# Early Miocene Woods of Egypt

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# EARLY MIOCENE WOODS OF EGYPT

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## ABSTRACT

Thirty-eight silicified eudicot wood samples were collected from a single locality in the early Miocene Gebel El-Khashab Formation exposed along the Cairo-Bahariya Oasis Desert Road of Egypt. This locality is remarkable because it is dominated by trunks of *Bombacoxylon*, family Malvaceae (32 samples). Whether this reflects the composition of the original regional vegetation or is a result of sorting during transport prior to fossilization is not known. These woods are characterized by having few, wide vessels, functional traits consistent with the tropical, warm humid climate suggested for the early Miocene of North Africa. Additionally, there is one sample each of wood resembling *Terminalioxylon* (Combretaceae) and *Cynometroxylon* (Leguminosae/Caesalpinioideae). Affinities of four other samples could not be determined. A list of all Miocene wood species of Egypt known to date is given along with general interpretations of the paleoclimate in the region and suggestions for future work.

***Keywords:*** *Bombacoxylon,* Malvaceae, Combretaceae, Leguminosae, Paleobotany, Cairo-Bahariya Desert Road, Gebel El-Khashab Formation.

## INTRODUCTION

The Miocene of Egypt is rich in petrified wood providing opportunities for reconstructing environments of that time and for investigating changes in vegetation and climate during the Neogene. To date, 33 species of angiosperm woods (about 47% of the total fossil wood flora of Egypt) have been described from 17 Miocene sites (Fig. 1). All these sites warrant additional investigation, *e.g.*, fossil palms have recently been described from site 15, but the 'dicots' from there have not been described (Kamal-El-Din *et al.* 2013). Lyons (1894) first published on the occurrence of fossil trees in the area between Cairo and Bahariya, but more than a century elapsed before they were first investigated paleobotanically by Mostafa (2009), who reported six species of eudicots: *Bombacoxylon langstoni* and *B. owenii* (Malvaceae), *Afzelioxylon welkitti, Cynometroxylon tunesense, Tetrapleuroxylon acaciae,* and *T. ingaeforme* (Leguminosae). Mostafa (2009) noted that *B. langstoni* and *T. ingaeforme* were new records for Egypt. A year later, El-Saadawi *et al.* (2010) reported two *Palmoxylon* species, *P. aschersoni* and *P. wadiai,* from the area.


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The objectives of this paper are: 1) provide additional data on woods of the early Miocene of Egypt by documenting the types of wood recovered from one site along the Cairo-Bahariya Oasis Desert Road, 2) compare this wood assemblage to other Egyptian Miocene wood floras, 3) make some general paleoclimatic inferences, and 4) suggest future work.

