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Contribution of Grain-size Trend to Sediment of a Microtidal Beach. Case of the Gulf of Tunis Bay (Cape Ferina-Cape Gammarth, Tunisia)

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ABSTRACT

Sediments collected from the nearshore, at the beach of the Gulf of Tunis, are used to understand the complex interactions between the grain-size pattern and the hydrodynamic process, under urban and natural effects. Generally, the nearshore sediment of the Gulf of Tunis has an average mean diameter of 0.35-0.085 mm while the coastline sediment is 0.25 mm, on an average. The grain size shows a coarsening trend at the beach slope, as a result of the action of the cross-shore current. On the other hand, the coarsening trend in the mean grain size is locally distorted at river mouths, sandy spits and harbor structures. Although the shoreline has been modified by human activity, the Gulf of Tunis has retained its natural configuration. The north-east and eastern longshore drift were interrupted by the sedimentary cell; which seems to be the factor for the bimodality of the grain population.

Key words: Grain-size trends, nearshore, sedimentary cell, longshore drift, Tunis gulf

INTRODUCTION

With respect to the current pressure of climatic changes, providing information on the present sedimentary structures, processes and relationships of the marine environment around coastlines worldwide, helps to understand how this system operates. The Gulf of Tunis has been the subject of considerable interest since as early as the mid-nineteenth century, focusing on the sedimentary processes on the littoral zone (Schoeller, 1939). According to the main studies carried out (Kouki, 1984; El Arrim, 1996), it seems that the coastal sediment in the Gulf is characterized by two different populations. The first is constituted by mud coming from the seasonal supplies of rivers and the second population is mainly composed of sandy sediments originating from the continuous reworking of erosion of the cliffs and the coastal drift throughout the beach, during storm events (Kouki, 1984; El Arrim, 1996; Ben Charrada, 1997). An abundance of fine sediment is provided to the Gulf of Tunis from natural sources such as rivers and cliffs (El Arrim, 1996; Essonni, 1998; Added *et al*., 2003; Chkioua, 2005; Afli *et al*., 2009; Helali *et al*., 2009; Zaaboub *et al*., 2009). The eastern part of the Gulf of Tunis shows the presence of sandy to silty-sand distribution on the intertidal zone (Essonni, 1998; Saidi, 2004). Such sediments are most often moved both by natural and human factors (Kouki, 1984; El Arrim, 1996; Sorgente *et al*., 2003; Chkioua, 2005).

Unfortunately, little is known about the amount and timing of the sand supply from the natural sources, largely due to the focus on quantifying coarser sand and gravel inputs into the littoral zone. Furthermore, it is difficult to quantify the relative inputs and potential impacts of fine sediments from human activities (such as beach nourishment and harbor dredging), when the natural processes have not been adequately characterized. Clearly, it would be very interesting to deduce a textural parameter that is characteristic of the beach profile under steady hydrodynamic conditions, independent of the changes in grain size of the supplied sediment. The distribution of such a parameter could be used in the prediction of sediment behavior and dispersion over the littoral profile, in response to new inputs of sediment from natural or man-induced processes. This article emphasizes the sedimentological investigations on the oriental nearshore of the Gulf of Tunis (Cape Ferina-Cape Gammarth) which is characterized by sandy and detritic facies. This investigation aims to study the grain size distribution and granulometric parameters, to better understand the local littoral sediment transport mechanism.

Study area description: The site under study is located on the north-eastern extremity of the coast of Tunisia, in the Gulf of Tunis, between 37°10'N, 10°16'E (Cape Ferina) and 36°55'N, 10°18'E (Cape Gammarth). The western bay of the Gulf of Tunis is a regular coastline with a series of lagoons on its northern and middle parts; the Ghar El Melah, Kalat El Andalous and Ariana lagoons (Fig. 1). The coastal area is bordered by rocky cliffs: Cape Gammarth and Cape Ferina which range in age from Pliocene to the Neotyrrhenian coastal deposits (Paskoff and Sanlaville, 1983). The low-lying coastal areas, such as, the river valleys of Medjerda and the lagoon's depression are covered by the Pliocene and quaternary coastal deposit (El Arrim, 1996).

The sandy beach, about 30 km long and 40-200 m wide, is lined with fairly well-developed coastal dunes in the middle part of the gulf (delta of Medjerda beach, Raoued beach) (Fig. 1). The dune ridge is unevenly spread from the south to the north; its width varies between 30 and 50 m southward of the bay, narrows down to just a few meters in the Gammarth and Raoued beaches, is the largest in the Medjerda valley (120-400 m) and almost disappears in front of the Ghar El Melah lagoon (Oueslati, 1993). It reappears on the north eastern ridge of the harbor structure but it does not exceed 80 m in the north. The tide is mixed, predominantly semidiurnal and microtidal, with a tidal range lower than 0.1-0.3 m.

The morphology of the Gulf is a result of the filling of the terrigenous origin since the end of the Holocene transgression, coming from the river Medjerda (Paskoff and Sanlaville, 1983). In the area of the northern Medjerda mouth, the beach does not seem to be affected by erosion. In fact, a sandy spit (Kalât Andalous) is disconnected from the coast and migrates to the mainland in the south-southwest (SSW) direction (Oueslati, 1993). The Gulf of Tunis is mainly fed by the river Medjerda in its western part. The sediment load is 10 g L^{-1}, increasing to 30 g L^{-1} in a flooding period, giving an annual total of 20,400 tonnes, of which 10% is composed of sand (Kalai, 1985; Essonni, 1998). The sediment is highly contaminated as a result of the considerable volume of wastewater that flows into it (Ben Charrada, 1997; Added *et al*., 2003; Helali *et al*., 2009).

The bathymetry of the bay, based on the general bathymetric map variations, shows that the 10 m isobath is 600 m from the beach at the northern ridge of the Ghar El Melah site. In front of the lagoon of Kallat Andalous, it moves from the coast (3000 m) while in the middle part, in front of the Medjerda delta, it gets closer by less than 1000 m. The nearshore slope is steeper in the Gammarth Cape at a 6 m depth and does not exceed 600 m from the beach.

