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FULL LENGTH ARTICLE

Late Holocene hydrographic settings of the northern Red Sea

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Abstract Temporal variability of the paleo-oceanographic setting of the northern Red Sea during the last 6 Ky was deduced from high-resolution faunal results and stable isotope records of planktonic foraminifera in three short cores sediment obtained by the German R/V Meteor vessel. In general, the investigated time interval is fundamentally comparable to the present day composition and distribution of planktonic foraminifera. However, interrupted short enhanced arid phase spanning the last 4–2 Ky appears to have existed in the northern Red Sea, and resulted in elevation of salinity and somehow productivity, as hypersaline, dense surface water favored vertical mixing of the water column resulting in an increase in productivity. This paleoclimatic reconstruction is revealed from the distinct gradient in the composition and distribution of planktonic foraminifera, as well as the significant distribution trend of *Globigerinoides ruber versus Globigerinoides sacculifer* correlated with the stable isotope records. Starting from the last 2 Ky to the present time, less strength arid conditions relative to the previous period prevailed, reflected from a gradual decrease in surface water salinity and productivity assuming that the present water conditions and consequently current climatic conditions began to develop from that time with minor fluctuations reaching the recent conditions.

Introduction

Mediterranean climate is influenced the Red Sea by seasonal wind systems (NNW winds) from the north, as well as the African and Arabian monsoon systems (SSE winds) from the south. The pattern and wind magnitude are strong factors over the Red Sea region represented by two wind systems. During summer, (June–August), the prevailing NNW winds blow throughout the basin. During winter, (September–May), the NNW winds are restricted to the northern region, allowing the SSE winds, corresponding to seasonal changes of the Arabian monsoon system, to influence the southern region resulting in a convergence zone around 19°N (Patzert, 1974; Eshel et al., 1994; Hamouda and El-Wahab, 2009, 2012). Surface and subsurface water masses circulation of the Red Sea is controlled by the seasonal wind system. During summer, a three-layer current system is generated, driven by NNW winds. Northern Red Sea surface water propagates into the Gulf of Aden, at the same time, nutrient-rich intermediate water proceeds northward as subsurface matter mass (Eshel and Naik, 1997; Smeed, 2004) while the third deep water layer outflows the highly-saline water mass from the northern Red

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Sea southward into the Gulf of Aden (Bower and Furey, 2012). During winter, winds over the southern Red Sea reverse and generate a two-layer current pattern. The surface water of Gulf of Aden (with normal salinity, ~37‰) flows northward into the Red Sea through the Strait of Bab el Mandeb, and it moves northward in more arid to semi-arid conditions. Extreme evaporation occurs leading to an increase in salinity to about 40‰ and density, permitting the formation of deep water during winter at the northern Red Sea (Edwards, 1987). Red Sea deep hypersaline water outflows southward into the Gulf of Aden and its renewal is regulated by seasonal deep-water formation during winter at the Gulf of Suez (average depth of 50 m) where a warm, highly saline, dense surface water sinks to deeper depths forming a warm (21.6–21.8 °C) and saline (40.5–40.6‰) intermediate and deep-water masses that extend southward and ventilate the Red Sea deep water (Cember, 1988; Woelk and Quadfasel, 1996). In addition to this, there is a minor annual contribution of Gulf of Aqaba water (Edwards, 1987; Eshel and Naik, 1997).

Several studies on stable oxygen and carbon isotopes of planktonic and benthonic foraminifera from the Red Sea revealed the detailed picture of water mass variation with association of global climatic changes during the Late Pleistocene and Early Holocene (e.g. Almogi-Labin et al., 1996; Ivanova, 1985; Locke and Thunell, 1988; Hemleben et al., 1989, 1996; Fenton et al., 2000; Siddall et al., 2003, 2004; Badawi, 2015; Badawi et al., 2005; Hamouda, 2009; Siccha et al., 2009; Abu-Zied et al., 2013). Individual species of planktonic foraminifera characterized by distinct ecological preferences and tolerance regarding temperature, salinity and productivity as well as biological lifestyles help in quaternary stratigraphy and paleoenvironmental reconstructions (Vincent and Berger, 1981; Kroon and Ganssen, 1989; Ravelo and Fairbanks, 1992, 1995; Rohling et al., 2004; Schiebel and Hemleben, 2005; Farmer et al., 2007; Edelman-Fürstenberg et al., 2009; Birch et al., 2013). The objective of this study is to investigate the abundance, distribution and stable isotope records of planktonic foraminifera in Late Holocene deep-sea short sediment cores recovered from the northern Red Sea and link these with climatic changes in the Red Sea during this interval.

