Palaeogeography, Palaeoclimatology, Palaeoecology 635 (2024) 111962

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

Miocene (Burdigalian) coastal lowland vegetation and palaeoclimate based on a palaeoenvironmental reconstruction of the Els Cardscolers site, Majorca, Spain

José Ma Postigo-Mijarra [a,*], Rafael Moreno-Domínguez [b], Yul Altolaguirre [c], Manuel Casas-Gallego [d], Eduardo Barrón [e]

[a] *Department of Biodiversity, Ecology and Evolution, Faculty of Biological Sciences, Complutense University of Madrid, José Antonio Novais St., 12, Madrid 28040, Spain*
[b] *Área de Paleontología, Departamento de Ciencias de la Tierra, Universidad de Zaragoza, Zaragoza, Spain*
[c] *ROCEEH Research Centre 'The Role of Culture in Early Expansions of Humans' of the Heidelberg Academy of Sciences, Senckenberg Research Institute, Senckenberganlage 25, Frankfurt am Main 60325, Germany*
[d] *Department of Geodynamics, Stratigraphy and Palaeontology, Faculty of Geology, Complutense University of Madrid, José Antonio Novais St., 12, Madrid 28040, Spain*
[e] *Museo Geominero, Instituto Geológico y Minero de España – CN-IGME-CSIC, Ríos Rosas 23, Madrid 28003, Spain*

ARTICLE INFO

Keywords:
Macroflora
Palaeoclimate
CLAMP analysis
Early Miocene
Balearic Islands

ABSTRACT

The early Miocene (Burdigalian) macroflora of the Els Cardscolers site (Majorca Island, Balearic Islands province, Spain) is studied here from a palaeoecological and taxonomical perspective. The study shows the presence of a palaeotropical flora with thermophilic and hygrophilic elements characteristic of a coastal wetland environment, formed by monocotyledons, *Lygodium gaudinii*, palms (*Sabalites* sp.), a predominance of shrubs with *Myrica lignitum* and the presence of accessory elements such as *Berberis kymeana*, *Engelhardia orsbergensis*, *Ziziphus paradisiaca*, *Sapotacites minor* and *Myrica longifolia.* Arboreal taxa like Lauraceae or Fagaceae and some Fabaceae species were also present. The temperature values obtained by CLAMP analysis are as follows: MAT: 17.6–19.9 °C, WMMT: 24.3–27.07 °C, and CMMT: 10.4–14.2 °C. These findings suggest a warm climate with little temperature seasonality. Precipitation values (e.g., GSP, MMGSP, Three_WET, and Three_DRY) suggest the absence of a summer-dry regime although a clear contrast in precipitation is inferred. The inferred climate is similar to that of other coeval regions of Southern Europe, although it stands out for its high values of CMMT. It is similar to the climate of the island of Evia in Greece. From a floristic point of view, the Els Cardscolers flora is similar to the Burdigalian site of Cristo Rei (Portugal), and a clear relationship with the floral complex of Ipolytarnóc-Luzern (Hungary) also can be inferred.

1. Introduction

The island of Majorca is the largest of the Balearic Islands. It is situated to the East of the Iberian coast. With an area of 3640 km^2, Majorca is formed geographically by the Tramuntana range to the Northwest, the Central ranges, which constitute a central band of low-altitude mountains, and the Llevant ranges to the Southeast. The Neogene continental deposits of the Tramuntana range show numerous lignite beds which contain mainly fossils of mammal bones, diatoms, charophytes, mollusks and other marine invertebrates as well as plant remains, being dated as Oligocene age by Déperet and Fallot (1921) and Fallot (1922). Later, different early Miocene sediments have also been identified in these deposits (e.g., Colom, 1967, 1972; Ramos-Guerrero et al., 1989; Sàbat et al., 2011).

Records of European Miocene floras related to islands are rare, in particular in the Mediterranean Region. In the eastern Mediterranean area, it is possible to find a small set of early Miocene sites on islands (e.g., Lesbos, Moudros, Lemnos) as well as sites of middle-late Miocene age (e.g., Kymi, Chios-Zyfia, Makrilia, Pitsidia, Kassanoi, Metochia) (Velitzelos et al., 2014; Zidianakis et al., 2020). However, to date, the early Miocene flora from Majorca is the only Neogene palaeobotanical insular reference in the western Mediterranean area. The plant remains come from the Coll de Bini outcrop (Els Cardscolers site, Fornalutx locality) in the Tramuntana range. This flora was firstly studied by Fallot and

---

[*] Corresponding author.
E-mail address: jpostigo@ucm.es (J.M. Postigo-Mijarra).

https://doi.org/10.1016/j.palaeo.2023.111962
Received 2 October 2023; Received in revised form 4 December 2023; Accepted 4 December 2023

Depape in 1928 who identified nine species (one conifer, two monocotyledons and six dicotyledons) from leaf remains. Arènes (1951) extended the list of taxa describing nine new species: *Zanthoxylum balearicum*, *Pseudopanax balearica*, *Leucothoe balearica*, *Fraxinus balearicus*, *Persea balearica*, *Proteoides* (?) *balearica*, *Myrica balearica, Machilus balearicus* and *Castanea balearica*. Later, Arènes and Depape (1954, 1956) and Bauzá Rullán (1961) revised a larger collection from Coll de Bini identifying a total of 29 taxa and describing two new species: *Acacia balearica* and *Myrica arenesi*. These authors compared this megafloral assemblage with Cretaceous, Paleogene and Neogene floras from Greenland, North America and Central Europe, inferring a seasonal, warm and humid climate, although tempered by the proximity of the sea. After this first taxonomical and palaeocological study, the Majorcan species described have been repeatedly considered for the analysis and interpretation of other Oligocene and Miocene Spanish macrofloras, hence its historic relevance (e.g., Sanz de Siria, 1981, 1993; Vicente i Castells, 1988; Tosal and Martín-Closas, 2016; Tosal et al., 2018).

The aims of this paper are: (1) revising and providing a detailed macrofloristic study of the Burdigalian assemblages of Majorca, (2) reconstructing the palaeovegetation and the palaeoclimate conditions of the area, and (3) comparing these results with other palaeobotanical and palaeoclimatic data from Central and Southern Europe.

2. Geographic and geological setting

The Balearic Islands represent the emerged part of the Balearic Promontory, a vast submarine threshold that makes up the extension of the Betic Range toward the *E*-NE (southeast of the Iberian peninsula) (Barón et al., 2004; Vera et al., 2004; Sàbat et al., 2011). The strong similarity between the rocks and the tectonic structure of the Balearic Islands and some units of the Betic Range has allowed considering them as adjacent parts of the western segment of the Perimediterranean Alpine Orogen (Fornós et al., 2002; Vera et al., 2004; Sàbat et al., 2011). The island of Majorca presents three different morphostructural domains: (i) the northern mountain range (Tramuntana range), (ii) the Central Zone and (iii) the eastern mountain ranges (Llevant ranges) (Rodríguez-Perea, 1984; Sàbat et al., 2011). The Neogene is composed of material of different ages depending on the mountain range. Thus, the Llevant ranges are dominated by Chattian to Aquitanian materials, while the Central and the Tramuntana ranges are formed of Aquitanian and Burdigalian sediments, respectively (Ramos-Guerrero et al., 1989; Sàbat et al., 2011). Although the Tramuntana range exhibits predominantly Mesozoic rocks which generally dip SE, it also comprises Miocene deposits which are placed in between the Mesozoic materials by the activity of thrust faults.

The Cenozoic of the Balearic Islands is divided into nine sequences which are formed of different lithostratigraphic units and delimited by discontinuities (Fornós et al., 2002; Vera et al., 2004; Sàbat et al., 2011). The sediments with plant remains are in the Coll de Bini outcrop at Els Cardscolers site (Fig. 1; 39° 48′ 18” N, 2° 46′ 13″ E, ca. 860 m a.s.l.) (Colom, 1975). These materials, which unconformably overlie Jurassic limestones attributed to the Lias (early Jurassic), correspond to the Sequence III of Fornós et al. (2002), which was defined as the Sant Elm Calcarenitic Formation (Rodríguez-Perea, 1984; Ramos-Guerrero et al., 1989; Vera et al., 2004; Sàbat et al., 2011). Overlying the deposits of the Sant Elm Calcarenitic Formation is the Banyalbufar Turbiditic Formation, which has been dated as late Burdigalian to early Langhian (Rodríguez-Perea, 1984; Ramos-Guerrero et al., 1989; Vera et al., 2004; Sàbat et al., 2011).

The fossiliferous series from the Sant Elm Calcarenitic Formation is made up of shallow marine and brackish-water lacustrine sediments (Fig. 1) and consists of (1) a detritical base with ostreids and scarce

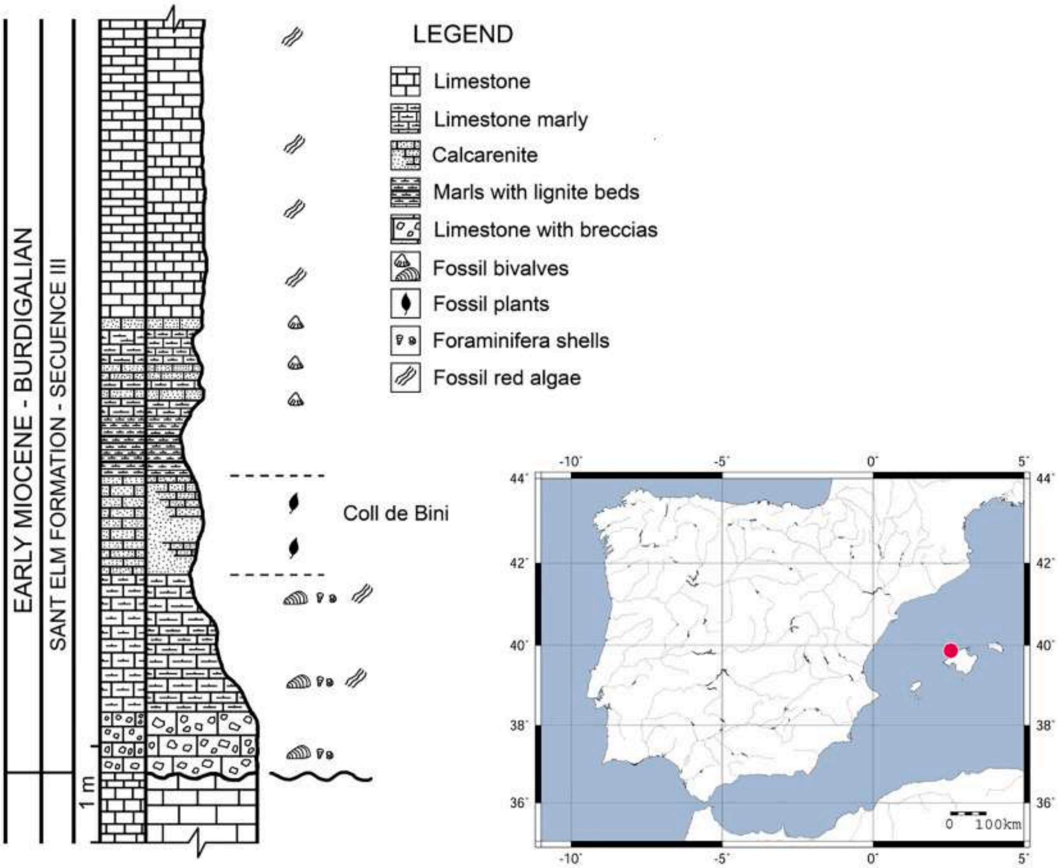

Fig. 1. Geographical setting and synthetic stratigraphic column showing the main units of the sequence at the Els Cardscolers site.

foraminifera, (2) levels of marly limestones with red algae and foraminifera, (3) lacustrine calcarenites with plant remains, (4) marls with bivalves, and (5) limestones with red algae and mollusk shells (Colom, 1975). The sediments in which the plant remains appear are related to lagoon-type facies typical of coastal areas in which sporadic brackish conditions occurred (see Rodríguez-Perea, 1984; Ramos-Guerrero et al., 1989).

The geochemical analysis of volcanic rocks from the Puig de l'Ofre whitin Secuence III dated with K—Ar indicate a Burdigalian age (19–18.6 ± 0.2 Ma) (Wadsworth and Adams, 1989; Mitjavila et al., 1990; Martí et al., 1992). This is consistent with the early Miocene age given by foraminifera from the outcrops of the Sant Elm Calcarenitic Formation (Oliveros et al., 1960; Rodríguez-Perea, 1984).

3. Methods

3.1. Material information and storage

A total of 309 specimens, preserved as impressions without cuticle from the Els Cardscolers site have been studied. They correspond mainly to dicotyledonous angiosperms (90.6%), being the rest of plant fossils from monocots and ferns. Most of the specimens analysed in this work were collected in the 1950s and are deposited in the collections of Juan Bauzá Rullán and Joan Arbona (MBCN and MBCN-Geología) of the Balearic Museum of Natural Sciences (Sóller, Majorca) and in the collections of J. Bauzá Rullán of the Society of Natural History of the Balearic Islands (SHNIB). The MBCN collection of J. Bauzá Rullán contains the historical fossils described by Arènes and Depape (1956). In addition, the recent collection of Josep Juárez (CB), deposited in the SHNIB, has been also studied.

The specimens are not well-preserved. Morphological characters, especially shape, margin and venation, when preserved, were used to describe the leaves (Ellis et al., 2009). Morphological studies were performed with a binocular microscope at 4 to 40 magnification. The photographs of the specimens were taken with a Canon EOS 40D digital camera. Earlier identifications of some specimens by other authors have been listed and detailed in Table 1 and Table 4 (Appendix A).

3.2. Climate-leaf analysis multivariate program (CLAMP)

The fossil plant samples obtained from the Els Cardscolers site showed sufficient morphotypes to conduct CLAMP analyses. CLAMP exploits the relationship between leaf form and environmental conditions. The guideline for using CLAMP (http://clamp.ibcas.ac.cn/; also see Yang et al., 2007, 2011) has been followed including the available datasets and spreadsheets. The following palaeoclimatic parameters have been estimated from 31 leaf physiognomic features displayed by the 20 fossil morphotypes from the Els Cardscolers site (Plate 4, Figs. 2–4; Appendix A): mean annual temperature (MAT), warmest month mean temperature (WMMT), coldest month mean temperature (CMMT), length of the growing season (GROWSEAS), growing season precipitation (GSP), mean monthly growing season precipitation (MMGSP), precipitation during three consecutive wettest months (Three_WET), precipitation during three consecutive driest months (Three_DRY), relative humidity (RH), specific humidity (SH) and Enthalpy (ENTHAL). Two calibration dataset files were used in our analysis: Physg3brcAz and GRIDMet3brAZ (Yang et al., 2007, 2011). The first meteorological calibration dataset (Physg3brcAz) consists of 144 modern vegetation sites, mostly from temperate regions of the Northern Hemisphere. These data set lacks samples from areas that experience extreme cold (Yang et al., 2011). The second data set, GRIDMet3brAZ, corresponds to gridded meteorological data from the same suite of locations included in Physg3brcAz. According to Yang et al. (2011), the meteorological datasets are likely to be biased toward local climates influenced by the presence of the vegetation itself and therefore are likely to represent local instead of regional climate. Here, the gridded datasets have been used since they may represent more accurately the regional climate.

Table 1
List of plant taxa from the Els Cardscolers site identified in the present study showing the diagnosis made in previous studies: a, Fallot and Depape (1928); b, Arènes (1951); c, Arènes and Depape (1956); d, Bauzá Rullán (1961). (–): information not available.

