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ORIGINAL RESEARCH ARTICLE

Heavy metals contamination and distribution of benthic foraminifera from the Red Sea coastal area, Jeddah, Saudi Arabia☆

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Summary The distribution of benthic foraminifera was studied in two stations in the coastal area, located around Jeddah, Red Sea coast, Saudi Arabia. Thirty-three species belonging to 15 genera, 14 families and three suborders were recorded in twenty samples. Some foraminiferal tests display abnormalities in their coiling, general shape of chambers and apertures. On the other hand, concentrations of Fe, Mn, Zn, Cu, Pb, Ni, Cr, and Cd were measured in the tests of the two most common living species of benthic foraminifera (*Sorites marginalis* and *Peneroplis planatus*). Significant spatial differences in the metal concentrations of benthic foraminifera were recorded at the two sites. Benthic foraminifera yielded significantly high concentrations of Fe, Mn, Pb and Cu, which may attribute to anthropogenic activities at the studied coastal areas. The anthropogenic activities have a considerable impact, besides other factors, in the abnormalities of foraminiferal test.

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1. Introduction

The Red Sea is a marginal marine basin that is entirely enclosed by African continent and Arabian Peninsula. The extreme evaporation rates in these arid to semi-arid regions result in high salinity of surface water masses with maximum values above 40‰ in the northern Red Sea (Badawi et al., 2005). The Saudi Red Sea coast extends for nearly 1932 km with numerous coastal lagoons, some of them locally known as Sharms (Hariri, 2008). The dumping of wastewaters from Jeddah in the Al-Arbaeen and Al-Shabab inlets which occur in the middle of Jeddah coast led to the occurrence of an estuarine circulation pattern in the inlets and surrounding areas (Abu-Zied et al., 2012; Basaham et al., 2011; El-Rayis and Moammar, 1998).

Foraminifera are very useful to study marine environmental conditions, because of their highest diversity and abundance in the sediments (Narayan and Pandolfi, 2010). Their tests provide the most abundant sediment particles in most marine environment (Piller, 1994). They also play an important role in short-term carbon cycling in the Oxygen Minimum Zone (OMZ) (Enge et al., 2014). Foraminifera can display varieties of test deformation caused by pathological morphogenesis, including extreme compression, double apertures, twisted coiling, aberrant chamber shape, and protrusions (Alve, 1991; Samir, 2000; Samir and El-Din, 2001; Yanko et al., 1994). Moreover, malformation of benthic foraminifera may be related to natural environmental stresses such as hypersalinity, change in trophic resources, and rapidly changing in other environmental conditions (Albani et al., 2007; Almogi-Labin et al., 1992; Armynot du Châtelet et al., 2004; Debenay et al., 2001; Mojtahid et al., 2008; Murray, 1973; Romano et al., 2009; Scott et al., 2005). Deformed tests appear to increase significantly in areas subjected to different types of pollutants, e.g., oil slicks (Venec-Peyre, 1981), sewage discharge (Watkins, 1961), agrochemicals (Bhalla and Nigam, 1986), high organic matter content (Caralp, 1989), and heavy metals contamination (Alve, 1991; Yanko et al., 1994, 1998).

Many studies of benthic foraminifera on the Red Sea deal with taxonomy or distribution and diversity (e.g., Aref and Madkour, 1999, 2000; El-Deeb, 1978; Haunold et al., 1997; Madkour and Youssef, 2011; Mohamed, 1996; Obaidalla, 1988; Ouda and Obaidalla, 1998). The study of benthic foraminifera as a tool for monitoring of the Red Sea environment has been relatively neglected since little information was published on the levels of heavy metals in benthic foraminifera of the western Red Sea coast (e.g., Madkour, 2004; Madkour and Youssef, 2009; Mansour et al., 2005; Ziko et al., 2001).

In the eastern Red Sea coast, many studies have been carried out on benthic foraminiferal abundance, distribution and their relation to environmental conditions (Abou Ouf, 1992a,b; Abou Ouf et al., 1988; Abou Ouf and El-Shater, 1993; Abu-Zied et al., 2012; Bahafzalah, 1979; Bahafzalah and El Askary, 1981; Gheith and Abou Ouf, 1996; Hariri, 2008; Yusuf, 1984). The present study focuses on the impact of the natural inputs and anthropogenic activities on the coastal areas along the Red Sea coast in Jeddah through the following: (1) investigating the distribution and abundance of benthic foraminiferal species in the two studied locations and the relationship between this distribution to the environmental stress; (2) determinig heavy metals in the benthic foraminifera; and (3) detecting the malformation in the foraminiferal tests.

2. Study area

Jeddah is a major city with a population of over 2.6 million and an area of 1500 km^2. The considerable increase in population of Jeddah in addition to about two million visitors during the pilgrimage season each year and the increase in tourism activities have polluted its coastal sea water. The coastal water receives different pollutants: untreated domestic sewage wastes, oil pollution from oil refinery of the Petromin factory, fish wastes from the big fish market, and probably desalination plant effluents. The wastes resulting from several processes related to these sources added a considerable amount of organic and heavy metals load to the study area.

The study area is located along the Red Sea coast, Jeddah, Saudi Arabia. Two coastal sites (Salman Bay and south Jeddah area) were sampled. The locations of these coastal areas are as follows: Salman Bay (Khalig Salman): 21°51′33″N, 38°58′45″E and south Jeddah area (Bahar Al Ganoob): 21°15′88″N, 39°8′18″E (Fig. 1).

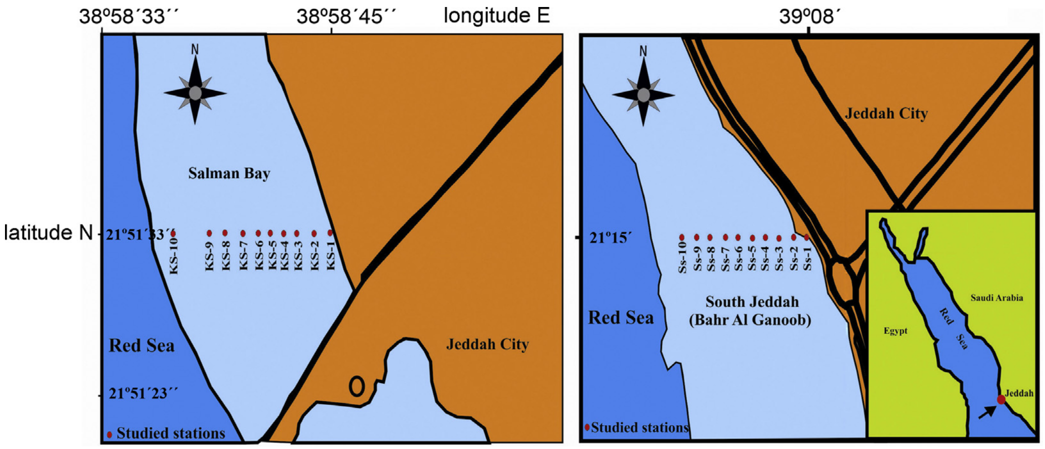

Figure 1 Location map of Salman Bay (Khalig Salman), north of Jeddah, and south Jeddah area (Bahar Al Ganoob), south of Jeddah.

Table 1 Locations and water depths of the collected samples.

South Jeddah				Salman Bay			
Station	Longitude	Latitude	Depth	Station	Longitude	Latitude	Depth
Ss-1	21°15′088″	39°08′181″	0	Ks-1	21°51′3307″	38°58′4503″	0
Ss-2	21°15′088″	39°08′180″	0.5	Ks-2	21°51′3305″	38°58′4504″	0.5
Ss-3	21°15′089″	39°08′179″	1.0	Ks-3	21°51′3304″	38°58′4503″	1.0
Ss-4	21°15′088″	39°08′180″	1.5	Ks-4	21°51′3304″	38°58′4502″	1.5
Ss-5	21°15′088″	39°08′182″	2.0	Ks-5	21°51′3306″	38°58′4502″	2.0
Ss-6	21°15′087″	39°08′179″	2.5	Ks-6	21°51′3307″	38°58′4502″	2.5
Ss-7	21°15′088″	39°08′179″	3.0	Ks-7	21°51′3304″	38°58′4502″	3.0
Ss-8	21°15′088″	39°08′182″	2.5	Ks-8	21°51′3302″	38°58′4502″	2.0
Ss-9	21°15′085″	39°08′182″	1.5	Ks-9	21°51′33.6″	38°58′44.9″	2.0
Ss-10	21°15′083″	39°08′183″	2.5	Ks-10	21°51′33.3″	38°58′44.6″	2.5

3. Material and methods

Twenty sediment samples were collected (Table 1) from the two studied locations in September 2013. Fifty grams from the upper two centimeters of sediment of each sample was washed over a sieve of 0.063 mm opening size to remove clay materials. The residue was then dried in drying oven at 70–80°C. Each sample was subdivided into two fractions (>250, and >125 μm) to pick the foraminiferal tests. 200–300 specimens were counted from the >250 μm fraction of each sample. The selected foraminiferal taxa were pictured using the scanning electron microscope (JSM-6380LA) of King Saud University.

