CHINESE JOURNAL OF GEOCHEMISTRY Vol. 26 No. 3 2007

DOI: 10.1007/s11631-007-0244-y

Sedimentary dynamics and ecological state of Nakta tidal flat (littoral), South of Sfax, Gulf of Gabès, Tunisia)

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Received June 23, 2006; accepted August 30 , 2006

Abstract The tidal flat of Nakta is located in the northern part of the gulf of Gabes and in the southern coast of Sfax. It corresponds to a flat reef protected from less topography, with a slope ranging between 2° and 4°, which borders the Gargour Wadi. The study sector is renowned to have moderate hydrodynamics which lasts almost for two millenary (^{14}C isotopic dating).

The sedimentological study of the Nakta tidal flat revealed different facies: fine-grained sand in the intertidal zone and carbonated muddy sand in the infratidal zone.

Equilibrium state of the Nakta ecosystem depends entirely on tide currents, which mainly inhibit drift currents. The Nakta tidal flat is characterized by a variety of faunal species (*Cerastoderma glaucum, Arca noe, Cardita antiquatus, Chlamys varied, Ruditapes deccussatus, Tapes rhomboids, Pinctada radiate,* etc.) and floristic diversities (*Halocnemum strobilacum, Halimione portulacoides, Enteromorpha linza, Ulva rigida, Cymodocea nodosa, Posidonia oceanica*). The species are abundant in the infratidal zone, while in its intertidal zone, faunal species remain little diversified and are dominated by limivorous diggering.

The paleogeographic study of the Nakta tidal flat showed the alternation of regression and transgression periods.

Key words littoral; sediment; mineralogy; halophilic species; radiochronology; paleogeography, heavy metal

1 Introduction

The littoral fringe of Sfax belongs to the plateau Sfax-Kerkennah, which corresponds to a platform of the crawls type (Purser, 1983). This sector contains the old Punic City «Thainat» and the old Roman City and Byzantine «Thaenae», and also shelters the urban part of Thyna (Serbagi, 2000).

Several studies, of sedimentological and hydrodynamic nature, were carried out on the coastal environments of the gulf of Gabès (Burollet et al., 1979; Shimi 1980; Paskoff, 1993; Ameri, 1984; Mahmoudi 1986; El Kihel, 1995; Essonni, 1998; Bali, 2002; Amrouni, 2002; Bardi, 2002; Khouildi, 2004; etc). This study will be focused only on the tidal flat of Nakta which is located at the south of the Salina and the complex of the SIAPE (Fig. 1).

It deals with the characteristics of the tidal flat of Nakta with respect to its physiographical, ecological and sedimentological features. The region of Sfax is arid with an average maximum air temperature of 26℃ and an average minimum temperature of 12℃; the highest recorded temperature is 40℃; the average annual rainfall is 82 mm/year. The dominant winds are of East-West sector (Ameri, 1984).

Tides are semidiurnal. Mean spring range is 1.6 m; mean neap range, 0.52 m; and the extreme range 1.8 m. The wave currents precede towards the N-N-W and those of ebb towards the S-S-E. The essential directions of the swell are: north-east, south-east, and south-south-west (Ameri, 1984).

The sandy, clayey and carbonated series watersheds of littoral Sfax are organized according to a Mio-Pliocene and Quaternary stratigraphic successions (Burollet, 1956).

