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Geophysical analysis of fault geometry and volcanic activity in the Erzincan Basin, Central Turkey: Complex evolution of a mature pull-apart basin

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ABSTRACT

The Erzincan Basin is one of several Neogene sedimentary basins developed by prolonged right-lateral strike-slip along the North Anatolian Fault Zone (NAFZ), the intracontinental transform defining the present boundary between the Eurasian Plate to the north and accreted Anatolian terranes to the south. The basin has a strong asymmetry and young (<780 ka) volcanic centers with widespread development of cross faults defining an advanced phase of pull-apart basin evolution. To isolate faults with no surface geomorphic or morphotectonic signatures in the young sedimentary cover, continuous magnetic profiles were conducted together with detailed interpretation of the regional Bouguer gravity map. This geophysical approach combined with surface mapping defines a fault geometry highlighting a series of buried structures including a fracture system 0.2–2.35 km wide which conforms to the volcanic lineaments seen at the surface. A model is developed for the evolution of the Erzincan Basin with a history commencing as a simple pull-apart by right-lateral strike-slip on the developing NAFZ, probably in Early Pliocene times. Subsequent interaction with a major left-lateral (Ovacık) fault (OF) caused the focus of motion on the NAFZ to shift to the southwest and develop a complex fishbone fracture system. This became the focus of volcanic activity on three lineaments which migrated progressively southwards toward the axis of the basin. Continuing motion on the OF transformed the south east margin of the basin into an extensional zone and the tectonic history of the basin has been further complicated by its proximity to a major transform intersection between the NAFZ and OF. The signatures of recent volcanism and the development of cross faults on which much activity is now concentrated define a mature pull-apart advancing toward extinction.

1. Introduction

The Eurasian Plate, the Anatolide/Tauride terranecollage (Anatolian Block) and the Arabian plate embrace the tectonic framework of Turkey with the collision between the latter two focussed along the Bitlis Suture Zone in the Late Miocene (Dewey and Şengör, 1979). Continuing northward movement of the Arabian Plate toward Eurasia is producing ongoing movement of Anatolian blocks to the west and causing c/elevation in East Anatolia and the Caucasus (McKenzie, 1972). The wedge-shaped convergence of the Anatolian Block at its eastern extension is constrained by the right-lateral North Anatolian and left-lateral East Anatolian faults with westward extrusion of blocks by tectonic escape accommodated primarily by motion along the North Anatolian Fault Zone (NAFZ) incentral-north Turkey. This fault is one of the most seismically-active strike-slip fault systems in the world and separates terranes accreted during demise of the Neotethyian Ocean to the south from the Pontide Orogen to the north. The continuing right-lateral motion was recorded during the 26 December 1939 Erzincan earthquake and subsequently by movements during the Erbaa 1942, Tosya 1943 and Gerede 1944 earthquakes. The NAFZ is recognized as a ~1200 km fault zone extending from Karlıova eastwards to Iran (Ketin, 1977); westwards it extends through the Aegean Sea to the Gulf of Saros (Ketin, 1969, 1976), and possibly to the Ionian Sea (Galanopoulos, 1965). Research in the region bordering this transform has focused mainly on neotectonic features of

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the fault zone, notably the effects of seismic events and the young volcanism. Studies examining regional geologic issues and providing broader syntheses are included in a wide range of papers (Arpat and Şaroğlu, 1975; Baş, 1979; Tatar, 1978; Koçyiğit and Tokay, 1985; Yılmaz, 1985; Dewey et al., 1986; Barka et al., 1987; Barka and Gülen, 1989; Kato et al., 1990; Koçyiğit, 1991a; Barka, 1992, 1993, 1996; Eyidoğan, 1993; Tüysüz, 1993; Yoshioka, 1996; Fuenzalida et al., 1997; Grosser et al., 1998; Chorowicz et al., 1999; Westaway and Arger, 2001; Hubert-Ferrari et al., 2002; Kaypak and Eyidoğan, 2002, 2005; Aktar et al., 2004; Temiz, 2004; Şengör et al., 2005; Karslı, 2006; Hartleb et al., 2006; Bektaş et al., 2007; Gökalp, 2007; Karslı et al., 2008; Kaypak, 2008; Doğru, 2010; Fraser et al., 2010; Özener et al., 2010; Fraser et al., 2012; Tatar et al., 2012; Fichtner et al., 2013; Karasözen et al., 2014).

Interpretations of pull-apart basin formation developed from the observational and analogue modeling approaches have seen a convergence of concepts in recent years (see Dooley and McClay, 1997; Rahe et al., 1998; Wu et al., 2009). Using an experimental simulation model Rahe et al. (1998) conclude that pull-apart basins develop in stages: initially steep-dipping normal faults control the edges whilst in the mature stages developing surface fractures migrate toward the center of the basin and contribute to an extinction process. During the late phase of basin formation as the tectonism approaches extinction the faults typically develop in a way which cuts the basin diagonally in the center. In the east of the Erzincan Basin beyond the area of the Erzincan plain NW–SE striking normal faults and E–W trending normal faults extend into the basin in the manner predicted for the mature stage of an asymmetric pull-apart. Both field observations and experimental simulation models indicate that these cross-basin faults cut the floor of the pull-apart and link with the master transform zones at advanced stages of extension (Zhang et al., 1989; Yoshioka, 1996; Rahe et al., 1998; Kuşcu, 2009).

