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INVESTIGATION OF GRAVITY ANOMALIES OF ÇANKIRI BASIN (NORTHERN CENTRAL ANATOLIA, TURKEY) USING THE BOUNDARY ANALYSIS AND ANALYTIC SIGNAL METHOD AND 3D MODELING

ÇANKIRI BASENİ (ORTA ANODOLU, TÜRKİYE) GRAVİTE ANOMALİLERİNİN SINIR ANALİZLERİ VE ANALİTİK SİNYALLERLE YORUMU VE ÜÇ BOYUTLU MODELLENMESİ

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ABSTRACT : The Cankiri Basin is one of larger basins in central Anatolia and generated by closing of the northern branch of Neotethys during the Late Cretaceous to Late Eocene. The analysis of gravity anomalies shows a lower density and thickened continental crust in the north of the study region. The lower density and thickened continental crust in the study region are consistent with Airy model accounting for isostasy. Power spectrum analysis of gravity data suggests five sources at depths ranging from 0.23 km to 10.8 km from the surface. Processing of the gravity data indicates that the NE-SW trending high zone controlled the eastern boundary of the Cankiri Basin (CB). The analytic signal method which is composed of vertical and horizontal field derivatives are common and useful method for interpretation of the gravity or/and magnetic data. The average sedimentary thickness of the CB determined the analytic signal depth model and 3D modeling of the gravity anomalies is determined as $\approx$4.4 km and $\approx$3.5 km, respectively.

Key Words: The Cankiri basin, the gravity anomalies, the power spectrum analysis, the analytic signal, 3D modeling

ÖZ : Çankırı Havzası orta Anadolu'daki en büyük havzalardan birisidir ve geç Kretesa-geç Eosen boyunca Neotetis'in kuzey kolunun kapanması ile oluşmuştur. Gravite anomalilerinin analizi, çalışma alanının kuzeyinde düşük yoğunluk ve kıtasal kabuk kalınlaşması göstermektedir. Çalışma alanındaki düşük yoğunluk ve kıtasal kabuk kalınlaşması isostasy için Airy modeli ile uyumludur. Gravite verilerine uygulanan güç spektrumu analizi, yüzeyden itibaren derinlikleri 0.23 km ile 10.8 km arasında değişen olası beş kaynağı önermektedir. Gravite verinin prosesi Çankırı Havzası'nın (CB) doğu sınırını kontrol eden KD-GB yönelimli bir yükselim zonuna işaret etmektedir. Gravite ve/veya manyetik anomali verilerinin yorumunda, alanın düşey ve yatay türevlerini kapsayan Analitik Sinyal yöntemi yaygın ve kullanışlı bir yöntemdir. Gravite anomalilerinin 3B modeli ve analitik sinyalden oluşturulan derinlik modellerinden, Çankırı Havzası'nda sırasıyla 3.5 km ve 4.4 km sedimanter kalınlıkları belirlenmiştir.

Anahtar Kelimeler: Çankırı havzası; gravite anomaliler; güç spektrumu analizi; analitik sinyal; üç boyutlu model

INTRODUCTION

Central Anatolia includes several Tertiary basins such as Çankırı, Beypazarı, Tuzgölü and Haymana basins. The Çankırı Basin (CB) is one of the biggest basins of central Anatolia.

In the study region, geophysical studies especially based on the interpretation of gravity and/or magnetic data have been limited. Ates et al., (1999) prepared the new aeromagnetic and gravity anomaly maps of Turkey. They showed that the intense anomalies in NW Turkey may be caused from the metamorphic basement rocks. The gravity anaomaly map of Turkey shows broadly E-W trending contours and thickened continental crust has negative gravity anomalies (Ates et al., 1999).

In interpretation of gravity anomalies of the study region was used several methods. To estimate the depth to the top of the bodies causing gravity anomalies, power spectrum analysis was applied by using the method of Spector and Grant (1970). The horizontal gradient method has been used since 1980s to locate geologic structure boundaries of the causative sources from gravity data. Blakely and Simpson (1986) have developed a method, based on horizontal gradient magnitude computed from the gravity anomaly data. The method achieves local maxima over or near contacts between rock units with different density contrast. In order to delineate the subsurface structure of the study area, the analytic signal method was applied to the gravity data of the study area. Firstly, the theory of analytic signal method was introduced by Nabighian (1972, 1974 and 1984). Roest et al., (1992) developed a generalization of the 3D analytic signal method. Nowadays, the 3D analytic signal method has been applied successfully to magnetic and/or gravity data by many authors (e.g. Klingele et al., 1991, Marson and Klingele 1993, Salem 2005). The analytic signal is formed by the horizontal and vertical gradient of the potential field anomaly. The amplitude of the analytic signal exhibits maxima over sources caused magnetic or gravity anomalies.

