العوامل المؤثرة على توزيع احجام الرواسب الساحلية تحت السطحية الضحلة لمصب وادي الحمض، شمال شرق البحر الأحمر، المملكة العربية السعودية

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المستخلص: تهتم هذه الدراسة بتوزيع الحجم الحبيبي للرواسب تحت السطحية الضحلة في مصب وادي الحمض على الساحل الشرقي للبحر الاحمر للمملكة العربية السعودية بهدف وصف وتفسير التغيرات المكانية والرأسية الرئيسية التي تتحكم بتوزيع خصائص حجم الحبيبات للسواحل منخفضة المد في المناطق الجافة. وقد أظهرت نتائج التحليل الحجمي لـ ٢٠٦ عينة مستخلصة من خمسة قطاعات رسوبية رأسية ضحلة تم جمعها من مسطحات المد والجزر ومصب وادي الحمض أن الرواسب رملية بشكل عام وبمتوسط حجم حبيبي يتراوح من الرمل إلى الرمل المتوسط وندرة كلا من الحصى والطين. وكانت رواسب القناة ومصب الوادي رديئة الى جيدة الفرز وذات حيود ناعم ومعامل تباين منخفض ما عدا في سحنة الجزء السفلي من قاعدة قطاعات القناة. بينما رواسب مسطحات المد والجزر في الجزء الجنوبي من منطقة الدراسة كانت متجانسة وذات احجام حبيبية متوسطة وذات حيود ناعم الى شديد النعومة ومعدل تباين منخفض. لكن الرواسب الشاطئية في اتجاه الشمال كانت عبارة عن رواسب رملية ناعمة الى ناعمة جدا جيدة الفرز وذات حيود شديد باتجاه الحبيبات الناعمة ومعامل تباين منخفض جدا. مما يشير الى ان توزيع وخصائص حجم حبيبات الرواسب في منطقة الدراسة تخضع للخصائص النسيجية للرواسب المتوفرة والعمليات الهيدروديناميكية اثناء عملية النقل والترسيب حيث ان الرواسب المتوفرة تعتمد على درجة العوامل المناخية المؤثرة وطريقة التجوية في صخور المصدر بالإضافة الى قوة التيار الناقل ومسافة النقل والعمليات الساحلية في مصب الوادي. فالمنطقة تمثل بيئات ترسيبيه مختلفة على طول الشاطئ والتي تتمثل ببيئة مسطحات المد والجزر بانحدار بسيط باتجاه البحر المفتوح في الجانب الجنوبي من مصب الوادي والتي تسود فيها الامواج وتتأثر بالتيارات المدية وبيئة الشاطئ الخطي في الجزء الشمالي من مصب الوادي والتي تسود فيها الامواج البحرية وبالتالي فان رواسب الجانب الشمالي تترسب تحت طاقة ترسيب عالية نوعا مقارنة برواسب الجانب الجنوبي من مصب الوادي.

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Fig. 6 CM diagram of the cores sediments

Conclusions

The grain size distribution and characteristics in the study area are controlled mainly by the texture of the original sediments, rolling and suspension mechanisms of transportation and depositional energy of the area. The available sediments at wadi channel and the mouth of the wadi are in-turn strongly influenced by waves, wind generated currents, riverine and tidal processes and sporadic storm waves. The study area displays alongshore variation in depositional setting of low gradient open coast inter-tidal flat that is wave dominated and tidally influenced to south, and wave dominated strand plain system to the north. The sediments of the

northern side were deposited under relatively higher energy condition compared to those at the wadi mouth and its southern side.

The vertical variations of grain size indicate that the depositional energy decreased upward and increased landward and the top facies were more sorted than the basal facies in all sediment cores. These variation denote that the sediment in the basal part of cores may be deposited under relatively high depositional energy condition compared to the upper parts. These may occurred probably during seasonal high rainfalls and high magnitude flash floods and/or the possible high energy coastal processes during times of sea breeze.

