Yerbilimleri, 2022, 43 (2), 96-120, 1059064

Hacettepe Üniversitesi Yerbilimleri Uygulama ve Araştırma Merkezi Bülteni (*Bulletin of the Earth Sciences Application and Research Centre of Hacettepe University*

YERBİLİMLERİ
Bulletin for Earth Sciences

ISSN: 2687- 2978

Natural and anthropogenic driving forces on Holocene coastline evolution of Lake Van (Eastern Anatolia): A geological approach

Van Gölü'nün (Doğu Anadolu) Holosen kıyı şeridi gelişimi üzerindeki doğal ve insan kaynaklı itici güçler: Jeolojik bir yaklaşım

SERKAN ÜNER[1*]

[1]Van Yüzüncü Yıl Üniversitesi, Jeoloji Mühendisliği Bölümü, Van, Türkiye

Geliş*(received)*: 17 Ocak (*January*) 2022 Kabul *(accepted):* 28 Mart (*March*) 2022

ABSTRACT

Coastal areas along the lakes are sensitive to climatic, hydrologic, and anthropogenic changes. These areas also reveal the interaction between natural driving forces and anthropogenic factors. Lake Van coastal region is a dynamic area heavily affected by natural processes and human activities. The present study focuses on Lake Van's coastline evolution and the associated driving forces. Natural driving forces influencing the changes in the coastline were determined as rock type, water-level fluctuations, wave and current action, tectonics, and fluvial-based processes. The lake's eastern coast is the most intensive region for erosion and deposition in terms of natural factors.

Most residents prefer to live in Lake Van's coastal areas, likely a large percentage of the world's population choice. Coastal settlements and their coastal protection structures such as embankments and harbours negatively affect the natural processes such as erosion, sediment transportation, and deposition. Dams and river reclamation channels build on rivers indirectly affect the coastal evolution by reducing the sediment input into the lake. These anthropogenic stressors on coastal evolution completely change the natural balance. Understanding all these environmental factors is an indicator of the existing circumstances of the Lake Van coastal area and provides a broader perspective to assess protection and management of this area.

Keywords: Anthropogenic activity, coastline, Eastern Anatolia, natural driving forces, Lake Van

ÖZ

Göl kıyıları iklimsel, hidrolojik ve insan kökenli değişimlere oldukça duyarlıdır. Bu alanlar aynı zamanda doğal itici güçler ile insan kökenli değişimler arasındaki etkileşimi ortaya koymaktadır. Van Gölü kıyıları, doğal süreçler ve insan aktivitesinden önemli şekilde etkilenen dinamik alanlardır. Bu çalışma Van Gölü kıyı *gelişimine ve bununla ilişkili itici güçlere odaklanmaktadır. Kıyı çizgisi değişimini etkileyen doğal süreçler kaya türü, su seviyesi oynamaları, dalga ve akıntılar, tektonizma ve flüvyal süreçler olarak belirlenmiştir. Van Gölü'nün doğu kıyıları, doğal aşınma ve depolanma süreçleri bakımından en duyarlı alanlardır.*

Dünya popülasyonunun önemli bir kısmının kıyılarda yaşaması gibi, bölge insanı da yaşamak için Van Gölü kıyılarını tercih etmektedir. Kıyı yerleşimleri ile setler ve limanlar gibi kıyı koruma yapıları, aşınma, sediman taşınması ve depolanma gibi doğal süreçleri olumsuz etkilemektedir. Barajlar ve nehir ıslah kanalları da, göle taşınan sediman miktarını azalttığı için dolaylı olarak kıyı gelişimini etkilemektedir. Bu insan kaynaklı baskılar, kıyı gelişimi üzerindeki doğal dengeyi tümüyle değiştirmektedir. Tüm bu çevresel faktörler, Van Gölü kıyı alanının mevcut koşullarının bir göstergesidir ve bu alanın korunması ve yönetimine ilişkin değerlendirmelerde daha geniş bir perspektif sunmaktadır.

Anahtar Kelimeler: *Doğal itici güçler, Doğu Anadolu, insan kökenli etmenler, kıyı çizgisi, Van Gölü*

https://doi.org/10.17824/yerbilimleri.1059064

*Sorumlu Yazar/ Corresponding Author: suner@yyu.edu.tr

INTRODUCTION

The coastline can be simply described as the boundary between the land and the sea/lake water where a large percentage of the world's population resides (Bird, 2008). These are defined as valuable areas ecologically and economically. Coastal zones are affected by intense natural factors, including global sea-level change, coastal erosion and sedimentation, tide, storm, and tectonics. They are influenced by several or all of these factors (Vafeidis et al., 2008; Ghost et al., 2015; Ai et al., 2019; Dai et al., 2019). While some coastal processes such as beach erosion, spit formation, or cliff retreat work at high speeds and allow researchers to observe changes in human life scales, coastal-sedimentation, tectonic deformation and sea-level changes need millennial time-scales (Dornbusch et al., 2008; Jabaloy-Sánchez et al., 2010).

Anthropogenic factors also impact coastal evolution. Residential on shore, embankments, wave-barriers, and harbours directly influence coastline, while dominant changes on the fluvial system such as dams and river-channel reclamations indirectly affect the coastline formation by changes in the sediment input (Gottgens and Evans, 2007; Yao and Wu, 2012; Zhang et al., 2013; Rameli and Jaafar, 2015; Karakuş et al., 2017; Ai et al., 2019). Natural or anthropogenic processes in the sea coasts are similarly effective in the large lakes (Niemi et al., 2007; Thompson et al., 2011; Smeltzer et al., 2012; Chraïbi et al., 2014; Lin and Wu, 2014).

Lake Van is a terminal lake located at an altitude of 1648 m above sea level in eastern Turkey (Figure 1a). The origin, age, water chemistry, water-level changes, climatic features, wetlands and ecological features of Lake Van have been studied by numerous researchers (Reimer et al., 2009; Kaden et al., 2010; Kuzucuoğlu et al., 2010; Huguet et al., 2011; Düzen and Aydın, 2012; Tomonaga et al., 2012; Çağatay et al., 2014; Kwiecien et al., 2014; Stockhecke et al., 2014; Aydın and Karakuş, 2016; Mochizuki et al., 2018). However, the evaluation of coastal development and processes in terms of natural and artificial factors is lacking.

It is an essential to understand the natural and anthropogenic factors shaping Lake Van's coastline for an optimum evaluation of the current coastal areas. Therefore, this study aims to (i) identify natural processes shaping the coastlines, (ii) determine the coasts affected mainly by natural processes, and (iii) introduce the artificial mechanisms interrupting the natural development of the coastline in Lake Van, using field observations, laboratory analyses of physical properties of rocks, and satellite images.

BACKGROUND

Lake Van is located on Eastern Anatolian Plateau formed by the continental collision between the Arabian and Eurasian plates. The velocity of the ongoing collision is 10–11 mm/yr on these plates' boundary (Reilinger et al., 2006). Lake Van, Muş, and Pasinler are some of the basins formed by compressional tectonic regime on the plateau (Şaroğlu and Güner, 1979; Şengör and Yazıcı, 2020).

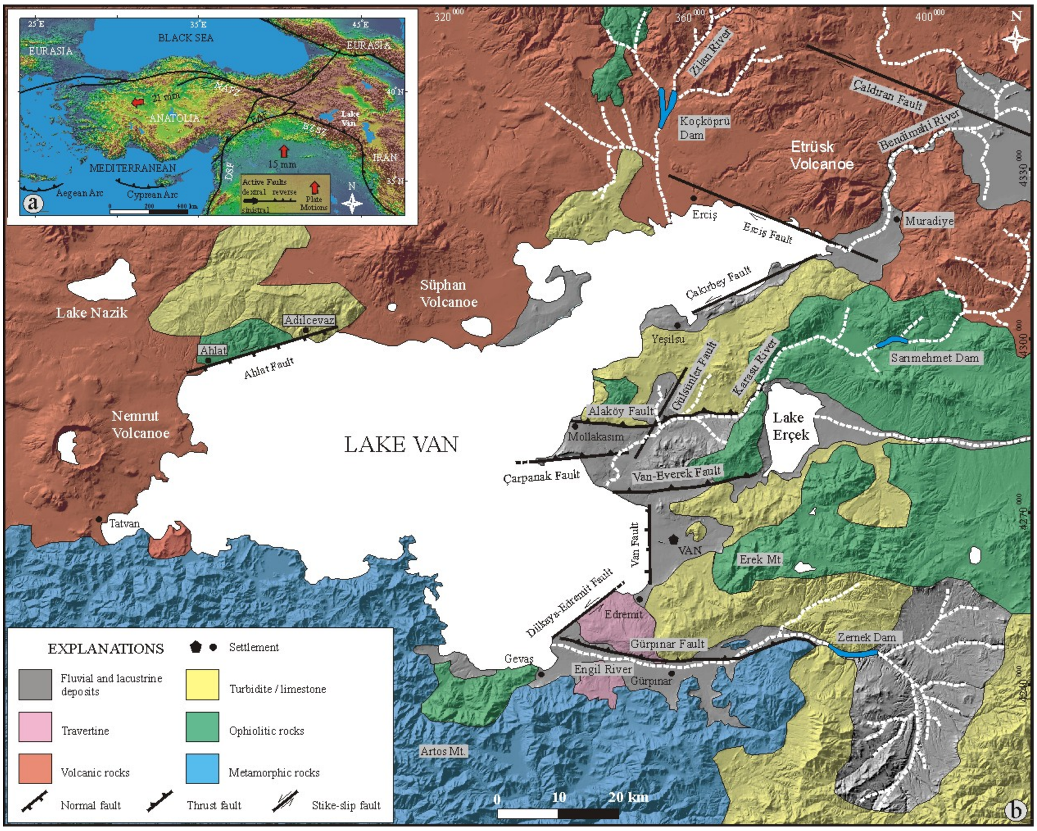

Figure 1. a) Major neotectonic features of Eastern Anatolia Plateau and adjacent areas. b) Geological map of Lake Van Basin (modified from Acarlar et al., 1991; Şenel, 2008; Koçyiğit, 2013).

