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Investigation of Crustal Thickness in Eastern Anatolia Using Gravity, Magnetic and Topographic Data

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Abstract—The tectonic regime of Eastern Anatolia is determined by the Arabia-Eurasia continent-continent collision. Several dynamic models have been proposed to characterize the collision zone and its geodynamic structure. In this study, change in crustal thickness has been investigated using gravity, magnetic and topographic data of the region. In the first stage, two-dimensional low-pass filter and upward analytical continuation techniques were applied to the Bouguer gravity data of the region to investigate the behavior of the regional gravity anomalies. Next the moving window power spectrum method was used, and changes in the probable structural depths from 38 to 52 km were determined. The changes in crustal thickness where free air gravity and magnetic data have inversely correlated and the type of the anomaly resources were investigated applying the Euler deconvolution method to Bouguer gravity data. The obtained depth values are consistent with the results obtained using the power spectrum method. It was determined that the types of anomaly resources are different in the west and east of the 40° E longitude. Finally, using the obtained findings from this study and seismic velocity models proposed for this region by previous studies, a probable two-dimensional crust model was constituted.

Key words: Crustal thickness, power spectrum, euler deconvolution, gravity model, eastern Anatolia.

1. *Introduction*

The dynamic structure of eastern Turkey is a key point for the characterization of the mechanism of the Arabia-Eurasia continent-continent collision, which shapes the general tectonic regime in Turkey (Fig. 1). To date, different interpretations have been suggested for the mechanisms of geodynamic structure of the area by investigating the velocity differences in the movements of the plates, elevations in topography, and volcanic activities in the region, and four models were proposed until 2003 (ROTSTEIN and KAFKA, 1982; MCKENZIE, 1972 and 1976; DEWEY *et al.*, 1986; PEARCE *et al.*, 1990). In these studies, by using the convergence tensions of the Arabia-Anatolian plates, it has been

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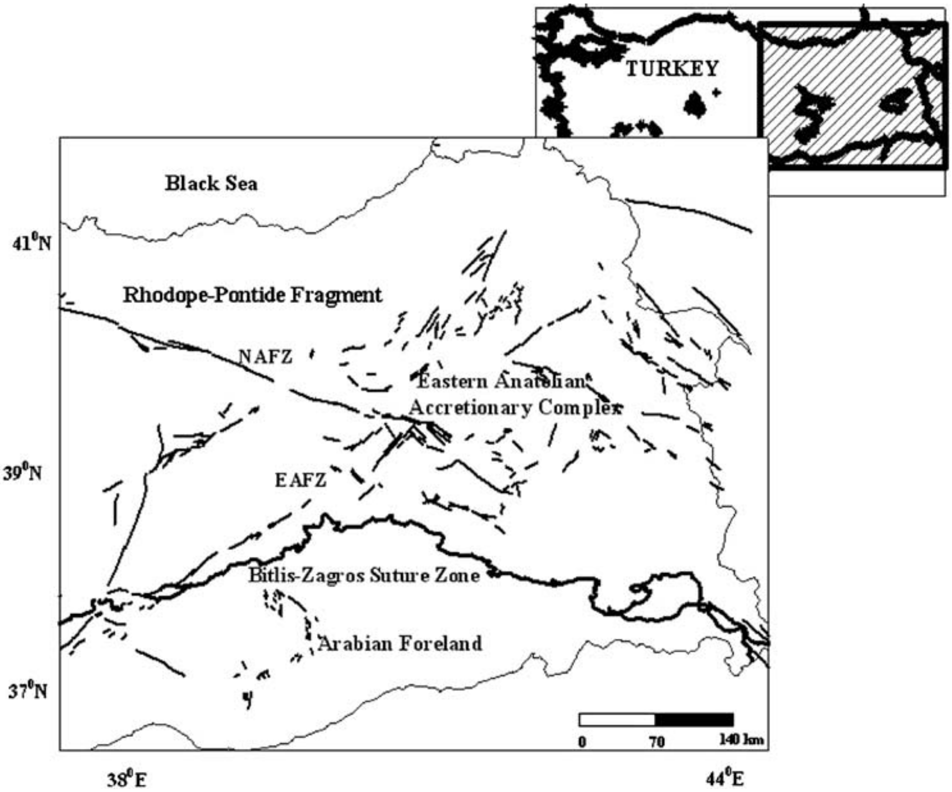

Figure 1
Location and main features of the study area, NAFZ: North Anatolian Fault Zone, EAFZ: East Anatolian Fault Zone.

emphasized that extensive shortening and thickening have initiated in the crust of the region.