Materials and methods

Three short sediment cores from the deep-sea bottom sediments of the northern Red Sea were obtained by the German R/V Meteor-Cruise, Leg M 31/2, (February 1995), between latitudes 25°31.3′ and 27°41.2′N (Fig. 1). The northern core MC 78 was collected at 27°41.200′N, 34°35.800′E, 1018 m water depth, with a core recovery of 27 cm. The central core MC 361 was collected at 25°44.982′N, 34°52.065′E, 720 m water depth, with a core recovery of 29 cm. The southern core MC 86 was collected at 25°31.300′N, 35°36.500′E, 941 m water depth, with a core recovery of 28.5 cm.

Sediment cores were sliced into sediment samples every 0.5 and 1 cm intervals. From each sample, about 5 g of wet sediment was dried, weighed, disintegrated with H_2O_2 (3.5%), and washed through a 30 mm mesh sieve. The residue was oven-dried at 40 °C. Subsequently, the samples were dry sieved into the fractions < 125 mm, 125–250, and > 250 mm, then weighed again. The fractions 125–250, and > 250 mm were investigated for their planktonic foraminiferal content. Planktonic foraminifera were identified according to Loeblich and Tappan (1988) and counted using a binocular microscope. Then, they were normalized to 1 g of dry sediment. Relative abundance was calculated to facilitate the comparison of the data sets providing percentage curves of the most frequent species. Relative abundance of all planktonic foraminiferal shell counts was conveyed by normalizing the number of each individual species relative to the total number of all identified species in each sample. Rare species that have relative abundance below of 0.5% or recorded in one sample have been skipped from the data set (Malmgern and Haq, 1982; Schmiedl et al., 1998). For stable isotope measurements of core MC 78, 15–20 tests of tropical–subtropical planktonic foraminiferal species *Globigerinoides ruber* and *Globigerinoides sacculifer* were picked from the > 250 µm fraction. Prior to analysis, selected tests were ultrasonically cleaned in a bath of warm water. The isotope measurements were carried out at the Department of Geosciences, Bremen University, Germany.

Results

Age model of the investigated cores

Sediment cores stratigraphy is developed based mainly on the graphical correlation of the measured stable oxygen isotope data of core MC 78 with the global SPECMAP d18O curve (Imbrie et al., 1984). The estimated age model of the Holocene section of core MC 78 (Fig. 2), is assumed to cover the last 6 Ky based on 14C data set of other cores in the Red Sea provided through personal communication with Ch. Hemleben, Tuebingen University, Germany. In addition, the resulting age model, sedimentation rate, and faunal pattern of the core MC 78 are in good agreement with published data of Red Sea core (Badawi et al., 2005; Siccha et al., 2009). The three studied cores can be stratigraphically correlated with each other, and the age model of MC 78 could be extrapolated to the other two investigated cores MC 361 and MC 86, where the maximum horizontal separation distance being ~234 km.

As such, they are belonging to the same basinal structures and stratigraphical setting, in which deposition is relatively continuous and uniform, with more or less limited variation in the average sedimentation rate for a short period.

Stable isotope signals

The stable isotope profiles of the index species *G. ruber* and *G. sacculifer* in the core MC 78 slightly fluctuate throughout the core. In general, the d18O of *G. ruber* is lighter than that of *G. sacculifer*. The amplitude of *G. ruber* signal throughout the core ranges between −0.83‰ and −0.03‰. The d18O of *G. sacculifer* ranges between −0.11‰ and 0.90‰ (Fig. 3). The d18O of *G. ruber* and *G. sacculifer* show relatively heavy values during the interval from about 4 to 2 Ky BP with an average value of −0.3 and 0.3, respectively (Fig. 3). The carbon isotope records of *G. sacculifer* and *G. ruber* exhibit two different values. *G. sacculifer* displays generally heavy values during the last 6 Ky BP, whereas the d13C curve of *G. ruber* shows a similar trend to that of *G. sacculifer* but in a much more irregular way. The d13C amplitude of the *G. ruber* varies between 1.12‰ and 1.87‰ and *G. sacculifer* varies between 2.19‰ and 2.86‰ (Fig. 3). Planktonic foraminifera.