INSIGHTS ON THE AGE, CLIMATE AND DEPOSITIONAL ENVIRONMENTS OF THE RUDEIS AND KAREEM FORMATIONS, GS-78-1 WELL, GULF OF SUEZ, EGYPT: A PALYNOCLOGICAL APPROACH

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Abstract

The pollen palynoflora of the mid-Tertiary Rudeis and Kareem formations encountered in the GS-78-1 well complements the previous dinoflagellate cyst results established in 2002 by El Beialy and Ali. Numerous pollen taxa are recorded from the regional palynoflora that allow a fuller reconstruction of the Miocene vegetation, climate, environment and age. By comparison with modern analogs, the Rudeis and Kareem palynofloras represent mixed vegetation that inhabited a variety of environments. Such seemingly anomalous composition may have resulted from depositional mixing of pollen from several vegetational units or from less distinct ecological zonation of vegetation in the Tertiary. A subtropical to warm temperate climate is inferred, although the palynoflora also includes taxa that today are tropical to subtropical (Mimosaceae, Caesalpinioceae). The palynoflora might suggest terrestrial climatic cooling as deduced from the dominance of Gramineae and Chenopodiaceae. Gramineae and Chenopodiaceae are probably locally indicative of cooler and drier (arid) climate (?Glacial phase). Chenopodiaceae, on the other hand, also indicate salt marsh (sabka) conditions. The palynomorphs suggest that there was at least four significant marine/non-marine incursions into the Gulf of Suez area during the Miocene. An interesting association of typical Eocene (Striatopollis, Margoceratites, Pefotrichopites) and Oligocene-Miocene taxa (Compositae, Malvaceae, Chenopodiaceae, Gramineae) occurs in both formations. However, Eocene taxa are absent in the Kareem Formation. Most of these types are not restricted stratigraphically. The stratigraphic ranges of taxa and the diversity of herbs suggest that the age of the Rudeis and Kareem formations is early Miocene to early middle Miocene respectively.

Key words: Rudeis, Kareem, Gulf of Suez, Pollen, Palaeoclimate, Palaeoenvironment, Miocene, Egypt.

Resumen

La palinoflora de las formaciones Rudeis y Kareem del Terciario medio descritas en el sondeo GS-78-1 complementa los resultados previos basados en el estudio de las asociaciones de dinoflagelados previamente publicados en el 2002 por El Beialy y Ali. Numerosos taxones polínicos han sido registrados de la palinoflora regional, lo que ha permitido realizar una reconstrucción completa de la vegetación, clima y ambiente que caracterizó al Mioceno. Por comparación con representantes actuales, las palinofloras de Rudeis y Kareem representan una vegetación mixta que habitaba una amplia variedad de ambientes. La anómala composición de tales asociaciones podría ser un resultado de un proceso de mezcla durante su deposición de varias unidades vegetales o de diferentes zonaciones vegetales ecológicas terciarias. Como resultado se infiere un clima entre subtropical a templado-cálido, aunque la palinoflora incluye taxones que actualmente son tropicales a subtropicales (Mimosaceae,
Caesalpiniaeae). La palinflora podría sugerir condiciones climáticas frías terrestres, como indicaría el dominio de Gramineae y Chenopodiaceae. Gramineae y Chenopodiaceae son probablemente indicativas de condiciones climáticas locales frías y secas (áridas) (?fase glacial). Chenopodiaceae, por otra parte, son indicativas de medios maraules (sabkha). Los palinomorfos sugieren que hubo al menos cuatro incursiones significativas marinas/no marinas en el Golfo de Suez durante el Mioceno. Una asociación interesante de taxones típicos eocenos (Striatopollis, Margococolpites, Perforcolpites) y oligocenos-miocenos (Compositae, Malvaceae, Chenopodiaceae, Gramineae) se presentan en ambas formaciones. Sin embargo, ciertos taxones eocenos están ausentes en la Formación Kareem, la mayoría de los cuales no tienen rangos estratigráficos restringidos. Los rangos estratigráficos de los taxones y la diversidad de las hierbas sugieren que la edad de las formaciones Rudois y Kareem es Mioceno inferior y Mioceno inferior-medio, respectivamente.

Palabras clave: Rudois, Kareem, Golfo de Suez, polen, paleoclima, paleoambientes, Mioceno, Egipto.

INTRODUCTION

The lack of knowledge on the Tertiary spores and pollen in Egypt has made it inordinately difficult to establish a misospore-pollen chronology that can be applied to important projects which had an exploration focus as in the Miocene deposits of the Gulf of Suez area.

Although very brief palynological results have been recorded from the Neogene in the Gulf of Suez area (Mahmoud, 1993; Ahmed and Pocknall, 1994; Pocknall et al., 1999; El Beialy and Ali, 2002) this is the only study in detail that has been made on pollen and spores. The previously published palynological information was mainly on the dinoflagellate cysts, but in the present work, the authors have taken a new step, that is a deviation from the purely dinoflagellate cyst studies to misospore and pollen investigations.