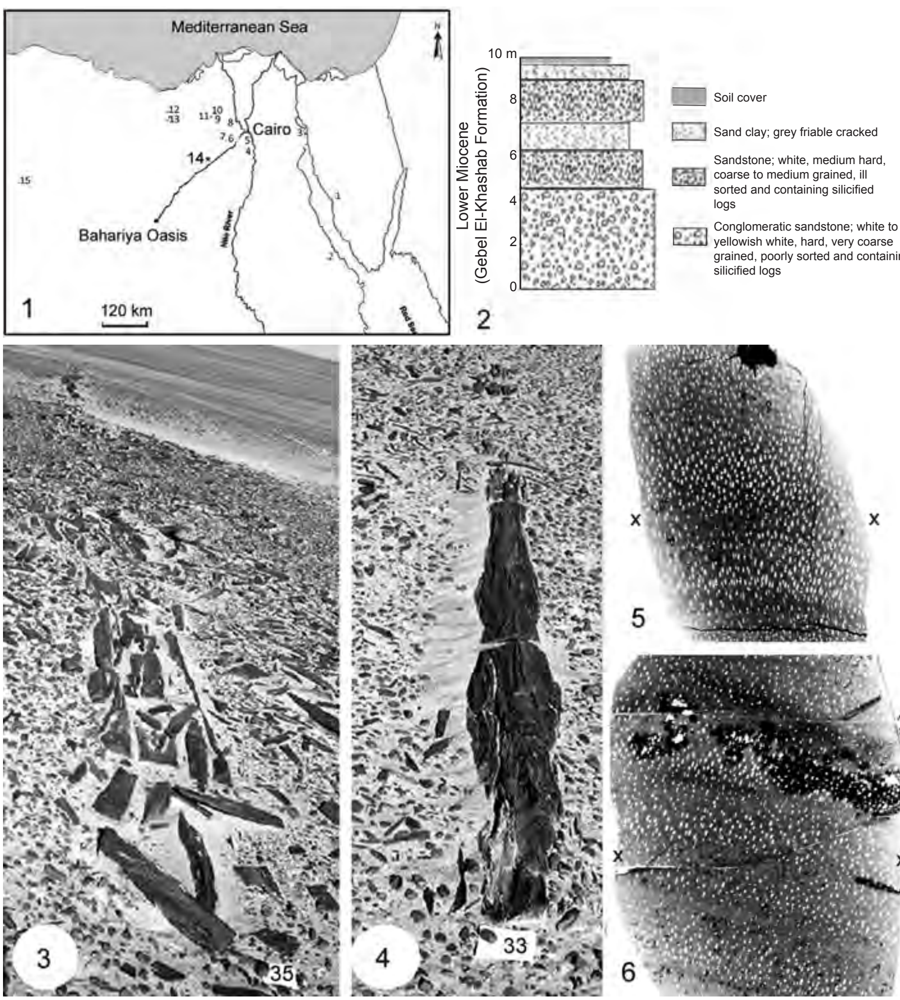


Figure 1. Map showing Miocene localities for Egyptian fossil wood. Numbers 4 & 9 represent two sites each. 1. Gebel Hadahid, 2. Gebel Dara in Suez, 3. Gebel Geneffa, 4. West of Giza Pyramids and Abu Roasch, 5. Gebel El-Khashab "Southern Petrified Forest" (SPF), 6. Qaret El-Raml, 7. Gebel Ruzza, 8. Dêr Abu Makâr, 9. Wadi Faregh and Garet Aujân, 10. Wadi Natrun, 11. Dêr Baramûs, 12. Bir Lebuk, 13. Moghra, 14. Study area. 15. Siwa Oasis. — Figure 2–6: 2: Lithostratigraphic section of Cairo-Bahariya Oasis Desert Road at the study area. – 3 & 4: Silicified trunks, numbers 35 and 33, at the locality. – 5 & 6: Macroscopic views of thin sections of *Bombacoxylon owenii* showing radial variation in vessel diameter and frequency. – 5: Sample 12ZN, width from ×–× = 1.9 cm; 6: Sample 24ZN, width from ×–× = 2.4 cm.

## MATERIALS AND METHODS

The locality lies along the Cairo-Bahariya Oasis Desert Road, at lat. 29° 41' 17–41" N and long. 30° 19' 23–54" E (Fig. 1, site No. 14). It is in the early Miocene Gebel El-Khashab Formation (Said 1962; Geological Survey of Egypt 1981); it is not established whether the formation is Aquitanian or the overlying Burdigalian. Figure 2 shows the lithostratigraphic section of the study area. The fossil woods occur as intact, segmented or fragmented tree trunks of different sizes and lengths that are found mingled or scattered on the sand surface or half buried in different orientations (Fig. 3, 4). The distance between any two neighboring trees varies and can be as little as five meters. No other plant remains were found. The study area represents only a small part of the region with silicified trunks, which extends for scores of kilometers on the right-hand side of and parallel to the Cairo to Bahariya Desert Road.

Forty silicified wood specimens (1ZN–40ZN), ranging between 5–10 cm in width and 10–20 cm in length, were collected during a one-day field trip in 2009. Two (27ZN and 38ZN) were palms and have been described (El-Saadawi *et al.* 2010). The majority (36) of the specimens were taken from large silicified trunks, ranging in length from 0.5 to 30 m, found lying on the sand surface. There were also two small specimens that were found loose at the locality. Preservation of the woods is fair to poor so that in some specimens it is not possible to see important diagnostic features such as vessel-ray parenchyma pit type or determine whether fibers are septate.

Ground thin sections of transverse, radial, and tangential sections were prepared according to the method described by Andrews (1961). Specimens and thin sections are deposited in the paleobotanical collections of the Department of Botany, Ain Shams University, Cairo. Thin sections of five specimens (2ZN, 10ZN, 12ZN, 24ZN, 39ZN) are deposited in the collections of the North Carolina Museum of Natural Sciences, Raleigh, U.S.A. Descriptions generally follow the terminology of the IAWA Hardwood List (IAWA Committee 1989). Affinities of the woods were investigated using the InsideWood database (InsideWood 2004-onwards; Wheeler 2011), by reading the family descriptions in “Anatomy of the Dicotyledons” (Metcalfe & Chalk 1950), and consulting references found on Kew’s Plant Micromorphology Database (http://kbd.kew.org/kbd/searchpage.do).

## RESULTS

Thirty-two specimens have features of *Bombacoxylon* (Malvaceae / Bombacoideae), one resembles *Terminalioxylon* (Combretaceae), and one resembles *Cynometroxylon* (Leguminosae / Caesalpinioideae). These woods are described and discussed below. Relationships of four specimens (1ZN, 9ZN, 16ZN, 40ZN) could not be suggested.

## DESCRIPTIONS AND AFFINITIES

*Family:* **Malvaceae**.
*Subfamily:* **Bombacoideae**.
*Genus:* ***Bombacoxylon*** Gottwald 1969.