Fig. 5 Bivariate plot between standard deviation and Skewness in phi

Fig. 4 Bivariate plot between mean size and standard deviation in phi

well sorted sediments are those with a mean size of more than 3.5Φ . This group includes one sample of facies a_1 in cores I; few samples of facies a_3 in core II; some samples of facies d in core III; and facies h and two samples of facies c_2 in core IV. These discriminations indicate that the second group is deposited in higher depositional energy than the other groups most probably due to the effect of flash flood. Both M_z and degree of sorting are strongly influenced by hydrodynamic processes, so in all depositional environments, the well sorted sediments will be in the range of fine sand size (Griffiths, 1967).

The relationship between standard deviation and skewness (Fig. 5) indicates that the very well to well sorted and moderately well sorted sediments in cores I, III, IV and V are clustered around the very fine skewed range and have a positive skewness value. However, the very well sorted to moderately well sorted and poorly sorted sediments in cores II and some samples in core I are clustered between the near symmetrical and very fine skewed range and have positive and negative skewness values. The wide range of skewness values indicates variable direction of transporting currents, waves and tides as well as a variable depositional energy (Rajasekhara Reddy, 2008; Ghandour, 2014). Positive skewness values particularly in the tidal flat deposits indicate that the normal distribution is strongly influenced by finer sizes and low depositional energy compared to the sediments in the northern locations (core V) which were deposited under relatively higher energy

condition. The negative skewness particularly in the northern part of the delta resulted from winnowing action by waves that are strong enough to remove finer particles.

C-M diagram.

The CM diagram helps to analyze transportation mechanism and to identify the modes of deposition (Passega, 1957; Passega 1977). The parameter C (five percentile of the grain size distribution) and M (the median) were plotted for phi values of the C and M obtained from cumulative curves in microns (Fig. 8). CM pattern is subdivided into segment namely PQ, QR and RS. Segment PQ indicates the coarse grains transported by rolling, while QR parallel to line $C=M$ represents the main channel deposits. Segment RS (uniform suspension) paralleling the M axis is represented by silt and clay indicating the role of uniform suspension in transporting these sediments. CM diagram clearly depicts that most of the samples of cores 1, 2, 3, 4 and 5 are fall in the field I, II and V and covering PQ segment suggesting transportation by rolling regime (Fig.6). Exception few samples in cores 1, 2, 3, 4 and 5 are located between VIII and VI. These exception indicate that the sediments of these samples with mean sizes less than 1Φ were transported as bedload, those with sizes varying from 1 and 2Φ are transported by saltation, and the sediments that have a mean size $> 2 \Phi$ are usually transported in suspension. The mode of transportation doesn't depend only on the range of grain size. It depends also on flow intensity and water depth

Spatial and vertical distribution of grain size parameters in the area of study (Fig. 3) show that the mean size and skewness values in sand sheet facies are fluctuated rapidly, whereas the standard deviation, Kurtosis and coefficient of variance values increased upward. This means that sand sheet facies is deposited under fluctuated depositional energy of unsteady flow velocity and interplay between fluvial and coastal processes.

In channel fill facies, the mean size and skewness values increased dramatically upward, whereas the standard deviation and Kurtosis values changed upward from poorly sorted to moderately sorted and are platykurtic. The coefficient of variance values were fluctuated between low and high. These variations indicate that channel fill facies was deposited during the highest activity of wadi channel when a peak of flow deposited a mixture of coarse sediments but the well sorted fine sediments up of these facies was deposited under waning flow. The fluctuated coefficient of variance values indicate that channel fill facies especially at the middle part of cores I and II and at the top of this facies in core II affected by other marine induced processes such as wind induced waves and currents and to a lesser extent the weak tidal currents, and indirectly affected by sea level fluctuation during deposition.

The densely burrowed argillaceous, massive sands facies which observed at the top of cores II, III and IV; at the basal part of core IV and in core V do not show clear trend of grain size parameters. This may be attributed to the homogenization by burrowing organisms which mix all sizes together.

