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Paleoenvironmental Conditions as Recorded by Globigerinoides Sacculifer and Globigerinoides Ruber from the Northern Red Sea

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Abstract: The distribution of *Globigerinoides sacculifer* and *Globigerinoides ruber* have been investigated to reconstruct the environmental conditions prevailed during the deposition of Late Pleistocene sediments in four cores from the central and northern Red Sea. The anticyclic relation between both species has been successfully used to identify ecostratigraphic events in the northern Red Sea. The foraminiferal assemblage in the southern Red Sea is strongly masked by imported specimens via the inflow of water from the Gulf of Aden. Its influence extends far beyond the convergence zone to the northern Red Sea. The dominance of *G. sacculifer* over *G. ruber* in Holocene sediments reflects normal marine conditions similar to those existed at present in the northern Red Sea. Strong south-north salinity and nutrient gradients have been developed during the LGM, due to reducing influx of water from the Gulf of Aden to the basin. The influence of Aden waters during the Upper Wuerm Pleniglacial in the southern Red Sea probably extended in some events to the central Red Sea and the salinity remained much below the tolerance limit of *G. sacculifer* and no aplanktonic zone has been developed. Rising salinity beyond 49 psu, the threshold for planktonic forams, resulted in the development of aplanktonic zone. Dust minerals carried by wind as well as the productivity are the main sources influencing the sedimentation rates and the composition of the sediments during the Holocene. Terrigenous input of material became more important during the Upper Wuerm Pleniglacial when large areas of the shelf were exposed.

Key words: Red sea, planktonic foraminifera, ecostratigraphy, upper wuerm pleniglacial, aplanktonic

INTRODUCTION

The Red Sea, having a length of more than 2000 km and a width of 300 km is like a long tube joining the Mediterranean Sea to the Indian Ocean. The climate over the Red Sea and the surrounding land masses is very arid and hot. High evaporation that exceeds 2 m year^{-1} (Morcos, 1970) and the absence of river inflow is balanced by a surface water inflow from the gulf of Aden, coupled with under-outflow of relatively higher salinity water from the Red Sea.

However, the interchange of water between both bodies, through the relative shallow Bab el-Mandib (137 m b.s.l), is more complicated, since the winds change with seasons. Associated with the Indian monsoon, the prevailing SEE winds in winter enhance the surface water inflow from the Gulf of Aden, above an existed subsurface outflow from the Red Sea. In summer the prevailing NW and NNW winds throughout the year force the surface water of the Red Sea to flow out and the inflow to the basin is reduced to a weak shallow subsurface currents (Smeed, 1997). Surface water currents derived by the SSE winds northward, while to the north of 20°N NW winds drive a weak surface current to the south, move toward each other with the result of convergence of surface waters at 20°-25°N (Patzert, 1972, 1974). The relative fresh and nutrient rich waters inter the Red Sea, moves northward as eastern and western boundary currents (Eshel and Naik, 1997). It becomes denser and the salinity rises up to 40.6 psu in the northern Red Sea, where relatively high saline intermediate and deep waters are formed and ensure the ventilation of the entire basin,

Arz *et al*. (2003) suggested that the formation of intermediate and deep water is largely dependent on the thermocline preconditioning of northward moving water and the interaction with dense subsurface water coming from the Gulf of Suez. However, different modes have been suggested for the renewal of the deep water in the Red Sea with varying results in the time average of residence time, range between 30 to 300 years (Manins, 1973; Cember, 1988; Woelk and Quadfasel, 1996).

The top of the pycnocline is changed seasonally. In summer the top has been given by Quadfasel and Baudner (1993) at 200 m water depth in the area 21-23° N and at 50 m depth in the southern Red Sea. In winter the pycnocline is almost diminished in the north, while the top lies at 70-80 m in the south. The surface water is saturated with oxygen (Weiss, 1970). The oxygen content decreases rapidly with depth and the minimum values have been found at 400-500 m depth in the north, rise gradually to

300-400 m depth in the southern Red Sea (Morcos, 1970; Grasshoff, 1975; Weikert, 1987; Quadfasel and Baudner, 1993; Woelk and Quadfasel, 1996). The top of the oxycline follows the same tendency and rises from 200 m depth in the north to 100 m depth in the south, indicating the importance of the Oxygen Minimum Zone (OMZ) in the southern Red Sea.

