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Vegetation and climate changes during the late Pliocene and early Pleistocene in SW Anatolia, Turkey

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ABSTRACT

Pollen analysis was done on lacustrine sedimentary sequences dated by micromammals as late Pliocene–early Pleistocene that outcrop in two Neogene graben basins from SW Turkey. This study shows vegetation changes from steppe-like to more forested environments, very similar to the cyclic oscillations related to late Pleistocene glacial–interglacial climate changes. *Artemisia* was abundant during cold–arid periods, indicating that this species was already widespread in this area during the latest Pliocene and the beginning of the Pleistocene. A review of pollen records from Anatolia agrees with this study, suggesting that the spreading of this arid species occurred during a major climatic change: the beginning of the first glaciations and probably a change in seasonality towards summer aridity. *Artemisia* temporarily disappeared from the region during warm–wet periods and thus we suggest that glacial–interglacial-type oscillations already occurred in the area during the late Pliocene–early Pleistocene.

Introduction

Anatolia (Fig. 1A) is today a biodiversity hotspot and has been a refuge area for plants that were previously widespread in the European and Mediterranean regions (Biltekin et al., 2015 and references therein). Warm-temperate species, which have almost completely (*Zelkova*) or completely (*Pterocarya*, *Liquidambar*, *Parrotia persica*) disappeared from other European and peri-Mediterranean regions naturally occur in this region (Quézel and Médail, 2003). The Anatolian vegetation during the Miocene was mostly subtropical but many of those species declined through the Neogene due to climate cooling and enhanced aridity in the area and the establishment of the Mediterranean-type seasonal precipitation rhythm (summer drought since 3.4 Ma) (Suc, 1984; Jiménez-Moreno et al., 2005; Suc and Popescu, 2005; Jiménez-Moreno et al., 2010). This process was probably enhanced during the Pleistocene with glacial–interglacial cycles (Popescu et al., 2010) and the increase of magnitude of these cycles after the mid-Pleistocene transition, with the change from a 41 ka- to 100 ka-dominated climate (Lisiecki and Raymo, 2005). Aridity adapted species, such as *Artemisia*, colonized the region in such paleoclimatic conditions (Biltekin et al., 2015). However, the timing of the spreading of *Artemisia* in this area coming from Asia (Yunfa et al., 2011) is not accurately dated and happened sometime between the late Miocene and early Pliocene (Popescu, 2006; Biltekin, 2010). In addition, the main climatic or biogeographic factor forcing this widespread development of *Artemisia* steppes in the area is not fully deciphered yet.

The climatic patterns and vegetation history of late Neogene and Quaternary sediments from the western Anatolian basins (SW Turkey; Fig. 1B) have not been studied in sufficient detail to date (see below). However, Neogene sedimentary successions of western Anatolian basins are well exposed and slightly deformed, and are rich in fossil fauna and flora providing an important source of information on the paleogeographic evolution of the individual basins as well as on the regional paleoclimatic conditions. In addition, extensive coals and coal-bearing deposits in the SW Anatolia contain potential archives to recognize regional paleoclimatic and paleobotanical patterns. Pollen analysis, together with other paleontological and paleoenvironmental proxies, carried out on these organic lacustrine sediments could be a very valuable tool for deciphering paleoenvironmental conditions.

Recently, a number of studies have focused on the tectonosedimentary development of the Çameli Basin and its surroundings, in an attempt to understand the tectonic and paleogeographic evolution of the eastern Mediterranean and Aegean regions. But so far little attempt has been made to draw vegetation patterns from the Çameli Basin as well as other western Anatolian basins. Besides, the only palynological studies on the western Anatolian basins concentrated in

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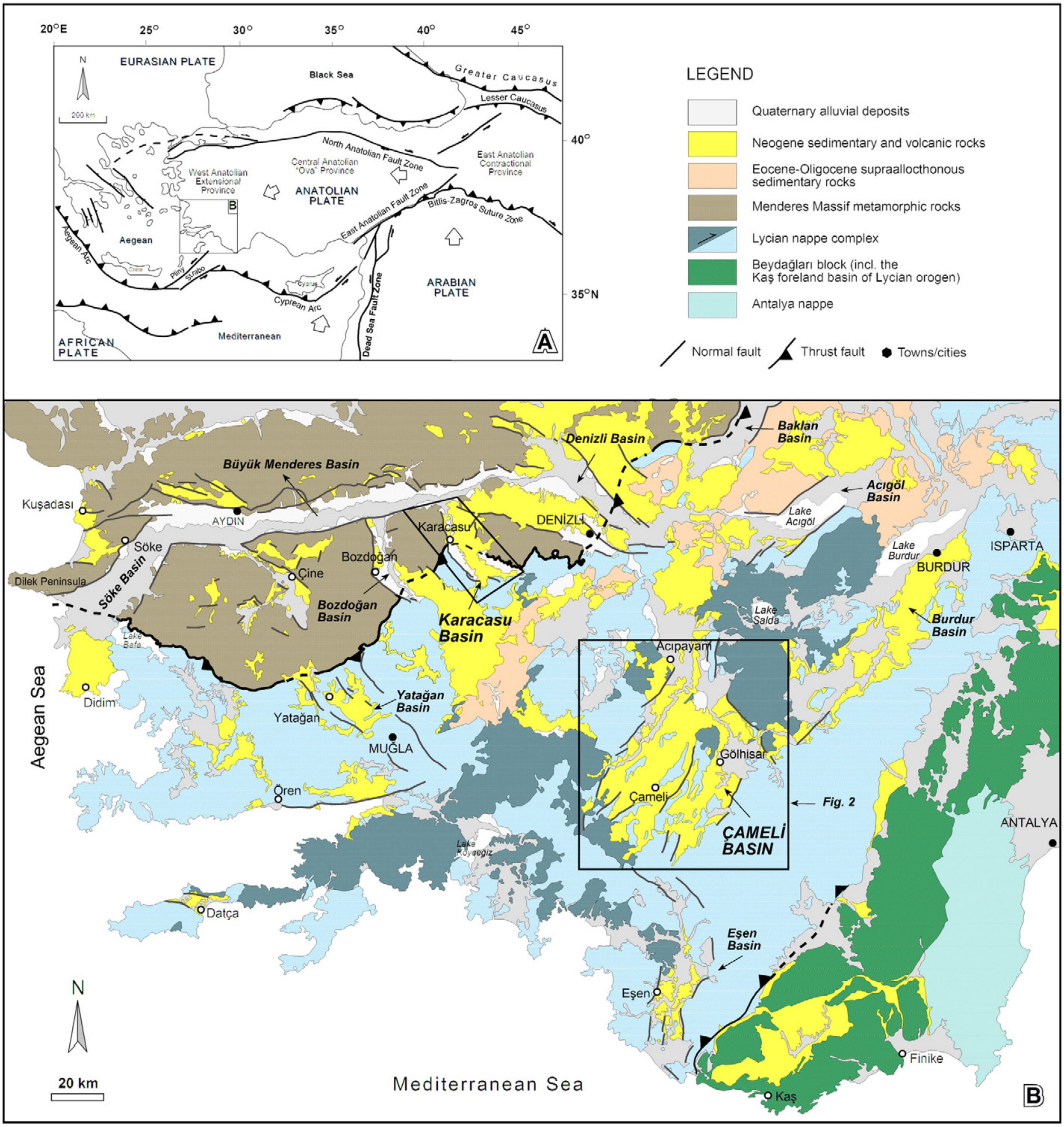

