e-ISSN: 2458-8156

Journal Homepage: http://dergipark.gov.tr/ejens

DergiPark AKADEMİK

EJENS

European Journal of Engineering and Natural Sciences

CODEN: EJENS

Revealing Tectonic Structure by Utilizing the Boundary Analysis Methods on Aeromagnetic Data of Bitlis Zagros Suture Zone and Its Surroundings, Turkey

Fikret Dogru[1]*, Oya Pamukcu[1]

[1] *Dokuz Eylul University, Engineering Faculty, Department of Geophysical Engineering, 35160, İzmir, Turkey*

**Corresponding Author email: fikret.dogru@deu.edu.tr*

Publication Info

Paper received:
29 May 2016

Revised received:
15 October 2016

Accepted:
01 March 2017

Abstract

Boundary analysis techniques which are analytic signal, total horizontal derivative (THDR), theta map, tilt angle, hyperbolic of tilt angle (HTA), normalized total horizontal gradient (TDX) and normalized horizontal derivative (NTHD), play an important role in interpreting potential field data. In this study, an enhanced total horizontal derivative of the tilt angle (ETHDR) method was utilized for comparison of results with the other edge detection filters. The sufficiency of the ETHDR method is indicated using theoretical models and field study. Compared with the formal methods, the ETHDR filter more detailed outcomes for buried models and is less sensitive to noise. Aeromagnetic anomaly of Bitlis Zagros Suture Zone (BZSZ) and its surroundings was used for field data. The eastern part of Turkey which has major tectonic structures such as East Anatolian Fault (EAF), Malatya Fault (MF) and Bitlis-Zagros Suture Zone (BZSZ), with the effect of Arabian Plate's northward motion, Anatolian block and Northeastern Anatolian Block escape to west and east, respectively. In the first stage field study, the discontinuities were not found recognizable in the results of boundary analysis methods. Then, pole reduction and upward continuation (5 km and 10 km) were applied to the aeromagnetic data for revealing the deeper effects on data. The same boundary analysis methods were applied to aeromagnetic data after pole reduction and upward continuation. The results were compared with each other and the anomalies were associated with the faults and previous studies. It is thought that there are tectonic boundaries that have not yet been identified geologically in the study area.

Key words

Edge detection, pole reduction, upward continuation, tilt angle, Bitlis-Zagros Suture Zone

1. INTRODUCTION

Boundary analysis method applications are crucial on magnetic anomalies to reveal tectonic structures and mine locations ([1], [2]). Accurate determination of source shape location is becoming the main purpose for interpretation and therefore enhanced methods are becoming more important in data interpretation [3]. There are various procedures that have been utilized to obtain edge detection, for example, analytic signal (AS), tilt angle (TA), theta map (TM) and etc. [4]. An enhanced total horizontal derivative of the tilt angle (ETHDR) method, which was proposed by Arisoy and Dikmen [4], was applied for the boundary analysis of aeromagnetic anomalies with the former methods. Before interpreting the field measurements, noise-corrupted theoretical models were utilized in order to determine spatial resolution of ETHDR method.

Then, same processes were applied on aeromagnetic data. When acceptable results could not be obtained from aeromagnetic data, pole reduction and upward continuation (for 5 km and 10 km) were applied on aeromagnetic data and then same analyzes were implemented. The data was used regarding western of BSZS and its surroundings. The area is so complex in terms of geological units and tectonics. The tectonic regime along the fault changes from east to west; collision zone of Bitlis-Zagros produced by northward movement of Arabian Plate with respect to Eurasia ([5]).

Anatolia, located in the Alpine-Himalaya basin, has taken the current form as a result of a very complicated movement in the Earth's crust. Continental rifting in the Eastern Mediterranean began at the end of Triassic and ended with the formation of the Mesozoic Neotethys ocean after the closure of the Paleotethys Ocean ([6]). The convergence of the African and Eurasian continents that began at the end of the Cretaceous ended with the closure of these ocean basins and the unification of continental parts in the vicinity ([6], [7]). The southern part of the Neotethys extending from southeastern Turkey known as the Bitlis ocean to Cyprus is completely closed due to the continental collision along the BZSZ of the Arab plate in the south and the Eurasian plate in the north ([6], [8]). East Turkey, in which BSZS has such a complex structure, has worked on many geodynamic processes in previous studies. For this reason, possible structure depths, effective elastic thickness of isostatic model, curie depth and corresponding heat flow calculations have been made and the change of crust thickness and boundaries of vertical and horizontal structures have been investigated and possible geophysical models have been established ([9], [10], [11], [12]). In the studies carried out, the BSZS and secondary structural elements that developed due to thrust have been investigated region-wide. In this study, BSZS and its fault locations are discussed in detail with the boundary analysis methods. As a result, gravity, magnetic and seismological studies have been evaluated together in the region.

2. METHODS

A number of methods have been proposed to make rough anomalies more apprehensible. The first filter developed for this purpose was the tilt angle [13], which is the ratio of the vertical derivative to the absolute value of the horizontal derivative of the potential field. The tilt angle is given by

$$Tilt = tan^{-1}\left(\frac{\frac{\partial T}{\partial z}}{THDR}\right) \tag{1}$$

Where,

$$THDR = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2} \tag{2}$$

T is the potential anomaly and THDR is the total horizontal derivative [14]. The tilt angle amplitudes are restricted to values between $-\pi/2$ and $+\pi/2$; thus the method delimitates the amplitude variations into a certain range. Tilt angle therefore functions like an automatic-gain-control filter, and therefore responds equally well to shallow and deep sources. The tilt angle produces a zero value over the source edges [4]. Wijns introduced the theta map (θ), which is the normalization of the THDR by the AS [15], is given by

$$cos\theta = \left(\frac{THDR}{AS}\right) \tag{3}$$

and

$$AS = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2} \tag{4}$$

AS is the analytic signal for the 3D case [16]. The theta map delineates model edges well, but the response of deeper bodies is diffused; consequently, it does not produce the expected sharp gradient over the edges. Recently, Cooper and Cowan presented the horizontal tilt angle method (TDX) as an edge detector [17]:

$$TDX = tan^{-1}\left(\frac{THDR}{\left|\frac{\partial T}{\partial z}\right|}\right) \tag{5}$$

