Mühendislik Bilimleri ve Tasarım Dergisi
10(1), 142 – 151, 2022
e-ISSN: 1308-6693

Journal of Engineering Sciences and Design
DOI: 10.21923/jesd.994057

Araştırma Makalesi Research Article

AN INVESTIGATION ON EDGE DETECTION OF STRUCTURES AND DEPTH ESTIMATION OF ISPARTA ANGLE REGION (SOUTHWEST TURKEY) USING AEROMAGNETIC DATA

Ezgi ERBEK KIRAN*

Suleyman Demirel University, Faculty of Engineering, Department of Geophysical Engineering, Isparta, Turkey

Keywords
Isparta Angle,
Analytic Signal,
Tilt Angle Derivative,
Aeromagnetic Data.

Abstract
This paper aims to delineate the subsurface structures and their depths located in the Isparta Angle region (SW Turkey) through the aeromagnetic data. The dataset has been processed via the well-known mathematical tools such as spectral analysis and derivative methods. First, to separate these anomalies from each other, the spectral analysis has been completed and high anomaly regions have been determined around Isparta city. This could be attributed to the fact that these values might be stem from magnetic bodies (like volcanic cones, caldera) located in the Golcuk volcanic region. In addition, the average depths of deep and shallow causative bodies have been calculated to be 6.72 km and 0.31 km, respectively. Secondly, to delineate the exact location and the depth to top of the sources, analytic signal transformation and tilt method have been applied to the residual anomalies. The maps show six regions which have the high magnetization values and these anomalies have been investigated in detail to delineate the upper depths of subsurface structures. Especially, the study showed that Golcuk volcanic occurrences, which are one of the crucial structures in the region, have a deeper root (around 3.47 km) and larger lying magnetic bodies underneath the surface.

ISPARTA AÇI BÖLGESİ (GÜNEYBATI TÜRKİYE) YAPILARIN SINIR TESPİTİ VE DERİNLİK TAHMİNİ ÜZERİNE HAVA MANYETİK VERİLERLE BİR ARAŞTIRMA

Anahtar Kelimeler
Isparta Açısı,
Analitik Sinyal,
Tilt Açısı Türevi,
Havadan Manyetik Veri.

Öz
Bu makale, Isparta Açı bölgesinde (GB Türkiye) yer alan yeraltı yapılarını ve derinliklerini aeromanyetik veriler aracılığıyla tanımlamayı amaçlamaktadır. Veri seti, spektral analiz ve türev yöntemleri gibi iyi bilinen matematiksel araçlar aracılığıyla işlenmiştir. Öncelikle bu anomalileri birbirinden ayırmak için spektral analiz uygulanmış ve Isparta ili çevresinde yüksek anomalili bölgeler belirlenmiştir. Bu durum, bu değerlerin Gölcük volkanik bölgesinde yer alan manyetik cisimlerden (volkanik koniler, kaldera gibi) kaynaklanıyor olabileceğine bağlanabilir. Ayrıca derin ve sığ kaynaklı cisimlerin ortalama derinlikleri sırasıyla 6,72 km ve 0,31 km olarak hesaplanmıştır. İkinci olarak, kaynakların tam yerini ve en üst noktaya kadar olan derinliğini belirlemek için rezidüel anomalilere analitik sinyal dönüşümü ve tilt yöntemi uygulanmıştır. Haritalar, yüksek manyetizasyon değerlerine sahip altı bölgeyi göstermiştir ve bu anomaliler, yeraltı yapılarının üst derinliklerini betimlemek için ayrıntılı olarak incelenmiştir. Özellikle çalışma, bölgedeki önemli yapılardan biri olan Gölcük volkanik oluşumlarının daha derin bir köke (yaklaşık 3.47 km) ve yüzeyin altında daha büyük manyetik kütlelere sahip olduğunu göstermiştir.

Alıntı / Cite
Erbek Kıran, E., (2022). An Investigation on Edge Detection of Structures and Depth Estimation of Isparta Angle Region (Southwest Turkey) Using Aeromagnetic Data, Journal of Engineering Sciences and Design 10(1), 142-151.

* Corresponding author / İlgili yazar: ezgierbek@sdu.edu.tr, +90-246-211-1368

Yazar Kimliği / Author ID (ORCID Number)	Makale Süreci / Article Process	
E. Erbek Kıran, 0000-0003-4627-8932	**Başvuru Tarihi / Submission Date**	11.09.2021
	Revizyon Tarihi / Revision Date	16.10.2021
	Kabul Tarihi / Accepted Date	21.10.2021
	Yayım Tarihi / Published Date	23.03.2022

1. Introduction

The magnetic method provides insight into a wide scale of the examination of alteration in magnetization, the definition near-surface volcanic rocks, the determination of the subsurface and surface, the recognition of the position of faults/contacts. It is based on the Earth's magnetic field and the variation in the magnetization of geological units. However, the analysis and interpretation of the magnetic method are much more complex due to the dipolar nature of the magnetic field and body magnetizations. Therefore, to cope with this issue, remarkable efforts have been conducted in the literature. To this end, various analysis techniques of the potential field data that aim to determine the subsurface structures and tectonic properties have been proposed. Reduce to pole (RTP) correction, for instance, was first developed by Baranov (1957) and later extended by Ansari and Alamdar (2009). Horizontal gradient of the potential field is the most popular method purposed by Cordell and Grauch (1985). On the other hand, Nabighian (1972, 1984) and Roest et al. (1992) showed that 2-D and 3-D analytic signal method is very useful to delineate the true boundaries of the causative sources. The other fundamental techniques are tilt angle derivative methods presented by Miller and Singh (1994) and total horizontal derivative of the tilt angle (Verduzco et al., 2004).