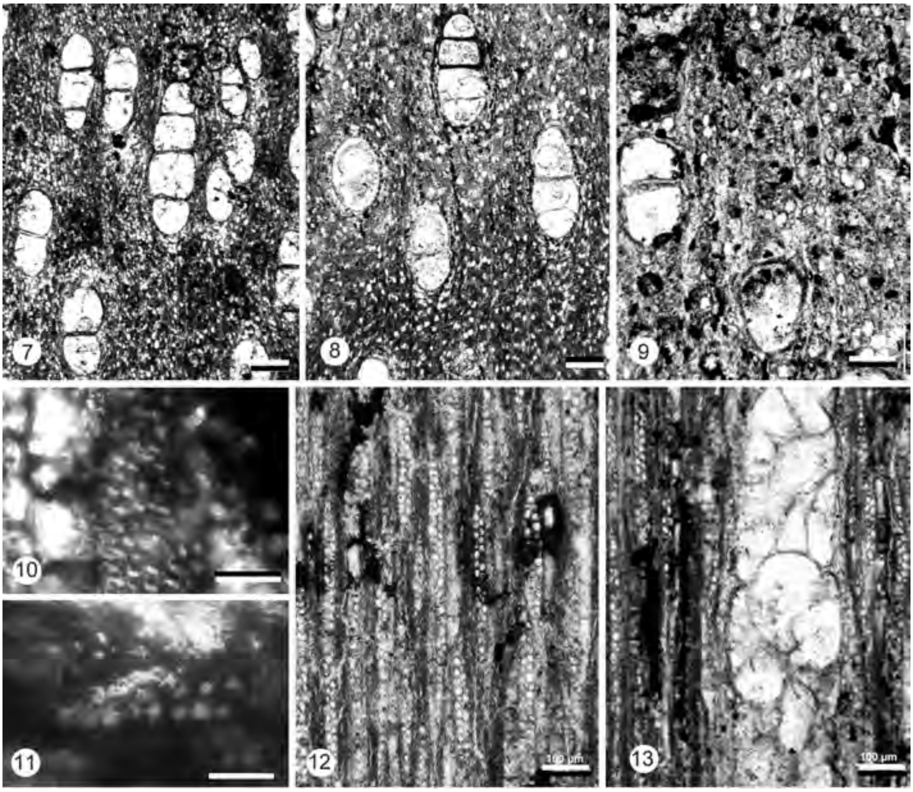

Fig. 7–13. *Bombacoxylon owenii*. – 7–9: Diffuse-porous wood, vessels solitary and in radial multiples (2–4), abundant diffuse-in-aggregates apotracheal parenchyma; 7: Sample 12ZN, TS; 8: Sample 10ZN; 9: Sample 24ZN. – 10: Crowded alternate intervessel pits, sample 10ZN, TLS. – 11: Vessel-ray parenchyma pits, sample 10ZN, RLS. – 12: Rays mostly 2-seriate, sample 10ZN, TLS. – 13. Tyloses, sample 10ZN, TLS. – TS = transverse section, TLS = tangential longitudinal section, RLS = radial longitudinal section. — Scale bar = 200 µm in 7, 8; 100 µm in 9, 12, 13; 20 µm in 10, 11.

*Species:* ***Bombacoxylon owenii*** (Carruthers) Gottwald 1969 (Fig. 5–13).

*Synonyms: Nicolia owenii* Carruthers 1870; *Caesalpinium owenii* (Carruthers) Schuster 1910; *Dombeyoxylon owenii* (Carruthers) Kräusel 1939.

*Description* based primarily on three of the better-preserved specimens: 12ZN, from a large 15 m long trunk, coordinates lat. 29° 41' 35" N, long. 30° 19' 43" E; 24ZN, from a fragmented 10 m long trunk, coordinates lat. 29° 41' 38" N, long. 30° 19' 37" E; and 10ZN, a small piece selected from scattered fragments, coordinates lat. 29° 41' 35" N, long. 30° 19' 45" E.

Additional specimens 3ZN–8ZN, 11ZN, 13ZN–15ZN, 17ZN–23ZN, 25ZN, 26ZN, 28ZN–37ZN.

Growth rings microscopically indistinct, but macroscopically samples tend to semi-ring porosity with radial variation in vessel diameter and density, suggesting seasonal variation in water availability (Fig. 5, 6). Vessels solitary (less than 50%) and in radial multiples of 2–4, solitary vessels oval in outline. Within the 27 samples of which it was possible to measure vessel diameter and density, the total range of randomly sampled tangential diameters was 165–250 µm, with mean tangential diameters ranging from 180 to 230 µm, and an overall average of 205 µm. Mean vessel frequency ranges from 3–13 vessels per sq. mm. Perforation plates exclusively simple with slightly oblique end walls. Intervessel pits crowded alternate, angular in outline, with oval apertures, 8–11 µm across. Vessel-ray parenchyma pits similar in size to intervessel pits. Abundant thin-walled tyloses obscure vessel element end walls, so the length of only a few elements could be measured with confidence, range 515–665 µm.

Axial parenchyma abundant apotracheal diffuse and diffuse-in-aggregates, not in regularly spaced uniseriate lines, parenchyma in contact with vessels by happenstance because of the abundance of diffuse-in-aggregates parenchyma; strands of up to 8 cells.

Rays 1–3-seriate, mostly 2-seriate (one region of 12ZN with anomalously wider rays that reach 5-seriate, possible reaction to wounding). Uniseriate ray heights of 4–17 cells, 67–340 µm; multiseriate ray heights 7–38 cells, and less than 500 µm high; rays usually 6–8/mm. Rays composed predominantly of procumbent cells with occasional square cells in the margins.

Fibers likely non-septate, thick-walled, pits not observed.

Storied structure absent. Crystals not observed.

***Affinities and comparisons***

Different combinations of features were used in searches of InsideWood. The combination of few wide vessels (40a, 41a, 48a, 49a, 50a) that are solitary and in radial multiples of 2–4 (9a, 10a, 11a), exclusively simple perforation plates (13p, 14a), alternate intervessel pitting (22p), vessel-ray parenchyma pitting similar in size to the intervessel pitting (32a), tyloses (56p), abundant diffuse and diffuse-in-aggregates axial parenchyma unaccompanied by continuous narrow bands of parenchyma (77p, 80a, 83a, 85a), axial parenchyma strands of more than 4 cells (90a, 91a), narrow 1–3-seriate rays that are less than 1 mm high and composed predominantly of procumbent cells (97p, 105a, 108a, 109a) and thick-walled fibers suggests these woods have features of the Malvaceae. A review of the family descriptions in Metcalfe and Chalk (1950) indicates that the combination of few wide vessels, simple perforation plates, alternate intervessel pits, abundant diffuse-in-aggregates axial parenchyma, narrow predominantly homocellular rays is one found in the Bombacaceae, now considered a subfamily of the Malvaceae, and Sterculiaceae, especially the genus *Dombeya*, also now in a subfamily of the Malvaceae, Dombeyoideae.