Taxon	Previous research
Lygodium gaudinii	*Lygodium gaudinii* [b]
(–)	*Abies ramesi*
Berberis kymeana	*Grevillea haeringiana* [c], cf. *Salix angusta* [a,b,c], cf. *Proteoides* (?) *balearica* [b]
Fabaceae gen et sp. indet.	(–)
Leguminocarpum sp. 1	*Acacia balearica* [c]
Leguminocarpum sp. 2	(–)
Leguminocarpum sp. 3	*Acacia balearica* [c]
Leguminocarpum sp. 4	(–)
Engelhardia orsbergensis	(–)
(–)	*Persea balearica*
(–)	*Fagus pliocenica*
Laurophyllum sp.	*Juglans acuminata* [c]
Myrica lignitum	*Castanea balearica* [b, c], *Leucothoe balearica* [b], *Laurus* aff. *praecellens* [c], *Myrica arenesi* [c], *Myrica faya* [c], *Nerium oleander* [a,b,c], *Pseudopanax balearica* [b, c], *Sapindus bilinicus* [c], *Quercus drymeja* [a,b,c], *Quercus elliptica* [c], *Machilus balearica* [b,c]
Myrica longifolia	(–)
(–)	*Diospyros brachysepala*
Ziziphus paradisiaca	*Cinnamomum* cf. *lanceolatum* [d],? *Ziziphus* sp. [d]
(–)	*Fraxinus balearica*
Sabalites sp.	*Sabalites* sp. [c]
(–)	*Phoenicites* sp.
(–)	*Smilax* [d]
Monocotyledons incertae sedis	*Thypha,* cf. *Phragmites oeningensis* [b,c]
Sapotacites minor	*Myrica balearica* [b,c]
Dicotylophyllum sp. 1 (aff. Fabaceae gen et sp. indet.)	*Zanthoxylum balearicum* [b, c]
Dicotylophyllum sp. 2	(–)
Dicotylophyllum sp. 3	*Grevillea haeringiana* [c]
Dicotylophyllum sp. 4	(–)
Carpolithus sp. 1 (aff. *Dioscoreaecarpum*)	*Acacia balearica* [c]

4. Results

This work involved the study of a set of 309 specimens, mainly dicotyledonous leaves (88.02%), monocotyledonous leaves (8.1%), legumes (2.26%), pteridophytes (1.29%) and winged fruits (0.32%). In total, at least ten plant families are present, and a total of twenty different taxa have been identified. Five taxa and a group of undetermined monocot leaves cannot be assigned to any particular family with certainty, although they constitute different morphotypes and give an idea of the floristic diversity of the plant community. Among the identifications from previous works, we can confirm only the presence of *Lygodium gaudinii* and *Sabalites* sp. (Table 1). Concerning this fact, it has not been possible to corroborate the presence of a significant number of species, which, although were described and figured by Fallot and Depape (1928), Arènes (1951) and Arènes and Depape (1956), were not found during our revision of the historical collections (Table 1 and Table 4, Appendix A). Concretely, these are: *Abies ramesi* (Fallot and Depape, 1928; Arènes, 1951; Arènes and Depape, 1956), *Diospyros brachysepala* (Arènes and Depape, 1956), *Fagus pliocenica* (Fallot and Depape, 1928; Arènes, 1951; Arènes and Depape, 1956), *Fraxinus balearica* (Arènes, 1951; Arènes and Depape, 1956), *Persea balearica* (Arènes, 1951; Arènes and Depape, 1956), *Smilax* sp. (Bauzá Rullán,

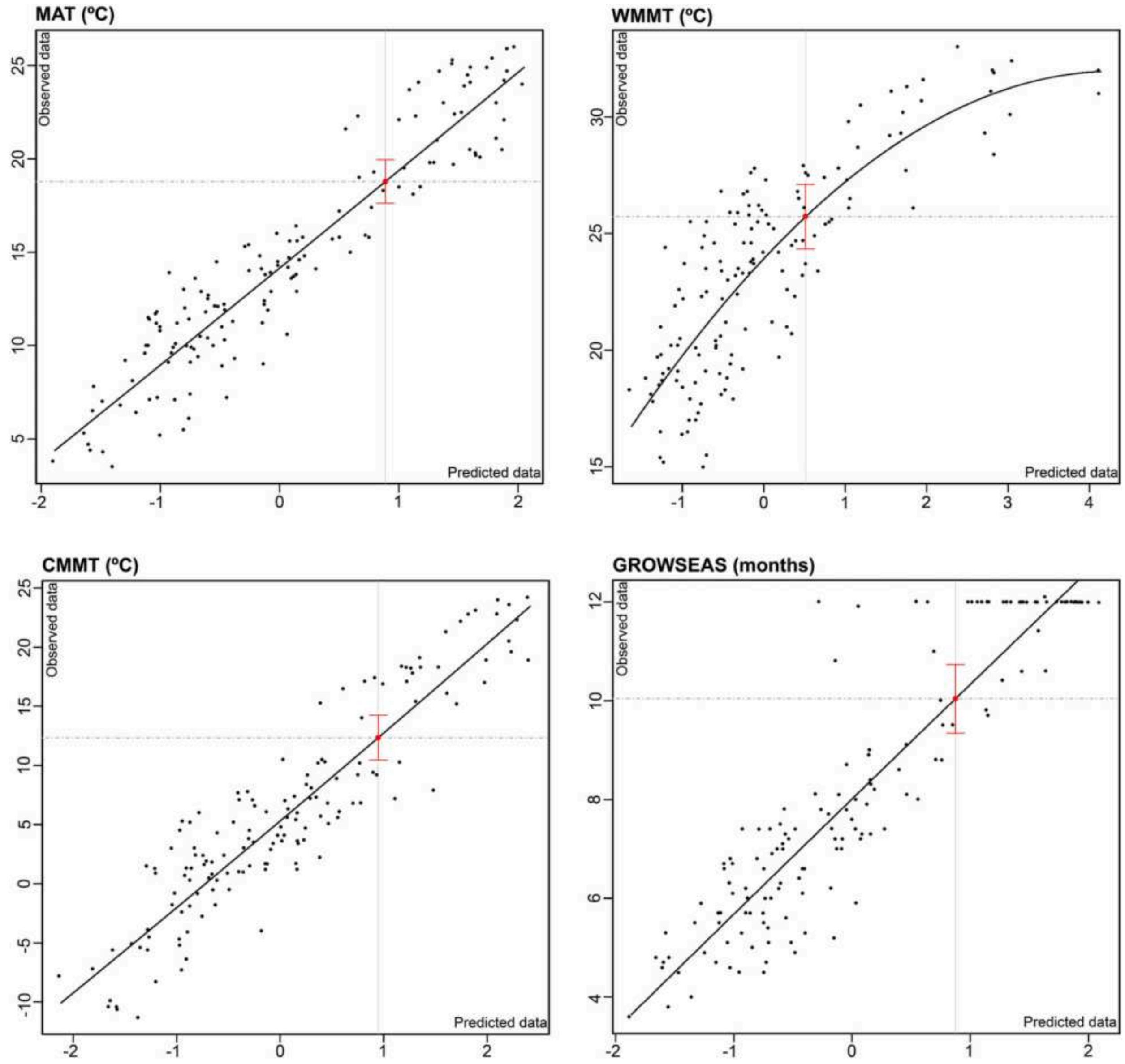

Fig. 2. CLAMP regression plots for MAT (mean annual temperature); WMMT (warmest month mean temperature); CMMT (coldest month mean temperature) and GROWSEAS (length of the growing season). These graphs have been generated by the CLAMP Online website. Modern calibration sites are shown as black circles and the Els Cardscolers site is plotted as a red circle. The uncertainties are shown as a red vertical bar. Dataset files used: Physg3brcAz_GRIDMet3brAZ. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

1961) and *Phoenicites* sp. (Arènes, 1951; Arènes and Depape, 1956). Besides, the species *Myrica arenesi*, *M. balearica*, *Castanea balearica*, *Proteoides* (?) *balearica*, *Acacia balearica* and *Zanthoxylon balearicum*, all of them described as new species from the flora of Mallorca, have been assigned to other taxa in this work (Table 1).

4.1. Systematic palaeobotany

4.1.1. Lygodiaceae

Lygodium gaudinii Heer (Plate 1, 1).

1855 *Lygodium gaudinii* Heer, p. 41, pl. 13, figs. 5–15.

1954 *Lygodium gaudinii* (Heer) Arènes and Depape, p. 1251.

1956 *Lygodium gaudinii* (Heer) Arènes and Depape, p. 3, pl. 15, fig. 1, pl. 19, fig. 1.

Material: MBCN-1706; MBCN-2497; MBCN-2693.

Description: fragments of sterile pinnae; 3.04–4.5 cm in length and 0.76–1.27 cm in width; pinnules asymmetrical, unilobates; base not preserved, apex rounded; margin entire; venation dichotomous, not anastomosing, midrib clearly visible, lateral veins oblique upward from midrib, bifurcating two to three times before reaching the margin.

Remarks: nowadays, *Lygodium* is a climbing and mainly pantropical fern (e.g. Wang et al., 2022). *Lygodium* fossils appear for the first time in the fossil record in the Late Cretaceous of North America (Manchester and Zavada, 1987; Gandolfo et al., 2000). Over the Eocene this fern was widespread in other parts in the world (e.g., Europe, Asia and Australia) disappearing in Europe in the late Miocene (Collinson, 2001; Rozefelds et al., 2017; Wang et al., 2022). Historically, the most cited fossil species in Europe are *Lygodium gaudinii* and L. *kaulfussii* (Collinson, 2001). They can be differentiated from each other based on their size and morphology of their leaflets (e.g., Manchester and Zavada, 1987; Collinson, 2001). Thus, *L. gaudinii* shows smaller and conical leaflets with pointed apices but not rounded. According to Bůžek and Konzalová (1983), although L. *gaudinii* may represent a younger type, both species may be treated as identical. Based on this criterion, we have kept the

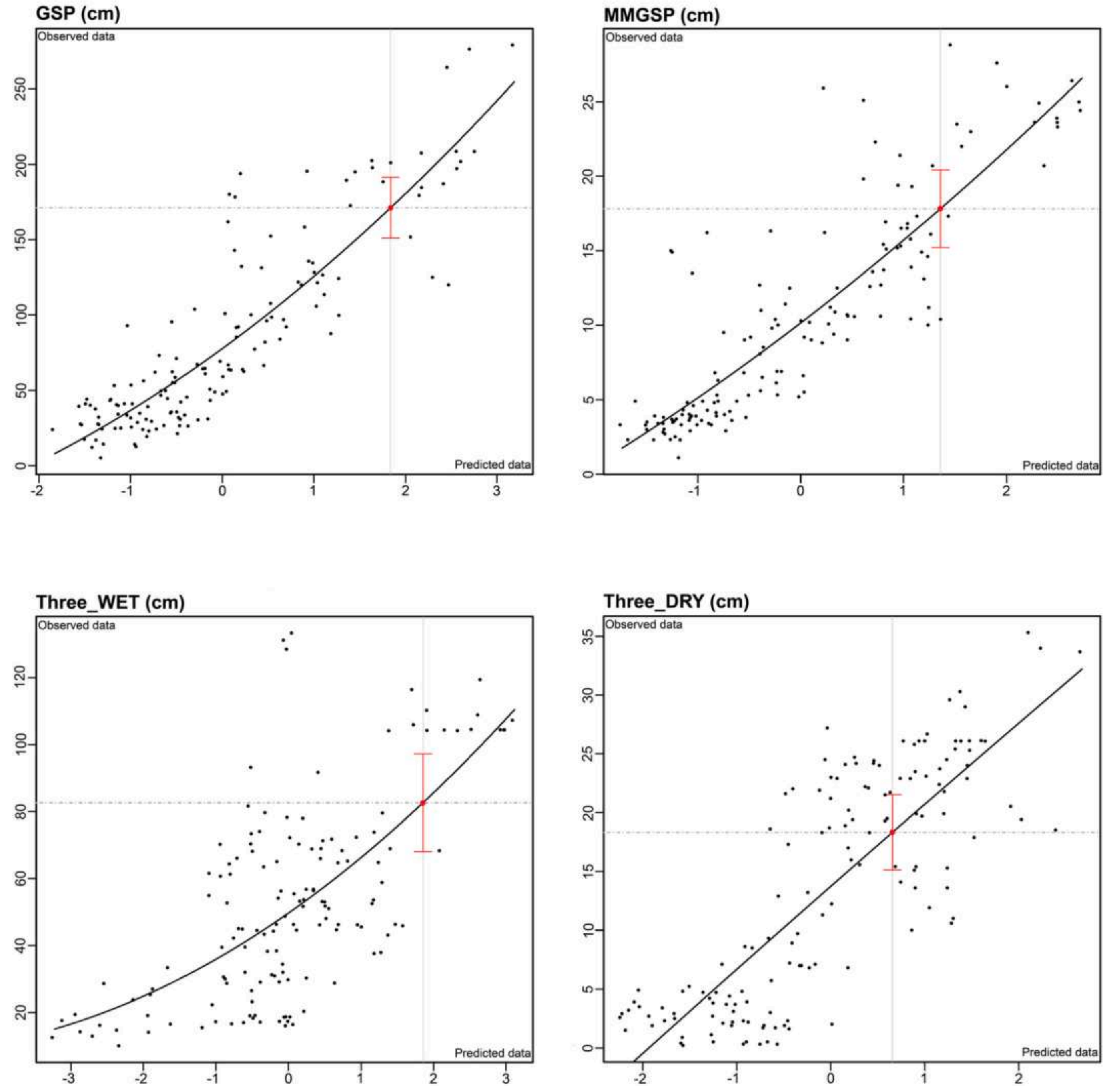

Fig. 3. CLAMP regression plots for GSP (growing season precipitation); MMGSP (mean monthly growing season precipitation); Three_WET (precipitation during the three wettest months) and Three_DRY (precipitation during the three driest months). These graphs have been generated by the CLAMP Online website. Modern calibration sites are shown as black circles and the Els Cardscolers site is plotted as a red circle. The uncertainties are shown as a red vertical bar. Dataset files used: Physg3brcAz_GRIDMet3brAZ. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

same species (*L. gaudinii*) for the megafossils of *Lygodium* from Majorca previously defined by Arènes and Depape (1954, 1956). *L. gaudinii* was widespread during the Oligocene and the Miocene in Central Europe (Belgium, Switzerland, Bulgaria, Germany) (e.g. Collinson, 2001), and in the Miocene of southern Europe (Greece) (e.g. Velitzelos et al., 2014).

4.1.2. Berberidaceae

Berberis kymeana (Unger) Kvaček and Erdei, (Plate 1, 2–3).
1861 *Grevillea kymeana* Unger, p. 60, text-fig. 17.
?1951 *Proteoides* (?) *balearica* Arènes, p. 79, fig. 1.7.
2001 *Berberis kymeana* Kvaček and Erdei, pp. 3–7, figs. 1g–k, fig. 2, fig. 4a.

Material: MBCN-17974; SHNIB-2271, MBCN-2507.

Description: Fragment of leaves linear-lanceolate, at least 6.9 cm in length and 0.4–0.6 cm wide (Plate 1, 2); apex absent; base broken, probably cuneate; margin badly preserved, possibly irregularly serrated; petiole absent. Midvein slightly bent, stout; venation pinnate possibly craspedodromous or semicraspedodromous; secondary venation fine with angle of divergence acute (≤30°) (Plate 1, 3) and course straight, joined probably in irregular areoles and abruptly curving near margins; third order veins randomly reticulate.

Remarks: Our specimens show morphological characteristics that

Fig. 4. Conceptual palaeoartistic reconstruction of the Burdigalian coast in Majorca Island. Author: Yul Altolaguirre.

relate them to the species *Berberis kymeana*. In particular, it shows clear similarities in venation, margin and shape with the specimens from the early Miocene flora of Kymi (Greece) (Kvaček and Erdei, 2001, fig. 1, K). In the past, these type of leaves were believed to be related to different genera belonging to the Proteaceae family such as *Grevillea*, *Lomatia* and *Hakea* (e.g., Unger, 1861, Unger, 1862, de Saporta, 1862; Saporta de Saporta, 1873). However, morphological and epidermal studies relate these fossils to several East Asian species of *Berberis* which inhabited dry slopes of the Himalayas and China (e.g., *B. lyceum*, *B. poiretii*, *B. vernae* or *B. lepidifolia*; Kvaček and Erdei, 2001). Possibly, the Majorcan specimens of *Proteoides* (?) *balearica* (Arènes, 1951) and *Grevillea haeringiana* (Arènes and Depape, 1956, pp. 17–18, pl. 15, figs. 18–22, pl. 19, fig. 11; specimens: MBCN-2506, 16,771, 17,722 and 17,731) may correspond to leaves of *B. kymeana*. However, their poor state of preservation does not let us make more precise considerations. Likewise, some fragmentary and lanceolate specimens with poorly preserved secondary venation and shape attributed to *Salix angusta* (Fallot and Depape, 1928, p. 15, figs. 7–9; Arènes and Depape, 1956, p. 8, pl. 15, figs. 6–8; specimens: MBCN-2499, 16,820) and probably other fossils such as IMG-0122, IMG-9364, IMG-9418, IMG-9422, MBCN-1899 and IMG-9533, could also be assigned to *B. kymeana*. In the Iberian Peninsula, this fossil barberry has also been found in the early Miocene site of Izarra (North Spain) (Barrón, 1999; Barrón et al., 2006).

4.1.3. *Fabaceae*

Fabaceae gen. et sp. indet. (Plate 1, 4).

Material: MBCN-16815.

Description: Poorly preserved leaflet, widely elliptic, 4.5 cm long and 2 cm wide; apex retuse; base not preserved; margin entire. Midrib straight and stout; venation pinnate brochidodromous; secondary venation poorly preserved and curved abruptly, emerging from the midvein with acute wide angle around 80°–85°; higher order venation not preserved.

Remarks: This type of leaflet with secondary veins emerging from the midvein with acute wide angles may be related to several species of fossil legumes from the Sarmatian of Oëhningen (Germany) such as *Ceratonia emarginata* (Heer, 1859, Pl. 134, figs. 17–18), *Dalbergia bella* (Heer, 1859, Pl. 133, figs. 14, 18–19), and *Leguminosites undulatus* (Heer, 1859, Pl. 138, fig. 59). Fossil leaflets similar in shape, size and venation from the Eocene of North America have also been related to extant *Swartzia* (Herendeen et al., 1992). Extant genera such as *Acosmium, Swartzia, Machaerium* or *Caesalpinia*, have leaves similar in shape, size and venation (Lewis et al., 2005).

Leguminocarpum sp. 1 (Plate 1, 5).

1956 *Acacia balearica* p.p. Arènes and Depape, pl. 17, fig. 11, pl.19, fig. 15.

Material: MBCN-16796, MBCN-16826.

Description: Two incomplete pods, symmetrical, elliptical, straight; size at least 4–4.5 cm long and 1.1–1.4 cm wide; base and apex not preserved; coriaceous epicarp with uniform surface texture; fruit margin slightly constricted, probably delimiting adjacent seed-bearing chambers; sutures externally visible, relatively thickened; fruit valve venation and wings absent; replum not visible.