Figure 1. (A) Tectonic map of the Aegean Sea and western Turkey showing the major tectonic structures (modified from Bozkurt, 2003); and (B) overview of the prominent extensional basins of western Anatolia surrounding the Çameli Basin (based on Konak, 2002; Konak and Şenel, 2002; Şenel, 2002; Turan, 2002).

the Oligocene and Miocene coal-bearing deposits (e.g., Benda, 1971; Becker-Platen et al., 1974, 1977; Akgün and Akyol, 1999; Akgün et al., 2007; Biltekin, 2010; Akkiraz et al., 2011; Kayseri-Özer, 2014; Biltekin et al., 2015) and little attempt was made to undertake any detailed palynology of the Pliocene and early Pleistocene deposits (Alçiçek and Jiménez-Moreno, 2013). Recently, an abundance of vertebrate and invertebrate fossil assemblages in the Çameli basin-fill have attracted researchers (Diepeveen, 2012; van Bennekom, 2013; Van den Hoek Ostende et al., 2015a, b), yet a study of the pollen assemblages as a climate proxy is lacking.

In this study, pollen analysis has been carried out on two sedimentary sequences of late Pliocene and early Pleistocene ages that outcrop in the Çameli Basin, SW Turkey (Fig. 2). These data have been compared with previously published pollen records from another site from the nearby Karacasu basin and with regional pollen data (Alçiçek and Jiménez-Moreno, 2013; Fig. 1B). These records demonstrate cyclic and paired changes in vegetation, lake level and sedimentation that appear to be linked to orbital-scale climate variability (i.e., "glacial–interglacial" cycles). Vegetation, climate and age implications are discussed within the context of the Neogene Northern Hemisphere glacial intensification.