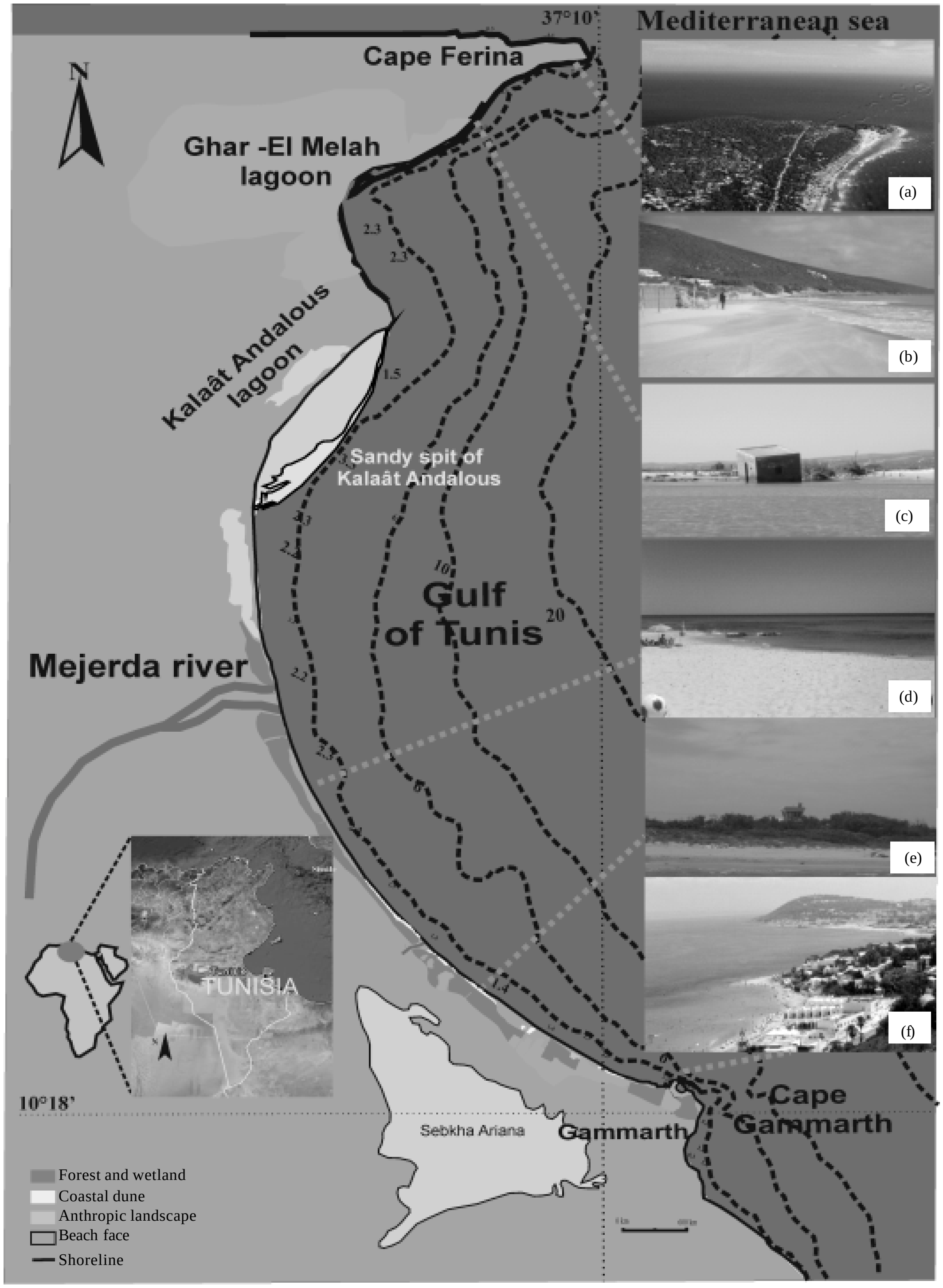

Fig. 1(a-f): Overview of the study area with an indication of the main morphological entities; the figure shows the position of the work feils site's from the north to the south (a) Cape Ferina, (b) Ghar-El Melah, (c) Kalaat Andalous, (d) Raouad beach, (e) Coastal Dunes and (f) Cape Gammarth beach

Table 1: Medium and exceptional active waves in the Cap Ferina beach (bay of the Gulf of Tunis; 1964-2002). Direction which do not exceed 15%. Hs.50: High of 50% significative wave recorded, Hs.01: High of 1% significative wave recorded in year

Direction	Hs.50	T.50	Hs.01	T.01
E (E)	1.1	7	2.8	12
E-SE (S68E)	1.4	8	3.2	12
SE (S45E)	1.3	8	2.9	11

Table 2: Medium and exceptional active waves in the Cap Gammarth (bay of the Gulf of Tunis; 1964-2002). Hs.50: High of 50% significative wave recorded, Hs.01: High of 1% significative wave recorded in year

Direction	Hs.50	T.50	Hs.01	T.01
N (N)	1.4	9	3.2	14
E (E)	1.1	7	2.2	10
NO-N (N23W)	1.1	7	2.5	11

Dynamic characteristics: The coastal zone of the Gulf of Tunis is under a seasonal wind regime accorded to the Mediterranean temperate climate. The local wind data supplied by the meteorological station of Ghar El Melah harbor, shows the prevailing wave directions for each season. Irrespective of the zero-wave periods, the results show a large scatter of directions (Table 1 and 2). Taking into account the directions of the bay shoreline, N30E in the northern gulf to N135E in the south, the most active winds blow from the east to the southeast in Cape Farina (Table 1). The most frequent waves landing on the Gammarth coast come from the north-west sector during the winter season. The eastern to south eastern direction dominates in spring. The north to north-northwest (N-NNW) wave direction is responsible for 74% of the activity observed (both from 1951-1971 and 1991-1995) in the Cape Gammarth region (Table 2). Table 2 indicates the wave characteristics (height and period) according to their origin, based on yearly sea states, respectively, exceeded by 50 and 1%. These visual data, observed on board commercial vessels, come from the database of the COADS (International Understanding Ocean-Atmosphere Dated Set), a North American project which has been gathering information dating back to 1784. The available compilation for the Tunisian coast takes into account information right from 1964. However, waves from the East (E) to South-South East (SSE) were recorded too. This distinction also reflects the seasonal distribution of winds, with a decrease in the E to SSE wind speed in winter (17% active winds) against nearly 13-22% during the other seasons (Station de Tunis Carthage (1951-1970 in Ben Charrada, 1997).

METHODOLOGY

Sediment analysis was carried out on samples of submarine sands taken from a water depth of between 1 and 6 m, onboard the INSTM zodiac. Beach samples were collected during November 2009, in the winter season. The sediment samples were gathered along every survey line of the beaches as follows: From the coastline level; from the swash zone at depths of 1-3 m and from the surf zone (4-6 m). Seven profiles were sampled (Fig. 2). A total of 42 samples underwent a grain size analysis by sieving. Grain-size distribution was characterized by using classic indices (average mean size Mz and/or median value Q2, sorting index σ, asymmetry index SK_I and kurtosis index K_G), according to Folk and Ward (1957). The microgranulometric analysis was undertaken by the Malvern Mastersizer 2000 which was designed for the measurement of particle size distributions within the range of 0.01-1000 microns. The Mastersizer 2000-associated software allows specifying material and dispersant characteristics, describing their refractive behaviour (Pye and Blott, 2004).