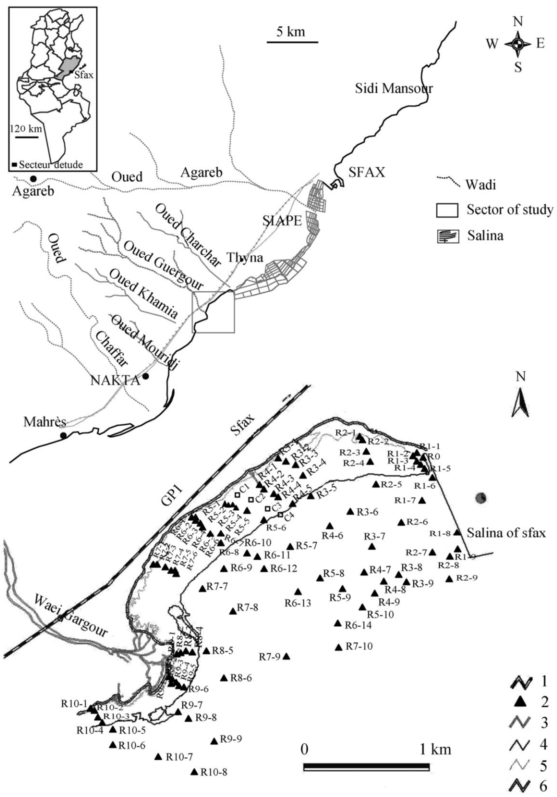

Fig. 1. Map showing the location of the study sector of surfaces and studied cores. 1. Road GP1; 2. localization of the samples; 3. réseaux hydrographique; 4. limit of the infratidal zone; 5. limit enters the intertidal zone and supratidal zone; 6. limit of supratidal zone.

2 Methods of analysis

During this study, the investigation of the study sector was carried out during the periods from spring tides and neap tides. Surface sediment samples were taken using a bucket of the Ekman type. The subsurface sediments were taken by a PVC tube (Φ 75 mm).

Topographic profiles were accomplished by planimetric measurements. These measurements were carried out using an electronic meter with a receiver and a target type " Combo Pro" of an accuracy of 99.5% over distances varying from 60 cm to 75 m.

The principle of altimetry measurements rests on progressive levelling as the diagram indicates it below. We use an automatic machine level of type NAN-2030.

To determine the shape of the field according to various studied profiles, it was necessary to put the machine level many times in stations (S_1, S_2 , S_3 .., S_n. Work was made gradually, the distance being from 50 to 60 m each time (Fig. 2).

The mineralogical study was based on X-ray diffraction analysis on powders in the case of crude

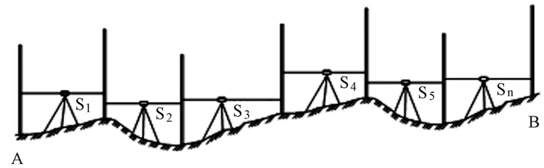

Fig. 2. Principle of walking on levelling.

sediment and on oriented aggregates with cobalt anticathode (CGR 45 tetha).

The dating of carbon ^{14}C has been made on carbonate sediment and was based on the advocated International Atomic Energy Agency (I.A.E.A.) method called spectrometry by liquid scintillation (Fontes, 1971). Radiocarbon ^{14}C measurements have been performed by CO_2 $ß^-$ counting at the Isotope and Palaeoclimatology Laboratory at the E.N.I.S. Sfax, Tunisia.

3 Results and discussion

3.1 Morphology and ecology of the Nakta tidal flat

The topography of the Nakta tidal flat sector is marked by a gentle slope ranging between 2° and 4° (Fig. 3). The topographical surveys and the follow-up of tide movements for the periods of spring tide make it possible to establish the following stages:

(1) The supratidal zone is broader in its northern part and on the side of Gargour Wadi towards the south

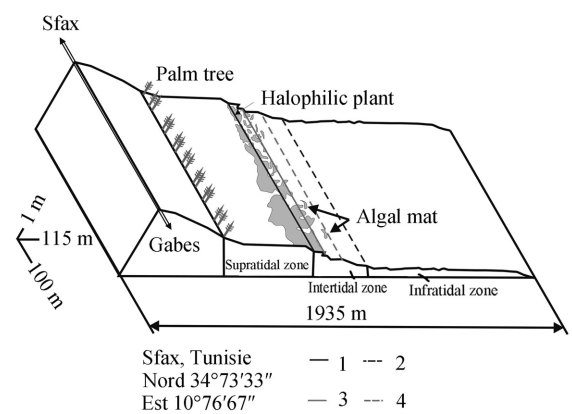

Fig. 3. Profile illustrating the variation of the tide range in the periods of equinoxes and neap tides. 1. High water of spring tide; 2. low water of spring tide; 3. high water of neap tide; 4. low water of neap tide. Maring: 1.8 m with equinox 29/03/2002; 0.52 m with dead water 21/01/2002.

