INTERPRETATION OF DEEP CRUSTAL STRUCTURE AND LINEAR FEATURES OF WESTERN ANATOLIA BY USING BOUGUER GRAVITY DATA

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Western Anatolia is an important region with its' complex tectonic history, the horst-graben system progressed under this regime and high seismic activity take place in Aegean Extension Region. The most important tectonic structures of this system are E-W trendly Gediz and Büyük Menderes grabens. Our study area is involving the western part of Büyük Menderes and Gediz grabens. The Bouguer gravity data was used to investigate topography of the deep crust layers and the tectonic structure of the basins. Bouguer gravity anomalies values of western Anatolia increase from east to west direction. Parker-Oldenburg algorithm has been used to obtain 3D Moho and basement topography and horizontal gradient, analytic signal and tilt angle methods has used to delineate linear features. As a result of 3D modelling process, we determined the maximum depth of Moho and basement is in Büyük Menderes graben as 35 km and 12.5 km, respectively. By detection of lineaments, new lineament map of study area is given in this study. The study area also, has been investigated by the seismic activity. The most of the earthquakes have been occurred in study area in depth to the basement.

Introduction

Western Turkey is tectonically complex high-deformed continental region that specified by N-S trendly extension and E-W trendly parallel grabens and their normal faults (Le Pichon et al., 1995; Reilinger et al., 1997; McClusky et al., 2000). The crustal deformation in the region comprises many geothermal systems, volcanism and high seismic activity.

The most common one of many different theories have been suggested about the development of this complicate tectonic structure is suggested by Şengör (1979) that the tectonic regime shaped by the effect of compression then extension regimes. The region is bounded from the east by Anatolian plate and North Anatolian Fault Zone and from the south by African plate (Fig. 1). By the western direction movement of Anatolian plate western Anatolia was compressed and western escape have taken placed and African plate subducted under Anatolian plate on the south, with this effect compression and extension regime occurred. Moreover, with the total effect of this regime the complicated tectonism developed. The most remarkable structures of this tectonic regime are the grabens, which were developed under the compression and extension regimes (Bozkurt, 2001).

The objective of this article is to determine the crustal structure and tectonical features of the region. The area between 27.00°-28.25° eastern longitudes and 37.50°-38.50° northern latitudes was selected as the study area including the main important graben structures of western Anatolia shown in Figure 1. We used the gravity data of the study area and obtained the three dimensional (3D) Mohorovicic discontinuity (Moho) and the basement topography, the undulation of crust layers within the grabens and the linear features of the region.

Tectonic setting

The Anatolian plate is a continental belt between the Eurasian, African and Arabian plates, it is bounded by the North Anatolian Fault and East Anatolian Fault in the east and the Northern Aegean Trench in the west has been moving westward (Şengör, Yılmaz, 1981; McClusky et al., 2000). The extension in western Anatolia is related to the northward movement of the Arabian plate in the east, this movement pushed Anatolia westwards through the North Anatolian Fault Zone and East Anatolian Fault Zone (Dewey, Şengör, 1979). African Plate was subducting northwards under the south Anatolian Plate along the Aegean-Cyprean subduction zone (Şengör and Yılmaz, 1981; Bozkurt and Mittwede, 2005). Four different shemas have been proposed as the cause of extension in the region (Bozkurt, 2001): **(i)** subduction roll-back along the Aegean–Cyprian trench (McKenzie, 1972; 1978; Le Pichon, Angelier, 1979; Le Pichon et al., 1995; Mercier et al., 1989; Jackson, McKenzie, 1984; Meulenkamp et al., 1988; Thomson et al., 1998); **(ii)** westward escape of the Anatolian plate along North Anatolian and East Anatolian fault systems (Dewey, Şengör, 1979; Şengör, Yilmaz, 1981); **(iii)** post-orogenic collapse of the crust over thickened during the closure of the northern branch of Neotethys (Dewey, 1988; Seyitoğlu, Scott, 1991); and **(iv)** different convergence rates along the Aegean–Cyprian subduction zone (Reilinger et al., 2006).

