

A fungal proliferation near the probable Oligocene/Miocene boundary, Nukhul Formation, Gulf of Suez, Egypt

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ABSTRACT – Moderately to well-preserved palynomorph assemblages were recorded from thirty samples of the Nukhul Formation (GH 404-2A Well), southern Gulf of Suez, Egypt. The taxa are dominated by highly diverse fungi, freshwater algae (e.g. *Botryococcus*, *Pediastrum*) beside a sparse record of spores and pollen. Marine palynomorphs, such as dinoflagellate cysts (dinocysts), are very rare. The stratigraphy and age of the Nukhul Formation is highly debated due to lack of diagnostic fossils (e.g. foraminifera, nanoplankton). It has been referred mostly to the Early Miocene; however, some recent publications interpret it as being of latest Oligocene–Early Miocene age. A prominent fungal proliferation composed of diverse and moderately well-preserved fungal spores, fungal fragments, fructifications and hyphae is recorded. This fungi-rich interval occurs mainly from 11370 to 11430 ft in the GH 404-2A Well. Such an observation has not been noted previously within the Nukhul Formation or its stratigraphic equivalents in Egypt. This putative ‘eco-event’ is probably associated with the well-known eustatic sea-level fall in the latest Chattian to early Aquitanian or at the Oligocene/Miocene boundary (OMB). It also seems possible that it may represent a more local event related to the rifting of the Gulf of Suez during this period. The high diversity of fossil fungi is interpreted herein as an indication of an episodic prevalence of humid climate at the end of a regressive phase, as also indicated by a lithological change near the top of the Shoab Ali Member of the Nukhul Formation. In addition, the co-occurrence of freshwater algae, mainly *Botryococcus* and *Pediastrum*, together with some aquatic fungal genera, such as *Involutisporonites*, *Paragrantsporites*, *Quilonia*, *Striadiporites* and *Reduviasporonites*, suggests the temporary existence of shallow, pond- or lake-like aquatic habitats, possibly related to tectonic activity. *J. Micropalaeontol.* 32(2): 183–195, July 2013.

KEYWORDS: *fungal palynomorphs, fungal proliferation, Oligocene/Miocene boundary, Nukhul Formation, Gulf of Suez, Egypt*

INTRODUCTION

There has been growing interest recently in fungal palynomorphs of different ages and areas all over the world (e.g. Lange & Smith, 1971; Sherwood-Pike & Gray, 1985; Jarzen & Elsik, 1986; Ediger & Alişan, 1989; Kumar, 1990; Srivastava & Binda, 1991; Takahashi, 1991; Eshet *et al.*, 1995; Visscher *et al.*, 1996; Kalgutkar, 1997; Parsons & Norris, 1999; Steiner *et al.*, 2003; Vajda & McLoughlin, 2004; Kalgutkar & Braman, 2008; Kar *et al.*, 2010; Krings *et al.*, 2010; van Geel *et al.*, 2011; Vajda, 2012). In contrast, no detailed palynological studies on fossil fungi have so far been carried out from Egyptian sediments or other North African and Arabian areas. Such fungal palynomorphs have been noted sporadically from the Tertiary and Cretaceous of this area (e.g. Abdel Mohsen, 1992; Ahmed & Pocknall, 1994; Mahmoud, 2000; El Beialy *et al.*, 2005; El Atfy, 2011) but without taking into consideration their potential for stratigraphic and palaeoenvironmental interpretations.

The present study is focused on the description of the fungal assemblages and their distribution through the Nukhul Formation in GH 404-2A Well, southern Gulf of Suez, Egypt (Fig. 1). Furthermore, we aim to apply fungal palynomorphs as a palaeoenvironmental indicator and to point out their potential use as a biostratigraphic proxy.

GEOLOGICAL SETTING

The Gulf of Suez is approximately 300 km long with an average width of 70 km and forms the northern extension of the Red Sea,

covering an area of about 25 000 km² at an average water depth of 55–100 m (Schlumberger, 1984; Young *et al.*, 2000). It extends to the NW from 27°30'N to 30°00'N and its width varies from about 50 km at its northern end to about 90 km at its southern end where it merges with the Red Sea (Bosworth & McClay, 2001). Tectonic subsidence and sedimentation were slow during the initial phase of rifting, which was related to the separation of the African and Arabian plates from the latest Oligocene to the Early Miocene (c. 24–15.5 Ma). The corresponding sedimentary succession shows an upward transition from continental volcanics and red beds of the Abu Zenima Formation to initially terrigenous clastics in fluvial, deltaic and littoral environments followed by marginal marine clastics of the Nukhul Formation (e.g. Scott & Govean, 1985; Patton *et al.*, 1994). The Gulf of Suez is the main oil-producing province in Egypt, with oil being produced from Palaeozoic, Mesozoic and Cenozoic rocks.

LITHOSTRATIGRAPHY

The Nukhul Formation was formally described by the Egyptian General Petroleum Corporation Stratigraphic Committee (EGPC, 1964). Its type section is 60 m thick at the tributary south of Wadi Nukhul, central Sinai coastal Gulf of Suez, Egypt (Fig. 1). In subsurface sections, its thickness varies from 0 m on structural highs to over 700 m in the depocentres of the rift sub-basins (Richardson & Arthur, 1988). The Nukhul Formation is in general poorly dated due to the scarcity of diagnostic foraminifera and nanoplankton (El-Heiny & Martini, 1981; Evans, 1988), but



Fig. 1. Location map of the studied well (GH 404-2A), the type section of the Nukhul Formation (Wadi Nukhul) and the type wells of the Shoab Ali and Ghara members, Gulf of Suez, Egypt. Map based mainly on GUPCO (1983).

it has been frequently assigned to the Early Miocene (e.g. Souaya, 1966; Andrawis & Abdel Malik, 1981; El-Heiny & Martini, 1981; Evans, 1988; El Heiny & Morsi, 1992; El-Barkooky *et al.*, 2006; Youssef, 2011) based on foraminifera, calcareous nannofossils and the relative stratigraphic position. Based on palynology (mainly dinocysts), the Nukhul Formation is dated as Early Miocene: Aquitanian and Aquitanian to mid-Burdigalian (Ahmed & Pocknall, 1994; Soliman *et al.*, 2012, respectively). Recently, Hewaidy *et al.* (2012) dated the Nukhul Formation as Late Oligocene–Early Miocene, based on planktonic and benthonic foraminifera from a surface exposure in Sinai. A similar age was postulated by Al-Husseini (2012) from the Gulf of Suez based on a tuned orbital-forcing glacio-eustatic time-scale (Fig. 2). The Nukhul Formation overlies pre-rift basement ranging in age from the Precambrian to Middle–Late

Eocene, depending upon the degree of uplift and erosion prior to Nukhul deposition (Richardson & Arthur, 1988).