We also used Kräusel's (1939) key in his comprehensive publication "Fossilen Laubhölzer Ägyptens" to look for similarities between the woods from this locality and these previously described woods. The key steps followed were 4) rays small, not obvious to the naked eye, 15) rays multiseriate or uniseriate and multiseriate; 23) rays multiseriate and uniseriate, not exclusively multiseriate; 34) rays mostly 2-seriate; 34) axial parenchyma paratracheal or diffuse or in short bands, not in long clearly defined

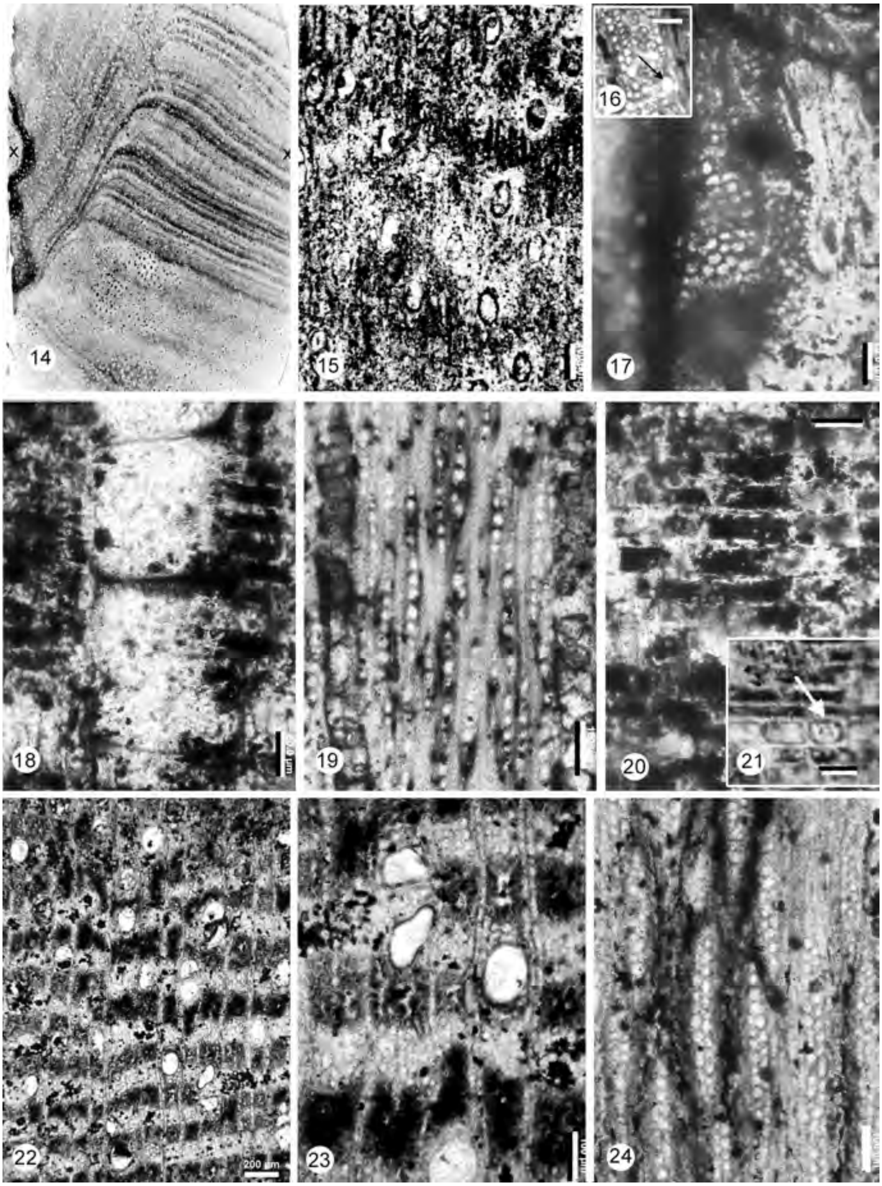


Fig. 14–21. cf. *Terminalioxylon edwardsii*, sample 2ZN. – 14: Macroscopic view of the thin section, distance from x - x = 2.3 cm. – 15: Diffuse-porous wood, vessels mostly solitary, some short radial multiples, vasicentric-confluent parenchyma, TS. – 16: Diffuse axial parenchyma, arrow, TS. – 17. Crowded alternate intervessel pits, TLS. – 18: Vessel element end walls near horizontal, simple perforation plates. – 19: Uniseriate rays, TLS. – 20: Procumbent ray parenchyma cells, TLS. – 21: Square ray cells, arrow, likely crystalliferous. – Fig. 22–24. *Cynometroxylon* sp., sample 39ZN. – 22, 23: Diffuse-porous, vessels solitary and in short radial multiples, banded parenchyma, thick-walled fibers, TS. – 24: Rays mostly 2-seriate, non-storied, TLS. — Scale bar = 200 µm in 15, 22; 100 µm in 18, 19, 23, 24; 50 µm in 16, 20, 21; 20 µm in 17.

bands; 35) axial parenchyma common, paratracheal or diffuse or both; 36) parenchyma diffuse, 38) diffuse parenchyma abundant, vessels 4–6 per $mm^2$. These steps lead to *Dombeyoxylon owenii,* now treated as a synonym of *Bombacoxylon owenii*. Because Kräusel's description and subsequent descriptions of woods assigned to the species (*e.g.*, Gottwald 1969, Oligocene of Tunisia) agree with the features observed in the Cairo-Bahariya woods, we are assigning these samples to *Bombacoxylon owenii*. This wood type occurs in North Africa, Tropical Africa and Europe and there are some differences in quantitative features (Beauchamp & Lemoigne 1973; Koeniguer 1976; Privé-Gill & Pelletier 1981; Selmeier 1985; Youssef 1993; Kamal-El-Din 1996, 2002; Mostafa 2009), with the narrowest mean tangential diameter (165 µm) reported for samples from the early Miocene of Bavaria (Selmeier 1985) and the widest (260 µm) reported for Egypt (Youssef 1993).