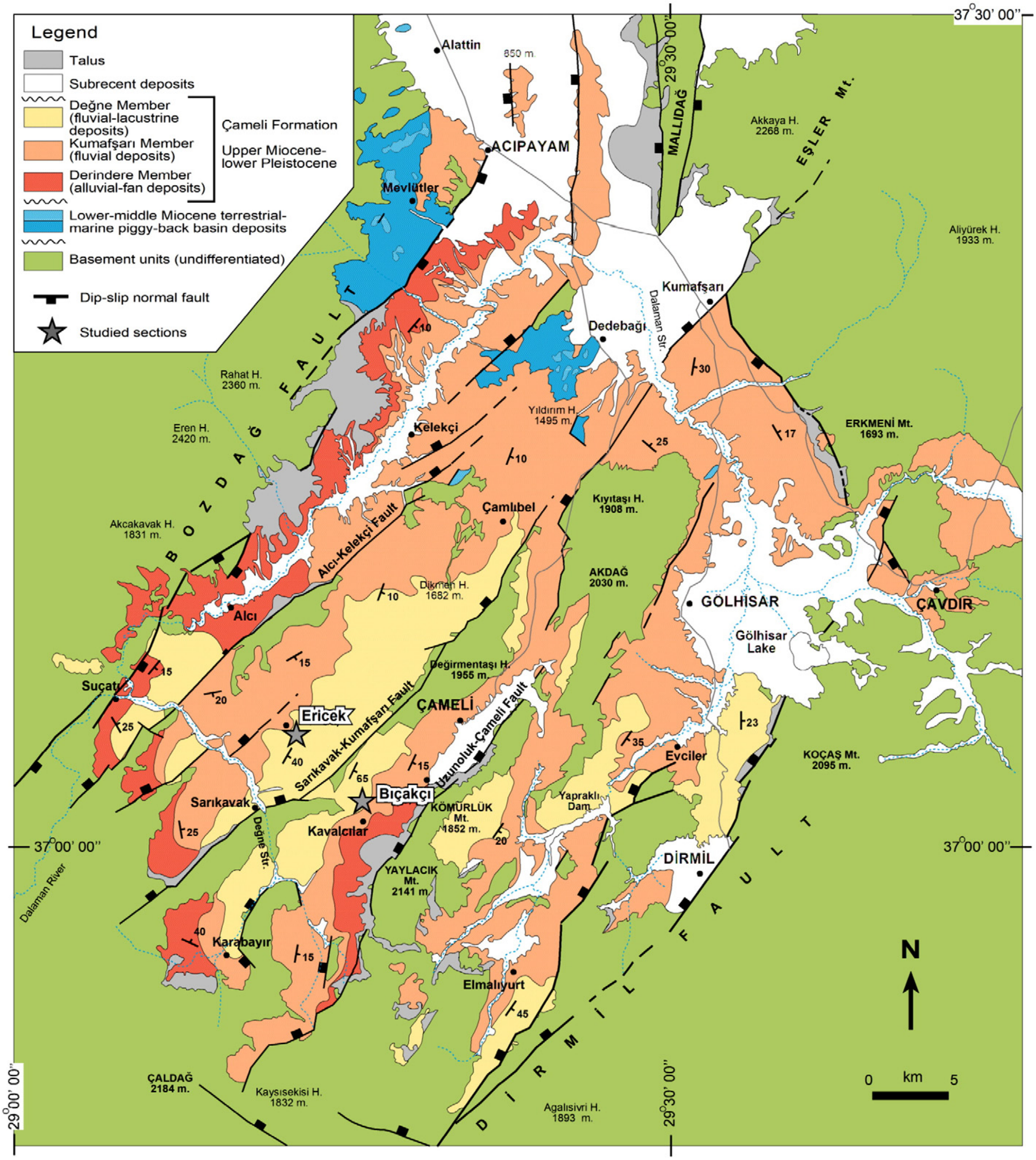

Figure 2. Geological map of the Çameli Basin (modified from Şenel (1997a, b, c); Alçiçek (2001); Alçiçek et al. (2005, 2006); Alçiçek and ten Veen, 2008; Akdeniz, 2011). The locations of the two studied outcrop sections are indicated with stars.

Geologic setting and basin stratigraphy

Western Anatolia is among the most active extensional regions in the world, where pervasive crustal extension in the Neogene and Quaternary led to the development of extensional grabens trending NW–SE, NE–SW, and E–W (Bozkurt, 2003). The NE–SW trending Çameli and NW–SE trending Karacasu basins are such grabens (Fig. 1B) in which Neogene-Quaternary basin-fill successions are well exposed and allowed the basin's history to be reconstructed. The successions of both basins shed new light on the paleogeographic evolution, paleoclimatic changes and tectonic development in southwestern Anatolia during the late Miocene to Quaternary.

The pre-Neogene bedrock in southwestern Anatolia (Fig. 1B) comprises Palaeozoic–Mesozoic metamorphic rocks of the autochthonous Menderes Massif and allochthonous Lycian nappes (e.g., Pamir and Erentöz, 1974; Okay, 1989; Sun, 1990) forming westernmost part of the Tauride orogen. The massif's core of augen gneisses is ca. 1000 m thick and surrounded by schists, marbles, and carbonates forming a dome-like structure. The Lycian allocthonous units contain Mesozoic recrystallized dolomitic limestones, marbles, and turbiditic sandstones, which are tectonically overlain by ophiolitic mélange. The bedrock units are overlain unconformably by the Neogene basin-fill deposits. These bedrock units are characterized by the closure of the Neotethyan oceanic basin during the Mesozoic–early Cenozoic that involved the genesis and emplacement of large-scale carbonate platforms and ophiolitic units (Collins and Robertson, 1997; 1998).

Çameli Basin

The Çameli Basin, ca. 40 km wide and 60 km long, is delimited by NE-trending basin-bounding normal faults (Alçiçek et al., 2005; Figs. 1B, 2). The basin resides on the Lycian nappes and consists of a series of NE-trending interconnected tilt-block compartments resulted from NW-dipping secondary normal faults that approximately divide the basin into almost four equal-sized compartments.

The sedimentary fill presents a general southeastward dip towards the northwest-dipping faults and is unconformably overlain by non-tilted Quaternary alluvial deposits, which are less than a few tens of meters in thickness. The basin-fill unit was originally mapped as the 'Neogene cover' of the Lycian nappes and assumed to be Pliocene in age (Becker-Platen, 1970; Erakman et al., 1982; Meşhur and Akpınar, 1984). More recently, the age of the succession has been determined as late Miocene (Vallesian/Tortonian) to early Pleistocene (Gelasian) based on terrestrial macro- and micro-mammal fauna (Alçiçek, 2001; Alçiçek et al., 2005; Van den Hoek-Ostende et al., 2015a, b). The basin-fill succession called as Çameli Formation has been grouped into three lithostratigraphic subunits referred to as the Derindere, Kumafşarı and Değne members, which consist of alluvial-fan, fluvial and lacustrine–fluvial deposits, respectively (Fig. 3A). In the central part of the basin, these members overlie each other in a 500 m thick sequence, but are laterally equivalent along the basin margins (Alçiçek, 2001; Alçiçek et al., 2005). The Derindere Member is composed of coarse-grained alluvial deposits and occurs typically in the lower- and upper-most parts of the basin fill along the basin margins. It is about 60 m thick with dark-red colored matrix-supported conglomerates and mudstones, and passes laterally and vertically into the fluvial and lacustrine members. Boundary relationship between the member and basement rocks is mainly faulted. The Kumafşarı Member is widespread in the northern part of the basin and in the middle stratigraphic level of the basin-fill, and consists of up to 146 m of stacked fluvial deposits characterized by a light yellow color. This member passes laterally and vertically into alluvial and lacustrine members. The Değne Member is composed of lacustrine deposits that vary 75–300 m in thickness. The unit is common in southern parts of the basin and mainly constitutes the upper part of the basin succession, and passes laterally and vertically into the fluvial and alluvial members, eventually resting directly on the basement. This member consists of three subunits: (1) a lower unit of alternating sandstone and mudstone, containing vertebrate remains, including rodent families (Arvicolidae, Muridae, Cricetidae, Gliridae) and one insectivore family (Soricidae) Ericek locality, late MN15 biozone, late Ruscinian, ca. 3.4 Ma; Van den Hoek Ostende et al. (2015a); (2) middle unit of lacustrine marl and limestone alternations; and (3) an upper unit of conglomerates, sandstones, mudstones, siltstones, carbonaceous shales, and coal deposits, containing vertebrate remains, including rodent families (Arvicolidae, Muridae, Cricetidae, Spalacidae) and one insectivore family (Soricidae) Bıçakçı locality, late MN17 biozone, middle Villanyian, 2.25–2.1 Ma; Van den Hoek Ostende et al. (2015b).