The aim of this work is two-fold: firstly to present data of our analysis of pollen and spores from the Miocene Rudois and Kareem formations, penetrated in the GS-78-1 well (Lat 29° 22' 50.14" N; Long 32° 36' 45.09" E, Fig. 1) which we know so little about their geographical distribution and their botanical affinities, and secondly to present the ranges of some of the more diagnostic pollen and spores. This microfossil recovery is sufficient to permit some preliminary interpretations of Miocene climate and depositional environments in the Gulf of Suez. It is hoped that spores and pollen will provide a reliable dating to the Rudois and Kareem formations taking into our consideration the dating scheme presented by El Beialy and Ali (2002) for the Miocene deposits of the GS-78-1 well, based on dinoflagellate cysts. This scheme can not be used with confidence as a framework for the interpretation of age. It is not an easy procedure to achieve due to the difficulty of calibrating the Miocene section in the Gulf of Suez with a global standard which makes it impossible to precisely determine the age ranges of the Miocene section in the GS-78-1 well. The Rudois and Kareem formations palynoflora are therefore interpreted within the context of palynoflora representing well dated Miocene deposits from the Nile Delta (Poumot and Bourrouilh, 1984; El Beialy 1988, 1990a, 1992) and the Gulf of Suez (Mahmoud 1993; Ahmed and Pocknall, 1994; Pocknall et al. 1999; El Beialy and Ali, 2002).

![Map showing the location of the GS-78-1 well, Gulf of Suez, Egypt.]
MATERIAL AND METHODS

Twenty-nine cuttings samples collected from the Rudeis and Kareem formations encountered in the GS-78-1 well, Gulf of Suez, Egypt were processed and analysed for spores and pollen.

Sample positions are shown with the simplified lithostratigraphy (Fig. 2).

A standard processing technique was performed on all samples. This involved cold chemical treatment of 10 gm of sediment with 40% HCl to remove the calcareous fraction and with 40% HF to remove the silicates; sieving with a 10 μm nylon mesh. Brief oxidation was applied for each sample and canada balsam was used as the mounting medium. The slides were examined to check for the presence of spores and pollen. Percentages were not used because of the low fossil recovery in some samples which may lead to anomalous values.

Light photomicrographs were taken using an Olympus microscope. For illustrated specimens (Plates 1 and 2) England Finder references are provided.

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**Figure 2**- Lithological column and total ranges of palynomorphs encountered in the Miocene of the GS-78-1 well, Gulf of Suez, Egypt.
All the preparation slides examined in this study are housed in the palynological collection of the Department of Geology, El Mansoura University, Egypt.

THE TAXONOMIC METHODOLOGY AND SYSTEMATIC PALYNOLOGY

The taxonomic allocation of the Tertiary pollen and spores follows Germenaad et al. (1968). They can be identified at the level of form genera in a conventional way within the International Rules of Botanical Nomenclature. In this short systematic section, we discussed the recent affinities, stratigraphic ranges, and sources of some of the less well-known pollen. For consistency all spore-pollen species identified in Fig. 2 are given names of fossil form-genera and species. Even though many can be referred to living species, as will be discussed, they are still retained under a form fossil nomenclature as this procedure avoids the likelihood of the incorrect assignment of the dispersed fossils (Germenaad et al., 1968). For full reference to genera and species see Jansonius & Hills (1976) and Ravn (1998).

Spores

a) Monolete spores
   Genus Verrucatosporites Pflug & Thomson in Thomson & Pflug, 1953
   Verrucatosporites sp.
   Pl. 1, Fig. D

b) Trilete spores
   Genus Baculatisporites Pflug & Thomson in Thomson & Pflug, 1953
   Baculatisporites cf. scabridus Playford 1982
   Pl. 1, Fig. L

Trilete spores bearing spinose processes are here compared to B. scabridus, which Playford (1982) described from the Neogene of Paupa New Guinea. The Egyptian form differs in having a less dense distribution of spines distally and in having a straight rather than sinuous laesurae. This form is present as a rare element through much of the Rudeis and Kareem samples. Either a fern or a bryophyte may have produced this type.

Genus Polypodiceaeosporites Potonić, 1956
Polypodiceaeosporites sp.
   Pl. 1, Fig. A

Similar forms are known from the late Tertiary-Quaternary of Egypt (Mahmoud, 2000). These spores are probably produced by fern families.

Genus Triporoletes Mchedlishvili 1960
Triporoletes cf. zlvispora Pactlota sensu Partridge 1978
   Pl. 1, Fig. B

Spores conforming to those from the living bryophyte genus Riccia are placed under this form genus. Stratigraphic range observed is late Eocene to Recent (Partridge, 1978). Similar records are known from the upper Tertiary-Quaternary of Egypt (Mahmoud, 1996, as Lycopodiaceae).

