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Mapping of major tectonic lineaments and a buried basement structure in the SW of central Anatolia – Türkiye, using aeromagnetic data

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Abstract

The study area is located in the Anatolide-Tauride Block which underwent stronger Alpine deformation and regional metamorphism throughout the geological history. This study aimed to identify discontinuities in the SW part of central Anatolia from the magnetic anomaly data. These discontinuities originated from the boundaries of anomalous intrusions and faults within the sedimentary region. For determining their depths, geometries and some other properties, the Reduction to the Pole (RTP), the power spectrum, upward continuation, Analytic Signal (AS), Tilt Angle (TA) and the Theta Angle [$\cos(\theta)$] methods were used. The spectral analysis showed that the average depths of the deeper and shallow magnetized sources were calculated as 8.64 km and 4.81 km, respectively. The third segment on the spectrum graphics (estimated as 1.96 km) is related with the sedimentary cover units. The results of the upward continuation, AS, TA and $\cos(\theta)$ revealed a magnetic lineation trend generally in the NW-SE direction and identified a deep-seated body buried under the sedimentary cover. In general, these magnetic lineaments are interpreted as the fault-related structures after correlation with the earthquake data and the oval magnetic anomaly is accepted as the product of a magnetic intrusion.

Key words: Magnetic Anomaly; Power Spectrum; Upward Continuation; Tilt Angle; Theta Angle

1. Introduction

The study area is located in the south of Konya province in the central part of Anatolides (partially in the Tavsanli-Afyon-Bolkardağı Zone) to the north of the Tauride Block (Fig. 1a). The Anatolide-Tauride Block has a complex tectonic history involving the Alpine orogeny, block rotations, and ophiolite emplacement. Due to the complex tectonic history of the Anatolide-Tauride platform, several geological studies have been executed to determine its geodynamic processes (e.g., McKenzie, 1978; Sengor and Yilmaz, 1981; Westaway, 1994; Dilek et al., 1997; Thomson and Ring, 2006), neotectonic rotations in the region (e.g., Tatar et al., 1996; 2002; Barka and Reilinger, 1997; Platzman et al., 1998; Bilim et al., 2015), structure and petrology of the Tauride ophiolites (e.g., Sengor and

Yilmaz, 1981; Dilek et al., 1990; 1999; van Hinsbergen et al., 2016). Because the previous studies focused on the structural geology and petrology; geophysical constraints remain sparse. There are few geophysical studies in central Anatolia, including the Konya province and surrounding area, although there are apparent anomalies to the S-SE of Konya city center. The gravity and magnetic data are the only available regional geophysical data for the large-scale investigations in this region such as the plate tectonic-related structures and magmatic intrusions into the crust in the W-SW part of the central Anatolia. The causative bodies of these anomalies do not outcrop on the surface although they are located at the boundary between the significant plates comprising the Anatolian assembly. The potential field data may contribute to the resolving details about the inter and intraplate relationships in central Anatolia related with the major plates that form the tectonic framework of Anatolia. Additionally,

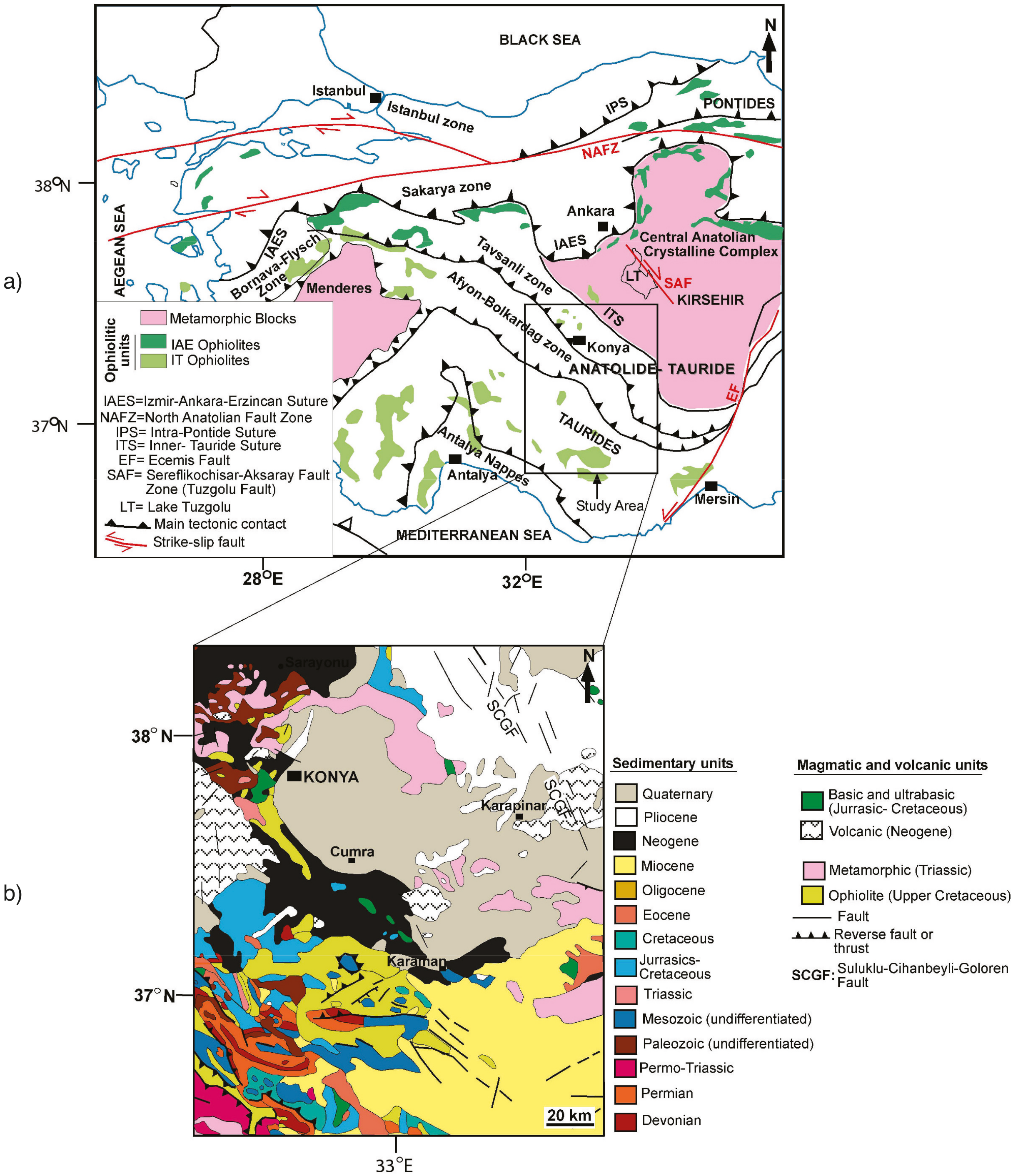

Figure 1. (a) The tectonic map of the western and central Türkiye (modified from Okay, 1986 and Advokaat et al., 2014). (b) Simplified geological map of the study area (modified from Bingol, 1989).

fault extensions that have not been clearly defined along the western part of central Anatolia until now can be precisely identified.

Ates and Kearey (2000) provided the gravity and pseudogravity models of the individual anomaly around Çumra. They named it as the "Konya Anomaly". It was concluded from the models that the causative bodies were intruded into the upper crust from the upper mantle (Ates and Kearey, 2000). Aydemir and Ates (2006) investigated the geometry and properties of the causative body of the most apparent anomaly in Türkiye: it is the NW-SE trending anomaly extending along the western part of the Lake Tuzgolu (named as the Suluklu-Cihanbeyli-Goloren – SCG anomaly). They suggested that the SCG anomaly resulted from a tilted dike and it is a deep-seated intrusion down to 15-16 km according to the 2D magnetic model. Three years later, Aydemir (2009) investigated the wrench tectonic model of central Anatolia considering the tectonic escape model by using the aeromagnetic, gravity, seismic and seismological data. He proposed that the counter-clockwise rotational movement of the Kirsehir Block to the east of Tuzgolu Basin has been driven by the Kirikkale-Erbaa and Sereflikochisar-Aksaray (Tuzgolu) faults. The area to the northernmost corner of Lake Tuzgolu might be the hinge point for this rotation, causing an intense earthquake activity. Later, Ates et al. (2012) studied the crustal structure of Türkiye from the regional gravity, magnetic and seismic reflection data. They determined that the average crustal thickness is about 34 km around the Konya region. Bilim et al. (2015) studied the block rotations and determined the Curie Point Depths of the magnetic sources along the NW-SE trending Suluklu-Cihanbeyli-Goloren (SCG) and Sereflikochisar-Aksaray Fault (SAF) zones. They estimated that the clockwise mean rotations along the SCG and the SAF are 52.6°E and 46.5°E, respectively. Recently, Erbek-Kiran et al. (2024) applied a power spectrum analysis, high-pass filter and second vertical derivative method (SVD) to the magnetic data of the inner and inner-east Anatolia, and proposed that the average depths of the deep and shallow causative sources in the Tuzgolu Basin are 11.37 km and 5.01 km.

