Bull. Min. Res. Exp. (2015) 151: 1-46

Bulletin of the Mineral Research and Exploration

http://bulletin.mta.gov.tr

THE LATE QUATERNARY TECTONO-STRATIGRAPHIC EVOLUTION OF THE LAKE VAN, TURKEY

Naci GÖRÜR[a*], M. Namık ÇAĞATAY[a], Cengiz ZABCI[a], Mehmet SAKINÇ[a], Remzi AKKÖK[a], Hande ŞİLE[a] and Sefer ÖRÇEN[b]

[a] *Istanbul Technical University, Faculty of Mines, Department of Geology, 34469 Maslak, Istanbul, Turkey*
[b] *Yüzüncü Yıl University, Faculty of Engineering and Architecture, Department of Geology, 65080, Campus, Van, Turkey*

Keywords:
Lake Van, Tectono-Stratigraphy, Lake Level Fluctuations, Climate

ABSTRACT

Many of the terraces around the Lake Van record a relatively short period of the much longer geological history of the Lake Van Basin. Their deposition took place during the last ca. 125 ka BP. They accumulated in a large array of shallow lake and lake margin environments, such as alluvial fan/braided river, beach, Gilbert-type delta, nearshore lake and offshore lake. Variability of their lithofacies provides evidence for climatic and tectonic controls of their depositional conditions. During their deposition high relief areas in the watershed delivered abundant detritus to the coastal areas of the lake. The sedimentation was therefore dominated by terrigenous clastic deposits. The highest concentrations of the coarse clastic sediments were at the mouths of the major streams where they formed Gilbert-type deltas. These river-dominated lacustrine deltas formed during rising lake levels and are relatively more abundant and thicker in the eastern margin of the lake, indicating that this margin mostly had a low-energy coast sheltered from the prevailing westerly winds. However, some areas of the same margin adjacent to deltas were also supplied with sediments by waves and storm-induced longshore currents to form beaches. Storms and storm-generated traction currents were perhaps active agents along the shores of the Lake Paleo-Van as suggested by the presence of the coarse-grained material in its nearshore facies. Somehow, during times of lake highstands, turbidity currents seem not to have played an important role in the sediment transportation along the lake margin, because the nearshore sediments hardly show any evidence of turbidite depositon, such as graded bedding and sole-marks. The offshore lake was relatively quite standing water, depositing laterally persistent, thinly-bedded to varved and fine-grained sandstones and mudstones in part with hydroplastic disruptions, such as slumps and convolute beddings. Because of the lack of sufficient datings of the terrace sequences around Lake Van, we cannot correlate them unequivocally. However, the absence of large-scale cyclicity within a given terrace sequence in each locality suggests that deposition of each terrace occurred during a separate lake level fluctuation each reaching to higher level than the modern lake level followed by a regression. The available age data suggest that high lake levels, reaching up to 1760 m asl, occurred during the last interglacial (MIS 5; 123-71 ka BP), 26-24 ka BP, 22-21 ka BP and 10-6 ka BP. The younging of the terrace deposits along with the decrease in elevation suggests either a gradual decline of lake level with time, or the effect of the cumulative uplift with time or both. The fluctuating lake level was probably due to a combination of climatic, volcanic and tectonic processes. Considering the hydrologically closed nature of the lake, climate probably played more important role than the others. Since the formation of the youngest terrace sediments of 6 ka BP, perhaps the climate in the basin has been mostly relatively more arid and evaporative. During the entire history of the lake (last 600 ka), geology of the area has been characterized by the neotectonic régime of Turkey with active dip- and strike-slip faults, resulting in the offshore lake the characteristic slump structures and convolute beddings, and eruptions of mainly the Nemrut Volcano.

* *Corresponding author: Naci Görür, gorur@itu.edu.tr*

1. Introduction

Lake Van is situated in eastern Anatolia. It is a 3522 m^2 basin with a maximum water depth of 455 m (Degens and Kurtman, 1978). It is the largest soda lake in the world (alkalinity =153 meq l^{-1}, pH=9.81) (Reimer et al., 2009). It also ranks the fourth-lake on Earth by volume (576 km^3). It has a closed drainage system with several perennial streams (e.g., Zilan, Ala Çay, Karasu, Dönemeç and Kotum), flowing down into the lake from the surrounding high mountains (Süphan and Nemrut volcanoes in north and west, Bitlis Massif in south, Eastern Van Mountains in east). These streams transport large amounts of sediments that have been accumulating in the lake basin during its 600 ka history (Litt et al., 2009; Stockhecke et al., 2014). Owing to the lake level changes due to climate, local tectonics and volcanism, these sediments were deposited at various elevations on the basin margins.

Up to now, some studies were carried out on the terraces to enlighten stratigraphic, tectonic and climatic evolutions of the Lake Van Basin. Most of them dealt with the determination of the different shoreline elevations and their ages in order to evaluate the lake-level changes and the regional climate events during or after the last glacial period (Valeton, 1978; Kempe et al., 2002; Kuzucuoğlu et al., 2010). In addition, studies on the varve record, bacterial diversity, palynology, geochemistry, bathymetry and volcano-seismicity of the lake itself also exist (Degens and Kurtman, 1978; Kempe and Degens, 1978; Wong and Finckh, 1978; Wong and degens, 1978; Degens et al., 1984; Kempe et al., 1991; Landmann, 1996; Landmann et al., 1996*a, b*; Kadıoğlu, 1997*a,b*; Wick et al., 2003; Şengör et al., 2003; Landmann and Kempe, 2005; Lopez-Garcia et al., 2005; Kaden et al., 2005; Utkucu, 2006; Horasan and Boztepe-Güney, 2007; Kuzucuoğlu, 2010; Kaden et al., 2010; Çukur et al., 2013; Sumita and Schmincke, 2013*a, b*; Stockhecke et al., 2014; Çağatay et al., 2014). Little work has been done on the sedimentology of the elevated lake terrace sediments, in spite of their spectacular outcrops in the relatively recently dissected lacustrine basin.

The purpose of this work is to discuss the tectono-stratigraphic evolution of the Lake Van Basin based on the study of the lacustrine terraces and their depositional environments in space and time. To achive this objective, we first summarize the geological and seismo-tectonic settings of the basin, then describe the terrace sediments in detail, and finally, by interpreting their depositional environments, we discuss the temporal evolution of the Lake Van Basin.

2. Setting

2.1 General Geology

The Lake Van Basin has a heterogeneous stratigraphic basement that crops out on the lake margins. Northern and western margins are underlain mostly by Neogene to Quaternary volcanic rocks and in part by Miocene clastic and carbonate sediments (Figure 1). The eastern margin is dominated by Upper Cretaceous to Oligocene ophiolitic mélange and flysch, forming the East Anatolian Accretionary Complex. The southern margin is represented mostly by Palaeozoic metamorphic rocks of the Bitlis Massif (Figure 1). All these rocks have acted as sources for the 700 m-thick sediments accumulated in the Lake Van since its formation about 600 ka BP (Litt et al., 2009; Stockhecke et al., 2014).

Mainly faults and folds characterize the geological structures in the Lake Van Basin (Şaroğlu and Güner, 1981; Güner, 1984; Şengör et al., 1985; Yılmaz et al., 1998; Toker and Şengör, 2011; Şengör et al., 2008; Çukur et al., 2013). Faults are represented predominantly by short and discontinuous strike-slip faults with an irregular distribution. They are common in the north and the east of the lake, striking NW-SE, NE-SW and E-W. The NW-SE- and E-W-striking faults are mostly dextral, whereas the NE-SW-striking ones are generally sinistral (Figure 1). Most of the strike-slip faults appear to be active and dominate the seismo-tectonics of the region. Beside them, a small number of active thrusts and normal faults are also observed in the close vicinity of the Lake Van. The thrust faults, which ruptured during the October 2011 Van Earthquake (M=7.1), also characterize the eastern margin between the Lakes Van and the Erçek (Akyüz et al., 2011; Erdik et al., 2012; Doğan and Karakaş, 2013; Fielding et al., 2013). Normal faults are seen in the area in association with the strike-slip faults. They mostly form where the strike-slip faults make releasing step-overs (i.e. the faults bounding the Northern Ridge in western part of Lake Van). Folds occur mostly in the east of the Lake Van, affecting the ophiolitic mélange and the associated formations. They are generally local, discontinuous and broad anticlines and synclines with a general NE-SW trend (Figure 11 in Şengör et al., 2008).

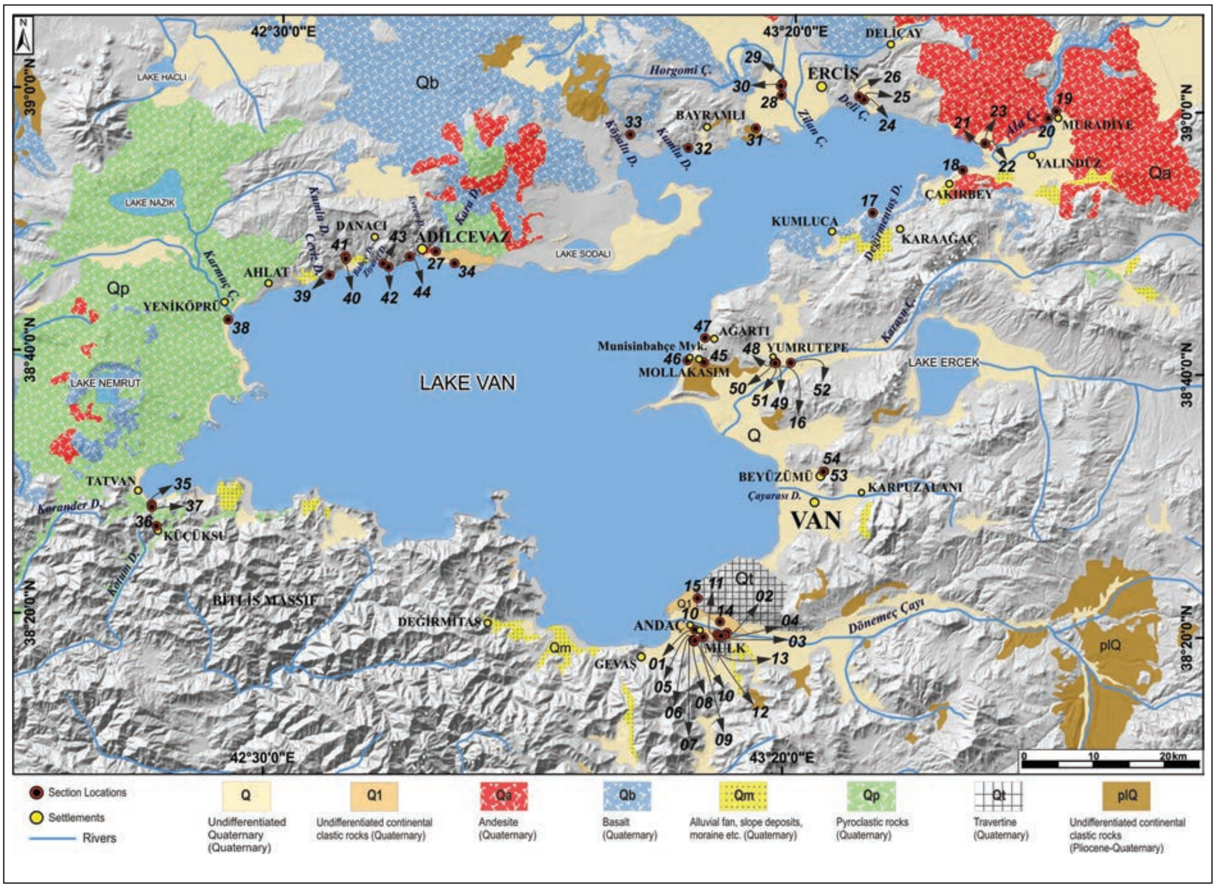

Figure 1- Geological map (compiled from Şenel and Ercan, 2002) of the Lake Van watershed, showing the locations of sites where terraces were studied.

The geology of the Lake Van Basin has been shaped mainly after the closure of the Bitlis Ocean in the medial Miocene (Şengör and Yılmaz, 1981; Şengör et al., 1985; Görür, 1992). This closure resulted from the collision of the Arabian and Eurasian plates and created the eastern Anatolian high plateau. The plateau is formed mainly from the East Anatolian Accretionary Complex, which developed south of the Rhodope-Pontide magmatic arc. It has a massive dome structure in part with smaller and local domes. The Lake Van Basin is located on such a local dome (the Lake Van dome, Şengör et al., 2008). It developed as part of the paleo-valley system of the River Euphrates in the E-W-trending Muş-Van Basin (Erinç, 1953; Wong and Degens, 1978; Degens et al., 1978; Şaroğlu and Güner, 1981; Güner, 1984; Şengör et al., 1985; Yılmaz et al., 1998; Şengör et al., 2008; Kuzucuoğlu et al., 2010; Çukur et al., 2013). The Muş and Van basins were separated by the eruption of the Nemrut Volcano about 600 ka BP (Yılmaz et al., 1998; Kuzucuoğlu et al., 2010; Litt et al., 2012).

2.2. Seismotectonics

The eastern Anatolian high plateau is still rising and undergoing an active deformation (Şengör et al., 2008). This is indicated in the Lake Van region by the occurrence of earthquakes of various intensities during the historical and instrumental periods. During the historical period, 13 earthquakes with epicentral intensities, ranging from VI to IX were recorded in the area. These events occurred in AD 1110, 1245, 1276, 1441, 1582, 1647, 1648, 1701, 1704, 1715, 1879, 1871 and 1881, causing a great damage in the settlements around the lake (Ergin et al., 1967). During the instrumental period (between 1930 and 2011), 87 earthquakes of magnitudes more than 4.0 occurred in the region (Horasan and Boztepe-Güney, 2007). Three of them were very destructive and large events, having magnitudes greater than 7.0. They were 1930, M=7.6 Iran, 1976, M=7.3 Çaldıran and 2011, M=7.2 Van earthquakes (Figure 2). Focal mechanism analysis indicates that most of these earthquakes resulted from the ruptures

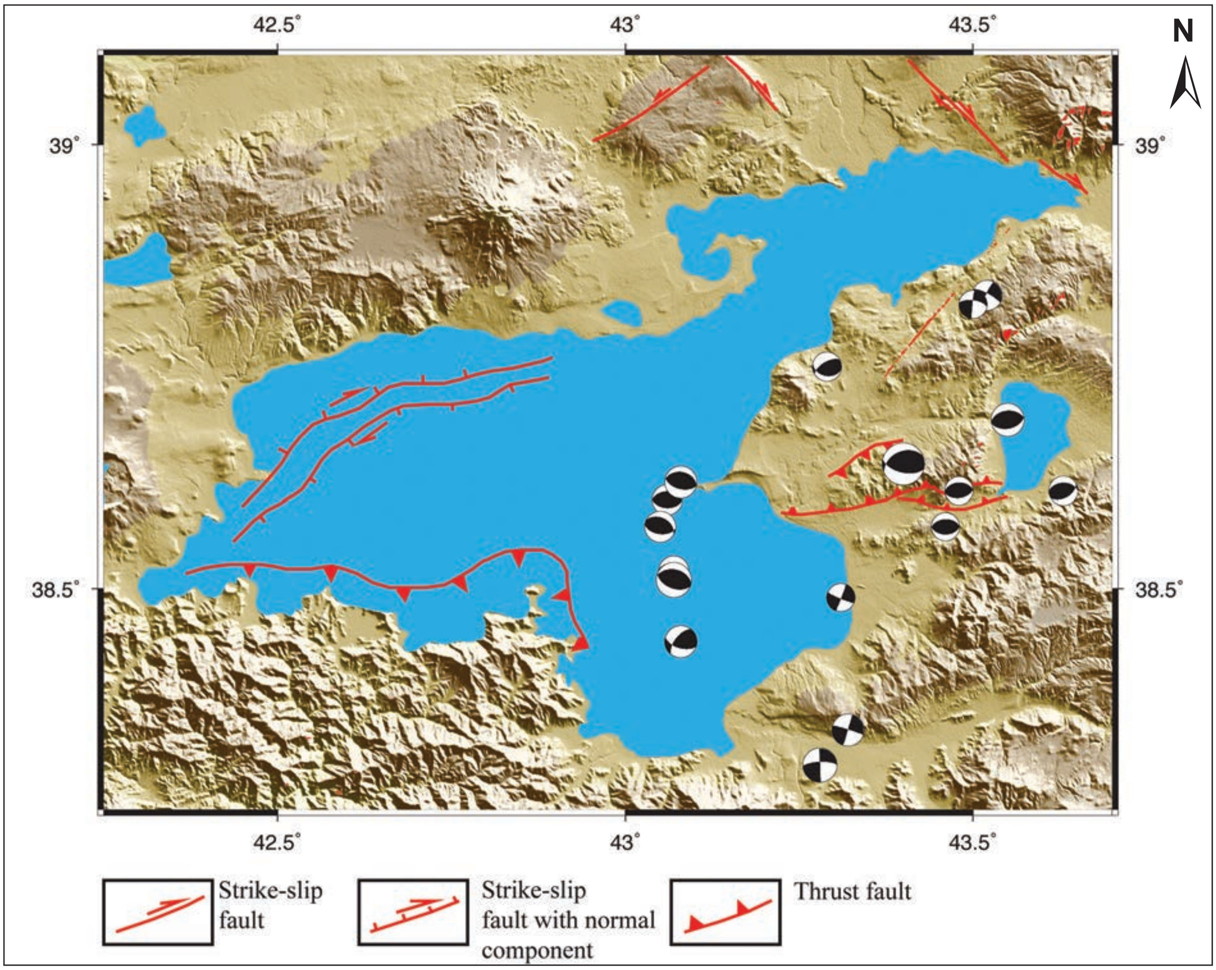

Figure 2- Seismotectonic map of the Lake Van and the surrounding region. Active faults are compiled from Emre et al. (2013) and Çukur et al. (2013), and focal mechanism solutions are from Harvard CMT catalogue (Ekström et al., 2012).

of the strike-slip faults, particularly those of the dextral ones. This is an expected result, because the dextral strike-slip faults outnumber both the sinistral strike-slip faults and the thrusts in the region. Thrust-related events mostly occur in the south and the east of the Lake Van in conformity with the distribution of these faults in the basin (Wong and Finckh, 1978; Şengör et al., 1985; Örgülü et al., 2003; Tan, 2004; Horasan and Boztepe-Güney, 2007). Majority of the earthquakes are shallow events generated predominantly in the upper 10 km of the crust.

3. Chronology, Sedimentology and Depositional Environments of the Terrace Sediments

3.1. Age of the Terrace Sediments

Terrace sediments crop out in the lake margins at various elevations, ranging from 1656 m to 1754 m (Figure 1). They are mostly confined to valleys and coastal areas where they display packages of ca. 3 m- to 25 m-thick offshore lake to marginal lake (nearshore lake, delta, beach and alluvial fan) facies with well-preserved sedimentary features, providing important clues to their depositional environments. Their available ages are compiled in Table 1. They are dated in Güzelsu (Dönemeç Çayı Valley), Beyüzümü (Çayarası Valley), Yumrutepe (Karasu Valley), Karahan Village, Adilcevaz (Kara Dere valley) and Kotum Dere Valley (Figure 1). The dating was made by previous studies using radiocarbon and $^{234}Th/^{238}U$ methods (Kempe et al., 2002; Kuzucuoğlu et al., 2010) and by us using Optically Stimulated Luminescence (OSL) method (Kuzucuoğlu et al., 2010; this study) (Table 1).

In the Dönemeç Çayı Valley (Güzelsu), mainly offshore lake sediments crop out at an elevation of 1705 metres above sea level (masl) and yield an age, ranging between 20.9 and 20.7 ^{14}C calib. ka BP

Table 1- The dates of terraces around the Lake Van. The compiled data are from Kuzuoğlu et al. (2010), Kempe et al. (2002), Mouralis et al. (2010), and this study.

