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Discrimination of Sources of Barium in Beach Sediments, Marsa Alam-Shuqeir, Red Sea Coast, Egypt

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Abstract. The concentration of barium in beach sediments between Marsa Alam and Shuqeir, along the Egyptian Red Sea coast was investigated. There is a southward increasing trend in the concentrations of carbonate, barium and strontium. The grain size of the studied sediments follows a converse trend where sediments tend to be finer from north to south. On the other hand, trend analysis showed that barium of unnatural source increases from south to north. The data analysed reveal that the main sources of barium are: 1) The carbonate source, which is clearly confirmed by the close relation of carbonate, barium and strontium and 2) Abnormal increase in the oil exploration industry, which may be responsible for the higher barium concentrations in the northern part of the studied area.

Introduction

At present the Red Sea differs from other oceanic bodies in having high temperatures (greater then 21ºC) and salinities (greater than 40‰) that persist throughout a well- mixed water column (Neumann and McGill, 1962 and Siedler, 1969). This unusual condition results from the high evaporation and low runoff in its drainage basin, and from the restricted exchange with the Gulf of Aden and the Indian Ocean; through the Strait of Bab el'Mandeb where depth is only 125 m (Milliman *et al.*, 1969).

The narrow coastal plain of the Egyptian Red Sea lies between the high, fringing mountains consisting mostly of crystalline rocks and the waters of the sea. Along the shores there is an almost continuous ridge of emergent reef terraces between 0.5 to 10 km wide. Between these terraces and the foot of the crystalline hills extends a sand gravel surface that is inclined towards the sea with gradients ranging from 1:80 to 1:200 (Sestini, 1965 and Akkad & Dardir, 1966). The width of this plain ranges from, less than one km to over 20 km (Said, 1969). The coastal plain at the northern part (Shuqeir area) is wide decreasing southward (Marsa Alam). The main sources of sediments to the Egyptian Red Sea beaches are the terrestrial deposits transported from the abutting basement crystalline rocks and Cretaceous-Tertiary sediments during the occasional runoffs through the numerous wadis. During previous work on metals in the Egyptian Red Sea beach sediments (Rifaat and El-Mamoney, this volume) we found that barium is abnormally enriched in these sediments over the natural concentrations recorded by many authors (*e.g.,* Martin and Meybeck, 1979 and Ure & Berrow, 1982). Barium is known to occur in marine organisms and seawater. It is precipitated, biogenically by marine organisms during the formation of their carbonate shells and skeletons, and chemically with iron-manganese oxides. Also, barium is precipitated in vicinity of active hydrothermal regions. The highest recorded natural concentration of barium in sediments is found in deep-sea clays (2300 ppm) (Turekian and Wedepohl, 1961). The present paper deals with analyses of sediments collected from the beach area from Marsa Alam to Shuqeir (Fig. 1). Discrimination between natural- and unnatural-barium in sediments may help defining the source, which contribute high barium flux to the beach environment. This discrimination was confirmed by determining the strontium in sediments of the study area since barium and strontium are closely related to each other and co-precipitated together during carbonate formation (Lippmann, 1973).

Materials and Methods

Representative sediment samples were collected from the beach face along the entire studied area, which extended from Marsa Alam city south (Latitude 25º4'29"N) to Shuqeir north (Latitude 28º-3'39"N) along the Egyptian Red Sea (Fig. 1 & Table 1). The beach face zone represents the region in which sediments transported by sea currents are deposited. The samples were analysed granulometrically following Folk (1974) to determine the grain size parameters. Chemical analysis included the determination of total carbonate, barium and strontium contents. The total carbonate content was determined according to Molnia (1974), whereas the barium and strontium contents were determined by Atomic Absorption Spectrophotometery using

