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On the Cretaceous mangroves of Bahariya Oasis, Egypt.

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Abstract:

Petrified stems (rhizomes) of a fern are described from Late Cretaceous (Cenomanian) beds in Bahariya Oasis. The discovered stems are related to *Paradoxopteris stromeri* Hirmer (fern rachii) and to *Weichselia reticulata* Stokes & Webb. (fern pinnae); both already known from also Cenomanian beds of this Oasis. Haloed axes are described from Late Cretaceous (Campanian) beds, i.e. younger than the beds containing the petrified stems. Comments on the nature of these axes, the affinities of the stems and the palaeoenvironments of the area in the two mentioned geologic ages (Cenomanian & Campanian) are given.

Key words:

Bahariya Oasis, Campanian, Cenomanian, Cretaceous, Egypt, Fossil mangroves, Osmundaceae

Introduction

Bahariya Oasis lies in the Western Desert of Egypt, about 320Km southwest to Cairo (Fig.1). It represents a morphological depression in the Eocene Limestone Plateau, where Late Cretaceous (Cenomanian, Campanian & Maastrichtian) deposits are exposed at a number of places (Fig.2 & Table 1).

The exposed Late Cretaceous rock units belong to three formations, namely Bahariya, Hefhuf (or Hufhuf) and Khoman Formations (Table 1). The main concern here is with the first two formations. Bahariya Formation is subdivided into three Members (Dominik, 1985; Bkhat, 2012), Table (1). The Gebel Ghorabi Member at the base consists of fluviatile sandstones. The overlying Gebel Dist Member is an estuarine sequence strongly affected by tides with some intercalations of lagoonal origin. About 100 fossil plant taxa have been reported from these two Members particularly the latter. The reported Plants

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Fig.1. Map of Egypt showing location of Bahariya Oasis (After Darwish and Attia, 2007, with modification).

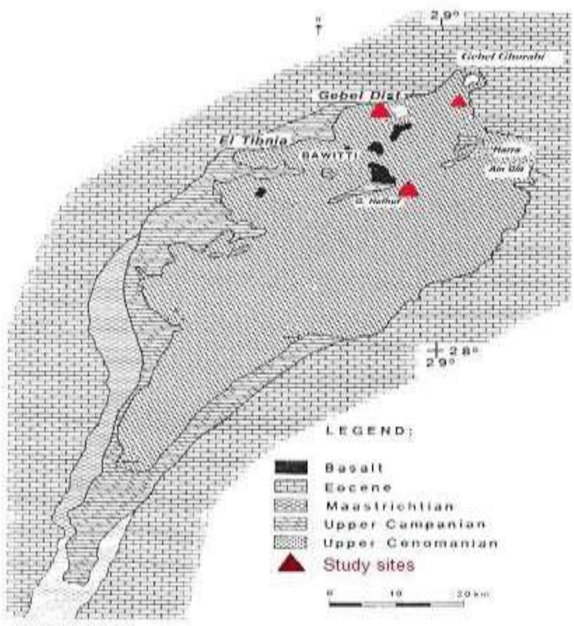

Fig. 2. Geological map of Bahariya Oasis showing study sites (G. Ghorabi, G. Dist, G. Hefhuf), capital town (Bawitti) and some other land marks (after Bkhat, 2012).

Table 1. Geologic Formations, Members, Ages and Periods mentioned in the text, G = Gebel (After Bkhat, 2012).

Formation	Member	Age	Period
		Oligocene Eocene Paleocene	Paleogene
Khoman	………………………………	middle Maastrichtian	Late Cretaceous
Hefhuf	………………………………	late Campanian	
Bahariya	El-Heiz G. Dist G.Ghorabi	late Cenomanian early late Cenomanian early late Cenomanian	

