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NEOGENE *PALMOXYLON* FROM TURKEY

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Abstract Tertiary fossil wood identifications of Turkey revealed many different gymnosperm and angiosperm genera and species. Within this lignoflora some *Palmoxylon* types were identified for the first time as *Palmoxylon coryphoides* Ambwani et Mehrotra, *Palmoxylon* sp. cf. *Trachycarpus* H. Wendl., and *Palmoxylon* sp. cf. *Borassus* L. The fossil palm-wood was collected from the sites in Seben and Gökçeada from early Miocene deposits, and from the site in Erikli from middle-late Miocene deposits. The presence of the palm trees in the Miocene Flora of the Anatolian and Aegean regions indicates a lowland riparian palaeoenvironment and warm-humid or subtropical palaeoclimate.

Keywords: *Palmoxylon*, fossil-species, Seben, Gökçeada, Erikli.

INTRODUCTION

In the recent decades, our information on the fossil lignoflora of Turkey has increased. The new identifications of petrified wood in Turkey showed a rich woody flora from the late Oligocene to the late Miocene. Some of the identified genera such as Sequoioxylon (Özgüven-Ertan, 1971, Kayacik *et al*., 1995; Akkemik *et al*., 2005; Sakınç *et al*., 2007, Akkemik & Sakinç, 2013, Akkemik *et al*., 2009), *Glyptostroboxlon* (Akkemik *et al*., 2017), *Podocarpoxylon* (Sakınç *et al*., 2007), *Engelhardioxylon* (Sakınç *et al*., 2007) are taxa completely extinct from Turkey, while other fossil forms (e.g. Sayadi, 1973; Selmeier, 1990; Dernbach *et al*., 1996; Aytuğ & Şanli, 1974; Eroskay & Aytug, 1982; Şanli, 1982; Akkemik *et al*., 2016 and Bayam *et al*., 2018) still have modern correspondents. Regarding with *Palmoxylon*, many studies were published in the world (e.g. Schenk, 1882; Mahabalé, 1958; Greguss, 1959, 1969; Kaul, 1960; Tomlinson, 1961, 1990; Prakash, 1962; Grambast, 1962, 1964; Trivedi & Verma, 1970; Roy & Ghosh, 1980; Privé-Gill & Pelletier, 1981; Ambwani & Mehrotra, 1990; Gottwald, 1992; Nambudiri & Tidwell, 1998; EL-Saadawi et al., 2004; Kahlert *et al*., 2005; Sakala, 2004; Dransfield *et al*., 2008; Thomas, 2011a,b; Thomas & De Franceschi, 2012, 2013; Kamal-EL-Din *et al*., 2013; Prasad *et al*., 2013; Nour-EL-Deen *et al*., 2017). Otherwise an extended list o References on *Palmoxylon* is published in the site CiteULike by Millevacs in: (Accessed 05.05.2018).

Within these studies Kamal-EL-Din *et al*. (2013) stated that Egypt is the richest African country having fossil-species of *Palmoxylon* with 16 species, after describing four *Palmoxylon* species, *P. deccanense* Sahni, *P. edwardsi* Sahni, *P. geometricum* Sahni, *P. prismaticum* Sahni, *P. pondicherriense* Sahni, *P. pyriforme* Sahni and *P. sagari* Sahni.

Thomas & De Franceschi (2013) made a valuable revision of the palm xylotomy, which is very useful for modern palm identification by the study of the palm stem microscopic structure and also useful for the fossil palms, as species of *Palmoxylon*. Descriptions were based mainly the general organization of the transverse section and the structure of the fibrovascular bundles as well as the ground parenchyma, taking the Coryphoideae as case-study.

As for Anatolian region, the palaeobotanical studies mentioned above revealed that the climate in the early Miocene was warmer, probably subtropical and much humid than the present climate. Palm trees growth even today under this kind of climate in Seben (Akkemik et al., 2016), European Part of Turkey and in the Island of Gökçeada in Aegean Sea (Güngör et al., 2018), but their distribution area was much wider through Turkey during Neogene. Under this discussion, the purpose of the present paper is to describe some fossil forms based on the study of their petrified remains.

MATERIAL AND METHODS

We had in study four samples that sowed the typical palm structure and were considered as fossil forms of *Palmoxylon*. They were coded as HOC25 (Akkemik *et al*., 2016), GOK01 and GOK269 (Güngör *et al*., 2018), and ERI01. They have been collected from Bolu-Seben-Hoçaş Fossil Site (HOC25), Edirne-Erikli (ERI01) and Gökçeada (GOK01 and GOK269) (Fig. 1). The samples were in-situ position in Bolu-Seben-Hoçaş Fossil Site (Fig. 2) and dispersed in the others (Fig. 3).

According to Akkemik *et al*. (2016), the age of fossil site in Seben-Hoçaş was 18.2±0.8 from the basalt samples. Similar ages were given by Keller et al. (1992), Toprak et al. (1996), and Wilson *et al*. (1997) including the ages of 17.6-24.8 Ma for volcanic activity in Galatean Volcanic Province. So, the age of Seben-Hoçaş Fossil Site is the early Miocene.

Güngör *et al*. (2018) specified that the geological age of Gökçeada as also early Miocene, bearing a similar wood flora with Lesbos Island (Süss & Velitzelos, 1997).

The fossil wood material (ERI01) in Erikli was found on the shore of Aegean Sea. Sakinç *et al*. (1999) explained geological background of Erikli, and its age is most probably middle-late Miocene.

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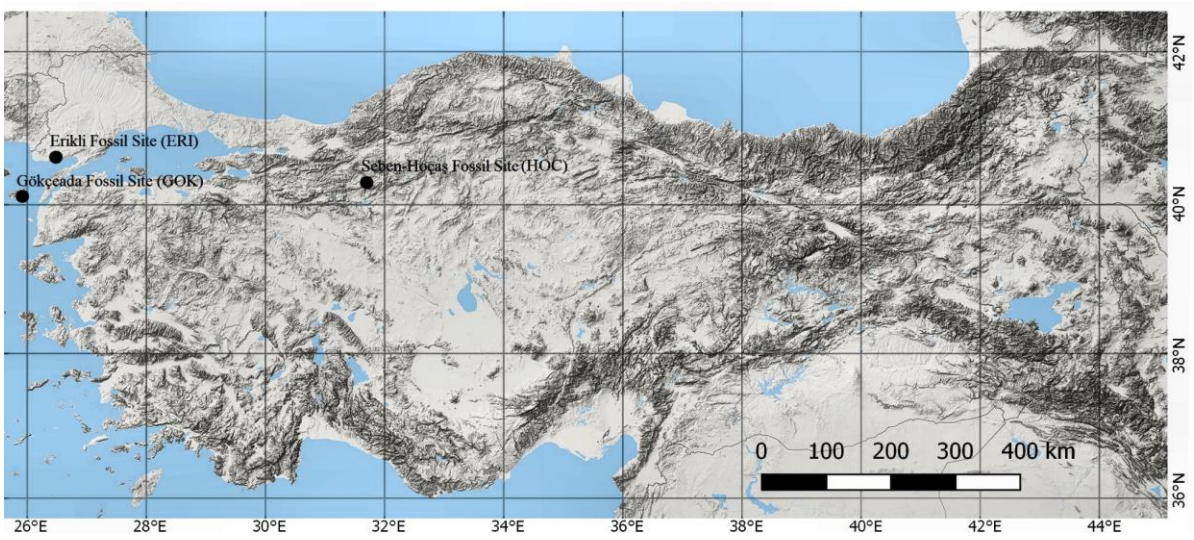

Fig. 1 The locations of the sampled materials.

