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Analysis of soft-sediment deformation structures in Neogene fluvio-lacustrine deposits of Çaybağı Formation, Eastern Turkey

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ABSTRACT

During the Neogene, both strike-slip and extensional regimes coexisted in eastern Turkey and, a number of fault-bounded basins associated with the East Anatolian Fault System developed. The Çaybağı Formation (Late Miocene–Early Pliocene) deposited in one of these basins consists of fluvio-lacustrine deposits.
Numerous soft-sediment deformation structures are encountered in this formation, particularly in conglomerates, medium- to coarse-grained tuffaceous sandstones and claystones: folded structures (slumps, convolute laminations, and simple recumbent folds), water-escape structures (intruded sands, internal cusps, interpenetrative cusps and sand volcanoes), and load structures (load casts, pseudonodules, flame structures, and pillow structures). These structures are produced by liquefaction and/or fluidization of the unconsolidated sediments during a seismic shock.
Consequently, the existence of seismically-induced deformation structures in the Çaybağı Formation and the association with a Neogene intraformational unconformity, growth faults, and reverse faults in the Çaybağı basin attest to the tectonic activity in this area during the Late Miocene and Early Pliocene. The East Anatolian Fault System, in particular the Uluova fault zone, is the most probable seismogenic source. Earthquakes with a magnitude of over 5 in the Richter scale can be postulated.

1. Introduction

The North Anatolian Fault System (NAFS) and the East Anatolian Fault System (EAFS) of Turkey are two of the most important, active continental, transform fault zones in the world (Fig. 1A). The NAFS has been more active since the early twentieth century. In contrast, the EAFS shows a low level of recent seismic activity despite its historical seismicity (Table 1) and geomorphological evidence. The present seismic quiescence, given the past historical activity, suggests that the EAFS may be "locked," accumulating elastic strain energy. Therefore, it could be as active and dangerous as the NAFS in the near future (Dewey et al., 1986; Çetin et al., 2003).

Processes that deform sediments include overloading, unequal loading, groundwater movements, cyclical and/or storm waves, and earthquakes (Owen, 1987, 1996). Seismic shocks lead to liquefaction and fluidization in unconsolidated sediments, causing penecontemporaneous deformation (Seilacher, 1969; Lowe, 1975). Seismites, or sediments with earthquake-induced deformation, have been described in many sedimentary environments; they are especially well-described from lacustrine sediments (Sims, 1973, 1975; Calvo et al., 1998; Rodríguez-Pascua et al., 2000; Rossetti and Góes, 2000; Upadhyay, 2003; Gibert et al., 2005; Neuwerth et al., 2006; Moretti and Sabato, 2007; Singh and Jain, 2007) and fluvial deposits (Allen and Banks, 1972; Plint, 1985; Guiraud and Plaziat, 1993; Owen, 1995; Dasgupta, 1998; McManus and Bajabaa, 1998; Upadhyay, 2003; Samaila et al., 2006).

The aims of this paper are (1) to describe the various types of soft-sediment deformation structures in fluvio-lacustrine settings, (2) to describe liquefaction and fluidization processes recorded within the Neogene fluvio-lacustrine deposits of the Çaybağı Formation, (3) to discuss their potential triggering mechanisms, and (4) to estimate the minimum magnitudes of earthquakes associated with the Neogene deformation structures.

2. Geological and tectonic settings

During the Neogene, both strike-slip and extensional regimes gave rise to a number of fault-bounded basins in eastern Turkey (Fig. 1B) (Şaroğlu and Güner, 1981; Şengör et al., 1985; Şaroğlu and Yılmaz, 1986). Tectonic evolution was largely influenced by the convergence of the Arabian and Anatolian plates (Fig. 1A). ENE–WSW oriented fold — thrust fault belts, strike-slip faults, and related basin formation are the result of the continental — continental collision between the northward-moving Arabian Plate and the Eurasian Plate during the Late Serravalian (Şaroğlu and Güner, 1981; Şengör and Yılmaz, 1981; Şengör et al., 1985; Dewey et al., 1986; Şaroğlu and Yılmaz, 1986).

