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Bottom sediments of the Arabian Gulf:
I. Sedimentological characteristics

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ABSTRACT

More than 100 bottom sediment samples of the Arabian Gulf were collected during a cruise in 1992. The area was covered through 17 traverses in a northeast–southwest direction to the axis of the Gulf. Sedimentological analyses were done for fifty-six samples of reasonable volume.

The recent marine bottom sediments of the Gulf are subdivided into seven textural classes: sand, silty sand, muddy sand, sandy silt, sandy mud, silt, and mud. Most of the study area is covered by muddy sediments, whereas sandy deposits are restricted to the western part (offshore Qatar and the United Arab Emarites) and around islands and bathymetric highs. The counter-clockwise circulation of current from the Indian Ocean probably led to deposition of finer sediments along the eastern (Iranian) side. Sediments along the eastern and north-western margins are poorly sorted, probably due to the effect of tidal currents, river influx and eolian deposition. Suspension is thought to be the most important process of transportation and deposition, hence low energy conditions prevail in these areas, particularly in the northern part.

Sedimentological characteristics reflect the interaction between autochthonous calcareous fragments mostly of biogenic origin, rock fragments derived from beachrocks and submerged reef flats, and allochthonous terrigenous detritus supplied to the area by dust storms and river deltas in the north and east.

Based on sediment distribution, the magnitude of bottom currents and the topographic nature of the Arabian Gulf, a north–south sediment transport from the northern part, parallel to the axis of the Gulf, is inferred.

INTRODUCTION

The Arabian Gulf is a shallow marginal sea trending NW–SE, and separated from the Arabian Sea of the Indian Ocean by the Straits of Hormuz. It is a foreland basin with high mountains on the Iranian margin (Zagros), presumably supplying clastic debris, and a gentle foreland margin to the south, with only an eolian clastic supply and abundant shallow marine carbonate production (Fig. 1). The marine bathymetry of the basin is asymmetric, sloping gently on the Arabian side and steeply on the Iranian flank. Consequently, its axis, which has an average depth of about 35 m, lies closer to the Iranian coast. The sea-floor also slopes gradually from the shallow deltaic northern part of Shatt Al-Arab to deeper waters in the south, where it reaches depths of 100 m deep at the Straits of Hormuz.

Bottom sediments are thought to be the final disposal sites for pollutants in a marine environment (Karchikoff *et al.* 1979). Although the bottom topography and surface sediments of the southern part of the Arabian Gulf have been the subject of study by several authors (Houbolt 1957; Sudgen 1963; Evans 1966; Kassler 1973; Purser 1973; Stoffers & Ross 1979), only limited work has been done on the northern part (Berry *et al.* 1970; Agrawi 1994; Agrawi & Darmonian 1986). With the exception of recently published work on the nearshore and offshore areas of Kuwait (Al-Bakri *et al.* 1984; Khalaf *et al.* 1984; Al-Ghadban 1990), most of the previous studies either concentrated on the tidal and nearshore sediments or covered large areas with limited sampling (Picha 1978; Khalaf *et al.* 1982).

In 1991 the tragic events of the Gulf War led to an environmental catastrophe following spillage of 6 to 10 million barrels of oil by Iraqi soldiers from eight abandoned tankers and export terminals near the coast of Kuwait (Thorhaug 1992). As part of the efforts exerted by the international community to assess the impact of this oil pollution, an integrated plan was adopted and sponsored by the Regional Organization for the Protection of the Marine Environment (ROPME), the Intergovernmental Oceanographic Commission (IOC), the United Nations Enviromental Programme (UNEP), and the US National Oceanic and Atmospheric Administration (NOAA). Arrangements were made for 140 scientists to cruise in the Arabian Gulf from February to June 1992 aboard the NOAA research vessel, "Mt. Mitchell". One of the main objectives of this plan was to study the physical and geological oceanography of the Gulf. As part of the assigned task, the Arabian Gulf was extensively surveyed using the vessel and two Rigid Hull Inflatable Boats (RHIBs) (Reynolds 1993), and a large number of samples of the bottom sediments of the Gulf were collected.

This work presents the first fruit of a series of geological and geochemical studies carried out to investigate the petroleum hydrocarbon and heavy metal pollutants that were transferred through the water column from the slick to the seabed to reside in offshore bottom sediments. This study sheds light on the textural characteristics and regional grain-size distribution of these sediments, which may control the partitioning and availability of the above pollutants within the benthic ecosystem of the Arabian Gulf.

PHYSIOGRAPHY AND OCEANOGRAPHY

The Arabian Gulf is a foreland basin with high mountains on the Iranian margin and a gentle foreland margin to the southwest. The average depth is 35 m with a maximum depth of 100 m near its narrow entrance (Fig. 1). Its elongated bathymetric axis separates two major geological provinces—the stable Arabian Foreland and unstable Irianian Fold Belt—which are reflected in the contrasting coastal and bathymetric morphologies of Arabia and Iran.

The arid, sub-tropical climate with frequent winds, and water temperatures and salinities reaching up to 33°C and 40‰, respectively (Literathy & Foda 1985), stimulate the formation of evaporitic minerals and the delivery of eolian dust to the basin. Fluviatile influx is limited to the Shatt Al-Arab estuary in the north and to