Saoudi & Khalil (1984) subdivided the Nukhul Formation into two members: the lower Shoab Ali Member with continental clastics which were deposited in the oldest syn-rift graben of the Gulf of Suez, and the upper Ghara Member which is distributed more widely. Due to lateral facies differences, Saoudi & Khalil (1984) distinguished three regional synonymous members: October Member, Ghara Member and Gharamul Member.

The Shoab Ali Member was originally described from the GH 385-1 Well (Saoudi & Khalil, 1984). It is composed predominantly of siliciclastics, mainly sand and sandstone. The sand is generally loose, colourless to pink or yellow, fine- to medium-grained and is coarser near the bottom. The sandstone is well- to fairly well-sorted, subrounded with streaks of reddish-brown shale

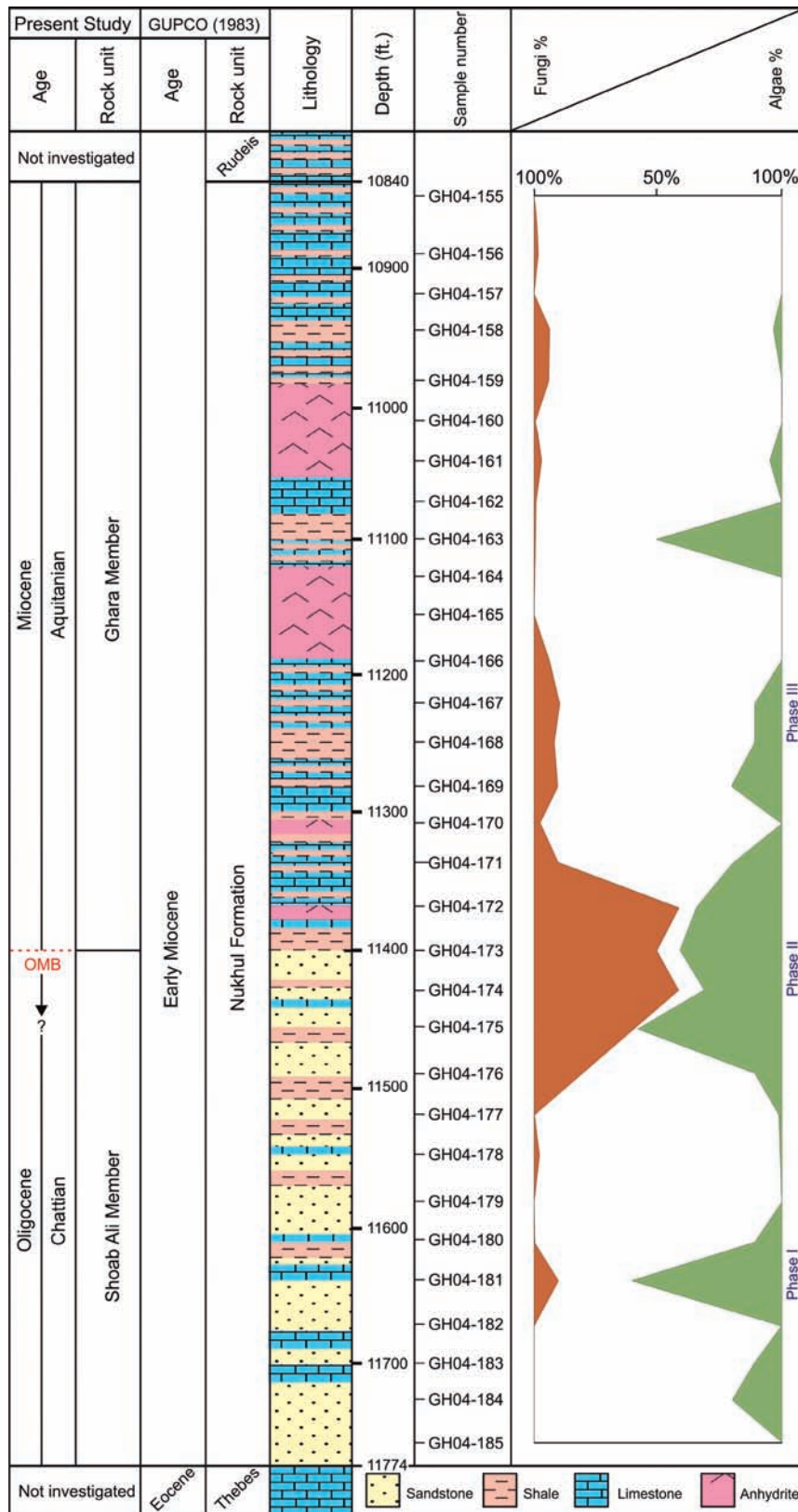


Fig. 2. Lithological log of the Nukhul Formation, GH 404-2A Well, Gulf of Suez, Egypt, modified after GUPCO (1983). The OMB is placed tentatively at the lithological boundary between the Shoab Ali and Ghara members (Hewaidy *et al.*, 2012, and this study). According to sequence stratigraphy, the OMB is somewhere below (Al-Husseini, 2012, as expressed by ? on the figure). The figure also shows the proportional distribution of fungi and algae in three phases.

and mostly barren of fossils. The Shoab Ali Member unconformably overlies the Thebes Formation.

In the current work, we apply the nomenclature of Saoudi & Khalil (1984) for the upper member, utilizing the term Ghara Member which geographically and lithologically fits best to our material. The Ghara Member was described originally from the Well GS 391-2 (Saoudi & Khalil, 1984), approximately 9 km from our studied well. It is composed mainly of white and hard anhydrite layers interbedded with sandstones, grey marls, calcareous shales and limestones. The Ghara Member follows the Shoab Ali Member conformably and is unconformably overlain by the Rudeis Formation (basal Rudeis Member) or its correlative the Mheiherratt Formation.

The studied interval in the GH 404-2A Well ranges from 10 840 ft to 11 774 ft. (934 ft thick), comprising both the Shoab Ali Member and the overlying Ghara Member (Fig. 2).