Bivariate plots

Bivariate plots between grain size parameters and transport/depositional processes of sediments are helpful in the application of grain size data (Folk and Ward, 1957; Griffiths, 1967; Friedman, 1968; Visher, 1969; Wang *et al.*, 1998; Malvarez *et al.*, 2001; Irudhayanathan *et al.*, 2011; Anithamary *et al.*, 2012; Rajganapathi *et al.*, 2013). These plots are helpful to interpret the energy conditions and medium of transportation (Passega, 1957; Rajganapathi *et al.*, 2013; Ghandour, 2014). The bivariate plots in addition help to interpret the mode of deposition and in turn help to identify the depositional environments (Folk and Ward, 1957; Passega, 1957; Visher, 1969). They further were used to differentiate between aeolian, beach and river sediments (Mason and Folk, 1958; Friedman, 1961). An attempt has been made here to utilize these bivariate plots in the sediments of the study area to reconstruct the transportation and depositional processes.

The bivariate plot between mean size M_z and degree of sorting (σ) enable to discriminate and clusters three groups (Fig. 4). The first one shows that the best sorted sediments are those with mean sizes of 1 to 3.5 Φ (fine sands). This group includes facies a_2 and most samples in facies a_1 in core I and b , a_4 , a_5 in core II; facies e , c_1 , and some samples of facies d in core III; facies f , g , c_2 and b in cores IV; and all facies in core V, respectively. The second group shows that the poorly sorted of sediments are those with mean size of 1.8 to 4 Φ . This group includes few samples from facies a_1 and a_2 in core I; and facies a_3 in core II. The third group shows that the very well to

Fig. 3 Vertical variation of grain size parameters in cores I to V

et al., 2009). The lower CV values < 0.4 indicate relatively well sorting but the higher CV values > 0.4 indicate relatively poor sorting sediments. The CV value is thus expected to be an indicator of the degree of wave winnowing. The CV values of the sediments in the study area varied from 0.1 to 2.8 Φ (Table 2). The average values of the sediments in cores I-V were 0.43, 0.52, 0.23, 0.26 and 0.11 ϕ , respectively (Table 1). The vertical variation of CV showed that most of samples are located approximately in the range of low CV, except some samples (see Fig 3-5). These intervals are observed at the middle part of cores I and II at depths (45 to 80 cm; 25 to 50 cm), and at the basal part of cores I, II, III, and IV at depths (125 to 147cm; 120 to 150 cm; 110 to 122cm; and 138 to 152 cm), respectively. These relatively higher interval values may be deposited under relatively high depositional energy condition compared to the other low values of CV intervals. These may occurred probably during seasonal high rainfalls and high magnitude flash floods and/or the possible high energy coastal processes during times of sea breeze.

Discussion

Grain size analysis in the area of study reflects the characters of the available sediments from the source and the influence of depositional processes, which are indirectly controlled by climate and sea level changes. The sediments are generally fine to medium and rarely coarse sands, transported

intermittently through the temporarily active Wadi Al-Hamd to the nearshore area during major flood seasons. In addition, beach and coastal sand dunes as well as the eroded nearshore sediments are possibly another source. The relatively fine to medium sands indicate that the area of study is of moderate and low energy condition with dominant rolling and suspension mechanisms of transportation. However, the basal parts of cores I, II, III and IV indicate relatively higher energy than those in the upper parts due to the increasing of the average medium and coarse sands. These variations may be due to increase of the activity of wadi during the deposition in the basal parts and decreased in the upper parts. In another way, the basal parts of these cores especially I, II and III express the character of fluvial deposits, while the upper parts of these cores reflect the character of reworked sediments and beach deposits. These sediments may be reworked and deposited when the channel was inundated during storm or increased tide current in winter season. On the other hand, the intensity of depositional energy increased to the northern part of the delta mouth and decreased to the southern of the delta because the sands in the updrift (northern) side are mature compared to the downdrift (southern) side. This is a general characteristic feature for most asymmetric wave influenced delta (e.g. Sf. Gheorghe Lobe in the Danube Delta (Giosan, 1993; Bhattacharya and Giosan, 2003; Ghandour et al., 2013).

upward. The basal part (facies b and subfacies c2) contains the coarsest sediments (the average M_z values are 2.6 and 1.9 Φ). The sediments of the middle and upper part displayed relatively homogeneous M_z values slightly fluctuated between very fine sands (M_z values $> 3 \Phi$) and fine sands (M_z values between 2 and 3 Φ). The M_z values in the sediments of core V (Fig.5) are relatively homogenous and slightly fluctuated between very fine to fine sands (3.5 to 2.6 Φ , with an average of 3.1 Φ).