In this study, Isparta Angle, which is bounded by Fethiye-Burdur Fault Zone (FBFZ), Afyon-Aksehir Fault Zone (AAFZ), and Cyprus Arc in the SW Anatolia, Turkey, was selected as a study area. It is an intersection region between the Hellenic arc and Cyprus arc. Exploring of the Isparta Angle region and its tectonic implications have great importance due to region current property. Although many studies have been carried out in the literature such as those of Barka et al., 1995; Yagmurlu et al., 1997; Glover and Robertson 1998; Dolmaz et al., 2003; Dolmaz , 2007; Beyhan and Keskinsezer, 2016; Oksum et al., 2019, the region is still a matter of debate. Thus, this paper aims to delineate the structural trends and causative sources by utilizing some of the aforementioned techniques. Besides that, the results obtained from the analysis and interpretation of aeromagnetic data will be discussed in terms of geological and tectonic background.

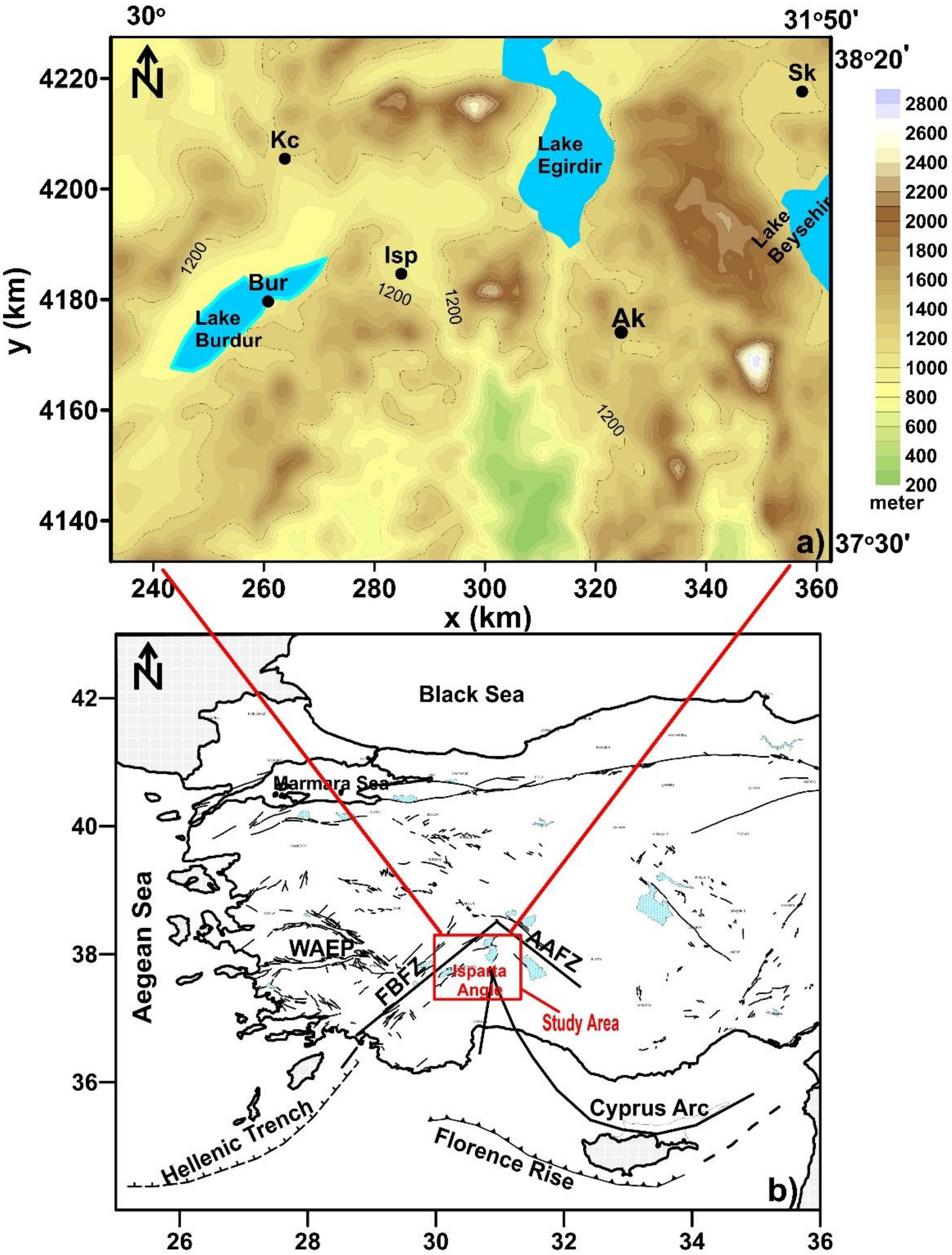

Figure 1. (a) Topography (elevation) map of the study area; (b) Simplified tectonic map of the Isparta Angle region. FBFZ: Fethiye-Burdur fault zone, AAFZ: Afyon-Aksehir fault zone, WAEP: Western Anatolian Extensional Province.