After seismological investigation in Eastern Anatolia beyond 2001 (Al-Lazki *et al.*, 2003, Gök *et al.*, 2003; Türkelli *et al.*, 2003; Sandvol *et al.*, 2003a, b; Zor *et al.*, 2003), new geodynamic processes (Şengör *et al.*, 2003; Keskin, 2003) were developed. It was noted in these new models that there was not as much crust thickening as had been cited in previous studies (Rotstein and Kafka, 1982, McKenzie, 1972 and 1976, Dewey *et al.*, 1986, Pearce *et al.*, 1990).

Şengör *et al.* (2003) and Keskin (2003) explained the new geodynamic process in the region within the framework of geologic evolution. These authors claimed that then east Anatolian Accretionary Prism was first shortened and thickened over the oceanic lithospheric slab and then, the slab detached from the accretion prism. They pointed out that the broken slab sank into the asthenosphere and disappeared in the course of time. Due to this process, they claim that crust thickening did not occur.

As a general approach, the power spectrum method is used in studies for the determination of crustal thickness using gravity data (BHATTACHARYYA, 1965 and 1966; SPECTOR and BHATTACHARYYA, 1966; JENKIS and WATTS, 1968; SPECTOR and GRANT, 1970; CIANCIARA and MARCAK, 1976; KARNER and WATTS, 1983; AKGÜN *et al.*, 1996). On the other hand, by using the moving windows power spectrum method developed by CIANCIARA and MARCAK (1976), changes in depth trough, a profile can be determined by windows which are moved by certain intervals.

Another method used for the estimates of structural parameters is the Euler deconvolution method, which determines location of the structure, its depth and the type of source by using horizontal and vertical derivatives of the anomaly (THOMPSON, 1982; REID *et al.* 1990; KEETING, 1998; BARBOSA *et al.* 1999; BEASLEY and GOLDEN, 1993; ZHANG *et al.*, 2000; ROY *et al.*, 2000; ÖZYALIN, 2003).

VON FRESE *et al.* (1982) investigated crustal thickness changes in a region by jointly studying magnetic and free air gravity anomalies. They pointed out the existence of certain geodynamic processes that result in crustal thinning and mantle intrusions in regions where the amplitude of magnetic anomalies decreased and that of free air gravity anomalies increased.

In this study, using gravity, magnetic and topographic data from the eastern Anatolian region, applications and evaluations have been carried out to determine the changes in crustal thickness. In the first stage, techniques of two-dimensional low-pass filtering and upward analytical continuation were used, and behavior of regional gravity anomalies with high negative amplitude in the eastern Anatolian plateau was investigated. Thereafter, the method of moving windows power spectrum was applied to gravity data; depth estimates were obtained and changes in crustal thickness were examined. At another stage of the application, in sections where free air gravity and magnetic data are inversely correlating, Euler deconvolution was applied to Bouguer gravity data, and the location and depth of the structure and the type of source were detected. In the last stage, findings obtained from this study and geodynamic processes in the region were examined together with the results of other geophysical and geological studies and a probable crustal model was formed.

2. *Methods*

2.1. *Moving Window Power Spectrum*

The accuracy of the spectrum estimation, which is a statistical approach, depends on the variance and average square error level. In this application, one-dimensional data are divided into equal divisions using a window function, spectrum for every division is obtained separately, and the values in different frequencies are then summed and their arithmetic mean value is calculated to obtain the spectrum (JENKIS and WATTS, 1968). In this method, power spectrum for each division, $\bar{S}(w)$, is given by CIANCIARA and MARCAK (1976)

$$\bar{S}(w) = \frac{1}{R}\sum_{r=1}^{R}\sum_{p=1}^{P} f_r^p(w, \alpha_1^{pr}, \alpha_2^{pr}, ...\alpha_n^{pr}) \exp(-2wh), \tag{1}$$

where R is the number of divisions, w is the angular frequency, h is the depth, α is the structure parameter and f is the function of anomaly. If, in equation (1), the following inversions

$$f_r^p(w, \alpha_1^{pr}, \alpha_2^{pr}, ..., \alpha_n^{pr}) = c^{pr} = \text{constant} \qquad C = \sum_{r=1}^{R}\frac{1}{R}\sum_{p=1}^{P} c^{pr}$$

are made (JENKINS and WATTS, 1968), the equation becomes

$$S = C.\exp(-2wh). \tag{2}$$

Taking the logarithm of the equation (2), the average depth of the structure causing anomalies is found as follows

$$\bar{h}_i = \frac{\ln S(w_{i+1}) - \ln S(wi)}{2(w_{i+1} - w_i)} \quad \text{i = 1, 2,........} \tag{3}$$