Site	Name	LON (°E)	LAT (°N)	Age	Horizon	Material	Method	Reference
Yumrutepe (YUM 4)	Van 05-49	43.311	38.673	>34000 BP	Shells at beach level	$CaCO_3$	Radiocarbon	Kuzucuoğlu et al. (2010)
Beyüzümü	Van 05-51	43.392	38.537	>31000 BP	Shells on top layer (above peat)	$CaCO_3$	Radiocarbon	Kuzucuoğlu et al. (2010)
Beyüzümü	Van 06-BT 10-15	43.392	38.537	>34000 BP	Top of 2.5 m peat sequence	Organic	Radiocarbon	Kuzucuoğlu et al. (2010)
Beyüzümü	Van 06-01	43.392	38.537	>30000 BP	Peat Layer 7b within (top) sequence	Organic	Radiocarbon	Kuzucuoğlu et al. (2010)
Beyüzümü	Van 06-67	43.393	38.537	n.d.	Paleosol in channel fill	Organic	Radiocarbon	Kuzucuoğlu et al. (2010)
Yumrutepe (YUM 1)	Van 06-61	43.311	38.673	n.d.	Paleosol buried below flood silts	Organic	Radiocarbon	Kuzucuoğlu et al. (2010)
Zeve 1 (Lower Karasu)	Van 07-1	43.227	38.592	n.d.	Paleosol in buried T4" alluvial terrace	Organic	Radiocarbon	Kuzucuoğlu et al. (2010)
Orene (Lower Zilan)	Van 07-13	43.314	39.012	n.d.	Paleosol in buried T4" alluvial terrace	Organic	Radiocarbon	Kuzucuoğlu et al. (2010)
Kırklar	Van 05-36b	43.607	38.968	24900±800 cal. BP	Black layer below tephra (sup.)	Organic	Radiocarbon	Kuzucuoğlu et al. (2010)
Kırklar	Van 05-36a	43.580	38.982	25700±600 cal. BP	Black layer below tephra (inc.)	Organic	Radiocarbon	Kuzucuoğlu et al. (2010)
Adilcevaz	Van 06-76a	42.748	38.806	5940-6185 cal. BP	Charcoal associated with ceramics	Charcoal	Radiocarbon	Kuzucuoğlu et al. (2010)
Adilcevaz	Van 06-76b	42.753	38.806	9470-9550 cal. BP	Charcoal in aceramic layers (base)	Charcoal	Radiocarbon	Kuzucuoğlu et al. (2010)
Güzeldere (Apricots)		43.220	38.336	20700±300 cal. BP	Organic matter (upper level)	Organic	Radiocarbon	Kempe et al. (2002)

Table 1- *continue*

Site	Name	LON (°E)	LAT (°N)	Age	Horizon	Material	Method	Reference
Kotum	06-33 sup.	42.309399	38.472325	102.2 +3.8/ -3.7 BP	Low travertine		U/Th	Kuzucuoğlu et al. (2010)
Kotum	06-33 inf.	42.309520	38.472297	102.1 +8.1/ -7.5 BP	Low travertine		U/Th	Kuzucuoğluet al. (2010)
Yumrutepe	OSL16	43.311347	38.673269	12±1.8 ka	Nearshore lake sediments (?)	Polymineral	OSL	This study
Kotum-Küçüksu Valley	VAN 021	42,314185	38,478190	117±5.2 ka	Pyroclastics (pumice fall)	Mineral	Ar/Ar	Mouralis et al. (2010)
Yumrutepe	OSL48-1	43.310298	38.674525	10±1 ka (n=9), 15±1 ka (n=25), 20±1 ka (n=9)	Nearshore lake sediments (?)	Quartz	OSL	This study
Adilcevaz	OSL27-1	42.757291	38.805548	10.3±1.1 ka	Nearshore lake sediments (lower level)	Polymineral	OSL	This study
Adilcevaz	OSL27-2	42.757291	38.805548	6.14±0.7 ka	Nearshore lake sediments (middle level)	Polymineral		
Adilcevaz	OSL27-3	42.757291	38.805548	8.2±0.92 ka	Nearshore lake sediments (upperlevel)	Polymineral	OSL	This study
Beyüzümü	OSL54	43.391304	38.537251	15±1 ka	Nearshore lake sediments	Quartz	OSL	This study

(Kempe et al., 2002) (Figure 1). In the Çayarası Valley (Beyüzümü) southeast of Van City, nearshore laminated lake sediments located at 1754-1761 masl elevations were dated ? 30-34 ^{14}C calib. ka BP using radiocarbon method (Kuzucuoğlu et al., 2010) and 15.1 ka using OSL method (this study). In Yumru Tepe in the Karasu Valley, beach and Gilbert-type delta deposits located at 1736 and 1712 masl elevations, respectively have 30-34 ^{14}C calib. ka BP, same as the age of the nearshore lake sediments in the Çayarası Valley (Kuzucuoğlu et al., 2010) (Table 1; Figure 1). Our OSL age for the same sequence at a higher elevation ranges from 10 to 20 ka BP with the most frequent ages occurring at 15.1 ka BP, whereas the age at the lower elevation is 12 ± 1.8 ka BP. Around the Karahan Village, another Gilbert-type delta sequence is exposed at 1690 masl elevation, for which Kuzucuoğlu et al. (2010) found ages varying between 24.9 and 25.7 ^{14}C calib. ka BP (Table 1). In the northern margin, around Adilcevaz (in the Kara Dere Valley), nearshore lake sediment located at an elevation of 1697 masl are dated between 6.1 and 10.3 ka BP by OSL method (this study). Kuzucuoğlu et al. (2010), however, report the formation of only up to 13 m high terraces above the present lake level near the river mouths during the early Holocene, between 5.9 and 9.7 ^{14}C calib. ka BP

So far the oldest dated terraces are found in the Kotum Dere Valley. According to Kuzucuoğlu et al (2010), the oldest terrace is dated to be older than 105 ka BP. This terrace reaches 1755 masl, about 110 m above the present lake level and 20 m above the present lake threshold, and was deposited during a period when pyroclastic deposits dammed the lake's outlet in the Kotum Valley. Another terrace in the lower Kotum Dere Valley (our Sections KOD1 GPS-035 and $KOD_{2,}$ GPS-037; Fig 1) reach 1730-1735 m, and is dated sometime between 100-35 ka, according to the $^{39}Ar/^{40}Ar$ and U/Th ages of the travertine and pumice units disconformably underlying the laminated terrace sediments (Kuzucuoğlu et al., 2010; Mouralis et al., 2010).

The dating of the terraces revealed that their age generally increases with their elevations. Older terraces commonly occur at high elevations in most part of the Lake Van Basin, except the terrace in the Kara Dere Valley in the Adilcevaz region, which yields younger age despite its high elevation (1697 masl; 50 m above the present lake level). However, the most previously published age data presented here on the terraces should be evaluated and used with caution, because the stratigraphic position, lithology, facies association, stratigraphic relations and depositional environment of the dated samples are not unequivocaly documented. Consequently, the terraces cannot be correlated facies by facies throughout the basin on the basis of the available ages. It is therefore difficult to discuss temporal and spatial evolution of their depositional conditions with the available age data. However, we consider that it would be reasonable to think that the terraces reflect the natural history of the Lake Van Basin over the last ~125 ka BP, the age of the so far known oldest dated terrace sediments.

In the following paragraphs, we describe the terraces first and than interpret their environments of deposition. Based on this interpretation we than reconstruct the depositional environmental conditions and discuss the tectono-stratigraphic evolution of the Lake Van Basin during the last ~125 ka BP.

The terraces were examined at 22 locations, including Dönemeç Çayı Valley (Güzelsu), Çayarası Valley Beyüzümü), Karasu Valley (Yumrutepe and Mollakasım), Munisinbahçe Mevkii, Boğaz Dere Valley, Hasan Dere Valley, Değirmentaş Dere Valley, around Village Çakırbey, Alaçay Valley, Village Karahan, Deliçay Valley, Zilan Valley, around Kaş Burnu, Kumlu Dere Valley, Çayır Mahallesi, Karadere Valley (Adilcevaz), Evren Deresi valley, Ziyaret dere valley, Kumlu Deere valley at Village Soğanlı, Ceviz Dere Valley, Karmuç Çayı Valley and Kotum Dere Valley (Figures 1, 33, 34 and 35).

3.2. Stratigraphic Sections studied in the Dönemeç Çayı Valley

3.2.1. Section-DÖN$_1$ (GPS-001, lat: 38.3332°, long: 43.1891°, elev: 1687 masl)

Description: This section was studied at the southern slope of the Dönemeç Çayı Valley, between the Villages of Andaç and Mülk (Figure 1). It is a 5 m-thick clastic and laterally persistent sequence, consisting mainly of very fine-grained and well-sorted sandstone with minor amounts of siltstone and claystone. The sandstone displays fine parallel lamination, micro cross-lamination and small-scale trough cross-stratification both in the lower and the upper parts of the section. In the middle part, it contains distinctive convolute lamination and flame structures (Figure 3).

Figure 3- Terrace section $DÖN_1$ in Dönemeç Çayı Valley, showing fine scale ripple lamination, trough cross-stratification, convolute lamination and flame structures. For location see figure 1.

Interpretation: These sediments were probably deposited in the offshore environment of the Paleo-Lake Van as suggested by such features as the lateral persistency, very fine grain size, lamination, small-scale cross-stratification, convolute lamination, and flame structures. These soft-sedimentation deformation structures are interpreted to form due to the seismic shocks, triggering liquefaction and/or fluidisaton of unconsolidated sediments (Üner, 2014). The absence of any fresh-water organisms in these sediments may have been due to the inhospitable soda water of the Paleo-Lake Van. The convolute laminations probably formed when the sediments were water saturated and perhaps subjected to earthquake shocks.

3.2.2. Section-$DÖN_2$ (GPS-002), lat: 38.3299°, lon: 43.2409°, elev: 1708 masl)

Description: This section is located in the southern flank of the Dönemeç Çayı Valley, 4.7 km east of the Section-$DÖN_1$ (Figure 1). It is made up of 7 m-thick yellowish green and upward-coarsening sandstone unit with various sedimentary structures. At the base of the section, sandstone is fine-grained, poorly-cemented and planar laminated that gradually passes upward into a fine to medium-grained and well-sorted sandstone with common bioturbation and bidirectional trough-shaped cross-stratification (up to 40 cm) (Figure 4). This cross-bedded and burrowed sandstone is followed by 30 cm-thick, whitish and thinly-bedded clayey carbonate or marl with an erosional contact. The section then continues towards the top with a well-sorted and medium-to coarse-grained sandstone, becoming pebbly at the top.

Interpretation: The upward-coarsening sequence of predominantly well-sorted sandstone with well-developed laminations, burrowings and bidirectional cross-stratifications seem to be representative of many of the features observed in the shoreface of a beach environment. The complex hydraulic conditions of this environment permit the accumulation of a wide range of sediments from fine sand to gravel with common burrowing structures and multidirectional trough cross-bed sets. The bidirectional trough cross-beds probably indicative of deposition under strong longshore current conditions. The erosion of these beds and the burrow tops indicate that this environment was subjected to modification by storm-generated waves. The clayey carbonates overlying the truncation surface perhaps represents the suspended sediments deposited as the storm wanes (Hayes, 1967; Howard, 1972; Reineck and Singh, 1972; Kumar and Sanders, 1976; Davidson-Arnott and Greenwood, 1976).

3.2.3. Section-DÖN$_3$ (GPS-003-004, lat: 38.3271°/3268, lon: 43.2359°/2356, elev: 1713/1715 masl)

Description: This section is exposed at the southern slope of the Dönemeç Çayı Valley, 600 m from Section-DÖN$_2$ described above (Figure 1). It starts at the base with 20 cm-thick brown, fine- to medium-grained sandstone overlain by up to 60 cm reddish to yellowish green mudstone with no internal structure, except some burrows and few discoidal pebbles in its lower parts. Above the mudstone is interbedded sandstone and 30 to 40 cm-thick green shale succeeded by 40 cm-thick and well-bedded sandstone with scoured-loaded basal contact. This sandstone and the underlying units are cut by a low-angle erosional surface, probably representing a basal glide plain at the base of a relatively small-scale slump or slide deposits . The section then continues upward with up to 2 m-thick poorly-sorted, ungraded

Figure 4- The sandstones in the terrace section-DÖN$_2$ show bidirectional planar cross-beddings and common bioturbation. For location see figure 1.

and monogenic conglomerate. It forms a mainly clast-supported and poorly- to moderately-sorted pebble assemblage. Pebbles are commonly angular to subrounded and mostly have platy or discoidal shape. They are composed predominantly of travertines derived from a nearby bedrock slope (Figure 1). The conglomerate commonly displays a lenticular geometry with erosional bases, characterizing different episodes of channeling into the underlying sediments. Toward the NE, this flat-lying conglomerate and the underlying sandstone sit on top of steeply NE-dipping interbedded sandstone and conglomerate and thus form a three-part structure, similar to that of a delta (Figure 5).

Interpretation: This section displays the features of a Gilbert- type delta. The burrowed mud and the interbedded shale and sandstone in the lower part of the section probably accumulated as prodelta sediments (bottomset) in the Lake Paleo-Van, whereas the overlying horizontal conglomerate and sandstone were deposited in the delta platform (topset). The steeply dipping interbedded sandstone and conglomerate were deposited as delta slope sediments (foreset). The Paleo-Lake Van was probably abutting a steep slope of an adjacent high where travertine deposits were exposed like today's elevated travertine highs in the section area. The high provided limited detritus to the lake from a short distance as indicated by the coarse grain size of the topset deposits and the angularity of the clasts in the conglomerate. However, the sediment supply was persistent enough to build a small Gilbert-type delta in the lake's margin. The erosional surface, cutting the delta platform may indicate channel erosion or a slide, occuring in the delta front.

3.2.4. Section-DÖN$_4$ (GPS-014, lat: 38.3732°, lon: 43.1925°, elev: 1705 masl)

Description: This section is located at the northern flank of the Dönemeç Çay Valley, 300 m south of the Dönemeç Village (Figure 1). It is about 10 m-thick sedimentary sequence that is essentially composed of yellowish green very fine- to fine-grained sandstones with various types of sedimentary structures (Figure 6). It starts at the base with 70 cm-thick laminated sandstone in part with cross-bedding. It is overlain

Figure 5- Section DÖN$_3$, showing steeply NE-dipping foreset beds of a Gilbert-type delta. The foreset beds are underlain by bottom-set beds of mudstone and fine-grained sandstone and overlain by conglomeratic topset beds. For location see figure 1.

with a rather sharp contact by about 30-40 cm-thick, thinly-bedded rippled sandstone sandwiched between two 10 cm-thick horizontal sandstone beds. This unit passes upward into another 1 m-thick sandstone package that consists predominantly of thin (5-10 cm) wave rippled sandstone beds separated by thin shale beds. The wave ripples appear to decrease in length and amplitude upward. The rippled sandstone package is succeeded by a 1.0-1.2 m-thick massive to faintly laminated and very fine-grained sandstone to clayey sandstone unit. Within this unit, a 10 cm-thick horizontal sandstone and a very-thinly-bedded and folded slump deposit are recognized (Figure 6). The unit is than followed by about 80 cm-thick sandstone package, containing three sandstone beds of 25 to 35 cm thickness. The sandstone beds with erosional bases are interbedded with very thin mudstone beds. Above the sandstone package, a 1.3 m-thick white sediment occurs. This sediment appears to be laminites with alternating millimetric laminae of microcrystalline carbonate and clastic material in various proportions. At the base of the laminites, few short water-escape structures, i.e. burst-through structures, are observed. The laminites pass upward into very fine sandstone of 1.5 m thick that seems thinly-bedded at the base and massive at the top (Figure 6).

Interpretation: The abundance of laminated to very finely-bedded sandstones throughout the sections suggests that these sediments originated in a low energy offshore environment of the Paleo-Van. However, the presence of small-scale wave rippled and cross-bedded sandstones indicate intermittent higher energy conditions and they were probably deposited by low velocity traction currents. The slump sheet and the overlying sandstones with erosional bases show some characteristic features of soft sediment deformation and turbidites, respectively. The former probably formed as a result of liquidization of unconsolidated sediments, whereas the latter accumulated by turbidity currents. Considering the high seismic activity of the Lake Van region, both processes were probably triggered by earthquake shocks. The carbonate-rich laminites most probably represent varves, resulting from seasonal sedimentation under relatively deep water (high lake level) conditions. High carbonate contents were

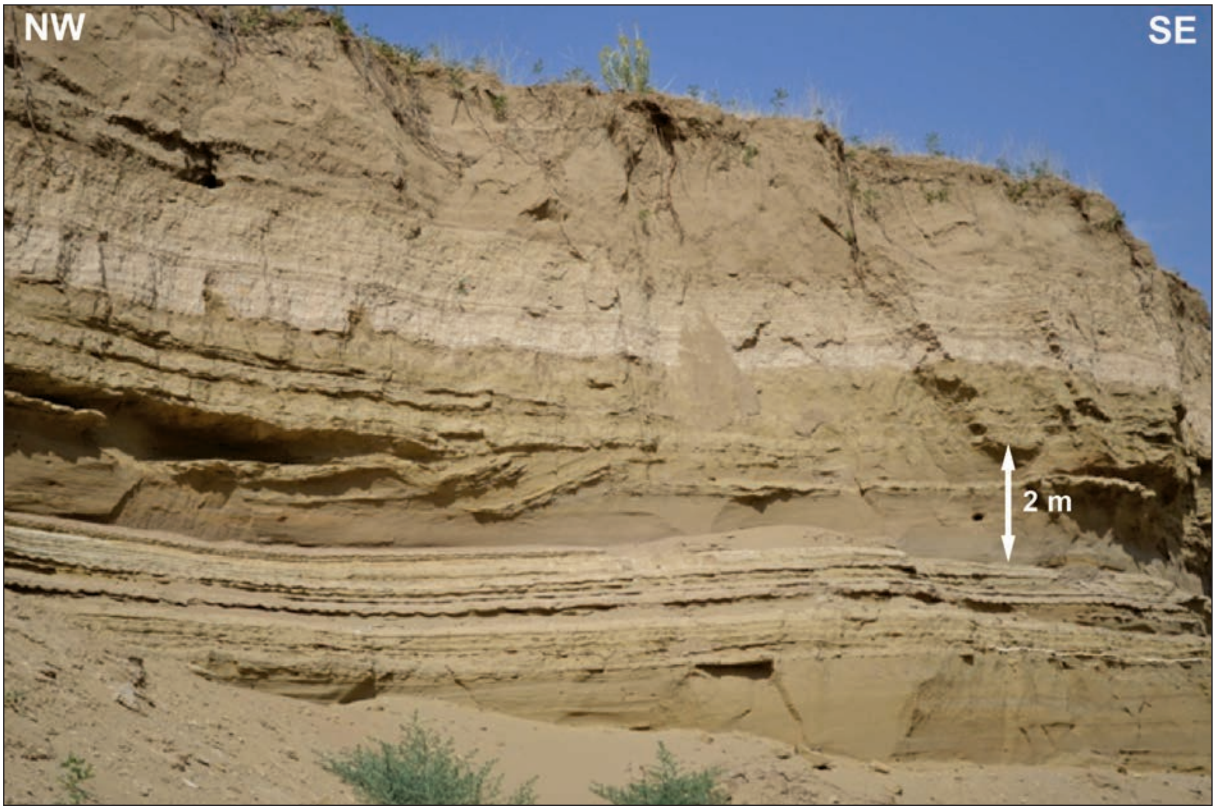

Figure 6- Section-DÖN$_4$ located on the northern flank of the Dönemeç Çay Valley, 300 m south of the Dönemeç Village (Figure 1). The section consists essentially of yellowish green, very fine-to fine-grained sandstones with laminites. The sequence shows slump and water escape structures. For location see figure 1.

probably induced by input of calcium-rich waters (Litt et al., 2009; Stockhecke et al., 2014; Çağatay et al., 2014).

3.3. Stratigraphic Section Examined in the Çayarası Valley, Beyüzümü District

3.3.1. Section-CV$_1$ (GPS-053-054, lat: 38.5373°/5372, lon: 43.3923°/3913, elev: 1761-1754 masl)

Description: This section is located about 1 km to the northeast of the Beyüzümü district of Van City (Figure 1). It is characterized, as a whole, by 25 m of sandstones, becoming more conglomeratic in upper parts (Figure 7). The sandstones are generally yellowish brown to beige in color and show various textures and sedimentary structures throughout the section. At the base of the section, there is horizontally-stratified sandstone with small pebbles, containing common and well-preserved fresh water bivalves (*Dreissena* sp). Above these fossiliferous coarse clastics is 1.5 m of gray, fine- to medium-grained sandstone with faint and discontinuous ripple marks. It passes upward across a sharp contact into a 50 cm-thick and massive clayey sandstone overlain by a 1.5 m-thick, white to beige and laminated mudstone (Figure 7). From this mudstone upward, the sequence continues with yellowish green to brown, locally fossiliferous, wave rippled sandstone, grading upward into brown laminated to massive sandstone alternating in part with rippled sandstone beds. To the top of the section, the sandstones are gradually overlain by about 5 m-thick, carbonate cemented and generally planar cross-bedded conglomerates in part with yellow sandstone interbeds, similar to the sandstones in the lower parts of the section.

All four radiocarbon dates from the Section-CV$_1$ terrace are indefinite and older than 30 ka BP (Kuzucuoğlu et al., 2010) (Table 1). Our single OSL age from the yellow laminated sand in the part of the section at 1754 m elevation is 15±1 ka BP, which is considerably younger than the radiocarbon ages of Kuzucuoğlu et al. (2010).

