ORIGINAL ARTICLE

The Holocene terraces of the desiccated Bor Lake and Neolithic occupation in Bor Plain, Central Anatolia, Turkey

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Abstract

The lacustrine sediments and geomorphological data from the Bor Plain situated at elevations between 1050 and 1100 m in southern Central Anatolia provide record between 9800 and 6700 yr cal BP of climate changes and events. The main aim of this study is to determine the relationship between the location of Neolithic sites and the deposition and recession phases of the lake during Holocene. The geomorphological history of the Bor Plain and palynological results allows us to reconstruct the relationship between the Holocene environment and reconstruction of Neolithic settlements within a spatially well-defined lacustrine landscape of ~ 600 km². A 75 ± 13 ka aged terrace, consisting almost entirely of calcite and situated about 76 m above the plain floor, indicates that the plain was covered with a paleolake in the transition from MIS 5 to MIS 4. Considering the low total organic carbon and the high $CaCO_3$ clay values, we conclude that the lake slowly receded in 9867 ± 39 cal BP. However, the presence of aquatic herbaceous forms such as Nymphaceae and Cyperaceae indicates an increase in the water level of the lake during 6776 ± 35 cal BP, after which it transitioned to a dried lake. Thus, the progression and recession phases of the lake became the determining factor in the site selection of Neolithic settlements on mounds by which are found the plain floor at elevations between 1090 and 1100 m in this period on the Bor Plain.

Keywords Holocene · Neolithic · Mound · Palynology · Climate change · Bor Plain

Introduction

The tendency of the climate to change relatively suddenly has been one of the most surprising outcomes of the study of Earth history, specifically that of the last 150,000 years (Taylor et al. 1993). Some and possibly most intensive climate changes (involving, for example, a regional change in mean annual temperature of several degrees Celsius) occurred on a timescale of a few centuries, sometimes decades, and perhaps even just a few years (Adams et al. 1999). In Turkey, climatic and geomorphological changes occurred in southern Central Anatolia during the Holocene (11,500 cal BP to Present) (e.g., Eastwood et al. 2007; Kuzucuoğlu et al. 1999; Roberts et al. 2011; Türkeş 2013) corresponding to the Prehistoric and Neolithic periods; mainly since the Last Glacial Maximum, and at the transition from the LGM to the Holocene, with several less important variations occurred during the Holocene. Examination of the evolution of lake records in Central Anatolia was carried out by research teams aiming at integrating on-site (geo-archeological, subsistence) and off-site (paleo-ecological) evidences (Asuati 2009). Nicoll and Küçükuysal (2013) present an overview of selected papers published since 2000 that interpret Late Quaternary multi-proxy paleoclimate records from Turkey and the surrounding areas of the Near-Middle East and Mediterranean region. They suggested that while most archives across the region agree on the basic timing of an early–middle Holocene wet period between 9600 and 5400 cal BP, the nature of sub-millennial variations observed on a global scale is not well constrained across the Near-Middle East and in North Africa. Berger et al. (2016) focused on Early Holocene rapid climate change records in the Mediterranean zone, which are under-represented in continental archives (9.2 to 8.2 ka events), and their impact on prehistoric societies. Eastwood et al. (2007) and Roberts et al. (2001) examined available pollen sequences from Central Anatolia. These sequences show that by the time of the first known Neolithic settlement

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in Cappadocia (c. 10,000 cal BP), the regional vegetation was oak–terebinth–juniper grass parkland.

Numerous Neolithic and late period settlements were formed near the desiccated Late Pleistocene Konya Lake (Karabıyıkoğlu et al. 1999; Boyer et al. 2006; D'Alfonso and Mora; Baird 2012; Maner 2017; Ayala et al. 2017), Salt Lake (Tuz Gölü), Akşehir-Eber lakes, desiccated Bor Lake and others. Özbaşaran (2011) attributes this situation to the suitable geographical conditions such as highlands forested with slopes, open steppes, wetlands, pluvial lakes, and springs located along the flanks of mountain ranges for settlements during ninth and eighth millennium B.C.E in Central Anatolia Region. Their shoreline and catchment were suitable for agricultural activities that started in the Neolithic period (11,500–11,000 cal. BP). Kuzucuoğlu et al. (2018a, b) give information about the environment of human life in the Mesolithic and Neolithic periods in Konya plain. In this study, it is suggested that the transportation of different types of grain-size sediments (clay–silt–sand–gravel) is the result of change in stream flows, lacustrine inputs, and climate. Other studies on climate change and the chronology of human societies have enabled us to see the relationships between archaeological artifacts and structures on one hand, and river and lake dynamics on the other (Vita-Finzi 1969; Van Andel et al. 1986; Howard et al. 2003; Boyer et al. 2006). The crux of the matter consists of correlating records of climate change with evidence for its specific impact on landscape resources exploited by past societies (e.g., vegetation, water sources), and the subsequent impact of such landscape transformations upon human choices, as reflected in prehistoric habitation practices and settlement patterns (Asouti 2009).

The environmental changes recorded in the Late Quaternary sediments have implications also for human occupancy of south central Turkey and the origins and development of agriculture and settled village life, as testified in Neolithic settlement sites (or mounds, in Turkish "höyük"), such as Çatalhöyük (Mellaart 1967; Hodder 1996), Aşıklı, Musular (Esin 1996; Kuzucuğlu 2013; Kuzucuoğlu et al. 2018a), and Can Hasan III (French et al. 1972) dating from ca. 8300 to 7000 BP. The relationship between archeological layers, rivers, and depositions and/or erosion during the occupation of these sites indicates depletion of precipitation during the first two millennia of the Holocene (Kuzucuoğlu 2013). Matessi et al. (2018), in their study on the 7000 cal BP period and older mound settlements in Bor Plain, examined the effect of climate change in Holocene on the road system and layout. The change in the environment of the Bor Plain indicates that it was linked to climate change at 4.2 ka BP, but in other cases, it was based on wars, new socio-economic conditions and new technologies. Berger et al. (2016) examine climate changes identified at c. 9.2 and 8.2 ka cal BP, and their possible links with prehistoric societies in the Mediterranean

region, with various regional focuses of which one details Central Anatolia. Kuzucuoğlu (2019) examined how Konya Plain was affected by the Last Glacier Maximum and subsequent climatic conditions, the progressive withdrawal phases of the existing lake in chronological order (from the end of Pleistocene to beginning of Holocene). Neolithic sites are found on the shoreline of the desiccated lake occupying the Bor Plain and its surroundings due to its particularly favorable geographic position and stratigraphic importance (Balatti and Balza 2012). D'Alfonso (2010) determined 37 sites dating from the Late Neolithic–Chalcolithic period through to the Middle Ages on the Bor Plain. In addition, Köşk Höyük, dated to the transitional period between Late Neolithic and Chalcolithic, i.e., at the end of the 6th millennium/beginning of 5th millennium BP (Öztan 2002), is located at the southern end of the Bor Plain. Taking into account the location of sites, the investigation of geomorphological settings and the reconstruction of their dynamic relationship to the desiccated Bor Lake and water resources provide valuable data on the contraction events of the lake.

In this study, we focus on three major points: (1) the relationship between lake deposition, conservation, and erosion during the occupation of Neolithic sites (between 7 and 6 ka cal BP); (2) considering changes in the lake levels, how the location of sites was affected by this process. In other words, how the elevation of sites was related to the recession and progression of the lake depending on climatic changes, and (3) as the water input of the Bor Basin depends mainly on rivers coming to the plain from mountains, how these data are to be reconciled with the cold and dry climatic conditions in terms of lake-level changes. To focus on lake-level changes, lake sediments located within terraces near the Neolithic sites and bottom of the lake were analyzed to infer climate variation through clay-mineral assemblages (Celeste et al. 2007).

The main purpose of this paper is to determine the relationship between the location of Neolithic sites and the lake-level changes during Holocene. In this paper, we focused only on Neolithic settlements on the terraces representing the shoreline and beginning of mid-Holocene, marked by a rapid retreat of the lake. Today, the Bor Plain is characterized by settlements and industrial activities along its margin. It is only partly used for agricultural cultivation, because some areas are unusable due to considerable salinity. Vegetable and fruit growing based on subsistence farming is practiced in the vicinity of the plain.

General settings

The study area comprises the Bor Plain (37º 56′ N, 34º 32′ E), which is a plain of flat topography located on the southern Central Anatolia Plateau (Fig. 1). Its elevations

Fig. 1 **a** Location of study area
(Bor Plain) situated in Central
Anatolia Region; **b** mountains
in immediate surroundings of
Bor Plain; **c** Digital Elevation
Model (DEM) of study area and
location of mounds (modified
from D'Alfonso, 2010)
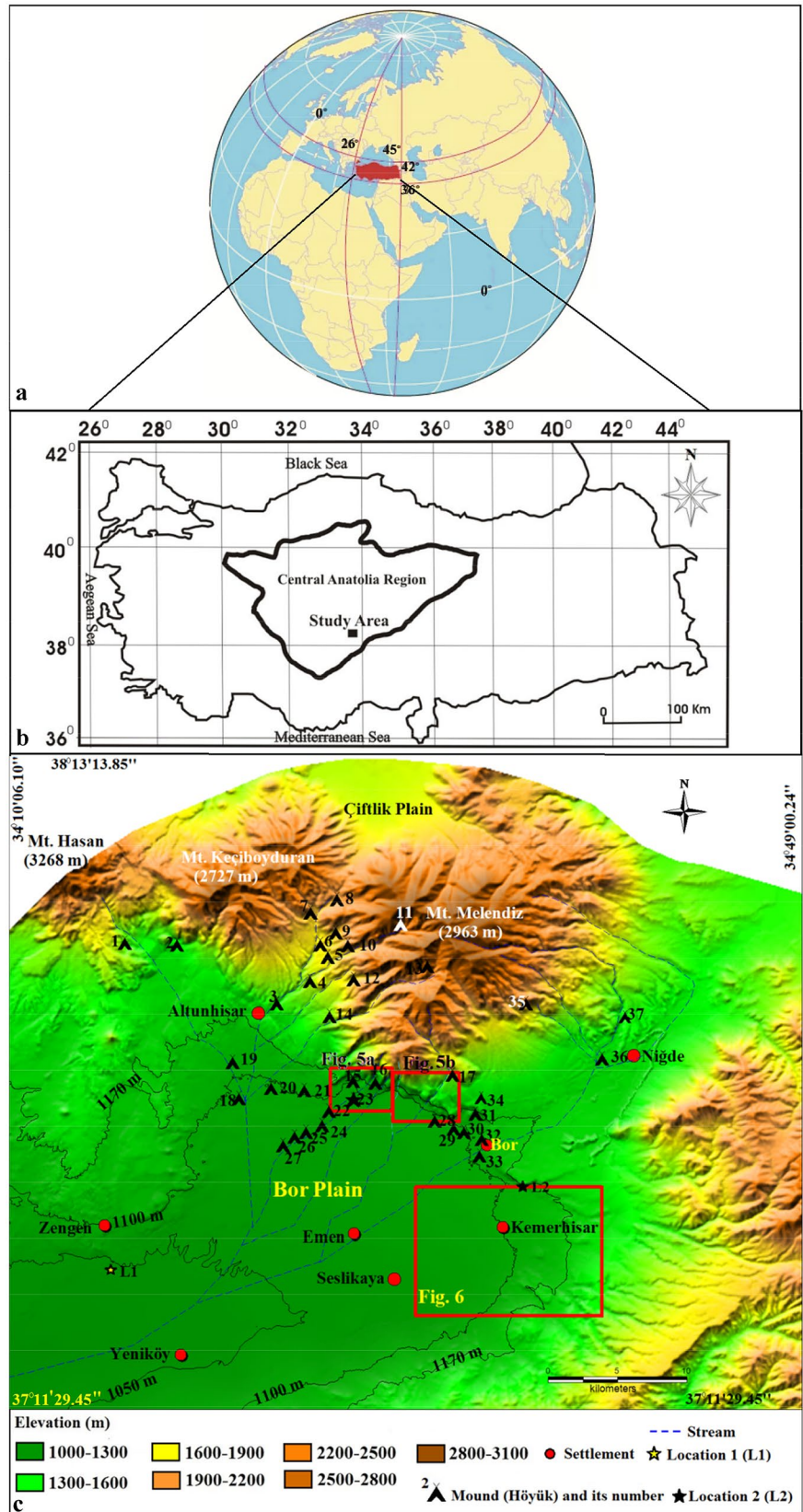
range from 1050 to 1100 m above sea level (Fig. 1). Several mountains surround the plain. Mt. Bolkar (to the south), which is a part of the Middle Taurus Chain, consists mainly of pre-Miocene marine sediments (Bolkar carbonate platform and other sedimentary rocks) (Dhont et al. 1999). Mt. İtulumaz (to the east), which is part of the Niğde Metamorphic Massif, consists of Paleozoic–Mesozoic marble and schist (Göncüoğlu 1986). The Melendiz, Keçiboyduran, and Hasan volcanics are located to the north and northwest of the plain (Fig. 1). According to Türkecan et al. (2004), the Melendiz volcanic complex (2963 m) consists of Upper Miocene, Pliocene, and Pleistocene products (Fig. 2). Another mountain located at the northern end of the plain, the Mount Keçiboyduran (2727 m) is a composite volcano with well-distinguished radial lava flows. These volcanites consist of a number of lava flows covered by volcanic (lava flows, pyroclastites) emitted later by Mt. Hasan (3263 m) (Türkecan et al. 2004).

As to Quaternary sediments (Fig. 3), Gürel and Lermi (2008) divided the Bor Plain into colluvial slopes, an alluvial plain, and a flat lacustrine plain filled-in by carbonate-rich silts. The plain is bordered by sandy-clayey beach ridges similar to those identified along the Konya plain in connection with the construction of the Çarşamba river fan. Roberts (1979) identified that the Konya plain was occupied by a paleolake dated to 23,000 to 17,000 yr BP.

Rivers from the surrounding mountains usually disappear before reaching the center of the present plain, where a marsh sometimes occurs. The Bor Plain displays geomorphological signs of containing a lake, and lake area variations. Such indications, in the form of ancient beaches, terraces, and lacustrine deposits, have been identified on the edges of the plain. This pattern is associated with the presence of Late Neolithic sites. Thirty-seven sites, dating from the Late Neolithic–Chalcolithic period through to the Middle Ages, have been identified and recorded by archaeologists (see Fig. 1) (D'Alfonso 2010; D'Alfonso and Mora 2010; Balatti and Balza 2012). During the LGM, the c. 20 m-deep "Paleolake Konya" (e.g., Roberts 1979) was filling the present Konya plain (western part of the paleolake), Eregli plain (middle part of the paleolake), and Karapinar plain (northern part of the paleolake). East of the present Eregli plain, the 600 km^2 wide Bor Plain seems also to correspond to the dry bottom of a lake. However, this system is today disconnected from the Paleolake Konya by altitudes > 20 m.

Aroun the Konya plain, coastal remains of the paleolake have been identified (wave-cut cliffs, raised shorelines) (Karabıyıkoğlu et al. 1999; Roberts et al. 1999; Fontugne et al. 1999; Reed et al. 1999).
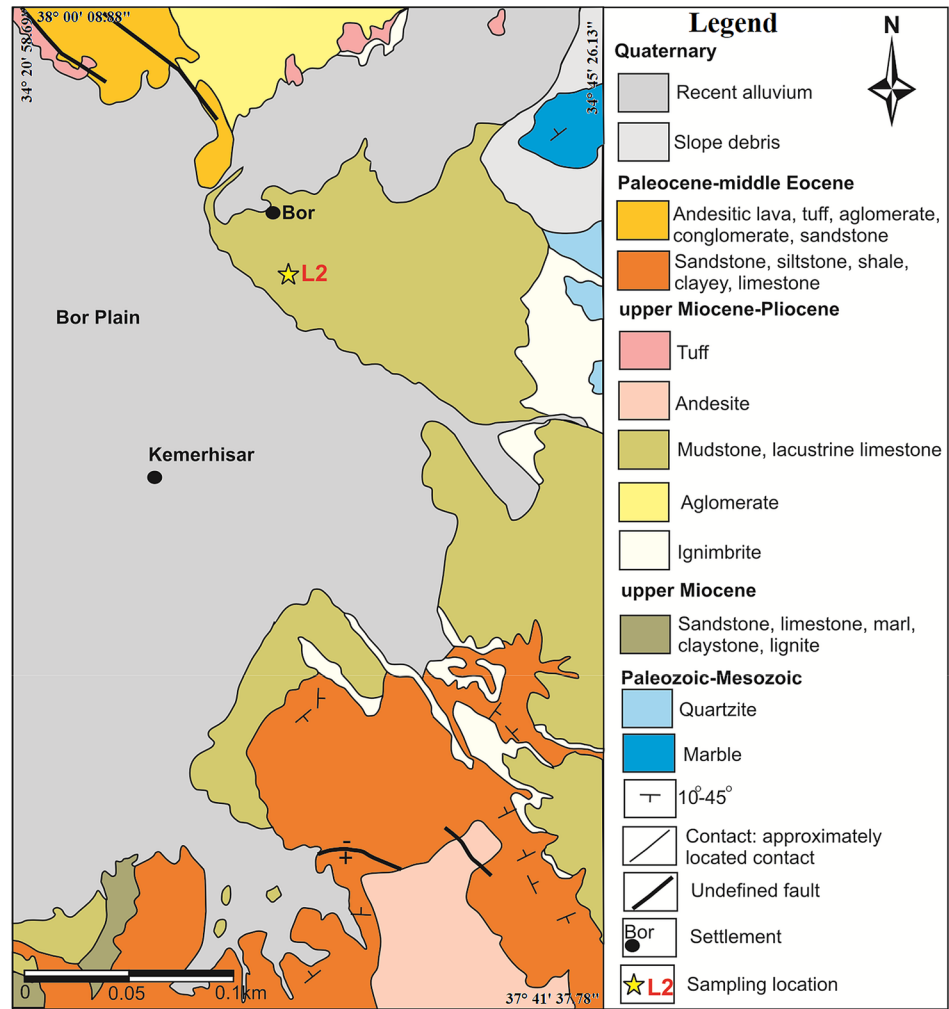
Today, the climate of the Bor Plain is semi-arid continental, with cold, wet winters and hot, dry summers. Mean annual precipitation over the plain floor is < 350 mm per annum and

