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Determination of crustal structure beneath the Çameli Basin (SW Turkey) using an aeromagnetic data

Funda BİLİM[1*], Fahriye AKAR[2]

[1,2] Department of Geophysical Engineering, Sivas Cumhuriyet University, Sivas,Turkey
fbilim@cumhuriyet.edu.tr, ORCID: 0000-0003-1098-4755,
fhrykcmzb@gmail.com, ORCID: 0000-0002-8445-0353

Abstract: The Çameli basin is situated at the southwestern Anatolia (Turkey), where is tectonically a very active region. The reduction to the pole (RTP), the upward continuation and the analytic signal (AS) methods were used in this study to determine the tectonic lineaments/bodies caused magnetic anomaly beneath the Çameli basin. The results show that the deep-seated magnetic bodies (at least 5 km deep) are possibly emplaced in the upper crust along the NE-SW trending faults. The AS map indicates that many of the causative sources appear elliptical shaped in the study.

Keywords: The Çameli Basin, Magnetic Anomaly, the Reduction to Pole (RTP), the Upward Continuation, the Analytic Signal (AS).

Çameli Havzası altındaki kabuksal yapıların havadan manyetik veri kullanılarak saptanması

Özet: Çameli havzası, tektonik olarak oldukça aktif olan Güneybatı Anadolu’da (Türkiye) yer almaktadır. Bu çalışmada Çameli havzasının altındaki manyetik anomaliye neden olan tektonik hatları belirleyebilmek için, Kutba indirgeme (RTP), yukarı uzanım ve analitik sinyal (AS) yöntemleri kullanılmıştır. Elde edilen sonuçlara göre, derin kaynaklı manyetik yapıların (en az 5 km) muhtemelen KD-GB yönelimli faylar boyunca üst kabuğa yerleşmiş olabileceği belirlenmiştir. AS haritası ise çalışma alanında anomali oluşturan kaynakların eliptik şekilli olduğunu belirtmektedir.

Anahtar Kelimeler: Çameli Havzası, Manyetik Anomali, Kutba İndirgeme, Yukarı Uzanım, Analitik Sinyal.

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1. INTRODUCTION and GEOLOGICAL SETTING

The Southeast of Western Turkey characterized by mainly extensional the Çameli basin on basement rocks (Fig. 1). The south of western Turkey exhibits complex tectonic events such as subduction of oceanic lithosphere, a N-S extension and continental escape (e.g., [1]). There are mainly three models to explain the neotectonic extension in western Anatolia: 1) Tectonic escape model: According to this model, the N-S tectonic crustal extension was caused by the westward tectonic escape of the Anatolia since the Late Serravalian [2] [3] [4]. 2) Back-arc spreading model: Le Pichon and Angelier [5] suggested that the extension is caused by back-arc spreading accompanied by roll-back of the Mediterranean subducted slab along the Hellenic arc since the late Serravalian and along the Cyprus arc. 3) Orogenic collapse model: This model proposed that the cause of the crustal extension is over thickening of crust along the İzmir-Ankara-Erzincan Neotethyan suture during late Oligocene-Early Miocene time [6] [7]. Över *et al.* [1] suggested that as the effect of the Hellenic arc was dominant in the west of SW Turkey, the Cyprus arc was dominant in the east of SW Turkey.

