Clim. Past Discuss., https://doi.org/10.5194/cp-2018-76
Manuscript under review for journal Clim. Past
Discussion started: 9 July 2018

Middle Miocene climate of southwestern Anatolia from multiple botanical proxies

Johannes M. Bouchal[1, 2,], Tuncay H. Güner[3], Thomas Denk[1]

[1]Department of Palaeobiology, Swedish Museum of Natural History, 10405 Stockholm, Sweden

[2]Department of Palaeontology, University of Vienna, 1090 Vienna, Austria

[3]Faculty of Forestry, Department of Forest Botany, Istanbul University, 34473 Bahceköy, Istanbul, Turkey

Correspondence to: Johannes M. Bouchal (johannes.bouchal@nrm.se) and Thomas Denk (thomas.denk@nrm.se)

Clim. Past Discuss., https://doi.org/10.5194/cp-2018-76
Manuscript under review for journal Clim. Past
Discussion started: 9 July 2018

Abstract

The middle Miocene climate transition (MMCT) was a phase of global cooling possibly linked to decreasing levels of atmospheric CO_2. The MMCT coincided with the European Mammal Faunal Zone MN6. From this time, important biogeographic links between Anatolia and eastern Africa include the hominid *Kenyapithecus*. Vertebrate fossils suggested mixed open and forested landscapes under (sub)tropical seasonal climates for Anatolia. Here, we infer the palaeoclimate during the MMCT and the succeeding cooling phase for a middle Miocene (14.8–13.2 Ma) of an intramontane basin in southwestern Anatolia using three palaeobotanical proxies: (i) Köppen signatures based on the nearest-living-relative principle. (ii) Leaf physiognomy analysed with the Climate Leaf Analysis Multivariate Program (CLAMP). (iii) Genus-level biogeographic affinities of fossil floras with modern regions. The three proxies reject tropical climates for the MMCT of southwestern Anatolia and instead infer warm temperate *C* climates. Köppen signatures reject summer-dry *Cs* climates but cannot discriminate between fully humid *Cf* and winter-dry *Cw*; CLAMP reconstructs *Cf* climate based on the low X3.wet/X3.dry ratio. Additionally, we assess whether the palaeobotanical record does resolve transitions from the warm Miocene Climatic Optimum (MCO, 16.8–14.7 Ma) into the MMCT (14.7–13.9 Ma), and a more pronounced cooling at 13.9–13.8 Ma, as reconstructed from benthic stable isotope data. For southwestern Anatolia, we find that arboreal taxa predominate in MCO floras (MN5), whereas in MMCT floras (MN6) abundances of arboreal and non-arboreal elements strongly fluctuate indicating higher structural complexity of the vegetation. Our data show a distinct pollen zone between MN6 and MN7+8 dominated by herbaceous taxa. The boundary MN6 and MN7+8, roughly corresponding to a first abrupt cooling at 13.9–13.8 Ma, possibly might be associated with this herb-rich pollen zone.

Keywords: Miocene; plant fossil; climate proxy; Köppen signatures; CLAMP; biogeography

Clim. Past Discuss., https://doi.org/10.5194/cp-2018-76
Manuscript under review for journal Clim. Past
Discussion started: 9 July 2018

1 Introduction

The middle Miocene (15.97–11.63 Ma, ICS-chart 2017/02, Cohen, 2013) is characterized by a warm phase lasting until ca. 15 Ma that was followed by a gradual cooling and the restoration of a major Antarctic ice sheet and first northern hemispheric glaciations (Holbourn et al., 2014). It has been suggested that the final closure of the Mediterranean gateway connecting the Mediterranean with the Indian Ocean and the resulting changes in ocean circulation might have been one of the reasons for the final expansion of the East Antarctic ice sheet around 14.8 Ma (Flower & Kennett, 1993). During the middle Miocene climate transition (MMCT) at 14.7 to 13.8 Ma a drop of sea surface temperatures of 6–7°C occurred (Shevenell et al., 2004). At the same time, different proxies to reconstruct atmospheric CO_2 levels for the Miocene Climatic Optimum (MCO), MMCT, and the succeeding more pronounced cooling, do not concur (Beerling & Royer, 2011). Specifically, stable isotope data from phytoplankton infer stable CO_2 levels for the Neogene, with minor fluctuations (MCO, 227–327 ppm, MMCT, 265–300 ppm; Beerling & Royer, 2011, table S1), while stomata densities from fossil leaves suggest a pronounced drop of CO_2 after the MCO (Beerling & Royer, 2011, table S1).

The European Mammal Faunal Zone MN6 (14.8–13.8 Ma; Neubauer et al., 2015) coincides with the MMCT. From this period world-famous vertebrate faunas are known from western Anatolia (e.g. Andrews & Tobien, 1977; Mayda et al., 2015) including the hominoids *Griphopithecus alpani* in Çandır and Paşalar, and *Kenyapithecus kizili* in Paşalar (Stringer & Andrews, 2011). Geraads et al. (2003) investigated the depositional environment and large mammal fauna of Çandır close to Ankara and inferred open landscapes for this locality. Bernor et al. (1979, p. 86) analysed community structure of Turkish and European middle Miocene faunas and suggested that "*faunas adapted to woodland conditions were present … at localities such as Paşalar and Yeni Eskihisar* [MN7-8]" while the "*Çandır fauna has a community structure more suggestive of closed woodland conditions*". This interpretation is

the exact opposite of that by Geraads et al. (2003). Recent investigations using carnivore guild structure suggest a "*mixed environment between tropical forest and open savannah landscape*s" for Çandır and Paşalar (Mayda et al., 2015). Strömberg et al. (2007) investigated phytoliths (plant silica bodies) from early to late Miocene deposits of Turkey and suggested that open, grass-dominated habitats had become common in Turkey and adjacent areas by the early Miocene (c. 20 Ma). In contrast, Kayseri-Özer (2017) using 'integrated plant record' (IPR) analysis (Kovar-Eder et al., 2008) suggested that various forest types covered most of western and Central Anatolia during the middle Miocene (*broad-leaved evergreen* and *mixed mesophytic forests* and ecotones between these forests).

Here we use a large data set from recently published macrofossils and pollen, spores and cysts from a well-dated middle Miocene basin in western Anatolia to infer palaeoclimate and palaeoenvironments using three palaeobotanical proxies: climate affinity of modern analogues ('nearest living relatives'; taxon-based approach), leaf physiognomy (a-taxonomic), and biogeographic affiliation of plant communities (also taxon-based). The following research questions are addressed: How do the three approaches resolve local climate conditions of Anatolia during a phase of global cooling, ca. 15–13 million years ago? Do different proxies agree on climate inference? Where do modern climates occur that correspond to middle Miocene climates of western Anatolia? Can the palaeobotanical record resolve transitions between MCO, MMCT, and the succeeding more pronounced cooling during the middle Miocene?

2 Material and methods

2.1 Geological setting

The Yatağan Basin is a southeast trending graben (50 km long, 15 km wide) in the province of Muğla, southwestern Turkey (Fig. 1). The Neogene basin fill is up to 600 m thick and divided into the Eskihisar Formation (early to middle Miocene), the Yatağan Formation (late

Miocene to early Pliocene), and the Milet Formation (middle to late Pliocene; Alçiçek, 2010). The Eskihisar Formation comprises the Turgut Member (reddened alluvial-fan deposits followed by fluviatile deposits and lignites) and the Sekköy Member (fossiliferous limnic marls and limestones); all economically exploited lignite seams of the Yatağan Basin are confined to the transition zone of these two members (Atalay, 1980; Becker-Platen, 1970). For the present study, we investigated the palaeobotanical content (pollen and plant macrofossils) of the upper Turgut and the Sekköy members exposed at the lignite mines of Eskihisar, Salihpaşalar, and Tınaz (Fig. 1.2). The age of the investigated sediments is well constrained by mammal fossils (Eskihisar lignite gallery locality, MN6, *Gomphotherium angustidens* Cuvier 1817, *Percrocuta miocenica* Pavlov et Thenius 1965, Bouchal et al., 2017; Yeni Eskihisar vertebrate locality, MN 7/8, The NOW Community, 2018), and by radiometric dates from the upper Sekköy Member (13.2 Ma ± 0.35, Becker-Platen et al., 1977). Hence, the investigated pollen zones (PZ) 1, 2, 2/3, and the Yeni Eskihisar pollen assemblage represent the Neogene mammal zones MN6 and MN7+8, 14.8–13.2 Ma; Neubauer et al., 2015). The layers from which most of the leaf fossils originate correspond to PZ 2. A ~20 m section comprised of limestone and clayey limestone between PZ 2/3 and the Yeni Eskihisar assemblage is barren of palynological content (Fig. 2).

