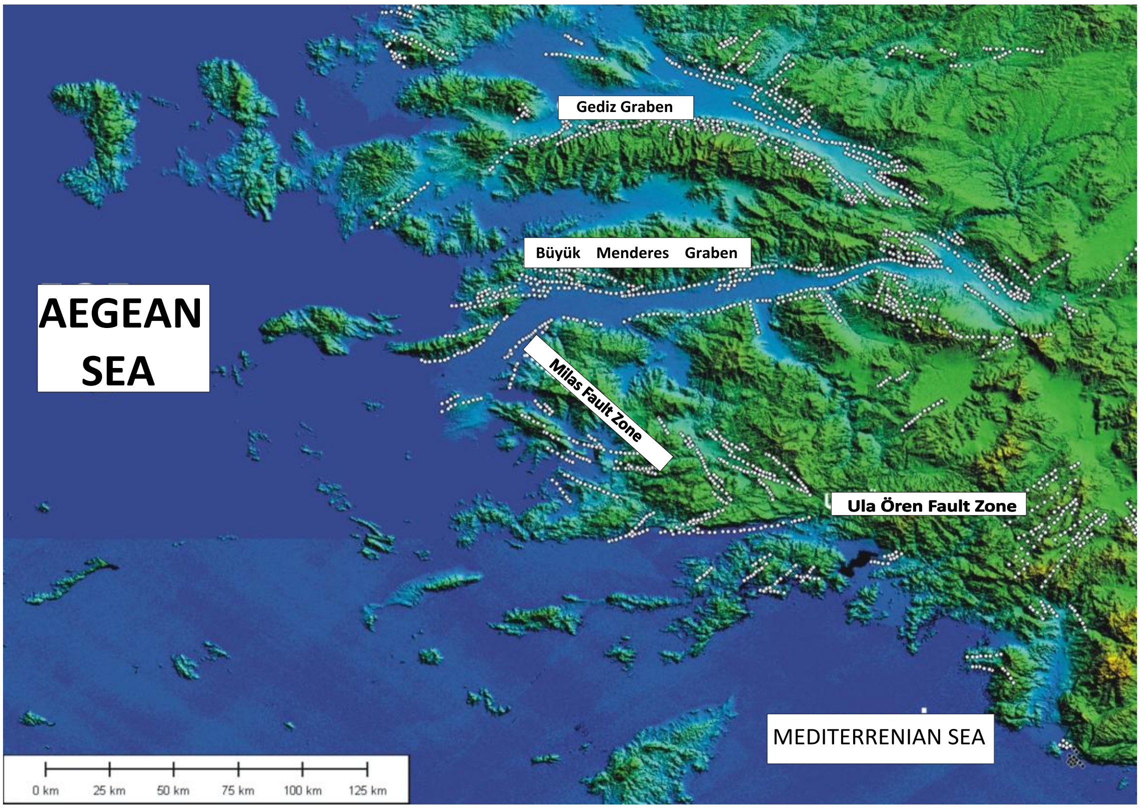


Figure 4: Topographical map of southwestern Anatolia region (has been changed)

Seismicity of the region

A series of earthquake events started in Gökova Bay on August 2, 2004 and continued with three medium-sized earthquakes with magnitudes of 5.0, 5.4 and 5.0. The first of the medium-sized earthquakes (M=5.0) was at 16:11 local time on August 3, the largest earthquake of the series (M=5.4) was at 06:01 am on August 4, and the third (ML=5.0) was on the same day. It happened at 07:19. Although the earthquakes did not cause any structural damage in the region, they caused injuries and significant financial losses due to panic. After the earthquakes, many tourists who were on holiday in the region interrupted their holidays and returned to their homes. In this region, earthquakes with a magnitude of 3.5 to 5 occur frequently on various dates. Figure 5 shows the seismic activity of the region. (The values are taken from the oil lamp observatory).