The main goal of this study is to determine the geometry, depth and locations of deep-seated magnetized sources and, mapping the geologic structures in relation to the fault systems in the study area because they have not been clearly delineated in the previous investigations. They are lineaments, faults, boundaries of the causative bodies revealed after the further enhancements or processing. These methods are the Reduction to the Pole (RTP), Radially Averaged Power Spectrum, Upward Continuation, Enhanced Analytic Signal (EAS), Tilt and Theta Angle. These methods applied onto the total magnetic data of the study area for the first time. The Suluklu-Cihanbeyli-Goloren – SCG anomaly is located at the boundary between the Kırşehir Block and the Menderes-Taurus Assembly. Moreover, SCGF zone was not precisely defined in the literature (i.e., Fig. 1b), it is shown as separate, short segments on all geological maps. Existence of such a major fault was mentioned by Yaltirak (2002). However, the fault zone was filled by a tilted dyke in the Early Oligocene (Aydemir and Ateş, 2006), it does not indicate a continuous fault elongation and does not show a regular seismicity. Therefore, our study will play a very important role in addressing these shortcomings, providing significant evidence. In addition, the Çumra Anomaly is the most important subduction-related magmatic emplacement along with the rarely observed intrusions in Anatolia (originated from the African subduction beneath the Eurasian Plate), outside of the Cappadocia region. Despite the well-known anomalies (e.g., SCG and Çumra), their origin, geometry and tectonic implications are poorly understood. Existing gravity and magnetic studies are all regional investigations and lack of high-resolution interpretation but aeromagnetic data provide insights into crustal architecture that improve models of deformation as given below.

2. Tectonic and geological setting

Turkish crustal assembly was formed during the Alpine orogeny after the collision of Laurasia and Gondwana in the Late Mesozoic. This collision divided Anatolia into three tectonic blocks, from the north to the south: the Pontides (assigned to Laurasia), the Anatolide-Tauride Block (Alpine continental block) and the Arabian Plate (the northern edge of the Gondwana) (e.g., Goncuoglu et al., 1997; Okay and Tüysüz, 1999). As a result of the collision and the closure of the Neo-Tethyan ocean during the Mesozoic-Cenozoic time, the geological structure of the Aegean region and Anatolia was formed (Sengor and Yilmaz, 1981).

The study area is located in the central portion of the Anatolide-Tauride Block (SW of the central Anatolia) and contains mainly, from north to south, Inner-Tauride Suture (ITS), Tavşanlı Zone, Afyon-Bolkardağı Zone and Taurides (Fig. 1a). The Intra-Tauride Suture (ITS) extends between the Kırşehir Massif (Gorur et al., 1984) (also known as the Central Anatolian Crystalline Complex-CACC, Goncuoglu et al., 1991) and the Tavşanlı and Afyon-Bolkardağı zones (Okay, 1984). Tavşanlı and Afyon-Bolkardağı zones are the tectonic sections belonging to the Anatolide

Block. The Tavşanlı Zone is a HP/LT metamorphic complex (Okay, 1984) and tectonically overlain by an ophiolite nappe consisting primarily of peridotite. It forms the north facing continental margin of the Anatolide-Tauride Block (Okay, 1984) and contains metamorphic rocks (e.g., phyllite, marble, metabasite), well-preserved blueschist and eclogite facies minerals formed during the Late Cretaceous (Sherlock and Kelley, 2002). The southern part of the Anatolide-Tauride Block is called the Taurides. The Taurides are characterized by the series of nappe systems consisted of the Paleozoic and early Mesozoic carbonates, Paleozoic to early Mesozoic volcano-sedimentary and epiclastic rocks, tectonically overlain by the Cretaceous ophiolite complexes and, Late Cretaceous and younger post-collisional sedimentary and volcanic units (Ozgul, 1976; Dilek et al., 1999; Collins and Robertson, 2003; Gursu et al., 2004).

The simplified geological map of the study area is given in Fig. 1b. The young cover units (mainly Quaternary) cover the surface. The ophiolitic rocks in the SW of the study area are located on the Tauride tectonic belt. Dilek et al. (1999) studied the structure and petrology of the Tauride ophiolites in detail. They divided ophiolites into three sections as the Inner, Intermediate and Outer zones. They proposed that these zones tectonically overlie the Mesozoic platform carbonates of the Tauride belt and commonly underlain by a Cenomanian ophiolitic mélange. Ophiolites are composed of tectonically disturbed mantle rocks, mafic-ultramafic cumulates and gabbros (Dilek et al., 1991). The NW-SE trending metamorphic rocks of the Afyon-Bolkardağı Zone outcropped mainly on the Konya and Karapınar axis (Fig. 1b). Candan et al. (2005) suggested that the Upper Palaeocene-Lower Eocene sedimentary rocks unconformably overlie the metamorphic rocks of the Afyon-Bolkardağı Zone, indicating a regional HP/LT metamorphism. The volcanic rocks are also observed as local patches, particularly in the west of Konya and the east of Karapınar (Fig. 1b). The Sülüklü-Cihanbeyli-Gölören Fault (SCGF) is shown in the upper right corner of the study area (Fig. 1b). Ozsayın and Dirik (2007) also named the SCGF as the “Sultanhanı Fault Zone”. The NW-SE trending SCGF includes strike-slip and normal fault components that extend approximately 500 km along the suture zone between the Taurides and Anatolide blocks (Pourteau et al., 2010).

3. Methodology

Reduction to the Pole (RTP)

Total magnetic anomalies cannot exactly be located above a causative body because the Earth’s magnetic field intensity is influenced by the magnetization of crustal magnetic rocks. If the magnetization and ambient field are not vertical, a symmetrical distribution of magnetization can be distorted. Reduction to the Pole (RTP) is the operation that converts the observed magnetic response into an anomaly as if the measurements were taken at the north magnetic pole where the induced magnetization and ambient field both would have been in the vertical direction (Baranov, 1957). The RTP anomaly can be obtained by multiplying the magnetic anomaly by $1/\emptyset m \emptyset f$ in the Fourier domain (Blakely, 1996). The parameters $\emptyset m$ and $\emptyset f$ are given as follows:

$$\emptyset m = \widehat{m_z} + i\frac{\widehat{m_x}k_x + \widehat{m_y}k_y}{|k|}, \text{ and } \emptyset f = \widehat{f_z} + i\frac{\widehat{f_x}k_x + \widehat{f_y}k_y}{|k|} \tag{1}$$

where; k is the wavenumber. $\hat{m} = (\widehat{m_x}, \widehat{m_y}, \widehat{m_z})$ and $\hat{f} = (\widehat{f_x}, \widehat{f_y}, \widehat{f_z})$ are the unit vectors in the direction of magnetization and in the direction of the ambient field, respectively (Blakely, 1996).

Radially averaged power spectrum

Spectral analysis of the potential filed data has been used extensively since 1970 (e.g., Spector and Grant, 1970; Connard et al., 1983; Mauss and Dimri, 1995; Nwankwo et al., 2008; Bilim, 2017; Aydemir et al., 2020; Yassah et al., 2025). Spector and Grant (1970) developed a radially averaged power spectrum method to determine the source depths of the magnetic anomalies. The power for the equal lengths of the wave vector is averaged in their method. In two-dimensional plane, it is dominated by the depth factor and decreases with the increasing distance to the source depth (Spector and Grant, 1970). The lower wavenumber segments represent deeper density contrast interfaces while the higher wavenumber segments usually represent shallower density contrast interfaces. The average depth (h) of the source can be estimated directly from the slope of the log radially averaged power spectrum by $h = -S/4\pi$, where S is the slope of the spectrum curve (Spector and Grant, 1970).

Upward continuation

The analytic continuation of potential fields is a powerful tool in transformation of geophysical potential fields (mainly in the gravity and magnetic fields). Continuation of the potential field data above the level of measurement is known as the upward continuation (Henderson, 1970; Henderson and Cordell, 1971). It attenuates anomalies with respect to wavelength; the shorter the wavelength, the greater the attenuation. Upward continuation can be achieved by the Fourier transformation of the magnetic data multiplying with the exponential term of $e^{-\Delta z|k|}$ considering $\Delta z > 0$, and the inverse Fourier transform of the product (Blakely, 1996). Here, Δz and k are upward continuation level ($\Delta z > 0$) and the wavenumber, respectively.