As Figures 14–24 show, the preservation of the next two wood types is not good and so the identification of these two types is tentative.

*Family:* **Combretaceae**.
*Genus:* ***Terminalioxylon*** Schönfeld 1947 emend. Mädel-Angeliewa & Müller-Stoll 1973.
*Species:* cf. ***Terminalioxylon edwardsii*** (Kräusel) Mädel-Angeliewa & Müller-Stoll.
*Material:* Specimen no. 2ZN (Fig. 14–21).
*Locality:* Cairo-Bahariya Oasis Desert Road, lat. 29º 41' 30" N, long. 30º 19' 52" E.
*Stratigraphic horizon:* Lower Miocene.

Growth rings present. Wood diffuse-porous. Vessels mostly solitary (70 %) and in radial multiples of 2–4 (30 %), solitary vessels oval to rounded in outline, mean tangential diameter 104 (70–158) µm, mean radial diameter of solitary vessels 167 (120–193) µm, 11 (7–23) per sq. mm. Perforation plates simple with horizontal end walls. Intervessel pits crowded alternate, polygonal in outline, 6–8 µm across. Vessel-ray pits similar to intervessel pits in size and shape throughout the ray cells. Mean vessel element length 358 (159–688) µm. Tyloses not observed.

Axial parenchyma vasicentric in 2–4 layers, tending to aliform, sometimes obliquely confluent between two vessels; rare diffuse apotracheal parenchyma and possibly marginal bands although the presence of bands could not be confirmed in radial sections.

Rays predominantly uniseriate, rarely biseriate, 4–16 cells, 80–566 µm high; 12–17 per mm. Rays predominantly composed of procumbent cells, homocellular to weakly heterocellular, occasionally with some near square crystalliferous cells in the body of the ray, non-storied.

Fibers thin- to thick-walled, likely non-septate, pits not observed.

Storied structure absent, crystals not observed, no evidence of chambered crystalliferous strands of axial parenchyma.

***Affinities and comparisons***

The combination of features seen in this wood is accommodated by Mädel-Angeliewa and Müller-Stoll's (1973) emended diagnosis of *Terminalioxylon:* growth rings distinct or indistinct, sometimes marginal parenchyma, vessels solitary and in short to long radial multiples (up to 14 vessels), perforations simple, intervessel pits alternate, vessel-ray parenchyma pits similar to intervessel pits, fibers septate or non-septate, axial parenchyma paratracheal, vasicentric narrow to broad, often more or less aliform, seldom also confluent, chambered crystalliferous strands present or absent, rays 1(–2) cells wide, homocellular or weakly heterocellular, solitary crystals frequently present, most in enlarged square to upright cells in rows in between procumbent ray cells. *Terminalioxylon* is a form genus for woods with features seen in *Terminalia, Anogeissus,* and *Combretum*. Mädel-Angeliewa and Müller-Stoll's 1973 study is the most comprehensive survey of *Terminalia* like fossil woods. In addition to emending the diagnosis of the genus and describing three new species, they reviewed all pre-1973 reports of *Terminalioxylon*.

Nearly 50 species of *Terminalioxylon* have been reported worldwide, from Africa, Central South Asia (especially India), South America, and Southeast Asia (Gregory *et al*. 2009). Comparison of *Terminalioxylon* species is difficult because some descriptions only report the total range for vessel diameter, not the mean, and it is not clear whether they might have counted vessels per sq. mm or vessel groups per sq. mm. Many species are based on poorly preserved or briefly described samples, with figures that do not clearly show all the features, *e.g*., septate vs. non-septate fibers, type of vessel-ray parenchyma pits, presence or absence of diffuse axial parenchyma, or clearly indicate whether crystals are present or absent. There is considerable overlap between the *Terminalioxylon* species.

Using Kräusel's (1939) key the following key steps apply: 4) rays small, 5) rays mostly uniseriate, rarely biseriate, 9) metatracheal parenchyma absent, 10) rays heterogeneous, and at this step in his key the only choices left are three species of *Evodioxylon*. Mädel-Angeliewa and Müller-Stoll (1973) subsequently determined these three species have affinities with the Combretaceae and transferred them to *Terminalioxylon*.

Previously described North African species of *Terminalioxylon* include *T. edengense* Boureau (1955), *T. edwardsii* (Kräusel) Mädel-Angeliewa and Müller-Stoll (1973), *T. fezzanense* Boureau (1958), *T. geinitzii* (Schenk) Mädel-Angeliewa and Müller-Stoll (1973), *T. intermedium* (Kräusel) Mädel-Angeliewa and Müller-Stoll (1973), *T. primigenium* (Schenk) Mädel-Angeliewa and Müller-Stoll (1973), and *T. tunesense* Fessler-Vrolant and Dupéron-Laudoueneix (1986). Of these, only *T. edwardsii* is described as having some diffuse parenchyma. It is possible that this Cairo-Bahariya wood is similar to this species, which was described as having septate fibers. We did not observe septate fibers in Specimen 2ZN, but its poor preservation makes it difficult to say with certainty whether or not the fibers are septate. The maximum diameter, presumably tangential diameter, of *T. edwardsii* vessels (220 μm) is greater than this wood, but the minimum is nearly the same (70 μm), so it seems probable that average diameters might be similar.

Of the *Terminalioxylon* from other continents as reviewed and described by Mädel-Angeliewa and Müller-Stoll (1973), the following species are most similar to this Egyptian wood as they have mostly vasicentric parenchyma, occasional diffuse parenchyma, marginal parenchyma bands absent, exclusively uniseriate rays composed mostly of procumbent cells: *T. matrohense* (Boureau) Mädel-Angeliewa and Müller-Stoll from the Neogene of Vietnam, and *T. mortandrense* Navale and *T. traumaticum* Ramanujam, both from the Tertiary of India and both with septate fibers. *Terminalioxylon* species from South America have more abundant paratracheal parenchyma, mostly aliform to confluent.