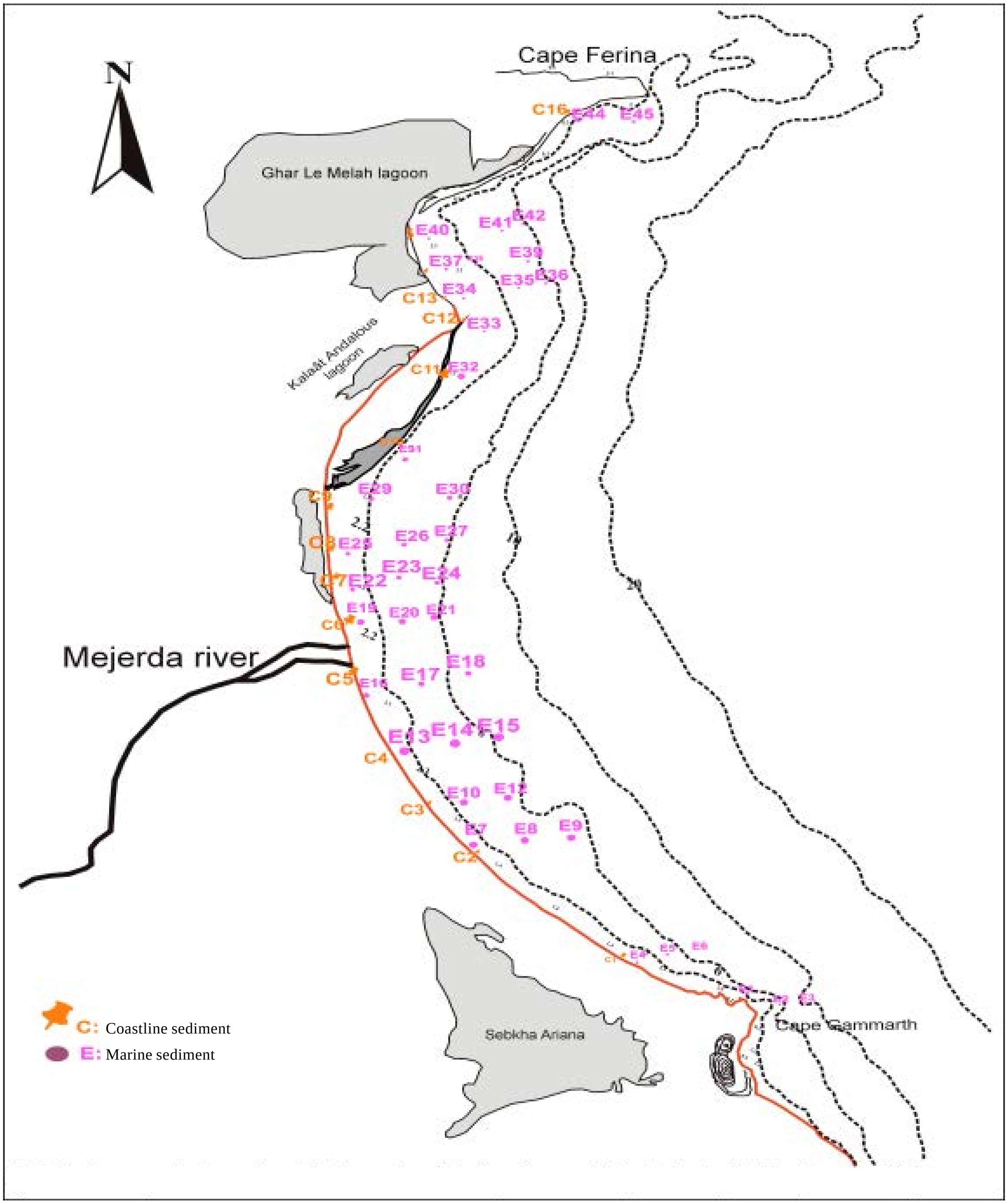

Fig. 2: Location map of surface sediments in the nearshore of the Cape Gammarth-Cape Ferina bay Tunisia (Novemver 2009)

RESULT AND DISCUSSION

Modal values: The granulometric analysis of the sands taken along the beaches of the Cape of Ferina-Cap Gammarth bay is summarized in Table 3. A large carbonate proportion (30-50%) is revealed in the samples. The carbonate fraction is represented by the remains of the marine shells and sea grasses. The grain-size analysis reveals a majority of unimodal sands (70% of the samples). The statistical mode values of the marine sediment show a presence of four sedimentary types, of which the classes with mean grain sizes of 0.140 and 0.280 mm dominate the finer modal value (silts and clay), with the coarser modal value being very subordinate (Fig. 3). It confirms the several sources of sediment supply (river, biogenic, cliff, etc.). With respect to the coastline samples, the bimodality appears in the southeast part of the Medjerda beach (C2, C3 and C4) and in the middle part of the bay (C8). Apart from the obvious unimodality of the sediment C6, C7, C12 and E4, E12; E31 (mode = 2.3-3 Φ), the negative skewness indicates intermixing with a coarser sediment fraction, as was observed by Bartholoma and Flemming (2007) and Amrouni *et al.* (2007). The simultaneous addition of two sedimentary types for increasing the proportions to the dominant sediment type, first, increases the asymmetry of the sediment which apparently remains unimodal. The mechanism of the mixture supplying several sedimentary types cannot be attributed to the reduction of sediment supply. Indeed, the Cape Ferina-Cape Gammarth bay is continually supplied by continental (river, lagoon, sebkha), eroded cliff and cape (Pliocene and Tyrrhenian) deposit and fluvial contributions through the Medjerda, as also from the eroding cliffs (Essonni, 1998). However, the sediment input to the beach from the Medjerda river is reduced due to construction of a dam.