A component of this tectonic regime is the East Anatolian Fault System (EAFS), which is a 30 km wide, 700 km long, and NE-trending sinistral, strike-slip megashear belt between the Anatolian plate in the

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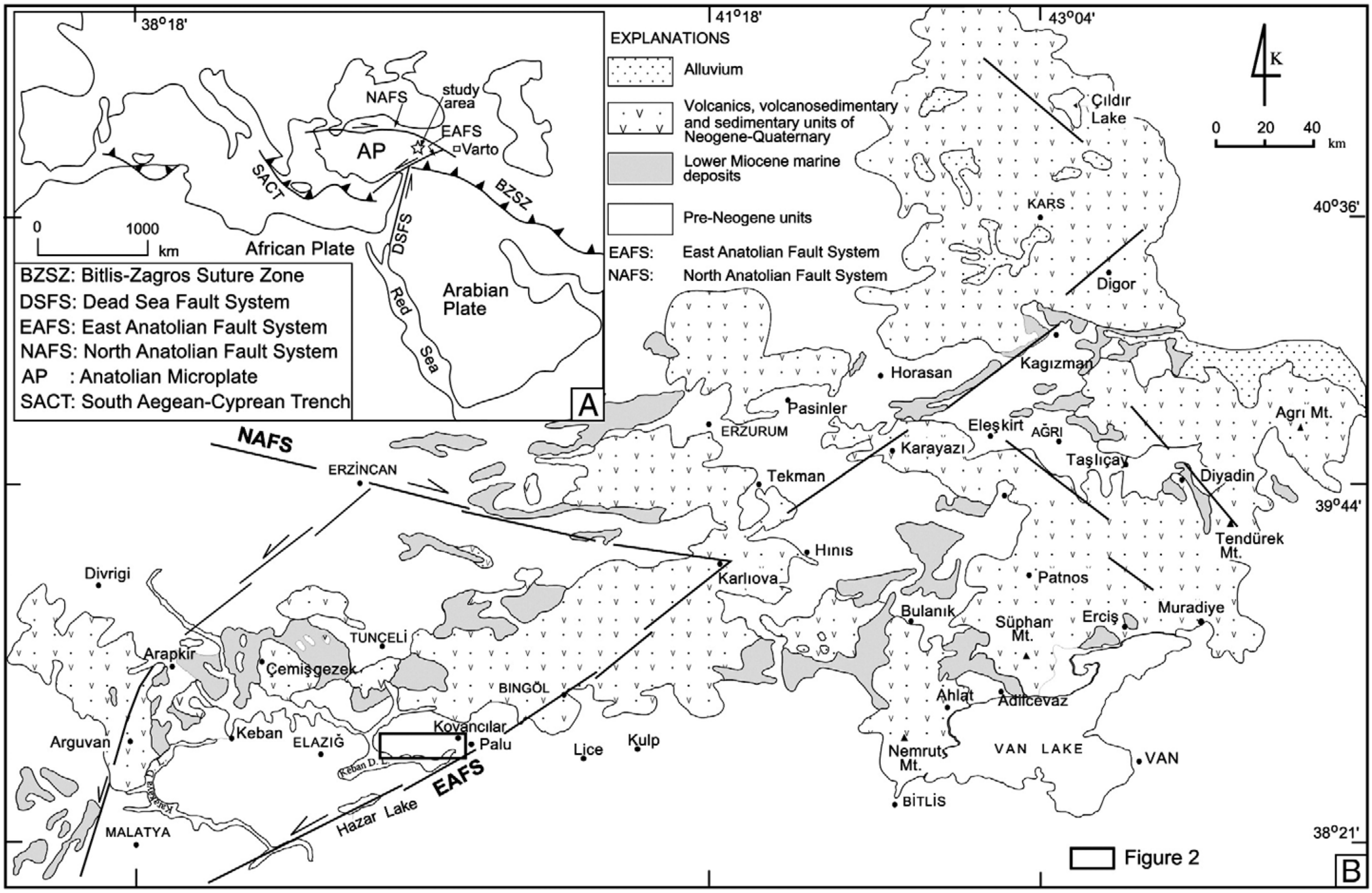

