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INVESTIGATION OF CRUSTAL STRUCTURE OF TURKEY BY MEANS OF GRAVITY DATA

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ABSTRACT.- During this work, the regional gravity data acquired earlier were used and in order to investigate the relations between geology - tectonics and elevation, isostatic map of Turkey, free air anomaly map and Bouguer anomaly maps were obtained, and comparisons with respect to elevations were carried out. For the thickness of the earth crust T = 0.32 - 0.08g relation was used. The best relation was obtained from Bouguer anomaly with +0.65 coefficient; the relation function was obtained as Y = - 72E + 7.77. Thickness of the crust of Turkey is estimated to be 31.4 km where it is the shallowest and 50 km where it is deepest.

Key Words: Turkey, Geophysics, Gravity, Free Air, Boguer, Crustal Thickness, Isostasy, Tectonics

INTRODUCTION

Regional gravity investigations were started in 1973 by General Directorate of Mineral Research and Exploration (MTA), during this work which lasted 15 years measurements were taken from 60648 stations and the work was finished in 1988. The measurements were taken from survey control points at intervals of 3 to 5 km and from points where coordinates could be provided on 1: 25000 scale topographical maps such as schools, mosques, road junctions, stream diversion points, etc. Limited gravity data obtained from Turkish Petroleum Company (TPAO) and General Command of Mapping (HGK) were included in our data.

During the field work Worden Master LaCoste Romberg 344 and 347 gravity meters were used. The international base value taken from Potsdam was transported to airports by HGK. HGK and MTA distrubuted these values throughout Turkey to establish the National Gravity Base Network.

Seismology which is a branch of geophysical disciplines provides very useful information on the structure of earth crust. Seismic refraction, seismic reflection and distibution of velocity of surface waves as well provide useful information to understand the crustal structure to some extent. Another auxiliary branch is gravity studies. Although it can not provide some adequate resolutions by itself, it provides useful information to support and to contravene the seismic investigations. For crustal structure, isostasy - topographical elevation and topographical elevation - geological factors can be related to propose geological models applicable. Besides, crustal structure and heat flow can be related (Woollard, 1959). The interrelations of Bouguer and elevation values play an important role in understanding the crustal structure (Qureshy, 1970).

In this study, free air, isostasy (Airy) and Bouguer maps were prepared to investigate their relations with elevations, tectonics and geology and then a crustal thickness map of Turkey prepared by use of Bouguer anomaly and elevation data was obtained. The relation T = 32 - 0.08g was used for the crustal thickness of the world during this work (Wollard, 1959).

The Eastern Mediterranean Region which is located on an earthquake belt between Gibraltar and Indonesia and forming an interesting belt

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with its structures similar to island arcs has been investigated by many researchers for gravity anomalies since 1930s. Recent developments have attributed significance to these investigations. Gravity anomalies of the Eastern Mediterranean and Anatolian were combined and related in order to seek a lineer relation between the gravity values and topographical elevations along these profiles (Özelçi, 1973).

In seismology and seismic works, measurement of the crustal waves or interpretation of the data obtained by artifical blasts have been significant for understanding the crustal structure and composition. During these works realized in Marmara, central Anatolia, Eastern Anatolia and Southeastern Anatolia, dynamites blasted in quarries and wells were used. The average crustal thickness for Central Anatolia is calculated as 36 - 40 km, and it was observed that the crust displaying lateral changes is thinner in northwest Anatolia compared to eastern Anatolia. Crustal thickness was measured as 41 km in Ağrı. A 220 km long and NW-SE trending profile transected a tectonically complex structure such as the Arabian - Anatolian plate. Thickness of the crust was measured to be between 38 - 42 km by seismic refraction studies (Bekler et al., 2005).

The surficial waves of the 1999 Turkish earthquakes obtained from the seismic stations located in western Greece were studied mainly for diffractions of Love waves and the crustal thickness of the northwestern Anatolia was calculated as about 33 km (Novotny et al., 2001).

By application of experimental relations to gravity anomaly data, it was determined that the crustal thickness values for Anatolia varies between 26.4 km and 49.5 km (Maden et al., 2005). Later on, two dimensional radial mean power spectrum technique was applied to anomaly map to find the average regional depth as 47 km. At the second stage, the one dimensional sliding window power spectrum method was applied to the same map to investigate the change in structural depths. It was determined as a result of this application that the depths varied between 38 - 52 km and the average crustal thickness is determined as 45 km (Akçığ et al., 2005).

GENERAL GEOLOGICAL STRUCTURE OF TURKEY

Geological structure of Turkey which is located in Alpine - Himalayan Orogenic Belt is dominated by Pan - African basement cropping out locally in some zones and continental zones formed during the evolution process of Tethyan Ocean (Paleo - and Neo - Tethys) and the paleotectonic zones formed by the oceanic suture belts located between them (Figure 1). These tectonic units extending in E - W diection in general were investigated by some researchers (i.e. Ketin 1966; Özgül 1976, 1984; Şengör and Yılmaz, 1981; Şengör et al., 1984; Şengör 1985; Görür 1987, 1988, 1991; Okay 1989; Koçyiğit et al., 1991; Tüysüz 1993; Görür et al., 1983; Yılmaz et al., 1994, 1995; Okay et al., 1996; Okay and Tüysüz 1999) for their forms, positions, distributions, contact relations, regional correlations and tectonical evolutions.

When the continental zones and suture belts with tectonic contacts were investigated from north the south, the Istranca Zone is located in northwest Turkey. Gneiss and metamorphic rocks are observed at the basement of the Istranca Zone which is comprised of Istranca Massif and Thrace Basin. On these lithologies, Triassic - Early Jurassic clastic and carbonate rocks which have undergone metamorphism in Middle Jurassic period are observed. These metamorphic rocks were unconformably overlain by Thrace Basin sequence which is comprised of clastics and carbonate rocks deposited during Middle Eocene - Recent (Aydın, 1974; Kasar and Okay, 1992; Okay et al., 2001). The Istranca Zone is separated by a tectonic contact of a strike slip fault from the Istanbul Zone (Okay and