Median grain size D_{50}: The sediment distribution shows a fining trend from the shoreline to the surf zone (6 m depth) (Fig. 4). Based on the morphology and sediment distribution, three zones can be defined on the shoreface of the Cape Ferina-Cape Gammarth bay:

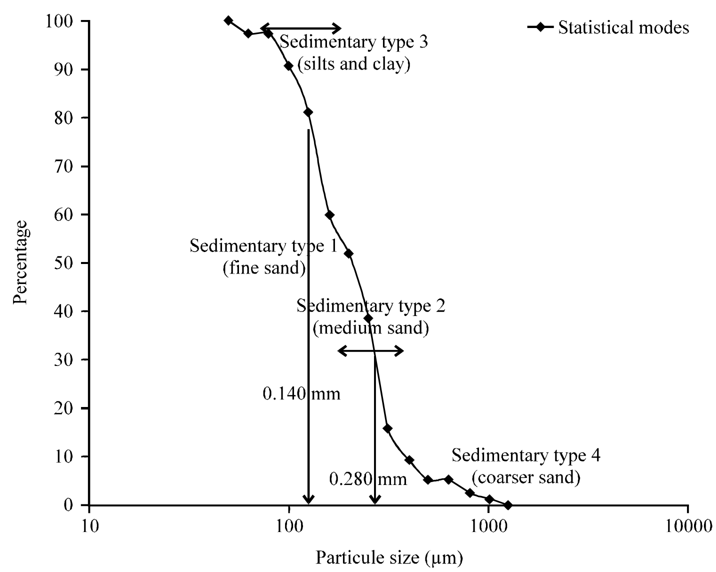

Fig. 3: Modal value of the sediments studied on the workfeild's beach (November 2009)

Table 3: Longshore and cross-shore variations in sediment size of the golf Tunis bay (November 1999), sorting, skewness and kurtosis (Folk and Ward, 1957 graphical parameter)

				Cape of Gammarth (Raoued beach)				Beach of Medjerda river				Kalaat Andalous spit				Cape Ferina (Ghar el Melah beach)			
Geomorphological unit	Zone	Number	Modality	Mz	σ	SKI	KG	Mz	σ	SKI	KG	Mz	σ	SKI	KG	Mz	σ	SKI	KG
Coastline	0 m	C1		2.00	0.46	-0.05	0.86												
		C2	Bimodal	2.46	0.29	-0.21	2.62												
		C3	Bimodal	1.39	0.51	0.19	1.22												
		C4	Bimodal					1.33	0.41	0.05	1.38								
		C5						1.49	0.39	0.06	1.68								
		C6						1.50	0.64	-0.07	1.03								
		C7						2.68	0.24	-0.21	1.23								
		C8	Bimodal					2.42	0.45	-0.20	1.04								
		C9										2.19	0.32	0.23	1.09				
		C11										2.12	0.30	0.55	1.40				
		C12										2.05	0.43	-0.24	1.27				
		C13														2.71	0.74	0.37	1.11
		C14														1.94	0.42	-0.08	1.28
		C15														1.91	0.29	-0.31	1.28
		C16														2.03	0.28	-0.27	1.49
Swach zone	-1 m	E7 (-1 m)		2.52	0.39	-0.34	1.67												
		E10 (-1 m)		2.37	0.42	-0.24	1.24												
		E 13 (-1 m)	Bimodal					2.30	0.60	-0.12	0.95								
		E16 (-1 m)						1.50	0.42	0.10	1.71								
		E19 (-1 m)	Bimodal					2.95	0.38	-0.03	1.40								
		E22 (1 m)						3.04	0.35	-0.04	1.52								
		E 25 (-1 m)										2.91	0.31	-0.12	1.70				
		E28 (-1 m)										2.33	0.49	0.18	1.06				
		E40 (-1 m)														1.97	0.32	-0.50	1.20
		E44 (-1 m)														1.86	0.32	-0.23	1.87
	-2 to 3 m	E3 (-2,4 m)		2.97	0.29	0.10	2.27												
		E4 (-2 m)		2.85	0.26	-0.12	1.56												
		E8 (-3 m)		2.91	0.36	0.35	1.59												
		E 14 (-3 m)	Bimodal					3.26	0.56	-0.24	1.68								
		E17 (-3 m)	Bimodal					3.11	0.80	-0.22	1.60								
		E20 (-3 m)	Bimodal					3.35	0.37	0.10	1.03								

Table 3: Continue

Geomorphological unit	Zone	Number	Modality	Cape of Gammarth (Raoued beach)				Beach of Medjerda river				Kalaat Andalous spit				Cape Ferina (Ghar el Melah beach)			
				Mz	σ	SKI	KG	Mz	σ	SKI	KG	Mz	σ	SKI	KG	Mz	σ	SKI	KG
		E 29 (-2, 3 m)										2.93	0.36	0.15	1.28				
		E31 (-2 m)										2.87	0.29	-0.10	2.43				
		E32 (-2 m)	Bimodal									3.14	0.50	0.13	0.41				
		E33 (-2, 4 m)	Bimodal									2.11	0.85	-0.31	0.95				
		E34 (-2 m)														2.67	0.48	-0.11	1.57
		E37 (-2 m)														2.14	0.39	0.02	2.06
		E45 (-3 m)														1.97	0.38	-0.26	1.74
Surf zone	-4 to -6 m	E1 (-6 m)	Bimodal	3.15	0.46	0.23	1.13												
		E5 (-4 m)		2.89	0.35	0.11	2.20												
		E6 (-6 m)		2.89	0.36	0.15	1.91												
		E9 (-5, 3 m)	Bimodal	3.30	0.48	0.47	0.96												
		E12 (-5 m)		3.28	0.68	-0.58	4.37												
		E15 (-5 m)	Bimodal					3.41	0.35	0.15	1.14								
		E23 (-4 m)						3.22	0.35	0.33	1.28								
		E24 (-5, 2 m)						3.56	0.27	0.23	2.49								
		E26 (-4 m)						3.52	0.37	0.44	1.63								
		E27 (-5, 6 m)										3.54	0.62	-0.89	2.09				
		E 30 (-5, 5 m)	Bimodal									2.75	0.90	-0.32	1.21				
		E35 (-4 m)	Bimodal													3.31	0.43	0.10	1.12
		E 36 (-5, 2 m)														3.42	0.54	-0.25	0.85
		E39 (-5, 7 m)														2.88	0.51	0.15	1.34
		E41 (-4 m)														1.90	0.43	-0.17	1.32
		E42 (-6 m)	Bimodal													2.50	0.60	-0.17	1.78

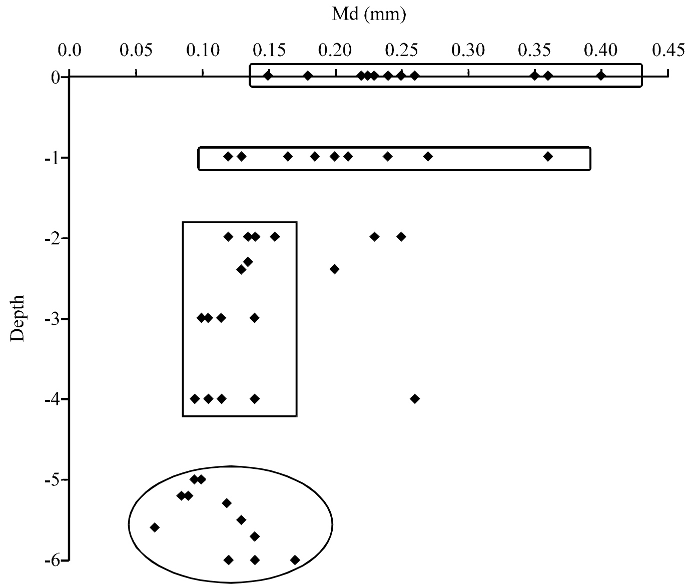

Fig. 4: Cross shore evolution of median index (Md) of coastline sample in the Cape Ferina-Cape Gammarth bay (November 2009)