The result of this regime caused the formation of mainly E-W trending horst-graben system. The mainly tectonic structures in the western Anatolia are E-W trending grabens and the most important of these grabens are Büyük Menderes and Gediz grabens. Akçığ (1988) recommended that E-W elongated graben regions in the Western Anatolia was the result of uplift on the upper mantle, and rift systems which were developed parallel to the N-S directional strain tectonic.

Bouguer gravity anomaly data

Bouguer gravity anomaly data of the study area was achieved from General Directory of Mineral Exploration and Research Company of Turkey (MTA) and Turkish Petroleum Corporation (TPAO). The surveys were obtained by 250-500 meters intervals and the data are gridded with 10 mGal intervals, Bouguer gravity anomaly map is given in Figure 2.

Bouguer gravity anomalies of Western Anatolia are generally decreased from east to west direction related to the thinning of the crust from E to W direction and high negative Bouguer gravity anomalies are shown in the grabens related to the thick sediment cover of the graben area.

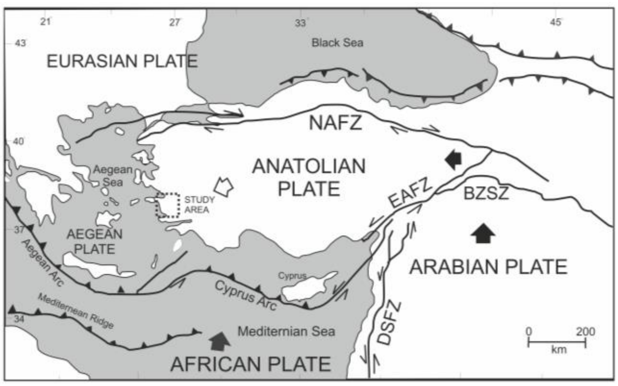


Figure 1. Location map of the study area

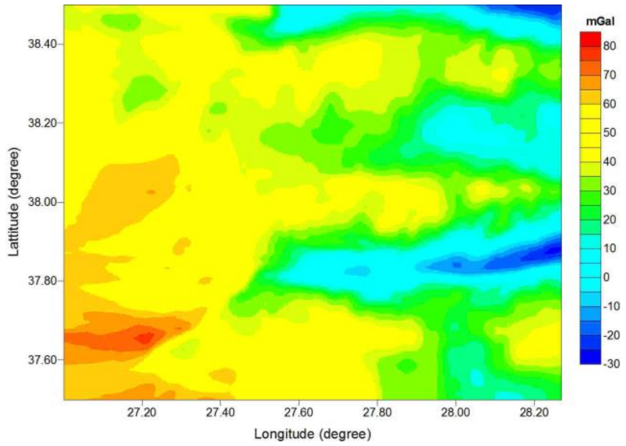


Figure 2. Bouguer gravity anomaly map of study area (Contour interval is 10 mGal)

The methods

One of the main tasks of geophysical study is to determine the geometry of the interface from gravity anomaly, Parker-Oldenburg algorithm was used to obtain the 3D geometry of interface topography from the relationship between the Fourier transform of gravity data and the sum of the interface topography's Fourier transformation. This algorithm is given as equation (1) iteratively from the given depth and density of an interface by Parker (1973), to calculate the gravity anomaly of uneven homogeneous layer by using the Fourier transform where, $F[\Delta g]$ represents Fourier transform of the gravity anomaly; G is the gravitational contrast; g represents the density contrast within the interface; k is wave number; z_1 is depth to the interface; z_0 is the average depth of horizontal interface. Oldenburg (1974) rearranged this equation to calculate the undulating interface depth.

$$F[z_1(x)] = -\frac{F[\Delta g(x)]e^{|k|z_0}}{2\pi Gg} - \sum_{n=2}^{\infty}\frac{|k|^{n-1}}{n!}F\left[z_1^{\,n}(x)\right]. \quad (1)$$

