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The Relationship Between the Environmental Conditions of the Jeddah Coast, Red Sea, and Benthic Foraminifera

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ABSTRACT. The occurrence and distribution of benthic foraminifera were studied in sewage-polluted and unpolluted nearshore sediments from the Jeddah coast. The number of foraminifera was found to be relatively higher in the sewage discharge areas. Sediments nearer to the discharge points were characterized by dead foraminifera, while the living ones were recorded only in those away from the sewage sources. Milliolina-dominated foraminifera assemblage, which is typical of subtropical carbonate environments, characterizes the nearshore sediments. However, near the sewage discharge areas, the abundance of Rotalina considerably increases.

The concentration of organic matter and total carbonates in the nearshore sediments are also affected by the sewage since the organic carbon of the polluted sediments is several times in excess of the average for the unpolluted sediments. Moreover, trace elements (Zn, Cu, Mn, Cd, Pb and Ni) contents in the polluted sediments are significantly higher than those in the unpolluted sediments. The distribution of these elements are directly related to the sources of sewage points in the study areas.

Introduction

It is well-known and established that the marine environmental factors play an important role in the occurrence and abundance of benthic foraminifera. The nearshore environments, particularly near the places of human habitation, receive a variety of pollution from the disposal of sewage sludge and industrial wastes. These huge amounts of pollutants, actually result in changing the normal hydrograpic conditions of these environments since these changes may be significant in disturbing the

natural ecosystem. Such a disturbance will have drastic effect on the microfauna including foraminifera either in their frequency distribution or their species abundance.

Watkins (1961) made the first study on the effect of sewage pollution on benthic foraminifera and recorded considerable variations in the size and distribution of some species in the discharge areas. Also, Bandy *et al.* (1965a,b) investigated the distribution patterns of benthic foraminifera in the sewage outfall areas of Santa Monica Bay, Southern California and evaluated the effect of pollution on the foraminifera.

Along the eastern Red Sea coast of Saudi Arabia and in the Arabian Gulf many studies (Bahafzallah 1979, Bahafzallah and El-Askari 1981, Yusuf 1984, Abou-Ouf 1982, and Abou-Ouf *et al.* 1988) were carried out on the recent foraminifera without tackling the important problem of pollution and its effect on the distribution of the benthic foraminifera in the marine environments. Therefore, the present work, a part of a larger study in the Saudi Arabian coastal lagoons, sets out to examine temporal and spatial trends of contamination in the nearshore regions of the Jeddah coast and thereafter the effect of these pollutants on the benthic foraminifera.

Study Area

The area of study, which is located approximately in the centre of the west coast of Saudi Arabia (between 40° and 38° longitude and 21° and 24° latitude), includes Masturah and Tuwwal Bays, Al Arbayeen Lagoon, and the South Cornishe (about 15 km South of Jeddah) (Fig. 1). The locations of these areas are given separately in figures (1, 2 and 3).

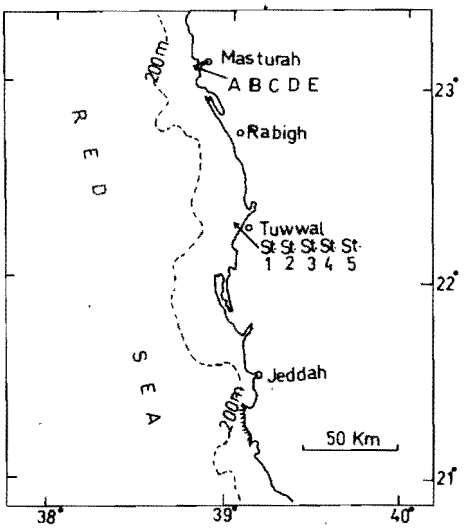

FIG. 1. Study area and sample locations in Masturah and Tuwwal regions.

