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The Traces of Earthquake (Seismites): Examples from Lake Van Deposits (Turkey)

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1. Introduction

The soft sediment deformation structures formed by liquefaction or fluidization in the unconsolidated and cohesionless sediments during deposition or later (Lowe, 1975; Owen, 1996). These structures composed of overpressure of sediments, storm waves, sudden oscillation of groundwater or seismic shakings (Allen, 1982; Owen, 1987, 1996; Molina et al., 1998).

All kinds of earthquake induced soft sediment deformation structures are called as "seismite" (Seilacher, 1969). Seismites frequently observed in lacustrine deposits alike other depositional environments (Sims, 1975; Hempton et al., 1983; Seilacher, 1984; Davenport & Ringrose, 1987; Ringrose, 1989; Mohindra & Bagati, 1996; Alfaro et al., 1997; Calvo et al., 1998; Rodriguez-Pascua et al., 2000; Bowman et al., 2004; Neuwerth et al., 2006; Moretti & Sabato, 2007). Seismites can occur with seismic tremor (M≥5) (Fukuoka, 1971; Kuribayashi & Tatsuoka, 1975; Atkinson, 1984; Ambraseys, 1988) and they use for determination of the location and density of seismic activity (Sims, 1975; Weaver, 1976; Hempton et al., 1983; Talwani & Cox, 1985; Scott & Price, 1988; Ringrose, 1989).

The purposes of this study are; to determine the types of deformation structures in Lake Van deposits, to interpret the triggering mechanism and to discuss the importance of these structures in regional tectonic.

2. Method of the study

This study completed in six steps: (1) to determine the locations of soft sediment deformation structures, (2) to prepare the measured sedimentological sections according to facies properties and depositional subenvironments, (3) to measure the dimension and geometry (shape, symmetry and depth) of deformation structures and to determine the lateral continuity of deformed layers, (4) to detect the liquefaction potential of deposits by the help of sieve analysis, (5) to investigate the active faults and earthquake records (M≥5) at surrounding area, and (6) to match the all data with previous studies.

3. Geological settings

Lake Van is the largest soda lake of the world which has 607 km^3 volume and 451 metres depth (Kempe et al., 1978). The lake was formed at least 500 kyr ago (Litt et al., 2009). Lake

Van Basin exist at Eastern Anatolia Plateau as the product of Middle Miocene collision of Eurasia and Arabian plates (Şengör & Kidd, 1979; Şengör & Yılmaz, 1981; Keskin et al., 1998) (Fig. 1).

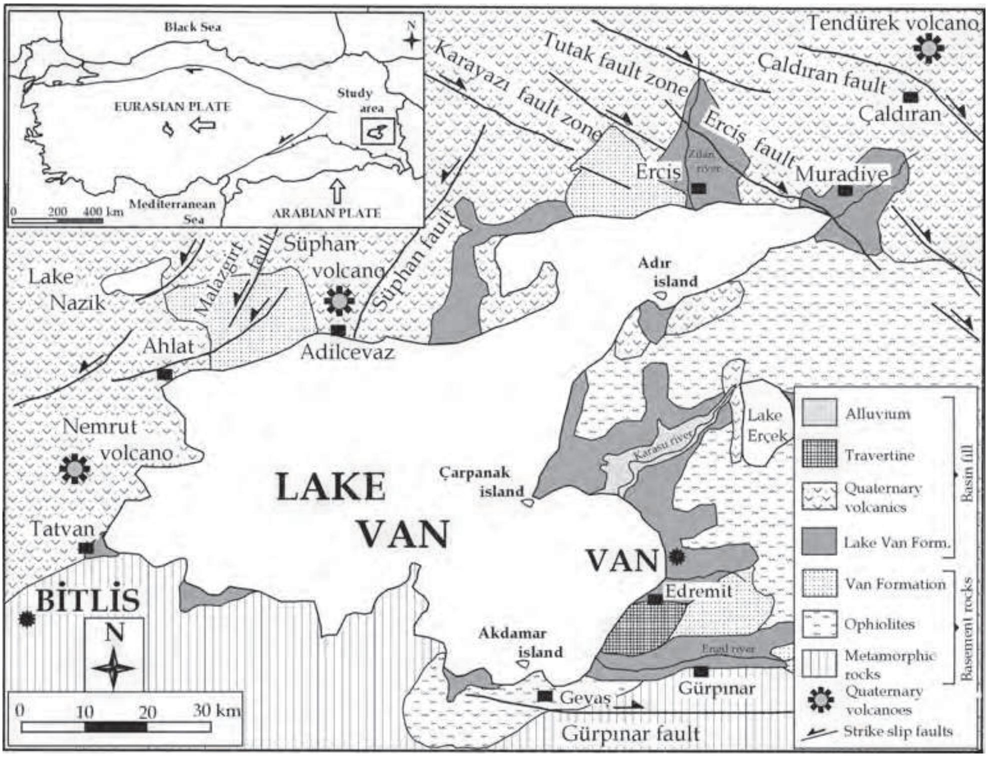

Fig. 1. Simplified geological map showing the active faults (Modified from Kurtman et al., 1978; Bozkurt, 2001; Koçyiğit et al., 2001).