TDX responds equally well to shallow and deep bodies, and also delineates the edges of all the bodies well. TDX has a much sharper gradient over the edges of the magnetized bodies. The proposed Etilt filter is the ratio of the vertical derivative to the total horizontal derivative of the AS:

$$Etilt = tan^{-1}\left(k \frac{\frac{\partial T}{\partial z}}{\sqrt{\left(\frac{\partial A}{\partial x}\right)^2 + \left(\frac{\partial A}{\partial y}\right)^2}} \right) \tag{6}$$

where

$$k = \frac{1}{\sqrt{dx^2 + dy^2}} \tag{7}$$

k is the dimensional correction factor. dx and dy are sampling intervals in the x and y directions, respectively. The dimensional correction factor, k, does not have an effect on the Etilt response.

$$ETHDR = \sqrt{\left(\frac{\partial Etilt}{\partial x}\right)^2 + \left(\frac{\partial Etilt}{\partial y}\right)^2} \tag{8}$$

The ETHDR delineates the edges of the all bodies better than the filters discussed above, as it produces a very sharp gradient over the edges of the bodies. Thus, structural interpretation is very easy and powerful using the ETHDR method.

3. UPWARD CONTINUATION

Upward continuation is a method that transforms anomalies measured on one surface into those that would have been measured on some higher surface. The upward-continued anomalies do not provide direct information about the source, but they can be instructive nonetheless. In particular, the process of upward continuation tends to attenuate anomalies caused by local, near-surface sources relative to anomalies caused by deeper, more profound sources. The potential data at two observation heights are related by the upward continuation operation [18],

$$T_h(x, y, \Delta h) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \frac{T_0(x', y')\Delta h}{[(x' - x)^2 + (y' - y)^2 + \Delta h^2]^{3/2}} dx'dy' \tag{9}$$

where $T_0(x, y)$ and $T_h(x, y, h)$ are respectively the potential data at two observation heights separated by a vertical distance Δh. Applying a two-dimensional Fourier transform to equation (1) yields a simpler form in which the Fourier transforms of the two quantities are related to each other by a simple upward continuation operator,

$$\tilde{T}_h(\omega_x, \omega_y, \Delta h) = e^{-\Delta h \omega_r} \tilde{T}_0(\omega_x, \omega_y) \tag{10}$$

where $\tilde{T}_0(\omega_x, \omega_y)$ denotes the Fourier transform of $T_0(x, y)$, (ω_x, ω_y) are wavenumbers in x- and y- direction, and $\omega_r = \sqrt{\omega_x{}^2 + \omega_y{}^2}$ is the radial wavenumber. The upward continuation operator attenuates with height the high-frequency content of a potential anomaly.

4. POLE REDUCTION

Pole reduction is an operator, which takes magnetic anomalies and changes their asymmetric form to the symmetric form which would have observed the causative magnetic bodies lain at the magnetic poles. The frequency domain operator is [19],

$$A'(u,v) = \frac{A(u,v)}{(\sin\theta + icos\theta\sin(\emptyset + \alpha))^2} \tag{11}$$

where A(u,v) is the amplitude at frequencies (u,v), θ and φ are the geomagnetic inclination and declination, respectively, and α is $\tan^{-1}$(v/u).

5. THEORETICAL STUDY

In this stage, synthetic magnetic anomaly of three prisms whose depths are 1, 3, 5 km were utilized for theoretical study (Figure 1). Inclination, declination and susceptibility values were taken as 90^o, 0^o and 0.1 SI respectively. Initially, the noise, %0.5, %5 and %10 of the maximum magnetic data amplitude, was added to magnetic anomaly for interpreting noise-corrupted conditions. The boundary analysis applications which are THDR, AS, Tilt angle, Theta map, TDX, Etilt and ETHDR methods were applied on noise-corrupted data (Figure 2 and Figure 3). Synthetic magnetic anomaly was obtained by using Potensoft program based on MATLAB [20].

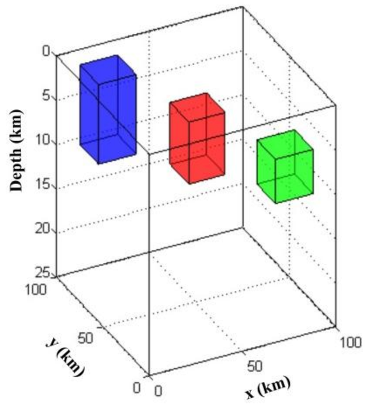

Figure 1. 3D view of theoretical model.