Inclusive graphic standard deviation (σ_I): Inclusive graphic standard deviation (σ_I) measures the degree of sorting of sediments which is related to the flow velocity condition and the depositional energy. The standard deviation values of the sediments in the area of study varied from 0.2 to 2.4 Φ with average 0.67 Φ . It is noteworthy to mention that the high degree of sorting is enhanced in the marine influenced sediments (cores III and V) ranging from moderately well sorted to well sorted. The degree of sorting in the sediments that were deposited in the delta plain (cores I and II) covers a wide range of sorting varying between poorly to well sorted. However, the majority of sediments are moderately to moderately well sorted (Fig. 3). Similarly, the degree of sorting of the intertidal flat sediments varied between moderately to moderately well sorted and rarely well sorted (Fig. 5).

Inclusive graphic skewness (SK_i): Inclusive graphic skewness measures the degree asymmetry of the frequency of distribution. It has been used to distinguish between beach, aeolian and fluvial sands. The sign of the skewness value is closely related to

depositional environment; i, e. negative skewness values indicate high energy and winnowing action, whereas positive values are attributed to relatively low energy conditions (Folk and Ward, 1957; Magesh et al., 2014). The values of skewness cover a wide range from -0.30 to 2.50 Φ coarse to fine skewed. The average of skewness values in the sediments of cores I-V are 0.45, 0.37, 0.75, 0.075 and 1.16 Φ respectively (positively skewed). The vertical variation of SK_i have shown that the majority of samples were strongly fine skewed to fine skewed. Exception to this observation is noted at the upper part of core V in sample 6 (Fig. 5), at the middle part of cores I and II in samples 16, 17; 10, 15, 16 and 17 and at the basal part of core II in samples (34, 35) that are negatively skewed (Fig. 3). Value of skewness can be indicate to the limited of grain size population. Rajasekhara Reddy and Varma (2008) indicated that positive skewness of sediments indicates the unidirectional transport (flood plain setting) or the deposition of the sediments in sheltered low energy environment, whereas negative skewed sediments indicates deposition at high energy environment. This assumption is applicable to the sediments of channel facies in cores I and II, except for the channel lag deposits at the base of facies a₂. The fine grained nature of the sediments and the interaction of more than one depositional process may complicate the interpretations of skewness values.

Coefficient of variance (CV): Coefficient of variance is a dimensionless value equal to the sorting (standard deviation) divided by the mean grain-size of their respective grain-size distribution (Yamashita

Fig.2 Vertical variation of gravel, sand and mud content in the studied cores

In the sediments of core II, the Mz values increased generally upward (upward fining trend). It fluctuates between 0.6 and 3.9 Φ (coarse to very fine sands). It is worth to mention that the general trend of the Mz is upward increase (fining upward) in the identified sedimentary facies. This relationship in the sediments of the upper part (facies b) was disturbed probably by the homogenization of intensive burrowing. The Mz values in the

sediments of core III (Fig.4) increased generally upward from 1.6 to 4.3 Φ (medium to very fine sands). The coarsest sediments (average Mz value of 1.8 Φ) was obtained from subfacies c1 at the basal part. The Mz values in the sediments of the middle and upper parts (facies d and e) varied from 2.5 to 4.3 Φ (fine sands to silt). The Mz values in the sediments of core IV varied from 1.6 to 4.3 Φ and generally displayed slight increase