Fig. 1. Simplified map showing major plates in the Mediterranean region (A), and distribution of the Neogene–Quaternary units in eastern Turkey (B) (after Bingöl, 1989).

northwest and the African and Arabian plates in the southeast. In the study area, the EAFS consists of five fault zones. These are, from north to south, the Elazığ fault zone, the Uluova fault zone, the Sivrice fault zone, the Adıyaman fault zone, and the Lice-Çermik fault zone (Aksoy et al., 2007). The southern edge of the Neogene basin in this study is bordered by the Uluova fault zone forming the Kargadağ–Master Mountains uplift.

The basement of the studied Neogene basin consists of the Upper Cretaceous Elazığ magmatic complex and Middle Eocene Kırkgeçit Formation (Fig. 2). The Upper Cretaceous magmatic complex consists of basalt, andesite, pillow lava, and agglomerate. The magmatic rocks are overlain by limestone, sandstone, and marl build-ups of the Kırkgeçit Formation. Neogene deposits (Çaybağı Formation) are mostly fine- to coarse-grained siliciclastic rocks, limestone, tuffite, mudstone, and peat deposited in a tectonically-controlled basin in a shallow lake and river system (Türkmen, 1991; Aksoy et al., 2005).

Table 1
List of large historical and instrumental earthquakes (Ms ≥ 6.6) on the EAFS (modified from Çetin et al., 2003).

Date	Magnitude (Ms)	Location	Reference
995	7.0–7.8	Palu	a
03/28/1513	7.4+	Malatya-Tarsus	b
05/29/1789	7.0+	Palu	a, b
06/20/1866	6.8−	Kulp	b, c
05/03/1874	7.1+	Gölcük (Lake Hazar) 1	a, b
03/27/1875	6.7	Gölcük (Lake Hazar) 1	a, b
03/02/1893	7.1+	South Malatya	a, b
12/04/1905	6.8	Malatya	a, b, d
05/22/1971	6.8	Bingöl	a, b, e, f, g
09/06/1975	6.6	Lice	a, b, h

(a) Ambraseys and Jackson (1998); (b) Ambraseys (1989); (c) Pınar and Lahn (1952); (d) Ambraseys and Finkel (1987); (e) Arpat and Şaroğlu (1972); (f) Seymen and Aydın (1972); (g) Keightly (1975); (h) Arpat (1977).

3. Sedimentological setting

The depositional environment of the Çaybağı Formation is analyzed in detail in this study. Five types of facies associations are identified: braided river, low-sinuosity river, lacustrine delta front, lacustrine shallow, and open lacustrine (Fig. 3). The braided river facies association consists of planar stratified conglomerate, planar and trough cross-stratified conglomerate, planar and trough cross-stratified sandstone, ripple cross-laminated sandstone, and planar laminated sandstone. The low-sinuosity river facies association is composed of planar stratified conglomerate, planar and trough cross-stratified conglomerate, planar and trough cross-stratified sandstone, ripple cross-laminated sandstone, planar laminated sandstone, grey claystone, and red mudstone. Grey claystone contains gastropod, bivalve, and ostracod fossils, such as *Cyprideis anatolica* Bassiouni, *Cyprideis pannonica* (Mehes), *Cyprideis torosa* (Jones), *Candona* (*Candona*) *parallela pannonica* Zalanyi, *Ilyocypris gibba* (Ramdohr), and *Candona neglecta* Sars.

The lacustrine deposits are divided into three facies associations. The coarse-grained, delta front facies association consists of Gilbert-type delta deposits composed of bottomset, foreset, and topset beds, mouth bar-type deposits, and levee deposits. Mouth bar-type delta front deposits consist of planar stratified conglomerate, planar and trough cross-stratified sandstone, and ripple cross-laminated sandstone. Levee deposits are characterized by climbing-ripple cross-laminated sandstone. The shallow lacustrine facies association has