- The shallowest and high-mobility zone (from the shoreline down to 1.5 m water depth) shows a heterogeneous distribution, the grain size fluctuates from silt (0.12 mm) to coarser sand (0.4 mm)
- The intermediate part between 2 and 4 m depth is characterized by the finest sediment (0.095-0.15 mm), with a coarser fraction (0.25 mm) dispersed at a 2 m depth
- A zone that is characterized by a strong sediment fining gradient marked at the 6 m depth part (0.4-0.063 mm). The decrease in cross-shore grain size from the coastline to the offshore area, has been described extensively in several sections of the Tunis Golf nearshore (Kouki, 1984; Essonni, 1998; Saidi, 2004), as also in the oriental Tunis golf (Soliman beach, Sebkhat El Melah)

Longitudinal evolution: The coastline sediment ranges from very fine to medium sand. Spatial granulometric evolution of the coastline samples along the bay show a general tendency of increasing grain size, from Cape Ferina toward the Cape Gammarth beaches. However, the Medjerda and Raoued beaches (i.e., C3, C4, C5 and C6) are marked by a coarser fraction, with medium grain size (0.36-0.4 mm) (Fig. 5). The coastline sediments are fine, well to very well sorted and negatively skewed, in the northern beaches of the bay (Ghar El Melh) but positively skewed in the spit of the Kalaat Andalous beach. The same grain size characteristic is observed in the Kalaat Andalous beach, with very fine sand, well to very well sorted and negatively skewed. Even as the Medjerda neighbors are marked by medium sand, poorly sorted and negatively skewed in the northnren part of the river's mouth, the sediment varies to medium sand, well sorted and positively skewed in the southeren part of the river's mouth. In the southern beach of the bay (Raoued), the sediment is fine to very fine, very well sorted and negatively skewed. (Fig. 6).

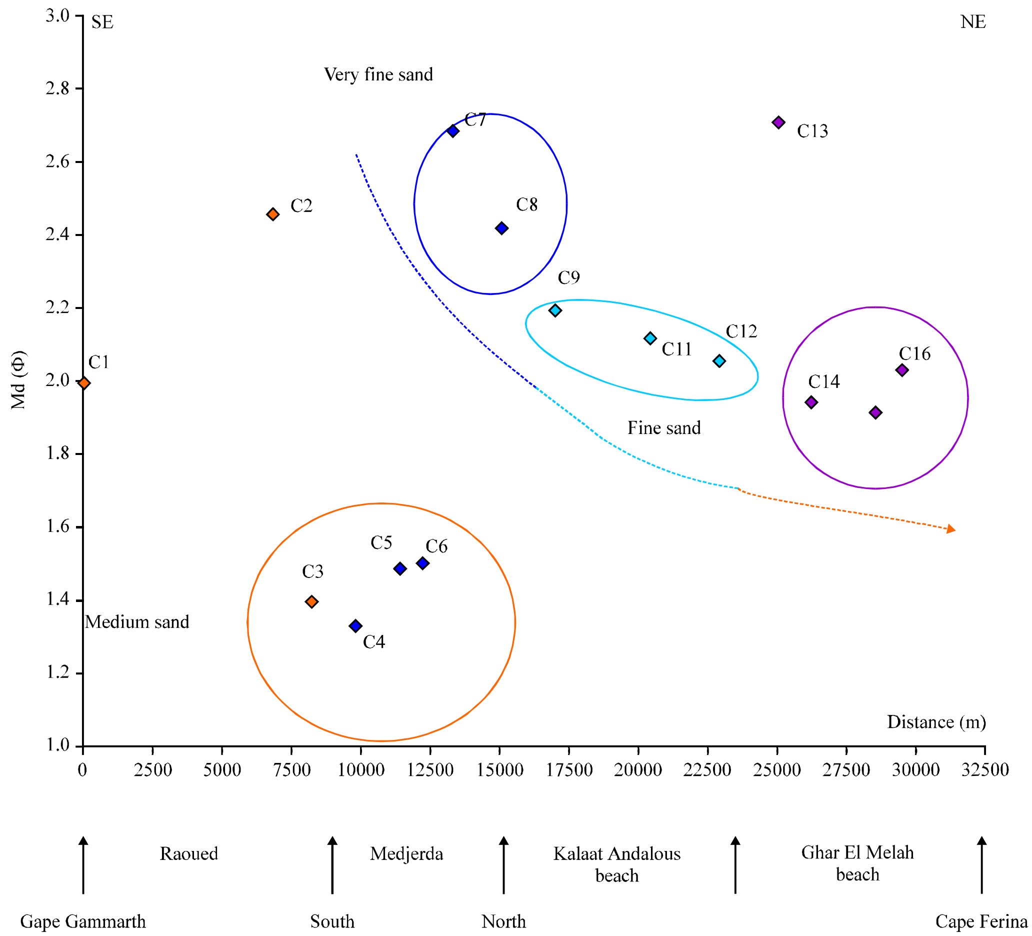

Fig. 5: Longitudinal evolution of median grain size Mz of coastline sample C1-C16 in the Cape Ferina-Cape Gammarth bay (November 2009)

There is no discernible longitudinal sorting trend along the nearshore of the beach in the gulf of Tunis. The majority of the coastal marine sediments is characterized by leptokurtic to very leptokurtic distribution, except the C1 (Raoued) sample which presents a platykurtic distribution.

The asymmetric index reveals that 60% of the samples exhibit coarse asymmetry. Thus, the samples are located in the middle part of the bay in the northern part of the Medjerda river (Fig. 7).

The sediment that presents asymmetry to a finer type is located at the Ghar El Melah and Kalaat Andalous beaches and is concentrated at the southeast of the Medjerda beach (Fig. 7). Skewness is a parameter that responds to transport direction and supply sources. A very negative skewness appears in such transition zones, due to the mixture of fine and coarse grain sizes (Blaeser and Ledbetter, 1980; Roman and Achab, 1998).

The sediments on the beach of the Gulf of Tunis generally decrease in grain size southward (Kouki, 1984; El Arrim, 1996; Chkioua, 2005) according the dominant longshore north-south (N-S) drift (McLaren and Bowles, 1985; Kouki, 1984; Oueslati, 1993). In this study it is observed that the longshore grain size decreases at the Gulf of Tunis from the north to middle part of the bay.