The lowering of sea level in glacial stages resulted in reduction of water exchange between the Red Sea and the Gulf of Aden, A strong salinity gradient to the north has been developed and the nutrients stripped as the water moves northward. The maximum salinity remained in the southern Red Sea below 45 psu, while in the north exceeded 50 psu, Upper limits of 55 and 57 psu were given by (Thunell *et al.*, 1988; Geiselhart, 1998), respectively and Arz *et al.* (2003) found that the salinity during the Last Glacial Maxima (LGM) in the northern Red Sea was 10 psu higher than the calculated salinity for the late Holocene and reached 50.6 psu, while the average temperature was 22.5C. Planktonic foraminifera recorded throughout the glacial strata from the southern Red Sea, core 172 p (15° 17. 7`N) indicate that the inflow of Indian waters to the Red Sea through the strait of Bab el-Mandib continued throughout the last glacial stage (Yusuf, 1976, 1978; Behairy and Yusuf, 1984). The oxygen isotopic values reported by Deuser *et al.* (1976) for the southernmost Red Sea and the Gulf of Aden suggested also the connection of both bodies during the last glacial period.

The inflowing of nutrients enriched surface water from the Indian Ocean to the Red Sea and its movement inward the basin, results in increasing salinity and relatively more oligtrophic conditions in the northern Red Sea. The distribution of planktonic foraminifera along a S-N transect reflects these changing conditions and shows two distinct distribution patterns (Fenton *et al.*, 2000). At present *G. ruber* dominates over *G. sacculifer* in the southern Red Sea. In the northern Red Sea, where the salinity exceeds 40 psu and relatively more oligitrophic conditions prevailed, *G. sacculifer* dominates over *G. ruber*. As might be expected the distribution pattern of both species in Holocene strata is most likely similar to their distribution at present since the environmental conditions prevailed at least in late Holocene are similar to those existed at present. The reverse relationship between *G. sacculifer* and *G. ruber* is controlled by many factors, including food-quantity and quality, the circulation pattern and the salinity-temperature tolerance limits for both species.

The anticyclic fluctuation between *G. ruber* and *G. sacculifer* has been successfully used in the stratigraphic subdivision of Red Sea cores (Olausson, 1971; Rish, 1976; Yusuf, 1978; Behairy and Yusuf, 1984) despite the reasons for this behavior.

Berggren and Boersma (1969) proposed that lowered temperature superimposed on high salinity controls the response of *G. ruber* in the Red Sea sediments. Yusuf (1978) proposed salinity changes to be of prime importance. He interpreted the absence of *G. sacculifer* and the dominance of *G. ruber* in glacial sediments as a result of hypersaline conditions generated by the lowering of sea level in glacial periods. Yusuf (1976) calculated the upper salinity limits for *G. ruber* at 50 psu, which may have led to the absence of this species in the last glacial interval from the central and northern Red Sea.

Experimental studies carried out by Bijma *et al.* (1990) on living species indicate also that the upper salinity limits for *G. ruber* and *G. sacculifer* could explain their anticyclic fluctuation in late Pleistocene sediments from the Red Sea. Based on the present day distribution pattern of the planktonic foraminifera particularly *G. sacculifer* and *G. ruber* in the Red Sea, this paper aims to define stratigraphic subdivision of late Pleistocene sediment cores from the central and northern Red Sea. Considering the new results obtained in the last years on living and disappearance of planktonic foraminiferal species, the distribution of the species investigated herein may help to reconstruct the environmental conditions under which Late Pleistocene sediments were deposited in the Red Sea.

MATERIALS AND METHODS

Sediment cores from the central and northern Red Sea between 20° and 26° N were collected with a box corer from Volcano, Thetis, New and Shaban deeps during the German research expedition in early 1984 with RV, Sonne (Fig. 1). Location, length of the sediment core and water depth of the four cores are given in Table 1. The core samples were kept at room temperature in an aluminum container before reaching the laboratory in which the cores stored in a deep-freezer. The samples were retrieved from a 2 cm wide strip along one side of the box core. At intervals of 10 to 20 cm sub-samples were used for the textural, mineralogical, geochemical and micropaleontological analyses. For micropaleontological investigation, the sediments were washed through 63 µ mesh-sieve and the fraction remained in the sieve was air-dried. Two hundred individual foraminiferal tests were identified in the sand fraction of each sample and the frequency of *G. sacculifer* and *G. ruber* were calculated.