Our goal in this paper is to present results of the power spectrum, horizontal gradient magnitude, analytic signal, and 3D modeling of the Bouguer anomalies from the CB. Thus, estimating the parameters of the subsurface features, such as horizontal locations and depths, we propose a new model in the study area.

TECTONIC AND GEOLOGICAL SETTING

The Neogene tectonic of Turkey is composed of a number of micro-continents (Sengor and Yilmaz, 1981; McClusky et al., 2000). Fig. 1a shows major tectonic units ad blocks in Turkey modified from Gursoy et al., (1998). Mainly there are three tectonic belts: i) the Pontides in the north, ii) Anatolides in the centre and iii) the Taurides in the south (Fig. 1a). The Pontides and the Anatolides are the eastern continuation of the Rhodope-Pontide fragments that include the Sakarya Continent and the metamorphic northern continuation of the Taurides, respectively (Sengor and Yilmaz, 1981). The Kirsehir Block is a part of the Anatolides.

The Cankiri Basin (CB) is located at the central Anatolia and one of the largest Tertiary basins. The CB is identified as the omega-shaped (Ω) basin by Kaymakci et al., (2003a). They said that the CB was the result of indentation of the Kirsehir Block into the Sakarya Continent during northwards migration accompanying closure of Neotethys. Kaymakci et al., (2003b) investigated the kinematics and structural development of the CB and determined the four phases: Phase 1 is Pre-Late Paleocene deformation regime. This regime is not seen in the southern part of the CB. Phase 2 is Late Paleocene to pre-Buldigalian transpression regime. Phase 3 is Early to Middle Miocene extension regime and Phase 4 is Late Miocene to present regional transcurrent regime.

The simplified geological map of the study region is given in Fig. 1b (modified from Bingol, 1989). The major structures in the study area are the NE-SW, NW-SE and E-W trending strike-slip normal faults, all of which splay off North Anatolian Fault Zone (NAFZ). The Ezinepazari- Sungurlu Fault Zone (ESFZ) is one of the major splays of the NAFZ and located at about southern area of the CB (Fig. 1b). The splay faults divide the Anatolian block into the EW trending wedge-like counter–clockwise rotating blocks (Bozkurt and Kocyigit, 1996). Taymaz et al., (2007) reported that although there is no general clockwise rotation, localized clockwise rotations as a result of shear of the lower crust and lithosphere in Cankiri and surroundings. Surface of the area is mostly covered by sedimentary units.

Kaymakci et al., (2003a) proposed the five sedimentary sequences in the CB as follows: 1) deep marine sediments, mafic volcanic rocks, shallow marine units, Paleocene littoral red clastic rocks, carbonates (the oldest sedimentary sequence-Late Cretaceous), 2) regressive flysch to molasses type succession intercalated with mafic to intermediate volcanic rocks, limestone (Late Paleocene to mid- Oligocene), 3) continental red clastic and evaporates (Late Eocene to mid-Oligocene), 4) fluvio-lacustrine deposits (Early Miocene to Pliocene), and 5) alluvial fan deposits, recent alluvium (The Late Pliocene- Quaternary).

A few small sized granitoids called as the Sulakyurt Granitoids (SG) are exposed at the south of Sulakyurt (Fig. 1b). The SG is collision-related central Anatolian I-type granitoids (Upper Cretaceous). These are derived from a hybrid source generated by mixing type interaction between underplating mafic magma and crustal felsic magma (Tatar and Boztug, 2005).