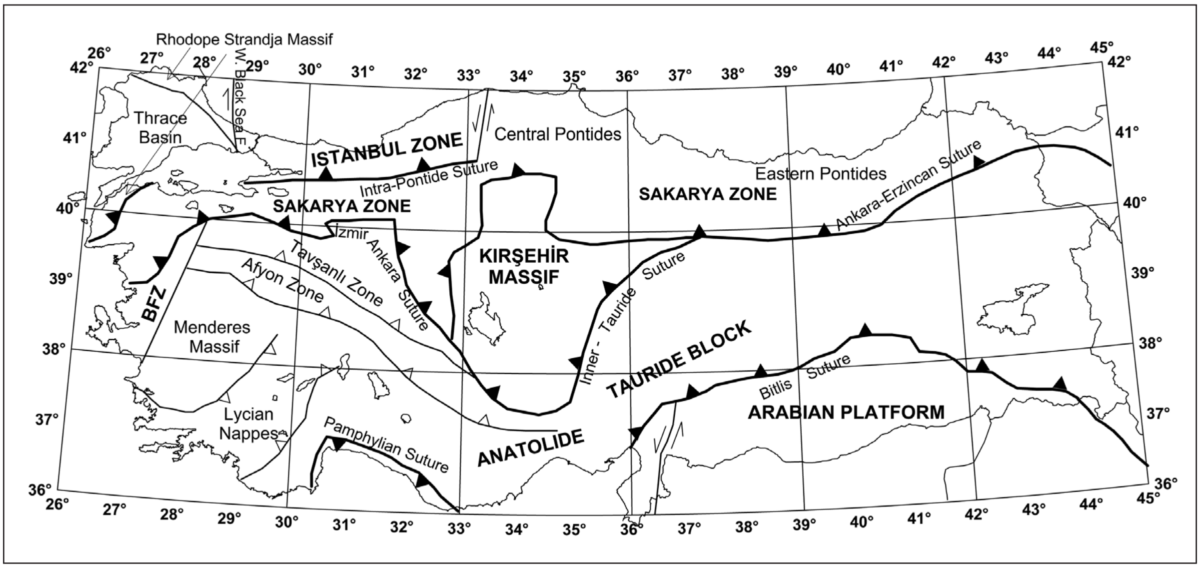

Figure 1- Map showing the structural units and suture zones of Turkey (changed from Okay and Tüysüz, 1999).

Tüysüz, 1999). At the basement of the Istanbul - Zonguldak Zone Pan - African basement rocks comprised of Precambrian gneiss, metagranite and amphibolite are located. This basement is overlain by an unmetamorphosed sedimentary sequence of Ordovician - Carboniferous age comprised of clastic and carbonate rocks (Kozur and Göncüoğlu, 1999; Ustaömer and Robertson, 2005). These Triassic clastics and carbonates unconformably overlie the lower sequences (Şengör and Yılmaz 1981; Yılmaz et al.,1995). Late Cretaceous - Eocene volcano - clastic rocks and carbonates are the cover rocks of the İstanbul - Zonguldak Zone (Okay et al., 1994; Görür and Okay 1996). Th eInner Pontide Suture separate the İstanbul - Zonguldak Zone from the Sakarya Zone (Şengör and Yılmaz, 1981). Late Cretaceous - Paleocene ophiolitic melange and Late Cretaceous - Eocene blocky flysch are located in Inner Pontide Suture (Okay and Görür,1995; Görür and Okay, 1996). The continental rock assemblage extending between Biga Peninsula and Eastern Black Sea forms the Sakarya Zone. The metamorphic massifs, namely Kazdağ, Uludağ and Pulur which are comprised of gneiss, marble and metaperidotites located at the basement of the Sakarya Zone have been affected by Hercynian orogeny. These massifs were tectonically overlain by Late Paleozoic - Triassic volcano - sedimentary rock assemblages (Karakaya Complex) which were affected by low grade metamorphism and intensely deformed and include limestone blocks (Bingöl et al., 1973; Okay et al.,1996; Duru et al., 2004). These rocks were transgressively overlain by Early Jurassic - Eocene carbonates and flysch sequence. In this sequence, especially in Eastern Black Sea volcanic products are quite widespread since Late Cretaceous period. Besides, intensive granitic intrusions of Late Paleozoic - Miocene age in Sakarya Zone were observed. The İzmir - Ankara - Erzincan Suture located south of the Sakarya Zone represent the north dipping subduction zone (Şengör and Yılmaz, 1981). This suture is accompanied by highly sheared ophiolitic rocks of Triassic - Cretaceous age and Late Cretaceous blocky flysch (Bornova Flysch Zone) and blueschists and ophiolitic rocks in Tavşanlı Zone (Okay, 1984, 1986; Erdoğan et al.,, 1990). To the south of the İzmir - Ankara - Erzncan Suture, the Central Anatolian Massif comprised of high grade metamorphic rocks is located. This crystalline massif which is intruded by Late Cretaceous granitic intrusions was unconformably overlain by clastic and carbonate rocks deposited between Late Maastrichtian - Recent (Erkan, 1975; Göncüoğlu, 1981; Seymen 1982; Gökten, 1986). The Central Anatolian massif is separated from the Tauride platform by the Inner Tauride Suture which is comprised of Late Cretaceous - Eocene ophiolitic rocks (Şengör and Yılmaz, 1981). To the south of İzmir - Ankara - Erzincan Suture and İnner Tauride Suture, the Menderes Massif and Taurus Platform are located. The Menderes Massif includes a core and cover units enclosing it (Dürr et al., 1978; Şengör et al., 1984; Konak, 2003). The core is comprised of augen gneiss and migmatites which represent the Pan - African basement. On the other hand, the cover units are constituted by Late Paleozoic - Eocene carbonate and clastic rocks. These lithologies were affected by regional metamorphism. The Taurus Platform is comprised of different tectonostratigraphic units and nappes which include platform, continental margin and oceanic lithologies deposited between Early Paleozoic - Tertiary were thrusted onto each other by Late Cretaceous - Eocene movements and were affected by metamorphism locally (Özgül, 1976; 1984). The Bitlis Suture which the boundary between Taurus Platform and Arabian Platform represents the southern branch of the Neo-Tethys Ocean which existed between Late Triassic and Early Miocene. The widespread ophiolitic nappes in Eastern and Southeastern Anatolia are the remnants of this ocean (Şengör and Yılmaz, 1981; Dewey et al., 1986). The Arabian Platform located to the south of Bitlis Suture is represented by a basement of oceanic and continental relicts which is intensively deformed and overlying clastic rocks deposited in pre-Late Permian times. The transgressively overlying Late Permian - Tertiary carbonate dominated sequence were deposited on and at the margins of the Arabian Platform (Perinçek, 1980; Perinçek et al., 1991; Şengör and Natal'in 1996).

BOUGUER, ISOSTASY AND CRUST MAPS OF TURKEY

Gravity method is used to analyse the structure of the crust and geological structures. In order to shape the basic scientific frame, and to include the early investigations carried out and the regional research, it is a primary tool to interprete the system. The regional gravity anomaly maps are useful for geographical distributions and the appearance of the basement rocks, for structural and lithological areas, crustal thinning regions, for areas in the lithosphere where masses are missing, for the geometry of the sedimentary basins, and for mapping the volcanic intrusive rocks and their distributions (Kwang et al., 1999).

In this study, density was taken as 2.67 gr/cm^3 for Bouguer anomaly map (Figure 2). During calculation of Bouguer value corrections for tides, latitude, topographical and elevations were made. Density was taken as 2.4 gr/cm^3 for topographical corrections. For latitude correction 1967 international gravitation Formula was used (Blakely, 1995). In latitude corrections the reduction surface is taken as sea level.