Interpretation: The widespread fine-to medium-grained sandstones of this section probably accumulated in a nearshore lake environment of the Paleo-Van rather than deeper water offshore

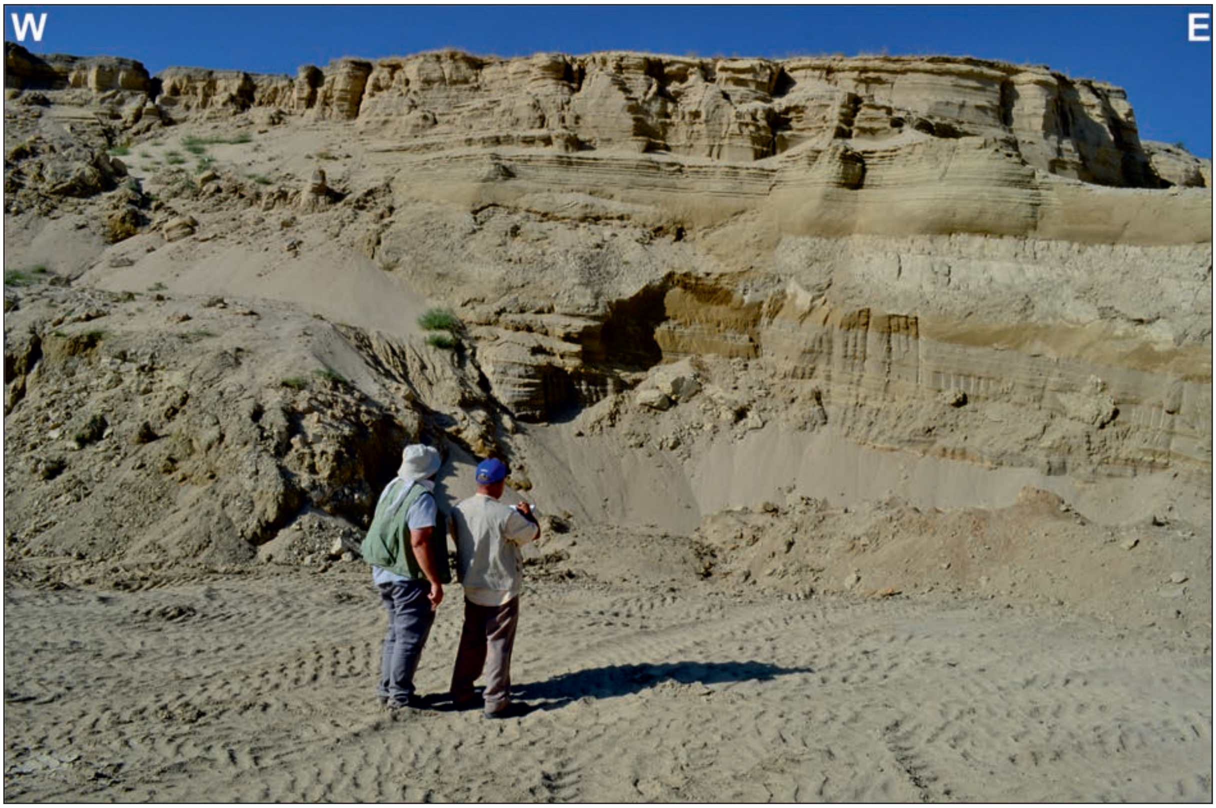

Figure 7- Section CV$_1$ in Çayarası Valley in Beyüzümü district, South of Van City. This 25 m-thick section consists mainly of sandstones with conglomerates in the upper parts. For location see figure 1.

environment, because they contain no evidence of turbidite, slump or varve deposition. Therefore, it is believed that most of the sand-sized material in this section was contributed by river inflow, leading to the deposition in nearshore environments under the influence of the shoreline processes, including current or wave activity (Sly, 1978; Piccard and High, 1981). Such processes could account for most of the features observed in the sandstones of this section. The presence of *Dreissena* sp. suggests that alkalinity and salinity of the lake water was low, possibly due to the proximity of the depositional site to the river mouth. The overlying cross-bedded coarse clastics indicate that the nearshore lake deposits graded upward into alluvial fan-fluvial facies, owing to either a drop in lake-level or an increase in sediment supply or both.

3.4. Stratigraphic Section in Yumrutepe in the Karasu Valley

In this valley, lake-related Quaternary sediments crop out about 1 km south of the Yumrutepe Village (Figure 1). They are composed mainly of interfingering coarse clastic deposits with various facies characteristics, indicating that they were deposited in different neighboring depositional environments. In order to show their lateral and vertical facies changes, these sediments are described below from three sections, located at different elevations.

3.4.1. Section-KV$_1$ (GPS-048-049-050, lat: 38.6748°, lon: 43.3096°, elev: 1733 masl)

Description: This section is a 3.5 m-thick sequence, commencing at the base with 1.0 m of greenish gray and massive pebbly mudstone overlain with a sharp and erosional contact by a 1.0 m-thick, brownish gray conglomerate (Figure 8). The conglomerate is composed of moderately sorted, subrounded to rounded small pebbles (<4 cm) with an orientation parallel to the bedding surfaces. The beds are thin (≤10 cm) with well-defined sharp basal boundaries. This conglomerate is succeeded by a red, grain-supported conglomerate unit without any bedding. The clasts of the red conglomerate are commonly rounded pebbles, showing normal

Figure 8- Section-KV1 in Yumrutepe, Karasu River Valley at 1733 masl. This sequence consists of greenish gray and massive pebbly mudstone in the lower part and brownish gray and red conglomerates in the upper part. For location see figure 1.

grading. The pebble size varies between 2 and 25 cm with an average of 4 cm.

Interpretation: The horizontally stratified conglomerate may be interpreted as deposits of a powerful stream. Its well-defined beds with nonerosive and erosive bases, moderate sorting, abundant rounded clasts with normal grading and absence of fossils support this interpretation. The tractional activity of turbulent streamflows was perhaps important in its deposition. This deposit compares closely to streamflood deposits and probably occupied a distal alluvial fan environment (Bluck, 1967; Steel, 1974; Steel and Wilson, 1975; Heward, 1978; Nilsen, 1982). The overlying unstratified red conglomerate with erosional base and normal grading probably represents a braided river channel.

3.4.2. Section-KV_2 (GPS-048-049-050, lat: 38.6733°, lon: 43.3095°, elev: 1736 masl)

Description: This section, located about 90 m above the present lake level, represents the highest part of the terrace section in Yumrutepe locality (Figure 1). Toward the south, the Section-KV_1 passes laterally into 7 m-thick Section-KV_2 that exhibits close stratigraphic and sedimentologic similarities to the former. It also contains brownish gray and red conglomerates in the same order as observed in the Section-KV_1 (Figure 9). At the base it consists of 1.5 m thick brownish gray conglomerate with some local sand lenses (Figure 9). The basal unit is overlain by thinly (10-15 cm) bedded, weakly cemented yellow sandsone, which is followed upwards across a truncation surface by SE-dipping beds of coarse sandstone with some conglomerate interbeds. These dipping beds are overlain by a flat lying and *Dreissena* sp. bearing coarse pebble conglomerate above a second truncation surface. This conglomerate unit is overlain by a 0.3-0.7 m-thick loosely cemented green fine sandstone. The overlying unit above the green sandstone and below the soil zone at the top of the section is the red conglomerate as observed in the Section- KV_1. It is generally unstratified or crudely stratified with abundant poorly-sorted sand or granule matrix. Large pebbles are generally subrounded to rounded pebbles with subordinate amount of boulders derived from a local source.

Interpretation: The moderately - to well - sorted fabric of the brownish gray conglomerate suggests tractive transport or reworking of the deposit. The planar and non-erosive bases of its beds in the upper and lower parts of the section exclude channelised, turbulent currents. Its size, shape, sorting, segregation into well-stratified layers and fossil content may indicate a beach face depositional environment for this sediment (Bluck, 1967; Clifton, 1973). These characteristic features probably resulted from reworking and winnowing by waves and storms in the backshore to foreshore sub-environments of a beach along the Paleo-Lake Van. The intervening sandstone with planar cross-bedding may support this interpretation. The presence of freshwater bivalves near the top of the sequence indicates considerably lower lake water salinity and alkalinity than those of the present-day lake waters.

The geographic positions and the stratigraphic relations of the Sections-KV_1 and KV_2 may indicate that the alluvial fan recognized in the former extended to the shore of the Paleo-Lake Van where its deposits were reworked to form the beach deposits of the latter.

Figure 9- Section-KV_2 in Yumrutepe, Karasu River valley at 1736 masl. It consists mainly of brownish gray and red conglomerates with some sandstone interbeds. Note the SE-dipping sandstone and conglomerate beds in the middle part of the section. See figure 1 for location.

The coarseness, poor sorting and granular matrix of the red conglomerate on top may suggest high water discharge, sediment supply and rapid deposition in the depositional area. The red color, erosional base and unfossiliferous nature of the conglomerate may indicate that this depositional area was a braided river.

3.4.3. Section-KV$_3$ (GPS-016, lat: 38.6732°, lon: 43.3113°, elev: 1712 masl)

Description: This section is a more than 10 m-thick sedimentary succession with horizontally- and steeply inclined-bedded units towards SE (Figure 10). The inclined-bedded unit is composed mainly of conglomerate and sandstone, dipping at 35-40 toward the east. Bed contacts are commonly sharp and their thickness avarages 30 cm with a range of 20-80 cm. Conglomerate is gray, clast-supported, moderately- to well-sorted and seems common in the lower parts of the unit. Sandstone is yellowish gray and thinly-laminated in part with wavy bedding.

The horizontally-bedded unit overlies the inclined-bedded unit with a sharp and planar contact. However, in places, pinch-outs between these units are also observed. The horizontally-bedded units start at the base with 40 cm of gray conglomerate and continue upward with yellowish gray sandstone. The conglomerate is clast-supported and moderately-sorted with subangular to rounded gravels, showing no channel structures. The overlying sandstone is fine- to medium-grained, thinly-laminated with common wavy and lenticular bedding. It also shows in places some soft sediment deformational structures, such as sedimentary dikes (Figure 11).

Age of terraces at Yumrutepe: OSL dating of quartz in the green sandstone unit in the upper part of section KV$_2$ at around 1735 masl provided an age of 15±1 ka BP (n=25) (Figure 9, Table 1). The other less reliable OSL ages from the same unit are 10±1 ka BP (n=9) and 20±1 ka BP (n=9). The poorly cemented, fine- to medium-grained, laminated yellow sandstone unit with horizontal beds above topset beds in Section-KV$_3$ at Yumrutepe at 1712 masl has an OSL age of 12±1.4 ka BP (Figure 11, Table 1).

Our OSL ages are considerably younger than radiocarbon ages of Kuzucuoğlu et al. (2010) for the

Figure 10- Section-KV$_3$ at Yumrutepe locality, showing SE-dipping foreset sandstone beds and horizontal conglomerate topset beds of a Gilbert-type delta complex. For location see figure 1.

Figure 11- The upper part of Section-KV_3 at Yumrutepe locality above the conglomeratic topset beds of Gilbert-type delta, showing soft sediment structures, such as water escape structures (arrow), in the fine to medium grained yellow sandstone. For location see figure 1.

same terrace sequences. These authors obtained a radiocarbon age greater than 34 ka BP from shells of *Dreissena* sp. around a 1735 masl in the Section KV_2. They concluded that this terrace (their C1'' transgressive series), located at 1730-1735 masl, formed sometime between100 ka BP and 34 ka BP. Located at ~1700 masl in the Yumrutepe locality, Kuzucuoğlu et al. (2010) defined yet another older transgressive fan delta series (C1') with its bottom set having an age older than 105 ka BP. This age is inferred from the age of Kotum ignimbrite that blocked the Kotum Valley (outlet of the Lake Paleo-Van) and resulted in a high lake level during, the Marine Isotope Stage-5 (MIS-5).

Interpretation: The section represents a Gilbert-type delta. The horizontally-bedded unit forms the topset, whereas the steeply-bedded unit forms the foreset deposits of the delta. The foreset deposits probably accumulated in response to bedload deposition and grain avalanching on a steep slope (Allen, 1984; Dunne and Hempton, 1984). The dike structures in the topset beds may indicate that pore-water pressure temporarily exceeded the lithostatic pressure in these sediments, leading to liquefaction. This condition was probably caused by a seismo-tectonic event, such as an earthquake shock.

3.5. Stratigraphic Section in the Munisinbahçe Locality

This section is located at the eastern coast of the Lake Van in the Munisinbahçe locality, 2 km west of the Village Mollakasım (Figure 1).

3.5.1. Section-MB$_1$ (GPS-046, lat: 38.6741°, lon: 43.1681°, elev: 1684 masl)

Description: This is about 6 m-thick succession of coarse clastic sediments, consisting of conglomerate, pebbly granulestone, pebbly sandstone and sandstone (Figure 12). Pebbly granulestone forms, at the base of the section, a light gray, 1m-thick, moderately to well-sorted and sub-rounded to rounded unit. This unit displays both a normal gradation (an upward grain size decrease) and a faint, NNW-dipping low-angle planar cross-bedding. The cross-bedding is highlighted by a foreset-parallel alignment of the small pebbles (Figure 12). The granulestone is overlain with a sharp and planar contact by a greenish gray and horizontally-stratified conglomerate. Normal grading is also apparent in this facies. Moderately- to well-sorted and well-rounded small pebbles (≤4 cm) grade upward into coarse sand. The thickness of the conglomerate slightly varies along the section; it is 1.0 m in the east and thins toward the west. This conglomerate passes upward across a sharp and planar surface into a 60 cm of moderately-sorted, rounded and clast-supported conglomerate with an overall lenticular geometry. In contrast with the underlying conglomerate, this unit shows reverse grading; i.e. finer clasts occur at the base and the relatively coarser clasts at the top. A 50 cm-thick pebbly coarse sandstone sits on this conglomerate above a sharp and probably erosional contact. This sandstone exhibits well-developed very fine horizontal stratification with the larger grains with their long axis parallel to the bedding surface. This well-bedded sandstone is succeeded by a 1.5 m-thick conglomerate that forms a mainly clast-supported,

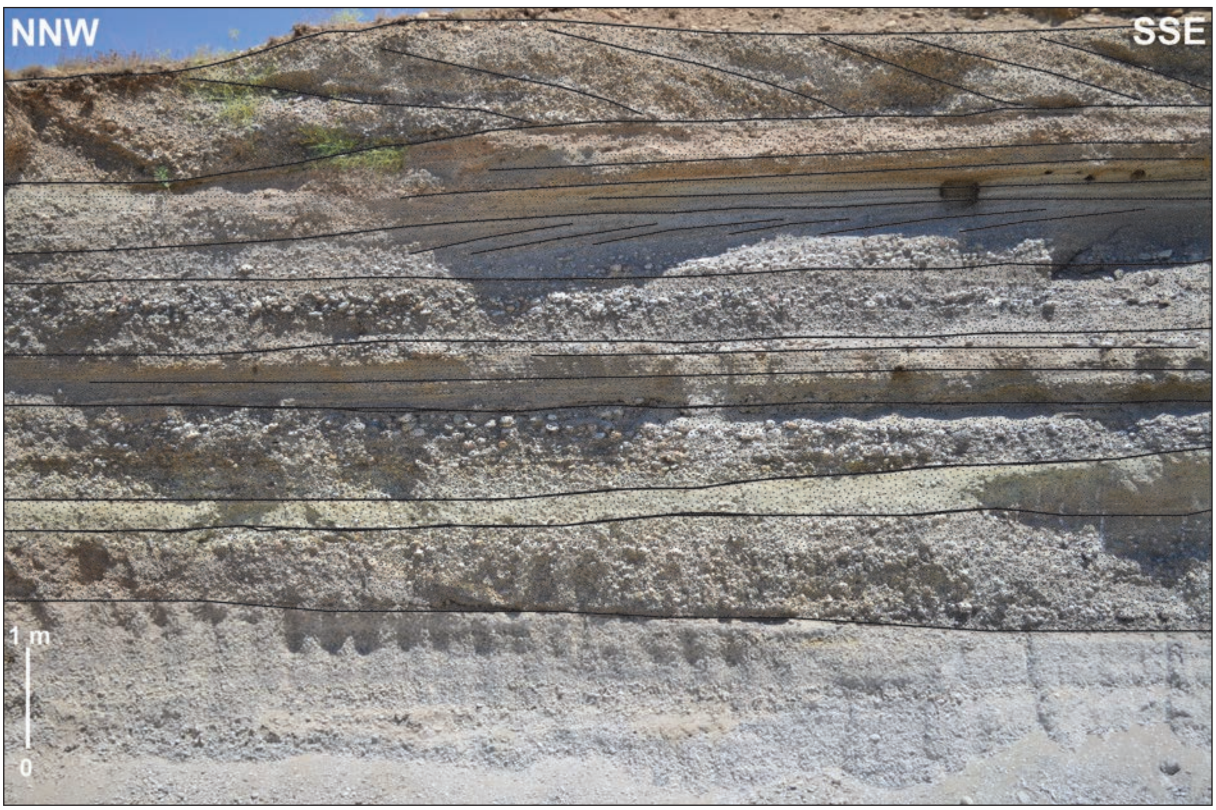

Figure 12- Section-MB$_1$ (GPS-046). This 6 m-thick succession consists of conglomerate, pebbly granulestone, pebbly sandstone and sandstone. Note the SSE-dipping cross-bedding in the top red conglomerate unit, which contrasts with the NNW-dipping cross-stratifications of the light gray conglomerate unit in the lower part. See figure 1 for location.

moderately-to poorly-sorted and generally well-rounded pebble (≤ 5 cm) assemblage. The base of the conglomerate body is sharp and probably erosive with a tabular surface. The upper boundary is gradational with an irregular and convex-up surface marking a transition into a 50 to 60 cm of light gray sandstone. This sandstone shows NNW-dipping planar cross-bedding and wedging out in the dip direction. Above this unit is 40-cm thick, red and pebbly coarse sandstone to granulstone with a sharp and erosional tabular base. It passes upward in turn into a 1 m-thick red conglomerate across a sharp and erosional surface. This red conglomerate is generally without grading, clast-supported and composed of a pebble and occasional cobble assemblage, showing a rather variable degree of sorting. It displays relatively a large-scale cross-bedding, usually only possible to identify from some distance. The inclined foreset strata are tabular and are composed of moderate-to well-sorted and mainly well rounded small pebbles. The cross-bedding in this red unit has SSE-dipping, contrasting with the NNW-dipping cross-stratifications of the lower light gray to greenish gray conglomerate (Figure 12).

Interpretation: The horizontal stratification in most of the light gray to greenish gray conglomerate beds of the Section-MB_1 reflects varying discharge and discontinuous accretion during deposition. The coarseness and the clast-supported texture suggest high water discharge and sediment concentrations in the depositional flows. Tractive transport and reworking (or recycling) are reflected by the abundance of the rounded clasts. Occurrence of the planar cross-beddings in the sandstone beds within these conglomerates indicates that turbulent flows were also important in their deposition. The NNW-dipping of these cross-beddings in the lower part suggests a southwesterly sediment transport direction. From the light of all these evidence the light gray to greenish gray conglomerates and the associated sandstones are interpreted to represent accretion and migration of channel bars in a braided stream or an alluvial fan environment (Rust, 1972; Bull, 1972; Nemec and Steel, 1984).

The red clastics in the upper part of the section probably represent a different episode of a braided river or alluvial fan deposition as suggested by their colour, erosional base and the cross-bedding with a dip opposite to that of the lower unit. The SSE-dipping planar cross-bedding in the red conglomerate indicates a northwesterly sediment transport direction during its deposition. The change of sediment source area may indicate a topographic differentiation in the region as a response to local tectonism.

3.6. Section studied in Mollakasım Village in the Boğaz Dere Valley

This section was studied on the western margin of the Boğaz Dere Valley, 700 m SE of the Mollakasım Village (Figure 1).

3.6.1. Section-BD_1 (GPS-045, lat: 38.6722°, lon: 43.1952°, elev: 1733 masl)

Description: This section is represented mainly by 10 m of light gray sandstone with variable sedimentary textures and structures throughout the section. Generally light gray, medium-to coarse-grained, well-sorted and rounded sandstone predominates with minor amounts of yellowish gray granulestone and conglomerate. The sandstone contains low-angle plane bedding, sub-horizontal plane lamination, ripple cross-lamination, bidirectional (N- and S-dipping) planar cross-bedding and trough cross-bedding (Figures. 13 and 14). The granulestone and very fine-grained conglomerates contain large amount of lithic carbonate grains and occur either in continuous beds (15 to 40 cm thick) in trough cross-beds or in small channels (Figure 14). When they form continuous beds, they have sharp upper and lower contacts and show in places normal or reverse grading.

Interpretation: The complex sequence of multidirectional sedimentary structures and variable sediment textures of the deposits in the Section-BD_1 suggest that these deposits probably accumulated in complex hydraulic conditions, such as the shoreface part of a beach environment. The trough cross-bedded facies were probably deposited in the surf zone by multidirectional current flow, whereas the bidirectional planar cross-bedded sediments were laid down in the upper shoreface by strong longshore currents. The coarser–grained deposits with graded bedding may have been resulted from storm-generated turbidity currents. The presence of small-scale channels and sharp truncation surfaces between the laminated bed sets indicate that high amplitude waves were periodically scouring the bottom of the depositional environment. The absence of large pebbles and cobbles in this beach may suggest that this area of the Lake Paleo-Van was either beyond the reach of the coarse clastics or such sediments were not available in this area and its close vicinity.