2. Geological Settings

The Isparta region located at the intersection of the Cyprus and Hellenic arc is a triangular- shaped region. It shares the boundary with the FBFZ at the west and the AAFZ at the east. Hence, the region has a complex geological and tectonically background and it has been gathering attention ever since Penck (1918) first explored. He investigated the Paleogenene stratigraphy and the main tectonic lineaments of the region (Poisson et al., 2003). In other respects, Isparta Angle is one of the most important and active tectonic structures in the Tauric belt and it is characterized by major extensional fault lineaments. This phenomenon is related with subduction zone located between African and Eurasia in the Mediterranean Sea. Isparta Angle suture zone with the trending N-S right-lateral faults separates the Western Anatolian Extensional Province (WAEP) from Anatolia Plateau (Glower and Robertson, 1998; Dolmaz, 2007). Robertson et al. (1996) pointed out that the Isparta Angle was formed by the clockwise rotation of the western side and counter-clockwise rotation of the eastern side during the Neotectonic period while Poisson et al. (2003) indicated that the Isparta Angle was resulted from the Tertiary closure of the Pamphylian Basin located to the south of the Taurus belt. In addition, it is divided into two parts (i.e., the western and the eastern limbs) by Egirdir- Kovada graben formed during the Triassic–Upper Cretaceous and the Early Paleocene (Fig. 2). The western part is characterized by NE- trending fault system while the eastern part is represented with the NW-trending fault system (Cengiz et al., 2006).

In terms of geological units, autochthonous and allochthonous rock units from the Paleozoic to Quaternary dominate in the southwestern part of Turkey (Dolmaz et al., 2018). The allochthonous sheets are gathered below three headers; Lycian nappes, Antalya nappes and Beysehir-Hoyran-Hadim nappes. The Lycian nappes situated at W and NW of the Isparta Angle is composite unit while the Antalya nappes consist of the ophiolites and the deep basinal sequences. Also, Beysehir-Hoyran- Hadim nappes includes carbonate platform units, basinal series and ophiolites (Monod, 1977; Poisson et al., 2003). Besides these, active volcanism products including Golcuk volcanics, andesite, trachyandesite, rocks of tuff, tuffite and pumice were formed during the Quaternary (Elitok et al., 2010). All those reveal the importance of the study area.

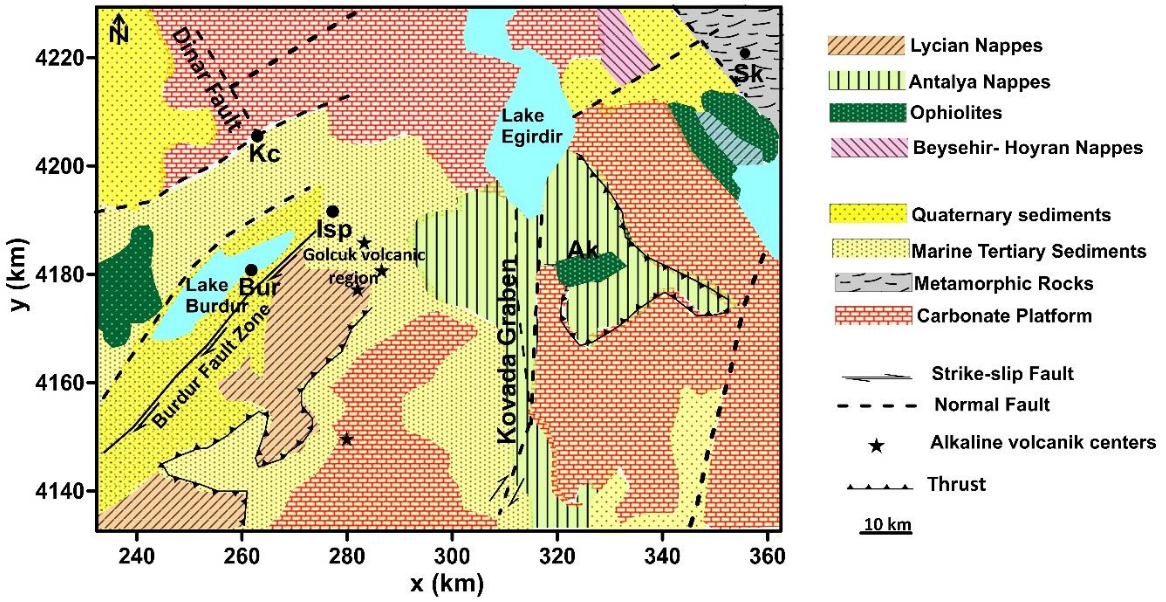

Figure 2. Simplified geological map of study area (modified from Yagmurlu et al., 1997; Dolmaz, 2007). Isp: Isparta, Ak: Aksu, Kc: Keciborlu, Sk: Sarkikaraagac

3. Material and Method

The aeromagnetic data used in this study were re-digitized from the study carried out by Ates et al. (1999). These data are recorded by the General Directorate of Mineral Research and Exploration of Turkey (MTA). The data including a period of 1979-1989 years were collected with 1-5 km profile interval and with an elevation of 600 m above ground level (Ates et al., 1999). As a first step, IGRF- 1982.5 (the International Geomagnetic Reference Field) was applied to them for reduction. To annihilate undesirable effects, as a second step, (such as earth's magnetic field and body magnetization) located on the anomaly, reduce to pole (RTP) technique (Baranov, 1957; Ansari and Alamdar, 2009) was employed. The RTP serves to be a filter allowing to eliminate the dipolar nature of magnetic anomalies. It also provides to transform magnetic anomalies from its asymmetric shape to symmetric shape.

The variance of aeromagnetic data in the study area is plotted as a map (see Fig. 3a) and it is observed that these values vary from -107 nT to 37 nT in the map. The map produced from the RTP operation is seen in Fig. 3b as well. During the application of the RTP operation, inclination and declination angles were taken as 54.6^{o} and 3.7^{o}, respectively. As can be seen from the map, RTP values range from -120 nT to 62 nT.

