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Textural Characteristics of Coastal Sediments Between Wadi Al-Fagh and Wadi Al-Qunfidah, Southeastern Red Sea

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ABSTRACT. Grain-size variation of sediments in different environments of the coastal zone between Wadi Al-Fagh and Wadi Al-Qunfidah, eastern Red Sea were studied. The wadi sediments are generally muddy gravely sand exhibiting a general downstream decrease in the mean grain-size. The bed material of wadis in the northern part of the study area is markedly finer than that of wadis in the southern part, where gravel-sized sediments are more common. The sediments distribution reflects short-lived flood flow patterns in the wadis. The remarkable changes in the texture characteristics of sediments of the northern wadis are considered to be due to the rainfall increase to the south. The dune sands of eolian origin are well to moderately sorted with a narrow range in the mean size (1.92-2.85ϕ).

Generally, the beach sediments are medium to fine sands, well to moderately sorted and to a great extent negatively skewed. The intertidal and subtidal sediments both exhibit a wide range of textural characteristics.

The intertidal sediments are generally coarser than those of subtidal zone. Also, in the south of the studied region, sediments from the tidal zones in the deltas fronting wadis Al Dugh, and Ahsibah, are markedly coarser than elsewhere in the region. In the north of the area, the relationships appear to be different particularly with respect to the intertidal sediments where the sediments from between the wadis is coarser than that in front of the wadis.

The terrigenous sediments from the wadis are mixed with locally produced carbonate in varying proportions in the beach and littoral zones. Such mixing and subsequent reworking by the nearshore processes result in the observed variation in texture. There does not, however, appear to be any correlation between mean size and the relative proportions of the carbonate to terrigenous material in the sediments.

Sedimentological studies on the nearshore environment of the eastern Red Sea of Saudi Arabia are very few. Bahafzallah and El-Askary (1981) investigated the textural characteristics of beach sands around Jeddah. Binda (1983) studied the grain-size distribution of eolian sands from Jeddah region. More recently, Durgaprasada Rao and Behairy (1986) carried out investigations on the nature and composition of shore-zone sediments between Jeddah and Yanbu.

These studies were, however, concentrated in the central and northeastern Red Sea region and up till now no systematic studies have been made in the southeastern region. The souteastern Red sea coast consists of mixed terrigenous and carbonate sediments as against the pure carbonate sediments which characterize the northeastern coast. The region offers, therefore, an interesting challenge to study the characteristics of deposits formed by mixing sediments of different sources. To this area, an investigation was carried out on the textural composition of coastal sediments from the area between Wadi Al-Fagh and Wadi Al-Qunfidah in the southeastern Red Sea (Fig. 1).

Wadi Al-Fagh forms an approximate northern climatic boundary to the area of southeastern Saudi Arabia that is influenced by monsoon rains. The rainfall increases towards the south and is responsible for a number of wadis which drain southwestward to the Red Sea (Jado and Zotl 1984). Deltas built out at the wadi mouths form a characteristic feature of the Al-Fagh - Al Qunfidah coastal zone and terrigenous sediment contribution throughout the region is evident from the long stretches of mud and sand that alternate with the frining reefs (Sheppard 1985). These occur in discontinuous 2-4 km long zones bound at either end by mangrove and mud flats. Sediments of the littoral zones comprise a mixture of carbonate and clastic material, each derived from very different sources. The carbonate sediments are predominantly skeletal material derived from the fragmentation of biogenic grains. Total carbonate content of these sediments varies between 1 and 80%. Sediments from the mouth regions of the wadis and about 85% of sediments in between wadis have carbonate values $< 10\%$. The rest of the sediments in between the wadis have carbonate contents ranging from 23-33% (Abou Ouf *et al.* 1988). The clastic traction is mostly mineralogic mineral transported from the coastal plain. The coastal plain, merging eastward from the shore zone, ranges from 10 to 30 km in width and is dissected by a number of wadis. Extensive areas of the plain are covered by pediment and flood plain deposits (Hadley and Fleck 1980). Tan to brown coloured Quaternary sand and gravel occupy the wadis, with fine-grained sand making up the flood plain deposits of the marginal areas. In addition to sediments mentioned above, eolian sands cover extensive areas of the plain and constitute the youngest Quaternary material areas in the study area.

Materials and Methods

Sediment samples were collectd from 6 major wadis, eolian dunes, beach and from the littoral zone (Fig. 1). Six to seven samples were obtained from each wadi with a sample interval ranging from 2 to 5 km. Fifteen samples were collected from various subenvironments of the eolian dunes. In the shore zone, fifty sediment samples were obtained from beach, intertidal and subtidal environments. Six of the shore zone sampling traverses were located opposite the mouths of the major wadis and the rest in between them.