Neotectonic period was started in Pliocene for the Eastern Anatolia Plateau and Lake Van Basin (Koçyiğit et al., 2001). This period is represented by N-S compressional regime. That compressional regime creates NW-SE trending dextral and NE-SW trending sinistral strike-slip faults (Şaroğlu & Yılmaz, 1986; Bozkurt, 2001; Koçyiğit et al., 2001) (Fig. 1). The region has a number of active faults that create earthquakes (M≥5). The Çaldıran Earthquake (1976) is the most known among these with their impact (M_s= 7.2) (Table 1).
Lake Van Basin stays on basement units which are Bitlis Metamorphic Complex, Upper Cretaceous Ophiolites and Oligocene-Miocene turbidites (Van formation). The basin fill

consists of Quaternary volcanic rocks (from Nemrut and Süphan volcanoes), contemporaneous lacustrine deposits, Late Quaternary travertines and alluvium (Fig. 2). Generally, lacustrine sediments locate in east and north of Lake Van (Fig.1). These sediments were deposited during the period of highest lake level (+105 m) in 115000 years ago (Kuzucuoğlu et al. 2010). The deformation structures (seismites) are observed in these lacustrine deposits.

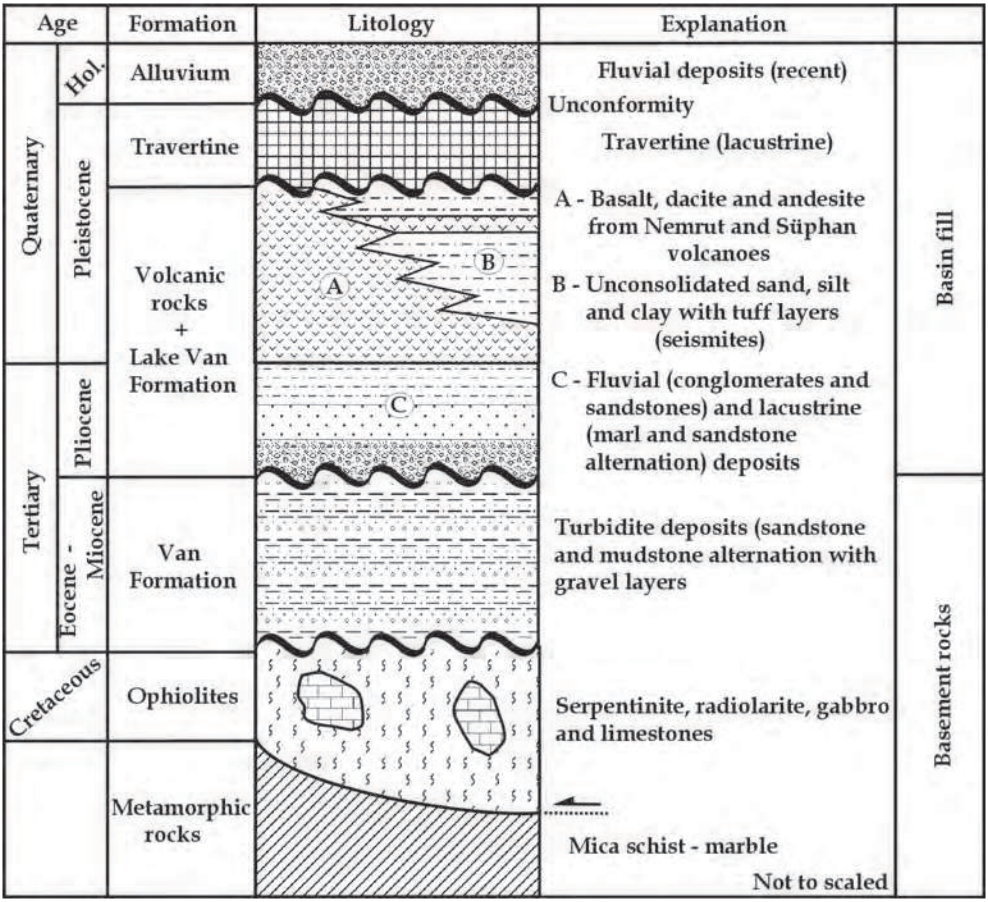

Fig. 2. Generalized stratigraphic columnar section of the study area (from Aksoy, 1988; Acarlar et al., 1991).