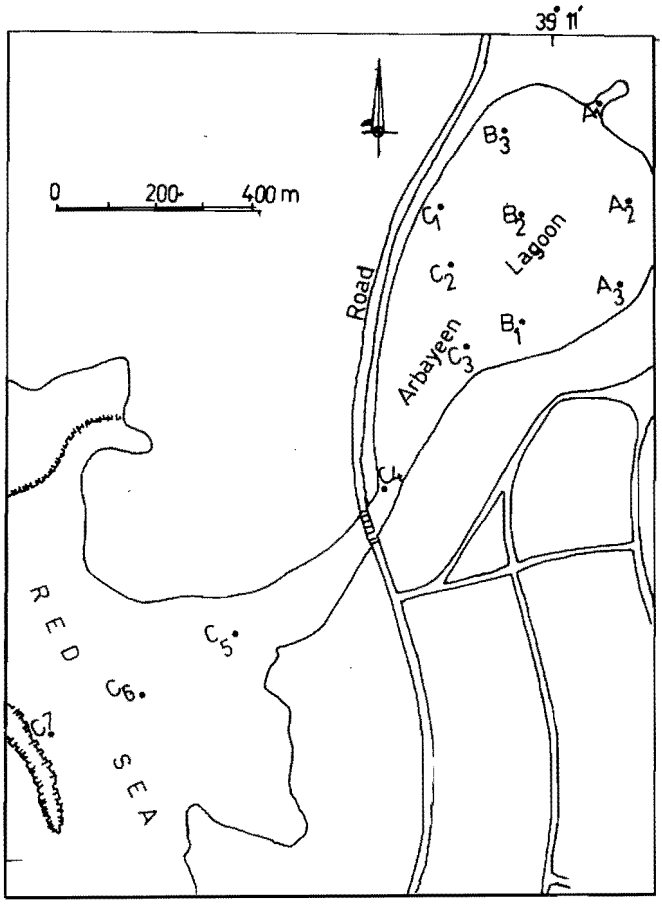

FIG. 2. Sample locations in Al Arbayeen lagoon.

The coasts of both Masturah and Tuwwal are characterized by a wide intertidal zone and unpolluted sediments which consist mainly of fine carbonate grains.

Al Arbayeen lagoon lies at the centre of the Jeddah city coast (Fig.3). It is small, with an area of approximately 25500 m^2, and connected to the Red Sea through an inlet. It is almost stagnant body of water due to the minimal exchange of water with the Red Sea. Also, it is a highly polluted area because of the many sources of contamination it receives (Fig. 4). Its depth varies from place to place but attains its maximum in the centre (about 6 meters) (Table 1).

The South Cornishe, which is adjacent to the urban area, is another sewage outfall on the coastal strip. This area is highly polluted and characterized by mangrove and bad odours. Its sediments are generally muddy with some sands of calcareous nature.

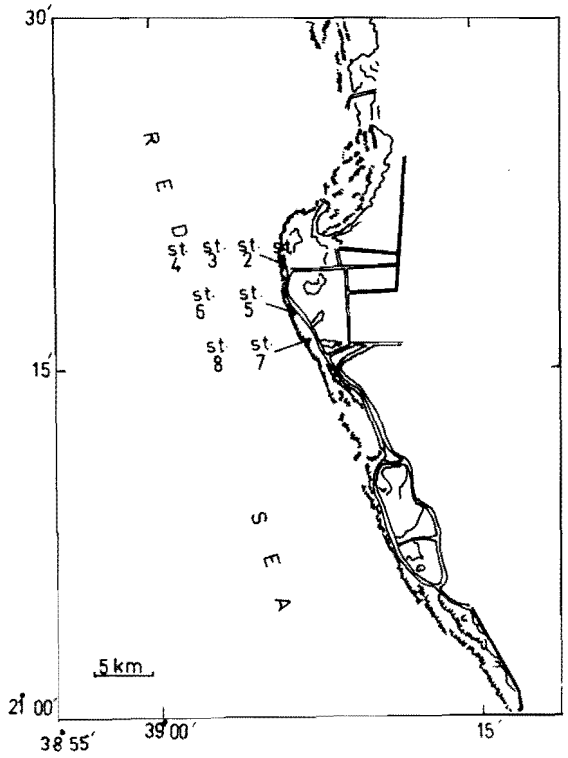

FIG. 3. Location of samples from south Cornishe.