Fig. 2 Geological map (modified from Ulu 2009) of northern part of Bor Plain and center, and location of drill core (location 1)
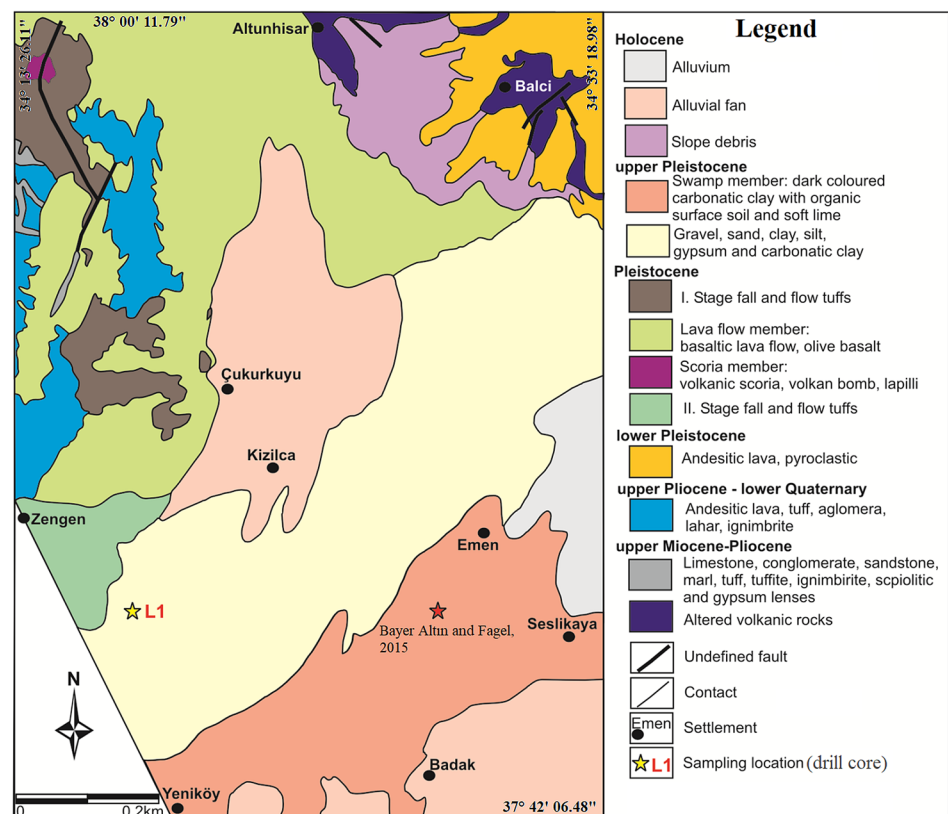
Fig. 3 Geological map (modified from Atabey et al. 1990) of south of Bor Plain and Location 2 where sample was taken

Legend N

Quaternary
- Recent alluvium
- Slope debris

Paleocene-middle Eocene
- Andesitic lava, tuff, aglomerate, conglomerate, sandstone
- Sandstone, siltstone, shale, clayey, limestone

upper Miocene-Pliocene
- Tuff
- Andesite
- Mudstone, lacustrine limestone
- Aglomerate
- Ignimbrite

upper Miocene
- Sandstone, limestone, marl, claystone, lignite

Paleozoic-Mesozoic
- Quartzite
- Marble
- 10°-45°
- Contact: approximately located contact
- Undefined fault
- Bor Settlement
- L2 Sampling location

a marked annual deficit in the water balance occurs during the summer months. Mean winter and summer temperatures are around freezing point and > 20ºC, respectively, with winter minima and summer maxima of around – 15 °C and + 35 °C (Türkeş 2005; Bayer Altın et al. 2012). The vegetation of the plain is dominated by Artemisia steppe, with open forests on volcanic (*Quercus* sp., wild fruit trees) and limestone (*Pinus* sp. and *Juniperus* sp.) slopes, when this vegetation has not been overgrazed or overcut for firewood (Bayer Altın 2010). In the past, agriculture on the plain was based on rain-fed crops together with semi-nomadic sheep husbandry. Today, agriculture is not practicable in the center of the plain due to salinity, but irrigation developed in its southern part (less in its eastern part) has led to the growing of other crops (vegetables and grapes/viticulture) and decreasingly, cereals.

Materials and methods

In the study, lake sediments have been predominantly studied in two ways: mineralogical analyses to characterize lake typology (the lake phase), and also by geomorphological methods (the terraces). Changes in the ancient lake sediments were examined from the lower to the upper layers, allowing for the identification of differences in limnic deposition.

To identify the vertical distribution of clay minerals, one stratigraphic section at the bottom of the plain was examined using a drill core showed as L1 code in Fig. 2. Four samples are taken from the lowest part of the plain (1060 m) and at a depth of 2 m from the surface. Two

of samples were analyzed for C^{14} dating. One sample (L2 code in Fig. 3) for Optically Stimulated Luminescence (OSL) dating was obtained from the lake terrace located on the eastern side of the plain. They were analyzed with respect to their mineralogical characteristics by X-ray powder diffraction (XRD) and dating analyses such as Radio Carbon (C^{14}) and OSL (Optically Stimulated Luminescence).

The mineralogical analysis was carried out at Gelogical Department of Niğde Ömer Halisdemir University, Niğde, Turkey using a PANalytical diffractometer with Cu-$K\alpha$ radiation on powdered bulk sediment. The relative abundance of minerals was estimated from the height of the main peak multiplied by the correction factors proposed by Cook et al. (1975). To identify the vertical distributions of clay minerals, the stratigraphic section in the bottom of Bor Plain was examined using drill core. Samples were prepared for clay-mineral analysis (size fraction < 0.002 mm) by separation of the clay fraction by sedimentation. The total clay (Tclay) mineral content is the total % of the clay minerals measured in bulk XRD.

Luminescence analyses of collected samples were conducted at the Luminescence Research and Archeometry Laboratory of Ankara University, Institute of Nuclear Sciences, Turkey. Samples taken for OSL analysis were opened under the weakened red light in the laboratory without seeing daylight with the help of opaque cores and reduced to 90–125 μ dimensions. Due to the high ages expected, the feldspar pIRIR dating technique adhered to the principles of age determination and samples passed through suitable chemicals were analyzed. For example, the grains were treated with 10% HCl and 10% H_2O_2 for the removal of carbonates and organics, respectively. Luminescence dating analysis results of L2 sample whose ages are calculated are given in Table 1.

Sediment core age was determined using accelerated mass spectrometry (AMS) radiocarbon dating facility available at Laboratory of Marmara Research Center, Istanbul, Turkey. The total carbonate in the samples was measured and age determined. The samples were dissolved in phosphoric acid and carbon dioxide reduced to carbon. Depending on the measured C^{14} amount in the samples, δC^{13} correction was made and the C^{14} age was determined. Carbonate content samples were picked at corresponding depths, as shown in Table 2. δC^{13} values are reported as ‰.

Two samples were dissolved in phosphoric acid and the carbon dioxide was reduced to carbon. To determine the environmental conditions (dry and humid), $CaCO_3$ and total organic carbon (TOC) were calculated as a percentage. The amount of $CaCO_3$ in the five samples was measured with a Schibler type calcimeter. Temperature and pressure regulations were taken into account for the measured value. At the first stage, all samples were air-dried naturally and ground to pass through a size

Table 1 The results of luminescence dating of the samples from the lake terrace developing at northeastern edges of the Bor Plain

Sample code	Depth (m)	g value	Used Aliq	Grain size (μm)	Eq. dose (Gy)	U (ppm)	Th (ppm)	K (%)	Water (%)	Cosmic dose rate (Gy ka^{-1})	External dose rate (Gy ka^{-1})	Internal dose rate (Gy ka^{-1})	Annual dose rate (Gy ka^{-1})	Fading corrected age (ka)
L2	9.0	1.6±0.2	16/16	90–125	108±15	1.78±0.07	7.47±0.3	0.92±0.04	30±5	0.09±0.01	1.55±0.06	0.03±0.01	1.58±0.06	75±13

Table 2 Range of δC^{13} values and C^{14} age correction for total carbonate in sediment samples

Depth (cm below land surface)	Sample type	C^{14} age (year BP)	δC^{13} (%)
145	Sediment	6776 ± 35	-3.9 ± 1.0
180	Sediment	9867 ± 39	-1.8 ± 0.8

of 10 mesh. Quality control was evaluated based on duplicates, method blanks. Organic carbon content of five samples from this drill core was also estimated by titration method suggested by Gaudette et al. (1974). The following formula was used to determine TOC content in samples:

$$\% \text{ Organic Carbone } = 10(1 - T/S)\left((1.0N\,(0.003)\,(100/W)\right), \tag{1}$$

where T is consumption of iron solution, S is consumption for blank, *1.0 N* is normality of dichromate, W is sediment weight, and *10* is dichromate volume.

The sediment sample was prepared for $CaCO_3$ analysis, and it was weighed between 0.5 and 2 g based on the lime content of the soil and transferred to the reaction bottle. The transferred soil was piled on one side of the reaction flask. About 4–5 ml of HCl was filled into the acid tube (it should be prepared by adding 1 volume of HCl to 3 volumes of water). The acid tube was placed in the middle of the reaction flask with the help of long forceps. It was ensured that the soil and acid come into contact in the "U" pipe calcimeter device. The stirring process was continued until the gas outlet is finished. After, the gas outlet is finished and the water levels in the "U" pipe are equalized. CO_2 gas volume from the scale on the "U" pipe is recorded by reading the temperature from the thermometer and the pressure from the barometer, and the lime content % is calculated with the help of the formula below

$$CaCO_3 = \frac{Vox0.4464}{A}, \tag{2}$$

where *Vo* is gas volume in cm^3 converted to normal conditions, *A* is sample amount in g, and *0.4464* is 1 mol $CaCO_3$
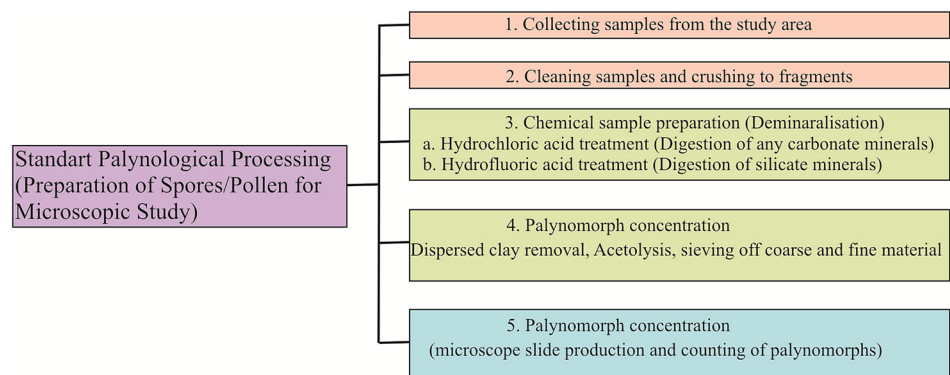
is the coefficient showing how much CO_2 will come out of *A* gram sample based on 1 mol of CO2 under normal conditions.

Also, fossil pollen analysis (palynological analysis) of the samples was performed. Two samples for pollen analysis were examined under a microscope using standard palynological techniques for disintegrating Quaternary sediments. Tilia and Tilia Graph software were used to construct the diagrams. Cluster analysis was performed by CONISS (Grimm 1987). The methodology of palynological analysis work was described by a schematic flowchart (Fig. 4).

The detailed geomorphology map we used was the Erol System, which is based on the Neogene and Quaternary erosion cycles of Turkey in relation to erosional surfaces and their correlated sediments, derived from 1:25,000 scale topography and geological maps. According to this system, denudational evolution of the Anatolian Peninsula and the Taurus Mountains to the south is a continuous process influenced by neotectonic phases, climatic changes, and sea-level oscillations since late Oligocene (Erol 1991). Denudational surfaces of different ages have been studied in relation to their correlated sediments (Erol 1991; Fairbridge et al. 1997). The age of the landform systems (Fig. 5) was indicated by Erol (1991) as DI, II, III, IV and the Pleistocene terraces as S levels. For studying paleolake levels, this system was applied, as in Fig. 5a. Based on this system, the relationship between the Holocene terraces and location of the mounds was detected (Fig. 5b).

Results

Geomorphology

As shown in the geological map, the Pleistocene terraces are found in front of the Pliocene surfaces (Ulu 2009; Oktay 1982). Under the influence of Pleistocene climate fluctuations and continuous subsidence in the central parts of the Tuzgölü Basin controlled by the Tuz Gölü Fault Zone (Dirik and Erol 2000; Kürçer and Gökten 2014), several step-like

Fig. 4 A summary of the standard, mineral acid-based palynological preparation technique (Riding 2021)

Standart Palynological Processing (Preparation of Spores/Pollen for Microscopic Study)

1. Collecting samples from the study area

2. Cleaning samples and crushing to fragments

3. Chemical sample preparation (Deminaralisation)
a. Hydrochloric acid treatment (Digestion of any carbonate minerals)
b. Hydrofluoric acid treatment (Digestion of silicate minerals)

4. Palynomorph concentration
Dispersed clay removal, Acetolysis, sieving off coarse and fine material

5. Palynomorph concentration
(microscope slide production and counting of palynomorphs)

Fig. 5 **a** Idealized cross-section showing relationship between denudational surfaces, terraces, and their correlated sediments. Abbreviations: D0: Oligocene denudational surface, DI: lower-to-middle Miocene peneplain, DII: upper Miocene pediments, DIII Pliocene fluvial accumulation surfaces, DIV: lowest Pleistocene fluvial accumulation surfaces, SY: old Pleistocene higher terraces, S0: middle Pleistocene middle terraces, SA: young Pleistocene lower Terraces, VT: Holocene valley bottoms, ma: lower-to-middle Miocene sediments, mu: upper Miocene sediments, pl: Pliocene sediments, T: pre-Miocene basement rocks, F: faults (modified from Erol, 1991). **b** Mounds on Holocene and Pleistocene terraces in front of Mt. Melendiz
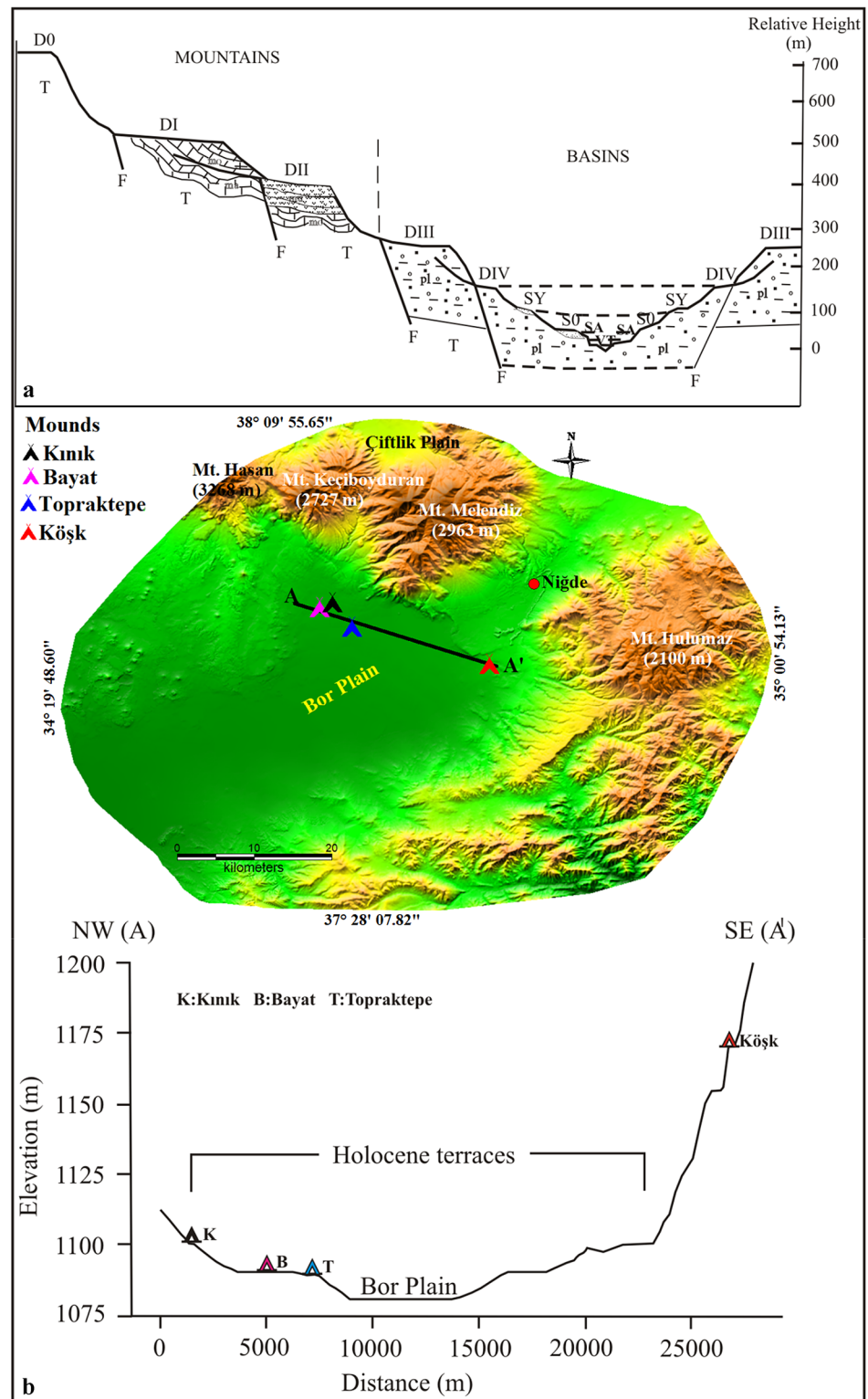
terraces had been developed around the Bor Plain. Long-term morphological development of the plain is controlled by Bor segment, which is a segment of this fault zone, is represented by the Holocene fault scarp NE of Kemerhisar (Kürçer and Gökten 2014). They are correlated to the younger alluvium and recent shorelines located in the south and north of the plain. The shoreline terraces of the Pleistocene Bor Lake are indicated on the geomorphological maps (Fig. 6a, b). This lake has left shoreline traces at 1110 m and 1100 m, from the lake level raised during Pleistocene, and
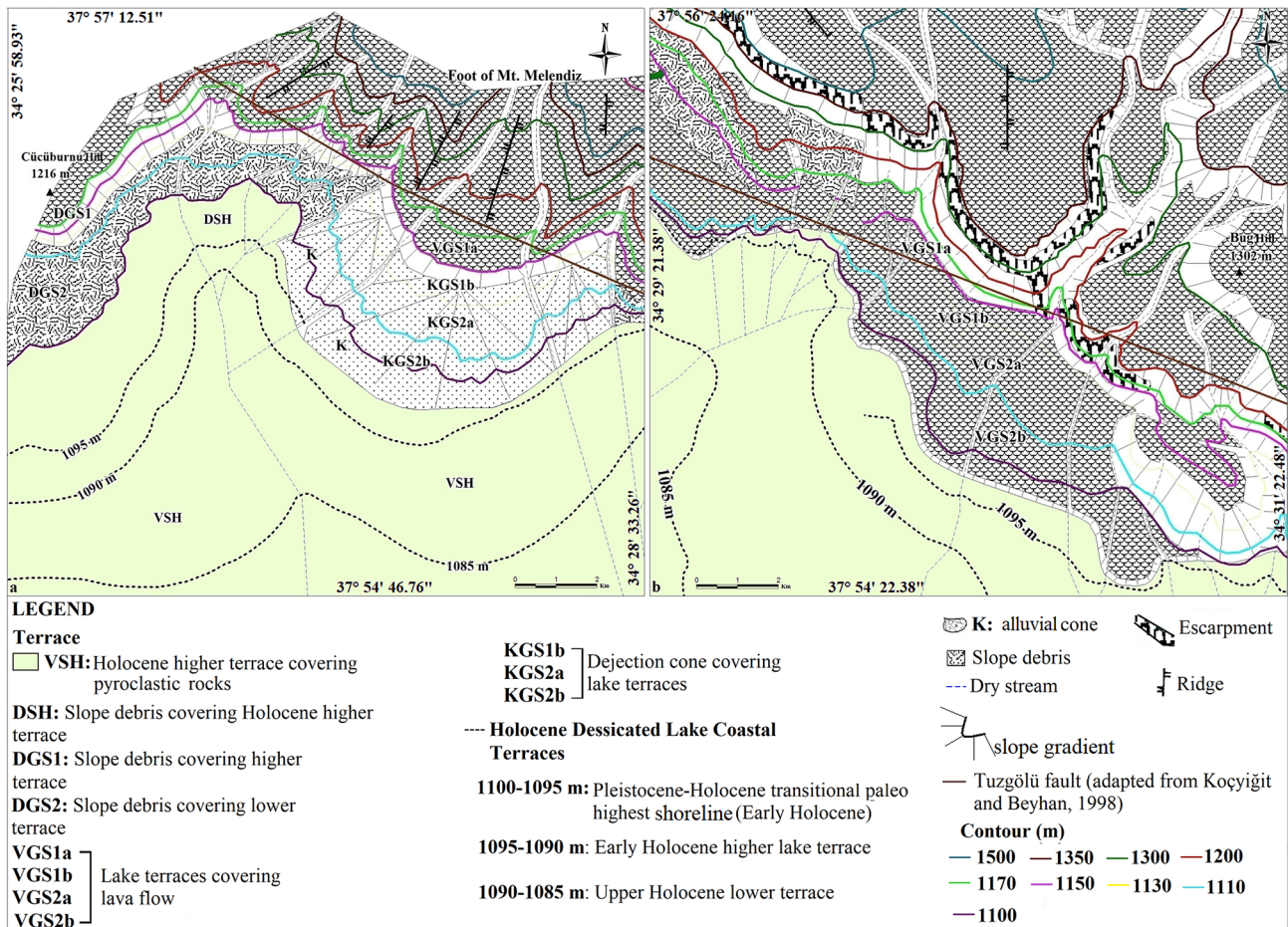
Fig. 6 Geomorphological map of northern part of Bor Plain. **a** Terraces are found either under alluvial cones and slope debris; **b** among lava flows and Holocene highest lake terrace covering scoria at foot of Mt. Melendiz