Fig. 2 In-situ trunk of *Palmoxylon* in Seben-Hoçaş Fossil Site.

Fig. 3 Dispersed wood trunk fragments including one of *Palmoxylon* in Gökçeada Fossil Site.

For wood identification, we realized thin sections from the samples of fossil wood along the three standard planes: transverse section (TS), or cross-section, radial longitudinal section (RLS) or simply, radial section and tangential longitudinal section (TLS) or simply tangential section. These standard planes of cutting in a palm stem are also valid since there is an oriented structure in the external and intermediary part, only in the central part of the stem is less important (see Mahabalé, 1958; Kaul, 1960; Greguss, 1959, 1968; Tomlinson, 1961)
The samples and sections were stored at the "Laboratory of Tree-ring Researches and Wood Anatomy" in Forest Botany Department of Faculty of Forestry, Istanbul University.
The first study was made on a biological microscope (LEICA DM2500 Light Microscope) and the microphotos were realized with a LEICA DSC295 type of camera.
The description and identification of the specimens was performed in the Geological Institute of Romania, in Bucharest. In identification, many references including fossil *Palmoxylon* species were used (e.g. Schenk, 1882; Mahabalé, 1958; Greguss, 1959, 1968, 1969; Kaul, 1960; Tomlinson, 1961, 1990; Prakash, 1962; Grambast, 1962, 1964; Trivedi & Verma, 1970; Roy & Ghosh, 1980; Privé-Gill & Pelletier, 1981; Ambwani & Mehrotra, 1990; Gottwald, 1992; Nambudiri & Tidwell, 1998; EL-Saadawi *et al*., 2004; Kahlert *et al*., 2005; Sakala, 2004; Dransfield *et al*., 2008; Thomas, 2011a, b; Thomas & De Franceschi, 2012, 2013; Kamal-EL-Din *et al*., 2013; Prasad *et al*. 2013; Nour-El-Deen *et al*., 2017).

SYSTEMATIC PALAEOBOTANY

Order **Arecales** Bromhead 1840 (in Reveal, 2004)
Family **Arecaceae** Berchtold et Presl, 1820 (nom. cons)
Genus *Palmoxylon* Schenk, 1882
Palmoxylon coryphoides Ambwani & Mehrotra, 1990
Fig. 4, photos a-i. Fig. 5, photos a-i.

Material: GOK01 and GOK259.
Locality: Gökçeada.
Formation: Kesmekaya Volcanics.
Age: Early Miocene.
Origin on the stem remains: Coming from unknown portion of the trunk.
Storage: This material is now kept under index GOK01 and GOK269 within the "Collection of fossil woods" in the Forest Botany Department, Forestry Faculty, Istanbul University.

Microscopic description: Theoretically the central cylinder, in cross section, is formed from three distinct parts: dermal, subdermal and central zones (see Mahabalé, 1958 and Kaul, 1960 quoting von Mohl, 1850) or external, intermediary and central (in euro-american school, see Tomlinson, 1961), or, respectively, subcortical zone - as a periferal sclerotic zone, transitional zone and central zone as was lastly stated by Thomas & De Franceschi (2013). For description, the shape, the size, the density of the fibrovascular bundles, their fibrous part and vessels, the quantity of parenchyma, the abundance and the arrangement of parenchymatous cells starch grained along to the fibrovascular bundles must be considered and also the phytoliths.
The studied specimens show in cross-section the central zone, but also at least a part of the transitional zone (especially the specimen GOK259), where fibro-vascular bundles of open collateral type appear, usually oriented with the vascular part to the centre of the stem and the fibrous part to outside, and having 2-4 large metaxylem vessels round to oval, and typical reniform sclerenchyma caps well developed, floating in the ground parenchyma tissue, often touching each other. The size of fvb is variable 400-500/360-475 µm (mean values: 421.25 / 403.75 µm, the phloematic (=anterior) sclerenchyma cap has r/tg.d = 116 / 372 µm, f / v ratio is 0.35 / 1 and the frequency, or density, is of 491.2 bundles/cm2.
The phloem appears protected under the median sinus of the sclerenchyma cap, a single island - as an undivided sieve plate, rarely apparently divided.
The metaxylem appear as 2-4(-6-8) vessels either oval or elliptic or, less round in cross-section or, sometimes, partitioned by the terminal inclined wall. They are usually large and thick-walled vessels, having in cross section 70-162.5 / 45-107.5 µm (mean values 107.7 / 65 µm) in diameters and 8-10 µm the simple wall. The size of metaxylem vessels is of 47 / 44.55 µm, and thick-walled, of 7-10 µm the simple wall. Vertically the walls of metaxylem vessels have scalariform pitting and annular thickenings sometimes ramified and anastomosed. The terminal wall is very inclined and bears a scalariform perforation with 8-18 thick bars and, sometimes, only simple perforation.
The protoxylem appear as unequally smaller vessels grouped beneath the metaxylem vessels or partially pushed between them, possibly because the sustained growing of the parenchyma from around. They have d=25/22.9 µm, and are relatively thick-walled: 3-5 µm in the simple wall.
The intrafascicular (or paravascular) parenchyma is constituted of uniform, relatively thin-walled (5-7 µm the simple wall), rounded-polyhedral cells which appear also rounded in cross-section and small-sized (15.5/5 - 25/10 µm). Adjacent to the metaxylem vessels appear in 1-2 rows regularly arranged, similar to a tabular parenchyma. The marginal 1-2 rows of sclerified paravascular parenchyma cells constitute a second sclerenchyma cap protecting the vascular zone also named ventral fibrous cap adjacent to the xylem.
The ground tissue (or the interfascicular parenchyma) is constituted by non-oriented rounded-polyhedral cells unequally sized, very emaciated or lobed cells, as they appear in cross section, usually thin-walled, and with possible starch-content. It represents the ground parenchyma with sustained growing of *Corypha* type. All around the fibrovascular bundle only tabular parenchyma can be seen, in 1-2 compact rows arranged. Fibrous bundles weren't observed.
The central zone in both the specimens studied is of *Corypha* type (von Mohl, in Thomas & De Franceschi, 2011) where the round to oval fibrovascular bundles are variably oriented, having 2-4(-6-8) metaxylem vessels and not too developed sclerenchyma caps of Reniforma to Lunaria type, all floating in the ground parenchymal tissue along with small fibrous bundles, more numerous in