2.2. Euler Deconvolution Method

Gravity function of a point source placed at points x_o, y_o and z_o, depending on measurement value ΔT, and structural index N, the two-dimensional Euler equation can be written as follows (THOMPSON, 1982):

$$(x - x_o)\frac{\partial \Delta T}{\partial x} - z_o\frac{\partial \Delta T}{\partial z} = -N\Delta T(x). \tag{4}$$

By rearranging this expression, the following equation is obtained

$$x_o\frac{\partial T}{\partial x} + z_o\frac{\partial T}{\partial z} = x\frac{\partial T}{\partial x} + NT(x). \tag{5}$$

Derivative values in equation (5) can be calculated from gravity or magnetic values obtained from the field of study. Unknown values in the equation are x_o, z_o and N, where, x_o, z_o represent the location of the point sources along the profile and the depth, while it is accepted that parameter N, which defines the rate of decrease depending on the structure type, changes between 0 and 3. In theoretical studies carried out by taking simple geometrical shapes like contact, dike, cylinder and sphere, values of structural index are found to be 0, 1, 2, 3, respectively (THOMPSON, 1982).

3. Application

Bouguer gravity, free-air gravity, aeromagnetic and topographic anomaly maps of Eastern Anatolia extending approximately between 37°–44° E longitudes and 37°–42° N latitudes with 1-km sampling intervals, which were used at the application stage of this study, were provided by the contributions of the Mineral Research Exploration Company of Turkey (MTA).

When the Bouguer gravity map of Eastern Anatolia in Figure 2 is examined, it can be seen that a regional anomaly with high negative amplitude is dominant. In order to investigate the long-wavelength variation of the high-amplitude anomaly in the region, the two-dimensional low-pass filtering and upward analytic continuation methods were applied to the data (Fig. 3). As can be seen from Figure 3, the high negative amplitude anomaly (∼ –180 mgal) begins just in the north of the Bitlis Suture Zone and continues to south of the orogenic belt taking place in Pontid Arc. The width of the negative

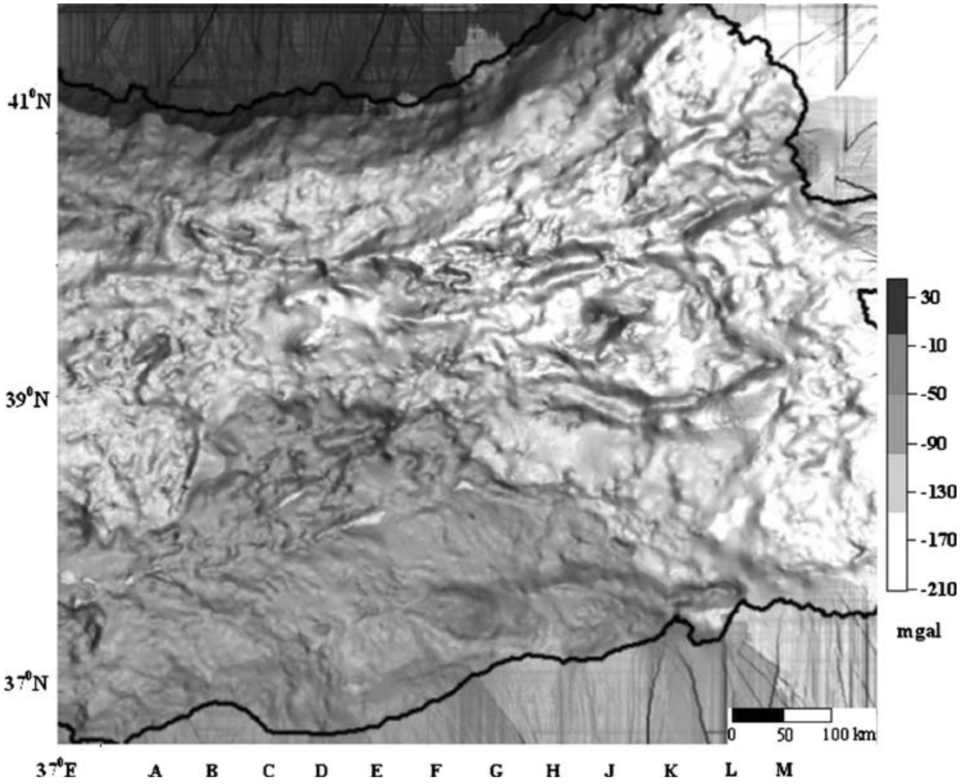

Figure 2
Bouguer gravity map of Eastern Anatolia.

anomaly in N-S direction is 200 km at 38° E longitude in the western part of the region and extends 400 km towards the eastern part.