belong to the pteridophytes, gymnosperms and angiosperms (monocots and dicots) and include mangroves, hydrophytes, tree-ferns etc.
The preserved plant organs are mainly impressions, and petrifactions of leaves, stems, fruits and an inflorescence. For details regarding fossil plant names descriptions, illustrations and sites of their occurrence see: Schuster (1911), Lebling (1919), Kräusel & Stromer (1924), Hirmer (1925,1927), Edwards (1933), Stromer (1936), Kräusel (1939), Said (1962,1990), Dominik (1985), Lejal-Nicol & Dominik (1987,1990), Lejal-Nicol (1990), Werner (1990), Shrank (1999), Lyon *et al.* (2001), Smith *et al.* (2001) and Darwish & Attia (2007). The basal parts of Gebel Dist Member were formerly called dinosaur beds, *Ceratodus* (= lung-fish) beds or plant beds because of their high amount of identified fossils (Lebling, 1919). In the upper parts of this Member, marine faunal elements increase accompanied by gradual increase of glauconitic material indicating a rise of the ancient Neotethys Sea level. In the overlying top member of Bahariya Formation, i.e. El-Heiz Member (Table1) no fossil plants were reported. The age of Gebel Dist Member and the underlying Gebel Ghorabi Member together with the fossils therein contained is early late Cenomanian (Dominik, 1985; Luger & Gröscke, 1989; Werner, 1990), see Table (1).

The second Late Cretaceous formation we are concerned with here is Hefhuf Formation (Table 1). This term (see Lebling, 1919; Said 1962; Bkhat, 2012) describes the section exposed at Gebel Hefhuf in the Bahariya Oasis depression (Fig.2) and is of late Campanian age (Table 1). Hefhuf Formation is a succession of dolostone beds with sandstone and sandy-clay interbeds which, in places, unconformably overlies El-Heiz Member. Fossil plants reported from this formation are petrified woods of two gymnosperms, two dicots and one monocot leaf impression. For details concerning fossil plant names, descriptions, illustrations and sites of their occurrence, see: Stromer (1936), Kräusel (1939). It is worthy to mention that these late Campanian fossil plants belong to genera and species other than those which existed before in the early late Cenomanian age (see Darwish & Attia, 2007).

In addition to summing up scattered information about fossil plants of Bahariya Oasis in one place here, the present publication aims further to describe, illustrate and comment on fossil plants recently collected from three sites in this Oasis, namely: the early late Cenomanian Gebel Ghorabi and Gebel Dist and the late Campanian Gebel Hefhuf.

Material and methods

Numerous petrified woody fragments were collected from Gebel Ghorabi and Gebel Dist, but mainly from basal parts of the latter. They were collected during short excursions to Bahariya Oasis and were usually found scatted loose on rock surface. They are flattened, brittle, of light to dark brown colour almost looking like dry wood pieces of extant plants. They vary in size but are generally under 10cm in length and 5cm in thickness. They possess longitudinal ridges alternating with furrows (Pl. I, Fig.1). For locations and elevations see Table2.

The only fossils met with in Gebel Hefhuf were cylindrical, slender or sometimes stout axes with irregular wavy outline as seen in transversely broken axes exposed on rock surface (Pl. I, Fig.2). They occur in large numbers and extend parallel to one another embedded in the rock matrix of an extended bed or layer in the mountain. How far deep they extend in this layer requires digging and excavation which could not be achieved during the limited time of the excursions. Each axis has a dark reddish colour in the centre, about 5 to 20mm in diameter, surrounded by a circle or a halo of light colour. These haloed axes may, hence, be referred to as mottles (Pl. I, Fig.2). For location and elevation of the collection site see Table (2).

Table 2. Locations and elevations of the fossiliferous sites at G. Ghorabi, G. Dist and G. Hefhuf in Bahariya Oasis and type of fossils in each site (after Bkhat, 2012). m = meter, asl = above sea level, G = Gebel, N = North, E = East.

Site	Latitude N	Longitude E	Altitude m-asl	Fossils
G. Hefhuf	28° 19´ 31´´	28° 59´ 17´´	139	haloed axes
G.Dist	28° 25´ 47´´	28° 55´ 38´´	130	wood fragments
G.Ghorabi	28° 26´ 31´´	29° 02´ 05´´	149	wood fragments

Small pieces of the extended fossiliferous rock layer of Gebel Hefhuf were chopped off using a geological hammer. The obtained rock pieces (about 10cm long and containing numerous haloed axes (Pl. I, Fig.2) were thin-sectioned following the procedure described by Andrews (1961) and Kamal-El-Din (1996).