2.2 Plant material

The investigated plant material comprises roughly 1800 macrofossils (mainly leaf fossils) collected between 2010 and 2017. Macrofossils represent 77 taxa, of which five belong to gymnosperms and 72 to angiosperms. Pollen, spores and cysts from five pollen zones (Fig. 2) represent 182 taxa, of which one is a fungus, 9 are algae, 17 moss or fern allies spores, 15 gymnosperms, and 140 angiosperms (Supplementary Material S1; for taxonomic descriptions of the plant taxa see Yavuz-Işık et al., 2011; Bouchal et al., 2016, 2017; Bouchal, in press; Güner et al., 2017).

Clim. Past Discuss., https://doi.org/10.5194/cp-2018-76
Manuscript under review for journal Clim. Past
Discussion started: 9 July 2018

2.3 Köppen signatures

Fossil taxa that are resolved to genus or sectional level were represented by extant members of the genera and sections as modern analogues. First, for accepted taxa (IPNI, http://www.ipni.org/index.html; most recent regional floras and monographs) their distribution ranges were determined. Then, 26 Köppen-Geiger climate types (see Supplementary Material S2 for detailed explanation of Köppen-Geiger climate types, and Kottek et al., 2006; Peel et al., 2007, Rubel et al., 2017; Global_1986-2010_KG_5m.kmz) were mapped on modern distribution ranges using Google Earth to establish 'Köppen signatures' (Denk et al. 2013) for each modern analogue. Representation of different climate types was first scored for each species within a genus as present (1)/absent (0). To summarize preferences for climate types of all modern analogues, we used an implicit weighting scheme to discriminate between modern analogues that are highly decisive (climatically constrained) vs. those that can be found in many climate zones. The sum of each modern species' Köppen signature is always one. For example, *Tilia chingiana* is present in two Köppen-Geiger climate types, *Cfa* and *Cfb,*which count as 0.5 for each type , while *Tilia americana* is present in ten Köppen-Geiger climate types (*As*, *Aw*, *Cfa*, *Cfb*, *Dfa*, *Dfb*, *Cwa*, *Cwb*, *BSk*, *BWh*), all counting as 0.1. The Köppen signature of a genus or section, the modern analogue of a fossil taxon, is the sum of its species' Köppen signatures for each climate type divided by the total number of scored species for this genus. By this, the percentage representation of each Köppen-Geiger climate type was determined for a genus/ section. In case of *Tilia*, the distribution ranges of 26 species resulted in a genus Köppen signature as follows: *Cfa*, 22.1%, *Cfb*, 14.7%, *Cwa*, 19.9%, *Cwb*, 9.1%, *Dfb*, 5.7%, for the five most common climate types. Fig. 3.1 shows all climate types realized in genus *Tilia*; Fig. 3.2 shows that the genus occurs predominantly in *Cf* and *Cw* Köppen-Geiger climate types and that tropical and desert

climates are nearly absent (see Supplementary Material S3 for genus-level scoring of Köppen-Geiger climate types for all plant taxa encountered in the Yatağan basin fossil assemblages). For taxa that are resolved to family-level only, mainly pollen taxa of herbaceous and a few woody angiosperm groups, the distributions of extant members of the family were combined into a general family distribution range and the corresponding Köppen-Geiger climate types determined.

Genus-level Köppen-Geiger signals were used to account for possible niche evolution within lineages/ species groups of a genus. For example, modern species of *Quercus* section *Ilex* are typical members of sclerophyllous, evergreen Mediterranean forest and shrubland vegetation thriving under a *Cs* (summer-dry warm temperate) climate in western Eurasia and along the western parts of the southern foothills of the Himalayas, but also occur in humid, mesophytic forests from Afghanistan to East Asia (*Cf* and *Cw* climates). To account for this climate niche variability, all species of sect. *Ilex* were scored for the general Köppen signature of sect. *Ilex*. Hence, the entire section was used as modern analogue, the nearest living relative (NLR), for several fossil species of *Quercus* sect. *Ilex*.

2.4 CLAMP

We inferred quantitative palaeoclimate parameters for the three Yatağan Basin floras using the Climate Leaf Analysis Multivariate Program (CLAMP) (Yang et al., 2011). CLAMP makes use of the relationship between leaf physiognomy and climate and, hence, is a non-taxonomic approach to palaeoclimate inference (Spicer, 2008). Modern and fossil leaf physiognomic data are positioned in multidimensional physiognomic space using high resolution gridded climate data and canonical correspondance analysis. For details on the methodology see the CLAMP website (http://clamp.ibcas.ac.cn).

For the present study, 36 different leaf characters were scored for 61, 63, and 14 dicotyledonous leaf morphotypes from three localities, Tınaz, Eskihisar, and Salihpaşalar (see

Clim. Past Discuss., https://doi.org/10.5194/cp-2018-76
Manuscript under review for journal Clim. Past
Discussion started: 9 July 2018

Supplementary Material S4 for scoring of morphotypes), following the CLAMP protocols (http://clamp.ibcas.ac.cn). At genus level, the floras of the Yatağan Basin show highest similarity with Eurasian extant woody angiosperms (Table 1), thus the PhysgAsia1 Calibration files dataset of CLAMP was used to position the fossil data.

2.5 Genus level biogeographic affinities

For all fossil taxa determined to genus level, the present distribution was tabulated indicating presence/absence of a genus in western Eurasia, East Asia, eastern North America, western North America, and Africa (Table 1).

3 Results

3.1 Climate inference from Köppen signatures (Fig. 5, Supplementary Materials S5, S6)

For the fossil plant assemblages warm temperate to temperate *C* and *D* climates accounted for almost 80% of the realized Köppen-Geiger climate types of all taxa in a fossil plant assemblage (using genus-level NLR). The sum of *Cf*, *Df*, *Cw* and *Dw* climates amounted to 60–70% in all assemblages (highest scores in macrofossil assemblages).

Overall, the best represented Köppen-Geiger climate types when using genus-level NLR were *Cfa* (warm temperate, fully humid, hot summer), followed by *Cfb* (warm temperate, fully humid, warm summer), *Cwa* (warm temperate, winter-dry, hot summer), and *Cwb* (warm temperate, winter-dry, warm summer). Summer-dry *Cs* climates were represented by 9–13% and arid (generally dry) *B* climates by 6–11% (Supplementary Materials S2, S5). Tropical (equatorial) climates (*A*) are represented by 9–11% in older assemblages, and 7–8% in the two youngest assemblages (PZ 2/3 and Yeni Eskihisar). Of 1555 modern species used to inform the Köppen signatures of the NLRs for the fossil taxa, 119 show (marginal???) range extensions into *Af* climate, 168 into *Am* (heavy monsoon), 85 into *As*, and 295 into *Aw* (Supplementary Material S3). Taxa extending in tropical climates are mainly species of

Celtis, *Smilax*, and *Viburnum*, *Quercus* sections *Quercus* and *Lobatae*, Juglandaceae subfamily Engelhardioideae, Oleaceae, and Sapotaceae. Exclusion of Köppen-Geiger climate signals extracted from cosmopolitan and/or gymnospermous taxa did not change the general trends (Supplementary Material S6).

3.2 CLAMP

Sixty-three morphotypes were scored for Eskihisar (Fig. 6; see Supplementary Material S4 for score sheets and other reconstructed climate parameters). Inferred values for mean annual temperature (MAT) were (11.2–) 12.6 (–14) °C, for coldest month mean temperature (CMMT) (0.3–) 2.3 (–4.4) °C, and for the three wettest months (X3.wet) (410–) 666 (–936) mm and for the three driest months (X3.dry) (148–) 204 (–262) mm. The ratio X3.wet/X3.dry was between 2.9 and 3.6. For Tınaz, the reconstructed MAT was (12.3–) 13.8 (–15.2) °C, CMMT (1.5–) 3.6 (–5.6) °C, X3.wet (420–) 700 (–980) mm, and X3.dry (146–) 205 (–260) mm. The ratio X3.wet/X3.dry was between 2.9 and 3.8. Values for Salihpaşalar are not considered here as they are based on a too small set of morphotypes (see Supplementary Material S4).