According to the Airy compensational mechanism, negative anomalies on the Bouguer gravity map are interpreted as regions with thick crust and excess mass (mountainous regions) or as hot regions with low density. For this purpose, preceding all, filtering and analytic continuation maps (Fig. 3) were compared with the topographic map (Fig. 4). Although the two types of maps seem to be similar in main features, close examination reveals that regions with the same elevations present different Bouguer gravity anomalies. For example, although the section in N-S direction on 40° E longitude on the topographic map in Figure 4 has a topography over 2000 meters, the section giving high amplitude negative anomaly on the filtering map (Fig. 3) has a boundary between 38.5°–39.5° N latitudes. This shows that the anomaly does not stem only from excess mass and it conveys the presence of another factor.

For the purpose of throughly investigating the depths in the region, moving window power spectrum was applied to Bouguer gravity data. Application was conducted in 12 profiles with 50 km intervals in N-S direction, and 512 km in length (Fig. 2, profiles A, B, C, D, E, F, G, H, J, K, L, M). In order to eliminate short wave changes in data, a simple smoothing technique was applied to all data. Then, average power spectrums for each profile were calculated using 234 windows which are 250 km long with a 10-km moving interval. The map for probable structural depths in the East Anatolia Region is shown in Figure 5.

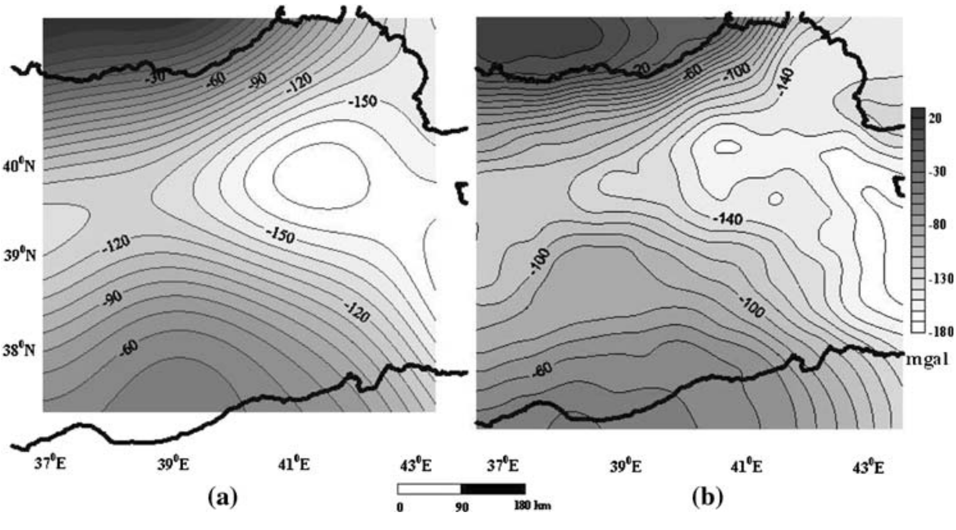

Figure 3
a) Low-pass filter map of Bouguer gravity data in Figure 2. b) Upward analytic continuation map of Bouguer gravity data in Figure 2.