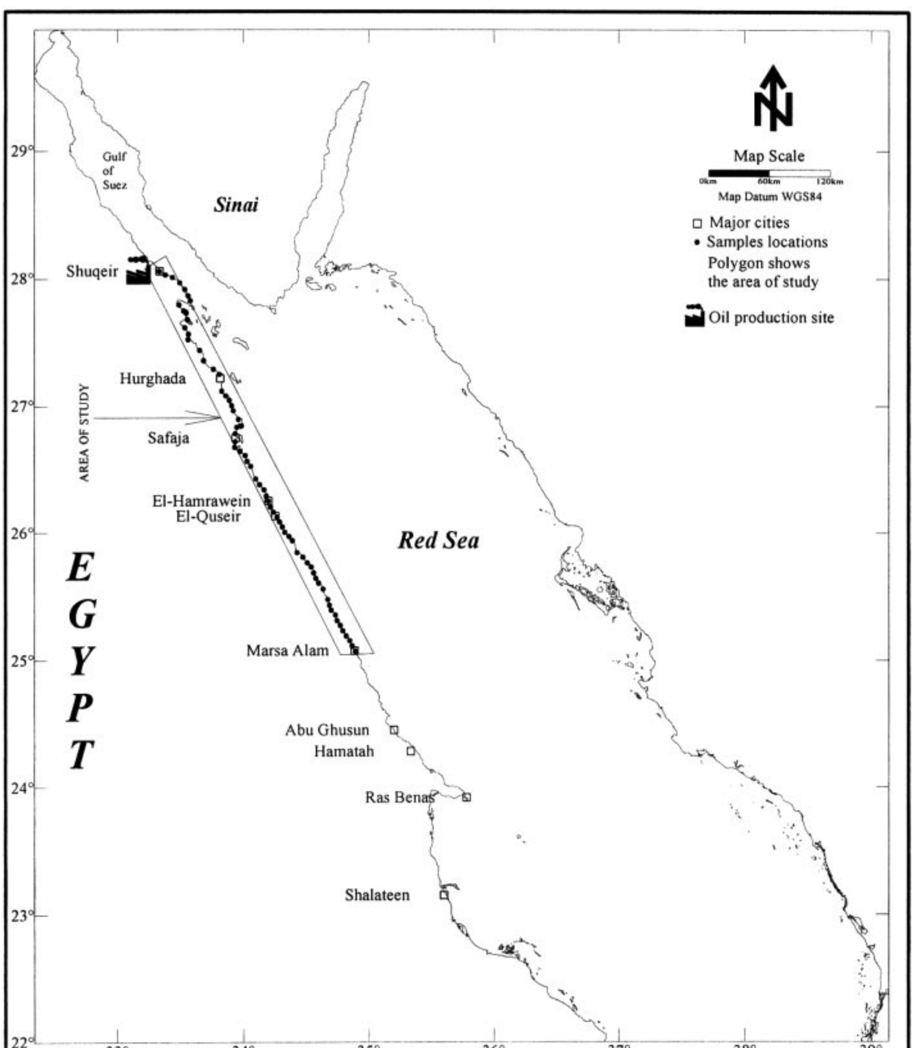

Fig. 1. Area of study and sampling locations.

TABLE 1. Locations of samples along the area of study.

Sample no.	Area	Latitude N (Deg.)	Longitude E (Deg.)
1	Marsa Alam City	25.0747	34.8978
2	3 km North Marsa Alam	25.1142	34.8736
3	9 km North Marsa Alam (Wadi Aslai)	25.1572	34.8517
4	14 km North Marsa Alam	25.1950	34.8222
5	19 km North Marsa Alam	25.2344	34.7972
6	24 km North Marsa Alam	25.2772	34.7778
7	28 km North Marsa Alam	25.3142	34.7503
8	35 km North Marsa Alam	25.3581	34.7358
9	40 km North Marsa Alam	25.3956	34.7036
10	45 km North Marsa Alam	25.4358	34.6911
11	82 km South Quseir	25.4792	34.6767
12	Gebel El'Gezira El'Hamra	25.5619	34.6389
13	Umm Qirayfat (67 km South Quseir)	25.6086	34.6047
14	60 km South Quseir	25.6453	34.5831
15	55 km South Quseir	25.6875	34.5639
16	51 km South Quseir	25.7331	34.5436
17	45 km South Quseir	25.7678	34.5147
18	42 km South Quseir	25.8094	34.4794
19	36 km South Quseir	25.8456	34.4325
20	25 km South Quseir	25.9397	34.3950
21	14 km South Quseir	25.9711	34.3669
22	11 km South Quseir	26.0058	34.3342
23	8 km South Quseir	26.0486	34.3156
24	Quseir City	26.0900	34.2922
25	Quseir City	26.1269	34.2717
26	10 km North Quseir	26.1653	34.2436
27	14 km North Quseir	26.2069	34.2197
28	20 km North Quseir	26.2528	34.2019
29	25 km North Quseir	26.2925	34.1864
30	30 km North Quseir	26.3419	34.1689
31	35 km North Quseir	26.3808	34.1328
32	40 km North Quseir	26.4283	34.1025
33	25 km South Safaja	26.5258	34.0642
34	20 km South Safaja	26.5664	34.0350
35	15 km South Safaja	26.6119	34.0181
36	10 km South Safaja	26.6425	33.9758

TABLE 1. Contd.

