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Journal of Science and Technology

E-ISSN 2146-7706

The correlation of b-value in the earthquake frequency-magnitude distribution, heat flow and gravity data in the Sivas Basin, central eastern Turkey

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ARTICLE INFO

Article history:
Received 04 October 2018
Received in revised form 17 June 2019
Accepted 18 June 2019

Keywords:
Seismicity
b-value
the Sivas Basin
the Maximum Likelihood Method

ABSTRACT

In this study, the seismicity in the Sivas Basin, central eastern Turkey from 1903 to 2018 is investigated by the Gutenberg and Richter relationship (1944) and the maximum likelihood method (Aki, 1965) to explore the b-value. The b-value is regarded as one of the important parameters representing the nature of the occurrence of earthquakes. Particularly, the b-value characterizes the state of stress in the crust. The Sivas Basin exhibits the low b-value (0.52 and 0.9), moderate/high heat flow values (70-80 mWm^{-2}), large negative anomalies owing to sedimentary basin and low seismicity and the epicenter distributions of earthquakes are located at the upper crust and along the Deliler-Tecer and Yukari Kizilirmak Fault Zones in the study region.

1. Introduction

The Gutenberg-Richter parameters (a, b) are used to examine seismic activity in an area. Particularly, b-value is an important parameter that describes the characteristics of an ensemble of earthquakes. The calculation of b-value has been successfully used by several authors since 1940's (e.g., Gutenberg and Richter, 1944; Aki, 1965; Scholz, 1968; Fiedler, 1974; Smith, 1981; Bender, 1983; Imoto, 1991; Burroughs and Tebbens, 2002; Bhattacharya and Kayal, 2003, Bridges and Gao, 2006; Katsumata, 2006; Bhattacharya et al., 2010; Mousavi, 2017; Chiba and Shimizu, 2018). The b-value can be related to the material heterogeneity, thermal gradient, volcanic activity, stress regime, tectonic events in the Earth's crust (Utsu, 1965; Scholz, 1968; Warren and Latham, 1970; Katsumata, 2006).

In the Sivas Basin, earthquake catalogs indicate that earthquakes generally have low magnitudes (3.5≤ Mb/Ms≤5.0) between 1903 and 2018. Although the basin is tectonically active, investigation of the seismic activity using b-value estimation is limited. Seismicity studies are generally concentrated on a regional basis. For example, Kalyoncuoglu et al. (2013) studied the b-value of the Aegean region. Bayrak et al. (2017) investigated the spatial variations of Gutenberg-Richter parameters in western Turkey. Ozturk (2018) studied the seismic hazard potential of the eastern Anatolia region. In this paper, the Gutenberg-Richter b-value for the Sivas Basin was estimated using the least-square fit method and the maximum likelihood method and the results were correlated with the gravity anomalies and heat flow values.

2. Regional Tectonics and Geology

The Sivas basin is located in the collision zone between the Pontides and Anatolides (Figure 1a). The boundaries of the basin are overthrusts to the north and left-lateral oblique faults with reverse components in the south (Figure 1b). According to Gursoy et al. (1992), the post-collisional tectonic development of the basin has been dominated by N-S to NW-SE compressional forces, commenced in mid-Eocene (post Lutetian) times and continued up to the present day. The basin was divided into subbasins by predominantly left lateral strike-slip oblique faults. There are two main east-west trending fault zones in the Sivas basin: 1) The Yukarı-Kızılırmak Fault Zone, and 2) The

Deliler-Tecer Fault Zone (Figure 1b). The Yukarı Kızılırmak Fault Zone has reverse motion with the upthrust hanging wall dipping to the south (Yilmaz and Yilmaz, 2006). The Deliler- Tecer Fault Zone is also reverse but dips to the north. The amount of upthrust increases towards the eastern part of the basin (Yilmaz and Yilmaz, 2006).