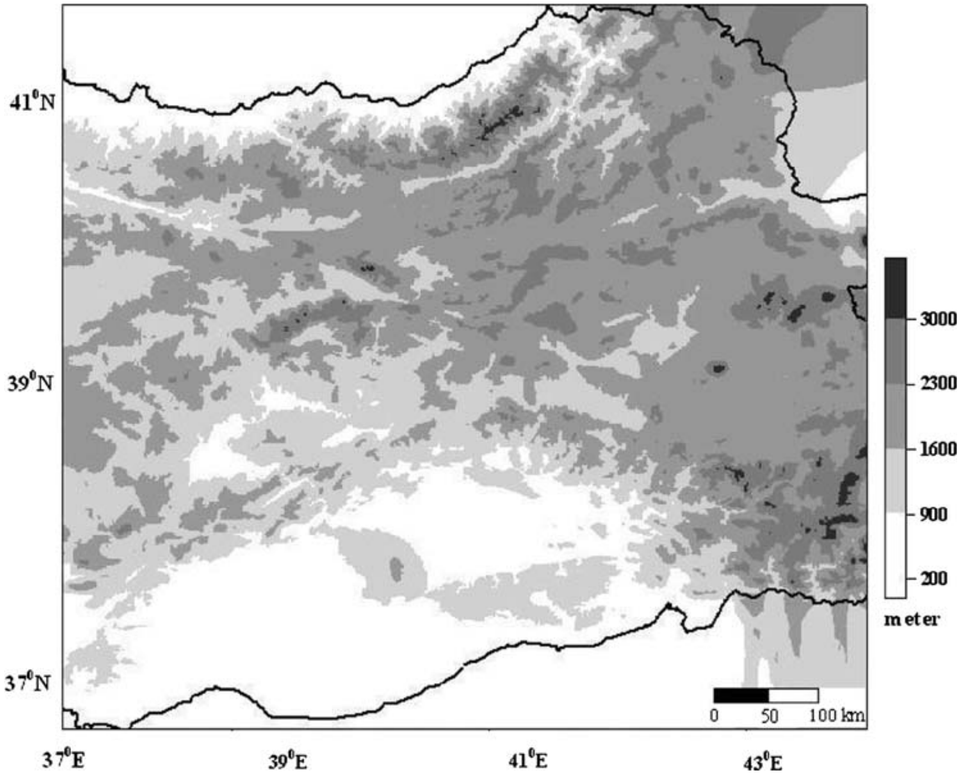

Figure 4
Topographic maps of the field of study.

Examination of the obtained depth map (Fig. 5) reveals that the depths in the region range from 38 to 52 km. When advanced in the northern direction in the section which lies between longitudes 38° E and 42° E, it was determined that crust thickness which increases as far as 39° N latitude decreases relatively as far as 40° N latitude. Particularly, the relative decreases ($\sim$45 km) in crustal thickness for the region between 39° and 40° N latitude are outstanding.

The purpose of a detailed investigation of the crust thickness in the region, N-S sections presenting inverse correlation between free air gravity (Fig. 6, profiles A, B, C) and aeromagnetic anomalies (Fig. 7, profiles A, B, C) were determined (Figs. 8–10). Sections presenting inverse correlation between free air gravity and aeromagnetic anomalies are marked by rectangular windows on the profiles. In order to investigate the changes within borders of the windows, the Euler deconvolution method was applied to Bouguer gravity data (Fig. 2, profiles C, E, G) in these profiles (Figs. 11–13).

Figures 11–14 reveal that borders of crust thickness in Eastern Anatolia were determined, especially of the sites where the thickness had been expected to be less.

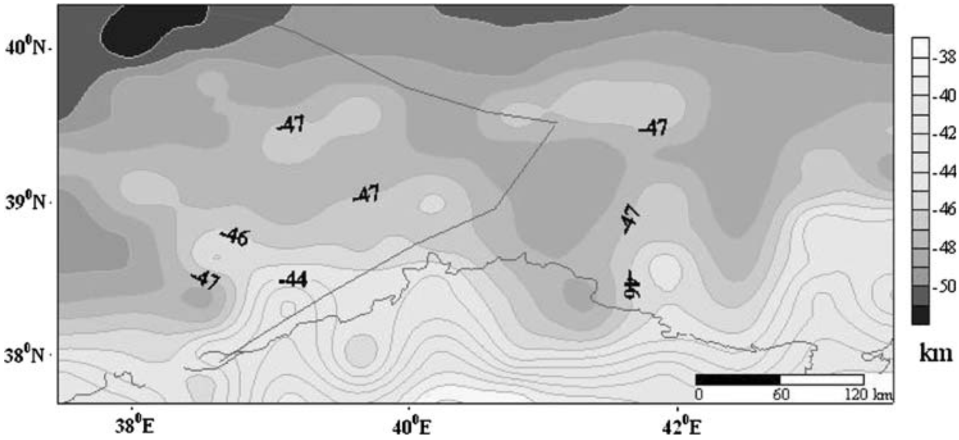

Figure 5
The map of possible structural depths belonging to the Eastern Anatolian Region obtained from the application of moving window power spectrum method on Bouguer gravity data.