Figure 13- The sandstone unit in Section-BD_1 shows low-angle plane bedding, sub-horizontal plane lamination, bidirectional planar cross-bedding. The sediments represent a beach environment. See figure 1 for location.

Figure 14- Section-BD_1 (GPS-045). The granulestone and very fine-grained conglomerates containing abundant lithic carbonate grains show trough cross-bedding and small channel structures. See figure 1 for location.

3.7. Stratigraphic Section Measured around the Hasan Dere Valley

This section is located on the Lake Van shore, 200 m south of the mouth of the Hasan Dere Valley (Figure 1).

3.7.1. Section-HD_1 (GPS-047, lat: 38.7034°, lon: 43.1960°, elev: 1656 masl)

Description: This section is exposed in a ~15 m high coastal cliff located 1.3 km west of the Village Ağartı (Figure 1). It is represented by a gray conglomerate alternating with brown sandstone toward the top of the section. The conglomerate forms two thick intervals (5 and 4 m, respectively) in the lower half of the section and is composed of well-rounded, moderately- to poorly-sorted polygenic clasts with a grain-supported texture. Although its clasts range in size from 1 to10 cm, the average clast size is about 3 to 5 cm. The conglomerate is massive and disorganized without any internal structures. However, a bed-parallel alignment of relatively coarser clasts is seen along its contact with the each brown sandstone interbeds. The brown sandstone dominates the upper half of the section and is characterized by well-developed horizontal lamination and banded texture. Bands probably consist of couplets formed by materials of different color, size and composition. The section is ended with a matrix-supported and fine-grained conglomerate unconformably overlying the lithologies descibed.

Interpretation: On the basis of its ungraded nature, lack of internal structure, disorganized fabric and clast-supported texture, the gray conglomerate may be interpreted as debris flows deposited rapidly by high concentration and viscosity flows (Johnson, 1970; Lowe, 1979 and 1982; Gloppen and Steel, 1981; Nemec and Steel, 1984). Its interbedded occurrence with the brown sandstone may indicate that the depositional site was a nearshore lake environment of the Paleo-Van as discussed below.

The fine lamination and varve-like banding in the brown sandstone may be suggestive criteria of lacustrine sedimentation. However, the alternation of this unit with the coarse gray conglomerate facies indicates that the depositional environment was intermittently high energy one, probably a transitional environment between the offshore and the shoreline, rather than a deep-water environment. The occurrence of the sand-sized material nearly exclusively in shoreline or nearshore settings of the modern lakes may support this interpretation (Sly, 1978; Picard and High, 1981). The coarse and fine clastic materials of the gray conglomerate and the brown sandstone were perhaps contributed by a river inflow or an alluvial fan into the lake where they were handled and reworked by shoreline processes and finally deposited as debris- and sheet-flow sediments. The alternation of the gray conglomerate and the brown sandstone may suggest either a series of changes in lake-level or a periodic increase in sediment contribution throughout their deposition.

3.8. Stratigraphic Section Studied Around the Değirmentaş Dere Valley

This section is measured on the coast of the lake Van, 500 m west of the Değirmentaş Dere valley (Figure 1).

3.8.1. Section-DT_1 (GPS-017, lat: 38.8662°, lon: 43.4640°, elev: 1675 masl)

Description: This section represents 5 m of lacustrine sediments, comprising a 2 m-thick yellowish gray sandstone unit sandwiched between two 1.5 m-thick gray conglomerate units (Figure 15). The conglomerates are generally poorly-sorted and composed of pebbles and occasionally cobbles and boulders. Each conglomerate unit displays a rather disorganized fabric. However an overall vertical corsening in clast size and a faint bed-parallel clast orientation are observed. The contacts of the conglomerate units with the sandstone unit appear to be sharp and nonerosional.

The yellowish gray sandstone is a fine-grained, well-laminated, banded and occasionally rippled facies, displaying an intra-formational angular unconformity along the whole length of the outcrop. The surface of the unconformity is sharp, tabular and shows no sign of erosion. With the horizontal and inclined beds above and below, it looks like a large-scale, low-angle planar cross-stratification.

Interpretation: The sediments of this section show stratigraphic and sedimentological resemblances to the sediments of the Section-HD_1 around the Hasan Dere Valley. Therefore, they may have been deposited under similar depositional conditions. The yellowish gray sandstone and gray conglomerate probably accumulated also as debris- and sheet-flow sediments in a nearshore lacustrine environment, forming a transitional zone between the offshore and

Figure 15- Section-DT_1 consists of a 2 m-thick yellowish gray sandstone unit sandwiched between two 1.5 m-thick gray conglomerate units. See figure 1 for location.

shoreline environments of the Paleo-Van. The intra-formational angular unconformity within the yellowish gray sandstone was perhaps cut by a slide (or channel erosion?) and rapidly filled by a prograding unit, leading to the large-scale horizontal to cross-stratified deposits observed.

3.9. Stratigraphic Section Measured Around the Village Çakırbey

3.9.1. Section-CB_1 (GPS-18, lat: 38.9219°, lon: 43.6089°, elev: 1676 masl)

Description: This section is located at the coast of the Lake Van, 2.6 km northeast of the Village Çakırbey (Figure 1). It is represented mainly by 20 m-thick, gravelly granulestone to coarse sandstone deposits, dipping steeply toward the west, i.e. toward the Lake Van (Figure 16). These sediments form two distinct sequences separated by a sharp erosional surface. The lower sequence consists mainly of 10 to 50 cm-thick and well-developed gravelly coarse sandstone beds with a dip of 40°. These beds are separated in places by conglomerate channels or interbeds. Conglomerate channels are up to 40 cm-thick and appear to be common in the upper slope of the dipping beds. The conglomerate interbeds are poorly- to moderately-sorted and usually clast-supported but have in places a considerable amount of sand matrix. Clasts are dominantly well-rounded to subangular and range from cobbles to small pebbles, with most averaging 2.5-3 cm in diameter. Clasts, particularly the larger and platy ones, seem to be imbricated parallel to the bedding.

The upper sequence starts at the base with a 3 m-thick, poorly-sorted and matrix-supported conglomerate and continues upward with a gravelly granulestone to coarse sandstone facies, similar to that of the lower sequence. The basal conglomerate has a sharp and erosional base and pinches out in the up-slope direction. In conformity with this pinching, the stratification in the upper sequence as a whole shows a marked down-slope divergence of bedding. The upper sequence beds have a dip angle smaller than that of the lower sequence, which results in the whole section appearing to be a large-scale single planar cross-bedding (Figure 16).

Interpretation: The facies association, facies characteristics, sedimentary structures and depositional dip (primary dipping) of the sediments in

Figure 16- Section-CB_1 is 20 m-thick and consists of gravelly granulestone to coarse sandstone, dipping steeply toward the west, i.e. toward the Lake Van, See figure 1 for location.

the Section-CB_1 indicate that they were deposited as foreset beds on the slope of a Gilbert-type fan delta developed in the Paleo-Van. The conglomerates were transported here probably by sediment gravity flows, including grain flows, debris flows or density currents. The erosional surface between the lower and the upper sequences was perhaps generated in the delta slope by a gravity-induced slump or a slide. This surface was than rapidly filled with the sediments of the prograding upper sequence units (Lewis, 1980; Lowe, 1982; Nemec and Steele, 1985; Todd, 1989; Nemec, 1990; Dorsey et al., 1995; Falk and Dorsey, 1998; Sohn, 2000; McConnico and Bassett, 2003, 2007).

3.10. Stratigraphic Section in the Ala Çay Valley

Two stratigraphic sections were measured in the Ala Çay Valley, around the Village Muradiye; one is located 870 m NW and the other one is situated 1475 m SW of the village (Figure 1).

3.10.1.Section-AC_1 (GPS-019, lat: 38.9987°, lon: 43.7593°, elev: 1706 masl)

Description: The section comprises 3.5 m of soft, friable, laminated and rippled sandstones without conglomerate. At the base, it consists of 40 cm-thick, beige to light brown and thinly-bedded to laminated coarse sandstone passing upward, through a 15 cm of rippled sandstone, into 80 cm-thick interbeded fine-grained and laminated sandstone and mudstone. Above this sandstone is a fine-grained sandstone of 80 cm thickness with common well-developed lamination and micro-cross-lamination. Then the section continues with a 70 cm of relatively darker brown cyclic deposit. This deposit is characterized by alternating 6-to 8-cm-thick layers of laminated fine sandstone and carbonate. The section ends up with 60 cm-thick sandstone with no discernable internal structure.

Interpretation: An offshore lacustrine origin for these sediments is interpreted primarily from stratigraphic, lithologic and structural considerations. Their thin-stratification, varve-like bedding, lamination, ripple-stratification, fine-grain size and the absence of pebbles may indicate deposition in the offshore lake environment of the Paleo-Van, because such depositional structures are common in central lake deposits (Picard and High, 1972).

3.10.2. Section-AC$_2$ (GPS-20, lat: 38.9897°, lon: 43.7467°, elev: 1681 masl)

Description: This section consists mainly of 4.5 m-thick interbedded sandstone, clayey sandstone and mudstone (Figure 17). The sandstone is generally beige to light brown and medium- to coarse-grained and forms mostly horizontal beds of 20 cm thickness. It also displays ripple structures towards the upper part of the section. The clayey sandstone is brown in color and shows a horizontal stratification with beds ranging in thickness from 15 cm to 50 cm. The mudstone is brown, laminated and contains in part thin and light-colored carbonate bands.

Interpretation: The Section-AC$_2$ is about 1420 m away from the Section-AC$_1$ to which it displays lithological similarities. The sediments exposed in the Section-AC$_2$ were also deposited in the offshore lake environment of the Paleo-Lake Van. The existence of appreciable amounts of mudstone in this section may further indicate that their depositional site was deeper than that of the Section AC$_1$.

3.11. Stratigraphic Section Measured Around the Karahan Village

3.11.1. Section-KAR$_1$ (GPS-021-022-023, lat: 38.9563°, lon: 43.6444°, elev: 1690 masl)

Description: This section is represented by a 4 m-thick sedimentary sequence with a flat-lying upper and inclined lower units (Figures 18 and 19). The contact between them is a sharp and erosive planar surface. The upper unit consists mainly of interbedded sandstone and conglomerate beds. Sand beds are 15 to 40 cm-thick, beige to yellowish brown, medium to coarse-grained, and moderately- to well-sorted with rare random pebbles scattered throughout the beds at the base of the section. Conglomerate beds are approximately 30 cm-thick, locally cross-bedded, well-sorted and mainly clast-supported with sub-rounded to rounded clasts. These sediments include well-preserved fresh water gastropods and mammalian bone fragments. The former is found in the sandstone beds, whereas the latter in the conglomerate beds.

The inclined lower unit is characterized mainly by 20 to 30 cm-thick and well-developed planar beds of gray granulestone to coarse sandstone, dipping at 30°-35° toward the SW, i.e. toward the Lake Van. These beds are often iron-stained and contain very small pebbles concentrated mostly on the bedding planes (Figure 19).

Interpretation: The facies associations described in this section indicate a Gilbert-type fan delta environment. The flat-lying sediments probably form subaerial to shallow-marine topset sediments. The presence of the mammalian bone fragments in the conglomerate and the well-preserved gastropods in the sandstone may be cited as evidence for this

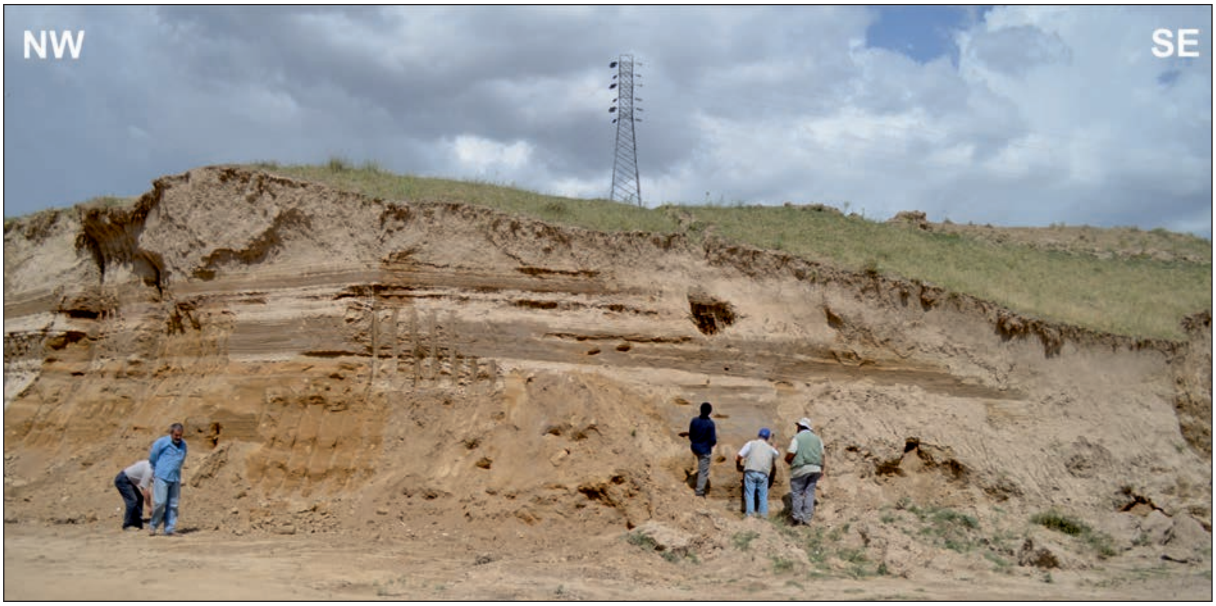

Figure 17- Section-AC$_2$ consists of 4.5 m-thick interbedded sandstone, clayey sandstone and mudstone with ligh coloured, thin carbonate beds. See figure 1 for location.

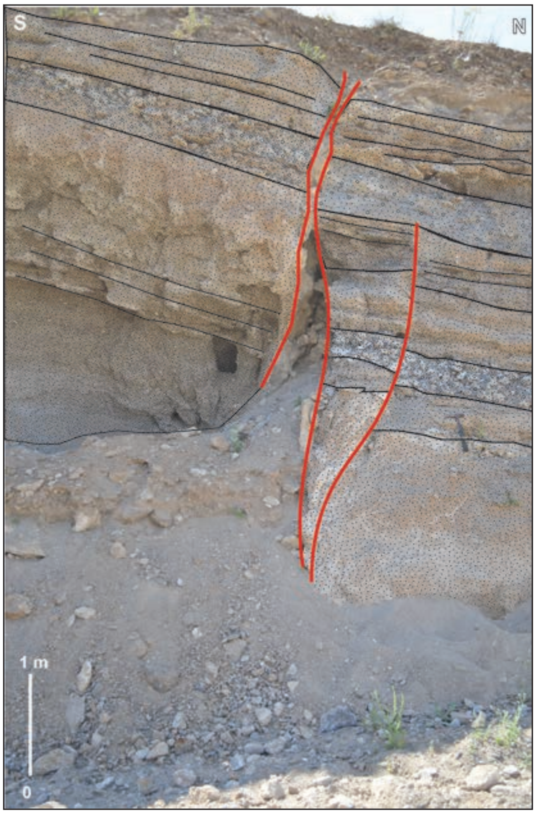

Figure 18- Section-KAR_1 is a 4 m-thick sequence consisting of a flat-lying upper unit of interbedded sandstone and conglomerate. See figure 1 for location.

Figure 19- Inclined lower unit in Section-KAR_1, consisting of 20 to 30 cm-thick and well-developed planar beds of gray granulestone to coarse sandstone. The beds dip toward the SW, i.e. toward the Lake Van and represent the foresets of a Gilbert type delta.

interpretation. The textural properties and sedimentary structures of the conglomerate may indicate that they were deposited by a braided river and perhaps reworked later by wave processes. The underlying inclined sediments perhaps developed as the foreset beds of the delta as a result of a grain-flow process (Nemec, 1990; Nichols, 2009). The stratigraphic relation of the flat-lying and the inclined sediments suggest that the delta was prograding into the lake as a result of either a drop in lake-level or an increase in the rate of sediment supply.

Age of the Karahan Village Terrace deposits: The Gilbert fan delta sequence was dated to be between 25.7 and 24.9 ka BP in the area (in Kırklar) by Kuzucuoğlu et al. (2010), using radiocarbon analysis of organic matter (Table 1). The level of this dated terrace is 1693 m, about 45 m above the present lake level.

3.12. Stratigraphic Section Measured in the Deliçay Valley

3.12.1. Section-DV$_1$ (GPS-24-25, lat: 39.0095°, lon: 43.4467°, elev: 1678 masl)

Description: The section displays throughout its 5 m thickness a yellowish brown, very finely-bedded to laminated very fine-to fine-grained sandstone in part with common symmetrical wave-ripple cross-lamination (Figure 20). In the lower part of the section, the sandstone is interbedded with white siltstone beds (10 cm), rich in microcrystalline carbonate. In the upper part of the section, there is a syndepositional deformation zone marked by convoluted and deformed sandstone laminations, varying in thickness from 30 cm to 90 cm.

Interpretation: The association of the following characteristics indicates that these sediments were deposited in the offshore of the Lake Paleo-Van: very fine bedding, lamination, fine texture, symmetrical wave-ripple cross-lamination, convolute-bedding and deformed laminations. Very fine bedding, lamination and fine grain size may suggest accumulation in a quiet standing water, below the wave-base. The common symmetrical wave-ripple cross-lamination may indicate that oscillatory flows existed in the environment. The convoluted and disturbed sandstone layers probably originated from soft-sediment deformation that may have been induced by seismic liquefaction and/or fluidization (Seilacher, 1969; Moretti et al., 2002).

Figure 20- Section-DV$_1$ includes 5 m thick yellowish brown, very finely-bedded to laminated, very fine-to fine-grained sandstone with symmetrical wave-ripple cross-lamination. For location see figure 1.

3.12.2. Section-DV_2 (GPS-026, lat: 39.0139°, lon: 43.4383°, elev: 1705 masl)

Description: This section is represented by ca. 5 m-thick yellow to yellowish brown very fine-grained to fine-grained sandstone with rare brown mudstone interbeds. Bed thickness is variable, ranging from 10 to 20 cm. Bed contacts are sharp. The beds display internal horizontal lamination, wavy lamination and micro cross-lamination. The sandstone displays in various levels, some soft-sediment deformational structures. Individual horizons are 25-30 cm-thick and laterally continuous for tens of metres. They are overlain and underlain by undeformed horizontal beds. The deformational structures in these flat-lying beds mostly include overturned folds (Figure 21).

Interpretation: This section probably represents the offshore lacustrine environment of the Paleo-Van. These sediments were deposited from suspension of fine-grained sediments with minor bedload influence. The occurrence of the soft-sediment deformational structures may be attributed to liquefaction and fludization induced by earthquake shock in the seismically active Lake Paleo-Van Basin.

3.13. Stratigraphic Section Measured in the Zilan Valley

3.13.1. Section-ZV_1 (GPS-028, lat: 39.0135°, lon: 43.3124°, elev: 1667 masl)

Description: This section represents a sedimentary succession, comprising 15 m thick mudstone in the lower and 10 m thick sandstone in the upper part. The mudstone is mainly dark greenish gray in color and displays well-developed horizontal lamination formed from greenish gray and brown silt- or claystone laminae.

The sandstone overlies the mudstone with a sharp and erosional contact. It is beige to brown, thinly- to medium-bedded, locally rippled and medium- to coarse-grained with some large-scale lenticular cross-bedding, dipping to the S.

Interpretation: The laminated mudstone indicates deposition in a low energy subaqueous depositional environment. It was perhaps deposited rhythmically from suspension due to absence of wave activity. It accumulated most probably in the relatively deep offshore environment of the Paleo-Van.

Figure 21- 31 Section-DV_2 (GPS-026) locally shows soft-sediment deformational structures, which also include overturned folds. See figure 1 for location.

Stratigraphic and sedimentological features of the sandstone may suggest that it was perhaps a distal distributary mouth bar formed near the lakeward limit of a deltaic distributary channel. The large-scale lenticular beddings in this facies may be interpreted as channelizing and scouring events. The progradation of the delta across the lake-floor of the Paleo-Van resulted probably in this coarsening-up section.

3.13.2. Section-ZV$_2$ (GPS-29-30, lat: 39.0253°, lon: 43.3111°, elev: 1694 masl)

Description: The section starts at the base with gray, thinly-bedded to laminated, coarse- to medium-grained and well-sorted sandstone and pebbly sandstone with a primary dipping of 30° to 40° toward the east (Figure 22). These sandstones are about 8 m-thick and pass upward abruptly into 3 m-thick, horizontally-bedded to laminated gray to brown sandstone, including thin (10-15 cm) interbeds of fine conglomerate. However, towards the top of the section, the thickness of the conglomerate beds increases (up to 60 cm). Both the inclined and the horizontal sandstone and conglomerate beds are cut by a large- scale slide or a channel filled with large-scale horizontal to cross-stratified gray sandstone, displaying internal lamination (Figure 22). The slide or channel deposits are also overlain by the horizontal beds.