Şekil 1. *a) Doğu Anadolu Platosu ve yakın çevresinin ana neotektonik özellikleri. b) Van Gölü Havzası'nın jeolojik haritası (Acarlar vd., 1991; Şenel, 2008; Koçyiğit, 2013'ten değiştirilerek).*

Approximately N-S oriented compressional tectonic regime is characterized mainly by E-W-trending reverse and NE-striking sinistral and NW-striking dextral strike-slip faults in Lake Van Basin (Dewey et al., 1986; Yılmaz et al., 1998; Özkaymak et al., 2011; Koçyiğit, 2013). Van-Everek, Gürpınar, and Alaköy reverse faults and Erciş, Çaldıran, Çakırbey, Karasu, and Gülsünler strike-slip faults are active faults of the basin (Koçyiğit, 2013; Okuldaş and Üner, 2013; Dicle and Üner, 2017; Sağlam Selçuk et al., 2017; Toker et al., 2017) (Figure 1b). Nemrut, Süphan, and Etrüsk volcanoes observed along the western and northern parts of the basin are the product of the collision-related magmatic activity (Figure 1b) (Aydar et al., 2003; Karaoğlu et al., 2005; Özdemir et al., 2011; Çubukçu et al., 2012; Oyan et al., 2016; Açlan et al., 2020).

Lake Van Basin, has been developing unconformably since Pliocene over the Miocene and older basement comprising metamorphic rocks (Bitlis Metamorphics) (Oberhänslı et al., 2010; Okay et al., 2010)(Figure 2a), Jurassic limestones (Figure 2b), Upper Cretaceous ophiolites (Yüksekova Mélange) (Şengör and Yılmaz, 1981; Üner, 2020)(Figure 2c), and Oligocene-Miocene turbidites (Acarlar et al., 1991; Gülyüz et al., 2020) (Figure 2d). These rocks are unconformably overlain by the Pliocene to Quaternary volcanic rocks (Figure 2e) and ancient lacustrine deposits of Lake Van (Degens et al., 1984; Stockhecke et al., 2014; Üner, 2018) (Figure 2f). Quaternary travertine (Figure 2g) and alluvium constitute the youngest basin fill (Şenel, 2008).

Lake Van Basin is the largest soda lake in the world, developed 600 ka ago (Stockhecke et al., 2014). It has a surface area of 3570 km^2, a volume of 607 km^3, a depth of 451 m (Kempe et al., 1978), and a coastline of 497.3 km. It is an alkaline lake with 9.8 pH and 22–23‰ salinity (Reimer et al., 2009; Kaden et al., 2010; Tomonaga et al., 2012). Four main rivers, namely Engil, Karasu, Bendimahi, and Zilan, and numerous temporary streams reach the lake.

The water budget of Lake Van depends on balanced precipitation, evaporation, groundwater supply and runoff. At Lake Van Region the annual average air temperature and precipitation are 9 °C (Düzen and Aydın, 2012) and 473.4 mm (Aydın and Karakuş, 2016), respectively. Their annual variations fluctuate the lake level up to 90 cm (Degens and Kurtman, 1978; Kaden et al., 2010; Stockhecke et al., 2012).

MATERIAL AND METHOD

The elements shaping the coastline of Lake Van are investigated in two sections as natural and artificial. The rock type, water-level fluctuation, waves and currents, tectonics, and fluvial-based processes constitute natural elements affecting coastal formation and deformation. In contrast, coastal settlements, coastal protection structures, and dams are artificial elements. This study evaluates natural and artificial processes with field observations, satellite images, and laboratory analyzes.

The field work was conducted along Lake Van's approximately 497 km long coastal area.

Thin sections of parent-rock samples were prepared to determine the mineralogical composition and to interpret the strength of these rocks. Additionally, some physical features of the coastal rocks, such as abrasion resistance, water absorption capacity, and apparent porosity rate, were determined by laboratory experiments. Böhme abrasion test was applied to the cubic samples cut into

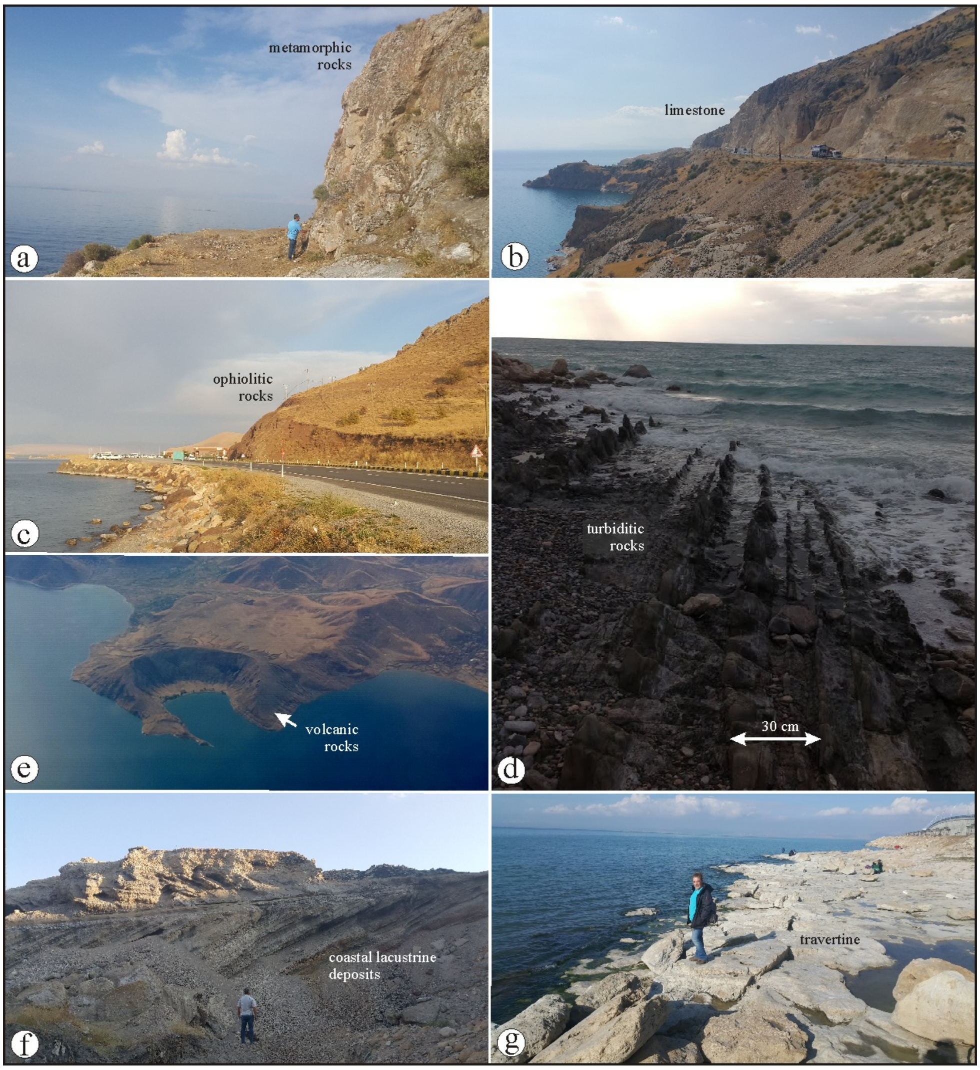

Figure 2. Field photographs of the; (a) metamorphic rocks, (b) limestone, (c) ophiolitic rocks, (d) turbiditic rocks, (e) volcanic rocks, (f) lacustrine deposits, and (g) travertine located on the coast of Lake Van.

Şekil 2. *Van Gölü kıyılarında gözlenen; (a) metamorfik kayaçların, (b) kireçtaşlarının, (c) ofiyolitik kayaçların, (d) türbiditik kayaçların, (e) volkanik kayaçların, (f) gölsel çökellerin ve (g) travertenlerin arazi fotoğrafları.*

70x70x70 mm^3 ± 1 mm to determine the abrasion resistance of these rocks.

Water absorption capacity and apparent porosity values were also calculated from dry and wet weights. All values were compared to interpret the erosion rates on the Lake Van coasts.

Tectonic structures in the coastal area and their geological characteristics were acquired from previous studies and compared to field observations. Long- and short-term water-level fluctuations with the wave and current activities and their effect on outcrops were also evaluated in terms of erosion and depositional processes in the field.