Gymnosperm pollen

Genus Ephedrites Bolkhovitina, 1953
Ephedrites sp.
   Pl. 1, Fig. H

Genus Inaperturpolisporites Pflug & Thomson in Thomson & Pflug, 1953

Remarks.–This form genus includes all alete pollen which were originally spherical in shape that may or may not tend to split along a symmetry plane through the equator (Thomson and Pflug, 1953).

Inaperturapollenites sp. A
Pl. 1, Fig. F

Specimens of this species are present as common elements in the two studied formations as circular pollen with a full range split. The ornamentation is smooth. The size measured along the line of gaping hiatus is 20-38 μm. This form is very similar to I. hiatus (Potonié) Thomson & Pflug, 1953, and Cupressacites backwitzensis Krutzsch, 1971. Forms classified within the form-genus Taxodiaceaeopollenites Kremp, 1949, are invalid since the latter taxon is considered a junior synonym (Wilkinson & Bouler, 1980).

Inaperturapollenites sp. B
Pl. 1, Fig. G

These pollen are similar to those of Inaperturapollenites sp. A, but have wider and more distinct folding of the exine. The size ranges from 35-50 μm.

Angiosperm pollen

a) Monocolopates
Genus Monocolopollenites Thomson & Pflug, 1953

Remarks.—Fossil monocolopate pollen identified from the Tertiary of Egypt include Monocolopollenites, Arecipites and Cycadopites, but the distinction between these is complex. We use Monocolopollenites for all non-reticulate monocolopate pollen, in which the ornament ranges from psilate to scabrate to granulate, and in which the colpus has variable structure (Thomson and Pflug, 1953). Arecipites, on the other hand comprises all reticulate pollen (Krutzsch, 1970). The cypsels may be absent from the Miocene of Egypt since there is no evidence for their presence within the megafossil record (Lejal-Nicol, 1990).

Monocolopollenites sp.
Pl. 1, Figs. O, P

This pollen has a generally oval shape with an ornamentation ranging from smooth (Pl. 1, Fig. O) or granulate (Pl. 1, Fig. P). The colpus is straight, slightly open. It usually traverses almost the entire length of the grain. The specimen illustrated in Plate 1, Figure O, is similar to Cycadopites foliiculilaris Wilson & Webster, 1964 and the other specimen (Pl. 1, Fig. P) is similar to Mauritiidites cf. crassibaculatus Van Hoeken-Klinkenberg 1964.

b) Tricolopates
Genus Perforiciculopites González Guzmán, 1967
Perforiciculopites digitatus González Guzmán, 1967
Pl. 2, Fig. K

Single grain, radially symmetrical, isopolar, prolate and tricolopate. Colpi eclecchiens, long, strongly intruding, with straight borders and pointed ends. Columellae digitate. Perforate teutum and psilate-scabrate sculpture. This form was described from the lower-middle Eocene of Colombia (González Guzmán, 1967). Identification of the fossil dispersed pollen with the pollen grains of Merremia glabra Hallier in Germeraad et al., 1968 (Convolvulaceae) is rather similar (Germeraad et al., 1968).

Genus Sulcisiculopites Srivastava, 1966

Remarks.—The form genus is for all tricolopate pollen compressed along the polar or equatorial planes which have a fine to coarse reticulate ornamentation. No distinction need be drawn with Tricolopodenopites Pflug & Thomson in Thomson & Pflug, 1953, since the latter doesn’t have a reticulate ornamentation (Srivastava, 1966).

Salixipollenites sp. A
Pl. 1, Fig. C

This is a prolate tricolporate pollen with a reticulate ornament and luminae measuring 0.6-0.9 μm in diameter. The muri are generally thin. The long axis measures 20-30 μm. This form is similar to Reticulopites (Van der Hammen) Pierce, 1961, recorded from the Miocene of the Gulf of Suez (Ahmed and Pocknall, 1994).

Salixipollenites sp. B
Pl. 1, Fig. R

This species has a characteristic baculo-reticulate ornamentation. The oblate grains are deeply trilobate. This form is present in small numbers in the examined intervals and is similar to Tricolpites reticulatus Corkson, 1947, and T. microreticulatus Van der Hammen, 1954.

Genus Striatopollis Krutzsch, 1959
Striatopollis caatuambo (González Guzmán) Ward, 1986
Pl. 2, Fig. J

Tricolpate pollen, colpi long, intruding with straight simple borders and pointed ends. Tectum striate, striae 1 μm thick, 1-1.5 μm wide, 1 μm apart, subparallel or slightly anastomosing. The specimen found in the present study agrees in all respects with González’ type material. This form was reported from the Eocene of Nigeria and Qatar (Takahashi & Jux, 1989a; El Beialy, 1998). The species is in closest resemblance with pollen of the genus Crudia, Fabaceae (Germerra et al., 1968).