Interpretation: This section is a typical succession of a Gilbert-type delta. The inclined sandstones represent foreset beds, whereas the horizontally layered sandstone and interbedded conglomerate may characterize the topset beds. The presence of large-scale channel or slide deposits toward the top of this section suggests that subaqueous slumping and downslope mass movement of sediments were taking place in the delta front environment. The slide surface appears to have been filled by the prograding deltaic sediments.

3.14. Stratigraphic Section Measured in the western part of the Kaş Burnu

3.14.1. Section-KB$_1$ (GPS-031, lat: 38.9710°, lon: 43.2719°, elev: 1727 masl)

Description: This section is of 7 m thick, consisting of pumice and sandstones (Figure 23). Pumice is seen in the lower part of the section and is

Figure 22- Section-ZV$_2$ in Zilan Valley, consisting of 8 m thick, gray, thinly bedded and laminated sandstone with eastward dips of 30° to 40° at the base, 3 m thick horizontally bedded and laminated sandstones in the middle, and large scale slide and channel sandstone and conglomerates on top, which are themselves covered by horizontally bedded sandstones. See figure 1 for location.

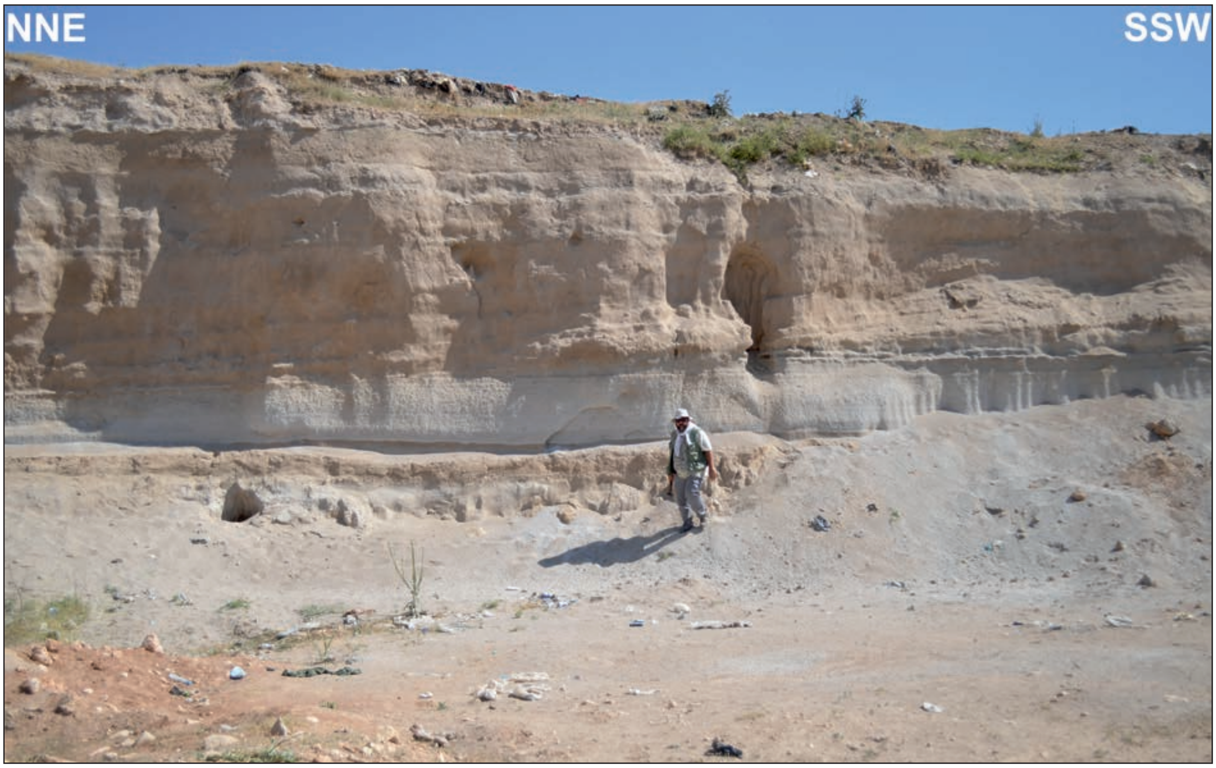

Figure 23- Section-KB$_1$ consisting of 2 m-thick pumice in the lower and 5 m-thick horizontally bedded sandstones in the upper part. See figure 1 for location.

characterized by highly vesicular texture without any apparent phenocrysts. It displays alternating white and dark gray laminae and bands. This 2 m-thick pumice is overlain conformably by 5 m-thick, light brown to beige and coarse-grained sandstone, passing upward into relatively finer-grained sandstone.

Interpretation: The finely banded and laminated texture of the pumice and the conformably overlying sandstones may indicate that they accumulated perhaps in a low-energy subaqueaous lake environment of the Paleo-Van. This major pumice deposit may probably correspond to the Nemrut Formation dated between 33.7 and 28.6 ka BP by Sumita and Schmincke et al. (2013*a, b*).

3.15. Stratigraphic Section Measured in the Kumlu Dere Valley

This section is located at the coast of the Lake Van, 500 m west of the Kumlu Dere Valley.

3.15.1. Section-KD$_1$ (GPS-032, lat: 38.9442°, lon: 43.1628°, elev: 1667 masl)

Description: This 15 m-thick section displays an intricately intermingled white to beige conglomerate and sandstone that are cut in places by low-angle erosional surfaces. The conglomerate is clast-supported with coarse, well-rounded and poorly-sorted clasts derived probably from a single source, namely the Adilcevaz Limestone forming the basement rock in the area. The sandstone is fine- to medium-grained and thinly-bedded to laminated. It forms a number of levels in the section either interfingering or alternating with the conglomerate with various thicknesses.

Interpretation: The poorly-sorted but clast-supported texture of the conglomerate with relatively well-rounded pebbles and boulders indicate that this sediment was deposited by currents of high water discharge and sediment concentration. The well-rounded clasts suggest that the transportation in these currents was mainly in traction mode. Thin bedding and lamination of the sandstone may indicate a relatively low energy depositional environment for this fine clastic rock. This environment seems to be a distal part of an alluvial fan extending into the lake. However, their complex contact relation suggests that both lithological units were deposited in an area adjacent to a steep relief from where streams flowed down the steep slopes, transporting the coarse conglomerate onto an alluvial fan that prograde into the Lake Paleo-Van.

3.16. Stratigraphic Section Measured around the Çayır Mahallesi, Adilcevaz

3.16.1. Section-CM_1 (GPS-034, lat: 38.7911°, lon: 42.7881°, elev: 1676 masl)

Description: The section is located on the coast of the lake, 2 km east of the Çayır Mahallesi. It commences with 2 m of gray pumice, passing upward, through a 40 cm-thick brown mudstone, into a 4 m-thick white travertine. In the mudstone, a faint lamination is observable. The travertine is coarsely crystalline limestone displaying abundant cavities of various sizes.

Interpretation: This gray pumice originated by eruption of most probably the Nemrut Volcano and deposited as airfall deposit in the Paleo-Lake Van. Deposition of this tephra unit was followed by the laminated brown mudstone. The travertine may have formed around a spring at the lake margin.

3.17. Stratigraphic Section Measured in the Easten Margin of the Kara Dere Valley

3.17.1. Section-KRD_1 (GPS-027, lat: 38.8055°, lon: 42.7571°, elev: 1697 masl)

Description: This section is about 20 m-thick, comprising in its lower half gray pebbly sandstone, showing very fine horizontal bedding and lamination (Figure 24). The pebbles are commonly small and rounded. Toward the top of the section, the gray pebbly sandstone starts to alternate with brown sandstone that dominates the upper half of the sequence together with interbedded light-gray, well-rounded pebble and cobble conglomerate and pebbly sandstone. The brown sandstone is hard, wave-rippled and forms protruding horizontal beds with sharp boundaries. Wave ripple-marks commonly occur in this sediment. The interbedded conglomerate and pebbly sandstone occur as continuous and discontinuous units of 0.1 m to 1.5 m thick with horizontal and planar cross-bedding. The dip of cross-beds is towards SSW. The sequence often displays in its various levels several large-scale erosional surfaces marked by iron oxide staining.

Interpretation: These sediments probably belonged to a nearshore setting of the Paleo-Van. Sheet flow currents, operating in the shoreface to nearshore environments, perhaps deposited the gray, horizontally layered pebbly sandstone and conglomerate. The brown sandstone was probably deposited in relatively in the deeper waters of the lake as indicated by its texture, lamination and wave ripples. The large-scale erosional surfaces or scars were perhaps made by slides and slumps caused by high sedimentation loading or storm.

Figure 24- The 20 m thick section-KRD_1 (GPS-027) in Kara Dere consists of horizontal bedded and laminated pebbly sandstone in the lower part and interbedded brown pebbly sandstone and conglomerate in the upper part. See figure 1 for location.

3.18. Stratigraphic Section Measured in the Evren Deresi Valley

3.18.1. Section-ED$_1$ (GPS-044, lat: 38.7981°, lon: 42.715°1, elev: 1683 masl)

Description: This section consists of 2 m thick sandstone in its lower and 3 m thick conglomerate in its upper part (Figure 25). The contact between these lithological units is sharp and planar. The sandstone is gray and medium- grained with thin horizontal bedding and lamination. These sedimentary structures are well-marked by their colours, displaying different shades of gray. The overlying conglomerate is brownish red in colour and show horizontal bedding. It consists of poorly to moderately sorted pebbles and local cobbles. Individual conglomerate beds mostly display a disorganized fabric, although some of them locally show bedding plane-parallel clast orientation.

Interpretation: The gray sandstone, with its thin horizontal bedding and lamination, may represent the relatively deep part of Paleo-Lake Van. The unconformably overlaying conglomerate may be interpreted as indicative of fluvial deposition. This conglomerate is certainly a product of a powerful stream. Its poor to moderate sorting lack of fossils and sheet-like or tabular beds with sharp, planar and non-erosional base support this interpretation. It probably represents accretion and migration of longitudinal bars of a braided stream (Rust, 1972), flowing into the lake.

3.19. Stratigraphic Sections Measured Around the Ziyaret Dere Valley

Two sections were measured in this area. First one (ZD$_1$) is 1 km to the east of the valley, whereas the second one (ZD$_2$) is 500 m to the west of the walley.

3.19.1. Section-ZD$_1$ (GPS-042, lat: 38.7846°, lon: 42.6814°, elev: 1673 masl)

Description: The section is characterized by a 20 m-thick succession of conglomerates and sandstones; the former predominate over the latter. Conglomerates occur in both the lower and the upper parts of the succession. The lower conglomerate is more than 10 m-thick, massive to poorly-bedded,

Figure 25- Section-ED$_1$ (GPS-044) in Evren Deresi Valley consists of 2 m thick sandstone in its lower and 3 m thick conglomerate in its upper part. Note the sharp and lanar contact between these units.

generally poorly-sorted and devoid of fossils (Figure 26). It is clast-supported and does not display any noticeable sedimentary structures. Its clasts are angular to subrounded and dominantly in pebble size. In the SE end of the section, it passes upward across a sharp and planar contact into 3.5 m-thick, gray, fine-to medium-grained and thinly-bedded to laminated sandstone (Figure 26). Toward the NE end of the section, this sandstone changes in colour to brown with similar lithological features. The brown sandstone forms here a large-scale channel structure (Figure 27). It is then succeeded by a conglomerate unit, forming the upper part of the section. This upper conglomerate is 3 m-thick, comperatively finer-grained and matrix-supported with inclined primary strata terminating on the horizontal beds of the brown sandstone, thus forming a downlap contact with this unit (Figure 27).

Interpretation: The lower conglomerate was probably deposited in an alluvial fan environment. Poor sorting, clast shapes and absence of fossil and bedding are all features of such depositional environment. The finely-bedded to laminated brown and gray sandstones probably represent the bottomset beds of a fan delta. The foreset beds are represented by the upper conglomerate, which were built out over the brown sandstone as the delta prograded. The deposition of the upper conglomerate perhaps occurred by debris flows as suggested by its poorly-sorted gravel in a sandy matrix (Namec, 1990). The sharp contact between the lower conglomerate and the overlying sediment is a disconformity, indicating that the delta setting developed over the alluvial fan when the lake level rose and lake waters inundated the marginal areas of the basin where alluvial fans were forming.

3.19.2. Section-ZD_2 (GPS-043, lat: 38.7885°, lon: 42.6724°, elev: 1666 masl)

Description: The section is composed mainly of 3.5 m-thick brown sandstone in the lower half and about 1.5 m-thick yellow and clayey sandstone in the upper half of the section. The brown sandstone is generally fine-grained and silty in part, containing thin (less than 15 cm) interbeds of conglomerate and coarse sandstone. It is characterized by well-developed horizontal laminae. The upper yellow sandstone conformably overlies the brown sandstone and displays striking syndepositional deformational

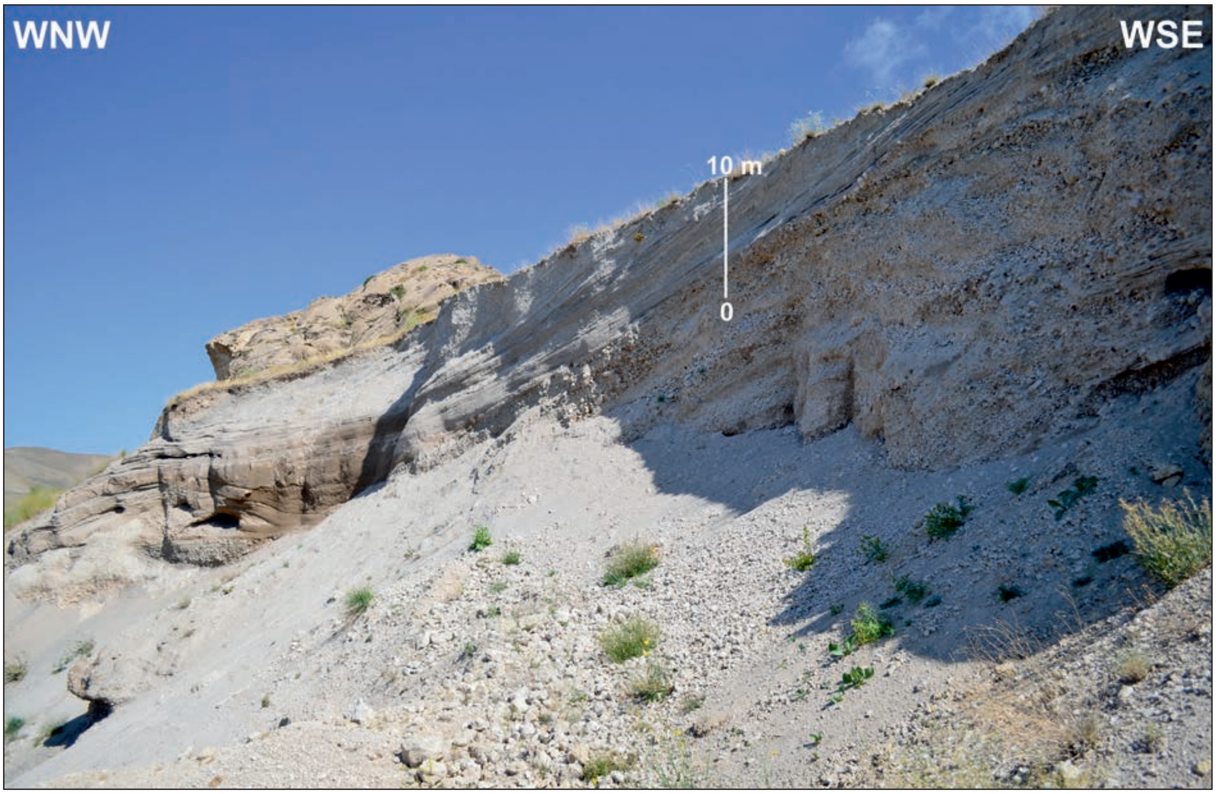

Figure 26- Section-ZD_1 (GPS-042) in Ziyaret Dere Valley consists of 20 m-thick succession of conglomerates and sandstones. Conglomerates occur in both the lower and the upper parts of the succession. See figure 1 for location.

Figure 27- 3 m thick upper conglomerate beds in upper part of Section-ZD_1 (GPS-042) in Ziyaret Dere forming a downlap contact with brown sandstone unit. See figure 1 for location.

structures, such as convolute lamination and flame structures.

Interpretation: The well-laminated brown sandstone facies may have accumulated on the lake-floor environment of the Paleo-Lake Van, not far away from the shoreline. The presence of conglomerate and coarse sandstone interbeds between this sandstone may indicate that this part of the lake was occasionally being fed by currents carrying coarse sediments from the shoreline. The yellow sandstone was also offshore lake sediment, which was most probably disturbed and deformed by seismic shaking.

3.20. Stratigraphic sections measured in the Kumlu Dere Valley at Soğanlı Village

3.20.1. Section-KDS_1 (GPS-040-41, lat: 38.7931°, lon: 42.6120°, elev: 1693 masl)

Description: This section is very similar to the Section-ZD_2 both in composition and stratigraphy. Its lower part consists of about 20 m of brown and coarse sandstone, in part with conglomerate and pebbly sandstone. The sandstone shows well-developed and laterally continuous lamination. It is overlain by 3 m-thick brownish sandstone, showing a large-scale convolute-bedding (Figure 28).

Interpretation: As stated in the interpretation of the previous section ZD_2, the laminated brown sandstone accumulated in the low-energy environment of the Paleo-Lake Van-floor and was severely deformed probably by seismic waves.

3.21. Stratigraphic Section Measured Around Ceviz Dere Valley

3.21.1. Section-CZ_1 (GPS-039, lat: 38.7724°, lon: 42.5861°, elev: 1663 m)

Description: This section was studied on the shoreline of the Lake Van, 150 m west of the Ceviz Dere. It is a 4 m-thick section, commencing with planar cross-bedded coarse sandstone overlain by a thin conglomerate bed. Above comes 2.5 m-thick, horizontally- bedded and dominantly brown mudstone to muddy sandstone, passing upward into coarse and pebbly sandstone.

Interpretation: The facies association of this section indicates that these sediments probably

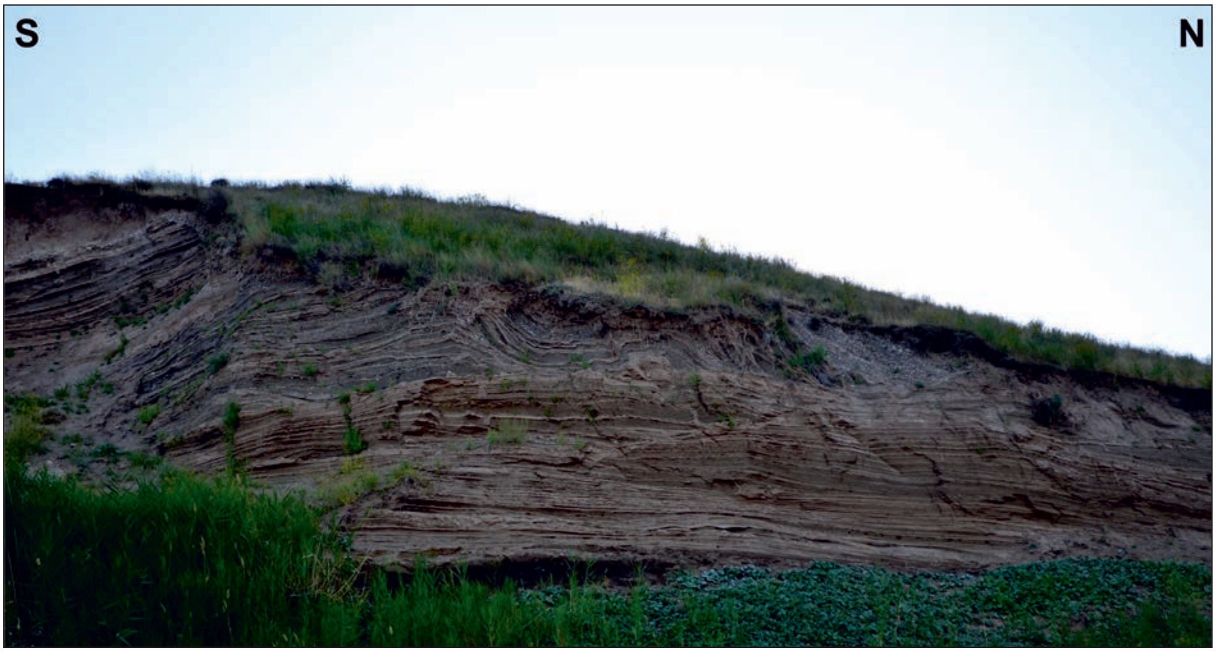

Figure 28- Section-KDS$_1$ (GPS-040-41) in Kumlu Dere Valley, Soğanlı Village, showing a large-scale convolute-bedding in brown sandstone. For location see figure 1.

accumulated in the nearshore environment of the Paleo-Lake Van. The cross-bedded sandstone and the overlyin conglomerate probably represent the foreshore to shoreface environments of a beach along the lake. The overlying brown mudstone and muddy sandstone were deposited nearshore environment during a rise in the water level of oscillating Lake Van.