Sample no.	Area	Latitude N (Deg.)	Longitude E (Deg.)
37	5 km South Safaja	26.6775	33.9342
38	Safaja City	26.7217	33.9372
39	7 km North Safaja	26.7861	33.9375
40	Abu Suma Bay	26.8364	33.9494
41	Ras Abu Suma	26.8475	33.9881
42	Sharm El'Naga	26.8992	33.9633
43	Sharm El'Arab	26.9667	33.9214
44	Marsa Abu Makhadij	27.0069	33.9075
45	20 km South Hurghada	27.0483	33.8908
46	15 km South Hurghada	27.0853	33.8608
47	10 km South Hurghada	27.1206	33.8289
48	12 km North Hurghada	27.2539	33.8119
49	15 km North Hurghada	27.2928	33.7619
50	20 km North Hurghada	27.3606	33.6853
51	27 km North Hurghada	27.4433	33.6539
52	35 km North Hurghada	27.5261	33.5622
53	40 km North Hurghada	27.5681	33.5658
54	50 km North Hurghada	27.6181	33.5364
55	Ras Jemsha	27.6836	33.5561
56	Ras El'Bahr	27.7336	33.5483
57	Gebel El'Zeit	27.7500	33.5272
58	Gebel El'Zeit	27.7986	33.4894
59	Gebel El'Zeit	27.8308	33.5808
60	South Ras El'Esh	27.8686	33.5622
61	Ras El'Esh	27.9192	33.5353
62	South Shuqeir	27.9692	33.4978
63	South Shuqeir	28.0133	33.4397
64	South Shuqeir	28.0314	33.3831
65	Shuqeir	28.0608	33.3358

the extraction procedure of Tessier *et al.* (1979). The results of grain size and chemical analyses are shown in Table 2.

Results and Discussion

The beach sediments in the study area are predominantly sands. The grain size of the sediments increases from south (Marsa Alam) to north (Shuqeir) (Fig. 2). This result was also noticed by Moussa *et al.* (1986). At Marsa Alam the beach sediments are moderately well sorted fine (mean size = 2.25 phi) to medium sands (mean size = 1.24 phi), while those at Shuqeir are moderately well to very well sorted medium (mean size = 1.63 phi) to very coarse sands (mean size = – 0.09 phi) (Table 2). The content of terrestrial deposits is the major control in determining the mean grain size of sedi-