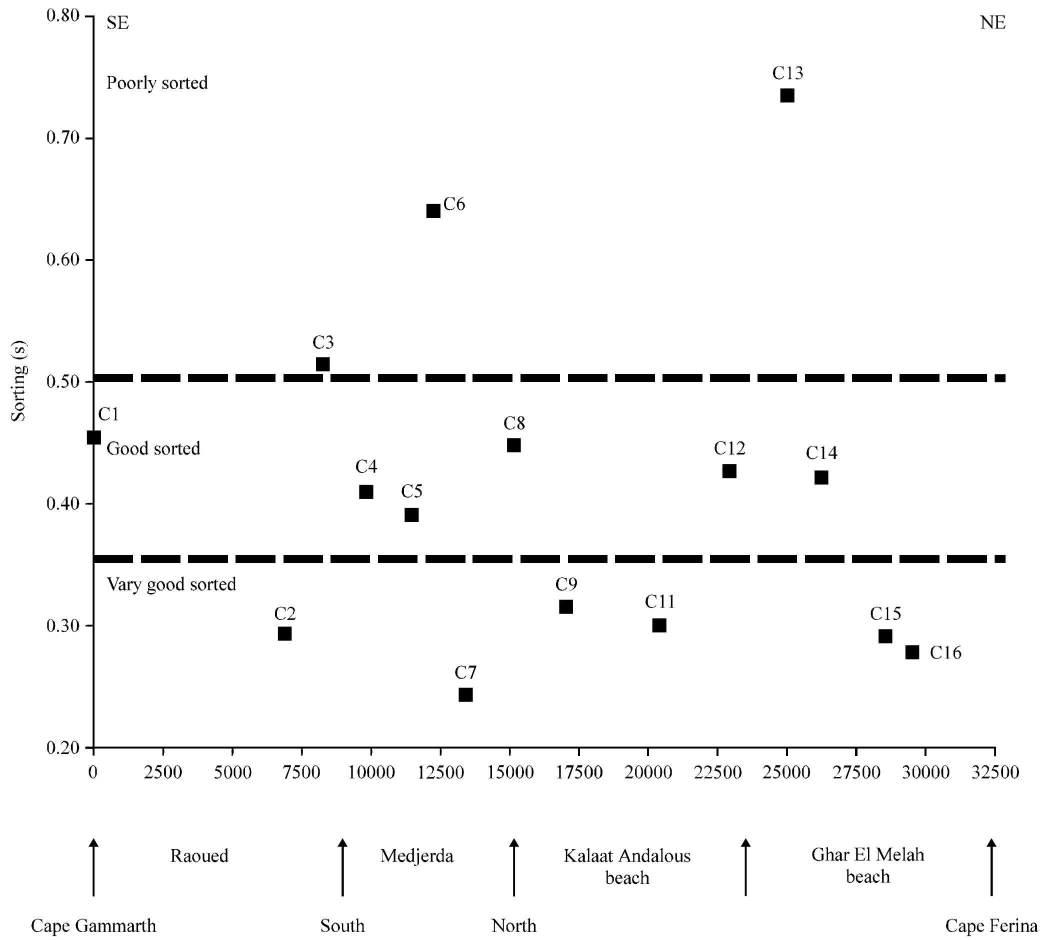

Fig. 6: Longitudinal evolution of sorting dustribution index of coastline sample C1-C16 in the Cape Ferina-Cape Gammarth bay (November 2009)

The zones characterised by coarser distribution appeared at the mouth of the Medjerda river or adjacent to the Kalaat Andalous spit deposit or human barrier. This grain size trend were explained to be the response of important hydrodynamic processes (local longshore drift and cross-shore current) (Chkioua, 2005) and/or due to the presence of harbor structures (Zeggaf, 1993, 1999). A decrease in the energy of the transporting medium in fluvial and channelized environments could be easily explained by a decrease in velocity, owing to changes in relief and friction (Muzuka and Shaghude, 2000). Such local disturbances were already observed and attributed to natural and manmade structures (river mouth/breakwater) which meant that the effect of these features was to locally alter the grain size distribution from the observed general trend (Kouki, 1984).

The topo-bathymetric modeling studies established by Louati and Zargouni (2009), along the Gulf of Tunis, nearshore, introduce the sediment cell concepts. Similar sedimentological investigations of the Mahdia bay (oriental Tunisia) are associated with the longitudinal perturbation to the local boundaries of the hydro-sedimentary cell (Amrouni *et al*., 2007; Amrouni, 2008; Amrouni and Abdeljaouad, 2009).

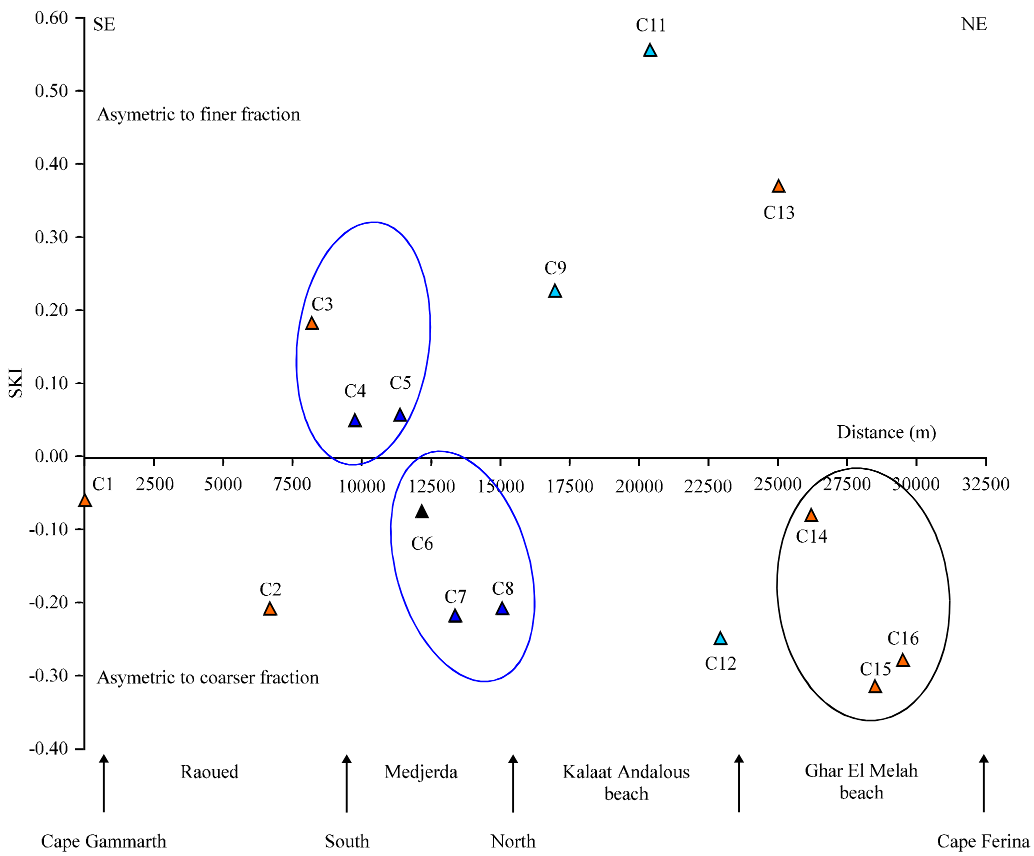

Fig. 7: Longitudinal evolution of skewness index of coastline sample C1-C16 in the Cape Ferina-Cape Gammarth bay (November 2009)