A sample splitter and, sometimes, coning and quartering method were used to obtain representative sediments from the bulk samples. Sediment samples

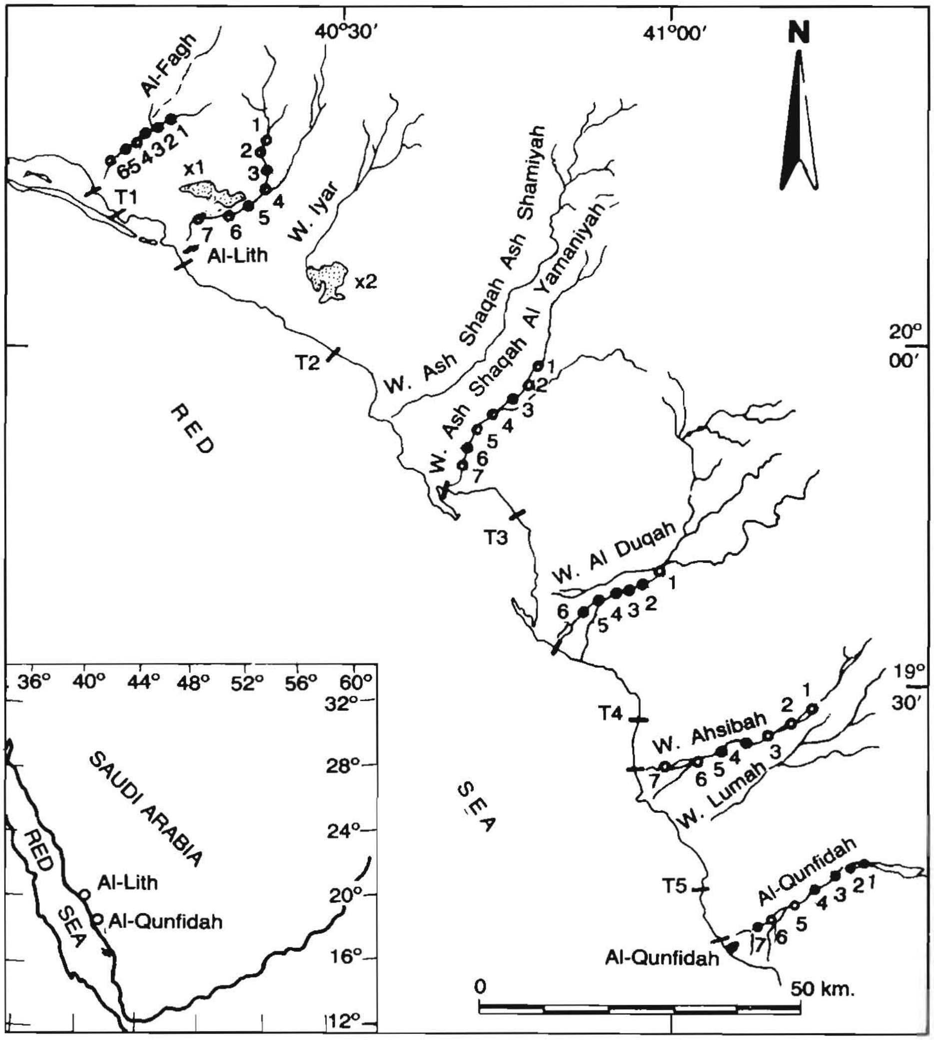


Fig. 1. Location map of the study area and sediment samples. (XI and X2 are the locations of dune sands: T1–T5 are the locations of littoral sediments in between the waids).

weighing about 100 gms were sieved through 1/2 phi interval sieves using an electrical shaker for 15 minutes. The fraction retained in each sieve was weighed and the relevant weight percentages and cummulative percentages were calculated. Cummulative curves were drawn and statistical parameters were determined following the procedure proposed by Folk (1980). Gravel was separated from the samples at 2 mm and silt + clay at 63 microns by wet sieving. These fractions, together with fraction, which lies between 2 mm and 63 microns were dried and, from the weight percentages of each, gravel: sand: silt + clay (mud) ratios were calculated.

Results

Mean grain-size, sorting, skewness and kurtosis of the sediments show a wide range of values and considerable spatial heterogeneity. The range and mean values of these are presented in table (1). Gravel, sand and mud ratios of the coastal sediments plotted in a triangular diagram are shown in Fig. (2).

Gravel-Sand-Mud Ratio

With the exception of a few littoral samples from opposite Wadi Al-Dugh which contain gravel, gravel-sized sediments occur mostly in the wadis, particularly in the upper reaches. Otherwise, it can be seen that the recent sediments of the study area are predominantly mixtures of sands and muds (Fig. 2). This includes Wadi Al-Lith which is unusual in having little or no gravel. The primary and secondary maximum size-grades of the sediments in different environments, however, vary considerably. While the chief ingredient of the