3.3 Genus level biogeography

The genus-level biogeographic analysis of the four Yatağan Basin floras ranging in age from 14.8 to 13.2 Ma (MN6 into MN+/8; Table 1) shows that closest biogeographic relationships are with the modern East Asian flora (54 of 59 taxa shared with East Asia), 48 and 44 genera are shared with the modern western Eurasian and eastern North American floras, respectively. Among modern tropical floras, closest relationships are with South America (21), followed by Africa (16) and northern/ north-eastern Australia (13). Most taxa extending to tropical regions are cosmopolitan (e.g. *Euphorbia*, *Drosera*, *Phragmites*), hence, of little discriminative power. This is also true for higher taxa such as Polygalaceae and Valerianoideae. The fossil

species *Smilax miohavanensis* belongs to a subtropical-tropical clade of extant species (Denk et al., 2015) and is the only member of this group in Eurasia; it has its last occurrence in the middle Miocene floras of the Yatağan Basin. Overall, the dominating biogeographic signal is a northern hemispheric one.

3.4 Changes in ratios arboreal to non-arboreal pollen

Ratios of arboreal pollen (AP) to non-arboreal pollen (NAP) change considerably among and within pollen zones of the Yatağan Basin assemblages (Table 2, Supplementary Material S7). Pollen zone 1 (main lignite seam) consistently has high percentages of AP (94–70%). In contrast, AP percentage values fluctuate throughout pollen zone 2, with values from 89 to 29. Pollen zone 2-3, only covered in the Tınaz section, records AP percentages of 50 to 19. Above, the MN7+8 assemblage of Yeni Eskihisar shows again a higher proportion of arboreal taxa (67%).

4 Discussion

4.1 Climate inference using Köppen signatures and CLAMP

Using Köppen signatures, we made a semi-quantitative reconstruction of the palaeoclimate of the Yatağan Basin during the middle Miocene. All Köppen signatures used here rely on the nearest-living-relative principle (Denk et al., 2013). Such approaches are prone to error because niche evolution may have occurred in lineages, the morphologically nearest living relatives (NLRs), a species or group of morphologically similar species, of fossil taxa may have different niches, and the shift is difficult to quantify (Ackerly, 2004; Grimm & Potts, 2016; Denk et al., 2017). Hence, we opted against applying quantitative NLR methods and determined Köppen signatures for fossil taxa using information from all extant species of a genus used as NLR to avoid bias from undetected niche shifts.

It is important to keep climatic niche shift in mind when using NLR based approaches to palaeoclimate inference and interpreting their results (cf. Grimm & Potts, 2016; Denk et al., 2017). In our dataset of 1555 modern species, 295 also occur in tropical *Aw* climates. Most of them belong to clades (monophyletic sections, genera, families) that occur in a wide range of climate types (e.g. Amaranthaceae, *Celtis*, white and red oaks). Others, such as *Engelhardia* are usually interpreted as tropical-subtropical evergreen element (Kvaček, 2007) based on the distribution range of the extant genera of the comprising subfamily, the Engelhardoideae. However, '*Engelhardia*' of the western Eurasian Cenozoic belongs to its own (extinct) section or genus *Palaeocarya* (Kvaček, 2007) with a stratigraphic range from Eocene to Pliocene. Pollen, foliage, and reproductive structures of fossil material clearly belong to subfamily Engelhardioideae but cannot be assigned to just a single modern genus *Engelhardia* (tropical Southeast Asia). Instead the fossil-taxon is a mosaic taxon having characteristics of both American and Asian members of the subfamily. Kvaček (2007) noted that the fossil genus/subgenus flourished in subtropical climates during the Eocene but in distinctly temperate climates with coldest month mean temperatures close to the freezing point in the Neogene, in stark contrast to the surviving four, likely relict genera of the Engelhardioideae. Hence, this extinct lineage of Engelhardioideae is not well represented by a single or the combination of all extant genera and their constituent species. Similarly, representatives of *Smilax havanensis* and allied species are part of a New World clade with most species occurring in tropical climates. However, the single Old World member of the clade, the fossil species *S. miohavanensis*, is known from early to middle Miocene strata of Anatolia and Central Europe (Denk et al., 2015). This fossil species formed part of plant assemblages that rule out tropical climates. In this case, inferring palaeoclimate from extant distribution data only inevitably will produce noise to the climatic signal.

Overall, the most common Köppen-Geiger climate types of NLR taxa of the Yatağan floras were warm temperate *C* types, and among *C* types fully humid *Cf* climates were better

Clim. Past Discuss., https://doi.org/10.5194/cp-2018-76
Manuscript under review for journal Clim. Past
Discussion started: 9 July 2018

represented than more seasonal *Cw* and *Cs* types (Fig. 5; Supplementary Material S5). *Cs* types played only a minor role; however, there was no clear preference of *Cf* over *Cw* climates in the representation of Köppen-Geiger climate types. Removing azonal taxa, or taxa commonly associated with higher elevations (conifers) did not affect the general signal.

In contrast, CLAMP is not based on NLR and hence not potentially biased by taxonomic error. Its combination with the Köppen signature analysis provides a powerful tool for climate inference and to discern between seasonal *Cw* (winter dry) and *Cs* (summer dry) and fully humid *Cf* climates can be made. Specifically, the ratio of the wettest and the driest month clearly distinguishes strongly seasonal summer rain (monsoon) climates (*Cw*; precipitation wettest month > 10x precipitation driest month, [$P_{wdry/sdry} < P_{wet/wwet}/10$]; Peel et al., 2007) from weakly seasonal, fully humid climates (*Cf*; precipitation wettest month << 10x precipitation driest month). Precipitation values for X3.wet and X3.dry inferred by CLAMP, and the ratio between these ranges being between 2.9 and 3.8 thus largely rules out a *Cw* climate (X3.wet and X3.dry are closely correlated to $P_{dry/wet}$). In conjunction with the Köppen signature results ruling out summer-dry conditions, the CLAMP precipitation and temperature estimates point towards cold subtropical to mild temperate *Cfa* climates at the margin to fully temperate *Cfb* climates.

4.2 Comparison to palaeoclimate and palaeoenvironment inferences from other proxies

A further refinement of previous climate and vegetation inferences can be made regarding the distinction between tropical ($T_{min} \equiv$ CMMT ≥ 18 °C), subtropical (X months with T ≥ 10° C; ~ MAT of xxx–xxx °C, and CMMT of xxx–xxx °C) and temperate climates. CLAMP consistently resolves MAT < 18 ºC and CMMT < 6 °C for the localities Eskihisar and Tınaz, and this agrees with the results from Köppen signatures and a previous qualitative assessment of palaeoenvironments in the Yatağan Basin (Güner et al., 2017). Both these results, rejecting strongly seasonal *Cw* climates, summer dry *Cs,* and tropical *A* climates (at least for non-

coastal areas) for the middle Miocene of western Anatolia, have implications for the reconstruction of palaeoenvironments of famous vertebrate localities in Anatolia that are assigned to MN6. The $\delta^{13}C$ composition from fossil tooth enamel at Paşalar, western Anatolia, MN6, indicates that animals were feeding on C_3 vegetation (Quade et al., 1995). The palaeoenvironment for this locality was determined as closer to Indian subtropical forests, with seasonal summer rainfalls (i.e. warm *Cwa* climates), semi-deciduous forest and dense ground vegetation (Stringer & Andrews, 2011; Mayda et al., 2015). Using carnivore guild structures Morlo et al. (2010) inferred open (Serengeti type, *Aw* climate) landscapes for the Central Anatolian MN6 vertebrate locality Çandır. Also, the NOW database (http://www.helsinki.fi/science/now/; The NOW Community, 2018) refers to Çandır as more open ("woodland biome", "open vegetation structure", "grassland with mosaic of forests") and to Paşalar as more forested landscapes ("subtropical", "closed vegetation structure", "semi-deciduous forests"). Bernor et al. (1979) using community structure of vertebrate faunas inferred densely wooded environments for Çandır. In a later study based on a taxonomic revision of carnivores, Mayda et al. (2015) proposed a mixed environment between tropical forests and open savannah landscapes for Çandır. It is important to note that these carnivore guild structure studies used only two modern calibration faunas to estimate palaeoenvironments, one tropical rainforest fauna in Guyana, and one savannah (tropical) fauna in the Serengeti (Morlo et al., 2010). Thus, using this proxy, only two environments can be reconstructed, tropical savannah or rainforest.

