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FACIES CHARACTERISTICS AND CONTROL MECHANISMS OF QUATERNARY DEPOSITS IN THE LAKE TUZ BASIN

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ABSTRACT

Keywords:

*Central Anatolia,
Quaternary, lake level
changes, sedimentology,
climate, tectonism.*

Although there are several studies discussing the pre-Neogene development of the Lake Tuz basin, which is the largest terrestrial basin in Turkey, investigations delineating the characteristics of the Neogene and particularly Quaternary period of this basin are quite limited. Whereas studies regarding such periods of the basin are quite informative for both active tectonics and climate change issues that are of significant public concern. In this study, results of field observations on temporal and spatial characteristics of Quaternary deposits in the Lake Tuz Basin and processes controlling these features are presented. For this, as a result of sequence studies conducted in 17 different areas, Quaternary units were described and examined under 12 lithofacies and 5 facies associations. Facies properties imply that tectonism is spatially determinant factor whilst climate is the dominant controlling mechanism in the Quaternary evolution.

1. Introduction

The Lake Tuz Basin in Central Anatolia is the largest terrestrial basin in Turkey (Figure 1). The basin with an area of about 15000 km² has been thought to be a deposition site since the upper Cretaceous (Görür and Derman, 1978; Turgut, 1978). Due to the plain morphology, which indicates that basin has a thick basin fill and has not been significantly affected by young tectonic activity, for many years the basin has been the subject of studies on economic resources such as oil and natural gas (Arıkan, 1975; Uğurtaş, 1975; Uygun, 1981; Aydemir and Ateş, 2008; Huvaz, 2009). In addition to these studies on Paleogene units, there are also other surveys regarding evaporitic characteristics of younger units and determination of mineral resources of economic value (Irion and Müller, 1968; Erol, 1969; Uygun and Şen, 1978; Çamur and Mutlu, 1996; Derman, 2003; Tekin et al., 2007). In all these

studies, the younger-stage evolution of the basin, which has been hitherto neglected, is of great importance as regards to both active tectonism and climate investigations. Within this scope, except for the half-century old pioneering and valuable efforts of Oğuz Erol (1969), limited number of studies and publications are available (Ulu et al., 1994a, b; Kashima, 2002; Kürçer and Gökten, 2012; Özsayın et al., 2013). On the other hand, there are exceptionally detailed studies on the Konya basin (just south of the Lake Tuz Basin) and the ancient Lake Konya (Roberts et al., 1979, 1999; Roberts, 1983; Karabıyıköğlü et al., 1999; Kuzucuoğlü et al., 1999; Leng et al., 1999; Reed et al., 1999). Since the study of Erol (1969), which was carried out beyond the means of today's conditions, the number of exposures in the region has been increased and the advancements in research techniques necessitated the elaboration of recent stage characteristics of the Lake Tuz Basin.

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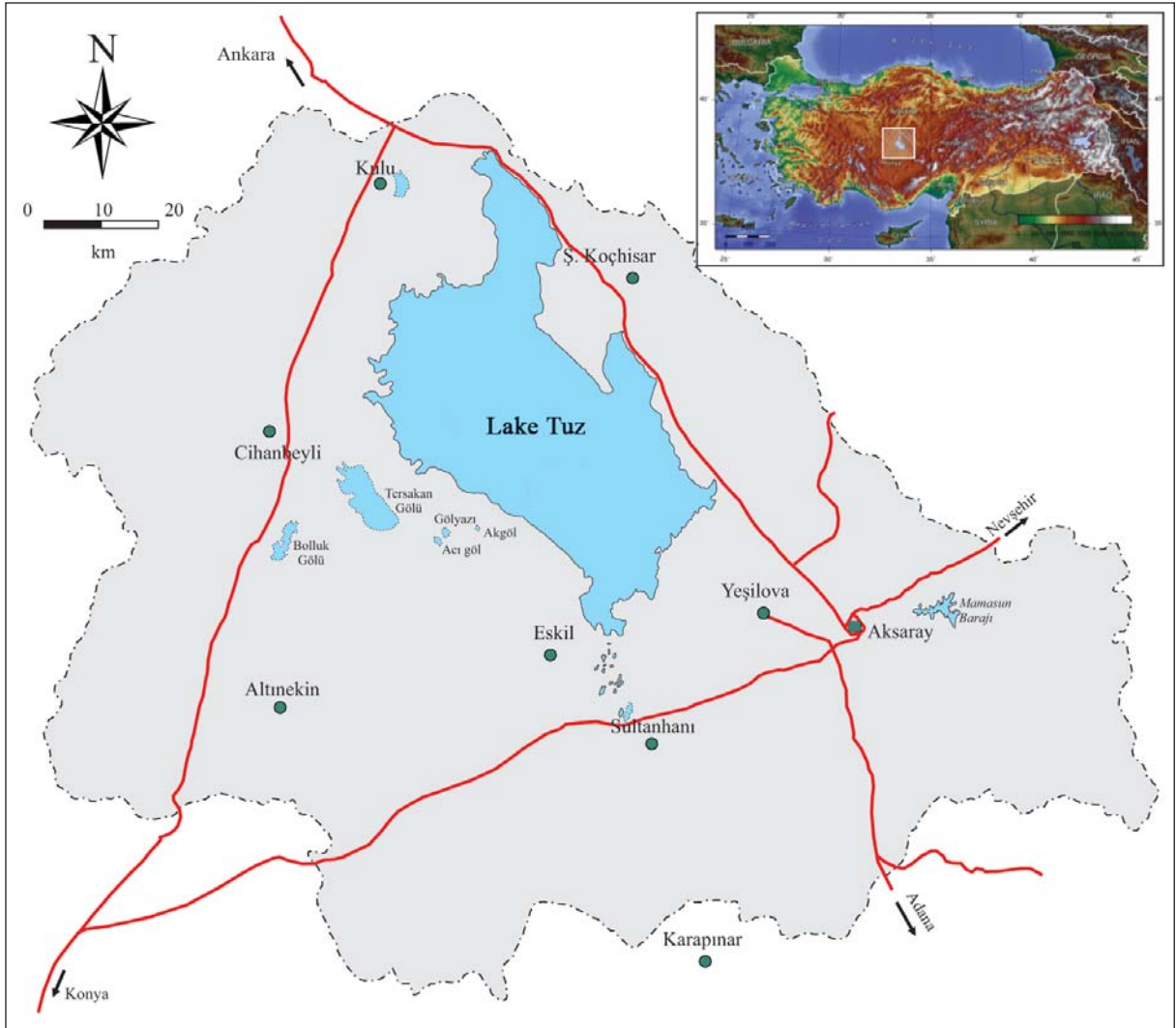


Figure 1- Location map of the Lake Tuz drainage basin.

Lacustrine deposition systems are the best places to study their origin and evolution in conjunction with tectonism and climate factors which directly affect these parameters (Karabıyıköğlü, 2003). These areas, which can be thought as natural archive systems with direct records of paleo/recent climate changes and tectonic controls, still have maintained their importance in the earth science since the pioneering works of Gilbert (1885, 1890). The interrelations between alluvial and lacustrine environments, particularly of Quaternary closed lake basins, record Pleistocene and Holocene tectonic- and climate-induced environmental changes and long-term sedimentologic and geomorphologic lake level oscillations as well (Karabıyıköğlü, 2003). The facies of Quaternary deposits in Lake Tuz Basin and processes that control these facies are the materials of present study.