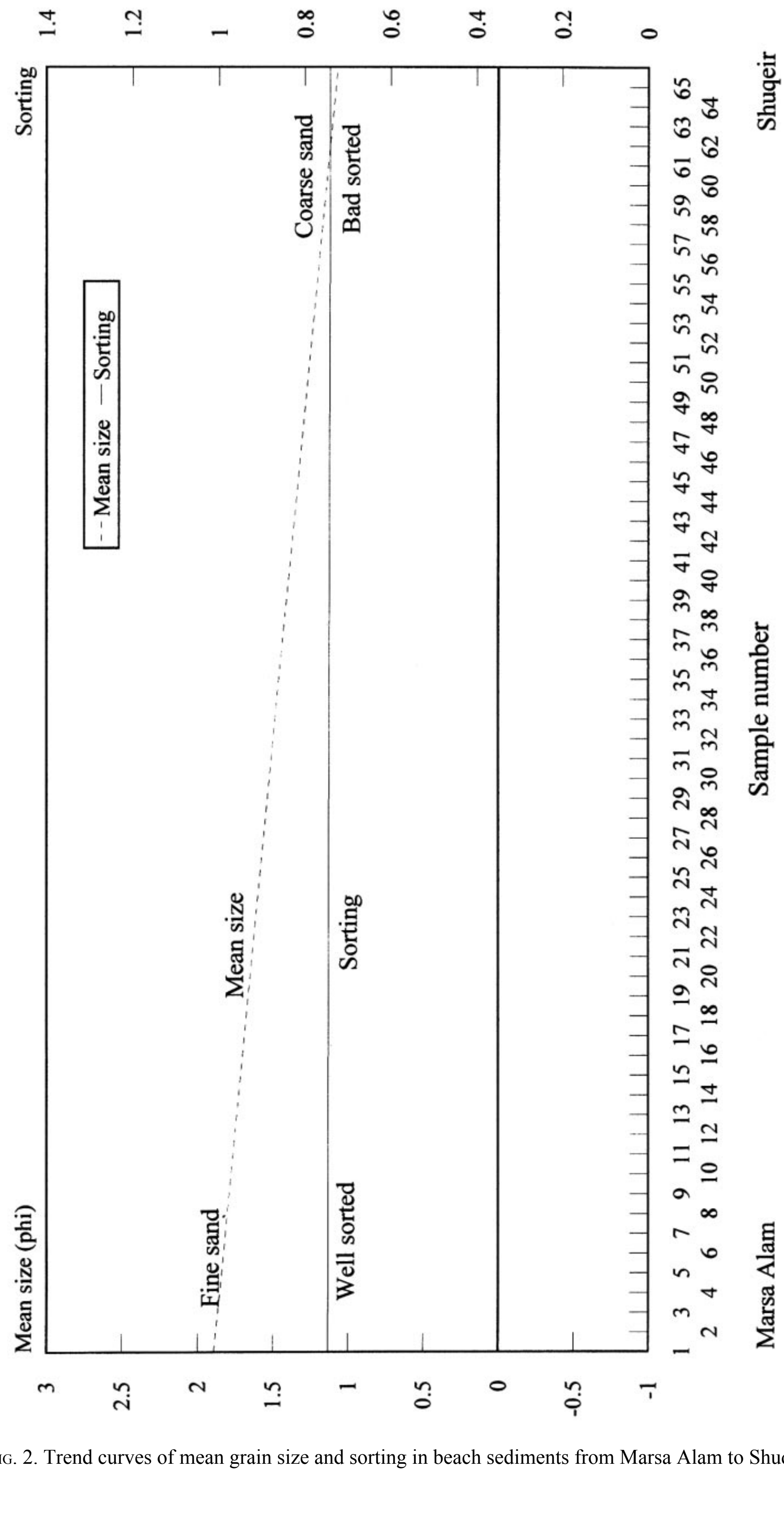

FIG. 2. Trend curves of mean grain size and sorting in beach sediments from Marsa Alam to Shuqeir.

TABLE 2. Textural and chemical parameters of sediments of the studied area.

Sample no.	Mean size (phi)	Sediment type	σ_I^*	Sorting	CO_3%	Ba ppm	$Ba/CO_3 \times 100$	Sr ppm
1	1.24	Medium sand	0.59	Moderately well sorted	22.8	2087	0.9	1153
2	2.25	Fine sand	0.67	Moderately well sorted	33.0	1469	0.4	2756
3	1.92	Medium sand	0.63	Moderately well sorted	48.9	1826	0.4	5536
4	2.21	Fine sand	0.59	Moderately well sorted	42.8	5394	1.3	5209
5	1.56	Medium sand	0.84	Moderately sorted	69.7	5939	0.9	9850
6	1.77	Medium sand	0.93	Moderately sorted	52.8	2149	0.4	6217
7	2.39	Fine sand	0.52	Moderately well sorted	11.5	1431	1.2	740
8	2.03	Fine sand	0.62	Moderately well sorted	70.3	4028	0.6	8784
9	1.03	Medium sand	0.65	Moderately well sorted	53.2	1595	0.3	5222
10	2.45	Fine sand	0.58	Moderately well sorted	40.3	1577	0.4	5490
11	2.47	Fine sand	0.58	Moderately well sorted	38.5	1479	0.4	5418
12	1.56	Medium sand	0.79	Moderately sorted	57.9	6776	1.2	8073
13	0.43	Coarse sand	0.47	Well sorted	63.4	3162	0.5	5651
14	1.69	Medium sand	0.65	Moderately well sorted	32.1	2559	0.8	3900
15	2.01	Fine sand	0.97	Moderately sorted	32.9	966	0.3	3353
16	1.68	Medium sand	1.16	Poorly sorted	68.7	3996	0.6	7428
17	1.11	Medium sand	0.61	Moderately well sorted	70.9	4863	0.7	5920
18	– 0.33	Very coarse sand	0.28	Very well sorted	14.8	573	0.4	347
19	1.22	Medium sand	1.17	Poorly sorted	59.3	3898	0.7	4787
20	1.14	Medium sand	0.62	Moderately well sorted	57.7	4923	0.9	8034
21	0.66	Coarse sand	0.84	Moderately sorted	92.0	3766	0.4	6467
22	2.00	Fine sand	0.62	Moderately well sorted	31.2	1880	0.6	3122
23	2.26	Fine sand	0.66	Moderately well sorted	37.9	2589	0.7	1211
24	2.22	Fine sand	0.83	Moderately sorted	23.2	611	0.3	1448
25	0.95	Coarse sand	0.81	Moderately sorted	87.0	1458	0.2	9257
26	1.35	Medium sand	1.13	Poorly sorted	79.6	5450	0.7	8073
27	1.51	Medium sand	0.60	Moderately well sorted	43.8	826	0.2	3579
28	2.36	Fine sand	0.50	Well sorted	25.7	3217	1.3	3996
29	2.24	Fine sand	0.59	Moderately well sorted	33.1	2300	0.7	3795
30	2.38	Fine sand	0.96	Moderately sorted	23.2	1906	0.8	1572
31	2.38	Fine sand	0.80	Moderately sorted	90.2	3640	0.4	12594
32	1.26	Medium sand	1.21	Poorly sorted	56.6	3394	0.6	6338
33	0.84	Coarse sand	1.06	Poorly sorted	71.0	2175	0.3	5767
34	1.85	Medium sand	0.70	Moderately well sorted	43.8	2247	0.5	4647
35	1.55	Medium sand	0.83	Moderately sorted	58.1	2379	0.4	5704
36	1.29	Medium sand	1.12	Poorly sorted	45.8	3028	0.7	5070
37	1.67	Medium sand	0.52	Moderately well sorted	22.6	1896	0.8	3701
38	1.33	Medium sand	1.34	Poorly sorted	27.6	2813	1.0	3128