The present equation (1) is a useful tool for calculation of density interface topography iteratively from Δg and z_0. From the beginning of the iteration, assignment of $z_1=0$ or an approximated value is assigned to the right part of the equation. Its inverse Fourier transform provides the first estimation of the topography. This topography value was used in calculation of the right hand sight of the equation to achieve the second topography approach. Until the convergence criterion is achieved; or until reaching the determined iteration number; or until the difference between successive steps is smaller than the convergence criterion, the iteration process continues. 3DINVER.M MATLAB program, developed by Gomez-Ortiz and Agarwal (2005) to compute 3D density geometry of the interface's from gridded gravity anomaly was used.

The horizontal gradient, analytic signal and tilt angle methods has been used to determine the lineaments. The horizontal gradient method has been used to locate the lateral changes in the density of near surface bodies. The horizontal gradient anomalies of the gravity data, give the maximum value over the edge of the body, if the edge is vertical (Cordell, Grauch, 1985). Its mathematical equation is presented in equation (2):

$$h(x,y)=\sqrt{\left(\frac{\partial g(x,y)}{\partial x}\right)^2+\left(\frac{\partial g(x,y)}{\partial y}\right)^2} . \qquad (2)$$

The analytic signal method was firstly used by Gabor (1946), than by Nabighian (1972) for interpretation of the potential field data. The analytic signal value of a potential field anomaly is defined as a magnitude of the total gradient of the field anomaly. Its mathematical equation is presented as Equation 3:

$$A(x,y)=\sqrt{\left(\frac{\partial g}{\partial x}\right)^2+\left(\frac{\partial g}{\partial y}\right)^2+\left(\frac{\partial g}{\partial z}\right)^2} \qquad (3)$$

The ratio of the vertical gradient ratio's arctangent to the total field horizontal gradient composes tilt angle. Miller and Singh (1994) then firstly introduce it; Verduzco et al. (2004) publicized it. The equation of tilt angle can be given as Equation 4:

$$\phi=\arctan\left[\frac{\left(\frac{\partial g}{\partial z}\right)}{\left[\left(\frac{\partial g}{\partial x}\right)^2+\left(\frac{\partial g}{\partial y}\right)^2\right]^{\frac{1}{2}}}\right]= \qquad (4)$$

$$=\arctan\left[\frac{\text{Vertical Derivative}}{\text{TotalHorizontalDerivative}}\right].$$

Results and discussion

3D Modeling of Moho and basement topography

With the aim of determining the tectonical structure of western part of Western Anatolia by using Bouguer gravity anomaly data the 3D Moho and basement topography by using the MATLAB 3DINVER.M program were modeled and the linear features were determined by using data processing methods with the POTENSOFT.M program**.** The enhanced Moho topography map is given in Fig.3. Moho topography is increased from east to west direction, it can be easily seen on the obtained Moho topography map, and there is an uprising on Moho undulations out of the graben areas. The crust depth of study area was determined as 35 km on the eastern side and rise to 24 km towards to west and 20 km towards to SW of study area. The maximum Moho depth indicates the grabens, which are the main important tectonic structures of the region, the determined maximum depth is 33-34 km in Büyük Menderes and Gediz grabens and the minimum depth is defined as 20-22 km in W and SW part of the study area. The Moho depth under the Menderes massive that is the one of most important geological structure of the region, is decreased. These results are similar with the recent studies; Riad et al. (1981) reported that the crust thickness was changed in range between 28-36 km in Western Anatolia, Akçığ et al. determined on their study in 1988 that there was uplift on upper mantle from Aegean region to Aegean Sea, it was averagely 30 km on Aegean Sea and crust thickness averagely 32 km on Aegean Sea side and reported that it reached 40 km on west to east direction inner side of Anatolia. The crust thickness of Aegean region reported as 30 km by Saunders et al. (1998), 33 km by Horasan et al. (2002), 29 km by Akyol et al. (2006) for Aegean region. Tezel et al. (2010) determined the Moho depth along a profile, which lies from Aegean Sea to Middle Anatolia, is 25 km to 35 km. And Cianetti et al. (2011) determined the Moho depth is 30 km for Western Anatolian region.We can say with the light of the other studies, there is uplift on Moho depth from east to the west direction in the study area.