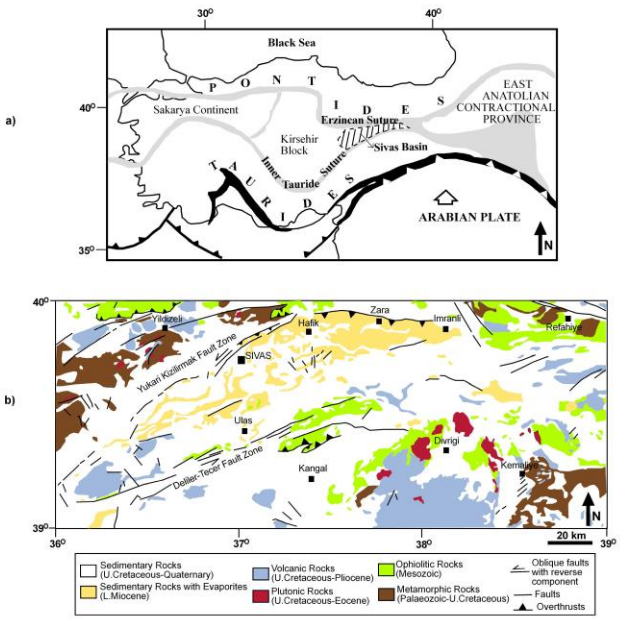

Figure 1. a) Tectonic units in Turkey and the Sivas Basin location (modified from Guezou et al., 1996 ans Gursoy et al., 1998); **b)** simplified geological map of the study area (modified from Yilmaz and Yilmaz, 2006; Yalcin-Erik et al., 2015).

Figure 1b shows the simplified geological map of the study area (modified from Yilmaz and Yilmaz, 2006; Yalcin-Erik et al., 2015). The basement of the Sivas Basin is composed of ophiolitic units originated from the northern branch of Neo-Tethys obducted onto the Tauride Platporm and its metamorphic equivalents, and represents mainly a suture zone developed between the Pontide Arc and Tauride Platform (Yılmaz and Yılmaz, 2006). The young sedimentary units of the basin overlie the basement. Small outcrops of plutonic rocks are mainly located around Divrigi and Yildizeli (Figure 1b). In addition, volcanic rocks have small outcrops to the south and SW of the Sivas Basin.

3. Data and Method

This study was carried out in the area bounded by the latitudes 39°-40° N and longitudes of 36°-39° E. Data were selected between 1903 and 2018, with the magnitudes of body-wave magnitude (Mb), and surface-wave magnitude (Ms), ≥ 3.5 from the International Seismological Centre (ISC) and the United States Geological Surveys (USGS) catalogues. Moment-magnitude (Mw) relations have played an important role in the earthquake mechanism studies since seismic source parameter determinations started in the early 1970's (Hanks and Boore, 1984). Recently, moment magnitude frequently has been used to estimate the seismic b-value of an investigated region (e.g., Gulal et al., 2016; Raub et al., 2017; Pudi et al., 2018). Using equations below developed by Scordilis (2006), all earthquake magnitudes converted to a uniform catalogue of $Mw \geq 4.0$:

$$Mw = 0.67\ Ms + 2.07,\ \ 3.0 \leq Ms \leq 6.1 \quad (1)$$

$$Mw = 0.99\ Ms + 0.08,\ \ 6.2 \leq Ms \leq 8.2 \quad (2)$$

$$Mw = 0.85\ Mb + 1.03,\ \ 3.5 \leq Mb \leq 6.2 \quad (3)$$

The b-value was estimated using two methods in this study:

3.1. The least-square fit method:

Earthquake frequency-magnitude distributions were developed by Gutenberg and Richter (1944) as

$$\log N(M) = a - bM,$$

where N(M) is the number of earthquakes with magnitude larger than M per year; a and b are the constant parameters. a-value is the measure of the regional level of seismicty and depends on the extent of the area, a number of earthquakes occurred in the region, the largest seismic magnitude and time interval (Gutenberg and Richter, 1944). The b-value is the slope of the frequency-magnitude distribution and related to the distribution of stress and strain (Utsu, 1965; Scholz, 1968). Scholz (1968) suggested an inverse relationship between the stress level in a given region and the local b-values. High b-value indicates a large number of small earthquakes and large heterogeneity (Tsapanos, 1990). Gutenberg and Richter (1944) found that b-values range from 0.45 to 1.5, Miyamura (1962) suggested that b-values change from 0.4 to 1.8 depending on the geological age of the tectonic area.

Using Equations 1, 2, and 3, a uniform catalogue $Mw \geq 4.0$ is constructed. Figure 2 shows the cumulative frequency-magnitude distribution of earthquakes. Linear straight line is fitted on the data using the least-square method. The completeness magnitude (Mc) of the data set is another important parameter for seismicity analysis (e.g. Woessner and Wiemer, 2005; Wiemer et al., 2009; Mignan et al., 2013). Mc is determined by plotting the cumulative number of events as a function of magnitude (Figure 2).

