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The structural elements and tectonics of the Lake Van basin (Eastern Anatolia) from multi-channel seismic reflection profiles

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A B S T R A C T

This study analyzed multi-channel seismic reflection data from Lake Van, Eastern Anatolia, to provide key information on the structural elements, deformational patterns and overall tectonic structure of the Lake Van basin. The seismic data reveal three subbasins (the Tatvan, northern and Ahlat subbasins) separated by structural ridges (the northern and Ahlat ridges). The Tatvan basin is a tilted wedge-block in the west, it is a relatively undeformed and flat-lying deep basin, forming a typical example of strike-slip sedimentation. Seismic sections reveal that the deeper sedimentary sections of the Tatvan basin are locally folded, gently in the south and more intensely further north, suggesting a probable gravitational “wedge-block” instability, oblique to the northern margin. The northern subbasin, bounded by normal oblique faults, forms a basin-margin graben structure that is elongated in a northeast-southwest direction. The east-west trending Ahlat ridge forms a fault-wedged sedimentary ridge and appears to offset by reverse oblique faults forming as a push-up rhomb horst structure. The Ahlat subbasin is a fault-wedged trough fill that is elongated in the west-east direction and appears as a horst-foot graben formed by the normal oblique faults. The northeast-southwest directed northern ridge is a faulted crestal terrace of a sublacustrine basement block. Its step-like morphology, in response to the downfaulting of the Tatvan basin, as well as its backthrusted appearance, indicates the normal oblique nature of the bounding faults.

The lacustrine shelf and slope show distinctive stratigraphic features; progradational deltas, submerged fluvial channels, distorted and collapsed beddings and soft sediment deformation structures, characterizing a highly unstable nature of shelf caused by strong oblique faulting and related earthquakes. The faulting caused uplift of the Çarpanak spur zone, together with the northeastern Erek delta, deformation of deltaic structures and subsequently exposing the shelf and slope areas. The exposed areas are evident in the angular unconformity surface of the Çarpanak basement block with the northeastern Erek delta and thinned sediments. The uplift resulted in the asymmetric depositional emplacement of the southeastern delta that is controlled by a series of ramp anticlines/low angle reverse faults. The Deveboynu subbasin and Varis spur zone form wide fault-controlled depressions with thick sediments that are elongated in the north-south direction. These subbasins appear as a small pull-apart boundary formed by normal oblique faults at the western end of the southeastern delta.

1. Introduction

Lake Van is located along the Eastern Anatolia orogeny, which is the continuation of the Alp/Himalayan orogenesis (Fig. 1). The geographic position of the lake is restricted to a region where the

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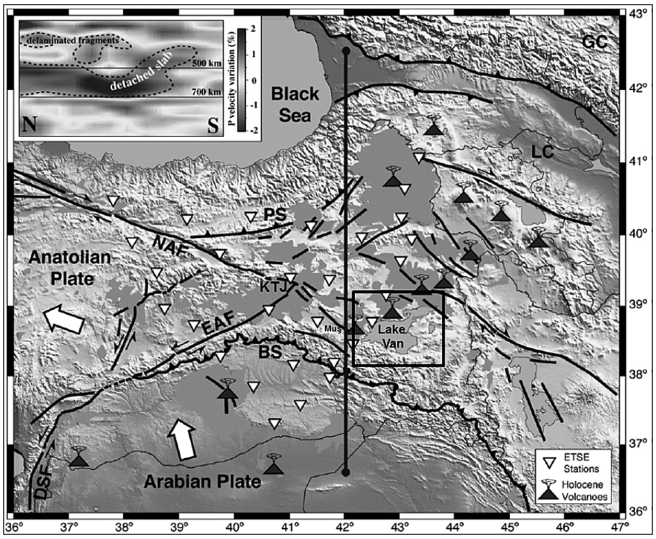

Fig. 1. Regional tectonic map of eastern Turkey with topographic relief, station locations of Eastern Turkey Seismic Experiment-ETSE array (inverted triangles), Neogene volcanics and Holocene volcanoes (triangles). The arrows indicate the direction of plate and fault motions. NAF, North Anatolian Fault; EAF, East Anatolian Fault; DSF, Dead Sea Fault; BS, Bitlis Suture; PS, Pontide Suture; LC, Lesser Caucasus; GC, Greater Caucasus. KTJ, Karlıova Triple Junction The north-south trending line shows the location of the seismic tomography. The enclosed areas characterized by positive anomalies are taken from Keskin (2007), and represent locations of detached slab and delaminated fragments of lithospheric mantle (Ozacar et al., 2008). The squared area shows the Lake Van basin. The inset figure shows the tomographic cross-section of from Faccenna et al. (2006) based on the seismic model of Piromallo and Morelli (2003).

Afro/Arabian Plate from the south meets the Eurasian Plate from the north and east (Fig. 1). Hence, the sediments of Lake Van offer a unique opportunity to study collision and post-collisional tectonics.