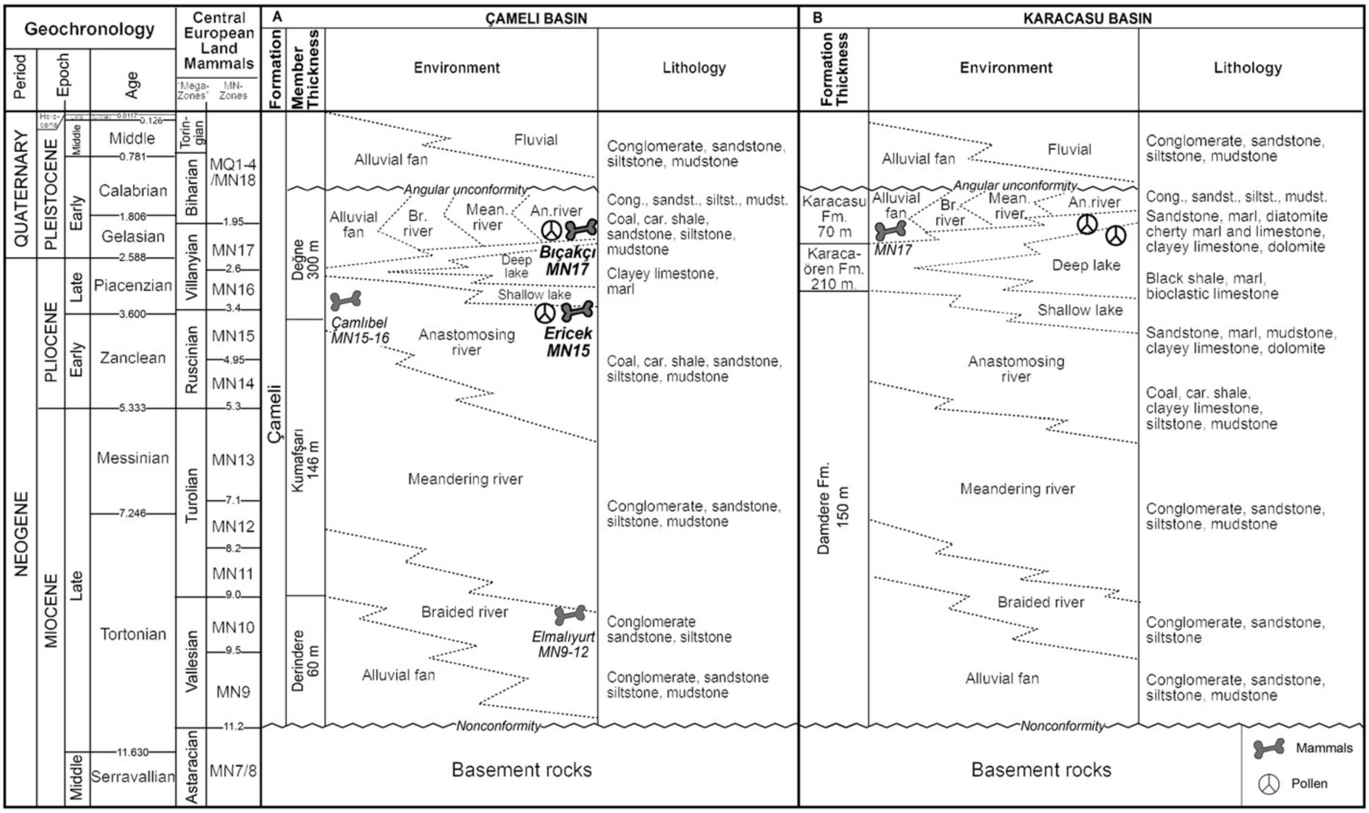

Figure 3. Composite stratigraphy of the studied basins. (A) Çameli Basin (based on Alçiçek et al., 2005; Sarac, 2003); (B) Karacasu Basin (based on Alçiçek and Jiménez-Moreno, 2013). The chronostratigraphic units are after Cohen et al. (2014) and the biostratigraphic units follow Hordijk and De Bruijn (2009).

Materials and methods

The Ericek locality is a roadside outcrop section ca. 13 km to the west of the Çameli town (37°04′12″ N, 29°11′55″ E; elevation of 950 m asl; Fig. 2). The Bıçakçı locality is also roadside outcrop section ca. 8 km to the southwest of the Çameli town (37°00′53″ N, 29°17′57″ E; 1200 m asl; Fig. 2). Both sedimentary sequences bear coal that has been actively quarried by local villagers. The landscape in this area is today characterized by open forest vegetation on the mountain slopes over grassy and dryer basins. The geomorphology in the area is mostly characterized by badlands. The Ericek locality was discovered in 2000 by M. Cihat Alcicek during his PhD study (Alçiçek, 2001) and the Bıçakçı locality was discovered by Gerçek Saraç during his study for MTA (Geological Survey of Turkey) during the early 1990s. Later, G. Saraç advised M.C. Alçicek to sample this locality and the first fossils were discovered by M.C. Alçicek by the summer of 2000.