Remarks: According to Wang (2012), this kind of fossil legume fruits,

Plate 1. Dicotyledonous leaves and legumes from Els Cardscolers site. Fig. 1. *Lygodium gaudinii* Heer (specimen MBCN-2693); Figs. 2–3. *Berberis kymeana* (Ung.) Kvaček and Erdei (specimen MBCN-17974), (2) aspect of the shape, margin and venation, (3) same specimen, detail of the venation; Fig. 4. Fabaceae gen. et sp. indet. (specimen MBCN-16815); Fig. 5. *Leguminocarpum* sp. 1 (specimen MBCN-16826); Fig. 6. *Leguminocarpum* sp. 2 (specimen MBCN-304); Fig. 7. *Leguminocarpum* sp. 3 (specimen MBCN-2697); Fig. 8. *Leguminocarpum* sp. 4 (specimen MBCN-16798); Fig. 9. *Engelhardia orsbergensis* (Wess. and Web.) Jähn., Mai and Walth. (specimen MBCN-1693). All specimens are housed in the Balearic Museum of Natural Sciences (MBCN). Scale bars: 1 cm.

previously attributed to *Leguminocarpon* Göppert and *Leguminosites* Bowerbank, as well as to other similarly spelt genera, have to be correctly included in the fossil-genus *Leguminocarpum* Dotzler. The morphology of these fossil legumes is similar to that of many other leguminous genera. For instance, they show some similarities to genera belonging to subfamily Caesalpinioideae, Mimosoideae and Faboideae (e.g., *Caesalpinia* L., *Acacia* Miller and *Dioclea* Kunth) (e.g., Herendeen et al., 1992; Kirkbride et al., 2003; Lewis et al., 2005). This kind of fossil morphology has been also related to the genus *Acacia* (Heer, 1859). However, there is not enough information to relate it to a single genus. This fruit shows some morphological analogies with that of *Leguminocarpum* sp. 1 from the Oligocene of the Ningming Formation of Guangxi, China (Fu-Jun et al., 2017, pl. 5, figs.1–2) and with another specimen described as *Leguminocarpon* sp. from the early Miocene of the south Slovakian Basin (Kováčová and Sitár, 2007). This fruit shows also some morphological analogies with that of fossil pods described as aff. *Ormosia* sp. from the early Miocene of the Ribesalbes-Alcora Basin (Postigo-Mijarra and Barrón, 2013, figs. 19–20). Moreover, our specimens resemble the one described as *Leguminosites* (Kovar-Eder et al., 2004, pl. 9, fig. 6) in the early Miocene of Parschlug (Austria).

Leguminocarpum sp. 2 (Plate 1, 6).

Material: MBCN-304, SHNIB-CB020.

Description: Pod symmetrical, straight, ca. 10.4 cm long and 1.2 cm wide; apex beaked, base beaked or rounded; fruit margin straight or slightly constricted; sutures externally visible; fruit wings absent; replum not visible; seed chambers in specimen MBCN-304 developed. One series of seven seeds, neither overlapping nor touching; seed ca. 1 cm long and ca. 0.7 cm wide; epicarp with surface texture uniform, not veined.

Remarks: Our specimens show clear analogies in shape, size and number of seeds with that of *Leguminosites hesperidum* (Kovar-Eder et al., 2004), which is a morphospecies that occurs in some time intervals such as the Egerian of Wind-brickyard (Hungary) (Kvaček and Hably, 1991; Hably, 1992) and the Sarmatian of Oëhningen (Germany) (Heer, 1859). In contrast, the specimen SHNIB-CB020 shows no contracted fruit margin. This type of legume morphology has been related previously to the genera *Acacia* and *Robinia* (Unger, 1864). Comparing this fossil legume with extant Fabaceae, we can infer some similarities to genera belonging to subfamily Mimosoideae and Faboideae (e.g., *Acacia*, *Dalbergia* and *Calpurnia*) (Kirkbride et al., 2003; Lewis et al., 2005). However, there is insufficient information to relate it to a single genus.

Leguminocarpum sp. 3 (Plate 1, 7).

1956 *Acacia balearica* p.p. Arènes and Depape, pl. 17, fig. 10, pl.19, fig. 16.

Material: MBCN-2697.

Description: Fruit complete, narrow oblanceolate, symmetrical, straight, c. 7.5 cm long and 1.7 cm wide; apex beaked, stipe-like structure at the base, 0.5 cm long; fruit margin not constricted; sutures externally visible; fruit wings absent; replum not visible; seed chambers not visible; epicarp with surface texture uniform, not veined.

Remarks: Our specimen shows some similarity in shape to the fossil pod from the Miocene of the Fukushima prefecture described by Tanai and Onoe (1959) as *Wistaria,* and to legumes of the extant genus *Wisteria*. However, in the genus *Wisteria*, both in extant and fossil species, the legumes are more elongated than in our specimen (Wang, 2012). Furthermore, the fragmentary nature of the fossil found in Japan and the lack of detail in the epicarp of the specimen from Mallorca do not allow a more precise identification. Leaflets related to the fossil species *Wisteria fallax* have been found in different European Miocene sites (Baranova, 1967; Bůžek, 1971). Other extant genera that bear fruit with some similarities in shape and size to our fossil specimen are *Acosmium* and *Acacia* (Kirkbride et al., 2003).

Leguminocarpum sp. 4 (Plate 1, 8).

Material: MBCN-16754, MBCN-16798.

Description: Two fragments of pods, symmetrical, straight, 3.5–5 cm long and 1.4–1.7 cm wide; apex and base not visible; fruit margin not constricted; sutures externally not visible; fruit wings absent; replum not visible; seed chambers developed. One series of four seeds, two of them fragmented; length slightly oblique to fruit length, neither overlapping nor touching; seed ca. 1.4 cm long and ca. 0.9 cm wide; epicarp with surface texture uniform, not veined.

Remarks: Because of its incomplete preservation and uncertain affinity, we describe the present fruit fossil under the fossil-genus *Leguminocarpum*.

4.1.4. Juglandaceae

Engelhardia orsbergensis (Wessel and Weber) Jähnichen, Mai and Walther (Plate 1, 9; Plate 2, 1–2).

1856 *Banksia orsbergensis* Wessel and Weber, p. 146, pl. 25, fig. 9a–d.

1977 *Engelhardia orsbergensis* Jähnichen, Mai and Walther, p. 323, pl. 9, fig. 4.

Material: MBCN-1693, MBCN-16853, SHNIB-CB021.

Description: Leaflets elliptic to lanceolate with lamina slightly asymmetrical, 4.5–5.5 cm long and 0.6–0.8 cm wide (Plate 1, 9); apex acute; base acute or cuneate; margin simply serrate; teeth small and narrow, spaced widely and regularly, similar in shape and size; apexes acute to acuminate, showing a slightly outward curve (Plate 2, 1); sinus shape rounded. Midrib moderate, slightly curved; venation pinnate craspedodromous to semicraspedrodomous; secondary veins numerous and dense, with >25 pairs of secondary veins arising from midvein at 45°–80° (Plate 2, 2); venation mostly straight, secondary vein angle smoothly increasing toward base; intersecondary veins usual; thin tertiary veins random reticulate.

Remarks: the set of anatomical features allows us to assign the fossil to the species *Engelhardia orsbergensis*, showing similar shape, margin and venation to specimens figured in Jähnichen et al. (1977, **Pl. 38,** fig. 1; **Pl. 39.** fig. 1; **Pl. 40,** figs. 1–3)**. This species can sometimes be mistaken for *Myrica longifolia*. However, the presence of rounded sinuses on the teeth distributed practically along the entire margin of the leaf, the elliptical shape of the lamina and the veins, with secondary of >45° and presence of intersecondary veins, allow this species to be differentiated from *M. longifolia* (Traiser et al.,** 2019**). Comparable specimens in shape and venation identified as *E. orsbergensis* have also been recorded in the** early Miocene Ipolytarnóc **site (Hably,** 1985**, pl. 24,** figs. **4–5; pl. 25,** fig. **4) and the** late early/early Middle Miocene **flora of** Parschlug **(Kovar-Eder et al.,** 2004**, pl. 6, figs. 10a–b).** This species was a thermophilic element of Eocene to Pliocene floras in Europe (Manchester, 1987; Kvaček, 2002; Hably, 2020). Iberian specimens related to this species have been recorded in the late Oligocene La Val site (Moreno-Domínguez et al., 2021), in the early Miocene site of Cristo Rey (Antunes et al., 1999) and in the middle Miocene of the Madrid Basin (Fernández-Marrón et al., 2002). Likewise, the presence of *Engelhardia* in Iberia has been recorded from pollen grains throughout the Cenozoic until the early Pleistocene (Postigo-Mijarra et al., 2009; Verdú et al., 2020).

4.1.5. Lauraceae vel. Fagaceae

Laurophyllum sp. (Plate 2, 3–4).

1956 *Juglans acuminata* A. Braun– Arènes and Depape, p. 14, pl. 15, fig. 15, pl. 19, fig. 10.

Material: MBCN-1701, 2496, 2500, 2509, 2511, 16,820, 16,833, 16,856; SHNIB-CB002, 006, 009, 023, 049.

Description: Elliptic or elliptic-ovate leaves, 3.3–9.8 cm long and 1.3–3.4 cm wide; symmetrical or slightly asymmetrical lamina; apex acute; base decurrent; margin entire; petiole 0.2 cm long. Midrib straight moderate to stout; venation pinnate brochidodromous; secondaries alternate, with 8–11 pairs of secondary veins arising from the midvein regularly at 35°–65°; vein angle markedly different in each side of the leaf in asymmetrical laminas; secondary vein angle uniform or smoothly increasing toward base; ultimate marginal venation looped; third and fourth order veins randomly polygonal reticulate.

Remarks: The shape and venation of some specimens (see SHNIB-

Plate 2. Dicotyledonous and palm leaves from Els Cardscolers site. Figs. 1–2. *Engelhardia orsbergensis* (Wess. and Web.) Jähn., Mai and Walth., (1) aspect of the margin and teeth (specimen MBCN-1693), (2) detail of venation (specimen MBCN-16853); Figs. 3–4. *Laurophyllum* sp. (Lauraceae vel Fagaceae), (3) aspect of brochidodromous venation (specimen MBCN-2500), (4) elliptic leaf (specimen SHNIB-CB002); Figs. 5–7. *Myrica lignitum* (Ung.) Sap., (5) narrow oblanceolate leaf (specimen MBCN-1821), (6) detail of semicraspedodromous venation, secondary veins with different angle of divergence in each half of the leaf (specimen MBCN-2501), (7) detail of tertiary and quaternary venation (specimen MBCN-16875); 8. Costapalmate leaf of *Sabalites* sp. (specimen MBCN-19847). All specimens are housed in the Balearic Museum of Natural Sciences (MBCN) except the SHNIB-CB002 from the Society of Natural History of the Balearic Islands. Scale bars: 1–2 = 1 cm; 4–7 = 0.5 cm; 8 = 4 cm.

CB002, MBCN-16856) suggest resemblances with those identified as "*Laurus*" *primigenia* from the early Miocene floras of Krezau (W Germany) and Lipovany (S Slovakia) (Ferguson, 1971, fig. 23 B, E–F; Sitár and Kvaček, 1997, pl. 2, fig. 4). Moreover, some specimens with asymmetrical laminas also show similarities with those from the early Miocene flora of Ipolytarnóc (N Hungary) attributed to *Laurophyllum heeri* (Hably, 1985, pl. 16, fig. 2). The relationship of these lauroid leaf fossils to a specific family remains unclear. Different epidermal studies have shown that some of these fossils, included in genera such as *Laurus* and *Persea*, can be clearly related to Fagaceae genera such as *Lithocarpus, Eotrigonobalanus* and *Castaneophyllum* (e.g., Givulescu, 1987; Kvaček and Walther, 2010; Winterscheid and Kvaček, 2016). For this reason, we cannot confidently attribute the studied specimen to a particular genus of Lauraceae nor Fagaceae.

4.1.6. *Myricaceae*

Myrica lignitum (Unger) Saporta (Plate 2, 5–7).

1847 *Quercus lignitum* Unger, p. 113, pl. 31, figs. 5–7.

1865 *Myrica lignitum* Saporta, pp. 102–103, pl. 5, fig. 10.

1951 *Quercus drymeia* Unger – Arènes, p. 82.

1951 *Castanea balearica* Arènes, p. 82, fig. 1.5, pl. 6, fig. 5.

1951 *Leucothoe balearica* Arènes, p. 77, fig. 1.1–2, pl. 6, figs. 1–2.

1951 *Pseudopanax balearica* Arènes, p. 76, fig. 1.8, pl. 6, fig. 8.

1956 *Castanea balearica* Arènes – Arènes and Depape, pp. 15–16, pl. 15, fig. 7.

1956 *Laurus* aff. *praecellens* Saporta – Arènes and Depape, pp. 19–21, pl. 17, fig. 7, pl. 19, fig. 12.

1956 *Myrica arenesi* Arènes and Depape, pp. 9–12, pl. 15, figs. 9–11, pl. 16, figs. 1–14, pl. 19, figs. 2–8.

1956 *Myrica faya* Aiton – Arènes and Depape, p. 13, pl. 15, figs. 12–13, pl. 19, fig. 9.

1956 *Nerium oleander* L. – Arènes and Depape, pp. 27–28, pl. 18, fig. 14.

1956 *Pseudopanax balearica* Arènes – Arènes and Depape, pp. 25–26, pl. 18, figs. 9–10, pl. 19, fig. 20.

1956 *Sapindus bilinicus* Ettinghausen – Arènes and Depape, pp. 24–25, pl. 18, figs. 7–8, pl. 19, fig. 19.

Material: MBCN-2492, 2495, 2501–2502, 2507, 2510, 2695, 2698, 16,744, 16,746, 16,751, 16,755–16,756, 16,759, 16,763–16,765, 16,767, 16771a, 16,773–16,774, 16,778–16,779, 16,784, 16,786, 16793a, 16793b, 16,795, 16,799–16,800, 16,802–16,804, 16,808, 16,810–16,812, 16,817–16,819, 16,821–16,825, 16,827, 16,832, 16,849, 16,851, 16,855–16,856, 16,859–16,862, 16,864, 16,875, 16,903, 17,716, 17,719–17,721, 17,723, 17,725–17,726, 17,728–17,732, 17,734–17,735, 17,740–17,741, 17,745, 17,748, 17,751, 17,753, 17,760, 17,763–17,764, 17,766, 17,769, 17,771, 17,777, 17,968, 17,983, 17,972, 17,975–17,976, 17,978, 19,848, 19,851; MBCNGeología-1692–1693, 1695–1696, 1704; SHNIB-2218, 2245, 2271–2272, 2277; SHNIB-CB005, 008, 012, 014, 022, 028, 030–032, 035–-037, 039–040, 042, 046, 053.

Description: Leaves elliptic, oblong, lanceolate or obovate, 3–12.5 cm long and 0.8–3.7 cm wide (Plate 2, 5–6); apex acute to attenuate; base cuneate to decurrent, sometimes asymmetrical; petiole straight, up to 4 cm; margin entire, entire in the lowermost third or serrate; leaf teeth widely spaced, small; tooth apex acute to rounded (Plate 2, 6); shape concave-convex, straight-straight and concave-straight; sinuses rounded to angular; midrib stout to moderate with course straight; venation pinnate semicraspedodromous but also craspedodromous, mixed craspedodromous when the base has the margin entire, and brochidodromous when all the margin is entire; secondary venation not dense, abruptly curved with >20 pairs of secondary veins arising from midvein at 45°– 75° (90°) (Plate 2, 7); secondary vein angle smoothly increasing toward base; intersecondary veins usual; third order veins random or orthogonal reticulate; fourth order veins orthogonal reticulate.

Remarks: Our samples show clear similarities in shape, venation and margin with those figured from the early Miocene Parschlug flora, Austria (Kovar-Eder et al., 2004, pl. 7, figs. 3b, 4b and 14d) and the late Miocene Kassanoi assemblage (Crete Island) (Zidianakis et al., 2020, figs. 11, 13 and 16). In addition, the shape and venation of the specimens MBCN-17730 and MBCN-19848 resemble the early Miocene leaves of *M. banksiaefolia*, described in the Rubielos de Mora Basin (E Spain) (Barrón and Diéguez, 2001). *M. lignitum* is the most abundant taxon in the Els Cardscolers site. This morphospecies has a remarkable heterophyllous nature (Kovar-Eder, 1982) as Velitzelos et al. (2002) also indicated for the early Miocene flora of Kymi (Greece). At this location, Unger (1867) described the species *Asclepias podalyrii*, *Laurinastrum dubium*, *Neritium longifolium* and *Olea noti*, from specimens with entire margin belonging to *M. lignitum*. Unger (1867) also identified *Myrica vindobonensis* and *Dryandroides hakeaefolia* from serrate leaves (Velitzelos et al., 2002) also belonging to *M. lignitum*. The Majorcan specimens with entire margin were erroneously described as *Leucothoe balearica*, *Myrica arenesi* (specimens MBCN-16773, 16,824, 17,729–17,730, 17,732, 19,848), *Laurus* aff. *praecellens* (specimens MBCN-16820, 16,833, 16,856), *Nerium oleander* (specimens MBCN-2511, 16,822) and *Sapindus bilinicus* (specimen MBCN-2510), whereas the serrate ones were attributed to *Castanea balearica*, *Myrica arenesi* (specimens MBCN-2695, 16,771, 16,825, 16,832, 17,731, 17,735, 17,975), *M. faya* (specimens MBCN-2495, 2698, 17,731), *Pseudopanax balearica* (specimen MBCN-2502) and *Quercus drymeja* (Arènes, 1951; Arènes and Depape, 1956; Colom, 1975).