Kadioglu and Ozsan (1998) studied gabbroic bodies outcropped within the SG and proposed that the gabbroic bodies were extended towards the depth within the SG from the boreholes data. Basement units of central Anatolia are outcrop in the east of the study area. These are the NE-SW and E-W trending Neo-Tethyan ophiolitic mélange and the E-W trending metamorphic units in the south of Corum (Fig.1b).

a)

b)

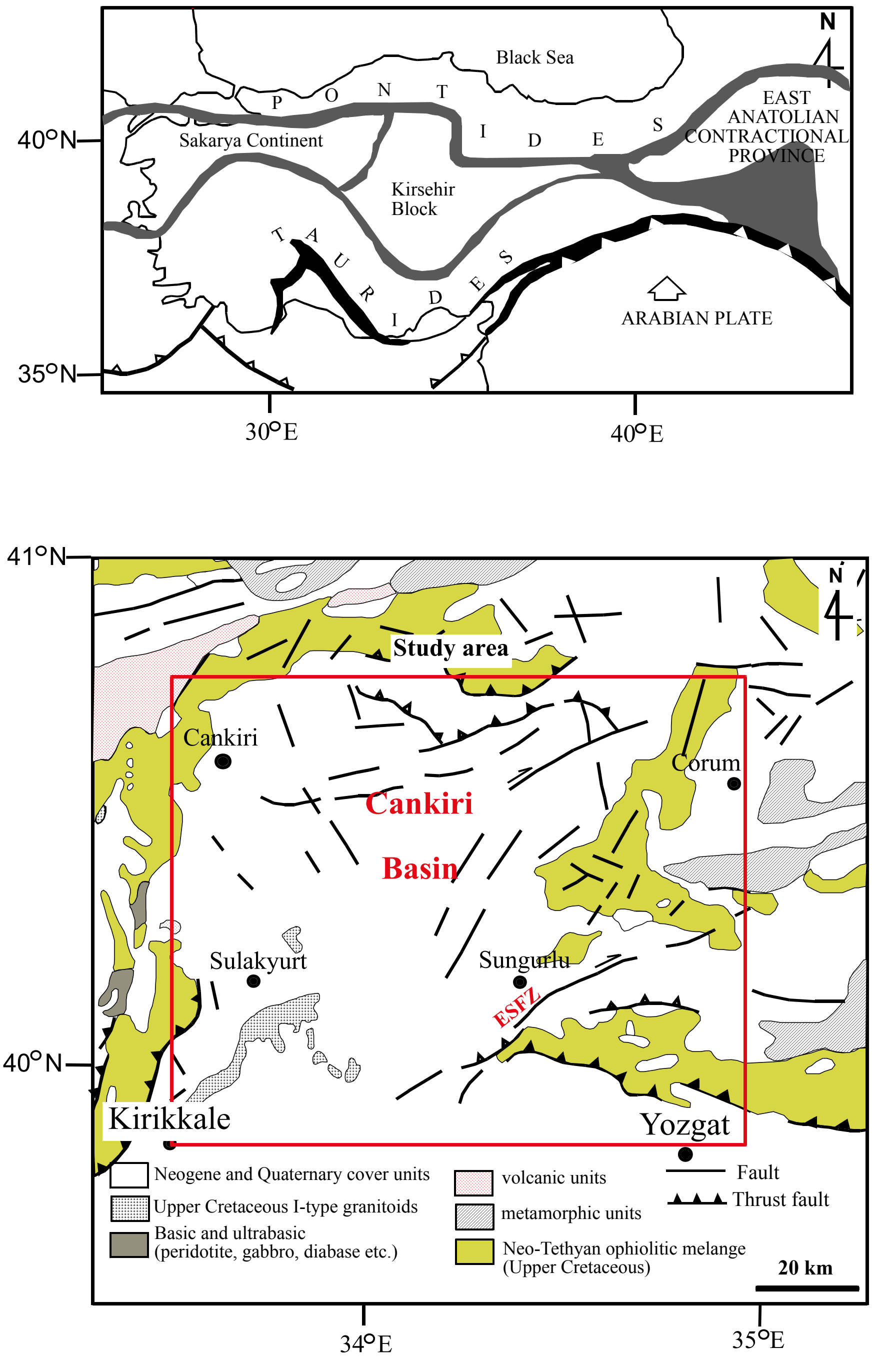

Figure 1: **a)** The major tectonic units and blocks in Turkey (modified from Gursoy et al., 1998). **b)** Simplified geology map of the study region (after Bingol, 1989). The box shows the study area. ESFZ: Ezinepazarı-Sungurlu Fault Zone.

Şekil 1: **a)** Türkiye'nin temel tektonik birimleri ve blokları (Gursoy et al., 1998'den düzenlenmiştir); **b)** Çalışma alanının sadeleştirilmiş jeoloji haritası (Bingöl, 1989'dan sadeleştirilmiştir). Dikdörtgen kutu çalışma alanını göstermektedir. ESFZ: Ezinepazarı-Sungurlu Fay Zonu.