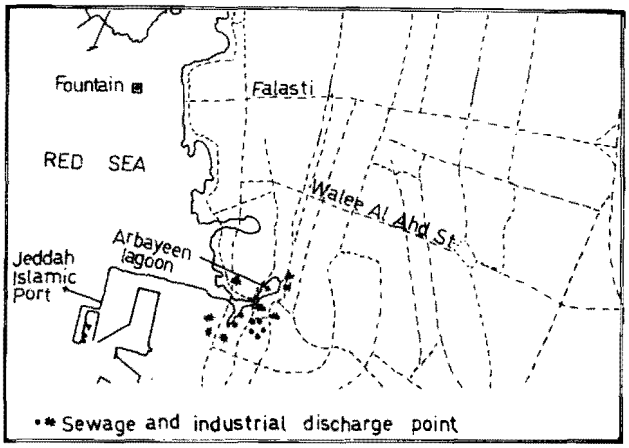

FIG. 4. Sewage and industrial discharge of Al Arbayeen lagoon.

TABLE 1. Depth, salinity and temperature of the water at the sampling sites.

Station	Depth (m)	Temperature T °C		Salinity %	
		Surface	Bottom	Surface	Bottom
Masturah					
1	0.05	26	26	41.486	–
2	0.1	25	25	40.448	–
3	0.3	24	24	40.323	–
4	1	24	24	40.174	–
5	1.45	24	23	40.151	–
Tuwwal					
6	0.07	34	–	41.548	–
7	0.15	30	29.5	40.084	–
8	0.2	30	30	40.11	–
9	1	31	30	40.048	–
10	1.5	30	29	39.987	–
Arbayeen Lagoon					
A1	1	31	–	33.124	23.862
A2	4	31.5	–	35.609	38.215
A3	4	31.5	–	35.499	43.123
B1	5-6	31	–	35.265	48.928
B2	5-6.5	31	–	35.837	55.12
B3	5	30	–	35.616	47.956
C1	4	30	–	36.031	48.753
C2	5	31	–	–	53.354
C3	5.5	31	–	32.393	42.859
C4	3	32	–	23.844	37.678
C6	3	30.2	–	–	38.722
C7	5	30	–	–	–
South Cornishe					
S1	0.45	24	23	29.08	–
S2	0.5	24	22	28.412	–
S3	0.5	24	24	40.06	–
S4	0.5	24	24	39.777	–
S5	0.3	24	23	–	–
S6	2	24	23	–	–
S7	0.1	–	24	–	–
S8	0.03	–	26	–	–

Material and Methods

i. Sampling

Bottom sediments were sampled at 31 stations in the study areas during February 1988. In addition, water samples were collected and some hydrographic measurements were also taken at the same sampling sites (Table 1). These stations were divided as follows: 5 in Masturah, 5 in Tuwwal, 8 in the South Cornishe and 13 in Al Arbyaeen lagoon (Fig. 1, 2, and 3).

Immediately after the collection, a part of the sediment sample was soaked in alcohol and rose Bengal to fix the living foraminifera.

ii. Methods

The grain-size frequency distribution of the sediment samples was determined by sieving (with 1/2 ϕ interval sieves) and the pipette method according to Folk (1974).

Chemical analysis was performed on the washed, dried and powdered sediment samples. Organic carbon was determined by a simple oxidation method following the technique of El Wakeel and Riley (1957). A calcimeter was used to determine the total carbonates.

A fraction of the sediment sample was dissolved in Hf and $HClO_3$. The precipitate was dissolved in 100 ml 1:3 HCl. From these solutions, the concentrations of Zn, Mn, Pb, Cu, Ni and Cd were determined using standard Atomic Absorption spectrophotometric techniques.

For foraminiferal analysis, a known amount of the dried sediments was washed through 2 mm and 63 microns mesh sieves to remove gravel and mud. The remaining sand fraction was air-dried and foraminifera were concentrated from the sediment by floatation techniques using carbon tetrachloride. The foraminiferal species were identified under a binocular microscope. About 300-400 grains were counted to estimate the number percentage of the living and dead foraminifera. Also, the percentage of the different species identified was estimated.

Results and Discussion

A. *Texture and Distribution of the Sediments*

The sediments from the study area exhibit a significant variation in grain size (Table 2). Sediments from Masturah and Tuwwal are medium sands, whereas those from South Cornishe are medium to fine sands. Al Arbaeen lagoon is characterized by fine muddy sediments ($> 63\ \mu$).