A part of each sample was preserved in Formalin (5%) in the field, and then stained with Rose Bengal to differentiate the dead and live foraminifera. The tests of two living foraminiferal species *Peneroplis planatus* and *Sorites marginalis* (Fig. 2) were picked. These species represent the most abundant benthic constituents of the study area and was selected for Fe, Mn, Zn, Cu, Pb, Ni, Cr, and Cd analyses. Approximately 50 mg from the picked tests in each sample were prepared into dry and clean Teflon Digestion beaker; 2 ml of HNO_3, 6 ml HCl and 2 ml HF were added to the Teflon beaker. Samples were digested on the hot plate at 120–150°C for approximately 40 min. The resulting digest was not clear, so it was filtered through Whatman filtered paper no. 42. The filtered digest was transferred to a 15 ml plastic tube and made up to mark using deionized water. A blank digest was carried out in the same way. The analytical determination of trace metals was carried out by ICP-MS (Inductively Coupled Plasma-Mass Spectrometer): NexION 300D (Perkin Elmer, USA).

4. Results

4.1. Benthic foraminifera

Thirty-three species belonging to 15 genera, 14 families and three suborders (Textularina, Rotalina and Miliolina) were recorded. The most common genera are *Sorites* and *Peneroplis* which attain 44% and 20% of the recorded fauna respectively. The other recorded genera were as follows: *Elphidum* (8%), *Calcarina* (5%), *Clavulina* (4%), *Spirolina* (3.5%), *Quinqueloculina* (3.2%), and *Spiroloculina* (1.5%). *Vertebralina*, *Amphistegina*, *Ammonia*, *Planulina*, *Cymbaloporella*, and *Triloculina* represent minor constituents (Table 2).

4.2. Heavy metals concentrations

Concentration of Fe in *Sorites marginalis* ranges from 7308 to 10,065 $\mu g\, g^{-1}$ in Salman Bay and from 5802 to 7533 $\mu g\, g^{-1}$ in south Jeddah area (Table 3). The Fe concentration in *Peneroplis planatus* in Salman Bay varies from 7221 to 8537 $\mu g\, g^{-1}$ and increased in south Jeddah area from 6750 to 10,494 $\mu g\, g^{-1}$ (Fig. 3). Concentrations of Mn have the same trend in *Sorites marginalis* and *Peneroplis planatus* where the concentrations in *Sorites marginalis* are: 21.6–32.4 and 6.8–13.5 $\mu g\, g^{-1}$ in south Jeddah area and Salman Bay respectively. In *Peneroplis planatus* the concentration of Mn is high and ranges from 18.7 to 36.3 $\mu g\, g^{-1}$ and from 11.3 to 38.2 $\mu g\, g^{-1}$ in south Jeddah area and Salman Bay respectively (Fig. 4). Concentrations of Cu range from 5.2 to 13.3 $\mu g\, g^{-1}$ in both species except for the *Peneroplis*

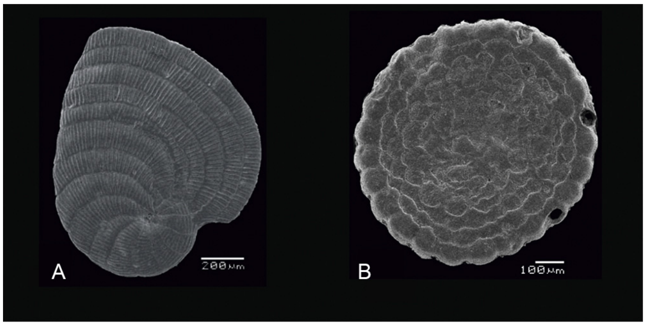

Figure 2 The picked two species for chemical analysis: (A) *Peneroplis planatus*, KS-9 and (B) *Sorites marginalis*, SS-6.

Table 2 Frequency and distribution of the benthic foraminifera in the study area.

G. no.	S. no.	Family	Genus	Species	Salman Bay	South Jeddah	Total	Sp. %
1	1		*Clavulina*	*Clavulina tricarinata*	103	12	115	3.90
	2	Textulariidae		*Clavulina angularis*	2	2	4	0.14
2	3	Hypraminidae	*Hypramina*	*Hypramina laevigata*	14	2	16	0.54
3	4	Spirolinidae	*Spirolina*	*Spirolina arietina*	55	54	109	3.69
4	5	Calcarinidae	*Calcarina*	*Calcarina calcar*	133	27	160	5.42
5	6	Vertebralinidae	*Vertebralina*	*Vertebralina striata*	5	3	8	0.27
6	7	Amphistiginidae	*Amphistigina*	*Amphistigina lessoni*	2	1	3	0.10
7	8		*Eliphidum*	*Eliphidum crispium*	90	140	230	7.80
	9	Eliphidiidae		*Elphidium advenum*	11	13	24	0.81
8	10	Soritidae	*Sorites*	*Sorites marginalis*	713	590	1303	44.17
9	11		*Peneroplis*	*Peneroplis planatus*	300	220	520	17.63
	12			*Peneroplis pertusus*	40	45	85	2.88
	13	Peneroplidae		*Peneroplis proteus*	4	5	9	0.31
10	14	Rotaliidae	*Ammonia*	*Ammonia beccarii*	1	1	2	0.07
11	15	Planulinidae	*Planulina*	*Planulina* cf. *wuellerstorfi*	2	1	3	0.10
12	16	Cymbaloporidae	*Cymbaloporella*	*Cym. tabellaeformis*	1	1	2	0.07
13	17			*Spiroloculina cuorrugata*	4	7	11	0.37
	18			*Spiroloculina communis*	4	7	11	0.37
	19			*Spiroloculina angulata*	4	7	11	0.37
	20	Spiroloculinidae	*Spiroloculina*	*Spiroloculina lucida*	2	6	8	0.27
14	21		*Triloculina*	*Triloculina affinis*	1	1	2	0.07
15	22			*Quinqueloculina mosharrafi*	8	9	17	0.58
	23			*Quinqueloculina aggutinous*	3	4	7	0.24
	24			*Quinqueloculina crassa*	3	4	7	0.24
	25			*Quinqueloculina partschii*	3	4	7	0.24
	26			*Quinqueloculina samoensis*	3	4	7	0.24
	27			*Quinqueloculina seminulum*	3	4	7	0.24
	28			*Quinqueloculina limbata*	3	4	7	0.24
	29			*Quinqueloculina subpolygona*	3	4	7	0.24
	30			*Quinqueloculina lamarkiana*	3	4	7	0.24
	31			*Quinqueloculina neostriatula*	3	4	7	0.24
	32			*Quinqueloculina laevigata*	3	4	7	0.24
	33	Hauerinidae	*Quinqueloculina*	*Quinqueloculina angularis*	2	3	5	0.17

planatus in sample Ks-7 which shows 34.6 $\mu g\,g^{-1}$ (Fig. 5). Zn concentration is very similar to that of Cu; the highest concentration of Zn (24.1 $\mu g\,g^{-1}$) is in *Peneroplis planatus* in sample SS-7 (Fig. 6). The concentrations of Pb in *Sorites marginalis* range from 3.4 to 18.4 $\mu g\,g^{-1}$ and from 5.6 to 27.3 $\mu g\,g^{-1}$ in Salman Bay and south Jeddah area respectively (Fig. 7). Pb displays its highest concentration in *Peneroplis planatus* in south Jeddah area (23.1–85.4 $\mu g\,g^{-1}$). Concentrations of Cd are relatively low with values lower than 1 $\mu g\,g^{-1}$ in the two sites (Fig. 8). The concentration of Cr in *Sorites marginalis* ranges from 12.4 to 39.8 $\mu g\,g^{-1}$ and from 29.5 to 100.6 $\mu g\,g^{-1}$ in south Jeddah area and Salman Bay respectively with the highest value (100.6 $\mu g\,g^{-1}$) in Station KS-10. The concentration of Cr in *Peneroplis planatus* varies between 39.3 and 86.6 $\mu g\,g^{-1}$ and between 20.9 and 58.1 $\mu g\,g^{-1}$ in south Jeddah area and Salman Bay respectively (Fig. 9). The concentrations of Ni in *Peneroplis planatus* range from 21.8 to 48.3 $\mu g\,g^{-1}$ and from 17.6 to 54.6 $\mu g\,g^{-1}$ while they range from 11.7 to 23.2 $\mu g\,g^{-1}$ and from 21 to 53.2 $\mu g\,g^{-1}$ in *Sorites marginalis* of south Jeddah area and Salman Bay respectively (Fig. 10).