at 1090 m, 1080 m, 1070 m, 1060 m, and 1050 m, marking Holocene contraction and expansion phases of the lake in the plain (Bayer Altın et al. 2015).

Although the lake shoreline and terraces are more advanced and distinctive at the northern margin (Fig. 6) of the plain than the southern margin (Fig. 7), high and low terraces are not easily differentiated nor identified at the foot of Mt. Melendiz. The lake extended to the steep slopes at the foot of Mt. Melendiz and thus was deeper than at the southern margin. The coarser sediments in this area supplied the material for the large, long shoreline consisting of sand and gravel transported by streams, especially the Küçüköz and Omar streams coming down from Mt. Melendiz. As a result of the geomorphologic conditions, lacustrine terraces are composed of sand and coarse gravel transported from talus by streams. These terraces are found either on the lava flows or under the alluvial cones and slope debris (Fig. 6a, b).

Accordingly, the lake persisted longer in this area than its southern part because of its deeper base along its northernmost limits. The maximum elevation of the lake is estimated to have been between 1170 and 1150 m. This level is an eroded terrace surface along the foot of Mt. Melendiz and it corresponds to the maximum level of the lava threshold north of the study area. To the west of the foot of Mt. Melendiz, alluvial cones would have developed on the beach of the oldest–highest (1170–1150 m) lake shoreline (SY1). Remains of lake terraces recognizable are found at 1080, 1070, 1060, and 1050 m, thus marking the Holocene recession with re-advances (see Fig. 9 for terraces). The Late Pleistocene lake terraces (SA1-2) are fairly extensive from south of Mt. Melendiz to north of the town of Bor. This indicates that basin formation continued until the end of Pleistocene and the beginning of Holocene.

During the wet periods, the lake level may have been reached the Cücüburnu threshold formed by lavas limiting the NW corner of the Bor Plain in the later stages of Upper Pleistocene, and at that time the alluvial cones to the east of Cücüburnu Hill probably started as a small cone growing according to the lake level on the Pleistocene-Holocene transitional shoreline (see Fig. 6a). From the end of Pleistocene,
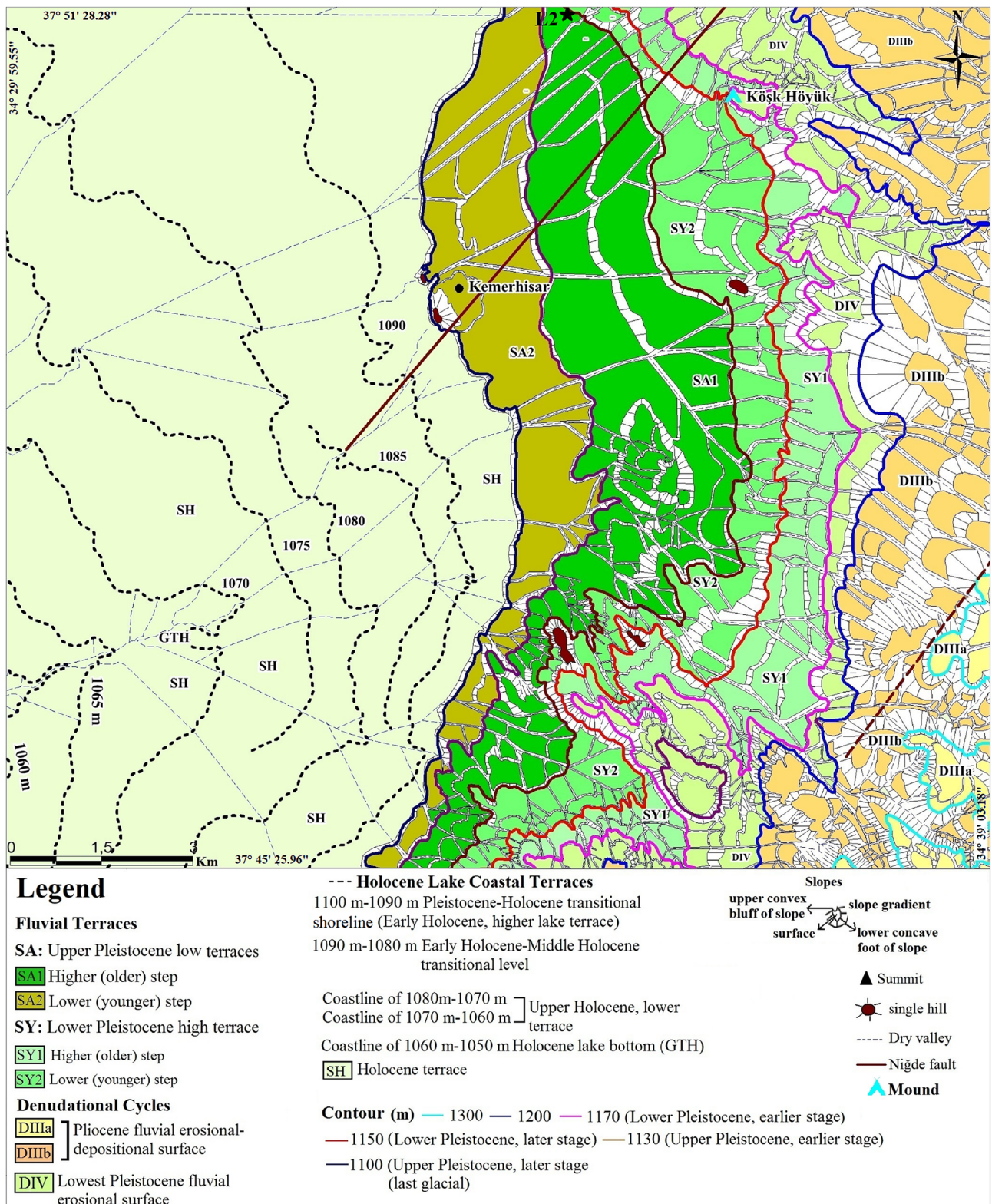
Fig. 7 Geomorphological map of southern and southeastern Bor Plain, also location of Köşk Höyük situated between 34°36′42.07″ E and 37°50′52.59″ N (UTM, ED50, Zone 36 N)

the shoreline terraces seem to have receded toward the bottom of the lake and several large and small cones spread on the lake bottom at the foot of Mt. Melendiz and Mt. Keçiboyduran. Therefore, the shoreline from 1100 to 1090 m is proposed as the highest terraces of Pleistocene-to-Early Holocene. This level represents the level of transition from Pleistocene to Holocene. By the time of the 1090 m level, milder and drier conditions prevailed and the receding lake left a flat area of fertile farmland suitable for occupation by Neolithic human societies. Therefore, the shoreline of 1090–1080 m is proposed as the transition between Early and Middle Holocene lowest terraces. In the Early Holocene, this new emerged land was populated with new villages dated Middle Holocene, i.e., Chalcolithic. The Holocene lake bottom must have extended from 1075 to 1050 m (actual bottom).

As to the Holocene terraces, they are the lowest and youngest terraces in the plain. The elevation of these terraces infers rapid climate changes during Holocene. In the study area, the Holocene traces are represented by the shoreline located in front of the Upper Pleistocene terraces, marsh deposits, alluvial fans located on the Upper Pleistocene terraces, and paleosols. At the southern margin of the plain (Fig. 7), traces of the lake are less obvious due to the wide alluvial plain with a low slope consisting of smaller grain-size detritic material deposited by streams coming from the mountainous areas.

Relationship between terraces and mounds on desiccated lake

The age of the sample coded L2 taken from the location called İftiyan is 75 ± 13 ka years (Fig. 7). It was formed during the transition from MIS 5 to MIS 4. MIS 5 is defined by Shackleton (1969) and Emiliani (1955) as the last interglacial era. This terrace is located 76 m above the lake floor, because it developed under fault control and has been identified as the highest terrace in Late Pleistocene. This indicates that the first large lake development occurred in Middle Pleistocene. That the lake level started to rise is evident from the accumulation of transgressive terrace sediments between 1110 and 1120 m. During this transition phase, the level of the lake reached approximately 70–60 m. This recession led to the establishing of Köşk Höyük, which was first settled from Late Neolithic to Early Chalcolithic (6350–4900 BP) (Öztan 2002), at 1170 m, just above the lacustrine terraces at this margin (Fig. 7).

In addition to geomorphological results, the earliest archeological remains prove the existence of human occupation, depending on climatic changes. The Neolithic peoples preferred fertile shoreline stretches, especially terraces near an easily available water supply. We focused our study on the sites located at the boundary of the plain

such as the Kınık, Topraktepe, Çıplaktepe, Kayı, Balcı, and Tuwana mounds. In the study area, except for Köşk Höyük and Tuwana (a Hittite name), all mounds dated to the Early Bronze Age (ca. 5000–3000 BP) are found between 1100 and 1080 m. Tuwana has been dated to the second half of the eighth century BP (Neo-Hittite) (Hawkins 1982). Kınık mound was occupied from Early Bronze Age I through to the Middle Ages (D'Alfonso 2010). The major occupation phase of the site corresponds to the Early and Middle Iron Age (twelfth–eighth century BP) (Hawkins 2000). In the north, Early Bronze Age mounds are concentrated between elevations of 1100–1080 m. They must have been established about the time that the 1080 m level was being formed, between 5000 and 3000 BP. Thus, human settlement and the inception of agriculture occurred during the recession period of the 1100 m lake. The shoreline of the 1100–1080 m lake has smaller grain-size gravels than the upper terraces. Indeed, a few gravels greater than 5–7 cm diameter in high shore traces were observed, whereas the gravels on the shoreline at 1100–1080 m are on average 1–2 cm in diameter. This is probably the result of a weak current in the lake and a moderate climate.

Ten sites out of the 30 Neolithic settlements were dated to either before Early Bronze Age II or after the Late Roman period (Balatti and Balza 2012). This indicates that the lake level, affecting distribution of the settlements, increased and decreased. A relatively younger part of the fans and talus which lie on the northern edge between the 1100 and 1090 m shoreline, and which extends from the foot of Mt. Melendiz to the mounds, grew after the recession from the 1090 m level. These fans are characterized by recession of the lake. The 1110 and 1100 m levels of the Bor Plain and the first two levels of other basins (from west to east; 1017–1010 m level of Konya Basin, 930–920 m level of Tuzgölü Basin and 1110–1105 m level of Sultansazlığı Basin, respectively) may be attributed to the last period of Pleistocene (Fig. 8a). The lake levels of these basins were formed at different elevations because of their differences in structure and topography. Therefore, Tuzgölü Basin has lower levels than other basins, because the topography of South-Central Anatolia descends gradually from east to west.

The 1090 m level confirms a fairly continuous recession during Holocene, because the mounds found at the levels mentioned above in the Konya, Tuzgölü and Bor basins were all dated to 6000–3000 BP (Mellaart 1961; Kansu 1944; D'Alfonso 2010). In addition, the Early Neolithic settlements were established far from the maximum extent of the lake shoreline and above this limit. If it is possible to reach a conclusion regarding the Bor Plain in respect of the impact of environmental change on human societies, we can say that past communities settled in the high and dry area of the basins during cold periods (when the level of the lake was high due to low evaporation) and near the shoreline during

Fig. 8 a Comparison of heights and ages of lake terraces surrounding desiccated Bor Lake. Ranking of basins is from west to east (data for Tuzgölü, Konya, and Sultansazlığı taken from Erol 1978, 1991, 1999) . **b** Fluvial deposition between two mud sediments transported by streams during humid conditions showing (side-by-side): increase in lake level and actual soil; recent drying of lake level at Çıplaktepe mound situated between 34°23′05.41"E and 37°54′05.72" N (UTM, ED50, Zone 36 N)
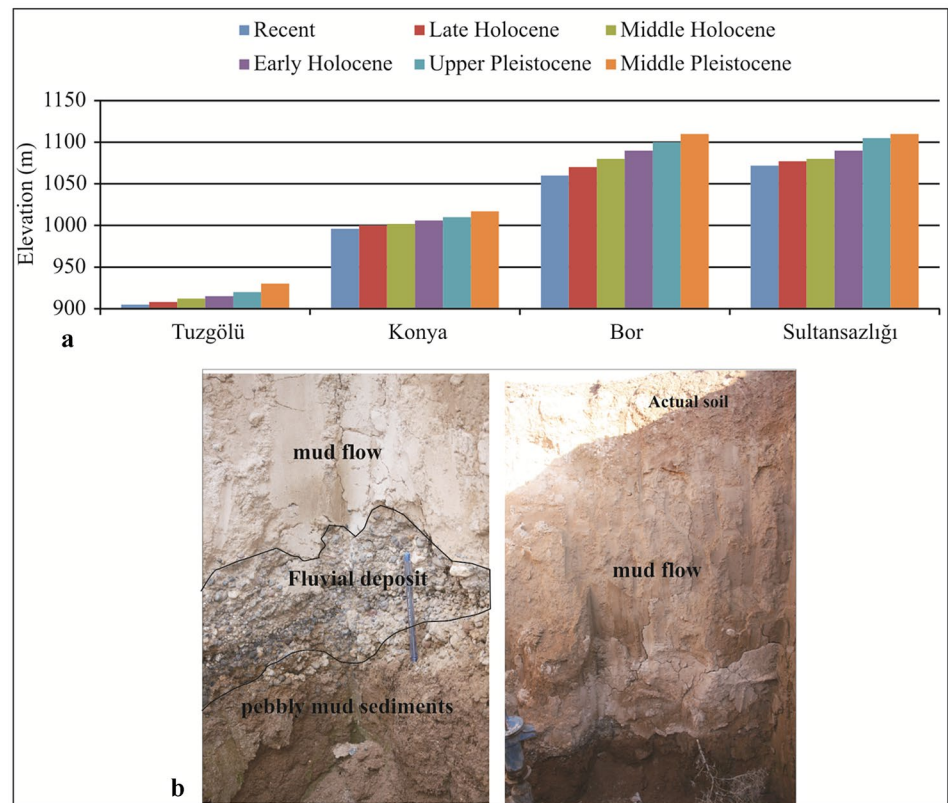
dry periods (when the lake level was low due to high evaporation). This is related to the fact that the plain surface is more suitable for walking upon, due to the retreat of surface water, during dry periods.