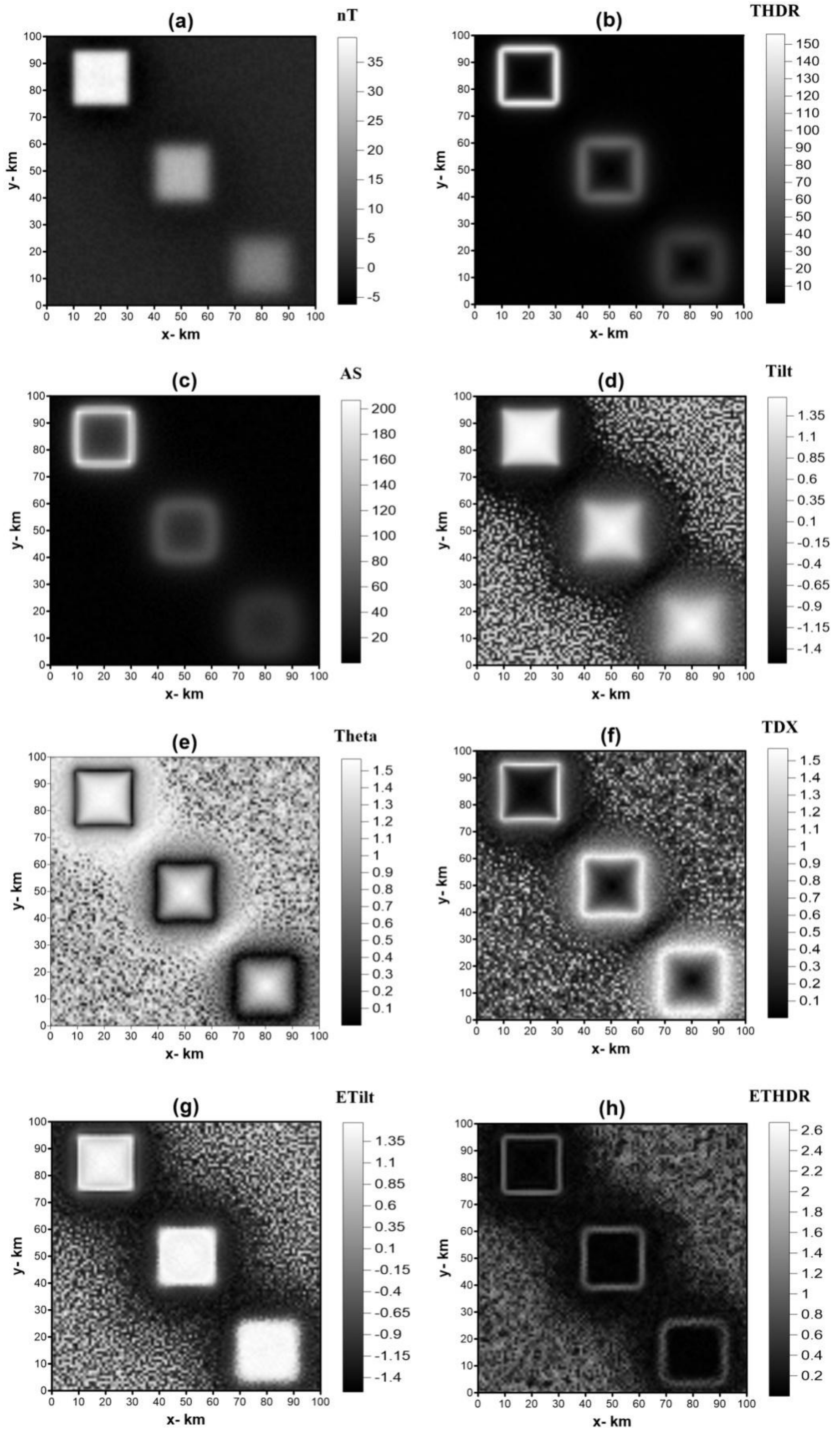

Figure 2. A comparison of boundary analysis filters: a) Theoretical magnetic data resulted from three prismatic bodies with depths of 1, 3 and 5 km. (Image covers 100x100 km area. Uniformly distributed random noise of amplitude equal to % 0.5 of the maximum magnetic data amplitude is added to the magnetic data. b) THDR image map of magnetic data. c) AS image map of magnetic data. d) TA image map of magnetic data. e) TM image map of magnetic data. f) TDX image map of magnetic data. g) Etilt image map of magnetic data. h) ETHDR image map of magnetic data.