The total change of Bouguer anomaly map of Turkey is located between -205 to + 80 mgal. The mean Bouguer value is -66 mgal.

On the Bouguer anomaly map, a positive belt extending between Eastern Black Sea and Mediterranean Sea is observed. This belt probably represents the masses with high density. A negative belt emerging from the east of the Salt Lake and extending to Eastern Anatolia, dominant over the high topography is observed. This belt is observed to reach negative values down to -185 mgal. Here, the thickness of the crust is higher with respect to coastal areas. The Great

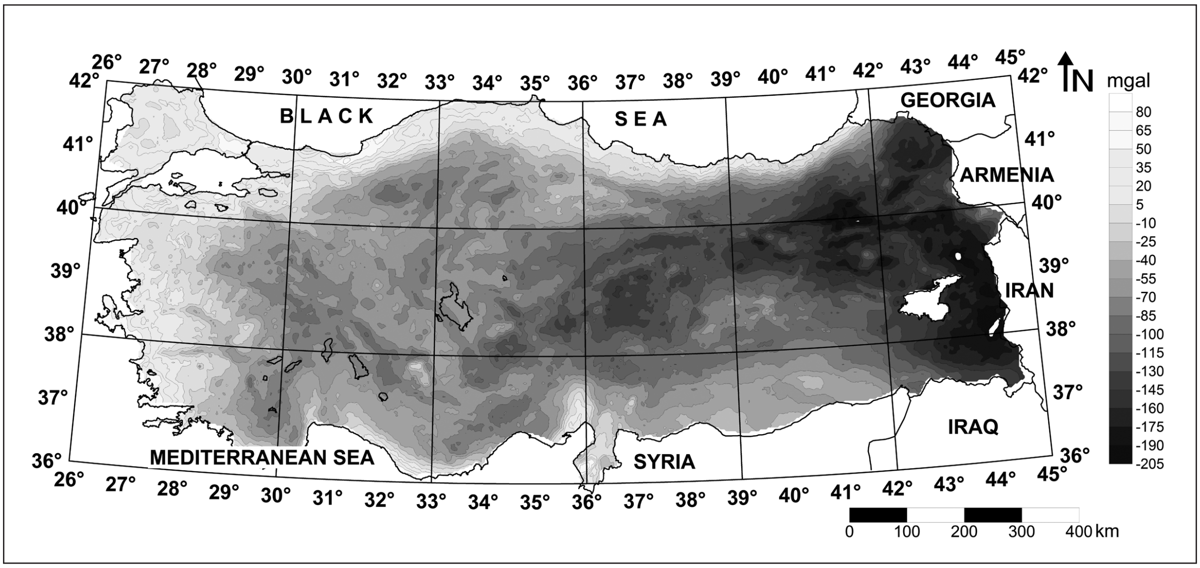

Figure 2- Bouguer gravity map of Turkey.

Menderes, Lesser Menderes and Gediz grabens can clearly be observed on the map.

Whee inconsistencies between the free air gravity and topographical maps are observed geological structures with different densities were indicated. When we look at the free air anomaly map, the positive anomalies extending between the Central Black Sea and Eastern Black Sea, the positive belt to the south of Lake Van, the positive belt to the east of Gulf of Antalya represent mountain ranges located here (Figure 3).

Airy and Pratt explained isostasy concept by two different hyphotheses in 1854 and 1855. Isostasy states the outer layer of the earth and dynamic equlibrium state of the surficial elevations based on the average densities of the underlain rocks. As a result of this theory, the surface of the earth, due to new loads and emoval of loads, move in up and down directions. For this reason, the isostasy concept is very important in describing the lithosphere. The isostatic correction is made to remove the gravity effect of the isostatic root. For isostatic correction and to acquire the maps Oasis Montaj 7.1 software and elevation and bathymetry data of NGDC (NOAA's National Geophysical Data Center) were used provided from the internet address http://www.ngdc.noaa.gov/mgg/topo/gltiles.html.

For regional isostasy calculation the Airy model was adopted (Simpson et al., 1983, 1986). First of all, the Moho depth was calculated from topographical data and then, three dimensional gravity effect extending down to 166.7 km depth of the root (Figure 4). The regional isostatic gravity data was extracted from the Bouguer gravity data to obtain the isostatic residual gravity map (Figure 5). It was observed that Kırşehir Massif, Sakarya Zone in the north, Arabian Platform in southeast, Anatolide - Tauride Block, and the NW - SE trending Tavşanlı and Afyon Zones are in good harmony with regional isostasy map of Turkey (Figure 4).

On Bouguer Map of Turkey changes between -205 to +80 mgal, and on residual isostasy map changes between -60 to +110 mgal were

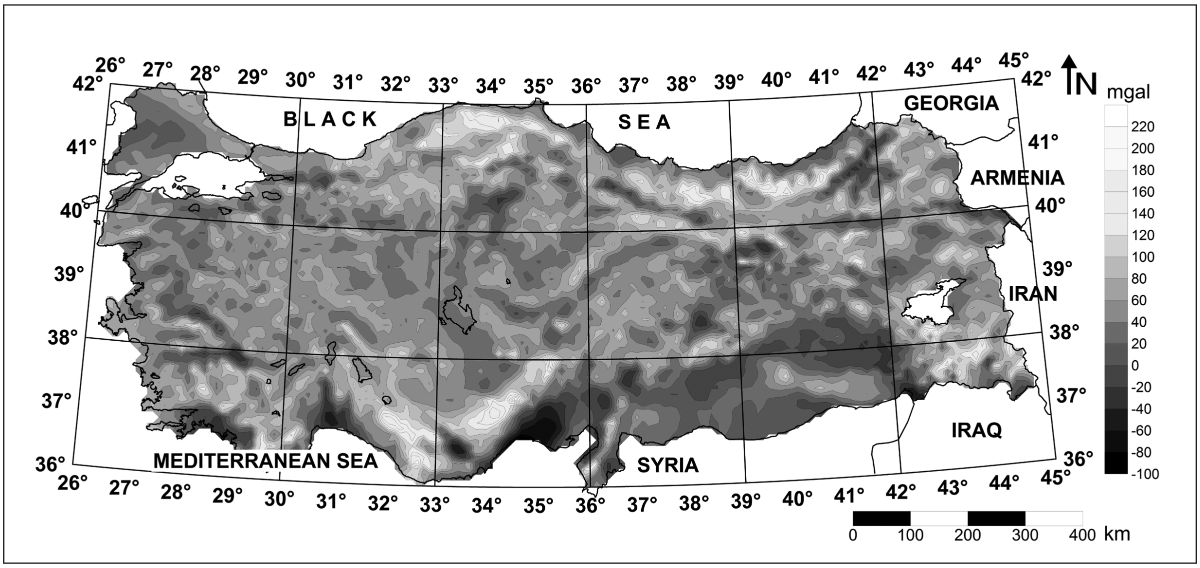

Figure 3- Free air gravity map of Turkey.