5. Discussion

5.1. Distribution of benthic foraminifera

The families of Soritidae, Peneroplidae and Hauerinidae dominate the foraminiferal assemblage in the study area (Table 2 and Fig. 11). Species of these families live in association with sea grass, which is widely distributed through the coastal areas (Mohamed et al., 2013). The abundance of Soritidae may be taken as a criterion for shallow, sheltered, warm marine environment (Madkour, 2013). This agrees with Abou El-Enein (1979) findings that the study area is a sheltered Bay with relatively weak wave action and agrees with the ecologic distribution of these taxa (Murray, 1973). The markedly high abundance of *Sorites* in the Arabian Gulf and the Red Sea reflects the warmer nature of these water bodies (20–40°C). The suborder Rotaliina is less abundant as it represents 5.8% (Fig. 11). The most abundant families of Rotaliina are the Elphidiidae and Rotaliidae which are represented by *Elphidium* and *Ammonia* respectively. The high percentage of Elphidiidae (8.6%) in

Table 3 Heavy metal concentrations (expressed as total contents) calculated in (A) south Jeddah area and (B) Salman Bay.

(A) South Jeddah

S. no	*Sorites marginalis*								*Peneroplis planatus*							
	Cr	Fe	Mn	Ni	Zn	Cd	Pb	Cu	Cr	Fe	Mn	Ni	Zn	Cd	Pb	Cu
SS1	12.4	6590.4	32.3	13.7	20	0.1	10.1	9.2	43.2	8621.1	34.3	25.2	12.5	0.07	30.2	9.8
SS2	12.5	6597.6	32.4	13.8	21	0.11	10.2	9.1	44.2	8521.1	36.3	28.2	16.5	0.1	34.2	10.6
SS3	13.6	6300.2	28.6	15.1	15.4	0.06	7.8	8.4	45.4	7080	24.5	26.7	14.3	0.1	33.2	9.5
SS4	14.5	6153.3	29.3	12.6	13.7	0.07	8.5	9.1	47.6	6750	18.7	22.3	15.2	0.08	29.8	8.7
SS5	19.2	5901.8	22.4	16.7	8.9	0.09	6.7	6.3	55.2	8060	27.4	30.5	12.4	0.07	27.4	6.5
SS6	23.8	6258.5	28.6	18	15	0.13	7.6	6.8	86.6	8478.3	34.8	42.4	16.3	0.12	51.2	9.3
SS7	39.8	7533.2	29.9	23.2	14.6	0.06	4.6	13.3	63.1	7872.4	36.2	37.2	24.1	0.09	85.4	13.8
SS8	33.2	6607.4	21.7	16.7	13.9	0.06	10.2	6.2	46.1	7090.9	23.7	24.5	17.9	0.07	23.1	9.7
SS9	30.2	6143.5	24.9	16.5	12.5	0.06	18.4	6.2	39.3	6782.7	19.2	21.8	11.7	0.1	28.8	6.2
SS10	15.1	5801.7	21.6	11.7	7.7	0.05	3.4	6.2	84.8	10,494	25.8	48.3	14.2	0.11	27.8	8.9

(B) Salman Bay

S. no	*Sorites marginalis*								*Peneroplis planatus*							
	Cr	Fe	Mn	Ni	Zn	Cd	Pb	Cu	Cr	Fe	Mn	Ni	Zn	Cd	Pb	Cu
KS1	32	7560.1	11.5	22.3	12.4	0.1	11.2	6	23.4	7340.2	12.3	17.6	14.3	0.07	8.2	4.9
KS2	29.5	7430.3	12.3	21.5	12.6	0.2	10.5	7.1	24.5	7234.3	15.4	18.3	15.4	0.08	7.4	5.2
KS3	35.6	7560.4	13.2	21	12.2	0.11	9.2	6.9	29.2	7450.1	16.2	19.1	17.2	0.06	6.3	6.3
KS4	31	7830.4	11.4	20.7	11.3	0.12	9.5	5.7	30.1	7220.4	11.3	18.2	16.5	0.1	5.7	4.7
KS5	30.4	7340.2	10.6	21.4	11	0.13	10.1	5.3	23.3	7330.4	18.7	19.1	10	0.07	8.1	6.1
KS6	44.4	7476.8	13.3	24.4	13.6	0.11	10.4	5.8	20.9	7852.9	38.2	18.2	15	0.09	9.1	5.9
KS7	38.5	7307.7	13.5	21.5	19.2	0.12	12.8	6.4	51.2	8536.9	19.7	54.6	16.8	0.22	27.3	34.6
KS8	31	7631.1	13.1	21.8	12.3	0.08	10	5.2	29.8	7608.7	11.5	19.4	9.4	0.09	7.5	6.2
KS9	36.4	7806.8	12	22.8	11.1	0.47	28.2	10.2	24.8	7220.9	13.4	18.5	11.9	0.09	5.6	14
KS10	100.6	10,064.9	6.8	53.2	11	0.1	7.1	9.7	58.1	8169	12.2	30.7	13.6	0.11	10.8	7

the studied localities as in the eastern Mediterranean and northern and western Red Sea supports the well-known opinion of Loeblich and Tappan (1964) that the species of this family are living in active environment. Occurrence of *Ammonia beccarii*, which increases under stressed environmental conditions such as abnormal salinity (Pokorny, 1965), is low in the studied area. The Red Sea is considered as euhaline-hyperhaline waters. The abundance of Hauerinidae may be considered as an indicator of shallow warm marine environment (Mohamed et al., 2013). The selected foraminiferal species are presented in Figs. 12 and 13.

5.2. Test abnormality

Morphological abnormalities are general features occurring among all benthic foraminifera. This phenomenon occurs in cold and warm water (Yanko et al., 1998). The presence of abnormal tests suggests natural environmental stresses, e.g., changes in ecological parameters (Closs and Maderia, 1968), extreme environmental conditions (Zaninetti, 1982), or pollution (Geslin et al., 2002). For a long time, it has been difficult to distinguish between abnormalities resulting from natural or anthropogenic stresses. Abnormal specimens

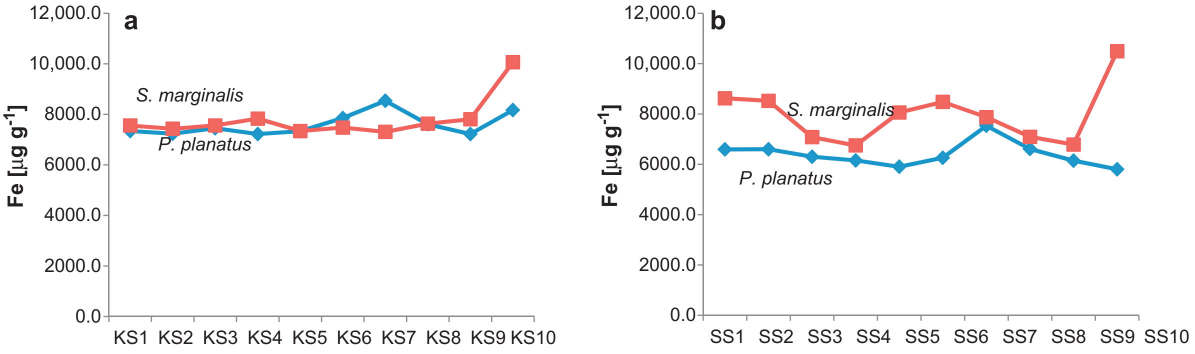

Figure 3 Fe concentrations in [μg g^{-1}] in *Sorites marginalis* and *Peneroplis planatus*: (a) Salman Bay and (b) south Jeddah area.

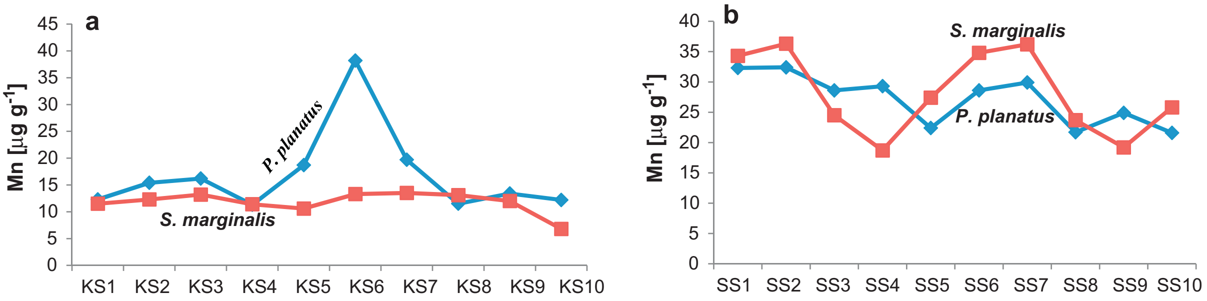

Figure 4 Mn concentrations in [µg g^{-1}] in *Sorites marginalis* and *Peneroplis planatus*: (a) Salman Bay and (b) south Jeddah area.