B. *Chemistry of the Sediments*

The bioavailability of trace elements in marine sediments is dependent on the metal species. The bonding of metals in particulate matter may come about through a variety of processes and mechanisms (Forstner *et al.* 1981). Trace metals may be in detrital particles of rocks, soils or organic material and combination of metals with organic molecules, followed by flocculation, absorption and precipitation may take place.

The interrelationship between sedimentary metal levels, organic content and sediment structure has been widely reported (Forest *et al.* 1978, Campbell and Loring 1980, Parker 1982). In general, highest concentrations of metals are found in areas where the finest sediments accumulate and organic matter concentrations are highest.

TABLE 2 Mean size, total carbonate and organic carbon contents of the sediments.

Station		Mean size 0	Total carbonate %	Organic carbon %
Masturah	1	1.12	96.3	0.20
	2	1.06	97.3	0.44
	3	0.88	98.3	0.50
	4	1.1	98.3	0.56
	5	1.56	94.3	0.63
Tuwwal	6	1.88	7.3	0.38
	7	1.93	9.3	0.32
	8	1.08	20.3	0.44
	9	1.48	33.3	0.44
	10	1.78	58.3	0.63
Arbayeei	A1		24.7	5.42
Lagoon	A2		30.7	6.98
	A3		40.7	8.31
	B1		44.7	8.47
	B2		30.7	8.63
	B3		29.7	8.00
	C1		44.7	4.72
	C2		44.7	5.06
	C3		62.7	3.34
	C4		32.7	5.3
	C5		47.7	5.66
	C6		57.7	8.32
	C7		76.7	6.71
South Cornishe	S1	2.9	74.3	0.69
	S2	1.05	89.3	1.78
	S3	1.5	93.3	1.35
	S4	1.5	99.3	0.75
	S5	2.8	86.3	0.69
	S6	2.68	88.3	0.69
	S7	2.3	67.3	0.75
	S8	3	67.3	0.69

i. *Organic Matter in Sediments*

Because of the influence of the organic material on metal concentrations, it was considered important to determine the concentrations of organic matter in the sediments. The organic carbon is highly concentrated in Al Arbayeen lagoon with values reaching as high as 8.63% (Table 2), with an average of (6.5%). Sediments from Tuwwal and Masturah are relatively poor in organic carbon (0.47% and 1.78%), while the South Cornishe sediments have moderate values (0.69%-1.78%). Figure 5 shows the organic carbon distribution in Al Arbayeen lagoon where the highest concentrations of organic matter (8-8.63%) were found in the central area of the lagoon. A positive correlation between the organic matter content and the metal concentrations in the sediments (Fig. 6a, b, c, e and f) agrees with the previous studies. The or-

ganic carbon reveals a negative correlation with the carbonate contents of the studied sediments (Fig. 7a), but doesn't show a clear relation with the grain size (7b).

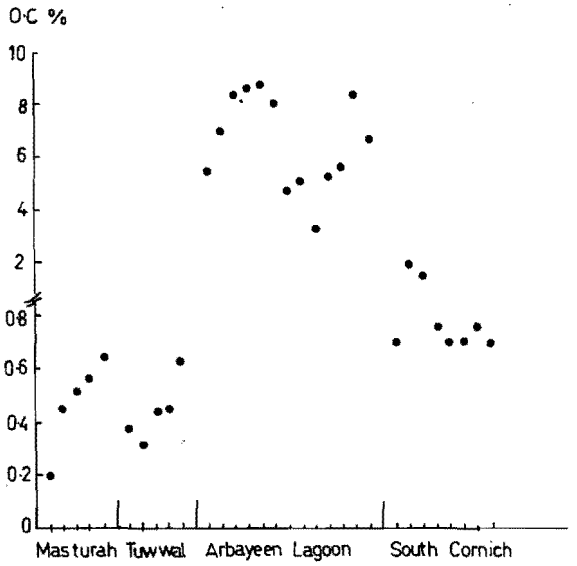

FIG. 5. Organic content in the studied areas.