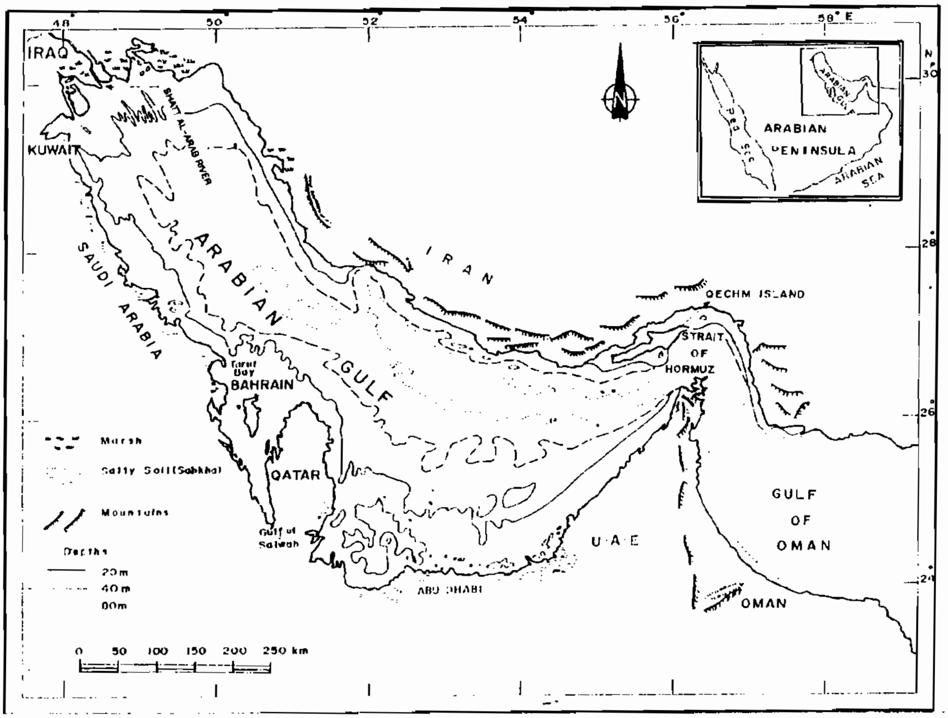

Fig. 1. Map showing the principal bathymetric provinces of the Arabian Gulf (partly after Purser, 1973).

the mountainous Iranian coast where terrigenous sediments and relatively pure carbonates form the shallow seas in front of the low desert of Arabia (Khalaf *et al.* 1984).

Due to the high air temperature, evaporation and the restricted nature of the area, a low circulatory surface-current flows from the Indian Ocean into the Arabian Gulf in a counter-clockwise pattern (Hartmann *et al.* 1971). The velocity of this current is highest along the eastern coasts of the Straits of Hormuz, decreasing gradually towards the head of the Gulf, and is lowest along the western and southwestern shores. In addition to the surface current, a vertical current also flows from the surface water to bottom of the area (Hartmann *et al.* 1971). Tidal currents play an important role in the sedimentation process in the sea basin (Seibold *et al.* 1973) and attain velocities of about 0.5–0.6 ms^{-1} near the coastal areas of the Gulf (Hartmann *et al.* 1971; Evans 1970). They are generally parallel to the axis of the northern and southern parts of the study area.

SAMPLING AND ANALYTICAL PROCEDURES

One hundred and twelve core samples of surface sediments were collected from the bottom of the Gulf floor (Fig. 2). Samples were taken using a Smith Macintype grab sampler which penetrated 12–15 cm. Five cm diameter clear acrylic tubing was used to obtain two replicate subsamples of each grab for subsequent analyses. Sediment samples at stations occupied by the RHIBs were obtained using a small Van Veen grab which holds about 300 cm^3 of sediment. The cores in this case were about 5 cm in

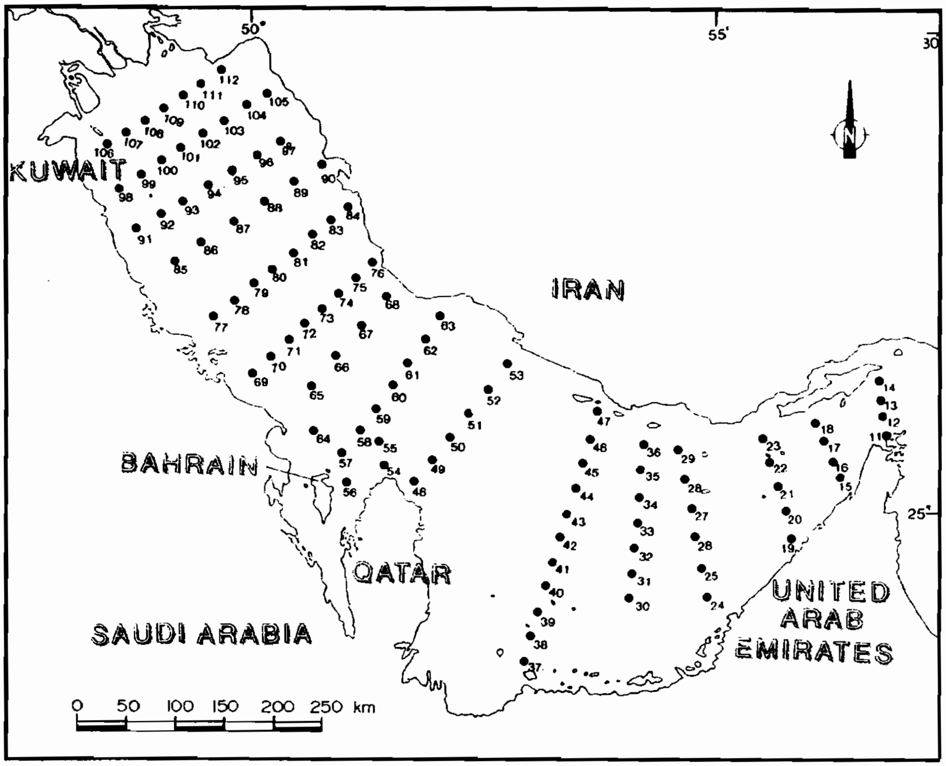

Fig. 2. Sampling stations in the Arabian Gulf.

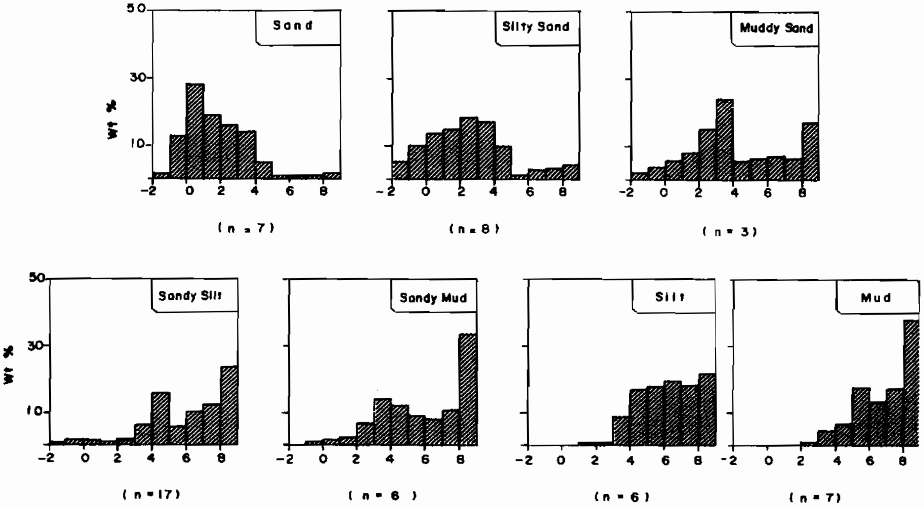

Fig. 3. Histogram of the average size distribution of the various textural classes of bottom sediments in the Arabian Gulf.