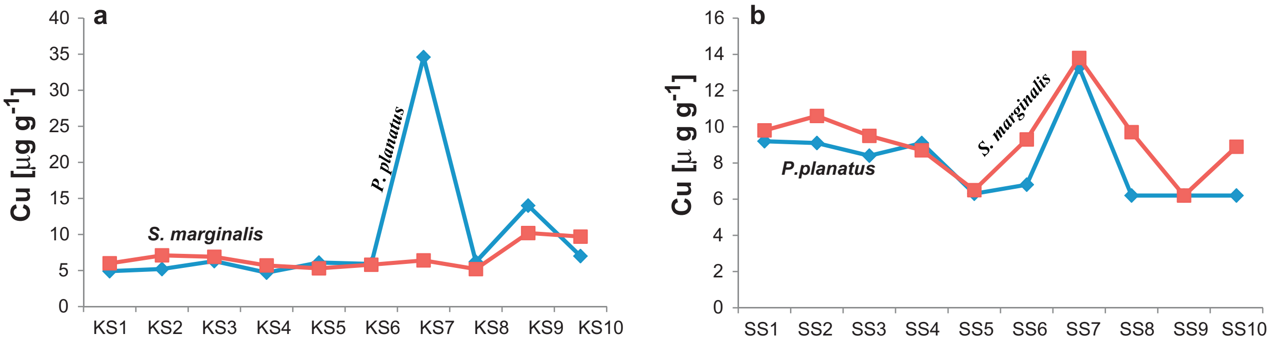

Figure 5 Cu concentrations in [µg g^{-1}] in *Sorites marginalis* and *Peneroplis planatus*: (a) Salman Bay and (b) south Jeddah area.

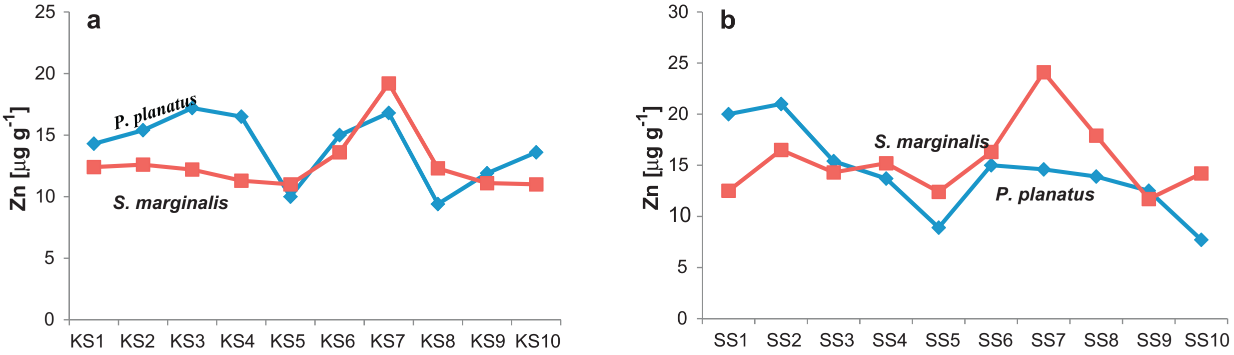

Figure 6 Zn concentrations in [µg g^{-1}] in *Sorites marginalis* and *Peneroplis planatus*: (a) Salman Bay and (b) south Jeddah area.

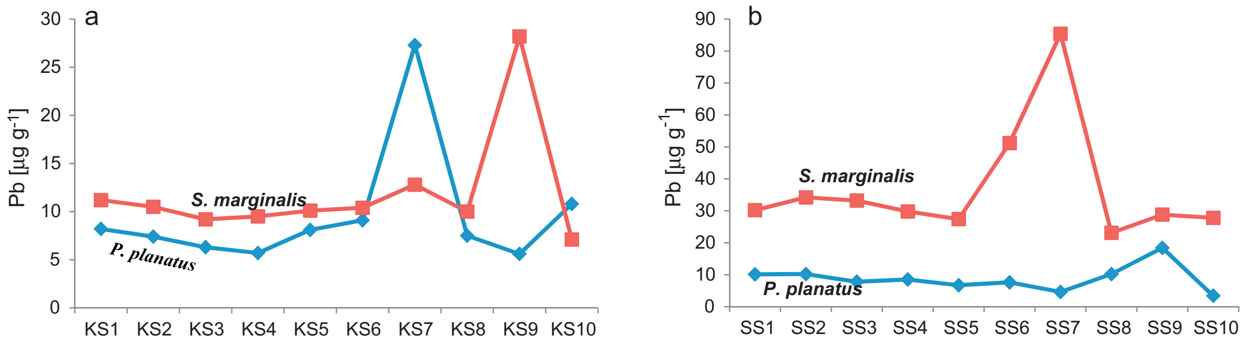

Figure 7 Pb concentrations in [µg g^{-1}] in *Sorites marginalis* and *Peneroplis planatus*: (a) Salman Bay and (b) south Jeddah area.

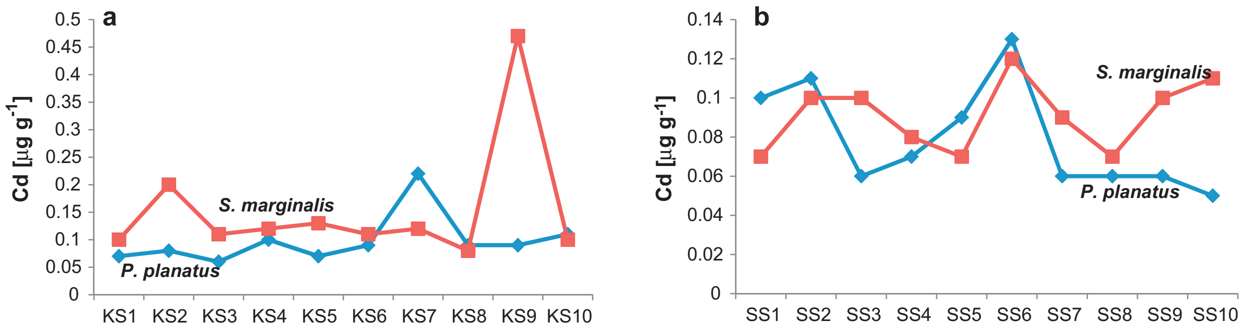

Figure 8 Cd concentrations in [µg g^{-1}] in *Sorites marginalis* and *Peneroplis planatus*: (a) Salman Bay and (b) south Jeddah area.

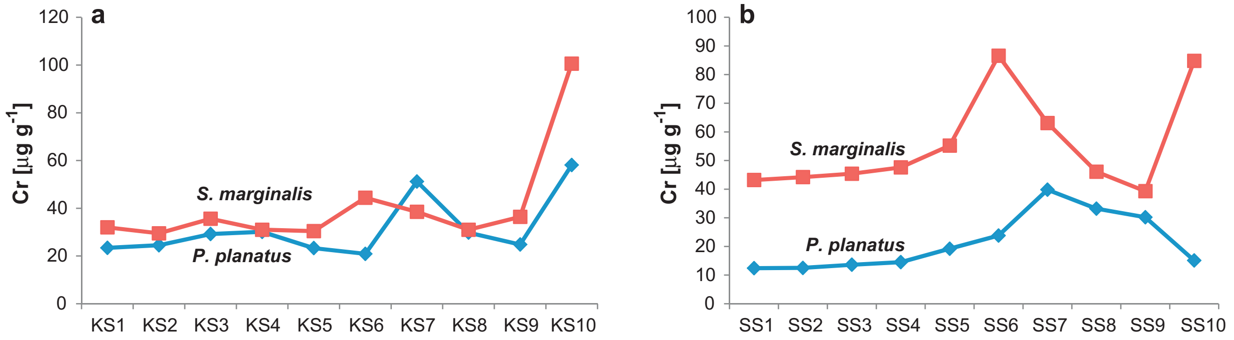

Figure 9 Cr concentrations in [µg g^{-1}] in *Sorites marginalis* and *Peneroplis planatus*: (a) Salman Bay and (b) south Jeddah area.

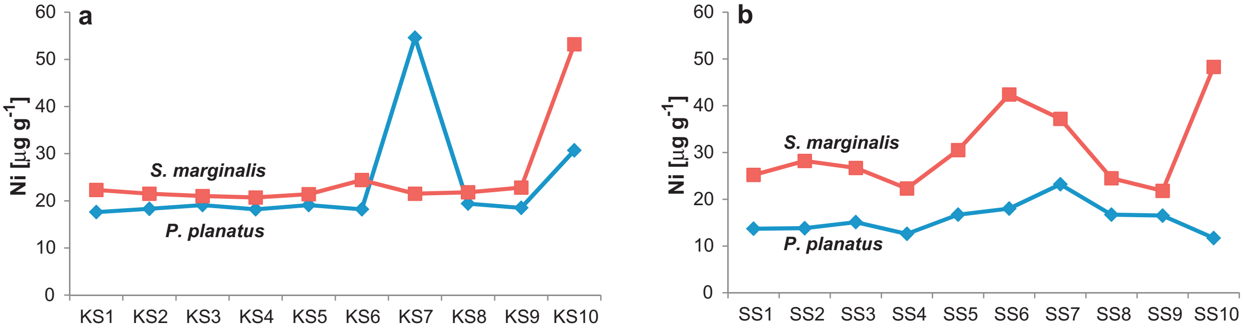

Figure 10 Ni concentrations in [µg g^{-1}] in *Sorites marginalis* and *Peneroplis planatus*: (a) Salman Bay and (b) south Jeddah area.

contain much greater values of Cu and Zn than non-deformed specimens (Yanko et al., 1998). Samir and El-Din (2001) pointed out those tests with twisted, compressed, and abnormal growth characterized by higher values of heavy metals than forms with protuberances. The abnormalities in foraminiferal tests in the studied area include: abnormal growth of the last formed chamber, protuberances, branched last chamber and abnormal test shape. Some foraminiferal species display a wide variety of abnormality caused by pathological morphogenesis including double aperture, aberrant chamber shape and extreme compression. This record indicates that environmental pollution is preserved within the foraminiferal tests of some specimens (Fig. 14).