MATERIAL AND METHODS

Thirty cutting samples retrieved from the Nukhul Formation from the GH 404-2A Well were prepared for palynological analysis following standard extraction techniques; HCl–HF–HCl treatment (e.g. Traverse, 2007), and finally sieving the residues using 10 µm nylon sieves. No oxidation methods were employed. The studied portion of the organic residue was stained with Safranin solution and then mounted on slides using ICI's Elvacite acrylic resin. The fungal assemblages were studied routinely under transmitted light microscope, followed by epi-fluorescence investigation to distinguish fungal spores from algae and other spores and pollen (Pl. 3, fig. M). Fungi were described and classified according to the relevant literature (mainly Elsik *et al.*, 1983; Kalgutkar & Jansonius, 2000) including the world-wide records of stratigraphically diagnostic taxa (e.g. Saxena, 2006; Palynodata Inc. & White, 2008). Characteristic representatives of the recorded taxa are illustrated on Plates 1–3. They were analysed and documented using a Nikon Eclipse 90i microscope, equipped with an infrared video system (specified in Brocke & Wilde, 2001) for studying dark-coloured to nearly opaque palynomorphs (e.g. Pl. 2, figs N, O). Specimen locations on the slides are given as England Finder coordinates. The relevant slides and residues are stored in the palynological collection (Section Palynology and Microvertebrates of the Palaeozoic) at the Senckenberg Research Institute and Natural History Museum, Frankfurt am Main, Germany.

RESULTS AND DISCUSSION

The studied samples yielded moderate to well-preserved fungal and algal palynomorphs, in relatively higher numbers compared to other palynomorphs (dinocysts, spores and pollen), reflecting a considerable fungal and algal proliferation especially within the interval 11 370–11 430 ft, with a lower concentration to 11 490 ft (Fig. 2).

Most of the investigated samples were poorly fossiliferous and few taxa were recorded. As we are dealing with cuttings, the occurrence and ranges of microfossils within the profile may be partially inconsistent in terms of small-scale stratigraphic accuracy.

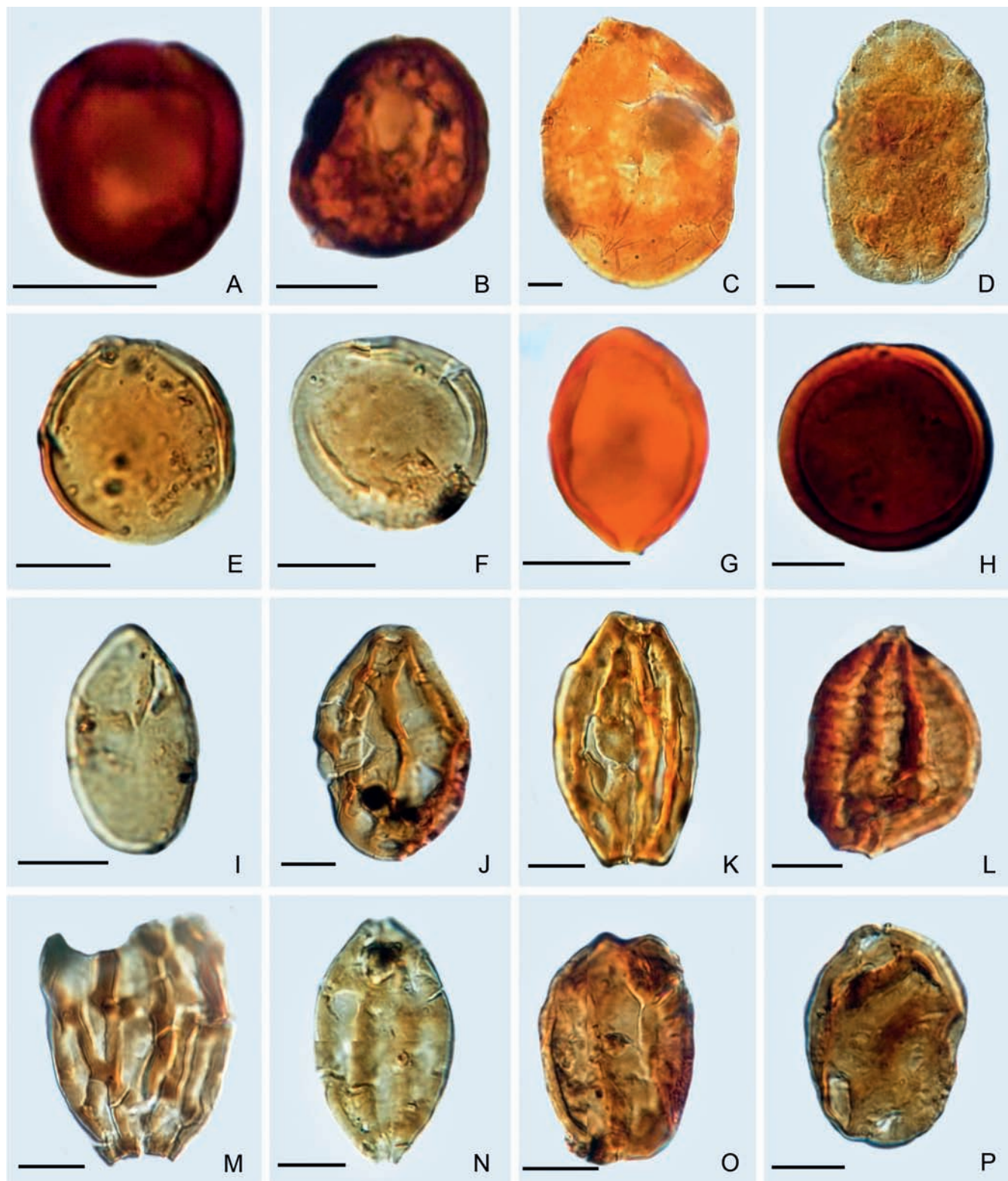
The microscopic examination clearly shows that the reported fungal assemblages did not result from a contaminating effect of sample storage as all samples were preserved in a similar way; also, fungal proliferation has been witnessed exclusively in a definite interval (Fig. 2). The melanized red-brown colour of the fungal taxa is also very characteristic of fossilized forms. Furthermore, the primary high hydrocarbon content of the samples may serve as a preservation medium against any biological attack by modern fungi.