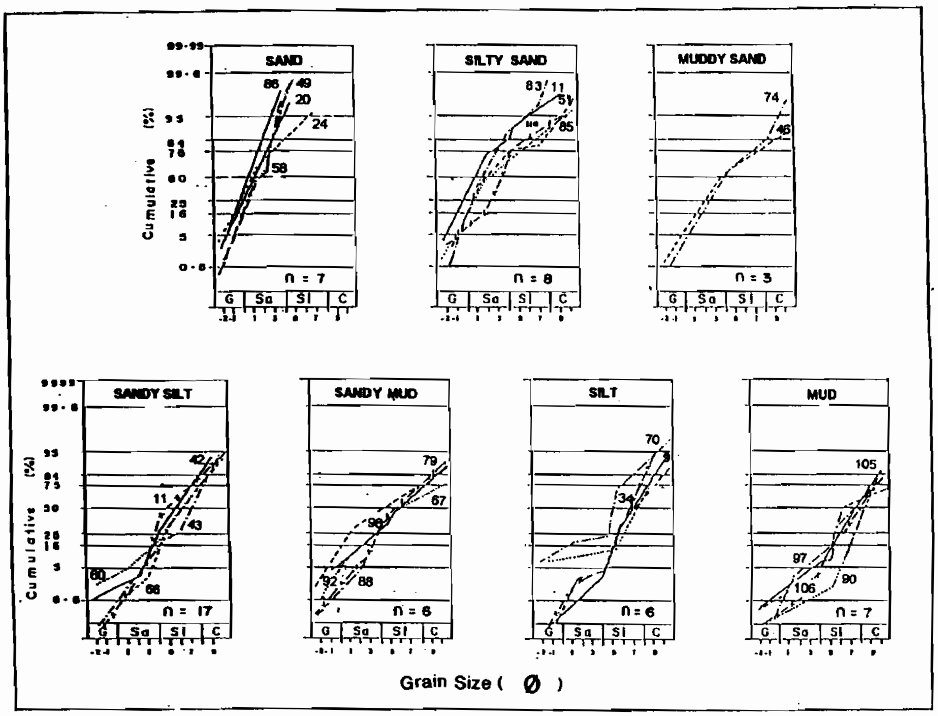

Fig. 4. Cumulative curves showing grain-size distribution of the various textural classes of bottom sediments in the Arabian Gulf G (Gravel); Sa (Sand); Sl (Silt) and C (Clay). Numbers in figure identify station numbers in Fig. 2.

depth. The average collected volume of samples was about 200 cm^3. All cores were then stored in a deep freezer.

Sandy sediments were dried at a temperature of 40° in an oven. The muddy sediments, on the other hand, were air dried. Prior to the sieving step, a hand lens and/or a binocular microscope were used to ensure the absence of any aggregates. In some sediment samples, decantation (removing small quantities of mud from the sediment sample) was employed. Separation of sand from mud by wet sieving was undertaken, followed by the separation of silt and clays using 0.5% sodium hexametaphosphate dispersant solution (Folk 1974).

Grain-size analysis of 56 collected samples were undertaken (due to reasonable volume) using standard sieving and sedimentation techniques (Folk 1974). Histograms and cumulative curves were plotted (Figs. 3 & 4). The percentages of the main size fractions (sand–silt–clay) and the statistical size parameters for all analyzed samples were computed using the formula of Folk & Ward (1957).

Preliminary microscopic examination of the coarse fraction sediment size was performed for several samples, using a binocular microscope.

TEXTURAL CLASSES

Table 1 summarizes the results of the grain-size analysis of bottom sediments. The percentages of sand, silt and clay fractions of the analyzed samples were plotted on a triangular diagram and the sediments were texturally classified in terms of Folk's

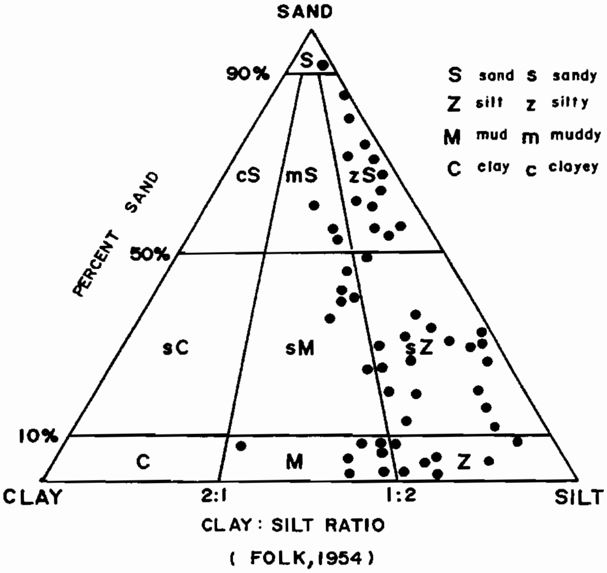

Fig. 5. Classification of bottom sediments (sand, silt and clay) in the Arabian Gulf according to grain-size distribution (based on nomenclature on Folk, 1974).

(1974) nomenclature (Fig. 5). Accordingly, the surface sediments can be subdivided into seven textural classes, namely sand, silty sand, muddy sand, sandy silt, sandy mud, silt, and mud. The average grain-size distributions of the various textural classes are presented as histograms and cumulative curves (Figs. 3 & 4).

The sand is composed, on average, of about 95% sand, 3.0% silt and 2.0% clay and has a unimodal distribution with a mode of coarse sand (1ϕ). The cumulative curves indicate the presence of a well developed and well-sorted population of sand grains supplied by saltation on the seafloor.

The average textural composition of the muddy sediments is 7% sand, 34% silt and 59% clay. Their cumulative curves reflect the dominance of the suspension population which is frequently composed of two sub-populations. Sandy muds are the second most dominant textural class. They have an average composition of 26% sand, 40% silt and 34% clay.

Between the nearshore sand deposits and the offshore mud and sandy mud deposits, transitional textural classes occur in the following sequence: silty sand, muddy sand, and sandy silt.

