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Research paper

Hypersaline benthic foraminifera from the Shuaiba Lagoon, eastern Red Sea, Saudi Arabia: Their environmental controls and usefulness in sea-level reconstruction

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ABSTRACT

The Shuaiba Lagoon is a fossil back-reef, hypersaline small basin located 80 km south of Jeddah city on the eastern Red Sea coast, Saudi Arabia. The surface sediments of the lagoon were investigated for their benthic foraminiferal content in order to correlate, in general, with environmental factors such as temperature, salinity, pH, sediment grain size, organic matter and, in particular, with tidal elevations to develop a training set for predicting sea-level changes in the lagoon. Hierarchical cluster analysis divided the benthic foraminifera in the Shuaiba Lagoon into four distinct faunal assemblages. *Quinqueloculina* cf. *Q. limbata* (Assemblage 1) and *Monalysidium acicularis* (Assemblage 2) assemblages dominated the intertidal–high subtidal areas (0.3 to −0.5 m, LAT). The *Peneroplis planatus–Sorites orbiculus* Assemblage 3 occurred abundantly at all subtidal elevations (0 to −1 m, LAT), whereas the *Quinqueloculina costata–Spiroloculina communis–Elphidium striatopunctatum* Assemblage 4 dominated the lowest elevations (<−1.5 m, LAT) in the lagoon. Canonical correspondence analysis indicated that the intertidal–high subtidal assemblages were positively correlated with tidal elevations in the Shuaiba Lagoon, consequently, their training set yielded a model predicting sea-level changes with a precision of ±0.16 m, but when they were incorporated with the lowest-elevation (low subtidal and below subtidal) assemblages, a wide error (±0.33 m) was produced. Abundance distributions of all assemblages were also affected by the other environmental factors such as salinity, organic matter and temperature, but pH was an important controlling factor on many assemblages due, likely, to high algal photosynthesis in algal-dense substrates. The effect of these factors on the predictability of the intertidal–high subtidal training set is unavoidable and it could be compromised by making a model from the different niches of the intertidal–high subtidal area.

1. Introduction

Benthic foraminifera of sheltered areas like salt-marshes, bays, estuaries and lagoons have good mutual relationships with the ambient environmental factors and when they get fossilized, the signals of these factors are preserved by accumulations of the tests even if they have been modified by post-mortem processes (e.g., Murray, 1986; Hayward et al., 1996; Wang and Chappell, 2001; Hippensteel et al., 2002; Buzas-Stephens and Buzas, 2005; Horton and Murray, 2006; Morvan et al., 2006; Vance et al., 2006; Horton and Murray, 2007; Wilson and Ramsook, 2007; Berkeley et al., 2008; Debenay and Payri, 2010; Abu-Zied et al., 2011a). In the intertidal of these areas especially of the temperate environments, the distribution of benthic foraminifera has been shown to be a direct function of altitude with the duration and frequency of intertidal exposure as the most important factors (Scott and Medioli, 1978, 1986; Jennings et al., 1995; Horton et al., 1999; Edwards et al., 2004a). Since the discovery of this direct relationship between intertidal benthic foraminifera and altitude (tidal elevation), many models (transfer function), using dead intertidal salt-marsh benthic foraminifera and their elevations according to the mean sea level (MSL), have been developed getting estimates for sea-level changes during the late Holocene with precisions between ±0.05 and 0.29 m (Edwards and Horton, 2000; Edwards et al., 2004b; Massey et al., 2006; Leorri et al., 2008; Kemp et al., 2009; Rossi and Horton, 2009; Callard et al., 2011; Wright et al., 2011). The most dominant and applied intertidal salt-marsh benthic foraminifera in these models are those of the organic-cemented agglutinated foraminifera such as *Jadammina macrescens*, *Trochammina inflata* and *Miliammina fusca*, whereas those of calcareous tests (e.g., *Elphidium williamsoni*, *Ammonia tepida*, *Haynesina* sp. and *Quinqueloculina* sp.) that occupy low-marsh and tidal flat are excluded from the models due to their alteration by dissolution leaving them without a modern analogue (Horton et al., 1999; Edwards and Horton, 2000; Rossi and Horton, 2009). This direct relationship between intertidal benthic foraminifera and elevation is, however, obscured by the interplay of others environmental factors such as

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salinity and climate (De Rijk, 1995; De Rijk and Troelstra, 1997). They suggested that the vertical zonation of salt-marsh benthic foraminifera (Great Marshes, Massachusetts) with respect to tidal frame could be an artefact of altitudinal changes in salt-marsh salinity. In the tropical environments, salinity and elevation are also considered the most important factors governing foraminiferal distribution (Hayward et al., 1999, 2004). When these areas become dominated by mangroves, taphonomic loss of foraminiferal tests due to post-mortem disaggregation is an important obstacle in the use of mangrove (mainly agglutinated) foraminifera in palaeoenvironmental reconstructions, hence the use of mid- to low-intertidal calcareous faunas of the tropical environments is essential as components/indicators for sea-level changes (Woodroffe et al., 2005; Woodroffe, 2009). However, in the salt-marshes of eastern Tasmania, Callard et al. (2011) confirmed the usefulness of salt-marsh foraminifera in sea-level reconstruction in the SW Pacific region where the foraminiferal training set was able to predict the sea-level changes with a precision of ±0.10 m.