THE PROCESSING OF THE GRAVITY DATA

Gravity data of the study region were obtained from the General Directorate of Mineral Research and Exploration (MTA) of Turkey (Ates et al., 1999). The data were tied to the Potsdam (981260.00 mGal) base value. All necessary corrections were made by MTA. The Bouguer correction was done for a density of 2.40 g cm^{-3}. Figure 2 shows the Bouguer gravity anomaly map of the study region. The azimuthally-averaged power spectrum method (Spector and Grant, 1970) was applied to the gravity anomaly data in order to determine the average top of the sources causing gravity anomalies (Fig. 3).

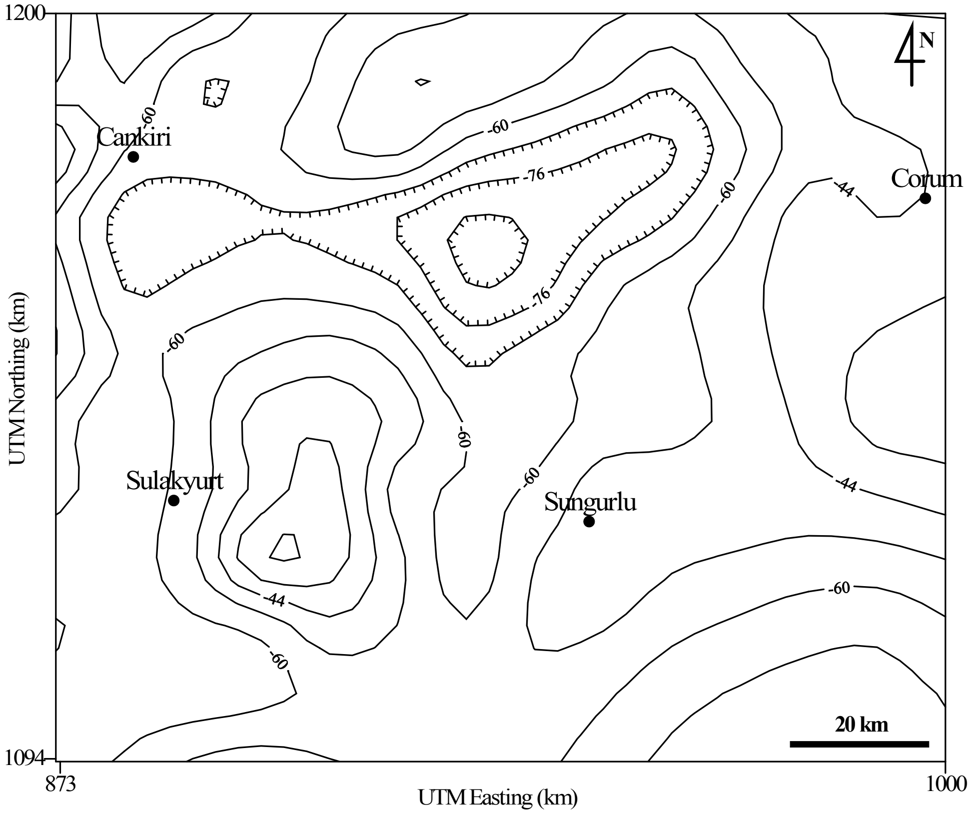

Figure 2: Bouguer anomaly map of the study region. Contour interval is 8 mGal.
Şekil 2: Çalışma alanının Bouguer anomali haritası. Kontur aralığı 8 mGal'dir.

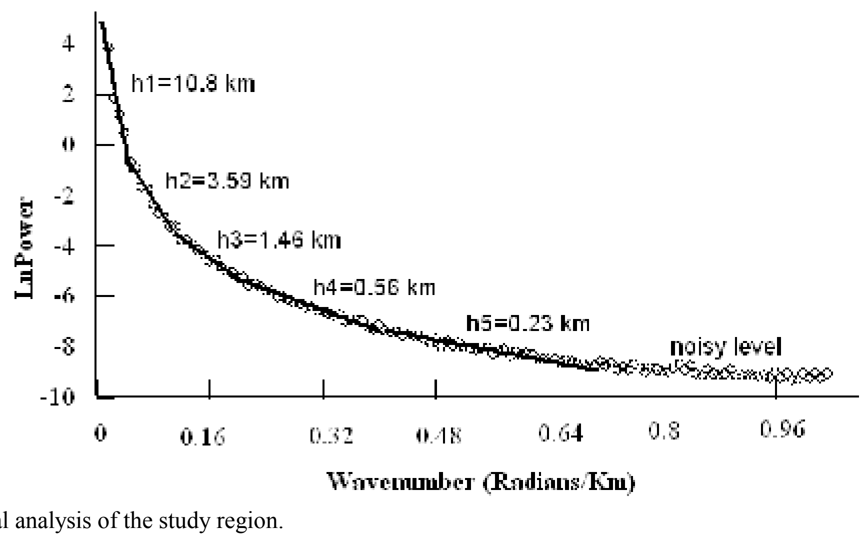

Figure 3: Spectral analysis of the study region.
Şekil 3: Çalışma alanının spectral analizi.