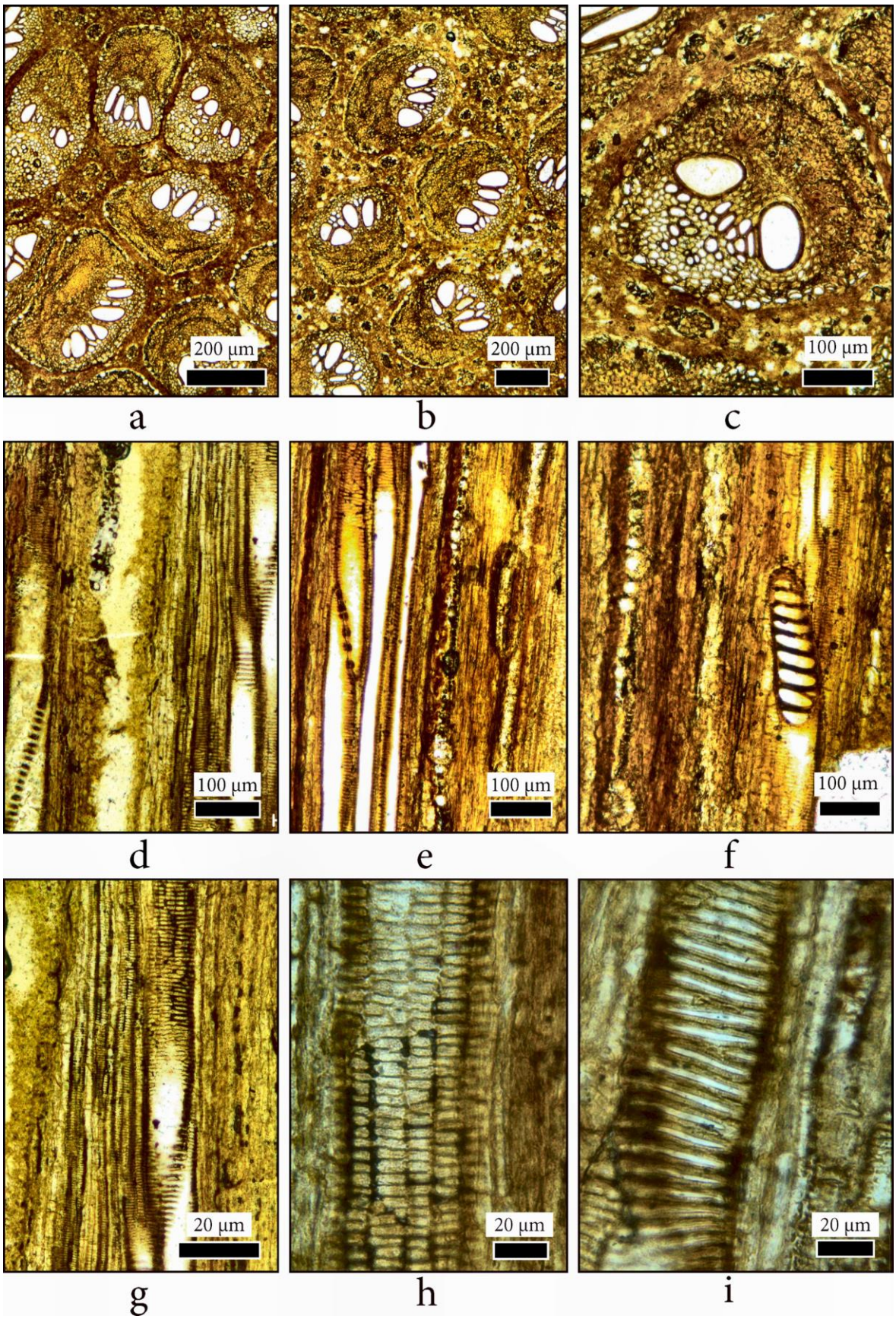

Fig. 4 *Palmoxylon coryphoides* Ambwani & Mehrotra, 1990. (GOK01). **a-c** Cross-section. Fibrovascular bundles (fvb) variably oriented in central zone; parenchymal ground tissue; fibrous bundles; **c** Detailed fvb-s displaying metaxylem and protoxylem vessels, phloem, reniform sclerenchyma cap, stegmata, and rounded by tabular parenchyma. Also ground tissue parenchymal cells and fibrous bundles can be seen. **d-i** Longitudinal sections. Metaxylem and protoxylem vessels with annular thickenings, scalariform pitting, and with scalariform perforated inclined plates. Also, long rows of stegmata can be seen. **g, i** Metaxylem and protoxylem vessels with annular bifurcated thickenings, and with scalariform perforated plate. **h** Metaxylem vessel with scalariform pitting.