Myrica longifolia Unger (Plate 3, 1).

1850b *Myrica longifolia* Unger, 29, Pl. 6, fig. 2.

Material: MBCN-16743.

Description: Symmetrical leaf-remain, linear to linear-lanceolate, 4.87 cm long and 0.52 cm wide; apex and base absent; margin irregularly serrate and spaced; tooth shape variable, straight-straight and concave-convex, occasionally spiny teeth; sinus shape rounded. Midvein straight and moderate; venation pinnate; secondary veins poorly preserved, craspedodromous or semicraspedodromous; delicate and spaced secondary venation curved with >12 pairs of secondary veins emerging at 40°–80°; tertiary venation not preserved.

Remarks: This specimen shows the typical characteristics in vein, margin and shape of *M. longifolia*. It has similarity with specimens similar in shape, margin and venation from the early Oligocene flora of Flörsheim (Germany) (Kvaček, 2004, pl. 9, figs. 6–8). *M. longifolia* is a predominantly Paleogene element which occurs together with subxeromorphic taxa such as *Comptonia schrankii*, *Cedrelospermum* and many Fabales in Central Europe (Knobloch et al., 1993). Possibly, this species [see the specimen of *Myrica arenesi* in Sanz de Siria, 1992, pl. 2, fig. 3] also inhabited xeric environments in the Iberian Oligocene together with *Tetraclinis brachyodon*, *Daphnogene lanceolata*, *Rhus assymetrica*, *Comptonia schrankii* and Fabales (Sanz de Siria, 1992; Tosal et al., 2019a, 2019b). *M. longifolia* has also been related to Miocene floras in Europe (e.g., Zhilin, 1989; Palamarev et al., 2000, 2005; Kováčová and Sitár, 2007). Particularly, *M. longifolia* has been found in Spanish early Miocene sites associated with xerophytic taxa such as *T. brachyodon* and *Berberis kymeana* in Izarra (Barrón et al., 2006), and *Celastrophyllum* sp., aff. *Cedrelospermum* sp. and Caesalpiniaceae in the Burdigalian of the Ribesalbes-Alcora Basin (Postigo-Mijarra and Barrón, 2013).

4.1.7. *Rhamnaceae*

Ziziphus paradisiaca (Unger) Heer (Plate 3, 2).

1845 *Daphnogene paradisiaca* Unger, p. 227.

1859 *Zizyphus paradisiacus* Heer, p. 337.

1961 *Cinnamomum* cf. *lanceolatum* (Unger) Heer – Bauzá Rullán, p. 51, Pl. 4, fig. 2.

1961 *Zizyphus* sp. – Bauzá Rullán, pp. 51–52, Pl. 4, fig. 3.

Material: MBCN-2276, 2494, 16,771, 16,794, 17,742, 19,849–19,850; SHNIB-CB003, 011, 013, 019, 025–026, 031, 043, 048.

Description: Leaves elliptic, ovate and lanceolate sometimes asymmetrical; 3.5–5.5 cm long and 1.4–2.24 cm wide; apex acute to

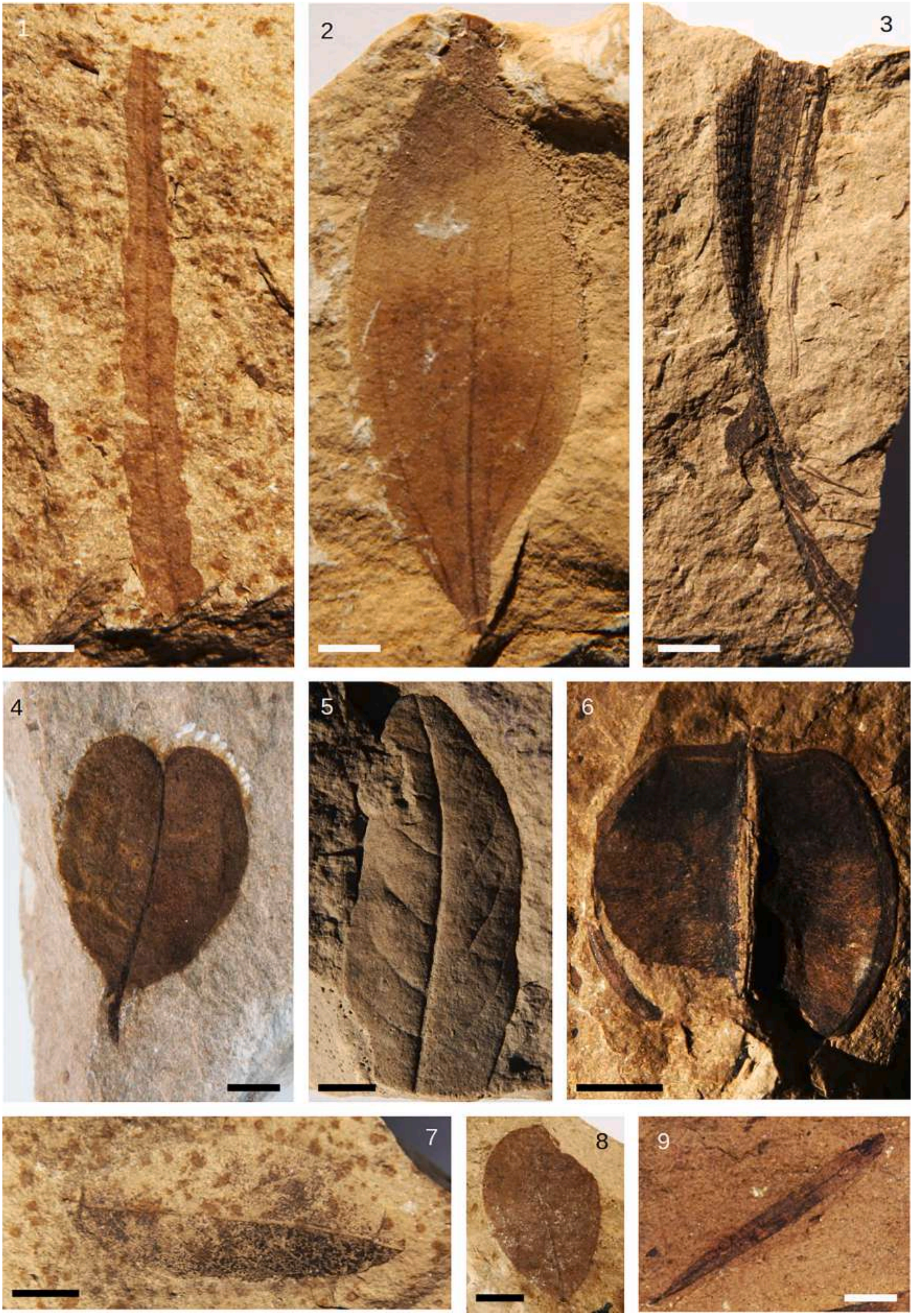

Plate 3. Leaves and fruits of monocots and dicotyledones from Els Cardscolers site. Fig. 1. *Myrica longifolia* Ung. (specimen MBCN-16743); Fig. 2. *Ziziphus paradisiaca* (Ung.) Heer (specimen MBCN-19849); Fig. 3. Folded fragment of a linear leaf of an undetermined monocotyledon (specimen MBCN-16777); Fig. 4. *Sapotacites minor* (Ung.) Heer (specimen CB-010); Fig. 5. *Dicotylophyllum* sp. 4 (specimen MBCN-1703); Fig. 6. *Carpolithus* sp. (aff. *Dioscoreaecarpum*) (specimen MBCN-17733); Fig. 7. *Dicotylophyllum* sp. 2 (specimen MBCN-16760); Fig. 8. *Dicotylophyllum* sp. 1, (specimen MBCN-16741); Fig. 9. *Dicotylophyllum* sp. 3 (specimen SHNIB-CB020). All specimens are housed in the Balearic Museum of Natural Sciences (MBCN) except the SHNIB-CB020 from the Society of Natural History of the Balearic Islands. Scale bars: 1–8 = 0.5 cm.

attenuate; base cuneate to convex, in some cases asymmetrical; petiole around 0.35 cm long; margin entire to slightly serrate; tooth apex obtuse; sinuses rounded. Midrib moderate and straight; venation acrodromous basal; sometimes one of the lateral secondary veins dichotomizes; presence of agrophic veins; tertiary venation percurrent with course straight, being its angle perpendicular to the midrib.

Remarks: The studied specimens show similar shape, margin and venation to those from the late early Miocene of Mecsek area, Hungary (Hably, 2020, pl. 18, e.g. figs. 4–5). The genus *Ziziphus* commonly occurred in South European Oligocene floras (Saporta de Saporta, 1862, 1863; Hably, 1979; Hably and Fernández-Marrón, 1998), but it is represented by the species *Z. zizyphoides*, which presents conspicuous toothed margin and narrower leaves (Unger, 1847). According to Hably (2020), *Z. paradisiaca* is characteristic of the early Miocene floras, occurring as an accessory element. In the Iberian Peninsula, *Ziziphus* has also been recorded in the Priabonian of Sarral (e.g., Hably and Fernández-Marrón, 1998; Tosal et al., 2018), the Oligocene sites of Cervera and Talladel (Sanz de Siria, 1996) and the Serravallian site of Montjuïc (Vicente i Castells, 1988), all of them in northeastern Spain. Nowadays, the species *Z. lotus* inhabits xerophytic environments in the southeast of the Iberian Peninsula.

4.1.8. Arecaceae

Sub-family Coryphoideae.

Sabalites sp. (Plate 2, 8).

1847 *Flabellaria major* Unger, p. 42, pl. 14.

1956 *Sabalites* sp. – Arènes and Depape, p. 7.

Material: MBCN-19847; SHNIB-CB004.

Description: Leaves costapalmate, with rounded shape; in the specimen MBCN-19847 exceeding 108 cm in perimeter; petiole straight, 2–4 cm; costa present, strong, 3–6 cm long, 1–3 cm wide; hastula not visible; primary leaf segments ca. 50–60 cm long and 1–2 cm wide; emerging directly from the apex of the petiole; around 36 leaflets in the above mentioned specimen, venation not visible.

Remarks: According to Read and Hickey (1972), this kind of costapalmate leaves must be assigned to the fossil-genus *Sabalites* Saporta de Saporta (1865). The similar fossil-genus *Palmacites* Brongniart (1822) exhibits pure palmate leaves. Numerous coryphoid palms such as *Sabal, Washingtonia, Serenoa* and *Chamaerops* exhibit similar costapalmate leaves, making it difficult to establish a clear relation with any current genus without additional data (Read and Hickey, 1972). The state of preservation of fossils does not allow to relate them to a single species of fossil palm. Some resemblances in the shape of leave, leaflets and costa are observed between *Sabalites campbelli* from the Paleogene of USA and *Sabal maior* from the Miocene of Germany (Kumar et al., 2023). In the Mediterranean region, a similar fragment of leaf related to *Sabalites* has been recorded in the middle Tortonian of Metochia, Gavdos Island (Zidianakis et al., 2020). In addition, Arènes (1951) also indicated the occurrence of pinnate palm leaves of *Phoenicites* in Majorca. However, we cannot confirm the presence of this genus in the studied assemblages.

Monocotyledons incertae sedis (Plate 3, 3).

1956 *Typha* sp. – Arènes and Depape, p. 6, Pl. 15, fig. 2.

1956 *Phragmites* sp. cf. *Phr. oeningensis* A. Braun – Arènes and Depape, p. 6–7, Pl. 15, fig. 3.

Material: MBCN-2504, 2506, 2508, 2509, 16,752, 16,758, 16,774, 16,777, 16,781, 16,797, 16,806, 16,807, 16,816, 16,820, 16,822, 16,828, 16,841, 16,848, 16,852, 17,717, 17,743, 17,756, Geología-1700.

Description: Fragmentary specimens with a broad linear leaf blade, over 1.4–9.53 cm long and 0.54–1.9 cm wide; apex and base not preserved; margin entire. Venation parallelodromous with >13 veins per leaf; sometimes with small parallel secondary veins between them. These veins sometimes show anastomoses between them (see specimens MBCN-16777, 2506).

Remarks: This type of leaf surely corresponds to several hygrophytic species of different families of monocotyledons such as Typhaceae, Poaceae and Cyperaceae.

Magnoliidae incertae sedis.

Sapotacites minor (Unger) Heer (Plate 3, 4).

1850a *Pyrus minor* Unger, p. 53, Pl. 38, figs. 16–24.

1859 *Sapotacites minor* Heer, p. 14, Pl. 103, fig. 9.

1866 *Bumelia minor* (Unger 1850) Unger: 25; Taf. 6, figs. 11–19.

?1951 *Myrica balearica* Arènes, p. 6, Pl. 1, fig. 4.

Material: SHNIB-CB010.

Description: Leaf symmetrical, obovate, 2 cm long and 1.7 cm wide; apex emarginated; base cuneate; margin entire; petiole 0.4 cm long. Midrib straight and moderate; venation pinnate brochidodromous; secondary venation poorly preserved, curved abruptly with 2–3 pairs of secondary veins arising from midvein at 80°–85°; marginal ultimate venation looped; possibly presence of intersecondaries; tertiary venation not preserved.

Remarks: the set of characteristics described allows us to assign the fossil to the morphospecies *Sapotacites minor*. Specimens assigned to genera such as *Sapotacites* and *Bumelia* which exhibit similar leaf architecture, are of difficult taxonomic affiliation (Jungwirth, 2004; Winterscheid, 2018). Some authors have related *Sapotacites minor* to Sapotaceae (e.g., Heer, 1869; Hofmann and Sachse, 2023). In fact, pollen related to this family and this morphospecies have been found together in the same sites (e.g., Suc and Fauquette, 2012; Hofmann and Sachse, 2023). However, other authors claim that *S. minor* and *Bumelia minor* must be considered the same species and they could probably be related to the Fabaceae family (Knobloch, 1969). A specimen similar in shape and size without conspicuous venation was found at the site and described as *Myrica balearica* Arènes (Arènes, 1951; Arènes and Depape, 1956). Unfortunately, this specimen could not be studied because it was not found in the studied collections. The morphoespecies *S. minor* (including *B. minor*) is cited in Europe from the Eocene to the middle Miocene (Bozukov et al., 2021). In the Iberian Peninsula, similar leaves to our specimen have been assigned to *S. minor* from the Miocene of Campo Grande (Heer, 1881), to *B. minor* from the Priabonian of Sarral and the Oligocene of Cervera (Fernández-Marrón, 1971; Sanz de Siria, 1992; Tosal et al., 2018) and to *M. balearica* and *B. minor* from the Burdigalian of Martorell (Sanz de Siria, 1981).

Dicotylophyllum sp. 1 (Plate 3, 8).

aff. Fabaceae gen et sp. Indet.

1951 *Zanthoxylum balearicum* Arènes, p. 75, fig. 1.5, pl. 6, fig. 3.

1956 *Pistacia terebinthus* L. – Arènes and Depape, p. 23, Pl. 18, figs. 4–5.

1956 *Zanthoxylum balearicum* Arènes – Arènes and Depape, p. 22–23, Pl. 18, figs. 1–3.

1975 *Zanthoxylum balearicum* Arènes –Colom, Fig. 136, 6.

Material: MBCN-2503, 2504, 16,741, 16,761, 16,768, 16,791.

Description: Leaflets? symmetrical suborbiculate, wide ovate or wide obovate, 1.7–3.3 long and 1.1–2.4 wide; apex rounded or slightly emarginated; base rounded to obtuse; margin entire; petiolule absent or short, around 2 mm. Midrib straight and moderate; venation pinnate brochidodromous; secondary venation badly preserved curved abruptly; angle of divergence acute moderate; higher order venation not preserved.

Remarks: This type of leaflets can be related to some specimens of *Robinia regeli* from the Egerian of Pomáz (Hably, 1994, Pl. 19, fig. 2), the Burdigalian-Helvetian of Znojmo (Knobloch, 1969, Abb. 26–27), the Sarmatian of Oëhningen (Heer, 1859, Pl. 132, figs. 21–25) and the Langhian of Sant Sadurni D'Anoia (Sanz de Siria, 1983–1984, Pl. 2, fig. 5). The obovate specimens also exhibit resemblances with these of "*Colutea*" *kvaceki* from the Egerian of Pomáz (Hably, 1994, pl. 19, figs. 3–5, 7–8).

Dicotylophyllum sp. 2 (Plate 3, 7).

Material: MBCN-16760.

Description: Leaflet? symmetrical, ovate, 3.2 cm long and 1.4 cm wide; apex acute; base not preserved, possibly acute; margin entire. Midrib straight and stout; venation pinnate brochidodromous;

secondary venation badly preserved curved abruptly; around seven pairs of secondary veins curved abruptly, emerging from the midvein with an angle acute moderate of 45°–50°; presence of badly preserved intersecondaries; higher order venation not preserved.