* *Corresponding author; fbilim@cumhuriyet.edu.tr*

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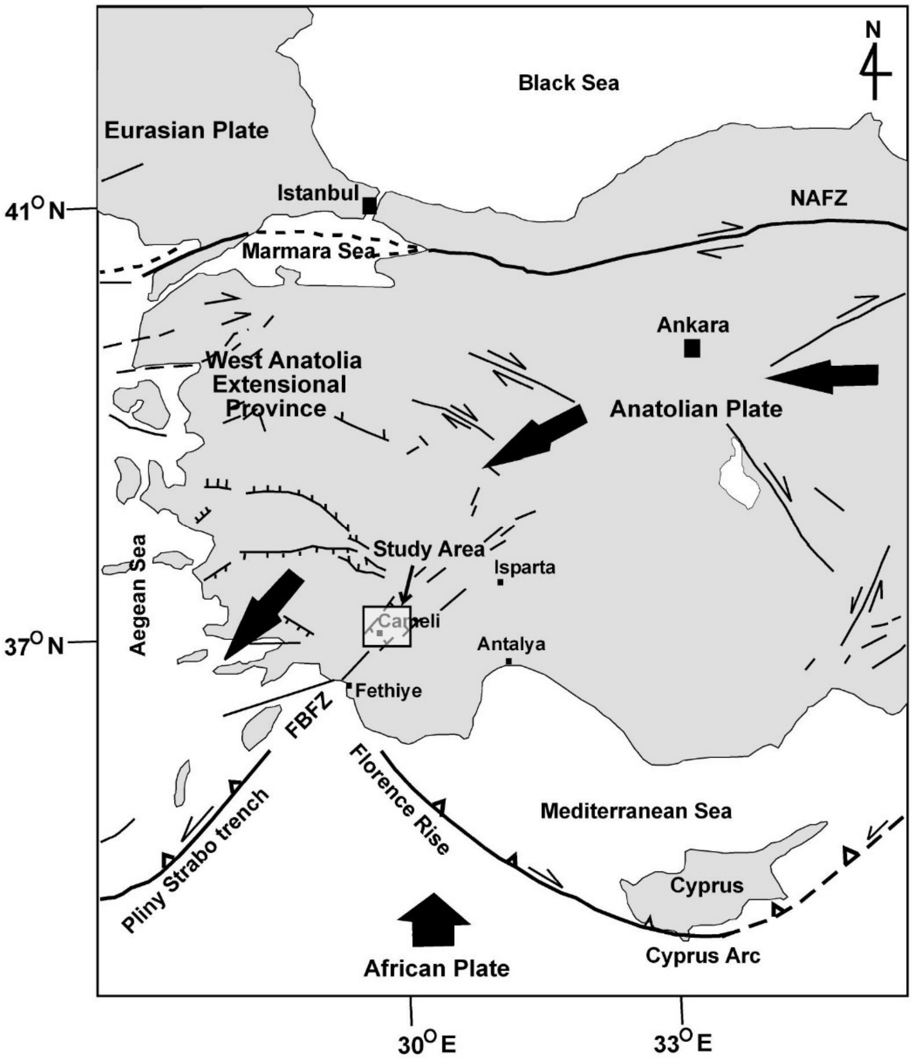

Figure 1. Tectonic map of western Turkey ([8] [9]).

Ten Veen *et al*. [10] proposed that the Çameli basin is characterized by varied from N-S to NNE-SSW trending oblique-slip normal faults resulted from E-W extension of western Anatolia (Fig. 2). The deposits of the basin are terrestrial and represent river, alluvial-fan, fan-deltaic and lacustrine settings [11]. The study area is covered mainly by young sediments, ophiolitic rocks and Lycian nappes (Fig. 2). The Lycian nappe forms the basement of the Çameli basin and consists of the Lycian thrust sheets, the Lycian melange unit and the Lycian ophiolites [12].

There are some geophysical investigation in western Anatolia covering the Çameli basin in literature [9], [13], [14]. Över *et al.* [9] suggested that the formation of Çameli basin is due to the NW-SE extension during Mio-Pliocene time using by the inversion of earthquake focal mechanism. Ates *et al.* [13] carried out re-evalution of both gravity and aeromagnetic data of Turkey. They proposed that the magnetic anomalies in the SW Turkey are weakly magnetic and deep origin. Paradisopoulou *et al.* [14] calculated the Coulomb stress changes from both the coseismic slip in large earthquakes and the slow tectonic stres buildup along the major fault segment in western Anatolia.