Graphic Mean size (Mz): The graphic mean (Mz) is the average size of the sediments used mostly as an index of the depositional energy, the amount of sediment availability and the character of the transporting agent. The mean size of the sediments in the area of study varied from 0.60 to 4.30 Φ (medium to very fine sand). The average Mz values in the sediments of cores I-V were 2.06, 2.12, 2.79, 2.89 and 3.11 Φ (fine sands), respectively. $2.06 < Mz < 3.11 \Phi$. The lowest Mz value ($\sim$ The sediments in the area of study is general homogeneous consisting of fine sands with 0.6 Φ ; coarse sands) was obtained from sample 40 in core II and the highest Mz value ($\sim$ 4.3 Φ ;

very fine sands) was obtained from samples 14 and 4 in sediment cores III and IV, respectively. It is worth to mention that the Mz values are consistent within the same core and increase generally upward (i. e. grain size decreases). The Mz values increase in the cores that were collected from landward and northward directions. The Mz values (Fig.3) in the sediments of core I range from 1 to 4.2 Φ . The sediments of the basal part (subfacies a1) displayed relatively homogeneous Mz values (averaging 1.9 Φ ; medium sands), whereas the upper part (facies a2) displayed an upward fining where Mz values increased from 1 to 2.6 Φ .

Table 1 The range and average of textural classes and grain size parameters of cores

Cores n		Grain size (%)			Fraction of sand %					statistical grain size parameters (Folk and Ward, 1957)				
		Gravel	Sand	Mud	V.C.S	C.S.	M.S.	F.S.	V.F.S.	Mz	S. D.	SK _t	K _G	C.V
Core I	Min.	0	11.3	1.2	0	0.3	2.9	3	1.2	1	0.5	-0.3	0.7	0.1
	Max.	16.8	98.8	87.5	11.4	34	62.7	66.5	16.6	4.2	2.4	0.7	4	1.4
	Mean	0.8	89.9	9.3	1.5	8.7	42.8	29.8	7	2.1	0.9	0.4	1.3	0.4
Core II	Min.	0	15.8	0.1	0	0.2	4.3	2.9	1.5	0.6	0.4	-0.3	0	0.1
	Max.	14.2	99.9	82.3	18.9	40	54.8	86.9	30.1	3.9	2.2	1	4.9	2.8
	Mean	2.1	89.2	8.7	2.9	9.4	27.8	39.4	9.7	2.1	0.9	0.4	1.2	0.5
Core III	Min.	0	10.4	0.1	0	0	0.3	1.4	3	1.6	0.3	0	0	0.1
	Max.	2	99.6	89.6	2	13	63.5	72.5	65.8	4.3	1	1.7	1.4	0.4
	Mean	0.2	89.9	9.9	0.3	1.7	16.2	41.8	29.9	2.8	0.6	0.8	1.1	0.2
Core IV	Min.	0	6.7	0.5	0	0	0.3	1	2.5	1.6	0.2	0.1	0.5	0.1
	Max.	5.4	99.2	93.3	1.4	12	63.4	73.2	67.8	4.3	0.9	2.5	2.1	0.5
	Mean	0.3	88.6	11.1	0.2	1.4	12.5	40.7	33.8	2.9	0.6	0.7	1.1	0.2
Core V	Min.	0	87.1	0.2	0	0	0.1	7.2	18	2.6	0.3	0	0.9	0.1
	Max.	3.6	99.8	12.9	1.4	0.6	3.9	78.6	87.5	3.5	0.8	1.5	2	0.3
	Mean	0.1	97.1	2.8	0	0	0.5	41.9	54.6	3.1	0.4	1.2	1.1	0.1

shoreline, and the wind-driven waves (up to 2.5 m high) and currents are amplified and associated with long-shore sediment transport. The coastal plain undergoes seasonal cycles of long dry summer emergence and short winter submergence.

Materials and Methods

Five shallow cores (1.46 – 1.76 m long) were collected manually using a pipe of PVC with 2 inches internal diameter. The cores were collected in a proximal-distal transect running parallel to the axis of the channel (Cores I-III) on the delta plain and along shore on both sides of the wadi mouth (Cores IV-V). The sedimentary facies of these cores were described by Gandour *et al.* (2016). The grain size analysis was carried out for a total of 206 sediment samples by dry sieving of which 38 from the sediments of core I, 43 from core II, 36 from core III, 42 from core IV, and 47 from core V. A well-known dry weight (~ 50 gm) was wet sieved through 63 μ m sieve to separate mud fraction from the coarse grains (sand and gravel). The coarse fraction was dried, weighed and sieved at 1 Φ interval using the mechanical shaker for 15 minutes following the method of Folk (1974). The frequency percentage (probability density) for each sieve fraction was calculated. The results of grain size analysis of the sand fraction were treated statistically using the method of Folk and Ward (1957). The three statistical parameters: graphic mean size (M_z), inclusive graphic standard deviation (σ_i) and inclusive graphic skewness (Sk_i) were calculated. The coefficient of variance (C. V.) which defined as the degree of sorting relative to the mean grain size was also determined (Yamashita *et al.*,

2009). Various bivariate plots between grain size parameters and the C-M diagrams (Passega, 1957) were established to determine the major controls on grain size characteristics and distribution.