The average top of the sources is calculated from $h=\frac{\ln power}{4\pi k}$ (Spector and Grant, 1970).

Where k is wavenumber. The power spectrum analysis indicated that the deeper source was located at a depth of 10.8 km.

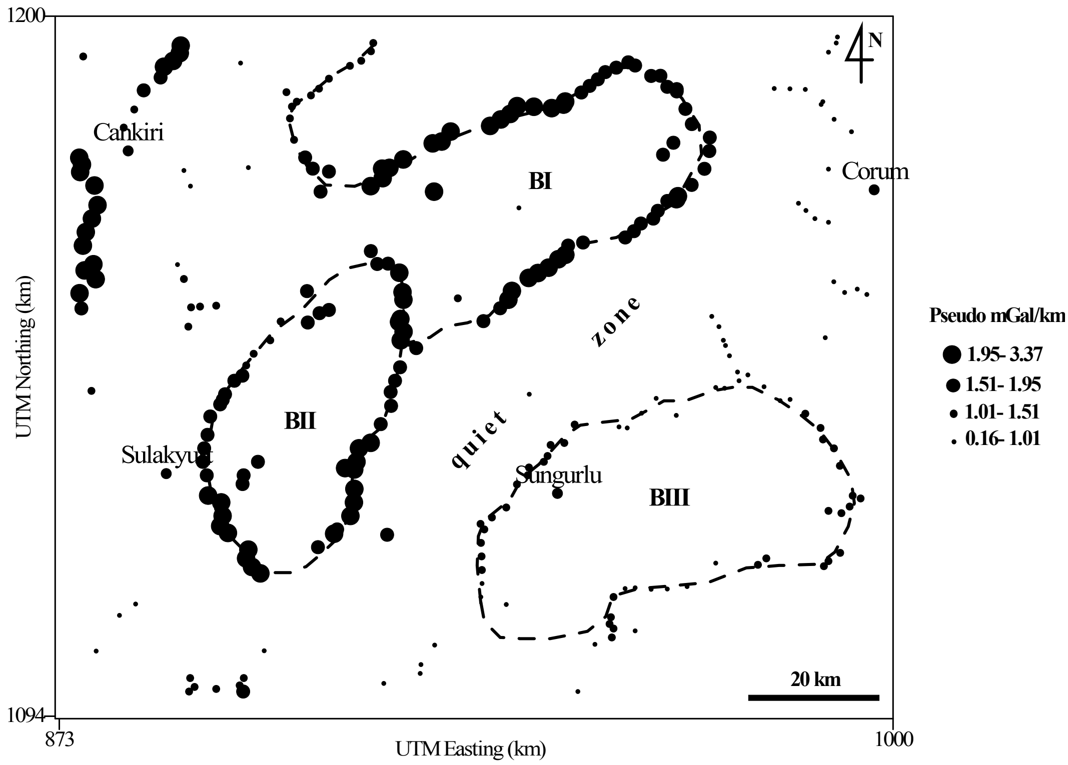

Figure 4: Locations of the maxima of horizontal gradient of Bouguer anomalies of northern central Anatolia. Size of circles is proportional to the magnitude of the gradient.

Şekil 4: Orta Anadolu kuzeyinin Bouguer anomalisinin yatay gradyentinin maksimumum lokasyonları. Dairelerin boyutları gradyenin genliği ile orantılıdır.

Figure 4 gives the maxima map produced from the maximum values of the horizontal gradient of gravity data using the method of Blakely and Simpson (1986) to determine the lateral density variation boundaries in the study region. Locations of the maxima of the horizontal gradient are shown as circles (Fig. 4). Size of circles is proportional to the magnitude of the gradient.