5.3. Zonation of pollutants in foraminiferal tests

Iron is an essential element in the marine ecosystem and consequently one of the most abundant elements in marine sediments of the Red Sea. Iron represents the maximum abundance of the studied metals during the present study. The high concentration in the study area is attributed to the influence of packing of cement shipments in Jeddah Harbor and the high contribution of terrigenous materials. The correlation matrix shows high positive correlation between Fe and each of Pb and Ni, which indicates that anthropogenic activities are the main source of Fe and other metals to the coastal areas (Table 4).

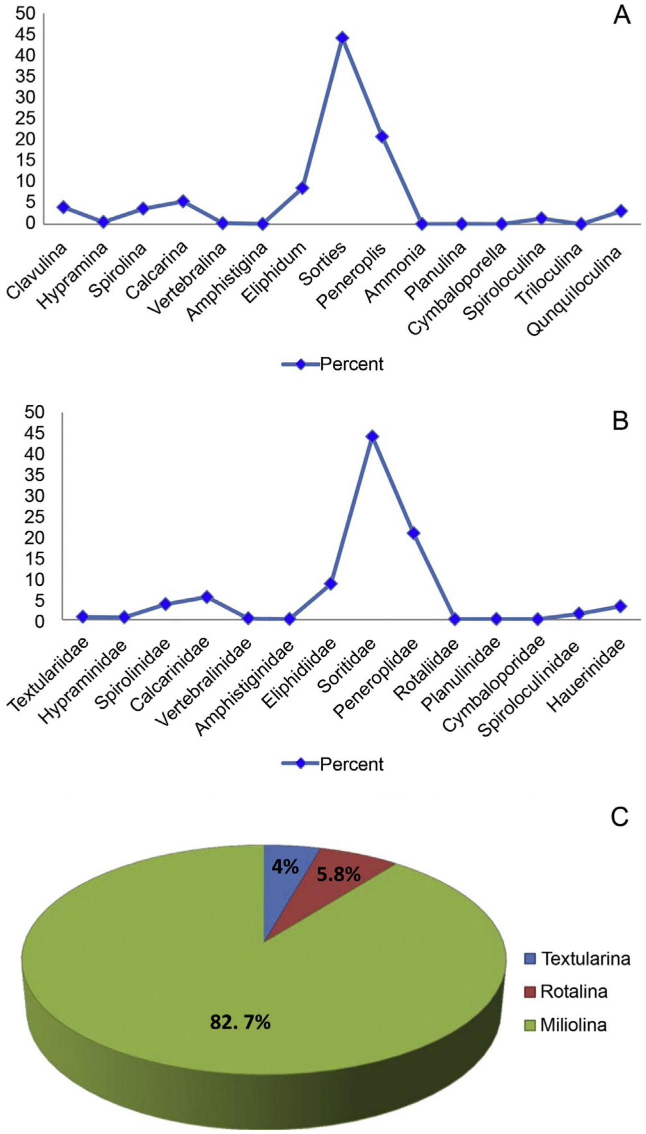

Figure 11 The frequency of the benthic foraminifera in the studied area: (A) by genera, (B) by family, and (C) by suborder.

Manganese is transported to the marine environment in the same way like iron. However, since Mn is related to and associated with iron in the conditions of accumulation and dissolution, it seems to co-operate with it in distribution in the studied area. However, the Mn concentration in *Sorites* is lower than in *Peneroplis* in south Jeddah area. The same concentration was recorded in foraminifera in the western side of the Red Sea (Madkour and Youssef, 2009).

Copper plays a biologically important role in the growth and life of most aquatic organisms. However, it may become toxic to the marine organisms if it exceeds a specific threshold (Kennish, 1992). The input of copper into marine environment comes from different sources, including mining, smelting, domestic and industrial activities and from algaecides and an antifouling applied to boat hulls (Fabrizio and Coccioni, 2012). Mansour et al. (2005) recorded that Cu content in foraminiferal tests varies from 0.32 $\mu g\ g^{-1}$ in *Ammonia beccarii* at El-Esh area to 86.7 $\mu g\ g^{-1}$ in *Operculinella cumingii* at Quseir Harbor. In comparison, foraminiferal tests in the present work have high concentrations of Cu compared to those recorded by Mansour et al. (2005). Also, Madkour (2004) stated that foraminiferal tests recorded high values of Cu concentrations compared to coral reefs and molluscan shells in Quseir and Safaga Harbors. Copper content in foraminiferal tests varies from 9.6 to 36.4 $\mu g\ g^{-1}$ in *Sorites* and *Spiroloculina* at Abu-Shaar lagoon of the Egyptian Red Sea Coast, respectively (Madkour and Youssef, 2009) which is the same range as in the present work in *Sorites* and *Peneroplis*. The concentration of Cu in the foraminiferal tests in the present work means that foraminiferal species have great ability to extract this metal from sediment and bioaccumulate it within its structure. The distribution of copper contents in these areas may attribute to the antifoulants containing copper and used to paint boat hulls. The correlation coefficients between Cu and Pb are 0.65, 0.50 and 0.33 for the studied species in the Salman Bay and south Jeddah area respectively (Table 4). This indicates that these two anthropogenic metals tend to accumulate under the same conditions.

Zinc is a naturally abundant element present as a common contaminant in agricultural, food wastes, manufacturing of pesticides as well as antifouling paints. Zinc plays an important role as an essential trace element in all living systems (Merian, 1991). Zn concentration was very similar to that of Cu. Zn concentration in foraminiferal tests is higher than that in coral reefs and molluscan shells in Quseir, Safaga, Hurghada Harbors, and El-Esh area (Mansour et al., 2005). However, these values are lower than those of the present work. Madkour (2004) found that Zn level in the foraminiferal tests varies from 3.14 $\mu g\ g^{-1}$ in *Amphistegina lessoni* at Hurghada Harbor to 26.53 $\mu g\ g^{-1}$ in *Textularia agglutinans* at Quseir Harbor. Zinc is mainly coprecipitated with calcium carbonate and substitute's calcium to form isomorphous zinc carbonate. Moreover, Zn concentration in the marine environment is least influenced by human impact, but it will continue to rise leading to ecological damage when it has long residence time in the environment. The main anthropogenic sources of zinc include zinc sulphate used in house construction, air-conditioning ducts, garbage cans, galvanized pipes, batteries and wear of automobile tires.

The high Pb concentration in the marine environments is attributed to several sources such as boat exhaust systems, oil spill, and other petroleum compounds from motor boats employed for fishing, and the sewage effluents discharged into water (Laxen, 1983), and all of these sources exist in the studied area. Atmospheric input of Pb generated from the automobile exhaust emission was also recorded in the study area which was situated close to the highway and the city roads (Badr et al., 2009). The atmospheric input were considered responsible for the introduction of Cd, Pb and Zn to the marine environment (Frignani et al., 1997). The main anthropogenic sources of Pb come from mining, shipment operations, oil refineries, power, desalination plants, domestic sewage, landfill and dredging. In comparison to corals and mollusks of the Quseir, Safaga, Hurghada harbors and El-Esh area, foraminifera tests have high values of Pb concentration (Madkour, 2004). The Pb values recorded by Madkour