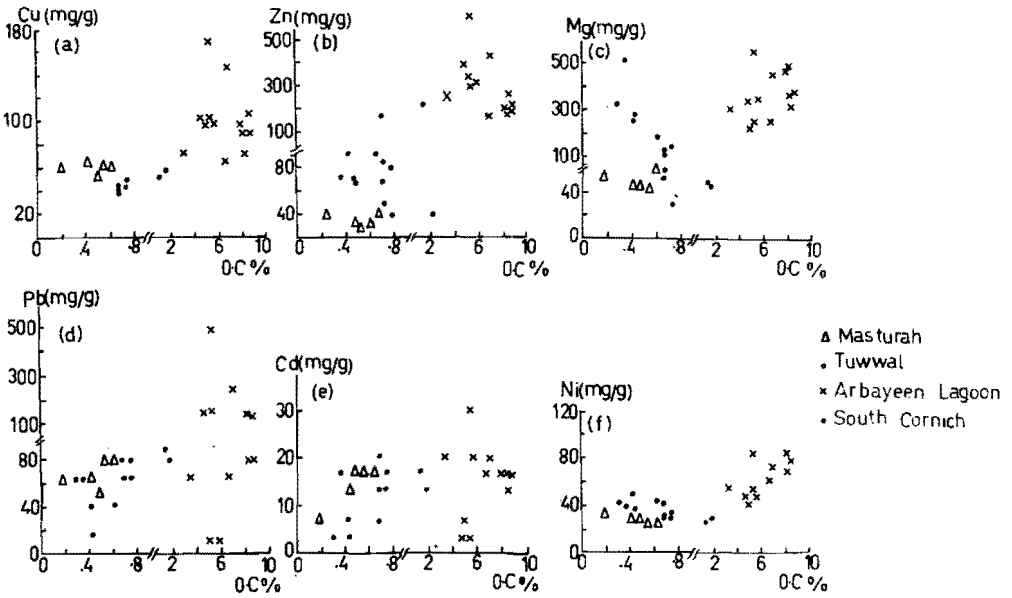

FIG. 6. Relationship between the organic carbon and trace elements contents.

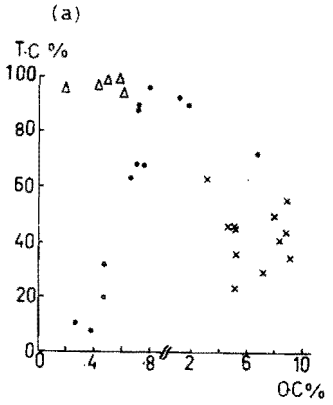

FIG. 7a. Relationship between total carbon and organic carbon contents.

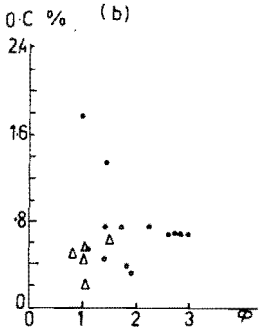

FIG. 7b. Relationship between organic carbon content and grain size of the studied sediments.

ii. *Total Metal Concentrations*

The concentrations of Zn, Mn, Pb, Cu, Ni, and Cd in the sediments of the study area are presented in Table 3. Generally, these elements are more concentrated in Al Arbayeen lagoon and South Cornishe than those in Tuwwal and Masturah sediments. In Al Arbayeen lagoon, the samples nearer to the sewage discharge points contain metal concentrations several times higher than those in the other sites (Fig. 8a, b, c, d, e, and f), so it appears that the main sources of these metals relate to these sewage discharge points.

TABLE 3. Trace element concentrations in the sediments.