Satellite images are one of the most useful tools for preparing coastal and deltaic environments inventory and detecting their changes (Durduran, 2010; Kuenzer et al., 2014; Flor et al., 2015; Ghosh et al., 2015; Zhang et al., 2016; Dai et al., 2019). Landsat images, obtained over 42 years (1977–2019), were analysed to investigate short-term changes along the Lake Van coast. These images were mostly used for determining beach, spit, and delta evolutions. They were also evaluated to identify fault zones overlapping with coastal areas. Seismic activities of these faults were checked from Kandilli Observatory and Earthquake Research Institute (KOERI) database.

Long-term wind-velocity records measured from six stations (Van, Erciş, Gevaş, Muradiye, Tatvan, and Ahlat) since 1960 were obtained from the Turkish State of Meteorological Service to evaluate wave activity on Lake Van coasts. Monthly maximum wind velocity records were compared with the most known wind-velocity scale (Beauford scale from Isemer and Hasse, 1991) to determine the maximum wave-height that can arrive at the coast.

DRIVING FORCES

Rock type

Lake Van developed on various basement rocks such as metamorphic, ophiolitic, volcanic, limestone, turbidite, and travertine/tufa. Because of the water-level fluctuations, Lake Van's ancient lacustrine and deltaic deposits are also observed in its modern coastal area (Figure 2).

South of Lake Van is covered by metamorphic and ophiolitic rocks. Precambrian to Cretaceous metamorphics, called Bitlis Massif, are composed of schist, gneiss, marble, and amphibolite (Oberhänslı et al., 2010). These subduction-related metamorphic rocks present a south-verging and tectonically imbricate structure (Okay et al., 2010). Lake Van's 106.9 km long southern coastline lies between Tatvan and Gevaş city centres consists of these metamorphic rocks. Metamorphic rocks are composed of chlorite-schist (Figure 3a) and hornblende+ plagioclase-rich amphibolite (Figure 3b). These amphibolites and chlorite-schists present water absorption capacity of 0.10-0.11%, apparent porosity rates of 0.23-0.26%, and abrasion resistance values of 0.14-4.98 $cm^3/50cm^2$, respectively (Table 1). Metamorphic rocks located on the southern coast show 34–56% topographic inclination.

The remaining southern coastline (approximately 14 km long) consists of ophiolitic rocks located around the Gevaş city centre, and called as Gevaş ophiolites. Ophiolitic rocks are also observed at the 7.1 km long northwest coast between Ahlat and Adilcevaz city centres. Upper Cretaceous ophiolitic rocks are made up of harzburgites and gabbros (Üner, 2020). While harzburgites contain olivine and pyroxene (Figure 3c), gabbros are composed of plagioclase and pyroxene (Figure 3d). Their water absorption capacities are 0.14-0.51%, apparent porosity rates 0.32-1.19%, and abrasion resistance values 1.13-6.33 $cm^3/50\ cm^2$, respectively (Table 1).

Roughly 140 km long north and west coast of Lake Van is composed of volcanic rocks. Pliocene to Quaternary collision-related volcanic rocks include basalt and pyroclastics derived from Nemrut, Süphan, and Etrüsk volcanoes (Maxcon, 1936; Karaoğlu et al.,

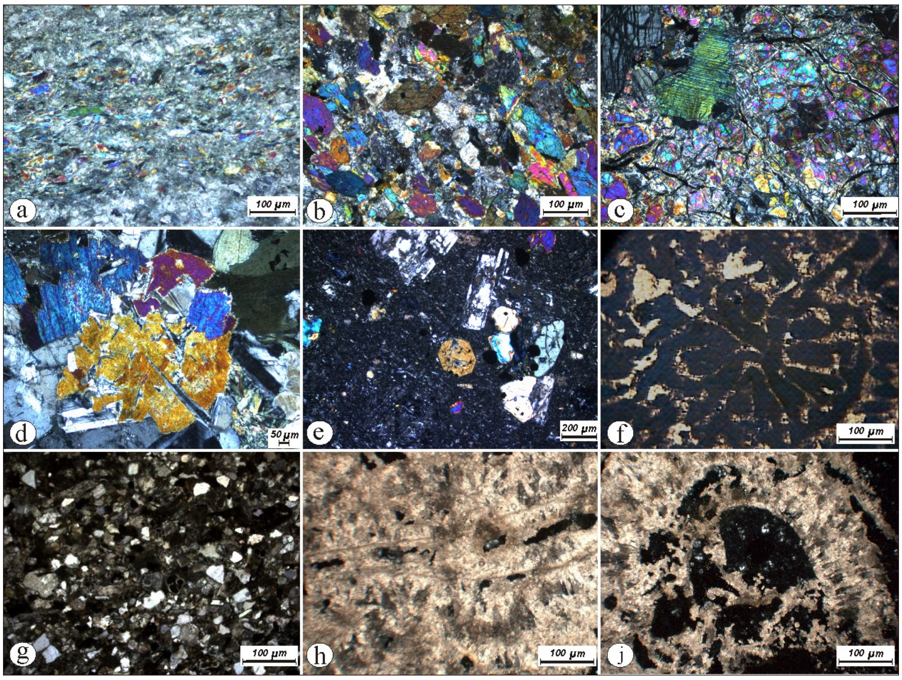

Figure 3. Photomicrographs of the; (a) chlorite-schist, (b) amphibolite, (c) harzburgite, (d) gabbro, (e) basalt, (f) limestone, (g) sandstone, (h) travertine, and (j) tufa samples obtained from the coasts of Lake Van.

Şekil 3. *Van Gölü kıyılarından elde edilen; (a) klorit-şist, (b) amfibolit, (c) harzburjit, (d) gabro, (e) bazalt, (f) kireçtaşı, (g) kumtaşı, (h) traverten, and (j) tufa örneklerinin incekesit görüntüsü.*

Table 1. Water absorption capacity, apparent porosity rate, and abrasion resistance test results of the different rocks sampled from the coastal area of Lake Van

Çizelge 1. *Van Gölü kıyısından örneklenen farklı kayaçların su emme kapasitesi, görünür gözeneklilik oranı ve aşınma direnci test sonuçları*

Sample No	Rock type	Water absorption (%)	Apparent porosity (%)	Abrasion resistance ($cm^3/50cm^2$)
1	Tufa	10.53	16.78	36.39
2	Travertine	2.93	6.06	10.55
3	Limestone	3.59	7.37	10.35
4	Sandstone	0.13	0.30	1.93
5	Basalt	0.31	0.73	2.03
6	Schist	0.11	0.26	4.98
7	Harzburgite	0.51	1.19	6.33
8	Amphibolite	0.10	0.23	0.14
9	Gabbro	0.14	0.32	1.13

2005; Ersoy et al., 2006; Özdemir et al., 2011; Oyan et al., 2016). Basaltic rocks with hypocrystalline texture contain plagioclase, augite, and enstatite minerals (Figure 3e). The basalt sample has a water absorption capacity of 0.31%, apparent porosity rate of 0.73%, and abrasion resistance value of 2.03 $cm^3/50cm^2$ (Table 1). The topographic inclination of these rocks differentiates on the coastal area of the lake appropriately to the geometry of these stratovolcanoes.

Lower Miocene Adilcevaz limestones represent the latest marine carbonates of the region, corresponding to the uppermost levels formed before the closure of the southern branch of the Neo-Tethys (Yeşilova and Yakupoğlu, 2007). These rocks are observed on the northwest coast of Lake Van between Adilcevaz and Ahlat city centres (22.8 km) and west of the Erciş city (3.8 km). Adilcevaz limestone is a mud-supported, fossiliferous-carbonate rock containing > 10% grains and can be defined as wackestone (Figure 3f). It has a water absorption capacity of 3.59%, an apparent porosity rate of 7.37%, and an abrasion resistance value of 10.35 $cm^3/50cm^2$ (Table 1).

The Oligocene–Miocene shallow- to deep-marine turbidites composed of sandstone-mudstone alternation with gravelly layers (Acarlar et al., 1991; Gülyüz et al., 2020) are observed along the 19.1 km coastline between Mollakasım and Yeşilsu villages at the east of Lake Van, and 6.8 km long in Ahlat at the west. The sandstone sample contains quartz minerals and rare fossil fragments (Figure 3g) with a water absorption capacity of 0.13%,apparent porosity rate of 0.30%, and abrasion resistance value of 1.93 $cm^3/50cm^2$ (Table 1).

The Quaternary terrestrial carbonates formed in fluvial and lacustrine environments constitute the Edremit travertine and tufa deposits (Yeşilova et al., 2015). The carbonates outcrop only 10.7 km along the southeast coast of Lake Van near Edremit city centre. Travertine with microcrystalline texture (Figure 3h) and tufa composed of phytoherm framestone facies (Figure 3j) have the water absorption capacity of 2.93-10.53%, apparent porosity rates of 6.06-16.78%, and abrasion resistance values of 10.55-36.39 $cm^3/50cm^2$, respectively (Table 1).

The longest coastline of Lake Van with 165.1 km is located on ancient and modern lacustrine and deltaic deposits. The lacustrine sequences are formed by horizontally bedded clays, silts, and fine- to coarse-grained sandy shallow lacustrine and gravelly shore deposits and are frequently observed in eastern and northern coasts of Lake Van near the Van and Erciş city centres.