STATISTICAL SIZE PARAMETERS

Grain-size parameters of the investigated sediment samples were calculated on the basis of their cumulative curves using the statistical equation developed by Folk & Ward (1957). Four statistical size parameters were calculated, namely, Graphic Mean Size ($M_z\phi$), Inclusive Graphic Standard Deviation (Sorting, δ_I), Inclusive Graphic Skewness (SK_I) and Graphic Kurtosis (K_G). The results of the grain-size analysis are given in Table 1, while values for the various textural classes are presented in Table 2.

Table 1. Results of grain-size analysis of bottom sediments in the Arabian Gulf.

Sample No.	Weight % of sizes classes			Sediment type	Sample No.	Weight % of size classes			Sediment type
	Sand	Silt	Clay			Sand	Silt	Clay	
9	5.3	67.5	27.2	Silt	65	24.7	50.1	25.2	Sandy silt
10	0.7	58.9	40.4	Mud	66	11.9	62.3	25.8	Sandy mud
13	10.9	72.9	16.2	Sandy silt	67	34.2	40.6	25.2	Silt
14	48.2	37.7	14.1	Sandy silt	70	9.9	71.0	19.1	Sandy silt
20	97.5		0.5	Sand	72	44.5	38.9	166.0	Sandy silt
21	56.5	34.8	8.7	Silty sand	73	49.4	37.9	12.7	Muddy sand
24	85		15	Sand	74	66.6	23.1	10.3	Sandy mud
25	68.0		32.0	Silty sand	79	38.1	40.2	21.7	Sandy silt
27	26.7	65.4	7.9	Sandy sand	80	17.6	56.8	25.6	Sandy silt
34	5.3	78.3	16.4	Silt	85	59.5	24.8	15.6	Silty sand
35	1.3	70.5	28.2	Silt	86	99.6		0.4	Sand
38	86.5	10.4	3.1	Silty sand	87	32.0	50.7	17.3	Sandy silt
39	74.8	20.8	4.4	Silty sand	88	36.7	39.3	24.0	Sandy mud
40	68.8	24.6	6.6	Silty sand	90	4.8	39.9	55.3	Mud
41	99.4		0.6	Sand	92	25.6	46.3	28.1	Sandy mud
42	27.0	58.1	14.9	Sandy silt	96	18.6	50.4	31.0	Sandy silt
43	19.4	55.1	25.5	Sandy silt	97	8.1	55.3	36.6	Mud
45	44.3	33.4	17.3	Sandy silt	98	41.1	31.9	27.0	Sandy mud
46	53.9	26.5	19.6	Muddy sand	99	1.5	49.6	48.9	Mud
47	54.5	31.2	14.3	Silty sand	100	19.0	63.6	17.4	Sandy silt
49	99.2		0.8	Sand	101	30.5	48.3	21.2	Sandy silt
51	67.3	25.6	7.1	Silty sand	102	6.0	62.8	31.2	Silt
52	0.7	74.4	24.9	Silty sand	105	6.8	57.0	36.2	Mud
58	99.2		0.8	Silt	106	5.9	49.7	44.4	Mud
59	99.3		0.8	Sand	107	52.4	27.7	19.9	Muddy sand
61	19.2	54.6	26.2	Sandy silt	108	31.8	45.8	22.4	Sandy mud
62	4.5	61.8	33.7	Silt	110	63.8	23.3	12.9	Silty sand
63	47.8	34.0	18.2	Sandy mud	111	66.6	15.3	18.1	Silty sand

Table 2. Summary of average statistical grain-size parameters and weight percentages of main size fractions of the various textural classes of bottom sediments in the Arabian Gulf.

Textural classes	Size parameters				Weight % of size classes		
	Mz (ϕ)	δ_I (ϕ)	SK_I	K_G	Sand	Silt	Clay
Sand ($n = 7$)	0.93	0.74	0.24	0.53	95.00	3.00	2.00
Silty sand ($n = 10$)	3.39	2.43	0.15	0.26	81.05	14.85	4.10
Muddy sand ($n = 3$)	4.51	3.17	0.38	1.00	61.90	24.00	14.10
Sandy silt ($n = 17$)	5.55	2.72	0.06	1.07	30.00	46.00	24.00
Sandy mud ($n = 57$)	4.97	3.68	0.20	0.97	25.80	40.20	34.00
Silt ($n = 6$)	6.31	2.32	−0.04	1.72	8.20	69.00	22.8
Mud ($n = 7$)	6.22	2.06	0.06	1.02	6.90	33.75	59.35

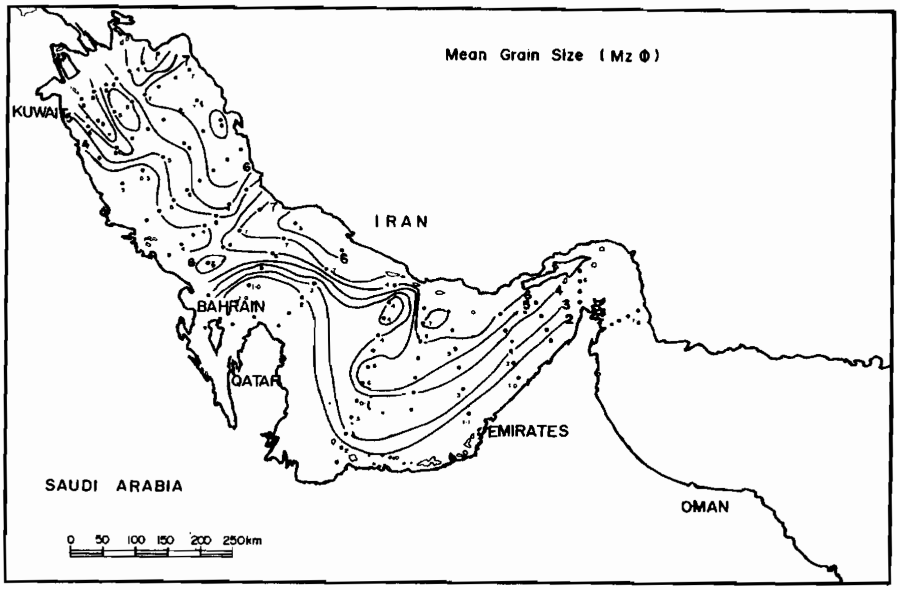

Fig. 6. Regional distribution of mean grain-size of bottom sediments in the Arabian Gulf.