Cross-shore evolution: The sediment located at the 0-1 m depth is characterized by fine to very fine sand which is very well sorted, negatively skewed and with leptokurtic distribution. The samples found in the Ghar El Melah beach and at northern beach of the Medjerda river are related to sandy facies, with medium sand (successively Mz = 1.86 Φ and 1.50 Φ), together with a fine tail (SKI = 0.1 α and 0.18 Φ) and platykurtic distribution. The median grain size decreases toward the lower depth (1-3 m) along the bay. There, the sediment is composed of fine to very fine sand (1.97 Φ<Mz<3.35 Φ) and the distribution is mainly mesokurtic to leptokurtic. However, the sediment remains negatively skewed at the Ghar El Melah and Medjerda beaches.

Subsequently, as the depth increases, the sandy facies becomes finer, that grain size varied between 1.90 to 3.56 Φ and is characterized by poorly sorted sediments that show mesokurtic to leptokurtic and positively skewed distribution. Both in the northern part of the Ghar El Melah and Medjerda beaches, the grain size presents a tendency to increase with depth. These zones are composed of sandy facies, leptokurtic, very well-sorted, with negative skewness. Only in the southern part of Ghar El Melah (E36 at 5.2 m water depth), the sediment is fine, poorly sorted and negatively skewed, with platykurtic distribution, related to a muddy facies.

The cross-shore trend of the nearshore zone (0-6 m) of the Gulf of Tunis has been revealed by several studies (Kouki, 1984; El Arrim, 1996; Saidi, 2004) to be an 'intermediate zone' or 'complex interaction'. In the study zone, the mean grain size decreases with increasing depth, except near the littoral area. This behavior is controlled by the local drift currents and the special marine bar

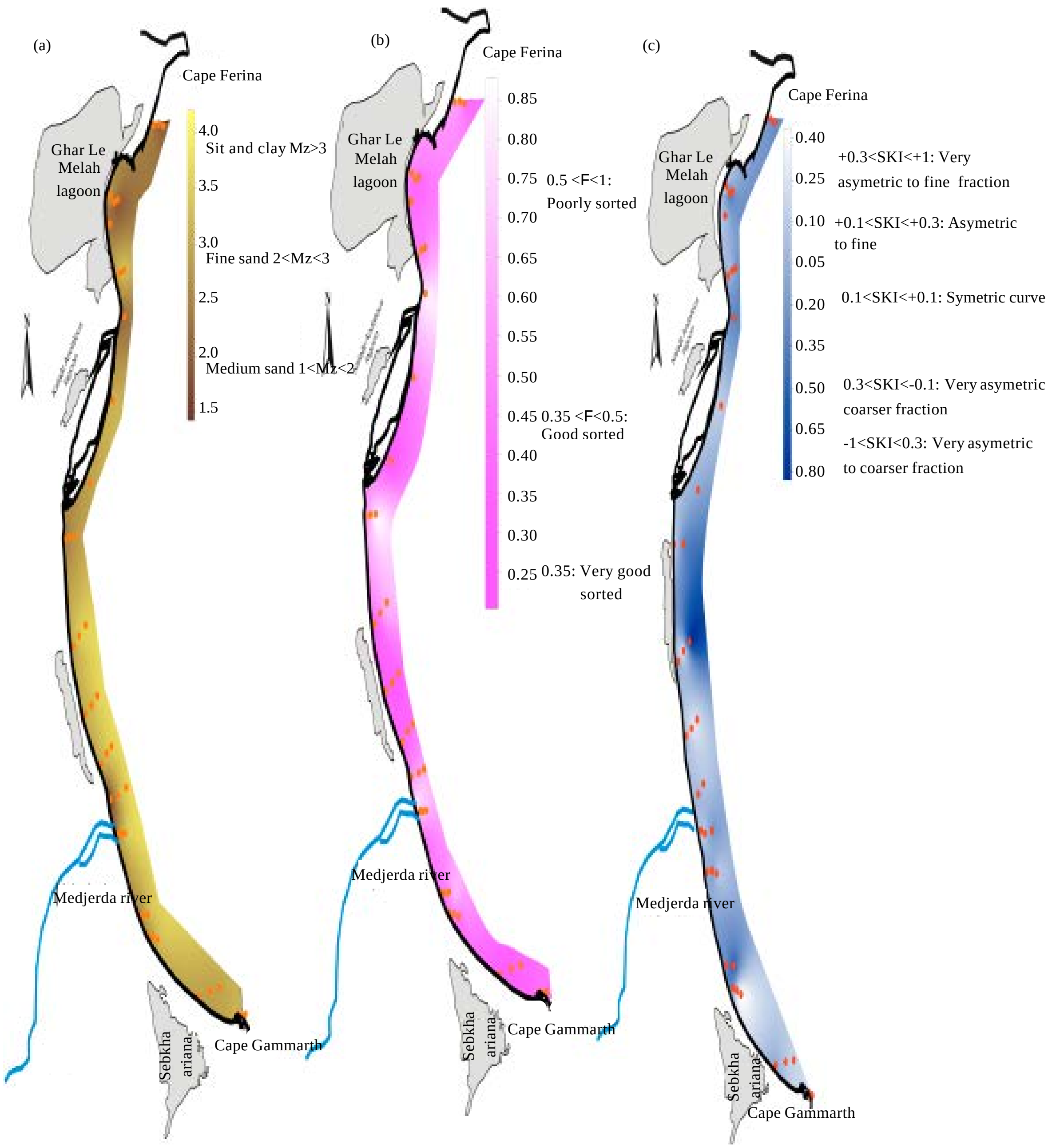

Fig. 8: Transversal grain size evlution of (a) Mz index in the cross shore sample (E1-E45), (b) Sorting evolution σ(E1-E45) and (c) Skewness SKI (E1-E45) in the Cape Gammarth-Cape Ferina bay (November 2009)

morphology, whereas, the sorting and asymmetry trends probably include the most active bar systems (inner and outer bars).