The obtained basement topography map of study area is given in Fig.4. The maximum basement level is 12.5 km in Büyük Menderes and Gediz grabens similarly. Minimum depth value is 5.5 km in the SW of the study area. These basement levels are coinciding with the value determined by Çiftçi, Bozkurt, (2010). In the determined basement topography map, the topography undulation is on match with the main fault system directions, which are on NW-SE and E-W direction.

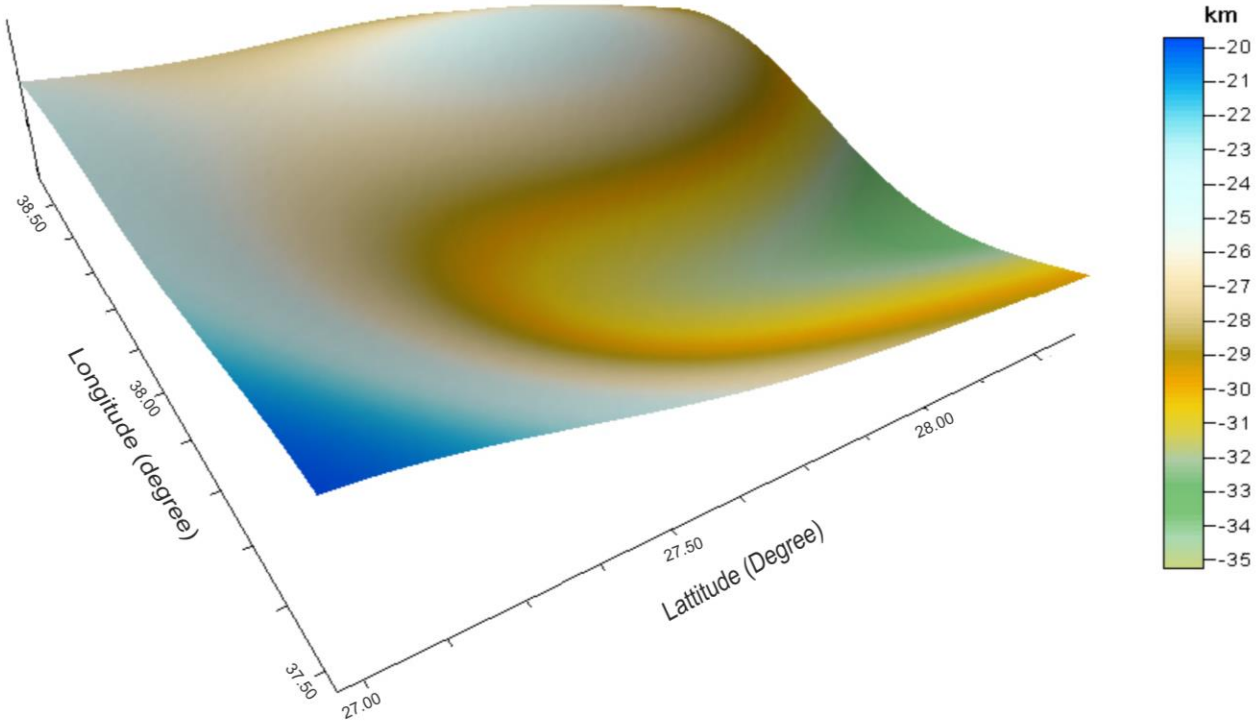


Figure 3. Moho topography map of study area derived from inversion of Bouguer gravity anomalies using Parker-oldenburg's algorithm