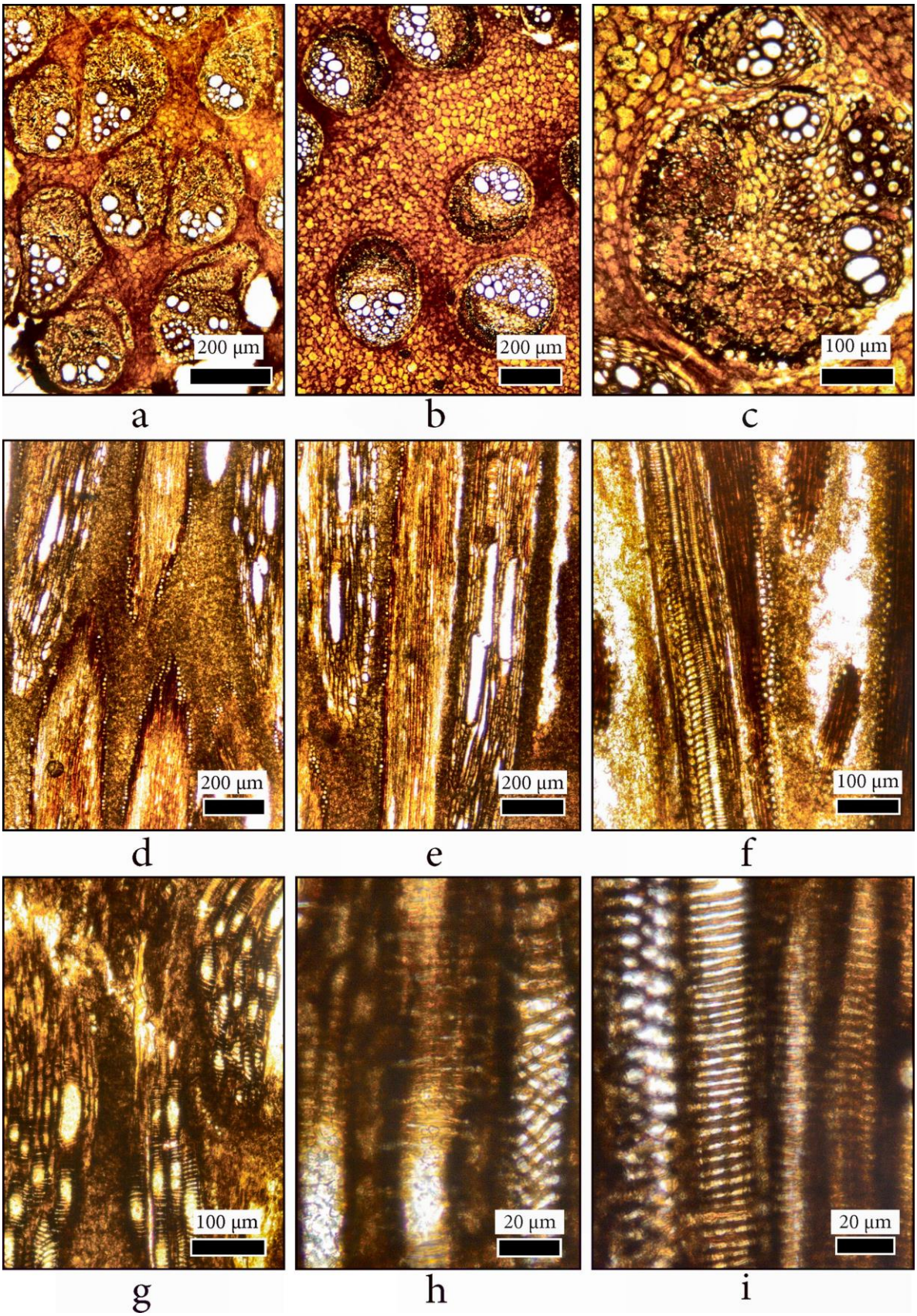

Fig. 5 *Palmoxylon coryphoides* Ambwani & Mehrotra, 1990. (GOK259). **a-c** Cross-section. **a** Transitional zone with fvb with reniform caps; parenchymal ground tissue; **b** Variably oriented fvb in central zone; parenchymal ground tissue; fibrous bundles; **c** Detailed fvb coupled with small fvb-s displaying metaxylem and protoxylem vessels, phloem, reniform sclerenchyma cap, stegmata, and tabular parenchyma. Also ground tissue parenchymal cells and fibrous bundles can be seen. **d-g** Longitudinal sections. Metaxylem and protoxylem vessels with annular or helical thickenings, scalariform pitting, and with scalariform perforated inclined plates. Fibrous sheaths of fvb marked by long rows of stegmata (d, f). **g-i** Metaxylem and protoxylem vessels with annular and helical thickenings and with simple perforation (i).

GOK01 specimen. Under the sclerenchyma cap a large median sinus is present, auricular sinuses were not observed. The sclerenchyma cap (also named anterior or dorsal cap, or phloematic fibrous sheath, or fibrous part adjacent to phloem) is constituted from vertically elongated fibrous cells with polygonal rounded cross-section, thick-walled and with rounded to point-like lumina. The size of the fibrovascular bundles is variable: 400-500/360-475 µm (mean values: 421.25/403.75 µm, the phloematic (=anterior) sclerenchyma cap has r/tg.d=116/372 µm, f/v ratio is 0.35/1 and the frequency (or density) is of 214 bundles/cm2. Signs of a centrifugal differentiation of the fibrous part seem to be absent.

The phloem, appear protected under the median sinus of the sclerenchyma cap, in a single island - as an undivided sieve plate, rarely apparently divided.

The metaxylem appear as 2-4(-6-8) vessels either oval or elliptic, or less, round in cross-section or, sometimes partitioned by the terminal wall. They are usually large and thick-walled vessels (7-8-10 µm the simple wall), having, in cross section, 70-162.5/45-107.5 µm (mean 107.7/65 µm) in diameters (smaller in specimen GOK259: 47.03/44.55). Vertically the walls of the metaxylem vessels have scalariform pitting and annular thickenings sometimes ramified. The terminal wall is very inclined and bears a scalariform perforation with 8-18 thick bars (fewer in the specimen GOK259: 3-5-8 bars) or even simple perforation.

The protoxylem is represented by 3-12 small round to oval vessels of 10-36 µm in diameters, more numerous in the specimen GOK259 (up to 30), and relatively thick walled (2-5 µm the simple wall). Vertically the protoxylem vessels present annular thickenings sometimes ramified, and short scalariform perforations.

The intrafascicular (or paravascular) parenchyma is constituted of uniform, thin-walled (1-2 µm the double wall), rounded-polyhedral cells which appear polygonal-rounded in cross-section, small-sized cells (round of 6-14 µm or elliptic of 12.5-25/5-15 µm). Adjacent to the metaxylem vessels appear in 1-2 regular rows of flattened cells arranged, like a tabular parenchyma. All the remained space is filled with compact non-oriented parenchyma cells. The marginal 1-3 rows of paravascular parenchyma is constituted by highly sclerified cells, thicker walled (3-6 µm the double wall), so forming a second sclerenchyma cap, which protect the vascular zone, also named ventral cap or fibrous part adjacent to the xylem.

The ground tissue or the interfascicular parenchyma is constituted by non-oriented very emaciated big cells as lobed cells, as they appear in cross section, usually thin-walled, and with possible starch content. It represents the ground parenchyma with sustained growing of *Corypha* type, the cells compressing each other. All around the fibrovascular bundle only tabular parenchyma can be seen, in 1-2 compact rows arranged.

The fibrous bundles are more numerous in specimen GOK01, floating in the ground parenchyma among the fibrovascular bundles. They have 15-19-25 fibers, or more, with polygonal rounded cross-section, very thick walls and point-like lumina. Often the fibers bear phytoliths as spherical stegmata, slightly spinulose, partially sunken in the basal wall of silica-cell wall. They are visible even in cross section, and appear in long rows in the longitudinal sections.

The phytoliths as spherical stegmata also appear, vertically, on the fibers of fibrous part of the fibrovascular bundles, numerous and in long rows arranged, covering large surfaces on the fibrous part of the bundle, also visible in cross-section around caps. Those spherical stegmata seem to bear rounded spines, and are partially sunken in the basal wall of the silica-cell. It seems that these stegmata had from the beginning a definitive size, since it seems that in time they didn't grew more. Also, they seem to connect the fibers with one another, thus enhancing the solidity of the structure.

Affinities and discussions: In cross section, the studied material presents a monocotyledonous fascicular structure, typical for the stem of palm tree, a member of the Family Arecaceae Berchtold et Presl, 1820 (nom.cons) also found in the scientific literature as Family Palmae Jussieu, 1789 (nom. cons. et nom. alt.) or as Family Arecaceae Schultz-Schultzenstein, 1832 (nom.cons.). The fossil correspondent, *Palmoxylon* is a genus name that generally defines "wood of Palm", in conformity with the original diagnosis of Schenk (1882). However, taking into account that other organs of the palm-plant are connected with the stem (rootlets, leaf axes, petioles, fruits, flowers, pollen, etc…), there are rare situations, in fossil, when you can find them together and describe them under a single name, as in "whole plant" palaeobotanical concept, (see Sakala, 2004), since they fossilize in different conditions, and usually they are described separately, under different genus names. Our studied petrified material clearly presents fascicular structure so, undoubtedly, they all can be attributed to the *Palmoxylon* genus. But with what kind of extant Palm can be compared? Because, taking into account the distribution of the anatomical elements composing the palm-stem we can guess the position in trunk of the studied sample, aspect which it's very important for description, interpretation and identification. Anyway the shape, the size, the components of the fibrovascular bundles and their numeric characters, the parenchyma of the ground tissue, its abundance and the arrangement and also the fibrous bundles and the phytoliths must be considered in the comparison with extant or fossil palm structures known from the already published studies.

The description of the fossil material have followed the classical model and with language used by botanists and palaeobotanists which have described the central cylinder of a palm-stem, in cross section, as formed from three distinct parts: dermal, subdermal and central zones (see Mahabalé, 1958 and Kaul, 1960 quoting von Mohl) or external, intermediary and central in euro-american school (see Tomlinson, 1961), or subcortical zone (as periferal sclerotic zone), transitional zone and central zone as was lastly stated by Thomas & De Franceschi (2013). From this point of view, the here studied specimens have enough details that send our attention to *Corypha* type structure from the subfamily Coryphoideae Burnett, the tribe Corypheae Martius in Endl.

To do a comparison with extant palms it is difficult since there are no exhaustive studies done on palm stem anat-

omy, only partial, due to the difficulties to obtain material of study, but the studies of Tomlinson, (1961, 1990), and of Thomas & De Franceschi (2013 with references) must be considered.