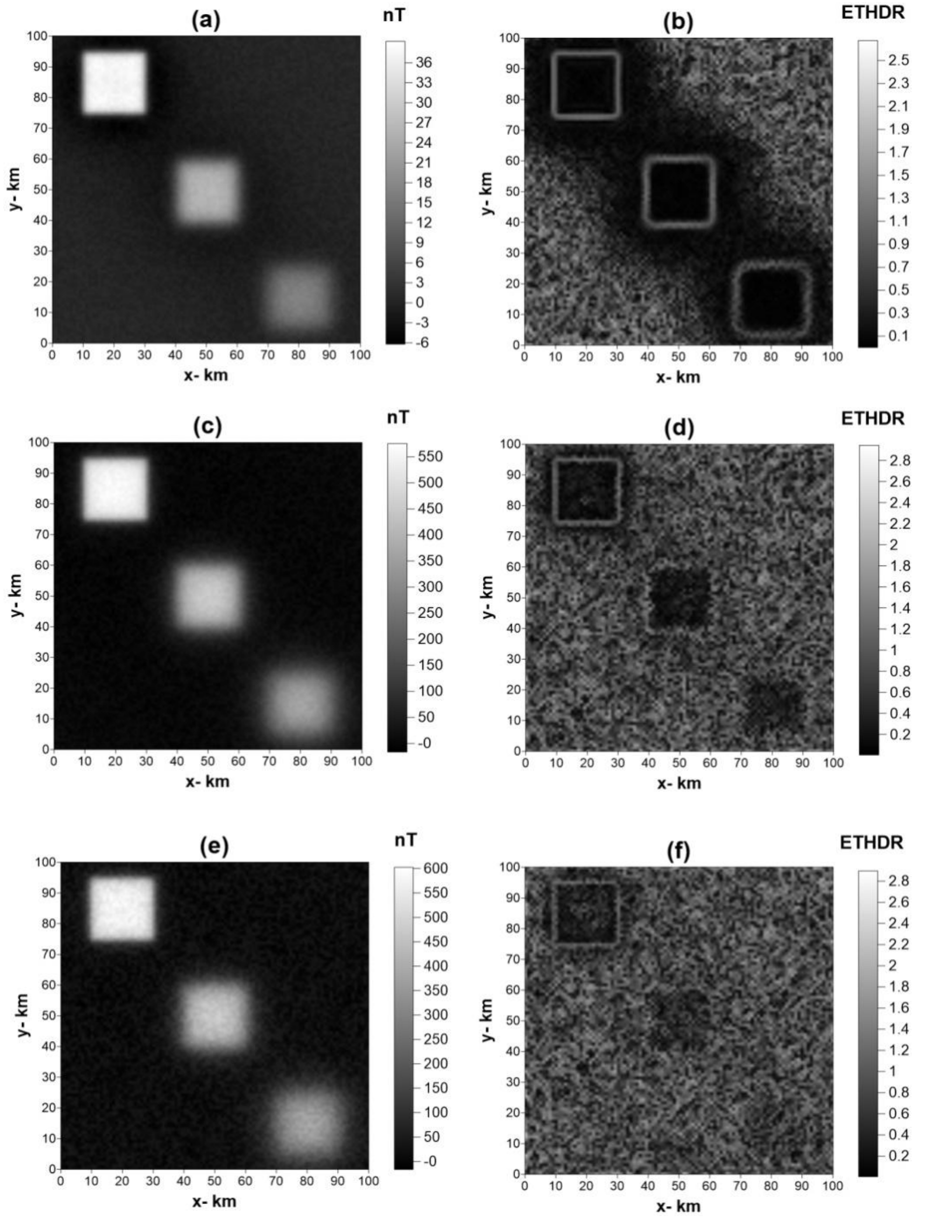

Figure 3. A comparison of different amounts of noise effects on the ETHDR responses. a) Magnetic data with uniformly distributed random noise of amplitude equal to % 0.5 of the maximum magnetic data amplitude is added to the magnetic data. b) ETHDR image map of magnetic data in Figure 3a. c) Magnetic data with uniformly distributed random noise of amplitude equal % 5 of the maximum magnetic data amplitude is added to the magnetic data. d) ETHDR image map of magnetic data in Figure 3c. e) Magnetic data with uniformly distributed random noise of amplitude equal % 10 of the maximum magnetic data amplitude is added to the magnetic data. f) ETHDR image map of magnetic data in Figure 3e.

6. FIELD STUDY

The study area is located in the West of Bitlis that includes complex geological units and faults. Application stage of this study was provided by the contributions of the Directorate of Mineral Research and Exploration of Turkey (MTA) ([21]). Figure 4 shows the location of the study area and known faults with topography.

Firstly, the boundary analysis methods were applied on aeromagnetic data without using any filters. Maximum anomaly areas are over the northeast of the study area and minimum anomaly areas are over the southwest of the study area (Figure 5a). The boundaries of the faults could not be seen clearly in the results of THDR and AS because of the effects of deeper structure (Figure 5b and 5c). It seems that the noise cause to repress effects of deeper structure because of the complex geological units in the area (Figure 5d, 5e and 5f). It requires pole reduction and other filters when examining the results of Etilt and ETHDR method (Figure 5g and 5h). The result of ETHDR could not be interpreted well because the anomaly contains the effects of all residual and regional underground structures, also complexity of area in terms of faults and variable topography.