TABLE 2. Contd.

Sample no.	Mean size (phi)	Sediment type	σ_I^*	Sorting	CO_3%	Ba ppm	$Ba/CO_3 \times 100$	Sr ppm
39	0.94	Coarse sand	0.72	Moderately sorted	2.9	ND	ND	ND
40	2.05	Fine sand	0.72	Moderately sorted	19.6	2336	1.2	3983
41	1.48	Medium sand	0.66	Moderately well sorted	21.5	2693	1.3	3229
42	1.79	Medium sand	0.58	Moderately well sorted	9.5	3162	3.3	894
43	1.72	Medium sand	0.98	Moderately sorted	16.0	3021	1.9	2114
44	0.84	Coarse sand	1.25	Poorly sorted	44.8	1183	0.3	5382
45	2.38	Fine sand	0.58	Moderately well sorted	28.2	1539	0.5	4548
46	2.16	Fine sand	0.83	Moderately sorted	46.7	1572	0.3	5331
47	2.25	Fine sand	0.75	Moderately sorted	8.0	1229	1.5	574
48	1.77	Medium sand	0.87	Moderately sorted	20.7	2273	1.1	1931
49	2.12	Fine sand	0.64	Moderately well sorted	13.7	1706	1.2	1207
50	1.65	Medium sand	0.74	Moderately sorted	20.2	1192	0.6	2729
51	1.40	Medium sand	0.87	Moderately sorted	22.4	951	0.4	2668
52	1.62	Medium sand	0.52	Moderately well sorted	6.5	393	0.6	484
53	1.74	Medium sand	0.75	Moderately sorted	23.0	1834	0.8	3741
54	1.01	Medium sand	1.11	Poorly sorted	34.1	1690	0.5	4495
55	1.49	Medium sand	0.33	Very well sorted	3.5	184	0.5	108
56	1.63	Medium sand	0.51	Moderately well sorted	31.1	994	0.3	1857
57	1.00	Medium sand	0.63	Moderately well sorted	8.7	3170	3.7	483
58	– 0.07	Very coarse sand	0.60	Moderately well sorted	28.0	2084	0.7	1561
59	0.30	Coarse sand	0.97	Moderately sorted	38.5	1551	0.4	3987
60	– 0.57	Very coarse sand			13.2	227	0.2	1078
61	1.00	Medium sand	0.90	Moderately sorted	55.0	1538	0.3	7176
62	– 0.33	Very coarse sand	0.34	Very well sorted	16.9	778	0.5	1232
63	1.63	Medium sand	0.69	Moderately well sorted	57.7	2757	0.5	6755
64	1.51	Medium sand	0.34	Very well sorted	54.9	3058	0.6	7113
65	– 0.09	Very coarse and	0.62	Moderately well sorted	40.8	2093	0.5	4037
Mean	1.48		0.74		38.8	2367	0.74	4251
St. Dev.	0.73		0.24		22.4	1406	0.61	2678
Min.	– 0.57		0.28		2.9	184	0.17	108
Max.	2.47		1.34		92.0	6776	3.65	12594

*σ_IInclusive graphic standard deviation.

ments, where most of the coarse sands are mainly quartz, feldspars, and other silicate mineral grains. However, the low contribution of terrestrial deposits to the shore in the south led to the fineness of beach sediments. This is because eroded carbonate grains are easier to be broken than silicate grains during reworking processes. The total carbonate of sediments ranges from 2.9% to 92.0% (Table 2) decreasing from south (Marsa Alam) to north (Shuqeir) (Fig. 3). This is also consistent with the data of Moussa *et al.* (1986).