Remarks: Due its shape, this leaflet presents similarities with those of *Cassia* figured by Heer (1859, Pl. 138). However, they show higher number of secondary veins appearing more than nine pairs. Due its shape and venation, the studied specimen also presents similarities with that of cf. *Cassia* sp. from the early Miocene of Lipovany (Sitár and Kvaček, 1997, p. 272, Pl. 5, fig. 1).

Dicotylophyllum sp. 3 (Plate 3, 9).

1956 *Grevillea haeringiana* Ettinghausen – Arènes and Depape, pl. 15, figs. 18–22, pl.19, fig. 11.

Material: SHNIB-CB020, MBCN-2506, MBCN-16671, MBCN-17722, MBCN-17731.

Description: Simple symmetrical, linear to linear oblong laminas, 6.2–7 mm long and 0.3–0.4 mm wide; apex acute to acuminate; base acute to cuneate; margin entire; petiole straight ca. 3 mm long. Only straight and normal midrib is preserved.

Remarks: This leaf type was assigned by Arènes and Depape (1956) to the family Proteaceae, being specifically identified as specimens belonging to the species *Grevillea haeringiana*. However, the lack of other complementary morphological characters and their appearance isolated from other possible parts of the same plant does not allow this identification to be confirmed.

Dicotylophyllum sp. 4 (Plate 3, 5).

Material: MBCN-1703.

Description: Leaf fragment possibly elliptic, 2.2 cm long and 1.3 cm wide; apex rounded; base not preserved; margin entire. Midrib moderate and straight; venation pinnate brochidodromous; secondary veins alternate and abruptly curved with around 7 pairs of secondary veins arising from midvein at 45°; secondary vein angle uniform; third order venation not preserved.

Remarks: Based on its leaf morphology this specimen may be related to different species from the Sarmatian of Oëhningen such as *Cassia hyperborea* Unger (Heer, 1859, Pl. 137, fig. 61) and *Phyllites juglandinus* Heer (Heer, 1859, Pl. 111, figs. 42–43). However, the lack of other specimens and cuticles prevent us to relate it to a particular taxon.

Carpolithus.

aff. Dioscoreaecarpum sp. (Plate 3, 6).

1956 *Acacia balearica* p.p Arènes and Depape, pl. 17, fig. 12, pl.19, fig. 14.

Material: MBCN-17733.

Description: fruit capsulate, three winged, flat compressed, oblong-elliptical, ca. 22 mm long, 18 mm wide. Wings 8 mm wide with barely visible horizontal striations. Base badly preserved and apex with apical projection 1 mm long. Marginal suture clearly thickened, ca. 1 mm wide.

Remarks: This fruit shows clear analogies with those present in some representatives of the family Dioscoreaceae (Manchester and O'Leary, 2010; Raz, 2017). Concretely, the fruit shows similarities in shape, structure and margin with the species *Dioscoreaecarpum marginatum* from the lower Oligocene of Hungary (Andreánszky, 1959) and *Dioscorea manchesteri* from the early Miocene flora of North Bohemia (Czech Republic) (Kvaček, 2019). Our fossil also shows some similarities in shape and size with the Eocene specimen of *Dioscorea* sp. from the Florissant flora (Manchester, 2001). However, in our specimen the presence of a pedicel is not visible due to its state of preservation. As the fine striation present on the wings is faintly visible and the base is not preserved, we cannot confirm with certainty the assignment to the morphogenus *Dioscoreaecarpum*.

4.2. CLAMP (Climate Leaf Analysis Multivariate Program)

The values of all palaeoclimatic variables were obtained by employing the CLAMP method along with their standard deviations as a measure of statistical uncertainty (Table 2; Appendix A). Graphs with the palaeoclimatic variables of CLAMP are shown in Figs. 2, 3 and 6 (see Appendix A).

Table 2
Climatic variables obtained by CLAMP analysis from the Els Cardscolers site.

DATA		Sampling Error (SE) (±)
MAT [°C]	18.80	1.15
WMMT [°C]	25.70	1.37
CMMT [°C]	12.30	1.90
GROWSEAS (month)	10.00	0.68
GSP (mm)	1711	200
MMGSP (mm)	178.2	26.1
THREE_WET (mm)	826	148.5
THREE_DRY (mm)	183	32
RH [%]	69.70	5.09
SH [g/kg]	9.70	0.99
ENTHAL [kj/kg]	33.00	0.45

Twenty morphotypes from the Collet de Bini outcrop were scored (Plate 4). The first variable to consider is MAT, which is estimated to be 18.8 ± 1.15 °C (ca. 17.6 to 19.9 °C). WMMT ranges from ca. 24.3 to 27.07 °C (25.7 ± 1.37 °C), while CMMT ranges from 10.4 to 14.2 °C (12.3 ± 1.9 °C). The length of the growing season (GROWSEAS) is 10 ± 0.68 months (from 9.32 to 10.68 months). Regarding the rainfall, GSP ranges from 1511 to 1911 mm (1711 ± 200 mm), corresponding to an average of 178.2 ± 26.1 mm per month (MMGSP). The precipitation for the three wettest months (Three_WET) ranges from 677.5 to 974.5 mm (826 ± 148.5 mm) and the precipitation for the three driest months (Three_DRY) ranges from 151 to 215 mm (183 ± 32 mm). The relative humidity (RH) is 69.7 ± 5.09% (64.61 to 74.79%). The results of SH and ENTHAL are estimated to have been 9.7 ± 0.99 g/kg and 33 ± 0.45 kj/kg, respectively. The completeness statistics provided by the CLAMP analysis is 0.88 (Appendix A), which is above the 0.6 cut off for reliability (see Yang et al., 2011).

5. Discussion

5.1. Palaeovegetation and palaeoecological considerations

Traditionally, the flora from the Burdigalian site of Els Cardscolers has been interpreted as having developed near a fresh-water pool characterized by the occurrence of *Sphaerium* and hygrophytic rivermarshed reed communities (e.g., Fallot and Depape, 1928; Arènes and Depape, 1956). However, the occurrence of bivalves of the *Cardium* group next to leaf remains as well as the lagoon-type facies show the existence of a coastal lagoon or wetland (Rodríguez-Perea, 1984). These wetlands were sometimes closed to the sea and had fresh water, as indicated by the presence of foliar remains of reed plants and *Sphaerium*. In other times, they communicated with the sea and had brackish or salty waters, as the presence of shells attributed to the *Cardium* group suggests (e.g., Rodríguez-Perea, 1984; Ramos-Guerrero et al., 1989; Sàbat et al., 2011). Arènes and Depape (1954) emphasized the presence of three fossil types, which would characterize the Majorcan flora: (i) the *Lygodium* fern, (ii) the abundant occurrence of *Myrica* and (iii) the presence of pods, which give an archaic character to the flora because they did not know recent European plants with close taxonomic affinities. Perhaps, the difficulty in finding affinities by the above-mentioned authors was due to the clear palaeotropical affinity of this flora (Mai, 1989, 1991). This affinity seems to be usual in other early Miocene insular Mediterranean paleofloras, like e.g., in the Evia Island, Greece (Kottis et al., 2002). On the other hand, Fallot and Depape (1928) indicated the existence of close mountains where wet climate developed allowing the existence of firs and beeches. However, after the taxonomic revision made in this work, montane elements have not been detected (Table 1).

The predominance of the morphospecies *Myrica lignitum* in the samples studied is remarkable. The abundance of *M. lignitum* indicates

Plate 4. Fossil morphotypes from Els Cardscolers site (Majorca, Spain) used for CLAMP determination. The number of the figures are correlative with the acronym done to each morphotype (see Appendix A). Fig. 1. Fabaceae gen. et sp. indet. (morphotype Co-1: specimen MBCN-16815); Figs. 2, 5–6, 8, 12, 18. *Myrica lignitum* (morphotype Co-2: specimen MBCN-16821, morphotype Co-5: specimen MBCN-16832, morphotype Co-6: specimen MBCN-16779, morphotype Co-8: specimen MBCN-16818, morphotype Co-12: specimen MBCN-16859, morphotype Co-18: specimen SHNIB-CB008); Fig. 3. *Dicotylophyllum* sp. 1 (morphotype Co-3: specimen MBCN-16768); Fig. 4. *Dicotylophyllum* sp. 2 (morphotype Co-4: specimen MBCN-16760); Figs. 7, 10. Undetermined leaves (morphotype Co-7: specimen MBCN-16816, morphotype Co-10: specimen MBCN-16876); Figs. 9, 14, 16, 20. Lauraceae vel Fagaceae (morphotype Co-9: specimen MBCN-16820, morphotype Co-14: specimen SHNIB-CB009, morphotype Co-16: specimen SHNIB-CB002, morphotype Co-20: specimen MBCN-2500); Figs. 11, 17. *Ziziphus paradisiaca* (morphotype Co-11: specimen MBCN-2494, morphotype Co-17: specimen SHNIB-CB003); Fig. 13. *Engelhardia orsbergensis* (morphotype Co-13: specimen MBCN-1693); Fig. 15. *Dicotylophyllum* sp. 4 (morphotype Co-15: specimen MBCN-1703); Fig. 19. *Sapotacites minor* (morphotype Co-13: specimen SHNIB-CB010). Scale bars: 1 cm.

azonal woody vegetation (Kovar-Eder and Kvaček, 2007) related to acidic soils (Kvaček, 1998; Kvaček and Hurník, 2000). Concretely, this species was characteristic of wetland and swamp habitats as well as of riparian environments over the Oligocene and Miocene in Europe (e.g., Moreno-Domínguez et al., 2015; Traiser et al., 2019). Nowadays, members of the family Myricaceae (e.g., *Myrica* and *Morella*) inhabit wetlands, marshes and bogs, although they can also be found in humid evergreen formations and coastal dunes (Lutzow-Felling et al., 1995; Herbert, 2005). In this study, a total of 123 specimens of *M. lignitum* have been studied, which represent 40.12% of the plant assemblage. Most specimens are medium to large in size. This lack of sorting based on leaf size allows us to classify these remains taphonomically as parautochthonous or, in some cases, autochthonous (see e.g., Kidwell et al., 1986; Fernández López, 1991; Greenwood, 1991; Behrensmeyer and Hook, 1992; Ferguson, 1995). It is possible that *M. lignitum* was the dominant species in the wetlands, forming woody and shrubby vegetation.

As accessory elements, trees with evergreen nothophyllous leaves related to *Laurophyllum* sp. probably also grew on moist soils and wet environments. However, their abundance and diversity are low, which clearly differs from other European assemblages of similar age (e.g., Givulescu and Olos, 1973; Hably, 1985; Sitár and Kvaček, 1997; Barrón and Diéguez, 2001). Possibly, ferns belonging to the genus *Lygodium* also inhabited these environments, which suggests a multilayered structure of the vegetation (e.g., Wang et al., 2022). Extant species of *Lygodium* are climbing ferns. However, it is arguable that all *Lygodium* species had this habit over the Cenozoic (Collinson, 2002). Likewise, the presence of taxa related to the Dioscoraceae family (aff. *Dioscoreaecarpum*) is compatible with the warm and wet climate inferred at Els Cardscolers site for the early Miocene (Manchester and O'Leary, 2010). Regarding *Engelhardia orsbergensis*, it was a tree whose leaflets are often found in the same fossil assemblages together with *Myrica* (Erdei et al., 2007; Knor et al., 2015; Hably et al., 2019; Traiser et al., 2019; Kvaček and Hurník, 2000). According to Kvaček (2007), this species exhibited great ecological amplitude ranging from subtropical to warm-temperate climatic conditions. It was probably a semi-evergreen or summer-green species that could also integrate deciduous forests, presenting, according to some authors, certain xerophytic traits (Hably, 1986; Erdei et al., 2011; Traiser et al., 2019). According to Ferguson (1985), when a tree with compound leaves loses its leaves, its leaflets fall gradually close to the parent tree. Therefore, the occurrence of *E. orsbergensis* leaflets in the studied assemblages suggests its presence as an accessory element in the authochtonous-parautochtonous wetland vegetation dominated by *M. lignitum*.

A relatively small number of Majorcan fossils may be related to drier environments, concretely: (i) *Berberis kymeana* which shows xeromorphic foliage and has been related to vegetation exhibiting this aspect (e.g., Kymi and Aix-en-Provence) (Kvaček and Erdei, 2001); (ii) *Ziziphus paradisiaca* which is considered as a rare accessory element that formed part of thermophilic subxerophytic communities in Europe during the Miocene (Kvaček and Teodoridis, 2007; Hably, 2020); (iii) *Myrica longifolia* which was a sclerophyllous and subxeromorphic element during the Paleogene (Knobloch et al., 1993; Collinson and Hooker, 2003), although it is also present in the early Miocene of Iberia (Barrón, 1999; Postigo-Mijarra and Barrón, 2013); (iv) different types of leaflets and pods attributed to Fabaceae, which in some cases can be compared with those of the xerophytic recent genera *Caesalpinia* and *Acacia*; (v) leaves of *Sapotacites* type which usually occur in microphyllous xerophytic assemblages (see e.g., Knobloch, 1969; Sanz de Siria, 1981, 1982); and (vi) costapalmate leaves of *Sabalites* sp. which are rare in the assemblage possibly due to a taphonomical bias related to their type of abscission. These leaves were not dehiscent, so when they died, their petioles bend toward the ground, rotting on the stem (Scheihing and Pfefferkorn, 1984). Probably, all these taxa integrated the zonal vegetation, which was probably composed of a mixture of plant communities, in which xerophytic and sub-xerophytic elements occurred, being mainly characterized by legumes and palms. The lack of conifers, especially *Pinus*, some arctotertiary elements (*Alnus*, *Carpinus*, *Zelkova*) and evergreen *Quercus* of the group *Ilex* constitutes a clear difference between the Majorcan Burdigalian and other early Miocene Mediterranean insular floras (e.g., Velitzelos et al., 1992; Kottis et al., 2002).

The vegetation inferred from the analysis of the Els Cardscolers site was mainly composed of palaeotropical elements which could be structured in three main bands in the wetland: (A) azonal higrophytic vegetation made up of reeds that developed in a fresh water environment not communicated with the sea; (B) azonal shrubby to arboreal vegetation in moist soils associated with *Myrica lignitum*, *Engelhardia orsbergensis, Lygodium,* Lauraceae vel. Fagaceae; (C) zonal shrubby vegetation with xerophytic and subxerophytic elements with *Berberis kymeana*, *Myrica longifolia*, *Sapotacites* sp., *Ziziphus* sp., Fabaceae and palms. However, a certain mix of floristic elements in the vegetation cannot be ruled out. The presence of some taxa such as *Sabalites* sp. as well as different species of *Leguminocarpum* could indicate the presence of these taxa in areas of azonal vegetation due, on the one hand, to the deficient dispersion of their remains, and on the other hand, in the case of legumes, to their wide ecological valence. As for the nothophyllous leaves of *Laurophyllum* sp., it is also possible that they were part of the zonal vegetation of the wetland environment as they could be related to genera compatible with lowland vegetation. Fig. 4 depicts a reconstruction of the vegetation in the wetland areas.

Probably the site with the closest similarities on the Iberian Peninsula is the Cristo Rei site, located at the current mouth of the Tagus River in Lisbon (Fig. 5), which is dated from 17.6 to 17 Ma (Antunes et al., 1999). In an environment that these authors consider compatible with an estuary, where there was an influx of coarse sands related to hydric transport by a large river, there is a floristic assemblage with certain similarities to that of the Els Cardscolers site. Thus, *Lygodium gaudinii*, *Myrica* cf. *lignitum*, cf. *Engelhardia orsbergensis* and different leguminous plants (e.g., *Podogonium oeningense* and *Gleditschia knorrii*) appear. Differentially, some arctotertiary taxa (e.g., *Populus serrulatus* and *Ulmus bronnii*) are also present, while palms and taxa such as *Berberis kymeana* are absent. Also noteworthy is the presence of a tooth of *Tomistoma lusitanica* (Crocodylia) on the site, which also appears in the Sant Elm Calcarenitic Formation at Majorca (Mas and Antunes, 2008).

In eastern Iberian Peninsula, there are no floras with similar characteristics to those of Els Cardscolers site in terms of floristic composition and sedimentary environments. At the early Miocene Rubielos de Mora and La Rinconada mine sites (Barrón and Diéguez, 2001; Barrón et al., 2006; Barrón and Postigo-Mijarra, 2011; Postigo-Mijarra and Barrón, 2013), the analysis of the plant assemblages indicated that, although palaeotropical elements were present (e.g., *Myrica lignitum*, *Trigonobalanopsis rhamnoides*, *Neolitsea paleosericea, Laurophyllum* spp.), the presence of conifer taxa such as *Pinus* sp., *Sequoia abietina*, *Torreya* sp. and several species of Cupressaceae as well as arctotertiary taxa such as *Populus*, *Salix*, *Alnus*, *Betula*, *Sorbus*, *Acer* and *Carpinus*, represent an important difference that indicates lacustrine environments of very different nature from those existing at the Els Cardscolers site.