Water-level fluctuation

Water-level fluctuation history of Lake Van including last 110 ka was obtained from ancient terrace and varve records (Degens et al., 1978; Landmann et al., 1996; Kuzucuoğlu et al., 2010; Çağatay et al., 2014; Akköprü et al., 2019). The highest water-level was determined as +108 m above the present level (105 ka B.P.) (Kuzucuoğlu et al., 2010). In contrast, the lowest level was recorded as -340 m below the present level (8.4 ka B.P.) (Degens et al., 1978). The water-level have remained the same for the last 3-4 ka, except for minor changes (Degens et al., 1978; Landmann et al., 1996; Çağatay et al., 2014). Water budget of Lake Van is calculated depending on precipitation, evaporation, surface runoff, and groundwater recharge. The annual average precipitation is 473.4 mm (Aydın and Karakuş, 2016) and its contribution to the volume of the lake is calculated as approximately of 2.5 km^3 water input (Kadıoğlu et al., 1997). The annual average air temperature also varies from -3.6 to 22.7 °C at coastal areas of Lake Van and amount of the annually water lost to the atmosphere by evaporation is defined as 5.08 km^3 (Düzen and Aydın, 2012).

The catchment area of Lake Van is 11,859 km^2 (Düzen and Aydın, 2012). Four major rivers (Engil, Karasu, Bendimahi, and Zilan rivers) and tens of perennial and seasonal streams drain into Lake Van. It has been calculated that annually 1.7 km^3 of freshwater is added to the lake volume by surface runoff (Kadıoğlu et al., 1997). Water loss of Lake Van due to evaporation is balanced by precipitation, surface runoff, and groundwater input. Annual variation on these components changes the lake level up to 90 cm (Degens and Kurtman 1978; Kaden et al., 2010; Stockhecke et al., 2012).

Beachrocks considered as one of the best indicators of former water levels (Bezerra et al.,2004;Desruelles et al., 2009) are frequently observed in different levels at the east and southeast coasts of Lake Van. Both subaerial (Figure 4a) and submerged sandy and pebbly beachrocks deposited parallel to coastline in topographically low-incline areas are indicating lake-level fluctuations for Lake Van.

Wave and current activity

According to monthly maximum wind-velocity records measured by the Turkish State Meteorological Service on coastal stations since 1960, the wind-velocity frequently reached the gale/storm-level with 17.2–32.6 m/s (Beauford scale from Isemer and Hasse, 1991). This level corresponds to a 5.5–11.5 m waveheight (Met Office, 2007). Moreover, the wind-velocity unexpectedly reached the hurricane-level (> 32.6 m/s) twice, with 42.3 m/s (Üner, 2018). That highest value corresponds to >14 m waveheight (Met Office, 2007).

Wind-generated waves can erode coastal rocks directly and indirectly (Carter, 1976; Kamphuis, 1987; Brown et al., 2005; Trenhaile et al., 2015; Da Silva et al., 2018). When the beach is narrow, a much higher rate of wave energy reaches the coastal rocks. The continuous movement of the waves causes the erosion of these rocks and makes an unstable slope for the formation of a cliff. This type of coast, shaped by the direct effect of the waves or by the wave-induced landslides, is particularly observed at the eastern coast of Lake Van (Figure 4b). The other morphologic structure formed by wave erosion is the natural arch. This rarely observed structure formed by carving of the ancient deltaic deposits with wave effect is located on the southern coast of Lake Van with a height of 3 m and width of 8 m (Figure 4c).

Some accumulation structures such as beaches and barrier spits formed by waves and related longshore currents are also observed in the coastal area of Lake Van. Beaches consisting of generally loose, unconsolidated sediment, ranging in size from very fine sand up to pebble, are narrow and straight or slightly concave (Figure 5a). These natural beaches have provided their sediments from various sources such as rivers, eroded cliffs and foreshores, and drifting lake-floor. Barrier spits are other accumulation structures formed by waves and longshore currents. The drifting shore material along the coastline by the waves that arrive obliquely to the coastline and accompanying longshore currents accumulates on an area where the shoreline curves and forms a barrier spit. Bays or lagoons created by that barrier at the landward of the accumulation are observed at the topographically low-incline areas in the east of Lake Van (Figures 5b, 5c).

Figure 4. Field photographs of the; (a) beachrocks, (b) cliffs, and (c) natural arch taken from the coast of Lake Van.

Şekil 4. *Van Gölü kıyılarından çekilen; (a) yalı taşı, (b) falez ve (c) doğal kemerlerin arazi fotoğrafı.*

Figure 5. Field photographs of the; (a) gravelly beach, (b) & (c) barrier spits taken from the eastern coast of Lake Van.

Şekil 5. *Van Gölü doğu kıyılarından çekilen; (a) çakıllı plaj, (b) ve (c) kıyı dilinin arazi fotoğrafı.*

Tectonics

Lake Van Basin is a compressional area characterized by N–S trending crustal shortening since its formation. This tectonic regime is represented by strike-slip faults as well as coeval reverse faults (Dewey et al., 1986; Yılmaz et al., 1998; Özkaymak et al., 2011; Koçyiğit, 2013). N–S trending normal faults are rare structural elements. The basin has numerous active faults that generate intense seismicity (Özkaymak et al., 2011; Koçyiğit, 2013; Akkaya et al., 2015; Sağlam Selçuk et al., 2017; 2020).

Active faults, namely Ahlat, Erciş, Çakırbey, Çarpanak, Van, and Dilkaya–Edremit, are located on the coastline of Lake Van (Figure 1b). The Ahlat Fault is an ENE–WSW-trending normal fault with a strike-slip component (Çukur et al., 2017). Approximately 25 km long fault lies between Ahlat and Adilcevaz city centres at the northwestern coast of Lake Van (Figure 1b). It deforms Upper Cretaceous ophiolites, Miocene turbidites, Quaternary volcanics and coeval lacustine deposits.

The NW–SE-trending Erciş Fault passes through the northern part of Lake Van, which is a dextral strike-slip fault with a normal fault component (Üner, 2019; Üner et al., 2019; Sağlam Selçuk and Kul, 2021). It deforms the Quaternary basalts originated from Etrüsk Volcanoe and lacustrine deposits of Lake Van. The Çakırbey Fault is another strike-slip fault (Koçyiğit, 2013) deforming the northeastern coast. Approximately 30 km long NE–SW-trending sinistral strike-slip fault cuts the Quaternary basalts and lacustrine deposits of Lake Van (Figure 1b).

The Çarpanak Fault located on the eastern coast is a nearly E–W-trending and northerly dipping reverse fault. Approximately 15 km long fault deforms the Pliocene to Quaternary fluvial and lacustrine deposits and forms a 7 km long peninsula (Figure 1b). The Van Fault is a 17 km long, N–S-trending, and westerly dipping normal fault. This tectonic structure, located on the Arabian–Eurasian compression zone, is observed along the eastern coast of Lake Van. It cuts the Quaternary lacustrine deposits of Lake Van (Figure 1b). Approximately 14 km long Dilkaya–Edremit Fault located on the southeastern coast is another sinistral strike-slip fault that deforms the Quaternary travertine and tufa deposits.

Fluvial-based processes

Four principal rivers, namely Zilan, Bendimahi, Karasu, and Engil and numerous temporary streams join Lake Van (Figure 6a). These principal rivers provide the main sediment input, whereas temporary streams yield a negligible amount of sediment. Zilan River, located in the northern part of Lake Van Basin, has a catchment area approximately of 1320 km^2. It collects their sediments from the erosion of the Upper Cretaceous ophiolitic rocks, the Quaternary volcanic rocks, and ancient lacustrine deposits of Lake Van. These sediments have been forming the Zilan Delta with a surface area of 5 km^2 (Figure 6b). The Bendimahi River is another main river located in the northern part of the bas in. It has a catchment area approximately of 1200 km^2, dominantly covered by the Quaternary volcanic and lesser ophiolitic rocks. It has a relatively small delta, namely the Bendimahi Delta, with a surface area of 2.2 km^2 (Figure 6c).

Karasu River is the longest fluvial system reaching Lake Van. It passes along the eastern part of the basin consisting of ophiolitic rocks, volcanic rocks, and fluvial and lacustrine deposits. Sediments collected from the approximately of 1490 km^2 catchment area have accumulated at the coastal area and have formed the Karasu Delta covering 1.4 km^2 (Figure 6d).

Figure 6. Google Earth satellite images showing; (a) drainage area of the fluvial systems, (b) Zilan Delta, (c) Bendimahi Delta, (d) Karasu Delta, and (e) Dönemeç Delta at the study area.

Şekil 6. *Çalışma alanındaki; (a) akarsu sistemlerinin drenaj alanlarını, (b) Zilan Deltası'nı, (c) Bendimahi Deltası'nı, (d) Karasu Deltası'nı ve (e) Dönemeç Deltası'nı gösteren Google Earth uydu görüntüsü.*

Engil River, located in the southeastern part, has the largest catchment area of the basin, approximately 2680 km^2. Sediments derived from the catchment area, covered with the Oligocene to Miocene turbiditic rocks, the upper Cretaceous ophiolitic rocks, and the Quaternary fluvial and lacustrine deposits, constitute the Dönemeç Delta with a surface area of 4.5 km^2 (Figure 6e).