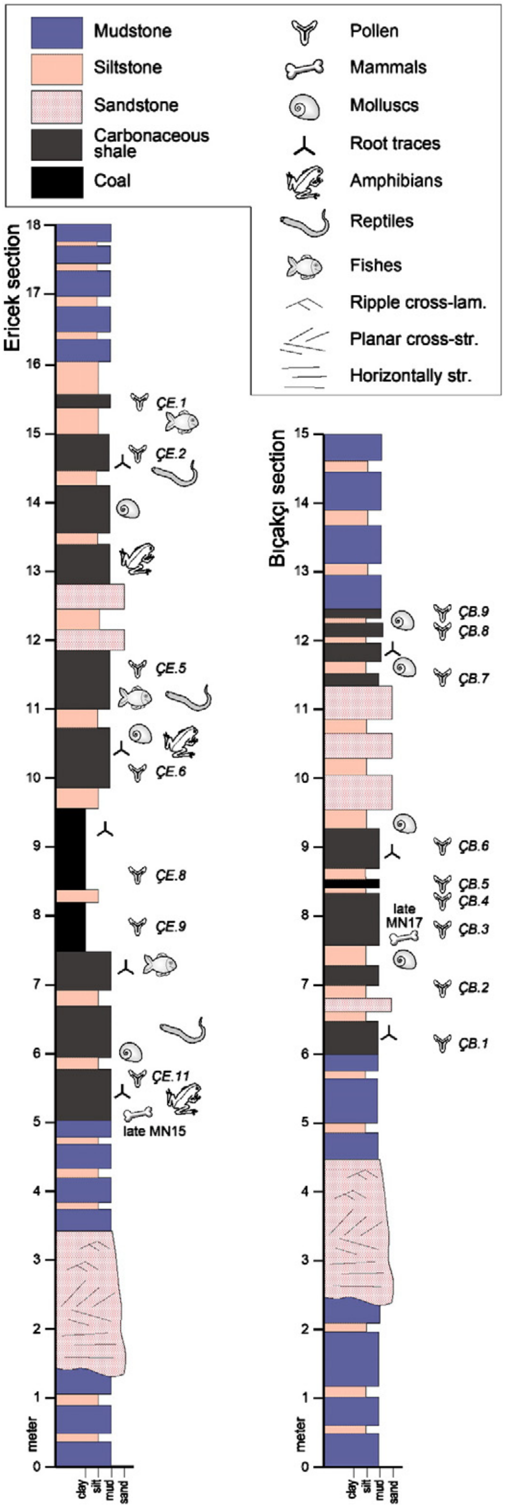

Figure 4. Lithologic logs of the Ericek and Bıçakçı outcrops from the Çameli Basin. Bones point to micromammal locations. The locations of the pollen samples are indicated.

Lithology and age from the studied sections

Detailed sedimentologic logging of both outcrop sections has been carried out (Fig. 4). Samples were preferentially collected from coal and organic-rich shale deposits of the Ericek and Bıçakçı sections. The Ericek section is characterized by coals, organic-rich shales, mudstones, siltstones and sandstones. Coal beds are found at 7.4–9.6 m (Fig. 4). The coal beds are tabular to lenticular, up to 15 cm thick and a few ten of meters in lateral extent. These deposits contain rootlets and mm-scale gypsum crystals. Organic-rich shales occur at 5–5.7 m, 5.9–6.6 m, and 6.9–7.4 m (Fig. 4). They contain plant detritus, micromammals (the glirid *Muscardinus* sp., the cricetid *Cricetulus* sp., the murids *Apodemus* cf. *dominans*, *Orientalomys* cf. *similis*, *Rhagapodemus* cf. *primaevus*, the arvicolid *Mimomys occitanus*, and the soricid *Asoriculus* sp.), freshwater molluscs (*Bythinia* sp., *Hydrobia* sp., *Pseudamnicola* sp., *Valvata* aff. *macrostoma*, ?*Gyraulus* sp., *Galba* sp. and *Vertigo* sp.), and fish (*Capoeta* sp., *Capoeta* cf. *C. damascina* or *C. seiboldi*, *Carassius* sp., Leuciscinae, ?*Squalius* sp., *Tinca* sp., *Barbus* sp., cf. Cobitidae, ?Gobiidae), frogs (?Palaeobatrachidae indet.(Anura), Anura indet.), salamanders (*Urodela* indet.) and snakes (Colubridae indet. (Serpentes)) (Van den Hoek Ostende et al., 2015a).

The Bıçakçı section is also characterized by coals, carbonaceous shales, mudstones, siltstones and sandstones. This section also bears coal beds between 8.4 and 8.6 m (Fig. 4). These are tabular to lenticular, up to 2 cm thick and are up to several tens of meters in lateral extent. Organic-rich shales also occur in the Bıçakçı section at 6–6.3 m, 7–7.4 m, 7.6–8.3 m, 8.7–9.5 and 11.4–12.5 m (Fig. 4). These deposits contain vertebrate fossils (the cricetids *Cricetulus* aff. *migratorius*, *Mesocricetus primitivus*, *Cricetus* sp., the arvicolids *Clethrionomys kretzoii*, *Mimomys pliocaenicus*, *Mimomys* gr. *tornensis*, *Pitymimomys pitymyoides*, *Borsodia* gr. *newtoni-arankoides*, *Kalymnomys* sp., the murids *Apodemus atavus*, *Apodemus* cf. *flavicollis*, the spalacid *Pliospalax* sp., and the soricid *Beremendia* sp.; Van den Hoek Ostende et al., 2015b) and freshwatersnails (*Bythinia leachi*, *Planorbis planorbis*, *Segmentina nitida*, *Lymnaea stagnalis*, *Stagnicola* sp., *Galba truncatula*, *Radix* sp., *Anisus spirorbis*, *Gyraulus piscinarum*, *Gyraulus crista*), freshwater bivalves (*Pisidium* spec.1 and 2) and terrestrial snails (*Oxyloma* cf. *elegans*, *Vertigo antivertigo*, *Vallonia pulchella*, *Imparietula brevior*).

Pollen analysis

Pollen analysis was carried out on seven samples from the Ericek section and nine samples from Bıçakçı section. Sample processing followed a modified Faegri and Iversen (1989) methodology and included digestion by acids (HCl and HF), heavy liquid separation ($ZnCl_2$; density = 2) and sieving (10 μm). The pollen residue, mounted in glycerol, was prepared on slides. Counting was performed at 400× magnification to a minimum pollen sum of 300 pollen grains. The raw counts were transformed to pollen percentages based on the pollen sum. A summary of important pollen types (higher abundances than 1%) is plotted in the composite Fig. 4. Percentages of *Botryococcus* and *Pediastrum* (algae) were calculated with respect to the total pollen + algae sum. Ratios of *Artemisia* + Amaranthaceae/Poaceae were also calculated and plotted in Fig. 5.