Station		Zn µg/g	Mn µg/g	Pb µg/g	Cu µg/g	Ni µg/g	Cd µg/g
Masturah	1	40	53.3	63	62	32	6.7
	2	33	43.3	63	66	28	23.3
	3	27	43.3	50	52	24	16.7
	4	30	40	77	62	22	16.7
	5	40	56.6	77	62	24	16.7
Tuwwal	6	90	516.7	63	58	38	16.7
	7	70	326.6	63	66	40	3.3
	8	70	253	13	72	48	3.3
	9	67	260	40	52	36	6.7
	10	90	180	40	66	44	16.7
Arbayeen Lagoon	A1	587	546.7	479.5	168	82	30
	A2	413	446.7	226.4	148	70	20
	A3	237	480	126	90	82	16.7
	B1	167	360	130	90	15.2	13.3
	B2	200	363	77	60	76	16.7
	B3	180	457	63	86	70	16.7
	C1	380	333	137	102	46	13.3
	C2	327	216.7	10	96	40	6.7
	C3	240	302	63	72	54	20
	C4	287	243	149.9	102	52	6.7
	C5	300	340	10	96	46	20
	C6	167	307	77	72	66	18.7
	C7	153	240	63	66	60	16.7
South Cornishe	S1	47	100	40	44	28	13.3
	S2	37	43.3	77	58	29	13.3
	S3	230	46.6	87	52	24	16.7
	S4	37	26.6	77	48	28	16.7
	S5	167	56.6	77	38	28	6.6
	S6	67	50	63	42	30	6.7
	S7	77	140	63	44	32	13.3
	S8	83	123	77	44	40	20

(T) Textulaia
(M) Miliolina
(R) Rotaliina

C. *Distribution of Benthic Foraminifera*

The present study was not intended as an ecological survey, though it is perhaps worth recording observations on the distribution of organisms for future reference.

The following foraminifera were identified in the sediment samples from the study area :

Textularia conica
Quinquloculina elegans
Spirolina arietina
Clavulina angularis
Peneroplis planatus
Elphidium discoidal

Ammonia becarii *Rosalina globularis*
Calcarina calcara *Cibicides lobatulus*

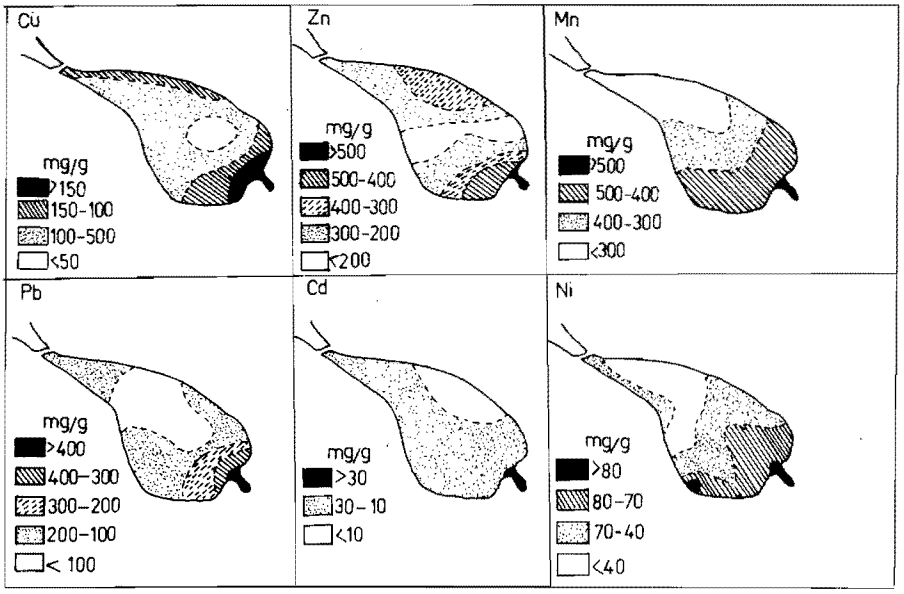

FIG. 8. Distribution of trace elements in Al Arbayeen lagoon sediments.