Genus Tricolopolitanites Pflug & Thomson in Thomson & Pflug, 1953
Tricolopolitanites spp.
Pl. 1, Figs. I, M, Q, U & Pl. 2, Fig. Q

The tricolporate pollen have a polar axis which is longer than the equatorial axis. The three colpi are arranged symmetrically about the polar axis, and stretch almost the full length of the body. The ornamentation is scabrate to faintly granulate. These specimens are very common components in the studied samples but have very little stratigraphic or botanical significance. The specimen figured in Plate 2, Figure Q, is similar to the recent pollen grain Merremia glabra (Hallier in Germerra et al., 1968), which has an affinity with the Convolvulaceae.

c) Tricolporates
Genus Areolipollis Clarke & Frederiksen, 1968
Areolipollis vesiformis Clarke & Frederiksen, 1968
Pl. 2, Fig. A

Prolate pollen grains tricolporate and not dicoporote as described by Clarke and Frederiksen (1968). The modern pollen grains are 3-colporate. This species exhibits areolate ornamentation. The specimens found in the present study constitute the first fossil record of this genus from Egypt. The grains bear affinity possibly with the Acanthaceae and/or Umbelliferae.

Genus Fenestrites Van Der Hammen, 1956
Fenestrites spinosus Van Der Hammen, 1956
Pl. 1, Fig. T

Single grain, radially symmetrical, isopolar, spherical. Colpi and port indistinct, probably tricolporate. Exine is differentiated into a pattern of insectate lacunae (fenestrae), 8-11 μm wide and tectate-columellate cristate. This species is typical for the liguliflorae pollen type of the Asteraceae (Compositae) which is produced by a large number of genera (Germerra et al., 1968).

Genus Margocolporites Ramanujam, 1966
Margocolporites vanwijfie Germerra et al., 1968
Pl. 2, Fig. B

Two specimens of this distinctive pollen type were recorded from the Rudies Formation. They conform closely to the original description given by Germerra et al. (1968) from the Tertiary of Venezuela. The reticulum of the intercolpi is, however, somewhat finer than in the type material, but falls within the range of variation described. Affinity probably with the Caesalpinioidea of the Fabaceae, Germerra et al. (1968) noted a close similarity with two species of Caesalpinia.

Genus Scabraticolporites Roche & Schuler in Ramanujam, 1966
Scabraticolporites sp.
Pl. 2, Fig. L

Genus Tricolporopollenites Pflug & Thomson in Thomson & Pflug, 1953

Remarks.–The name Tricolporopollenites is very much a convenient name with which to describe common occurring pollen which have no known value in palynological interpretation.
Tricloropollinodites sp. A
Pl. 1, Figs. E, N

Prolate tricolpate pollen. The colpi and equatorial pores are distinct. The ornamentation is plicate. The exine is thin. Specimens have been found in the two studied formations. The specimen illustrated (Pl. 1, Fig. E) is similar to Cutiplferopollinodites pusillus (Potonié) Potonié 1951 recorded from the Oligocene of Egypt (Kedves, 1985).

cf. Elaeocarpaceae sensu Truswell et al., 1985
Pl. 1, Fig. J

Some tiny, smooth-walled tricolpate pollen grains (Pl. 1, J), of diameter 25 μm, are here compared informally to Elaeocarpaceae. They occur sporadically throughout the sampled sequence, in frequencies of up to 1% of the total pollen count.

d) Stephanoconulopales

Genus Retistephanopollispites
Leidelmeyer, 1966

Remarks. —Retistephanopollispites is used here for the radially symmetrical, isopolar, oblate, 6-7 colpate pollen. The ornamentation is reticulate-foveolate, luminae oval to circular, 1-2 μm in diameter. Muri 1.00 μm wide.

Retistephanopollispites williamsi Germena et al., 1968
Pl. 2, Fig. H

This species is comparable to the form identified from the Campanian/Maastrichtian of the Red Sea area (El Beialy, 1995). Miocene of the Nile Delta (El Beialy, 1990a, 1992) and the upper Miocene (Tortonian) of the Gulf of Suez (Ahmed and Pockna, 1994). The combination of 5-6 short apertures, spongy columellate structure and reticulate-foveolate tectum is so far only known from Cenolophonaceae. It is therefore important to identify the R. williamsi with this Indo-Malayan species (Germena et al., 1968).

e) Stephanoconulopales

Genus Psilastephanopollispites
Leidelmeyer, 1966
Psilastephanopollispites laevigatus
Salard-Cheldolaf, 1979
Pl. 2, Fig. E

Genus Pterocaryopollispites Raatz, 1937

The species observed from the Miocene of the Gulf of Suez appears to have a much thicker wall than the form referred to Pterocaryopollispites stellatus (Potonié) Raatz, 1937, from the Oligocene of Central British Columbia (Piel, 1971). Affinity probably with the Juglandaceae. This form is similar to Verrustephanopollispites complanatus Salard-Cheldolaf, 1978, and Pterocarya stellata (Potonié) Martin & Rouse, 1966.