In a broader European context, the floristic assemblage of Els Cardscolers site has similarities with the so-called floral complex of Ipolytarnóc-Luzern (Mai, 1995), which is characteristic of the early Burdigalian. Both cases represent thermophilic floras characteristic of humid subtropical forests with a shared presence of taxa such as palms, *Myrica*, *Laurophyllum*, Leguminosae div. sp., *Ziziphus*, *Engelhardia*, and ferns (e.g. *Lygodium*) as well as a scarcity of deciduous elements (Knobloch et al., 1975; Hably, 1985; Mai, 1995). These floras are represented at the sites of Ipolytarnóc, Lipovany, and Luzern, which were also close to the coast at the time of their formation (Fig. 5). The site of Els Cardscolers shows, to a lesser extent, certain similarities with other contemporary sites in Eastern Europe such as Lesbos and Lemnos islands in Greece, with the presence of taxa such as *Myrica*, *Engelhardia* and palms (Velitzelos et al., 2014). Possibly, the similarities with all these sites are related to the fact that fossil plant assemblages deposited in

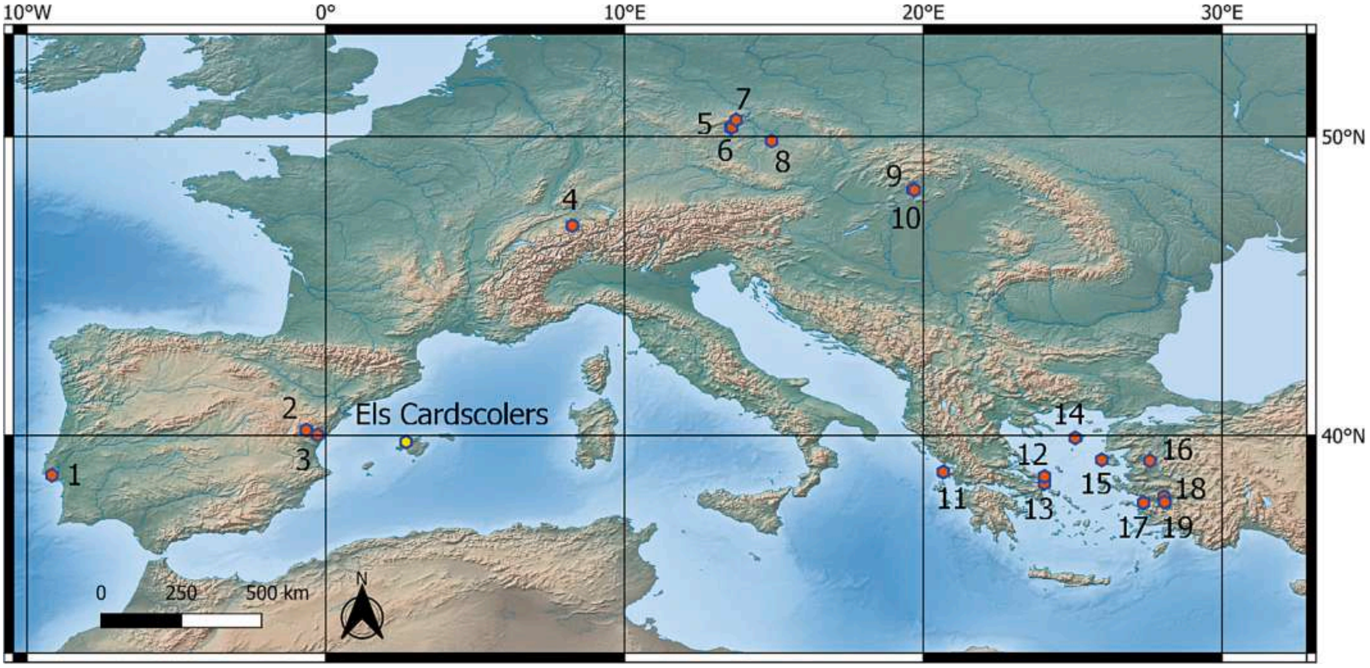

Fig. 5. Sites cited in the text with palaeobotanical or palaeoclimatic information for the Burdigalian. 1. Cristo Rei, 2. Rubielos de Mora, 3. Ribesalbes mine, 4. Luzern, 5–6, Holedeč, Čermníky, 7. Bílina Delta, 8. Přívlaky, 9. Ipolytarnóc, 10. Lipovany, 11. Spanokhorion, 12. Kymi, 13. Evia Island, 14. Lemnos, 15. Lesbos, 16. Manisa-Soma, 17. Aydın-Söke, 18. Aydın-Başçayır, 19. Aydın-Kuloğulları.

coastal areas that originated in warm environments do not favour the presence of certain floristic arctotertiary elements, which are more characteristic of intramontane basins such as *Fagus*, *Betula*, *Alnus*, and also conifers (e.g., *Pinus*, *Torreya*, *Sequoia, Cupressus, Tetraclinis)* as can be seen in other European coeval sites (e.g., Güvem, Parschlug, La Rinconada, Rubielos de Mora) (Postigo-Mijarra and Barrón, 2013; Velitzelos et al., 2014; Kafetzidou et al., 2022).

5.2. Palaeoclimate of the Els Cardscolers site during the Burdigalian

In a broad European context, the data obtained through the CLAMP analysis of the samples from the El Cardscolers site stand out for several reasons. On the one hand, they provide climatic data from the south-western part of the continent, a region in which there are few records (Postigo-Mijarra et al., 2022; Fig. 5). On the other hand, they provide climatic information from a Burdigalian flora existing in a coastal area.

Considering the results derived from CLAMP analysis, the mean annual temperature (MAT) was 17.6 to 19.9 °C (18.8 °C ± 1.15), the mean of the warmest month (WMMT) was 24.3 to 27.07 °C (25.7 °C ± 1.37) and the coldest month mean (CMMT) was 10.4 to 14.2 °C (12.3 °C ± 1.9) (Fig. 2). In general, high temperature values can be observed for all three parameters. However, the difference between WMMT and CMMT obtained suggests a moderate seasonal contrast in temperature. These conditions of high temperature with high annual minimums are also consistent with the presence of thermophilic species such as *Engelhardia orsbergensis* (Hably, 2020) and fauna also found in the Sant Elm Calcarenitic Formation in Majorca attributable to *Tomistoma* cf. *lusitanica* (Crocodylia), which is considered to be a stenothermic species of tropical or subtropical affinity characteristic of marshy or estuarine areas (Mas and Antunes, 2008).

Estimates for growing season precipitation (GSP) range from 1511 to 1911 mm (1711 ± 200 mm), with an average of 178.2 ± 26.1 mm per month (MMGSP). This suggests high values for precipitations throughout the year. CLAMP data for Three_WET range from 677.5 to 974.5 mm (826 ± 148.5 mm) and from 151 to 215 mm (183 ± 32 mm) for the three driest months (Three_DRY). This shows the absence of a summer-dry regime, although it also indicates a seasonal contrast in precipitation (Fig. 3) (Peel et al., 2007). In addition, the length of the growing season precipitation (GROWSEAS) shows a high value of 10 ± 0.68 months.

Modern climate for the Els Cardscolers site is given in Table 3. Comparing both climates, we can infer that in both cases we have similar high temperatures throughout the year, as indicated by the values of MAT, CMMT and WMMT (Table 3). The differences are much clearer with respect to precipitation, both annual and for the warmer and drier months (see Table 2 values for Three_WET/Three_DRY and MPWarm and MPDry), with the early Miocene climate being generally wetter than at present. These data show a significant amount of precipitation over the year and a clear and low seasonality. The occurrence of sub-xeromorphic taxa together with thermophiles, such as *Engelhardia*, also suggests that a seasonal subtropical climate prevailed near the coast of Majorca during the Burdigalian.

According to the Köppen–Geiger climatic classification system, the present-day climate of the Els Cardscolers site is the temperate Csa climate characterized by dry-hot summers. This is the most common climate type in the Balearic Islands (Peel et al., 2007; Chazarra et al., 2018). Nevertheless, the early Miocene climate at the Els Cardscolers site represents a climate type Cfa, i.e., a temperate climate without dry season during the warmest period, and with summer temperatures above 22 °C (Peel et al., 2007). This is evident from the Three_DRY data for the early Miocene, accounting for 151 to 215 mm of the total precipitation, being modern Three_DRY data around 50–55 mm (see https://climate-data.org; Chazarra et al., 2018). At present, the Cfa climate type can be found in the northeast of the Iberian Peninsula, in a mid-altitude band bordering the Pyrenees and the Iberian System, and in some regions of Europe such as northern Italy and the Black Sea coastal area (Peel et al., 2007).

The climatic data obtained from the Els Cardscolers site differ substantially from those from sites located in the easternmost part of the Mediterranean. Thus, the Burdigalian and late Burdigalian–early Langhian age sites of Manisa-Soma, Aydın-Söke, Aydın-Kuloğulları, and Aydın-Başçayır (Turkey) (Kayserý Özer and Emre, 2022; Table 3, Fig. 5) clearly show a less rainy climate and lower temperatures, both in winter and in terms of mean annual temperatures, as shown by the CMMT and

Table 3
Main climatic variables obtained by CA, CLAMP and LMA analysis for selected European outcrops. Early Miocene: Přívlaky, Čermníky, Holedeč and Bílina Delta (Mach et al., 2014; Teodoridis and Kvaček, 2015). Burdigalian: S141 Borehole (Pais, 1981; Barrón et al., 2010); Manisa-Soma (Kayserý Özer and Emre, 2022); Ramblian–early Aragonian: Rubielos de Mora (Barrón et al., 2010). La Rinconada mine (LRM) (Postigo-Mijarra et al., 2022); Late Burdigalian: Spanokhorion and Evia Island (Kayserý Özer et al., 2014); Late Burdigalian-Early Langhian: Aydın-Söke, Aydın-Kuloğulları and Aydın-Başçayır: (Kayserý Özer and Emre, 2022). Abbreviations: MAT (mean annual temperature), CMMT (mean temperature of the coldest month), WMMT (mean temperature of the warmest month), MAP (mean annual precipitation), MPWet (mean precipitation of the wetter month), MPWarm (mean temperature of the warmest month), MPDry (mean precipitation of the driest month), MART (mean annual range of temperature), GSP (growing season precipitation), TWET (Three_WET) (precipitation during three consecutive wettest months) and TDRY (Three_DRY) (precipitation during three consecutive driest months). CA: Coexistence Approach; CLAMP (Climatic Amplitude Method); LMA (Leaf Margin Analysis), Modern (modern climatic data for Fornalutx village obtained from Chazarra et al. (2018) and https://es.climate-data.org, the latter one in square brackets). Values of the standard deviations are in brackets.

SITE	MAT [°C]	CMMT [°C]	WMMT [°C]	[mm]	MPWet [mm]	MPWarm [mm]	MPDry [mm]	MART [°C]	GSP	TWET [mm]	TDRY [mm]
Přívlaky	CA: 13.3–18.9 CLAMP 8.5 (1.2)	CA: −0.1–12.2 CLAMP −3.3 (1.9)	CA: 24.3–28.1 CLAMP: 21.3 (1.4)	897–1355	-	-	-	-	-	580 (138)	165 (32)
Čermníky	CA: 13.3–18.9 CLAMP: 10.3 (1.1)	CA: 0.1–9.2 CLAMP: 0.6 (1.9)	CA: 24.3–27.9 CLAMP: 21.2 (1.4)	897–1355	–	–	–	–	–	636 (138)	153 (32)
Holedeč	CA: 13.3–17 CLAMP: 9.4 (1.1)	CA:0.2–6.2 CLAMP: −1.4 (1.9)	CA: 25.2–27.5 CLAMP: 21.4 (1.4)	897–1258	-	-	-	-	-	594 (138)	159 (32)
Bílina Delta	CA: 15.6 CLAMP:12.2 (1.3)	CA: 3.8 CLAMP: 3.4 (2.6)	CA: 24.7–26.4 CLAMP: 21.4 (1.7)	1194	-	-	-	-	-	-	-
S141 Borehole	15.7–16.6	5–12.5	26.5–26.6	1122–1355	–	–	–	–	–	–	–
Manisa Soma	14.75	4.99	23.92	1105	–	–	–	18.93	–	–	–
Rubielos de Mora	12.9–16.1	0.6–2.7	23.8–25.6	1036–1058	-	-	-	22.6	-	-	-
La Rinconada	CA: 10–16.5 CLAMP: 11.48 (1.18) LMA: 13.68 (3.65)-13.97 (3.56)	CA: 4.3–4.8 CLAMP: 0.84 (1.85)	CA: 25–26.4 CLAMP: 23.31 (1.53)	CA: 1217–1297	116–164	118–131	16–56	20.2–22.1	1455.2 (333.3)	717.5 (140.2)	386.5 (92.6)
Spanokhorion	9.1–10.8 or 15.6–21.3	(−2.7)–1.1 or 5.0–13.3	24.7–43.0	823–1520	204–227	79–125	8–43	34.65 or 24.7	–	–	–
Evia Island	17.0–18.4	6.2–12.5	26.5–32.0	1146–1322	225–227	79–125	8–32	19.9	–	–	
Aydın Söke	15.33	5.39	24.38	1068	–	–	–	18.99	–	–	–
Aydın Kuloğulları	15.57	5.03	24.36	1060	–	–	–	19.33	–	–	–
Aydın Başçayır	15.43	5.60	23.61	1083	–	–	–	18.01	-	-	-
Els Cardscolers	18.8 (1.15)	12.3 (1.9)	25.7 (1.37)	–	–	–	–	13.4	1711 (200)	826 (148.5)	183 (32)
Modern	17.1 [15–17.5]	10 [5.0–7.5]	25.5 [22.5–25.0]	485 [700–800]	70 [70–100]	22 [20–30]	6 [5–10]	15	–	188	49

MAT values. Likewise, it represents a more contrasted climate as shown by the MART values (ca. 18–19.3 °C) with the values in Els Cardolers site being ca. 13.4 °C. Similarly, CA and CLAMP values from the Central European early Miocene sites of Přívlaky, Čermníky, Bílina Delta, and Holedeč also show a climate with overall lower precipitation and higher thermal contrast (Mach et al., 2014; Teodoridis and Kvaček, 2015; Table 3, Fig. 5). The main difference between Els Cardscolers and the above-mentioned sites concerns the values of the CMMT. Among the Iberian sites of Burdigalian age, at Rubielos de Mora, La Rinconada and S 141 Borehole (Barrón et al., 2010; Postigo-Mijarra et al., 2022), the main difference with El Cardscolers site is again the lower temperature values for winter and annual averages (see CMMT and MAT, Table 3). Similarly, these sites also show lower values for precipitation, indicating in general somewhat more contrasting conditions with respect to both parameters. These climatic values could be related to the presence of different conifers and arctotertiary species in these sites.

Probably the climatic conditions from the island of Evia (Greece) are the most similar to those obtained in Majorca, especially regarding temperature values, since the annual minimums of both sites are comparable (Kayserý Özer et al., 2014). However, in Majorca, the climate obtained would probably be somewhat rainier, if MPWet values from Evia are compared with those of GSP, Three_WET, and Three_DRY from the Els Cardsdolers site (Table 3). Likewise, similar parallelisms can be made with Spanokhorion (Greece), although different climatic parameters were obtained for this site, which makes it difficult to compare with Els Cardscolers (Kayseri-Ozer et al., 2014; Table 3).

6. Conclusions

The results obtained from the analysis of the macrofloristic and paleoclimatic data from the Els Cardscolers site provide these fundamental conclusions:

1. After reviewing the materials in the considered assemblages, we can confirm the presence of only two taxa identified in previous works: *Lygodium gaudinii* and *Sabalites* sp. The species *Myrica arenesi*, *M. balearica*, *Castanea balearica*, *Proteoides* (?) *balearica*, *Acacia balearica*, *Pseudopanax balearica* and *Zanthoxylon balearicum*, which were described as new species in previous works, have been reassigned to other genera and species. The occurrence of the following taxa could not be confirmed: *Abies ramesi*, *Diospyros brachysepala*, *Fagus pliocenica*, *Fraxinus balearica*, *Persea balearica, Phoenicites* sp. and *Smilax* sp.

2. The flora has an eminently palaeotropical character, developing a coastal lowland formation. As a whole, it forms vegetation with thermophilic and hygrophilic elements, as well as with the presence of elements adapted to certain seasonality, with species such as *Lygodium gaudinii*, *Myrica lignitum*, *Berberis kymeana*, *Engelhardia orsbergensis*, *Sabalites* sp., *Ziziphus paradisiaca*, *Myrica longifolia*, *Sapotacites minor*, aff. *Dioscoreaecarpum*, Lauraceae vel. Fagaceae and different taxa belonging to the family Fabaceae. The flora of the Els Cardscolers site shows similarities with the Iberian site of Cristo Rei (Portugal) and can be related to the thermophilic subhumid subtropical floras of the floral complex of Ipolytarnóc-Luzern.
3. The climatic values obtained for MAT, WMMT, and CMMT suggest a moderate seasonal contrast in temperature indicating high values for all seasons. Those for precipitation (MMGSP, GSP, Three_WET, and Three_DRY) are also high and suggest the absence of a summer-dry regime but also indicate a seasonal contrast in precipitation. The values obtained in Els Cardscolers are similar to those obtained in other areas of southern Europe for the Burdigalian, although they stand out for their higher temperatures, particularly CMMT. The values from the early Miocene Island of Evia (Greece) are probably the most similar to Els Cardscolers. These climatic parameters are consistent with the presence of thermophilic species of humid environments with a certain annual seasonality concerning rainfall (e.g., *Engelhardia orsbergensis* and *Berberis kymeana*).

Supplementary data to this article can be found online at https://doi.org/10.1016/j.palaeo.2023.111962.