GRAPHIC MEAN SIZE ($M_z\phi$)

The graphic mean size of the bottom sediments range between 0.93ϕ (0.52 mm) and 6.31ϕ (0.013 mm) in the sand and silt deposits, respectively. The mean grain-size of the bottom sediments in the study area is contoured in Fig. 6. It appears that the mean grain-size correlates broadly with the bathymetric contours (Fig. 1).

In general, the mean grain-size map shows a gradual decrease in the mean size parameters of the bottom sediments from the western side towards the eastern side of the Arabian Gulf. The finest mean size values are recorded in the northwestern part (southeast of Kuwait), as well as in the far eastern part, close to the Iranian side. The pattern of mean grain-size contours is more complicated along three specific areas, namely, northwestern, off Bahrain, and on the southern part, reflecting the degree of the sediment variability in these areas.

SORTING (δ_1)

The bottom sediments range in sorting from poorly sorted (3.68ϕ) to moderately sorted (0.74ϕ). Again, variation in the degree of sorting reflects the variability of the grain-size distribution in the study area. Table 2 indicates that sandy mud and muddy sand are the most ill-sorted sediment types, while silt and sand deposits are better sorted.

The regional distribution of sorting (standard deviation) is shown in Fig. (7). It can be deduced that sorting distribution has some similarities with the mean grain-size map (Fig. 6). Areas with finer sediments are generally poorly sorted (2.7ϕ on average; Table 2) as compared with areas covered by relatively coarser sediments (2.1ϕ on average). This can be seen from samples taken near the Iranian coast as well as from the northwestern area. This process might infer the influence of tidal currents in

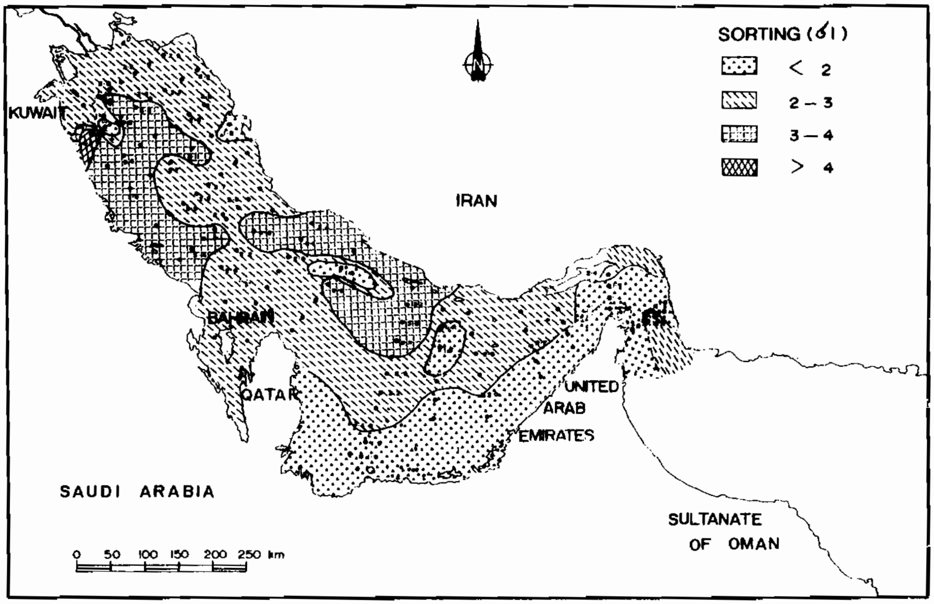

Fig. 7. Regional distribution of standard deviation (sorting) of bottom sediments in the Arabian Gulf.

conjunction with other processes such as river influx and deposition of eolian sediments in these areas.

INCLUSIVE GRAPHIC SKEWNESS (SK_I)

Sediment samples may be similar in average size and in sorting, but their size frequency distribution may differ significantly in symmetry. Skewness measures the degree of asymmetry as well as the "sign" (+ for fine skewness and – for coarse skewness). The formula used for such measurement includes 90% of the curve (Folk & Ward 1957). For the inclusive Graphic Skewness, symmetrical curves and those with excess coarse material have negative skewness.

The sediments sampled range from near symmetrical (–0.04) in silt facies to strongly positive skewness (0.38) in muddy sand facies, and are distributed in several parts of the study area, especially in the southern zone. The average skewness values of the different facies in bottom sediments are given in Table 3.

Table 3. Average skewness values of the different facies in bottom sediments.

Facies	Inclusive graphic skewness	
Sand	+0.24	Positive
Silty sand	+0.15	Positive
Muddy sand	+0.38	Strongly positive
Sandy silt	+0.06	Near symmetrical
Sandy mud	+0.20	Positive
Silt	–0.04	Near symmetrical
Mud	+0.06	Near symmetrical

Table 4. Average values of Kurtosis of the various facies.

Facies	Kurtosis	
Sand	0.53	Very platykurtic
Silty sand	0.26	Very platykurtic
Muddy sand	1.00	Mesokurtic
Sandy silt	1.07	Mesokurtic
Sandy Mud	0.97	Mesokurtic
Silt	1.72	Very leptokurtic
Mud	1.02	Mesokurtic

The majority of the studied sediments (including the coarser ones) have positive skewness, which might indicate the effect of tidal currents in reworking these sediments (excess of fine material). Positive skewness also reflects the magnitude of the eolian contribution to the area.

KURTOSIS (K_G)

Kurtosis measures the degree of sorting of the central portion of frequency distribution curves with respect to the sorting of tails. If the central portion is better sorted than the tails, the curve is said to be excessively peaked or leptokurtic. If the tails are better sorted than the central part, the curve is flat peaked or platykurtic, and if the two portions are equal then it is mesokurtic (Folk & Ward 1957).

The Arabian Gulf bottom sediments range in Kurtosis from very leptokuric (1.7) in the silt facies, to very platykurtic (0.53), in the sand facies. It was found that most of the studied samples are mesokurtic, especially those of the muddy sand, sandy silt and sandy mud facies. The average values of kurtosis of the various facies are given in Table 4.

This mesokurtic nature of the studied sediment would imply the existence of somewhat dominant tidal currents that affect the bottom sediments of the study area.

COARSE FRACTION COMPONENTS

It was possible through preliminary microscopic examination to group the grain types of the sand fraction in the investigated samples under biogenic components, quartz, rock fragments and feldspars.