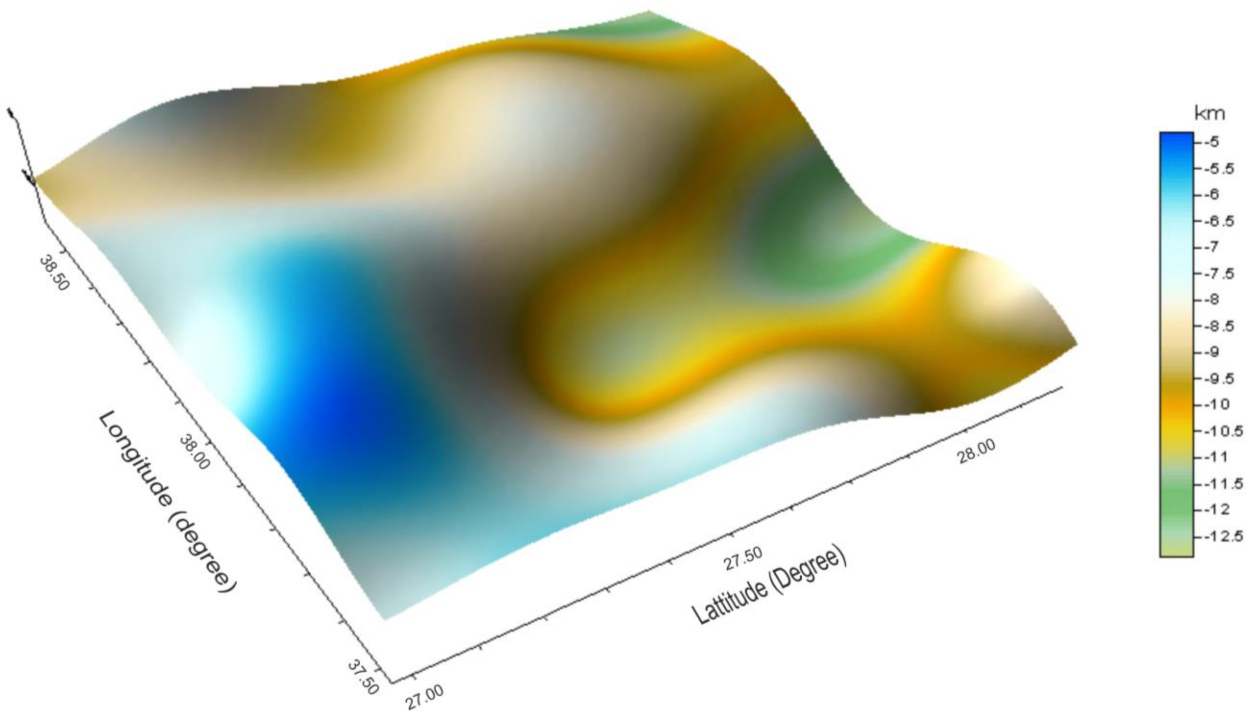


Figure 4. Basement topography map of study area derived from inversion of Bouguer gravity anomalies using Parker-oldenburg's algorithm

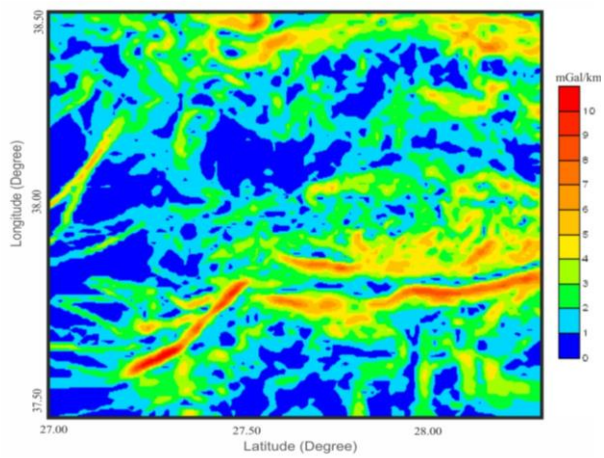
Detection of lineaments

To detect the linear features of the study area, the horizontal gradient, and analytic signal and tilt angle methods have been used to Bouguer gravity anomaly data of the study area, the produced maps are given in Fig.5. In the horizontal gradient map of the study area, the maximum values indicate the areas represented by high negative values on Bouguer gravity anomaly map and those areas indicate the highest depth in graben areas (see Fig.5a). The strong gradient values of horizontal gradient correspond to boundaries of Büyük Menderes and Gediz grabens lie on E-W direction.