(30 m), and becomes narrower (10 m).

This zone is characterized by the abundance of sand (80%) in surface sediment. Surface of a pond is occupied by clay and sand showing prismatic cracks (15 cm). Cracks of this size appear on the floors of ponds and channels as soon as they are drained, indicating that the shrinkage is a result of dewatering rather than desiccation. In the dry season a sheet of halite covers the sediments.

This zone is colonized by floristic species which tolerate severe conditions of salinity, e.g. *Halocnemum strobilacum* and *Halimione portulacoïdes.*

The fauna of the supra-tidal zone is reduced and is limited to the level of its lower part than digging crabs and annelids with bioturbation trace.

(2) The intertidal zone corresponds to the major part of the tidal flat. The larger tidal range is 100 m and 400 m with a maximum at the time of the spring tide (Fig. 4).

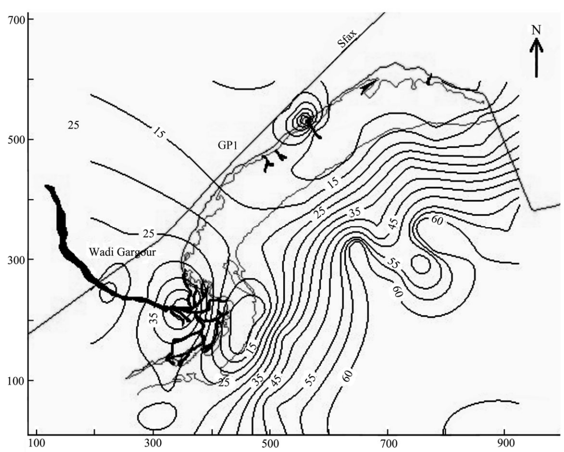

Fig. 4. Map showing the distribution of $CaCO_3$ % in the surface sediments of the Nakta bay.

Halophilic floristic species, primarily *Halocnemum strobilacum* and *Halimione portulacoïde,* are recognized in the higher part of the intertidal zone. This vegetation is partly-entering crossed by tidal channels. The microcliffs or slopes which can reach 1m in height typify the limit of this zone.

Ulva rigida species typical of an intertidal and higher infratidal zone is often associated with *Enteromorpha linza,* witch supports difference in salinity. In the spring tide these algae connect up the tide channels and the Wadis. This zone with strong energy is covered by gastropods (*Turritella*). *Murex* overwhelms the totality of the intertidal zone; they are associated with lamellibranchiata of *Rudutapes* and *Cerastoderma glaucum* genus.

In the limit with the infra-tidal zone appears *Cymodocea nodosa* which is a thermophilic species characteristic of the higher infra-tidal zone, *Cystoceira compressed, Alcidium coralinium, Fragile Codium* and *Polysiphonia lanosa*.

The intertidal zone reveals the presence of some benthic foraminiferae such as *Elphidium (E aculeatum, E crispum), Penoroplis planatus, Massilina secans* (etc) whose majority is badly preserved.

(3) The infratidal zone marks the stage of biodiversity and constitutes the privileged field of *Cymodocea nodosa, Posidonia oceanica* and other phanerogams.

To 300 m of the line of the coast where the seagrasses with *Cymodocea nodosa begins* are relayed towards the broad coast by a mixed herbarium with *Cymodocea* and *Posidonia* (to 800 m of the line of coast). It is associated with other species such as: *Halimida tuna, Cystoseira compressed, fragile Codium,* etc.