Both the specimens having a splendid fascicular structure were attributed to *Palmoxylon* genus. But, again, what kind of *Palmoxylon*? Until now over 250 species of *Palmoxylon* were described all around the world but few of them send to an extant correspondent, so it is very difficult to obtain an answer. However, we tried to find a similar type of palm, extant or fossil, having the following features: arboreal habit, numerous relatively big fibrovascular bundles in the central part of the stem, with sclerenchyma cap of Reniforma type tending to Lunaria type and fibrous bundles floating in a compact parenchymal ground tissue with signs of sustained growing, all around the fibrovascular bundles only tabular parenchyma in 2-3 regular rows is present. Also, in the fibrovascular bundles the phloem is usually undivided, rarely apparently divided, and the 2-4(6-8) large metaxylem vessels have simple or scalariform perforations with thick bars, and scalariform pitting.

In an important attempt to realize a program of computer-aided identification for Palm stem anatomy, Thomas (2011a,b) and Thomas & De Franceschi (2012, 2013) took the Coryphoideae as case study. In their papers we found quite interesting suggestions of affinity of our studied specimens with the typical Coryphoideae. Deeply comparing the xylotomical characters of our specimens with the xylotomy of the present day genera as quoted by Tomlinson (1961, 1990, 2011) and by Thomas & De Franceschi (2013) we found a similar combination of features in the genus *Corypha* L., an extant Palm native and spread in India, Malaysia, Indonesia, New Guinea, the Philippines and northeastern Australia (Cape York Peninsula, Queensland) (Wikipedia, accessed in 20.04.2018). Its species are fan-palms, trees of 20-40 m high, with the leaves with a long petiole (2-5m) terminating in a rounded fan of numerous leaflets.

From the fossil forms of *Palmoxylon* we tried to compared our structures with some fossil forms of so called "Reniformia group" and we took into account all the available descriptions of so named "sabaloid Palms" (in fact from Coryphoideaea subfamily after last phylogenetic classification of Arecaceae of Dransfield *et al*., 2005), usually having reniform sclerenchyma caps of the fibrovascular bundles, as were described by Schenk (1883), Berry (1924), Chiarrugi (1933), Rao & Menon (1964), Menon (1965), Trivedi & Verma (1971a, b), Prakash (1962), Grambast (1957, 1964), Greguss (1954, 1959, 1969), Prive-Gill & Pelletier (1981), Gottwald (1992), Nambudiri & Tidwell (1998), Kahlert et al. (2005), Iamandei & Iamandei (2006), Nour-El-Deen *et al*. (2017) where sometimes is specified a possible extant correspondent, being oriented mainly to *Sabal*, to *Trachycarpus* or to *Chamaerops*. It was only Grambast (1962) that has seen in his *Palmoxylon* sp., of Complanata type, similitude with the extant *Corypha* L.

The resemblance of our structures with the extant *Corypha* as it is figured and described by Tomlinson (1961), the similitude shown by our material with the fossil form described by Grambast (1962) and considered of *Corypha* type, confirmed by the papers of Thomas & De Franceschi (2012, 2013) support this identification.

The microscopical details observed in our specimens are similar with those comprised in the species diagnosis given by Ambwani & Mehrotra (1990) also, regarding the aspect of the fibrovascular bundles, type of parenchyma and of stegmata and allow us to attribute the studied material to this taxon with the name *Palmoxylon coryphoides* Ambwani & Mehrotra, 1990.

Palmoxylon sp. cf. *Trachycarpus*
Fig. 6, photos a-i.

Material: HOC25.
Locality: Bolu-Seben-Hoçaş Fossil Site.
Formation: Hançili Formation.
Age: Early Miocene.
Origin on the stem remains: Lower part of an in situ petrified palm stem.
Storage: This material is now kept under the index HOC25 within the "Collection of fossil woods" in the Forest Botany Department, Forestry Faculty, Istanbul University.

Microscopic description: The studied sample shows in cross-section only the central zone with fibro-vascular bundles of collateral type, usually variably oriented, having 2-4(-6-8?) metaxylem vessels and not too developed sclerenchyma caps of Reniforma type to Lunaria type, floating in the ground parenchymal tissue along with few small fibrous bundles. Under the sclerenchyma cap a large median sinus is present, but auricular sinuses were not observed. The sclerenchyma cap is constituted from vertically elongated fibrous cells with polygonal rounded cross-section, thick-walled and with rounded or point-like lumina. The size of fvb is variable: 650-900/650-750 µm (mean values: 783/700 µm), the phloematic (=anterior) sclerenchyma cap has r/tg.d=315/466.6 µm, f/v ratio is o.68/1 and mean density is of 122.8 bundles/cm2. Signs of a centrifugal differentiation of the fibrous part seem to be absent.

Also "the diminutive fibrovascular bundles" (Prasad et al. 2013), seem to be "initials of foliar bundles" and appear as smaller fibrovascular bundles having well developed sclerenchyma cap of Reniforma type constituted from fibers smaller in cross-section and an elongated vascular part with 2 metaxylem vessels, sometimes tylosed, and numerous protoxylem vessles, small, grouped. However, few details can be seen on the phloem and paravascular parenchyma though they are present in the structure of the foliar bundle.

The phloem in the normal fibrovascular bundles appear as protected under the median sinus of the sclerenchyma cap, in a single island - as an undivided sieve plate and the phloem cells are discernible.

The metaxylem appears as 2-4 (sometimes 6-8?) vessels, either oval or elliptic or round (less) in cross-section or, sometimes, because are partitioned by the very inclined terminal wall, the apparent number of vessels grows. They are usually large and thick-walled (9-12 µm the simple wall), having in cross section 241.6/156.6 µm the mean diameters. Vertically, the walls of metaxylem vessels have scalariform pitting and thick annular or helical