The best example of this is the Tuwana settlement (now named "Kemerhisar"). A double site was found in the area where Kemerhisar (now a small town) is located. One of the sites is Tuwana ancient settlement. Another is found on Ambar Hill, which was an earlier occupation, located to the northwest of Kemerhisar. The evidence at Tuwana is more complex. Archeologists consider that the findings discovered under ruins dating to the Hellenistic, Roman, and Byzantine periods are from the pre-Classical age (Rosada and Lachin 2010). Our opinion is that the earliest occupation was on Ambar Hill. Findings dated to the Late Hittite Period were found on this site (Çınaroğlu 1987). This hill was probably occupied from the Classical age to the Hellenistic period, and then deserted. A site (e.g., late Hellenistic) was established on the surface of the plain, which is the current location of Tuwana. There is no evidence as to why the site on Ambar hill was deserted. However, we can suggest that past societies who lived on the hill moved down to the plain during the Early Hellenistic period due to retreat of the lake waters.

Thus, past societies could easily walk along the bottom of the plain. A settlement was established on high land (Ambar Hill) due to occasionally rising (transgression) of the lake

level before this period. This implies that the site could have moved from the higher land to the flat surface of Bor Plain (Çınaroğlu 1987).

The general recession of the lake was interrupted by a number of minor transgressions (Fig. 8b). Sediments with small round gravels between two mud deposits were mass/ sediment gravity flows in character; these deposits include a matrix that supported gravel and pebbly mud sediments transported by gravity, representing subaerial deposition by cohesive debris flow and pebbly mud flows on the alluvial fan environment that developed along the basin's margin at the foot of Mt Melendiz. Following deposition, the overlying fluvial sediments indicate recession of the lake level. This was followed by another transgression corresponding to the 1080 m level. According to archeological findings, the increase in lake level occurred either before Early Bronze Age II or after the Late Roman period. Both fluvial and lacustrine phases of the accumulation must therefore represent climatic fluctuation.

The main streams and tributaries from Mt. Melendiz flowed together into the lake to the north of Kayı village and Çıplaktepe mound near to Kayı village. This area was completely covered by lacustrine deposits consisting of sandy sediments deposited by a probably shallow Holocene lake including waves and currents. However, these drainage systems are now completely dried up. There are numerous water supplies such as streams and their tributaries at the

back of these mounds, from Mt. Melendiz. The Holocene valley bottoms testify to the presence of spring water around the mounds, utilized for agriculture, even during dry periods. During this period, the population mainly preferred to live at a distance of 1100–1090 m from the water supplies in hill settlements. In other words, even if the lake water receded, a water supply was available near the settlements for the survival of crops. The Köşk mound is found at the back of the Roman pool fed by a water spring and at an elevation of 1150 m, suggesting the presence of a water spring near the mound—essential for the survival of settlements—even during a dry climate. Ten mounds in the northern part of the plain were partially covered by lake deposits (Fig. 9). After the lake retreat phase, in which the Early Bronze Age settlements began to be established, the blocks and large pebbles were covered by calcrete. In this area, all surface materials of the ten sites can be dated to either before Early Bronze Age II or after the Late Roman period (D'Alfonso 2010).

Age and mineral content based on XRD

Small changes in climate resulted in major changes in geomorphological processes (i.e., erosion, runoff, etc.), fluctuations of lake level and sediments deposited in the Bor Plain. Location 1 (L1 of location shown in Figs. 1 and 2) corresponds to the bottom of the plain and includes lake bottom sediments representing stages of regressive events in the lake-level changes. The mean elevation of the locality is 1070 m asl. It was examined reached to a depth of 2 m from the bottom by a hand drill from the bottom of the plain. The C^{14}age of samples taken from depths of 145 cm and 180 cm was 6776 ± 35 cal yr BP and 9867 ± 39 cal yr BP, respectively.

The mineral content of four samples taken from this lacustrine deposit was examined. Its sediments comprise detritic minerals. The assemblage of clastic minerals contains augite, calcite, muscovite, goethite, and cristobalite. K-feldspar is present in trace amounts and less than 6% (Fig. 9a). Augite is present and the maximum values are in all parts of the core vary between 42 and 56%. Augite is followed by calcite and muscovite and their value varies from 14 to 20% and 11% to 19%, respectively. Values of

cristobalite and goethite vary from 5 to 10% and from 7 to 10%, respectively. Augite abundance in the lower part of the core implies an increase in clastic flux. The $CaCO_3$ ratio is 53% at 180 cm, 31% at 145 cm, 34% at 100 cm and 29% at 70 cm. The TOC ratio could not be determined at 180 cm and 145 cm (Fig. 10a). However, this ratio increases slightly and is 1% at depths of 100 cm and 70 cm. Palygorskite is the most dominant clay mineral followed by sepiolite, chlorite, kaolinite, and illite. Values of palygorskite range between 55 and 58%. It increases at 100 cm up to values as high as 58%. Values of sepiolite range between 15 and 17%. The presence of sepiolite in this part is an indication of significant evaporation. Chlorite, illite, and kaolinite are other dominant clay minerals. The presence of chlorite, kaolinite, and illite varies from 11 to 13%, 9% to 10%, and only 6%, respectively (Fig. 10b). Quartz is less than 5% and is found in trace amounts.

Location 2 (L2) is found in the area called "İftiyan" located between the Bor and Kemerhisar settlements (see Figs. 1 and 3 for location). This site is located between 37°51′33″–37°51′23″ north and 34°35′10″-34°35′12″ east. L2 is a cliff consisting of a lacustrine deposit located immediately behind the mounds. The deposit is interpreted as a lacustrine terrace marking the former extent of a now desiccated Late Pleistocene lake. The mean elevation of L2 is 1125 m. The lowest part of the Bor Plain is 1050 m. The deposit consists completely of lacustrine layers. Calk-tuff is found between the lacustrine layers. The deposit consists of an intimate mixture of clay and calcite. The thickness of this deposit is about 5 m. L2 is formed substantially of calcite which is 53% of the total mineral assemblage. Other minerals found are muscovite (15%), phillipsite (12%), cristobalite (11%), and plagioclase (10%) (Fig. 11). The dominant clay mineral is palygorskite (72%), and the other clay minerals formed are sepiolite (16%), illite (8%), and kaolinite (4%). The age of this sample was determined as 75 ± 13 ka (end of MIS 5a) using OSL analysis. A high rate (above 50%) of calcite, palygorskite, and $CaCO_3$ and a low TOC value indicate the presence of an aridification phase at this level.

Fig. 9 Late Holocene regression traces and rocks covered by calcrete after regression due to drought near Balcı mound situated between 34°26′55.86″ E and 37°55′45.87″ N (UTM, ED50, Zone 36 N)
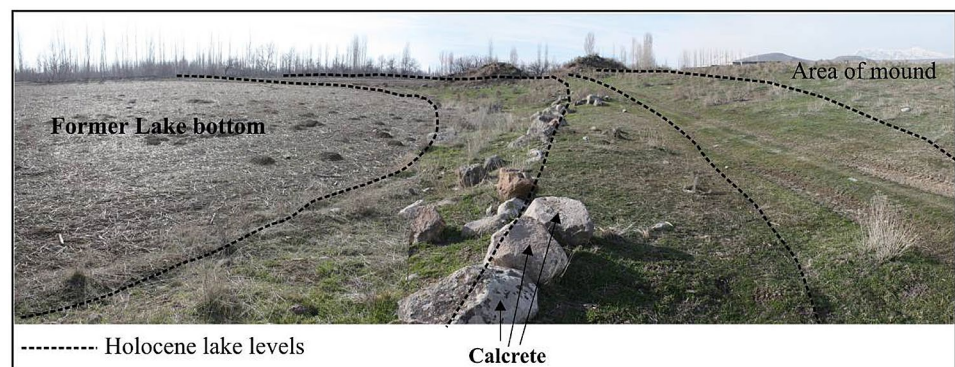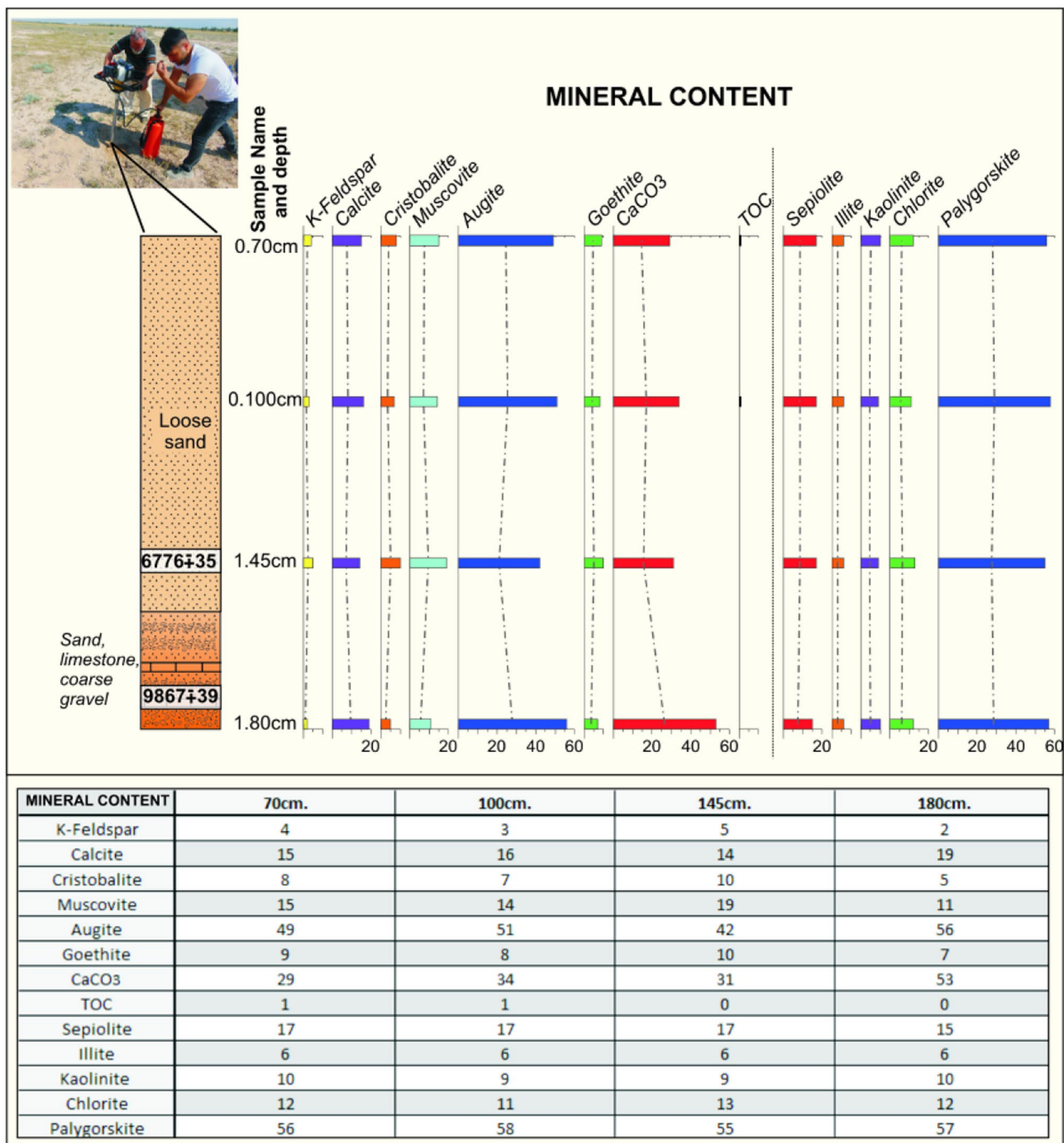
Fig. 10 **a** L1 samples obtained from first 2 m using drilling equipment at bottom of plain; **b** stratigraphy, mineral content, and C[14] age from drilling core of lacustrine sediments obtained at this level

| MINERAL CONTENT	70cm.	100cm.	145cm.	180cm.
K-Feldspar	4	3	5	2
Calcite	15	16	14	19
Cristobalite	8	7	10	5
Muscovite	15	14	19	11
Augite	49	51	42	56
Goethite	9	8	10	7
CaCO3	29	34	31	53
TOC	1	1	0	0
Sepiolite	17	17	17	15
Illite	6	6	6	6
Kaolinite	10	9	9	10
Chlorite	12	11	13	12
Palygorskite	56	58	55	57

Palynoflora of the Bor Plain

In this study, two palynofloras were identified from the samples of Locations 1 and 2 (see Figs. 1 and 2 for location). Despite the existence and dominance of the coarse clastic sediments in these locations, the samples collected from the thin clay levels include palynomorphs for the palaeovegetational and palaeoclimatic interpretations (Figs. 12 and 13).

The first microflora of Location 2 was recorded from the sample (L2) collected from the İftian area. The collected sediments of the L2 sample were deposited at the end of the MIS 5a period (end of MIS 5) based on the OSL analysis

Fig. 11 Percentage of minerals according to x-ray patterns of < 250 μm fraction in ~ 2 m for L2 paleolake sediment sequence. CaCO₃ and TOC percentages in this sediment
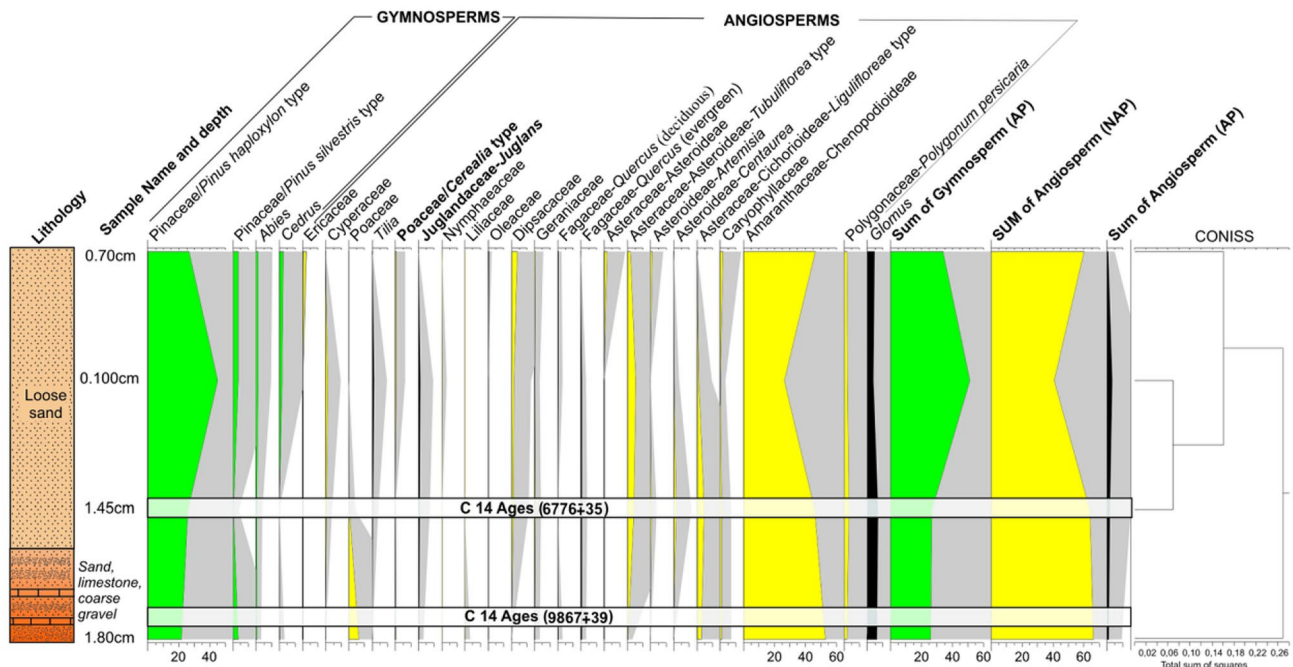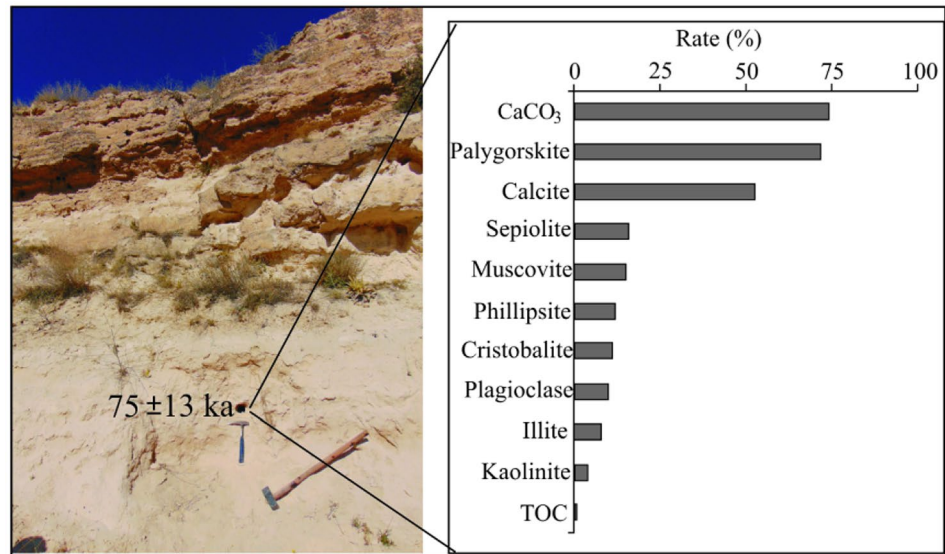

Fig. 12 Simplified pollen diagram showing distribution of main pollen types for the Location 2 in the Bor Plain

results (75 ± 13 ka). The identified palynoflora of the L2 sample is not diverse; however, the percentage abundance of the pollen is high. The main pollen type is Pinaceae-*Pinus haploxylon* type and it is abundantly recorded in the sample. Ephedraceae of the NAP (non-arboreal pollen) pollen grains was identified in moderate abundance in the L2 palynospectra. Additionally, Amaranthaceae-Chenopodioideae, and Ranunculaceae-*Thalictrum* of the NAP have a high percentage and are observed with Ephedraceae. Besides, Asteraceae/Asteriodeae, Oleaceae, and Fagaceae-*Quercus*

evergreen type are less percentage, and these are accompanied by gymnosperm and herbaceous angiosperm pollen. *Glomus*, which is a non-pollen palynomorph (NPP) that indicates the presence of erosional areas, was identified in abundance, and this palynomorph is accompanied by a moderate abundance of algal forms.