The analytic signal method (Nabighian 1972, 1974, 1984; Klingele et al., 1991, Roest et al., 1992) was applied to the gravity data to understand the distribution of sources caused gravity anomalies in the study region (Fig 5a). Klingele et al., (1991) defined the 3D AS for gravity data as a complex vector

$$AS(x,y)=\frac{\partial g}{\partial x}\hat{x}+\frac{\partial g}{\partial y}\hat{y}+i\frac{\partial g}{\partial z}\hat{z},$$

where i is the complex number; $\hat{x}$, $\hat{y}$ and $\hat{z}$ are the unit vectors in x, y and z directions, respectively and g is gravity data. Real and imaginary parts of AS forms the horizontal and vertical derivatives, respectively. The amplitude of the AS is given by

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

The feature of the amplitude of AS is a bell-shaped symmetric function and the maximum value is exactly over the top of the sources.

Then, the analytic signal depth map was produced (Fig. 5b). Finally, gravity anomalies of the study region were modeled three-dimensionally (3-D) by a computer program developed by Cordell and Henderson (1968) (Fig. 6). Detailed mathematical backgrounds of the methods, mentioned above, can be found in given references.

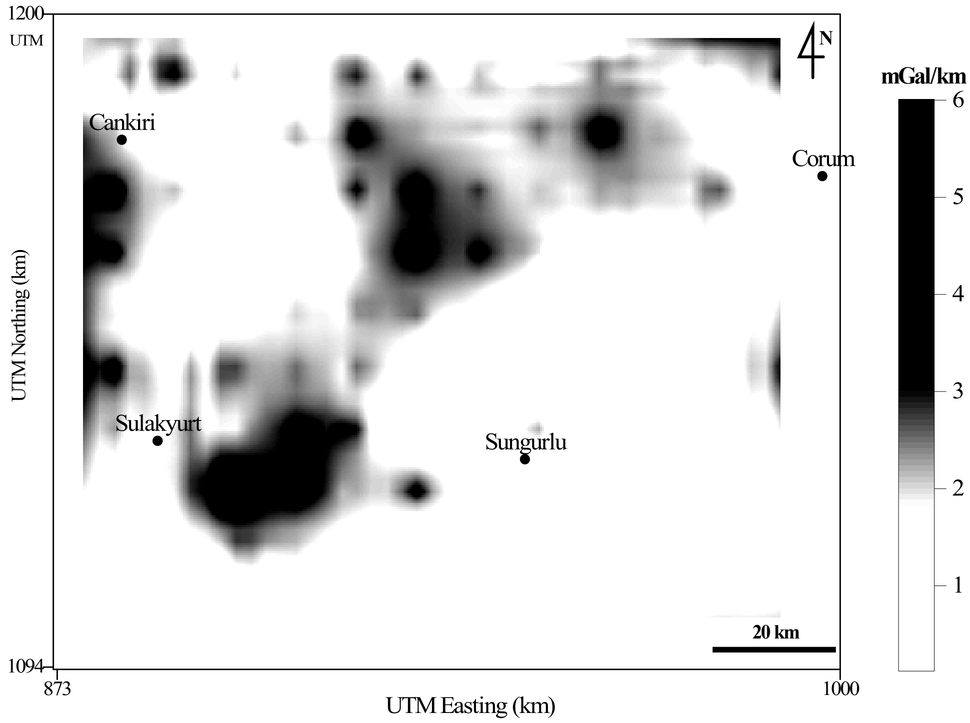

Figure 5: **a)** The analytic signal map produced the gravity anomaly data.
Şekil 5: **a)** Gravite anomali verisinden elde edilen analitik sinyal haritası.