3.22. Stratigraphic Section Measured Around Karmuç Çayı Valley

3.22.1. Section-KC$_1$ (GPS-038, lat: 38.7122°, lon: 42.4242°, elev: 1660 masl)

Description: This section is measured near the shore of the Lake Van, 850 m west of the Karmuç Valley. It is of 17 m thick and characterized by yellowish gray sandstone, including interbeds of conglomerate in various levels. The sandstone is fine-grained, horizontally-laminated and wave-rippled in part with low-angle large-scale cross-stratification. It forms a thick and distinct unit in the upper part of the section. The interbedded conglomerates are planar cross-stratified, with well-rounded pebble size grains and commonly erosional basis.

Interpretation: These sediments were probably deposited in the nearshore environment, forming a transitional zone between the offshore and the shoreline of the Paleo-Lake Van. Their low-angle cross-stratification and wave ripple-marks suggest wave-agitation in this environment. The cross-bedded conglomerates with erosional basis may indicate coarse-grained sediment influx by various currents from the shoreline. The thick occurrence of the laminated sandstone towards the top of the section suggest deepening of the lake.

3.23. Stratigraphic Section Measured in the Kotum Dere Valley

3.23.1. Section-KOD$_1$ (GPS-035, lat: 38.4757°, lon: 42.3091°, elev: 1656 masl)

Description: The section is made up of 8 m-thick, yellow and thinly-bedded to laminated travertine in its lower part and a succession of yellowish gray siliciclastic sediments in its upper part. The contact between these two facies associations is sharp and marked by a thin (15 cm) basal conglomerate. The siliciclastic sediments are characterized by finely-bedded to laminated and locally cross-bedded sandstone in part with conglomerate interbeds (Figure 29). The cross-beds dip to the NE, i.e. toward the modern Lake Van.

Interpretation: The travertine constitutes the stratigraphic basement in the area. The laterally continuous layering and lamination of this unit may indicate that it formed in the littoral environment of

Figure 29- Section-KOD_1 (GPS-035) in lower Kotum Dere Valley consists of 8 m-thick, yellow and thinly-bedded to laminated travertine in its lower part and yellow gray, finely-bedded to laminated sandstone with conglomerate interbeds in the upper part. A 15 cm thick basal conglomerate marks the base of the sandstone unit above the travertine. For location see figure 1.

the paleo-lake where the subaqueous vegetation favoured the precipitation of the travertine. Regional considerations and sedimentary structures of the upper clastic succession suggest a nearshore lake environment for these sediments.

3.23.2. Section-KOD_2 (GPS-037, lat: 38.4721°, lon: 42.3095°, elev: 1670 masl)

Description: The section comprises various sandstone facies, sitting on a travertine above a disconformity. The sandstone at the base is 1.5 m-thick, silty and fine-grained. It is followed upwards by a 1 m-thick polygenic conglomerate with an erosional base. The conglomerate forms a lensoidal horizon, parallel to the bedding above and below. It is overlain by 3.5 m thick brown and medium-bedded to laminated sandstone, with local slump structures or convolute beddings sandwiched between horizontally-bedded to laminated sediments (Figure 30). Large-scale slide surfaces are also seen in the section.

Interpretation: Facies characteristics and their comparison with the similar facies of the sections described elsewhere around the Lake Van suggest that these sandstones and the associated conglomerate accumulated in a nearshore lake environment of the Paleo-Van. Horizontal thin bedding, lamination and convolute bedding within the sandstone all support this interpretation. The conglomerate was perhaps transported into the lake by traction currents from the shore. The large-scale sliding surfaces indicate rapidly prograding sediments on an unstable slope.

Age of Kotum Vallley terraces: The travertine underlying the terraces in the Kotum Valley have been dated at 102 ka BP by Kuzucuoğlu et al. (2010), using $^{230}Th/^{234}U$ method (Table 1), Elsewhere in the Kotum Valley the terraces are underlain by 4 m thick pumice fall, in which feldspars yielded an age of 117±5.2 ka BP, using $^{39}Ar/^{40}Ar$ method (Mouralis et al., 2010) (Table 1). Therefore, the two terrace sections described in the lower Kotum Valley in this study are younger than about 100 ka BP. According to Kuzucuoğlu et al. (2010), these terraces reach levels of 1730-1735 masl (ca. 85 m above the present lake level).

Figure 30- Section-KOD_2 (GPS-037) in the upper Kotum Dere Valley, showing slump structures and convolute beddings sandwiched between horizontally-bedded to laminated sandstone in the upper part of the section. For location see figure 1.

4. Discussion

4.1. Reconstruction of Depositional Environments: Tectono-Stratigraphic Evolution of the Lake Van Basin

Before reconstructing the interpreted depositonal environments and their paleogeographic distribution in the Lake Van Basin, we list the features common to all the studied terrace sections below:

Sections are commonly thin, ranging in thickness between 3 and 25 m. Relatively thick sections (i.e. more than 15 m) are found in the valleys situated to the north and west of Lake Van. They are generally regressive in nature, showing upward shallowing and coarsening sequences.

The sections do not show a distinct large-scale cyclicity characterized by packages of alternating well-developed upward-fining and –coarsening sequences separated by erosional contacts. Instead, relatively small-scale lateral and vertical facies changes or interfingerings are observed in the marginal lake sediments.

Terrace sediments consist predominantly of terrigenous clastic material with limited lithological diversity. Sandstone and conglomerate are the predominant lithologies throughout the sections. Distinct carbonate units exist as travertine or tufa in a few sections and mostly constituting the stratigraphic basement of the terrace sections where observed. No evaporites or other chemical sediments are found in the study area.

Terrace sediments hardly contain any biota. The fauna occasionally found in these deposits includes usually fresh-water gastropods and bivalves (*Dreissena* sp.).

The terraces around the Lake Van are mostly made up of clastic sediments accumulated in various lake-related depositional environments, including alluvial fan/braided river, beach, delta, nearshore and offshore. These depositional environments are characterized by distinct physical, chemical and biological conditions, including the fauna and flora, geology, geomorphology, climate, and, for subaqueous environments, the depth, temperature, salinity, and current and wave regimes. Therefore, if the variability of the depositional environments of the terrace sediments, based on facies changes, are discussed with emphasis on these conditions, it may be possible to enlighten, to a certain extent, the local tectonics and the climate prevailed in the Paleo-Lake Van basin during its geological history. In the following paragraphs, we make such an attempt to deal mainly with the depositional conditions of the sedimentary environments in the Paleo-Lake Van basin.

4.1.1. Alluvial Fan/Braided River Environment

The alluvial fan/braided river sediments are recognized in the Sections-KV_1, KV_2, MB_1, KD_1, ED_1 and ZD_1. Although they are not significant in the basin in terms of volume, they are important because their deposition is sensitive to tectonic and climatic controls. They imply vertical tectonic activity during or immediately prior to their deposition. The sections-KV1, KV2 and MB1 are measured in the Karasu Valley and Munisinbahçe locality (around Mollakasım) (Figure 1). These areas are located just to the N and NW of the Çomaklıbaba Mountain that is bounded from north and south by active thrust faults. It is quite possible that these faults uplifted the Çomaklıbaba mountainous area that provided debris and increased stream competence to accumulate the terrace deposits. Of course, these alluvial fans/braided rivers may have also developed due to base-level lowering, as in the case where the River Karasu has eroded its floor at a more rapid rate than its tributary streams have (Carryer, 1966; Bull, 1972). The other three sections (KD_1, ED_1 and ZD_1) are situated in the northern margin of the Lake Van where the NE-SW striking strike-slip faults occur in the adjacent high areas (Figure 1). These faults may have created uplift in the catchment areas which provided sediments to the alluvial fans/braided rivers, reaching to the Lake Paleo-Van. This interpretation is supported by the geology of the region as discussed in Section 2.1. This basin lies in the center of a dome structure underlain by the thinnest crust in the eastern Turkey. It has been rising since the closure of the Bitlis Ocean in the medial Miocene with the development of significant strike- and dip-slip faults, resulting in a topographic differentiation in the region (Şengör et al., 1985, 2008).

Most of the modern alluvial fans occur in arid or semi-arid regions (Bull, 1972; Blair and McPherson 1994). Perhaps, the Lake Paleo-Van also had arid climate during the formation of the alluvial fans/braided rivers recognized in the terraces. However, the well-bedded and clast-supported coarse conglomerates of the alluvial fans in the area studied indicate that they were deposited by sheet flood processes under wet conditions (Harvey et al., 2005). This may suggest that there was enough water supply in the Lake Paleo-Van Basin to the mainstream channels leading towards the fans. The water source may be the rainfall over the entire basin or snowmelt runoff from all or part of the basin during the warm and wet interstadials.

4.1.2. Beach Environment

The beach deposits are best seen in the Dönemeç Çayı (Section-$DÖN_2$), Karasu (Section-KV_2) and Boğaz Dere (Section-BD_1) Valleys that are bounded by high terains with many distributary streams, extending down to the main valleys. The existence of the beach deposits in these areas indicates that these valleys were once invaded by the Lake Paleo-Van and the water level of the lake was 60 to 85 m higher than the present lake level (1648 m asl). It seems that the Streams Dönemeç Çayı, Boğaz Dere, Karasu and their distributary creeks transported abundant detritus to the lake where they were handled and reworked by shoreline processes in some parts of the valleys. The beaches developed along the skirts of the adjacent highs and therefore they were probably narrow and limited in spatial distribution. The narrowness of the beaches and their rapid sideward or upward passages into finer-grained nearshore lake or coarser-grained alluvial fan/braided river sediments may have been resulted from the reduced wave activity and lack of tidal effects in the Paleo-Lake Van. However, the wave energy on the beaches was high enough to rework and accumulate the well-sorted, –rounded and cross-rippled sandstones in part with conglomerates in these environments. These sediments were perhaps shaped under the effects of wave swash-backwash along the beaches.

The beach deposits clarly mark lake level and therefore their occurrence at various elevations, such as 1708 m asl (Section-$DÖN_2$), 1733 m asl (Section-BD_1) and 1736 m asl (Section-KV_2) indicates that the lake-level was much higher and variable in the past. The absence of large-scale cyclicity in the studied terraces suggest that the lake level changes do not appear to represent great fluctuations in water depth of the Lake Van. It rather show a an apparent gradual drop in water level from 1755 masl at ~125 ka BP to its modern level at 1647 m, as suggested by the younging ages of the shoreline facies with decreasing elevation. However, considering the closed nature of the Lake Van, the intensive late Quaternary volcanism and active tectonics of the area, it is most likely that Lake Van has been subjected to significant lake level fluctuations under the influence of climatic, tectonic and volcanic processes (e.g., see Sumita and Schmincke, 2013*a, b*). The effect of the climate on the lake-level was through evaporation-precipitation balance. The Lake Van level was generally higher during interglacial and interstadials than that during glacial and stadials, according to the sedimentological, palynological and isotopic evidence from the sediments cored within the lake (Çağatay et al., 2014, Stockhecke et al., 2104; Litt et al., 2014). As discussed in Section 2.1, the Lake Van Basin and the surrounding areas have been subjected to convergent tectonics since the medial Miocene. Owing to this tectonics, the marginal lake facies or terraces may have been uplifted gradually to upper elevations. During the formation of the marginal lake facies, the climate was probably drier, providing suitable conditions for excessive evaporation. These circumstances during the stadials may have resulted in a gradual fall in the water level, leading to the contraction of the lake. As the lake shoreline shifted towards the basin center, its margins were exposed gradually to subaerial conditons where the weathering and erosional processes modified the sediments. This development increased the sediment supply and the sediments thus provided were deposited at the margins as beach and delta deposits during the fall in water level.

4.1.3. Delta Environment

Gilbert-type delta deposits mostly occur in the eastern margin of the Paleo-Van and they are best observed in the Dönemeç Valley (Sections-DÖN$_3$), Karasu Valley (Section-KV$_3$), Çakırbey Village (Section-CB$_1$), Karahan Village (Section-KAR$_1$), Zilan Valley (Section- ZV$_2$) and the Ziyaret Dere Valley (Section-ZD$_1$). Their concentration along this gradually rising margin is not surprising, because this type of coarse-grained deltas usually form where high sediment supply, high water flux and steep basin margin are available (Postma, 1990; Çukur et al., 2013). As mentioned in the discussion of the beach environment above, the uplift of the eastern margin created steep topography to supply coarse-grained sediments, while the dropping lake-level caused the marginal streams to downcut to new base levels and carried the detritus to deposit the prograding Gilbert-type deltas. During this time, with high erosion rates due to low vegetation cover, the climate was perhaps the major factor enhancing the sediment supply and runoff, despite the glacial conditions prevailed in the area as suggested by the ages of these sediments. Glaciers probably played an important role in streamflow régimes with the release of their meltwaters perhaps during the interstadials of Late Glacial period. Recent studies on borehole stratigraphic secions recovered by the PaleoVan project of the International Continental Drilling Program (ICDP) shows that increased snow precipitation and meltwater delivery to Lake Van during the Late Glacial (Çağatay et al., 2014; Kwiecien et al., 2014).

A Gilbert-type delta environment usually has low energy with limited water agitation. In this environment, fluvial processes predominate over the wind-induced wave and currents. Therefore, the distribution of the Gilbert-type deltas in the Lake Paleo-Van Basin may suggest that the eastern margin of this lake was a low-energy coast sheltered from winds. Probably the prevailing wind was perhaps blowing either from the north or south and thus not affecting much the eastern shore. The Gilbert-type deltas may also provide evidence for the depth of the Lake Paleo-Van, because the lake water level determined the heights of the foreset. Considering the heights of the foresets, its depth perhaps did not exceed few tens of metres where the deltas formed.

4.1.4. Nearshore Lake Environment

This environment was recognized in the Sections-CV$_1$, -HD$_1$, -DT$_1$, -KRD$_1$, –KC$_1$ and KOD. It formed a transitional zone between the beach and the offshore lake environments. Sandstones with subordinate conglomerates are the dominant facies. The presence of these sediments requires a physical mechanism capable of transporting them to the environment, because transitional zone environments are generally below the wave-base and mostly accumulate finer-grained sediments. The existence of coarser-grained sediments in this environment is mostly resulted from deposition during heavy storms. In the stormy weathers, much coarse-grained sediments are eroded from beaches and are brought to transitional zones. This was perhaps the case along the Plaeo-Lake Van shores where storms were apparently active during the deposition of the nearshore sediments. The relatively coarse-grained sediments of the aluvial fans, beaches and the Gilbert-type deltas along the lake coast acted during storms as sources for these sediments. The subordinate conglomerates were laid down in the vicinity of the stream mouths, whereas the sandstones and minor amounts of mudstones with wave ripples and very fine parallel laminations may have been spread out farther to the deeper waters where relatively finer grains could accumulate. These sediments were perhaps transported to these depositional sites by storm-generated traction currents or river-inflow currents deflected along the lake margin. Turbidity currents seem not to have played an important role in the sediment transportation, because the Paleo-Van nearshore sediments show no evidence of turbidite depositon, such as graded bedding and sole-marks. The existence of large-scale slump scars in the nearshore sediments indicates gravitational instabilities in this environment. The environment was perhaps often subjected to shocks from storms, earthquakes or sudden adition of more sediment (Dyskstra, 2004; van Rensbergen et al., 1999; Schnellmann et al., 2002, 2005; Chapron et al., 2006; Volland, et al., 2007; Toker et al., 2007).

4.1.5. Offshore Lake Environment

Offshore lake sediments are best exposed in the Sections-DÖN$_1$, -DÖN$_4$, -AC$_1$, -AC$_2$, -DV$_1$, -DV$_2$, -ZV$_1$, KB, -CM$_1$ -ZD$_2$ and -KDS$_1$. Deposition of these sediments in quiet, standing water is suggested by the laterally persistent facies, thin-stratification, varves, fine grain size and hydroplastic disruptions, such as slumps and convolute beddings. The processes thought to be responsible for their deposition were perhaps downslope directed tractional currents near the shore and settling from suspension furthest out in the lake. The varve sedimentation in this lake seems to be a characteristic process and certainly represent seasonal settling from suspension in deep waters (Kempe, 1977; Stockhecke et al., 2012). Oxygen isotopes, Mg/Ca ratios in carbonates, and pollen and charcoal data from these annually laminated sediments revealed that there was an arid climate event with low lake levels in the Paleo- Lake Van Basin with treeless steppe vegetation during the Late Glacial (ca. 14 ka varve years; Landmann et al., 1996*a, b*, 2011; Çağatay et al., 2014); wet climatic conditions were established in the basin during the Holocene time (Wick et al., 2003; Çağatay et al., 2014). The well preservation of the varve sediments in the Paleo-Van lake environment suggests that the lake floor was inhospitable for the benthic life. This hostility was perhaps due to its extreme chemical water composition with high alkalinity and salinity at the time (Gessner, 1957; Danulat and Selçuk, 1992; Landmann, 1996*a, b*). The high salinity (22 ‰) and sodium and bicarbonate rich waters was resulted from the weathering of the volcanic rocks in drainage basin and evaporation in a closed basin. The lake occasionaly deposited tufa in the Section-CM$_1$ and microbiolites in the shallow offshore areas, indicating involvement of blue-green algae and bacteria in carbonate deposition in the lake (Kempe et al., 1991; Lopez-Garcia et al., 2005).

The convolute beds and fluid escape structures are mostly restricted to single layers bounded by undisturbed beds above and below. These structures in the terrace sedimentary sequences may be interpreted to have been triggered by paleo-earthquakes, considering the seismically active nature of the (Ambraseys, 1988; McCalpin and Nelson, 1996; Türkelli et al., 2003; Litt et al., 2009). Their occurrence at different elevations (DÖN$_4$: 1700 asl, KDS$_1$: 1693 m asl, DÖN$_1$: 1687 m asl, DV$_1$: 1678 m asl and ZD$_2$: 1666 m asl) suggests that these seismic events recurred at least five times during the last 34 ^{14}C ka BP. Unfortunately the exact time of the earthquakes cannot be given, because the individual convolute beds could not be dated in this study. These events may have been generated in the area either by ground shaking by eaertquakes or by the eruption of the Süphan or Nemrut Volcanos. Among the sections studied, only two sections (KB1 and CM1) between Erciş and Adilcevaz contain volcanic material associated with the offshore lake sediments. The sections occur at two different elevations of 1676 m asl and 1727 m asl. If the difference in the elevations was not caused by tectonics, the Süphan or Nemrut Volcanos must have been erupted twice during 9.7-5.9 ka BP interval according to the age of the nearby Section-KRD$_1$ in Karadere Valley in Adilcevaz.

4.2. Terraces and lake level changes

Presence of old lake terraces at various elevations around the Lake Van Basin suggest significant lake level changes over the last ~125 ka. This is also supported by the presence of lowstand deltas and onlap sequences in the subaqueous seismic reflection profiles (Damcı et al., 2012; Çukur et al., 2013 and 2014). The lake terraces observed around Lake Van are believed to represent relatively high water level periods of Paleo-Lake Van relative to its present lake level, even though tectonic uplift can account for some of their elevation.

As pointed out in Section 3.1, the age data on the various terraces around the Lake Van are insufficient for their basin wide stratigraphic correlation, and thus for reaching sound conclusions about the lake level changes and the role of tectonic uplift in their present elevation. However, some preliminary conclusions can be reached concerning the general long-term lake level oscillations. The following assumptions are used when discussing the lake level changes of the Paleo-Lake Van, using the old lake terraces:

The Gilbert-type deltas observed in the valleys around Lake Van were deposited during rising lake level.

The parallel finely bedded and laminated clayey silt and sandstone facies were deposited in relatively deep water (e.g.,Landmann et al., 1996*a, b*; Kempe et al., 2002; Stockhecke et al., 2013; Çağatay et al., 2014).

The hydrological system in the watershed of Lake Van and the lake level follow a general wet and high-stand interglacial versus dry and low-stand glacial pattern (Stockhecke et al., 2014; Çağatay et al., 2014). However, there are exceptions to this general trend, as evidenced by some terraces dated between 26 and 21 ka BP (Kuzucuoğlu et al., 2010), which may be associated with snow melting during interstadials periods of Late Glacial (Çağatay et al., 2014)..