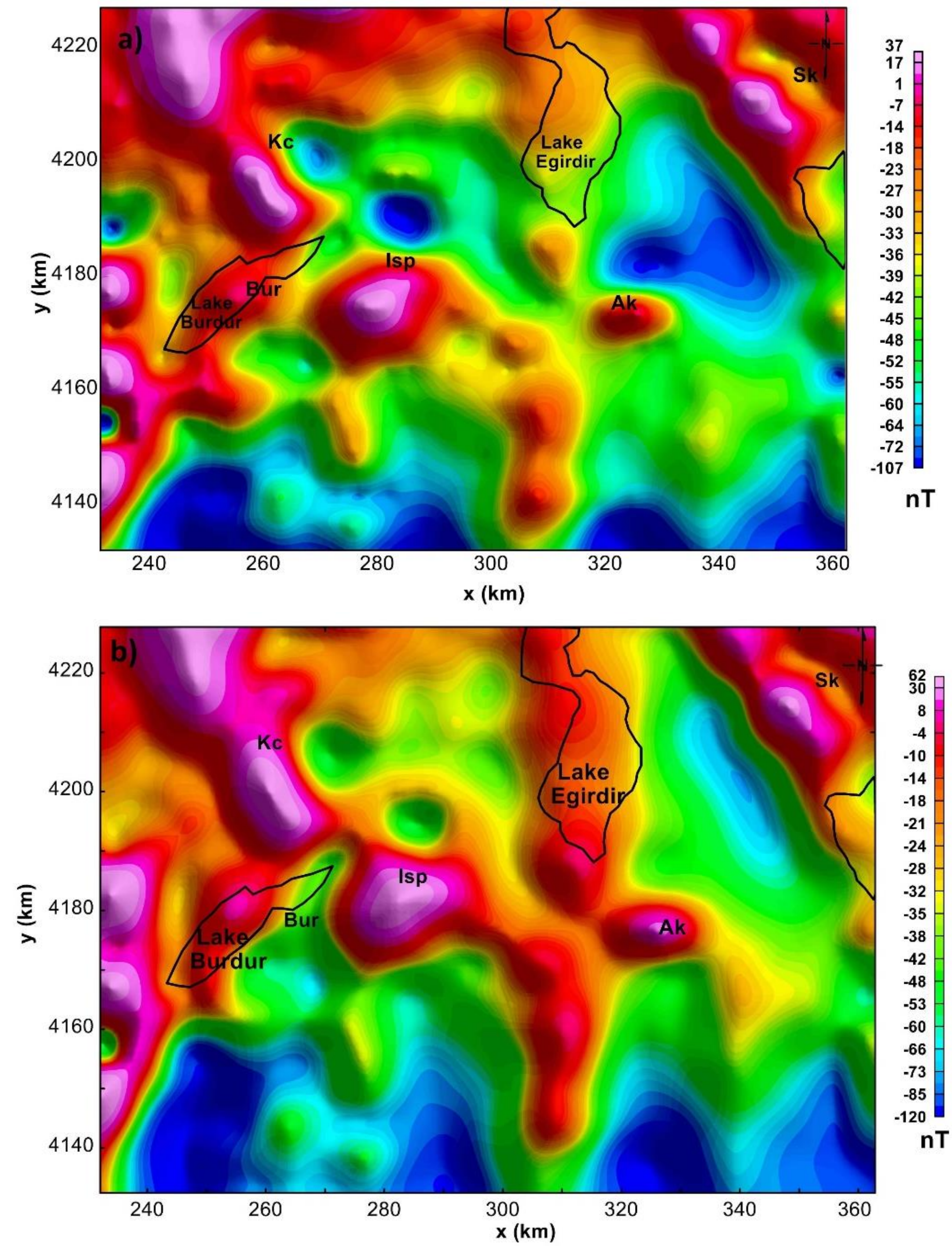

Figure 3. (a) Aeromagnetic map of Isparta Angle region in nT; (b) RTP anomaly map of Isparta Angle region in nT

In addition, spectral analysis developed by Spector and Grant (1970) has been applied to the RTP data in order to separate the regional and residual components of potential field data. By doing so, it is possible that the region can be divided into three segments with the averaged depths of causative sources ranged from 0.31 km to 6.72 km. The first segment represents the average depth of deeper magnetized sources and it has been calculated to be 6.72 km whereas the average depths of much shallower magnetized bodies have been calculated to be 1.60 km and 0.31 km, respectively for other segments (see Fig. 4).