Barium in beach sediments of the study area ranges between 182 ppm and 6776 ppm with a

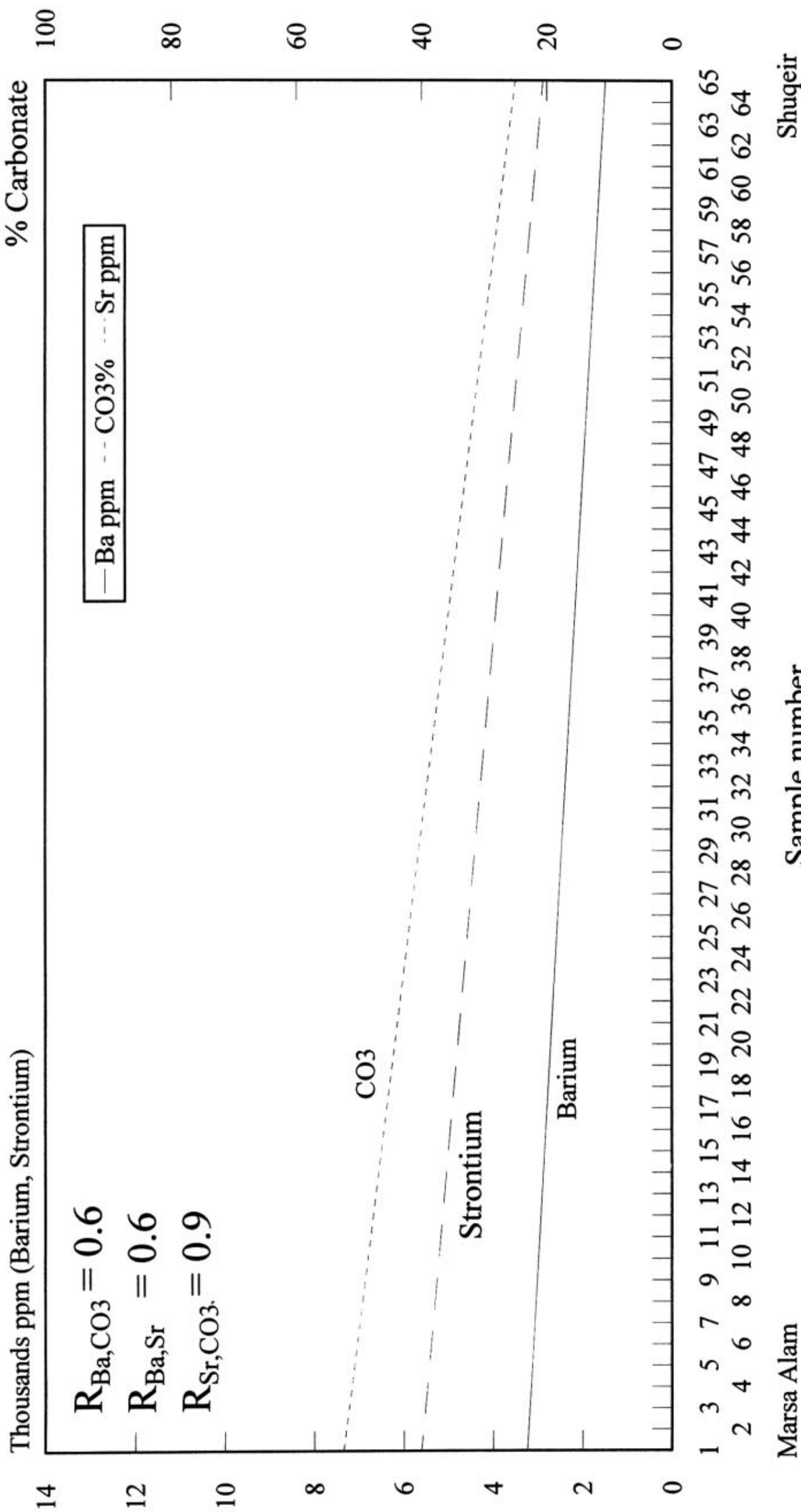

FIG. 3. Trend curves of barium, strontium and carbonate in beach sediments from Marsa Alam to Shuqeir.