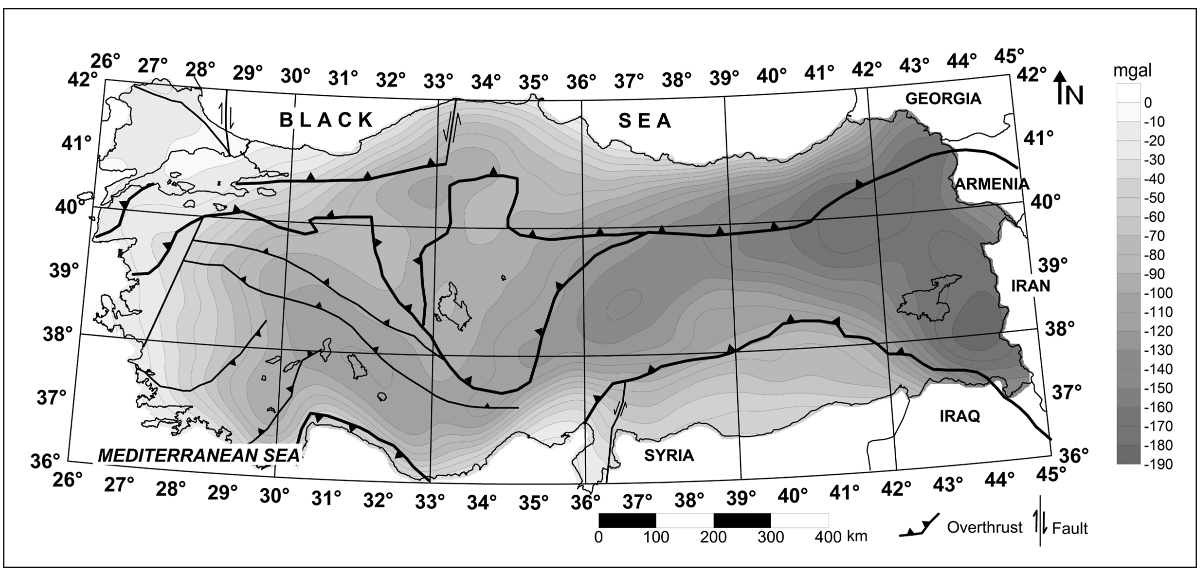

Figure 4- Regional isostasy map of Turkey.

observed. The root effect on Bouguer map was removed up to +110 mgal. The most prominent feature of the isostatic residual map is the removal of the large negative belt observed on the Bouguer map in Eastern Anatolia. This indicates that the effect of isostatic root is quite high.

The Bouguer, free air and isostasy maps were examined and the relations between gravity and elevation were studied. The lineer relation between the gravity data and elevation data were plotted on graphics (Figure 6) and the related information was transferred in Table 1. There are

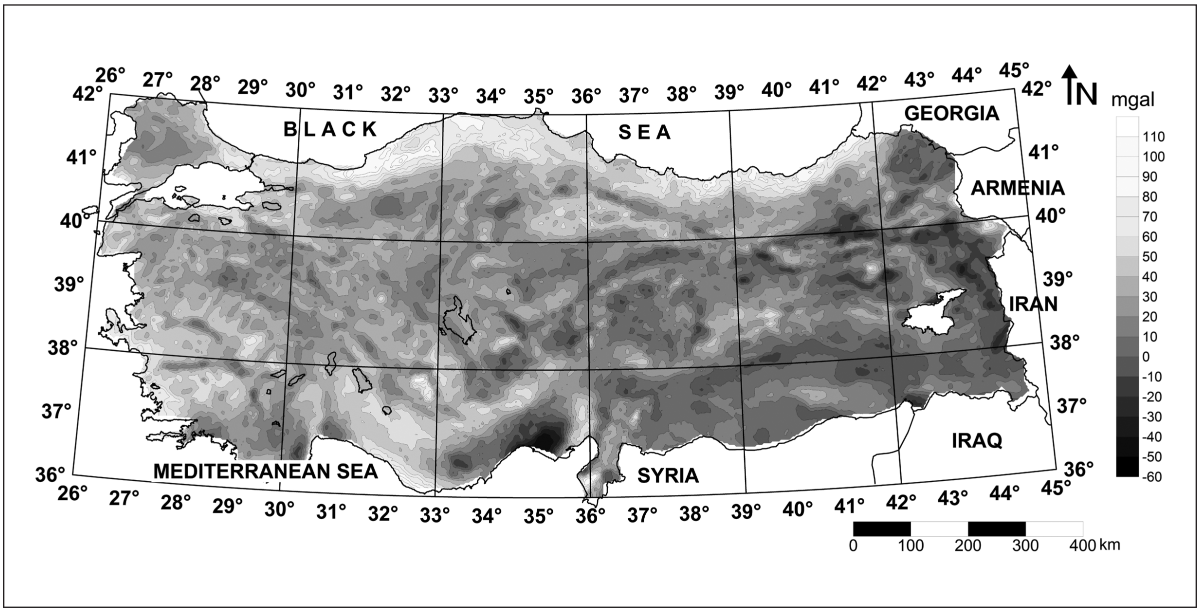

Figure 5- Residual isostasy map of Turkey.

60648 stations in dataset. Statistical relations of each anomaly type was revealed (regression) and their relation coefficients were calculated. The most appropriate relation coefficient (+0.65) was obtained from Bouguer anomaly values.

The regressional equivalence, Y=-72.2E+ 7.77, found for the Bouguer anomaly type as observed in Table 1 is used in Woollard (1959) equation and

T = 32-0.08(-72.2E+7.77) = 31.38+5.77E

was obtained and crustal thickness map of Turkey was prepared (Figure 7).

The change in crustal thickness was found as 18.6 km. Although the highest crustal thickness was observed in Eastern Anatolia, it was observed that the thickness of crust changed between 34 - 36 km along the Arabian Platform. The abrupt change in thickness between İstanbul and Sakarya Zones is remarkable.

Relation of Bouguer Anomaly with Geology and Tectonics

The Bouguer anomaly values observed in Figure 2 changes between -205 to +80 mgal, in total 285 mgal, throughout Turkey. The areas characterized by the lowest average Bouguer anomaly values on the map are: 1. Anatolide - Tauride Block, 2. Kırşehir Massif, 3. Afyon Zone, 4. Arabian Platform, 5. Lycian Nappes, 6. Tavşanlı Zone, 7. Sakarya Zone, 8. Menderes Massif.

The areas with the highest average values are:

1. Bornova Flysch Zone, 2. İstanbul Zone, 3. Thrace Basin (Rhodope - Istranca Massifs).

The lineer relation information obtained from the dataset, intercept values of related geological / tectonic units, dip, relation coefficients, average elevation information, average Bouguer anomaly values and the number of stations were calculated (Table 2).