2. Pre-Quaternary Basement Units

The Lake Tuz Basin in western part of the central Anatolia is a tectonic deposition site filled with late Cretaceous-Quaternary sediments with a measurable thickness of 5000 m (Figure 2). The basement under this thick fill is represented mostly by the Central Anatolian Crystalline Complex and the Kütahya-Bolkardağı Metamorphics (Erler et al., 1991; Göncüoğlü et al., 1991, 1992, 1993, 1996; Akıman et al., 1993; Türeli et al., 1993; Yalınız et al., 1996, 2000; Yalınız and Göncüoğlü, 1998; Dirik and Erol, 2003; Kadioğlü et al., 2003; Göncüoğlü, 2011).

The basin fill starts with a terrestrial unit consisting of red colored clastics which unconformably set above the basement unit at east and west parts of the study area (Figure 3). It is

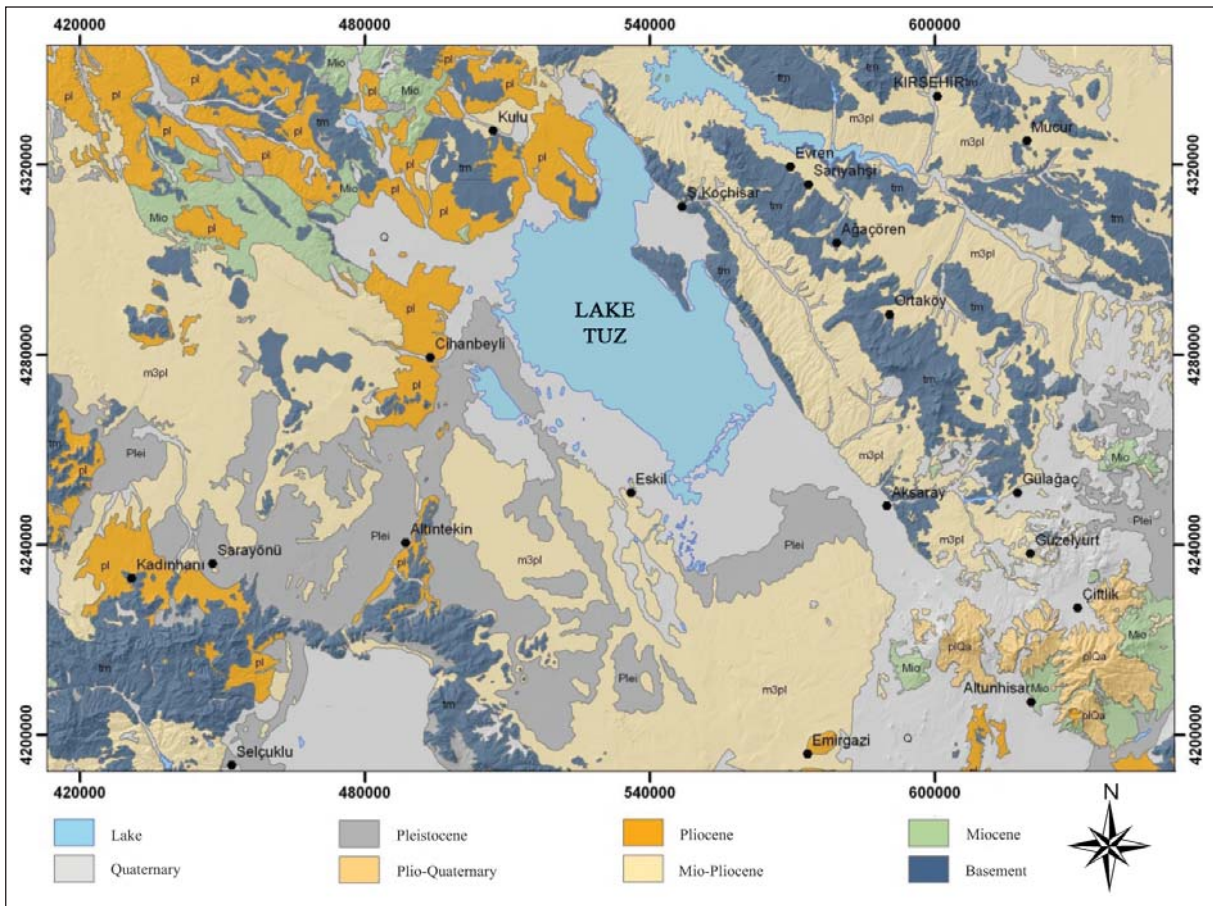


Figure 2- 1:500.000 scaled geology map of Lake Tuz Basin and its surrounding (compiled from MTA, 2002).

believed that this unit composing of alluvial fan deposits was developed under the control of border faults in the basin which opened in the late Cretaceous (Çemen et al., 1999). Above this red clastic unit is a thick sequence which was deposited in shallow-deep-shallow marine environments (Figure 3; Sirel, 1975; Ünalın et al., 1976; Görür and Derman, 1978; Görür, 1981; Dellaloğlu and Aksu, 1984; Görür et al., 1984; Atabey et al., 1987; Oktay and Dellaloğlu, 1987; Özer, 1988; Sonel et al., 1995; Göncüoğlu et al., 1996; Dellaloğlu, 1997; Çemen et al., 1999; Varol et al., 2000; Derman, 2003; Derman et al., 2003; Dirik and Erol, 2003; Ayyıldız, 2006; Uçar, 2008; Huvaz, 2009; Nairn, 2010). Mio-Pliocene deposits represented by terrestrial clastics and carbonates which unconformably overlie the underlying units are the second most widespread unit in the study area after the Quaternary deposits (Figure 2). Because Quaternary deposits are interfingering with the Mio-Pliocene unit, it is important to describe characteristic features of both units.

The Mio-Pliocene deposits start at the bottom with coarse clastics and light brown, loosely-

compacted conglomerate-sandstone alternation. They continue to the middle parts with yellowish mudstone-sandstone alternation and end up with greenish, yellowish gray marl and limestone (Figure 4; Ulu et al., 1994a, b; Uçar, 2008). Cross-bedding and lensoidal geometry are very common in clastic levels. The unit also contains tuff and gypsum levels. It discordantly overlies underlying lithologies and according to ostracoda species collected from limestone levels the age of unit is suggested to be Pliocene by Tunoğlu et al. (1995) and Beker (2002) and based on spore and pollen data a Mio-Pliocene age is given by Dellaloğlu (1997).

3. Quaternary Units

Quaternary studies have become a separate discipline since active tectonic studies have gained more importance as the mankind could predict his future with the ascertaining of paleo-climate data (Kazancı and Gürbüz, 2012). Young units, so called alluvium in previous works, were not subjected to detailed investigation and therefore they have come