Table 1. Mean and range of the values of grain-size parameters

Environment	Mean size (ϕ)	Sorting σ_I	Skewness SKI	Kurtosis $K_{\overline{g}}$
Wadi	−0.23−5.63 2.1	0.57−2.75 1.22	−0.55−0.45 −0.12	0.73−1.98 1.25
Dune	1.92−2.85 2.52	0.45−1.11 0.62	−0.23−0.2 0.11	0.08−1.87 1.01
Beach	0.09−2.65 1.76	0.44−1.85 0.84	−0.23−0.13 0.07	0.74−1.4 1.12
Intertidal	1.22−6.00 3.33	0.48−2.9 1.16	−0.14−0.31 0.06	0.88−2.0 1.16
Subtidal	1.63−5.3 3.3	0.43−3.11 1.26	−0.34−0.56 0.11	0.79−1.7 1.17

dunes varies from 2-3ϕ, those of the wadi and beach sediments range between 1ϕ and 2ϕ. The primary maxima of the intertidal and subtidal sediments lie within 3ϕ and 4ϕ size grades.

Mean size (Mz)

Wadi sediments ranging between coarse sand and fine silt exhibit largest variations in the mean size from −0.23ϕ to 5.63ϕ. In all the wadis studied, there is an overall decrease in the mean grain size of the sediment downstream. Upper wadi sediments are coarse with an average mean grain size of 1.4ϕ while lower wadi sediments are relatively finer, with mean sizes varying from 1.31−5.63ϕ. At the same time, bed material of wadis in the northern part of the study area is markedly finer than that of wadis in the southern part, where gravel-sized sediments are more common.

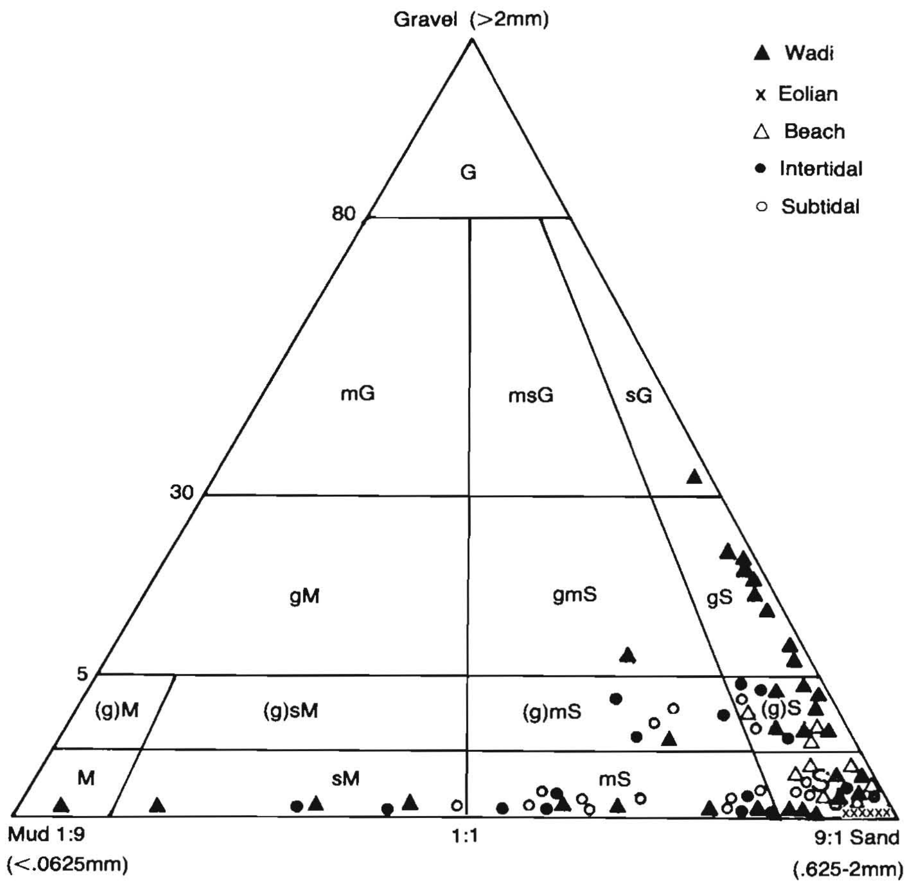


Fig. 2. Traingular diagram showing the texture of the sediments in different environments.

The mean-size of the beach sediments varies from 0.9ϕ to 2.65ϕ with an average of 1.8ϕ. There does not, however, appear to be any correlation between mean size and the relative proportions of the carbonate to terrigenous material in the sediments (Figs. 4,5). Furthermore, no systematic latitudinal variation in the mean size of beach sediments could be discerned in the region (Fig. 4).

The intertidal and subtidal sediments both exhibit a wide range of mean size values from 1.22ϕ (medium sand) to 6.07ϕ (medium silt) and 1.63 to 5.3ϕ respectively. Ninety percent of the sediments from both environments have, however, mean sizes between 2.4ϕ and 3.8ϕ. At the same time the intertidal and subtidal sediments from areas in between the wadis show a narrow range in mean grain-size than those from in front of the wadis. Furthermore, throughout the region (Fig. 4), the intertidal sediments are coarser than the subtidal with the exception of location (T_2). It can also be seen (Fig. 4) that in the south of the region, sediments from the tidal zones in the deltas fronting wadis Al-Dugh and Ahsibah, are markedly coarser than elsewhere in the region. It is interesting to note that, in the north of the area, the relationships appear to be different particularly with respect to the intertidal sediments. Here sediments from between the wadis are coarser than those from in front of the wadis.