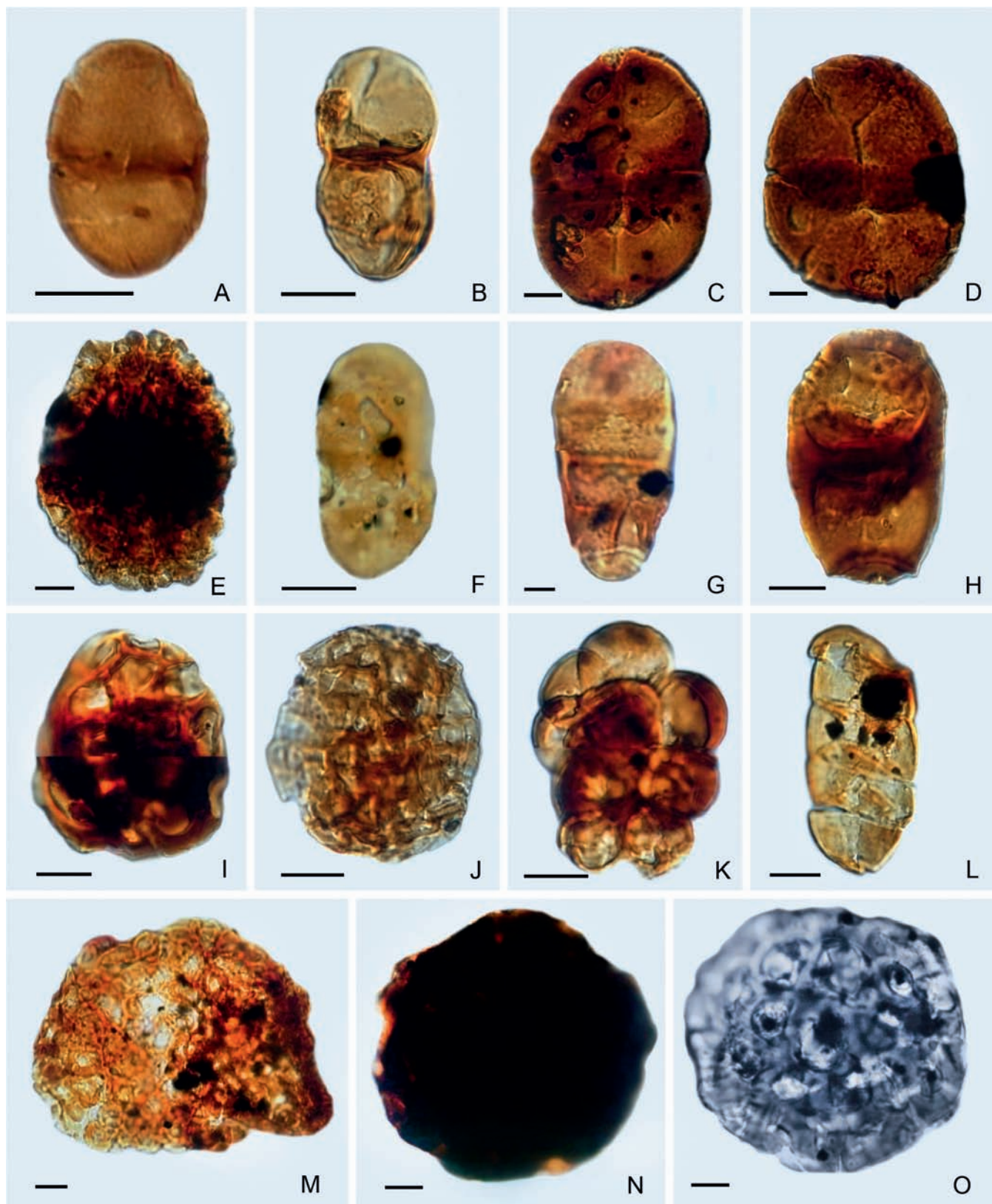
The fungal remains (including spores, fructifications and hyphae) are common in the studied samples and they contribute up to >50% of the total palynomorph assemblage, especially within the fungi-rich interval (11 370–11 430 ft, Fig. 2). It is also worth mentioning that no definite taxonomic group of fungi dominates – as is clear from the recorded taxa. Representative taxa are grouped and sorted (Fig. 3; Table 1) depending on the number of cells in fungal spores under descriptive headings (monocellate, dicellate and multicellate), fruiting bodies and fungal hyphae, rather than being classified under the system for Fungi Imperfecti of Saccardo (1899).

The presence of this well-developed fungal proliferation follows a clear lithological change from coarse-grained siliciclastics to fine-grained marls, limestones and evaporites at the boundary between the Ghara and Shoab Ali members of the Nukhul Formation. Moreover, freshwater algae, such as *Botryococcus* and *Pediastrum*, occur partly synchronous to the fungal proliferation and in relatively similar concentration around this interval.

Also, the investigated material lacks or has very few dinocysts, spores and pollen which could serve for biostratigraphic purposes, but it may be possible to locate the OMB (at least provisionally) at or near the lithostratigraphic boundary between the two members of the Nukhul Formation. This is based on age determinations from spores and pollen in the present well and in SA-E6A Well, which indicate that the upper part of the Shoab Ali Member is Late Oligocene in age (El Atfy *et al.*, in press). The proliferation of the fungi and freshwater algae may serve to correlate between well sections at the postulated OMB (Fig. 2). The fungal palynomorphs also support a terrestrial origin deposited within a regional terminal regressive phase, indicated by the dominance of siliciclastics and, palynologically, by the frequent abundance of phytoclasts (El Atfy *et al.*, in press). Indeed, the fossil fungi are frequently found in both terrestrial and aquatic environments, although the terrestrial group usually appears to be dominant based on their higher diversity and greater relative frequencies

Explanation of Plate 1. Fungal palynomorphs from the Nukhul Formation, GH 404-2A Well, Gulf of Suez, Egypt: monocellate fungal spores. **fig. A.** *Exesisporites annulatus*; GH04-174-1; EF X35-1. **fig. B.** *Exesisporites neogenicus*; GH04-176-1; EF B31-1. **fig. C.** *Inapertisporites* sp.; GH04-174-1; EF O53-1. **fig. D.** *Inapertisporites* sp.; GH04-176-1; EF D48-2. **fig. E.** *Inapertisporites circularis*; GH04-172-1; EF D41-1. **fig. F.** *Inapertisporites communis*; GH04-174-1; EF P30-2. **fig. G.** *Monoporisporites macrosporus*; GH04-172-2; EF J45-2. **fig. H.** *Monoporisporites traversii*; GH04-172-1; EF J43-4. **fig. I.** *Spirotremesporites* cf. *clinatus*; GH04-176-1; EF G45-3. **fig. J.** *Striadiporites* sp.; GH04-172-2; EF P32-4. **fig. K.** *Striadiporites boletelloides*; GH04-176-1; EF O47-1. **fig. L.** *Striadiporites bistriatus*; GH04-168-2; EF A58-3. **fig. M.** *Striadiporites reticulatus*; GH04-174-1; EF M39-4. **fig. N.** *Striadiporites restriatus*; GH04-176-1; EF U33-3. **fig. O.** *Striadiporites inflexus*; GH04-174-1; EF D53-3. **fig. P.** *Striadiporites spiralis*; GH04-174-1; EF E29-2. An England Finder reference (e.g. EF X35-1) follows the sample number (e.g. GH04-174) and slide number (e.g. –1, –2) for each specimen. All images are transmitted light photomicrographs; scale bars 10 µm.