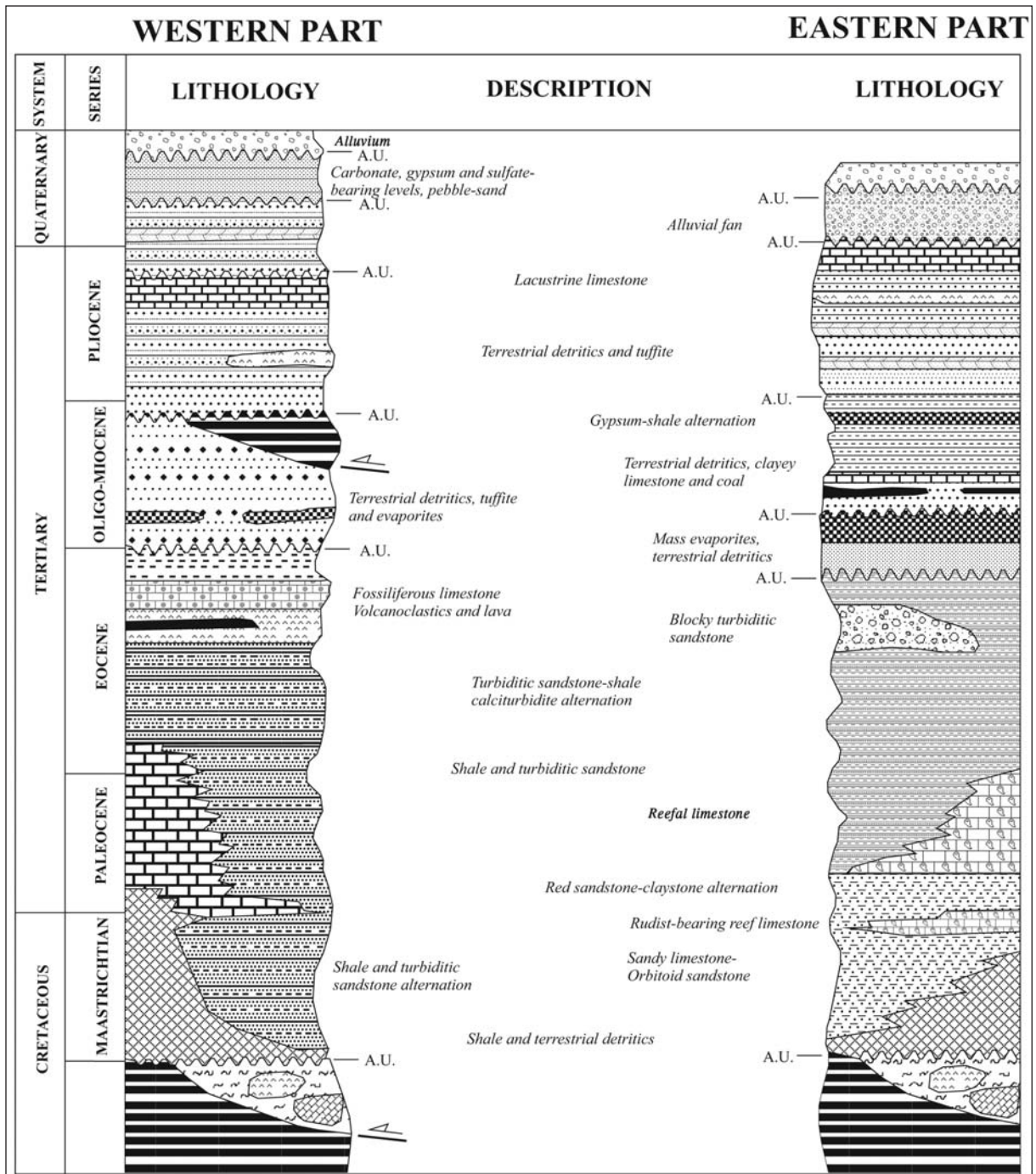


Figure 3- The generalized stratigraphic sections of eastern and western parts of the Lake Tuz Basin (compiled from Dirik and Erol, 2003)

into prominence. Recently this approach has been getting more popular giving rise to investigation in the formation scale of units, which are mapped previously as “young deposits”, “recent units” and “alluvium”. Likewise, in previous studies on the Lake Tuz Basin, Quaternary deposits that are mapped as alluvium were first mentioned by Erol (1969) and

named by Ulu et al. (1994a, b) as the Tuzgözü formation of Pleistocene-Quaternary age (Figure 4). Although their bottom-top relations may be different, in recent studies this nomenclature has been frequently adopted (Dirik and Erol, 2003; Özsayın, 2007; Özsayın and Dirik, 2007). In the present study sedimentary facies properties described belong to

Upper System	System	Series	Thickness (m)	Lithology	Explanation
CENOZOIC	QUATERNARY	PLEISTOCENE-HOLOCENE	110		Carbonaceous clay or carbonate mud interlayered at the top with organic material and recent evaporites in ephemeral lakes, covered with dark colored soil
					White, beige, yellow claystone-limestone
					Well rounded sand or silt with limestone and well sorted sand and silt with carbonate matrix
					Well sorted, well rounded, partly cemented and partly grain-supported pebble, sand and silt consisting of coastal deposits with locally tabular geometry and cross-bedded layers
					Discontinuity
	TERTIARY	MIO-PLIOCENE	450		Limestone
					Clay and marl with partly gypsum levels
					Thin-medium bedded, partly cross bedded, sandstone, siltstone and thin bedded sandy limestone alternation
					Grayish colored, poorly sorted, partly graded, medium-thick bedded, polygenic conglomerate with sandstone interlayers

Figure 4- The generalized stratigraphic section for young deposits of the Lake Tuz Basin (from Ulu et al., 1994).

mentioned adopted unit. This unit is quite important to propound characteristics of old shore lines of Lake Tuz which covered a larger area in the Pleistocene.

In previous works units that are mapped as Plio-Quaternary together with late Pliocene levels have been studied as the Quaternary units considering that the time range of Quaternary era was expanded from 1.8 Ma to 2.6 Ma with an update of International Stratigraphic Guide in 2009 (Mascarelli, 2009; Kazancı, 2009).

Today's Lake Tuz Basin comprising the study area is the Quaternary equivalent of a large and long-

lived deposition system. The Miocene units are ended with firm carbonate unit which facilitates separation of these units from younger ones. Drilling works and measured stratigraphic sections in the same region indicate that Pliocene and Quaternary deposits resemble each other in many aspects and stratigraphic borders cannot be often distinguished (Gürbüz, 2012). It was noticed during the surface investigations that red colored Pliocene sediments which are overlain by the Quaternary deposits are loosely compacted and in some sites easily distinguished with their firm character.

As indicated above, lowermost parts of the unit can be only determined with samples from relatively deep boreholes and seismic sections. DSI well logs indicate that lithology of unexposed parts is almost similar to that of exposed rocks. As revealed from drilling data, Quaternary deposits in the basin attain a maximum thickness of 190 m and dominant lithofacies at depths are represented by lacustrine clays (Gürbüz, 2012). It is concluded that facies observed in the upper and lower parts of Quaternary deposits are quite similar.

4. Sedimentology

In order to determine spatial and temporal environmental properties and sedimentary evolution of Quaternary units in the Lake Tuz Basin, areas operated by the private sector as aggregate quarry and the trenches opened by the General Directorate of Highways for extraction of material to be used for road construction and maintenance were utilized and detailed surveys were conducted in 17 different areas and sections with thickness exceeding 10 m were evaluated. Along these sections, 12 lithofacies and 5 facies unit were described (Table 1; Figure 5). Sequences for which facies analysis is completed are from the uppermost part of Tuzgözü formation. They are mostly old lake shore terraces and their equivalent lacustrine deposits differentiated by Erol (1969) are at between 912-980 m. In facies descriptions, definitions of Miall (1978, 1996) and facies described for the Konya Basin (Karabıyıkoglu, 2003) were considered, which has similar geologic history and geographic features with the study area.

4.1. Lithofacies characteristics of Quaternary deposits

F1- Massive, matrix supported pebble facies: It is red or light/dark brown colored, mostly matrix supported and has slight amount of sand and fine pebble

Table 1- Facies and facies associations of Quaternary deposits based on surface data. Some lithofacies and their explanations are from Miall (1996) and Karabiyikoğlu (2003).