The Neogene-Quaternary pull-aparts along the NAFZ show the typical wedge-shaped form with widths up to 10 km focused at zones of high seismic activity (Koçyiğit, 1989; Barka et al., 2000; Şengör et al., 2005). The Erzincan Basin is amongst the largest and best-defined of these basins. Earthquake activity motivated by strike-slip during the last century has highlighted surface fractures which diverge from the edge faults and these are typically observed in the center of these basins (Gürbüz and Gürer, 2009). Although the pull-aparts are surrounded by topography formed by large fault scarps at active faults along their edges, the surface fractures linked to the major recent earthquakes are characteristic of faults cross-cutting the basin floor; this is a typical indicator of an advanced stage of development. It is widely recognized that these faults migrate from the edgesas pull-apart basins move toward extinction (Şengör, 1979; Aydın and Nur, 1982; Hempton and Dunne, 1984; Şengör et al., 1985; Koçyiğit, 1990, 2003).

The Erzincan Basin has a length of 50 km and width of 10 km, and contains an extensive Plio-Quaternary infill with trachyandesitic-dacitic, rhyolitic and basaltic volcanism widely developed in the NE corner (Baş, 1979; Hempton and Linneman, 1984; Adıyaman et al., 2001; Linneman, 2002; Karslı, 2006; Akpınar, 2010; Tatar et al., 2013). The basin has all the attributes of a typical rhomboidal pull-apart developed between two parallel master segments of the NAFZ (Şengör, 1979; Aydın and Nur, 1982; Hempton and Dunne, 1984; Şengör et al., 1985 and see Fig. 1). Within the basin a conjugate geometry is evident between the NAFZ, the North East Anatolian Fault (NEAFZ) and the Ovacık Fault (OF) (Barka and Gülen, 1989; Kaypak and Eyidoğan, 2002); these are the defining framework faults (Fig. 1).

A range of interpretive models have been proposed to explain the evolution of the basin. These may be summarized as follow: (i) a rhomboidal pull-apart with both sides controlled by active faults (Aydın and Nur, 1982; Hempton and Dunne, 1984). (ii) A basin opened under the influence of multiple fault branches such as the Yedisu, Avcıdağ, Ovacık and NEAFZ (Barka and Gülen, 1989; Kaypak and Eyidoğan, 2005); specifically Barka and Gülen (1989) recognize three contrasting segments to this sector of the NAFZ and interpret the location and geometry of these segments in terms of the development of the root structure of the basin. (iii) A basin opening controlled by pull-apart but influenced by simultaneous lateral uplift, and related to initiation in Late Miocene times of south southeast-north northwest oriented thrusting along the Sivas Basin (Temiz, 2004). (iv) A two stage opening with the first stage comprising left-lateral block movement along the Ovacık Fault combined with clockwise rotation and the second stage resulting from right-lateral block movement along the NAFZ (Chorowicz et al., 1999).

A series of Neogene to Quaternary-aged dacitic-rhyolitic-basic volcanic cones is present along the north edge of the Erzincan Basin (Fig. 2). The volcanic centers near the northern margin of the basin are clearly linked to the NAFZ (Ketin, 1969; Baş, 1979; Hempton and Linneman, 1984; Adıyaman et al., 1998; Karslı, 2006) the trace of this transform along the northern edge of the basin indicates that the young cones near to this margin (and comprising the bulk of the volcanic activity within the basin) are parallel to, but displaced from, the trend of the master fault. An additional cone at Molla Hill is recognized in the south of the basin (Fig. 2) and the present study has also identified further small volcanic outcrops southeast of Pulur village on Pulur Hill which are also near-parallel to the master fault in this area. Karslı (2006) and Karslı et al. (2008) show that the volcanic activity has a post-collisional chemical signature contrasting with the older volcanism in this region. Some of the cones contain perlite and have been subject to several age dating studies; these determinations include estimated age ranges of 0.273–0.246 Ma (Baş, 1979; Hempton and Linneman, 1984; Linneman, 2002), <0.012–0.140 Ma (Adıyaman et al., 2001) and 0.102–0.140 Ma (Karslı, 2006). All volcanic activity occurred within the Brunhes Normal Polarity Chron (<780 ka, Tatar et al., 2013).

The Erzincan Basin has been affected by destructive earthquakes during both historic and recent times. Barka et al. (1987) noted evidence for 25 large historic earthquakes in the Erzincan Basin whilst Ambraseys (1970), Ambraseys and Finkel (1988), Barka and Gülen (1989), Barka (1996) and Grosser et al. (1998) describe evidence showing that major destructive earthquakes with maximum intensities over magnitude 8.0 (Barka et al., 1987; Fraser et al., 2012) occurred in the eastern part of the NAFZ including the Erzincan Basin in the years 1043 or 1045, 1254, 1668, 1939. Whether the 17th August 1668 earthquake is comparable with 1939 earthquake in terms of its destructiveness is unclear but it caused widespread damage resulting in the destruction of towns and villages (Ambraseys and Finkel, 1988, 1995). The 26th December 1939 earthquake on the NAFZ is the most significant instrumentally-recorded earthquake. Surface ruptures, generated by this earthquake are observed from Sansa Valley in the northeast of Erzincan to Ezinepazarı town in the east of Amasya city (Pamir and Ketin, 1941; Ketin, 1969). Egeran and Lahn (1944), Ketin and Rösli (1953), Ketin (1969), Ambraseys (1970), Dewey (1976), Barka and Cadinsky-Cade (1988), Barka (1992, 1996), Stein et al. (1997), Fraser et al. (2010) and Fraser et al. (2012) have all identified rupture segments on the NAFZ resulting from the 1939 Erzincan earthquake. Ketin (1969), Barka (1996) and Fraser et al. (2012) report a total length of surface rupturing generated by this earthquake of 340–360 km.

In this study, a field research aimed to investigate development of crustal deformation depending on tectonic events in the regional scale and neotectonic evolution of Erzincan Basin using geological and geophysical methods. The present study uses potential field