f) Monoporadites

Genus Graminidites Cookson, 1947
Graminidites sp.
Pl. 1, Fig. K

Graminidites is thin-walled pollen and reveals an infragranulate structure. They have a smooth to scabrate ornamentation. The pore is well defined and without a distinct annulus. Graminidites is better known from the Palaeogene and Neogene of Egypt (Kedves, 1981, 1985; El Beialy and Kora, 1987; El Beialy, 1992). The fossil species closely resembles non-cultivated Poaceae (Gramineae) pollen.

g) Triroradites

Genus Monipites Wodehouse, 1933
Monipites sp.
Pl. 2, Fig. G
Genus Polyatriopollispites Pflug, 1953
Polyatriopollispites sp.
Pl. 1, Fig. S
Genus Triorites Muller, 1968
Triorites tenuissimus Muller, 1968
Pl. 2, Fig. F

This is oblate triroradite pollen with a triangular amb and convex sides. Pores are situated equatorially and the apertures protrude over the surface, with the surrounding exine slightly thickened.

h) Periporadites

Genus Peripropollispites Pflug & Thomson in Thomson Pflug, 1953
Peripropollispites sp.
Pl. 2, Fig. C

The illustrated specimen has a circular amb. The pores are arranged meridionally. The ornamentation is smooth to scabrate. The specimen figured here
resembles those recorded from the Oligocene-Miocene of Egypt (Kedves, 1981, 1985; El Beialy, 1992; Ahmed and Pocknell, 1994). It is also similar to Polyspora multiporosa Kars 1985 and Chenopodium pollis multiplex (Weyland & Pflug) Krutzsch, 1966.

i) Obligate polads

Genus Acaciapollenites Mildenhall, 1972
Acaciapollenites myroisporites (Cookson) Mildenhall, 1972
Pl. 2, Fig. D

This species occurs as a rare component in some samples, which puts the basal occurrence of Acaciapollenites early in the early Eocene of the Western Desert of Egypt (Guinet et al., 1987) and its uppermost occurrence in the Plio-Pleistocene of the Nile Delta (Saad et al., 1987). Similar late Miocene and late Oligocene-early Miocene reports were made by Partridge (1978), Truswell et al. (1985) and Torricelli and Biffi (2001) from the Angola Basin off the west Coast of Africa, Australia and Tunisia respectively. This fossil pollen is referable to the subfamily Mimosoideae of the Leguminosae as compared with the species of Acacia illustrated by Maley (1972) from the recent pollen spectra of Lake Chad and by Sowunni (1973) from Nigeria. The earliest occurrence of this pollen in Australia is from the early Miocene (Stover and Partridge, 1973).

Miscellaneous

Foraminiferal test linings
Pl. 2, Fig. M

These occur abundantly in the Rudeis and Kareem formations.

Fusiformisporites sp.
Pl. 2, Fig. O

These fungal spores occur rarely in the investigated samples.

Multicellularisporites sp.
Pl. 2, Fig. N

These fungal spores occur abundantly in the investigated samples of the Rudeis and Kareem formations, with no value in palynological interpretation.

Genus Ovoidites Potonié, 1951
Ovoidites sp.
Pl. 2, Fig. I

This form of freshwater algae possesses a furrow, which traverses the entire long axis of the specimen. This microfossil type appears to be similar in its apertural configuration to specimens of Ovoidites illustrated by Zippi (1998). Ovoidites is known from the Pliocene-Pleistocene of central Egypt (Mahmoud, 2000).

AGE ASSESSMENT

A diverse assemblage of spores and pollen was recovered from the Tertiary subsurface section of the GS-78-1 well (Table 1). Their distribution is illustrated in Fig. 2. and mounted on plates 1 and 2. Not illustrated are Echipterisites estelae Germeraad, Hopping & Muller, 1968, and the bisaccate pollen for which no satisfactory specimens could be located.

Age determination for the Tertiary subsurface section of the GS-78-1 well, based on dinoflagellate cysts (El Beialy & Ali, 2002) has provided an excellent framework against which to describe the distribution of fossil spores and pollen in the well. It should be noted, however, that the apparent lowest occurrences in time of the individual species may be erroneous. There is undoubtedly considerable uphole contamination which tends to artificially extend the ranges downward. It is for this same reason that we rely mostly on highest occurrence data.

Rudeis Formation

Some of the taxa which appear to be confined to, or occur more frequently in the Rudeis Formation include Perforicolpites digitatus, Fenestrites spinosus, Margoocolpites vanwijheii, Striatopolpis catahumus and Areolipollis vespiiformis. Perforicolpites digitatus was firstly described from the early-middle Eocene of Colombia (González Guzmán, 1967). It has, however, been reported from the late Oligocene of New Zealand (Pocknell, 1982). This species has also been reported from the early-middle Oligocene of Australia (Truswell et al., 1985) and the late Eocene/Oligocene of the Sudan (Kaska, 1989). This taxon also has a fossil record extending into the late Neogene off the west Coast of Africa (Partridge, 1978). This species was reported by Germeraad et al. (1968) from the Caribbean area and Nigeria occurring for the first time approximately at the base of the
Verrucatosporites usmensis Zone (late middle Eocene–late Eocene), but, while continuously present in the former area up to Recent, in Nigeria disappearing from the record in the upper part of the Magnastratiotes howardi Zone (early Miocene). In Borneo it is present at least from the base of the Echitriculporites spinosus Zone (middle Miocene) upwards. The record of this species from Venezuela (Rull, 2001) provides a clear indication that P. digitatus does extend into the early Miocene.