Thin-ground sections (transverse and longitudinal) were likewise prepared from the petrified woody fragments of Gebel Ghorabi and Gebel Dist using this same technique.

GPS was used for location purposes of the collected fossil specimens and suitable equipment for their photography in the field and laboratory.

Results and descriptions

Microscopic examination of thin sections of the fossils under study showed that the woody fragments of Gebel Ghorabi and Gebel Dist, though not well preserved, clearly belong to fern stems or, rhizomes and that no cellular structure whatsoever is preserved in case of the haloed axes or mottles but only mineral matter had replaced their tissues completely. The exact nature of these haloed axes, therefore, remains unknown, however, superficial comparisons with extant plant structures having similar appearance is always possible.

In transverse section of one of the better preserved rhizomes, the stem (though incomplete) possesses what appears to be a dissected polycyclic stelar structure, oval in shape (Pl. II, Fig.1) measuring about 15-20mm in diameter, consisting of an elliptic central vascular cylinder, measuring about 3-6mm in its short and long diameters and consisting of 10 vascular strands (Pl. II, Fig.1, 2). However, the exact nature of the stele (dictyostele, amphiphloic, ectophloic, perforated...etc) could not be figured out from the examined section so also the existence of what appears to be a leaf-trace-shaped vascular bundle in the centre of the stem (PI. II. Fig. 2). The central cylinder is surrounded by leaf traces that vary in shape (Kidney, horse-shoe, C or other related shapes, see; Pl. II, Fig.1; Pl.III, Fig.1,2; Pl. IV, Fig. 1,2) probably representing different stages of development. The leaf traces are arranged in concentric rings or in a close spiral with their concave side facing inside (Pl. II, Fig.1). Solid cylindrical cores encircled by a relatively narrow zone of outer light tissues are thought to represent root traces (Pl. III, Fig.1,2). Tissues particularly thin-walled, are replaced by mineral matter and preservation is generally very poor to allow for a more comprehensive description and no more information could be gained from the study of longitudinal sections (Pl. V, Fig. 1,2) which keeps the description of these fossil rhizomes restricted to their more general features.

Comparisons and discussion

The anatomy of the present fern rhizome shows general features of fossil and extant osmundaceous and marattiaceous rhizomes, including size of stem, size and shape of stele, shape and arrangement of leaf traces …etc. (e.g. Edwards, 1933; Eames, 1936; Miller, 1967; Matsumoto & Nishida, 2003; Taylor *et al.* 2009; Bomflerur *et al.*, 2014a,b). The shape of the present stele in cross section is, however, elliptic and not rounded, which may be due to compression during fossilization.

The literature shows that osmundaceous ferns, in contrast to their limited diversity today (only about 20 extant species in 14 genera (Kramer,1990)) have a rich and diverse (about 200 species) fossil record (e.g. Arnold, 1964; Miller, 1971; Tidwell & Ash, 1994; Tian *et al.*, 2008; Bomfleur *et al.*, 2014b; Wang *et al.*, 2014) ranging in age from Late Permian to the present (see Table 3) (e.g. Miller, 1967;Taylor *et al.*, 1990; Serbet & Rothwell,1999; Matsumoto & Nishida, 2003). Fossil Osmundaceae were of worldwide distribution being reported form Africa, America, Antarctica, Asia, Australia, and Europe (Kräusel, 1939; Miller, 1967; Phipps *et al.*, 1998; Bomfleur *et al.*, 2014b) comprising from 150-200 species (Matsumoto & Nishida, 2003; Stewart & Rothwell, 1993; Taylor & Taylor, 1993; Tidwell & Ash, 1994; Rothwell *et al.*, 2002; Bkhat, 2012). The literature shows also that 50 out of the reported fossil osmundaceous species are based on permineralized rhizomes (Matsumoto & Nishida, 2003) and that; the earliest unequivocal record of fossil *Osmunda* rhizomes (Bomfleur *et al.*, 2014b) is of Early Jurassic age (Table 3).

Table 3. Part of the Geologic Time Table showing ages referred to in the text (mainly after Bkhat, 2012). Ya = years ago, mya = million years ago.