This level is marked by the abundance of macrofaunae, where there are increasing lamellibranchiata: *Arca noa, Cardite antiquatus, Clamys varied, Rudutapes decussatus, Tapes rhomboïdes, Pinctada radiata etc,* of the gasteropodae such as *Certhidae Bullidae Gibbulla Murcidae, Conidae,* sea urchins, starfishes, fish and so many cephalopodae.

On the meadow with *Cymodocea* several species of benthic foraminifera proliferate: *Ammonia beccarii, Elphidium (E aculeatum, E crispum), Pénoroplis (P. planatus* and *P. pertusus), Massilina sécans, Spiroloculina antillarum, Spiroloculina ornata*.

In the zone of *Posidonia*, the foraminiferae are generally well preserved, and so diversified: *Buccella granulate, Peneroplidaes (P. planatus etP. pertusus), Discorbis, Sorites variabilis, Massilina secans, Quinqueloculina (Q cliarensis, Q pulchella, Q variolata, Q vulgaris), Triloculina (T rotunda etT. trigonula)* and *Elphidium*.

3.2 Sedimentological study

3.2.1 Lithology

The distribution of grain sizes shows that the sand fraction is concentrated in the supratidal zone (90% on average) and in the intertidal zone (85%). The fine fraction is of wide range and concentrated in the infratidal zone (60%–70%), witch is characterized by less hydrodynamic tidal channel length ranging between 10–50 m and occupied essentially by fine fraction (70%) (Fig. 5).

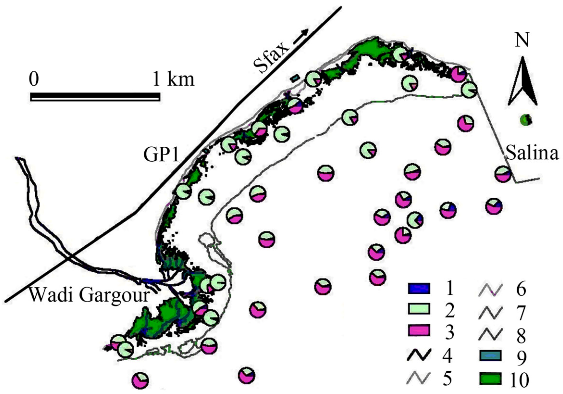

Fig. 5. Map showing the distribution of surface samples of various particle shapes. 1. Fraction>2 mm; 2. 63 μm <fraction<2 mm; 3. fraction<63 μm; 4. network hydrographic; 5. limit of the zone supratidal; 6. limit enters the intertidal zone and supratidal zone; 7. limit of the zone infratidal; 8. Road GP1; 9. treatment plants of the product of the sea; 10. vegetation halophilic.

All surface sediments are carbonated with high rates (60%) in the infratidal zone (Fig. 6). The distribution of different facies depends on energy and hydrodynamics. Lithosequence can be subdivided on four elementary sequences:

(1) Supratidal zone: The core is composed of three levels. Upper sediments which represent horizon 1 (H_1) are composed of fine sand, containing lamellibranchiate (*Loripes lucinalis)* and gastropod (*Turritella communis)*. Horizon 2 (H_2) is composed of medium-grained sand, with quartz, bioclastic and grey-dark and black

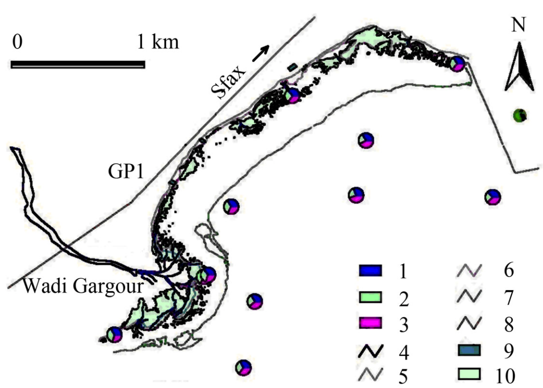

Fig. 6. Map showing the distribution of clay in the tidal flat of Nakta. 1. Kaolinite (%); 2. illite (%); 3. smectite (%); 4. network hydrographic; 5. limit of the zone supratidal; 6. limit enters the intertidal zone and supratidal zone; 7. limit of the zone infratidal; 8. Road GP1; 9. treatment plants of the product of the sea; 10. vegetation halophilic.