Fenestrites spinosus was restricted to the middle and upper part of the F. spinosus Zone (middle Miocene) onwards (Germerra et al., 1968) in Nigeria and the Caribbean area. This pollen taxon belongs to the Liguliflore type of the Asteraceae (Compositae). Although this family has a fossil record extending questionably into the Oligocene (Leopold, 1969) it is first reliably recorded on all continents from early to middle Miocene (Germerra et al., 1968; Stover and Partridge, 1973; Williams, 1975) and generally and consistently and abundantly in late Miocene or younger sediments (Partridge, 1978).

Margaroculporites vanwijhei has not previously been reported from Egypt. M. vanwijhei was reported by Germerra et al. (1968) as having an Eocene-Recent range in the Caribbean, an Oligocene-Recent range in Borneo, and an Oligocene-Eocene range in West Africa. Extratropical records of the species are those from the late Oligocene in Southland New Zealand (Pocknell, 1982), late Neogene of southern Africa (Partridge, 1978), and the early-middle Oligocene of south Australia (Truswell et al., 1985).

Striatopollis catatamus first occurs in lower Eocene deposits in Colombia (González Guzmán, 1967), Nigeria (Takahashi and Jux, 1989a), Venezuela (Colmenares and Teran, 1993) and Qatar (El Beialy, 1998). It also occurs in the Caribbean area and in Nigeria from the base of the Retribvirriculporites triangulum Zone upwards (late Palaeocene-early Eocene) as suggested by Germerra et al. (1968).

This is the first record of S. catatamus from the Miocene of Egypt; it has, however, been reported from the upper Eocene to Oligocene strata of the Sudan (Kaska, 1989), the Neogene of southern Africa (Partridge, 1978) and the early Miocene of Venezuela (Rull, 2001).

The GS-78-1 site has also provided a good fossil record of Areolopollis vesiformis, which is present in the Rudeis Formation. This is the first evidence to be published that A. vesiformis is present in the Miocene of Egypt. Most previous accounts suggest that it appeared in Upper Tertiary sediments of Nigeria (Clarke and Frederiksen, 1968). The Umbelliferopollenites poisseniensis Kirchner, 1984, record from the late Oligocene of southern Bavarian pitch coal mine district (Kirchner, 1984) might be conspecific.

Acaciapollenites myriosporites has its earliest occurrence in the early Miocene of Australia (Stover and Partridge, 1973), late Neogene of Africa...
Polyadapolliites Pflug & Thomson in Thomson & Pflug, 1953, recorded from the late Oligocene-early Miocene of Tunisia (Torrècelli and Bifiti, 2001) may be similar and therefore a younger Neogene age may seem plausible to the Rudeis Formation.

It can be concluded that collateral evidence concerning the age of the Rudeis Formation in the GS-78-1 well is available in the form of a few number of fossil pollen discussed above. The pollen assemblage is interpreted to have a general early Neogene range. On the basis of documented stratigraphic ranges, the age can be further restricted to early Miocene. This is based on the overall composition of the Rudeis Formation, which contains a substantial number of taxa that are common in the Miocene palynofloras of Angola (Partridge, 1978) and the Nile Delta which is largely composed of taxa typical of the Miocene (El Beialy, 1990b, 1997), but also includes several taxa more characteristic of the Palaeogene (e.g., Pistillipollinites Rouse, 1962, El Beialy, 1988). This mixture of plant types, along with stratigraphic relations is also used to infer an age of early Miocene for the Rudeis Formation palynoflora as supported by other findings based on forams and nanoplankton (El-Heiny & Martini, 1981), nanoplankton (Evans, 1988; Said, 1990) and dinoflagellate cysts (El Beialy and Ali, 2002).

Kareem Formation

The foregoing discussion indicates the marked similarity between the Kareem fossil assemblage and other Miocene assemblages from the Nile Delta and the Gulf of Suez. It is sometimes difficult, however, to consistently differentiate early and middle Miocene assemblages in the Gulf of Suez area. The only difference is that in the Rudeis Formation an apparent anomaly exists in the occurrence of Eocene taxa in the GS-78-1 pollen palynoflora. The overlying Kareem Formation, on the other hand, contains an abundance of herbs in the pollen palynoflora suggesting that the age is early to middle Miocene, based on dinoflagellate cysts (El Beialy and Ali, 2002) rather than early Miocene as originally inferred by the Egyptian Stratigraphic Sub-Committee (1974).