With the above considerations, considering its >100 ka age (Kuzucuoğlu et al., 2010), the highest terraces reaching 1761 masl in the Beyüzümü district (Çayarası Valley) and 1755 m in the Kotum Valley was likely deposited during marine isotope stage 5e (Eemean), as corroborated by the organic carbon-rich, finely laminated sediments of this stage analyzed in the ICDP PaleoVan cores (Stockechke et al., 2013, 2014). The deposition of this terrace, located at 110 m above the present lake level and 20 m above the present lake's threshold, is associated with pyroclastic deposits damming the lake's outlet in the Kotum Valley. Another terrace in the lower Kotum Dere Valley, close to the river mouth, represented by our Sections KOD1, GPS-035 and KOD_2 GPS-037) (Figure 1), reaches up to 1730-1735 masl (Kuzucuoğlu et al., 2010) and was probably deposited during a later substage of the last interglacial (i.e., MIS 5a). This conclusion is supported by high lake levels evidenced by the multiproxy analyses of ICDP cores recovered from Lake Van (Çağatay et al., 2014), and the presence of peat (swamp) deposits under the ~80 ka BP old İncekaya basaltic hyaloclastite unit located at 1777 masl elevation (Sumita and Schmincke, 2013*a*). Such a high elevation (41 m above the present lake level and 40 m above the sill in Kotum) of the peat representing the lake level at the time is most likely partly due to tectonic uplift.

In the absence of age data, another alternative for the age of the delta in the the lower reaches of the Kotum Valley is 30-34 ka BP during which dramatic changes are recorded in the total organic and inorganic carbon contents and stable oxygen and carbon isotope values of sediments in the ICDP stratigraphic section (Çağatay et al., 2014) and an onlapping sequence in seismic sections occurs (Çukur et al., 2014). All these evidence indicate a rapid lake level rise. This rapid increase in the lake level was most probably the result of melt water delivery with low ‰^{18}O and ‰^{13}C values, caused by the D-O event following H4 (ca 35 ka BP; Wolff et al, 2010; Blockley et al., 2012). This transgression also corresponds in time with the Nemrut volcano activity leading to the deposition of the Nemrut formation, which was associated with the caldera forming eruption of 10 km^3 of magma (Sumita and Schmincke, 2013*a*).

The Gilbert fan delta observed at 1690 m in Karahan Village (GPS-021, 022, 023; Kırklar) near the northern shore of Lake Van was deposited during 26-24 ka according to the radiocarbon dating of Kuzucuoğlu et al. (2010) (Table 1). This suggests that the lake level reached an altitude of at least 45 m above the present level during that time. Even though there are no supporting ages, Kuzucuoğlu et al. (2010) suggests that co-eval terrace sediments are also present in Yumrutepe in the Karasu Valley in the east and in the Engil River Valley in the southeast of the lake. The same authors also state that the coastal cliff terrace at Mollakasim (GPS-047) represents abrasion type terrace formed during a regression after the lake level transgression during 26-24 ka BP.

Most of the terraces deposited in the valleys close to the river mouths are dated to two periods: 22-21 ka BP and 10-6 ka BP. The terraces are in the form of Gilbert type delta sequences. Those belonging to the first period were dated in Güzelsu in Engil River valley by Kempe et al. (2002). Terraces of similar age are also found in Mollakasım (GPS-045) in Karasu and in Kotum, Zilan, Karasu, and Bendimahi river valleys. These terraces reach up to 1700 m elevation.

The transgressive episode during 22-21 ka BP was followed by a drastic lake level fall, reaching to minimum levels durig 16-14 ka BP (Landmann et al., 1996*a, b*; 2011). This lakel level fall is also supported by deposition of dolomite, low TOC and increased rate of mass flow events in the ICDP borehole sections (Çağatay et al., 2014; Stockhecke et al., 2013), and subaqueous prograding deltas at ca -200 m in the seismic sections in the Northern and Tatvan basins (Damcı et al., 2012; Çukur et al., 2014).

The last period of coastal terrace deposition occurred during the early Holocene. The most representative of these young terraces is the one near Adilcevaz in the Karadere valley, which has been dated between 10 and 6 ka BP (Table 1). During this time, the lake level reached 1676 masl (~30 m above the present lake level). These terraces were deposited during a transgression following the major regression at 16-15 ka BP and a somewhat smaller scale regression during the Younger Dryas (Landmann et al., 1996*a, b*, 2011; Çukur et al., 2014; Çağatay et al., 2014).

5. Conclusions

On the basis of the preceding discussions, the following summary and conclusions may be given:

1. The terraces studied around the Lake Van record the last ca. 125 ka of the 500-ka-long geological history of the Lake Van Basin as suggested by the oldest terrace sediments dated in the Çayarası Valley (Beyüzümü) and Kotum Dere Valley at 1754-1761 masl elevations.

2. The terrace sediments formed from clastic sediments accumulated in a large array of relatively shallow lacustrine environments, such as offshore lake, nearshore lake, Gilbert-type delta, beach and alluvial fan/braided river.

3. The terraces deposited in the form of Gilbert type fan deltas around Lake Van represent deposition during transgressive episodes. Such episodes are observed during MIS5, 34-30 ka, 26-24 ka BP, 22-21 ka BP and 10-6 ka BP.

4. The level was controlled by climate, tectonism and volcanism. The interglacial and interstadial periods were generally characterized by high lake levels with the sediments supplied mostly by running waters as wet conditions were established in the area. During the during interstadial periods of the Last Glacial meltwaters from snow and ice contributed water and sediment to the lake. Volcanism contributed tephra, volcanoclastic sediments and may have caused changes in the elevation of the lake's outlet, thereby influencing the lake levels. Tectonic uplift or warping associated with the dip-slip and/or strike-slip faults also affected the lake level and increased the sediment input.

5. Variability of shoreline and delta facies provides evidence for the distribution of wave energy and the effects of paleowinds. Higher wave energy existed along the northern margin and in some parts of the eastern margin of the Paleo-Lake Van where the beach and the nearshore lake sediments were strongly affected by lake processes. The relatively coarse grain size of these sediments and their reactivation surfaces suggest that strong winds or storms were an active agent in transportation and deposition in the Paleo Lake -Van. The dominant wind direction was perhaps from south to north as indicated by the distribution of the beach and the nearshore lake sediments.

6. The beach sediments mark the shoreline of the Paleo-Lake Van. They occur at three elevations: 1708, 1733 and 1736 m masl. (Sections-$DÖN_2$, BD_1 and KV_2, respectively). The deposits at the last two elevations may have been thought to be the products of the same shoreline if the 30 m ground pixel resolution of the ASTER DEM data is considered. On the basis of their sub-depositional environments, the paleo-shorelines may be placed at 1740 (shoreline-1) and 1710 (shoreline-2) masl (Figures 31 and 32). The age of the former is ca. ≥ 30-34 ka BP, whereas that of the latter is 20.7-20.9 ka BP as suggested by the dating of the beach or the associated lacustrine sediments more or less at the same elevations in the Karasu and Dönemeç Çayı Valleys, respectively. 1740 m maximum lake-level dictates that no lacustrine facies younger than ≥ 30-34 ka BP can be found above the elevation of 1740 m in the lake basin. Therefore, the terrace sediments at the elevations of 1754-1761 masl in the Çayarası Valley (Section-CV_1) must have been elevated to these hights by a fault zone, extending between the villages Kalecik and Değirmen as described first by Ketin (1977) (Figure 1).

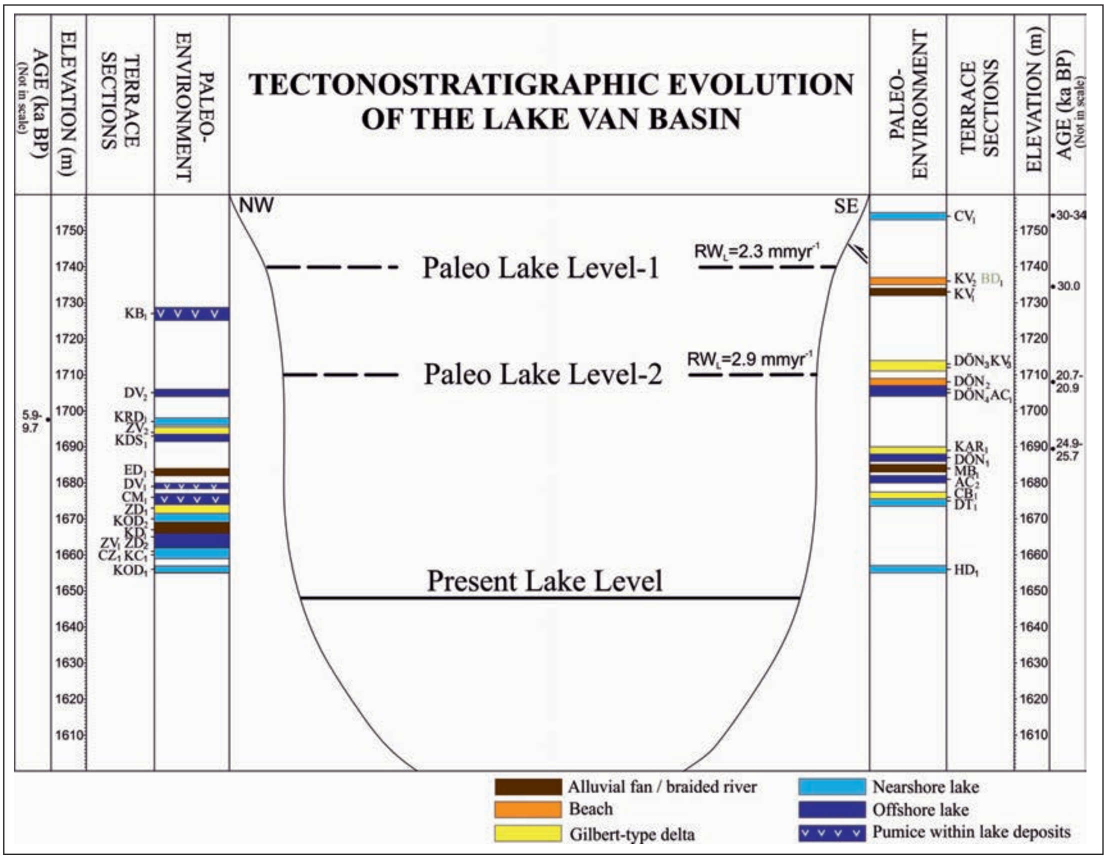

Figure 31- The scheme summarizing the lake level changes, on the basis of palae-environments of the Lake Van.

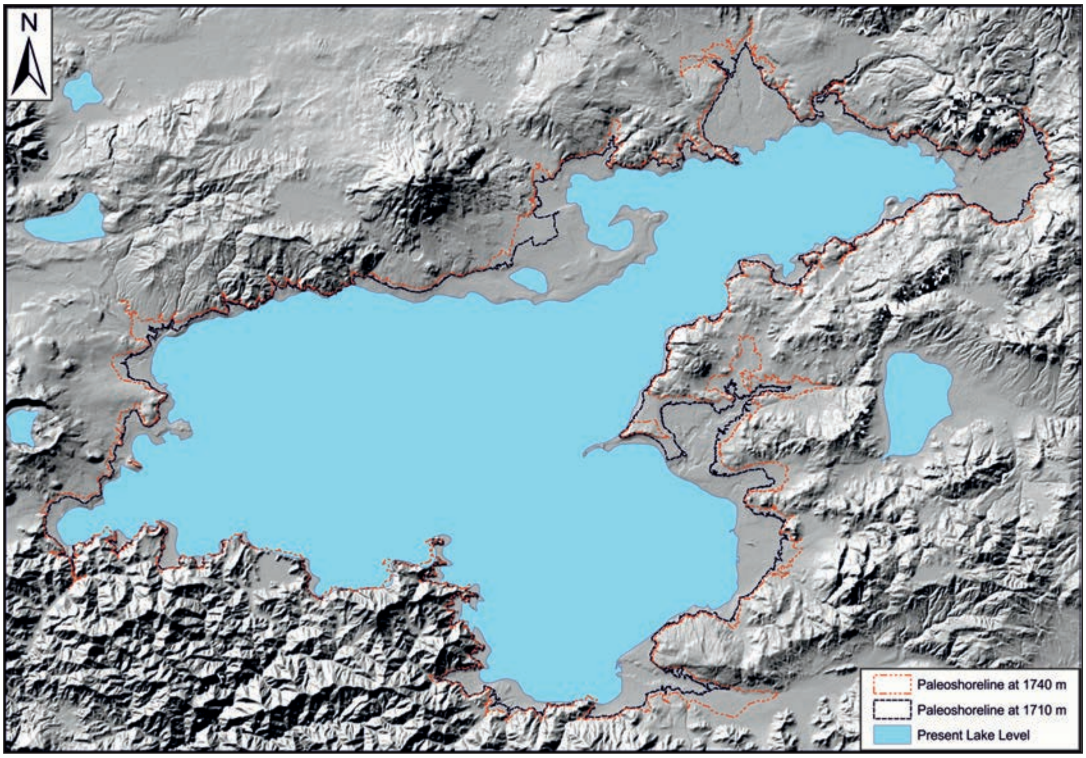

Figure 32- The map of the palaeoshoreline at 30-34 and 20.7-20.9 ka BP at 1740 and 1710 m, respectively.

7. Beside the present shoreline, the recognition of another two paleoshorelines in the Lake Van Basin suggests changes in the lake-level during the deposition of the terrace sediments examined (Figure 31). The consistent younging of the paleo-shorelines toward low elevations suggests that these changes took place as a gradual drop in lake-level, rather than by fluctuations. The lack of large-scale cyclicity in the terrace successions also supports this interpretation. The present lake-level was attained in probably three stages during the last ~30 ka BP. The lake-level dropped first from 1740 to 1710 masl from ~32 ka BP to 21 ka BP and then a further drop occurred to about 200 m below the present lake level at about 15-14 ka BP, as evidenced in sedimentary sections recovered from within the lake (Figure 32). A rise to the present level of 1647 masl occurred in the latest glacial and early Holocene. The drops were probably caused by both climate and tectonic processes, although the former may have been more effective. Particularly, the changes in the amounts of precipitation and evaporation with time must have played an important role. From the shoreline elevations and their ages, rate of the water level drop was calculated as 2.3 mm yr^{-1} for the first stage and 2.9 mm yr^{-1} for the second stage. The first and second stages of lake-level drops took place before and after the Last Glacial Maximum.

Acknowledgements

This study was supported by ITU-BAP Project No. 36595.

Received: 12.11.2014
Accepted: 18.06.2015
Published: December 2015

References

Akyüz, H. S., Zabcı, C., Sançar, T. 2011. Preliminary report on the 23 October 2011 Van earthquake, Istanbul Technical University, Istanbul, Turkey

Allen, J. R. L. 1984. Developments in Sedimentology, Sedimentary Structures. *Elsevier*, 663 p.

Ambraseys, N. N. 1988. Engineering seismology. *Earthquake Engineering and Structural Dynamics* 17, 1-105.

Blair, T. C., Mc Pherson, J. G. 1994. Alluvial fans and their natural distinction from rivers based on morphology, hydraulic processes, sedimentary processes and facies assemblages. *Journal of Sedimentary Research* 64, 450-589.

Blockley, S.P.E., Lane, C.S., Hardiman, M., Rasmussen, S.O., Seierstad, I.K., Steffensen, J.P., Svensson, A., Lotter, A.F., Turney, C.S.M., Ramsey, C.B., INTIMATE members. 2012. Synchronisation of palaeoenvironmental records over the last 60,000 years, and an extended INTIMATE1 event stratigraphy to 48,000 b2k. *Quaternary Science Reviews* 36, 1-222.

Bluck, B. J. 1967. Deposition of some Upper Old Red Sandstone conglomerate in the Clyde area: a study in the significance of bedding. *Scot. J. Geol*. 3, 139-167.

Bull, W. B. 1972. Recognation of Alluvial-Fan Deposits in the Stratigraphic Record. (Rigby, J. K., Hamblin, W. K. (Ed.). Recognation of Ancient Sedimentary Environments. *Society of Economic Paleontologists and Mineralogists*. Special Publication 16, 63-83.

Carryer, S. J. 1966. A note on the formation of alluvial fans..*New Zealand Jour. Geology and Geophysics* 9, 91-94.

Chapron, E., Ariztegui, D., Mulsow, S., Villarosa, G., Pino, M., Outes, V., Juvignie, E., Crivelli, E. 2006. Impact of the 1960 major subduction earthquake in Northern Patagonia (Chile, Argentina). *Quaternary International*. 158, 58-71.

Clifton, H. E. 1973. Marine-nonmarine facies change in middle Miocene rocks, southeastern Caliente Range, California; in Sedimentary facies changes in Tertiary rocks- California Ti'ansverse and southern Coast Ranges. *Annual Meeting AAPG-SEPM-SEG*., 55-57.

Çağatay, M.N., Öğretmen, N., Damcı, E., Stockhecke, M., Sancar, Ü., Eriş, K.K., Özeren, S., 2014. Lake level and climate records of the last 90 ka from the Northern Basin of Lake Van, eastern Turkey. *Quaternary Science Reviews* 104, 97-116.

Çukur, D., Krastel, S., Demirel-Schülter, F., Demirbağ, E., İmren, C., Niessen, F., Toker, M., PaleoVan-Working Group 2013. Sedimentary evolution of Lake Van (Eastern Turkey) reconstructed from high-resolution seismic investigations. *International Journal of Earth Sciences (Geol. Rundsch.)* 102 (2), 571-585.

Çukur, D., Krastel, S., Schmincke, H-U, Sumita, M., Winkelmann, D., Çağatay, M.N., Meydan, A.F., Damcı, E., Stockhecke, M. 2014. Seismic stratigraphic evolution of the Lake Van, eastern Turkey. *Quaternary Science Reviews* 104, 63-84.

Damcı, E., Çağatay M. N., Krastel, S, Öğretmen, N., Çukur, D., Ülgen, U.B., Erdem, Litt, T., Anselmetti F.S. Eriş,K.K., ICDP PaleoVan Scientific Party. 2012. Lake level changes of Lake Van over the Last 400 ka: Evidence from Deltas in Seismic Reflection Data and ICDP Drilling. *European Geosciences Union (EGU) General Assembly*, 22-27 April 2012, Vienna, 626.

Danulat, E., Selçuk, B. 1992. Life history and environmental conditions of the anadromous *Chalcalburnus tarichi* (Cyprinidae) endemic to the extremely alkaline Lake Van, Eastern Anatolia, Turkey. *Arch. Hydrobiol.* 126: 105-125.

Davidson Arnott, R. G. D., Greenwood, B. 1976. Beach and Nearshore Sedimentation. Davis, R. A., Ethington, R. L. (Ed.). *Soc. Econ. Paleontol. Mineral.* Special Publication 24, 149-168.

Degens, e.t., Kurtman, F. 1978. The geology of Lake Van. *Maden Tetkik ve Arama Genel Müdürlüğü Press*, 158p.

Degens, E.T., Wong, H.K., Kempe, S., Kurtman, F. 1978. A Van Gölü'nün Jeolojik Gelişimi: Bir Özet. Degens, E.T., Kurtman, F. (Ed.). The Geology of Lake Van. *Maden Tetkik ve Arama Genel Müdürlüğü*, 147-158.

Degens, E.T., Wong, H.K., Kempe, S., Kurtman, F. 1984. A Geological study of Lake Van, Eastern Turkey. *Geologische Rundschau* 73, 701-734.

Doğan, B., Karakaş, A. 2013. Geometry of co-seismic surface ruptures and tectonic meaning of 2011 Mw 7.1 Van earthquake (East Anatolian Region, Turkey). *Journal of Structural Geology* 46, 99-114.

Dorsey, R. J., Umhoefer, P. J., Renne, P. R. 1995. Rapid subsidence and stacked Gilbert-type fan deltas, Pliocene Loreto basin, Baja California Sur, Mexico. *Sedimentary Geology*. 98, 181-204.

Dunne, L. A., Hempton, M. R. 1984. Deltaic sedimentation in the Lake Hazar pull-apart basin, south-eastern Turkey, *Sedimentology* 31, 401-412.

Ekström, G., Nettles, M., Dziewoƒski, A.M., 2012. The global CMT project 2004–2010: Centroid-moment tensors for 13,017 earthquakes. *Physics of the Earth and Planetary Interiors* 200–201, 1-9.

Emre, Ö., Duman, T.Y., Özalp, S., Elmacı, H., Olgun, Ş., Şaroğlu, F., 2013. Açıklamalı Türkiye Diri Fay Haritası Ölçek 1:1250000 (Active Fault Map of Turkey with an Explanatory Text 1:1250000 scale), 89 pp., *Maden Tetkik ve Arama Genel Müdürlüğü*, Ankara.

Erdik, M., Kamer, Y., Demircioğlu, M., Şeşetyan, K. 2012. 23 October 2011 Van (Turkey) earthquake. *Natural Hazard* 64, 651-665.

Ergin, K., Güçlü, U., Uz, Z. 1967. Türkiye ve civarının deprem kataloğu (A Catalof of earthquakes for Turkey and surrounding area), *İstanbul Teknik Üniversitesi, Maden Fakültesi Ofset Baskı Atölyesi*, İstanbul

Erinç, S. 1953. Doğu Anadolu Coğrafyası. *İstanbul Üniversitesi Yayınları*, İstanbul.