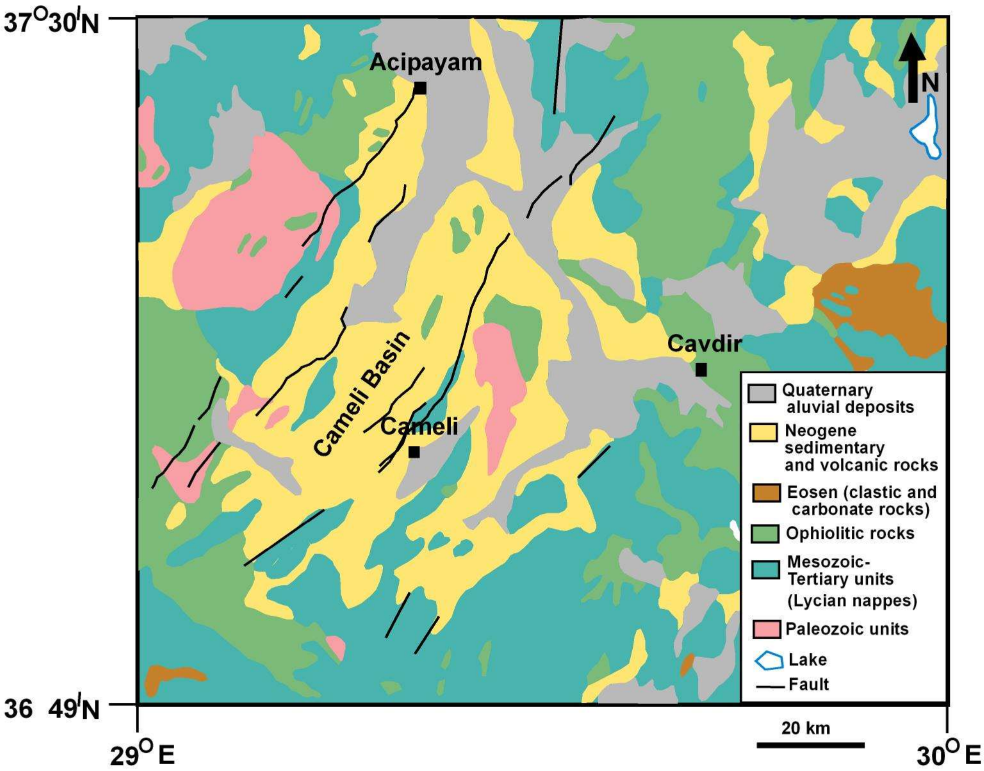

Figure 2. Geology of the Çameli Basin ([15], [16], [17]).

Akar ve Özel [18] created a 2D gravity model of the Çameli basin and applied the Analytic signal (AS) to the total magnetic data without applying the reduction to the Pole process (RTP). The purpose of this study, the determination of buried a bodies/crustal structures and boundaries of the basin caused the magnetic anomaly under the study region. The RTP, upward continuation and the AS method were applied the reziduel total aeromagnetic data and we provide new results.

2. METHOD

2.1. Reduction to the Pole

A shape and location of magnetic anomaly are affected from the geomagnetic field and remanent magnetization of rocks. The dipolar properties of the geomagnetic field vary with respect to the any latitude and longitude. Anomalies are observed as asymmetric shape and do not appear on their sources. For a solution of this problem, reduction to the pole method (RTP) [19] [20] is applied to the magnetic anomaly data in frequency domain. The RTP anomalies act like that the magnetic field would be measured at the north magnetic pole, where induced magnetization and ambient field both would be directed vertically down [21]. The RTP process is given as,

$$F(\Delta T_r) = F[\psi_r]\, F(\Delta T) \text{ [21].} \tag{1}$$

Where $F(\Delta T_r)$ is the Fourier transform of the RTP of a magnetic field, $F(\Delta T)$ is the Fourier transform of the magnetic field. Inverse Fourier transform of this function is the RTP of the anomaly and

$$F[\psi_r]=\frac{1}{\Theta_m\Theta_f}=\frac{|k|^2}{a_1k^2{}_x+a_2k^2{}_y+a_3k_xk_y+i|k|(b_1k_x+b_2k_y)},\qquad |k|\neq 0, \tag{2}$$

$$a_1=\hat{m}_z\hat{f}_z-\hat{m}_x\hat{f}_x$$
$$a_2=\hat{m}_z\hat{f}_z-\hat{m}_y\hat{f}_y$$
$$a_3=-\hat{m}_y\hat{f}_x-\hat{m}_x\hat{f}_y$$
$$b_1=\hat{m}_x\hat{f}_z+\hat{m}_z\hat{f}_x$$
$$b_2=\hat{m}_y\hat{f}_z+\hat{m}_z\hat{f}_y$$

The dipole moment ($\hat{m}$) = ($\hat{m}_x, \hat{m}_y, \hat{m}_z$); the ambient field ($\hat{f}$) $=(\hat{f}_x, \hat{f}_y, \hat{f}_z)$.

2.2. Upward continuation

Upward or downward continuation process has been applied for many years to determine the magnetic anomaly of subsurface geological bodies at measured on any surface [22]. Upward continuation reduces short wavelength anomalies from data. Data are smoothed in this process. Upward continuation equation is given by Blakely [21],

$$F(\Delta T_u)= F[\psi_u]\, F(\Delta T) \tag{3}$$

Where $F(\Delta T_u)$ is the Fourier transform of the upward continued field.

$F[\psi_u]=e^{-\Delta z|k|}$, $\Delta z > 0$.

Where $|k = 2\pi\lambda|$ is the wavenumber, λ=the full wavelength, z= the continuation level. The negative sign in the exponent shows upward continuation (away from the sources of the field).

2.3. Analytic signal

The Analytic Signal (AS) process is one of the most popular methods in order to determine the location of the causative bodies, edge detection of subsurface tectonic lineaments caused magnetic anomaly,

The AS can be given as the sum of the vertical and horizontal gradients of the magnetic anomaly in 3D by:

$$A(x,y)=\frac{\partial\Delta T}{\partial x}i+\frac{\partial\Delta T}{\partial y}j+\frac{\partial\Delta T}{\partial z}k \tag{4}$$

Here, i, j and k are unit vectors in the x, y and z directions, respectively [23].