None of the species described post-1973 are similar to this Miocene Egyptian wood. *Terminalioxylon pachitanensis* (Miocene of Java, Sukiman 1977), whose description lacked details on intervessel and vessel-ray parenchyma pits, tended towards banded parenchyma and has more biseriate rays. The well-preserved *T. sulaimanense* (Oligocene of Pakistan, De Franceschi *et al*. 2008) differs in having well-defined marginal parenchyma and more abundant (16–20 rays per mm) and taller rays (12–20, up to 50 cells high). *Terminalioxylon palaeomannii* (middle Miocene of India, Prakash 1981) differs in having only scanty paratracheal parenchyma and predominantly heterocellular rays. *Terminalioxylon belericum* (Miocene of India, Prakash *et al*. 1992) has regular parenchyma bands. Harsh, Sharma, and Suthar (1992) described three species from the Tertiary of Bikaner, India: *T. bikanerense* with confluent bands of parenchyma, *T. eo-olivari* with narrower vessels (45–91.5 μm) that are commonly in radial multiples, *T. vasicentricum* with vessels commonly in radial multiples and mostly septate fibers. *Terminalioxylon concordiensis* (Pleistocene of Argentina, Brea & Zucol 2001) has diffuse-in-aggregates parenchyma, septate fibers, and only 4–8 rays per mm, which is exceptionally low for *Terminalia*.

Van Vliet (1979) prepared a synoptical key to the 43 species of extant *Terminalia* he studied and presented in tabular form data from the literature for an additional 30 species. The key included categories for six features we were able to observe in this fossil: vessels per $mm^2$ (0–10, 11–30), percentage of solitary vessels (50–95 %), intervessel pit size (6–8 μm), type of vessel-ray parenchyma pitting (similar to intervessel pitting), axial parenchyma distribution (vasicentric-aliform, aliform-confluent), ray width (predominantly uniseriate).

Only one, *Terminalia polyantha* (SE Asia), of the 43 extant species agreed in these six categories with this Egyptian specimen. Species sharing five of the six features are: *T. acuminata* (South America), *T. ivorensis* (Africa), *T. superba,* (Africa), differing in intervessel pit size; *T. catappa* (Asia), T. *foetida* (Malesia), *T. mollis* (Africa), *T. samoensis* (Malesia), rays not predominantly uniseriate; *T. chebula* (Asia), fewer than 50 % solitary vessels; and *T. lucida* (South America), confluent to banded parenchyma. It is not sensible to equate this Miocene wood with any one species as information is lacking for many *Terminalia* species.

*Family:* **LEGUMINOSAE**.
*Subfamily:* **Caesalpinioideae**.
*Genus:* ***Cynometroxylon*** Chowdhury & Ghosh 1946.
*Species:* ***Cynometroxylon*** sp. (Fig. 22–24).
*Material:* One specimen, no. 39ZN; a loose fragment of 0.7 m in length and 0.16 m in diameter.
*Coordinates:* lat. 29° 41' 17" N, long. 30° 19' 40" E.

Growth rings indistinct. Wood diffuse-porous. Vessels solitary (75 %) and in radial multiples of 2–4 (25 %), solitary vessels oval to rounded in outline, mean tangential diameter 100 (80–113) µm, mean radial diameter of solitary vessels 149 (129–177) µm, 7 (6–13) per sq. mm. Perforation plates simple with oblique end walls. Intervessel pits probably alternate. Mean vessel element length 200 (93–333) µm. Tyloses not observed.

Axial parenchyma abundant, in regularly spaced wavy bands 3–6 cells broad, alternating with fiber bands of almost the same width.

Rays 1–3-seriate (mostly 2). Uniseriate rays 4–15 cells in height, biseriate rays 9–24 cells in height, triseriate rays 16–28 cells in height. Some rays join end-to-end, reaching 47 cells in height. Ray height 273–1312 µm. Rays with procumbent body cells and usually with 1 row of marginal square cells. 6–7 / mm. Non-storied.

Fibers likely non-septate, thick- walled, pits not observed.

***Affinities and comparisons***

The features described above are accommodated by the diagnosis of *Cynometroxylon* Chowdhury and Ghosh as given by Müller-Stoll and Mädel (1967), *i.e.*, diffuse-porous wood with vessels solitary and in short radial multiples, simple perforations, small alternate intervessel pits, vessel-ray parenchyma pits similar, non-septate libriform fibers, axial parenchyma in bands that are narrower than the alternating fiber bands, rays 1–4 cells wide, homocellular or weakly heterocellular. The most commonly reported species is *Cynometroxylon holdenii* (Gupta) Prakash & Bande (Gregory *et al.* 2009), with multiple occurrences in the Neogene of India and Southeast Asia.