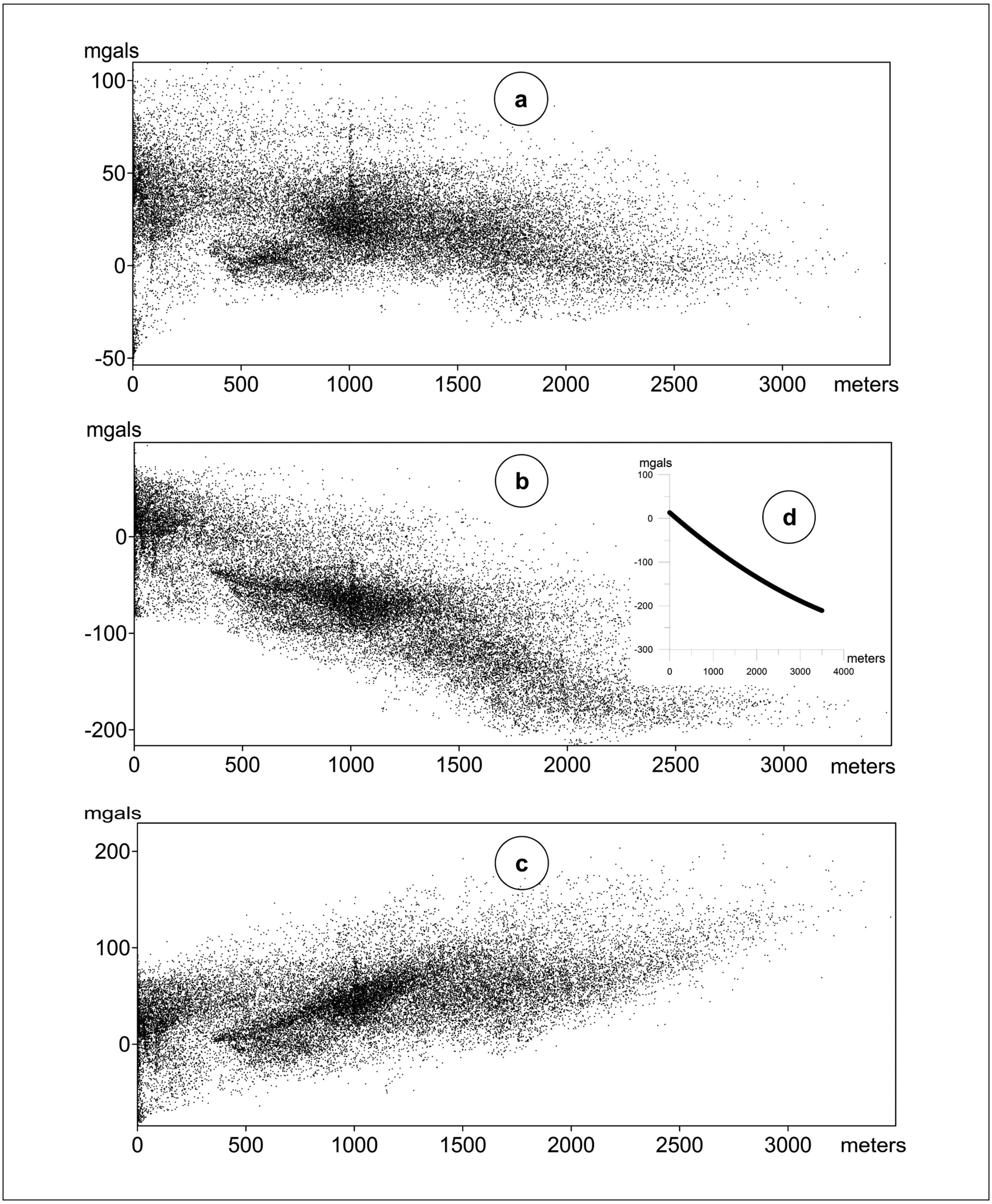

Figure 6- Behaviour of the isostasy (a), Bouguer (b) and free air anomalies (c) by altitude changes; The polynomial relation of second degree between Bouguer and altitude (d).

Table 1- Regressional equivalence for gravity data of Turkey.

Anomaly Type	Regressional equivalence Y mgal, E km	Coefficient of relation	Number of points
Bouguer	Y= -72.2 E +7.77	+0.65	60648
Free Air	Y= 32.7 E +11.9	+0.33	60648
Isostasy - Airy	Y= -11 E +34.75	+0.11	60648

Table 2- Relations between Bouguer anomaly and elevation for different geological and tectonic units.

Geological / Tectonic Unit	Intercept mgal	Dip mgal/km	Relation coefficient	Average elevation (m)	Average Bouguer anomaly (mgal)	Number of stations
Anatolide – Tauride Block	-6.08	-67	0.6	1269	-91.2	29866
Afyon Zone	-27.5	-35	0.3	1117	-66.7	3097
Bornova Flysch Zone	13.2	-5.5	0.006	283	11.7	1032
Lycian Nappes	-10	-45	0.4	1018	-56	2798
Menderes Massif	2.7	-23	0.1	515	-14.6	2809
Tavşanlı Zone	-17.1	-39.7	0.3	960	-55.3	2427
Arabian Platform	-33.9	-41	0.3	765	-65.4	7830
İstanbul Zone	40.6	-50.5	0.37	521	14.27	1603
Rhodope - Istranca Massif	33.9	-24	0.1	228	28	715
Kırşehir Massif	-51.8	-25.3	0.2	1097	-79.5	3577
Sakarya Zone	13.3	-61.7	0.6	1031	-50.3	11617
Thrace Basin	15.4	15.3	0.01	139	17.6	1645

Regression relations were calculated for free air anomaly, Bouguer anomaly and isostasy map. Graphics showing the relation between the elevation and isostasy, Bouguer and free air were plotted (Figure 6). The points of isostasy anomaly versus elevation were scattered between -50 mgal and +100 mgal, the dip was found as -11 and the intercept value as 34.75. The relation coefficient is +0.11 (Figure 6a).

The general scattering in Bouguer anomaly versus elevation behaviour was betwen +60 and -200 mgal; the dip was -72.2 and the intercept value was calculated as 7.77 mgal. The relation coefficient is +0.65 (Figure 6b).

The intercept value of the free air anomaly was calulated as 11.9 mgal and the dip is 32.7; the relation coefficient was calculated as +0.33. The general scattering of the points was between -80 and +200 mgal (Figure 6c).