Era	Period	Age	(years ago)
Cenozoic	Quaternary	Holocene Pleistocene	(11400 ya- To day) (2.5 mya-11400 ya)
	Neogene	Pliocene Miocene	(5.3- 2.5 mya)
	Paleogene	Oligocene Eocene Paleocene	 (55.8-33.9 mya)
Mesozoic	Late Cretaceous	Maastrichtian Campanian Santonian Coniacian Turonian Cenomanian	 (83.5-70.6 mya) (99.6-93.6 mya)
	Early Cretaceous		
	Jurassic Triassic		(199.6-145.5 mya) (251-199.6 mya)
Paleozoic	Permian Carboniferous		(280-251 mya)

It would naturally be of great interest to compare and find out the evolutionary relationship between the present, early late Cenomanian, rhizomes of Bahariya Oasis and such a large number of structurally preserved osmundaceous rhizomes reported from geologic ages earlier to, as well as, later than them. At this point, it must be mentioned that of no less interest is to find out also the relationship between the present fossil rhizomes and other related osmundaceous (marattiaceous, according to Edwards, 1933) remains reported previously from the Cenomanian of Bahariya Oasis particularly the impressions of fronds (pinnae and pinnules) assigned to the tree-fern *Weichselia reticulata* Stokes & Webb. by Hirmer (1925) and the petrifactions of specimens considered to be stems of an extinct osmundaceous fern, assigned to *Paradoxopteris stromeri* Hirmer (= *Osmundites* (?) *Stromeri* Hirmer) by Hirmer (1925, 1927) but later regarded by Edwards (1933) to be rachises probably of *Weichselia* fronds with a structure which has no exact parallel in any living or fossil fern but with marattiaceous rather than osmundaceous affinities. It is therefore probable that these organs (i.e the fronds *Weichselia reticulata*, the rachii *Paradoxopteris stromeri* which lack any sign of central stele and the present rhizomes with a cyclic central stele and leaf traces very similar to those of *Paradoxopteris stromeri* as illustrated by Hirmer (1925) and Edwards (1933) belong to one plant related to Marattiaceae (Particularly *Angiopteris* see Edwards, 1933) or Osmundaceae or representing an extinct allied group. It is worth mentioning that *Weichselia* was of worldwide distribution, being recoded in Africa, America (Northern and Southern), Asia and Europe (Edwards, 1933) and the fossil record of Marattiaceae extends back to the Carboniferous (Taylor *et al.* 2009), Table (3). Therefore careful search and intensive excavation at the fossil–rich early late Cenomanian sites (Gebel Dist, Gebel Ghorabi and mangrove-dinosaur unit) of Bahariya Oasis seem necessary before going into further theoretical speculations regarding relationships between all these fossils; discovery of better preserved and more informative specimens is quite probable. However, the existence of the studied fossil rhizomes in these early late Cenomanian sites indicates that their palaeo-environment must have been of swampy nature similar to that of the extant cosmopolitan representatives of Osmundaceae (Miller, 1967) and probably also Marattiaceae (see Taylor *et al.* 2009). This supports previous works of many authors who reported on numerous fresh-water and mangrove plants as *Avicennia*, *Equisetum, Nelumbites, Weichselia* ….etc (e.g. Hirmer, 1925; Stromer, 1936; Kräusel, 1939; Darwish & Attia, 2007), in addition to animal remains (bones, teeth….) of dinosaurs, crocodiles, fishes… etc. (e.g. Dominik, 1985; Smith *et al.*, 2001) from the early late Cenomanian age of Bahariya Oasis. This floral and faunal assemblage proves a significant continental influence on the marginal marine sedimentation showing that these fossiliferous sites were probably ecologically similar to modern mangrove habitats (see Smith *et al.*, 2001; Bkhat, 2012).