CRediT authorship contribution statement

José Ma Postigo-Mijarra: Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation, Conceptualization. **Rafael Moreno-Domínguez:** Writing – review & editing, Supervision, Methodology, Formal analysis, Data curation. **Yul Altolaguirre:** Writing – review & editing, Supervision, Investigation, Formal analysis. **Manuel Casas-Gallego:** Writing – review & editing, Investigation, Formal analysis. **Eduardo Barrón:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

The authors have no relevant financial or non-financial interests to disclose. The authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or nonfinancial interest in the subject matter or materials discussed in this manuscript. The authors have no financial or proprietary interests in any material discussed in this article.

Data availability

No data was used for the research described in the article.

Acknowledgments

We thank Enrique Peñalver, Isabel Rábano, Pedro A. Robledo, Ana Sevillano, Graciela Delvene and José Mª López (CN IGME-CSIC), Carolina Constantino (Museu Balear de Ciències Naturals), the Societat d'Història Natural de les Balears and, especially, Enric Pedrón and Josep Juárez for their inestimable assistance in the fieldwork and for their interesting discussions on many aspects of the Burdigalian flora from the Majorca Island. This work was performed as part of the PID2020-119836GB-100 and NECLIME projects.

References

Andreánszky, G., 1959. Contributions à la connaissance de la flore de l'Oligocène inférieur de la Hongrie et un essai sur la reconstruction de la flore contemporaine. Acta Bot. Acad. Sci. Hung. 5, 1–37.

Antunes, M.T., Pais, J., Balbino, A., Mein, P., Aguilar, J.P., 1999. The Cristo Rei section (lower Miocene). Distal fluviatile environments in a marine series, plants, vertebrates, and other evidence, age. Ciên. Terra (UNL) 13, 141–155.

Arènes, J., 1951. Contribution à l'étude de la flore fossile burdigalienne des Baléares. Bol. R. Soc. Esp. Hist. Nat. Geol. 49, 73–85.

Arènes, J., Depape, G., 1954. Sur una flore burdigalienne à *Lygodium gaudini* Heer et à Myricacées des Îles Baléares (Majorque). C. R. Hebd. Sean. Acad. Sci. 238 (11), 1250–1252.

Arènes, J., Depape, G., 1956. La flore burdigalienne des Îles Baléares (Majorque). Rev. Gén. Bot. 63, 347–390.

Baranova, M.A., 1967. Novye dannye po verchnemiocenovoj flore Primorja: Betulaceae, Salicaceae. Leguminosae. Bot. Zh. 52, 53–61.

Barón, A., Fornós, J.J., Gelabert, B., Obrador, A., Pomar, L., Ramos, E., Sàbat, F., 2004. Baleares. In: Vera, J.A. (Ed.), Geología de España. SGE-IGME, Madrid, pp. 450–464.

Barrón, E., 1999. Estudio macroflorístico del afloramiento Mioceno de concreciones carbonáticas de Izarra (Álava, España). Aspectos tafonómicos, paleoecológicos y bioestratigráficos. Rev. Esp. Paleontol. 14 (1), 123–145.

Barrón, E., Diéguez, C., 2001. Estudio macroflorístico del Mioceno Inferior lacustre de la cuenca de Rubielos de Mora (Teruel, España). Bol. Geol. Min. 112 (2), 13–56.

Barrón, E., Postigo-Mijarra, J.Mª., 2011. Early Miocene fluvial-lacustrine and swamp vegetation of La Rinconada mine (Ribesalbes-Alcora basin, eastern Spain). Rev. Palaeobot. Palynol. 165, 11–26.

Barrón, E., Hernández, J.Mª., López-Horgue, M.A., Alcalde-Olivares, C., 2006. Palaeoecology, biostratigraphy and palaeoclimatology of the lacustrine fossiliferous beds of the Izarra Formation (lower Miocene, Basque-Cantabrian Basin, Álava province, Spain) based on palynological analysis. Rev. Esp. Micropaleontol. 38 (2–3), 321–338.

Barrón, E., Rivas-Carballo, M.R., Postigo-Mijarra, J.Mª., Alcalde-Olivares, C., Vieira, M., Castro, L., Pais, J., Valle-Hernández, M., 2010. The Cenozoic vegetation of the Iberian Peninsula: a synthesis. Rev. Palaeobot. Palynol. 162, 382–402.

Bauzá Rullán, J., 1961. Nueva contribución al estudio de la flora fósil de Mallorca. Bol. Soc. Hist. Nat. Balears 7 (1–4), 49–59.

Behrensmeyer, A.K., Hook, R.W., 1992. Paleoenvironmental contexts and taphonomic modes in the terrestrial fossil record. In: Behrensmeyer, A.K., Damuth, J.D., DiMichele, W.A., Potts, R., Sues, H.-D., Wing, S.L. (Eds.), Terrestrial Ecosystems through Time. Evolutionary paleoecology of terrestrial plants and animals. Univ. Chicago Press, Chicago, pp. 15–38.

Bozukov, V., Vatsev, M., Ivanov, D., Simov, N., 2021. New fossil flora from Palaeogene sediments near Bersin village (SW Bulgaria). Rev. Bul. Geol. Soc. 82 (3), 102–104.

Brongniart, A., 1822. Description dos végétaux fossiles du terrain de sediment supérieur. In: Cuvier, M.G., Brongniart, A. (Eds.), Description geologique des environs de Paris, Paris, pp. 353–402.

Bůžek, Č., 1971. Tertiary flora of the northern part of Pětipsy area (North-Bohemian Basin). Rozpr. Ústř. Úst. Geol. 36, 1–118.

Bůžek, Č., Konzalová, M., 1983. A fertile *Lygodium* from the Cypris Formation fo the Cheb Basin (West Bohemia, Czechoslovakia). Cas. Miner. Geol. 28, 31–39.

Chazarra, A., Flórez, E., Peraza, B., Tohá, T., Lorenzo, B., Criado, E., Moreno, J.V., Romero, R., Botey, R., 2018. Mapas climáticos de España (1981–2010) y ETo (1996–2016). AEMET, Agencia Estatal de Meteorología, Ministerio de Transición Ecológica Spain.

Collinson, M., 2001. Cainozoic ferns and their distribution. Brittonia 53 (2), 173–235.

Collinson, M., 2002. The ecology of Cainozoic ferns. Rev. Palaeobot. Palynol. 119, 51–68.

Collinson, M.E., Hooker, J.J., 2003. Paleogene vegetation of Eurasia: framework for mammalian faunas. Deinsea 10, 41–83.

Colom, G., 1967. Los depósitos lacustres del Burdigaliense superior de Mallorca. Mem. R. Acad. Cienc. Artes Barcelona 38 (5), 327–395.

Colom, G., 1972. Les bassins lacustres tertiaires de l'île de Majorque (Baléares). Rapp. Comm. Intern. Mer Méditerr. 20, 535–538.

Colom, G., 1975. Geología de Mallorca, vol. II. Diputación Provincial de Baleares, Palma de Mallorca.

de Saporta, G., 1862. Études sur la végétation du sud-est de la France à l'époque tertiaire. Ann. Sci. Nat., Bot. 4ème ser, 17, 191–311.

de Saporta, G., 1863. Études sur la végétation du Sud-Est de la France à l'époque tertiaire. Ann. Sci. Nat., Bot. 4ème série, 19, 5–124.

de Saporta, G., 1865. Études sur la végétation du Sud-Est de la France à l'époque tertiaire. Ann. Sci. Nat. Bot. 5ème ser. 3 (10), 5–152.

de Saporta, G., 1873. Études sur la végétation du Sud-Est de la France à l'époque tertiaire. Supplément I. Ann. Sci. Nat., Bot. 5ème ser., 18, 23–146.

Déperet, C., Fallot, P., 1921. Sur l'âge des formations à lignites de l'île de Majorque. C. R. Acad. Sci. Paris 172, 790–795.

Ellis, B., Daly, D.C., Hickey, L.J., Johnson, K.R., Mitchell, J.D., Wilf, P., Wing, S.L., 2009. Manual of Leaf Architecture. Cornell University Press.

Erdei, B., Hably, L., Kázmér, M., Utescher, T., Bruch, A., 2007. Neogene flora and vegetation development of the Pannonian domain in relation to palaeoclimate and palaeogeography. Palaeogeogr. Palaeoclimatol. Palaeoecol. 253, 131–156.

Erdei, B., Hably, L., Selmeczi, I., Kordos, L., 2011. Palaeogene and Neogene localities in the North Hungarian mountain range. Studia Bot. Hung. 42, 153–183.

Fallot, P., 1922. Étude géologique de la Sierra de Majorque. Ph.D. thesis.. Librairie Polytechnique Ch. Béranger, Paris et Liege.

Fallot, M.P., Depape, G., 1928. Les gisements de Burdigalien à plantes de Majorque. Ann. Soc. Géol. Nord 53, 5–19.

Ferguson, D.K., 1971. The Miocene flora of Kreuzau, Western Germany. 1. The leaf-remains. Verh. K. Ned. Akad. Wed. Afd. Natuurkd. Ser. 2 60 (1), 1–297.

Ferguson, D.K., 1985. The origin of leaf-assemblages - New light on an old problem. Rev. Palaeobot. Palynol. 46, 117–188.

Ferguson, D.K., 1995. Plant part processing and community reconstruction. Eclogae Geol. Helv. 88 (3), 627–641.

Fernández López, S., 1991. Taphonomic concepts for a theoretical biochronology. Rev. Esp. Paleontol. 6 (1), 37–49.

Fernández-Marrón, M.T., 1971. Estudio paleoecológico y revisión sistemática de la flora fósil del Oligoceno español. PhD Thesis.. Universidad Complutense de Madrid, Spain.

Fernández-Marrón, M.T., Fonollá Ocete, J.F., Jiménez Rodrigo, J.C., 2002. Primeros datos Paleobotánicos y Palinológicos de una flora miocénica procedente de la unidad intermedia en el sector central de la cuenca de Madrid. Geogaceta 31, 177–180.

Fornós, J.J., Pomar, L., Ramos, E., 2002. Tertiary: Balearic Island. In: Gibbons, W., Moreno, T. (Eds.), The Geology of Spain. The Geological Society, London, pp. 327–334.

Fu-Jun, M., Song, L., Bai-Nian, S., De-Fei, Y., Jun-Ling, D., Feng-Tai, Z., Qiu-Jun, W., 2017. Legume fruits from the Oligocene Ningming Formation of Guangxi, China, and their biogeographical and palaeoclimatic implications. Rev. Palaeobot. Palynol. 244, 192–202.

Gandolfo, M., Nixon, K., Crepet, W., Ratcliffe, G., 2000. Sorophores of *Lygodium* Sw. (Schizaeaceae) from the late cretaceous of New Jersey. Plant Syst. Evol. 221, 113–123.

Givulescu, R., 1987. Über die wahre Natur von *Laurus primigenia* Unger aus dem Chattien des Schiltals (Valea Jiului-Petroşani, Kreis Hunedoara, SR Rumänien). Fed. Repert. 98, 403–409.

Givulescu, R., Olos, E., 1973. Paläobotanische studiem im Tertiär Siebenbürgen. Geol. Inst. Mem., Bukarest 19, 1–61.

Greenwood, D.R., 1991. The taphonomy of plant macrofossils. In: Donovan, S.K. (Ed.), The Processes of Fossilization. Bellhaven Press, London, pp. 141–169.

Hably, L., 1979. Some data to the Oligocene flora of the Kiscellian Tard Clay, Hungary. Ann. Hist.-Nat. Mus. Nat. Hung. 71, 33–53.

Hably, L., 1985. Early Miocene plant fossils from Ipolytarnóc, N Hungary. Geol. Hung., Ser Paleontol. 45, 73–256.

Hably, L., 1986. The macroflora of the borehole Kiscell-1 in Budapest. Ann. Hist.-Nat. Mus. Nat. Hung. 78, 31–40.

Hably, L., 1992. Distribution of legumes in the Tertiary of Hungary. In: Herendeen, P.S., Dilcher, D.L. (Eds.), Advances in Legume Systematics: Part 4. The Fossil Record. The Royal Botanic Gardens, Kew, pp. 169–187.

Hably, L., 1994. Egerian plant fossils from Pomáz, Hungary. Fragm. Mineral. Palaeontol. Budapest 17, 5–70.

Hably, L., 2020. The Karpatian (late early Miocene) flora of the Mecsek area. Acta Palaeobot. 60 (1), 51–122.

Hably, L., Fernández-Marrón, M.T., 1998. A comparison of the Oligocene floras of the Tethyan and Central-Paratethyan areas on the basis of Spanish and Hungarian macroflora. Tertiary Res. 18 (3–4), 67–76.

Hably, L., Erdei, B., Sebe, K., 2019. Thermophilous elements from the late Miocene flora of Pécs-Danitzpuszta (Mecsek Mts, Hungary) – confirmed by cuticular analysis. Studia Bot. Hung. 50 (1), 9–17.

Heer, O., 1859. Flora Tertiaria Helveticae. Die Tertiäre Flora der Schweiz, vol. III. Die gamopetalen and polypetalen Dicotyledonen, Wurster and Company, Winterthur.

Heer, O., 1869. Miocene Baltische flora. W. Koch, Königsberg, Germany.

Heer, O., 1881. Contributions à la flore fossile du Portugal. Section de Travaux Géologiques du Portugal. Impr. Acad. R. Sci, Lisbon.

Herbert, J., 2005. Systematic and Biogeography of Myricaceae. Ph.D. Thesis,. University of St Andrews, St Andrews, UK.

Herendeen, P.S., Crepet, W.L., Dilcher, D.L., 1992. The fossil history of the Leguminosae: Phylogenetic and biogeographical implications. In: Herendeen, P.S., Dilcher, D.L. (Eds.), Advances in Legume Systematics, Part 4. The Fossil Record. Royal Botanic Gardens, Kew, London, UK, pp. 303–316.

Hofmann, C.H., Sachse, M., 2023. SEM pollen analysus of Miocene deposits of Entrischenbrunn (Bavaria, Germany) reveal considerable amounts of pollen of subhumid and sclerophyllous together with azonal water plants reflecting the vegetation mosaic of a braided river system. Rev. Palaeobot. Palynol. 308, 104787.

Jähnichen, H., Mai, D., Walther, H., 1977. Blätter und Früchte von *Engelhardia* Les. ex Bl. Juglandaceae aus dem europäischen Tertiär. Fed. Repert. 88 (5–6), 323–363.

Jungwirth, E., 2004. The determination and taxonomic problems of Palaeogene fossil macroflora from Slovenia and Croatia. Nat. Croat. 13 (2), 187–196.

Kafetzidou, A., Kouli, K., Zidianakis, G., Kostopoulos, D.S., Zouros, N., 2022. The early Miocene angiosperm flora of Akrocheiras in Lesvos Petrified Forest (North Aegean, Greece) – preliminary results. Rev. Palaeobot. Palynol. 296, 104559.

Kayserý Özer, M.S., Emre, T., 2022. Palaeovegetation and paleoclimate in the SW Turkey – a study based on the early-middle Miocene coal-bearing sediments from the Büyük Menderes Graben. Rev. Palaeobot. Palynol. 297, 104560.

Kayserý Özer, M.S., Akgün, F., Mayda, S., Kaya, T., 2014. Palynofloras and vertebrates from Muðla-Ören region (SW Turkey) and palaeoclimate of the middle Burdigalian–Langhian period in Turkey. Bull. Geosci. 89 (1), 137–162.

Kidwell, S.M., Fürsich, F.T., Aigner, Th., 1986. Conceptual framework for the analysis and classification of fossil concentrations. Palaios 1, 228–238.

Kirkbride, J.H., Gunn, C.R., Weitzman, A.L., 2003. Fruits and seeds of genera in the subfamily Faboideae (Fabaceae), volume 1 and 2. U.S. Department of Agriculture. Tech. Bull. 1890, 1–1212.

Knobloch, E., 1969. Tertiäre Floren von Mähren. Moravska Museum, Brno, p. 201.

Knobloch, E., Bůžek, C., Holy, F., Kvaček, Z., Némejc, C., Sitár, V., 1975. Significant Megafloral Assemblages in the Neogene of Central Europe. In: Biozonal Division of the Upper Tertiary Basins of the Eastern Alps and the West Carpathians. Geol. Surv. Prague, pp. 87–100.

Knobloch, E., Kvaček, Z., Bůžek, C., Mai, D.H., Batten, D.J., 1993. Evolutionary significance of floristic changes in the Northern Hemisphere during the late cretaceous and Palaeogene, with particular reference to Central Europe. Rev. Palaeobot. Palynol. 78, 41–54.

Knor, S., Kvaček, Z., Wappler, T., Prokop, J., 2015. Diversity, taphonomy and palaeoecology of plant–arthropod interactions in the lower Miocene (Burdigalian) in the Most Basin in North-Western Bohemia (Czech Republic). Rev. Palaeobot. Palynol. 219, 52–70.

Kottis, T., Ioakim, C., Velitzelos, E., Kvaček, Z., Denk, T., Velitzelos, D., 2002. Field Guide to the Neogene of the Island of Evia – Early Miocene Flora of Kymi. Univ. Athens, Athens.

Kováčová, M., Sitár, V., 2007. Early Miocene flora of the south Slovakian basin. Acta Palaeobot. 47 (1), 163–181.