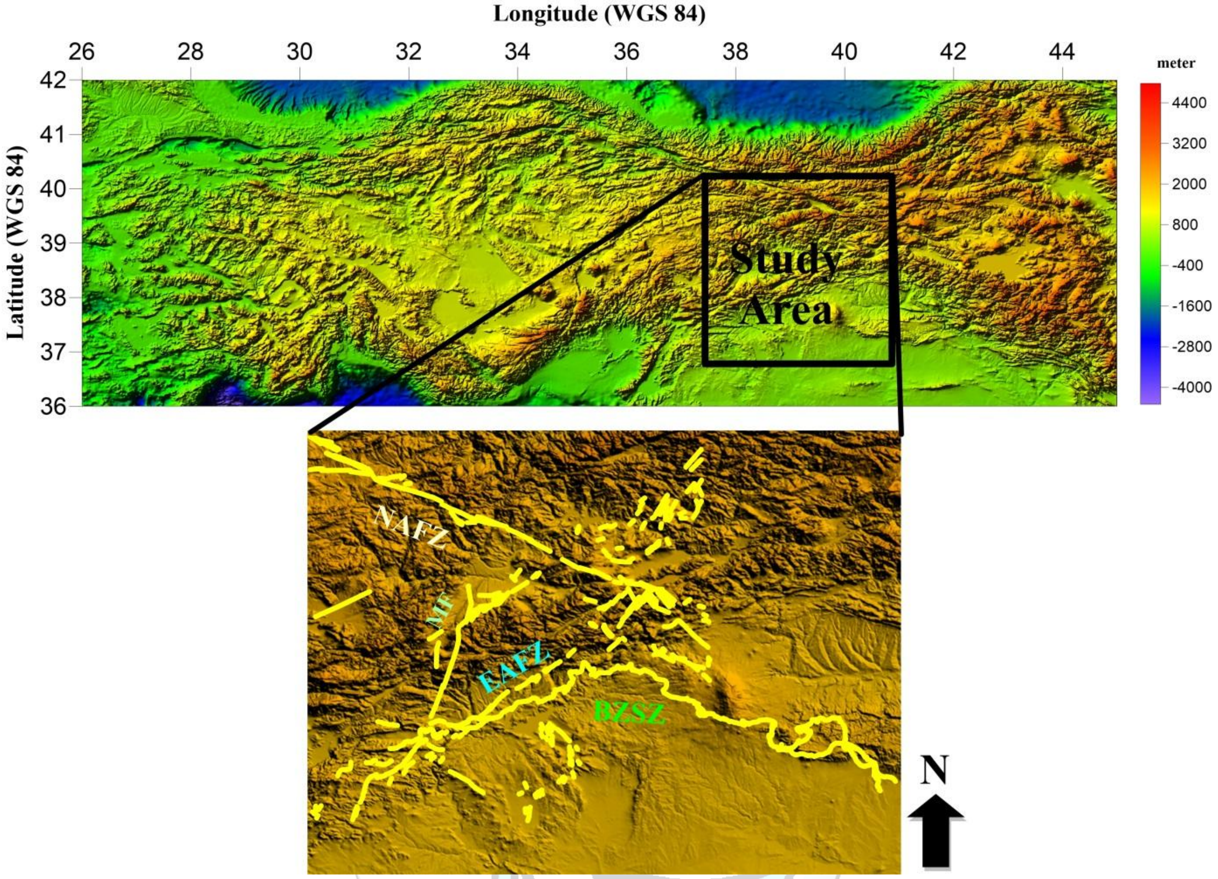

Figure 4. Location of the study area (Topography data are taken from http://topex.ucsd.edu/cgi-bin/get_srtm30.cgi)(NAFZ: North Anatolian Fault Zone, MF: Malatya Fault, EAFZ: East Anatolian Fault Zone and BZSZ: Bitlis-Zagros Suture Zone).

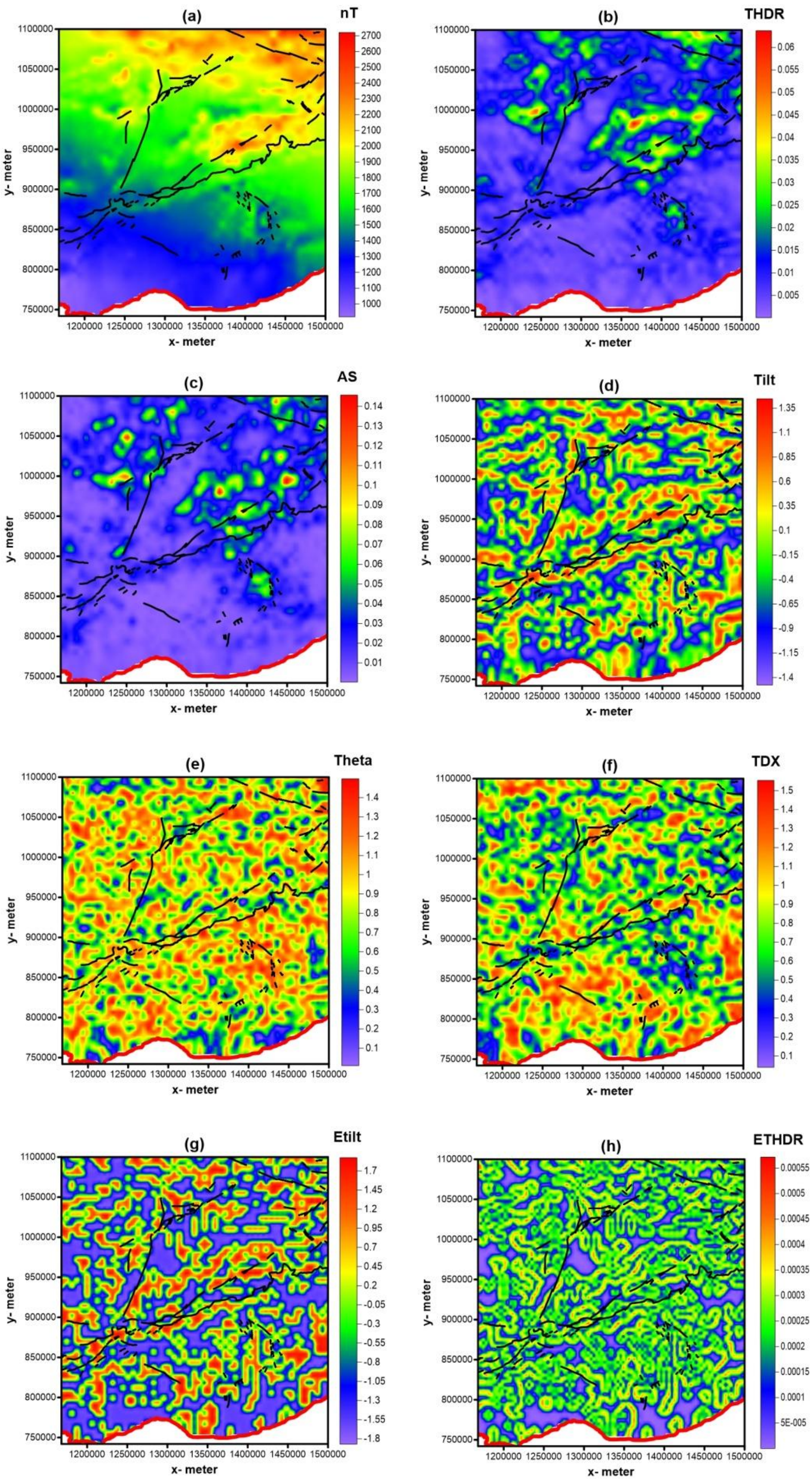

Figure 5. Magnetic anomaly and the results of boundary analysis: a) Magnetic anomaly of the west of Bitlis and its surroundings, b) The result of THDR, c) The result of AS, d) The result of tilt angle, e) The result of theta map, f) The result of TDX, g) The result of Etilt, h) The result of ETHDR method.