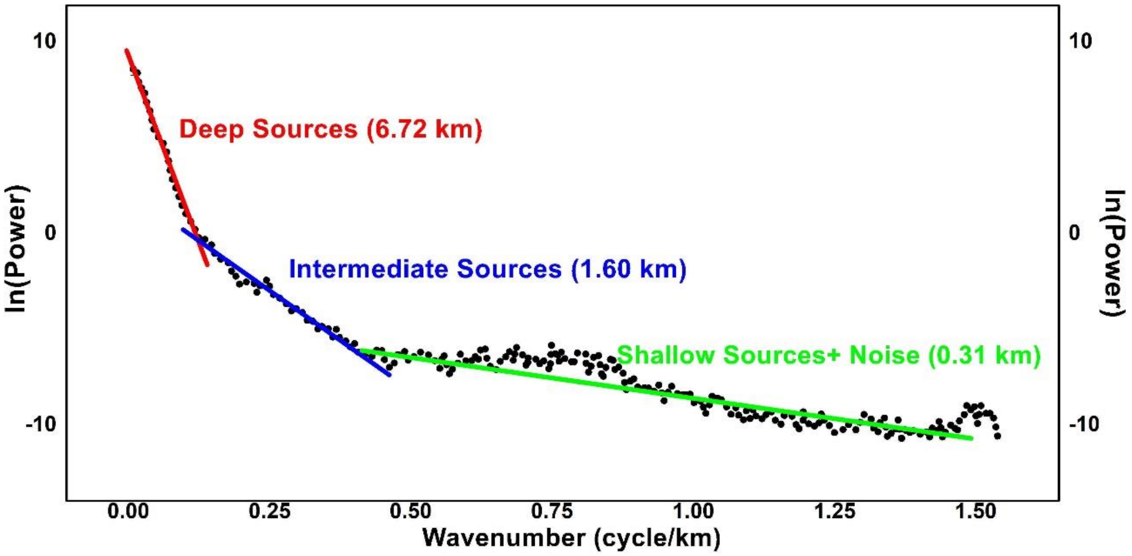

Figure 4. Radial average power spectrum and depth estimation for deep and shallow sources

3.1. Analytic Signal Transformation

Analytic Signal (AS), which is based on the vertical and horizontal derivatives of the potential field data, allows determining the location of the causative structure. The 2-D AS transformation was developed by Nabighian (1972) and it was later improved to the 3-D by Nabighian (1984). Roest et al. (1992) also defined as;

$$AS = \sqrt{(\frac{\partial T}{\partial x})^2 + (\frac{\partial T}{\partial y})^2 + (\frac{\partial T}{\partial z})^2} \qquad (1)$$

where T is the total magnetic anomaly. $\frac{\partial T}{\partial x}, \frac{\partial T}{\partial y}$, and $\frac{\partial T}{\partial z}$ are the gradients of the magnetic field in the x, y and z-directions, respectively. The AS is widely used in the magnetic investigation because of the fact that it is independent of magnetization directions. The method has proved that the maximum amplitudes of the analytic signal are located over the edge of causative sources (Nabighian, 1972, 1984; Roest et al., 1992).

3.2. Tilt Angle Derivative Method

The tilt angle derivative (Tilt) method allows us to determine the trends/contacts region and boundaries of the magnetic bodies. The tilt angle is formulated by Miller and Singh (1994), as seen in Eq. 2

$$Tilt = \arctan\left[\frac{\frac{\partial T}{\partial z}}{\sqrt{(\frac{\partial T}{\partial x})^2+(\frac{\partial T}{\partial y})^2}}\right] \qquad (2)$$

The amplitudes of the Tilt method range from $-\pi/2$ to + $\pi/2$ due to the arctangent trigonometric function. The zero contours are located over the edges of the structures. The Tilt shows positive amplitudes over the magnetic sources whereas the negative amplitude values are also located outside of the magnetic bodies. In addition, Salem et al. (2007) improved the tilt-depth method to estimate the upper depth of the interpreted contact. According to this, $\pm\pi/2$ Radians ($\pm 45^{o}$) contours provide estimation of the upper depth for the sources. This method has an advantage in that it does not require any geological knowledge (Wang et al., 2016).

4. Results

The analysis procedure of aeromagnetic data via the abovementioned techniques are given step-by-step as follows: i) eliminate the effects stem form by the dipolar nature of the earth utilizing RTP operation, ii) separate the regional and residual anomalies at a different wavelength with spectral analysis of the data, iii) apply the AS and Tilt method to delineate the exact location of the structures.

By a closer look at Figs. 3a and 3b, the high magnetic anomalies are clearly observed around Isparta (Isp), Sarkikaraagac (Sk), Keciborlu (Kc), Aksu (Ak) and Kovada Graben area while the negative anomalies are located in the southern part of the region. Especially, strong anomalies around the Aksu correspond to ophiolite units while the other high magnetic intensity in Isparta could be associated with the existence of active volcanism products (e.g., Golcuk volcanics).

Besides, the residual anomaly map shown in Fig. 5 was constructed by applying a high pass filter with the cut-off frequency of 0.40 cycle/km. The map shows that the Isparta basin, composed of having low-magnetic susceptibilities rocks, (alluvial units) is characterized by negative magnetic anomalies. However, Alkaline volcanic centers (see in Fig. 2) displayed high magnetic values.