The Kareem Formation palynoflora contains a high proportion of taxodiaceous conifers, Schizaeaceae, Poly Podiaceae, Gramineae, Compositae, Chenopodiaceae, Malvaceae, Epideraceae and Onagraceae. The chiefly herbaceous families Gramineae, Compositae and Malvaceae though known from older sediments, they first appear consistently in the Neogene (Leopold, 1969). Pollen referable to the non-cultivated grass (family Gramineae) is common in the productive samples of the Kareem Formation. The rise in the abundance of the grass pollen is a feature characteristic of the Neogene pollen record (Germeraad et al., 1968). The periporate pollen retrieved from the Kareem Formation, and referable to the family Chenopodiaceae/Amaranthaceae have a consistent fossil record back as far as the Oligocene (Stover and Partridge, 1973).

In conclusion, although herbs are abundant in the pollen palynoflora and they have no biot stratigraphic importance at that time, they may be locally used to assign the age of the Kareem Formation to early to middle Miocene, based on comparison with the Weaverville pollen palynoflora, USA (Barnett, 1989).

PALAEOECOLOGICAL AND PALAEOClimatological Significance

The spores and pollen assemblages recovered from the Rudeis and Kareem formations encountered in the GS-78-1 well are preserved through sedimentation in a relatively deep water environment to an outer continental shelf deposits to upper bathyal (distal) environments (El Beialy and Ali, 2002). Observed incursions of terrestrial elements in the Rudeis Formation may have been carried about within the basin of deposition by the waters of the Mediterranean Sea, or that they were displaced into a deep water environment (El Beialy and Ali, 2002). Conditions were dominated floristically by wet-loving plants, which inhabit the flood-plain ecosystem. Evidence comes from the presence of the dispersed pollen Salixpollinites in the Miocene of the Gulf, which are similar to pollen from modern plants and the dinoflagellate cyst Tuberculodinium vancampae (Rossignol) Wall, 1967. Salixpollinites grows in wet, damp and humid conditions (Wilkinson and Boulter, 1980). T. vancampae may be an indicator of more humid conditions because it is more tolerant of fresh water input than many other dinoflagellates (Morzade-Kerfourn, 1992). It is obvious that T. vancampae tends to be more common at times of abundant Pitus and is seldom common in assemblages dominated by Polyphaeridium zoharyi (Rossignol) Bujak et al., 1980, a species more tolerant of high salinity (Pocknall et al., 1999). Wet-loving plants are associated with trees, shrubs and herbs, probably occupying various niches which are preserved at certain levels of the section studied. There is also a
persistent coniferous vegetation or upland palynofloras represented by the bisaccate pollen, which are related to the modern *Pinus*, and the taxodiaceous conifer pollen most like that of a more autochthonous *Taxodium*-like swamp forest element, which remained rather long in the Palaeogene of Egypt (Kedves, 1985; Takahashi and Jux, 1989b). Another confirmatory evidence for humidity also comes from the presence of the fern spore *Polypodiaceoiosporites* in the Rudeis Formation. It is often regarded as being indicative of damp and humid conditions (Wilkinson & Boulter, 1980).

The Tertiary climate of the Gulf of Suez may also be inferred by comparing the modern and ancient vegetational assemblages and also on the assumption that present ecological requirements were also similar in the Tertiary (Barnett, 1989). Nearly all the modern taxa represented by the Gulf of Suez palynomorphs are subtropical to warm temperate (e.g., *Taxodium*, Gramineae, Chenopodiaceae, Polysspodiaceae). In contrast, Malvaceae are typically tropical to cool temperate (Fig. 3).

The above types of mixed vegetation were found in Egypt near the Nile Delta (El Beialy, 1988; Pounot and Bouroullec, 1984). This mixing can be understood if we assume that ecological requirements have not changed appreciably through time, and palynomorphs from various intervals are mixed at the site of deposition. An alternative interpretation is that some taxa were adapted to different conditions in the Tertiary.

![Figure 3: Stratigraphic ranges (worldwide) of key palynomorphs that are represented in the Miocene pollen flora of the GS-78-1 well, Gulf of Suez, Egypt.](image)

<table>
<thead>
<tr>
<th>Epoch</th>
<th>Fossil Families</th>
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<tbody>
<tr>
<td>Eocene</td>
<td><em>Calamophytites</em></td>
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<td><em>Parahelicaspora</em></td>
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<td></td>
<td><em>Lagusanites</em></td>
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<td></td>
<td><em>Mammothites var. ramosissimus</em></td>
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<td></td>
<td><em>Cherophyta</em></td>
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<td></td>
<td><em>Chenopodiaceae</em></td>
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<td></td>
<td><em>Mammillarodendron</em></td>
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<td><em>Pteridophyllophyllum</em></td>
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<td><em>Aceritex</em></td>
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Figure 3: Stratigraphic ranges (worldwide) of key palynomorphs that are represented in the Miocene pollen flora of the GS-78-1 well, Gulf of Suez, Egypt.
and/or vegetational zonation in the Gulf of Suez was not pronounced. However, throughout the Tertiary the Earth underwent important climatic changes and the region that now is Egypt was not an exceptional place. Therefore taphonomical processes such as reworking are possibly responsible for this mixing of the Gulf of Suez palynoflora.