Our plant-proxy based climate reconstruction unambiguously rejects a tropical climate for the middle Miocene Yatağan Basin and major biogeographic patterns strongly suggest northern hemispheric affinities. Similar environmental conditions as reconstructed in our study have been inferred for most of western Anatolia during the late early and middle Miocene (Kayseri-Özer, 2017). Most proxies currently used to infer climate and vegetation in western Anatolia during the middle Miocene (carnivore guild structures, vertebrate community

structure, plant functional types, plant macrofossils, pollen and spores; Mayda et al., 2015, 2016; Kayseri-Özer, 2017; Güner et al., 2017; Bouchal et al. 2016, 2017; Bouchal, 2018) clearly infer forested vegetation with varying contributions of open vegetation. In contrast, Strömberg et al. (2007) found that "*all Miocene phytolith assemblages point to relatively open vegetation, such as savanna or open woodland dominated by open-habitat grasses, or a mixture of grassland and wooded areas*". This result may be strongly biased (see Jokela, 2015, p. 44) and increased diversity of grass types in the phytolith record may not actually indicate the presence of widespread open, grass-dominated landscapes.

4.3 Modern climate analogues

The inferred climate for the middle Miocene Yatağan Basin plant assemblages is characterized by MAT 11–15 °C, coldest month mean temperature (CMMT) 0–6 °C, MAP ca. 1000–2000 mm, and ratios of X3.wet/X3.dry 2.9–3.8. A non-exhaustive search for climate stations with this combination of climate parameters (Supplementary Material S8) identified a single closest match, Pacific central Honshu of Japan. X3.wet/X3.dry ratios and MAT are similar to the upper limits of the ranges reconstructed for the middle Miocene Yatağan Basin. East Asian *Cf* climates are generally characterized by distinct summer rain maxima. The modern vegetation of Japan is home to many plant taxa that are currently absent from western Eurasia but were abundant in Neogene plant assemblages of western Eurasia (e.g. *Cephalotaxus*, *Cryptomeria*, *Torreya*, *Alangium*, *Camellia*, *Castanopsis*, *Cercidiphyllum*, *Daphniphyllum*, *Eurya*, *Fatsia*; Mai, 1995; Miyawaki, 1984; see also Milne, 2004). These taxa require warm and humid equable climates.

A further close match is the area from northern Turkey via Georgia to northern Iran, the Euxinian-Hyrcanian region (Supplementary Material S8). Climates at the transition between *Csa* and *Cfa/b* of the region north of Istanbul have up to 1166 mm MAP (Ustaoğlu, 2012) and other climate parameters in this area match the Miocene climate of southwestern Turkey

inferred by CLAMP. Towards the humid north-eastern part of Turkey, X3.wet/X3.dry ratios are lower (2.4 for Rize, Hopa and Poti and Kobuleti in adjacent western Georgia). Further to the east, south of the Caspian Sea, Rasht and Kiashahr have *Cfa* and borderline *Csa* to *Cfa* climates with slightly more pronounced seasonality than the reconstructed climate for the Miocene of southwestern Turkey (X3.wet/X3.dry ratios 4.4 and 4.2). In contrast, X3.wet/X3.dry ratios in modern Mediterranean western and southwestern Turkey amount to 25 (Izmir) and 21.8 (Muğla, Yatağan Basin). It is noteworthy that modern *Cf* climates of the Euxinian-Hyrcanian region differ markedly from those of the Pacific part of Honshu by their summer minima in rainfall (Supplementary Material S8). This feature indicates a (weak) Mediterranean influence in this region. According to Biltekin et al. (2015) the Anatolian refugium emerged after the retreat of the Paratethys Sea in the Pliocene and increasing monsoon influence (increased summer rainfall???) over the north-eastern Mediterranean region (the latter accounting for the much higher summer precipitation in the Euxinian-Hyrcanian than in the Mediterranean region). The Mediterranean climate type in Europe appeared first during the late Pliocene and early Pleistocene (ca. 3.2–2.3 Ma; Suc, 1984) coinciding with first large-scale north hemispheric glaciation in the North Atlantic (Denk et al., 2011).

4.4 Detection of Miocene global climatic changes in the terrestrial fossil record

High-resolution benthic stable isotopic data provide a detailed chronology of (global) climatic changes across the Miocene Climatic Optimum (MCO), the middle Miocene Climatic transition (MMCT), and the subsequent more pronounced cooling (Holbourn et al., 2014). The terrestrial record usually does not provide the same temporal resolution but allows focussing on regional patterns. The transition from MCO to MMCT has previously been documented in high-resolution palynological analyses. For example, Jiménez-Moreno et al. (2005) investigated a core from the Pannonian Basin and observed a decline of megathermic

taxa at the transition MCO to MMCT. Also Ivanov & Worobiec (2017) reported a decrease of thermophile taxa for the transition for Bulgaria and Poland. In southwestern Anatolia, Kayseri et al. (2014) investigated three localities in the Muğla-Ören area south of the Yatağan Basin, which are dated by vertebrate fossils as early and late MN5 and thus correspond to the MCO. These authors report a few warmth-loving elements (palms, *Avicennia*) that are missing in the younger strata of the Yatağan Basin. This could be due to the deltaic setting of these floras as opposed to the intramontane setting of the Yatağan Basin floras. In general, the floras of the Muğla-Ören area are very similar to the floras of the Yatağan Basin (Bouchal. et al., 2017). However, a striking difference with the MN6 and MN7+8 assemblages of the Yatağan Basin is the almost entire absence of herbaceous taxa (non-arboreal pollen) in the MN5 assemblages of Ören (Table 2). This may indicate the presence of more closed forest vegetation of the laurisilva type. The assemblages of the Yatağan Basin, show fluctuating arboreal to non-arboreal pollen (AP:NAP) ratios with a peak of NAP in the transition zone MN6 to MN7+8 (pollen zone PZ 2–3). This peak could possibly correspond to a sharp cooling detected in the benthic stable isotopic data at 13.9-13.8 Ma (Holbourn et al., 2014). In the European mammal stratigraphy (Neubauer et al., 2015) the boundary MN6 to MN7+8 is at 13.9 Ma. Above PZ 2–3, the radiometrically dated Yeni Eskihisar pollen assemblage clearly belongs to MN7+8. Here, woody taxa are again more prominent. Thus, although the correlation of pollen zone 2–3 with the cooling event at 13.9–13.8 Ma is highly speculative, it is clear that the MCO in southwestern Anatolia was characterized by laurisilva vegetation with little contribution of herbaceous taxa. During the MMCT the main woody taxa did not change much, but herbaceous taxa played a much greater role. This indicates higher structural complexity of the vegetation. The presence of early hominids in western Anatolia during this time might be connected to this more complex vegetation. It is unclear at present, whether these changes were accompanied by changes in concentrations of atmospheric CO_2. The compilation of reconstructed CO_2 values across the Cenozoic from hundreds of proxy data (Beerling &

Royer, 2011) shows that there is no agreement between different proxies for the MCO and the subsequent middle Miocene climate cooling. Phytoplankton stable isotopic data suggest nearly stable CO_2 concentrations (MCO, 227–327 ppm, MMCT, 265–300 ppm; Beerling & Royer, 2011, table S1). In contrast, stomata densities from fossil leaves suggest a pronounced decline of CO_2 across this interval.

Author contribution

JMB and TD designed the study. TD wrote the first draft of the manuscript. TG made the CLAMP analysis, JMB made the Köppen signature analysis. All authors discussed the data and contributed to the final version of the manuscript.

Acknowledgements

This work was supported by the Swedish research Council [grant no. 2015-03986 to TD].

References

Ackerly, D. D.: Adaptation, niche conservatism, and convergence: comparative studies of leaf evolution in the California chaparral, Am. Nat., 163, 654–671, 2004.

Alçiçek, H.: Stratigraphic correlation of the Neogene basins in southwestern Anatolia: Regional palaeogeographical, palaeoclimatic and tectonic implications. Palaeogeogr. Palaeoclimatol. Palaeoecol. 291, 297–318, 2010.

Andrews, P. and Tobien, H.: New Miocene locality in Turkey with evidence on the origin of *Ramapithecus* and *Sivapithecus*, Nature, 268, 699–701, 1977.

Atalay, Z.: Muğla-Yatağan ve yakın dolayı karasal Neojen'inin stratigrafi araştırması, Bull. Geol. Soc. Turkey, C23, 93–99, 1980.