Least variation in mean-sizes is noticed in the eolian dunes which consist mainly of fine to medium sands. In the dunes, the sediments from the crest are relatively coarser (2.05-2.57ϕ) than the stoss and lee side (2.15--2.73ϕ). Furthermore, the mean size of sediment from the stoss side is lower than that from the lee side. Folk (1971) recorded similar grain size distribution in eolian dunes and inferred that dune crests are coarsest and better sorted because they are comprised of the mostly easily saltated fine sand.

Standard deviation

Even though there are wide variations in the standard deviation values of the sediments from different environments and within each environment, some general relationships can be recognized. The dune and beach sediments are, to a great extent, well to moderatly sorted with former being better sorted than the latter (Table 1). Contrarily, there is a wide range in the standard deviation values of wadi, intertidal, and subtidal sediments, each ranging from well sorted to very poorly sorted (Table 1). A scatter plot of mean size versus standard deviation (Fig. 3) shows that, in very general terms, the medium-grained sediments are the best sorted and that sorting worsen, both in the fine-grained and the coarse-grained wadi, intertidal, and subtidal sediments. Regionally it can be seen that there is some variation in sorting characteristics. Beach sediments are less well sorted in the north in the area between wadis Al-Lith and Al-Fagh (Fig. 4). Intertidal and subtidal sediments tend to be less well sorted in the south around wadis Al-Dugh and Ashibah and in the extreme north at Wadi Al-Fagh. There