Results

The sediments at the area of study are heterogeneous in texture, consisting mainly of allochthonous siliciclastic and rarely biogenic, calcareous sediments. Generally, the sediments are sand dominated and containing negligible amounts of gravel and mud. The average sand content in the study area is about 91.1%, among which the fine to very fine, and medium sands are the dominant. The sediments of cores I and II yield the highest average medium sand content; 42.7 and 27.8 %, respectively (Table 1). The gravel-sand-mud distribution of the sediments is displayed in Figure 2. Gravels (granule size) are rarely identified only from the sediments of cores I and II defining the base of channel facies. Mud was recorded from most cores with low abundance. It is absent from the sediments of core V (strandplain). These distribution illustrate that the sand percent in cores I, II, III and V increase landward and fluctuate upward except in thin layers which have high percent of mud.

Statistical analyses

The grain size parameters including mean size (M_z), inclusive graphic standard deviation (σ_i), and inclusive graphic skewness (Sk_i) were determined statistically according to Folk and Ward (1957), and Yamashita *et al.* (2009). The vertical variations of these parameters are shown in (Fig. 4).

summer months. The coastal plain of the area can be classified as wave-dominated and tidal influenced systems (Boyd *et al.*, 1992; Ghandour *et al.*, 2013). It is displaying a semidiurnal micro-tidal regime, with a spring

and neap tide range of 0.7 m and 0.5 m, respectively. The strength of flood currents, although relatively weak, is still stronger than the almost negligible ebb currents.

Fig. 1: Location map and location of cores in the study area

The climate of the area of study is arid with low sporadic rainfall (from 0.5 to 116 mm/y). Rainfall falls mostly in the winter months between October and March in the form of short-duration showers generally associated with thunderstorms. It is influenced by Mediterranean cyclones, which bring winter rains, and this region is also sensitive to the effects of the North Atlantic oscillation, which leads to periods of greater or lesser aridity approximately every 6 years (Felis *et al.*, 2000; Brázdil *et al.*, 2009). During the rare flood seasons, water levels in the Wadi Al-

Hamd reach ~3 m high. Temperature varies between 11°C and 39.9°C and can rise in summer to 47.58 °C. The prevailing wind in the northern Red Sea is from the NNW to SSE over the entire year, essentially aligned with the central (long) axis of the Red Sea. In winter time, wind-blown to the NE, SSE, and rarely to N and SW with speed varying from 2 to 10 m/s. The N and NE winds influence the movement of water in the shallow coastal inlets adjacent to the coastal plain, especially during winter sea breezes. These breezes produce significant wave energy at the

which are controlled by sea level and climate changes (Gruijters *et al.*, 2005; Angusamy and Rajamanickam, 2006; Yamashita *et al.*, 2009; Rajganapathi *et al.*, 2013). Grain size studies of recent and ancient coastal plain sediments were and still a target for several studies (e. g. Gruijters *et al.*, 2005; Angusamy and Rajamanickam, 2006; Yamashita *et al.*, 2009; Rajganapathi *et al.*, 2013). Most of these studies have been carried out in areas of humid climate with relatively high sedimentation rate and contain a wide range of sediment textures. The textural analysis of the Red Sea coastal plain and nearshore sediments of Saudi Arabia was a target for many studies (Abou Ouf and El Shater, 1992; Gheith and Abou Ouf, 1996; Sagheer, 2008; Wasel, 2008; Khawfany, 2009).