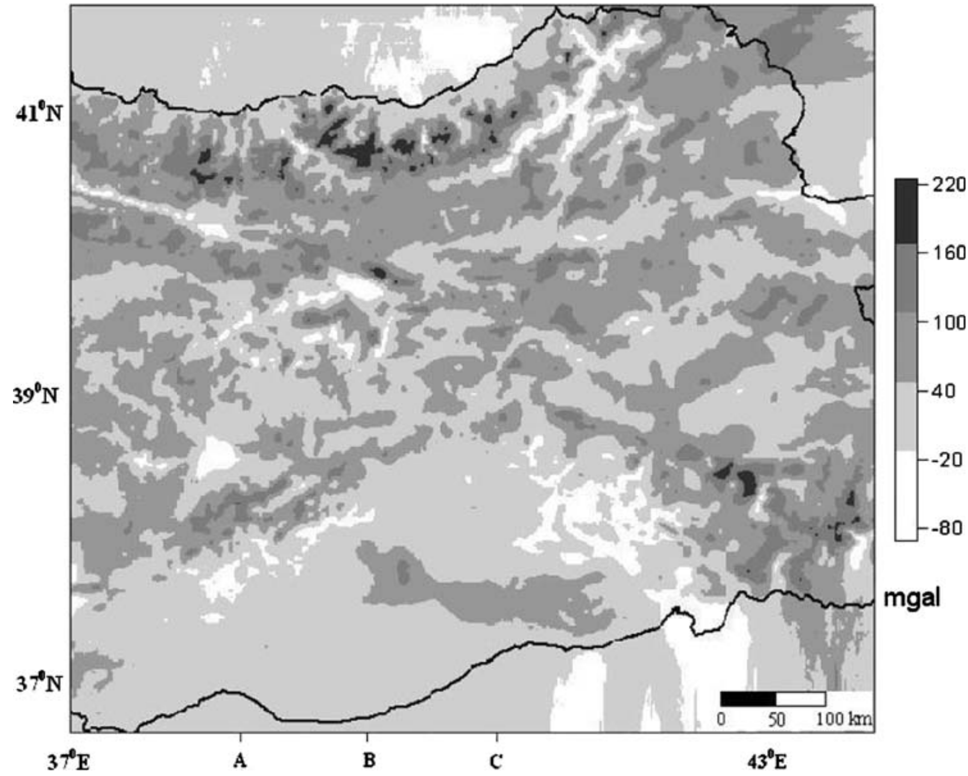

Figure 6
Position of the profiles chosen from the free air gravity map of the Eastern Anatolia Region.

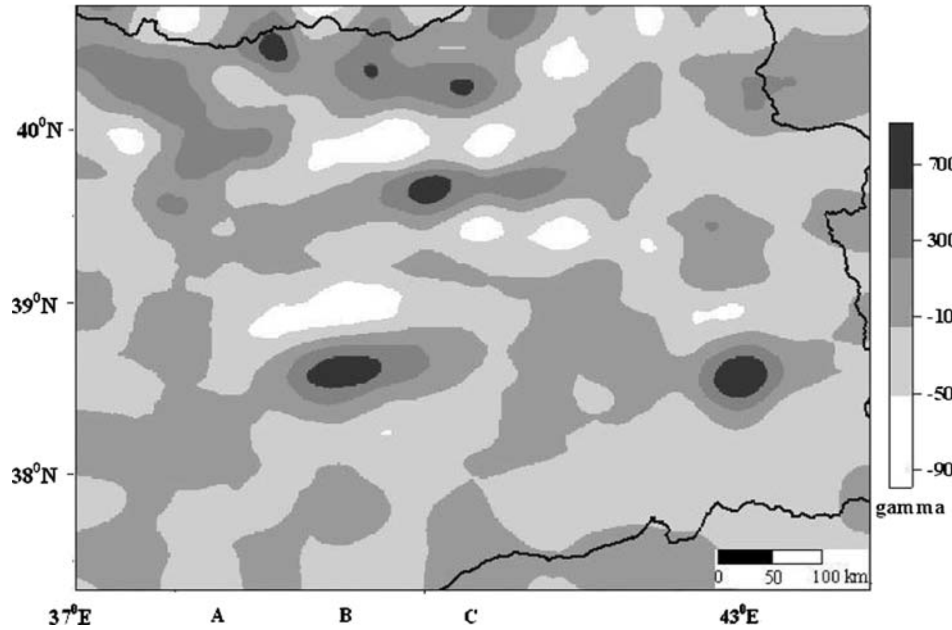

Figure 7
Position of the profiles chosen from the aeromagnetic map of the Eastern Anatolia Region.

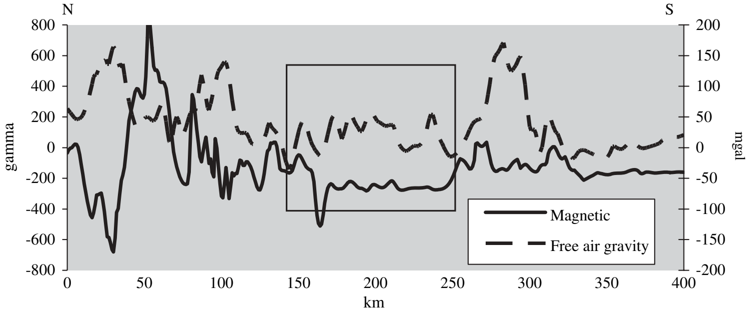

Figure 8
Sectional values of profile A.

Sections in which the depth shows a decrease and sections in which free air gravity and magnetic anomalies present inverse correlation, show consistency in all profiles.