The amplitude of the AS can be given as follows;

$$|A(x,y)| = \sqrt{\left(\frac{\partial \Delta T}{\partial x}\right)^2 + \left(\frac{\partial \Delta T}{\partial y}\right)^2 + \left(\frac{\partial \Delta T}{\partial z}\right)^2} \qquad (5)$$

3. ANALYSIS and DISCUSSION

The aeromagnetic data were obtained from the General Directory of Mineral Exploration and Research (MTA) of Turkey (Fig. 3) (CÜBAP Project: M567). International Geomagnetic Reference Field (IGRF) was removed from the data using by Baldwin and Langel's program [24]. The residual total aeromagnetic anomaly map is shown in Figure 3.

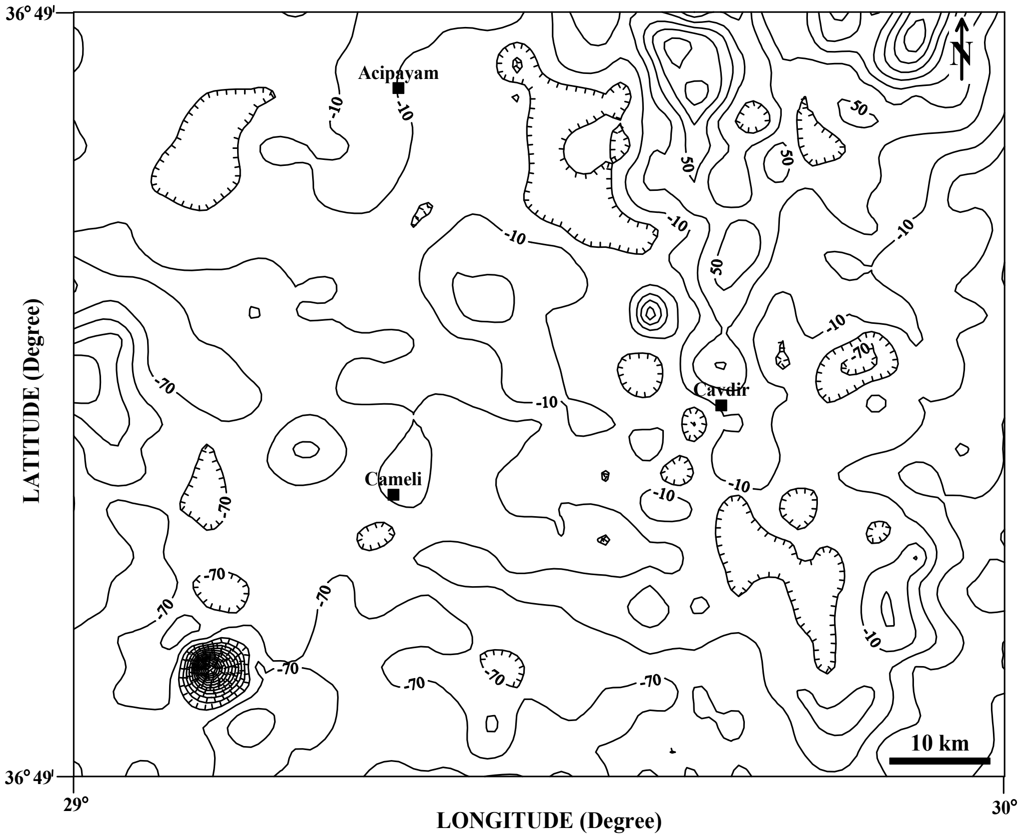

Figure 3. The aeromagnetic anomaly map of the study area. Contour interval is 30nT.

Polarity axes of anomalies are generally in the N-S direction. The RTP process were applied to the magnetic data using a magnetic declination ~4° E and inclination ~55° N (Fig. 4). Magnetic anomalies are correlated mainly with geological rocks outcropping at the surface. The high frequency anomalies are originated mainly by shallow magnetic sources. The low amplitude anomalies to the center of the study area are associated with Çameli basin-fill units contain Quaternary alluvial deposits and Neogene sedimentary rocks, whereas the distinctive high amplitude anomalies can be related to basement rocks (mainly Lycian ophiolites) (Figs.2 and 4).

Alçicek et al. [25] said that in the basin centre, lacustrine facies, alluvian fan and fluvial deposits reach up to 500 m in thickness.