Regarding the geology of the late Campanian site of Gebel Hefhuf, where the haloed axes or mottles occur, it may be said in brief, that it represents an area of low tides, extensive exposures and sandy intertidal flats (Bkhat, 2012). The mottles themselves are important and of significance as they are indicators of ancient Neotethys sea-level and shoreline and most likely they represent organic matter buried in soil below or near the water table much as characterized nowadays by the pneumatophores (respiratory roots) of mangrove plants as *Avicennia marina* (Pl. VI, Fig. 1) or by stems and roots of mangrove-associates as the rushes (e.g. sea rush or *Juncus maritimus*) (Pl. VI, Fig. 2). The dense occurrence of the mottles in the rock matrix (Pl. I, Fig. 2) is quite comparable to the dense growth of the pneumatophores of *Avicennia* (Pl. VI, Fig. 1) or the axes (basal parts of stems and upper parts of roots) of *Juncus* plants which grow in dense swamps around the mangrove (Pl. VI, Fig. 2). The roots *of Juncus* plants commonly give a strong vertical structure that may extend to depths of >20cm in the soil in which they are rooted (Bkhat, 2012). Sand build-up is sometimes seen trapped around the roots and the bases of the stems of modern marsh plants (as *Juncus*) to heights of several centimeters which lead to limonitic hardpan development accompanied by precipitation of hematite and formation of sand haloes around buried plant axes (stems or roots) which can be compared with the haloed axes or mottles described in the present study (see Bkhat, 2012). Here again further excavation and collection of better preserved fossil specimens at Gebel Hefhuf would be rewarding as mentioned above with Gebel Ghorabi and Gebel Dist.

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Plate I

Fig. 1. A flattened petrified wood fragment collected from Gebel Dist. About natural size.

Fig. 2. Numerous haloed axes (mottles) embedded in rock matrix. Specimens collected from Gebel Hefhuf

Plate II

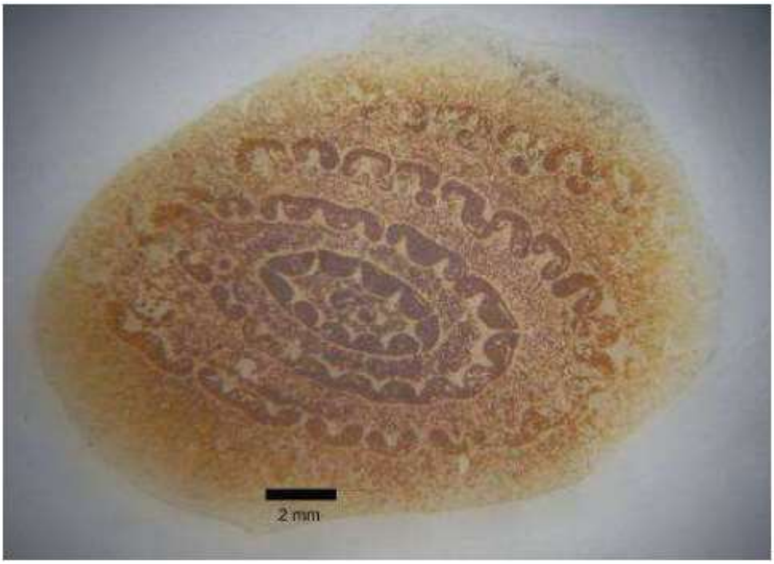

Fig. 1. A fern rhizome (from Gebel Ghorabi) in transverse section showing central vascular cylinder surrounded by whorls of c-shaped leaf traces.

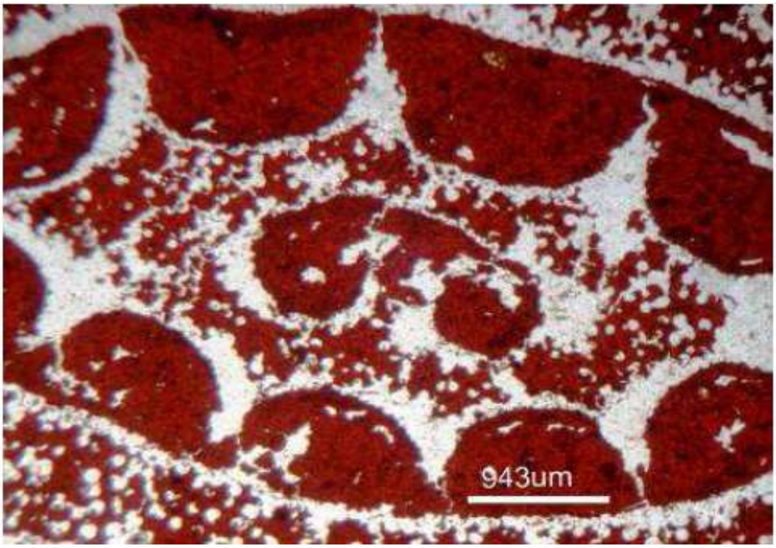

Fig. 2. Central vascular cylinder of a fern rhizome (from Gebel Ghorabi) in transverse section.