Date	Lat.	Long.	Depth (km)	Mag. (M_s)	Date	Lat.	Long.	Depth (km)	Mag. (M_s)
851	40.00	44.60	-	**5.2**	1941	39.45	43.32	20	**5.9**
856	40.00	44.60	-	**5.3**	1945	38.41	43.76	60	**5.2**
858	40.00	44.60	-	**5.2**	1945	38.00	43.00	30	**5.2**
1840	39.70	44.40	-	**6.8**	1945	38.63	43.33	10	**5.4**
1857	38.40	42.10	-	**6.7**	1966	38.14	42.52	28	**5.2**
1869	38.40	42.10	-	**5.0**	1966	38.10	42.50	50	**5**
1871	38.50	43.40	-	**5.5**	1968	38.15	42.85	53	**5**
1881	38.50	43.30	-	**5.0**	1972	38.23	43.86	46	**5**
1884	38.40	42.10	-	**6.1**	1976	38.61	43.20	56	**5.2**
1891	39.15	42.50	-	**5.5**	1976	39.17	43.95	33	**7.2**
1894	38.50	43.30	-	**5.0**	1976	39.09	43.71	49	**5.2**
1900	38.50	43.30	-	**5.0**	1976	39.18	43.71	46	**5.2**
1902	39.00	43.30	-	**5.0**	1976	39.31	43.66	53	**5.2**
1903	39.10	42.50	30	**6.2**	1977	39.35	43.48	24	**5**
1907	39.10	42.50	30	**5.2**	1977	39.29	43.62	46	**5.2**
1907	39.10	42.50	30	**5.4**	1977	39.27	43.70	39	**5.3**
1908	38.00	44.00	30	**6**	1977	39.13	43.90	34	**5**
1913	38.38	42.23	10	**5.5**	1977	39.31	43.53	38	**5.2**
1915	38.80	42.50	30	**5.7**	1979	39.12	43.91	44	**5.2**
1924	38.00	43.00	30	**5.2**	1988	38.50	43.07	49	**5.6**
1929	38.00	42.00	30	**5.2**	2000	38.41	42.95	48	**5.5**

Table 1. Earthquake records with magnitude 5 and higher occured in the study area (from Utkucu, 2006; KOERI, 2009), (Lat. = Latitude, Long. = Longitude, Mag. = Magnitude)

4. Deformation structures (Seismites)

Soft sediment deformation structures are observed in horizontally bedded, sandy, silty and clayey lacustrine deposits of Lake Van. Deformation structures exist in different levels of these shallow water deposits with the other sedimentary structures as cross-beds and wave ripples. Soft sediment deformation structures are classified differently according to morphologic properties or occurrence processes of the structure (Rossetti, 1999; Dramis & Blumetti, 2005; Neuwerth et al., 2006; Taşgın & Türkmen, 2009).

In this study, soft sediment deformation structures, observed in lacustrine deposits of Lake Van, were classified as contorted structures (simple-complex convolute bedding and ball-pillow structures), load structures (flame structures) and water escape structures (dish and pillar structures).

4.1 Contorted structures

Two types of contorted deformation structures exist in lacustrine deposits. These are simple-complex convolute bedding and ball-pillow structures.

4.1.1 Simple and complex convolute bedding

Simple and complex convolute structures are observed frequently in sandy and silty lacustrine sediments of Lake Van. These structures consist of little anticline or syncline like convolutions. The dimensions of these structures access up to 130 cm wide and 70 cm high. Simple convolute beds occur from one folded layer (Fig. 3a), while complex structures are composed of an outer trough and irregular inner laminates (Fig. 3b).
Simple and complex convolute structures may occur by overpressure, seismic shaking or storm waves. The convolute structures are bounded by undeformed horizontal beds in lacustrine sediments of Lake Van. This undeformed beds support the seismic origin suggestion (Cojan & Thiry, 1992). Additionally, the existence of folds at the centre of the complex convolute structures display the repeated tectonic activities (Bhattacharya & Bandyopadhyay, 1998).