The other microflora of Location 1 was obtained from the samples collected from the 1.80 m sedimentary sequence (see Figs. 1 and 2 for location). All samples are composed of diverse palynoflora and have a high percentage of
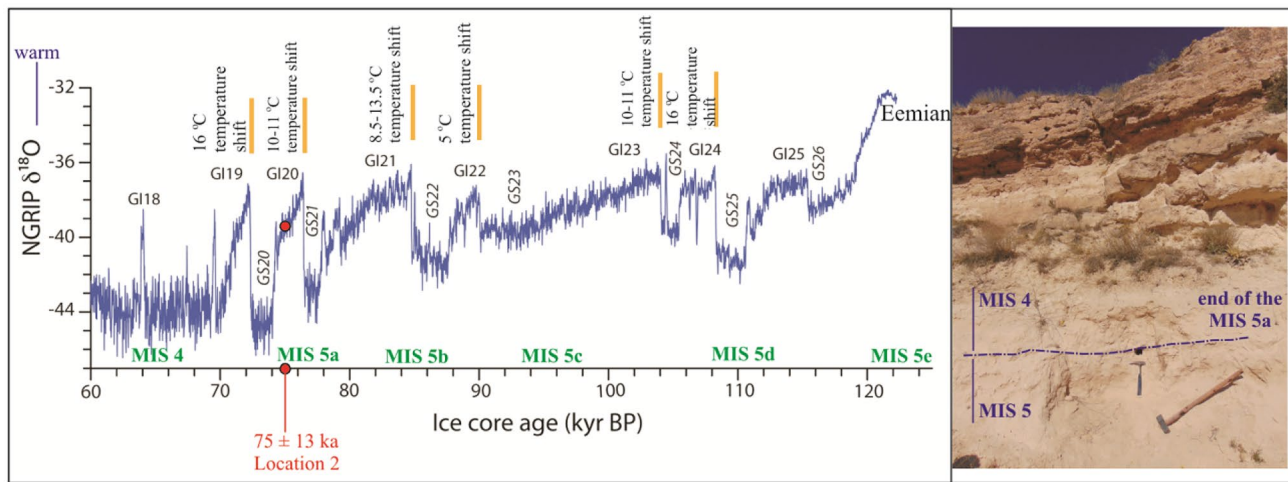
Fig. 13 δ18O record of Greenland ice core NGRIP between 60 and 125 ka. Original data given by Wohlfarth (2013), and sample location (red dot of Location 2)

abundance (Fig. 12). Palynoflora in the lower part of the section indicates a difference from the middle and upper parts. The claystone sample of 1.80 cm, which was deposited in 9867 ± 39 yr BP, is represented abundantly by Pinaceae-*Pinus haploxylon* type of the gymnosperm pollen (20%) and Amaranthaceae-Chenopodioideae of the NAP (~55%) (herbaceous angiosperm pollen). Additionally, Pinaceae-*Pinus silvestris* type, *Abies,* and *Cedrus* of the gymnosperm pollen are less abundant in the palynoflora. The angiosperm pollen are not rich in the sample and these are characterized by the less abundant Poaceae, Cyperaceae, Geraniaceae, Asteraceae/Asteriodeae Tubulifloreae type, Asteraceae / Cichorioideae ligulifloreae type, Caryophyllaceae, and *Polygonum persicaria* (Polygonaceae) of the NAP pollen and Juglandaceae-*Juglans,* Fagaceae-*Quercus* evergreen and deciduous types of the AP pollen grains. In addition, *Glomus* of the NPP was recorded (Fig. 12).

The palynoflora of the sample collected in the section at 1.45 cm (6776 ± 35 yr BP) indicates slight differences of the palynoflora compared to 1.80 cm (Fig. 12). The main types of this sample are Pinaceae-*Pinus haploxylon* type of the gymnosperm pollen (~25%) and Amaranthaceae-Chenopodioideae of the NAP (~50%). The gymnosperm and angiosperm pollen (AP) diversity of the 1.45 cm sample significantly decreases, and these are represented by low percentage of *Abies*, Pinaceae-*Pinus silvestris* type, Juglandaceae-*Juglans,* Fagaceae-*Quercus* evergreen, and *Tilia*. In samples from this level, the percentages of herbaceous pollen (Poaceae, Cyperaceae, Geraniaceae, Asteraceae/Asteriodeae tubulifloreae type, Asteraceae /Cichorioideae liguliforeae type, Asteraceae-*Centaurea*, Amaranthaceae-Chenopodioideae, Caryophyllaceae, and *Polygonum persicaria*) increase. The percentage abundance of *Artemisia* also increased relatively and reached its highest value, and also

the *Ceralia* type (Poaceae) is not observed in the palynospectra (Fig. 11). *Glomus* of the NPP was observed.

Toward the upper part of the Sect. (100 cm), the microflora drastically changes. The maximum value of the Pinaceae-*Pinus haploxylon* type of the gymnosperm pollen (~50%) and minimum value of Amaranthaceae-Chenopodioideae of the NAP (~25–30%) were recorded in the sample at 100 cm. Besides this, other gymnosperm pollen species consisting of the Pinaceae-*Pinus silvestris* type, *Abies* and *Cedrus* have low values, and these pollen species are accompanied by *Pinus haploxylon* type. Additionally, the AP pollen grains of the angiosperms represented by *Tilia*, Juglandaceae-*Juglans*, Fagaceae-*Quercus* evergreen and deciduous types are of low percentage in the palynospectra at 100 cm. Herbaceous species of the NAP are diverse and abundant in the palynoflora, and these are characterized by Cyperaceae, Geraniaceae, Nymphaceae, Asteraceae/Asteriodeae tubulifloreae type, Asteraceae /Cichorioideae liguliforeae type, Asteraceae-*Artemisia,* Asteraceae-*Centaurea*, Amaranthaceae-Chenopodioideae, Caryophyllaceae, and *Polygonum persicaria*. Besides this, the *Cerealia* type (Poaceae) was recorded at this level. *Glomus* of the NPP was identified (Fig. 12).

At the end of the Sect. (0.70 cm), the percentages of gymnosperm pollen (Pinaceae-*Pinus haploxylon* and *silvestris* types, *Abies* and *Cedrus)* decrease. However, the maximum values of the Pinaceae-*Pinus silvestris* types, *Abies,* and *Cedrus* were reached at this level sample. The main pollen type of the NAP is Amaranthaceae-Chenopodioideae (40–50%), as in the other samples. Besides this, other herbaceous pollen species characterized as Ericaceae, Geraniaceae, Dipsacaceae, Asteraceae/Asteriodeae, Asteraceae/Asteriodeae tubulifloreae type, Asteraceae-*Artemisia*, Amaranthaceae-Chenopodioideae, Caryophyllaceae, and

Polygonum persicaria were identified in the palynoflora (Fig. 12). The AP pollen species of the 0.70 cm sample are only represented by Oleaceae, Fagaceae-*Quercus* evergreen and deciduous types. Additionally, the *Cerealia* type (Poaceae) was recognized at this level. *Glomus* of the NPP and a high percentage of fungal spores, cuticle pieces, and zooclasts were also recorded.

Discussion

Mineralogical content and indicators of environmental changes

A variety of clay minerals that are commonly found in modern continental saline environments and clays also form a considerable portion of the sedimentary successions accumulated under evaporitic conditions in continental settings of the past (Calvo et al. 1999). Quantitative analysis of the mineral content of carbonated sediments allows us to produce additional data in evidence of parallel or non-parallel time variations of the proportions of the sediment components, which may behave in-phase, out-of-phase, or independently from one another (Kuzucuoğlu et al. 1999). Inoue et al. (1998) suggest that a high value of calcite indicates less saline waters and a smaller extent of evaporation in the Konya Basin. Calcite precipitation is usually attributed to periods having a high water level and low rates of evaporation (Landmann et al. 1996). Solotchina et al. (2009) suggest that sediments from the last glacial contain carbonates, signifying a positive trend in the lake's water budget, for instance, that Lake Hovsgol in Mongolia. A similar condition was observed in Konya Basin. During wetter periods, the carbonate mud flats surrounding the lake flooded and the lake possibly expanded to the full size of this basin (Kuzucuoğlu et al. 1999). Warmer temperatures lower the frost line, which promotes the weathering of clay minerals and these processes provide a higher influx of sediment and the preservation of the clay minerals in the lake's sediments (Celeste et al. 2007). Clay minerals reflect strong physical decomposition and weak chemical decomposition in the study area. The mineral content of the samples taken from the lowest part of the Bor Plain shows that the level of the lake had significantly receded in ~9800 BP (in swampy areas) and was completely dried up in ~6700 BP. The formation period of these samples corresponds to the warm period of Holocene Climatic Optimum: 9000–5000 BP.

Using this approach, the value of calcite and palygorskite in the sample of Location 2 indicates cold-dry conditions (see Fig. 11 for value of minerals). On the other hand, in the L1 sample, the amount of $CaCO_3$ and TOC from the bottom to the surface indicates that the lake level receded to form marshes and then was completely dry. In addition,

in the upper parts, suddenly increasing cristobalite values show that the temperature gradually increased in Holocene. The presence of palygorskite and sepiolite supports this condition in all levels. Palygorskite indicates the processes of evaporation and capillary attraction throughout most arid phases. The Bor Plain sediment fill reflects Holocene climatic changes. However, TOC presence at location 1 (albeit 1%) also shows sensitivity to local factors which can be explained by a low water level and variability of water input, i.e., increasing humidity leading to small transgressions. TOC reflects the amount of organic matter in the sediment. If the amount of TOC is high, it usually means high vegetation due to the humid climate, while a low amount means low vegetation due to a dry climate (Tyson 1995). An extremely low value of the total organic carbon in lake sediments is seen in hyper-arid regions (Dong et al. 2018). Thus, it can be suggested that there was a short-term wet period in the Bor Plain after 6700 BP. During wetter periods, mud flats with calcite and TOC indicate that flooding occurred around the lake and the water level of the lake possibly rose to fill the whole plain. Similar results were reported also by Kuzucuoğlu et al. (1999) in the Konya Basin (see Fig. 15 for correlation).

Such variations in both locations may be due to three possible causes: (i) primary precipitation of calcite and palygorskite. The lowest quartz values within the sequence occurred during a period of increasing aridity. This implies a transportation means linked more to run-off than to wind action; (ii) an inverse ratio between Tclay and calcite values indicates change in the climate, and (iii) the environment must have been exposed to alkaline–saline solutions in arid to semiarid climatic conditions with possible wet intervals owing to seasonal fluctuations. These fluctuations were repeated at least four times from Holocene to the present.

Palaeovegetation and palaeoclimate of the Bor Plain and correlations based on the palynology

In this study, palaeovegetational and palaeoclimatic interpretations belong to the two different time intervals of the Quaternary; the end of the MIS 5, and 10,000–5000 BP.

End of the MIS 5 period

In Greenland ice core $\delta^{18}O$ records, the high-frequency and distinct palaeoclimatic fluctuations during the last glacial period were first recorded by Dansgaard et al. (1993); also, data from the Greenland ice cores (GISP and GRIP) provided the first chronologies in which terrestrial and marine records could be compared. It was determined that during the MIS 5d-5a interval, there existed many more distinct and rapid shifts between warm interstadials and cold stadials in these cores (Grootes et al. 1993; Dansgaard et al. 1993)

than palynological and/or marine records on land (de Beaulieu and Reille 1984, Reille et al. 1998; Behre 1989). The subdivision of MIS 5 into the sub-stages MIS 5e, 5d, 5c, 5b, and 5a was separated by Shackleton (1969), and the author's stratigraphic compartmentalization is widely employed for marine sediment sequences, and correlations with terrestrial and ice core archives.

Based on the palynological data of Europe, the open vegetation with steppe elements (*Artemisia*, Poaceae, Ephedraceae, and Amaranthaceae-Chenopodioideae) is widespread during the stadials. Besides, summer temperature values during the MIS 5d and MIS 5b differ little from the MIS 5c and 5a in Europe (Klotz et al. 2004; Kühl et al. 2007). Overall, low precipitation values were recorded during the cold MIS 5d and 5b compared to the warm MIS 5c and 5a (Klotz et al. 2004; Kühl et al. 2007). In this study, the obtained age of Location 2 is 75 ± 13 ka, and also, this time corresponds to the end of the MIS 5a (Fig. 13). The abundance of Pinaceae-*Pinus haploxylon* type in the Location 2 pollen spectra could indicate the existence of precipitation in the middle and high land areas during the end of MIS 5a. However, the presence and abundance of the open vegetation with steppe elements represented by Ephedraceae, Amaranthaceae-Chenopodioideae, and Ranunculaceae-*Thalictrum,* Asteraceae/Asteriodeae could be interpreted as climatic change from the warm MIS 5a to the MIS 4. Furthermore, this transition interval in the Bor Plain could have been dry and different from the European data, based on the palynological evidence. In addition, abundantly existence of *Glomus* indicates erosion supporting the dry palaeoclimatic conditions. The high rate ($>50\%$) of palygorskite and calcite, and the low $CaCO_3$ value in the sample of Location 2, support dry climatic conditions.

Between 10,000 and 5000 BP

The autecology of palaeovegatation types in Anatolia is useful in the reconstruction of past environments. For this reason, we selected some palynomorph records from 'terrestrial' lake sediments in this study, namely, Gölhisar, Yeniçağ-Abant, Eski Acıgöl, and Van Lake. The eastern Mediterranean palynomorphs association is over-represented by Fagaceae-*Quercus* and Pinaceae-*Pinus.* Fagaceae-*Quercus* evergreen type (*Quercus ilex* and *Q. coccifera*) can tolerate the drought of summer. However, their pollen requires significant winter precipitation, and it also reacts to low winter temperatures (Roberts et al. 2011). On the other hand, Fagaceae-*Quercus* deciduous type (*Quercus cerris*-type, *Q. robur* and *Q. pubescens*) requires higher soil humidity, especially in summer, but can tolerate dry and cold winters. Gymnosperm pollen taxa [e.g., Pinaceae-*Pinus* spp., *Cedrus, Abies*, and Cupressaceae (Juniperus spp.)] are ubiquitous in Anatolia. However, some species

of these pollen taxa (e.g., *Pinus pinea*, *P. halepensis,* and *P. brutia*) are able to tolerate summer drought conditions and colder high topographic regions (*P. sylvestris* and *P. nigra*). Besides, *Abies* belongs to mountainous vegetation units (Roberts et al. 2011). Amaranthaceae-Chenopodioideae of the herbaceous pollen species are steppic indicators and these can adapt to saline and arid conditions. Additionally, *Artemisia* prefers less aridity in the environment and is cold-tolerant (Roberts et al. 2011). Pollen of the Poaceae family is well dispersed in the vegetation and the existence of these pollen species can point to spring and summer moisture. In Anatolia after the Climatic Optimum in ~ 7.000–5.500 BP, the generally noticeable progress of drought and human-based destruction, existence of different processes in different areas, observation of environmental events in different forms and intensity, and the composition of the trees vegetation has changed the diversity of species. Although forested areas have re-spread in some places, these events show that the same extent of forest as during the Climatic Optimum was not reached again.

Considering the palynological findings obtained from the samples of Bor Plain (Location 1), it can be said that Pinaceae-*Pinus* in the Bor Plain was widespread in the mid-elevation areas, although Pinaceae-*Pinus* is not recorded as abundantly as it was in the Gölhisar Lake and Yeniçağ-Abant areas in ~ 9000–7000 BP (Van Zeist and Bottema 1991; Eastwood et al. 1999, 2007; Roberts et al. 2011) (Fig. 14). The presence of *Abies*, *Cedrus,* and *Pinus sylvestris* type belonging to the gymnosperm pollen indicates the existence of high topographical areas in the environment. Also, unlike the records of Lake Van, *Pistacia,* and *Ephedra* were not identified in the Bor Basin (Van Zeist and Woldring 1978; Van Zeist and Bottema 1991; Litt et al. 2009). It was observed that in 6776 ± 35 yr BP in the Bor Plain (Holocene Optimum), the herbaceous pollen species (Poaceae, Cyperaceae, Geraniaceae, Asteriodeae tubulifloreae type, Cichorioideae ligulifloreae type, *Centaurea* and Amaranthaceae-Chenopodioideae, and Caryophyllaceae) were abundant and diversity increased. Accordingly, it can be said that herbaceous vegetation was common in low orographic areas of the Bor Plain. After 6776 ± 35 yr BP, the humidity increased relatively based on the pollen record of the sample obtained from 0.100 cm (Fig. 14). The presence of aquatic herbaceous forms such as Nymphaceae, Cyperaceae, and Ericaceae and abundant fungal spores and zooclasts indicate an increase in the water level of the lake. According to the elemental analysis of sediments deposited in these humid conditions, high TOC values support increasing humidity. As well as, the diversity of AP pollen is remarkable, and it was observed that gymnosperm pollen species were accompanied by *Juglans*, *Quercus* evergreen, and *Tilia* in middle and high topographic areas (Fig. 14). The forest represented by various plants in the Bor Plain could have developed as a result of

Location/ Reference	~ 9500-8600 BP	~8600-5200 BP	~ 5200-3500 BP
Gölhisar Lake Eastwood et al. (1999, 2007)	*Pinus* (~ 65%); remainder of zone has lower values of *Pinus, Quercus, Juniperus*. NAP incudes Compositae, Gramina and ferns. Cyperaceae (~15%) and *Glomus*; ~ 40%. (Low to high AP: 25-70%).	*Pinus* (30-70%); *Quercus cerris*-type (~5-10%), *Q. coccifera*-type (~10-20%), *Juniperus* (~5-10%), *Artemisia* (~5%), Chenopodiaceae (~5-15%), Gramina (~10-30%), *Cerealia* type (~5 %). (High and fluctuating AP: 60-80%).	*Pinus* (~ 60%); *Q. cerris*-type (~5-10%), marked decrease in *Q.coccifera*-type (~ 5%) and *Juniperus* (~ 3%). *Cedrus* (~5%), Gramineae (~10-15%), ferns (~15%). (High AP: 70-90%).