mean of 2367 ppm. This mean concentration is higher than the mean concentrations of barium in shales: 580 ppm, carbonate: 10 ppm (Turekian and Wedepohl, 1961), mean crust: 500 ppm, mean sediment: 460 ppm (Bowen, 1979), river sediment: 600 ppm (Martin and Meybeck, 1979), soil: 568 ppm (Ure and Berrow, 1982) and is similar to deep sea clays: 2300 ppm (Turekian and Wedepohl, 1961). The higher coprecipitation amount of hydrous oxides in the deep-sea clays provide an explanation for the particularly strong enrichment of barium in these deposits (Förstner and Wittmann, 1981). However, this explanation does not apply in the area of study due to the higher seawater temperature and stronger agitation conditions, that may hinder high precipitation of hydrous oxides in the nearshore environment of the Egyptian Red Sea. On the other hand, barium and strontium correlate well with total carbonate content (Fig. 3), as the two elements decrease from south to north following the same spatial distribution of carbonate. The association of barium and strontium are noticed by many authors (*e.g.*, Bowen, 1956; Pilkey & Goodell, 1963; Mauchline & Templeton, 1966 and Livingston & Thompson, 1971). These authors have shown that barium and strontium are precipitated as carbonate in the form of aragonite either chemically from seawater or biogenically by marine organisms. Lippmann (1973) reported that barium is associated with aragonite and that Madreporarian corals – the dominant species of corals along the Egyptian Red Sea – are 100% aragonite. Again, the coprecipitation of barium and strontium with carbonate cannot account, solely, for the high concentration of barium in the beach sediments of the Red Sea, especially that barium in carbonate sediments does not exceed ~500 ppm (Bowen, 1956; Milliman, 1974). Therefore, the concentrations of barium in sediments of the study area are multiplied by the reciprocal of carbonate content to eliminate the effect of carbonate. The results (Fig. 4) showed that non-carbonate barium increases from south (Marsa Alam) to north (Shuqeir), where oil exploration and production processes are operated. Oil exploration in the Egyptian Red Sea is restricted to the Gulf of Suez and the northern part of the Red Sea proper. The effect of barium-bearing mud used during drilling operations of oil wells is prominent at Shuqeir city, the case that is also noticed by Holmes (1982) in the Gulf of Mexico, where barium is enriched in sediments due to its high content in drilling mud. Other sources of barium could be neglected; these are barium enrichment by organic matter (Mauchline & Templeton, 1966; Wakefield & O'Sullivan, 1996 and Rutten *et al*., 1999 and barium contributed by hydrothermal solutions (Eriksson *et al*., 1997; Souissi *et al*., 1997 and Cronan & Hodkinson, 1997) since the first is very low to explain for the high barium concentrations in sediments of the area of study and secondly the areas of known hydrothermal activities are too far and deep to contribute high barium concentrations to the beach sediments of the study area.

Conclusion

Barium is enriched in beach sediments of the Egyptian Red Sea coast. The oil drilling and exploration industry may contribute a high flux of the element resulted from the drilling mud. The concentration of barium in sediments can be used successfully to trace the effect of oil industry on the adjacent marine environment.