4. Discussion

From the application of moving windows power spectrum, it was determined that crustal thickness which is 42 km in the south Bitlis Suture Zone extends up to 50 km in

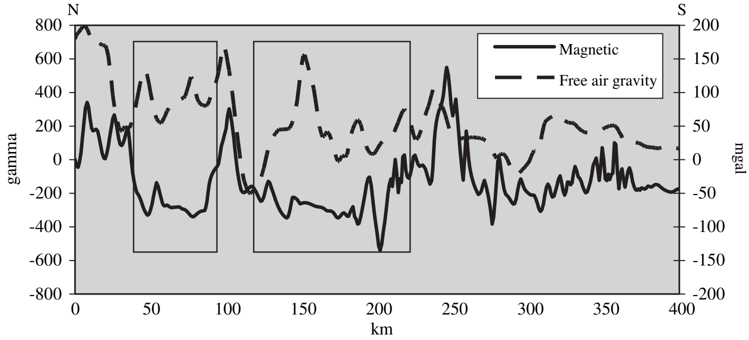

Figure 9
Sectional values of profile B.

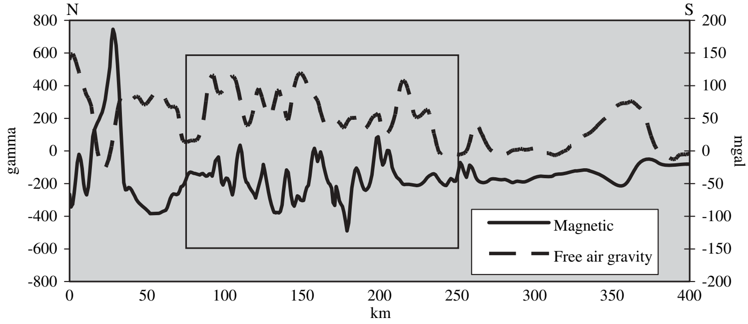

Figure 10
Sectional values of profile C.

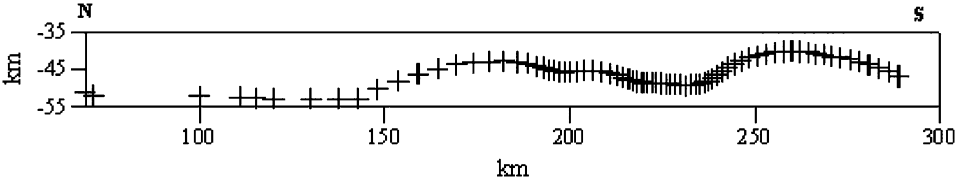

Figure 11
Application of Euler deconvolution method on Bouguer gravity data of profile C in Figure 2.

the north Anatolian fault region. It was determined that there was no crust thickening along the suture zone but that there was considerable thickening beginning from the Bitlis suture zone towards Pontides extending in the northern of the eastern Anatolia plateau. This result is not consistent, especially with crustal thickening models expected in the accretionary zone in the region (ROTSTEIN and KAFKA, 1982; MCKENZIE, 1972 and 1976; DEWEY *et al.*, 1986; PEARCE *et al.*, 1990). Crust thicness determined overlaps with values

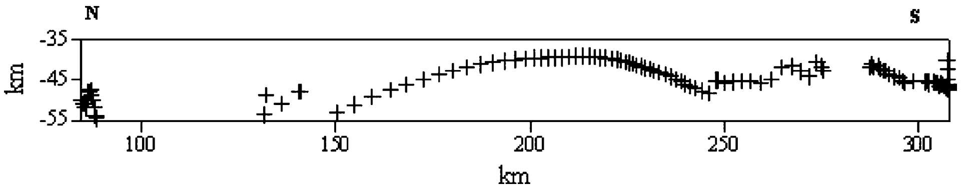

Figure 12
Application of Euler deconvolution method on Bouguer gravity data of profile E in Figure 2.

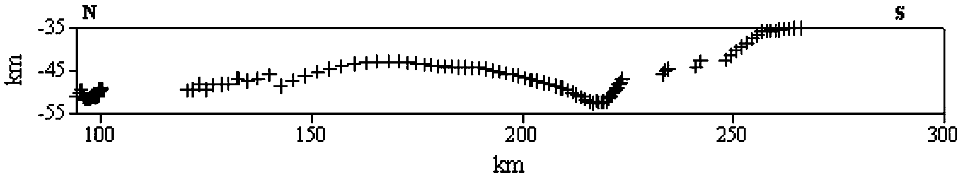

Figure 13
Application of Euler deconvolution method on Bouguer gravity data of profile G in Figure 2.