Based on the subdivision of the core sequences the sedimentation rates have been calculated, using time intervals of 0-11 and 12-27 ka for the Holocene and the Upper Wuerm Pleniglacial, respectively.

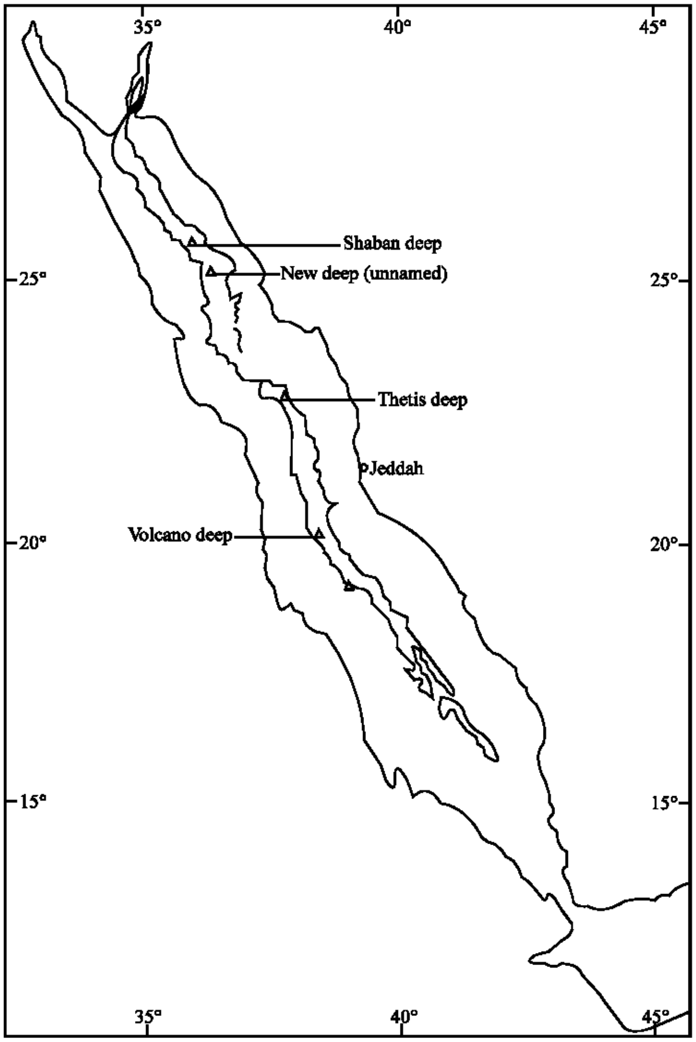

Fig. 1: Location of the Deeps in the axial trough of the Red Sea

Table 1: Location, length and water depth of the studied cores

Core No.	Name of the deep	Length of core (m)	Lat. N	Long. (E)	Water depth (m)
KL-282	Volcano	1.90	20° 01′.	38° 26. 7′	2000
KL-320	Thetis	5.00	22° 47.4′	37° 35. 7′	1769
KL-366	New Deep	3.00	25° 1.7′	36° 16. 2′	1585
KL-379	Shaban	6.00	26° 13.6′	35° 22. 5′	1444

RESULTS

The most common spinose species in the studied sediments are : *Globigerinoides ruber*, *Globigerinoides sacculfer*, *Globigerinella siphonifera*, *Globoturborotalita rubescens*, *Globoturborotalita tenella* and *Orbulina univera*, The stratigraphic subdivion of the cores as shown in Fig. 2 is based on the frequency distribution of *G. sacculfer* and *G. ruber*. The dominance of *G. sacculfer* in respect to *G. ruber* indicates normal marine conditions similar to those existed at present.

In the Early and Late Holocene the planktonic foraminifera make up to 90% of the sand fraction. Their abundance decreases to 30% of the sand fraction at some levels where the pteropods occur in huge numbers. *G. sacculifer*, *G. ruber*, *G. siphonifera* and *O. universa* are the most abundant species and contribute more then 90% of all specimens in this interval. However, this interval is characterized by the dominance of *G. sacculifer* in respect to *G. ruber*. Benthic foraminifers occur throughout the Holocene strata but in small quantities (<2%).

Hypersaline conditions coupled with changes in the circulation pattern caused by the lowering of sea level prevailed during the last glacial are indicated by the dominance of *G. ruber* over *G. sacculifer*, *G. ruber* and absence of *G. sacculifer* or by completely disappearance of the planktonic foraminifal assemblage, including the benthic foraminifers. The most abundant group among the benthic foraminifers is Miliolidae, particularly Triloculina.