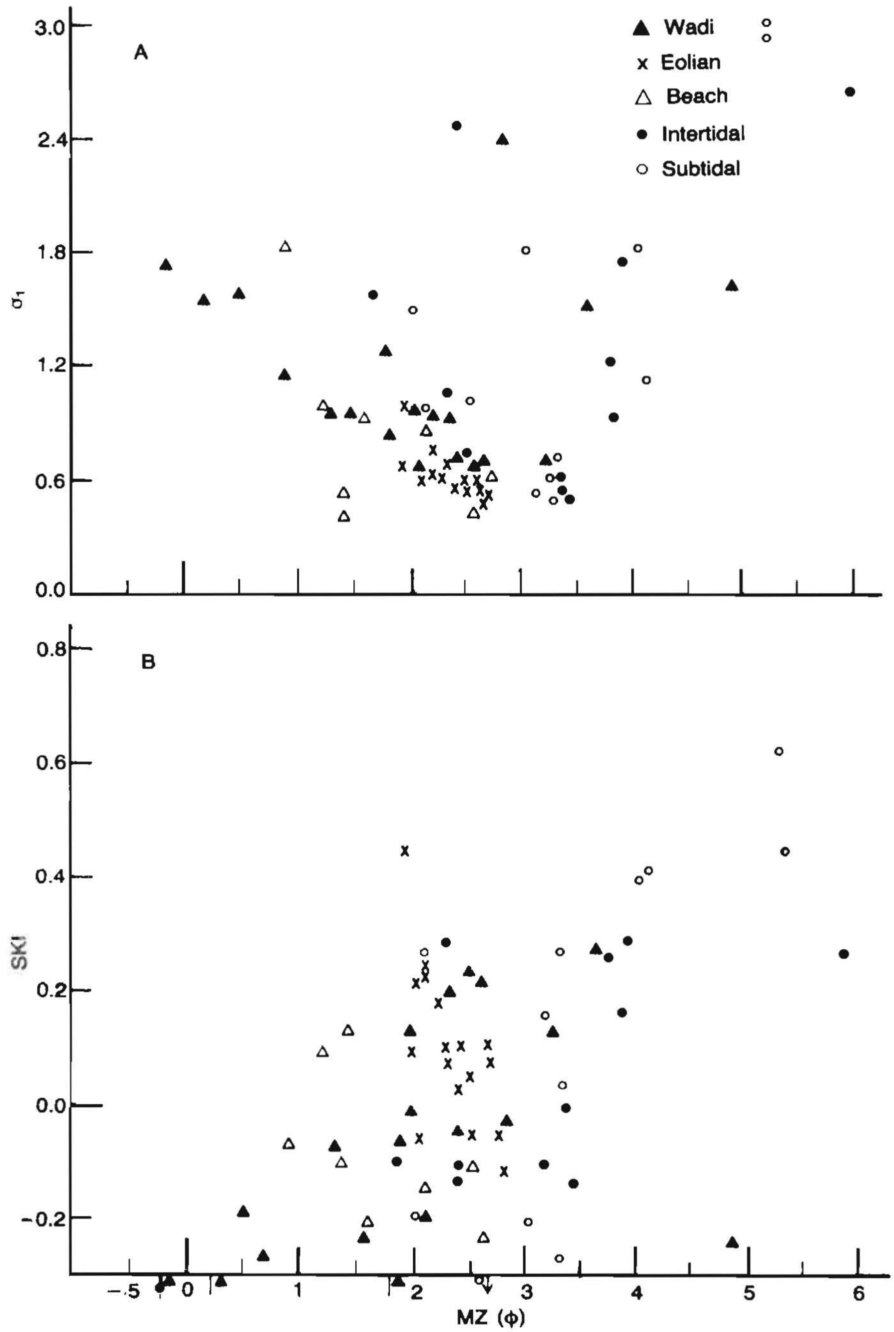


Fig. 3. Scatter plot of mean size (Mz) *vs.* sorting (σ_1) and skewness (sk) in the coastal zone sediments.

would also appear to be a slight tendency for subtidal sediments to be better sorted than intertidal in the deltaic areas although Wadi Yamaniyah is a noteable exception (Fig. 4.)

Inclusive graphic skewness

The phi skewness values of the wadi, intertidal and subtidal sediments are more erratic than those of the beach and eolian sediments. Most of the beach sediments are negatively skewed, whereas the eolian sediments are positively skewed. A scatter plot of mean size versus skewness (Fig. 3) indicated that in the wadi, intertidal and subtidal environments, coarse sediments are negatively skewed and fine sediments are positively skewed.

Kurtosis

There is not much variation in the kurtosis values of the sediments in different environments. The beach and eolian sediments, which vary from platykurtic to leptokurtic can, however, be grouped together. The wadi, intertidal and subtidal sediments form another group with kurtosis varying from platykurtic to very leptokurtic.

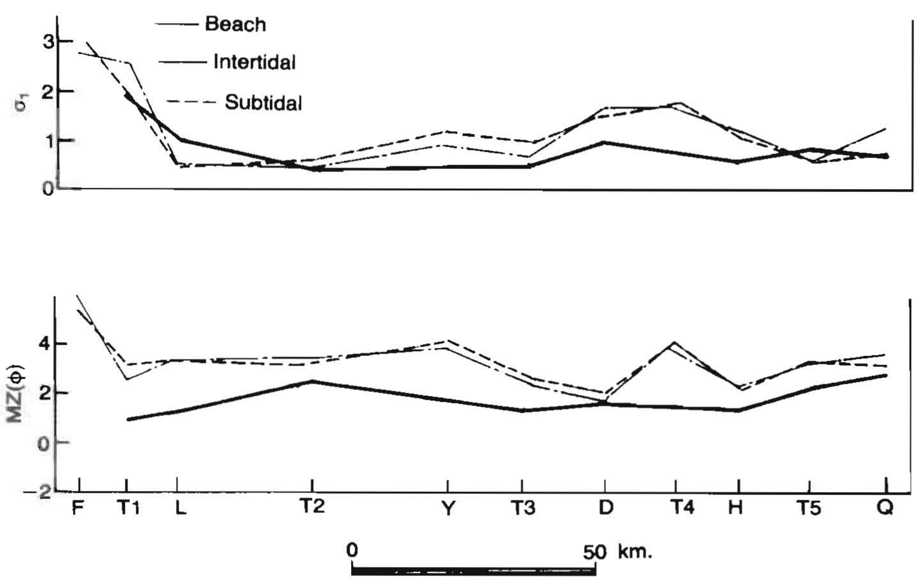


Fig. 4. Latitudinal variation (N-S) in mean size (Mz) and sorting (σ_1) of the littoral sediments (Y-wadi al Fagh; L-wadi Al Lith; Y-wadi Yamaniyah; D-wadi Dugh; H-wadi Ahsibah; Y-wadi Qunfidah).

Bivariate plot, of mean size versus standard deviation and Kurtosis versus skewness:

Bivariated plots (Folk & Ward 1957, Friedman, 1961, Moiola and Weiser 1968) of size parameters discussed above were constructed (Fig. 5) to investigated whether the boundaries suggested by the above authors as distinguishing between sediments from different environments is applicable to the study area. In figure (5A), it can be seen that the bulk of the wadi, eolian dune and beach sediments fall into the mixed river, dune field. In fig. (5B), the bulk of the dune material falls within the dune/eolian flat fields (Mason and Folk *ibid*) although an apprecible amount has lower kurtosis and negative skewness values. This is also the case with the beach sediments which fall well outside the field proposed by Mason and Folk (*ibid*) although they do conform to the limits proposed by Moiola and Weiser (*ibid*).