In an arid microtidal coast, such as the Red Sea, beach sediments consist largely of sand sized skeletal remains except at the mouth of wadis. The sediments of the wadis which are supplied by intermittent floods, with few contribution from aeolian supply. They are the main conduits for detrital siliciclastic to the shorezone environment. Sedimentation and sediment transportation in the nearshore area at the mouth of these wadis are intermittent and sporadic depending on rainy seasons and high magnitude of flash floods. The sediments in these areas are dynamic and subjected to continuous erosion, mixing, reworking and homogenization (Ghandour, 2014). Sediments re-distribution along the coast is controlled mainly by wind induced currents and waves, and to lesser extent by the negligible tidal and fluvial currents. The present study describes the general grain size characteristics and the

spatial and vertical variations in grain size parameters of shallow subsurface sediments in the vicinity of Wadi Al-Hamd, NE Red Sea coast, Saudi Arabia. The major controls on grain size distribution and degree of sorting in such an arid microtidal coast are also of interest.

Area of study

The area of study is located at the coastal plain at the mouth of Wadi Al-Hamd, northern Red Sea, about 55 Km south of Al Wajh, Saudi Arabia (Fig. 1). The area of study is located between latitudes 25°57'49.08"N and 25°58'3.96"N and between longitudes 36°42'37.02"E and 36°43'30.56"E. Wadi Al-Hamd is the largest wadi in this area, with a length of approximately 165 km, and it extends from the mountain scarp near Al-Medina City. It flows inland to the NW and drains into the Red Sea. This wadi is an occasionally active and is an important conduit for fresh water and sediments during major flood seasons. The downstream area of Wadi Al Hamd is covered by the Cretaceous-Quaternary terraces and the Recent sediments.

The mouth of Wadi Al-Hamd takes a form of an asymmetric delta flanked by a strand plain with a relatively steep foreshore profile to the north and a wide, gently sloping intertidal flat to the south (Ghandour *et al.*, 2013). Many common landforms are observed such as beach ridges, submerged sand bars that are parallel to slightly oblique to the shoreline, coastal sand dunes, sabkhas, intertidal flats, and intertidal inundated distributary channels. The distributary channels, which represent the seaward extension of Wadi Al-Hamd, is inundated up to ~2 km inland by winter storms, whereas they remain dry during

Controlling factors on the grain size distribution of shallow subsurface coastal sediments at the mouth of Wadi Al-Hamd, northeastern Red Sea, Saudi Arabia

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Abstract. The present study concerned with grain size distribution of shallow subsurface sediments at the mouth of Wadi Al-Hamd, NE Red Sea coast, Saudi Arabia. The objectives of the study are the description and interpretation of the controlling factors on the spatial and vertical variations in grain size parameters. Grain size analysis of 206 samples belonging to five shallow cores collected from the tidal flat at the mouth of Wadi Al-Hamd showed that the sediments are generally sandy; with a mean size ranging from fine to medium sand and rarely gravel and mud. The channel fill sediments showed poor to well sorting, strongly fine skewed and low coefficient of variance except at the base of channel. The southern lower intertidal flat sediments are heterogeneous moderate to well sorted fine to medium sands, fine to strongly fine skewed and low coefficient of variance. The beach sediments to the north are well sorted fine to very fine sands, strongly fine skewed and low coefficient of variance. The size and distribution of sediments are controlled by the texture of the available sediments, hydrodynamics during transportation and depositional. The available sediments are controlled by the climatically controlled degree and type of weathering at the source, length and power of transporting agent and the gradient of the route. The study area displays alongshore variation in depositional setting from a low gradient inter-tidal flat to south and wave dominated strand plain system to the north.

Keywords: Wadi Al-Hamd, grain size, depositional energy, arid coast, strand plain, CM Diagram.

Introduction

Grain size characteristic of sediments is one of the most widely used method for examination of recent sediments, because grain size distribution provides clues to the nature of sediments that deposited under varied physical conditions. Thus, grain size characteristics of

sediments can be used in a collaboration with litho- and bio-facies to interpret depositional and transportation dynamics (Yamashita *et al.*, 2009; Ganesh *et al.*, 2013; Ghandour, 2014). In coastal plain setting, grain size distribution is strongly affected by depositional processes