Afterwards, pole reduction and upward continuation (5 km and 10km) were applied to the aeromagnetic data and then same boundary analysis methods were implemented to the data. When applying to pole reduction and upward continuation, the maximum and minimum anomaly areas changed. The effects of deeper bodies were revealed after upward continuation (Figure 6a, Figure 7a). The results of THDR and AS did not change more than the results of unfiltered data but anomalies are smoother (Figure 6b, 6c, 7b, 7c). The results of Etilt, TDX, tilt and theta map give information about the tectonic structures of area (Figure 6d, 6e, 6f, 6g; Figure 7d, 7e, 7f, 7g). The result of ETHDR gives apparent anomaly in the BSZS especially related to low amplitude anomaly areas (Figure 6h and Figure 7h). The increase of the analytical extension level has clarified the location of the tectonic elements.

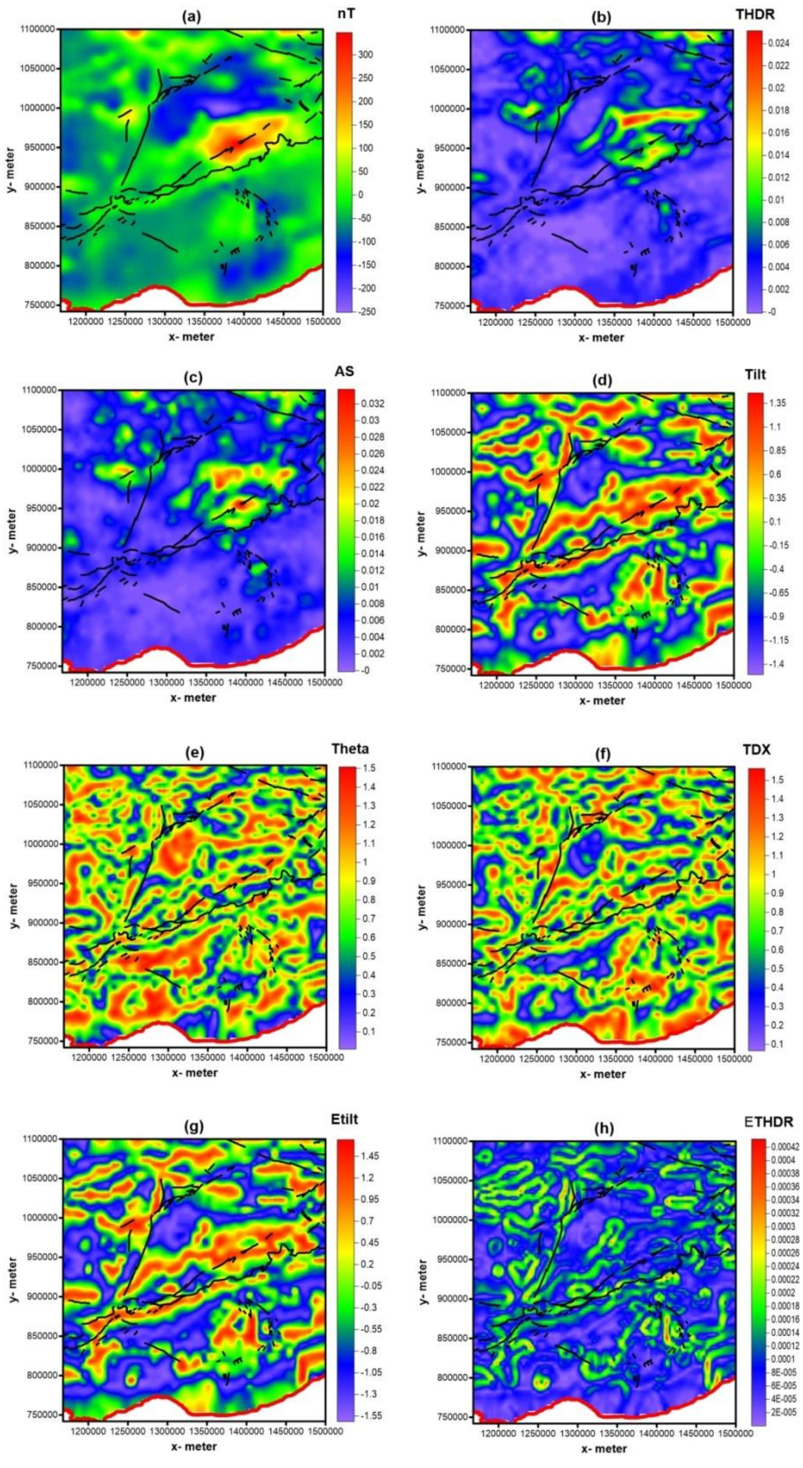

Figure 6. Upward continuation of magnetic anomaly (5km) and the results of boundary analysis: a) Upward continuation of magnetic anomaly of the west of Bitlis and its surroundings, b) The result of THDR, c) The result of AS, d) The result of tilt angle, e) The result of theta map, f) The result of TDX, g) The result of Etilt and h) The result of ETHDR method.