Results

Pollen spectra in the Çameli Basin are dominated by herbs and shrubs (Fig. 5), including Poaceae, Asteraceae and many xerophytes such as *Artemisia*, Amaranthaceae or *Ephedra* (in yellow and orange in the pollen diagram). Relatively low percentages of arboreal pollen (AP) are recorded (average AP = 20.3%). The tree assemblage is dominated by *Pinus*, temperate (deciduous *Quercus*, *Liquidambar*, *Fraxinus*) and Mediterranean (*Olea*, evergreen *Quercus*) species. Mid- and high-elevation altitudinal conifers such as *Cathaya*, *Cedrus*, *Abies* and *Picea* are present. *Salix*, *Alnus or Liquidambar* are representative of riparian tree species. Hygrophilous plants also occur (in blue in the pollen diagram), with *Nymphaea*, Cyperaceae and *Myriophyllum* as the most abundant. *Botryococcus* and *Pediastrum* Algae are present, notably in the Bıçakçı section.

Significant changes are recorded in the pollen between the Ericek (ca. 3.4 Ma) and Bıçakçı (ca. 2.25–2.1 Ma) sections. The most significant change is the appearance of *Artemisia* in the Bıçakçı section, with high percentages (values between 9 and 33%). Also, many hygrophilous plants and algae occurred for the first time (*Nymphaea*, *Myriophyllum*, *Botryococcus*) or increased (*Pediastrum*) in the Bıçakçı section.

Discussion

Vegetation

Relatively low percentages of arboreal pollen points to an open landscape in SW Turkey during the late Pliocene and early Pleistocene. Grasses (Poaceae) and other herbs and shrubs, including various arid adapted species such as Amaranthaceae, *Artemisia* or *Ephedra*, dominated the steppe-like landscape. This agrees with the very similar late Pliocene and early Pleistocene pollen data from the neighbor Karacasu basin (ca. 100 km NW of Çameli Basin; Alçiçek and Jiménez-Moreno, 2013; Fig. 7). *Artemisia*, a hardy herbaceous plant and shrub that usually grows in dry or semiarid habitats, is at present widespread in Europe and the Mediterranean area. However, it was absent or at least nearly absent from this area until relatively recently (early Miocene; Biltekin, 2010). *Artemisia* was quite abundant (ca. 20%) in the Bıçakçı and the neighboring Dandalas (Karacasu Basin) pollen record confirming that the *Artemisia* steppe was well established in the region during the late Pliocene and early Pleistocene (Popescu, 2006; Jiménez-Moreno et al., 2007b; Biltekin et al., 2015). This agrees with other studies showing that *Artemisia* first established in the central Anatolian plateau sometime in the Oligocene (Biltekin, 2010; Yavuz-Işık and Toprak, 2010), possibly originating from an arid or semiarid region in Central Asia (i.e., Tibetan Plateau; Yunfa, et al., 2011). *Artemisia* got widespread and covered the whole Mediterranean area sometime during the Pliocene and early Pleistocene (Traverse, 1982; Suc and Popescu, 2005; Popescu, 2006; Biltekin, 2010). The timing of the spreading of *Artemisia* in Anatolia and later on in Europe makes sense because this is the time of the beginning of the glaciations, general aridification and origin of seasonal Mediterranean climate in the Mediterranean area (Suc, 1984; Biltekin, 2010; Yunfa et al., 2011; Jiménez-Moreno et al., 2013; Biltekin et al., 2015).

The tree assemblage was dominated by *Pinus*, temperate (deciduous *Quercus*, *Liquidambar*, *Parrotia*, *Fraxinus*) and Mediterranean (*Olea*, evergreen *Quercus*) species. Mid- and high-elevation altitudinal conifers including *Cathaya*, *Cedrus*, *Abies* and *Picea* are present. These taxa probably grew locally in more humid environments at higher elevation in the nearby mountains. Riparian tree species occurred directly around the lake (*Salix*, *Alnus*, *Liquidambar*). Hygrophytes and aquatic plants and algae grew in and around the paleolake. Cyperaceae, *Nymphaea* and *Myriophyllum* were the most abundant. The lake was probably deep, clear and its surface waters contained enough oxygen to support abundant colonies of photosynthetic algae such as *Botryococcus* and *Pediastrum* (Smittenberg et al., 2005). These freshwater algae live at present in very diverse lake environments from very oligotrophic waters to brackish (Smittenberg et al., 2005).

This study shows occurrences of *Liquidambar* and *Parrotia* (mostlikely *P. persica*) (Fig. 5) and pollen data from Karacasu Basin (Alçiçek and Jiménez-Moreno, 2013; Fig. 7) also showed occurrences of *Engelhardia* and *Pterocarya* in the late Pliocene and early Pleistocene. These are thermophilous and hygrophilous species that are relic from more mesic and warmer climates in the past, when they were widely distributed in Europe (e.g., Jiménez-Moreno and Suc, 2007; Jiménez-Moreno et al., 2007a). The causes of these extinctions are generally explained by successive coolings in the northern hemisphere and Mediterranean aridification since *ca.* 14 Ma (Biltekin et al., 2015). At present, these species are completely lacking (*Engelhardia* only occurs in SE Asia) or are restricted in the Middle East to warm and humid refuge areas of SW Turkey (*Liquidambar*); coastal areas of Anatolia (*Pterocarya*) and the coastal area of the Caspian Sea in northern Iran (*Pterocarya*, *Parrotia persica*) (Quézel and Médail, 2003; Sefidi et al., 2011; Biltekin et al., 2015). This study shows the continuous occurrence of *Liquidambar* in the area in the late Pliocene and early Pleistocene in SW Anatolia until Present. On the other hand, *Engelhardia*, *Pterocarya* and *Parrotia* disappeared from SW Turkey sometime in the Pleistocene (see Biltekin et al., 2015 for more details).