Enhanced Analytic Signal (EAS)

The analytic signal (AS) of the gravity and magnetic data is a useful technique for determination of geological boundaries of the causative sources and tectonic lineaments (Nabighian, 1972; 1974). The most critical advantage of the AS is that it is not affected by the direction of the total magnetization of the causative bodies. In the 3D case, the simple AS amplitude (|Ao|) is defined by Roest et al. (1992) as follows:

$$|Ao(x,y)| = \sqrt{\left(\frac{\partial Mx}{\partial x}\right)^2 + \left(\frac{\partial My}{\partial y}\right)^2 + \left(\frac{\partial Mz}{\partial z}\right)^2} \quad (2)$$

where, M is the magnetic anomaly.

Hsu et al. (1996) developed the enhanced analytic signal (EAS) method for the interpretation of potential field anomalies in 3D. They defined the amplitude of the second order EAS as given below:

$$|A_2(x,y)| = \sqrt{(\nabla^2 Mx)^2 + (\nabla^2 My)^2 + (\nabla^2 Mz)^2} \quad (3)$$

where, $\nabla^2 = \frac{\partial^2}{\partial z^2}$, $Mx = \frac{\partial Mx}{\partial x}$, $My = \frac{\partial My}{\partial y}$, and $Mz = \frac{\partial Mz}{\partial z}$.

Tilt Angle (TA)

Miller and Singh (1994) introduced the Tilt Angle method (TA) to enhance the images of the magnetic anomaly (M) and defined its formula, as follows:

$$TA = tan^{-1}\left(\frac{\partial M/\partial z}{\partial M/\partial h}\right) \quad (4)$$

where,

$$\frac{\partial M}{\partial h} = \sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial y}\right)^2}$$

TA is measured in either radians or degrees and it is not affected from the induced magnetization of the causative bodies. The tilt value is 0º over or near the edge while it is positive just above the magnetic sources. The boundaries of sources are determined by the zero contours in the map. Tilt angle is limited in the range of –90 º to 90 º (Miller and Singh, 1994).

Theta angle

Wijins et al. (2005) presented the theta angle method derived from the analytic signal for detecting edges of the magnetic sources. The theta angle [cos (θ)] is calculated in x, y and z directions using the formula given below,

$$\cos(\theta) = \frac{\sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial y}\right)^2}}{\sqrt{\left(\frac{\partial Mx}{\partial x}\right)^2 + \left(\frac{\partial My}{\partial y}\right)^2 + \left(\frac{\partial Mz}{\partial z}\right)^2}}, \tag{5}$$

where, M is the magnetic field anomaly (Wijins et al., 2005).

All applied methods are given in Fig. 2 as a flowchart.

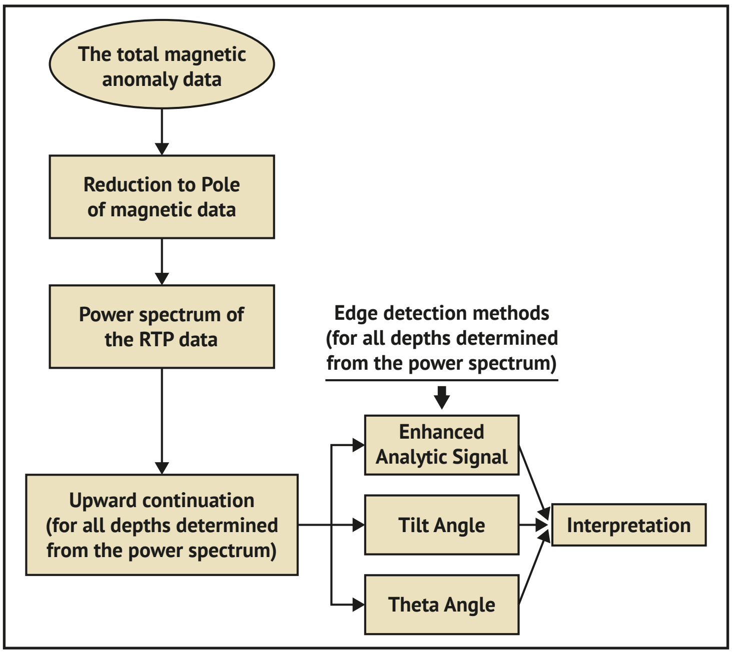

Figure 2. Workflow of the applied methods during the analysis of the magnetic anomalies.

4. Data and analysis

Ates et al. (1999) mapped the aeromagnetic anomalies of Türkiye entirely for the first time. They obtained the data from the General Directorate of Mineral Research and Exploration of Türkiye (MTA). Total field acquisition of the aeromagnetic data was performed along the flight lines with 2 km spacing at the 600 m flight altitude (constant altitude above the ground level) and all necessary corrections including diurnal variations have been applied by MTA. The "International Geomagnetic Reference Field (IGRF)" removal process from the survey data was performed using the program of Baldwin and Langel (1993). The total aeromagnetic anomalies of the study area is given in Fig. 3. The magnetic anomaly values in the study area range from −150 to 550 nT (Fig. 3).

Two high intense anomalies with positive and negative polarities are quite apparent in the study area: One of them is oriented in the NW-SE direction around Çumra town (named as the Çumra Anomaly in this study) and the other is oriented in the same (NW-SE) direction along the SCGF (Fig. 3).

Firstly, the RTP filter was applied to the aeromagnetic anomaly data of the study area to reduce the asymmetry due to the inclination and declination of the Earth's magnetic field (Fig. 4). The declination and inclination angles of the Earth's magnetic field were taken as 4°E and 55°N, respectively. In the RTP map, the anomaly to south of

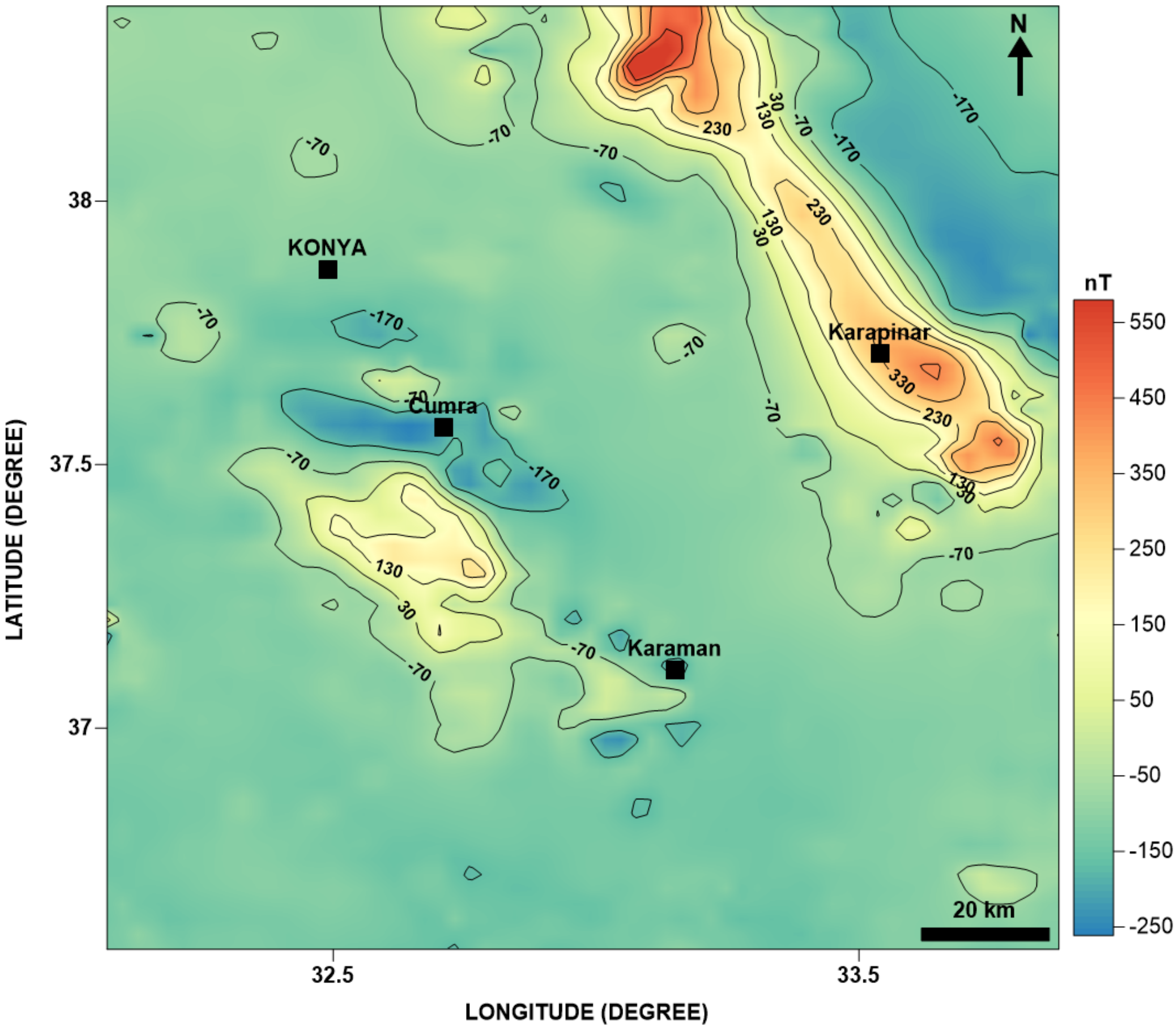

Figure 3. The total field aeromagnetic anomaly map of the study area. Contour Interval: 100 nT.