Location/ Reference	9000 BP		~3300 BP
Gölhisar Lake Roberts et al. (2011)	Conifer-dominated forest (*Pinus, Juniperus, Cedrus, Abies*) along with some *Quercus*.		Deposition of the Santorini tephra layer, there is a clear increase in pollen types associated with anthropogenic activity such as arboriculture

Location/ Reference	12,000-6500 BP	6500-4500 BP	4500-4000 BP
Eski Acıgöl Roberts et al. (2001, 2011)	Steep rise of Gramineae and a significant decline of *Artemisia*/Chenopodiaceae point to increased moisture supplied in the growing season.	AP species, in particular *Quercus* and *Corylus*, were fairly common.Hazel and some other mesic arboreal taxa decline, although the expansion of oak woodland continues to the top of zone 3 after which it is immediately followed by a marked and permanent decline. Maximum AP values, comprising *Quercus* and *Corylus* were not achieved until ~5300 BP.	Pinaceae-*Pinus* becaomes the dominant arboreal pollen taxon, assciated with increases in steppic herbs, notably *Artemisia*, Compositae and chenopods. At present no pine species are growing in the area. Overgrazing and felling of trees for timber and fuel have presumably led to lower pollen production in the catchment of the lake and caused the overrepresentation of pine pollen carnied by longdistance airborne transport.

Location/ Reference	~ 10,320-6900BP	~6900 BP-Present	
Yeniçağ and Abant lakes Van Zeist and Bottema (1991)	At the beginning of the Holocene (~10,000 BP), the increase in temperature combined with the increase in humidity prevented the re-propagation of the steppe by the expansion of the forest. The steppe eas replaces by *Quercus-Juniperus* woodlands with low herbaceous pollen content. The conifer forest (*Abies, Pinus*) became widespread during this period. In the next zone, various deciduous tree species such as *Fagus, Corylus, Carpinus betulus* are seen and in the period of 7300-6900 BP, cool-deciduous forest (*Ulmus, Fagus, Corylus, Carpinus betulus*) partially replaces the conifers (*Abies, Pinus*).~9000 BP initially deciduous forests containing *Acer, Ulmus, Quercus, Carpinus betulus* and *Corylus* already existed, conifers containing *Pinus* and *Abies* are locally important in the higher elevations.	Increase of *Pinus nigra* between 6900 BP and 4500 BP and *Quercus* spp.the dominant forest, the *Fagus-Abies*, is found naturally at higher altitudes and *Pinus sylvestris* at the altitude close to the upper tree border.*Cerealia* type pollen values are relatively high and the presence of *Plantago lanceolata* type reflects grazing. Forest vegetation (partly *Pinus* increased) is partially regained and the appearance of vegetation is shaped by the spread of *Pinus, Quercus, Juniperus* woodlands in the Yeniçağ and Abant areas. The appearance of *Olea* and *Quercus calliprinos* of Mediterranean origin constitutes another evidence of human influence. Mixed *Abies-Fagus* forest at~8000-4000 BP.	From ~3700 BP, there is a significant decrease in other mesic trees and *Abies* and an increase in mainly deciduous *Quercus* and conifers (mainly *Pinus*).

Location/ Reference	9800-6400 BP	6400-3400 BP	
Van Lake Van Zeist and Woldring (1978), Van Zeist and Bottema (1991)	The high herbaceous pollen abundance indicates the presence of steppe and desert-steppe conditions. Its mountainous part is afforested with *Quercus, Pistacia* and *Betula*, Chenopodiaceae dominates,and *Artemisia*, Poacea, Compositae and Umbelliferae accompany it. Observation of *Ephedra* abundantly (desert-steppe) and domination of probable desert-steppe vegetation with the abundance of *Artemisia* and Chenopodiaceae.	AP pollen abundance gradually increases and forest vegetation becomes widespread. Graminea replacing Chenopodiaceae and *Artemisia*, which dominate the herbaceous ground cover. The proliferation of *Qurcus, Acer* and *Betula*, especially *Pistacia*, the development of forest-steppe vegetation first in the area and then the spread of *Quercus* in this forest.	

Location/ Reference	11,000-6000 BP	6200-4000 BP	4000 BP-Present
Van Lake Litt et al. (2009)	The excessive increase in Ephedra represents the beginning of the climatic deterioration in the "Younger Dryas", and its duration can be dated as 11,620-10,460 BP. The Early Holocene environment was defined by the high herbaceous (Germineae and other herbaceous) content including steppic indicators, together with the significant abundancen of *Pistacia*. During the Early Holocene, dry spring and summer and summer weather conditions, high steppe-fire probabilities caused a 3000-year delay in the expansion of deciduous *Quercus* forests, with a maximum *Quercus* spread of~6000 BP.	The high *Quercus* abundance, forest-steppe maximum expansion, and 5000 BP *Juniperus* spread.	After 4000 BP, drought incresed again and current climatic conditions were established. It is revealed that 3800 BP started and the change in vegetation with increased human influence in the last 600 years is reflected by the high abundance *Juniperus*, decrease of *Quercus*, the appearance of *Juglans*, and an inrease in herbaceous and *Plantoga lanceolata*.

Location/ Reference	9867 ± 39yr BP	6776 ± 35yr BP	~6000 BP-Present
Bor Plain (This study)	Abundantly Pinaceae-*Pinus* haploxylon type of the gymnosperm pollen (20%) and Amaranthhaceae-Chenopodioideae of the NAP (~55%). *Pinus sylvestris* type, *Abies* and *Cedrus* are less abundant. Less abundant Poaceae, Cyperaceae, Geraniaceae, Asteriodeae Tubulifloreae type, Cichorioideae ligulifloreae type, Caryophyllaceae and *Polygonum persicaria* of the NAP pollen and *Juglans, Quercus* evergreen and deciduous types of the AP pollen grains.	The main types are *Pinus haploxylon* type (~25%) and Amaranthaceae-Chenopodioideae of the NAP (~50%).The less percentage of *Abies, Pinus sylvestris* type, *Juglans, Quercus* evergreen and *Tilia*. Percentage of the herbaceous pollen (Poaceae, Cyperaceae, Geraniaceae, Asteriodeae tubulifloreae type, Cichorioideae ligulifloreae type, Centaurea, Amaranthaceae-Chenopodioideae, Caryophyllaceae and Polygonum persicaria) increased.	The percentages of *Pinus haploxylon* and sylvestris types, *Abies* and *Cedrus* decrease. The maximum values of the Pinus silvestris types, *Abies* and *Cedrus* obtained. The main type pollen of the NAP is Amaranthaeceae-Chenopodioideae (40-50%). Ericaceae, Geraniaceae, Dipsacaceae, Asteriodeae tubulifloreae type, *Artemisia*, Amaranthaceae-Chenopodioideae, Caryophyllaceae and *Polygonum persicaria* are defined. Sporadically *Cerealia* observed.

Fig. 14 Sporomorph composition of selected areas (Gölhisar Lake, Eski Acıgöl, Yeniçağ-Abant, Van Lake, and Bor Plain)

the favorable climatic conditions observed in the Holocene Optimum period.

In general, according to the palynological results of the Bor Plain, the diversity of gymnosperm pollen indicates similarities with records from other areas. However, the AP pollen diversity is very low in the Bor Plain and different from the gymnosperm pollen. An abundance of the *Quercus* form was not recorded in all the samples from the Bor Plain.

In addition, the presence of *Glomus* throughout the section, and its occasional increase, indicates the presence of erosion. The existence of erosion is supported by the abundance of kaolin in Location 1. The sporadic presence of *Cerealia* pollen and lesser amount of *Juglans* in the palynoflora of after 6776 ± 35 yr BP indicates human effects. In addition, the fact that the *Ceralia* form cannot be abundantly included in the palynoflora shows that the settlers experimented with wheat cultivation. However, they could not continue due to the lack of appropriate climatic and environmental conditions. In addition, it was observed that a dry period again started from the end of the section in Location 1, according to the existence of *Abies*, *Cedrus*, *Pinus silvestris,* and *Artemisia* after the Holocene Optimum period.

Today, the Bor Plain is completely dry and has settlements and an industrial area on its margins. It is partly used for crop cultivation, although there are unserviceable areas due to salinity on the surface of the plain.

Palaeoenvironmental conditions and implications for the vicinity of the mounds

The area of the lake started to shrink in the Early Holocene due to decreasing precipitation and increasing evaporation. The shoreline of 1006 m on the Bor Plain represents the Early Holocene-Middle Holocene transitional level, as in the Konya-Ereğli Basin (Erol 1991). According to Roberts (1979), a wedge of lacustrine sediments represents a phase of lake advance and recession up to a maximum water level of about 1006 m in Karaman sub-basin of the Konya Basin. This transition level is found between 1090 and 1080 m in the Bor Plain. The desiccated Bor Lake gradually began to shrink and experienced a marked dry period during Holocene. However, this lake did not dry out completely in this period. In the Konya-Ereğli and Tuzgölü basins, Erol (1971, 1981, 1991) observed a northerly-to-southerly direction and larger pebbles in the spits of the shorelines, as well as a southerly direction and gradually smaller pebbles on spits of the Holocene shoreline. Roberts (1979) proposed that the last major phase of high lake levels in the Konya Basin occurred between 23 and 17 ka; after 17 ka during the late glacial epoch, the basin seemed to have been largely dry. Inoue et al. (1998) suggest that the Konya Basin had a cold and wet climate in the glacial epochs and experienced a dry and hot climate in the last interglacial period and Holocene. The start of the most humid climatic phase in central Anatolia was determined as ca. 7.9 ka and this lasted until ca. 6.5 ka, which signifies the beginning of the mid-Holocene dry phase (Kuzucuoğlu 2015; Mattessi et al. 2018). However, dry conditions are more evident in the Bor Basin from ca. 6.7 ka.

In the Holocene climatic records from the eastern Mediterranean, a wet-to-dry transition phase followed the

Climatic Optimum (c. 7000–6000 yr. BP) (Kuzucuoğlu et al. 2011). This transition lasted from the sixth to third millennia BP (Roberts et al., 2011), while the development of complex societies is accelerated in parallel (Cardarelli et al. 2010). To understand the Holocene scenario of the Bor Plain and its vicinity, the geomorphic position of mounds has to be considered. Geomorphological investigations show that colluvial slopes, and alluvial and lacustrine plains characterize the area around the Kınık mound. According to Roberts et al. (1999), formation of colluvial deposits such as alluvial fan deposition led to the formation of low-energy during periods of a low lake level (e.g., during Holocene). Study of stratigraphic sections of this ancient basin on the Bor Plain in the vicinity of the village of Altunhisar highlights the presence of typical conglomerate–sand–mudstone–carbonate cycles, which are the result of lake-level fluctuations caused by periodic changes in climate over the last 8000 years (Gürel and Lermi 2010). Regarding Holocene, the environment shows a period of paleosols, marsh, and shallow lake sedimentation, which can be dated to between Chalcolithic and the Early Bronze Age (6000–5500 yr BP) (Balatti and Balza 2012), followed by a drought period characterized by calcareous-rich mud stone levels (Gürel and Lermi 2008). Similarly, the age of the settlement in the mound is dated between 6000 and 7000 BP at Tepecik Höyük, which is located in Çiftlik Plain to the north of Bor Basin. It has been determined that the plain was partly a lake, and the settlement was located on the lake shore (Bıçakçı and Faydalı 2002; Bıçakçı 2007).

In the Bor Plain, as in Konya-Ereğli Basin, there are numerous mounds dated to Early Bronze Age I (Çınaroğlu 1987; Hawkins 2000; Rosada and Lachin 2010). These mounds represent small and short-lived settlements. According to (Erol 1978), by the time the 1002 m level in the Konya-Ereğli Basin was reached, milder and drier conditions were dominant; making occupation of the flat areas possible for farming. Roberts et al. (1999) suggest that rivers entering the Konya Plain built up fan-shaped masses of alluvium during Holocene; and on the fans are found large numbers of ancient mounds which have been partly buried by Holocene alluviation. According to Boyer et al. (2006), dramatic changes to the settlements are probably associated with a cessation of local alleviation and the initiation of a new alluvial regime, most probably between Early Bronze Ages II and III, ~ 4500 cal. BP.

This suggests that the lake level may have receded from 1100 to 1080 m in Early Bronze II. In the period that followed Early Bronze II, the lake level did not rise above 1100 m. If so, the Kınık mound was deserted before the Iron Age. All the lake records indicate that the time period from 4000 to 3300 BP was a wet phase within the overall cooling and drying trend that commenced during mid-Holocene (Roberts et al. 2011). These dates correspond to periods of lake level rise and a humid climate. This

suggests a relationship between episodes of environmental change and the resulting fluctuation of lake levels with settlement distribution leading to the development of human settlements on the lake shores during specific periods and their subsequent abandonment (Ballatti and Balza 2012).

The evidence points to the climate before Early Bronze Age II being cooler and wetter than the Climatic Optimum and drier than Holocene. From this, we can infer a relationship between Neolithic settlements and the fluctuation of Holocene lake levels (Fig. 15a–e). Numerous studies (Yasuda et al. 2000; Miller 2007; Roberts et al. 1999; Karabıyıkoğlu 1999) on isotopes, pollen, geomorphological evidence, and archeological data from Konya and its immediate surroundings support the scenario of wetter climatic conditions before Early Bronze Age II. In fact, paleoenvironmental data show a sharp shift toward the end of Middle Holocene (ca. 2500–2000 BP) from a moister climate to the aridity that generally characterizes Late Holocene in the region (Balatti and Balza 2012). The nature of the Mid-Holocene climatic transition in the Eastern Mediterranean is an important issue in terms of understanding the environmental effects on early civilization in the region (e.g., Rosen 2007), and is also significant in terms of the teleconnections that control long-term change in the Mediterranean climate. Links between Eastern Mediterranean lake records and north Atlantic and Indian Monsoon climate systems have been proposed (Bartov et al. 2003; Jones et al. 2006). The relative strengths of the summer and winter seasons are also important as to whether these links have been consistent over time (Jones and Roberts 2008). According to Asouti (2009), after c. 6500 cal. BP, when diluted lake conditions dominated, there was a permanent fall in lake levels, with maximum salinity levels probably being achieved around 3000–2000 cal. BP. According to this reconstruction, during the Late Bronze and Iron ages, the plain experienced a phase of dryness (Balatti and Balza 2012).

The archeological evidence in reconstructing mid-Holocene landscape of the Bor Plain signifies a territory characterized by considerable shrinkage of the lake and recession of the lake from the 1100 mlevel, with which lacustrine deposits are associated, to a point below Kayı, Topraktepe, and Çıplaktepe mounds between an elevation of 1090 mand 1080 m. Erol (1981) suggests that there must have been at least three main advance phases and several minor oscillations during Holocene in the Konya, Tuzgölü, and Burdur basins. The present climate must be slightly drier, although probably not warmer, than the Climatic Optimum, since the prehistoric mounds and recent villages are coincidental in their distribution (Erol 1984). It can be said that in spite of limited re-advances in the lake level, the Bor Lake may have progressively receded during Holocene. According to Berger et al. (2016), the findings obtained from Kayı and Bayat

Neolithic settlements in the north of Bor Plain were followed by humid and dry climatic conditions for 9000 years.

At another drill core taken from the bottom of Bor Plain (Bayer Altın and Fagel 2015), the upper part of the drilled core is composed of dark- and light-colored mud and clay sediments and the end of this part is composed of calcrete. Figure 16 shows a correlation between the Konya and Bor basins. The characterization of the sediments indicates that the Bor Plain stratigraphy contains mud, clay, and calcrete layers from the lowest to upper strata, which reflects a Holocene climate and gradual change from wet (marshy) conditions to dry conditions. The old lake covering Bor Plain has receded to form a swamp. There are still narrow swamps to the south of Kemerhisar today.

This episode also appears in the upper part of the cores drilled in some sub-basins of the Konya Plain. A freshwater system is indicated by shells and marshy deposits in the Konya core (C^{14} dated 4.9 ka cal. BP and U-Th dated 5.5 ± 2.2 ka) (Kuzucuoğlu et al. 1999). The same results were recorded by Inoue et al. (1998). Fontugne et al. (1999) identified two phases of Holocene lake and marsh renewals, dated to 6.9–6.4 ka and 5.4–4.7 ka cal. BP. According to Kuzucuoğlu et al. (1999), the absence of a lacustrine record in the Konya Basin during the 9–6.8 ka cal. BP Holocene Climatic Optimum, which is also the time of the Neolithic population explosion with incipient domestication of cereals, possibly following natural selection of the 'tough rachis' mutation in wheat and barley by the extreme aridity of the preceding Younger Dryas (Rossignol-Strick, 1999), points to an increased effect by evaporation, possibly due to the derivation of precipitation by the Taurus orographic barrier (Kuzucuoğlu et al. 1999).