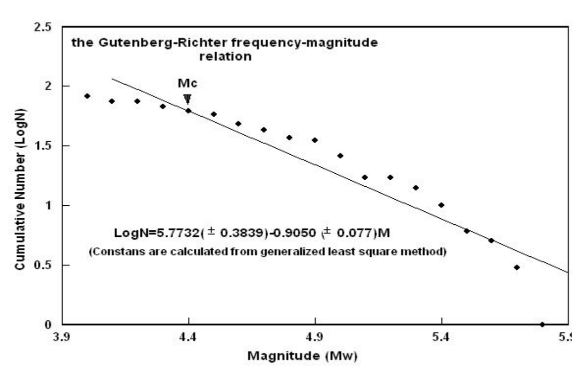

Figure 2. Cumulative frequency-magnitude distribution of earthquakes. Linear straight line is fitted on the data for determination of Mc, a and b-values.

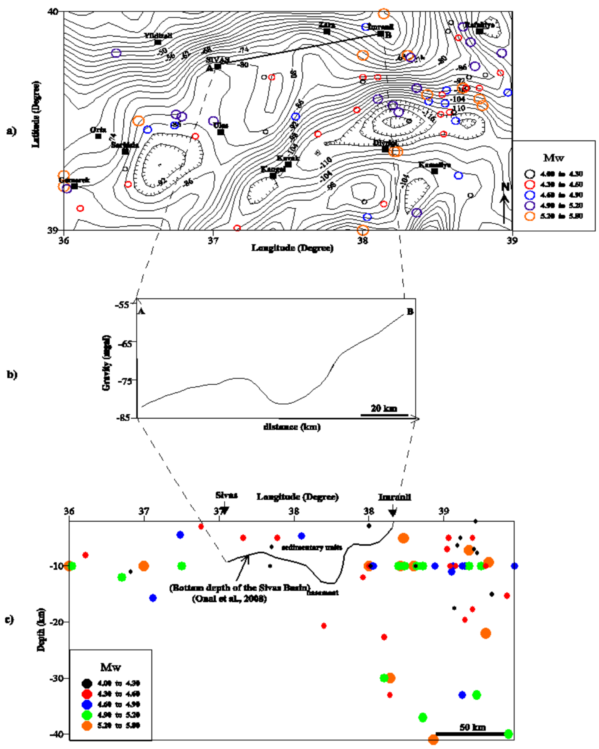

Figure 3. a) Bouguer anomaly map of the study area. Contour interval is 3 mGal. Circles show the epicenter distributions of earthquakes with Mw≥ 4.0 between 1903 and 2018. **b)** Gravity anomaly profile along AB-section given in Figure 3a. **c)** distribution of earthquakes with depth. Black line shows the depth of the Sivas Basin determined by Onal et al. (2008) from 3-D gravity model.

3.2. The maximum likelihood method:

The b-value can be estimated from the maximum likelihood method (Aki, 1965; Bender, 1983; Utsu 1999; Kalyoncuoglu et al., 2013; Nava et al., 2017) given as:

$$b = \frac{\log e}{\left(\sum_{i=1}^{N} \frac{M_i}{N}\right) - Mc} \qquad (4)$$

Where e and N is the base of natural logarithm (e=2.1718) and number of earthquakes, respectively. Mc= The completeness magnitude.

3. Discussion and Conclusions

Although the Sivas Basin is not tectonically active region and there are not large earthquake occured (for example Ms$\geq$5.9), it is an important region for located within the wedge-shaped eastern margin of the Anatolian Block between the North Anatolian Fault Zone (NAFZ) and the Eastern Anatolian Fault Zone (Gursoy et al., 1998) (Figure 1). Dogru et al. (2018) estimated the b-values between 0.5 and 1.0 along the central part of the NAFZ (north of Sivas). In addition, they suggest that low b- values are associated with high strain values regions along NAFZ. Therefore b-value was estimated in the study area because there are the possible relationships between the b-value and a crustal heterogeneity, volcanic activity, earthquake occurrence, geothermal potential. The a- and b-values for the Sivas Basin from Gutenberg and Richter (1944) relationship using the least-square fit method were estimated as 5.77 and 0.90, respectively (Figure 2). The estimated high- b value for the Sivas Basin may indicate the insufficiencie of the data or low seismic activity. In addition, b-value was estimated by using the maximum likelihood method as 0.52 (completeness, Mc=4.4). According to the result of the maximum likelihood method, there may be high rheological strength in the crust. However, frequent seismic activity in the Sivas Basin was not observed until the date. The estimated low-b value from the maximum likelihood method may be resulted from overthrusts or left-lateral oblique faults with reverse components on the boundaries of the Sivas Basin. In addition, low-b value may be associated with thick crust in the study region.