Discussion

The wide range of sediment textures occurring in the coastal sediments reveals the varying energy conditions in different environments. Further, variability in the sources of the sediments and the reworking processes operative in the littoral zone cause the observed variations in the grain-size characteristics of the sediments. The coarse bed material of the wadis and the general fining of the sediments downstream indicate heavy runoff and a gradual decrease in the transporting capacity downstream. Fining of sediments along the transport paths has been noticed in most geological situations (Pettijohn 1975) and such decrease in size of the sediments is considered to be due to the reduced competence of the streams (Blatt *et al.* 1980) in the flow direction. In current deposited sediments, Eyles (1987) reported that coarse grains are concentrated in the head of the flow with progressively finer grain-sizes in the tail of the current. In the wadis, however, the general rather than progressive decrease in the grain-size of the sediments downstream suggest discontinuous rapid flows and short travel distance in each flow. Conditions conductive to the production of these relationships are characteristic of the climate of the region. The wadis are ephemeral and active sediments transport in the channels takes place only during flash floods caused by occasional cloud bursts, which are typical of the study area (Al Sayari and Zotl 1978). Flash floods are, in addition, highly localized and of variable intensity. This regional element in their flow pattern is clearly reflected in the textures of the wadi sediments in that, gravel-sized sediments occur through out the course of some wadis, extend up to considerable distances or in others, and confined to upstream areas only in some.

The silty clay or clay-sized sediments in the mouths of the wadis indicated that while the coarse sediments lag behind, the fine sediments are transported