The biogenic grains are represented mainly by the shells and shell fragments of bivlaves (molluscs), gastropods, and echinoids with lesser quantities of foraminifera, bryozoans and sponge spicules. The very coarse and coarse sand fractions are almost totally composed of biogenic grains dominated by molluscan shell fragments.

The weight percentages of acid soluble material ($CaCO_3$%) in the bottom sediments of the Arabian Gulf were found to vary from about 27 to 98% (Al-Ghadban & Jacob, 1993). Indeed the highest concentrations of $CaCO_3$ content (98%) were recorded in the parts of the study area where sand and sandy sediments are dominant, namely the western part of the southern half of the study area (Fig. 8). It is believed that the nature of the material in these locations (largely composed of cemented shells, shell fragemnts and algal fragments) is responsible for the high carbonate content in the bottom sediments (Al-Ghadban & Jacob 1993).

Quartz grains were recorded in considerable amounts in the sand fraction of the samples with frequency percentages ranging between 15 and 55%. Al-Ghadban &

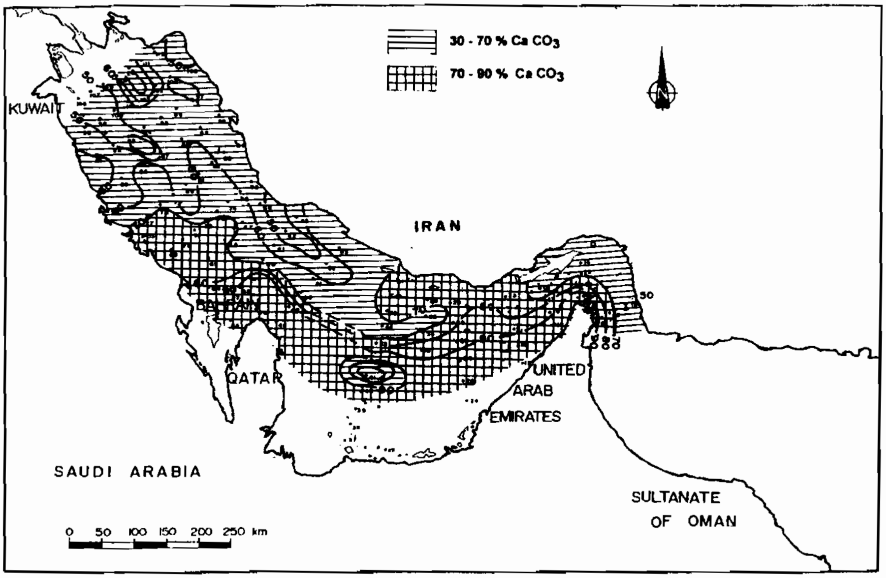

Fig. 8. Regional distribution of carbonate content of bottom sediments in the Arabian Gulf (after Al-Ghadban & Jacob 1993).

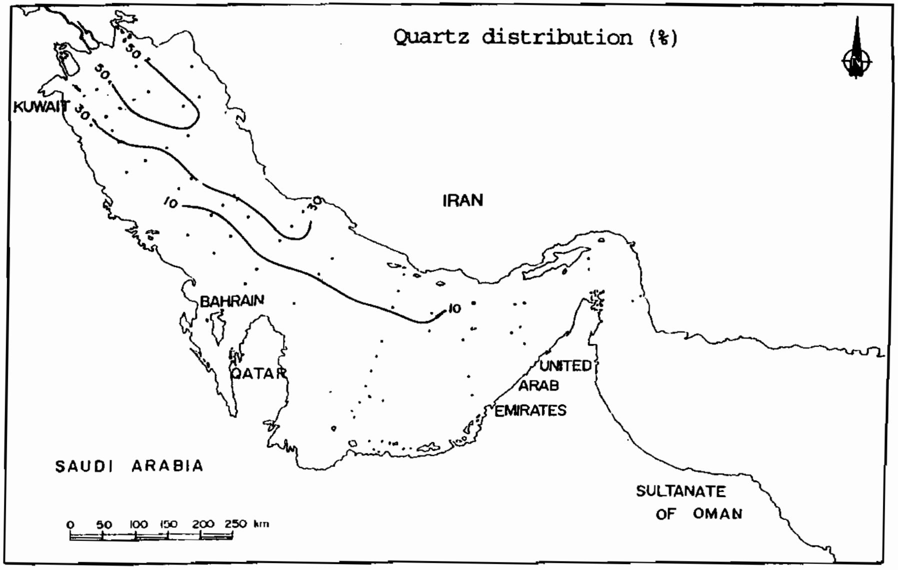

Fig. 9. Regional distribution of quartz (in percentage) of sediments in the Arabian Gulf.

Jacob (1993) also noticed that quartz content increases in percentage with the decrease in grain size, being commonly concentrated in the fine and very coarse fractions and almost absent in the coarse and very coarse fractions. Unlike the biogenic components, the quartz content tends to be concentrated in the northern half of the study area (Fig. 9).

Rock fragments (mostly carbonate) are usually concentrated in the very coarse and

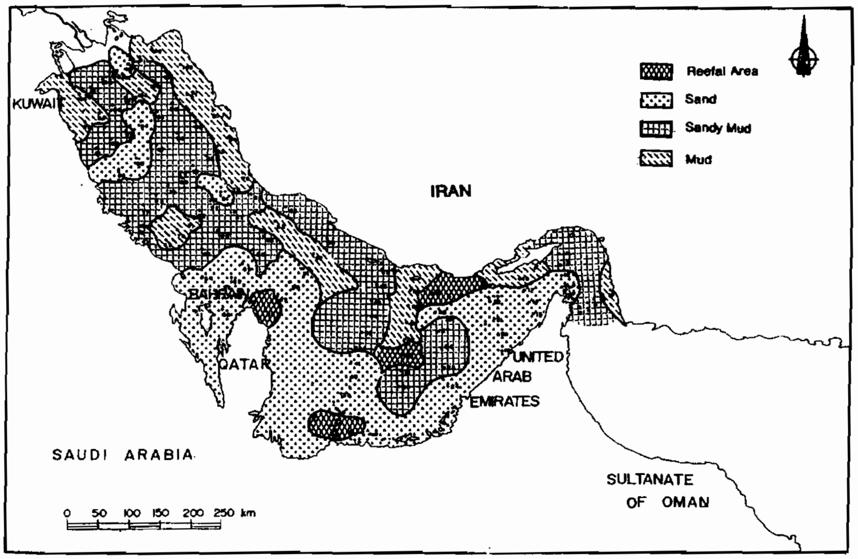

Fig. 10. Regional sediment distribution of the textural classes of bottom sediments in the Arabian Gulf.

coarse sand fractions. They are abundant in sediments located close to reef areas and near the bathymetric highs.