Plate III

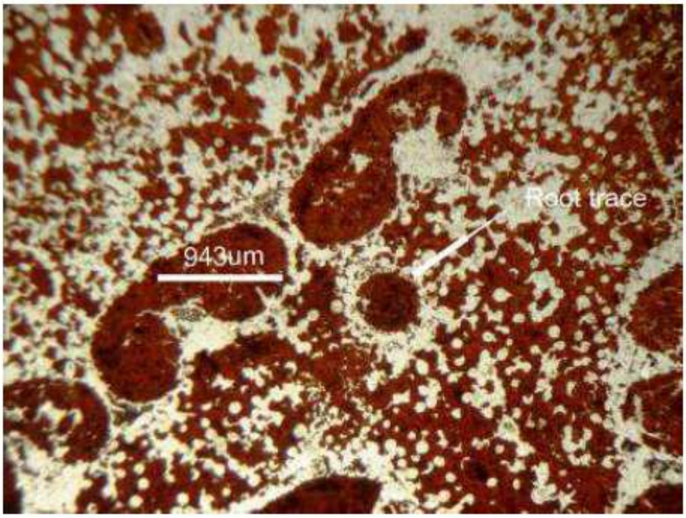

Fig. 1. A root trace between two leaf traces in transverse section of a fern rhizome from Gebel Ghorabi.

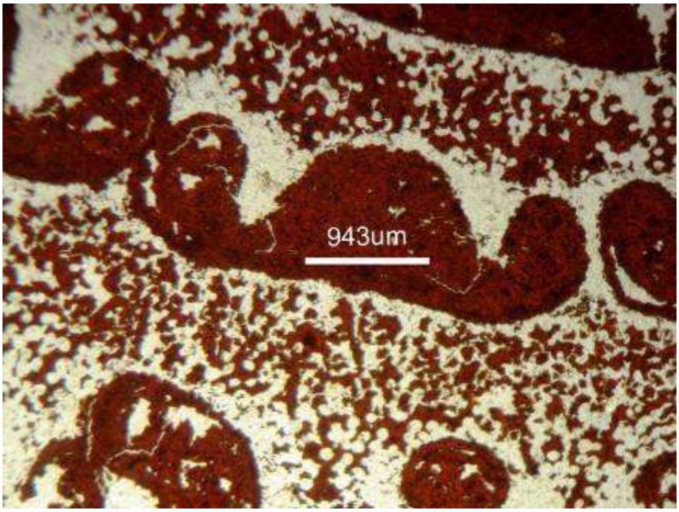

Fig. 2. A fern rhizome from Gebel Ghorabi in transverse section showing root and leaf traces.

Plate IV

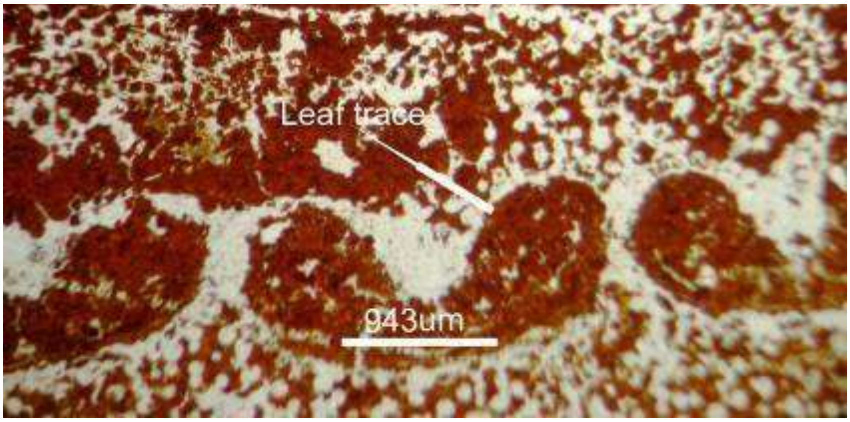

Fig. 1. Leaf traces in transverse section (Gebel Ghorabi).