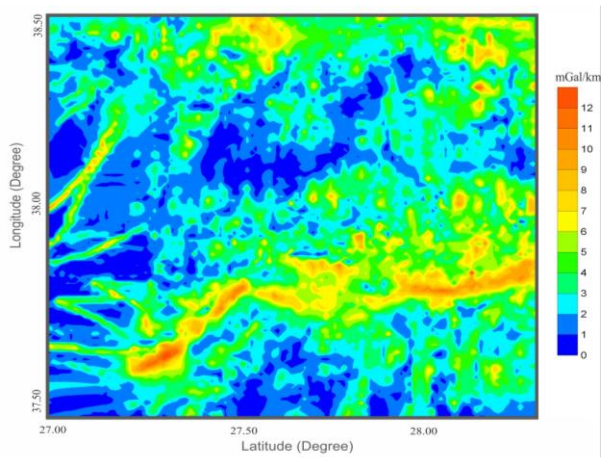
In the analytic signal map of Bouguer gravity anomaly data (Fig. 5b), the strongest gradient values are seen on E-W trendily in the graben area of Büyük Menderes graben and in the northern side of the study area in Gediz graben. Figure 5c shows the results of tilt angle map of the study area, the zero values on the tilt angle maps indicate the boundaries of grabens, the positive values represent Menderes massive and negative values represent the graben fillings.

These three maps lead us to determine the tectonical lineaments of the study area. The common area with maximum horizontal gradient and analytic signal values and the zero values of tilt angle indicates the existence of a lineament. By this way, we have determined the new lineaments map given in Figure 6 and compared with the active fault map given by MTA.

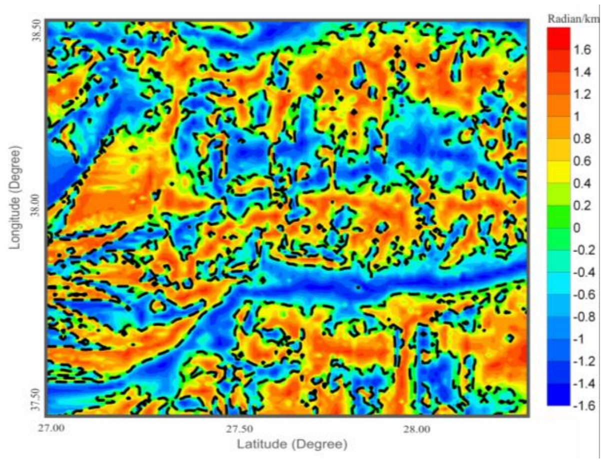
To interpret the lineaments with seismic activity, the earthquakes have been occurred between the times period 2005-2015 have been used. The region has a high seismic activity; the western part of the area is more active than the eastern part. The epicentral distribution of these earthquakes is given in Fig.7. Most of the earthquakes have been occurred below the basement level as seen in Fig.8.



a)



b)



c)

Figure 5. a) Horizontal gradient b) Analytic signal c) Tilt angle maps of study area

Conclusions

In this study, the undulations of the deep crust layers in western Anatolia have been presented. The maximum Moho depth is determined as 34-35 km in the east and minimum Moho depth is 20-22 km in the west. There is uplift on Moho level on Western Anatolia region from east to west direction and it decreases on the Menderes massive, this is a result of strain, which released to the compression of Hellenic subduction. This strain caused a decant on the region and graben areas occurred as a result of this. The basement level is range 5 km to 12 km. The most of the earthquakes have been occurred in depth to the basement. Beside this there are also, deep epicentral earthquakes have taken place beneath the basement in the region.