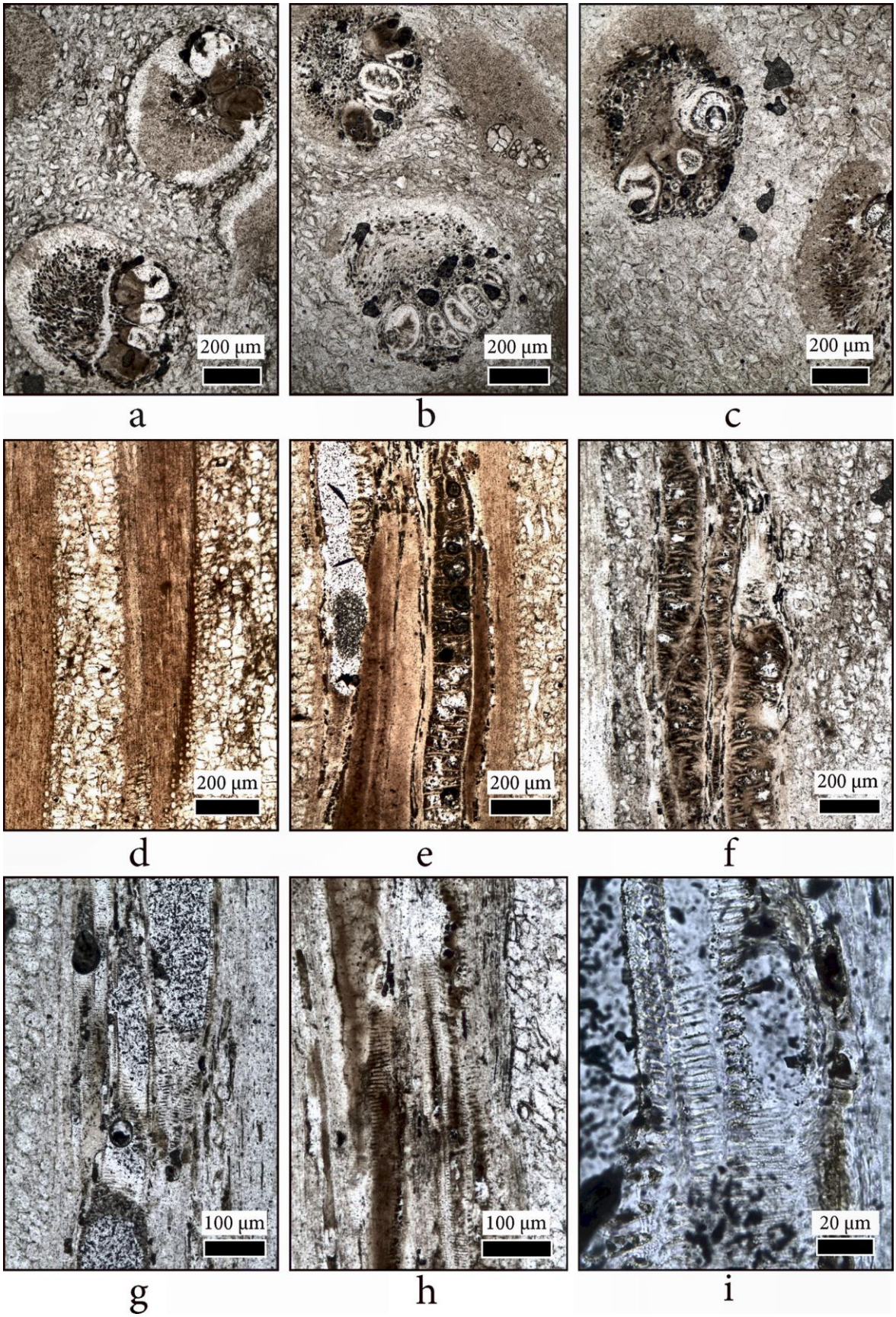

Fig. 6 *Palmoxylon* sp. cf. *Trachycarpus* H.Wendl. (specimen HOC25). **a-c** Cross-section. Fibrovascular bundles (fvb) variably oriented in central zone; compact parenchymal ground tissue, tabular parenchyma around fibros par of fvb; radiant parenchyma around vascular par of fvb; small fvb-s as young foliar bundles; details of fvb-s: metaxylem and protoxylem vessels, phloem, reniform sclerenchyma cap, stegmata. **d-i** Longitudinal sections. Fibrous sheaths of fvb marked by long rows of stegmata (d). Metaxylem and protoxylem vessels with annular and helical thickenings, scalariform pitting, and with scalariform perforations, parenchymal ground tissue (e-i).

thickenings. The terminal wall is not very inclined and bears a scalariform perforation with numerous (5)8-13 thick bars. Often, inside, a fungal attack is present. The protoxylem is represented by numerous 7-10 (sometimes more) small polygonal-rounded vessels of 30-80 µm the diameter and relatively thick walled (4-5 µm the simple wall). Vertically the protoxylem vessels present thick annular or helical thickenings sometimes with bifurcations connecting each other, and also, scalariform perforations.

The intrafascicular or paravascular parenchyma is constituted of few uniforms, relatively thin-walled (4-6 µm the double wall) rounded-polyhedral cells which appear polygonal-rounded in cross-section, small-sized cells (d=14-16 µm), and this because the large vessels occupy the major part of the vascular part of the fvb. Adjacent to the metaxylem vessels appear in 1-2 rows regular of flattened cells, arranged like a tabular parenchyma. Possibly, 1-2 marginal rows of paravascular parenchyma slightly sclerified cells represent a cup protecting the vascular zone, forming a small ventral sclerenchyma cap.

The ground tissue or the interfascicular parenchyma is constituted of slightly emaciated big cells, relatively thin-walled (3-4 µm the double walls), in fact rounded-polyhedral cells slightly lobed and very unequal which, in cross section, appear polygonal-rounded and lobed, of 16/24 - 40/60 µm in diameters. It represents the ground parenchyma with sustained growing of *Corypha* type. Around the sclerenchyma cap of fibrovascular bundles tabular parenchyma can be seen, in 1-2 compact rows arranged, but around the vascular part a radiant parenchyma appear, sometimes disturbed by compression due to the sustained growing of the ground parenchyma from around. The fibrous bundles are absent.

Often the fibers of the sclerenchyma sheath of the fibrovascular bundles bear phytoliths as spherical stegmata, slightly spinulose, partially sunken in the basal wall of the silica-cell, in long rows arranged, visible in the longitudinal sections. Here also, it seems that these stegmata connect the fibres one with another, thus enhancing the solidity of the structure, and probably had not a continuous growing.

Affinities and discussions: The studied specimen has an obvious monocotyledonous fascicular structure, typical for a palm-stem, which sustain its attribution to *Palmoxylon* genus. It shows, in cross-section, characters of the central zone of *Corypha* type with fibrovascular bundles of open collateral type usually variably oriented, including also the "diminutive fibrovascular bundles" (see Prasad *et al*. 2013), possibly as initial of foliar bundles (or leaf traces) which appear as smaller fibrovascular bundles having well developed sclerenchyma cap of Reniforma type, undivided phloem, 2-4(6-8) metaxylem vessels with annular or helical thickenings, scalariform perforations, numerous protoxylem vessels, paravascular parenchyma compact few, tabular-like parenchyma around vessels and organized as ventral cap, ground tissue as compact parenchyma polygonal-rounded and lobed, signs of sustained growing of *Corypha* type and also organized around the fibrous cap of the fibrovascular bundles as tabular parenchyma in 1-2 compact rows arranged, around the vascular part radiant parenchyma appear; fibrous bundles are missing, phytoliths appear on the fibrous part of the fibrovascular bundles - as spherical stegmata slightly spinulose in long vertical rows arranged.

Taking into account these details and comparing them with those comprised in the studies of Tomlinson (1961, 1990) and Thomas & De Franceschi (2013) we believe that the most similar extant palm is *Trachycarpus* H.Wendl., an arboreal palm from the Subfamily Coryphoideae Burnett - Tribe Trachycarpeae Satake - Subtribe Rhapidinae J.Dransf. et al., a palm which is native to Asia, from the Himalaya east to eastern China. For a specific affinity of the studied material we took into account also some published studies on fossil forms with reniform sclerenchyma cap, or similar.

Thus, Chiarrugi (1933) have described three different palm-species from the Cretaceous of Somalia: *P. benadirense*, of Reniformia type, *P. scebelianum*, of Lunaria type and *P. somalense*, of Cordata type. They would be interesting for comparison but our specimen has very few details in the vascular zone. *Palmoxylon eocenum* described by Prakash (1962) is also of Reniformia type, but the problem is the same.

P. parthasarathyi of Rao & Menon (1964) has sclerenchyma caps of Lunaria and Reniformia type and it was considered of Cocos type.