Lake Van is a dome-shaped basin that lies in a tectonic depression formed through a combination of normal and strike-slip faulting and thrusting (Fig. 1) (Sengor and Kidd, 1979; Sengor et al., 1985, 2008; Dewey et al., 1986; Toker, 2011; Toker and Sengor, 2011; Cukur et al., 2013a, b). This faulting caused regional volcanism, hydrothermal activity (Degens and Kurtman, 1978; Kipfer et al., 1994; Keskin, 2003; Sengor et al., 2003, 2008) and several destructive earthquakes (Toker and Ecevitoglu, 2012b, a; Bayrak et al., 2013; Toker, 2013b, a; Toker and Ecevitoglu, 2013; Utkucu et al., 2013; Toker, 2014). The lake also contains three of the five sub-active volcanic centers in Eastern Anatolia (Fig. 1). The lake is near the Karlıova triple junction (KTJ) and this allows fluids from the Earth's mantle to accumulate in Lake Van (Litt et al., 2009, 2011; Tomonaga et al., 2014) and the nearby crater lake of the Nemrut volcano (Fig. 1; Kipfer et al., 1994; Tomonaga et al., 2014). The lake and the surrounding areas are of special interest since they are located almost above the rifting of an inferred slab-break off or above the edge of the lithospheric delamination (Sandvol et al., 2003; Sengor et al., 2003, 2008). This finding appears to be consistent with the results of previous geophysical studies and the presence of a number of big volcanic edifices (mainly stratovolcanoes), some of which (the Nemrut and Süphan volcanoes) have been recently active as revealed in the documentation concerning Lake Van sediments (volcanic ashes, tephras and pyroclastic deposits) (Litt et al., 2009, 2011; Cukur et al., 2013a, b; 2014a, b). The sediments of Lake Van have been targeted by a deep-drilling project of the International Continental Scientific Drilling Program (ICDP, www.icdp-online.org) to understand the glacial and interglacial cycles during the last 600 ka (Litt et al., 2009, 2011; Toker, 2011; Toker and Sengor, 2011; Litt et al., 2012; Cukur et al., 2013a, b; Baumgarten et al., 2014; Cagatay et al., 2014; Cukur et al., 2014a, b; Kwiecien et al., 2014; Litt and Anselmetti, 2014; Litt et al., 2014; Randlett et al., 2014; Stockhecke et al., 2014a, b; Tomonaga et al., 2014; Vigliotti et al., 2014). The analysis of the varved sediments of Lake Van has shown critical information on the past environmental conditions prevailing in Lake Van (Kaden et al., 2010; Tomonaga et al., 2011a, b; Tomonaga et al., 2014).

Extensive geophysical and geological research has been carried out by various teams on diverse topics and in different areas in Eastern Anatolia (Cukur et al., 2013a, 2014a, b, 2016); however, an overall understanding of the structural setting of Lake Van and the surrounding area is still lacking. No definitive agreement has yet been reached among geoscientists on the fundamental nature of tectonic processes that form and shape Lake Van (Cukur et al., 2016). The lake is known to have been formed by orogenic processes (e.g., Sengor et al., 1985; Dewey et al., 1986; Kocyigit et al., 2001) but there are still vigorous debates about the coexistence of extensional and strike-slip basin formation within a thrust-ramp setting (Sengor et al., 1985; Dewey et al., 1986; Kocyigit et al., 2001; Toker, 2011; Toker and Sengor, 2011). The morpho-tectonic and hydrological features of Lake Van are intimately connected to global plate tectonics since at plate margins the morphology tends to develop rapidly (Kempe and Degens, 1978). These studies noted the lake had a rift-valley-like basin form, although no rifting had occurred, rather there was a convergence of plates (Sengor et al., 2003, 2008). However, the possibility of rifting in the lake is still a question to be answered (Toker, 2011; Toker and Sengor, 2011). The different types of problems that arise from the research concerning the Lake Van basin offer challenges to the scientific community. Understanding the upper crustal deformation (e.g., strike-slip tectonics) and basin formation has spawned scientifically rich multidisciplinary on-going observational and theoretical efforts involving the Eastern Turkey Seismic Experiment (Sandvol et al., 2003) and ICDP-PaleoVan-2004 project (Litt et al., 2009, 2011, 2012, 2014).

New insight into the Lake Van basin has been triggered, primarily, by the seismic reflection and Geo-chirp data, and the preliminary results of the tectonics, magmatism and structural deformation in the lake (Toker, 2011; Toker and Sengor, 2011). The morphology and the sedimentary processes in Lake Van have been documented by seismic profiles (Cukur et al., 2013a, b; 2014a, b). However, the structural elements and tectonic nature of the Lake Van basin have not been clearly reported yet (Cukur et al., 2016). Our previous research on the tectonics and on the magmatism in Lake Van (Toker, 2011; Toker and Sengor, 2011), as well as the earthquake-induced soft sediment deformation and delta degradation process for shallow water setting (Toker, 2011); set the first basis for our evaluations in this study. The main aim of our study is, therefore, to document the overall structural elements of Lake Van using multi-channel seismic reflection profiles. Moreover, we discuss the main structural elements and their relationship with tectonics and sedimentation and obtain a reasonably clear idea about the fundamental nature of tectonic processes that form and shape Lake Van. The present study has given some important constraints on the structural evolution of Lake Van and has provided a more comprehensive understanding of the thin-skinned tectonics and strike-slip deformation in deep orogenic lakes.

2. Tectonic and physiographic setting

Lake Van (43.0°E and 38.5°N) is located in Eastern Anatolia (Fig. 1), Turkey, at an altitude of 1648 m above the sea level (m.a.s.l.). Lake Van has a maximum water depth of about 450 m and it is the deepest and largest lake in Turkey and at 576 km^3 the fourth largest terminal lake in the world. The lake measures 130 km from west-southwest to east-northeast and has a surface area of