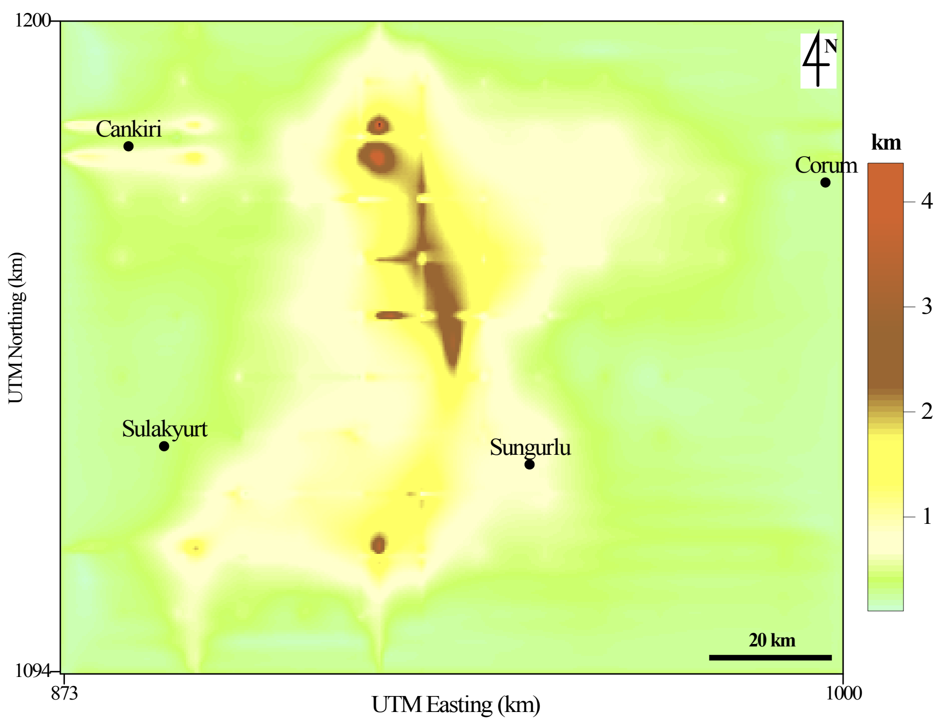

Figure 5: **b)** The depth map produced from the analytic signal data of the study region. Insert circles show the distribution of the maxima of the horizontal gradient of the gravity data.
Şekil 5: **b)** Çalışma alanının analitik sinyal verisinden üretilen derinlik haritası. Daireler gravite verisinin yatay gradyentinden maksimumlarının dağılımını göstermektedir.

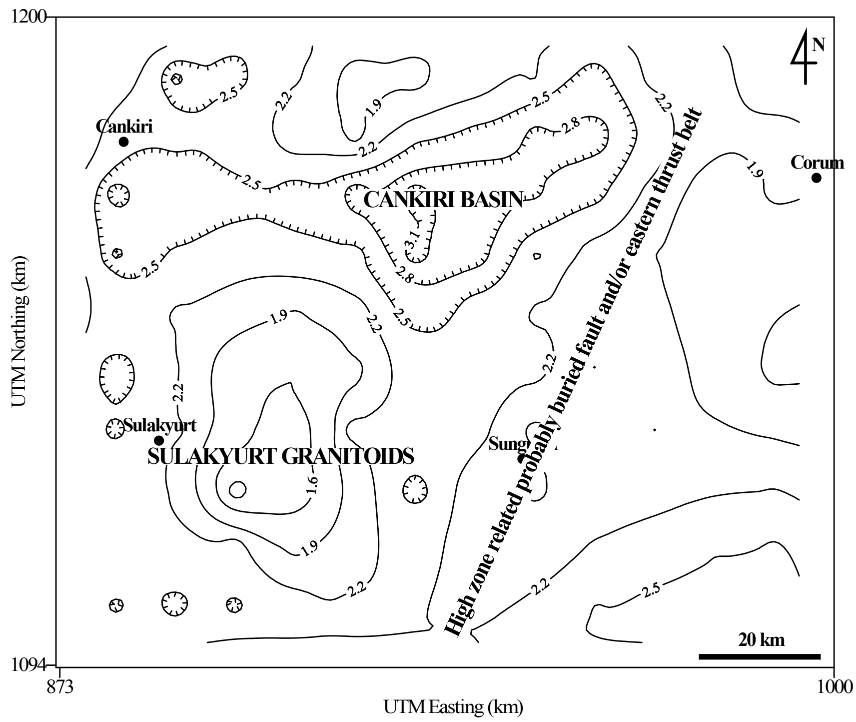

Figure 6: Three-dimensional gravity model of the Cankiri Basin. Contour interval is 0.3 km.
Şekil 6: Çankırı havzasının üç boyutlu gravite modeli. Kontur aralığı 0.3 km.

DISCUSSION AND CONCLUSION

The gravity anomalies of the CB reflects mainly surface geology, cover mostly Quaternary and Neogene deposits, except for the east of Sulakyurt and the east of the study region (Figs. 1b and 2). In the study region two remarkable anomaly closures are that in the north of the region, the W-E trending gravity values decreases between Cankiri and Corum (below -84 mGal) and another in the east of Sulakyurt about elliptical shape anomaly closure increase above -28 mGal (Fig. 2).