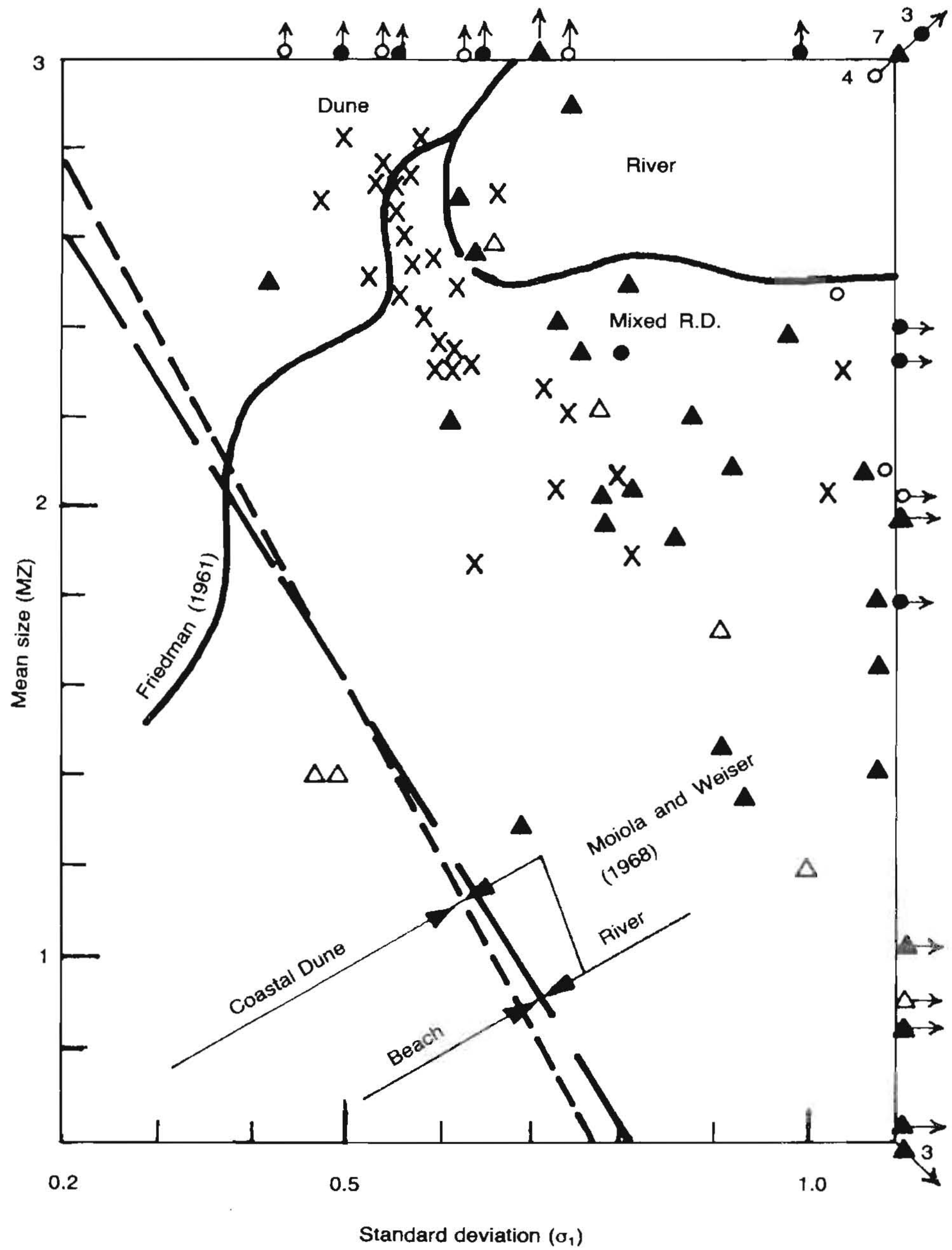
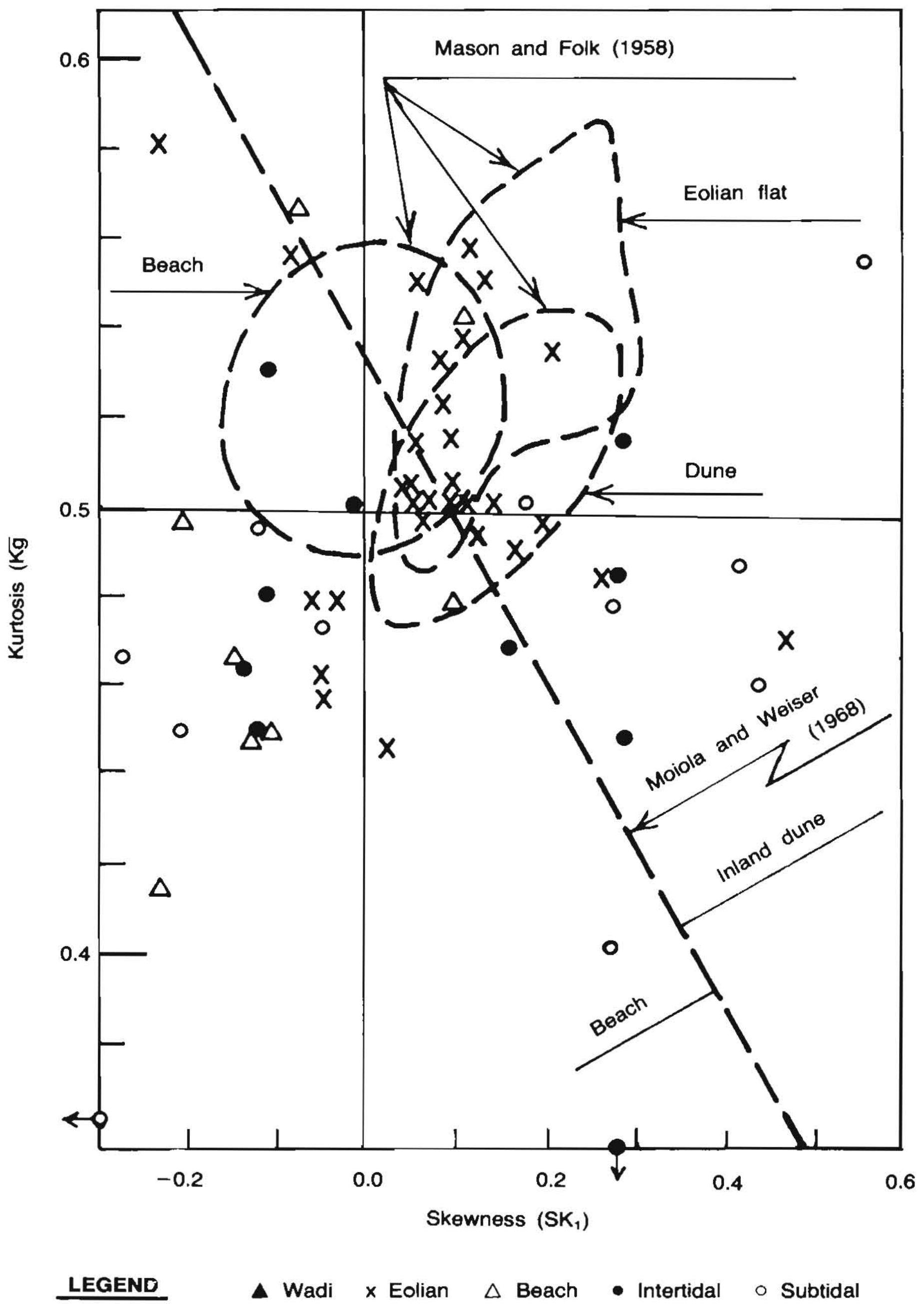


Fig. 5. Bivariate plot of mean size (Mz) *vs.* standard deviation (σ_1) and skewness *vs.* kurtosis of the sediments with boundaries after Friedman (1961); Moiola and Weiser (1968) and Mason and Folk (1958).