The relation between the Bouguer and elevation obtained by a polynom of second degree is

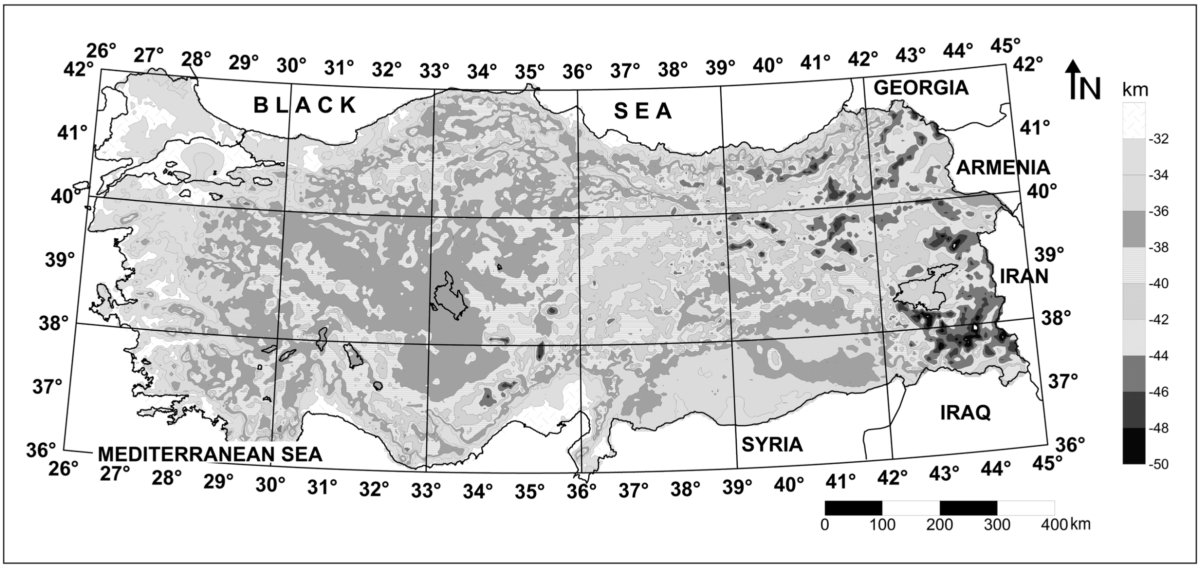

Figure 7- Crustal thickness map of Turkey.

shown in figure 6d. This graphic obtained is in good harmony with the Bouguer anomaly calculated for the world by Woollard (1959).

When we consider the relation coefficient, in relation of Bouguer, free air and isostasy anomalies with elevation, the best harmony was provided in Bouguer anomaly with the value of +0.65.

Five different profiles were shot considering the geology and the structural units in the region. The first four profiles were in roughly N - S direction and were 400 - 600 km long. The fifth profile was in E - W direction and was 1500 km long (Figure 8). In order to see the change in crustal thickness the fault systems and zones (Koçyiğit et al., 2005) cut by the five profiles were shown with abbreviated names such as KAFS: North Anatolian Fault System, IEFZ: İnönü - Eskişehir Fault Zone, TGFZ: Salt Lake Fault Zone, KDAFZ: Northeast Anatolian Fault Zone, DAFS: East Anatolian Fault Zone, OAFZ Central Anatolian Fault Zone.

Along the profile 1 which emerges in Thrace Basin and extends to Anatolide - Tauride Block, the crustal thickening begins at 32 km and the same thickness continues along the Sakarya Zone and reaches to 36 km around the mid - Menderes Massif. In Lycian Nappes region in the southeast, the thickness vary between 37 - 39 km and at the southern end of the profile the crustal thickness drops drastically to 34 km (Figure 9).

The profile 2 which extends between the İstanbul Zone and Anatolide - Tauride Zone is 45 km long. The crustal thickness for the İstanbul Zone on profile 2 is 32 km and along the Sakarya Zone it reaches to 36 - 37 km. Towards the southern end of the profile, the thickness varies at levels of 1 - 2 km (Figure 10).

The profile 3 extends between the Sakarya Zone and Anatolide - Tauride Block. The crustal thickness is about 36 - 37 km at the beginning of the profile and where the Sakarya Zone is cut by the North Anatolian Fault, it reaches to 40 km. The crustal thickness at Kırşehir Massif decrease

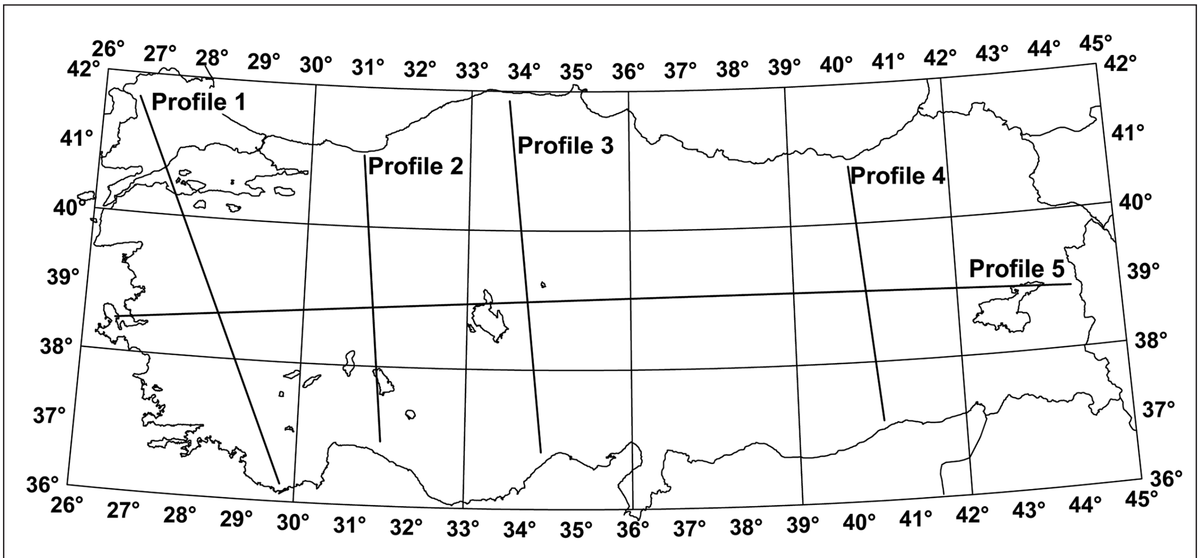

Figure 8- The location of the profiles for determining the crustal thickness.