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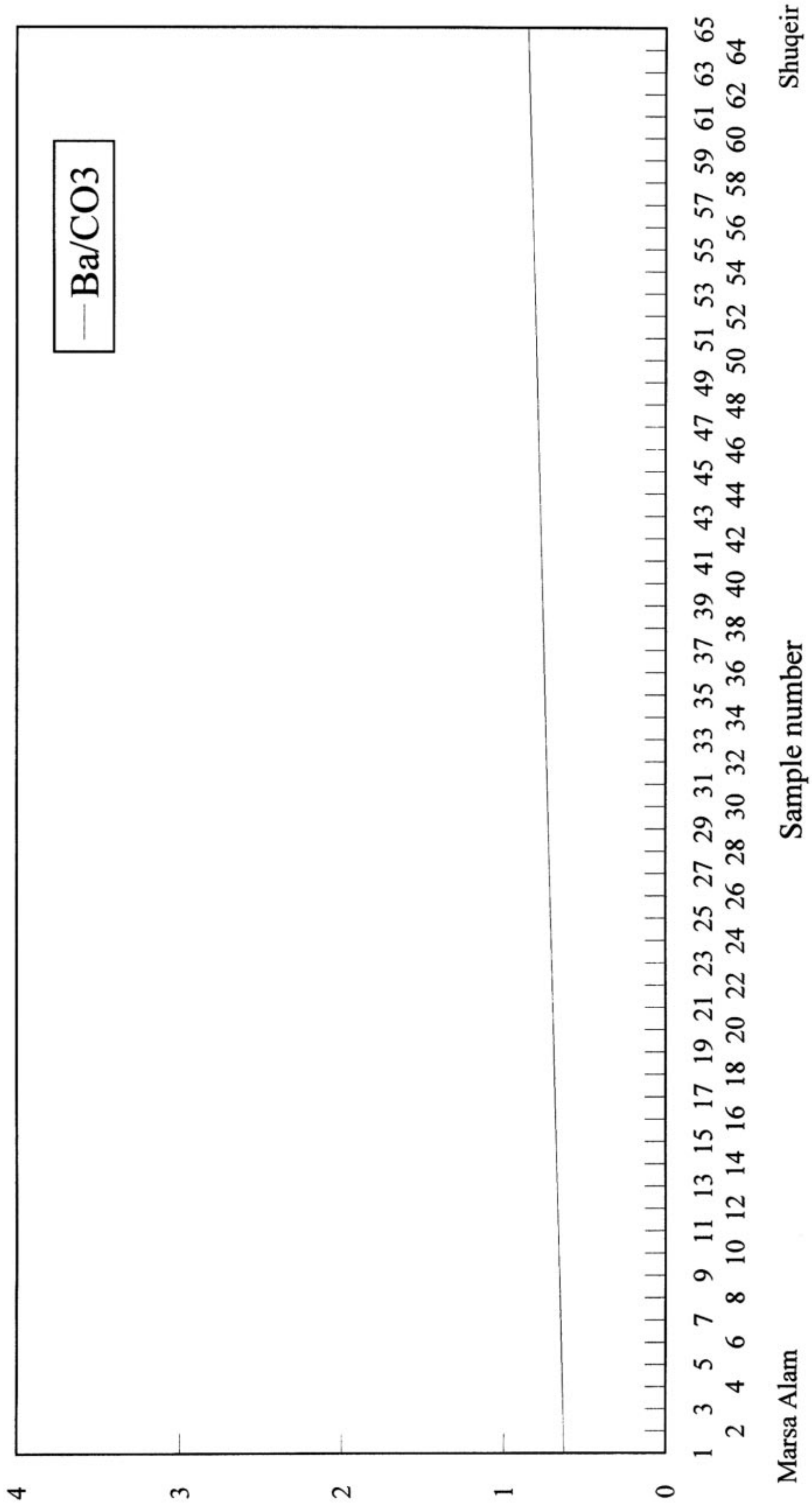

FIG. 4. Trend curve of Ba/CO_3 in beach sediments from Marsa Alam to Shuqeir.

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مصـادر الباريـوم فى الرسـوبيات الشاطئيـة بين شقـير ومـرسى علم على ساحـل البحـر الأحمـر لمصر

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المستخلص . تم تتبع تركيز عنصر الباريوم فى الرسوبيات الشاطئية على طول الخط الساحلى للبحر الأحمر بين مدينتى شقير ومرسى علم . ونظراً لتلازم كل من الباريوم والسترونشيوم فقد تم تعيين تركيز السترنشيوم ، بالإضافة لنسبة الكربونات فى الرسوبيات المعنية ، حيث ظهر اتجاه عام لزيادة محتوى الرسوبيات من كل من الباريوم والسترونشيوم والكربونات من الشمال (شقير) إلى الجنوب (مرسى علم) . كما بين فحص حبيبات الرسوبيات أن لها إتجاهاً عاماً معاكساً للاتجاه السابق ذكره ، حيث يقل قطر الحبيبات كلما اتجهنا من الشمال (رمل متوسط وكبير الحجم ذو تصنيف متوسط وجيد جداً) إلى الجنوب (رمل ناعم ومتوسط ذو تصنيف متوسط وجيد) . وقد أشارت النتائج إلى وجود أكثر من مصدر للباريوم فى الرسوبيات موضع الدراسة ، أحدهما طبيعى ويمثله الكربونات ، وآخر غير طبيعى من النشاط الاستكشافى لمكامن البترول ويزيد هذا الأخير من الجنوب إلى الشمال ، وترجع الزيادة الملحوظة إلى استخدام طين يحتوى على الباريوم أثناء حفر الآبار الاستكشافية .