Becker-Platen, J. D.: Lithostratigraphische Untersuchungen im Känozoikum Südwest-Anatoliens (Türkei) (Känozoikum und Braunkohlender der Türkei, 2), Beih. Geol. Jb., 97, 1–244, 1970.

Becker-Platen, J. D., Benda, L., and Steffens, F.: Litho- und biostratigraphische Deutung radiometrischer Altersbestimmungen aus dem Jungtertiär der Türkei, Geol. Jb., B25, 139–167, 1977.

Bernor, R.L., Andrews, P.J., Solounias, N., Van Couvering, J.A.H.: The evolution of "Pontian" mammal faunas: some zoogeographic, palaeoecologic and chronostratigraphic considerations. Annales Géologiques des Pays Helléniques. Tome hors série [special issue] 1979, 1, 81–89, 1979.

Biltekin, D., Popescu, S.-M., Suc, J.-P., Quézel, P., Jiménez-Moreno, G., Yavuz-Işık, N., and Çağatay, M. N.: Anatolia: A long-time plant refuge area documented by pollen records over the last 23 million years, Rev. Palaeobot. Palynol., 215, 1–22, 2015.

Bouchal, J. M.: The middle Miocene palynofloras of the Salihpaşalar lignite mine (Yatağan Basin, southwest Anatolia): environmental characterisation and comparison with coeval palynofloras from adjacent subbasins, Palaeobiodiversity and Palaeoenvironments, in Press, 2018.

Bouchal, J. M., Mayda, S., Grímsson, F., Akgün, F., Zetter, R., and Denk, T.: Miocene palynofloras of the Tınaz lignite mine, Muğla, southwest Anatolia: taxonomy, palaeoecology and local vegetation change, Rev. Palaeobot. Palynol., 243, 1–36, 2017.

Bouchal, J. M., Zetter, R., Grímsson, F., and Denk, T.: The middle Miocene palynoflora and palaeoenvironments of Eskihisar (Yatağan Basin, southwestern Anatolia): a combined LM and SEM investigation, Bot. J. Linn. Soc., 182, 14–79, 2016.

Cohen, K.M., Finney, S.C., Gibbard, P.L., and Fan, J.-X. The ICS International Chronostratigraphic Chart. *Episodes* 36:199–204, 2013 (updated 2017). http://www.stratigraphy.org/index.php/ics-chart-timescale

Corbett, S. L. and Manchester, S. R.: Phytogeography and fossil history of *Ailanthus* (Simaroubaceae), Internatioonal Journal of Plant Sciences, 165, 671–690, 2004.

Denk, T., Grimm, G. W., Grímsson, F., and Zetter, R.: Evidence from "Köppen signatures" of fossil plant assemblages for effective heat transport of Gulf Stream to subarctic North Atlantic during Miocene cooling, Biogeosciences, 10, 7927–7942, 2013.

Denk, T., Grímsson, F., Zetter, R., and Símonarson, L. A.: Late Cainozoic Floras of Iceland: 15 Million Years of Vegetation and Climate History in the Northern North Atlantic., Springer, Heidelberg, New York, 2011.

Denk, T., Velitzelos, D., Güner, H. T., Bouchal, J. M., Grímsson, F., and Grimm, G. W.: Taxonomy and palaeoecology of two widespread western Eurasian Neogene sclerophyllous oak species: *Quercus drymeja* Unger and *Q. mediterranea* Unger, Rev. Palaeobot. Palynol., 241, 98–128, 2017b.

Denk, T., Velitzelos, D., Güner, H. T., and Ferrufino-Acosta, L.: *Smilax* (Smilacaceae) from the Miocene of western Eurasia with Caribbean biogeographic affinities, Am. J. Bot., 102, 423–438, 2015.

Flower, B. P. and Kennett, J. P.: Middle Miocene deepwater paleoceanography in the southwest Pacific: relations with East Antarctic Ice Sheet development., Paleoceanography, 10, 1095-1112, 1995.

Geraads, D., Begun, D., and Güleç, E.: The middle Miocene hominoid site of Çandir, Turkey: general palaeoecological conclusions from the mammalian fauna, Courier Forschungs-Institut Senckenberg, 240, 241–250, 2003.

Grimm, G. W. and Potts, A. J.: Fallacies and fantasies: the theoretical underpinnings of the Coexistence Approach for palaeoclimate reconstruction, Clim. Past, 12, 611–622, 2016.

Güner, H. T., Bouchal, J. M., Köse, N., Göktaş, F., Mayda, S., and Denk, T.: Landscape heterogeneity in the Yatağan Basin (southwestern Turkey) during the middle Miocene inferred from plant macrofossils, Palaeontogr. B, 296, 113–171, 2017.

Holbourn, A., Kuhnt, W., Lyle, M., Schneider, L., Romero, and O., Andersen, N.: Middle Miocene climate cooling linked to intensification of eastern equatorial Pacific upwelling. Geology, 42, 19–22, 2014.

Inaner, H., Nakoman, E., and Karayigit, A. I.: Coal resource estimation in the Bayir field, Yatağan-Muğla, SW Turkey, Energy Sources A, 30, 1005–1015, 2008.

Ivanov, D. and Worobiec E.: Middle Miocene (Badenian) vegetation and climate dynamics in Bulgaria and Poland based on pollen data, Palaeogeogr. Palaeoclimatol. Palaeoecol., 467, 83–94, 2017.

Jia, L.-B., Manchester, S. R., Su, T., Xing, Y.-W., Chen, W.-Y., Huang, Y.-J., and Zhou, Z.-K.: First occurrence of *Cedrelospermum* (Ulmaceae) in Asia and its biogeographic implications, J. Plant Res., 128, 747–761, 2015.

Jiménez-Moreno, G., Rodríguez-Tovar, F.-J., Pardo-Igúzquiza, E., Fauquette, S., Suc, J.-P., Müller, P.: High-resolution palynological analysis in late early-middle Miocene core from the Pannonian Basin, Hungary: climatic changes, astronomical forcing and eustatic fluctuations in the Central Paratethys. Palaeogeogr. Palaeoclimatol. Palaeoecol., 216, 73–97, 2005.

Jokela, T.: The high, the sharp and the rounded: paleodiet and paleoecology of Late Miocene herbivorous mammals from Greece and Iran. PhD thesis, University of Helsinki. 2015. http://urn.fi/URN:NBN:fi-fe2017112252491.

Kayseri-Özer, M. S.: Cenozoic vegetation and climate change in Anatolia — A study based on the IPR-vegetation analysis, Palaeogeogr. Palaeoclimatol. Palaeoecol., 467, 37–68, 2017.

Kayseri-Özer, M.S., Akgün, F., Mayda, S., Kaya, T.: Palynofloras and vertebrates from Muğla-Ören region (SW Turkey) and palaeoclimate of the Middle Burdigalian–Langhian period in Turkey. Bull. Geosci. 89, 137–162, 2014.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., and Rubel, F.: World map of the Köppen-Geiger climate classification updated., Meteorol. Z., 15, 259-263, 2006.

Kovar-Eder, J., Jechorek, H., Kvaček, Z., and Parashiv, V.: The Integrated Plant Record: An essential tool for reconstructing Neogene zonal vegetation in Europe, Palaios, 23, 97–111, 2008.

Kvaček, Z.: Do extant nearest relatives of thermophile European Cenozoic plant elements reliably reflect climatic signal?, Palaeogeogr. Palaeoclimatol. Palaeoecol., 253, 32-40, 2007.

Kvaček, Z., Velitzelos, D., and Velitzelos, E.: Late Miocene Flora of Vegora, Macedonia, N. Greece, Korali Publications, Athens, 2002.

Magri, D., Di Rita, F., Aranbarri, J., Fletcher, W., González-Sampériz, P.: Quaternary disappearance of tree taxa from Southern Europe: Timing and trends. Quat. Sci. Rev. 163, 23–55, 2017.

Martinetto, E.: The role of central Italy as a centre of refuge for thermophilous plants in the late Cenozoic., Acta Palaeobot., 41, 299–319, 2001.

Mayda, S., Koufos, G. D., Kaya, T., and Gul, A.: New carnivore material from the Middle Miocene of Turkey. Implications on biochronology and palaeoecology, Geobios, 48, 9–23, 2015.