Anthropogenic Factors

Some anthropogenic activities directly or indirectly affect the natural development of the coasts. Settlements, coastal protection structures such as embankments and wave-barriers, and harbours directly influence the coastline, while powerful changes on the fluvial system such as dams and river-channel reclamations indirectly affect as they change the sediment input (Kraus and McDougal, 1996; Dean and Dalrymple, 2002; Gottgens and Evans, 2007; Lin and Wu, 2014; Ai et al., 2019). Six city centres are located on the coastal area of Lake Van, namely Van, Erciş, Edremit, Ahlat, Adilcevaz, and Tatvan (Figure 1b).

Coastal utilization areas of these cities are rapidly spreading, and coasts are preferred for all kinds of structures such as buildings, factories, highways, and airport. Embankments are the most common structures protecting these coastal areas (Figure 7a). Coastal transportation coevally increases with these cities' population growth, resulting in the construction of numerous new harbours (Figure 7b).

Dams used for various purposes such as water storage, irrigation, and fishing were built on the three main rivers (Engil, Karasu, and Zilan rivers) mentioned above. These are the Zernek Dam, built in 1988, on the Engil River, the Sarımehmet Dam (1991) on the Karasu River, and the Koçköprü Dam (1992) on the Zilan River (Figure 6a). These dams have obstructed significant amount of sediments since their construction.

Channel reclamation activity is another anthropogenic modification of the fluvial system. Regulations applied to river channels, which pass through city centres, reduce sediment budget as it prevents erosion. This type of structure is observed on Zilan and Engil rivers at the city centres of the Erciş and Gürpınar. The decrease in sediment yield due to these dams and reclamation channels directly affects the development of the coastal zone.

DISCUSSION

Effect of rock type on coastal evolution

Various types of rocks form Lake Van coasts. Mineralogical composition, textural characteristics, and physical pr operties of these rocks, such as water absorption, apparent porosity rate, and abrasion resistance, are closely related to the shaping of these coasts. The southern coast of the lake is composed of schist, amphibolite, harzburgite, and gabbro. These rocks have low (< 1%) apparent porosity and water absorption capacity (Table 1), indicating high rock strength. In addition, Böhme abrasion resistance test values of these rocks are lower than 7 $cm^3/50cm^2$ (Table 1) which corresponds to low abradable rock class (Özvan and Direk, 2020). Relatively high values (4.98 and 6.33 $cm^3/50cm^2$) obtained from schist and harzburgite samples, indicating lesser abrasion resistance, may be explained by the segregation layers between the platy mica minerals in schists and alteration degree of the harzburgites.

Western and northern coasts are composed of basaltic rocks and rarely limestones. Basaltic rocks have low apparent porosity and water absorption capacity (< 1%) and a low abradable rock feature (2.03 $cm^3/50cm^2$) (Table 1). The high abrasion resistance value of these rocks is due to the hardness of the plagioclase minerals and the fine-crystalline fine-crystalline texture of the rock. Limestones observed in a limited area in the north have a relatively higher apparent porosity ratio (7.37%) and water absorption capacity (3.59%).

The Böhme abrasion test value of 10.35 $cm^3/50cm^2$ corresponds to moderate abradable rock level with a value between 7 and 20 $cm^3/50cm^2$, according to the classification proposed by Özvan and Direk (2020). This value can be attributed to the porous structure of fossiliferous limestone.

The eastern coast of Lake Van consists of the Miocene sandstones, the Quaternary terrestrial carbonates (travertine and tufa), and

Figure 7. Field photographs showing; (a) embankments and (b) Akdamar Harbour constructed on Lake Van coasts.

Şekil 7. *Van Gölü kıyılarında yapılmış; (a) kıyı seti ve (b) Akdamar Limanı'nın arazi fotoğrafı.*

coeval semi-consolidated lacustrine deposits. Sandstones have low apparent porosity and water absorption capacity (< 1%) and a low abradable rock feature (1.93 $cm^3/50cm^2$) (Table 1). This abrasion resistance value may vary depending on the thickness and position of the sandstone beds. On the contrary, travertines and tufas have high apparent porosity (6.06 and 16.78%) and water absorption (2.93 and 10.53%) rates, respectively (Table 1). The Böhme abrasion test value of the travertine sample (10.55 $cm^3/50cm^2$) corresponds to moderate abradable rock class with a value between 7 and 20 $cm^3/50cm^2$, while the test value of the tufa sample (36.39 $cm^3/50cm^2$) falls into the abradable rock class (> 20 $cm^3/50cm^2$) according to the classification proposed by Özvan and Direk (2020). Thin bedded and semi-consolidated shallow lacustrine and coastal deposits representing the longest coastline of Lake Van have the lowest abrasion resistance.

Lake-level change and coastal evolution

Lakes are extremely sensitive environments to climate-induced lake-level fluctuations (Street-Perrott, 1980; Adams and Wesnousky, 1998; Haghani et al., 2016; Sato et al., 2016). Especially in areas with low topographic inclination, small-scale water-level changes can cause the coastline to shift a considerable distance towards land or lake. Even though an annual variation on water budget changes the lake-level up to 90 cm (Degens and Kurtman, 1978; Kaden et al., 2010; Stockhecke et al., 2012),

it is accepted that the water level of Lake Van has remained the same for the last 3-4 ka, except for minor changes (Degens et al., 1978; Landmann et al., 1996; Çağatay et al., 2014). The formation of beachrocks on the coasts of Lake Van (Figure 4a), which requires several century vertical stability of the coastline (Neumeier, 1998; Vousdoukas et al., 2007; Çiner, 2009; Desruelles et al., 2009), supports this idea.

Wave and current effect on coastal evolution

Coastlines are dynamic systems shaped by the energy of waves and currents. Wind-induced waves and related longshore currents provide most of the power for erosion, transportation, and deposition of sediments. Although Lake Van is a closed basin surrounded by high mountains such as Nemrut, Süphan, Artos, and Erek, the wind-velocity can reach the hurricane-level with a maximum value of 42.3 m/s (Üner, 2018) corresponding to wave-heights up to 14 m (Met Office, 2007).

Coastal erosion results from the power of the hydraulic action and the erosive action of transported sediments. Wave action is extremely variable depending on the morphology of the coast and the physical characteristics of the bedrock (Bird, 2008). The best examples of wave erosion determined on the shores of Lake Van are cliff formation (Figure 4b) and the natural arches excavated on rocky coasts (Figure 4c).

Natural beaches and barrier spits represent accumulation structures formed by wave and current activity on the Lake Van coasts. Sandy and pebbly narrow beaches are frequently observed on straight or slightly concave parts of the eastern coasts of Lake Van. Barrier spits formed by the accumulation of sediments drifted by waves and longshore currents on the river mouths or the bays are also observed on the topographically low-inclined zones at the same coasts of the lake. Whereas some of these barriers create lagoons, some are used as natural harbours (Figure 5b).

Effect of tectonics

Lake Van is located north of the continental collision zone between the Arabian and Eurasian plates. Numerous faults and dense seismicity indicate ongoing tectonic activity for the region (Özkaymak et al., 2011; Koçyiğit, 2013; Akkaya et al., 2015; Sağlam Selçuk et al., 2020; KOERI, 2021). Some active faults with various characteristics such as Ahlat, Erciş, Çakırbey, Dilkaya–Edremit (strike-slip faults), Çarpanak (thrust fault), and Van (normal fault) cause some of Lake Van coasts to be linear (Figure 1b). Besides, earthquakes and vertical displacements induced by active faults in the hinterland can increase the sediment yields reaching the lake.

Delta Formation

Deltas formed where the sediment accumulation rate in the river mouth exceeds the rate of sediment distribution by waves, and currents are one of the most known agents that shape the coastlines. The development of a delta may be influenced by short-term climate change, rapid water-level fluctuations, coastal processes, and tectonics (Bird, 2008).

Primary sediment input to Lake Van is provided by major rivers such as Zilan, Bendimahi, Karasu, and Engil. Their deltas can be classified according to their morphology. While Zilan and Dönemeç deltas represent fluvial-dominated delta morphology, Karasu and Bendimahi deltas show wave-dominated delta characteristics (after Coleman and Wright, 1975). Lake Van and its deltas are not affected by tides.

The evolution of the Bendimahi Delta is significantly affected by tectonic deformation. It was forced to migrate 1.5 km to the north with all components due to the capture of the Bendimahi river canal by the Erciş Fault (Üner, 2019). Nowadays, that coastline consists of a wave-dominated delta and an abandoned river mouth (Figure 6c).

Anthropogenic stressors

Marine coastlines are extremely important due to the concentration of population near the coasts (Bird, 2008). A similar focus is valid for lake shores. Coastal settlements require coastal protection structures such as embankments, wave-barriers, and harbours. But these protection structures prevent some natural processes like erosion, sediment transportation, and deposition on the coast. The depositional formations such as beach or barrier-spits and the erosional structures like cliffs are negatively affected from these artificial coastal conditions (Kraus and McDougal, 1996; Dean and Dalrymple, 2002; Lin and Wu, 2014). Furthermore, the rigid coastal structures can cause higher waves due to reflection and create more erosion at near-shore (Miles et al., 2001).