REGIONAL DISTRIBUTION OF SEDIMENTS

Data obtained from the grain-size analysis and textural classification of bottom sediments in the Arabian Gulf were used to construct a map showing the regional distribution of the various textural classes (Fig. 10). The map reveals that most of the study area is covered with fine-grained sediments namely mud, silt, sandy mud and sandy silt, which mostly occupy the deeper offshore areas as well as the sheltered sites. On the other hand, the relatively coarse-grained sediments (sand, muddy sand and silty sand) occur in narrow belts in the western areas, particularly near Qatar and the Trucial Coast of the UAE, and as patches on and around islands and the rocky bottoms of the bathymetric highs. It should be mentioned here, that this classification is more detailed than the study by Wagner & Tagt (1973). In their study, Wagner & Tagt have classified the bottom sediments into three main classes, namely sands, muddy sands and muds. Their classification, despite its general agreement with the present classification, was somewhat conservative and therefore would be difficult to use in relation to the hydrodynamic regime in the area. The current study, on the other hand, is characterized by a good geographic coverage and therefore enables the production of detailed sediment classes.

According to Hunter (1983) and Lardner *et al.* (1993), tidal currents in the eastern part of the Arabian Gulf are usually higher than those measured at the western part (Fig. 11). Also, in a recent study by Awosika *et al.* (1993) verify that the average speed of ebb exceeds that of flood tidal currents, and thus the sediment transport movement in the northern area is trending southward.

The regional distribution of mean size (Fig. 6) and standard deviation (Fig. 7) indicate that the sediments near the Iranian side are somewhat finer in size than those

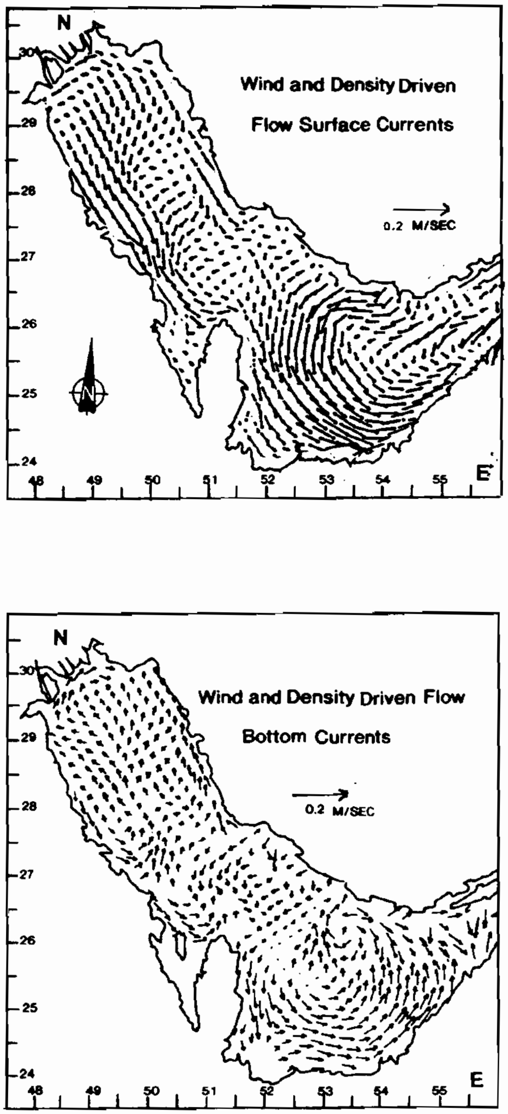

Fig. 11. Wind and density driven flow for surface and bottom currents (after Lardner *et al.*, 1993).

of the western part of the Arabian Gulf. The two areas with poorly sorted sediments, i.e., the area near the Iranian Coast and the NW area, might indicate the effect of tidal currents in conjunction with other processes such as river-influx (including possible supply from Iranian side) and eolian deposition.

The mean size ($Mz\phi$) and sorting (δ_I) regional distribution maps speak in favor of the effect of the counterclockwise current that has been inferred in literature (Hartmann *et al.* 1971; Reynolds 1993). The cumulative curves of the analyzed sediments showed that the suspension population is dominant in most samples and the traction population is either absent or poorly developed, while the saltation population is only well developed in the sandy sediments. It is obvious, therefore, that suspension is the most important process of transportation and deposition, and hence the overall picture of the enviroment is represented by low energy conditions, especially in the northern area.

The offshore area is characterized by strong tidal currents, particularly near the Iranian side (more that 2 knot: 1 m/sec (Hartmann *et al.* 1971; Reynolds 1993). Waves and surface currents generated by prevailing winds are the other main factors responsible for the variation of the energy level in the study area. The northern Arabian Gulf circulation is predominantly driven by the year-round NW Shamal (North) winds, with surface flow along both coasts in a southerly direction (Perrone, 1981). Northern areas with relatively shallow depths (20 m) and southward transport movement would be subject to a minimum degree of agitation. Along the Iranian coast, the flow is intensified by baroclinic forces produced by river outflow (Reynolds 1993). As the Shamal winds spread southward, they approach a cold front blowing from the SW (Kaus or Shakki winds) and a monsoon circulation in the Gulf of Oman producing winds trending NW/SE in winter and SE in summer. Due to the channelling of the low-level air flow by the Zagros mountains of western Iran, the strongest of the southerly winds occur on the eastern and northeastern (Iranian) side of the Arabian Gulf (Reynolds 1993), thereby intensifying agitation in these areas. Thus, wind-induced currents together with wave and tidal current action are more vigorous in the southern areas and, hence, produce a higher energy level than in the northern areas.

The association of the relatively coarse-grained deposits in the relatively high energy zone, with reef flats, indicate the importance of these rocky areas as a source of the sand fractions. As shown earlier, the sand fraction is largely composed of biogenic components and carbonate rock fragments which are produced by *in situ* breakdown of the rocky bottoms and coastal material both by organic activity and wave and current action.