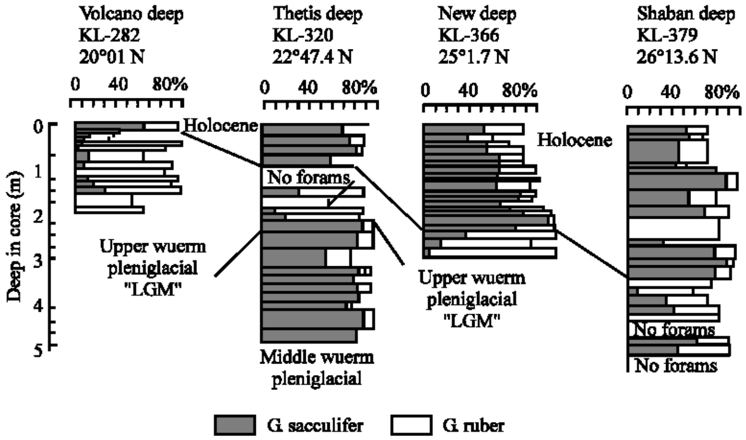

Fig. 1: Frequency distribution of *Globigerinoides sacculifer* and *Globigerinoides ruber* in young pleistocene sediments from central and northern Red Sea

Table 2: Approximates of sedimentation rates cm/1000 year) during the different epochs in the deeps

Core No.	Holocene 0-11ka	Upper Wuerm Pleniglacial LGM 12-27 ka
KL-282	1.8 cm	>11.2 cm
KL-320	8.2 cm	8.1 cm
KL-366	20.5 cm	>4.7 cm
KL-379	30.9 cm	>13.7 cm

The occurrence of argonitic pteropods indicates that no selective dissolution of foraminiferal tests has took place In the Middle Wuerm pleniglacial. All species that observed in the Holocene are present but in different proportions. G. *sacculifer* makes up to 60% of the total foraminiferal assemblage, follow by small, thick shelled *G. ruber*, while the pteropods are scarce.

The calculated sedimentation rates vary widely from one deep to another. They range from 8.1 cm in Thetis Deep to >13.7cm/1000year in Shaban Deep during the Upper Wuerm Pleniglacial and from 1.8 cm in Volcano Deep to 30.9 cm in the Shaban Deep during the Holocene (Table 2).

DISCUSSION

General distributions of planktonic foraminifera: The present distribution of planktonic foraminifera in the Red Sea is more related to the circulation pattern in the Red Sea, derived by its natural connection to the Indian Ocean and the extremely high evaporation rate as well as the prevailing winds throughout the year. *G. sacculifer* dominates the foraminiferal fauna in the northern Red Sea, while *G. ruber* is the dominant species in the south, with substantial numbers of *G. siphonifera*, *Globigerinita glutinata* and *Globorotalia menardii*, among others. The area between 17° and 22° N in which equal populations of *G. sacculifer* and *G. ruber* occur, separates the northern from the southern Red Sea (Auras-Schudnagies *et al.*, 1989; Kroon, 1991). *G. ruber* completely dominates the planktonic foraminiferal assemblage in the water of the Gulf of Aden while *G. sacculifer* does not exceed 10%. In top sediments G. ruber makes up to 26% while *G. sacculifer* does not exceed 2% (Ivanova, 1985). In the southern Red Sea *G. ruber* decrease in occurrence relative to the Gulf of Aden, while *G. sacculifer* increases. In addition to that *G. ruber* is a shallow water species, while *G. sacculifer* reproduce at around 80 m depth (Bijma and Hemleben, 1994), or deeper (Reiss *et al.*, 1980, 1999; Reiss and Hottinger, 1984). Therefore it is expected that *G. ruber* is the most important species in respect to *G. sacculifer* transported via the water-inflow from the Gulf of Aden to the Red Sea, Consequently the frequency distributions of both species in the southern Red Sea may shifts in the interest of *G. ruber*. However, It is most likely that the population of *G. ruber* in the water column and in top sediments in the southern Red Sea is strongly masked by displaced specimens from the Gulf of Aden. The decreasing tendency of *G. ruber* northward in the southern Red Sea is most likely related to the decreasing influence of the Aden population to the north as well as to the overall south-north decreasing tendency of nutrient content, that results in decreasing zooplankton diversity and primary productivity (Halim, 1984; Weikert, 1987). Sustainable inflow indicated by shifting of the absolute and relative peak abundance of *G. ruber* and *G. siphonifera* toward the north, has been observed by Auras-Schudnagies *et al.* (1989). They found that the presence of the non-spinose species *G. menardii* in surface waters of the northernmost Red Sea and the oxygen isotope values of this species indicate that *G. menardii* population in the Red Sea were expartiated. The south-north nutrient and salinity gradients as well as the circulation pattern produced unfavorable conditions in the northern Red Sea, probably better tolerated from *G. sacculifer* than *G. ruber*. *G. sacculifer* dominates the foraminiferal fauna in the water column and in the top sediment, even by reproduction cycle of 29 days compared with a cycle of 14 days for G, ruber (Reiss and Hottinger, 1984). However, the dominance of *G. sacculifer* in respect to *G. ruber* in the northern Red Sea can not be explained with the salinity control alone, even not with the low nutrient content. It must be seen as a result of combined factors including the diet preferences of both species. *G. ruber* is an herbivorous species feed mainly on phytoplankton (Auras-Schudnagies *et al*., 1989), while *G. sacculifer* is carnivorous species and has a variety of diets, partly on algae (Anderson, 1983) but prefers calenoids (capepods) that bound to the mesopelagic zone in the central Red Sea, (Hemleben *et al*., 1989). In agreement with Auras-Schudnagies *et al.* (1989) it is believed that the diet preference is most likely the main factor that affects the populations of both species at present time in the northern Red Sea, where *G. ruber* at disadvantage due to the strongly limited nutrient supply. The reducing abundance of *G. sacculifer* in the southern Red Sea probably related to the oxygen minimum zone (OMZ) that occurs within the reproduction habitat of *G. sacculifer*, while in the northern Red Sea the (OMZ) lies distinct below.