Milne, R. I.: Phylogeny and biogeography of *Rhododendron* subsection *Pontica*, a group with a tertiary relict distribution, Mol. Phylogenet. Evol., 33, 389–401, 2004.

Miyawaki, A.: A vegetation-ecological view of the Japanese archipelago, Bulletin of the Institute of Environmental Science and Technology, 11, 85–101, 1984.

Morlo, M., Gunnell, G. F., and Nagel, D.: Ecomorphological analysis of carnivore guilds in the Eocene through Miocene of Laurasia. In: Carnivoran Evolution: New Views on Phylogeny, Form, and Function, Goswami, A. and Friscia, A. (Eds.), Cambridge University Press, Cambridge, UK, 2010.

Neubauer, T. A., Georgopoulou, E., Kroh, A., Harzhauser, M., Mandic, O., and Esu, D.: Synopsis of European Neogene freshwater gastropod localities: updated stratigraphy and geography, Palaeontogia Electronica, 18.1.3T, 1–7, 2015.

Peel, M. C., Finlayson, B. L., and McMahon, T. A.: Updated world map of the Köppen-Geiger climate classification., Hydrol. Earth System Sci., 11, 1633-1644, 2007.

Quade, J. and Cerling, T. E.: Expansion of C4 grasses in the Late Miocene of Northern Pakistan: evidence from stable isotope paleosols., Palaeogeogr. Palaeoclimatol. Palaeoecol., 115, 91–116, 1995.

Rubel, F., Brugger, K., Haslinger, K., and Auer, I.: The climate of the European Alps: Shift of very high resolution Köppen-Geiger climate zones 1800–2100. Meteorologische Zeitschrift, 26 (2), 115–125, 2017. DOI:10.1127/metz/2016/0816.

Shevenell, A. E., Kennett, J. P., and Lea, D. W.: Middle Miocene Southern Ocean cooling and Antarctic cryosphere expansion., Science, 305, 1766-1770, 2004.

Spicer, R. A.: CLAMP. In: Encyclopedia of Paleoclimatology and Ancient Environments Gornitz, V. (Ed.), Springer, Dodrecht, 2008.

Stringer, C. and Andrews, P.: The Complete World of Human Evolution, Thames & Hudson, London, 2011.

Strömberg, C.A.E., Werdelin, L., Friis, E.M., Saraç, G.: The spread of grass-dominated habitats in Turkey and surrounding areas during the Cenozoic: phytolith evidence. Palaeogeogr., Palaeoclimatol., Palaeoecol. 250, 18–49, 2007.

Suc, J.-P.: Origin and evolution of the Mediterranean vegetation and climate in Europe, Nature, 307, 429–432, 1984.

The NOW Community.: New and old worlds database of fossil mammals (NOW). Licensed under CC BZ 4.0 Release 2008. Published on the Internet. Last accessed 23-04-2018. http://www.helsinki.fi/science/now/

Ustaoğlu, B.: Comparisons of annual meanprecipitation gridded and station data: An example from Istanbul, Turkey, Marmara Coğrafya Dergisi, 26, 71–81, 2012.

Wang, Q., Dilcher, D. L., Lott, T. A.: *Podocarpium* A. Braun ex Stizenberger 1851 from the middle Miocene of Eastern China, and its palaeoecology and biogeography. Acta Palaeobot. 47, 237–251, 2007.

Yang, J., Spicer, R. A., Spicer, T. E. V., and Li, C.-S.: 'CLAMP Online': a new web-based palaeoclimate tool and its application to the terrestrial Paleogene and Neogene of North America, Palaeobiodiversity and Palaeoenvironments, 91, 163, 2011.

Yavuz-Işık, N., Saraç, G., Ünay, E., and de Bruijn, H.: Palynological analysis of Neogene mammal sites of Turkey - Vegetational and climatic implications, Yerbilimeri, 32, 105–120, 2011.

Supplementary Material.

S1: A. Number of fossil-taxa (macrofossils and microfossils) from four middle Miocene localities (including one macrofossil horizon and four pollen zones - PZ) in the Yatağan Basin.

B. All fossil-taxa recorded from four Yatağan Basin floras (14.8–13.2 Ma; MN6 into MN7–8).

S2: Definition of Köppen-Geiger climate types (Kottek et al., 2006, Peel et al., 2007).

Clim. Past Discuss., https://doi.org/10.5194/cp-2018-76
Manuscript under review for journal Clim. Past
Discussion started: 9 July 2018

S3: Köppen-Geiger climate type signatures of all genera represented in micro and macrofloras of the Yatağan Basin.

S4: Coding of leaf physiognomic characters for morphotypes from three macrofloras. Output pdf files from online CLAMP analysis (http://clamp.ibcas.ac.cn).

S5: Heat maps showing precise representation of different Köppen-Geiger climate types for all fossil assemblages.

S6: Köppen signature diagrams excluding cosmopolitan and gymnospermous taxa.

S7: Arboreal to non-arboreal pollen ratios for three sections, of the Yatağan Basin.

S8: Modern climate stations comparable to the middle Miocene climate of the Yatağan Basin, southwestern Anatolia. Climate data from CLIMATE-DATA.ORG (https://sv.climate-data.org/info/sources/) and Ustaoğlu (2012). Selected Walter-Lieth climate diagrams illustrate qualitative difference between Euxinian-Hyrcanian and Japanese (Honshu) *Cf* climates.

Clim. Past Discuss., https://doi.org/10.5194/cp-2018-76
Manuscript under review for journal Clim. Past
Discussion started: 9 July 2018

Tables and Figures

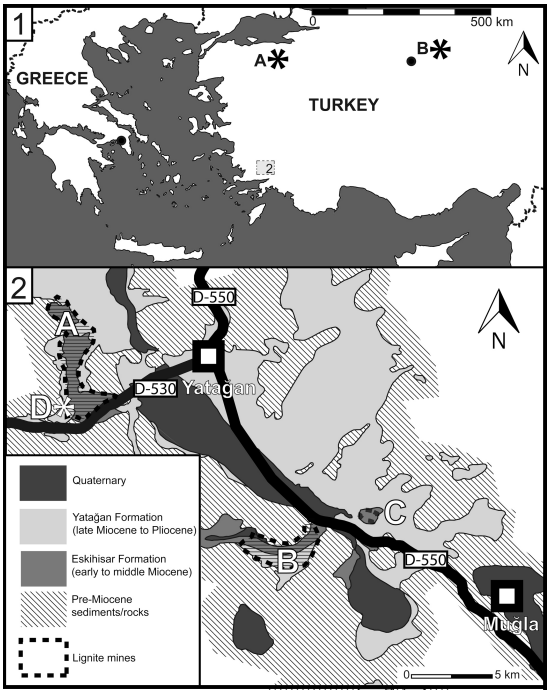

Figure 1. Geographic and regional geologic setting of the Yatağan basin. **1.** Map showing the geographical position of the Yatağan Basin (2) and the MN6 vertebrate fossil localities (*) Paşalar (A) and Çandir (B). **2.** Simplified regional geological map of the Yatağan Basin based on Becker-Platen (1970) and Atalay (1980); lignite mines Eskihisar (A), Tınaz (B), Salihpaşalar (C); vertebrate fossil locality (*) Yeni Eskihisar MN7/8 (D).