Facies	Explanations	Facies Association	
Massive, matrix-supported pebble facies	Debris flow deposits, red, dark brown colored, matrix supported. Angular, sub-angular grains. Maximum grain size is 60 cm	Alluvial fan	Basin margin deposits
Massive, red mud facies	Flood plain deposits; red silt and sand lenses, interlayered with matrix supported pebble facies		
Lateral bedded pebble and sand facies	Debris flow deposits, light brown colored poorly sorted moderate to well rounded	Fluvial	Deposits within the basin
Cross bedded, brown pebble and sand facies	River bar deposits; reddish brown colored, moderate to well sorted, well rounded, matrix supported		
Lateral and parallel bedded fine sand, silt and clay facies	Flood plain deposits; red to brown colored		
Ripple-planar sand facies	Wave-current ripples, symmetrical, well sorted lensoidal	Fan delta	
Cross bedded, gray pebble and sand facies	Lateral transition deposits; asymmetrical, moderate to well sorted	Beach	
Laminated sand and silt facies	Parallel laminated, well rounded, well sorted, grain components are dark heavy minerals and light colored quartz		
Clayey carbonate facies	White, grizzly colored	Lake flat	
Massive, beige mud facies	Lake floor sediments, beige, grizzly colored		
Evaporites	Gypsums interlayered with clayey carbonate and marls		
Travertines	Cones or patches with diameter up to a few hundred m		

bounding (Figure 6). Pebbles in the facies are scattered within mud cement. Angular-subangular pebbles are varied depending on the lithology of source rock. Grains are of mostly coarse size and blocks of 60 cm are also found. Massive character and chaotic structure of the unit indicate deposition of debris flow as a result of mass movements.

F2- Massive red mud facies: This facies is composed of red, light/dark brown colored massive mud deposits and silt-clay levels and lenses with lesser amount of pebble (Figure 6). As reflected by textural and color tone differences, bedding is peculiar. Clastic material packing within the facies is indicative of wind-blown process whilst mud deposits indicate that suspended materials are deposited in stagnant water conditions and therefore the unit can be described as flood plain sediment which is observed to alternate with the matrix supported pebble facies.

F3- Lateral bedded pebble and sand facies: This facies is represented by light brown colored, poorly sorted and moderate to well rounded, lateral or low-angle parallel layered mud and grain-supported pebble and sand deposits (Figure 6). Deposits that are found as lenses or mantling within or on the debris flow type sediments with grain size up to block range reveal that they occur not only as debris flows but also over-saturated flood flows as a result of intense rainfall and subsequent ceasing (Karabiyikoğlu, 2003).

F4- Cross bedded, brown pebble and sand facies: This facies is composed of reddish brown, moderate to well sorted, well rounded, grain-supported pebble and sand deposits (Figure 6). Internally graded cross beddings show that bed load is transported in lateral direction (Rust, 1978). The facies which is deposited on an erosional surface has a limited lateral extent. The unit consisting of river bar deposits changes laterally and vertically to flood plain deposits.

F5- Lateral and parallel bedded fine sand, silt and clay facies: The unit consists of lateral- and parallel-bedded, red and brown fine detrital materials and shows tens of meter lateral extent. It is generally observed below and/or above the lateral- and cross-bedded pebbles (Figure 6). Contacts between the layers are sharp and transitional. In this fine-material facies plant root relicts and desiccation cracks are noticeable. The unit as a whole is a flood plain deposit but fine sand and silt levels within it are crevasse deposits.

F6- Ripple-planar sand facies: This facies is composed of well sorted, tabular-shaped pebble, sand and silt deposits displaying lateral extent and lensoidal geometry with a limited distribution (Figure 6). The unit is in symmetrical form and represented by sigmoidal and wedge-shaped geometry and comprises wave flow and wave deposits of a few to 10-15 cm thickness.

F7- Cross bedded, gray pebble and sand facies: The unit with an asymmetric form and combined sets is

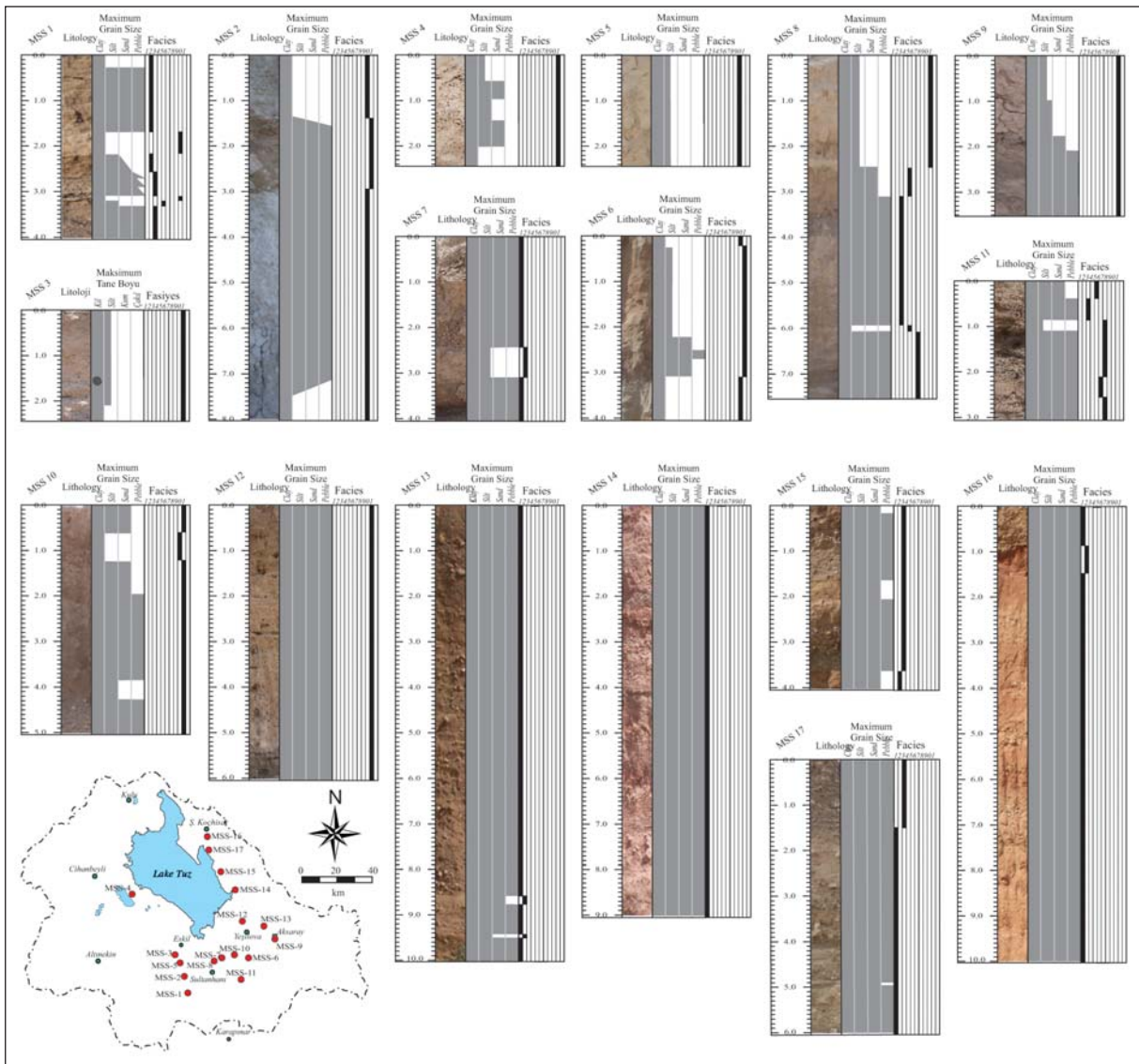


Figure 5- Measured sections and location map of Quaternary deposits on which detailed sequence observations are available.

composed of medium-poorly sorted, medium-well rounded, cross bedded, grain supported pebble and sand deposits (Figure 6). Grain components are varied with respect to spatial distribution of deposits and are mostly of limestone and volcanic rock origin. Erosional forms on the lower surfaces are in planar or trough geometry. Fine mud laminations noticed between the sets are indicative of stagnant water conditions. This facies is generally associated with ripple-planar sand facies. The unit is simply a lateral transition deposit.