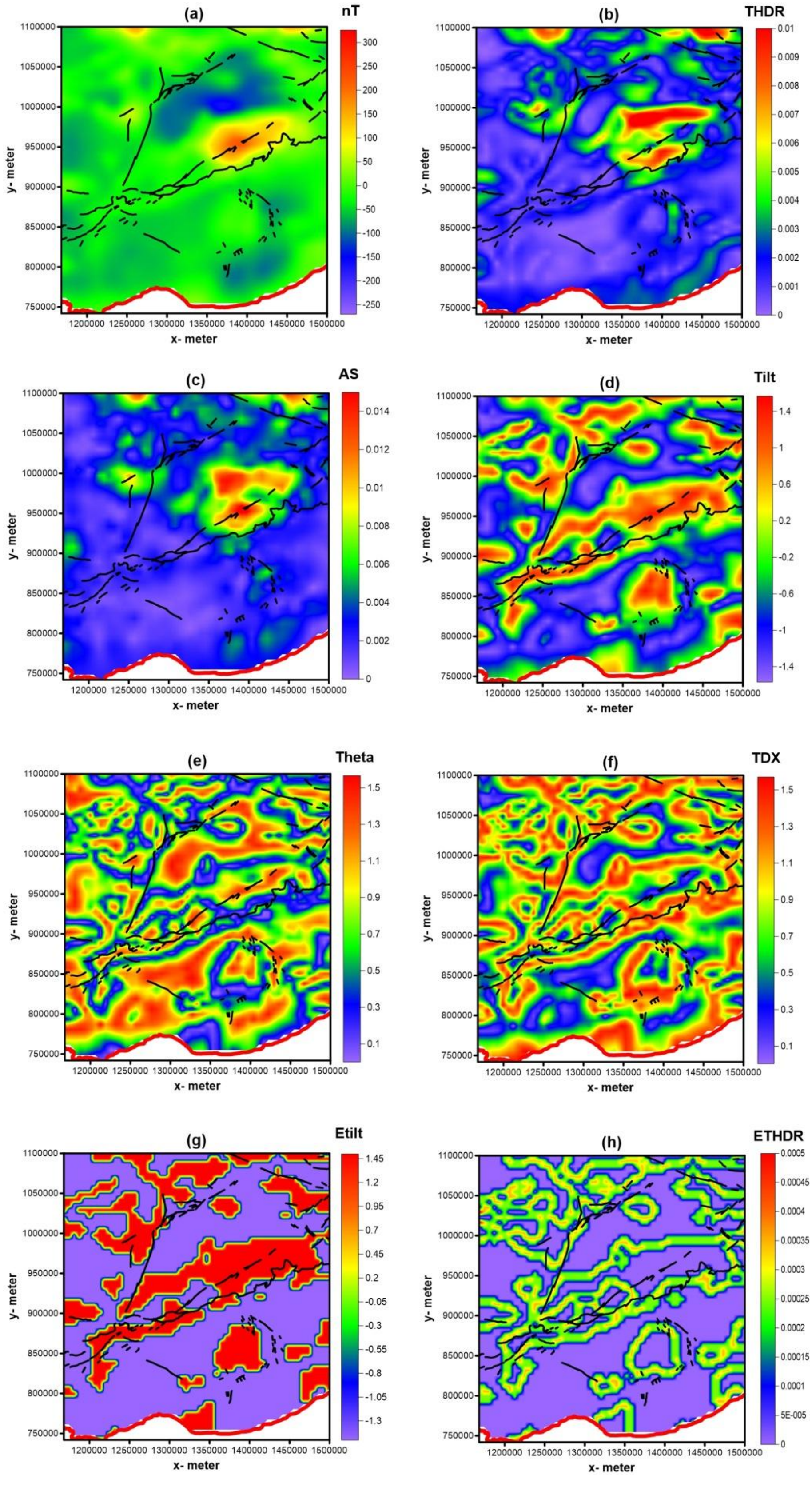

Figure 7. Upward continuation of magnetic anomaly (10km) and the results of boundary analysis: a) Upward continuation of magnetic anomaly of the west of Bitlis and its surroundings, b) The result of THDR, c) The result of AS, d) The result of tilt angle, e) The result of theta map, f) The result of TDX, g) The result of Etilt and h) The result of ETHDR method.

CONCLUSIONS

According to theoretical studies, the results of THDR and AS methods gave similar anomalies, maximum values were found over the prisms in both results but boundary of deeper body was not clear (Figure 2b and 2c). It seems that the ratio of the noise increased in the results of tilt angle, theta map, TDX, Etilt and ETHDR methods but ETHDR was outperformed for determining the boundaries of buried structures from former methods and also ETHDR method is less sensitive the noise (Figure 2d, 2e, 2f and 2g). For comparison, uniformly distributed random noise of amplitude equal %0.5, %5 and %10 of the maximum magnetic data amplitude was added to synthetic magnetic anomaly (Figure 3a, 3c and 3e). The results are acceptable until the results of %10 noise-corrupted data, because the deeper bodies are not recognizable after %5 noise (Figure 3b, 3d and 3f).

As field study, THDR, AS, Tilt, Theta map, TDX, Etilt, ETHDR boundary analysis methods were implemented successfully to the pole reduced and analytical extended (5 km and 10 km) aeromagnetic data which was collected by MTA in the eastern part of Turkey. The results of theta map and TDX could not explain the relationship between any tectonic or differences of geological units. The areas that offer close to zero amplitude are related to extension of BZSZ in the results of AS and THDR. The results of AS and THDR are related to geological unit differences and the result of ETHDR is related to tectonic elements. Also as a result of field application, it was found that the success of methods was increased due to applying filtering to anomaly before the application of boundary analysis methods. The relationship between the maximum-minimum amplitude transitions in the results of Figure 6d, 6g and 7 d, 7e, 7f, 7g, 7h and BZSZ and fault locations in the field applications has been successfully determined. Starting from this point of view, there are boundaries that cannot be identified as tectonic elements because they have not been identified yet, so detailed geological field observations should be made.

Pamukçu et al. (2014) observed a relative increase in heat flow values in the north of Bitlis Thrust in the study of the heat flow change in the region obtained from the curie depths calculated using magnetic data throughout Eastern Anatolia [11]. Within the scope of this study, the high amplitude regions in the applications of Figure 6 and Figure 7b and Figure 7c are in agreement with the high heat flow amplitude region that was detected [11]. When the vertical derivative values applied to Bouguer gravity anomaly values in the region are examined, an increase in vertical derivative values is observed [12]. These findings are indicative of the structural element or elements that are continuous in both gravity and magnetic properties in the high-amplitude regions of the applications of Figure 6 and Figure 7b and 7c.