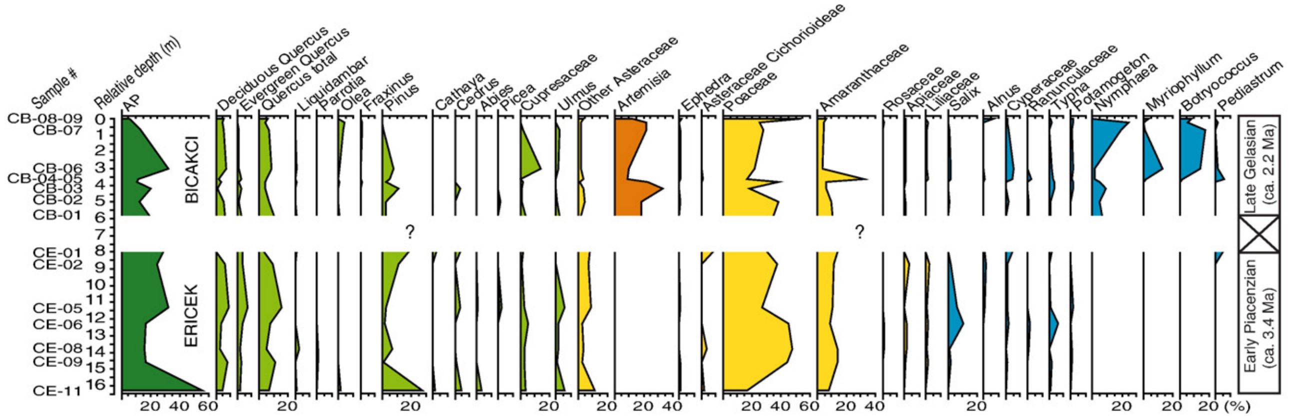

Figure 5. Pollen records from the Çameli Basin (Ericek and Bıçakçı outcrop section). Note that the depth is relative (check previous figure for real depth in the section). AP = arboreal pollen. In green are the arboreal taxa, in yellow herbs and xerophytes (*Artemisia* in orange) and in blue hygrophytes/aquatic plants and algae. The estimated age is indicated on the right.

Climate changes

The high abundance of herbs and shrubs (usually under-represented in pollen spectra, see Favre et al., 2008) and the low representation of tree taxa (requiring more water to grow) in the pollen records from SW Turkey show that climate in this area was generally arid during the late Pliocene and early Pleistocene. This agrees with previous pollen and climate studies that show that climate in Anatolia was arid since the Miocene (Popescu, 2006; Jiménez-Moreno et al., 2007b). However, temperate and hygrophilous tree species occurred, indicating relatively more humid environments in the nearby mountains or around the lake. The occurrence of Mediterranean adapted species such as *Olea* and evergreen *Quercus* also indicate that climate might have been seasonal at that time, with a marked summer drought. Climate was probably warmer than today as shown by the occurrences of thermophilous tree taxa such as *Engelhardia* (Fig. 5), *Pterocarya* or *Parrotia* (Fig. 7), which are today widespread in warmer environments (i.e., SE Asia; Wang, 1961).

Important vegetation and climate changes are recorded in the late Pliocene and early Pleistocene pollen records from the studied area (Figs. 5–7). In both neighbor basins the major pollen changes are very similar but in opposite directions and show the alternation of *Artemisia* steppe, indicating cold and arid periods, and more grassy (Poaceae) and forested vegetation, pointing to warmer and wetter conditions. These changes can be clearly seen in the synthetic pollen record from the Çameli Basin (Fig. 6), where *Artemisia* (representing steppe), *Quercus* total (representing forest) and the "aridity pollen index" (ratio of *Artemisia* plus Amaranthaceae to Poaceae) are represented. This ratio was calculated following Fowell et al. (2003), who suggested the aridity pollen index to distinguish dry steppe from moist meadow steppe and forest steppe vegetation in north-central Mongolia. It was done assuming that *Artemisia* and Amaranthaceae characterize arid environments, whereas Poaceae are more abundant in comparatively more humid conditions. The validity of this ratio was proven by previous studies by Cour and Duzer (1978), who established a similar index based on modern pollen data, opposing Asteraceae and Poaceae, which they used as "aridity vs. humidity" proxy and by Bachiri Taoufiq et al. (2008), who also used it for paleoclimatic inferences in a Miocene pollen record from Morocco.

In the Çameli Basin, the Ericek pollen record shows relatively warm and humid conditions in which *Artemisia* is lacking and the more modern record from Bıçakçı shows significant colder and drier climate that would favor the development of *Artemisia* steppe. These changes are confirmed by the mammals, Ericek showing a predominance of forest species, whereas Bıçakçı is dominated by steppe elements such as cricetids and various voles (Van den Hoek Ostende et al., 2015b). The opposite is observed in the Karacasu Basin (Fig. 7): the occurrence of an *Artemisia* steppe first and subsequently grassy forest (Alçiçek and Jiménez-Moreno, 2013). These changes are very similar to the ones observed in more modern Pleistocene pollen records from the area showing orbital-scale climate cyclicity (i.e., Europe: Suc and Popescu, 2005; Leroy, 2007; Suc et al., 2010; DSDP Site 380: Popescu et al., 2010; Armenia: Joannin et al., 2010).

Surprisingly, our records show that *Artemisia* seems to temporarily disappear from SW Turkey during the late Pliocene–early Pleistocene warm–wet periods (Figs. 5–7). Perhaps *Artemisia* was still under boundary climatic conditions and cyclic climate conditioned its occurrence or absence in the area. Alternatively, *Artemisia* could have gotten restricted to higher elevations in the area, far from the studied basins where their pollen could not be dispersed. The lack of a detailed age control for the studied sedimentary sequences prevents us from locating these warm–wet vs. cold–arid periods in time (i.e., correlation with the isotope record of Lisiecki and Raymo (2005)) or giving an estimation of their duration (i.e., whether they are forced by orbital cycles and what kind) but permits us to suggest that glacial–interglacial-type oscillations already occurred during the late Pliocene–early Pleistocene in SW Turkey.