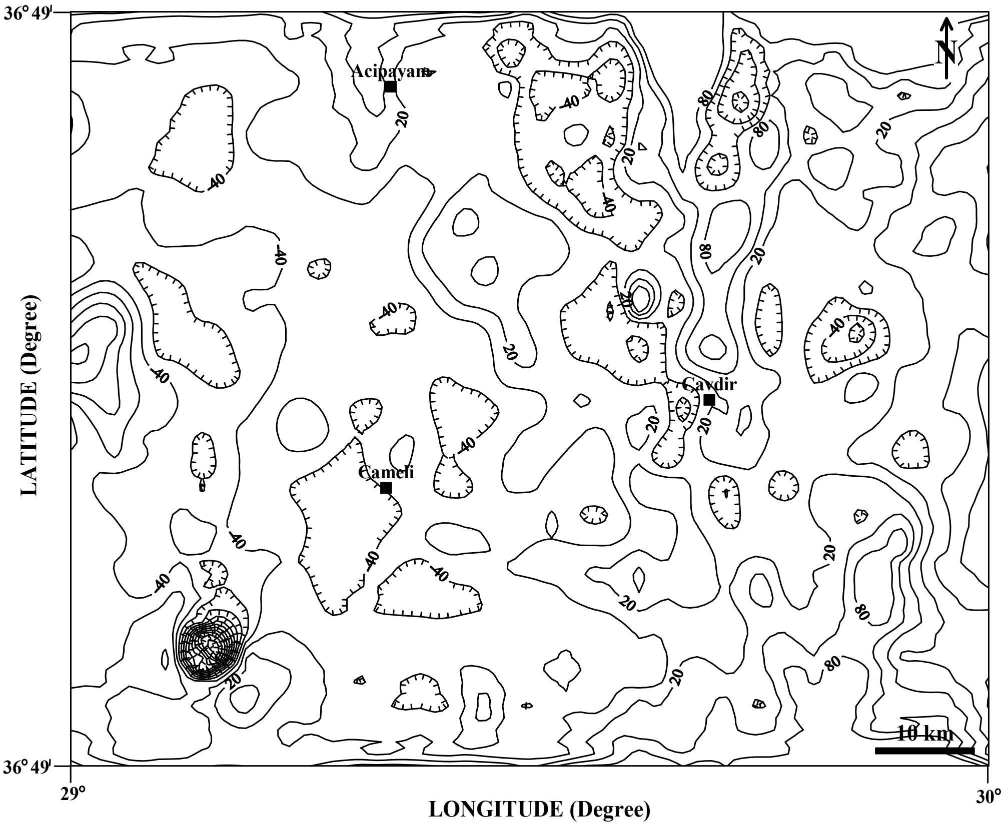

Figure 4. the RTP anomaly map of the study region. Contour interval is 30nT.

To eliminate the effect of shallow magnetic sources and determine the deep distribution of magnetic sources was applied the upward continuation to RTP-magnetic data for 0.5 km, 3 km and 5 km (Fig. 5). Magnetic source bodies under the study area extend down to greater depths (Fig. 5c). MOHO depth is changed approximately range 26 to 34 km [26].

The AS method was applied to 0.5, 3 and 5km upward continued magnetic data of the study region, to determination the locations and distribution of magnetic bodies/lineaments (Figure 6). Bilim [27] suggested from estimated Curie depths that the magnetic basement may be located at the upper crust in centre of the western Anatolia. Seven magnetic bodies in the form of ellipses were identified from the AS map (Fig. 6, A1-7). Figure 6 suggest that the magnetic bodies (possibly ophiolites) extend down to deeper levels of the upper crust. Our results are consistent with [23], [24]. In this study, two tectonic discontinuities (possibly lineaments) are determined at a depth of 5 km (Fig. 6c, dashed line called L1 and L2). The NE-SW trending elliptical magnetic bodies spread along L1-L2 tectonic lineaments (Fig. 6c).