(Kalgutkar & Braman, 2008). In our assemblages, terrestrial taxa, such as *Dicellaesporites*, *Diporicellaesporites*, *Multicellites*, *Scolecospores* and *Pluricellaesporites*, prevail.

Long-ranging fungal taxa that have been recorded previously from Paleogene as well as Neogene strata include the following genera: *Inapertisporites*, *Lacrimasporonites*, *Spirotremesporites*, *Biporopsilonites*, *Dicellaesporites*, *Diporicellaesporites*, *Dyadosporites*, *Tetraploa/Frasnacritetrus*, *Involutisporonites*, *Fusiformisporites*, *Multicellaesporites*, *Meliolinites*, *Pluricellaesporites*, *Basidiosporites*, *Staphlosporonites*, *Dictyosporites*, *Papulosporonites*, *Polycellaesporonites*, *Callimothallus*, *Phragmothyrites*, *Stomiopeltites*, *Trichothyrites*, *Paragranatisporites*, *Involutisporonites*, *Reduviasporonites* and *Striadiporites*.

The recorded fungal assemblages are highly diverse and contain a large proportion of long-ranging taxa. Van der Hammen (1954) was the first to incorporate the relative abundance of fungal palynomorphs in a stratigraphic study and, subsequently, Varma & Rawat (1963) raised such an application to the species level. The implementation of fungal palynomorphs in biostratigraphy is still not widely used in comparison, for example, with those of the 'standard' foraminifera, calcareous nannofossil or dinocyst biostratigraphies within the Tertiary. However, the growing interest among palaeontologists in fungal remains and knowledge about their geological record is continually improving (Elsik, 1996; Kalgutkar & Jansonius, 2000; Taylor & Krings, 2010).

Generally, long-ranging fungal taxa that have been recorded previously from Paleogene as well as Neogene strata at generic level are not useful for stratigraphic consideration. Only some taxa at species level may show good biostratigraphic potential (e.g. *Striadiporites* spp., *Palaeoamphisphaerella pirozynskii*, Pls 1–3; Fig. 3). Other forms that have been recorded from Neogene sediments but are absent in the Paleogene are: *Quilonia* spp., *Exesisporites* spp. and *Brachysporisporites* spp. and, as a result, they may have some biostratigraphic significance.

The following discussion summarizes some relevant taxa at the postulated OMB. The genus *Striadiporites* is an important taxon regarding biostratigraphy and palaeoecology; in our material several specimens can be assigned to this genus. One of them, *Striadiporites* sp. (Pl. 1, fig. J; Fig. 3) is similar to *Striadiporites* sp. of Elsik (1996). This species was used to distinguish Neogene from Paleogene strata in the Gulf of Mexico and the Pacific Northwest, USA. A morphologically similar specimen was also recorded from the Miocene of India (Banerjee & Nandi, 1992). *S. reticulatus* (Pl. 1, fig. M; Fig. 3) was first described from India by Varma & Rawat (1963) as a good stratigraphic marker for the Early Miocene. Moreover, this species was also recorded from the Oligocene–Early Miocene of India (Kalgutkar & Jansonius, 2000). *S. sanctaebarae* (Fig. 3) was also first reported from India by Varma & Rawat (1963) and proposed by them as a good

stratigraphic marker for the Early Miocene. In Turkey, *S. sanctaebarae* was recorded from the Eocene–Oligocene and Late Miocene (Tortonian–Messinian) (Ediger, 1981; Ediger & Alişan, 1989; Ediger *et al.*, 1996). Younger records include the Middle–Late Miocene of Clarkia in Idaho (Sherwood-Pike, 1988). However, it was recently also reported from the Paleocene of Pakistan (Soomro *et al.*, 2010). In our samples, taxa of this genus occur mainly just below, at or just above the assumed OMB and thus this genus could be regarded as a good biostratigraphic marker for this interval.

Phragmothyrites concentricus (Pl. 3, fig. C; Fig. 3) was originally described from the Early Miocene in north central Idaho by Phipps & Rember (2004). This species is reported here from the top of the Shoab Ali Member.

Palaeoamphisphaerella pirozynskii (Pl. 2, fig. F; Fig. 3) was originally published from the Early Miocene (Ramanujam & Srisailam, 1980), and it was also reported from the Miocene (Mallesham *et al.*, 1989) of India. In our samples, *P. pirozynskii* occurs at the top of the Shoab Ali Member and at the base of the Ghara Member (the ?OMB interval).

Exesisporites neogenicus (Pl. 1, fig. B; Fig. 3) was first described by Elsik (1969) from the Early Miocene of the Gulf of Mexico, and subsequently recorded from the Middle–Late Eocene (Bera & Banerjee, 1995) and Early Miocene (Mandaokar, 2002) of India. In our samples *E. neogenicus* occurs both near the top of the Shoab Ali Member and at the base of the Ghara Member (the ?OMB interval).

Dicellaesporites keralensis (Pl. 2, fig. B; Fig. 3) was described originally from Early–Middle Miocene (Kumar, 1990) and subsequently from the Early Eocene (Samant, 2000) of India. This species is reported here from the top of the Shoab Ali Member.

FUNGAL SPIKE

Fungal spikes in the geological record are well known to co-occur with certain bio-events and have been documented from different geographical localities and time periods (e.g. Eshet *et al.*, 1995; Visscher *et al.*, 1996; Steiner *et al.*, 2003; Vajda & McLoughlin, 2004). Moreover, fungal spikes are also considered to have the potential to characterize ecostratigraphic or even biostratigraphic boundaries (Parsons & Norris, 1999). The well-known and widespread fungal proliferation near the Permian–Triassic boundary has frequently been interpreted as widespread devastation of arboreal vegetation, a major decrease in standing biomass and the build-up of decaying vegetation on land (e.g. Visscher & Brugman, 1986; Visscher *et al.*, 1996, 2011; Steiner *et al.*, 2003). However, to our knowledge this is the first time that a comparable fungal proliferation has been documented in the Tertiary, except only for a record at the Cretaceous–Tertiary boundary from New Zealand (Vajda & McLoughlin, 2004). This peak was interpreted