Reiss *et al.* (1980) correlate the present day north-south trend of species abundance in the Gulf of Aqaba and northern Red Sea with nutrient content and to some extent with temperature. They found that the influence of *G. sacculifer* on the total standing crop is evident both within the Gulf of Aqaba and outside in the northernmost Red Sea.

Low nutrients may explain the reducing abundance of *G. ruber* in the northern Red Sea but food quality and variety of diet account for the abundance of *G. sacculifer*.

Holocene: The top intervals of all sediment cores investigated herein are characterized by the dominance of *Globigerinoides sacclifer* in respect to *Globigerinoides ruber*. It predominates even in the Gulf of Aqaba (Almogi-Labin, 1984). Substantial numbers of *G. siphonifera*, *O. universa*, *G. rubescens*, *G. tenella*, among others, are present. The huge numbers and diversity of the planktonic foraminifera and the dominance of *G. sacculifer* over *G. ruber* can be seen as a result of reestablishment of normal marine conditions similar to those existing at present in the Red Sea and ascribe these intervals to the Holocene Epoch (Fig. 2). The observed few individuals of *G. menardii* in Holocene strata of core KL-282 (20° 01. 0′ N) can be seen as displaced specimens from the Gulf of Aden. Few species of *G. menardii* have been recorded by Ivanova (1985) in the southern Red Sea at 17°53. 3′ N. It is obvious that the influence of displaced specimens from the Gulf of Aden extends to the convergence zone. This is in agreement with the limited occurrence of G. menardii (northward to 23°50′ N) suggested by Reiss and Hottinger (1984) and with the recorded G. *menardii* at 27°32′ N in Holocene strata by Herman (1968). However, considerable variations exist in the abundance of foraminiferal species at different levels of the Holocene. *O. universa* dominates with 60% in sample 60-70 cm at the site 22°47. 4′ N and *G. siphonifera* and *O. universa* make up to 49% of the total planktonic forams in the top 100 cm of the core KL-379 (26°13. 0′ N). On the other hand at 26°13 0′ in the samples 80-90 and 110-120 cm the ratio between *G. sacculifer* and *G. ruber* is displaced in favor of the latter. However, a southward increasing tendency of *G. siphonifera* was not observed. These variations are probably related to changing conditions throughout the Holocene, including nutrient supply that may differ in time and space.