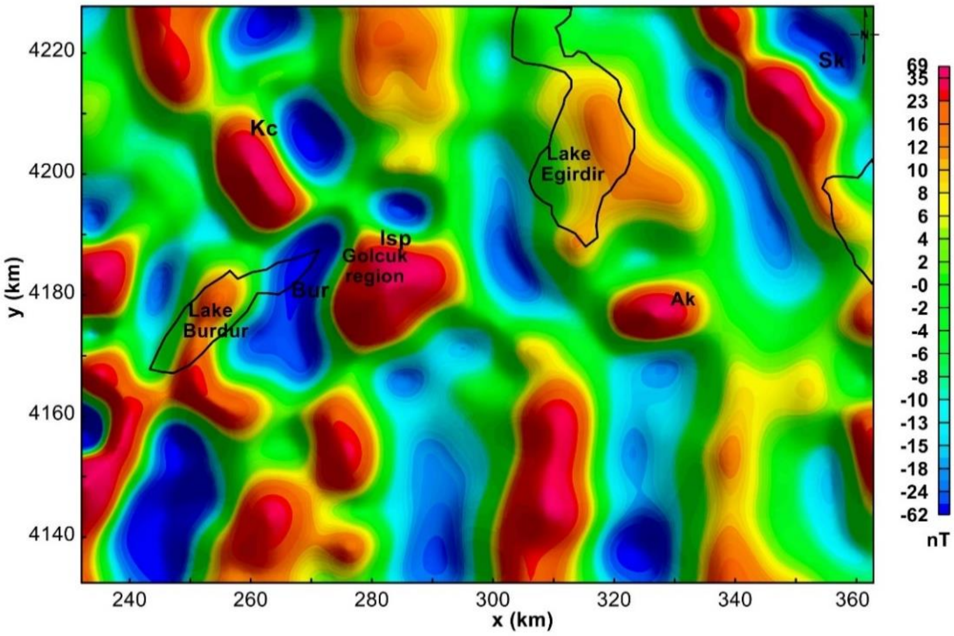

Figure 5. High-pass filtered magnetic anomaly map of the region

In this study, the AS transformation has been applied to the residual anomalies of the region. The map in Fig. 6 shows that four structures are located around Isparta City and these magnetic bodies (like volcanic cones, caldera) could be associated with the Golcuk volcanic region. The other maximum values are located around the Keciborlu and Aksu region, which may be related to the buried magnetized bodies and ophiolitic mass beneath the alluvial cover, respectively. In addition, the anomalies around Keciborlu may be caused by the Dinar fault system. The anomalies situated at the western part of Burdur Lake correspond to ophiolitic rocks (see Fig. 2). In addition, it is thought that the high magnetization in the NE of the map (around Sarkikaraagac) might be caused by Beysehir-Hoyran ophiolitic rocks deployed on metamorphic rocks and sedimentary units. All these outcomes are in good agreement with the previous study conducted by Dolmaz (2007).

In addition, the Tilt map has been produced from RTP data to determine the possible subsurface structure and their upper depths in the region (see Fig. 7). The map illustrates the zero contours corresponded to the edge of the structures and six important structures (labeled with A, B, C, D, E, F) were selected from the map to estimate the upper depths of bodies. The structure A might be associated with the Golcuk Crater lake area composed of the trachyandesite and andesitic rocks. The structures (volcanic cone, trachytic lava dome etc.) located in the Pliocene Golcuk volcanism region display high-amplitude anomalies on the map. By applying tilt-depth method, the calculated upper depths of these causative sources are listed in Table 1. As seen from this Table, the upper depths of the structure range between 3.6 and 4.3 km from the west edge to the east edge while the depths in north-south directions range from 2.8 km to 3.2 km, respectively. The Structure B located around Keciborlu region shows high-amplitude values and the region is represented by carbonate platform and marine tertiary sediments (see Fig. 2).

Table 1. The depths to top of the Golcuk region obtained from the tilt-depth method.

Structure A	Tilt-Depth (km)
West Edge	3.6 km
East Edge	4.3 km
North Edge	2.8 km
South Edge	3.2 km

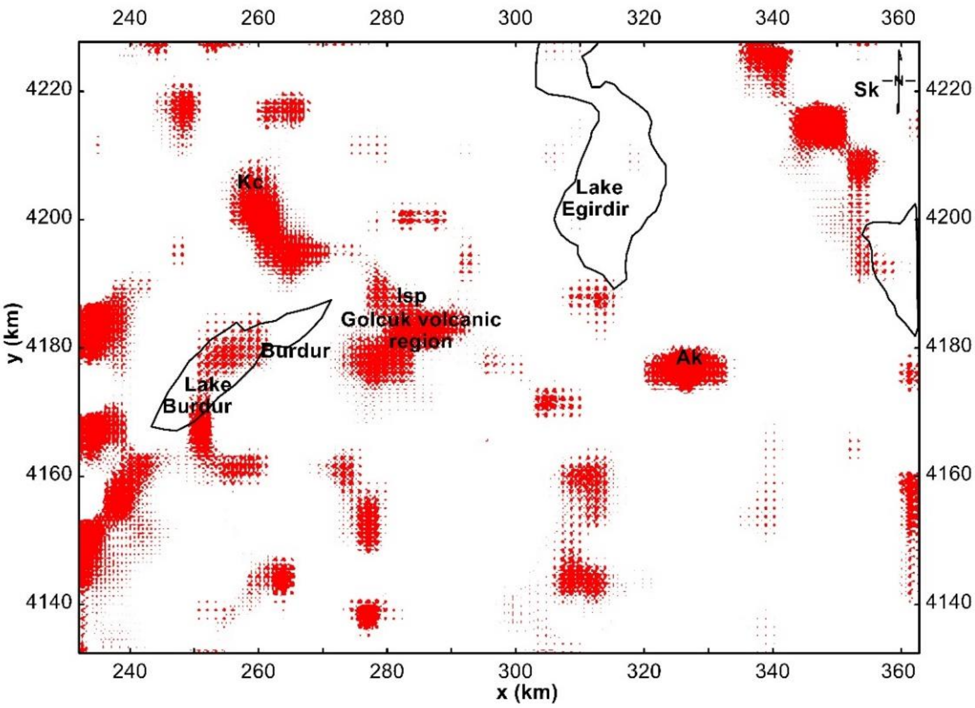

Figure 6. Analytic Signal transformation image map of Isparta Angle region

Considering surface geology, these high amplitudes could be caused by existence of a magnetized body under the surface and the upper depths of the bodies were computed around 3.1 km. It is considered that this anomaly may be signature of the Dinar fault. The structure C is situated at the southern part of the map and the map showed that high values in N-S direction can be correlated with the northern border of the Cyprus arc and Kovada Graben region (see Fig. 1b). However, the structure F located around Lake Egirdir displayed high values on the Tilt map whereas any high amplitudes were not observed at the AS map. Both Tilt of residual anomalies show N-S lineament trend from northern part to southern part of the study area. The structure D also represented by the ophiolite outcropped to surface around the Aksu region. The solutions of the Tilt map indicated that the ophiolite mass has a deeper root beneath the surface and the upper depths of the mass range from about 2.8 to 3.7 km, with an average of 3.25 km. The last remarkable structure labeled with E in the map is located around Sarkikaraagac. It is thought that the structure with the NW-SE trending line was caused by Beysehir-Hoyran ophiolite nappes described by Dolmaz (2007). However, this study shows that the mass outcropped to surface lied along approximately 20 km in the NW-SE direction underneath the metamorphic rocks.