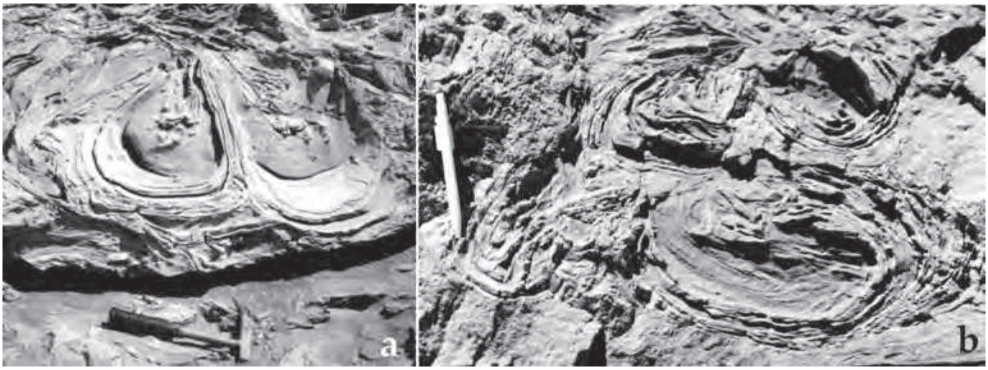

Fig. 3. (a) Simple convolute bedding and (b) complex convolute bedding in lacustrine deposits of Lake Van.

4.1.2 Ball and pillow structures

These structures are observed in sandy and silty deposits of Lake Van. They are composed of spherical or semi-spherical sand bodies in silty deposits (Fig. 4). This sand balls are covered by a silty crust. They have laminations at the inner part of the structures. Some structures are remaining connected to the overlying bed or the others are completely isolated from the bed. These structures in Lake Van sediments are very similar to presented in previous works (Hempton et al., 1983; Allen, 1986; Rossetti, 1999).
Ball and pillow structures occur with liquefaction of unconsolidated sediments. Because of the seismic tremors, liquefied sand size sediments are merged each other and create a ball-like structure (Montenat et al., 1987; Ringrose, 1989; Cojan & Thiry, 1992; Rodriguez-Pascua et al., 2000).

4.2 Load structures

The load balance of the unconsolidated sediments may change by landslide, rock fall or seismic waves. The load structures are formed by that load changing. These structures contain the load marks, pseudo-nodules and flame structures. Merely flame structures exist in lacustrine deposits of Lake Van.

Fig. 4. Ball and pillow structures observed in silty and sandy lacustrine deposits of Lake Van.

4.2.1 Flame structures

Flame structures are observed in sandy and silty deposits of Lake Van. These structures are formed by penetration of silty sediments to sandy deposits. These structures have different dimensions in lacustrine deposits of Lake Van (Fig. 5). They access up to 80 cm wide and 70 cm high. Generally flame structures comprise over pressure, but they can also be formed by seismic tremors (Visher & Cunningham, 1981; Dasgupta, 1998).

4.3 Water escape structures

Water escape structures are formed by sudden movement of pore-water to the upper level of deposits. Dish and pillar structures are formed by that mechanism in lacustrine sediments of Lake Van.

4.3.1 Dish and pillar structures

Dish and pillar structures are frequently observed in sandy and silty deposits of Lake Van. They consist of water movement in unconsolidated sediments due to sudden over pressure or seismic waves. The movement of pore water composes dish-like structures with folding of layers. These dish-like structures are seperated with vertical channels, called as pillars (Fig. 6).

Dish and pillar structures are observed in different sizes in lacustrine deposits of Lake Van. The dimensions of these structures access up to 100 cm wide and 50 cm high. The shape of dish structures may change depending on amount of pressure, movement velocity of pore water and the degree of consolidation. These structures in Lake Van deposits are very similar to presented in previous works (Lowe & LePiccolo 1974; Lowe 1975; Neuwerth et al., 2006). Dish and pillar structures may occur with seismic shakings (Plaziat & Ahmamou, 1998; Moretti et al., 1999).

Fig. 5. Flame structures observed in lacustrine deposits of Lake Van.

5. Trigger mechanism

The most known occurence of soft sediment deformation structures are overpressure of sediments (Lowe & LoPiccolo, 1974; Lowe, 1975), storm waves (Molina et al., 1998; Alfaro et al., 2002) and seismic shakings (Seilacher, 1969; Lowe, 1975; Sims, 1975; Rossetti, 1999; Vanneste et al., 1999; Jones & Omoto, 2000; Rodriguez-Pascua et al., 2000; Bowman et al., 2004). Deformation structures in lacustrine deposits of Lake Van were evaluated in the light of these trigger mechanism. There is not any evidence or data about overpressure of sediments or the effect of storm waves. Therefore, seismic shaking mechanism were investigated in detailed.