Upper wuerm pleniglacial = (LGM): The lowering of the sea level during glacial stages resulted in reduction of the water exchange between the Red Sea and the Indian Ocean. The atmospheric circulation and the winds prevail to day undergone some changes during glacial stages and so the circulation pattern in the Red Sea. A strong salinity and nutrient south-north gradients have been developed. The Consequent effect, hypersaline and strong oligtrophic conditions prevailed during the last glacial in the northern Red Sea (Yusuf, 1978; Locke and Thunell, 1988; Rohling, 1994; Hemleben *et al*., 1996). The distribution of the planktonic foraminifera in glacial sediments of the northern Red Sea show two specific features, clearly indicated in cores KL-279, KL-320 and KL-282. The first pattern was observed in KL-282, at the site 20° 01. 0′ N. No aplanktonic zone has been observed in the last glacial interval. Unlike the Holocene *G. ruber* dominates the assemblage and occurs throughout the core sequence, while *G. sacculifer* is reduced in numbers or at some levels is completely absent. The pteropods with *Creseis acicula* increase in abundance and constitute up to 40% at depth 17-200 cm. The presence of *G. ruber* and *G. sacculifer* indicates that the salinity remained below 47 psu. The absence and occurrence of *G. sacculifer* in the Upper Wuerm Pleniglacial at the site 20° 01 0′ indicate that the salinity fluctuated throughout the Upper Wuerm Plenglacial around 47 psu. Increasing salinity above 47 psu, the threshold for *G. sacculifer,* resulted in termination of this species while decreasing salinity below the threshold caused the reappearance of *G. sacculifer* (Fig. 2). It is most likely that the salinity fluctuated around a narrow range, caused by influx fluctuations from the Gulf of Aden but most likely not exceeded 49 psu, the threshold of *G. ruber*. Almogi-Labin *et al.* (2000) reported a maximum activity of the NE monsoon in the Gulf of Aden from 60-13 k, resulted in expansion of these winds over the entire Red Sea and more inflow of Aden waters to the basin. In the same manner Geiselhart (1998) reported that the fluctuating MIS-2 isotopic values in KL-32, further to the south, are caused by influx fluctuations from the Gulf of Aden. Therefore the limited continuation of fauna during LGM in the southern Red Sea was related to salinities that remained at or below 45 psu. The occurrence of planktonic foraminifera throughout LGM sediment in the southern Red Sea indicates that the inflow of water from the Gulf of Aden kept the salinity probably much below the tolerance threshold of planktonic foraminifera (Yusuf, 1976, 1978; Deuser *et al.*, 1976; Fenton *et al.*, 2000). The influence of Aden waters during the Upper Wuerm Pleniglacial in the southern Red Sea probably extended in some events to the central Red Sea at the site 20° 01. 0′N.

The second specific feature is characterized by the disappearance of the planktonic foraminifera and even the pteropods. However the aplanktonic zones in each of the cores, KL-320 and KL-379 are separated through 20-35 cm intervals enriched with planktonic foraminifera (Fig. 2). The distribution pattern of *G. sacculifer* and *G. ruber* and the mineralogical results indicate the following: In Thetis deep (KL-320) the mineralogical composition of the Upper and Lower aplanktonic zone are characterized by the minerals, lepidocrocite, pyrite, magnetite and calcite, while the foraminiferal layer (140-160 cm) that separate both parts of the aplanktonic zone, consist of lepidocrocite, gypsum, pyrite and calcite. On the other hand the Upper part (185-200 cm) of the Middle Wuerm Pleniglacial that directly underlain the aplanktonic zone is composed of lepidocrocite, mg-calcite and goethite and at 200-210 cm of calcite, mg-calcite, quartz, dolomite, feldspar, kaolinite and illite. The only beds with similar composition to the foraminiferal layer are only found in the Holocene with the composition ranges from lepidocrocite, calcite and gypsum to calcite, lepidocrocite, gypsum and kaolinite. Since gypsum is confined only to the Holocene strata; it is believed that the foraminiferal layer within the aplanktonic zone is the result of reworked Holocene beds and pyrite that completely absent in the Holocene strata is probably added from the surrounding Upper Wuerm Pleniglacial sediments.