The intense low amplitude gravity anomaly closure between Cankiri and Corum are associated with the CB and reflect the thick sedimentary basement. The intense high amplitude anomaly closure in the east of Sulakyurt may be associated with the granitoids underlying the young cover units (Fig. 2). It is proposed that these buried granitoids can be belonging to the NE-SW trending SG, exposed at the south of the town of Sulakyurt (Fig. 1b).

Power spectrum analysis of gravity data in Fig. 3 suggests five sources at depths ranging from 0.23 km to 10.8 km from the surface. Three geologic boundaries are determined from the horizontal gradient map (Fig. 4). The maxima of the horizontal gradient reflect the boundaries of the CB and buried the SG. These are labeled as BI and BII on the map, respectively (Fig. 4). Third geologic boundary (BIII, Fig. 4) is interesting, because it can not be seen in the gravity anomaly (Fig. 2) and the analytic signal map (Fig. 5a). BI and BII are separated from BIII via the NE-SW trending zone shown in Fig. 4. We observe from Fig. 5a and Fig. 5b that BI and BII sources can be easily identified and the depths obtained from the analytic signal show an increase in BI as a decrease in BII.

The 3D gravity depth model was produced for the CB (Fig. 6). One of the results determined from the 3D gravity model is that the NE-SW trending high zone (parallel to the 2.2 km contour in Fig. 6) probably constitutes the eastern margin of the CB in the east. This high zone may be related with the buried faults and eastern thrust belt (Fig. 1b). Another result is that the deepest of the in-fill of the CB is $\approx$ 3.5-4 km (Fig. 6). This result also suggests that the h_2 depth of 3.54 km estimated from the spectral analysis of the gravity data can constitute the basement depth of the CB (Fig. 3). The average sedimentary thickness of the CB determined in this study is similar to the result of Kaymakci et al., (2003a) suggested that the CB comprises more than 4 km thick sedimentary in fill. The depths obtained from the analytic signal method also support this result for the CB (Fig. 5b). The shallow h_3, h_4 and h_5 depths inferred from Fig. 3 may be intermediate levels inside CB. The depth to the upper surface of the deepest bodies is estimated to be 10.8 km from gravity data (Fig. 3). The average thickness of the crust is determined as $\approx$38 km by Saunders et al., (1998). As a result, it can possible to suggest that the ophiolitic and metamorphic bodies regarded as consisting of fragments of the basement rocks in the study area could be intruded into the upper crust (up to ≈10.8 km from surface obtained from power spectrum analysis (Fig. 3)).

ÖZ

Orta Anadolu'da yer alan havzalardan biri olan Çankırı Havzası (ÇH), Türkiye'nin en büyük Tersiyer havzalarından biridir. ÇH, Kretase-Eosen'de Sakarya Kıtası ile Kırşehir Bloğunun çarpışması sonucunda oluşmaya başlamıştır. Çarpışma sonrası dönemde, büyük olasılıkla hem sıkışmalı hem de genişlemeli tektonik rejim hakim olmuştur. Kuzeyde Pontidler ve Kuzey Anadolu Fayı, güneyde Kırşehir Metamorfik Masifi, batıda ve doğuda Neo-Tetis'in kapanması ile ortaya çıkan ofiyolitik birim ile sınırlandırılmıştır. Çalışma alanının genel jeolojisi incelendiğinde büyük bölümünün Neojen ve Kuvaterner genç örtü birimi ile kaplı olduğu görülmektedir. Temelinde Neo-Tetis'in kalıntıları, Sakarya Kıtası ve Kırşehir Bloğuna ait birimler yer alır. Çalışma alanının GB bölümünde yüzlek veren Sulakyurt granitoidi dikkat çekmektedir. Çalışma alanında yüzlek veren ofiyolitik birimler, omega şeklindeki (Ω) Çankırı Havzası'nın kenarlarını sınırlamaktadır.

Bu çalışmada, Çankırı Havzasının Bouguer gravite anomali verileri değerlendirilmiştir. Gravite verilerine uygulanan yatay gradyent yöntemi ile elde edilen maxspot haritasından, havzanın doğusunu sınırlayan KD-GB gidişli büyük bir olasılıkla faylarla ilişkili bir paleo-yükselim bölgesi saptanmıştır. Gravite verilerinin üç boyutlu modellenmesinden ve analitik sinyal derinlik haritasından Çankırı Havzası'nda sedimanter kalınlığı 3.5-4.4 km olarak belirlenmiştir.

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