Figure 3a shows the Bouguer gravity anomalies in the study area. They are good correlation with the main faults (Figure 1b). The anomalies in the Sivas Basin are integrated with the effects of fractures, faults and intrusive bodies of basement, where there are changes in the density of the rock masses (Buyuksarac, 2007; Bektas, 2013). Therefore, faults can be identified on gravity anomaly map. The major trend of the contours related to the fault zones is along southwest-northeast direction, parallel to the trend of the basin. There are two prominent closure of gravity lows: 1) between Ulas and Sarkisla (about -92 mGal), and 2) around Divrigi (about -121 mGal) (Figure 3a). The low gravity values in these areas can be correlated with the thick-crustal structures and also thick sedimentary basin fill in the study region (Onal et al., 2008). The gravity values increase towards the north particularly between Sivas and Imranli (about -56 mGal) (Figure 3b). Onal et al. (2008) produced the three-dimensional gravity model of the Sivas Basin. They found that deepest parts (12-13km) of the basin were located beneath Hafik, to the south of Zara and at the S-SE of Imranli (Figure 3c). The crustal thickness of the study area was determined as about 40 km by Zor (2008). When Figure 3c is examined, it is seen that the focal depths of earthquakes are mainly located in the upper crust (< 20 km), around10 km, where they were determined as the upper crustal discontinuities associated with the volcano-sedimentary successions by Angus et al. (2006).

The epicentres of earthquakes are densely located to the north of Divrigi in relation with the Deliler-Tecer Fault Zone (Figure 4). The distribution of the epicenters of events shows that the Deliler-Tecer and Yukari Kizilirmak Fault Zones are still active in the study area. The heat flow values of the Sivas Basin are about 80 mWm^{-2} obtained from Ilkisik (1995) (Figure 4, red lines). The typical heat flow values are 70-80 mWm^{-2} in back-arc regions and more than 80-100 mWm^{-2} in the volcanic regions (Hyndman and Lewis, 1999). Generally, the Sivas Basin exhibits the low b-value (0.52 and 0.9), moderate/high heat flow values, large negative anomalies owing to sedimentary basin and low seismicity.

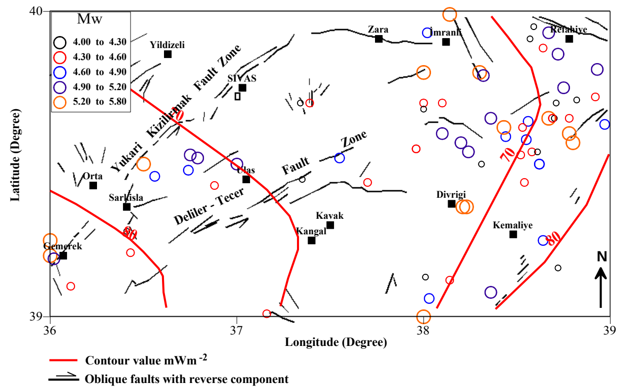

Figure 4. The correalation map of heat flows (red lines obtained from Ilkisik,1995) and the epicenter distributions of earthquakes. Contour interval 10 mWm^{-2}.

Acknowledgements

Authors are grateful to the General Directorate of Mining Research and Exploration (MTA) of Turkey for the gravity data.

References

Aki, K. 1965. Maximum likelihood estimate of b in the formula log(N)=a-bM and its confidence limits. Tokyo University Bulletin Earthquake Research Institute, 43, 237-239.

Angus, D.A., Wilson,D.C., Sandvol, E., Ni, J.F. 2006. Lithospheric structure of the Arabian and Eurasian collision zone in eastern Turkey from S-wave receiver functions. Geophysical Journal International 166, 1335-1346.