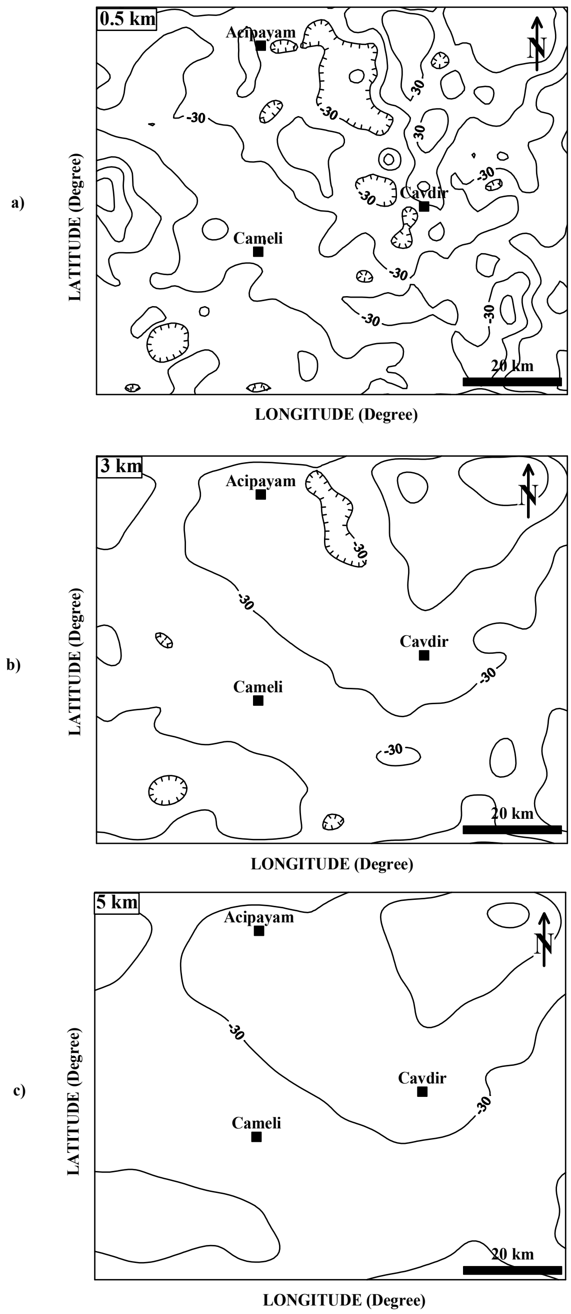

Figure 5. The upward continuation map of the RTP anomaly data. a) 0.5km, b) 3km, and c) 5km. Contour interval is 30nT.

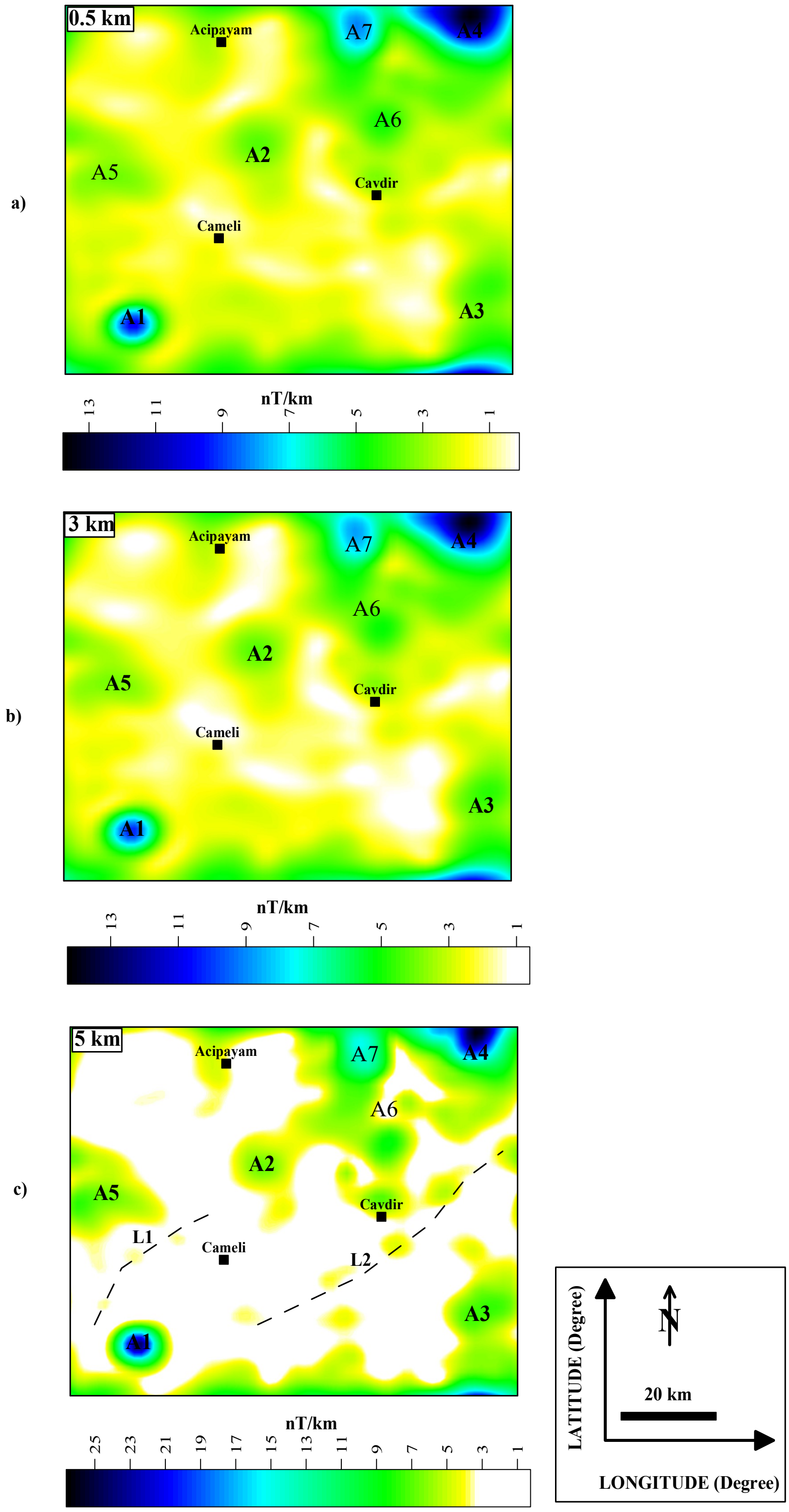

Figure 6. The Analytic signal anomaly map of the upward continuation data. a) 0.5km, b) 3km, and c) 5km.