Clim. Past Discuss., https://doi.org/10.5194/cp-2018-76
Manuscript under review for journal Clim. Past
Discussion started: 9 July 2018

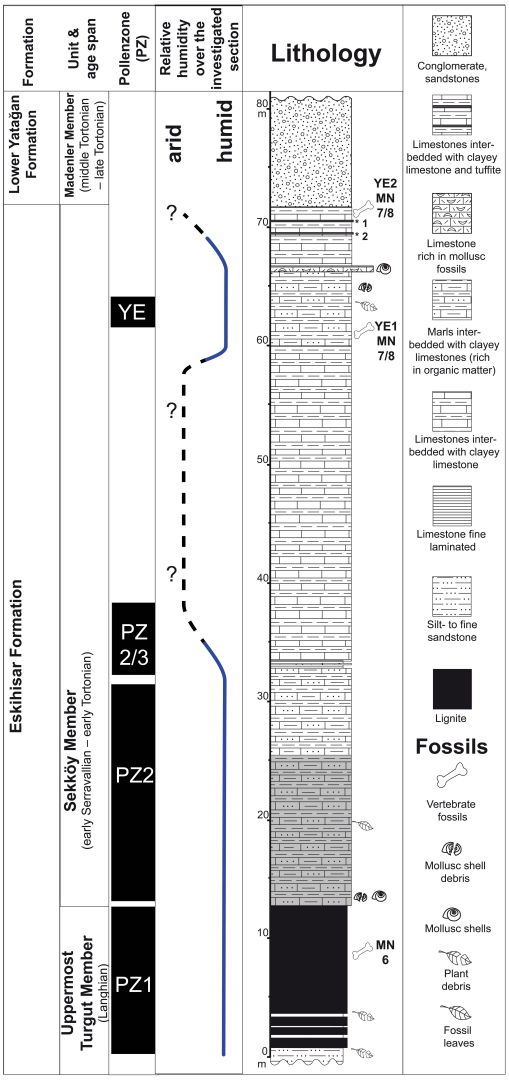

Figure 2. Generalized lithostratigraphic column for the Eskihisar lignite mine and pollen zones (PZ). The main part of the investigated plant macrofossils originates from ca 10 m thick deposits overlying the exploited lignite seams (part of the section highlighted in grey corresponding to PZ 2). Yeni Eskihisar 2 (YE2) and Yeni Eskihisar 1 (YE1) vertebrate fossil localities (Becker-Platen et al. 1977). Radiometrically dated tuff layers (*), 1* 11.2 ± 0.2 Ma, 2* 13.2 ± 0.35 Ma (Becker-Platen et al. 1977).

Clim. Past Discuss., https://doi.org/10.5194/cp-2018-76
Manuscript under review for journal Clim. Past
Discussion started: 9 July 2018

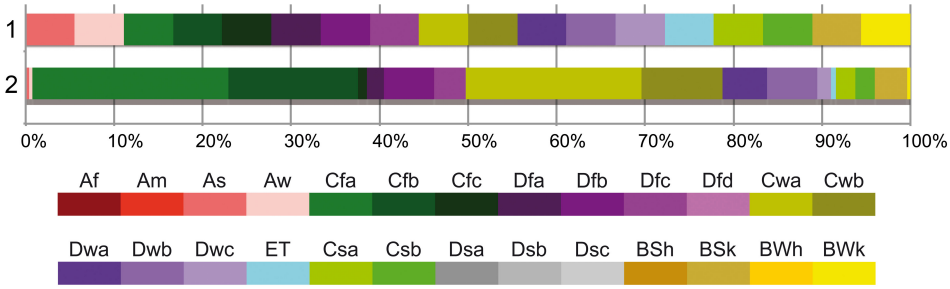

Figure 3. Köppen signal for genus *Tilia* extracted from 26 extant species. **1**. Köppen-Geiger climates in which *Tilia* is present. **2**. Combined Köppen signature of all 26 extant *Tilia* species.

Clim. Past Discuss., https://doi.org/10.5194/cp-2018-76
Manuscript under review for journal Clim. Past
Discussion started: 9 July 2018

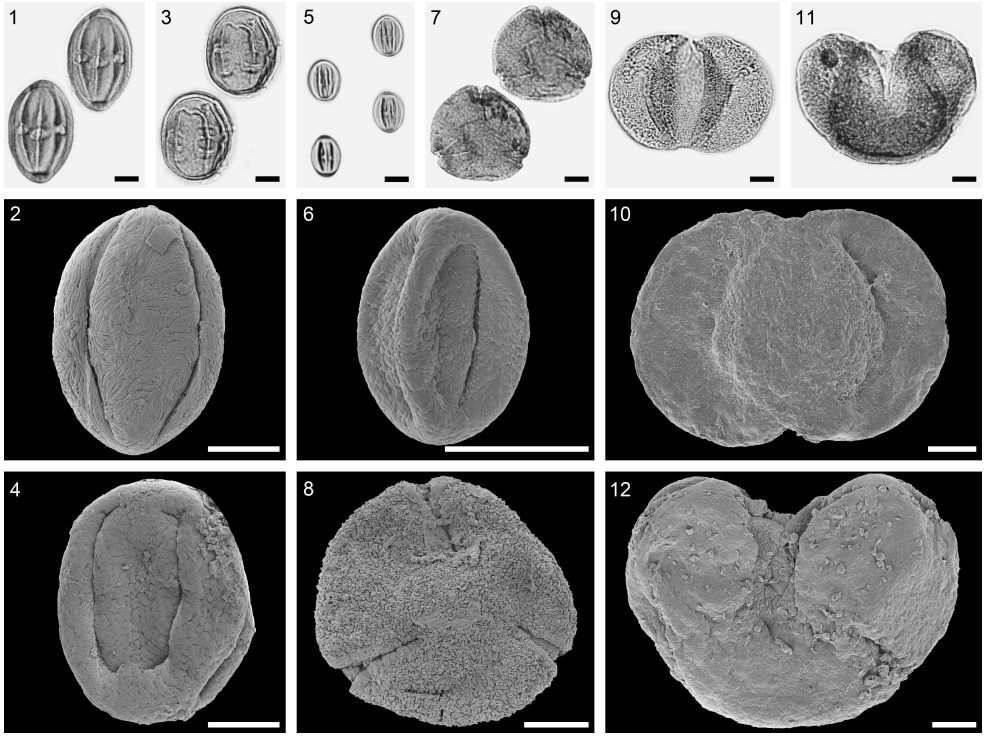

Figure 4. Selected pollen grains LM (1, 3, 5, 7, 9, 11) and SEM (2, 4, 6, 8, 10, 12) micrographs of the same fossil pollen grain of the Eskihisar (E), Tınaz (T), and Salihpaşalar (S) sections. **1–2**. *Nitraria* sp., EV (E, S153567). **3–4**. Sapotaceae gen. indet., EV (T, S143604). **5–6**. *Decodon* sp., EV (S, S153635). **7–8**. *Fagus* sp., PV (T, S143621). **9–10**. *Cathaya* sp., (9) PV, (10) PRV (S, S153632). **11–12**. *Cedrus* sp., EV (E, S153590). EV = equatorial view, PV = polar view, PRV = proximal view. Scale bar = 10µm (1–12).

Clim. Past Discuss., https://doi.org/10.5194/cp-2018-76
Manuscript under review for journal Clim. Past
Discussion started: 9 July 2018

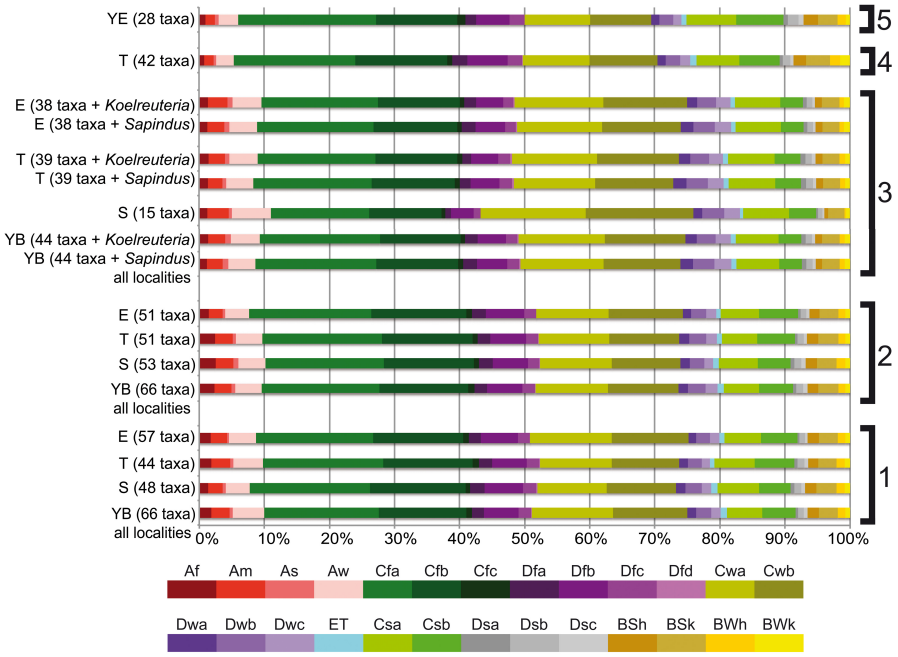

Figure 5. Köppen signals for the Yatağan Basin floras. **1.** Pollen zone (PZ) 1 (MN6; 14.95–13.9 Ma) of the Eskihisar (E), Tınaz (T), and Salihpaşalar (S) localities and the combined signal of all present taxa from PZ 1 of the three Yatağan Basin localities (YB). **2.** PZ 2 (MN6) of E, T, S, YB. **3.** Macrofossil (MF) assemblages (same level as PZ 2) of E, T, S. **4.** PZ 2/3 of T. (younger than Yeni Eskihisar vertebrate locality). **5.** Yeni Eskihisar vertebrate locality pollen assemblage (MN7/8, younger than radiometric age 13.2 Ma).