Kovar-Eder, J., 1982. Eine Blätterflora des Egerien (Ober-Oligozän) aus marinen Sedimenten der Zentralen Parathetys im Linzer Raum (Österreich). Beitr. Paläont. Österr. 9, 1–134.

Kovar-Eder, J., Kvaček, Z., 2007. The integrated plant record (IPR) to reconstruct Neogene vegetation: the IPR-vegetation analysis. Acta Palaeobot. 47 (2), 391–418.

Kovar-Eder, J., Kvaček, Z., Ströbitzer-Hermann, M., 2004. The Miocene flora of Parschlug (Styria, Austria) – revision and synthesis. Ann. Naturhist. Mus. Wien 105 (A), 45–159.

Kumar, S., Hazra, T., Spicer, R.A., Hazra, M., Spicer, T.E.V., Bera, S., Khan, M.A., 2023. Coryphoid palms from the K-Pg boundary of Central India and their biogeographical implications: evidence from megafossil remains. Plant Divers. 45, 80–97.

Kvaček, Z., 1998. Bílina: a window on early Miocene marshland environments. Rev. Palaeobot. Palynol. 101, 111–123.

Kvaček, Z., 2002. Late Eocene landscape, ecosystems and climate in northern Bohemia with particular reference to the locality of Kučlín near Bílina. Bull. Czech Geol. Surv. 77 (3), 217–236.

Kvaček, Z., 2004. Revisions to the early Oligocene flora of Flörsheim (Mainz Basin, Germany) based on epidermal anatomy. Senckenb. Lethaea 84, 1–73.

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

Kvaček, Z., 2019. *Dioscorea manchesteri* Kvaček, sp. nov., a new fossil species from the early Miocene flora of North Bohemia (Czech Republic). Acta Palaeobot. 59 (2), 367–371.

Kvaček, Z., Erdei, B., 2001. Putative proteaceous elements of the *Lomatites*-type reinterpreted as new *Berberis* of the European Tertiary. Plant Syst. Evol. 226, 1–12.

Kvaček, Z., Hably, L., 1991. Notes on the Egerian stratotype flora at Eger (Wind brickyard), Hungary, Upper Oligocene. Ann. Hist.-Nat. Mus. Natl. Hung. 83, 49–82.

Kvaček, Z., Hurník, S., 2000. Revision of early Miocene plants preserved in baked rocks in the North Bohemian Tertiary. Acta Mus. Natl. Pragae ser. B – Hist. Nat. 56 (1–2), 1–48.

Kvaček, Z., Teodoridis, V., 2007. Tertiary macrofloras of the Bohemian massif: a review with correlations within Boreal and Central Europe. Bull. Geosci. 82 (4), 383–408.

Kvaček, Z., Walther, H., 2010. European Tertiary Fagaceae with chinquapin-like foliage and leaf epidermal characteristics. Fed. Rep. 121, 248–267.

Lewis, G.P., Schrire, B.D., Mackinder, B.A., Lock, M. (Eds.), 2005. Legumes of the World. Royal Botanic Gardens, Kew.

Lutzow-Felling, C.J., Gardner, D.E., Markin, G.P., Smith, C.L.W., 1995. *Myrica faya*: Review of the Biology, Ecology, distribution, and Control, Including an Annotated Bibliography. In: University of Hawai` i at Manoa, Technical Report, 094, p. 57.

Mach, K., Teodoridis, V., Matys Grygar, T., Kvaček, Z., Suhr, P., Standke, G., 2014. An evaluation of palaeogeography and palaeoecology in the Most Basin (Czech Republic) and Saxony (Germany) from the late Oligocene to the early Miocene. N. Jb. Geol. Paläont. (Abh.) 272 (1), 13–45.

Mai, D.H., 1989. Development and regional differentiation of the European vegetation during the Tertiary. Plant Syst. Evol. 162, 79–81.

Mai, D.H., 1991. Palaeofloristic changes in Europe and the confirmation of the Arctotertiary-Paleotropical geofloral concept. Rev. Palaeobot. Palynol. 68, 29–36.

Mai, D.H., 1995. Tertiäre Vegetationsgeschichte Europas. Fischer, Jena.

Manchester, S.R., 1987. The fossil history of the Juglandaceae. Monogr. Syst. Bot. 21, 1–137.

Manchester, S.R., 2001. Update on the megafossil flora of Florissant, Colorado. Proc. Denver Mus. Nat. Sci. 4, 137–161.

Manchester, S.R., O'Leary, E., 2010. Phylogenetic distribution and identification of fin-winged fruits. Bot. Rev. 76, 1–82.

Manchester, S.R., Zavada, M.S., 1987. *Lygodium* foliage with intact sorophores from the Eocene of Wyoming. Bot. Gaz. 148, 392–399.

Martí, J., Mitjavila, J., Roca, E., Aparicio, A., 1992. Cenozoic magmatism of the Valencia trough (western Mediterranean): relationship between structural evolution and volcanism. Tectonophysics 203, 145–165.

Mas, G., Antunes, M.T., 2008. Presència de *Tomistoma* cf. *lusitanica* (Vianna I Moraes, 1945) (Reptilia: Crocodylia) al Burdigalià inferior de Mallorca (Illes Balears, Mediterrània occidental). Implicacions paleoambientals. Boll. Soc. Hist. Nat. Balears 51, 131–146.

Mitjavila, J., Ramos-Guerrero, E., Martí, J., 1990. Les roches pyroclastiques du Puig de l'Ofre (Serra de Tramuntana, Majorque): position géologique et datation K-Ar. C. R. Acad. Sci. Paris 311, ser. 2, 687–692.

Moreno-Domínguez, R., Díez, J.B., Jacques, F.M.B., Ferrer, J., 2015. First macroflora data from La Val (Late Oligocene/Early Miocene), Estadilla (Huesca, Spain). Hist. Biol. 27 (3–4), 469–489.

Moreno-Domínguez, R., Postigo-Mijarra, J.Mª., Barrón, E., 2021. Palaeoclimatic reconstruction for the late Oligocene La Val fossil site (Estadilla, Huesca, Spain) based on CLAMP and LMA. Palaeogeogr. Palaeoclimatol. Palaeoecol. 567, 110302.

Oliveros, J.M., Escandell, B., Colom, G., 1960. El Burdigaliense superior salobre-lacustre en Mallorca. Mem. Inst. Geol. Min. Esp. 61, 267–348.

Palamarev, E., Kitanov, G., Staneva, K., Bozukov, V., 2000. Fossil flora from Paleogene sediments in the northern area of the Mesta Graben in the Western Rhodopes. II. Analysis and stratigraphic importance of the flora. Phytol. Balcan. 6 (1), 3–11.

Pais, J., 1981. Contribuição para o conhecimento da vegetação Miocénica da parteocidental da Bacia do Tejo. In: Ph.D., thesis. Univ. Nova Lisboa, Portugal.

Palamarev, E., Bozukov, V., Uzunova, K., Petkova, A., Kitanov, G., 2005. Catalogue of the Cenozoic plants of Bulgaria (Eocene to Pliocene). Phytol. Balcan. 11 (3), 215–364.

Peel, M.C., Finlayson, B.L., McMahon, T.A., 2007. Updated world map of the Köppen–Geiger climate classification. Hydrology and earth system sciences discussions. Eur. Geosci. Union 11 (5), 1633–1644.

Postigo-Mijarra, J.Mª., Barrón, E., 2013. Zonal plant communities of the Ribesalbes-Alcora Basin (La Rinconada mine, eastern Spain) during the early Miocene. Bot. J. Linn. Soc. 172, 153–174.

Postigo-Mijarra, J.Mª., Barrón, E., Gómez-Manzaneque, F., Morla, C., 2009. Floristic changes in the Iberian Peninsula and Balearic Islands (south-West Europe) during the Cenozoic. J. Biogeogr. 36, 2025–2043.

Postigo-Mijarra, J.Mª., Altolaguirre, Y., Moreno-Domínguez, R., Barrón, E., Casas-Gallego, M., 2022. Climatic reconstruction at the early Miocene La Rinconada mine (Ribesalbes-Alcora Basin, eastern Spain) based on Coexistence Approach, CLAMP and LMA analysis. Rev. Palaeobot. Palynol. 304, 104714.

Ramos-Guerrero, E., Rodríguez-Perea, A., Sabat, F., Serra-Kiel, J., 1989. Cenozoic tectosedimentary evolution of Mallorca island. Geodin. Acta 3 (1), 53–72.

Raz, L., 2017. A review of the fossil record for Dioscoreaceae. Bot. J. Linn. Soc. 183 (4), 495–508.

Read, R.W., Hickey, L.J., 1972. A revised Classification of Fossil Palm and Palm-like Leaves. Taxon 21 (1), 129–137.

Rodríguez-Perea, A., 1984. El Mioceno de la Serra Nord de Mallorca (Estratigrafía, Sedimentología e implicaciones estructurales). Ph.D. thesis.. Universitat de Barcelona, Spain.

Rozefelds, A.C., Dettmann, M.E., Clifford, H.T., Carpenter, R.J., 2017. *Lygodium* (Schizaeaceae) in southern high latitudes during the Cenozoic—a new species and new insights into character evolution in the genus. Rev. Palaeobot. Palynol. 247, 40–52.

Sàbat, F., Gelabert, B., Rodríguez-Perea, A., Giménez, J., 2011. Geological structure and evolution of Majorca: Implications for the origin of the Western Mediterranean. Tectonophysics 510, 217–238.

Sanz de Siria, A., 1981. La flora burdigaliense de los alrededores de Martorell (Barcelona). Paleontol. Evol. 16, 3–13.

Sanz de Siria, A., 1982. La flora del Mioceno Medio de las cercanías de Martorell. But. Inf. Inst. Paleontol. Sabadell 14 (1–2), 49–61.

Sanz de Siria, A., 1983. Aportación al conocimiento de la flora pliocénica de los alrededores de Papiol (Barcelona). Paleontol. Evol. 18, 151–171.

Sanz de Siria, A., 1992. Estudio de la macroflora oligocena de las cercanías de Cervera (colección Martí Madern del Museo de Geología de Barcelona). Treb. Mus. Geol. Barcelona 2, 269–379.

Sanz de Siria, A., 1993. Datos sobre la paleoclimatología y paleoecología del Neógeno del Vallès-Penedès según las macrofloras halladas en la cuenca y zonas próximas. Paleontol. Evol. 26–27, 281–289.

Sanz de Siria, A., 1996. La macroflora oligocena de la cuenca de Cervera, Lérida, España (Colección del Museu Comarcal de Cervera). Treb. Mus. Geol. Barcelona 5, 97–141.

Scheihing, M.H., Pfefferkorn, H.W., 1984. The Taphonomy of land plants in the Orinoco Delta: a model for the incorporation of plant parts in clastic sediments of the late Carboniferous age of Euramerica. Rev. Palaeobot. Palynol. 41, 205–240.

Sitár, V., Kvaček, Z., 1997. Additions and revisions to the early Miocene flora of Lipovany (Southern Slovakia). Geol. Carpath., Bratislava 48 (4), 263–280.

Suc, J.-P., Fauquette, S., 2012. The use of pollen floras as a tool to estimate palaeoaltitude of mountains: the Eastern Pyrenees in the late Neogene, a case study. Palaeogeogr. Palaeoclimatol. Palaeoecol. 321–322, 41–54.

Tanai, T., Onoe, T., 1959. A Miocene flora from the northern part of the Joban coal field. Japan. Bull. Geol. Surv. Jpn. 10, 261–286.

Teodoridis, V., Kvaček, Z., 2015. Palaeoenvironmental evaluation of Cainozoic plant assemblages from the Bohemian Massif (Czech Republic) and adjacent Germany. Bull. Geosci. 90 (3), 695–720.

Tosal, A., Martín-Closas, C., 2016. Taphonomy and paleoecology of the Oligocene flora from Cervera (Catalonia, Spain) and their implication in palaeoclimatic reconstruction. Rev. Palaeobot. Palynol. 233, 93–103.

Tosal, A., Sanjuan, J., Cartanyà, J., Martín-Closas, C., 2018. Taphonomy and palaeoecology of the uppermost Eocene flora from Sarral (Eastern Ebro Basin): Palaeoclimatic implications. Palaeogeogr. Palaeoclimatol. Palaeoecol. 497, 66–81.

Tosal, A., Sanjuan, J., Martín-Closas, C., 2019a. Foliar adaptations of *Rhus asymmetrica* sp. nov. from the Oligocene of Cervera (Catalonia, Spain). Palaeoclimatic implications. Rev. Palaeobot. Palynol. 26, 67–80.

Tosal, A., Valero, L., Sanjuan, J., Martín-Closas, C., 2019b. Influence of short- and long-term climatic cycles on floristic change across the Eocene-Oligocene boundary in the Ebro Basin (Catalogne, Spain). C. R. Palevol. 18, 925–947.

Traiser, C., Dalitz, H., Krause, M., Lange, J., Roth-Nebelsick, A., Kovar-Eder, J., 2019. Digiphyll - a Digital Tool for Competence Building in Palaeobotany for Teaching and Research. Version 1.0;. Staatliches Museum für Naturkunde Stuttgart. http://digiphyll.smns-bw.org.

Unger, F., 1847. Chloris Protogaea. Beitrage zur Flora der Vorwelt, Wilhelm Engelmann, Leipzig.

Unger, F., 1861. Neu-Holland in Europa. W. Braunmüller, Wien.

Unger, F., 1862. Wissenschaftliche Ergebnisse einer Reise in Griechenland und in den jonischen Inseln. W. Braunmueller, Wien.

Unger, F., 1864. Sylloge plantarum fossilium. II. Denkschr. Kaiserl. Akad. Wiss. Math.-naturwiss. Cl, 22, pp. 1–36. Wien.

Unger, F., 1867. Die fossile Flora von Kumi auf der Insel Eubpoea. Denkschriften der Kaiserlichen Akademie der Wissenschaften. Mathematisch-Naturwissenschaftliche Classe 27, 27–87.

Velitzelos, E., Bůžek, Č., Kvaček, Z., 1992. Contribution to the lower Miocene flora of Alive (Island of Evia, Greece). Doc. Nat. 74, 10–25.

Velitzelos, E., Kvaček, Z., Denk, T., Velitzelos, D., 2002. Palaeontology and palaeobotany. In: Velitzelos, D. (Ed.), Field Guide to the Neogene of the Island of Evia — Early Miocene Flora of Kymi. Field Guide, 6th Europ. Palaeobotany–Palynology Conf. University of Athens.

Velitzelos, D., Bouchal, J.M., Denk, T., 2014. Review of the Cenozoic floras of Greece. Rev. Palaeobot. Palynol. 204, 56–117.

Vera, J.A., Ancochea, A., Calvo-Sorando, J.P., Barnolas-Cortinas, A., Bea-Carredo, F., 2004. Geología de España. Instituto Geológico y Minero de España, p. 884.

Verdú, V., Pausas, J.G., Postigo-Mijarra, J.Mª., Barrón, E., Casas-Gallego, M., Arroyo, J., Carrión, J.S., 2020. Phylogenetic diversity in the Iberian flora through the Cenozoic. Environ. Exp. Bot. 170, 103888.

Vicente i Castells, J., 1988. La flora fòssil de Montjuïc (Barcelona). Societat d' Història Natural, Santa Coloma de Gramenet.

Wadsworth, W.J., Adams, A.E., 1989. Miocene volcanic rocks from Mallorca. Proc. Geol. Assoc. 100, 107–112.

Wang, Q., 2012. Nomenclatural notes on *Leguminosites* and several taxonomically relevant names (fossil Leguminosae). Taxon 61 (4), 871–877.

Wang, Z., Shi, G., Sun, B., Dong, Ch., Yin, S., Wu, X., 2022. *Lygodium* with in situ spores from the middle Miocene of Southeast China and its paleoclimatic implication. Rev. Palaeobot. Palynol. 296, 104545.

Winterscheid, H., 2018. Revision of a late Oligocene florule from the south-western edge of the lower Rhine Basin (western Germany). Acta Palaeobot. 58 (1), 49–60.

Winterscheid, H., Kvaček, Z., 2016. Late Oligocene macrofloras from fluviatile siliciclastic facies of the Köln Formation at the south-eastern border of the lower Rhine Embayment (North Rhine-Westphalia, Germany). Acta Palaeobot. 56, 41–64.

Yang, J., Wang, Y.F., Spicer, R.A., Mosbrugger, V., Li, Ch.S., Sun, G.S., 2007. Climatic reconstruction at the Miocene Shanwang Basin, China, using leaf margin analysis, CLAMP, coexistence approach, and overlapping distribution analysis. Am. J. Bot. 94 (4), 599–608.

Yang, J., Spicer, R.A., Spicer, T.E.V., Sen Li, Ch., 2011. 'CLAMP Online': a new webbased palaeoclimate tool and its application to the terrestrial Paleogene and Neogene of North America. Palaeobiodivers. Palaeoenviron. 91 (3), 163.

Zhilin, S.G., 1989. History of the Development of the Temperate Forest Flora in Kazakhstan, U.S.S.R. from the Oligocene to the early Miocene. Bot. Rev. 55, 205–330.

Zidianakis, G., Iliopoulos, G., Zelilidis, A., Kovar-Eder, J., 2020. Three (middle to) late Miocene plant macroremain assemblages (Pitsidia, Kassanoi and Metochia) from the Messara–Gavdos region, southern Crete. Acta Palaeobot. 60, 333–437.