In Shaban deep the Upper part (435-465 cm) of the aplanktonic zone consist of calcite, quartz, dolomite, feldspar, pyrite, kaolinite and illite. In addition to these minerals, hematite occurs throughout the Lower part (500-580 cm) of the aplanktonic zone. The foraminiferal layer (465-500 cm) composed of the minerals, calcite, quartz, dolomite and pyrite. The Holocene that overlain the aplanktonic zone consist mostly of calcite, mg-calcite, quartz, dolomite, pyrite, feldspar, kaolinite and illite. Only the top layer (0-15 cm) is composed of the same minerals observed in the foraminiferal layer. Therefore it is most likely that the foraminiferal layer in which *G. sacculifer* dominates over *G. ruber*, originates from the Holocene particularly the top sediment.

Following the salinity values suggested for the last glacial period and the tolerance temperature and salinities obtained through experimental studies (Bijma *et al.*, 1990; Hemleben *et al.*, 1989) it is most likely that the salinity was responsible for the termination of *G. ruber* and to a far extent of *G. sacculifer* during the Upper Wuerm Pleniglacial in the northern Red Sea. Gradually rising salinities resulted in the disappearance of *G. sacculifer* by passing the threshold 47 psu, followed by *G. ruber* when the salinity in excess of 49 psu. In agreement with Winter *et al.* (1983), Reiss and Hottinger (1984) and Halicz and Reiss (1981) it is believed that *G. ruber* dominates in glacial sediments when the estimated salinity values were less than 50 psu and terminated when the salinity exceeded 50 psu. Auras-Schudnagies *et al.*, (1989) suggested that the disappearance of *G. ruber* and *G. glutinata* is related to the partially diachronous crossing of a salinity threshold around 49 psu. Based on micropaleontological and oxygen isotope data, increasing salinities beyond the salinity tolerance of planktonic foraminifera, resulted in the development of an aplanktonic zone, (Rohling *et al.*, 1998; Fenton, 1998; Geiselhart, 1998; Almogi-Labin *et al.*, 1991; Fenton *et al.*, 2000). This may explain the absence of planktonic foraminifera even the pteropods in the aplanktonic zones in cores KL-320 and KL-379.

Indeed the hypersaline conditions and the lateral expansion and intensification of the OMZ during MIS-4, 3 and 2, adversely affect the reproduction habitat of *G. sacculifer* and result in a diachmorous elimination of trace populations of *G. sacculifer* northward. These conditions completely terminated *G. sacculifer* throughout the Red Sea and may lead to the disappearance of mesopelagic pteropods (Almogi-Labin *et al.*, 1998; Fenton, 1998; Geiselhart, 1998; Fenton *et al.*, 2000).

Sedimentation rates: The sediment deposition rates vary widely from one deep to another, even during a particular period (Table 2). The cores KL-282, KL-366 and KL-379 extend back to have terminated in the last glacial period. The thickness of the Upper Wuerm Pleniglacial sediments in KL-320 is 130 cm and the calculated deposition rate is 8.1 cm/1000 year (Table 2). It lies within the range given by Ivanova, (1985) for the Red Sea and close to the values reported by Stoffers and Ross

(1977) for the area on the edge of axial trough about 5 km east of the Atlantic II Deep. The obtained value herein is very close to the sedimentation rate, 8.5 cm/1000 year given by Almogi-Labin *et al.* (1991) for the Upper Wuerm in the central Red Sea (KL 13).

The studied sediments from the central and northern Red Sea are composed of admixture of different constituents derived from various sources. The most important component of glacial sediments are carbonate minerals, derived mainly either from a biogenic source or/and from the surrounding land areas. Chemical processes also might contribute partly significant amount of micro-carbonate to the deep sediments (Stoffers and Ross, 1977; Stoffers *et al.*, 1990). In the Thetis Deep the carbonate content is significantly low and concentrated in certain layers. In contrast the general uniformity in the nature of minerals in Shaban Deep indicate a steady state mixing of sediments from various sources. The dominance of calcite followed by quartz, dolomite, kaolinite and illite in glacial sediments of Shaban Deep and the absence of the planktonic foraminifera and pteropods as a main biogenic source point to the importance of the surrounding land areas as a major contributor of carbonates to the deep particularly during the Upper Wuerm Pleniglacial. This resulted in higher sedimentation rates than in the Upper Wuerm Pleniglacial of the Thetis Deep even by addition of metaleferous sediments. The distribution pattern of detrital minerals such as quartz, dolomite, feldspar and clays, particularly kaolinite suggest an uninterrupted supply of detrital material which may influence at different degrees the sedimentation rates in the deeps. Kaolinite is the predominant clay mineral in the eolian dust over the Red Sea and also in the near shore sediments (Schroeder, 1984; Behairy *et al.*, 1985). It is most likely that fine terrigenous material have been derived mostly via the atmosphere, while coarse fragments as observed in the lower portion of KL-366 were delivered by gravity flows.