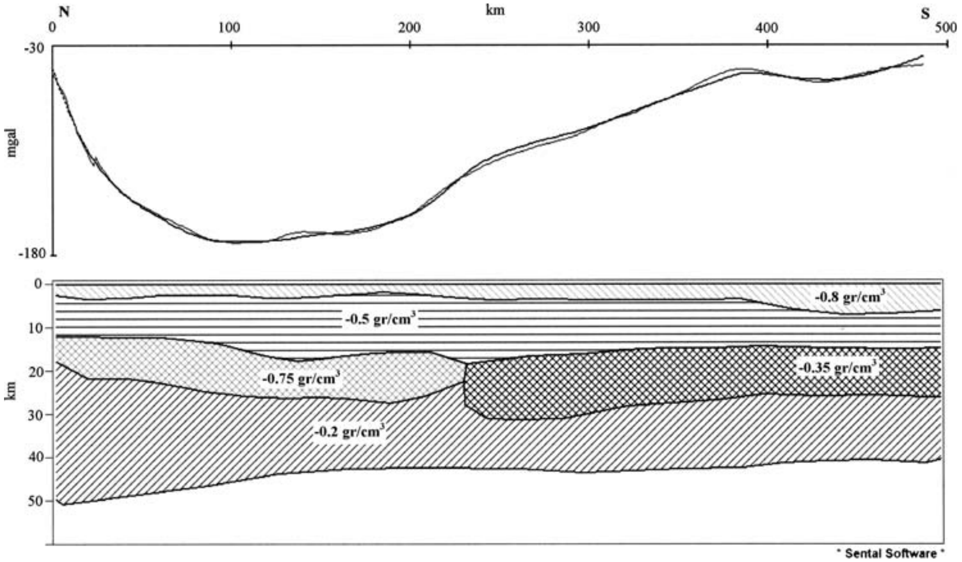

Figure 14
Geophysical model of profile G in Figure 2.

of crust thickness determined in this zone by Zor *et al.* (2003). These results support the crust thinning model proposed for the region by Şengör *et al.* (2003) and Keskin (2003).

Values of thickness determined by applying the Euler deconvolution method (Figs. 11–13) point to the fact that thinning in the crust begins at nearly 40° E longitude and continues in the eastern and northern directions. This finding overlaps with those obtained from power spectrum application (Fig. 5). Analysis of the Euler deconvolution application provides the solution of the dike model for the source type causing the anomaly in the western part of the region (Fig. 6., profiles A–B), and towards the east, it gives the solution of the contact model (Fig. 6, profile C). This result brings forth the possibility that the type of source that creates an anomaly east and west of longitude 40° E has a different feature.

In the field of study, in sections where free air gravity and aeromagnetic data present inverse correlating on, geophysical data from previous studies are: high heat flow of mW/m^2 (Tezcan and Turgay, 1989; Pamukçu, 2004), absence of *Sn* wave (Gök *et al.*, 2003), and the presence of very low *Pn* velocity (Al-Lazki *et al.*, 2003). Von Frese *et al.*, (1982) mentioned the presence of crust thinning and of certain geodynamic processes that cause mantle intrusions in this kind of areas. On the other hand, Şengör *et al.* (2003) explained the dynamic process of the accretionary of prism of eastern Anatolia by partial melting of the lower part that was exposed to astenospherical temperatures. When all findings were investigated together, litosphere seems to-geht thinner where free air gravity and aeromagnetic data have an inverse relation while the astenosphere rises considerably and the crust becomes considerably thinner.

Using the densities calculated through the use of seismic velocities obtained by Zor *et al.* (2003) in the region, Bouger gravity data belonging to profile G in Figure 2 were modeled using the Talwani (Talwani *et al.*, 1959) method (Fig. 14). The section where the gravity of the anomaly decreased corresponds to the section where the structural depth is less than expected in particular. Zor *et al.* (2003) determined the existence of the Low Velocity Layer, especially in this section, at 15-km crustal thickness on average. The presence of low-velocity layers in a region brings into discussion the concept of low density. Besides the fact that the lithosphere is becoming thin, and the atmosphere is becoming high causes a decrease in density due to the factor of temperature. These approaches show the presence of low amplitude gravity anomaly.

5. Results

Regional anomaly showing high negative amplitude and reaching up to – 180 mgal in the region stems from the low-density zone formed due to high temperatures.

Average depth values determined from the application of power spectrum begins from 38 km in the South and reaches 52 km in the North.

Crustal thickness was determined to be changing from 40 to 45 km in sections that present inverse correlation between free air gravity and aeromagnetic data according to the Euler deconvolution application. Moreover, values of structural index determined as a result of application suggest that the lithosphere has different properties on the east and west sides of longitude 40° E.

Examination of the lithosphere proposed for the region and the crust thinning model that comes about as a result of thinning in the lithosphere, support the results obtained from this study.

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