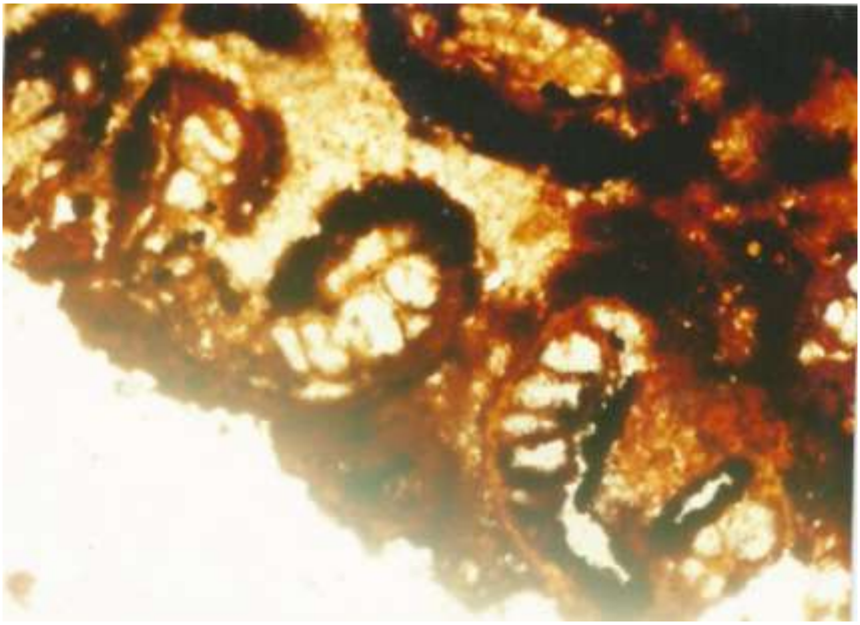

Fig.2. Leaf traces in transverse section, showing poorly preserved xylem tracheids, much enlarged (form Gebel Dist).

Plate V

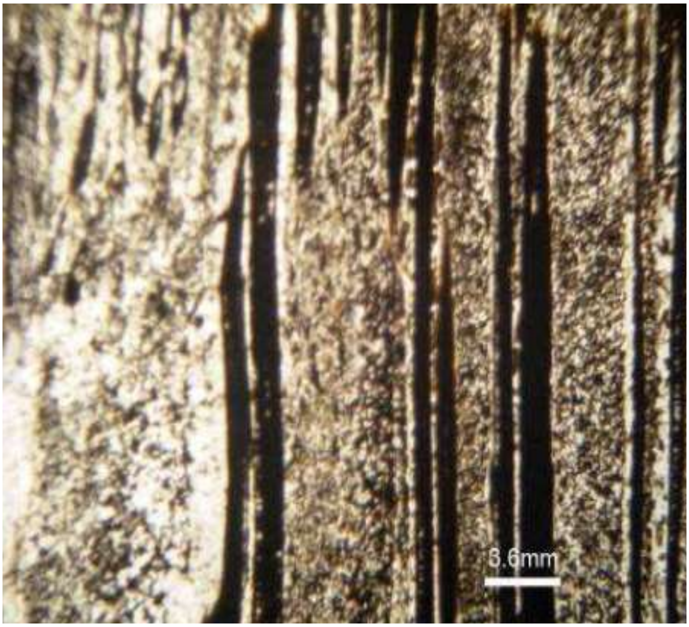

Fig. 1. A fern rhizome from Gebel Ghorabi in longitudinal section.

Fig. 2. A fern rhizome from Gebel Ghorabi in longitudinal section (much enlarged).

Plate VI

Fig. 1. Dense growth of pneumatophores of mangrove (*Avicennia marina*) in muddy-sand substrate, After Gregory *et al*. 2006.

Fig. 2. Dense swamps of *Juncus* plants in the foreground and mangrove in the background (height of spade=90 cm), after Gregory *et al*., 2006.