According to the spatial grain size distribution (Fig. 8), the mean grain size distribution appears to decrease from the swash to surf zones. However, the cross-shore trend of the grain size collected between the surf-swash zones, can be subdivided into three compartments across the bay:

- The northern sector, where the medium sand is the dominant fraction, with good sorting and positively skewed
- In the central part of the bay, the sediment is characterized by a fine to very fine fraction, poorly sorted and negatively skewed. The boundaries of the sector are located at the mouth of the Medjerda river
- The southern part is marked by decreasing of the texture to silt and clay, with very good sorting, positively skewed, probably associated with the prodeltaic accumulation.

On the other hand, on the nearshore, the grain-size trend was locally distorted at the river mouth (northern Medjerda), lagoon (Ghar El Melah beach) and harbor structures (Raouad beach). In fact, the sediment was poorly sorted and positively skewed, with a leptokurtic distribution. Coarser material at/or close to the natural and manmade structures (river mouth/sandy spit/breakwater portuary structures) meant that the effect of these local features altered the grain-size distribution from the observed general trend. Also, bimodality distribution was associated with the heterogeneous population that appeared locally which reflected the local cross-shore current.

CONCLUSION

This spatial evolution of the sediment texture of the submarine beach confirms that the morphodynamics of the work sites are characterized by the existence of a bidirectional longshore local drift; (1) From north to south and (2) The seasonal drift from the south east to north west, intersected by a local sedimentary cell which seems to be the factor of the bimodality and mixing of different grain populations observed at the nearshore of the Tunis Gulf.

An abundance of muddy-sand sediment is provided to the Gulf of Tunis from natural sources, such as, rivers and cliffs. According to the grain size investigations, the dimensional structure of the grain size assemblage is interpreted as a mixture of the sources.

However, the grain size tendency of the cross-shore evolution, associated with longitudinal evolution, allows the interpretation of four sedimentary cells separated by natural (river, spit) and human (harbor) barriers (Fig. 9).

Thus, there is a dominant north to south longshore drift associated with the seasonal SE-NW drift. The segmentation of the near beach into cells of littoral circulation is eventually related to the rip-currents created by wave refraction. Unfortunately, the consequence of relative inputs and potential impacts of human activities (such as beach nourishment and harbor dredging), cause an imbalance in the natural sedimentary distribution of sand supply, for example, degradation of the upper beach, coastline retreat surrounding the harbor sectors, contamination of the marine sediment by river discharge and so on.

The gradient of grain size distribution is related to interactions between the different transport processes in the profile as well as the grain sizes available in the littoral zone. Another source of complexity of sediment distribution to the study area is caused by the morphodynamics of the outer and inner bars. However, if a littoral profile is affected by artificial nourishment or the sediment is supplied by natural processes with a different grain size, in comparison to the original deposits, a new grain size distribution has to be established.

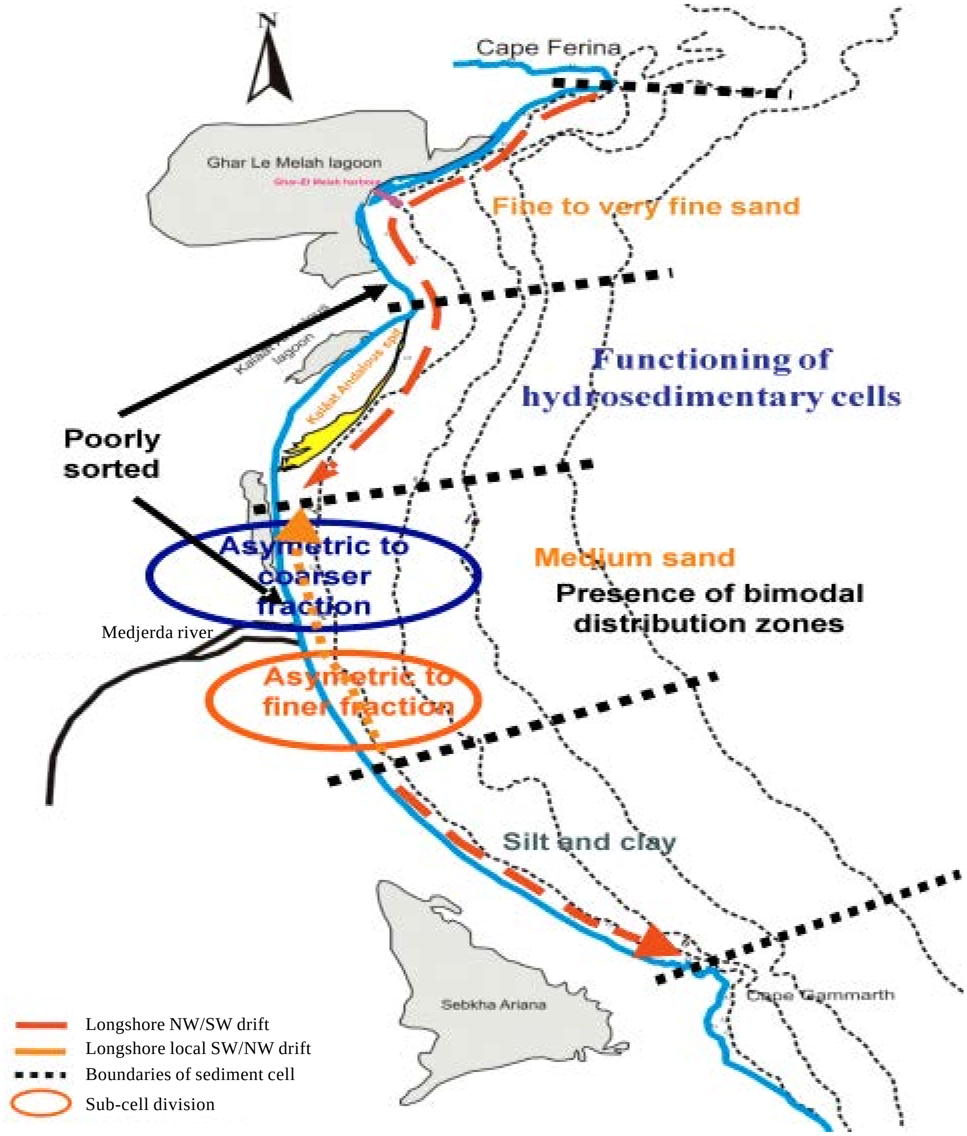

Fig. 9: Sediment cell boundaries: Sediment sinks (spit, delta deposit, lagoon, cliffs), managment structures and littoral drift divides in the Cape Ferina-Cape Gammarth bay

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