Explanation of Plate 2. Fungal palynomorphs from the Nukhul Formation, GH 404-2A Well, Gulf of Suez, Egypt. **figs A–F.** Dicellate fungal spores: **A**, *Dicellaesporites inaequalis*; GH04-176-1; EF Y52-1; **B**, *Dicellaesporites keralensis*; GH04-174-1; EF P30-1; **C**, *Dyadosporites solidus*; GH04-170-1; EF X30-2; **D**, *Dyadosporites bhardwaji*; GH04-168-1; EF D38-1; **E**, *Dyadosporites* cf. *reticulatus*; GH04-172-1; EF T60-2; **F**, *Palaeoamphisphaerella pirozynskii*; GH04-174-1; EF P30-1. **figs G–O.** Multicellate fungal spores: **G**, *Anatolinites* cf. *dongyingensis*; GH04-162-2; EF H49-2; **H**, *Paragranatisporites* cf. *vermiculus*; GH04-174-1; EF O38-3; **I**, *Dictyosporites moruloides*; GH04-181-1; EF N48-4; **J**, *Dictyosporites morularis*; GH04-174-1; EF X41-1; **K**, *Involutisporonites* sp.; GH04-168-2; EF P63-4; **L**, *Meliolinites* cf. *nivalis*; GH04-181-1; EF W31-1; **M**, *Palambages* sp.; GH04-170-1; EF M35-1; **N**, *Papulosporonites enormis*; GH04-176-1; EF Y39-3; **O**, *Papulosporonites enormis*; GH04-176-1; EF Y39-3. An England Finder reference (e.g. EF X35-1) follows the sample number (e.g. GH04-174) and slide number (e.g. –1, –2) for each specimen. All images are transmitted light photomicrographs with the exception of fig. O which is an infrared image; scale bars 10 µm.

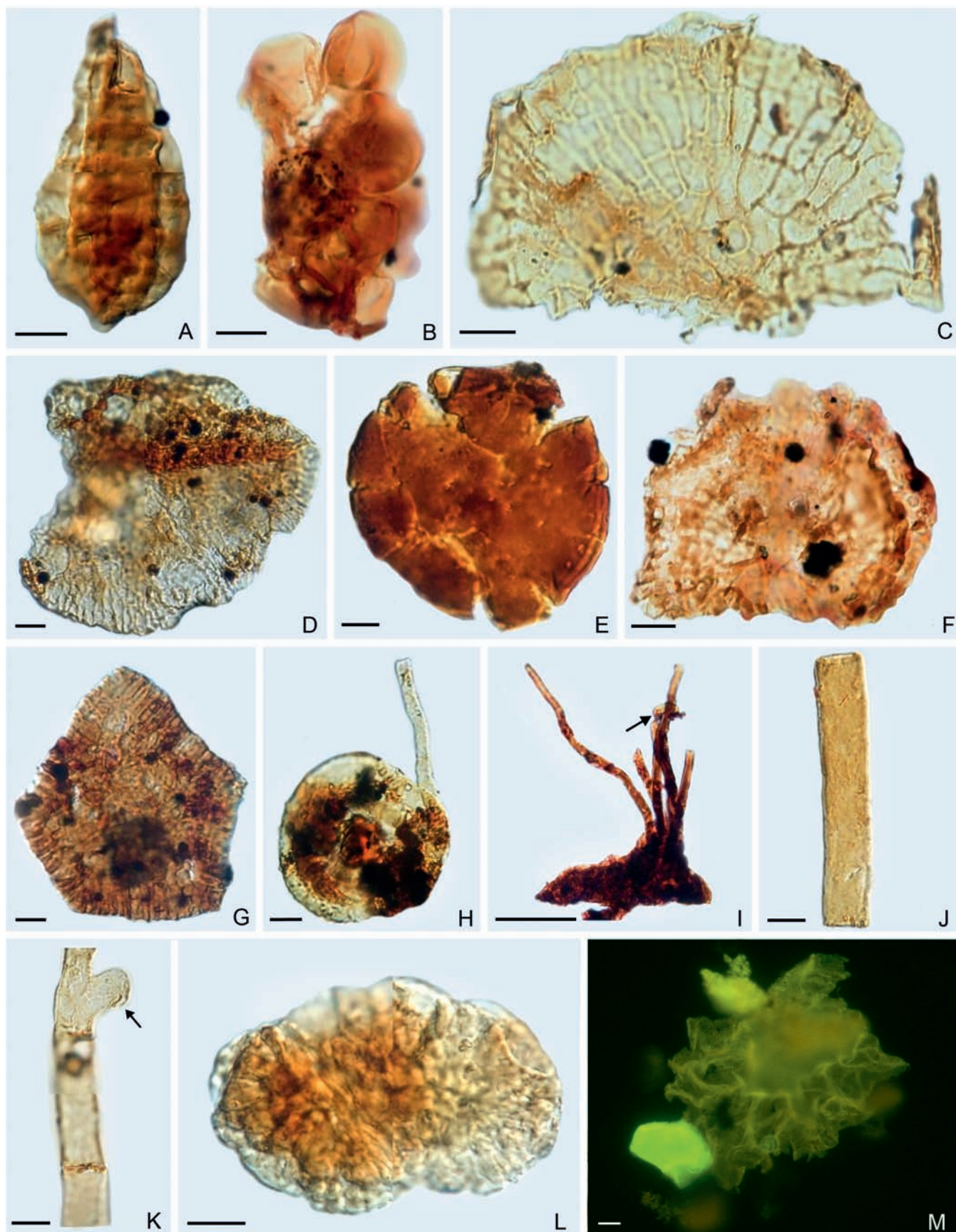


Table 1. List of species and authors from Figure 3.