The other contribution of this study is the new upgraded lineaments map the west of western Anatolia. This study result may shed light on the future tectonical studies in the Western Anatolia.

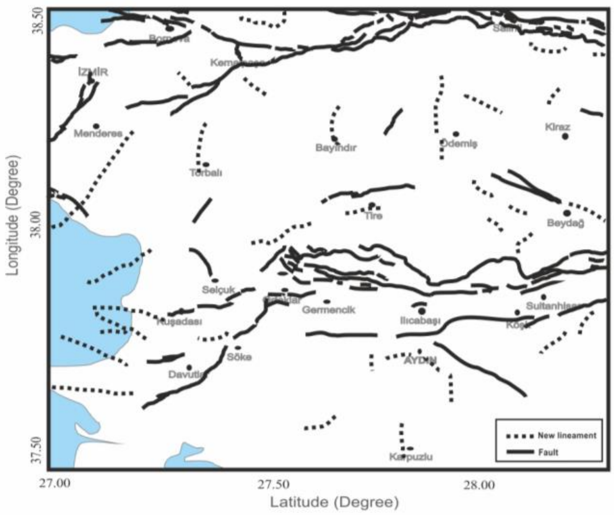


Figure 6. New lineaments map of the study area

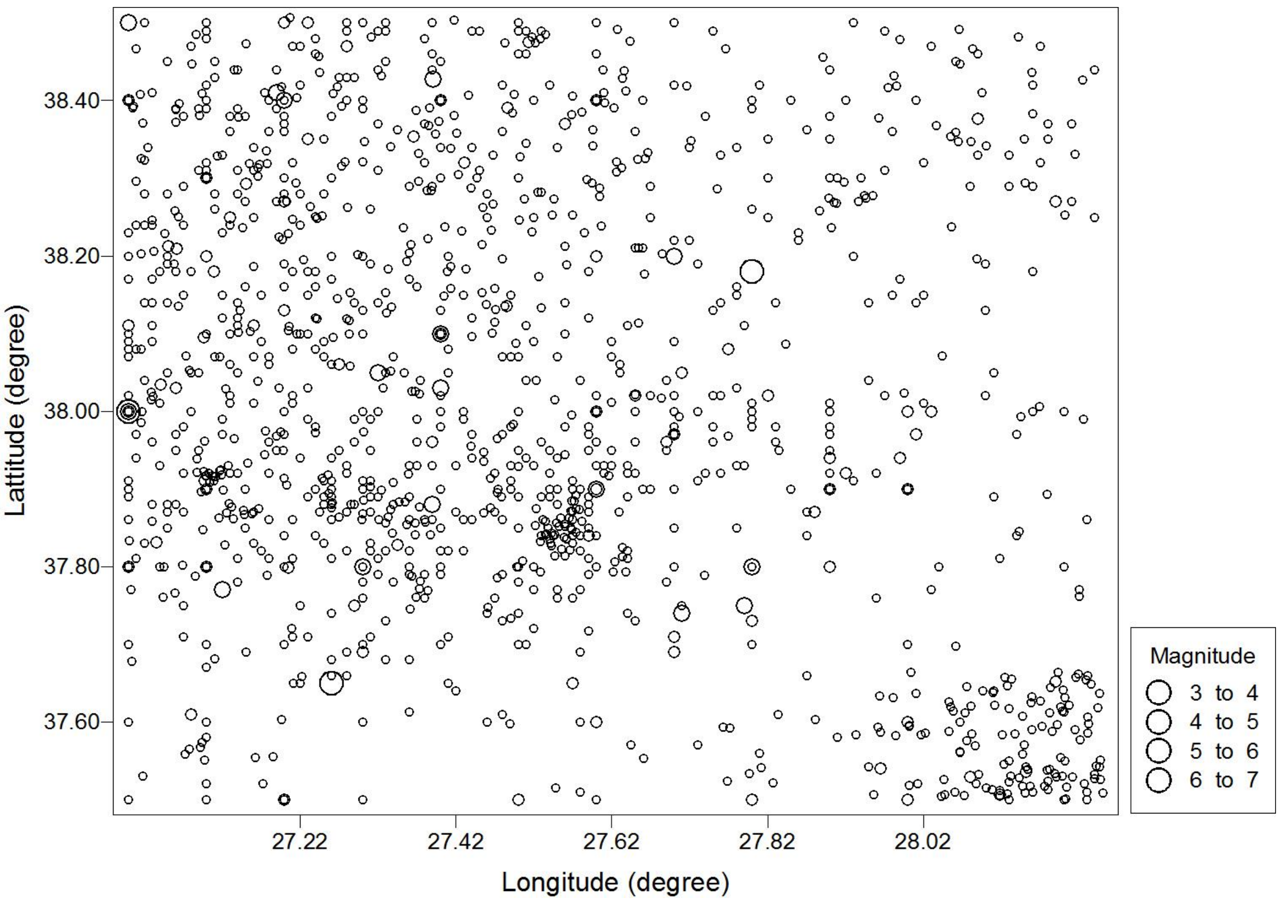


Figure 7. Epicentral distribution of the eartquakes occured in the study area.

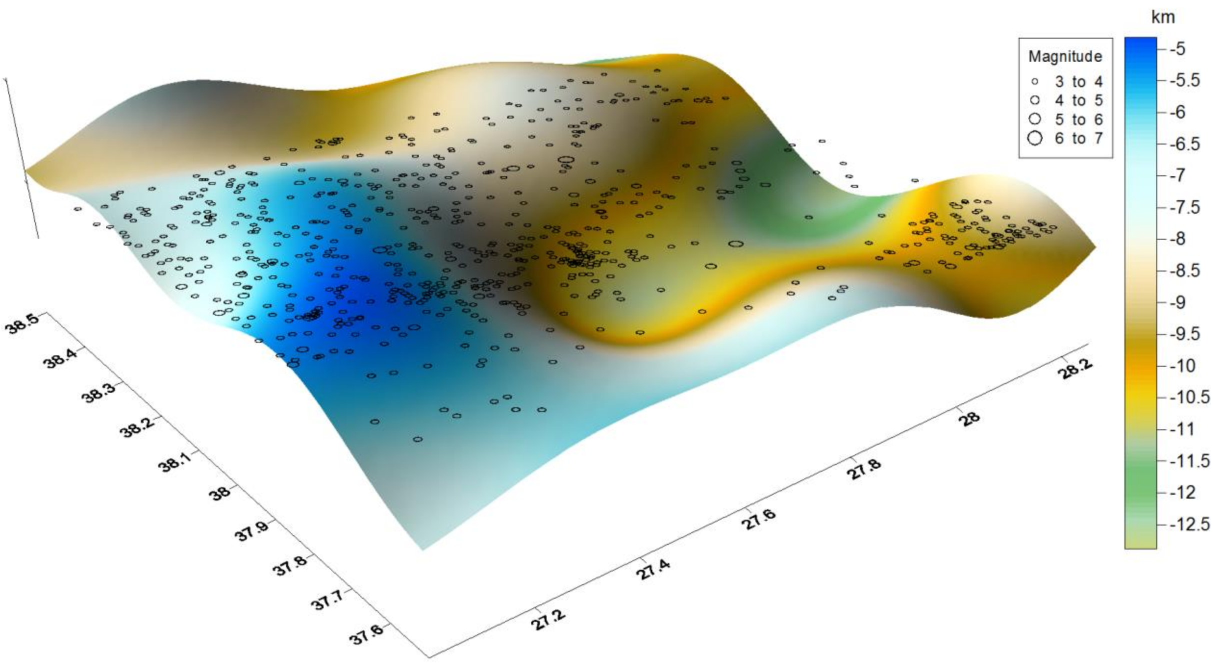


Figure 8. Epicentral distribution of the eartquakes occured below the basement level

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