Dams and river reclamation channels can cause another anthropogenically-induced change in lake characteristics. The decrease in sediment yield due to these structures directly affects the development of the coastal zone. In order to determine the effect of dams on deltaic sediment yield on Lake Van coasts, three rivers containing dam (Zilan, Karasu, and Engil rivers) and their deltas (Zilan, Karasu, and Dönemeç deltas) were investigated using Landsat satellite images. The Koçköprü Dam constructed in 1992 on the Zilan River dramatically affected the sediment yield carried to the Zilan Delta. A significant decrease in the dimensions of the Zilan Delta is clearly observed between the pre-dam to post-dam satellite images (Figs. 8a). A similar change is valid for the Karasu Delta. After the construction of the Sarımehmet Dam in 1991 on the Karasu River, a visible retreat occurred in the Karasu Delta (Figs. 8b).

The Dönemeç Delta is the largest deltaic system developed along the Lake Van coasts and formed by the sediments collected from the catchment area of the Engil River. The sediment supply to the delta has significantly decreased with the construction of the Zernek Dam in 1988 (Figure 8c). Although sediment yield is not the only component affecting delta development, the change in all these deltas after the construction of the dams is remarkable.

All the natural elements mentioned above are the dominant factor in shaping the coasts of Lake Van since its formation, but anthropogenic stressors on coastal evolution such as coastal settlements, dams, and coastal protection structures highly change the natural balance.

CONCLUSIONS

In this study, the elements that shape the approximately 497 km coastline of Lake Van were determined with field observations, satellite images, and laboratory experiments. The factors shaping the Van Lake coastline can be distinguished as natural and anthropogenic. While natural elements consist of rock type, water-level changes, waves and longshore current activity, tectonics, and fluvial-based processes, the human impact Lake Van coastal evolution occurs through the coastal protection structures and the dams and river reclamation channels built on the streams.

The coasts of Lake Van exhibit different characteristics against erosional elements such as waves, longshore currents, and water-level changes due to the diversity of coastal rocks and their different abrasion resistance. These elements are also effective for deposition features.

The eastern coasts of Lake Van are the most intensive region for erosion and deposition because of the low abrasion resistance of the existing rocks and the low topographic slope. These coasts that consist mainly of semi-consolidated lacustrine deposits and coastal carbonates (travertine and tufa) retreat rapidly. Other coastal parts are limitedly affected by wave and current erosion and water-level fluctuation due to high abrasion resistant rocks such as amphibolite, basalt, harzburgite, and schist. Additionally, numerous faults located on Lake Van coastlines such as Ahlat, Erciş, Çakırbey, Van, Dilkaya–Edremit, and Çarpanak are structural elements that directly shape the coastal area.

Coastal settlements and their coastal protection structures, dams on rivers and river

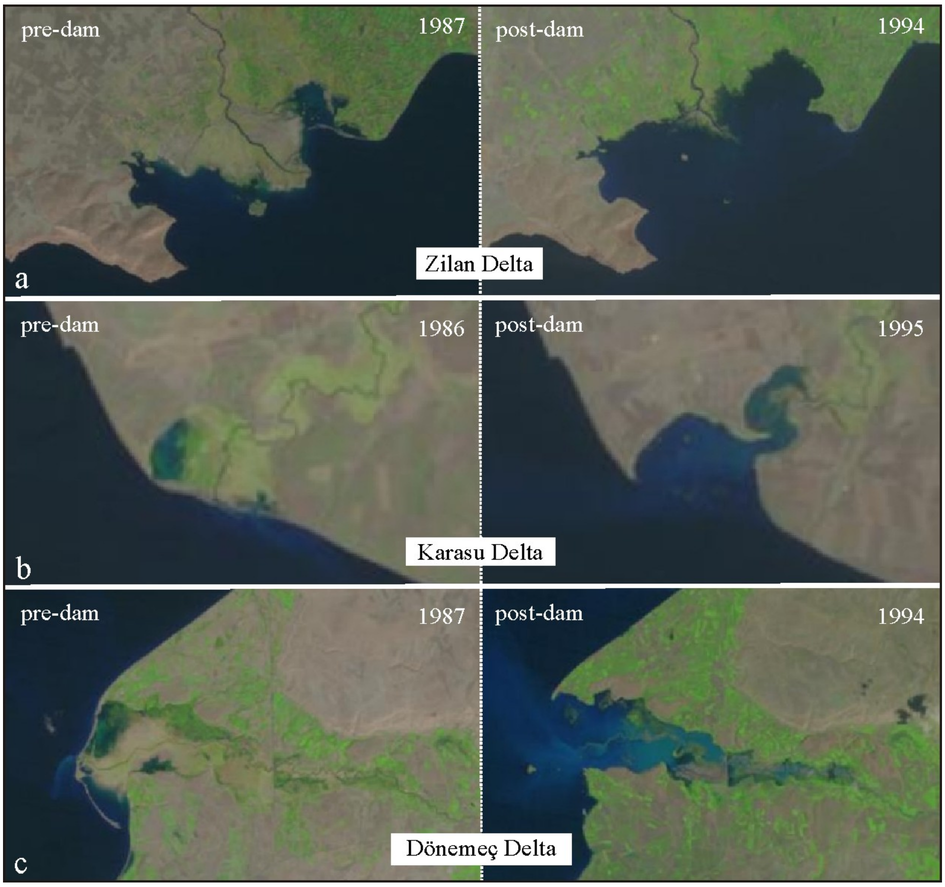

Figure 8. Landsat satellite images showing the evolution of; (a) Zilan Delta before and after Koçköprü Dam was built, (b) Karasu Delta before and after Sarımehmet Dam was built, and (c) Dönemeç Delta before and after Zernek Dam was built.

Şekil 8. *(a) Zilan Deltası'nın Koçköprü Barajı öncesi ve sonrası, (b) Karasu Deltası'nın Sarı Mehmet Barajı öncesi ve sonrası ve (c) Dönemeç Deltası'nın Zernek Barajı öncesi ve sonrası değişiminin Landsat uydu görüntüsü.*

reclamation channels negatively affect the aforementioned natural processes such as erosion, sediment transportation, and deposition. These anthropogenic stressors on coastal evolution completely change the natural balance. Global and regional climate changes and related storms, floods, and drought are also clear indicators of this human impact on natural processes.

ACKNOWLEDGEMENT

The author is grateful to Levent Selçuk, Tijen Üner, and Erman Özsayın for their help and suggestions. The author wish to express their thanks to two anonymous reviewers for their valuable and constructive comments on the manuscript.

REFERENCES

Acarlar, M., Bilgin, A.Z., Elibol, E., Erkan, T., Gedik, İ., Güner, E., Hakyemez, Y., Şen, A.M., Uğuz, M.F. and Umut, M., 1991. Geology of the eastern and northern part of Lake Van. The Mineral Research and Exploration Institute of Turkey (MTA) Technical Report Nr. 9469.

Açlan, M., Oyan V. and Köse, O., 2020. Petrogenesis and the evolution of Pliocene Timar basalts in the east of Lake Van, Eastern Anatolia, Turkey: A consequence of the partial melting of a metasomatized spinel–rich lithospheric mantle source. Journal of African Earth Sciences, 168, 103844, 1–18.

Adams, K.D. and Wesnousky, S.G., 1998. Shoreline processes and age of the Lake Lahontan high-stand in the Jessup embayment, Nevada. Geological Society of American Bulletin, 110, 1318–1332.

Ai, B., Zhang, R., Zhang, H., Ma, C. and Gu, F., 2019. Dynamic process and artificial mechanism of coastline change in the Pearl River Estuary. Regional Studies in Marine Science, 30, 100715, 1–12.

Akkaya, İ., Özvan, A., Tapan, M. and Şengül, M.A., 2015. Determining the site effects of 23 October 2011 earthquake (Van province, Turkey) on the rural areas using HVSR microtremor method. Journal of Earth System Sciences, 124 (7), 1429–1443.

Akköprü, E., Aydin, F. A. and Doğu A. F., 2019. Van Gölü se viye değişimlerinin Engil Çayı Deltası jeomorfolojisi üzerine etkisi ve Dilkaya H öyüğü ile ilişkisi. Türk Coğrafya Dergisi, 72, 45–51.

Aydar, E., Gourgaud, A., Ulusoy, İ., Digonnet, F., Labazuy, P., et al. 2003. Morphological analysis of active Mount Nemrut stratovolcano, eastern Turkey: evidences and possible impact areas of future eruption. Journal of Volcanology and Geothermal Research, 123, 301–312.

Aydın, H. and Karakuş, H., 2016. Estimation of evaporation for Lake Van. Environmental Earth Sciences, 75, 1275, 1–19.

Bezerra, F.H.R., Amaral, R.F., Lima-Filho, F.P., Ferreira, A.V., Sena, E.S. and Diniz, R.F., 2004. Beachrock fracturing in Brazil. Journal of Coastal Research, 42, 169–182.

Bird, E., 2008. Coastal Geomorphology: An Introduction. John Wiley & Sons, 411 p.

Brown, E.A., Wu, C.H., Mickelson, D.M. and Edil, T.B., 2005. Factors Controlling Rates of Bluff Recession at Two Sites on Lake Michigan. Journal of Great Lakes Research, 31, 306–321.

Carter, C.H., 1976. Lake shore erosion, Lake County, Ohio: Setting, processes, and recession rates from 1876–1973. Ohio Div. Geological Survey Report No. 99.