Falk, P. D., Dorsey, R. J. 1998. Rapid development of gravelly high-density turbidity currents in marine Gilbert-type fan deltas, Loreto Basin, Baja California Sur, Mexico. 45, 331-349.

Fielding, E. J., Lundgren, P. R., Taymaz, T., Yolsal Çevikbilen, S., Owen, S. E. 2013, Fault-slip source models for the M 7.1 Van Earthquake in Turkey from SAR Interferometry, pixel offset tracking, GPS and seismic waveform analysis, *Seismological Research Letters* 84 (4), 579-593.

Gessner, F. 1957. Van Gölü, zor Limnologie des grossen Soda Sees in Ostanatolien (Türkei). *Arch. Hydrobiol.* 53, 1-22.

Gloppen, T. G., Steel, R. J. 1981. The deposits, internal structure and geometry of six alluvial fan – fan-delta bodies (Devonian, Norway) – a study in the significance of bedding sequences in conglomerates. In: *F. G: Ethridge (Ed.) Non-Marine deposits – Models for Exploration. Soc. Econ. Paleontol. Mineral.*, Spec. Publi. 31, 49-69.

Görür, N. 1992. A tectonically controlled alluvial fan which developed into a marine fan-delta at a complex triple junction: Miocene Gildirli Formation of the Adana Basin, Turkey. *Sedimentary Geology*. 81, 243-252.

Güner, Y. 1984. Nemrut yanardağının jeolojisi, jeomorfolojisi ve volkanizmasının evrimi, *Jeomorfoloji Dergisi* 12, 23-65.

Harvey, A. M., Mather, A. E., Strokes, M. 2005. Alluvial fans: geomorphology, sedimentology, dynamics – introduction. A review of alluvial-fan research *in* Harvey, A. M., Mather, A. E., Stokes, M. (Eds) Alluvial Fans Geomorphology, Sedimentology, Dynamics, *Geological Society* Special Publication 251, 1-7

Hayes, M. O. 1967. Hurricanes as geological agents, south Texas coast. *Bulletein American Association of Petroleum Geologists* 51, 937-942.

Heward, A. P., 1978. Alluvial fan and lacustrine sediments from the Stephanian A and B (La Magdalenai Cinera-Matallana and Sabero) coalfields, northern Spain. *Sedimentology* 25, 451-488.

Horasan, G., Boztepe-Güney, A. 2007. Observation and Analysis of Low-Frequency Crustal Earthquakes In Lake Van and its Vicinity, Eastern Turkey. *Journal of Seismology* 11, 1-13.

Howard, J. D. 1967. Georgia coastal region, Sapelo Island, U.S.A. Sedimentology and biology. VIII. Conclusions. *Senckenbergiana Marit* 4, 217-222.

Johnson, A. M. 1970. Physical processes in geology: San Francisco. Freeman. *Cooper and Company*, 577 p.

Kaden, H., Peeters, F., Lorke, A., Kipfer, R., Breenwald, M., Tomonaga, Y. 2005. Mixing processes in Lake Van (Turkey). *9th European Workshop on Physical Processes in Natural Waters (extended abstract).* Lancaster, UK.

Kaden, H., Peeters, F., Lorke, A., Kipfer, R., Tomonaga, Y., Karabıyıkoğlu, M. 2010. Impact of lake level change on deep-water renewal and oxic conditions in deep saline Lake Van, Turkey. *Water Resources Research* 46, W11508.

Kadıoğlu, M., Sen, Z., Batur, E. 1997*a*. The greatest soda-water lake in the world and how it is influenced by climatic change. *Ann. Geophysicae* 15, 1489-1497.

Kadıoğlu, M., Sen, Z., Batur, E. 1997*b*. The greatest soda-water lake in the world and how it is influenced by climatic change. *Ann. Geophysicae* 15, 1489-1497.

Kempe, S. 1977. Warvenchronologie und organische Geochemie des Van Sees, Ostrrürkei, Ph.D. thesis, *Mitt. Geol. Palaeontol. Inst. Univ. Hamburg*.

Kempe, S., Degens, E.T. 1978. Lake Van varve record: the past 10.420 years. Degens, E.T., Kurtman, F. (Ed.). Geology of Lake Van. *Maden Tetkik ve Arama Genel Müdürlüğü Yayınları*. Ankara, 56-63.

Kempe, S., Kazimierczak, J., Landmann, G., Konuk, T., Reimer, A., Lipp, A. 1991. Largest known microbialities discovered in Lake Van, Turkey. *Nature* 349, 605-608.

Kempe, S., Landmann, G., Müller, G. 2002. A floating varve chronology from the last glacial maximum terrace of Lake Van/Turkey. *Research in deserts and mountains of Africa and Central Asia* 126, 97–114.

Ketin, İ. 1977. Van Gölü ile İran sınırı arasındaki bölgede yapılan jeoloji gözlemlerinin sonuçları hakkında kısa bir açıklama. *TJK Bült*. 20, 79-85.

Kumar, N., Sanders, J. E. 1976. Characteristics of shoreface storm deposits: modern and ancient examples, *J. Sediment. Petrol*. 46, 145-162.

Kuzucuoğlu, C., Christol, L., Mouralis, D., Doğu, A.F., Akköprü, E., Fort, M., Brunsteın, D., Zorer, H., Fontugne, M., Karabıyıkoğlu, M. 2010. Formation of the Upper Pleistocene terraces of lake Van (Turkey). *Journal of Quaternary Science* 25, 1124–1137.

Kwiecien O, Stockhecke, M., Pickarski, N., Litt, T., Sturm, M., Anselmetti, F., Haug, G. 2014. Dynamics of the last four glacial terminations recorded in Lake Van, Turkey. *Quaternary Science Reviews* 104, 42-52.

Landmann, G. 1996. Van See/Türkei: Sedimentologie, Warvenchronologie und regionale Klimaent-wicklung der letzten 15.000 Jahre. Doktora Tezi, *Hamburg Üniversitesi* (unpublished).

Landmann, G., Reimer, A. ve Kempe, S. 1996*a*. Climatically induced lake level changes at Lake Van, Turkey, during the Pleistocene / Holocene transition. *Global Biochemical Cycles* 10, 797-808.

Landmann, G., Reimer, A., Lemcke, G., Kempe, S. 1996*b*. Dating Late Glacial abrupt climate changes in the 14.570 yr long continuous varve record of Lake Van, Turkey. *Palaeogeography, Palaeoclimatology, Palaeoecology* 122, 107-118.

Landmann, G., Kempe, S. 2005. Annual deposition signal versus lake dynamics: Microprobe analysis of Lake Van (Turkey) sediments reveals missing varves in the period 11.2–10.2 ka BP. *Facies* 51, 143-153.

Landmann, G., Steinhauser, G., Sterba, J.H., Kempe, S., Bichler, M. 2011. Geochemical fingerprints by activation analysis of tephra layers in LakeVan sediments, Turkey. *Applied Radiation and Isotopes* 69, 929–935.

Lewis, D. W. 1980. Storm-generated graded beds and debris flow deposits with Ophiomorpha in a shallow offshore Oligocene sequence at Nelson, South Island, New Zealand, *N. Z. J. Geol. Geophys*. 23, 353-369.

Litt, T., Krastel, S., Sturm, M., Kipfer, R., Oercen, S., Heumann, G., Franz, S. O., Ulgen, U. B., Niessen, F. 2009. 'PALEOVAN', International Continental Scientific Drilling Program (ICDP): site survey results and perspectives. *Quaternary Science Reviews* 28, 1555-1567.

Litt, T., Anselmetti, F.S., Baumgarten, H., Beer, J., Çağatay, N., Cukur, D., Damci, E., Glombitza, C., Haug, G., Heumann, G., Kallmeyer, J., Kipfer, R., Krastel, S., Kwiecien, O., Meydan, A.F., Orcen, S., Pickarski, N., Randlett, M., Schmincke, H., Schubert, C.J. Sturm, M., Sumita, M., Stockhecke M.,, Tomonaga, Y., Vigliotti, L., Wonik, T. 2012. The PALEOVAN Scientific Team, 500,000 Years of Environmental History in Eastern Anatolia: The PALEOVAN Drilling Project. *Sciencetific Drilling* 14, 18.

Litt, T. Pickarski, N., Heumann, G. 2014. A 600,000 Year Long Continental Pollen Record from Lake Van, Eastern Anatolia (Turkey). *Quaternary Science Reviews*.

López-García, P., Kazmierczak J., Benzerara, K., Kempe, S., Guyot, F., Moreira, D. 2005. Bacterial diversity and carbonate precipitation in the giant microbialites from the highly alkaline Lake Van, Turkey. *Extremophiles* 9, 263-274.

Lowe, D.R. 1979. Sediment gravity flows: Their classification and some problems of aplication to natural flows and deposits, in Doyle, L. J., Pilkey, O. H. (Eds.) *Geology of continental slopes: Society of Economic Paleontologists and Mineralogits Special Publication* 27, 75-82.

Lowe, D. R. 1982. Sediment gravity flows II: depositional models with special reference to the deposits of high density turbidity currents. *Journal of Sedimentary Petrology* 52, 279-297.

Mc Calpin, J. P., Nelson, A. R. 1996. Introduction to Paleoseismology in *McCalpin, J. P. (Ed.) Paleoseismology*, Academic Press, New York, pp. 1-32

McConnico, T.S., Bassett, K.N. 2003. Quaternary Gilbert-style fan deltas and Podocarp forests along the modern transpressional Hope fault, New Zealand. *Geological Society of America* 35, 510.

McConnico, T. S., Bassett, K. N. 2007. Gravelly Gilbert-type fan delta on the Conway Coast, New Zealand: Foreset depositional processes and clast imbrications. *Sedimentary Geology* 198, 147-166.

Moretti, M., Pieri, P., Tropeano, M. 2002. Late Pleistocene soft-sediment deformation structures interpreted as seismites in paralic deposits in the city of Bari (Apulian forelan, southern Italy). Geological Society of America, Special Paper 359.

Mouralis D., Kuzucuoğlu C., Scaillet S., Doğu A-F., Christol A., Akköprü E., Fontugne M., Zorer H., Guillou H. 2010. Les pyroclastites du sud-ouest du lac de Van (Anatolie orientale, Turquie): implications sur la paléo-hydrographie régionale. *Quaternaire* 21, 417-433.

Nemec, W. 1990. Deltas – remarks on terminology and classification. In: Coarse-grained Deltas. Colella, A. and Prior, D. B. (Ed.). International Association of Sedimentologists. *Blackwell Scientific Publications*, Special Publication 10, Oxford, 3-12.

Nemec, W., Steel, R. J. 1984. Alluvial and Coastal Conglomerates: Their signifcant features and some comments on gravelly mass-flow deposits. In: Sedimentology of Gravels and Conglomerates – Memoir 10, 1-34.

Nemec, W., Steel, R. J. 1985. Stacked, shore-attached, sheet sandstones in a Paleocene inland seway succession (Endalen Member, Spitsbergen) (abs): International Association of Sedimentologists, 6th European Regional Metting, Lleida, Spain. 321-324.

Nichols, G. 2009. Sedimentology and Stratigraphy. *Wiley-Blackwell*, 419 p.

Nilsen, T. H. 1982. Alluvial fan deposits: In: Scholle, P. A., Spearing, D. (Eds.), Sandstone depositional environments. *Mem. Am. Assoc. Pet. Geol*. 31, 49-86.

Örgülü, G., Aktar, M., Turkelli, N., Sandvol, E., Barazangi, M. 2003. Contribution to the seismotectonics of eastern Turkey from moderate and small size events. *Geophysical Research Letters* 30, 8040.

Picard, M. D., High, L. R. 1972. Recognition of ancient sedimentary environments. Rigby, J. K., Hamblin, W. K. (Ed.). *Soc. Econ. Paleontologists Mineralogists Special Publication* 16, 108-145.

Picard, M. D., High, L. R. 1981. Physical stratigraphy of ancient lacustrine deposits. In: Ethridge, F. G., Flores, R. M., Recent and ancient nonmarine depositional environments: Models for exploration. *Society of Economic Paleontologists and Mineralogists*, Special Publication 31, 233-259.

Reimer, A., Landmann, G., Kempe, S. 2009. Lake Van, Eastern Anatolia, hydrochemistry and history. *Aquat. Geochem*.15, 195-222.

Postma, G. 1990. Depositional achitecture and facies of river and fal deltas: a synthesi, in: Colella, A., Prior, D.B. (Eds.), Coarse Grained Deltas, *Int. Assoc. Sedimento.,* Spec. Publ. 10, 13-27

Rust, B. R. 1972. Structure and Process in a braided river, *Sedimentology* 18, 221-245.

Reineck, H. E., Singh, I. B. 1975. Depositional Sedimentary Environments. *Springer Verlag*, 439 .

Schnellmann, M., Anselmetti, F. S., Giardini, D., McKenzie, J. A., Ward, S. N. 2002. Prehistoric earthquake history revealed by lacustrine slump deposits. *Geology* 30, 1131-1134.

Schnellmann, M., Anselmetti, F. S., Giardini, D., McKenzie, J. A., Ward, S. N. 2005. Mass movement-induced fold-and-thrust belt structures in unconsolidated sediments in Lake Lucerne (Switzerland). *Sedimentology* 52, 271-289.

Seilacher, A. 1969. Fault-graded beds interpreted as seismites. *Sedimentology* 13, 155-159.

Sly, P. G. (1978). Sedimentary Processes in Lakes. In: Lerman, A. (Ed.) *Lakes*, Springer New York**:** 65-89.

Sohn, Y. K. 2000. Depositional Processes of Submarine Debris Flows in the Miocene Fan Deltas, Pohang Basin, SE Korea with Special Reference to Flow Transformation. *Journal of Sedimentary Research* 70, 491-503.

Steel, R. J. 1974. New Red Sandstone floodplain and piedmont sedimentation in the Hebridean Province. *J. Sedim. Petrol*. 44, 336-357.

Steel, R. J., Wilson, A. C. 1975. Sedimentation and tectonism (?Permo-Triassic) on the margin of the North Minch Basin,. *J. Geol. Soc. London* 131, 183-202.

Stockhecke, M. Anselmetti, F.S., Meydan, A.F. Odermatt, D., Sturm, M. 2012. The annual particle cycle in Lake Van (Turkey). *Palaeogeography, Palaeoclimatology, Palaeoecology* 333-334, 148–159..

Stockhecke, M., Anselmetti, F.S., Sturm, M. 2014. Past seismic activity in Eastern Anatolia recorded over several glacial/interglacial cycles in the sediments of Lake Van. *Quaternary Science Reviews*.

Stockhecke, M., Kwiecien, O., Vigliotti, L., Anselmetti, F.S. Beer, J., Çağatay, M.N., Channell, J.E.T,. Kipfer, R., Lachner, J., Litt, T., Pickarski, N., Sturm, M. 2014. Chronostratigraphy of the 600,000 year old continental record of Lake Van (Turkey). *Quaternary Science Reviews*. 104, 8-17.

Stockhecke, M., Sturm M., Brunner, I., Schmincke, H.-U., Sumita, M., Kwiecien, O., Çukur, D., Anselmetti, F.S. 2014. Sedimentary evolution and environmental history of Lake Van (Turkey) over the past 600,000 years. *Sedimentology* 61(6), 1830-1861.

Sumita, M., Schmincke, H.U. 2013*a*. Impact of volcanism on the evolution of Lake Van II: Temporal evolution of explosive volcanism of Nemrut Volcano (eastern Anatolia) during the past ca. 0.4 Ma. *Journal of Volcanology Geothermal Research* 253, 15–34.

Sumita, M., Schmincke, H.U. 2013*b*. Impact of volcanism on the evolution of Lake Van I: evolution of explosive volcanism of Nemrut Volcano (eastern Anatolia) during the past >400,000 years. *Bulletin of Volcanology 75*, 714.

Şaroğlu, F., Güner, Y. 1981. Doğu Anadolu'nun jeomorfolojik gelişimine etki eden öğeler: Jeomorfoloji, tektonik, volkanizma ilişkileri. *TJK Bülteni* 24, 39-50.

Şenel, M., Ercan, T. 2002, 1:500000 Ölçekli Türkiye Jeoloji Haritası, Van Paftası, *Maden Tetkik ve Arama Genel Müdürlüğü*, Ankara

Şengör. A.M.C., Yılmaz, Y. 1981. Tethyan evolution of Turkey: A plate tectonic approach. *Tectonophysics* 75, 181-241.

Şengör. A.M.C., Görür, N., Şaroğlu, F. 1985. Strike-slip faulting and related basin formation in zones of tectonic escape: Turkey as case study. Biddle, K.T., Christie-Blick, N. (Ed.). Strike-slip faulting and basin formation. Spec. Publ. Soc. Econ. Paleontol. *Mineral* 37, 227-264.

Şengör, A., Özeren, S., Genç, T., Zor, E. 2003. East Anatolian high plateau as a mantle supported, north-south shortened domal structure. *Geophysical Research Letters* 30, 24.

Şengör, A.M.C., Özeren, M.S., Keskin, M., Sakınç, M., Özbakır, A.D., Kayan, İ. 2008. Eastern Turkish high plateau as a small Turkic-type orogen: Implications for post-collisional crust-forming processes in Turkic-type orogens. *Earth-Science Reviews*. 90, 1–48.

Tan, O. 2004. Kafkasya, Doğu Anadolu ve Kuzeybatı İran Depremlerinin Kaynak Mekanizması Özellikleri ve Yırtılma Süreçleri, Doktora Tezi, İTÜ Fen Bilimleri Enstitüsü, İstanbul (unpublished).

Todd, S. P. 1989. Stream-driven, high-density gravelly traction carpets: possible deposits in the Trabeg Conglomerate Formation, SW Ireland and some theoretical considerations of their origin. *Sedimentology* 36, 513-530.

Toker, M., Krastel, S., Demirel-Schlueter, F., Demirbağ, E., İmren, C. 2007. Volcano-seismicity of Lake Can (Eastern Turkey): A comparative analysis of seismic reflection and three-component velocity seismogram data and new insights into Volcanic Lake Seismicity. *Earthquake Symposium Kocaeli*. 22-26 October 2007, 103-109.

Toker, M., Şengör, A. M. C. 2011. Van Gölü havzasının temel yapısal unsurları, tektonik ve sedimanter evrimi, Doğu Türkiye, *İTÜ Dergisi* 10 (4), 119-130.

Türkelli, N., Sandvol, E., Zor, E., Gök, R., Bekler, T., Al-Lazki, A., Karabulut, H., Kuleli, S., Eken, T., Gürbüz, C., Bayraktutan, S., Seber, D., Barazangi, M. 2003. Seismogenic zones in Eastern Turkey. *Geophysıcal Research Letters* 30, 8039-8042.

Utkucu, M. 2006. Implications for the water level change triggered moderate (M ? 4.0) earthquakes in Lake Van basin, Eastern Turkey. *Journal of Seismology* 10, 105-117.

Üner, S. 2014, Seismogenic structures in Quaternary lacustrine deposits of Lake Van (eastern Turkey), *Geologos* 20 (2), 79-87.

Valeton, I. 1978. A morphological and petrological study the terraces around Lake Van, Turkey. Degens, E.T. and Kurtman, F. (Ed.). Geology of Lake Van. *MTA Publications* 169, 64-80.

Van Ransbergen, P., De Batist, M., Beck, C. 1999. High-resolution seismic stratigraphy of glacial to interglacial fill of a deep glacigenic lake: Lake Le Bourget, Northwestern Alps, France. *Sediment Geol*. 128, 99-129.

Volland, S., Sturm, M., Lukas, S., Pino, M., Müller, J. 2007. Geomorphological and sedimentological evolution of a lake basin under strong volcano-tectonic influence: the seismic record of Logo Calafquen (south-central Chile). *Quaternary International*. 161, 32-45.

Wick, L., Lemcke, G., Sturm, M. 2003. Evidence of Lateglacial and Holocene climatic change and human impact in eastern Anatolia: high resolution pollen, charcoal, isotopic and geochemical records from the laminated sediments of Lake Van, Turkey. *The Holocene* 13, 665–675.

Wolff, E. W., Chappellaz, J., Blunier, T., Rasmussen, S. O., Svensson, A. 2010. Millennial–scale variability during the last glacial: The ice core record. *Quaternary Scienc. Reviews* 29, 2828–2838.

Wong, H.K., Degens, E.T. 1978. The bathymetry of Lake Van; eastern Turkey. Degens E.T., Kurtman F. (Ed.). The Geology of Lake Van. *MTA Press*. Ankara, 6-10.

Wong, H.K, Finckh, P. 1978. Shallow structures in Lake Van. Degens, E.T., Kurtman, F. (Ed.). Geology of Lake Van. *MTA Yayınları*. Ankara, 20-28.

Yılmaz, Y., Güner, Y., Şaroğlu, F. 1998. Geology of the Quaternary volcanic centres of the east Anatolia. *Journal of Volcanology and Geothermal Research* 85, 173–210.