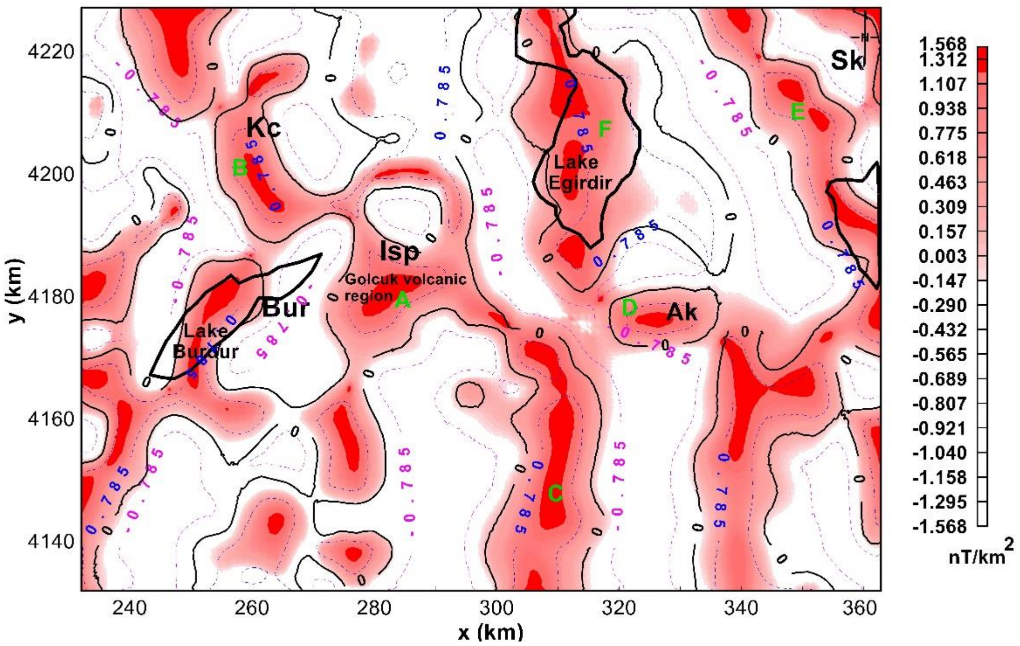

Figure 7. Tilt map of the RTP data. Black dash lines show zero contour of the tilt angle

5. Discussion and Conclusions

The main goal of this study is to analyze and interpret the aeromagnetic data for the Isparta Angle region. To delineate the boundaries of the structure located in the region, AS transformation has been utilized to the residual anomalies and the regions showing high amplitude have been detected. The radius of the structure around Keciborlu, which is thought to be a buried mass, covers an area of approximately 6.5 km while the ophiolitic mass located in Aksu shows a large and high value closure (approx. 8 km in radius). In addition to those, the maps produced by AS transformation and Tilt method show that Golcuk volcanic occurrences has a deeper and larger root (the average upper depth of the structure is around 3.47 km) underneath the surface. Furthermore, the causative source around Isparta can be defined as an ellipsoid shape with dimensions of approximately 23 km and 17 km at the E-W and N-S directions, respectively (Fig 7). Also, the strong anomalies around Sarkikaraagac are good accordance with the existence of ophiolitic mass. In addition to this observation, Fig 7 has shown that this mass may be continued under metamorphic rocks and sedimentary units in the NW- SE directions. However, this causative mass has not been observed on the surface geology map. Hence, this observation is defined for the first time in literature. Besides those, the strike-slip fault and normal fault zones with the N-S trending in Kovada graben have been clearly characterized by the zero contours. Similar observations have been detected for the Burdur fault zone. The zero contours elongate in the NE-SW direction and the result is in accordance with geological investigations. Consequently, the important structures of the Isparta Angle region and their edges have been revealed in detail by this study. Moreover, after calibration with known structures or other derived potential field products (AS and Tilt), the results have been interpreted geologically with better confidence.

Acknowledgement (Teşekkür)

The author would like to thank the Mineral Research and Exploration Institute of Turkey for the use of magnetic data.

Conflict of Interest (Çıkar Çatışması)

No conflict of interest was declared by the author.

References (Kaynaklar)

Ansari, A.H., Alamdar, K., 2009. Reduction to the pole of magnetic anomalies using analytic signal. World Applied Sciences Journal, 7, 405-409. https://pdfs.semanticscholar.org/0c68/ba1ed775ac6c2007504e41f5db3e68f3b5ed.pdf.

Ates, A., Kearey, P., Tufan, S., 1999. New gravity and magnetic maps of Turkey (Research Note). Geophysical Journal International, 136, 499-502.

Baranov, V., 1957. A new method for interpretation of aeromagnetic maps: Pseudo-gravimetric anomalies. Geophysics, 22, 359-383.