Grambast has described in 1957 a *Palmoxylon gignacense* of reniform type but not too similar to our specimen, and in 1962 has described a *Palmoxylon* sp. of Complanata type, similar to *Corypha*, so, different of our specimen;

Again Grambast (1964) describing a new material bring into discussion the possible affinities of *Palmoxylon vestitum* (Saporta) Stenzel with the extant *Phytelephas*, *Trachycarpus*, *Chamaerops*.

Other forms of reniform type described by Greguss as Tertiary "sabaloid palms" from Hungary as *Palmoxylon sabal* (?) (Greguss, 1954), *P. hungaricum* (Greguss, 1959) similar to *Livistona* and also *Palmoxylon dorogense*, *P. sabaloides* and *P. lacunosum* var. *axonense* Watelet (Greguss, 1969), which are definitely different of our studied material.

Trivedi & Verma (1970) have described *P. keriense* of reniform-type, considered *Cocos*-like Palm.

From the 4 forms described by Kramer (1974) only *Palmoxylon* sp. form 2 is included into Cordata type, but the figuration as drawings and photos seem to contradict the attribution to cordate or lunaria type (sensu Stenzel, 1904), all of them seem to be of reniform type, so it's difficult to compare our material with it, but is clearly different.

Privé-Gill & Pelletier (1981) described a *Palmoxylon* sp. of reniform type, however specifying their doubts in a phrase: "depending of the region of the stem studied, you can have a lot of groups of Stenzel and Sahni".

Gottwald (1992) described some specimens of *Palmoxylon* as *P. fasciculosum* Vater, 1884 and *Palmoxylon* sp. (form 3 - Kramer, 1974) recognizing Lepidocarioid affinities, with the extant *Myrialepis* and *Plectocomiopsis* and respectively with *Daemonorops*, which could be very interesting. But *Palmoxylon* cf. *variabile* Vater, 1884 has sabaloid affinities. Nambudiri & Tidwell (1998) have been described *P. hebbertii*, also of reniform type, but is different of our specimen.

Kahlert et al. (2005) have described a palm of Maastrichtian to Palaeocene age from the island Hiddensee (Baltic Sea) *P. bautschii* of Vaginata-Reniformia type with numerous metaxylem vessels, but clearly different of our specimen.
The late Cretaceous species *Palmoxylon, techerense* described by Iamandei & Iamandei (2006), is also of reniform type, but has clear Sabaloid affinities.
Other good references were brought by EL-Saadawi *et al*. (2004) and Kamal-EL-Din *et al*. (2013) who described some fossil palm woods of Egypt, doing also a summary of the fossil African described Arecaceae ranging from Cretaceous to Quaternary.
After this discussion on the xylotomic affinities of our specimen with other fossil forms already described it is obvious that our specimen has not enough well preserved details to identify it with a fossil form, or to describe a new species, even if it is well resembled with the extant *Trachycarpus* (see discussion above) so, we attribute it to *Palmoxylon* sp. cf. *Trachycarpus* H.Wendl.

Palmoxylon sp. cf. *Borassus* L.
Fig. 7, photos a-i.

Material: ERI01.
Locality: Edirne-Erikli.
Formation: volcano-sedimentary.
Age: Middle-Late Miocene.
Origin on the stem remains: Unknown part of the trunk.

Microscopical description: The studied specimen keeps only the central zone of the central cylinder which is also of *Corypha* type (von Mohl, in Thomas & De Franceschi, 2013), with the fibro-vascular bundles sometimes variably oriented, having very developed reniform sclerenchyma caps, badly preserved vascular part with a single one large metaxylem vessel and compact parenchymal ground tissue. The fibrous bundles are usually missing.
The fibrovascular bundles (fvb) have are very typical with sclerenchyma cap of Reniforma type, well developed, with a small median sinus, with rounded auricular lobes, but without auricular sinuses. The sclerenchyma cap is constituted from vertically elongated fibrous cells with polygonal cross-section, thick-walled and with small rounded or point-like lumina. The size of the fibrovascular bundles is variable, the mean diameters have 1075/877.7 µm, the phloematic (=anterior) sclerenchyma cap has the r/tg mean diameters of 836.1/238.9 µm, f/v ratio is 1.43/1 and the fvb density is of 168.85 bundles/cm2. There are no signs of a centrifugal differentiation of the fibrous part, which is typical for *Corypha*-type structures.
The phloem, usually protected under the median sinus, rarely can be seen as a single island (as undivided sieve plate) but usually compressed or destroyed by lysis.
The metaxylem appears in cross-section usually as a single one round vessel (only sometimes 2-3), often very badly preserved or not visible. Otherwise all the vascular part is very badly preserved or is even disappeared. That round metaxylem vessel seems to be a large one, of about 60-80 µm the diameter in cross section, and is not too thick-walled. Vertically the walls of metaxylem vessels have scalariform pitting and annular thickenings slightly thicker, also difficult to see due to the bad preservation. Their terminal wall is very inclined and bears a scalariform perforation with 7-12 or more thick bars, also only partially preserved.
The protoxylem, difficult to observe in cross section, is represented by 3-6 small round to oval vessels. Vertically the protoxylem vessels present annular thickenings, and scalariform perforations, details also difficult to observe due to the bad preservation of the vascular part.
The intrafascicular or paravascular parenchyma cannot be observed in detail, but seems to be constituted of rounded, small uniform, thin-walled cells, rounding and protecting the xylem vessels.
The ground tissue (the interfascicular parenchyma) appear in cross section compact as large polygonal rounded big turgid cells often slightly elongated of 30/50 - 40/70 µm, which are usually thin walled and represents the ground parenchyma with sustained growing of *Corypha* type. Around the fibrous part of the fibrovascular bundles tabular parenchyma appears, in 1-3 compact rows arranged, but around the vascular part radiant parenchyma appears.
Fibrous bundles are usually absent, or very rare.
Phytoliths (as stegmata) on the fibers of the sclerenchyma caps of the fibrovascular bundles are not obvious, maybe due to the bad preservation, or simply are missing.

Affinities and discussions: The general aspect of the structure of the studied sample which is obviously fascicular of palm stem type sustains its attribution to *Palmoxylon* genus.
The essential xylotomical features of our specimen preserving the central zone of the central cylinder which is of *Corypha* type, and has the fibrovascular bundles with very developed sclerenchyma caps of Reniforma type, with a small median sinus, with rounded auricular lobes, but without auricular sinuses, and no signs of a centrifugal differentiation of the fibrous part, which is typical for *Corypha*-type structures. Due to the badly preserved vascular part where few details on the phloem - usually compressed or destroyed by lysis, on the large metaxylem vessels - one or 2(3?) - which display in longitudinal view annular thickenings, scalariform pitting, and scalariform perforations can be seen, but details of the protoxylem vessels and of the paravascular parenchyma cannot be observed. The ground tissue appears in cross section as compact interfascicular parenchyma with sustained growing of *Corypha* type. Also, round the fibrous part of the fibrovascular bundles tabular parenchyma appears, in 1-3 compact rows arranged, and around the vascular part a radiant parenchyma appears. The fibrous bundles are usually missing, and phytoliths (as stegmata) on the fibers of the sclerenchyma caps of the fibrovascular bundles were not observed or are missing.
Evaluating all these xylotomical details it seems that our specimen mostly resembles *Borassus* L., an arboreal palm of Subfamily Coryphoideae Burnett - Tribe Borasseae Mart. in Endl. - Subtribe Lataniinae Meisner, as it appears described and figured by Tomlinson (1961, 1990), Dransfield *et al*. (2008) and Thomas & De Franceschi (2013). This kind of fan-palm also known as Palmyra pam, is native to tropical regions of Africa, Asia a New