The dead and alive foraminifera percentages in the sediments are given in Table 4 and Fig. 9. The total number of foraminifera is relatively higher in areas near the sewage discharge points (Al Arbayeen lagoon and South Cornishe) compared to that of the Tuwwal and Masturah. On the other hand, the living foraminifera percentage is relatively higher in the unpolluted areas than those of polluted ones. In Al Arbayeen Lagoon the samples are devoid of living foraminifera. A few living foraminifera were present in the channel connecting the lagoon to the open sea. Additionally, it is more important to mention that most of the foraminifera species in Al Arbayeen lagoon are characterized by small shells with thin wall. The small size of test may be explained on the basis that the largest test formed under the coolest conditions (Bradshaw 1961). Where as the temperatures recorded in the study areas are relatively high (Table 1). The thin thickness of the test may be accounted for by the low content of carbonate (Table 2). The lack of living foraminifera in Al Arbayeen Lagoon may be related to its abnormal conditions discussed previously. The conditions which make it unfavourable for life. This corresponds to Murray's opinion (1973) since beneath the suspended sewage field there are few or no living foraminiferaids, but away from this, either as an aurole or as downcurrent field, abundance of living individuals increases to twice or more than that of the adjacent unpolluted shelf. On the other hand, the presence of dead foraminifera shells in Al Arbayeen Lagoon, may be due to the winnowing of transport factors including waves and tides from other sites in which the foraminifera have been living.

TABLE 4. Dead and alive foraminifera percentages in the sediments

Area	Samples	Total	Alive	%	Dead	%
Masturah	1	36	6	16.6	30	83.4
	2	127	33	25.9	94	74.1
	3	148	36	24.3	112	75.7
	4	194	35	18	159	82
	5	232	29	12.5	203	87.5
Tuwwal	6	100	4	4	96	96
	7	95	5	5.3	90	94.7
	8	92	7	7.6	85	92.4
	9	105	11	10.5	94	89.5
	10	102	12	11.8	90	88.2
South Cornishe	S1	226	31	13.7	195	86.3
	S2	95	25	26.3	70	73.7
	S2B	102	18	17.6	84	82.4
	S3	227	74	32.6	153	67.4
	S4	230	79	34.3	151	65.7
	S5	346	61	17.6	285	82.4
	S6	494	108	21.9	386	78.1
	S7	292	27	9.2	265	90.8
	S8	171	28	16.4	143	383.6
Arbayeen Lagoon	A1	4	–	0.0	4	100
	A2	24	–	0.0	24	100
	A3	140	–	0.0	140	100
	B1	77	–	0.0	77	100
	B2	276	–	0.0	276	100
	B3	74	–	0.0	74	100
	C1	250	–	0.0	250	100
	C2	29	–	0.0	29	100
	C3	51	–	0.0	51	100
	C4	185	3	1.6	182	98.4
	C5	130	2	1.8	111	98.2
	C6	620	25	4.03	595	95.97
	C7	360	7	1.9	353	98.1

In the unpolluted sediments, the pure carbonates of Masturah have more living foraminifera than the mixed clastic carbonate sediments of Tuwwal. This may be due to either the better aeration of Masturah sediments since they are the coarser sediments (Table 2) and this in turn, is favourable for foraminifera life (Boltovskoy 1966), or to water temperature recorded in this area ranging between 23-25°C which provides optimum conditions for the reproduction of foraminifera (Bradshaw 1961).

Conclusion

The sediments in the study area exhibit a remarkable variation in the grain size and composition ranging from medium sand to mud and from pure carbonate grains to grains of terrigenous origin. The organic matter of the sediments, in areas subjected to sewage discharge (Al Arbayeen Lagoon and South Cornishe of Jeddah City), is relatively too high compared with that of unpolluted area. It is positively correlated with metal concentration, but negatively with carbonate content.

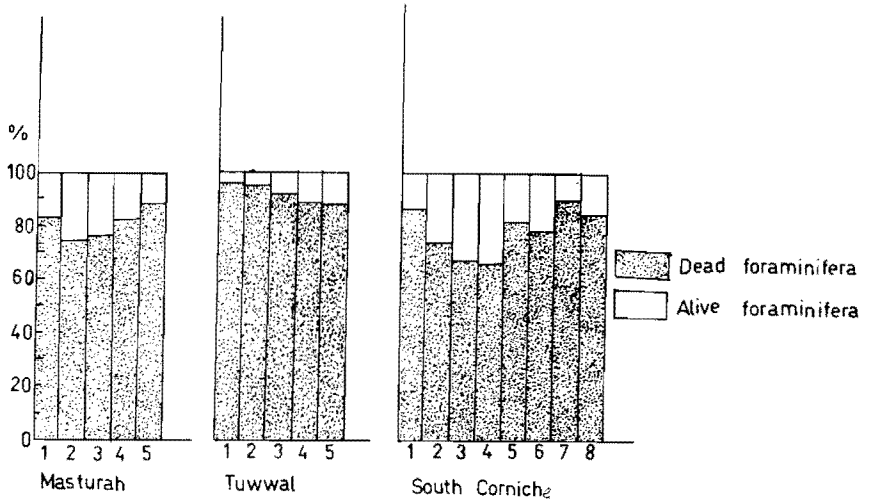

FIG. 9. The percentage occurrence (by number) of live and dead foraminifera in the studied areas.