Local conditions seem to essentially influence the sedimentation rates. Rao (1984) reported that periodical hydrothermal activity occurs in all deeps, but the intensity seems to vary from one deep to another. Only in the Thetis Deep the high intensity during the Upper Wuerm Pleniglacial produced metaliferous sediments. In the other deeps the sediments are diluted with organo-detrital materials to produce sediments similar to the normal deep Red Sea sediments (Rao, 1984). However, the contribution of the planktonic foraminifera and pteropods to the glacial strata was hampered, while the influx of detrital sediment from the surrounding land areas relatively increased when the sea level dropped several tens of meters in the Red Sea and large areas of the shelf were exposed.

Higher sedimentation rates were observed in Holocene sediments. They vary widely between 1.8 cm in KL-282 in the central Red Sea and 30.9 cm/1000 year in Shaban Deep in the north (Table 2). The obtained rate in Shaban Deep is very close to the rate (28 cm/1000 year) given by Seeberg-Elverfeldt *et al.* (2004) for the mid-Holocene in the same deep. It is worthy to note that the sedimentation rates show a marked increasing tendency from the central to the northern Red Sea. Accumulation rates of 18 cm/1000 year as reported by Ivanova (1985) at 24° 42. 1′N and 5.8 cm/1000 year given by Yusuf (1978) at 21° 16. 48′N fit very well in this tendency. However, it is most likely that the uppermost of the core KL-282 that represents the early-Holocene has been lost. Based on soil sequence stratigraphy in the coastal plain of Israel, Gvirtzman and Wieder (2001) found that the longer interval from 40 to 12.5 ka is characterized by wet conditions, the shorter interval from 11.5 to present, which represent the Holocene epoch, is characterized by fluctuations mostly of dry conditions. They found strong indications that significant amount of atmospheric dust settled in the coastal plain of Israel particularly during the dry episode. Mineral aerosol carried by predominant wind blows from, between N and NW as far as 18°N as well as the seasonal input of dust pulses that originated in Khamasin dust storms, contribute high amount of terrigenous material to the deep sediment. Guerzoni et al (1999) reported that eolian deposition in the offshore waters of the entire Mediterranean basin makes up to >80% of the deep-sea sediments. It is apparent therefore that the deserts and arid lands surrounding the northern Red Sea act as a massive mineral aerosol reservoirs supplying fine material during the Holocene epoch to the deeps. The decreasing supply of mineral aerosol with remoteness from the continental sources may explain to a far extent the decreasing tendency in the sedimentation rates from north to south in the northern and central Red Sea. It clearly points to the wind directions prevailed during the Holocene. The variations of the accumulation rates from one deep to another are mostly related as discussed above, to various sources, differ in their relative flux magnitude to the deep sediment in space and time. The dust minerals carried by wind as well as the productivity are the main sources influencing the sedimentation rates and the composition of the sediments in the Holocene. The high content of silt and clay fractions reported by Rao (1984) suggests that the atmospheric fluxes mostly exceed the influx from biogenic sources, even by reestablishing of normal marine conditions and higher productivity, except in the sand layers, where the planktonic foraminifera and pteropods dominate.

CONCLUSIONS

The anticyclic fluctuation between *G. sacculifer* and *G. ruber* in Jung Pleistocene sediments can be explained by the upper salinity limits of both species. It can be used for stratigraphical subdivision of core sequences from the northern Red Sea. The Holocene is characterized by the dominance of *G. sacculifer* in respect of *G. ruber*, while the later mostly dominates the assemblage during the Upper Wuerm Pleniglacial. During the Upper Wuerm Pleniglacial periodically influx fluctuation to the basin influenced the planktonic foraminiferal fauna up to the convergence zone, kept the salinity below the threshold of planktonic foraminifera and no truly aplanktonic zone has been developed. In the northern Red Sea rising salinity above 49 psu during the Upper Wuerm Pleniglacial resulted in the development of aplanktonic zone. The sedimentation rates are mainly related to the productivity, supply of terrigenous material and hydrothermal activity. The decreasing tendency of the sedimentation rates from north to south in Holocene strata is mostly related to the decreasing supply of mineral aerosol with remoteness from the deserts surrounding the northern Red Sea.

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