Some of the Neolithic settlements in the Bor Plain were established by the lake and some on the foot of mountains. The settlements concentrated on the lake shore show that the lakes were extremely determiner in the choice of settlement in this period. This can be clearly identified not only in the Bor Basin but also from the Neolithic and Early Chalcolithic Period settlements of the surrounding regions. The edges of many pluvial lakes were also selected as living areas in Hacılar, Suberde, Erbaba, Can Hasan III, Çatal Höyük, and Aşıklı mounds located in the Central Anatolian Plateau and Lakes region (Western Taurus) (Mellart 1967; Erol 1997; Kuzucuoğlu 2002, 2013; Dedeoğlu 2008; Kuzucuoğlu et al. 2018a; Kuzucuoğlu, 2019). According to Erol (1997), the Late Pleistocene and Mid-Holocene segments of the basins located in Central Anatolia and the Lakes regions are covered with fertile farmland, occupied by ancient villages dating mostly from Early Bronze Age. The main reason for this situation is that, after the Paleolithic Age, due to the warmer and drier climatic conditions, with the recession of the water levels of the lakes and the change in the coastal lines, fields suitable for agriculture were opened to
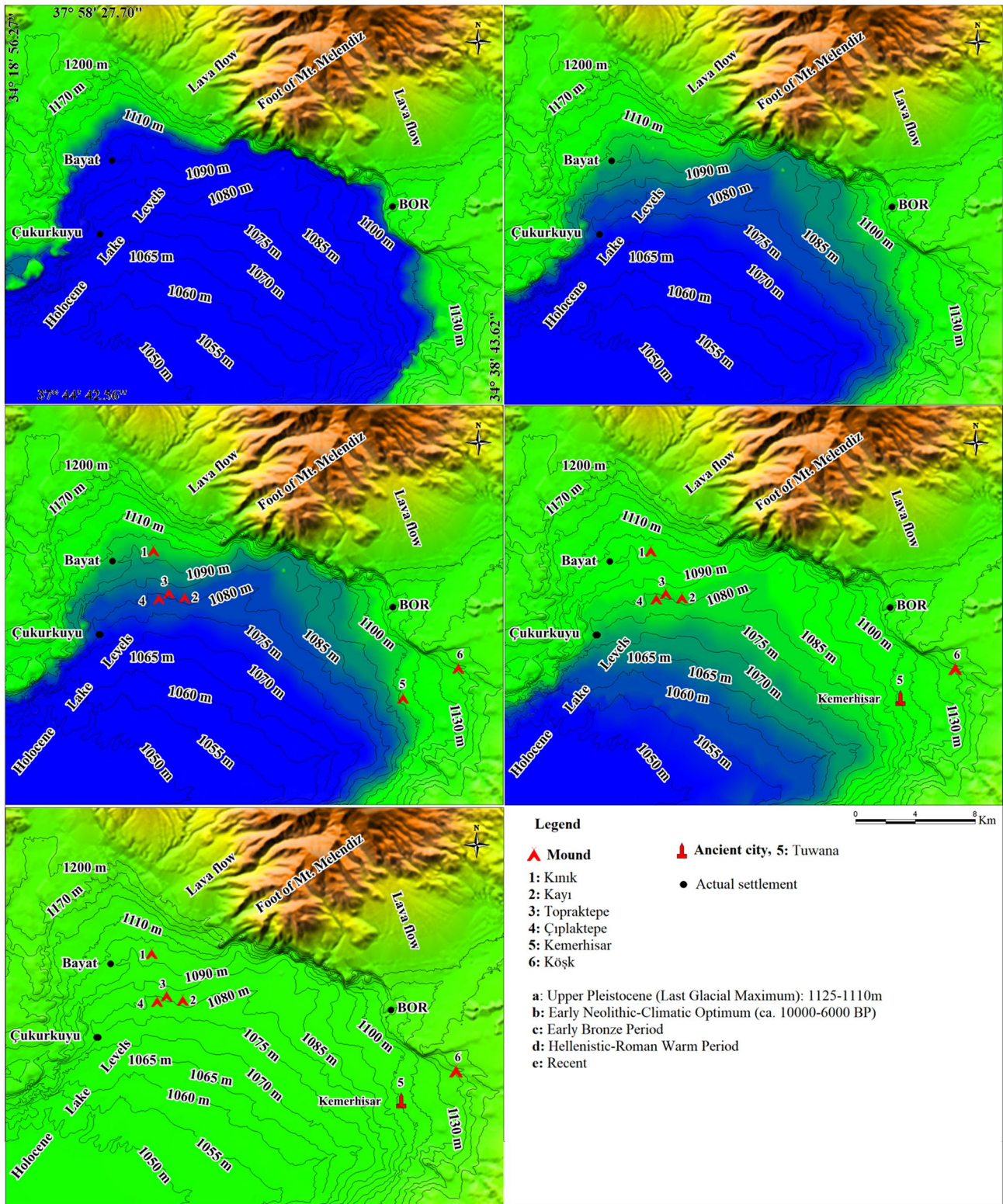
Fig. 15 Recession and re-advance periods of Bor Lake from Upper Pleistocene to recent times. Location of mounds and relationship between mound and Holocene lake levels. This area is situated between 34°18′50.27″ E, 34°38′43.62″E, 37°58′27.70″ N and 37°44′42.56″ N
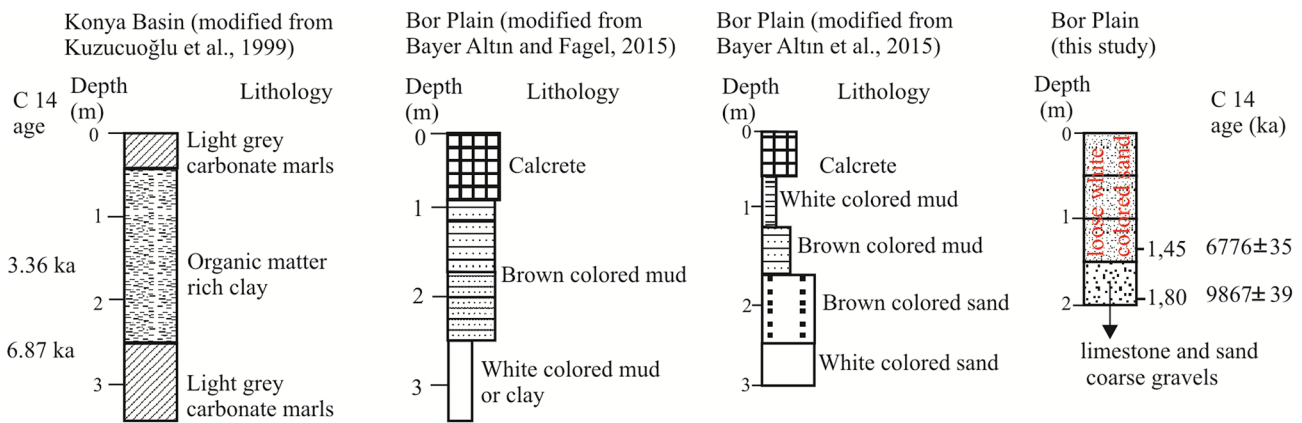
Fig. 16 Lithologic and chronostratigraphic comparison of Konya Basin (Kuzucuoğlu et al., 1999) and Bor Plain sediments

settlement. Increased erosion at Holocene periods in the plain, or accelerated aggradation in smaller catchments, is thus related partly to the Late Holocene climatic desiccation, but also to the increasing impact of human activities such as land-use practices on landscape during the Mid-Holocene as in the Konya Basin and Euphrates Valley (Kuzucuoğlu and Mouralis 2004; Kuzucuoğlu 2019). In this study, we argue that distributions of Neolithic settlements were well predicted by a combination of ecological reliability and lake terraces knowledge during the Mid-Holocene when climate and shorelines were still moving. The relationship between lake terraces and neolithic settlements will make an important contribution to archaeological studies.

Conclusions

The Bor Plain was covered by a wide and deep lake in Middle Pleistocene (MIS 5). The regression of the lake began in the transition from Middle Pleistocene to Upper Pleistocene. The regression continued until the end of Holocene, with less obvious oscillations. The lowest shore corresponding to Upper Pleistocene was between 1100 and 1110 m. This resulted in the formation of terraces in the second phase and the lake level reached approximately 60–40 m. After this phase, the lake retreated significantly in Late Pleistocene–Early Holocene. At the beginning of Holocene, the lake was at a level of 1075–1085 m and reached a depth of 20–25 m. A dry period occurred, representing intense evaporation of the lake, and there was a significant decrease in lake level. However, this lake was still a swamp in 9000–7000 BP. Since 6700 BP, a suitable environment formed for the establishment of mounds when the lake completely and rapidly dried up.

Thus, we demonstrated a relationship between lake-level changes and Neolithic sites. From geological and geomorphological investigation of sediment cores from the bottom of the lake occupying Bor Plain, covering 6700 cal. BP, it can be concluded that the sediments in the lake are highly sensitive records of short-term climatic changes during Holocene in southern Central Anatolia. Differences in humidity led to significant changes in the lake level, weathering, and fluvial input, clearly reflected in the geomorphological (terraces) and mineralogical proxies, i.e., Tclay, calcite, cristobalite, and palygorskite. In particular, changes in the amount of these minerals indicate an alternation of cycles between wet and dry periods. Occurrence of a marshy surface coincided with Neolithic occupation. Palynological analysis has shown that it is no coincidence that Neolithic societies settled in the Bor Plain. The presence of *Abies*, *Cedrus,* and *Pinus sylvestris* type belonging to gymnosperm pollen indicates that mountainous areas surrounding Bor Plain were covered with forests consisting of these trees in 10,000–9000 BP.

The old Bor Lake receded toward an elevation of 1100 m, and then, Early Neolithic sites are found on the plain surface between 1100 and 1090 m. These sites, dating from the beginning of the sixth millennium, must have been established after the formation of terraces at an elevation of 1100 and 1090 m. After this period, recession of the lake was accelerated by drought. A new alluvial regime began after ~4500 cal. BP that was characterized by less marshy conditions. The long-term climatic trend during the past ~6700 years is toward more arid conditions. This is also reflected in palynological findings. The sporadic presence of Cerealia pollen in Ceralia form and less abundant Juglans in the palynoflora indicates human influence; wheat cultivation was attempted after 6776 ± 35 yr BP.

Short-term climate oscillations occurred in this period, comprising three expansions (rise of lake level) and four recession phases of variable length. The recession phases were during the Early Neolithic–Early Bronze I

(6500–5500 yr BP), Early Bronze II (Late Neolithic), Climatic Optimum, and Roman warm period. The expansion phases were before Early Bronze II and after the Roman warm period (see Fig. 15d, e). This means that recessions of the lake were not continuous and sometimes expansions took place. The lake paused at 1100, 1090, 1080, 1070, and 1060 m for a long time and then gained its present condition, i.e., as a plain. In addition, Bor Lake dried up later than the Konya Lake and volcanic activity, continuing until Holocene, contributed to the lake's drying up. The Bor Plain was preferred by Neolithic societies from the Early Bronze Age and during Early Holocene and Mid-Holocene depending on recession phases of the lake due to the availability of fertile farmland.

References

Adams J, Maslin M, Thomas E (1999) Sudden climate transition during the Quaternary. Prog Phys Geogr 23(1):1–36

Asouti E (2009) The relationship between Early Holocene climate change and Neolithic settlement in Central Anatolia, Turkey: current issues and prospects for future research. Documenta Praehistorica 26:1–5

Atabey E, Göncüoğlu CM, Turhan N (1990) 1/100,000 Scale Geology Map, Kozan-J19 section of the map. General Directorate of Mineral Research and Exploration Publish, Ankara

Ayala G, Wainwright J, Waller J, Hodara C, Lloyd JM, Leng M, Doherty C (2017) Palaeoenvironmental reconstruction of the alluvial landscape of Neolithic Çatalhöyük, central southern Turkey: the implications forearly agriculture and responses to environmental change. J Archaeol Sci 86:30–43

Baird D (2002) Early Holocene settlement in central Anatolia: problems and prospects as seen from the Konya Plain. In: Thissen L, Gerard F (eds) The Neolithic of Central Anatolia. Internal developments and external relations during the 9th-6th millennia cal. BP. Ege Yayınları, Istanbul

Baird D (2007) The Boncuklu project: the origins of sedentism, cultivation and herding in central Anatolia. Anatolian Archaeology 13:14–17

Baird D (2012) The Late Epipaleolithic, Neolithic and Chalcolithic of the Anatolian Plateau, 13,000–4000 BC. In: Potts DT (ed) A companion to the archaeology of the ancient Near East. Wiley-Blackwell, Malden

Balatti S, Balza EM (2012) Kınık Höyük and Southern Cappadocia (Turkey): geo-archaeological activities landscapes and social spaces. In: Hofmann R, Moetz FK, Müller J (eds) International Workshop on socio-environmental dynamics over the last 12,00 years the creation of landscape II. Verlag Dr. Rodolf Habelt GmbH, Bonn

Bartov Y, Goldstein SL, Stein M, Enzel Y (2003) Catastrophic arid episodes in the Eastern Mediterranean linked with the North Atlantic Heinrich events. Geology 31:439–442

Bayer Altın T (2010) Distribution of pleteaus (Yayla) and sheep-barns according to topographic factors around melendiz and hasan mountains. Coğrafi Bilimler Dergisi 8(2):189–211 ((**in Turkish**))

Bayer Altın T, Barak B, Altın BN (2012) Change in precipitation and temperature amounts over three decades in Central Anatolia, Turkey. Atmospheric and Climate Sciences 2:107–125

Bayer Altın T, El Ouahabi M, Fagel N (2015) Environmental and climatic changes during the Pleistocene-Holocene in the Bor Plain, Central Anatolia, Turkey. Palaeogeogr Palaeoclimatol Palaeoecol 440:564–578

Bayer Altın T, Fagel N (2015) Environmental and climatic changes in the Bor plain from Pleistocene to Holocene. Report No. TUBİTAK-BİDEB2219 Project (Unpublished).

Behre KE (1989) Biostratigraphy of the last glacial period in Europe. Quatern Sci Rev 8:25–44

Berger J-F, Lespez L, Kuzucuoğlu C, Glais A, Haurani F, Barra A, Guilaine J (2016) Interactions between climate change and human activities during the early to mid-Holocene in the Eastern Mediterranean basins. Clim past 12:1847–1877

Bıçakçı E, Faydalı E (2002) Tepecik-Çiftlik 2000 studies. 23rd excavation results meeting. Ankara: Republic of Turkey Ministry of Culture and Tourism Publications. (in Turkish).

Bıçakçı E (2007) Tepecik-Çiftlik. The oldest monuments of humanity 12,000 years ago Anatolia. Karlsruhe 135–470.

Bordaz J (1969) The suberde excevations, South-Western Turkey: an Interim report. Türk Arkeoloji Dergisi XVII/2: 43–71.

Boyer P, Roberts N, Baird D (2006) Holocene environment and settlement on the Çarşamba alluvial fan, South-Central Turkey: integrating geoarchaeology and archaeological field survey. Geoarchaeology 21(7):675–698

Calvo JP, Blanc-Valleron MM, Rodríguez-Arandía JP et al (1999) Authigenic clay minerals in continental evaporitic environments. In: Thiry M, Simon-Coinçon R (eds) Palaeoweathering, palaeo-surfaces and related continental deposits. Springer, Oxford, pp 129–151

Cardarelli A, Frangipane M, Cazzella A, Peroni R (2010) Le Ragioni del Cambiamento/Reasons for Change. Scienze delle Antichità 15, Roma La Sapienza.

Celeste AA, Francus P, Brigham-Grette J (2007) Sedimentology, clay mineralogy and grain-size as indicators of 65 ka of climate change from El'gygytgyn Crater Lake, Northeastern Siberia. J Paleolimnol 37:105–122

Çinaroğlu A (1987) New Iron Age Discoveries around Niğde. Anadolu 2. IX. Excavation Results. Republic of Turkey Ministry of Culture and Tourism Publication, Ankara.

Cook HE, Johnson PD, Matti JC, Zemmels I (1975) Methods of sample preparation and x-ray diffraction data analysis. Initial Repts. Deep Sea Drilling Project Natl. Sci Foundat 38:999–1007

D'Alfonso L (2010) Geo-Archaeological Survey in Northern Tyanitis and the Ancient History of Southern Cappadocia. In: D'Alfonso L, Balza ME, Mora C (eds) Geo-archaeological Activities in Southern Cappadocia. Italian University Press, Pavia

D'Alfonso L, Mora C (2010) Viaggi anatolici dell'Universita di Pavia. Rapporto preliminare della quarta campagna di ricognizione archeologica nella Tyanitide settentrionale (2009). Athenaeum 98:569–576

Dansgaard W, Johnsen SJ, Clausen HB et al (1993) Evidence for general instability of past climate from a 250-kyr ice-core record. Nature 364:218–220

de Beaulieu JL, Reille M (1984) The pollen sequence of Les Echets (France): a new element for the chronology of the Upper Pleistocene. Géogr Phys Quat 38:3–9

De Meester T (1970) Soil map of the Great Konya Basin, Turkey. Wageningen, Research Report, Agricultural University, Netherlands

Dedeoğlu F (2008) Cultural Transformation and Settlement System of Southwestern Anatolia from Neolithic to LBA: A Case Study from Denizli/Çivril Plain. In: Córdoba JM, Molist M, Pérez CM, Rubio I, Martínez S (eds.) Proceedings of the 5th International Congress on the Archaeology of the Ancient Near East, Madrid, pp 687–601.

Dhont D, Chorowicz J, Yürür T (1999) The Bolkar Mountains (Central Taurides, Turkey): a Neogene extensional thermal uplift? Geol Bull Turk 42:69–87

Dirik K, Erol O (2000) Tectonomorphological evolution of Tuzgölü and surrounding area, Central Anatolia-Turkey. Türkiye Petrol Jeologları Derneği Özel Sayı 5:27–46 ((**in Turkish**))

Dong S, Li Z, Chen Q, Wei Z (2018) Total organic carbon and its environmental significance for the surface sediments in groundwater recharged lakes from the Badain Jaran Desert, northwest China. J Limnol 77(1):121–129

Eastwood WJ, Roberts N, Lamb HF, Tibby JC (1999) Holocene environmental change in southwest Turkey: a palaeoecological record of lake ve catchment–related changes. Quatern Sci Rev 18:671–696

Eastwood WJ, Leng MJ, Roberts M, Davis B (2007) Holocene climate change in the eastern Mediterranean region: a comparison of stable isotope and pollen data from Lake Gölhisar, southwest Turkey. J Quat Sci 22:327–341

Eastwood WJ, Gümüşçü O, Yiğitbaşıoğlu H, Haldon JF, England A (2009) Integrating palaeoecological and archaeo-historical records: Land use and landscape change in Cappadocia (central Turkey) since late Antiquity. In: Vorderstrasse T, Roodenberg J (eds) Archaeology of the Countryside in Medieval Anatolia. Pihans, Leiden.