Seismic waves may form deformation structures (seismites) in unconsolidated sediments becuse of changing of pore water pressure, existence of impermeable layers in sequence and

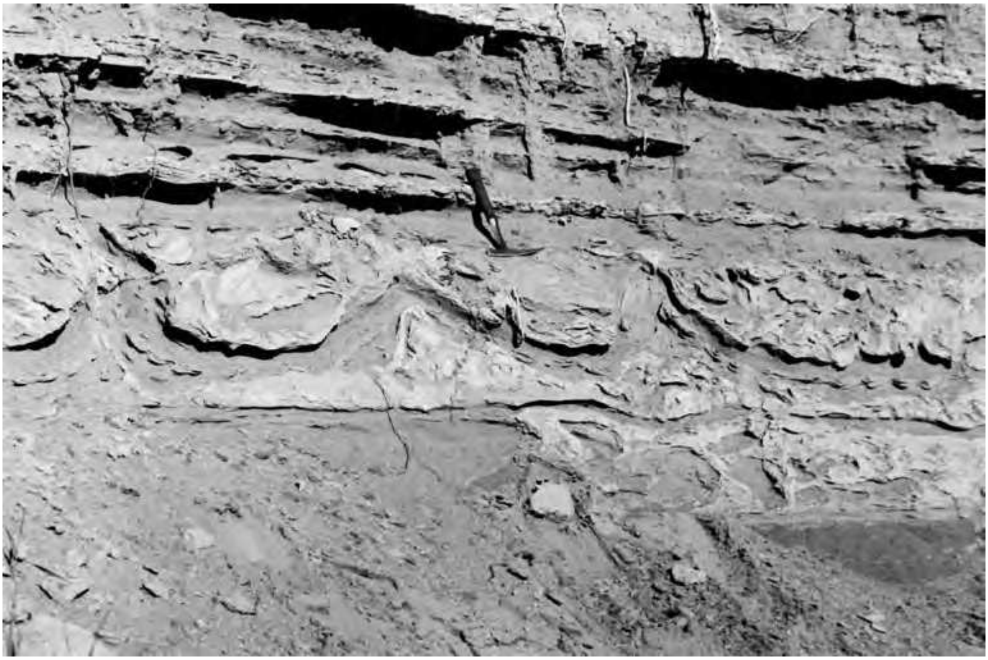

Fig. 6. Dish and pillar structures occured by the movement of pore water in sediments.

Fig. 7. Deformation structures observed among the undeformed parallel layers at different levels.

heterogeneity of grain size. Whenever, deformation structures in Lake Van deposits were evaluated for seismic origin; (1) grain size of the deformed sediments stay in liquefaction range (Port and Harbour Research Institute of Japan, 1997), (2) deformation structures are frequently observed in different levels of sequence which dissociated with undeformed, parallel beds (Fig. 7), (3) shapes, dimensions, geometry, sedimentologic and geotechnic properties of deformation structures are very similar to presented in previous works (Sims, 1975; Rossetti, 1999; Vanneste et al., 1999; Jones & Omoto, 2000; Bowman et al., 2004), (4) the region is very active for earthquakes (M≥5) and (5) soft sediment deformation structures in lacustrine deposits of Lake Van provide all criteria for the called as seismite (Sims, 1975; Obermeier, 1998; Rossetti, 1999).

6. Conclusion

In this study, the shapes, dimensions and locations of soft sediment deformation structures and facies properties and depositional environments of Quaternary aged lacustrine deposits of Lake Van are investigated. According to these features, deformation structures are classified into three parts as contorted structures, load structures and water escape structures.

Earthquake records show the tectonic activity (M≥5) of Lake Van and surrounding area. This data suggest that, the earthquakes should effect the lacustrine deposits in time of deposition (Late Quaternary). The deformation structures are frequently observed in different levels of lacustrine deposits. These deformed layers are the evidence of the repeated tectonic activity (M≥5) that effect the Lake Van deposits.

The relationship between the earthquake moment magnitude and the distance from epicenter to liquefaction locations appeal to the geologists. This distance may be more than 100 km in big earthquakes (M>7). According to locations and the distribution of soft sediment deformation structures, these structures should be formed by more than one faults activities.

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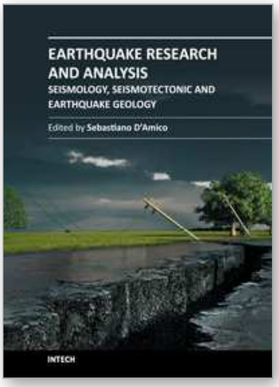

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