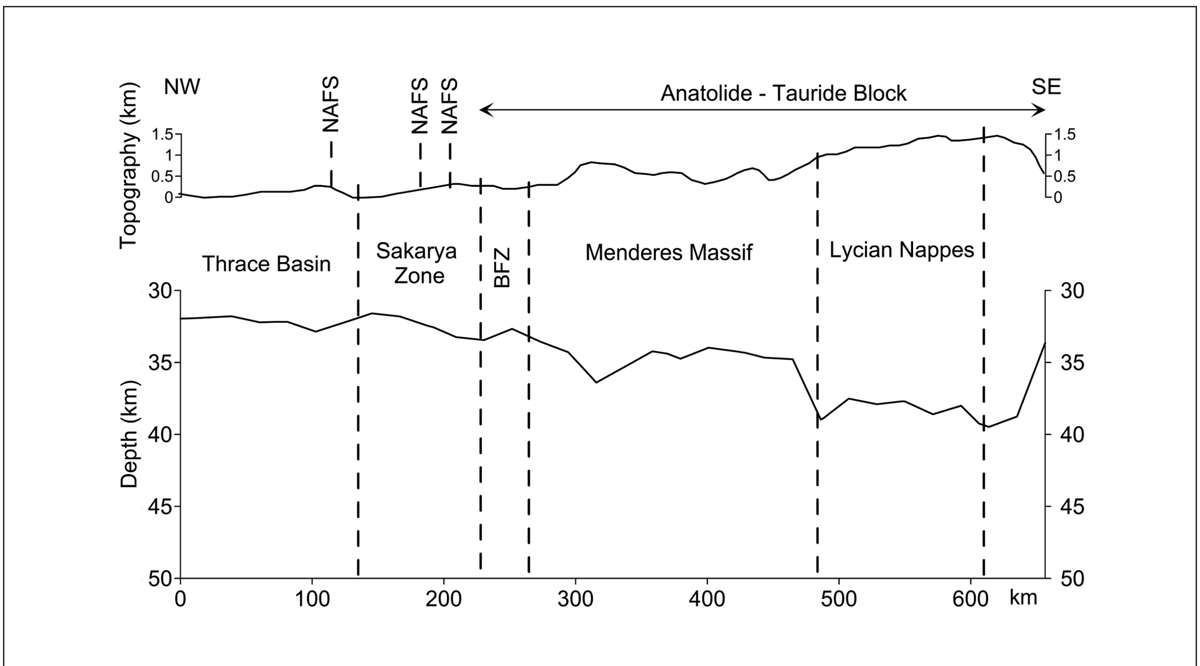

Figure 9- The vertical section of the profile 1 in NW-SE direction showing topography and crustal thickness.

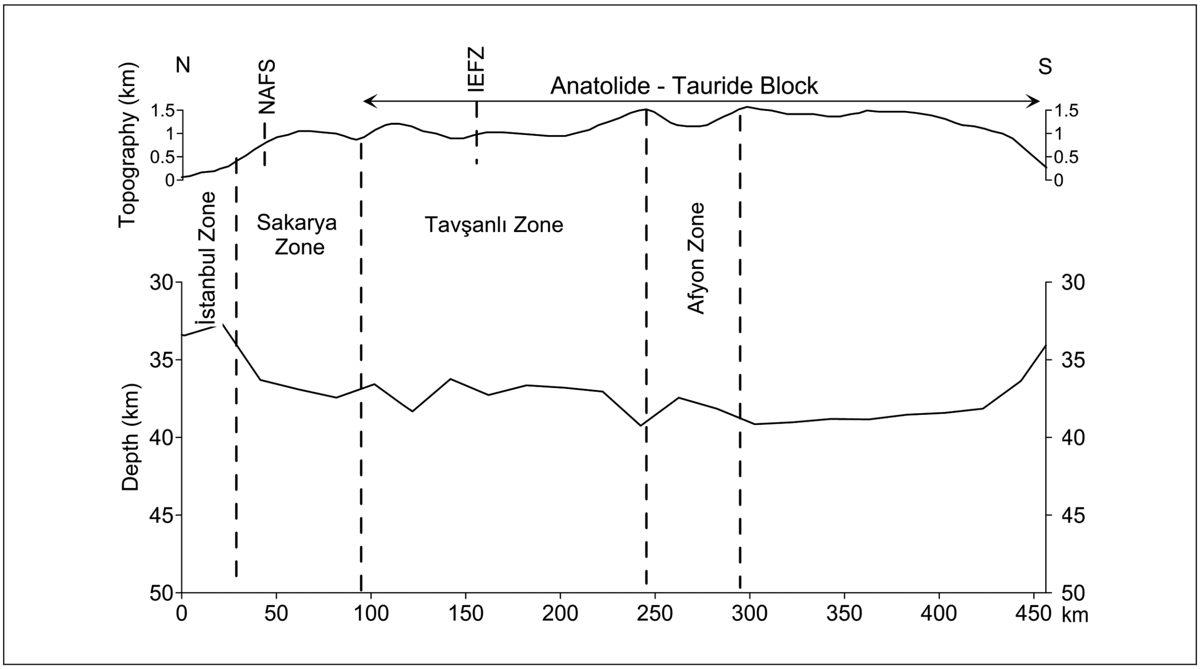

Figure 10- The vertical of the profile 2 in N-S direction slowing topography and crustal thickness.

down to 35 km gradually southward. Where the profile cuts the Afyon Zone the crustal thickness reaches its maximum, 44 km. At the end of this zone, with the emerge of the Anatolide - Tauride Block the thickness drops down to 35 km (Figure 11).

The 400 km long profile 4 which extends between the Sakarya Zone and Arabian Platform the crustal thickness begins with 36-37 km, however, depth reaches to 42-43 km. The crustal thickness of the Anatolide - Tauride Block traversed in this section gets thinner from north to south and drops down to 37 km. Here the crustal thickness of the Arabian Platform is observed as 35 - 36 km (Figure 12).

Along the profile 5 which extends in E - W direction, the amounts of crustal thickness along the traversed sections are as follows: 32 - 34 km at Bornova Flysch Zone, 33 - 37 km at tectonically active Menderes Massif, 37 km at Afyon Zone, 36 -39 km at Tavşanlı Zone, 37 km at Sakarya Zone, 36 - 39 km at Kırşehir Massif, 37 - 44 km at Anatolide - Tauride Block. It is observed that along the profile 5 the crustal thickening is from west to east (Figure 13).

CONCLUSIONS

During this study using the gravity data Bouguer, free air and isostasy maps were produced. Data of the maps were related to elevation and the relation coefficients were calculated. With +0.65, Bouguer data has given the best results in relation coefficients compared to free air and isostatic data. Bouguer map was taken as basis to calculate the crustal thickness in Turkey.

As a result of calculating the crustal thickness of the whole Turkey regression equivalence was calculated as Y = -72.2 E + 7.77. Besides, different regression relations were found for each tectonic zone in Turkey.