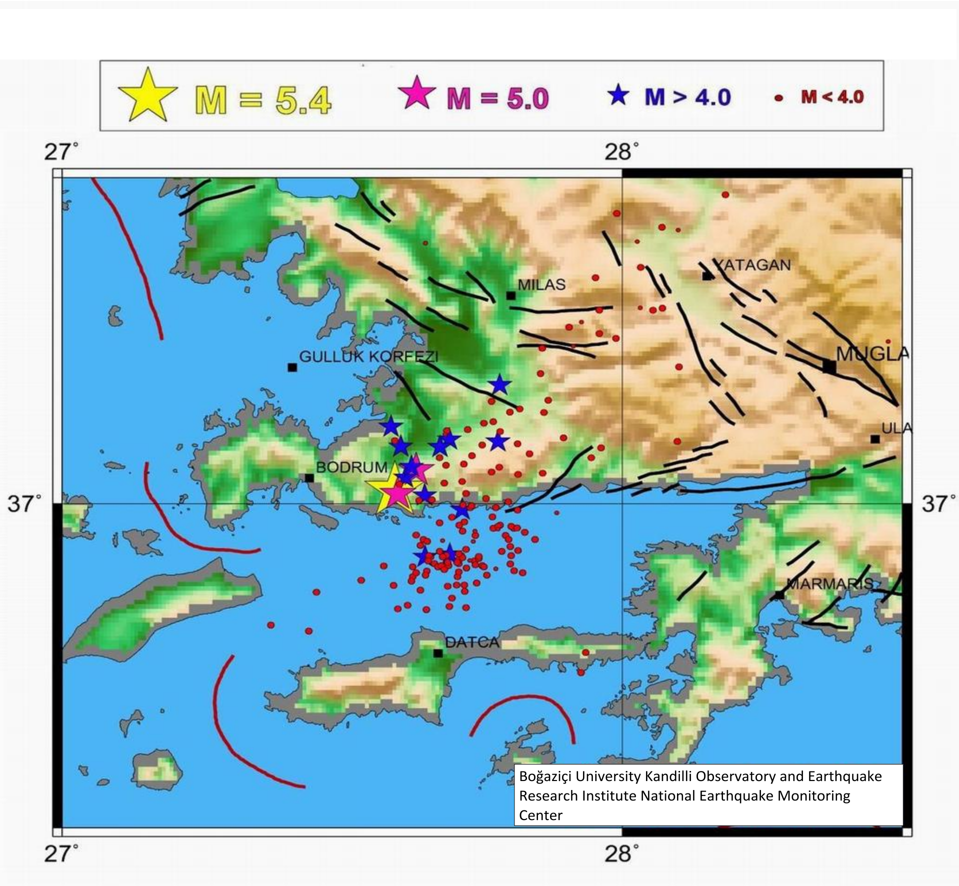


Figure 5: Earthquake activity in the region

Applying Steerable Filters to field data

The gravity anomaly map of the Southwest Anatolia region was used as a field study. It is striking that there is a large number of outlets here. When the Bouguer anomaly map of the region is examined, it is observed that towards the Aegean Sea, it approaches lower gravity anomaly values towards the eastern Anatolia region, where the gravity data show higher values.