Another approach to interpreting palaeoclimate is based on the fluctuations in the Gramineae and Pinus pollenites abundance curves (Fig. 4) and the presence of the dinoflagellate cysts Spiniiferites spp., as reported by Pocknall et al. (1999) from the Pliocene of the Gulf of Suez area. The curve indicates that the vegetation of the Gulf of Suez fluctuated from grassland Savanna with very few forest elements (dry phase) to a shrubland forest landscape in which Pinus pollenites and other conifers were the common components (humid phase). But, however, the percentage of bisaccate pollen grains in the Kareem Formation could also be explained by means of change of regional winds. Likewise, the high percentages of Poaceae and Chenopodiaceae (Fig. 5) may indicate grassland. Spiniiferites spp. are most common at the same time that Gramineae dominates the assemblages. These cooler water dinoflagellates (Edwards, 1992) together with the dominance of Gramineae are probably indicative of cooler and drier (arid) climate (Glacial phase). During the last glacial episode when conditions were cool and dry in low latitudes (present day tropics), grassland-Savanna was the most common vegetation type (Van der Hammen, 1974). Chenopodiaceae are generally more common with the grassland Savanna assemblage and indicate dry, arid, salt marsh conditions (sabkha) as deduced from the Pliocene of the Gulf of Suez (Pocknall et al., 1999).

This warm and arid episode is supplemented by the presence of Monocolopollenites and the dinoflagellate cyst Polyplastridium zoharyi. The relative frequency of Monocolopollenites is particularly moderate in the two studied formations, and some would interpret this as evidence of a warming of the climate in the early/middle Miocene. The presence of P. zoharyi, which is adapted to high salinity waters (Morad-Kerfoum, 1992) could possibly be an indicator of arid conditions. In this study, however, P. zoharyi is common at times in both the dry (grassland-Savanna) and humid (shrubland forest) phases, suggesting that the oscillation in its abundances is more related to local

<table>
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<tr>
<th>TAXON</th>
<th>Tropical</th>
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<th>Warm Temperate</th>
<th>Cool Temperate</th>
<th>Boreal</th>
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<td>Pediadrum</td>
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<td>Lycopodium</td>
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<td>Pinus</td>
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<td>Compositae</td>
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<td>Malvaeae</td>
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<td>Pterocarya</td>
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FIGURE 4—Climatic ranges of extant taxa represented by palynomorphs in the Rudies and Kareem formations, GS-78-1 well, Gulf of Suez, Egypt. (Modified after Barnett, 1989).
environmental changes than to regional climatic changes. The presence of P. toharyi may indicate the prevalence of tropical to subtropical conditions during the sedimentation of the Kareem Formation (El Beialy and Ali, 2002).

CONCLUSIONS

The Rudeis and Kareem pollen palynoflora recovered from the GS-78-I well may be especially significant in recording the presence of typically Palaeogene taxa in the early-middle Miocene of the Gulf of Suez. The closest modern analogs for such associations are the palynofloras of southeastern Asia, and North America. Modern vegetation in those regions grows in a fairly warm, mild subtropical climate. A similar climate in the Gulf of Suez area during the mid-Tertiary may have allowed the Palaeogene taxa to exist.

The pollen assemblage examined from the Rudeis Formation is interpreted to have a general early Neogene age range. On the basis of documented stratigraphic ranges, the age can be further restricted to early Miocene based on the presence of a group of pollen that were first recorded from the Tertiary strata in the modern tropics, although in low numbers; these include Acaciapollenites myriosporites, Arecopollenites vespiformis, Fenestrites spinosus, Margococcolpitites vanwijheii, Perforocollites digitatus and Striulopolis catatumbus.

The samples examined from the Kareem Formation contained long-ranging taxa belonging to the families Gramineae, Compositae, Malvaceae and Chenopodiaceae. The abundance of herbs in the pollen palynoflora was sufficient only to verify early to early middle Miocene age to the Kareem Formation in the GS-78-I well, based on similar findings from the Weaverville pollen palynoflora, USA (Barnett, 1989).

Vegetation on land during the Miocene fluctuated from dry (cool) grassland-Savanna to humid (warm) shrubland forest dominated by Pinuspollenites. The presence of Compositae and Gramineae was taken as an indication of drier habitats and areas of lower rainfall. Their presence also indicates open steppe or grassland conditions during this interval (Piel, 1971).

Locally, Chenopodiaceae occupied brackish swampy sites of deposition. In the Kareem Formation conifers together with Gramineae dominate with a more typical Mediterranean climate, which is also established during the Mio-Pliocene of the Nile Delta (Poumot and Bouroulec, 1984) and the Pliocene of the Gulf of Suez (Pocknell et al., 1999).

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