There are five other species reported for India. Species reported from North Africa are *Cynometroxylon schlagintweitii* Müller-Stoll and Mädel (Lemoigne 1978; Vozenin-Serra & Privé-Gill 1989; Kamal-El-Din & El-Saadawi 2004), a species which Awasthi (1992) suggested should be subsumed into *C. holdenii*, and the Oligocene *Cynometroxylon tunesense* Delteil-Desneux (Delteil-Desneux 1981; El-Saadawi *et al.* 2011). Additionally, there are *Cynometroxylon* sp. reports from North Africa and Tropical Africa (one each), and Plio-Pleistocene woods assigned to three different present-day species (Gregory *et al.* 2009). This early Miocene Egyptian wood described above has features that approximate the description of *Cynometroxylon tunesense* by Delteil-Desneux (1981): vessel tangential diameter 120 µm, approximately 5 vessels / sq. mm, banded axial parenchyma mostly 4–5 cells broad, rays mostly 2–3-seriate and homocellular to heterocellular. Unfortunately, in their description of *Cynometroxylon holdenii,* Bande and Prakash (1980) only provided the range of vessel tangential diameters, 75–350 µm, this maximum exceeds that of this Egyptian sample or any other sample subsequently assigned to *C. holdenii*. Bera and Banerjee (2001) provided data on the mean (105 µm) and range (9–152 µm) for the sample that they assigned to *C. holdenii*. Other features of *Cynometroxylon holdenii* include 4–6 vessels / sq. mm, banded axial parenchyma 3–8 cells broad, ray features are similar to those given for *C. tunesense*. Neogene woods from Thailand that were assigned to *C. holdenii* have vessels that range from 70–148 µm in tangential diameter, 11–22 vessels / sq. mm, rays 1–4(–5)-seriate, and axial parenchyma bands 5–12 cells broad (Vozenin-Serra *et al.*

1989). Given that it is difficult to compare quantitative features of the different species because some descriptions are missing information, we prefer to assign this Egyptian wood to the genus and note that it shares some features with both *C. holdenii* and *C. tunesense* as they were originally described.

## DISCUSSION

*Bombacoxylon owenii* (Malvaceae) is the dominant species at this locality with 63 of the 78 specimens that Mostafa (2009) and we collected being *Bombacoxylon owenii*. This species also is dominant in the early Miocene Gebel El-Khashab site (SPF, see Fig. 1 site no. 5), accounting for 26 of 39 specimens (Kamal- El-Din 1996). It is the most widespread species in the Miocene of Egypt, occurring at 12 of 17 sites shown in Figure 1. Not only is it widespread in Egypt (from Oligocene to Quaternary), but it is reported from six other African countries, as well as Asia and Europe (Gregory *et al.* 2009). Kräusel (1939) considered *B. owenii* from Wadi Schait (Shait) in southern Egypt to be Miocene, but subsequently the age of this Wadi was proposed to be Cretaceous (Lejal-Nicol 1990). If this age is correct, this extends considerably the range of *B. owenii* in Egypt. *Bombacoxylon* species have been reported from the Cretaceous of North America (Wheeler & Lehman 2000) and Ethiopia (Dupéron-Laudoueneix & Dupéron 1995).

*Bombacoxylon* dominates many wood assemblages, but, as Table 1 shows and as was noted earlier, the Leguminosae is the most diverse eudicot family in the Miocene wood floras of Egypt (Kamal-El-Din & El-Saadawi 2004). Only members of the subfamilies Caesalpinioideae and Mimosoideae occur in the Miocene of Egypt. This contrasts with present-day Egypt where the Papilionoideae is the dominant subfamily (Kamal-El-Din & El-Saadawi 2004). Arecaceae is represented in the Miocene wood flora by fourteen species.

Of the 16 Egyptian Miocene sites described previously, the most diverse are Gebel Ruzza (early Miocene) and Wadi Faregh (late Miocene) with 10 species each, followed by Gebel El-Khashab (early Miocene) with eight species, and Siwa Oasis (middle Miocene) with seven species. The remaining 12 sites have between one and five species. None of these sites have been collected extensively. Thus, further collections are important so that a better understanding of the characteristics and composition of early to late Miocene woody vegetation can be obtained and the variability within wood types better defined. Given that Morley and Richards (1993) and Salard-Cheboaldaeff (1979) suggested that North Africa had tropical and predominantly everwet climatic conditions in the early Miocene followed by drier more seasonal climates in the middle Miocene, there is an opportunity to see if this change in climate is reflected in changes in wood functional traits, *e.g.*, a decrease in vessel diameters and increase in vessel frequency.

The mode of occurrence of the fossil trunks (*i.e.*, fragmented trunks and logs) and the absence of other plant remains such as twigs, roots, branches, barks and soft parts indicates that the woods were not preserved *in situ* but transported from where they grew before silicification. Consequently, the anatomical features of the fossil woods

Table 1. Miocene fossil wood floras of Egypt.

Based on references: 1) Schuster 1910; 2) Kräusel & Stromer 1924; 3) Kräusel 1939; 4) Boureau *et al*. 1983; 5) Youssef 1993; 6) Dupéron-Laudoueneix & Dupéron, 1995; 7) Kamal-El-Din 1996; 8) Kamal-El-Din & Rifaat 2001; 9) El-Saadawi *et al*. 2002; 10) El-Saadawi *et al*. 2004; 11) Kamal-El-Din & El-Saadawi 2004; 12) Mostafa 2009; 13) El-Saadawi *et al*. 2010; 14) Kamal-El-Din *et al*. 2013; 15) The present work. Locality numbers as given in Fig. 1. Locality ages: e = early Miocene, m = middle Miocene, l = late Miocene, M = Miocene, subdivision not known, P = present.