Karaman, around the southern boundary of the study area, draws attention that it is not visible from the magnetic anomaly map. Therefore, it deserves special research.

Secondly, the radially averaged power spectrum of the RTP data was used to estimate the average depths to the top of magnetic sources (Fig. 5). Figure 5 indicates three segments. The first segment with steeper slope corresponds to deeper magnetic sources and exhibits relatively high power at low wavenumbers. The second and third segments represent progressively shallower ensembles of magnetic sources. The shortest-wavelength portion of the spectrum is dominated by the noise (Spector and Grant, 1970). The average depths of deeper and intermediate magnetized sources were calculated as 8.64 km and 4.81 km, respectively. The third segment was estimated as 1.96 km, which may indicate the sedimentary thickness.

Thirdly, the upward continuation (Fig. 6) was applied to examine the distribution of magnetic sources at depths based on the spectral analysis (Fig. 5). Upward continuation transforms the potential field measured on one surface to the field that would be measured on another surface farther from all sources. This transformation attenuates anomalies with respect to wavelength; the shorter the wavelength, the greater the attenuation. That is, it acts like low-pass filter (Blakely, 1996). Upward continuation, also, tends to accentuate anomalies caused by deep sources at the expense of anomalies caused by shallow sources. The height of upward continuation is dependent on the choice of a researcher. In this work, we chose the three heights of upward continuation from the power spectrum of magnetic data in the study area for separating causative sources from various depths and enhancement of the shorth wavelenght magnetic anomalies associated with faults and other structural discontinuities or/and magnetic bodies.

Then, the EAS, TA and the Theta Angle (cos $[\theta]$) methods were applied to each of the upward continuation levels of the anomaly data. Figures 7, 8 and 9 show the results of the EAS, TA and the cos (θ) methods, respectively.

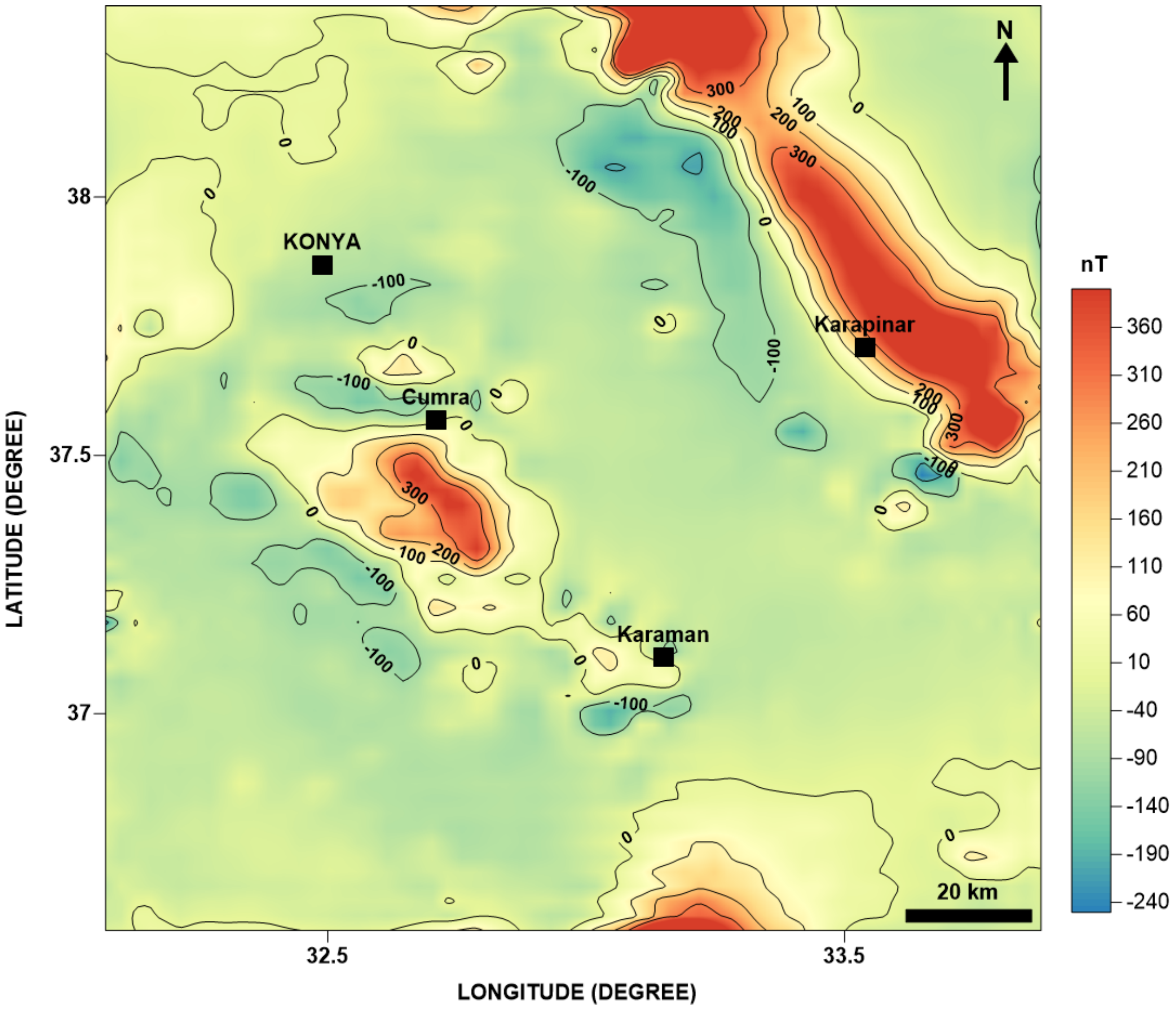

Figure 4. Reduction to the Pole (RTP) map produced from the magnetic anomaly map. Contour Interval: 100 nT.

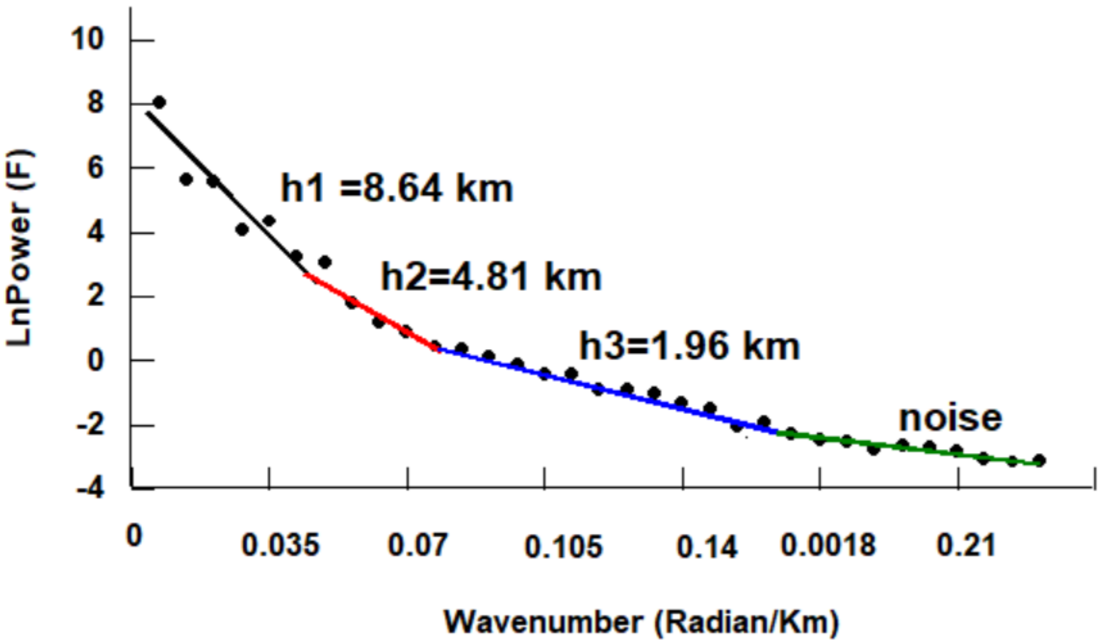

Figure 5. Radially averaged power spectrum of the study area.