The concentrations of Zn, Mn, Pb, Cu, Ni, and Cd, are generally higher in Al Arbayeen Lagoon and South Cornishe than those of Tuwwal and Masturah. These highly concentrated metals are mainly correlated with the sewage discharge points.

The foraminifera species identified in the study areas are: (1) *Textularia conica*, (2) *Clavulina angularis*, (3) *Quinqulocolina elegans*, (4) *Peneroplis planatus*, (5) *Spirolina arietina*, (6) *Elphidium discoidal*, (7) *Ammonia becarii*, (8) *Rosalina globularis*, (9) *Calcarina calcara*, (10) *Cibicides lobatulus*. The total number of foraminifera is relatively higher in sediments of polluted areas than those of unpolluted areas but the living foraminifera percentage is so low in Al Arbayeen Lagoon that they are almost non-existent. The small test and thin wall, which characterize the identified species, were accounted for by the relatively higher water temperature and low content of carbonate.

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العلاقة بين الظروف البيئية لساحل منطقة جدة بالبحر الأحمر والمثقبات القاعية

محمد أبو عوف و عبد الحميد الشاطر

كلية علوم البحار ، جامعة الملك عبد العزيز ، جدة - المملكة العربية السعودية

المستخلص . درست رواسب كل من خليج مستورة وخليج ثول وبحيرة الأربعين وشاطيء الكورنيش الجنوبي لمدينة جدة من الوجهة الأحفورية والجيوكيميائية . وقد أوضحت هذه الدراسة مايلي :

أ) أن هذه الرواسب تُظهر تغيرًا ملحوظًا من حيث حجم الحبيبات ومكوناتها ؛ إذ يتراوح حجم هذه الحبيبات من الرمل المتوسط إلى الغِرْيَن ومن حبيبات الكربونات إلى حبيبات ذات أصل قاري .

ب) أن محتوى المادة العضوية في الرواسب التي لوثت بمياه الصرف الصحي يكون كبيرًا جدًا إذا ما قورن بتلك التي لم تتعرض للتلوث ، وأن علاقة هذا المحتوى العضوي مع تركيزات الفلزات في هذه الرواسب كانت علاقة طردية ، أما مع نسب الكربونات فكانت عكسية .

جـ) أن تركيز كل من الزنك والمنجنيز والرصاص والنحاس والنيكل والكادميوم كان عمومًا أعلى في كل من بحيرة الأربعين والكورنيش الجنوبي عنه في كل من خليج ثول وخليج مستورة ، وأن تركيز هذه العناصر الثقيلة مرتبط أساسًا بأماكن الصرف الصحي .

د) أن هذه الرواسب تحتوى على الأنواع الآتية من المثقبات (الفورامنيفرا) :

١ - تكستولاريا كونيكا	٢ - كلافيولينا انجيولارس
٣ - كونكولكيولينا إليجانس	٤ - بنيروبلس بلاناتس
٥ - سبيرولينا أرْيتينا	٦ - الفيديوم ديسكويدال
٧ - أمونيا بكرياي	٨ - روزالينا جلوبيولارس
٩ - كالكارينا كالكارا	١٠ - سبيسَيْدس لوباتيولايس

هـ) أن العدد الكلي للمثقبات في الرواسب الملوثة أكثر منه في غير الملوبة مع أن المثقبات الحية تكاد تنعدم في بحيرة الأربعين الملوثة . كما أن صغر الصدفة ورقة سمكها لأجناس المثقبات في هذه الرواسب يعزي إلى حرارة الماء المرتفعة نسبيًا،وكذلك قلة المحتوى الكربوناتي .