F8- Laminated sand and silt facies: This facies is composed of parallel-laminated, well rounded and well sorted slightly pebble and dominantly sand and

silt deposits (Figure 6). It has a thickness of 3-8 cm and grains are composed of dark colored heavy minerals and light colored quartz. Deposits that correspond to lower sections of F6 and F7 facies show lateral continuity as long as overlying units are not significantly eroded.

F9- Clayey carbonate facies: The unit which consists of white, grizzly and pinkish colored clayey carbonate and marl deposits is interlayered with F10 and F11 facies or occurs as a thick massive level below and above these facies (Figure 6). Depending on deepening and shallowness of the environment color tone of unit changes occasionally and the pebble-size material of debris flow is also noticeable.

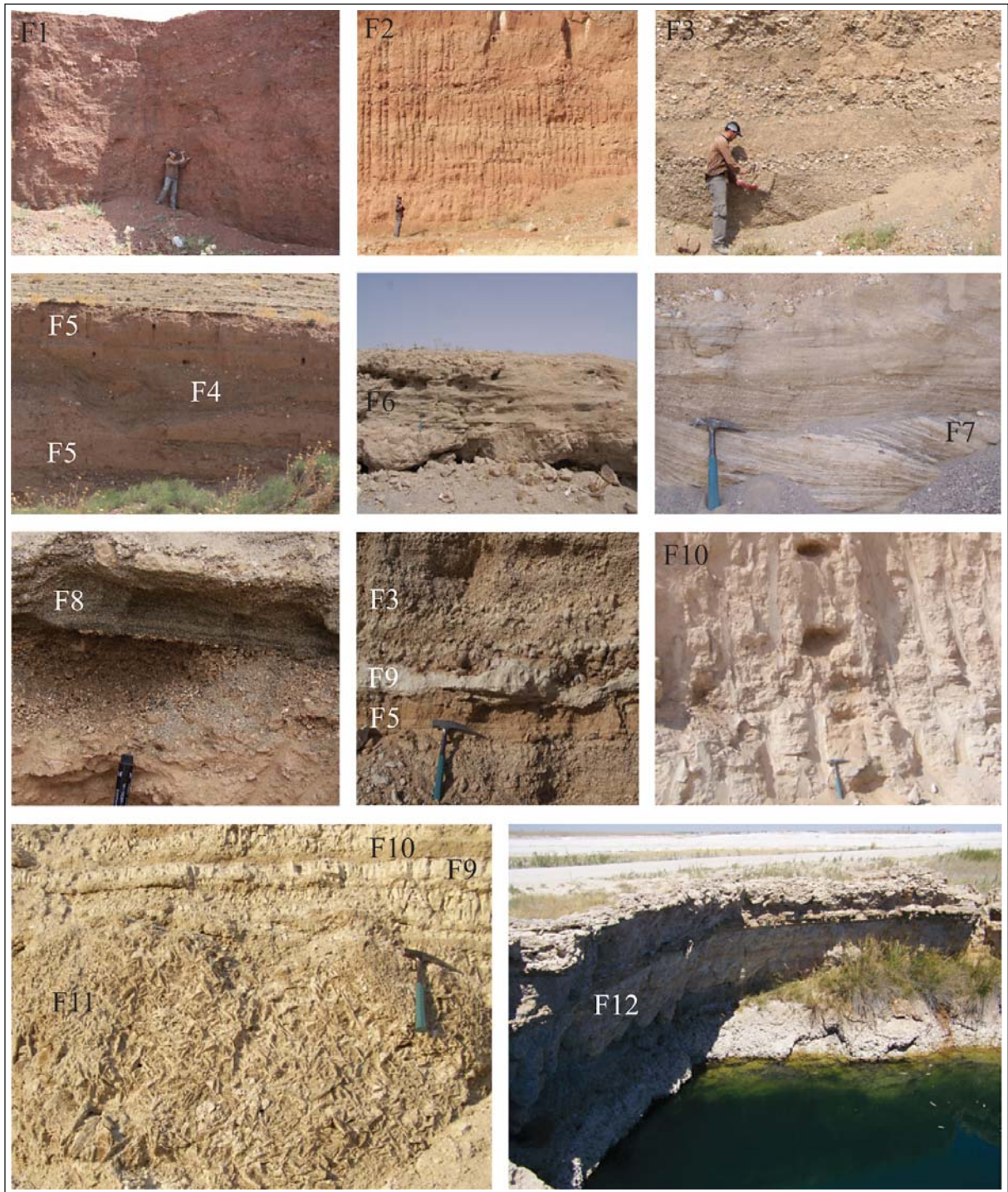


Figure 6- Typical exposures for lithofacies characteristics of Quaternary deposits in the study area. Compare with descriptions given in table 1.

F10- Massive, beige mud facies: The unit is generally in beige, light brown colors but shows dark gray/blackish levels depending on organic material input (Figure 6). Like F9 facies, it rarely contains pebbly flood sediments. In deposits dominated by organic matter herbaceous plant relicts are observed.

F11- Evaporite facies: The unit which is alternated with clayey carbonate and marls is represented by beige, yellow gypsums. It is found as 3-20 cm thickened layers and longitudinal and transverse massive masses within Quaternary units at western part of the basin (Figure 6).

F12- Travertine facies: This facies is determined on old lake flats rather than measured stratigraphic sections (Figure 6). Therefore, stratigraphically it is the youngest unit and can be considered as an independent occurrence with respect to other basin deposits. In areas particularly close to western border of the basin the facies has a conical morphology and is represented by a number of about 60 white travertine cones with diameter ranging from a few to a few hundred m (Figure 7a; Erol, 1967, 1968). At this area aforementioned lithofacies contains abundant plant relicts and relevant pore texture (Figure 7b) and therefore can be named tufa, as will be explained under facies association in the forthcoming section, we name the unit “travertine” since it is more common than the term “tufa” as also described by Erol (1967, 1968). Travertine deposits are also found around thermal water springs in the Aksaray region.

4.2. Depositional environments of Quaternary deposits

As mentioned in previous sections, Quaternary deposits were formed during the closure of the basin. Facies and their spatial distributions indicate that the present sequence with a larger water mass surrounding the recent Lake Tuz covers shore and backshore facies. In this section, facies associations corresponding to depositional environments of each studied facies are introduced. The facies associations are grouped based on their genetic relations (Miall, 1978; Rust, 1978).

FBI- Alluvial fan deposits: This association is composed chiefly of red, light/dark brown, massive, matrix supported pebble facies (F1) and massive red

mud facies (F2) (Table 1). In addition, lateral or low-angle layered pebble and sand facies (F3) is also slightly observed. This association that is mainly represented by debris flow and flood plain deposits is particularly traced along the eastern border of the basin. At this area, alluvial fan deposits occur in a narrow belt between the recent shore line of Lake Tuz and the Tuzgözü fault, in front of fault scarps at west part of basin, in areas excavated for material extraction and along the valleys opening to the Lake Tuz. Following the lake deposits, alluvial fan deposits represent the second widespread facies association in the basin. During the field studies, 10-m thickened sequences of these units were examined and it was noticed that alluvial fan facies has lateral and/or low-angle planar surfaces. Particularly most of late Quaternary fans preserve their ideal geometries. The early Quaternary fans overlain by these fans are laterally coalescence.