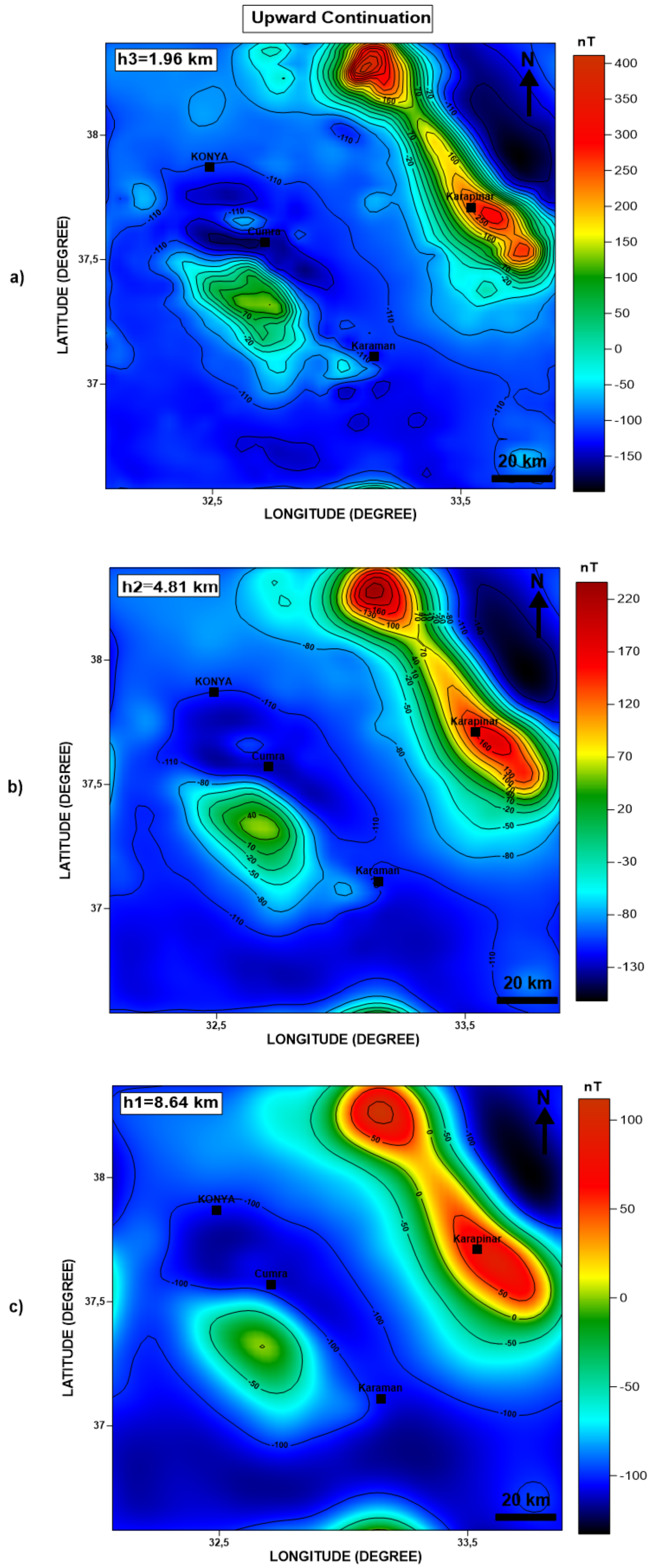

Figure 6. Upward continuation anomalies at different altitudes obtained from the power spectrum: (a) 1.96 km; (b) 4.81 km and (c) 8.64 km.

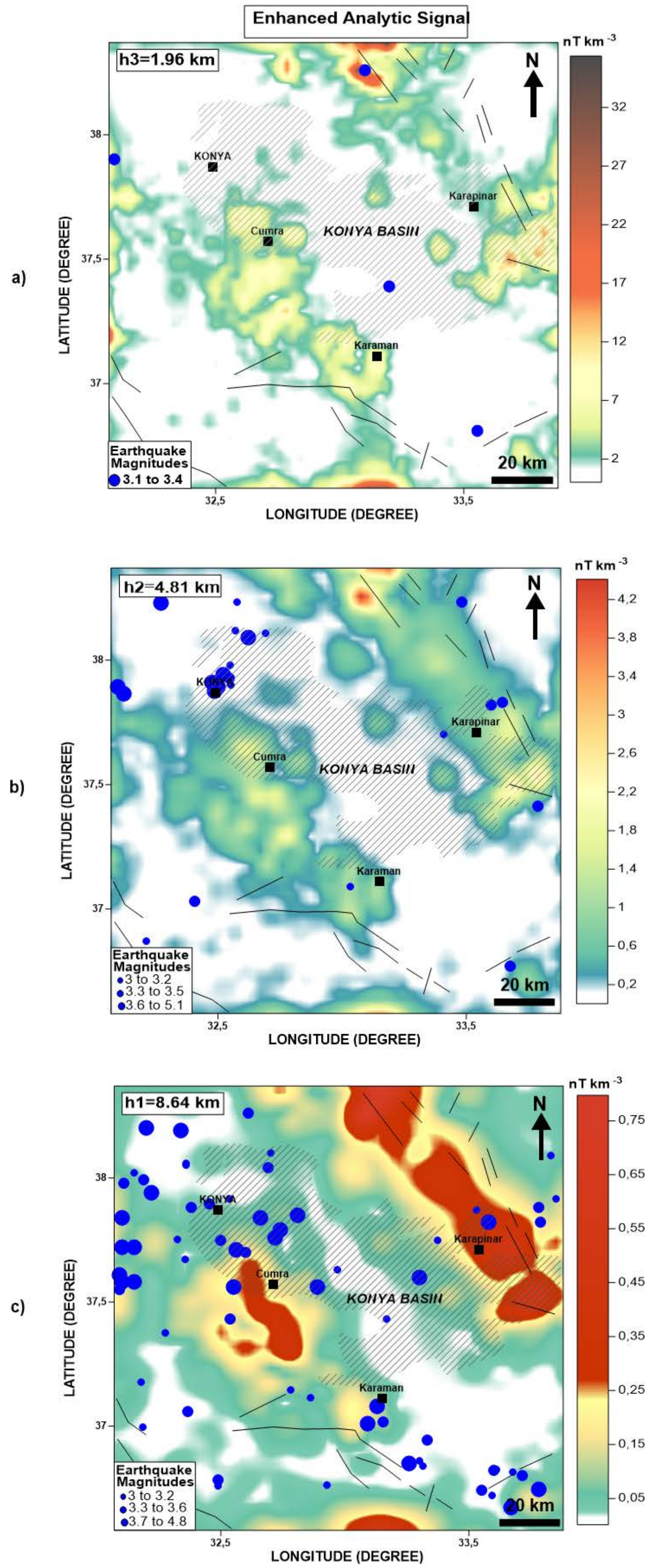

Figure 7. The EAS maps applied onto the upward continuation maps (a) 1.96 km; (b) 4.81 km and (c) 8.64 km. Blue circles show the epicenters of the earthquakes since 1972 with the magnitudes ≥3.

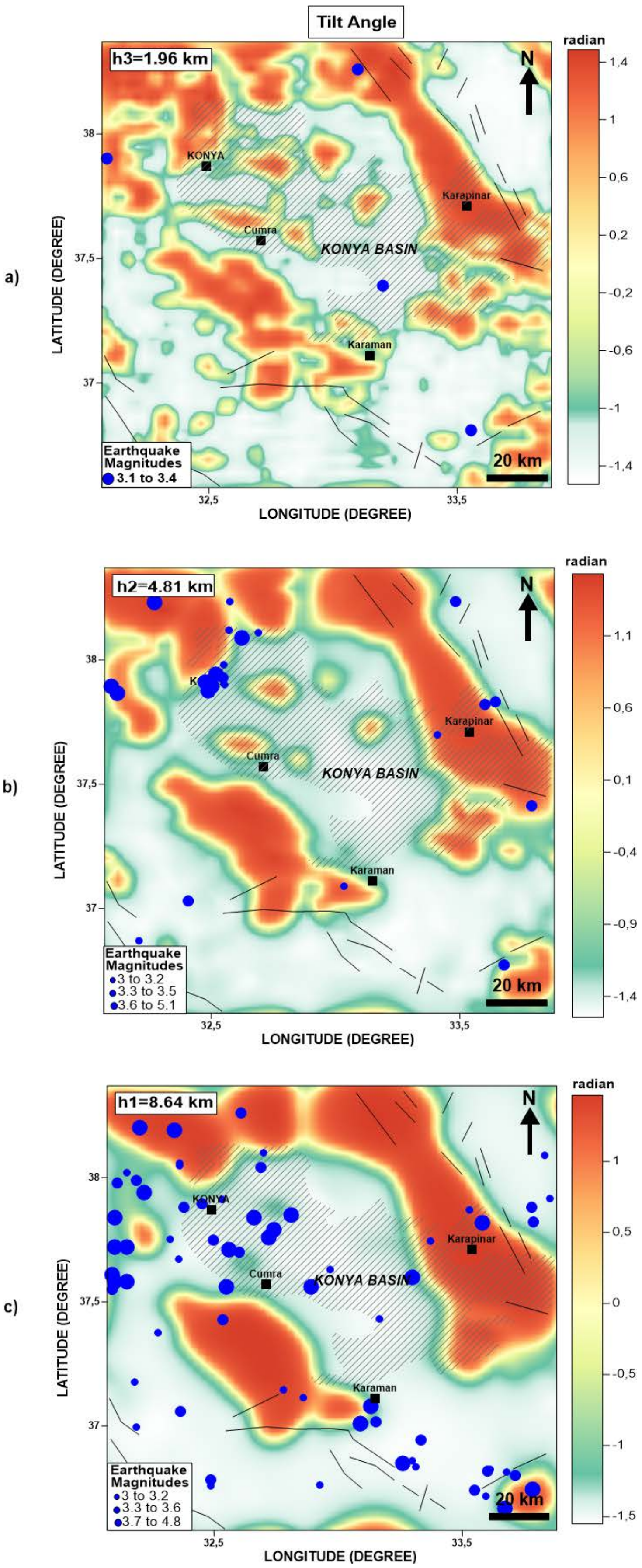

Figure 8. The Tilt Angle (TA) maps applied onto the upward continuation maps (a) 1.96 km; (b) 4.81 km and (c) 8.64 km. Blue circles show the epicenters of the earthquakes since 1972 with the magnitudes ≥3.