Bayrak, E., Yilmaz, S., Bayrak, Y. 2017. Temporal and spatial variations of Gutenberg-Richter parameter and fractal dimension in Western Anatolia, Turkey. Journal of Asian Earth Sciences, 138, 1-11.

Bektas, O. 2013. Thermal structure of the crust in Inner East Anatolia from aeromagnetic and gravity data. Physics of the Earth and Planetary Interiors, 221, 27-37.

Bender, B. 1983. Maximum likelihood estimation of b values for magnitude grouped data. Bulletin of the Seismological Society of America, 73, 831-851.

Bhattacharya, P.M, Kayal, J.R. 2003. Mapping the b-values and its correlation with the fractal dimension in the northeast region of India. Journal of Geological Society of India 62, 680-695.

Bhattacharya, P.M., Kayal, J.R., Baruah, S., Arefiev, S.S. 2010. Earthquake source zones in northeast India: Seismic tomography, fractal dimension and b-value mapping. Pure and Applied Geophysics, 167, 999-1012.

Bridges, D.L., Gao, S.S. 2006. Spatial variation of seismic b-values beneath Makushin Volcano, Unalaska Island, Alaska. Earth and Planetary Science Letters, 245, 408-415.

Burroughs, S.M., Tebbens, S.F. 2002. The upper-truncated power law applied to earthquake cumulative frequency-magnitude distributions: evidence for a time-independent scaling parameter. Bulletin of the Seismological Society of America, 92, 2983-2993.

Buyuksarac, A. 2007. Investigation into the regional wrench tectonics of Inner East Anatolia (Turkey) using potential field data. Physics of the Earth and Planetary Interiors, 160, 86-95.

Chiba, K., Shimizu, H. 2018. Spatial and temporal distributions of b-value in and around Shinmoe-dake, Kirishima volcano, Japan. Earth, Planets and Space 70, 122.

Dogru, A., Gorgun, E., Aktug, B., Ozener, H. 2018. Seismic hazard assessment of the central north Anatolian fault (Turkey) from GPS-derived strain rates and b-values. Geomatics, Natural Hazards and Risk, 9, 356-367.

Fiedler, B.G. 1974. Local b-values related to seismicity. Tectonophysics, 23, 277-282.

Guezou, J.C., Temiz, H., Poisson, A., Gursoy, H. 1996. Tectonics of the Sivas Basin:Neogene record of the Anatolian accretion along the Inner Tauric suture. International Geology Review, 38, 901-925.

Gulal, E., Tiryalioglu, I., Kalyoncuoglu, U.Y., Erdogan, S., Dolmaz, M.N., Elitok, O. 2016. The determination of relations between statistical seismicity data and geodetic strain analysis, and the analysis of seismic hazard in southwest Anatolia. Geomatics, Natural Hazards and Risk, 7, 138-155.

Gursoy, H., Piper, J.D.A., Tatar, O., Mesci, L. 1998. Palaeomagnetic study of the Karaman and Karapinar volcanic complexes, central Turkey: neotectonic rotation in the south-central sector of the Anatolian Block. Tectonophysics, 299, 191-211.

Gursoy, H., Temiz, H. Poisson, A. 1992. Recent faulting in the Sivas area (Sivas basin, central Anatolia, Turkey). Bull. Engineering Faculty, Cumhuriyet University, Sivas-Turkey Series A, Earth Sciences 9, 11-17.

Gutenberg, B., Richter, C. 1944. Frequency of earthquakes in California. Bulletin of the Seismological Society of America, 34, 185-188.

Hanks, T.C., Boore, D.M. 1984. Moment-Magnitude relations in theory and practice. Journal of Geophysical Research, 89, B7, 6229-6235.

Hyndman, R.D., Lewis, T.J. 1999. Geophysical consequences of the Cordillera-Craton thermal transition in southwestern Canada. Tectonophysics, 306, 397-422.

Ilkisik, O.M. 1995. Regional heat-flow in western Anatolia using silica temperature estimates from thermal springs. Tectonophysics, 244, 175–184.

Imoto, M. 1991. Changes in the magnitude-frequency b-value prior to large ($M \geq 6.0$) earthquakes in Japan. Tectonophysics, 193, 311-325.

Kalyoncuoglu, U.Y., Elitok, O., Dolmaz, M.N. 2013. Tektonik implications of spatial variation of b-vaues and heat flow in the Aegean region. Marine Geophysical Researches, 34, 59-78.