FB2- Fluvial deposits: The fluvial deposits are found at margins and within the basin and are composed of red and light/dark lateral layered pebble and sand facies (F3), cross bedded, brown pebble and sand facies (F4) and lateral and parallel bedded fine sand, silt and clay facies (F5) (Table 1). Regarding the features of facies association, the deposits are composed of debris flow mostly reflecting braided and meandering river systems, flood flow, river bar, flood plain and crevasse deposits. Deposits which are laterally and vertically transitional to alluvial fan association at margins are very common particularly at east and southeast parts of the basin. At southeast part of the basin, they are in lateral transitional to fan delta deposits (FB3) and in vertical transitional to lake flat deposits (FB5).



Figure 7- (a) Travertine cones around the Lake Bolluk; (b) Close view of structures with abundant plant relicts.

FB3- Fan delta deposits: This facies association is composed of gray, grizzle and beige ripple-planar sand (F6) and cross bedded, gray pebble and sand (F7) facies. This association is crucially important to reflect the deep character of paleo Lake Tuz (Table 1). Field observations indicated that they are exposed in wide areas just above and in front of the Obruk Plateau in southern part of the basin. The facies is occasionally laterally transitional to fluvial deposits and mostly in vertical transitional to lacustrine muds. This association shows a sequence character with grain size getting coarser to the top and then getting finer. These deposits are well observed along shorelines and correspond to 955 and 930 m of Erol (1969). They are generally composed of volcanic rock fragments and deposits transported by rivers are derived from volcanites at south and southeastern parts of the area. The sequence at the upper level is coarse grained whilst deposits in the lower part (~930 m) are made up of relatively finer grains. Sequences investigated within their own borders display 1.5-2 m thickness indicating relatively deep and high-energy water environment.

FB4- Beach deposits: These deposits that are composed of laminated sand and silt facies (F8) just below the delta sediments represented by the least areal and volumetric distributions (Table 1). However, they are critically important to reveal a larger beach environment which might have an old paleogeographic meaning since sandbank develops in only wave-dominant shores. This means that water depth is relatively higher. From this point of view, it can be said that water level in the old Lake Tuz might occasionally attain depths sufficient enough to generate large waves.

FB5- Mud flat deposits: This association with the widest distribution in the basin is composed of clayey carbonate (F9), massive, beige mud (F10), evaporite (F11) and travertine (F12) facies (Table 1). Lake deposits which have the least thickness but wider exposure area are found to be quite thickened in boreholes opened in the basin (Gürbüz, 2012). The unit was mostly deposited in shallow and calm lacustrine conditions, however considering bluish/greenish colored lower levels, it might also indicate a setting where deep lacustrine environment changes to fluctuating or relatively shallow conditions. Evaporites in western part of basin may be evident for this shoaling process. As stated by Ford and Pedley (1996), travertines at west of basin are mostly laterally and vertically in transition with lacustrine facies indicating that alkaline spring waters

flow into a lacustrine area and intense algae production in shallow conditions are accompanied by aquatic plants (Alçiçek et al., 2004). In systems where lake margins are directly leaned on basement rocks such carbonate formations might be indicative of concurrent tectonism and groundwater recharge to the lake. Erol (1967-68, 1969) described these occurrences along the shore as travertine cones (Atabey, 2003). These formations with detailed lithofacies descriptions can be termed as tufa because they have abundant plant relicts and pore structures. In lacustrine environments tufas develop at depths less than 1 m (Atabey, 2003). If the lake water is salty they can be generated by bacteria and blue-green algae accumulations around the freshwater manifestations (Pedley, 1990; Atabey, 2003). Pentecost (1993), Pentecost and Viles (1994) and Ford and Pedley (1996) combined all tufa descriptions under the travertine term and classified travertines with respect to temperature condition (Atabey, 2003). In the literature, America, Europe and all Spanish-speaking countries (21 countries), tufa description is considered within the context of travertine and not used as a different term (Atabey, 2003).

5. Discussion: Control Mechanisms

Sequence examinations in the field indicate that Lake Tuz, which is recently receded to the northeast of the basin, covered large areas in the Pleistocene towards the south and west (Figures 5, 8). Fan delta sequences and very thick, widespread lake basement deposits imply that depth of paleo Lake Tuz was much more than that of present-day. Taking into account the surface area and water depth of this high-energy lake, the Lake Tuz is classified as large lake (500-5000 km²) and very shallow lake (1-5 m) by Kazancı (2012), however in Pleistocene it was a very large lake (~7500 km²) with respect to area and shallow or moderate-depth lake (20-100 m) with respect to depth. Similar approaches for the Lake Tuz were first put forward by Salomon-Calvi and Kleinsorge (1939) and their study was improved nearly half-century ago by Oğuz Erol who first used the geomorphologic data. In addition, based on his studies in southeast part of the basin, Kashima (2002) suggested that in late Pleistocene (about 20 ka before present) the Lake Tuz floor was 15 m higher than today. In the Konya basin which is the equivalent of Lake Tuz basin, a lacustrine environment covering an area of about 4500 km² with depth of 25-30 m was reported in late Pleistocene (see Karabıyıköğlü and Kuzucuoğlü, 1998). Since these two large Pleistocene lakes are within the same recharge area and are interconnected regarding

groundwater dynamics, conjugate results from these lakes are not too much surprised.

The closed basin lakes are very sensitive to changes at the bottom of basin. In general, tectonism controls the surface area of basin and, in case of contemporaneous with the deposition, it defines the

characteristics of deposition systems. The climate is primarily responsible for the amount of water that enters to the basin via precipitation and drainage and removed from the basin through evaporation. Other factors such as the effect of climate on vegetation and the amount of sediment transported also play important role in this process (Ilgar, 2004).