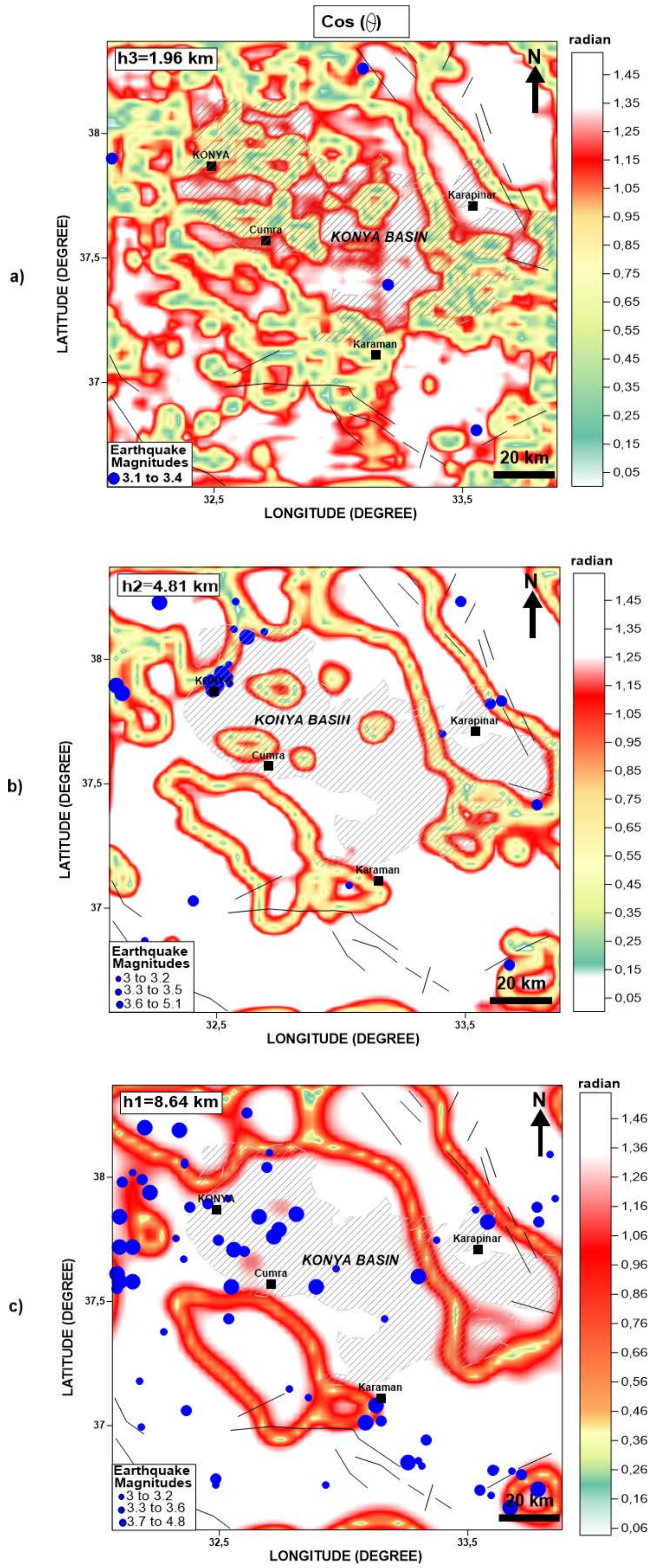

Figure 9. The Theta Angle [cos (θ)] maps applied onto the upward continuation maps (a) 1.96 km; (b) 4.81 km and (c) 8.64 km. Blue circles show the epicenters of the earthquakes since 1972 with the magnitudes ≥3.

5. Discussions and conclusions

In the study area, the upward continuation and the EAS, TA, and the cos (θ) methods applied onto the upward continuation anomaly data for three levels in central Anatolia for the first time in order to detect the edges and enhance the anomaly causative sources. The main reason for this application is to resolve the relationships between the major plates in central Anatolia. The other reason is to identify the faults along the western part of central Anatolia.

Two prominent high magnetic anomalies are visible on Figs. 3 and 4: one of them is located at the upper right corner of the study area. Aydemir and Ates (2006) named this NW-SE trending anomaly as the SCG Anomaly. The causative intrusive body emplaced in the boundary zone between the Kırşehir Block in the east and the Menderes-Taurus Platform in the west, particularly the Afyon-Bolkardağı Zone of the Menderes-Taurus Complex. Because the intrusion (Aydemir and Ateş, 2006) has a deep root through the east (down to 17 km) and it was intruded into the western boundary fault of the Tuzgölü Basin (also mentioned by Yaltirak, 2002) at the end of Eocene-Early Oligocene as a tilted dyke, its thickness does not exceed 3 km according to the modeling study (Aydemir and Ates, 2006). Considering its age and thickness, the temperature contribution to the metamorphic process would have been limited (only around the intrusion interval within the fault). Ateş et al. (2005) and Bilim et al. (2015) prepared the CPD map of the central Anatolia and this region. Their studies do not indicate high heat flow in this region. Additionally, it does not reflect an apparent seismic activity according to the earthquake epicenters (Aydemir and Ates, 2006).

The other anomaly named the "Çumra Magnetic Anomaly" is located between Çumra and Karaman. It is likely to originate from the deep-seated ophiolitic rocks of the Tauride tectonic belt According to previous modelling study (Ates and Kearey, 2000). However, there is no borehole data to provide the information about the exact lithology, depth and the origin of this intrusion. Knowledge about the depths of these intrusives are limited (only power spectrum analysis). The Tauride ophiolites and mafic dike intrusions in the Tauride Belt consist mainly of tectonized mantle rocks, mafic-ultramafic cumulates, gabbros, sheeted-dike complexes and the extrusive rocks of a complete ophiolite sequence (Dilek et al., 1999).

The radially averaged power spectrum suggests three mean depths to the top of sources 8.64 km, 4.81 km, and 1.96 km (Fig. 5). The third segment (at 1.96 km) probably arised from the sedimentary thickness in the shallow Konya Basin. Bilim et al. (2015) estimated Curie Point Depths (CPDs) from the aeromagnetic data to determine the thermal structure of central Anatolia. They found that the average depth of the magnetic crust was 16.7 km. The deepest source in the power spectrum stays in this magnetic crust. Figure 6 shows the upward continuation results of the RTP magnetic data that was used to decompose the crustal magnetic anomalies at three depths determined from the power spectrum (Fig. 5). As seen in Fig. 6a to 6c, the attenuation rate of the shallow-source anomalies is more apparent than the deep-seated anomalies. There may be some small size blocks originated from the main causative bodies.

Figures 7, 8 and 9 present the results of the EAS map, TA map, and the cos [θ] map applied onto the upward continuation data for the depths: a) 1.96 km; b) 4.81 km and c) 8.64 km, respectively.

When all three maps are examined, the edges of deep sources are clearly identifiable in the cos (θ) map. Figure 9c identifies locations of three deep-seated bodies caused the magnetic anomalies in the large NW-SE oriented elliptical SCG Anomaly. Two of these are in the north and northeast of the Konya Basin while the other is in the southwest of the basin, near Çumra (Çumra Anomaly). The linear anomaly extends parallel to the Tuzgölü Fault (which is indicated as SAF in Fig. 1a) in the NW-SE direction and their elongations are consistent with the westward counter clockwise rotation and tectonic escape model suggested by Şengör et al. (1985).

In the Konya Basin, small circular magnetic bodies detected at 1.96 and 4.81 km on the EAS, TA, and the cos (θ) maps may be related to the basic and ultrabasic rocks of the Afyon-Bolkardağı Zone beneath the cover unit. They are not observed at 8.64 km. The metamorphic rocks of the Afyon-Bolkardağı Zone are unconformably overlain by the Upper Palaeocene-Lower Eocene sedimentary rocks, (Candan et al., 2005).