| Taxon \ Locality, age | 1<br>e | 2<br>M | 3<br>M | 4a<br>e | 4b<br>e | 5<br>e | 6<br>e | 7<br>e | 8<br>l | 9a<br>l | 9b<br>l | 10<br>l | 11<br>l | 12<br>l | 13<br>l | 14<br>e | 15<br>m | Unk | Ref | No. Sites |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **EUDICOTS** | | | | | | | | | | | | | | | | | | | | |
| ANACARDIACEAE | | | | | | | | | | | | | | | | | | | | |
| *Glutoxylon symphonioides* | | | | | | | | | | P | | | | | | | | | 3, 6 | 1 |
| CLUSIACEAE (GUTTIFERAE) | | | | | | | | | | | | | | | | | | | | |
| *Guttiferoxylon fareghense* | | | | | | | | | | P | | | | | | | | | 3 | 1 |
| COMBRETACEAE | | | | | | | | | | | | | | | | | | | | |
| *Combretoxylon* sp. | | | | | | | | | | | | | | | | | | P | 4, 6 | 1 |
| *Terminalioxylon geinitzii* | | | | P | | P | | P | P | P | | | | | | | | | 3, 5, 7, 11 | 5 |
| *T. intermedium* | | | | P | | | | | | | | | | | | | | P | 4, 5, 6 | 2 |
| *T. primigenium* | | | | | | P | | P | | P | | | P | P | | | | | 1, 3, 7, 11 | 5 |
| cf. *Terminalioxylon edwardsii* | | | | | | | | | | | | | | | | P | | | 15 | 1 |
| LEGUMINOSAE | | | | | | | | | | | | | | | | | | | | |
| *CAESALPINIOIDEAE* | | | | | | | | | | | | | | | | | | | | |
| *Afzelioxylon welkitii* | | | | | | | | P | | | | | | | | P | | | 11, 12 | 2 |
| *Cynometroxylon schlagintweitii* | | | | | | | | P | | | | | | | | | | | 11 | 1 |
| *C. tunesense* | | | | | | | | | | | | | | | | P | | | 12 | 1 |
| *C.* sp. | | | | | | | | | | | | | | | | P | | | 15 | 1 |
| *Detarioxylon aegyptiacum* | P | | | | | P | | | | P | | | | | P | | | | 3, 7, 8 | 4 |
| *MIMOSOIDEAE* | | | | | | | | | | | | | | | | | | | | |
| *Leguminoxylon albizziae* | | | | | | | | | | P | | | | | | | | | 3 | 1 |
| *Mimosoxylon tenax* | | | | | | P | | | | | | | | | | | | | 7 | 1 |
| *Tetrapleuroxylon acaciae* | | | | | | | | | | | | | | | | P | | | 12 | 1 |
| *T. ingaeforme* | | | | | | | | | | | | | | | | P | | | 12 | 1 |
| MALVACEAE | | | | | | | | | | | | | | | | | | | | |
| *Bombacoxylon langstoni* | | | | | | | | | | | | | | | | P | | | 12 | 1 |
| *B. owenii* | | P | P | P | | P | | P | | P | P | P | P | P | P | P | | | 3, 5, 7, 11 12, 15 | 12 |
| *Sterculioxylon giarabubense* | | | | | | | | | | P | | | | | | | | | 3 | 1 |
| MORACEAE | | | | | | | | | | | | | | | | | | | | |
| *Ficoxylon blanckenhornii* | | | | | | | | | | | | | | | P | | | | 3 | 1 |
| *F. cretaceum* | | | | | P | | | | | P | | | | P | | | | | 3 | 3 |
| **MONOCOTS** | | | | | | | | | | | | | | | | | | | | |
| ARECACEAE | | | | | | | | | | | | | | | | | | | | |
| *Palmoxylon aschersoni* | | | | | P | | P | P | | P | P | P | | P | P | P | | | 2, 9, 13 | 9 |
| *P. compactum* | | | | | | | | P | | | | P | | | | | | | 10 | 2 |
| *P. deccanense* | | | | | | | | | | | | | | | | | P | | 14 | 1 |
| *P. edwardsi* | | | | | | | | | | | | | | | | | P | | 14 | 1 |
| *P. geometricum* | | | | | | P | P | P | | | | | | | | | P | | 10, 14 | 4 |
| *P. indicum* | | | | | | P | | | | | | | | | | | | | 10 | 1 |
| *P. lacunosum* | | | | | | | | | P | | | | | | | | | | 2 | 1 |
| *P. libycum* | | | | | | P | | | | | P | P | P | | | | | | 2, 9 | 4 |
| *P. pondicherriense* | | | | | | | | | | | | | | | | | P | | 14 | 1 |
| *P. prismaticum* | | | | | | | | | | | | | | | | | P | | 14 | 1 |
| *P. pyriforme* | | | | | | | P | P | | | | | | | | | P | | 10, 14 | 3 |
| *P. rewahense* | | | | | | | P | | | | | | | | | | | | 10 | 1 |
| *P. sagari* | | | | | | | | | | | | | | | | | P | | 14 | 1 |
| *P. wadiai* | | | | | | | P | P | | | | | | | | P | | | 10, 13 | 3 |
| Total number of species / site | 1 | 1 | 1 | 3 | 2 | 8 | 5 | 10 | 2 | 10 | 3 | 4 | 3 | 4 | 4 | 10 | 7 | 2 | | |

cannot be taken as an indication of the climate at the locality, but of the general region. The predominance of woods with few, wide vessels is consistent with the warm, humid climate suggested for the early Miocene of the region. In the future, we hope to do taphonomic studies and map the orientation and sizes of the trunks at the various Miocene localities in Egypt and also search for localities where the woods are *in situ*.

*Bombacoxylon owenii* is not only reported from Egypt, but also from India and Pakistan (Dupéron *et al*. 1996; Gregory *et al*. 2009). Other shared taxa are twelve *Palmoxylon* species (El-Saadawi *et al*. 2004) and *Cynometroxylon schlagintweitii* (Kamal-El-Din & El- Saadawi 2004; Müller-Stoll & Mädel 1967). The paleobiogeographic implications of these similar appearing taxa needs further investigation. They may be additional evidence of floristic exchange between India and Africa as recently discussed by Shukla *et al*. (2013).

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