Katsumata, K. 2006. Imaging the high b-value anomalies within the subducting Pacific plate in the Hokkaido corner. Earth Planets and Space, 58, e49-e52.

Mignan, A., Jiang, C., Zechar, J.D., Wiemer, S., Wu, Z., Huang, Z. 2013. Completeness of the Mainland China earthquake catalog and implications for the setup of the China Earthquake forecast testing center. Bulletin of the Seismological Society of America, 103, 845-859.

Miyamura, S. 1962. Magnitude-frequency relations and its bearing to geotectonics. Proceeding of the Japan Academy, 38, 27-30.

Mousavi, S.M. 2017. Spatial variation in the frequency-magnitude distribution of earthquakes under the tectonic framework in the Middle East. Journal of Asian Earth Sciences, 147, 193-209.

Nava, F., Marquez-Ramirez, V., Zuniga, F., Avila-Barrientos, L., Quinteros-Cartaya, C. 2017. Gutenberg-Richter b-value maximum likelihood estimation and sample size. Journal of Seismology, 21, 127-135.

Onal, K.M., Büyüksaraç, A., Aydemir, A., Ateş, A. 2008. Investigation of the deep structure of the Sivas Basin (innereast Anatolia, Turkey) with geophysical methods. Tectonophysics, 460, 186-197.

Ozturk, S. 2018. Earthquake hazard potential in the Eastern Anatolia region of Turkey: seismotectonic b and Dc-values and precursory quiescence Z-value. Frontiers in Earth Science, 12, 215-236.

Pudi, R., Roy, P., Martha, T.R., Kumar, K.V., Rao, P. R. 2018. Spatial potential analysis of earthquakes in the western Himalayas using b-value and thrust association. Journal of the Geological Society of India, 91, 664-670.

Raub, C., Martinez-Garzon, P., Kwiatek, G., Bohnhoff, M., Dresen, G. 2017. Variations of seismic b-value at different stages of the seismic cycle along the north Anatolian fault zone in northwestern Turkey. Tectonophysics, 712-713, 232-248.

Scordilis, E.M. 2006. Empirical global relations converting Ms and mb to moment magnitude. Journal of Seismology, 10; 225-236.

Scholz, C.H. 1968. The frequency-magnitude relation of microfracturing in rock and its relation to earthquakes. Bulletin of the Seismological Society of America, 58, 399-415.

Smith, W.D. 1981. The b-value as an earthquake precursor. Nature, 289, 136-139.

Utsu, T. 1965. A method for determining the value of b in a formula log(N)=a-bM showing the magnitude frequency for earthquakes. Geophysical Bulletin, 13, 99-103.

Tsapanos, T.M. 1990. b-values of two tectonic parts in the circum Pasific belt. Pure and Applied Geophysics, 134, 229-242.

Utsu, T. 1999. Representation and analysis of the earthquake size distribution: a historical review and some new approaches. Pure and Applied Geophysics, 155, 509-535.

Warren, N.M., Latham, G.V. 1970. An experiment study of thermal induced micro-facturing and ist relation to volcanic seismicity. Journal of Geophysical Research, 75, 4455-4464.

Wiemer, S., Giardini, D., Fah, D., Deichmann, N., Sellami, S. 2009. Probabilistic seismic hazard assessment of Switzerland: best estimated and uncertainties. Journal of Seismology, 13, 449.

Woessner, J., Wiemer, S. 2005. Assessing the quality of earthquake cataloques. Estimation the magnitude of completeness and its uncertainty. Bulletin of the Seismological Society of America, 95, Doi:10.1785/012040007.

Yalcin-Erik, N., Aydemir, A., Buyuksarac, A. 2015. Investigation of the organic matter properties and hydrocarbon potential of the Sivas Basin, central eastern Anatolia, Turkey, using rock-eval data and organic petrography. Journal of the Petroleum Science and Engineering, 127, 148-168.

Yilmaz, A., Yilmaz, H. 2006. Characteristic features and structural ecolution of a post collisional basin: The Sivas Basin, central Anatolia, Turkey. Journal of Asian Earth Sciences, 27, 164-176.

Zor, E. 2008. Tomographic evidence of slab detachment beneath eastern Turkey and the Caucasus. Geophysical Journal International, 175, 1273-1282.