Clim. Past Discuss., https://doi.org/10.5194/cp-2018-76
Manuscript under review for journal Clim. Past
Discussion started: 9 July 2018

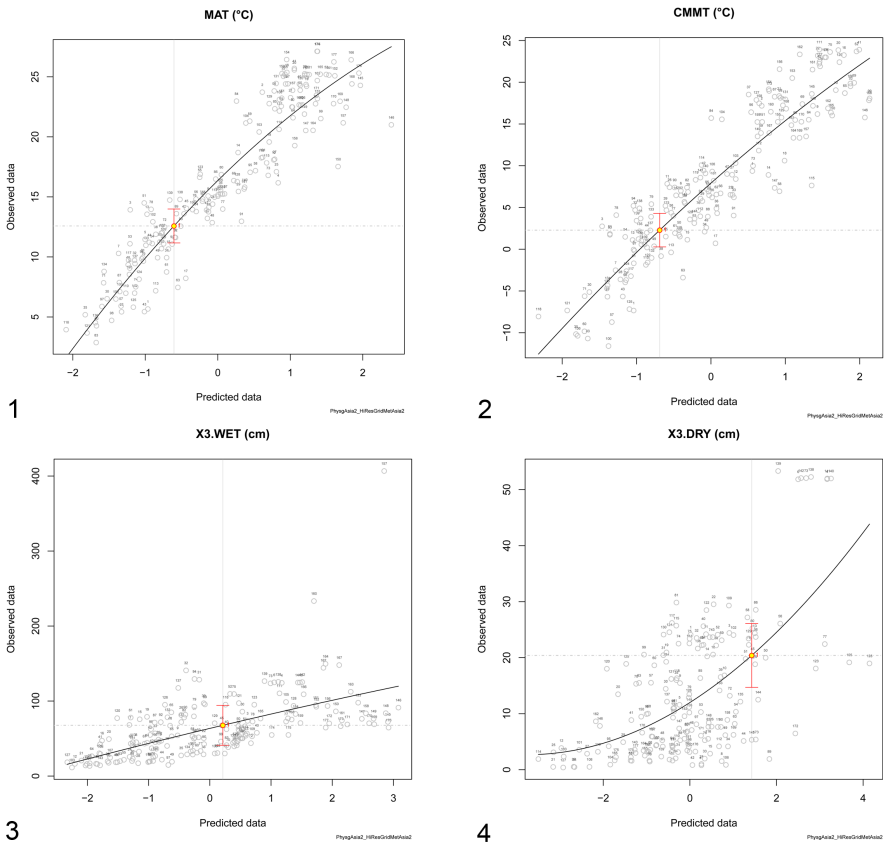

Figure 6. CLAMP climate inference for the macrofossil assemblage of Eskihisar (same level as PZ 2). **1.** Mean annual temperature (MAT). **2.** Coldest month mean temperature (CMMT). **3.** Precipitation of the three wettest months. **4.** Precipitation of the three driest months.

Clim. Past Discuss., https://doi.org/10.5194/cp-2018-76
Manuscript under review for journal Clim. Past
Discussion started: 9 July 2018

Table 1

Latest occurrence W Eurasia	Fossil-taxon (genus level)	wEUR[f]	EA	eNA	wNA	SA	AF	AUS
	Ephedra	+	+	+	+	+	+	
Pliocene?[a]	*Glyptostrobus*		+					
Taxodium-type, < 0.1 Ma[a]	*Taxodium*			+	+			
0.5-0.4 Ma[a]	*Cathaya*		+					
	Cedrus	+	+					
	Picea	+	+	+	+			
	Pinus	+	+	+	+			
0.4-0.3 Ma[a]	*Tsuga*		+	+	+			
	Acer	+	+	+	+			
late Pliocene[b]	*Ailanthus*		+					
	Alnus	+	+	+	+	+		
no data	*Apios*		+	+				
	Betula	+	+	+	+			
	Buxus	+	+	+	+	+	+	
	Buxus (balearica type)	+	+					
	Carpinus	+	+	+				
< 0.1 Ma[a]	*Carya*		+	+				
	Castanea	+	+	+				
Pliocene[c]	*Cedrelospermum*†	+	+		+			
	Celtis	+	+	+	+	+	+	+
	Centranthus	+	+					
	Corylus	+	+	+	+			
Pleistocene[d]	*Decodon*			+				
	Drosera	+	+	+	+	+	+	+
	Erica	+					+	
	Erodium	+	+	+	+	+	+	+
0.6 Ma[a]	*Eucommia*		+					
	Euphorbia	+	+	+	+	+	+	+
	Fagus	+	+	+				
	Fraxinus	+	+	+	+			
	Ilex	+	+	+	+	+	+	+
	Juglans	+	+	+	+	+		
	Linum	+	+	+	+	+	+	+
	Liquidambar	+	+	+				
	Lonicera	+	+	+	+			
	Ludwigia	+	+	+	+	+	+	+
Pliocene[d]	*Mahonia*		+					
	Nitraria	+	+				+	+
	Ostrya	+	+	+				
	Parrotia	+						
	Persicaria	+	+	+	+	+		
	Phragmites	+	+	+	+	+	+	+
no data	*Picrasma*		+	+	+	+		
Pleistocene[e]	*Podocarpium* †	+	+					
	Polygonum	+	+	+	+			
	Populus	+	+	+	+			
	Pterocarya	+	+					
	Quercus	+	+	+	+	+		
	Rumex	+	+	+	+	+	+	+
	Salix	+	+	+	+	+		
	Scabiosa	+					+	
	Smilax	+	+	+	+	+	+	+
14.8-13.8 Ma	*Smilax (havanensis* group*)*			+		+		
	Sorbus	+	+	+	+			
	Sparganuium	+	+	+	+			+
	Tilia	+	+	+	+			
	Typha	+	+	+	+	+	+	+
	Ulmus	+	+	+	+			
	Viburnum	+	+	+	+	+		
	Zelkova	+	+					
	No. of genera/region	48 wEUR[f]	54 EA	44 eNA	36 wNA	21 SA	16 AF	13 AUS

Table 1. Genus-level biogeographic affinities of fossil-taxa of the Yatağan Basin floras. [a]Magri et al., 2017; [b]Corbett & Manchester, 2004; [c]Jia et al., 2015; [d]Martinetto, 2001; [e]Wang et al., 2007; [f]including northern Africa; † extinct genus.

Clim. Past Discuss., https://doi.org/10.5194/cp-2018-76
Manuscript under review for journal Clim. Past
Discussion started: 9 July 2018

wEUR = western Eurasia, EA = East Asia, eNA = eastern North America, wNA = western North America, SA = South America, AF = Africa (excluding northern Africa), AUS = Australia.

Clim. Past Discuss., https://doi.org/10.5194/cp-2018-76
Manuscript under review for journal Clim. Past
Discussion started: 9 July 2018

Table 2

Pollen Zone	AP	NAP	
Hüssamlar	90	10	16.8 Ma
Kultak	90	10	MN5
Karacaağaç	96	4	
Tınaz PZ1	75,00	25,00	14.8 Ma
	94,20	5,80	
	0,00	0,00	MN6
	0,00	0,00	
	75,58	24,42	
	85,00	15,00	
	0,00	0,00	
Tınaz PZ2	54,13	45,87	
	89,22	10,78	
	62,04	37,96	
	86,82	13,18	
	28,66	71,34	
	46,04	53,96	
	0,00	0,00	13.9 Ma
Tınaz PZ2-3	19,01	80,99	(?)MN7+8 *
	0,00	0,00	MN7+8
	50,44	49,56	
Yenieskihisar	67,00	33,00	13.2 Ma

* = perhaps linked with 13.9-13.8 Ma cooling event (Holbourn et al., 2014)
AP = arboreal pollen (angiosperms)
NAP = non-arboreal pollen (angiosperms)
wavy line = profiles separated by tens of meters of sediment barren of pollen

Table 2. Arboreal to non-arboreal pollen ratios in southwestern Anatolia across the MCO, MMCT and subsequent cooling phase.