The Red Sea is a semi-enclosed, marginal basin occurring mostly under a tropical–subtropical climate and having microtidal (<1 m) conditions (Morcos, 1970). The intertidal benthic foraminifera of Red Sea lagoons could offer good opportunities to reconstruct former sea-level changes during recent history (Holocene). Many studies (e.g., Ahmed and Sultan, 1992; Al-Washmi and Gheith, 2003; Hariri, 2008; Al-Barakati, 2010; Abu-Zied et al., 2011a) have dealt with the Shuaiba Lagoon, but no attempt has been made to study and correlate the intertidal benthic foraminifera with the tidal elevations (or sea-level changes) in the Red Sea and particularly in the Shuaiba Lagoon. Therefore, this study will examine the benthic foraminifera of the Shuaiba Lagoon in order to correlate them with the prevailing environmental factors, as well as with elevation to develop an internal training set that may be capable of reconstructing former sea-level changes in this area.

2. Site characteristics

Shuaiba Lagoon is a hypersaline small basin (14.3 km^2), located ~80 km south of Jeddah City (Saudi Arabia) on the eastern Red Sea coast between latitudes 20° 42′ to 20° 51′ N and longitudes 39° 26′ to 39° 32′ E (Fig. 1). It occurs under warm and dry climate throughout the year with scarce rainfall (63 mm/yr) and no riverine inputs. The Shuaiba Lagoon water depth averages 1 m, whereas the deepest area (up to 3 m) occurs in the southern-centre of the lagoon (Abu-Zied et al., 2011b). The water exchange between the Shuaiba Lagoon and Red Sea is maintained by a very narrow inlet (about 60 m wide and 6 m deep) permitting two water layers to pass through. One exits the lagoon as warm, high saline (44‰), subsurface outflow and the other (Red Sea water) enters the lagoon as cold, less saline (38‰), surface inflow (Abu-Zied et al., 2011b). This water exchange is forced by wind stress, tidal currents and thermohaline circulation (Ahmed and Sultan, 1992; Al-Barakati, 2010; Abu-Zied et al., 2011b).

A considerable part (10%) of the Shuaiba Lagoon is covered by mangrove trees (Fig. 1). Its western side is bordered by old, raised coral reef terraces, probably of Pleistocene age (Skipwith, 1973; Al-Sayari and Zötl, 1978) with elevations between 1 and 3 m a.s.l. The other sides of the lagoon are bordered by low land (0.5–1 m a.s.l) that comprises sand-sized alluvium and sabkha. The Shuaiba Lagoon tidal range from the local lowest astronomical tide (−36 cm from the MSL) to the local highest astronomical tide (26 cm HAT from the MSL) is ~0.6 m (Saudi Aramco Tide Tables, 2010), but the daily tidal range of 0.25 m is similar to that of the central Red Sea (Lisitzin, 1974).

3. Methods

Forty three surface sediment samples were collected from different environmental niches in the Shuaiba Lagoon, during May–June 2010.

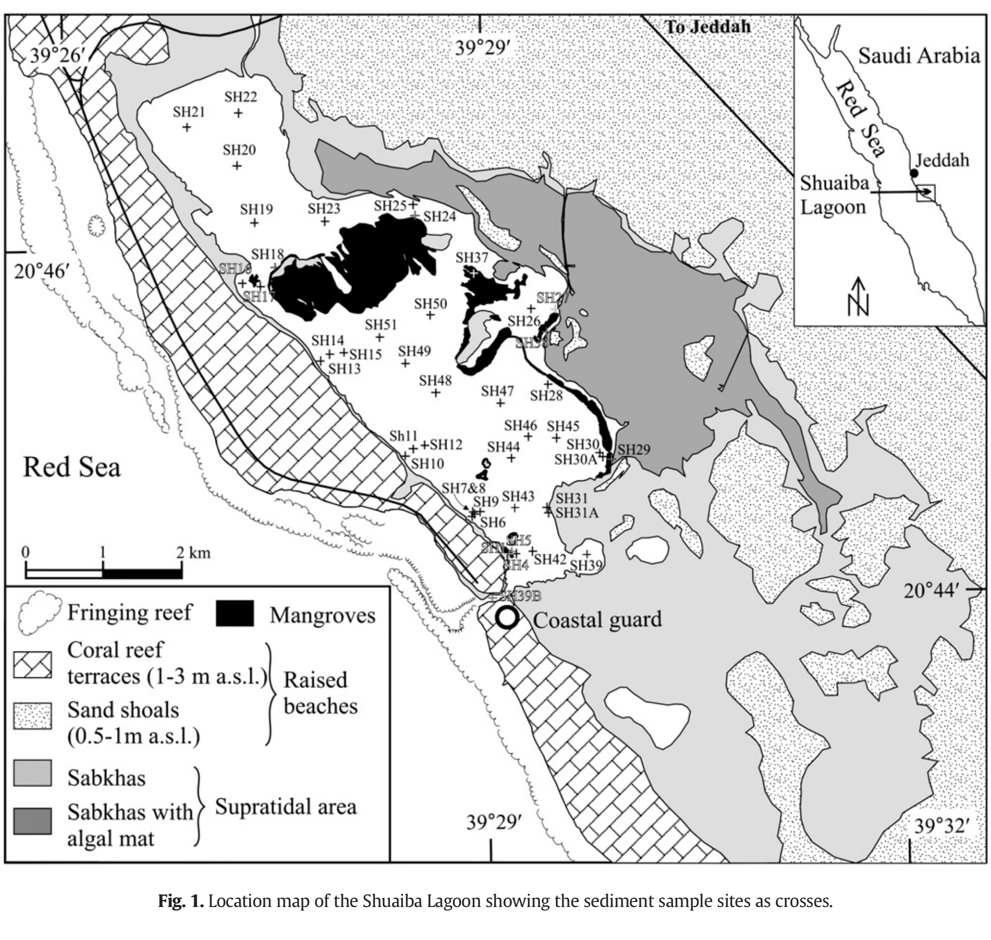

Fig. 1. Location map of the Shuaiba Lagoon showing the sediment sample sites as crosses.