4. CONCLUSIONS

1. The upward continuation of RTP anomalies reflects not only the boundary of the Çameli basin but also deep tectonic discontinuities.
2. In the study area, seven deep-seated magnetic sources are determined from the analytic signal map applied to the upward continuation of RTP anomaly data. The causative sources appear generally as circular bodies. In addition, they are possibly located at upper crust and structurally controlled.
3. It can be suggested from Fig.6c that NE-SW trending eliptical magnetic bodies may be related with two tectonic discontinuities/linements determined in this study.

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References

[1] S. Över, S. Özden, A. Pınar, H. Yılmaz, Z. Kamacı, U.C. Ünlügenç, "Late Cenozoic stres state distributions at the intersection of the Hellenic and Cyprus arcs, SW Turkey," *J. Asian Earth Sci*., vol. 132, pp. 94-102, Dec. 2016, doi:10.1016/j.jseaes.2016.10.003.
[2] A.M.C. Şengör, "The North Anatolian transform fault:its age, ofset and tectonic significance," *J. Geol. Soc*., vol. 136, pp. 269-282, June 1979, doi:10.1144/gsjgs.136.3.0269.
[3] J.F. Dewey, A.M.C. Şengör, "Aegean and surrounding regions: complex multiplate and continuum tectonics in a convergent zone," *Geo. Soc. Amer. Bull*., vol. 90, pp. 84-92, 1979, doi:10.1130/0016-7606(1979)90<84:AASRCM>2.0.CO;2.
[4] A.M.C. Şengör and Y. Yılmaz, "Tethyan evolution of Turkey: a plate tectonic approach," *Tectonophysics* vol. 75, pp. 181-241, June 1981, doi: 10.1016/0040-1951(81)90275-4.
[5] X. Le Pichon and J. Angelier, " The Hellenic arc and trench systems: a key to the neotectonic evolution of the eastern Mediterranean area," *Tectonophysics* vol. 60, pp. 1-42, Nov. 1979, doi: 10.1016/0040-1951(79)90131-8.
[6] J.F. Dewey, "Extensional collapse of orogens," *Tectonics* vol. 7, pp. 1123-1139, Dec. 1988, doi:10.1029/TC007i006p01123.
[7] G. Seyioğlu and B.C. Scott, "Late Cenozoic crustal extension and basin formation in west Turkey," *Geol. Mag*., vol. 128, pp. 155-216, Mar 1991, doi: 10.1017/S0016756800018343.
[8] A. Barka, "The North Anatolian fault zone," Ann. Tecton. vol. 6, pp. 164-195, 1992.
[9] S. Över, S. Özden, A. Pınar, H. Yılmaz, U.C. Ünlügenç, Z. Kamacı, "Late Cenozoic stres field in the Çameli Basin, SW Turkey," *Tectonophysics* vol. 492, pp. 60-72, Sep. 2010, doi: 10.1016/j.tecto.2010.04.037.
[10] J.H. ten Veen, S.J. Boulton, M.C. Alçiçek, "From palaeotectonics to neotectonics in the Neotethys realm: The importance of kinematic decoupling and inherited structural grain in SW Anatolia (Turkey)," *Tectonophysics* vol. 473, pp. 261-281, Jul. 2009, doi: 10.1016/j.tecto.2008.09.030.
[11] M.C. Alçiçek, N. Kazancı, M. Özkul, "Multiple rifting pulses and sedimentation pattern in the Çameli Basin, southwestern Anatolia, Turkey," *J. Sed. Geo*., vol, 173, pp. 409-431, Jan. 2005, doi:10.1016/j.sedgeo.2003.12.012.
[12] R.Oberhansli, J. Partzsch, O. Candan, "First occurrence of Fe-Mg-carpholite documenting a high-pressure metamorphism in metasediments of the Lycian Nappes, SW Turkey," In. J. Earth Sci., vol. 89, pp. 867-873, 2001, doi: 10.1007/s005310000103.

[13] A. Ates, P. Kearey, S. Tufan, "New Gravity and Magnetic Maps of Turkey." *Geophys. J. Int.*, vol.136, pp.499-502, Feb. 1999, doi: 10.1046/j.1365-246X.1999.00732.x.