The horizontal location of the causative body of the severe magnetic anomaly around Çumra located at the south of the Konya Basin is more clearly visible in Fig. 9c than Fig. 7c and Fig. 8c. According to Figs. 7c, 8c, and 9c, we suggest that the basement depth of Çumra magnetic body associated with the ophiolite rocks could extend to depths greater than 8.64 km in the upper crust, which is 35-36 km thick in average in the central Anatolia (Ateş et al., 2012; Tezel et al., 2013).

Aydın and İşseven (2018) studied the gravity anomaly around Çumra using the spectral analysis of the anomaly and proposed that the causative body for the gravity anomaly is buried at a depth of about 4.8 km. In addition, they claimed that the intense gravity anomaly of Çumra originates from an ophiolite block emplaced during the closure of the Tethys Ocean. However, Erbek and Dolmaz (2019) suggested that the estimated basement depth is about 9.4 km according to the analytical signal and the tilt methods applied onto the gravity anomaly of Çumra. This depth is almost identical with our results.

In Figs. 7, 8 and 9, blue circles indicate the earthquake epicenter distributions since 1972 with the magnitude ≥3 at continuation levels. The data was taken from the catalogue of the General Directorate of Disaster Affairs of Türkiye. The region exhibits low seismicity with low magnitude earthquakes that predominantly occurred at the shallow depths above 8.64 km because the intrusive causative body emplaced relatively at shallow depths during the Late Eocene-Early Oligocene (Aydemir and Ateş, 2006). From Figs. 7c, 8c and 9c, it can be concluded that the crustal seismic source zone extends along a tectonic line (fault-oriented, intrusive-filled zone) in the NW-SE direction from the upper left to the lower right corner of the map.

Because there is no intensive seismic activity creating devastating earthquakes in the region and the lack of deep sedimentary deposition in the study area, no seismic reflection data and no detailed field data acquired on the surface. Due to these reasons given above, the gravity and magnetic data are the only geophysical information to help the geological studies to understand the tectonic framework and for resolving uncertainties in the crustal structure in central Anatolia. In case of having other types of geophysical data for any reason or any exploration target in the future, we believe that our results will be confirmed and this paper will be a key reference for the future investigations.

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Data and material availability. The authors have no right to disclose the datasets used in this study. They could be obtained from MTA.

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Conflict of Interest Statement. We confirm that no known conflicts of interest are associated with this publication. No significant financial support has been received for this work that could have influenced its outcome. We confirm that the manuscript has been read and approved by all named authors and that no other persons have satisfied the criteria for authorship but are not listed. We further confirm that all have approved the order of authors listed in our manuscript. We confirm that we have given due consideration to protecting the intellectual property associated with this work and that there are no impediments to publication, including those related to intellectual property, that would affect the timing of publication. In doing so, we confirm that we have complied with the regulations of our institutions regarding intellectual property. We understand that the Corresponding Author is the sole contact for the Editorial process, including communication with the Editorial Manager and direct contact with the office. He is responsible for communicating with the other authors regarding progress, revisions, and the final approval of proofs. We confirm that we have provided current, correct e-mail addresses that are accessible by the Corresponding Author and have been configured to accept e-mails.

References

Advokaat, E. L., D. van Hinsbergen, N. Kaymakci, R. L. M. Vissers et al. (2014). Late Cretaceous extension and Palaeogenerotation-related contraction in Central Anatolia recorded in the Ayhan-Buyukkisla basin, Int. Geol. Rev., 56, 1813-1836, doi:10.1080/00206814.2014.954279.

Ates, A., P. Kearey and S. Tufan (1999). New gravity and magnetic maps of Turkey, Geophys. J. Int., 136, 499-502, doi:10.1046/j.1365-246X.1999.00732.x.

Ates, A. and P. Kearey (2000). Interpretation of gravity and aeromagnetic anomalies of the Konya Region, South Central Turkey, J. Balkan Geophys. Soc., 3, 37-44.

Ates, A., F. Bilim and A. Buyuksarac (2005). Curie point depth investigation of Central Anatolia, Turkey, Pure Appl. Geophys., 162, 357-371, doi:10.1007/s00024-004-2605-3.

Ates, A., F. Bilim, A. Buyuksarac, A. Aydemir et al. (2012) Crustal structure of Turkey from aeromagnetic, gravity and deep seismic reflection data, Surv. Geophys., 33, 869-885, doi:10.1007/s10712-012-9195-x.

Aydemir, A. (2009) Tectonic investigation of Central Anatolia, Turkey using geophysical data, J. Appl. Geophys., 68, 321-334, doi:10.1016/j.jappgeo.2009.02.002.

Aydemir, A. and A. Ates (2006). Interpretation of Suluklu-Cihanbeyli-Goloren Magnetic Anomaly, Central Anatolia, Turkey: An integration of geophysical data, Phys. Earth Planet. Inter., 15, 167-182, doi:10.1016/j.pepi.2006.06.007.

Aydemir, A., F. Bilim, B. Avci and S. Kosaroglu (2020). Geophysical Investigation of the Geothermal Potential Under the Largest Volcanic Cover in Anatolia: Kars Plateau, NE Turkey, Pure Appl. Geophys., 177, 919-939, doi:10.1007/s00024-019-02317-x.

Aydın, N. G. and T. İşseven (2018). What is the reason for the high Bouguer gravity anomaly at Çumra, Konya, Central Anatolia?, Turkish J. Earth Sci., 27, 318-328, doi:10.3906/yer-1801-17.

Baldwin, R. T. and R. Langel (1993). Tables and maps of the DGRF 1985 and IGRF 1990, International Union of Geodesy and Geophysics Association of Geomagnetism and Aeronomy, IAGA Bull., 54, 158.

Baranov, V. (1957). A New Method for Interpretation of Aeromagnetic Maps, Pseudo-Gravimetric Anomalies, Geophys., 22, 359-363, doi:10.1190/1.1438369.

Barka, A. and R. Reilinger (1997). Active tectonics of the Eastern Mediterranean region: deduced from GPS, neotectonic and seismicity data, Ann. Geophys., 40, 3, 587-610, doi:10.4401/ag-3892.

Bilim, F., A. Aydemir and A. Ates (2015). Determination of block rotations and the Curie Point Depths of magnetic sources along the NW-SE-trending Sülüklü-Cihanbeyli-Gölören and Şereflikoçhisar-Aksaray Fault Zones, Central Anatolia, Turkey, Geodin. Acta, 27, 202-212, doi:10.1080/09853111.2014.986873.

Bilim, F. (2017). Investigating Moho depth, Curie Point, and heat-flow variations of the Yozgat Batholith and its surrounding area, north central Anatolia, Turkey, using gravity and magnetic anomalies, Turkish J. Earth Sci., 26, 410-420, doi:10.3906/yer-1706-2.

Bingol, E. (1989). 1/2,000,000 scale geologic map of Turkey. Ankara: Publication of the General Directorate of Mineral Research and Exploration (MTA) of Turkey.

Blakely, R. J. (1996). Potential Theory in Gravity and Magnetic Applications, Cambridge Press, Cambridge, 441, doi:10.1017/CBO9780511549816.

Candan, O., M. Cetinkaplan, R. Oberhansli, G. Rimmele et al. (2005). Alpine high-P/low-T metamorphism of the Afyon Zone and implications for the metamorphic evolution of Western Anatolia, Turkey, Lithos, 84, 102-124, doi:10.1016/j.lithos.2005.02.005.

Collins, A. and A. H. F. Robertson (2003). Kinematic evidence for Late Mesozoic-Miocene emplacement of the Lycian Allochthon over the western Anatolide Belt, SW Turkey, Geol. J., 38, 295-310, doi:10.1002/gj.957.

Connard, G., R. Couch and M. Gemperle (1983). Analysis of aeromagnetic measurements from the Cascade Range in central Oregon, Geophysics, 48, 376-390, doi:10.1190/1.1441476.

Dilek, Y., P. Thy, B. Hacker and S. Grundvig (1999). Structure and petrology of Tauride ophiolites and mafic dike intrusions (Turkey): Implications for the Neo-Tethyan ocean, Geol. Soc. Am. Bull., 111, 1192-1216, doi:10.1130/0016-7606(1999)111<1192:SAPOTO>2.3.CO;2.

Dilek, Y., P. Thy, E. M. Moores and T. W. Ramsden (1990). Tectonic evolution of the Troodos ophiolite within the Tethyan framework, Tectonics, 9, 811-823, doi:10.1029/TC009i004p00811.

Dilek, Y. and D. L. Whitney (1997). Counterclockwise P-T-t trajectory from the metamorphic sole of a Neo-Tethyan ophiolite, Turkey, Tectonophysics, 280, 295-310, doi:10.1016/S0040-1951(97)00038-3.