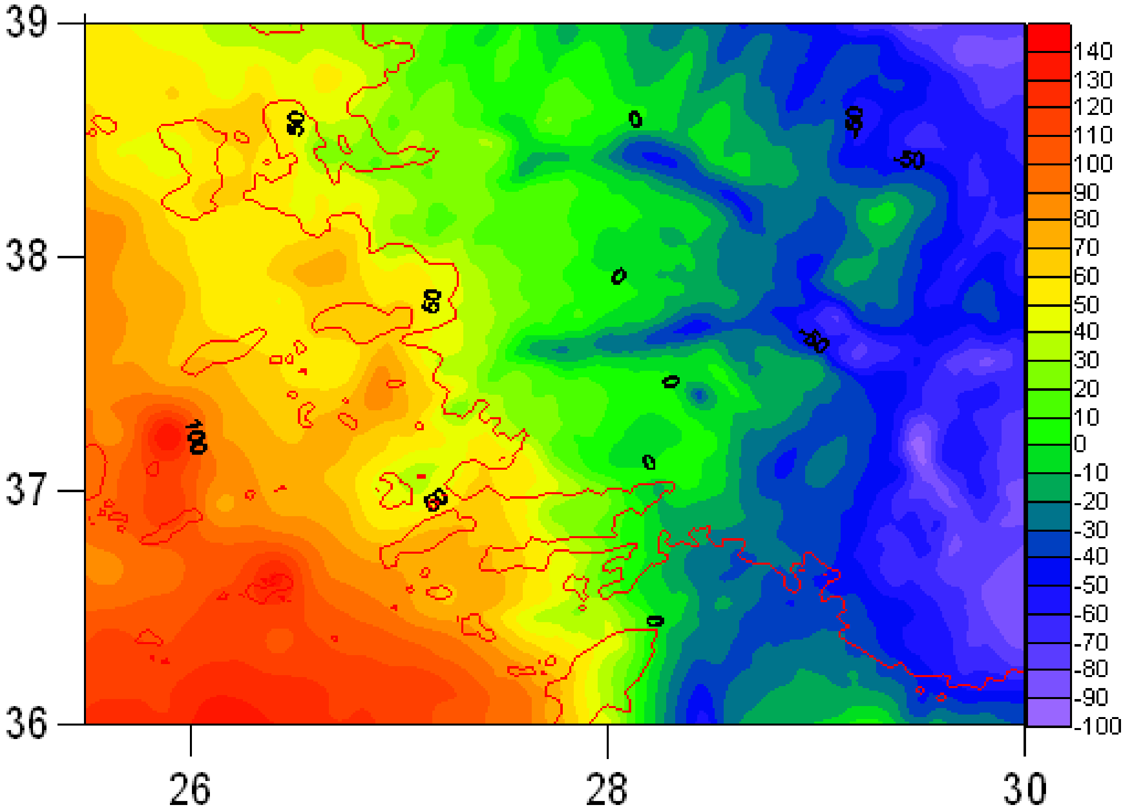


Figure 6: Bouguer Anomaly Map

Results and Discussion

Directional Filters are a frequently used method in Electronics Engineering in recent years to reveal the secrets of images from various directions. In addition, directed filters were applied to various synthetic data produced and successful results were obtained. In this study, fault detection is made by applying a geophysical data. As a result, while 90 and 120 degrees gave better results in detecting vertical roots, successful results were obtained in detecting horizontal angles in other degrees tried (Figure 7). As a result, we can detect structure boundaries by applying Steerable Filters to gravity anomaly maps. The fractured structure of the Southwest Anatolian region is clearly observed in the relief maps obtained from Steerable Filters. It is observed that these fault lines observed on land continue in the Gulf of Gökova. It is the continuation of the fault lines obtained as a result of seismic studies, especially in Gökova Bay, towards the land.

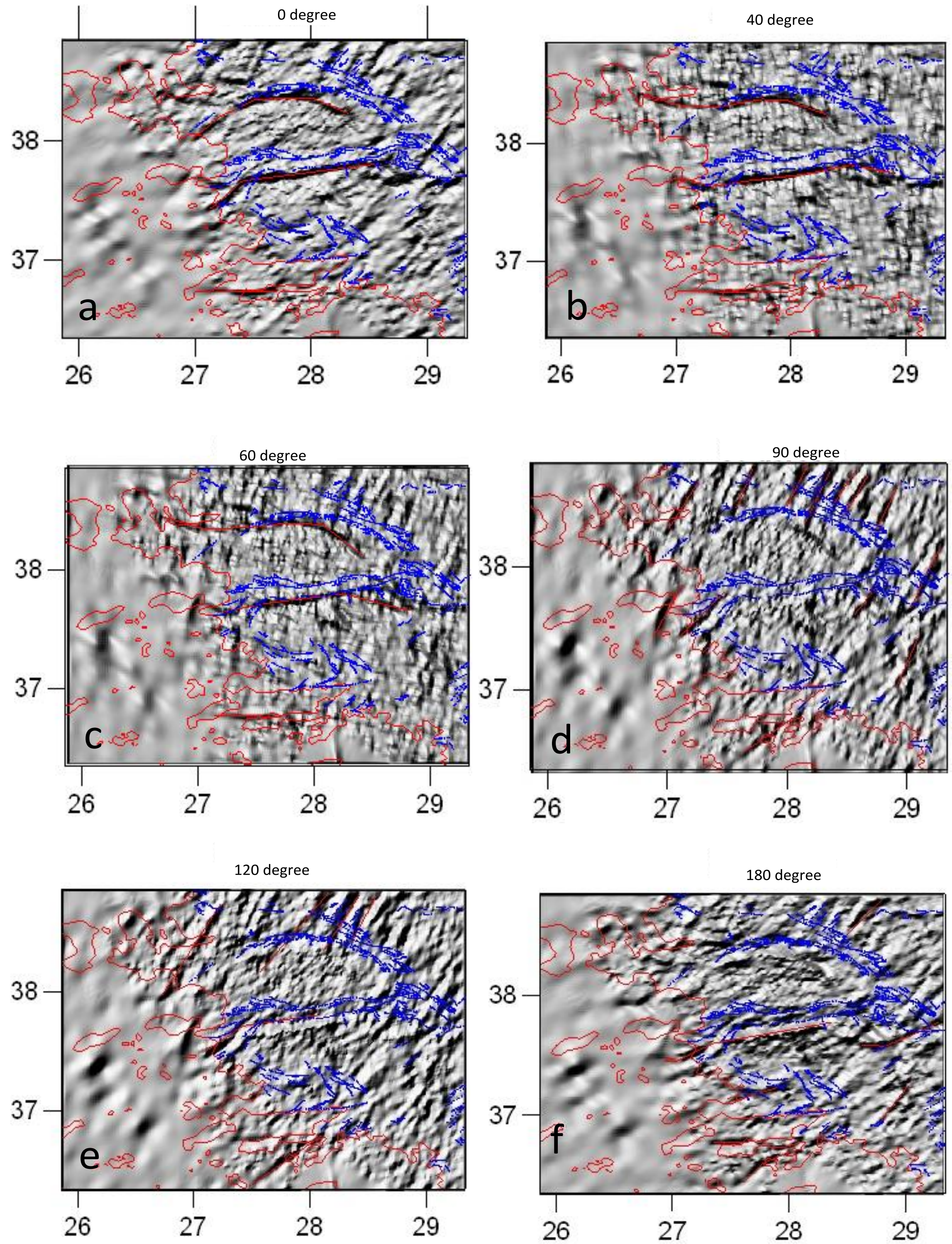


Figure 7: As a result of applying Steerable Filters to the gravity anomaly map around Southwest Anatolia, at a.0 degrees, b. at 40 degrees, c. at 60 degrees, d. at 90 degrees, e. at 120 degrees, f. at 180 degrees, obtained results

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