As a conclusion, as the level of applied upward continuation to the aeromagnetic field increases the success of the applied boundary analysis methods to the analytical extended data is determined by observations made with locations of the structural elements. Successful monitoring of structural elements with increasing level of analytical extension to the aeromagnetic data in the study area suggests that the source location of the anomaly is deep in and around BZSZ. This finding is coherent with the results of the study on depth distribution of the earthquakes in the Eastern Anatolian region, the seismogenic layer of BZSZ and its surroundings is thicker than the northern part [23].

ACKNOWLEDGEMENTS

In this study, the data of TUBITAK No:101Y124 project and DEU 02.KB.FEN.084 project were used. We would like to thank the project employees.

REFERENCES

[1]. M. Pilkington and P. Keating, *Geologic applications of magnetic data and using enhancements for contact mapping, EGM international workshop Adding new value to electromagnetic, gravity and Magnetic methods for exploration*, Capri, Italy, pp 11-14, 2010.
[2]. F. Dogru, O. Pamukcu, and C. Pamukcu, Determination of Mine Location by Using Edge Detection Methods: A Case Study of Sivas-Divrigi. Science PG Earth Science, 5(4), 56-61, 2016.
[3]. N. Bournas and H.A. Baker, Interpretation of magnetic anomalies using the horizontal gradient analytic signal, Annali di Geofisica, 44 (3), pp 506-526, 2001.
[4]. M.O. Arisoy and U. Dikmen, Edge Detection of Magnetic Sources Using Enhanced Total Horizontal Derivative of the Tilt Angle, Bulletin of the Earth Sciences Application and Research Centre of Hacettepe University, 34 (1), pp 73-82, 2013.
[5]. C.O. Faccenna, J. Bellier, , C.P. Martinod and V. Regard, Slab Detachment Beneath Eastern Anatolia: A Possible Cause for the Formation of the North Anatolian Fault, Earth and Planetary Science Letters, Vol. 242, pp. 85-97, 2006.
[6]. A.M.C. Şengör, Y. Yılmaz, Tethyan evolution of Turkey: a plate tectonic approach, Tectonophysics, 75, pp. 181-241, 1981.
[7]. A.M.C. Şengör, Natal'in B.A, Turkic-type orogeny and its role in the making of the continental crust , Ann. Rev. Earth Sci. 24 , pp. 263-337, 1996.
[8]. J. F. Dewey, M.R. Hempton, W.S.F. Kidd, F.A.M.C. Saroglu, and A.M.C. Şengör, Shortening of continental lithosphere: the neotectonics of Eastern Anatolia—a young collision zone. Geological Society, London, Special Publications,19(1), 1-36, 1986.
[9]. O.A. Pamukçu, Z. Akçığ, Ş. Demirbaş, and E. Zor, Investigation of crustal thickness in Eastern Anatolia using gravity, magnetic and topographic data, Pure and Applied Geophysics, 164(11), pp.2345-2358, 2007.
[10]. O.A. Pamukçu and Z. Akçığ, Isostasy of the Eastern Anatolia (Turkey) and discontinuities of its crust, Pure and Applied Geophysics, 168(5), pp.901-917, 2011.
[11]. O. Pamukçu, Z. Akçığ, M. Hisarlı and S. Tosun, Curie Point Depths and Heat Flow of Eastern Anatolia (Turkey), Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 36(24), pp.2699-2706, 2014.

[12]. O., Pamukçu, T. Gönenç, A.Y. Çirmik, Ş. Demirbaş and S. Tosun, Vertical And Horizantal Analysis Of Crustal Structure In Eastern Anatolia Region, Bulletin of the Mineral Research and Exploration, (151), 2015.
[13]. H.G. Miller and V. Singh, Potential field tilt: a new concept for location of potential filed sources, Journal of Applied Geophysics, 32, pp 213-217, 1994.
[14]. L. Cordell and V.J.S. Grauch, Mapping basement magnetization zones from aeromagnetic data in The San Juan Basin, New Mexico. In: W.J., Hinze, Ed., The utility of regional gravity and magnetic anomaly maps: Society Exploration Geophysics, Tulsa, Oklahoma, 181-197, 1985.
[15]. C. Wijns, C. Perez and P. Kowalczyk, Theta map: edge detection in magnetic data, Geophysics, 70(4), pp 39-43, 2005.
[16]. W.R. Roest, J. Verhoef and M. Pilkington, Magnetic interpretation using the 3-D analytic signal, Geophysics, 57(1), pp. 116-125, 1992.
[17]. G.R.J. Cooper and D.R. Cowan, Enhancing potential field data using filters based on the local phase, Computer and Geosciences, 32, pp 1585-1591, 2006.
[18]. R.J. Blakely, Potential theory in gravity and magnetic applications, Cambridge University Press, 1995.
[19]. V. Baranov, A new method for interpretation of aeromagnetic maps: Pseudo-gravimetric anomalies, Geophysics, 22, 359-383, 1957.
[20]. M.O. Arisoy and U. Dikmen, Potensoft: MATLAB-based software for potential field data processing, modeling and mapping. Computer and Geosciences, 37, 935-942, 2011.
[21]. MTA (Directorate of Mineral Research and Exploration, Turkey) 1979. Aeromagnetic Map of Eastern Turkey [unpublished].
[22]. URL: http://topex.ucsd.edu/cgi-bin/get_srtm30.cgi
[23]. N. Turkelli, E. Sandvol, E. Zor, R. Gok, T. Bekler, A. Al-Lazki, ... & S. Bayraktutan, Seismogenic zones in eastern Turkey. Geophysical Research Letters, 30(24), 2003.