Erol O (1971) Geomorphological evidence of the recessional phases of the pluvial lakes in the Konya, Tuzgölü and Burdur basins in Anatolia. Annals of the Geographical Research Institute 3(4):13–52

Erol O (1978) The quaternary history of the lake basins of Central Anatolia and Southern Anatolia. In: Brice WC (ed) The environmental history of the near east and middle east since the late ice age. Academic Press, London

Erol O (1979) The Neogene and Quaternary erosion cycles of Turkey in relation to the erosional surfaces and their correlated sediments. Bulletin of Geomorphology 8:1–40 ((**in Turkish**))

Erol O (1980) Quaternary pluvial and interpluvial conditions in Anatolia and environmental changes especially in South-central Anatolia since the last glaciation. Ann Geogr Res Inst 9(9):5–16

Erol O (1991) The relationship between the phases of the development of the Konya-Karapinar obruks and the Pleistocene Tuz Gölü and Konya pluvial lakes, Turkey. Deniz Bilimleri Ve Coğrafya Enstitüsü Bülteni 7:5–49 ((**in Turkish**))

Erol O (1999) A geomorphological study of the Sultansazlığı Lake, central Anatolia. Quatern Sci Rev 18:647–657

Erol O (1981) Quaternary pluvial and interpluvial conditions in Anatolia and environmental changes in south-central Anatolia since the last glaciation. In: Frey W, Uerpmann HP (eds) Beitrage zur Umweltgeschichte des Vorderen Orients. Wiesbaden: Beih. Zum Tübinger Atlas des Volderen Orient. Reihe A (Naturwissenscahften) vol 8, pp 101–109

Erol O (1984) Geomorphology and neotectonics of the pluvial lake basins in the Taurus Belt and South Central Anatolia. In: Tekeli O, Göncüoğlu CM (eds) International Symposium on Geology of the Taurus Belt. General Directorate for Mineral Research and Exploration, Ankara.

Erol O (1997) Geomorphologic arguments for mid-to late hocene enviromental change in Central Anatolian (Pluvial) Lake Basins. In: Dalfes HN, Kukla G, Weiss H (eds) Climate change in the third millenium BC. NATO ASI, Book Series 49, Global Enviromental Change 49, Springer, Heidelberg, pp 321–350.

Esin U (1996) Aşıklı, ten thousand years ago: a habitation model from Central Anatolia. Habitat II:31–42 ((**in Turkish**))

Fairbridge R, Erol O, Karaca M, Yılmaz Y (1997) Background to Mid-Holocene Climatic Change in Anatolia and Adjacent Regions. In: Dalfes HN, Kukla G, Weiss H (eds) Third Millennium BP Climate Change and Old World Collapse. NATO ASI, Book Series l Global Enviromental Change 49, Springer, Heidelberg, pp 595–610.

Gérard F, Thissen L (eds) (2001) The Neolithic of Central Anatolia: internal developments and external relations during the 9th-6th Millennia CAL BP. Ege Yayınları, İstanbul.

Fontugne M, Kuzucuoğglu C, Karabiyikoğlu M, Hatte C, Patre J-F (1999) From Plenisglacial to Holocene. A ^{14}C chronostratigraphy of environmental changes in the Konya plain. Turkey Quatern Sci Rev 18:573–591

French D, Hillman G, Payne S, Payne RJ (1972) Excavations at Can Hasan III. In: Higgs E (ed) Papers in economic prehistory: studies by members and associates of the British Academy major research project in the early history of agriculture. Cambridge University Press, Cambridge, pp 1969–1970

Fuhrmann A (2002) Geochemical indicators of paleoenvironmental and paleoclimatic change in ancient and recent lake deposits: facies models, facies distributions and hydrocarbon aspects Dissertation, Berlin Technical University.

Galan E, Pozo M (2011) Palygorskite and sepiolite deposits in continental environments. Description, genetic patterns and sedimentary settings. In: Galan E, Singer A (eds) Developments in Clay Science 3. Elsevier, Amsterdam

Gaudette HE, Flight WR, Toner L, Folger W (1974) Aninexpensive titration method for the determination of organic carbon in recent sediments. J Sediment Petrol 44:249–253

Göncüoğlu CM (1986) Geochronological data from the southern part (Niğde area) of the Central Anatolian masif. MTA Dergisi 105–106:83–96

Grimm EC (1987) CONISS: A Fortran 77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares. Comput Geosci 13:13–35

Grootes PM, Stuiver M, White JWC, Johnsen SJ, Jouzel J (1993) Comparison of the oxygen isotope records from the GISP2 and GRIP Greenland ice cores. Nature 366:552–554

Gürel A, Lermi A (2008) Geo-archaeological activities in southern Cappadocia, Turkey. In: D'Alfonso L, Balza ME, Mora C (eds) Geo-archaeological activities in southern Cappadocia—Turkey. StMed 22. Italian Universty Press, Pavia

Gürel A, Lermi A (2010) Pleistocene-holocene fills of the Bor-Ereğli Plain (Central Anatolia): recent geo-archaeological contributions. In: D'Alfonso L, Balza ME, Mora C (eds) Geo-archaeological activities in Southern Cappadocia. Pavia University Press, Pavia

Hawkins JD (1982) The Neo-Hittites States in Syria and Anatolia. In: Boardman J, Edwards IES, Hammond NGL, Sollberger E (eds) The Prehistory of the Balkans, the Middle East and the Aegean World, Tenth to Eighth Centuries BP Cambridge. The Cambridge Ancient History III Part I., Cambridge

Hawkins JD (2000) Corpus of the Hieroglyphic Luwian Inscriptions. Vol. I: Inscriptions of the Iron Age. Part 2: Text, Amuq, Aleppo, Hama, Tabal, Asur Letters, Miscellaneous, Seals, Indices. de Gruyter, Berlin.

Hodder I (1996) On the surface: Çatalhöyük 1993–95. Çatalhöyük Project Vol. 1. Monograph 22. Cambridge Press, London

Howard AJ, Macklin MG, Passmore DG (2003) The alluvial archaeology of Europe. Swets Publishers, Rotterdam

Inoue K, Saito M, Naruse T (1998) Physicochemical, mineralogical, and geochemical characteristics of lacustrine sediments of the Konya Basin, Turkey, and their significance in relation to climatic change. Geomorphology 23:229–243

Jones MD, Roberts N (2008) Interpreting lake isotope records of Holocene environmental change in the Eastern Mediterranean. Quatern Int 181:32–38

Jones MD, Roberts N, Leng MJ, Türkeş M (2006) A high-resolution late Holocene lake isotope record from Turkey and links to North Atlantic and monsoon climate. Geology 43:361–364

Kansu SA (1944) Finds of Mesolithic culture in Anatolia. Dil Ve Tarih-Coğrafya Fakültesi Dergisi 2:673–682 (**(in Turkish)**)

Karabıyıkoğlu M, Kuzucuoğlu C, Fontugne M (1999) Facies and depositional sequences of the Late Pleistocene Göçü shoreline system, Konya basin, Central Anatolia: implications for reconstructing lake-level changes. Quatern Sci Rev 18:593–609

Klotz S, Guiot J, Mosbrugger V (2003) Continental European Eemian and early Würmian climateevolution: comparing signals using different quantitativereconstruction approaches based on polen. Global Planet Change 36:277–294

Kühl N, Litt T, Ohlwein C, Hanse A (2007) Eemian and Early Weichselian temperature and precipitation variability in northern Germany. Quatern Sci Rev 26(25):3311–3317

Kürçer A, Gökten YE (2014) Paleoseismological three dimensional virtual photography method, case study: Duru-2012 Trench, Tuz Gölü Fault Zone, Central Anatolia, Turkey. Türkiye Jeoloji Bülteni 57:45–71 (**(in Turkish)**)

Kuzucuoğlu C (2013) Geomorphology of the Melendiz River in Cappadocia (Turkey): setting of pre-pottery Neolithic sites of Aşıklı and Musular, and climate reconstruction during the onset of the Holocene. Geogr Fis Dinam Quat 36:95–105

Kuzucuoğlu C (2015) The rise and fall of the Hittite State in central Anatolia: how, when, where, did climate intervene. In: Beyer D, Henry O, Tibet A (eds) La Cappadoce méridionale de la préhistoire à la période byzantine, 3èmes Rencontres d'archéologie de l'IFEA. IFEA, Istanbul

Kuzucuoğlu C, Karabıyıkoğlu M, Parish R (1998) The dune systems of the Konya Plain (Turkey). Their relation to the environmental changes in Central Anatolia during Late Pleistocene and Holocene. Geomorphology 23:257–271

Kuzucuoğlu C, Bertaux J, Black S, Denefle M, Fontugne M, Karabıyıkoğlu M, Kashima K, Limondin-Lozouet N, Mouralis D, Orth P (1999) Reconstruction of climatic changes during the Late Pleistocene, based on sediment records from the Konya Basin (Central Anatolia, Turkey). Geol J 34:175–198

Kuzucuoğlu C, Dörfler W, Kunesch S, Goupille F (2011) Mid- to late Holocene climate change in central Turkey: the Tecer Lake record. The Holocene 21(1):173–188

Kuzucuoğlu C, Dumoulin J-P, Saulnier-Copard S (2018a) Geomorphological and Palaeoenvironmental Setting of Aşıklı Höyük. In: Özbaşaran M, Duru G, Stiner M (eds) The early settlement at Aşıklı Höyük, Essays in Honor of Ufuk Esin. Ege Yay, Istanbul

Kuzucuoğlu C, Demir M, Gürel A, Dumoulin J-P, Maner Ç (2018b) From post-LGM to Holocene evolution of environments in the Ereğli Basin: first results from geological indicators. NÖHÜ, Mühendislik Fakültesi Özel Sayı 3(7):1214–1219

Kuzucuoglu C (2019) Geomorphological landscapes in the Konya Plain and surroundings. In: Kuzucuoğlu C, Çiner A, Kazancı N (eds) Landscapes and landforms of Turkey. Springer, Berlin

Kuzucuoğlu C (2002) The environmental frame in Central Anatolia from the 9th to 6th millenia cal BC. An introduction to the study of relations between environmental conditions and the development of human societies. In: Gerard F and Thissen L (eds.) Internal Developments and External Relations During the 9th – 6th Millennia Cal BC, Ege Yayınları, Istanbul, pp 33–58.

Landmann G, Reimer A, Kempe S (1996) Climatic induced lake level changes of Lake Van/Turkey during the transition Pleistocene/Holocene. Global Biogeochem Cycles 10(4):797–808

Litt T, Krastel S, Sturm M, Kipfer R, Örcen S, Heumann G, Franz SO, Ülgen UB, Niessen F (2009) "Paleovan", International Continental Scientific Drilling Program (ICDP): site survey results ve perspectives. Quatern Sci Rev 28:1555–1567

Maner C (2017) Preliminary report on the forth season of the Konya-Eregli survey (Keyar) 2016. Anatolia Antiqua XXV: 95–113.

Matessi A, Dalkılıç E, D'Alfonso L (2018) Settlement patterns, ancient routes and envıronmental change in south Cappadocia (Turkey), during the Holocene. Niğde Ömer Halisdemir Üniversitesi Mühendislik Bilimleri Dergisi 7(3):1107–1112

Mellaart J (1961) Early cultures of the south Anatolian Plateau. Anatol Stud 11:159–184

Mellaart J (1967) Çatal Hüyük: A Neolithic town in Anatolia. Thames and Hudson, London

Miller R (2007) Civilizing climate. Social response to climate changes in the ancient near East. Altamira Press, Plymouth

Mizota C, Toh N, Matsuhisa Y (1987) Origin of cristobalite in soils derived from volcanic ash in temperate and tropical regions. Geoderma 39:323–330

Nicoll K, Küçükuysal C (2013) Emerging multi-proxy records of late quaternary palaeoclimate dynamics in Turkey and the surrounding region. Turk J Earth Sci 22:126–142

Oktay FY (1982) Stratigraphy and geological evolution of Ulukışla and its surroundings. Türkiye Jeoloji Kurumu Bülteni 25:15–23 (**(in Turkish)**)

Özbaşaran M (2011) The Neolithic on the plateau. In: Mc Mahon G, Steadman S (eds) The Oxford handbook of ancient Anatolia: (10.000–323 BCE). Oxford University Press, Oxford

Özbek M (2009) Remodeled human skulls in Köşk Höyük (Niğde) Neolithic Village. J Hacettepe Univ 26:146–162 (**(in Turkish)**)

Öztan A (2002) Köşk Höyük: anadolu arkeolojisine yeni katkilar. TÜBA-AR 5:55–69

Öztan A (2003) Anadolu'da bir Neolitik ve Kalkolitik yerleşme: Köşk Höyük. Colloquium Anatolicum II:69–86

Reed JM, Roberts N, Leng MJ (1999) An evaluation of the diatom response to Late Quaternary environmental change in two lakes in the Konya Basin, Turkey, by comparison with stable isotope data. Quatern Sci Rev 18:631–646

Reille M (1998) Pollen et spores d'Europe et d'Afrique du nord, supplement 2 Laboratoire de Botanique Historique et Palynologie. Springer, Marseille (**(in French)**)

Riding JB (2021) A guide to preparation protocols in palynology. Palynology. https://doi.org/10.1080/01916122.2021.1878305

Roberts N (1979) The geomorphological development of the Karaman Region, South Central Turkey. Bull Geomorphol 8:77–83

Roberts N (1982) A note on the geomorphological environment of Çatal Höyük, Turkey. J Archaeol Sci 9(4):341–348

Roberts N, Black S, Boyer P, Eastwood WJ, Griffiths HI, Lamb HF, Leng MJ, Parish R, Reed MJ, Twigg D, Yiğitbaşoğlu H (1999) Chronology and stratigraphy of Late Quaternary sediments in the Konya Basin, Turkey: results from the KOPAL project. Quat Sci Rev 18:611–630

Roberts N, Reed J, Leng MJ, Kuzucuoglu C, Fontugne M, Bertaux J, Woldring H, Bottema S, Black S, Hunt E, Karabiyikoglu M (2001) The tempo of Holocene climatic change in the eastern Mediterranean region: new high-resolution crater-lake sediment data from central Turkey. The Holocene 11:721–736

Roberts N, Eastwood W, Kuzucuoğlu C, Fiorentino G, Caracuta V (2011) Climatic, vegetation and cultural change in the eastern Mediterranean during the mid-Holocene environmental transition. The Holocene 21(1):147–162

Roberts N, Reed JM (2009) Mediterranean lakes, wetlands and Holocene environmental change. In: Woodward J (ed) The Physical Geography of the Mediterranean 1st ed. Oxford: Oxford University Press.

Roberts N, Boyer P, Merrick J (2007) The KOPAL on-site and off-site excavations at Çatalhöyük. In: Hodder I (ed) Excavating Çatalhöyük: Reports from the 1995–1999 seasons. McDonald Institute

Monographs 37. Cambridge: McDonald Institute for Archaeological Research and British Institute.

Rosada G, Lachin MT (2010) Excavations at Tyana/Kemerhisar. Republic of Turkey Ministry of Culture and Tourism Publication, Ankara, p 32

Rosen AM (2007) Civilizing Climate. Social Responses to Climate Change in the Ancient Near East. Altamira Press, Plymouth.

Rossignol-Strick M (1999) The Holocene climatic optimum and pollen records of sapropel 1 in the eastern Mediterranean, 9000–6000 BP. Quatern Sci Rev 18:515–530

Sant DA, Mathew G, Khadkikar SA, Gogte V, Gundurao TK (2003) Co-existent cristobalite and iridium at 65 Ma, Anjar Intertrappeans, Kachchh, Western India. Cretac Res 24:105–110

Shackleton NJ (1969) The last interglacial in the marine and terrestrial records. Proceedings of the Royal Society London B 174:135–154

Singer A (2002) Palygorskite and sepiolite-the enigmatic clay minerals. Berichte Der Deutchen Ton Tonmineralgruppe 9:203–216

Solotchina EP, Prokopenko AA, Kuzmin MI, Solotchin PA, Zhdanova AN (2009) Climate signals in sediment mineralogy of Lake Baikal and Lake Hovsgol during the LGM-Holocene transition and the 1-Ma carbonate record from the HDP-04 drill core. Quatern Int 205(1–2):38–52

Taylor KC, Alley RB, Doyle GA, Alley RB, Grootes PM, Mayewski PA, White JWC, Barlow LK (1993) The flickering switch of late Pleistocene climate change. Nature 361:432–436

Türkecan A, Kuzucuoğlu C, Mouralis D, Pastre J-F, Atıcı Y, Guillou H, Fontugne M. (2004) Upper Pleistocene Volcanism and Paleogeography in Cappadocia, Turkey. Report No. 10652. General Directorate of Mineral Research and Exploration, Ankara.

Türkeş M (2005) Climate of southern part of the Middle Kızılırmak Sub-Region (Cappadocia District) and its vulnerability to desertification. Ege Coğrafya Dergisi 14:73–97 (**(in Turkish)**)

Türkeş M (2013) Climate Changes: from the Cambrian to the Pleistocene, and from the Late Holocene to the 21st Century. Ege Coğrafya Dergisi 22:1–25 (**(in Turkish)**)

Tyson RV (1995) Sedimentary Organic Matter. Chapman and Hall, London

Ülgen UB, Franz OS, Biltekin D et al (2012) Climatic and environmental evolution of Lake Iznik (NW Turkey) over the last ~4700 years. Quatern Int 274:88–101

Ulu Ü (2009) 1/100.000 Scale Geology Map, Karaman-M32 section of the map, No: 127. General Directorate of Mineral Research and Exploration, Ankara.

Van Zeist W, Woldring H (1978) A Postglacial pollen diagram from Lake Van in East Anatolia. Rev Palaeobot Palynol 26:249–276

Van Andel TH, Runnels CN, Pope KO (1986) Five thousand years of land use and abuse in the Southern Argolid, Greece. Hesperia 55:103–128

Vita-Finzi C (1969) The Mediterranean valleys. Cambridge University Press, Cambridge

Wohlfarth B (2013) A review of Early Weichselian climate (MIS 5d-a) in Europe, Svensk Kärnbränslehantering AB. Technical Report No. TR-13–03, Swedish Nuclear Fuel and Waste Management Co.

Yang B, Wang J, Liu J (2019) A 1556 year-long early summer moisture reconstruction for the Hexi Corridor. Northwestern China Sci China Earth Sci 62:953–963

Yasuda Y, Kitagawa H, Nakagawa T (2000) The earliest record of major anthropogenic deforestation in the Ghab Valley, Northwest Syria: a Palynological Study. Quatern Int 73–74:127–136

Zeder M (2011) The origins of agriculture in the Near East. Curr Anthropol 52:221–235

Van Zeist W, Bottema S (1991) Late Quaternary vegetation of the Near East. Beihefte zum Tübinger Atlas de Vorderen Orients, Reihe A18. Dr Ludwig Reichert Verlag, Wiesbaden.