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|---|
| <i>Anatolinites dongyingensis</i> (Ke & Shi, 1978) Elsik <i>et al.</i> , 1990 |
| <i>Brachysporisporites catinus</i> (Elsik & Jansonius, 1974) Kalgutkar & Jansonius, 2000 |
| <i>Dicellaesporites inaequabilis</i> Martínez-Hernández & Tomasini-Ortiz, 1989 |
| <i>Dicellaesporites keralensis</i> Kumar, 1990 |
| <i>Dictyosporites morularis</i> (Salard-Chebouldaëff & Locquin, 1980) Kalgutkar & Jansonius, 2000 |
| <i>Dictyosporites moruloides</i> (Salard-Chebouldaëff & Locquin, 1980) Kalgutkar & Jansonius, 2000 |
| <i>Dyadosporites bhardwaji</i> (Varma & Rawat, 1963) Kalgutkar & Jansonius, 2000 |
| <i>Dyadosporites reticulatus</i> (Ramanujam & Rao, 1979) Kalgutkar & Jansonius, 2000 |
| <i>Dyadosporites solidus</i> (Ke & Shi, 1978) Song in Song <i>et al.</i> , 1999 |
| <i>Exesisporites annulatus</i> Kalgutkar, 1993 |
| <i>Exesisporites neogenicus</i> Elsik, 1969 |
| <i>Inapertisporites circularis</i> (Sheffy & Dilcher, 1971) Kalgutkar & Jansonius, 2000 |
| <i>Inapertisporites communis</i> Song & Li in Song <i>et al.</i> , 1989 |
| <i>Meliolinites nivalis</i> Selkirk, 1975 |
| <i>Monoporisporites macrosporus</i> (Salard-Chebouldaëff & Locquin, 1980) Kalgutkar & Jansonius, 2000 |
| <i>Monoporisporites traversii</i> (Ediger & Alisan, 1989) Kalgutkar & Jansonius, 2000 |
| <i>Palaeoamphisphaerella pirozynskii</i> Ramanujam & Srisailam, 1980 |
| <i>Papulosporonites enormis</i> (Ediger, 1981) Kalgutkar & Jansonius, 2000 |
| <i>Paragranatisporites vermiculus</i> (Ediger, 1981) Kalgutkar & Jansonius, 2000 |
| <i>Phragmothyrites concentricus</i> Phipps & Rember, 2004 |
| <i>Polycellaesporonites acuminatus</i> (Rouse & Mustard, 1997) Kalgutkar & Jansonius, 2000 |
| <i>Reduviasporonites qingfengensis</i> (Song & Luo, 1989) Song in Song <i>et al.</i> , 1999 |
| <i>Spirotremesporites clinatus</i> Elsik, 1990 |
| <i>Striadiporites bistriatus</i> (Ke & Shi, 1978) Norris, 1986 |
| <i>Striadiporites boletelloides</i> Salard-Chebouldaëff & Locquin, 1980 |
| <i>Striadiporites inflexus</i> (Ke & Shi, 1978) Norris, 1986 |
| <i>Striadiporites reticulatus</i> Varma & Rawat, 1963 |
| <i>Striadiporites retistriatus</i> (Ke & Shi, 1978) Kalgutkar & Jansonius, 2000 |
| <i>Striadiporites sanctaebarae</i> Elsik & Jansonius, 1974 |
| <i>Striadiporites</i> sp. Elsik, 1996 |
| <i>Striadiporites spiralis</i> (Song & Li, 1989) Kalgutkar & Jansonius, 2000 |

to represent a dramatic increase in the available substrates for saprophytic organisms provided by global forest dieback after the Chixculub impact (Vajda *et al.*, 2001).

In the current study, we present the first evidence of a fungal proliferation from sediments deposited at or within an interval

close to the supposed OMB of Egypt (Fig. 2). The recorded proliferation appears in three phases, which are composed mainly of fungal spores, fungal fragments, fructifications and hyphae together with freshwater algae. The first (minor) phase is displayed in sample GH04-181 at 11 640 ft. The second or main phase occurs in the fungi-rich interval between 11 370 ft and 11 430 ft, which is overlain by a third (minor) phase in sample GH04-167 (11 220 ft). The width of the main peak may be explained partly as a result of blurring due to the use of cutting samples, but it seems highly unlikely that the different individual peaks are the result of such a distortion (Fig. 2). Altogether, these three proliferations document a fungal peak or acme accompanied by a lithological change from siliciclastics to calcareous rocks which we believe probably represents the transition from the Oligocene to the Miocene.

Kar *et al.* (2010) recorded a comparable high proportion of fungal hyphae, spores and microthyriaceous ascostromata in Early Miocene sediments in India, whereas spores and pollen grains were relatively rare and of low diversity, similar to our material. Hence, at a first glance this record of fungal palynomorphs from a unit in India of comparable age could be interpreted as an indication of an inter-regional eco-event and support the presence of a close relationship in the composition of fungi from different areas in the Early Miocene or around the OMB, respectively. But, indeed, it clearly needs much more information from other areas of the world to establish such an event and to exclude taphonomic effects, in order to compare these findings with, for example, the famous end-Palaeozoic fungal spike at the Permian–Triassic boundary or that at the Cretaceous–Tertiary boundary (e.g. Eshet *et al.*, 1995; Vajda & McLoughlin, 2004).

PALAEOENVIRONMENTAL INTERPRETATION

Fossil fungal palynomorphs exhibit a great variability in their morphology and have good potential as indicators for past ecosystems. Their presence in sedimentary sequences provides significant and reliable proxies in understanding the depositional environments as well as to support palaeoclimatic inferences (Pirozynski, 1976; Stubblefield & Taylor, 1988; Kalgutkar & Braman, 2008; Singh & Chauhan, 2008). Recently, there has been a remarkable increase in the application of fossil fungi in both biostratigraphical and palaeoenvironmental studies; in particular, they are known to adapt and respond quickly to environmental stress and disturbance (Pugh & Boddy, 1988). Furthermore, certain fungal taxa are useful in palaeoenvironmental determinations based mainly on the ecological significance of their extant or modern analogues with well-known environmental preferences, e.g. as principal decomposers of organic matter they are of distinct significance for ecosystem dynamics (e.g. Taylor & Krings, 2010). In general, a rich diversity of fungal

Explanation of Plate 3. Fungal palynomorphs from the Nukhul Formation, GH 404-2A Well, Gulf of Suez, Egypt. **figs A–G.** Fungal fruiting bodies: **A**, *Polycellaesporonites acuminatus*; GH04-158-1; EF O61-4; **B**, *Reduviasporonites* cf. *qingfengensis*; GH04-168-2; K EF X51-4; **C**, *Phragmothyrites concentricus*; GH04-174-1; EF Y50-3; **D**, *Phragmothyrites* sp.; GH04-174-1; EF O53-1; **E**, cf. *Stomiopeltites* sp.; GH04-181-1; EF S35-1; **F**, *Trichothyrites* sp.; GH04-168-2; EF B34-3; **G**, *Trichothyrites* sp.; GH04-168-2; EF F40-0. **figs H–K.** Fungal hyphae: **H**, *Palaeomyces* sp.; GH04-176-2; EF Q42-1; **I**, GH04-176-3; EF Q40-4; **J**, non-septate fungal hyphae; GH04-176-1; EF X33-2; **K**, hyphopodiate fungal hyphae with conspicuous septations and hyphopodia at the arrow; GH04-174-1; EF U43-4. **figs L, M.** Freshwater algae: **L**, *Botryococcus* sp.; GH04-172-2; EF V48-2; **M**, *Pediastrum* sp.; GH04-172-1; EF K40-4. An England Finder reference (e.g. EF X35-1) follows the sample number (e.g. GH04-174) and slide number (e.g. –1, –2) for each specimen. All images are transmitted light photomicrographs with the exception of fig. M which is a fluorescence image; scale bars 10 µm.

Black Sea. Although we are aware of the ongoing discussion concerning whether *Reduviasporonites* represents fungi or algae, we follow here the 'classical' interpretation as fungal remains, as recently supported by Visscher *et al.* (2011). In addition, a routine fluorescence investigation has been employed to ensure chitinous rather than an algal origin for all reported taxa including *Reduviasporonites*.