[14] P.M. Paradisopouou, E.E. Papadimitriou, V.G. Karakostas, T.Taymaz, A. Killias, S.Yolsal, "Seismic hazard evaluation in western Turkey as revealed by stress transfer and time-dipendent probability calculations." *Pure Appl. Geophys*., vol. 167, pp. 1013-1048, Aug. 2010, doi: 10.1007/s00024-010-0085-1.

[15] E. Bingol, "Geological map of Turkey (Scale: 1/2.000.000)," *General Directorate of Mineral Reaearch and Exploration (MTA)*, Ankara, 1989.

[16] H. Alçiçek, F.P. Wesselingh, M.C. Alçiçek, G. Jimenez-Moreno, F.J. Feijen, L.W. van den Hoek Ostende, S. Mayda, A.S. Tesakov, "A multiproxy study of the early Pleistocene palaeoenvironmental and palaeoclimatic conditions of an anastomesed fluvial sequence from the Çameli Basin (SW Anatolia, Turkey)," *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, vol. 467, pp. 232-252, Feb. 2017, doi:10.1016/j.palaeo.2016.08.019.

[17] M. Özkaptan, N. Kaymakçı, C.G. Langereis, E. Gülyüz, A.A. Özacar, B. Uzel, H. Sözbilir, "Age and kinematics of the Burdur Basin: Inferences for the existence of the Fethiye Burdur Fault zone in SW Anatolia (Turkey)," *Tectonophysics* vol. 744, pp. 256-274, Oct. 2018, doi: 10.1016/j.tecto.2018.07.009.

[18] F.Akar and O. Özel, "Çameli bölgesi'nin 3-boyutlu gravite ve manyetik yapısı ve depremsellikle ilişkisi." ÖHÜ Müh. Bilim. Derg., cilt. 7, sayfa. 1192-1197, 2018, doi: 10.28948/ngumuh.502440.

[19] V. Baranov, "A new method for interpretation of aeromagnetic maps: Pseudo-gravimetric anomalies," *Geophysics* vol.22, pp.359-383, Apr. 1957, doi: 10.1190/1.1438369.

[20] V. Baranov and H. Naudy, "Numerical calculation of the Formula of reduction to the magnetic pole," *Geophysics* vol. 29, pp. 67-79, Feb. 1964, doi: 10.1190/1.1439334.

[21] R.J. Blakely, "Potential theory in gravity and magnetic applications," Cambridge Univ. Press, Cambridge, U.K., 1995, pp.441.

[22] R.G. Henderson and I. Zietz, "The upward continuation of anomalies in total magnetic intensity fields," *Geophysics* vol. 14, pp. 517-534, Oct. 1949, doi: 10.1190/1.1437560.

[23] W.R. Roest, J. Verhoef, M. Pilkington, "Magnetic interpretation using the 3D analytic signal," *Geophysics* v. 57, pp. 116-125, Jan. 1992, doi: 10.1190/1.1443174.

[24] R.T. Baldwin, R. Langel, "Tables and Maps of the DGRF 1985 and IGRF 1990," *IAGA Bulletin*, ISGI Publications, France, vol. 54, pp. 103-185, 1993.

[25] M.C. Alçiçek, S. Mayda, J.H. teen Veen, S.J. Boulton, T.A. Neubauer, H. Alçiçek, A.S. Tesakov, G. Saraç, H.Y. Hakyemez, F. Göktaş, A.M. Murray, V.V. Titov, G. Jimenez-Moreno, Y. Büyükmeriç, F.P. wesselingh, J.M. Bouchal, F.A. Demirel, T.T. Kaya, K. Halaçlar, M. Bilgin, L.W. van den Hoek Ostende, "Reconciling the stratigraphy and depositional history of the Lycian orogen-top basins, SW Anatolia," Paleobiodiver. Paleoenviron., vol. 99, pp. 551-570, Dec. 2019, doi:10.1007/s12549-019-00394-3.

[26] A. Ateş, F. Bilim, A. Büyüksaraç, A. Aydemir, Ö. Bektas, Y. Aslan, "Crustal structure of Turkey from aeromagnetic, gravity and deep seismic reflection data," *Surv. Geophys.,* vol. 33, pp. 869-885, Sep. 2012, doi: 10.1007/s10712-012-9195-x.

[27] F. Bilim, "Investigation into the tectonic lineaments and thermal structure of Kutahya-Denizli region, Western Anatolia, from using aeromagnetic, gravity and seismological data," *Phys. Earth Planet. Inte*r., vol. 165, pp. 135-146, Dec. 2007, doi: 10.1016/j.pepi.2007.08.007.