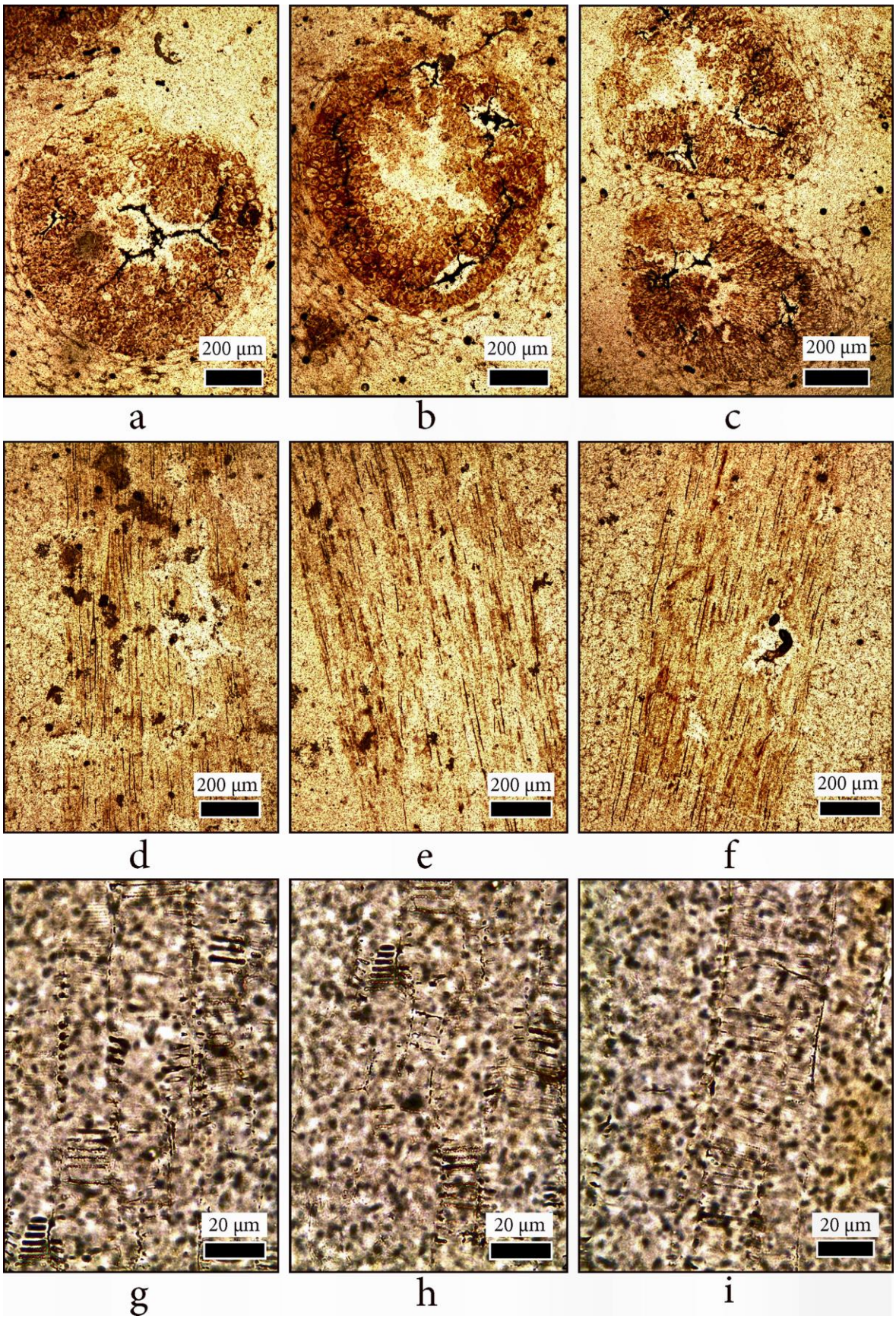

Fig. 7 *Palmoxylon* sp. cf. *Borassus* L. (ERI01). **a-c** Cross-section. Central zone with fvb with sclerenchyma cap of Reniforma type; compact parenchymal ground tissue; tabular parenchyma around the sclenchyma cap, and radiant parenchyma around the vascular part of the fvb. **d-f** Longitudinal section. Fibrous sheaths of fvb and compact ground parenchyma. **g-i** Metaxylem and protoxylem vessels with annular thickenings, and with scalariform perforations (g).

Guinea.

For a specific attribution of the studied material we have taken into account the studies on some published identifications of fossil forms, considering especially the palms of Reniforma type. Many forms affiliated to this group substantially differ of our specimen, sometimes having affinities with different other extant forms.

Taking into account the similarities with an extant form of Boraseae, we have chosen a comparison with the few fossil forms already considered of *Borassus* type.

So, comparing the structure of our specimen with the fossil species described by Schenk (in Zittel, 1883), *Palmoxylon zittelii* and *P. ascheronii* we observed a resemblance especially with the last one, regarding the shape of sclerenchyma cap of fvb, and of the parenchymal ground-tissue aspect. Otherwise, later, *Palmoxylon aschersonii* Schenck was described again from Paleogene and Neogene deposits of Algeria and also from the Lower Miocene of Libya, and was compared with the extant species *Borassus aethiopum* Mart. (see Louvet & Magnier, 1971; Boureau, 1947; Boureau et al., 1983)

Petrified Miocene palm stems described from India by Mahabalé (1959), Sahni (1964), Roy & Ghosh (1980) as *Palmoxylon coronatum* have also affinities with the extant *Borassus* L. and resembles with our specimen also.

However, since the material don't offer enough xylotomical details for a specific identification with an already described form or to describe a new species, we consider enough to attribute to our here studied specimen the name *Palmoxylon* sp. cf. *Borassus* L.

CONCLUSIONS

Three types of *Palmoxylon* were identified in this study: *Palmoxylon coryphoides* Ambwani et Mehrotra, *Palmoxylon* sp. cf. *Trachycarpus* H. Wendl., and *Palmoxylon* sp. cf. *Borassus* L. This is the first attempt for description of fossil palms in Turkey, and it is likely to find new remains of fossil palms especially in the western Anatolia with further studies.

These three types identified here by xylotomical studies send to some extant correspondent types. All the localities of origin of the fossils are situated in a region of Turkey where no palm species naturally grows at present (Fig. 1). The modern representatives of these three types of palms grow mainly in tropical regions of Africa, eastern Asia (including India, China, Malaysia, Indonesia, New Guinea, the Philippines) and northeastern Australia.

A similar rich palm flora was identified in the Aegean Greek region (Velitzelos *et al*. 2017, paper in progress).

The presence of these palm species in the Aegean and Anatolian regions indicates that the palaeoclimate in the early Miocene was warmer and wet to subtropical, allowing of the growth of these types of palm trees on the southern flank of Paratethys Sea. This conclusion regarding the palaeoclimate, at least of the early Miocene, in the western Turkey also agrees it those given by Akkemik *et al*. (2016), Denk *et al*. (2017 a,b,c) and Güner *et al*. (2017).

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