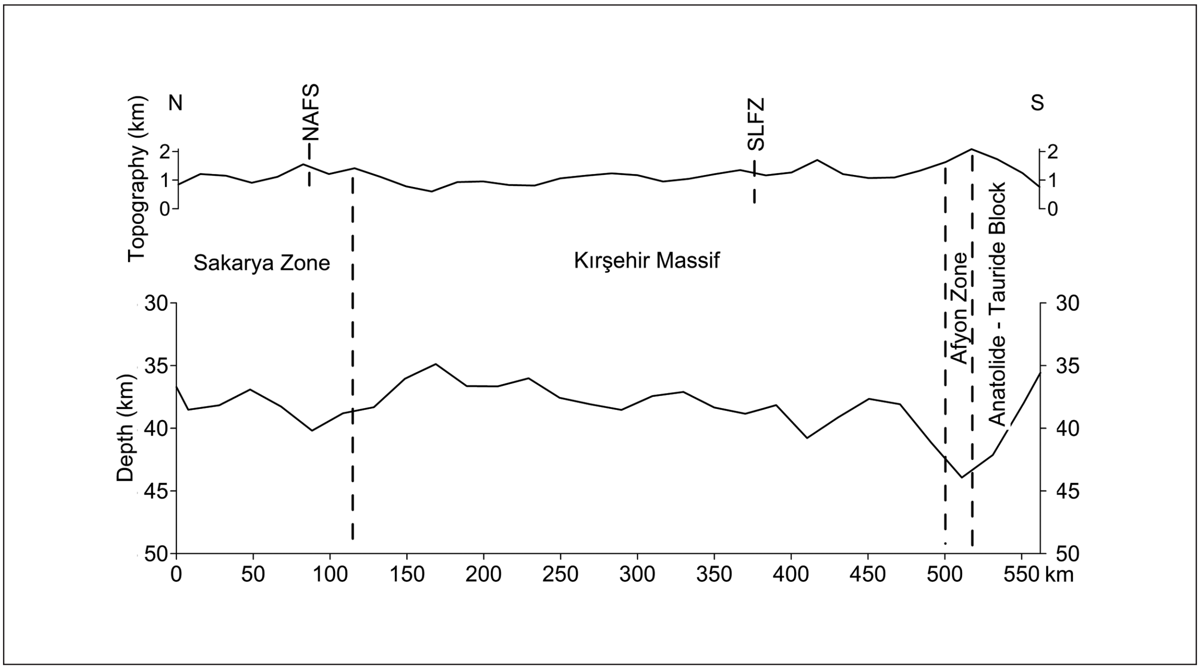

Figure 11- The vertical section of the profile 3 in N-S direction showing topography and crustal thickness.

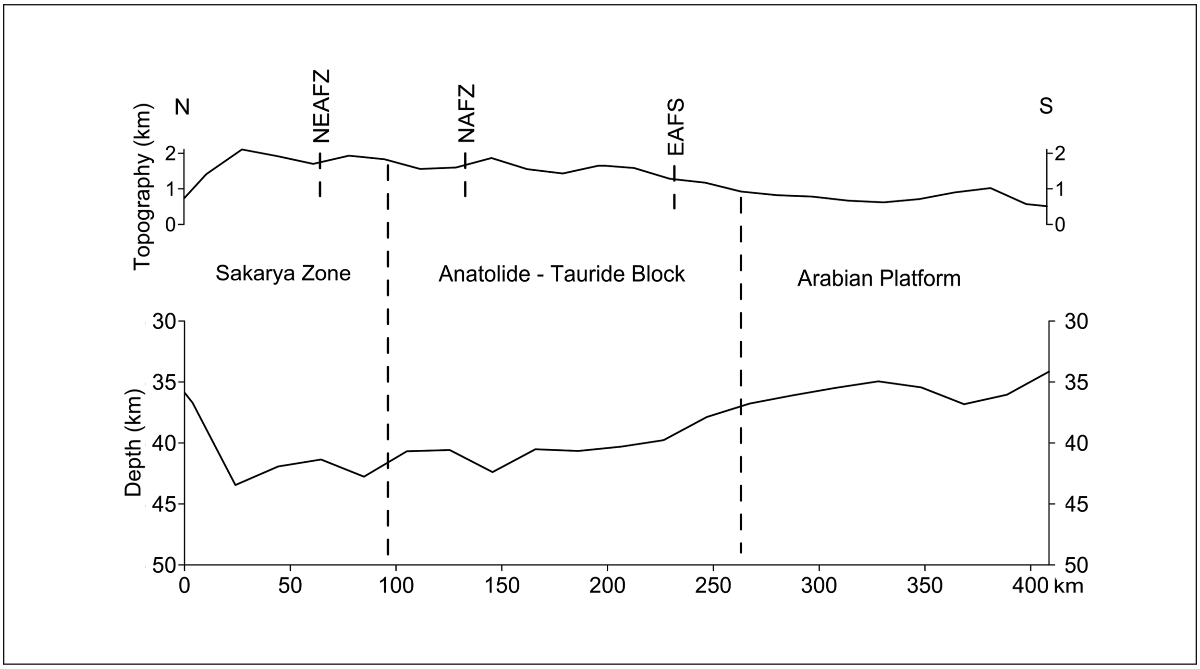

Figure 12- The vertical section of the profile 4 in N-S direction showing topography and crustal thickness.

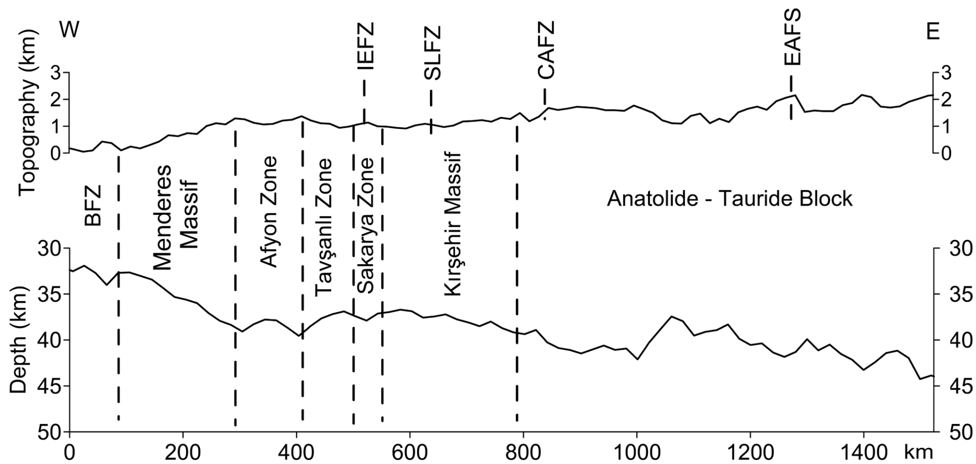

Figure 13- The vertical section of the profile 5 in N-S direction showing topography and crustal thickness.

In crustal thickness map of Turkey, complying with the tectonic activity, crustal thickness is observed in the east. Kırşehir Massif and western Anatolia displays relative crustal thinning. It was observed that the isostatic regional gravity map and the map showing the tectonic zones and suture boundaries prepared by Okay and Tüysüz (1999) were found to be consistent with each other.

Where the tectonic zones are present, in order to investigate the regional crustal thickness, the crustal thickness data were detailed along 5 profiles. As it can be seen on the crustal thickness map of Turkey, the shallowest crust is measured as 31.4 km while the deepest crust is 50 km.

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