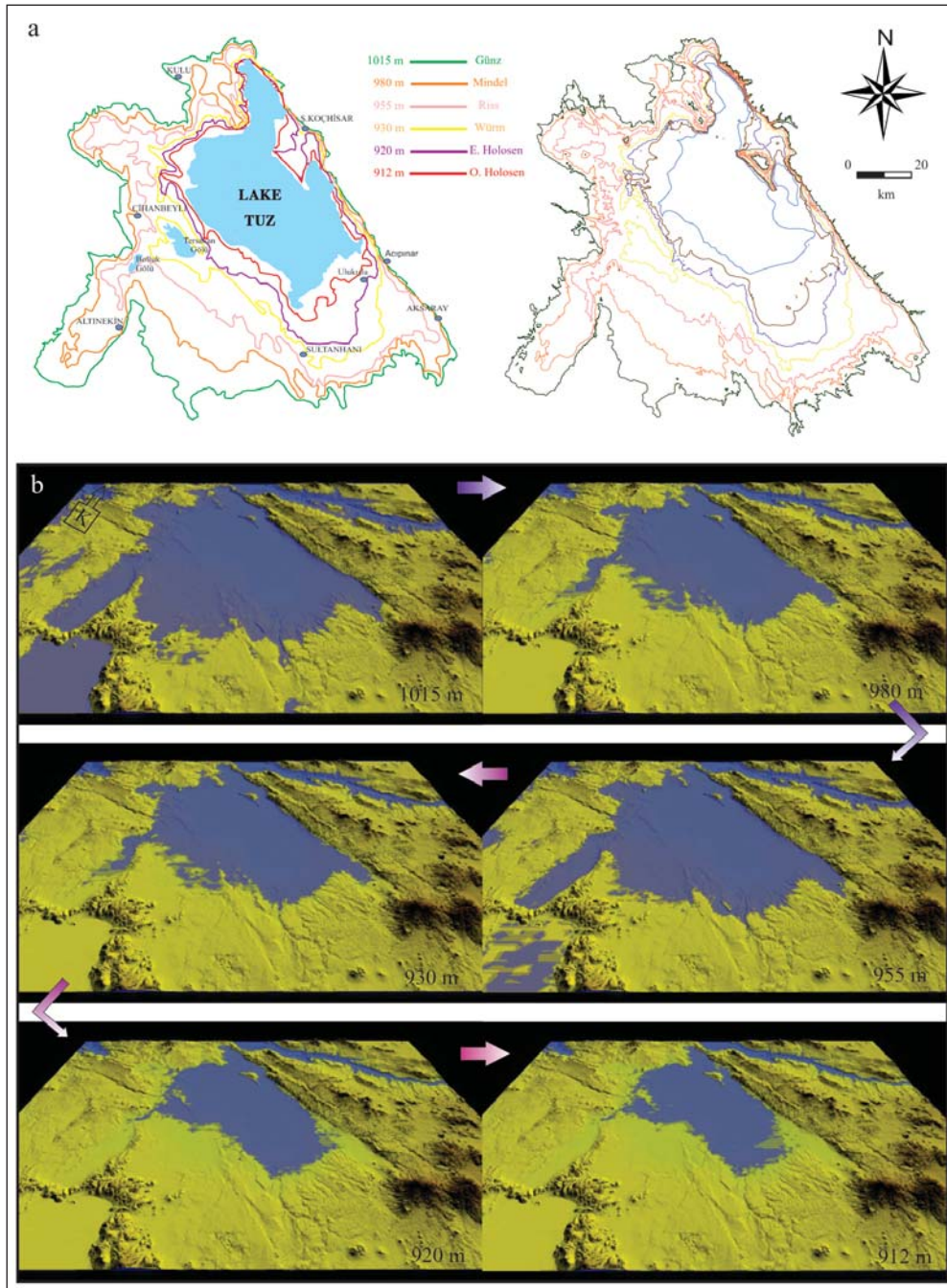


Figure 8- (a) On 1:100.000 scaled map distributions of variations and stages of shore line of Lake Tuz (Erol, 1969) in the Quaternary (left) and reconstructed shore lines of Erol (1969) on 1:25.000 scaled map (right); (b) spatial distribution of Quaternary shore lines of Erol (1969) reconstructed with respect to recent topography and their relation with surrounding areas based on this topography.

As stated by Erol (1969; Figure 8), in the Lake Tuz basin there is a lacustrine sediment distribution which gradually covered and/or leaved both Lake Tuz sub-basin and other sub-basins such as Kulu, Yeniceoba, Altınekin and Tersakan (Figures 8, 9 and 10). Spatial distribution of these deposits can only be controlled by tectonic events. Although, like in other regions in Turkey, an apparent steepness showing the effect of tectonic disturbance is not noticed in morphology, these sub-basins, in regional scale, are ultimately separated from each other by structural factors and thus, most are active even though the region is seismologically inactive (Figures 9, 10). The main ones of these structures are Eskişehir fault zone (Şaroğlu et al., 1987; Altunel and Barka, 1998; Ocakoğlu, 2007), Yeniceoba, Cihanbeyli and Altınekin fault zones (Çemen et al., 1999; Dirik and Erol, 2003; Özsayın, 2007; Özsayın and Dirik, 2007, 2011; Akıl, 2008; Gürbüz, 2012; Özsayın et al., 2013), Tersakan-Sultanhanı fault zone (Gürbüz, 2012) and Tuzgölü fault zone (Beekman, 1966; Şaroğlu et al., 1987; Leventoğlu, 1994; Çemen et al., 1999; Koçyiğit, 2003; Toprak, 2003; Kürçer and Gökten, 2012). Alluvial fan deposits, which are well developed particularly at east of the basin, are deposited under the control of NW-SE extending Tuzgölü fault. The results of dating studies of Kashima (2002) and Kürçer and Gökten (2012) indicate that fan deposits are formed at the beginning of Holocene. This implies that the high lake level in late Pleistocene was lowered because of climate-

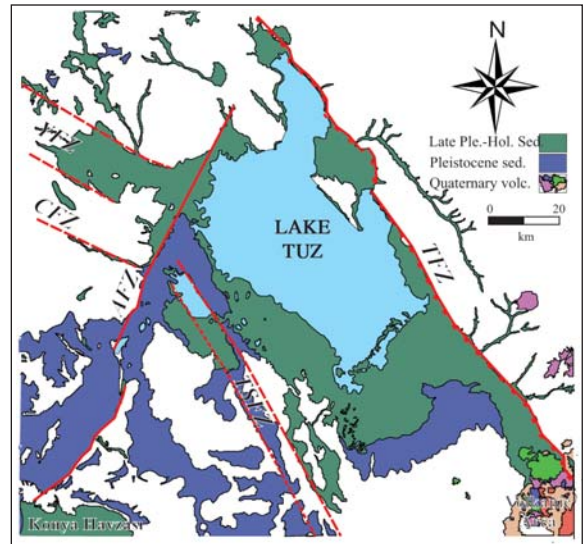


Figure 9- Simplified map of Quaternary units in the study area and major structural elements controlling them (distribution and ages of units are compiled from MTA, 2002). Compare the spatial distribution of faults with shore lines in figure 8. TFZ – Tuzgölü Fault Zone; TSFZ – Tersakan-Sultanhanı Fault Zone; AFZ – Altınekin Fault Zone; YFZ – Yeniceoba Fault Zone; CFZ – Cihanbeyli Fault Zone.

induced effects. In addition, the Quaternary volcanism at south of basin is another agent controlling the amount and diversity of material transported to the basin. This is supported by the