Chraïbi, V.L.S., Kireta, A.R., Reavie, E.D., Cai, M. and Brown, T.N., 2014. A paleolimnological assessment of human impacts on Lake Superior. Journal of Great Lakes Research, 40, 886–897.

Coleman, J.M. and Wright, L.D., 1975. Deltas, Models for Exploration (ed. by M. L. Broussard), Houston Geological Society p. 99.

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

Çiner, A., Desruelles, S., Fouache, E., Koşun, E. and Dalongeville, R., 2009. Beachrock formations on the Mediterranean Coast of Turkey: Implications for Holocene sea level changes and tectonics. Geological Bulletin of Turkey, 52 (3), 257–296.

Çubukçu, H.E., Ulusoy, İ., Ersoy, O., Aydar, E., Gourgaud, A. and Herve, G., 2012. Mt. Nemrut Volcano (Eastern Turkey): temporal petrological evolution. Journal of Volcanology and Geothermal Research, 209-210, 33–60.

Çukur, D., Krastel, S., Tomonaga, Y., Schmincke, H., Sumita, M., et al. 2017. Structural characteristics of the Lake Van Basin, eastern Turkey, from high-resolution seismic reflection profiles and multibeam echosounder data: geologic and tectonic implications. International Journal of Earth Sciences, 106 (1), 239–253.

Dai, C., Howat, I.M., Larour, E. and Husby, E., 2019. Coastline extraction from repeat high resolution satellite imagery. Remote Sensing of Environment, 229, 260–270.

Da Silva, G.V., Murray, T. and Strauss, D., 2018. Longshore wave variability along non-straight coastlines. Estuarine Coastal and Shelf Science, 212, 318–328.

Dean, R.G. and Dalrymple, R.A., 2002. Coastal Processes with Engineering Applications. Cambridge UniversityPress, Cambridge.

Degens, E.T. and Kurtman, F., 1978. The Geology of Lake Van. The Mineral Research and Exploration Institute of Turkey (MTA) Publication 169, 158 p.

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

Desruelles, S., Fouache, E., Çiner, A., Dalongeville, R., Pavlopoulos, K., Koşun, E., Coquinot, Y. and Potdevin, J.L., 2009. Beachrocks and sea level changes since Mid-Holocene: Comparison between the insular group of Mykonos-Delos-Rhenia (Cyclades, Greece) and the southern coast of Turkey. Global Planetary Change, 66, 19–33.

Dewey, J.F., Hempton, M.R., Kidd, W.S.F., Şaroğlu, F. and Şengör, A.M.C., 1986. Shortening of continental lithosphere: the neotectonics of Eastern Anatolia- a young collision zone. Geological Society of London, Spe. Pub., 19, 3–36.

Dicle, S. and Üner, S., 2017. New active faults on Eurasian-Arabian collision zone: Tectonic activity of Özyurt and Gülsünler faults (Eastern Anatolian Plateau, Van-Turkey). Geologica Acta, 15 (2), 107–120.

Dornbusch, U., Robinson, D.A., Moses, C.A., Moses, C.A. and Williams, R.B.G., 2008. Temporal and spatial variations of chalk cliff retreat in East Sussex, 1873 to 2001. Marine Geology, 249, 271–282.

Durduran, S.S., 2010. Coastline change assessment on water reservoirs located in the Konya Basin Area, Turkey, using multi-temporal Landsat imagery. Environmental Monitoring & Assessment, 164, 453–461.

Düzen, H. and Aydın, H., 2012. Sunshine-based estimation of global solar radiation on horizontal surface at Lake Van region (Turkey). Energy Conversion and Management, 58, 35–46.

Ersoy, O., Chinga, G., Aydar, E., Gourgaud, A., Çubukcu, H.E. and Ulusoy, İ., 2006. Texture discrimination of volcanic ashes from different fragmentation mechanisms: a case study, Mount Nemrut stratovolcano, eastern Turkey. Computers & Geosciences, 32, 936–946.

Flor, G., Flor-Blanco, G. and Rey, J., 2015. Dynamics and morpho-sedimentary interactions in the lower mesotidal estuary of Villaviciosa (NW Spain): A management proposal. Geologica Acta, 13(2), 107–121.

Ghost, M.K., Kumar, L. and Roy, C., 2015. Monitoring the coastline change of Hatiya Island in Bangladesh using remote sensing techniques. ISPRS Journal of Photogrammetry and Remote Sensing, 101, 137–144.

Gottgens, J.F. and Evans, J.E., 2007. Dam Removals and River Channel Changes in Northern Ohio: Implications for Lake Erie Sediment Budgets and Water Quality. Journal of Great Lakes Research, 33, 87–89.

Gülyüz, E., Durak, H., Özkaptan, M. and Krijgsman, W., 2020. Paleomagnetic constraints on the early Miocene closure of the southern Neo-Tethys (Van region; East Anatolia): Inferences for the timing of Eurasia-Arabia collision. Global Planetary Change, 185, 103089, 1–13.

Haghani, S., Leroy, S.A.G., Wesselingh, F.P. and Rose, N.L., 2016. Rapid evolution of coastal lagoons in response to human interference under rapid sea level change: a south Caspian Sea case study. Quaternary International, 408, 93–112.

Huguet, C., Fietz, S., Stockhecke, M., Sturm, M., Anselmetti, F.S. and Rosell-Mele, A., 2011. Biomarker seasonality study in Lake Van, Turkey. Organic Geochemistry, 42, 1289–1298.

Isemer, H.J. and Hasse, L., 1991. The scientific Beauford equivalent scale: Effcts on wind statistics and climatological air-sea flux estimates in the North Atlantic Ocean. Journal of Climatology, 4, 819–836.

Jabaloy-Sánchez, A., Lobo, F.J., Azor, A., Bárcenas, P., Fernández-Salas, L.M., Díaz del Río, V. and Pérez-Peña, J.V., 2010. Human-driven coastline changes in the Adra River deltaic system, southeast Spain. Geomorphology, 119, 9–22.

Kaden, H., Peeters, F., Lorke, A., Kipfer, R., Tomonaga, Y. and 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., Şen, Z. and Batur, E., 1997. The greatest soda-water lake in the world and how it is infuenced by climatic change. Annual of Geophysics, 15, 1489–1497.

Kamphuis, J.W., 1987. Recession rate of glacial till bluffs. J. of Waterway, Port, Coast. Ocean Engineering, 113, 60–73.

Karakuş, H., Aydın, H. and Erdem, O., 2017. A Hydrologic Restoration Attempt of theDried Akgöl Wetland (Central Anatolia, Turkey) Wetlands, 37, 837–850.

Karaoğlu, Ö., Özdemir, Y., Tolluoğlu, A.Ü., Karabıyıkoğlu, M., Köse, O. and Froger, J.F., 2005. Stratigraphy of the volcanic products around Nemrut Caldera: Implications for reconstruction of the caldera formation. Turkish Journal of Earth Sciences, 14, 123–143.

Kempe, S., Khoo, F. and Gürleyik, Y., 1978. Hydrography of Lake Van and its drainage area. ss. 30–44. Degens, E.T., Kurtman, F., (Eds): The Geology of Lake Van. The Min. Res. Expl. Inst. of Turkey (MTA) Publication 169, 158 s.

Koçyiğit, A., 2013. New field and seismic data about the intraplate strike-slip deformation in Van region, East Anatolian Plateau, E. Turkey. Journal Asian Earth Sciences, 62, 586–605.

KOERI 2021. Kandilli Observatory and Earthquake Research Institute. http://www.koeri.boun.edu.tr (accessed 23.03.2021).

Kraus, N.C. and McDougal, W.G., 1996. The effects of seawalls on the beach: Part 1. An updated literature review. Journal of Coastal Research, 12 (3), 691–701.

Kuenzer, C., van Beijma, S., Gessner, U. and Dech, S., 2014. Land surface dynamics and environmental challenges of the Niger Delta, Africa: remote sensing-based analyses spanning three decades (1986–2013). Applied Geography, 53, 354–368.

Kuzucuoğlu, C., Christol, A., Mouralis, D., Doğu, A.F., Akköprü, E., et al. 2010. Formation of the Upper Pleistocene terraces of Lake Van. Journal of Quaternary Science, 25, 1124–1137.

Kwiecien, O., Stockhecke, M., Pickarski, N., Heumann, G., Litt, T., Sturm, M., Anselmetti, F., Kipfer, R. and Haug, G.H., 2014. Dynamics of the last four glacial terminations recorded in Lake Van, Turkey. Quaternary Science Review, 104, 42–52.

Landmann, G., Reimer, A., Lemcke, G. and Kempe, S., 1996. Dating late glacial abrupt climate changes in the 14,570 year long continuous varve record of Lake Van, Turkey. Palaeogeograph Palaeoclimatology Palaeoecology, 122, 107–118.

Lin, Y.T. and Wu, C.H., 2014. A field study of nearshore environmental changes in response to newly-built coastal structures in Lake Michigan. Journal of Great Lakes Research, 40, 102–114.

Maxcon, J.H., 1936. Nemrut Krater Gölü. MTA Dergisi, 5, 45–49.

Met Office, 2007. The Beaufort scale. National Meteorological Library and Archive, Sheet No 6.