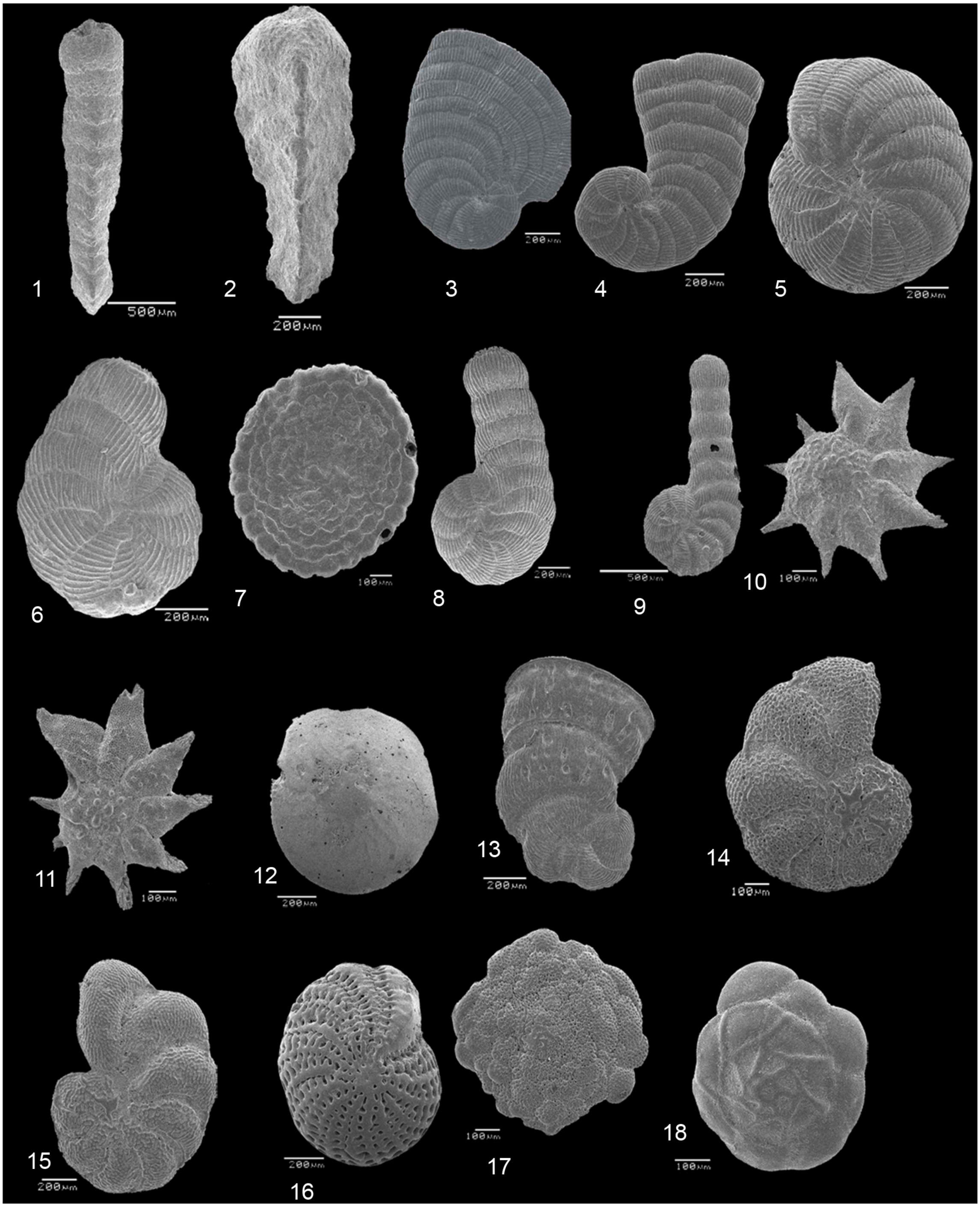

Figure 12 1: *Clavulina tricarinata*, SS-10; 2: *Clavulina angularis*, SS-8; 3: *Peneroplis planatus*, KS-9; 4: *Peneroplis planatus*, KS-10; 5: *Peneroplis pertusus*, KS-9; 6: *Peneroplis proteus*, SS-10; 7: *Sorites marginalis*, SS-10; 8: *Spirolina arietina*, SS-10; 9: *Spirolina arietina*, SS-10; 10: *Calcarina calcar*, SS-10; 11: *Calcarina calcar*, SS-8; 12: *Amphistegina lessoni*, SS-7; 13: *Vertebralina striata*, SS-8; 14: *Planulina* cf. *wuellerstorfi*, KS-9; 15: *Planulina* cf. *wuellerstorfi*, SS-10; 16: *Elphidium advenum*, SS-9; 17: *Cymbaloporetta bradyi*, SS-2; 18: *Ammonia beccarii*, SS-10.

(2004) and Madkour and Youssef (2009) in foraminiferal species are similar to those records in the present work. Pb, Cr and Ni showed the same distributional patterns with the highest concentration in *Peneroplis planatus* in the south Jeddah area (85.4, 86.6, and 48.3 $\mu g\ g^{-1}$ respectively). Pb is most probably of industrial origin and is expected to be carried to the inlets via mixed wastewater effluents (El Sayed and Basaham, 2004) or by boat-engine fuel spills, since they were specifically accumulating in these areas (Abu-Zied et al., 2012).

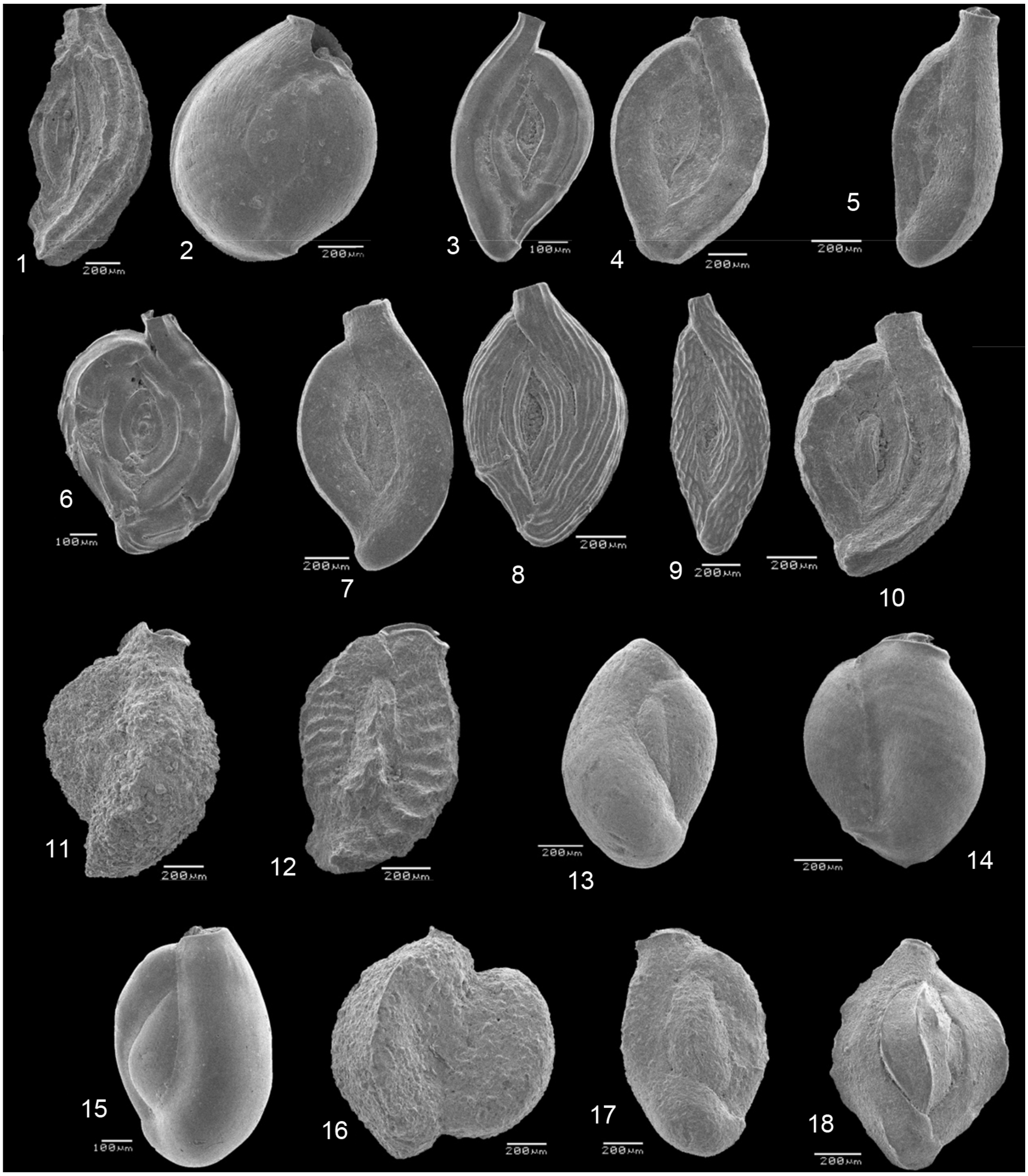

Figure 13 1: *Quinqueloculina angularis*, KS-9; 2: *Quinqueloculina neostriatula*, SS-8; 3: *Spiroloculina communis*, SS-7; 4: *Spiroloculina angulata*, SS-8; 5: *Spiroloculina* sp. 1, SS-8; 6: *Spiroloculina* sp. 2, SS-8; 7: *Spiroloculina angulata*, SS-8; 8: *Spiroloculina angulata*, SS-8; 9: *Spiroloculina corrugata*, SS-8; 10: *Spiroloculina lucida*, SS-8, KS-10; 11: *Quinqueloculina agglutinans*, KS-10; 12: *Quinqueloculina mosharrafi*, KS-10; 13: *Quinqueloculina limbata*, SS-2; 14: *Quinqueloculina lamarckiana*, SS-2; 15: *Quinqueloculina seminulum*, SS-2; 16: *Quinqueloculina* sp. 1; 17: *Quinqueloculina* sp. 2; 18: *Quinqueloculina samoensis*, SS-2.