The pollen record from both basins shows a significant increase in algae, *Botryococcus* and *Pediastrum*, and other hygrophilous plants (Cyperaceae, *Nymphaea*) during cold–arid periods (Figs. 5 and 7). An increase in aridity would trigger lower pond or lake levels in the area, favoring blooms of *Pediastrum* and *Botryococcus* through eutrophication (e.g., Prat and Daroca, 1983; Chepstow-Lusty et al., 2005) and making more surface area for hygrophilous plants to grow. Increases in algae have also been interpreted as a signal of deepening in lake environments (Anderson et al., 2011; Jiménez-Moreno et al., 2011; Jiménez-Moreno and Anderson, 2012). This would agree with Prentice et al. (1992) who explained how high lake levels could have been reached in the Mediterranean area during glacial times. Both hypotheses could be possible for the Çameli Basin sedimentary sequence, as the studied sedimentary facies in the two sequences are very similar and evidences of deeper lake environment are lacking in the Bıçakçı sediments (Fig. 3).

Conclusions

The pollen analysis of sediment outcrop sections from the late Pliocene–early Pleistocene from Çameli Basin, Turkey allowed us to reconstruct the vegetation and climate. We compared this study with other pollen records from this Anatolian area and we obtained the following main conclusions:

- Pollen data indicate that vegetation during the late Pliocene–early Pleistocene was typical of an open and steppe environment. Riparian tree species occurred around the paleolakes and Mediterranean, temperate and conifer trees grew at higher elevations.
- This vegetation points to a generally arid climate and the occurrence of thermophilous species (i.e., *Engelhardia*, *Pterocarya*, *Parrotia*) indicates that climate was most-likely warmer than today.
- We observed the presence of a clear humid–arid climate cyclicity that forced the vegetation in this area. These cycles were similar to glacial–interglacial-type oscillations.

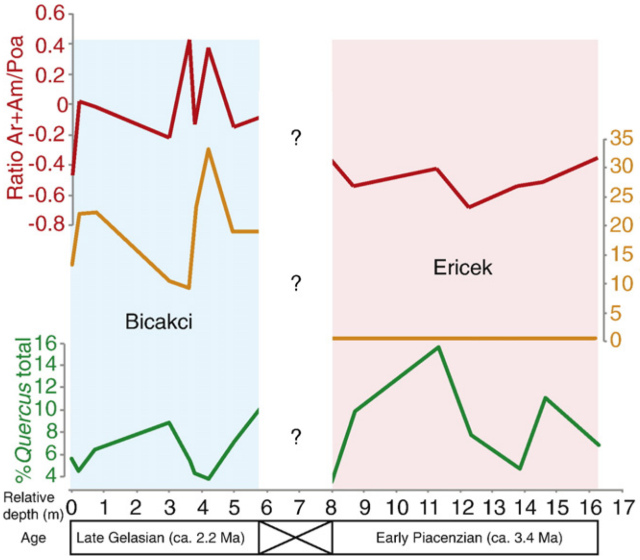

Figure 6. Simplified pollen record from the Çameli Basin (Ericek and Bıçakçı outcrop section). Note that the depth is relative (see Fig. 4 for real depth in the section). Red and blue shading indicate relatively warm–humid and cold–arid periods, respectively.

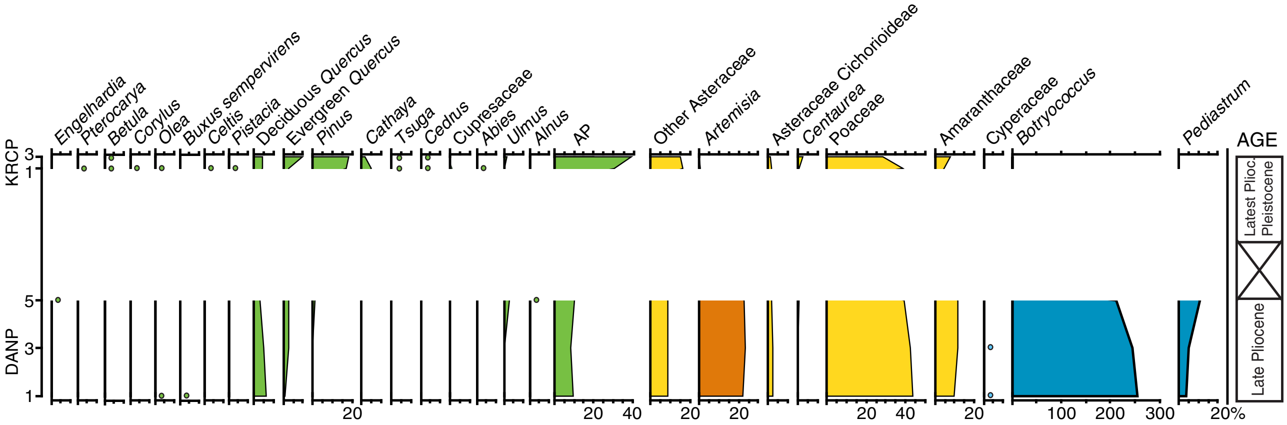

Figure 7. Pollen records from the Karacasu Basin (DANP: Dandalas and KCRP: Karacaören outcrop section). Note that the depth is relative (see Alçiçek and Jiménez-Moreno, 2013 for a more detailed description). AP = arboreal pollen. In green are the arboreal taxa, in yellow herbs and xerophytes (*Artemisia* in orange) and in blue hygrophytes/aquatic plants and algae. The estimated age is indicated on the right. Modified after Alçiçek and Jiménez-Moreno (2013).

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