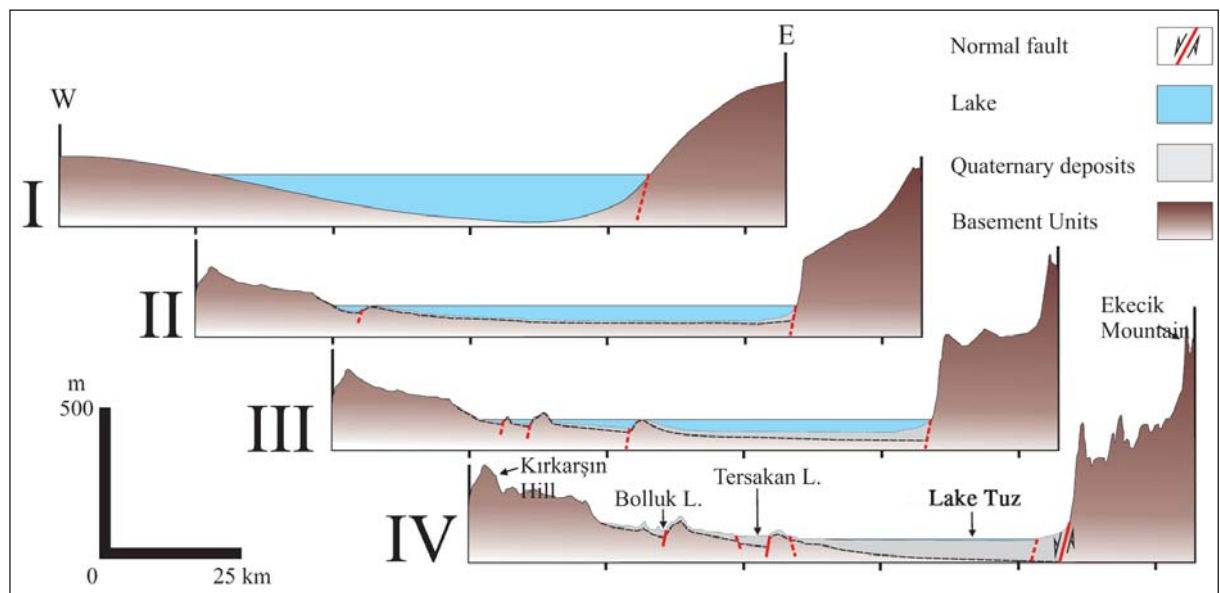


Figure 10- Evolution of Lake Tuz basin in E-W direction in time-independent 4 different stages. Sketch showing the fragmentation of paleo lake area and Quaternary deposition sites while basin has been gradually collapsing to gain its recent shape since the early Pleistocene.

volcanic origin of components in clastics comprising the beach deposits and Pleistocene fan delta which is exposed along the southern part.

Special structures of conical-shaped travertine deposits at west have a unique meaning to the basin regarding tectonic and climate events. In the area where cones widely occur, their linear-like appearance, as stated previously by Erol (1967-68), is indicative of a structural control. This is also supported by the presence of an active fault along this line, which is named Zıvarık fault by Erol (1969), Konya fault zone by Eren (2003), Konya-Bulok fault zone by Koçyiğit (2003) and Altınekin fault in several studies (Çemen et al., 1999; Dirik and Erol, 2003; Özsayın and Dirik, 2007, 2011; Gürbüz, 2012). On the other hand, climate was also shown to be powerful agent in development of travertine deposits. Although these cones seem to be developed along a structurally-controlled line in that part of basin, individual structures with their conical geometry may indicate that each cone is associated with water manifestation. As mentioned in the previous section, development of these deposits is related with freshwater flux. Moreover, individual structure of travertines requires different geochemical conditions for the fluids by means of chemistry and temperature (Pedley, 1990). Cold freshwaters that precipitate such cones might have been released into a saline and relatively hot lacustrine environment. This indicates that chemistry and temperature of Bolluk lake water during the deposition of travertines are very similar to those of present time.

Considering the width and relatively deeper water level of lake that occupied the basin during the Pleistocene, water-evaporation balance that could recharge this lake must have been much greater than current difference ($50 \times 10^3 \text{ m}^3/\text{y}$) which is in favor of recharge waters. It is revealed from the morphology of the Lake Tuz drainage basin is that, for such a region, where river network is not beyond the borders of Lake Tuz and Konya basins, the expected direct recharge from the rainfall and groundwater is more than the current value. Since the basin under investigation is a closed one, evaporation process will be very limited and takes place under wet/rainy conditions. These conditions are also suggested for the Konya basin which is the equivalent of Lake Tuz basin (Karabıyıkoglu, 2003). Although there are findings implying intermittent short-term wet and cold climate conditions in last period of Pleistocene, pollen analysis yielded strong data to suggest this period was arid and cold (van Zeist and Bottema,

1982, 1991; Bottema, 1987). This contradiction is explained by Roberts (1983) as the facilitation of low evaporation by cold and cloudy climate conditions (Karabıyıkoglu, 2003).

On the other hand, it should be taken into account that during the Pleistocene lake basin was connected to the Konya basin to the south and therefore it must have had a wider recharge area. This, in turn, means that Lake Tuz is recharged from a wide area through the Taurus Mountains at south. Moreover, the river network must have been established by strong-flow streams rather than today's ephemeral low-current streams. This is strongly supported by the presence of fan delta sediments on old shorelines extending along the southern part of the basin. It is thought that the "Konya Plain Main Discharge Canal" is connected to Lake Tuz via a natural channel between the two basins and as a result, the region, in a large scale, has been regarded as the "Konya Closed Basin" (Figure 11). Although groundwater is interconnected under these basins, there has been no surface water connection with the exception of discharge canal. In the frame of Konya Wastewater Treatment Facility project which was taken into operation in 2009, discharge canal was disconnected. Therefore, Lake Tuz closed basin and Konya closed basin should be investigated separately. As mentioned previously, in Pleistocene these basins were connected to each other, however, by Holocene the basins were disconnected as a result of different climatic and tectonic controls.

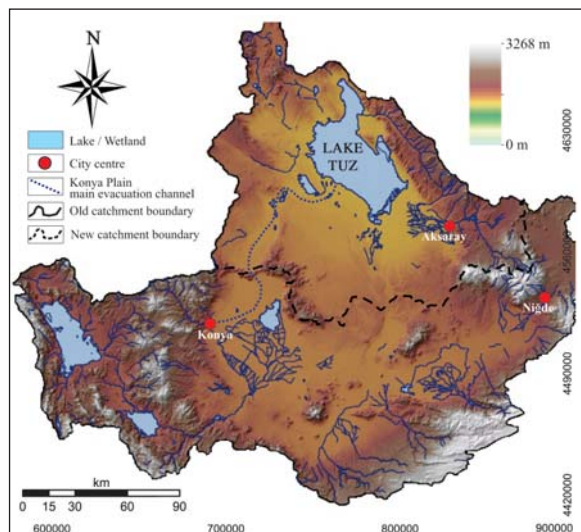


Figure 11- The old border of Lake Tuz drainage basin within the Konya Closed Basin and the border of new surface drainage basin that has been narrowed by the termination of the Konya Plain Main Discharge Canal.

Lake level fluctuations presented by Erol (1969) spatially coincide with our results. Therefore, it is possible to say that studies of Erol (1969) are far beyond the expectations of that period and the boundaries he suggested for lake shore oscillations are confirmed by our observation of proposed deposits. However, such consistency by means of morphosedimentary could not be noticed temporally because all fluctuations have been previously linked to fluvial stages.

6. Results

In this study detailed sequence examinations were carried out particularly in south and east parts of the Lake Tuz basin and as a result the Quaternary deposits were differentiated under 12 lithofacies and 5 facies units. As shown from the these facies distributions, the Lake Tuz, which corresponds to large and very shallow lake category, in Pleistocene covered an area nearly 5 times larger than its present area which classifies the Lake Tuz into a very large, shallow/moderate depth lake. Considering spatial characteristics of lithofacies, material was transported to the lake chiefly from east and southeastern parts where morphology is controlled by tectonism and volcanism. Tectonism played an important role in recession of lake area gradually into recent position. Sub-basins which are the relicts of Lake Tuz such as Bolluk, Tersakan, Eşmekaya lakes and several waterlands have been situated as separate benches within depressions formed by several faults. In the basin lake flat deposits are the most widespread deposits which are followed by alluvial fan sediments. During the Pleistocene which was prevailed by tectonism and climate dynamics, the amount of water recharging the basin is believed to be greater than recent time, however, a slight change in water level due to low relief of basin floor resulted in the expansion of lake. Therefore, in the basin there is no well-developed fluvial system reaching to the lake. Climate-induced lake level drop at the beginning of Holocene gave rise to deposition of thick alluvial fan sequences at eastern part of basin which is controlled by the Tuzgözü fault.

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