Cadmium is a conductor element in the environment and act as a cumulative poison (Roy, 1997). Environmental Protection Agency (EPA) listed cadmium as one of 129 priority pollutants and listed among the 25 hazardous substances. Cadmium should not be dumped into the sea, since it is included on the black list (Clark et al., 1997). The main sources of Cd to the marine environment are mainly anthropogenic through the refinement and use of Cd, Cu and Ni smelting and atmospheric input (Kennish, 1996) in which most of these metals are deposited in bottom sediments (Clark et al., 1997). Concentrations of Cd were relatively low with values lower than 1 $\mu g\ g^{-1}$, where Cd abundances in the natural environment range from 0.1 to 0.3 $\mu g\ g^{-1}$ (Kabata-Pendias and Pendias, 1984). Cadmium enters the test of foraminifera as a substitute for calcium (Marchitto et al., 2000). The anthropogenic sources of this metal into the studied area may include discharge of refining wastes and untreated sewage effluents. A negative correlation was detected between Cd and all other redox sensitive metals (Cr, Ni, Cu, and Cd) except for Pb where positive correlation

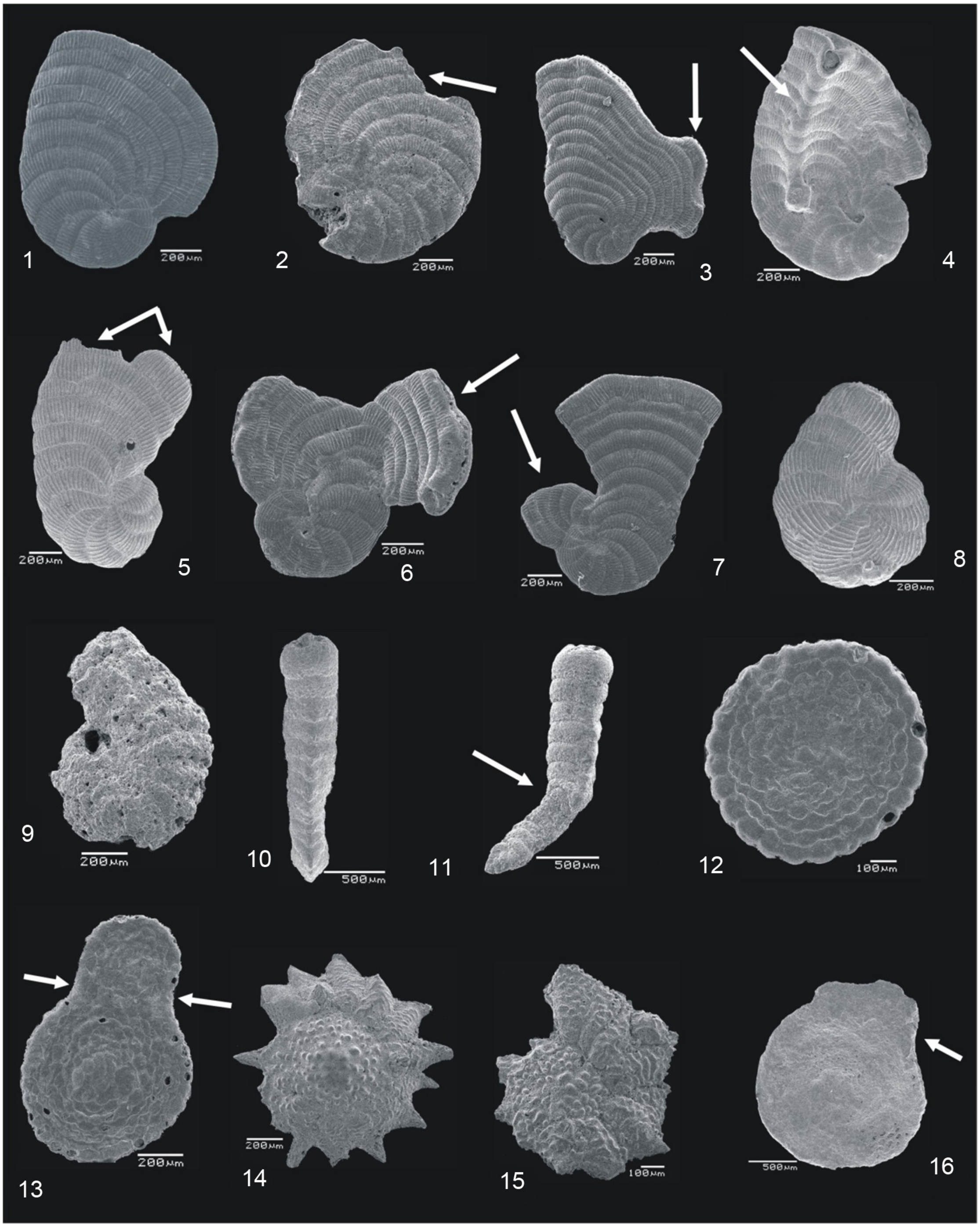

Figure 14 1: *Peneroplis planatus* with normal test, Ks-9; 2: *Peneroplis planatus* with deformed test, SS-8; 3: *Peneroplis planatus* with abnormal growth of the last formed chamber, SS-7; 4: *Peneroplis planatus* with protuberances, SS-10; 5: *Peneroplis planatus* with abnormal growth with the last chamber divided into two branches, SS-10; 6: *Peneroplis planatus* abnormal growth with a new branch of the test, KS-9; 7: *Peneroplis planatus* abnormal growth with a new branch of the test, SS-6; 8: *Peneroplis* proteus with normal test, SS-10; 9: *Peneroplis proteus* with brittle test, SS-10; 10: *Clavulina tricarinata* with black spots distributed in whole of the test (weakly appeared depending on the coating), SS-10; 11: *Clavulina tricarinata* curved at the end of the triserial part, SS-8; 12: *Sorites marginalis* with normal circular test but also black, KS-10; 13: *Sorites marginalis* with abnormal test elongated, SS-6; 14: *Calcarina calcar* with normal test the spines is preserved, KS-10; 15: *Calcarina calcar* with brittle test and the spines is not preserved, KS-8; 16: *Sorites marginalis* with abnormal test and black test, SS-10.

Table 4 Correlation coefficients between eight heavy metals in *Sorites marginalis* and *Peneroplis planatus* tests of (A) south Jeddah area and (B) Salman Bay.

(A)

	Cr	Fe	Mn	Ni	Zn	Cd	Pb	Cu
Cr	1							
Fe	**0.83**	1						
Mn	0.16	0.41	1					
Ni	**0.97**	**0.89**	0.29	1				
Zn	0.17	0.21	**0.59**	0.24	1			
Cd	0.31	0.31	0.30	0.40	0.37	1		
Pb	0.71	**0.52**	0.39	**0.72**	0.50	0.29	1	
Cu	0.32	0.42	**0.64**	0.39	**0.66**	0.08	0.50	1

(B):

	Cr	Fe	Mn	Ni	Zn	Cd	Pb	Cu
Cr	1							
Fe	**0.91**	1						
Mn	−0.25	−0.20	1					
Ni	**0.84**	**0.87**	−0.16	1				
Zn	−0.07	−0.16	−0.04	0.05	1			
Cd	0.10	0.13	−0.12	0.20	−0.12	1		
Pb	0.15	0.21	−0.17	0.44	0.09	**0.85**	1	
Cu	0.28	0.38	0.24	**0.71**	0.20	0.35	**0.65**	1

(0.85) is recorded (Table 4). This may refer to the deposition of Cd, without change in oxidation state, except in the presence of H_2S; it is usually removed from solution as insoluble cadmium sulfide (Gwenaelle et al., 2002).

Chromium is a heavy metal with toxic potential for marine environment with background concentration in uncontaminated sediments of $<20\ \mu g\,g^{-1}$ (Oana, 2006). Chromium enters the marine environments mainly by atmospheric pollution. Anthropogenic sources as cooling towers, industrial discharge into the water and runoff from urban areas are the principal sources. The most positive correlation of Cr was detected with Ni (0.97) (Table 4).

The Ni content in *Peneroplis planatus* is higher than the value recorded in the same species ($5.95\ \mu g\,g^{-1}$) at Marsa Shuni lagoon, Egyptian Red Sea coast (Mansour et al., 2005). Nickel, which is quite abundant in the Earth's crust, enters surface waters from the dissolution of rocks and soils, biological cycles, atmospheric fallout, industrial processes, and waste disposal (Prego et al., 1999). On the other hand, De Carlo and Spencer (1995) show that Ni and Co do not display trends indicative of large anthropogenic contribution to the sediments.

5.4. Heavy metal clusters

Table 5 Some statistical parameters of the heavy metals of the clusters computed by (Ward's method) cluster analysis based on 8 variables of heavy metals in foraminiferal species at the study areas.