Mason and Folk (1958)
Eolian flat
Beach
Dune
Moiola and Weiser (1968)
Inland dune
Beach
0.6
0.5
0.4
Kurtosis (Kg)
−0.2
0.0
0.2
0.4
0.6
Skewness (SK_1)
LEGEND
▲ Wadi
x Eolian
△ Beach
● Intertidal
○ Subtidal

downstream and were deposited in the mouths and in the littoral zone. As indicated by the total carbonate contents, which spread between 1 and 80 percent (Abu Ouf *et al.* 1988), the terrigenous sediments from the wadis are mixed with locally produced carbonate in varying proportions in the beach and littoral zones. Such mixing and subsequent reworking by the nearshore processes resulted in the observed variations in texture. The sediments of the beach are relatively coarser than the intertidal and subtidal sediments (Fig. 4). This is interpreted as due to the dispersal of fine sediments seaward by wave energy. The winnowing action by the waves not only produces coarser sediments but also, in general, a higher degree of sorting in the beach sediments. From the sediment distribution pattern it would appear that active sediment sorting by the waves is confined to a narrow zone in the beach. This is in accordance with the low waves and tidal conditions which are characteristic of the southeastern Red Sea. Lack of reworking, variability in the sources of the sediments produce a complex mosaic of fine sands and muds in the intertidal and subtidal zones. As indicated by the variations in the grain-size parameters, the littoral sediments in front of the wadis are relatively more influenced by the terrigenous input than those in between them. The best example for that influence is that the beach sediments are less well sorted than the tidal sediments in the wadi Al-Lith region where a big delta have been built out in front of that wadi and that is also confirmed by the low percentage of the total carbonate in the sediments of that cite (Abu-Ouf *et al.* 1988). Merefield (1984) reports that variations in grain-size characteristics of nearshore sediments are arise from the variations in the sources of the sediments and from the effect of different processes which have transported and reworked the sediments.

The failure of the sediments to fall in the suggested grain-size limits of Folk and Ward (1957) and Friedman (1961) for different environments is due to the differences in the climatic conditions and relative energy levels within each environment. Short lived periodic run off creates variable flow patterns in the wadis, which are quite different from the normal fluvial systems. Further, the coastline of Al-Lith, Al-Qunfidah is essentially tideless and is little effected by the wave energy that is dissipated in the reef flats. Amaral and Pryor (1977) consider the bivariated plots may not be applicable in all situations as they ignore the effect of regional variation in grain size; climate sedimentation rate and energy levels within the environment. Further, as Carter (1982), in a mixed carbonate quartz sand encountered in recent coastal sediments, the conventional statistics may not be applicable in delineating depositional processes or environment.

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الخصائص النسيجية لرواسب الساحل الجنوبي الشرقي للبحر الأحمر في المنطقة الواقعة بين وادي الفاجة ووادي القنفذة

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لقد درست المتغيرات الحجمية لحبيبات رواسب البيئات المختلفة في النطاق الساحلي للبحر الأحمر وذلك للمنطقة الواقعة بين وادي الفاجة ووادي القنفذة وأوضحت الدراسة مايلي :-

١ - أن رواسب الوديان عموماً رملية حصوية وأن متوسط أحجام حبيباتها يتناقص طردياً في اتجاه المصب.
٢ - ان متوسط أحجام حبيبات الوديان في الجزء الشمالي من منطقة الدراسة أقل بكثير من متوسط أحجام حبيبات رواسب الوديان في الجزء الجنوبي حيث تسود الحبيبات ذات حجم الحصى.
٣ - أن توزيع الرواسب يعكس طبيعة السيول المنقطعة في الوديان.
٤ - ان التغير الملحوظ في الخصائص النسيجية لرواسب الوديان الشمالية عزي إلى زيادة هطول الأمطار في ذلك الجزء.
٥ - ان رمال الكثبان الريحية النشأة ذات فرز معتدل وأن لها مدى حجمي بين $1.92\ \Phi$ و $2.85\ \Phi$.
٦ - ان رواسب الشاطيء تتكون عموماً من رمال متوسطة إلى دقيقة الحجم وأنها معتدلة الفرز، وتميل إلى أن تكون خشنة الحبيبات.

٧ - أن الـرواسب البين مـدية Intertidal والتحت مـديه Subtidal تعـرض مـدى واسع من الخصائص النسيجية وان الرواسب البين مدية أكثر خشـونة من الرواسب التحت مديـة وأنها أيضاً أكـثر خشونـة أمام الـدلتاوات المقـابلة للوديان الجنوبية منها في أي مكان آخر.

٨ - أن الخصائص النسيجية للرواسب في شمال منطقة الدراسة مختلفة إلى حد ما عن باقي أجزاء منطقة الدراسـة وخصوصـاً الرواسب المـدية حيث أنها تكون أكثر خشونة في المناطق التي بين الوديان عن تلك التي أمام الوديان.

٩ - أن الـرواسب القـادمـة من الـوديـان تختلط بنسب متفـاوتـة بكـربـونـات النطاقات الساحلية والقريبة منها، وان مثل هذا الاختلاط بـالاضافـة إلى التفتيت المتعـاقب بواسـطة العمليات السـاحليـة يؤدي إلى الاختـلافـات الملاحظة في الخصائص النسيجية.

١٠ - ليس واضحـاً أن هناك عـلاقـة مـا بـين متـوسط حجم الحبيبـات ونسبـة الكربونات إلى المواد القارية.