The existence of isolated ascocarps of epiphyllous microthyriaceous fungi, such as *Phragmothyrites* (Pl. 3, figs C–D), *Trichothyrites* and *Callimothallus*, also supports the assumption of a warm and humid climate during the deposition of the Nukhul Formation (mainly within the defined ?OMB interval), similar to the interpretation for the Milk River Formation (Kalgutkar & Braman, 2008). The same is true for the presence of epiphyllous microthyriaceous fruiting bodies that are generally taken as a reliable indicator of warm temperate to tropical climatic conditions (Lange, 1976; Kalgutkar & Braman, 2008). The co-occurrence of *Meliola/Meliolinites* (Pl. 2, fig. L) with epiphyllous fungi is also indicative for high humidity coupled with high temperature (Dilcher, 1963; Singh & Chauhan, 2008).

Due to the scarcity of outcrop information, limited palaeontological data and intense tectonics, it is difficult to establish a definite depositional regime for the Nukhul Formation; however, a rather complex depositional scenario can be envisioned (cf. El Atfy *et al.*, 2013). For example, Carr *et al.* (2003) postulated two contemporaneous environments for the deposition of the Nukhul Formation: (1) an open-shelf offshore to shoreface environment; and (2) a structurally controlled estuary. Both the recorded fungal palynomorphs and freshwater algae, in addition to the overall sparse and rare record of marine dinocysts, support the depositional model of a structurally controlled estuary or freshwater to brackish lake. In addition, it has been mentioned previously by Lorente (1986) that an absence of marine microplankton, a dominance of fungal remains and an abundance of the local flora are usually characteristics of coastal plain deposition including that of estuaries. Autochthonous fungal remains occur abundantly in moist-wet environments, e.g. river-bank deposits (Jarzen & Elsik, 1986), lake-beds (Wolf, 1966) and inter-tidal marginal marine environments (Hughes, 1968; Lorente, 1986; Srivastava & Binda, 1991).

Fungi thrive not only during such climatic-controlled humid conditions, but always in wetlands (and other) ecosystems, e.g. peat swamps, and may expand during the humid conditions (cf. Kloosterboer-van Hoeve *et al.*, 2006), probably located at the margin of a large body of water. It is possible that such peat deposits (not directly recorded in our material) may have been eroded and/or reworked during the initial phase of the transgression which is evidenced by the clear lithological change from sandstones to shales around 11 400 ft, marking the top of the Shoab Ali Member.

As our main observed fungal proliferation is most likely situated close to or at the OMB, it may be possible that the lowstand (top Shoab Ali Member) prior to the observed transgression (basal Ghara Member) may be related to the Mi-1 glaciation event of Miller *et al.* (1991), which resulted in eustatic sea-level changes (regression during glaciation, transgression during deglaciation). This glaciation represents the first occurrence of a full-scale ice-sheet on Antarctica (Zachos *et al.*, 2001) and its effects on sea-level fall and probably global climate changes have been reported previously from localities as far north as Denmark

(Larsson *et al.*, 2010; and citations therein). The presence of more than one fungal/algal peak probably represents the results of different transgressive pulses of varying magnitude.

Indeed, due to extensive tectonic movements during the deposition of the Oligocene–Miocene sediments of the entire Gulf of Suez basin, it seems likely that the regression/transgression processes, which have led to the assumed erosion of sediments enriched in fungal remains, may have been caused or overprinted by more local or regional tectonic movements and not only due to glacio-eustatic sea-level changes or taphonomic considerations.

CONCLUSIONS

The palynological examination of 30 samples from the Nukhul Formation of the GH 404-2A Well, Gulf of Suez, Egypt, revealed the presence of a prominent proliferation of fungal and algal palynomorphs which 'peaked' at the boundary between the Shoab Ali and Ghara members within the Nukhul Formation. The fungal proliferation, which is recorded in the present study for the first time, may probably represent an eco-event at or near the assumed OMB in the Gulf of Suez. Species, such as *Exesisporites neogenicus*, *Palaeoamphisphaerella pirozynskii*, *Striadiporites* sp., are considered here as potentially stratigraphically diagnostic to characterize the OMB interval.

The presence of such a fungal proliferation is most likely an indication of humid and warm climatic conditions beginning at the turning point from a regressive to a transgressive phase. It probably took place through several small pulses of transgression during the terminal lowstand. The presence of three phases of fungal and algal proliferation could be an indicator of such a process. The succeeding calcareous lithology of the Ghara Member is progressively characterized by evaporites which are interpreted to reflect arid conditions. This may have led to increased erosion and contemporaneous redeposition.

Moreover, co-occurrence of freshwater algae, such as *Pediastrum* and *Botryococcus*, with some aquatic fungal genera, such as *Involutisporonites*, *Paragrantisporites*, *Quilonia*, *Striadiporites* and *Reduviasporonites*, suggests the existence of shallow, lake/pond-like or lacustrine aquatic habitats, probably related to the rifting activities or sea-level rise during the initial transgressive phase. This phase is characterized by erosion and probably due to ongoing transgression(s), subsequent erosion and accumulation.

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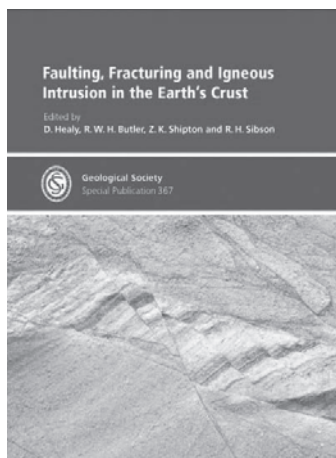
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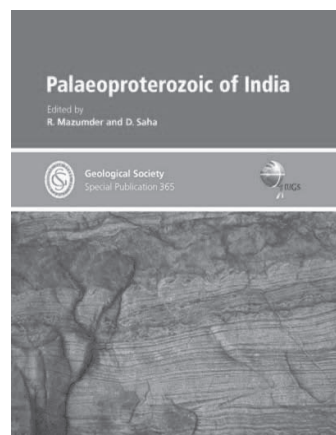
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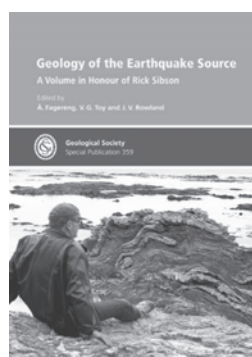
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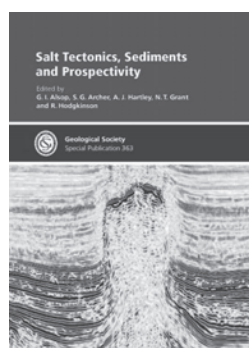
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