Barka, A., Reilinger, R., Saroglu, F., Sengor, A.M.C., 1995. The Isparta angle: its importance in the neotectonics of the eastern Mediterranean region. Piskin, O., Ergun, M., Savascin, M.Y., Tarcan, G., (ed.). IESCA-1995 Proceedings 3-17.

Beyhan, G., Keskinsezer, A., 2016. Investigation of the gravity data from Fethiye-Burdur Fault Zone using the Euler deconvolution technique. Geomechanics and Geophysics for Geo-Energy and Geo-Resources, 2, 195-201.

Cengiz, O., Sener, E., Yagmurlu, F., 2006. A satellite image approach to the study of lineaments, circular structures and regional geology in the Golcuk Crater district and its environs (Isparta, SW Turkey). Journal of Asian Earth Sciences, 27, 155-163.

Cordell, L. Grauch, V.J.S., 1985. Mapping basement magnetization zones from aeromagnetic data in the San Juan Basin, New Mexico. In: Hinze WJ (Ed.), The Utility of Regional Gravity and Magnetic Anomaly Maps. Society of Exploration Geophysicists, 181-197. http://dx.doi.org/10.1190/1.0931830346.ch16

Dolmaz, M.N., Hisarlı, Z.M., Orbay, N., 2003. Interpretation of Bouguer gravity data of Burdur Basin. Istanbul Journal of Earth Sciences Journal, 16, 23-32.

Dolmaz, M.N., 2007. An aspect of the subsurface structure of the Burdur-Isparta area, SW Anatolia, based on gravity and aeromagnetic data, and some tectonic implications. Earth Planets Space, 59, 5-12.

Dolmaz, M.N., Oksum, E., Erbek, E., Tutunsatar, H.E., Elitok, O., 2018. The nature and origin of magnetic anomalies over the Gölcük caldera, Isparta, SW Turkey. Geofizicheskiy Zhurnal-Geophysical Journal, 40, 145-156.

Elitok, O., Ozgur, N., Druppel, K., Dilek, Y., Platevoet, B., Guillou, H., Poisson, A., Scaillet, S., Satir, M., Siebel, W., Bardintzeff, J.M., Deniel, C., Yilmaz, K., 2010. Origin and geodynamic evolution of late Cenozoic potassium-rich volcanism in the Isparta area, southwestern Turkey. International Geology Review, 52, 454-504.

Glover, C. and Robertson, A., 1998. Neotectonic intersection of the Aegean and Cyprus tectonic arcs: extensional and strike-slip faulting in the Isparta Angle, SW Turkey. Tectonophysics, 298, 103-132.

Miller, H.G., Singh, V., 1994. Potential field tilt-a new concept for location of potential field sources. Journal of Applied Geophysics, 32, 213-217.

Monod, O., 1977. Recherches Geologiques dans le Taurus Occidental au Sud de Beysehir (Turquie). Ph.D. thesis, Universite´de Paris-Sud, Orsay, France, 442, (unpublished).

Nabighian, M.N., 1972. The analytic signal of two-dimensional magnetic bodies with polygonal cross-section: its properties and

use for automated anomaly interpretation. Geophysics, 37, 507-517.
Nabighian, M.N., 1984. Toward a three-dimensional automatic interpretation of potential field data via generalized Hilbert transforms: Fundamental relations. Geophysics, 49, 780-786.
Oksum. E., Dolmaz, M.N., Pham, L.T., 2019. Inverting gravity anomalies over the Burdur sedimentary basin, SW Turkey. Acta Geodaetica et Geophysica, 54, 445-460. https://doi.org/10.1007/s40328-019-00273-5.
Penck, W., 1918. Die tektonische Grundzu¨ge Westkleinasiens. Eiszeitalter- Stuttgart.
Poisson, A., Yagmurlu, F., Bozcu, M., Senturk, M., 2003. New insights on the tectonic setting and evolution around the apex of the Isparta Angle (SW Turkey). Geological Journal, 38, 257-282.
Robertson, A.H.F., Dixon, J.E., Brown, S., Collins, A., Morris, A., Pickett, E., Sharp, I., Ustaomer, T. 1996. Alternative tectonic models for the Late Palaeozoic-Early Tertiary development of Tethys in the Eastern Mediterranean region, Palaeomagnetism and Tectonics of the Mediterranean Region, edited by Morris, A., Tarling D.H., Geological Society of London, Special Publication, 109, 239-263. https://doi.org/10.1144/GSL.SP.1996.105.01.22.
Roest, W.R., Verhoef. J., Pilkington, M., 1992. Magnetic interpretation using the 3-D analytic signal. Geophysics, 5, 116-125.
Salem, A., Williams, S., Fairhead, J.D., Ravat, D., Smith, R., 2007. Tilt-depth method: A simple depth estimation method using first-order magnetic derivatives. Leading Edge, 26, 12.
Spector, A., Grant, F.S., 1970. Statistical models for interpreting aeromagnetic data. Geophysics, 35, 293-302
Verduzco, B., Fairhead, J.D., Green, C.M., McKenzie, C., 2004. New insights into magnetic derivatives for structural mapping. The Leading Edge, 23, 116-119.
Wang, Y.G., Zhang, J., Ge, K.P., Chen, X., Nie, F.J., 2016. Improved tilt-depth method for fast estimation of top and bottom depths of magnetic bodies. Applied Geophysics, 13, 249-256.
Yagmurlu, F., Savascin, Y., Ergun, M. 1997. Relation of alkaline volcanism and active tectonism within the evolution of the Isparta Angle, SW Turkey. Geological Journal, 15, 717-728.