	Cr	Fe	Mn	Ni	Zn	Cd	Pb	Cu
Cluster 1 (17 foraminiferal tests)								
S	7.6	172.7	5.5	2.6	2.8	0.0	7.1	2.8
Min	23.3	7080.0	10.6	17.6	9.4	0.1	4.6	4.7
Max	46.1	7631.1	29.9	26.7	19.2	0.2	33.2	14.0
X	32.8	7377.4	15.6	21.1	13.8	0.1	10.8	7.2
Cluster 2 (4 foraminiferal tests)								
S	20.5	59.9	7.8	13.6	2.0	0.1	10.7	12.4
Min	43.2	8478.3	19.7	25.2	12.5	0.1	27.3	9.3
Max	86.6	8621.1	36.3	54.6	16.8	0.2	51.2	34.6
X	56.3	8539.4	31.3	37.6	15.5	0.1	35.7	16.1
Cluster 3 (6 foraminiferal tests)								
S	17.0	147.2	12.6	7.3	4.9	0.2	29.3	3.2
Min	20.9	7806.8	11.4	18.2	11.1	0.1	9.1	5.7
Max	63.1	8169.0	38.2	37.2	24.1	0.5	85.4	13.8
X	44.1	7931.9	22.9	26.7	14.6	0.2	28.4	8.2
Cluster 4 (2 foraminiferal tests)								
S	11.2	303.4	13.4	3.5	2.3	0.0	14.6	0.6
Min	84.8	10,064.9	6.8	48.3	11.0	0.1	7.1	8.9
Max	100.6	10,494.0	25.8	53.2	14.2	0.1	27.8	9.7
X	92.7	10,279.5	16.3	50.8	12.6	0.1	17.5	9.3
Cluster 5 (5 foraminiferal tests)								
S	15.9	92.9	6.9	4.2	4.0	0.0	10.5	1.5
Min	12.4	6590.4	18.7	13.7	11.7	0.1	10.1	6.2
Max	47.6	6782.7	32.4	22.3	21.0	0.1	29.8	9.2
X	29.0	6665.6	24.9	17.7	16.4	0.1	17.8	7.9
Cluster 6 (6 foraminiferal tests)								
S	6.5	199.0	3.4	2.5	3.2	0.0	5.1	1.3
Min	13.6	5801.7	21.6	11.7	7.7	0.1	3.4	6.2
Max	30.2	6300.2	29.3	18.0	15.4	0.1	18.4	9.1
X	19.4	6093.2	25.9	15.1	12.2	0.1	8.7	7.2

S, standard deviation; Min, minimum; Max, maximum; X, average.

Statistical computations (cluster analysis) were performed with the program SPSS using a hierarchical cluster analysis (Ward's method). Based on 8 heavy metals (Fe, Mn, Zn, Cu, Pb, Ni, Cr and Cd) concentration, benthic foraminiferal species from the studied area are divided into six main clusters (Fig. 15; Table 5). Cluster 1 contains 17 samples (43% of the total samples) and is characterized by high concentrations of Fe ($X = 7377\ \mu g\,g^{-1}$, $S = 173\ \mu g\,g^{-1}$) and Cr ($X = 32.8\ \mu g\,g^{-1}$, $S = 7.6\ \mu g\,g^{-1}$). Cluster 2 includes four samples with high concentrations of Fe ($X = 8539\ \mu g\,g^{-1}$, $S = 60\ \mu g\,g^{-1}$), Cr ($X = 56\ \mu g\,g^{-1}$, $S = 21\ \mu g\,g^{-1}$), and Ni ($X = 38\ \mu g\,g^{-1}$, $S = 14\ \mu g\,g^{-1}$). The 6 samples of cluster 3 are separated by high concentration of Pb ($X = 28.4\ \mu g\,g^{-1}$, $S = 29.3\ \mu g\,g^{-1}$). This cluster indicates that the general trends of lead contents are increasing offshore. Cluster 4 includes only two samples and is characterized by the highest concentrations of heavy metals compared to the other clusters: Fe ($X = 10{,}280\ \mu g\,g^{-1}$, $S = 303\ \mu g\,g^{-1}$) and Cr ($X = 93\ \mu g\,g^{-1}$, $S = 11.2\ \mu g\,g^{-1}$). These two samples are the deepest samples in the two locations. Cluster 5 consists of 5 samples (13% of the total samples). This cluster has medium concentrations of heavy metals. The six samples of cluster 6 have the lowest concentrations of heavy metals compared to the other clusters.

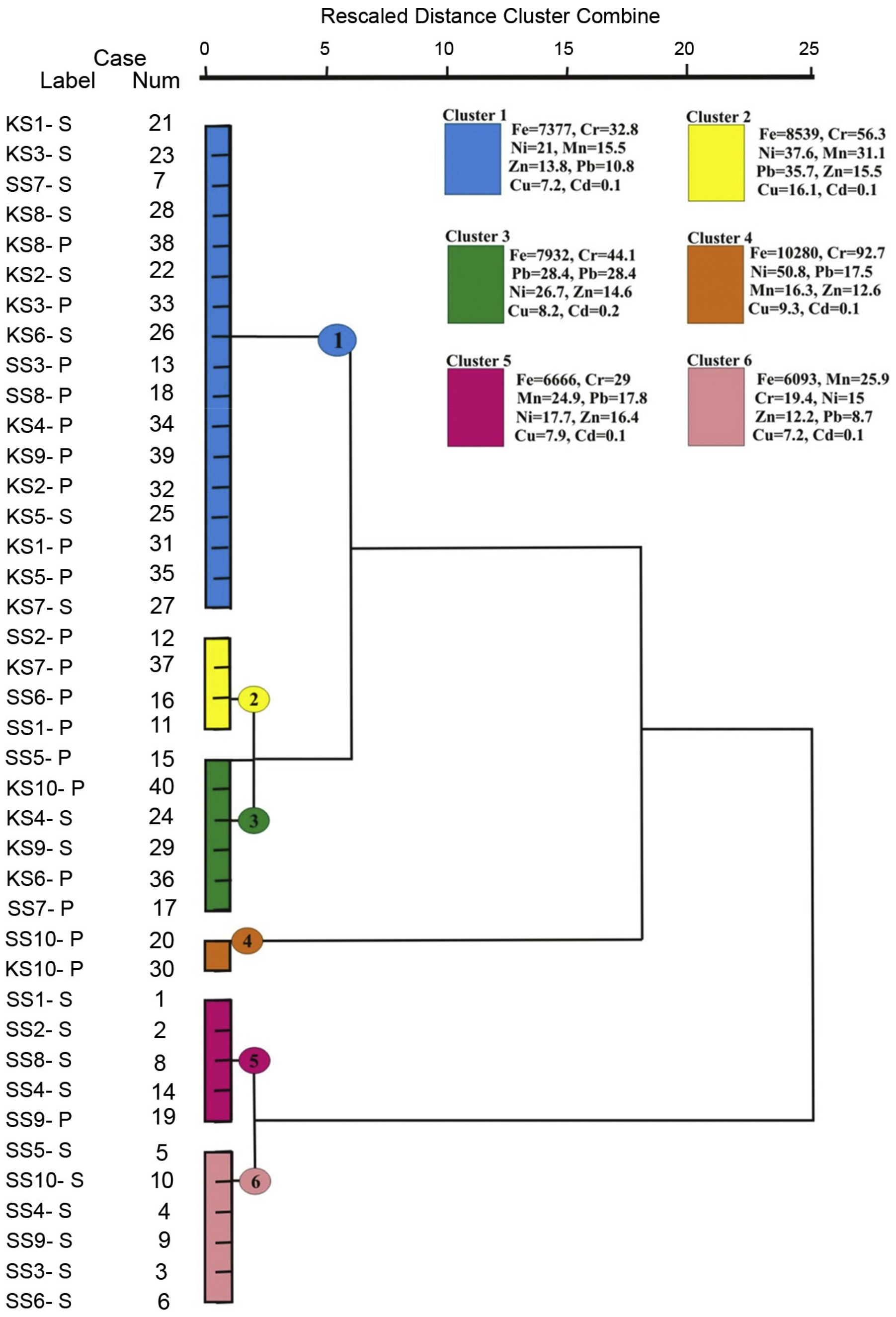

Figure 15 Dendrogram from cluster analysis (Ward's method) of heavy metals in foraminiferal species from the study area. KS, the Salman Bay; SS, South Jeddah area; S, *Sorites marginalis*; P, *Peneroplis planatus*.

6. Conclusion

The present study yielded 33 benthic foraminiferal species belonging to 15 genera, 14 families and three suborders. The families Soritidae, Peneroplidae and Hauerinidae dominated the foraminiferal assemblage in the study area. Some foraminiferal species displayed abnormalities in their coiling, general shape of chambers and the apertures. The concentrations of Cr, Fe, Mn, Ni, Zn, Cd, Pb, and Cu in the tests of living *Sorites marginalis* and *Peneroplis planatus* showed that the coastal areas are virtually influenced by anthropogenic activities. The anthropogenic activities have a considerable impact, beside other factors, in the abnormalities of benthic foraminifera.

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