Erbek-Kiran, E., A. Ates and M. N. Dolmaz (2024). The correlation between the active/buried faults and aeromagnetic data in inner and inner east Anatolia, Turkey, Ann. Geophys., 67, GT324, doi:10.4401/ag-9079.

Erbek, E. and M. N. Dolmaz (2019). Çumra-Konya Bölgesindeki Yüksek Genlikli Gravite Anomalilerine Neden Olan Yapıların Araştırılması, Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 23, 1000-1005, in Turkish, doi:10.19113/sdufenbed.586407.

Goncuoglu, M. C., K. Dirik and H. Kozlu (1997). General Characteristics of pre-Alpine and Alpine Terranes in Turkey: Explanatory notes to the terrane map of Turkey, Annales Géologique de Pays Héllenique, 37, 515-536.

Goncuoglu, M. C., V. Toprak, I. Kuscu, A. Erler et al. (1991). Geology of the western part of the Central Anatolian Massif, Part 1: Southern Section, Unpubl. Report No. 2909, Turkish Petroleum Company, in Turkish.

Gorur, N., F. Y. Oktay, I. Seymen and A. M. C. Sengor (1984). Palaeo-tectonic evolution of the Tuzgolu basin complex, Central Turkey: Sedimentary record of a Neo-Tethyan closure, in The Geological Evolution of The Eastern Mediterranean, A. H. F. Robertson and J. E. Dixon (Editors), Geol. Soc. London, Spec. Publ., 17, 455-466, doi:10.1144/gsl.sp.1984.017.01.34.

Gursu, S., M. C. Goncuoglu and H. Bayhan (2004). Geology and geochemistry of the Pre-early Cambrian rocks in the Sandikli area: implications for the Pan-African evolution of NW Gondwanaland, Gondwana Res., 7, 923-935, doi:10.1016/S1342-937X(05)71075-3.

Hasozbek, A., M. Satır, B. Erdoğan, E. Akay et al. (2011). Early Miocene post-collisional magmatism in NW Turkey: geochemical and geochronological constraints, Int. Geol. Rev., 53, 1098-1119, doi:10.1080/00206810903579302.

Henderson, R. G. (1970). On the validity of the use of the upward continuation integral for total magnetic intensity data, Geophysics, 35, 916-919, doi:10.1190/1.1440137.

Henderson, R. G. and L. Cordell (1971). Reduction of unevenly spaced potential data to a horizontal plane by means of finite harmonic series, Geophysics, 36, 856-866, doi:10.1190/1.1440295.

Hsu, S. K., J. C. Sibuet and C. T. Shyu (1996). Highresolution detection of geologic boundaries from potential-field anomalies: An enhanced analytic signal technique, Geophysics, 61, 373-389.

Mauss, S. and V. Dimri (1995). Potential-field power spectrum inversion for scaling geology, J. Geophys. Res., Solid Earth, 100, 12605-12616, doi:10.1029/95JB00758.

McKenzie, D. (1978). Active tectonics of the Alpine-Himalayan belt, the Aegean Sea and surrounding regions, Geophys. J. Royal Astro. Soc., 55, 217-254, doi:10.1111/j.1365-246X.1978.tb04759.x.

Miller, H. G. and V. Singh (1994). Potential Field Tilt a New Concept for Location of Potential Field Sources, J. Appl. Geophys., 32, 213-217, doi:10.1016/0926-9851(94)90022-1.

Nabighian, M. N. (1972). The analytic signal of twodimensional magnetic bodies with polygonal crosssection: its properties and use for automated anomaly interpretation, Geophysics, 37, 507-517, doi:10.1190/1.1440276.

Nabighian, M. N. (1974). Additional comments on the analytic signal of two dimensional magnetic bodies with polygonal cross-section, Geophysics, 39, 85-92, doi:10.1190/1.1440416.

Nwankwo, L. I., P. I. Olasehinde and C. O. Akoshile (2008). Spectral analysis of aeromagnetic anomalies of the northern Nupe basin, west central Nigeria, Global J. Pure Appl. Sci., 14, 247-252, doi:10.4314/gjpas.v14i2.16807.

Okay, A. I. (1984). Distribution and characteristics of the north-west Turkey blueschists, Geol. Soc., London, Spec. Publ., 17, 455-466, doi:10.1144/GSL.SP.1984.017.01.33.

Okay, A. I. (1986). High-pressure/low-temperature metamorphic rocks of Turkey, Geol. Soc. Am. Memoir, 164, 333-347, doi:10.1130/MEM164-p333.

Okay, A. I. and O. Tuysuz (1999). Tethyan sutures of northern Turkey, Geol. Soc. London, Spec. Publ., 156, 475-515, doi:10.1144/GSL.SP.1999.156.01.22.

Ozgul, N. (1976). Some geological aspects of the Taurus orogenic belt (Turkey), Bull. Turkish Geol. Soc., 19, 65-78, in Turkish with English abstract.

Ozsayin, E. and K. Dirik (2007). Quaternary Activity of the Cihanbeyli and Yeniceoba Fault Zones: Inönü-Eskisehir Fault System, Central Anatolia, Turkish J. Earth Sci., 16, 471-492.

Platzman, E. S., C. Tapirdamaz and M. Sanver (1998). Neogene anticlockwise rotation of central Anatolia, Turkey: preliminary palaeomagnetic and geochronological results, Tectonophysics, 299, 175-189, doi:10.1016/S0040-1951(98)00204-2.

Pourteau, A., O. Candan and R. Oberhansli (2010). High-pressure metasediments in central Turkey: constraints on the Neotethyan closure history, Tectonics, 29, TC5004, doi:10.1029/2009TC002650.

Roest, W. R., J. Verhoef and M. Pilkington (1992). Magnetic interpretation using 3D analytic signal, Geophysics, 57, 116-125, doi:10.1190/1.1443174.

Şengor, A. M. C. and Y. Yılmaz (1981) Tethyan evoluation of Turkey: A plate tectonic approach, Tectonophysics, 75, 181-241, doi:10.1016/0040-1951(81)90275-4.

Sengor, A. M. C., N. Gorur and F. Saroglu (1985). Strike-slip faulting and related basin formation in zones of tectonic escape: Turkey as a case study, Soc. Econ. Paleont. Miner. Spec. Pub., 37, 227-264, doi:10.2110/pec.85.37.0227.

Sherlock, S. and S. Kelley (2002). Excess argon evolution in HP-LT rocks a UVLAMP study of phengite and K-free minerals, NW Turkey, Chem. Geol., 182, 619-636, doi:10.1016/S0009-2541(01)00345-X.

Spector, A. and F. S. Grant (1970). Statistical model for interpreting aeromagnetic data, Geophysics, 35, 293-302, doi:10.1190/1.1440092.

Tatar, O., H. Gürsoy and J. D. A. Piper (2002). Differential neotectonic rotations in Anatolia and the Tauride Arc: palaeomagnetic investigation of the Erenlerdag Volcanic Complex and Isparta volcanic district, south-central Turkey, J. Geol. Soc., 159, 281-294, doi:10.1144/0016-764901-035.

Tatar, O., J. D. A. Piper, H. Gürsoy and H. Temiz (1996). Regional significancevof neotectonic counterclockwise rotation in Central Turkey, Int. Geol. Rev., 38, 692-700, doi:10.1080/00206819709465353.

Tezel, T., T. Shibutani and B. Kaypak (2013). Crustal thickness of Turkey determined by receiver function, J. Asian Earth Sci., 75, 36-45, doi:10.1016/j.jseaes.2013.06.016.

Thomson, S. N. and U. Ring (2006). Thermochronologic evaluation of post collision extension in the Anatolide orogen, western Turkey, Tectonics, 25, TC3005, doi:10.1029/2005TC001833.

van Hinsbergen, D. J., M. Maffione, A. Plunder, N. Kaymakci et al. (2016). Tectonic evolution and paleogeography of the Kirşehir Block and the Central Anatolian Ophiolites, Turkey, Tectonics, 35, 983-1014, doi:10.1002/2015TC004018.

Westaway, B. (1994). Present-day kinematics of the Middle East and eastern Mediterranean, J. Geophys. Res., 99, 2071-2090, doi:10.1029/94JB00335.

Wijns, C., C. Perez and P. Kowalczyk (2005). Theta map: Edge detection in magnetic data, Geophysics, 70, L39-L43, doi:10.1190/1.2194525.

Yaltirak, C. (2002). Tectonic evolution of the Marmara Sea and its surroundings, Marine Geol., 190, 493-529, doi:10.1016/S0025-3227(02)00360-2.

Yassah, H. N., K. M. Onuoha, A. W. Mode, K. Ezakiel et al. (2025). Estimation of Curie-point depth, heat flow and geothermal gradients in Shelleng area and environs, norteastern Nigeria from aeromagnetic data, Acta Geophys., 73, 203-220, doi:10.21203/rs.3.rs-3381248/v1.

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