Miles, J.R., Russel, P.E. and Huntley, D.A., 2001. Field measurements of sediment dynamics in front of a seawall. Journal of Coastal Research, 17 (1), 195–206.

Mochizuki, A., Murata, T., Hosoda, K., Dulmaa, A., Ayushsuren, C., Ganchimeg, D., Drucker, V.V., Fialkov, V.A., Depci, T., Üner, T., Oğhan, F. and Sugiyama, M., 2018. Distribution of trace elements and the influence of major-ion water chemistry in saline lakes. Limnology and Oceanography, 63, 1253–1263.

Neumeier, U., 1998. Le rôle de l'activité microbienne lors de la cimentation précoce des beachrocks (dépôtsmarins littoraux). Thèse de Doctorat, Université de Genève,152 p.

Niemi, G.N., Kelly, J.R. and Danz, N.P., 2007. Environmental Indicators for the Coastal Region of the North American Great Lakes: Introduction and Prospectus. Journal of Great Lakes Research, 33, 1–12.

Oberhänslı, R., Candan, O., Bousquet, R., Rimmele, G., Okay, A. and Goff, J., 2010. Alpine high pressure evolution of the eastern Bitlis complex, SE Turkey. In: M., Sosson, N., Kaymakçı, R. A., Stephenson, F., Bergerat, V., Starostenko, (eds). Sedimentary Basin Tectonics from the Black Sea and Caucasus to the Arabian Platform. Geological Society of London, Spe. Pub., 340, 461–483.

Okay, A., Zattin, M. and Cavazza, W., 2010. Apatite fission-track data for the Miocene Arabia-Eurasia collision. Geology, 38 (1), 35–38.

Okuldaş, C. and Üner, S., 2013. Geomorphological properties and tectonic activity of Alaköy fault (Lake Van basin–eastern Anatolia). Bulletin of Earth Sciences, 34 (3), 161–176.

Oyan, V., Keskin, M., Lebedev, V.A., Chugaev, A.V. and Sharkov, E.V., 2016. Magmatic evolution of the early Pliocene Etrüsk stratovolcano, eastern Anatolian collision zone, Turkey. Lithos, 256–257, 88–108.

Özdemir, Y., Blundy, J.D. and Güleç, N., 2011. The importance of fractional crystallization and magma mixing in controlling chemical differentiation at Süphan Stratovolcano, eastern Anato lia, Turkey. Contributions to Mineralogy and Petrology, 162, 573–597.

Özkaymak, Ç., Sözbilir, H., Bozkurt, E., Dirik, K., Topal, T., Alan, H. and Çağlan, D., 2011. Seismic geomorphology of the October 23, 2011 Tabanlı-Van earthquake and its relation to active tectonics of East Anatolia]. Journal of Geological Engineering, 35, 175–199.

Özvan, A. and Direk, N., 2021. The relationships among different abrasion tests on deteriorated and undeteriorated rocks. Bulletin of Engineering Geology and the Environment, 80, 1745–1756.

Rameli, N.L.F. and Jaafar, M., 2015. Changes of coastline a study Case of Carey island-morib coast, selangor, Malaysia. Malaysia-Japan Model Technology Partnership, 10, 301–309.

Reilinger, R., McClusky, S., Vernant, P., Lawrence, S., Ergintav, S., et al. 2006. GPS constraints on continental deformation in the Africa–Arabia–Eurasia continental collision zone and implications for the dynamics of plate interactions. Journal of Geophysical Reseach, 111 (B05411), 1–26.

Reimer, A., Landmann, G. and Kempe, S., 2009. Lake Van, Eastern Anatolia, hydrochemistry and history. Aquatic Geochemistry 15, 195–222.

Sağlam Selçuk, A., Erturaç, M.K., Üner, S., Özsayın, E. and Pons-Branchu, E., 2017. Evolution of Çamlık fissure–ridge travertines in the Başkale basin (Van, Eastern Anatolia). Geodinamica Acta, 29 (1), 1–19.

Sağlam Selçuk, A., and Kul, A.Ö., 2021. Long-term slip rate estimation for Erciş Fault in East Anatolian Compressive Tectonic Block from geologic and geomorphologic field evidence. Geological Journal, 56, 5290–5310.

Smeltzer, E., Shambaugh, A. and Stangel, P., 2012. Environmental change in Lake Champlain revealed by long-term monitoring. Journal of Great Lakes Research, 38, 6–18.

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

Stockhecke, M., Kwiecien, O., Vigliotti, L., Anselmetti, F.S., Beer, J., et al. 2014. Chronostratigraphy of the 600.000 year old continental record of Lake Van (Turkey). Quaternary Science Review, 104, 8–17.

Street-Perrott, F.A., 1980. The relative importance of climate and hydrogeological factors in influencing lake level fluctuations. Palaeoecology of Africa, 12, 137–158.

Sato, Y., Matsuoka, H., Okamura, M. and Kashima, K., 2016. Late Holocene environmental changes of coastal lagoon inferred from a fossil diatom analysis of sediment core from Lake Hamana, central Japan. Quaternary International, 397, 317–329.

Şaroğlu, F. and Güner, Y., 1979. The active Tutak fault, its characteristics and relations to the Çaldıran Fault. Yeryuvarı ve İnsan, 4, 11–14.

Şenel, M., 2008. 1/100.000 Scaled Geological Maps of Turkey (Van–K50 Quadrangle). Publications of General Directorate of Mineral Research and Exploration, Ankara, Turkey.

Şengör, A.M.C. and Yazıcı, M., 2020. The aetiology of the neotectonic evolution of Turkey. Mediterranean Geoscience Reviews, 2, 327–339.

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

Thompson, T.A., Lepper, K., Endres, A.L., Johnston, J.W., Baedke, S.J., et al. 2011. Mid Holocene lake level and shoreline behavior during the Nipissing phase of the upper Great Lakes at Alpena, Michigan, USA. Journal of Great Lakes Research, 37, 567–576.

Toker, M., Şengör, A.M.C., Demirel Schluter, F., Demirbağ, E., Çukur, D., İmren, C., Niessen, F. and PaleoVan-Working Group 2017. The structural elements and tectonics of the Lake Van basin (Eastern Anatolia) from multi-channel seismic reflection profiles. Journal of African Earth Sciences, 129, 165–178.

Tomonaga, Y., Blattler, R., Brennwald, M.S. and Kipfer, R., 2012. Interpreting noble-gas concentrations as proxies for salinity and temperature in the world's largest soda lake (Lake Van, Turkey). Journal Asian Earth Sciences, 59, 99–107.

Trenhaile, A.S., Porter, N.I. and Prestanski, K., 2015. Shore platform and cliff notch transitions along the La Paz Peninsula,southern Baja, Mexico. Geologica Acta, 13(2), 167–180.

Üner, S., 2018. Late Quaternary lacustrine storm deposits: sedimentological properties and regional significance (Lake Van Basin-Eastern Turkey). Arabian Journal of Geosciences, 11, 582, 1–12.

Üner, S., 2019. The effect of tectonism on deltaic wetland migration: A case study from Bendimahi River Delta System (Lake Van-Eastern Turkey). Journal of Great Lakes Research, 45 (5), 864–871.

Üner, S., Özsayın, E. and Sağlam Selçuk, A., 2019. Seismites as an indicator for determination of earthquake recurrence interval: A case study from Erciş Fault (Eastern Anatolia-Turkey). Tectonophysics, 766, 167–178.

Üner, T., 2020. Listwaenitization and enrichment of precious metals in the hydrothermal mineralization zones of serpentinites in Sugeçer-Van (Eastern Anatolia, Turkey). Geochemistry: Exploration, Environment, Analysis, 20, 68–79.

Vafeidis, A.T., Nicholls, R.J., McFadden, L., Tol, R.S., Hinkel, J., et al. 2008. A new global coastal database for impact and vulnerability analysis to sea-level rise.

Journal of Coastal Research, 24(4), 917–924.

Vousdoukas, M.I., Velegrakis, A.F. and Plomaritis, T.A., 2007. Beachrock occurrence, characteristics, formation mechanisms and impacts. Earth Science Review, 85, 23–46.

Yao, C.H. and Wu, Z.Y., 2012. Shoreline migration and scour-and-silting alternation in the Lingdingyang estuary over past 30 year. Journal of Marine Sciences, 03, 44–55.

Yeşilova, Ç., Üner, S., Güngör Yeşilova, P., Açlan, M. and Alırız, M.G., 2015. Facies Properties and Depositional Environments of Quaternary Aged Edremit Travertine (Lake Van Basin-Eastern Anatolia). Turkish Sedimentology Working Group, travertain & Tufa Workshop, 5-8 Nov 2015, Denizli, 54–55.

Yeşilova, Ç. and Yakupoğlu, T., 2007. Microfacies Properties of Adilcevaz Limestone (North of Lake Van). Geological Bulletin of Turkey, 50 (1), 27–38.

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

Zhang, S., Liu, Y., Yang, Y., Suna, C. and Liet, F., 2016. Erosion and deposition within Poyang Lake: evidence from a decade of satellite data. Journal of Great Lakes Research, 42 (2), 364–374.

Zhang, X.K., Zhang, X. and Yang, B.H., 2013. Coastline extraction using remote sensing based on coastal type and tidal correction. Remote Sensing for Land & Resources, 25 (4), 91–97.