Obviously, the general topography and climate affect the overall textural characteristics of the bottom sediments. Because of the aridity and the relief there is a considerable supply of fluvial coarse clastics to the Arabian Gulf environment. A review of the Holocene geological history of the Tigris-Euphrates-Karun delta (Larsen & Evans 1978) and the structural evolution of the Inner Sea (Kassler 1973) revealed that the northern half of the NW-corner of the Arabian Gulf is an integral part of the ancient delta which is presently submerged. Also, it is now recognized that sediments are transported southward from the small river deltas along the eastern (Iranian) side into the Gulf (Purser 1973; Literathy & Foda 1985). On the other hand, eolian sediments transported to the area by dust storms and the prevailing NW-winds represent a major contributor to the total sediment budget (Kukal & Saadallah 1973).

The occurrence of coarse sediments in the western side and on or around the bathymetric highs are the direct result of the prevalence of a higher energy level in these locations. Large shells and shell fragments from nearshore and submerged reefs are abraded by current and wave action. In these relatively shallow areas, the mechanical and biological breakdown of large skeletal grains provides fine debris which is systematically removed by winnowing towards deeper areas leaving a lag deposit of coarse material rich in shell fragments of mollusca. A decrease in turbulence of bottom waters in deeper areas provides the most favourable condition for the deposition of fine sediments. It can be concluded, therefore, that the molluscan shell fragments are associated with coarse-grained sediments and these reflect a high energy environment. Based on the foregoing discussion, it is suggested that the overall picture of the recent marine bottom sediments of the Arabian Gulf depends on the interaction between autochthonous calcareous fragments mostly of biogenic origin, rock fragments derived from beachrocks (only in nearshore areas), submerged reef flats, chemical precipitation, and allochthonous terrigenous detritus supplied to the area mainly by dust storms and river deltas in the far northern areas and along the Iranian side. The sedimentation is also influenced to a great extent by the hydrodynamic status and kinetic energy level of the water body, nature of coastal and bottom material, bottom topography and climate.

The nature of the sediments and the tidal current patterns, as well as the bathymetry and low energy characteristics, all suggest that the northern part of the Arabian Gulf, in general, represents a deposition environment with somewhat low sediment movement. Since the average speed of ebb exceeds that of flood tidal currents, the net transportation distance of the sediment in the northern study area is southward. More sediment transport is taking place in southern areas of relatively higher energy, which include the southern offshore area as well as the eastern and western parts. It is inferred that the sediments move N–S with a net sediment transport parallel to the axis of the Gulf.

CONCLUSIONS

1. The recent marine bottom sediments of the Arabian Gulf consist of seven textural classes; namely, sand, silty sand, muddy sand, sandy silt, sandy mud, silt, and mud. The regional distribution of these classes reveals that most of the area is covered with muddy sediments, whereas sandy deposits are restricted to the western area, particularly offshore Qatar and the UAE, and are found in patches on and around islands and the rocky bottoms of bathymetric highs.
2. The regional distribution of standard deviation (sorting) indicates that the bottom sediments near the Iranian coast and the NW-area are poorly sorted. This might indicate the effect of tidal currents, river-influx and deposition of eolian sediments in these areas.
3. The regional distribution of the mean size and sorting speaks in favour of the possible effect of the counterclockwise circulation of current from the Indian Ocean, which probably led to the deposition of finer sediments along the eastern Iranian side than are found in the western side.
4. Predominance of the suspension population in the cumulative curves suggests that suspension is the most important process of transportation and deposition, and hence low energy conditions prevail in the Gulf environment, particularly in the northern area.
5. Sedimentological characteristics of bottom sediments in the Gulf reflect the interaction between autochthonous calcareous fragments mostly of biogenic origin, rock fragments derived from beachrocks and submerged reef flats, and allochthonous terrigenous detritus supplied to the area mainly by dust storms and river deltas in the far northern area and along the Iranian side.
6. The nature of sediments, patterns of tidal currents and differences in the speed of ebb and flood as well as bathymetry and low energy characteristics, all infer a N–S sediment transport parallel to the axis of the Arabian Gulf from a northern

area with relatively low sediment movement to a southern area with relatively high sediment movement.

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الخصائص الرسوبية لرواسب القاع في الخليج العربي

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خلاصة

تم جمع أكثر من ١٠٠ عينة من الرواسب القاعية في الخليج العربي أثناء الرحلة العلمية البحرية في ١٩٩٢، وذلك من خلال عمل ١٧ قطاع باتجاه شمال شرق - جنوب غرب المنطقة ثم أجريت التحاليل المخبرية المناسبة لخمسة وستين عينة ذات حجم مناسب للدراسة.

وقد بينت الدراسة الحالية أن قاع الخليج العربي مغطى بسبعة أنواع من الرواسب القاعية وهي: الرمل، الرمل الغريني، الرمل الطيني، الغرين الرملي، الطين الرملي، الغرين والطين. وقد وجد أن القاع الشمالي لمنطقة البحث مغطى معظمه بالرواسب الطينية، في حين تتركز الرواسب الرملية في القطاع الغربي بمحاذاة مناطق التضاريس المرتفعة وخاصة الجزء البحري المصاحب لمنطقة قطر والإمارات العربية المتحدة.

ويمكن اعتبار التيار البحري السائد والذي يأخذ مسار عكسي لعقارب الساعة من العوامل السائدة التي تساعد على ترسيب الرواسب الطينية. وإتضح أن الرواسب في المنطقة الشرقية والشمالية الغربية من الخليج تمتاز بتصنيف رديء مما يعكس تأثير التيارات البحرية السائدة إلى جانب تأثير الأنهار والعواصف الترابية. هذا ولقد بينت الدراسة بأن الرواسب الناتجة من العواصف الترابية هي السائدة إذا ما قورنت بباقي الرواسب. وعليه يمكن إعتبار البيئة الشمالية للخليج ذات طاقة ضعيفة نسبيا مقارنة بالمنطقة الجنوبية للخليج. كما نوقشت في البحث مصادر تلك الرواسب والتي تشمل: رواسب العواصف الترابية، رواسب شط العرب، رواسب الأنهار من الجانب الإيراني، إلى جانب التكسير الميكانيكي والبيولوجي للأصداف البحرية والتي تشكل غالبية الرواسب.

إن ظروف توزيع الرواسب القاعية وقوة واتجاه التيارات البحرية السائدة وطبوغرافية قاع الخليج جميعها تعطي مؤشرا على حركة الرمال القاعية وذلك من الشمال إلى الجنوب بشكل يوازي محور الخليج.