extraclasts. The fauna includes lamellibranches and gastropods. The base of the core corresponds to horizon 3 (H_3), which is composed of muddy sand with millimetric and centimetric conglomerate lithoclasts and rounded to sub-round quartz grains cemented by very fine micrite.

(2) Intertidal zone: Two elementary sequences are divided in this zone. The core, C_2, is taken in the superior intertidal zone and is composed of two levels. The bottom of the core corresponds to H_2 as is described in the supratidal zone. It is surmounted by a level (H_4) composed of fine sand with lithoclasts of mudstone texture. Fauna includes fragments of lamellibranchiate and gastropod.

The second core was taken in the intertidal zone with the limit of infratidale zone corresponding to two horizons formed by H_2 at the bottom surmounted by fine sand enriched in silt and clay and fragments of *posodonia oceanica* which corresponds to horizon 5 (H_5).

(3) Infratidal zone: The elementary sequence is formed by the succession of H_2 in the substructure, H_5 at intermediate level and H_4 at the summit.

3.2.2 Sedimentary structures

The sedimentary structures, both physical and organic, reflect a variety of transport processes and they are our most perfect indicators of the types and strengths of currents that transport sediments.

3.2.3 Physical structures

Ripple marks are an indicator of paleenvironment and palegeography, in the Nakta tidal flat there are two types of ripples:

Interferenceripple marks appear primarily at the level of the higher intertidal zone; resulting from the interference between more than one wave set or between waves and currents with divergent directions (Collinson and Thompson, 1984).

Lingoïd ripples usually have asymmetrical profiles with highly sinous crest. They have steeper, concave-upwards lee faces and more gently sloping convex-upwards stoss sides. Such ripples resulted from currents flowing in one direction only. There is, however, a continuum of asymmetrical, current ripples ranging from straight-crested through sinuous-crested to lingoïd in shape (Fig. 7).

3.2.4 Biogenic structures

Fig. 7. Circular holes with central mound produced by -searching flamingoes in the intertidal zone at the level of Gargour.

Fig. 8. Appearing of exhausts of gas and habitat of annelida in the tidal flat of Nakta.

Fig. 9. Algal mat of the intertidal zone at the level of the tidal flat of Nakta.

(1) Algal mat covering the whole of the intertidal zone is presented in lenticular form and interlaminated with sand and mud. Its thickness varies from 5 to 20 cm. These algal constructions are present at their surface of the shrinkage cracks (Fig. 8).

(2) Circular holes, about 0.5 m in diameter with a hill in the middle, are identified especially in the higher intertidal zone. This structure with a central mound is produced by food-searching flamingos (Fig. 9).

(3) Cavities of gas exhaust occupying the entire intertidal zone (Fig. 9).

3.2.5 Granulometry

Sandy facies analysis showed that the grains are fine to very fine in size (Mz =2.5 Φ). Sorting, a measure of the range of grain sizes, generally reflects energy levels in the depositional environment and the stability of those energy conditions over time (Lewis and Mc Conchie, 1994). In this area studied, the sorting (δ) value is 0.35 Φ on average. Sands are always composed of well sorted matrix-free sands because waves continuously winnow fines away, and either coarse concentrates or heavy grains in the highest-energy locales.

3.2.6 Mineralogy

Surface sediments are composed essentially of quartz witch accounts for 95% in the supratidal zone, and only minor feldspars (2%–18%) and carbonates such as magnesian calcite and dolomite in variable proportions with high percentage in the infratidale zone (60%) (Fig. 10).

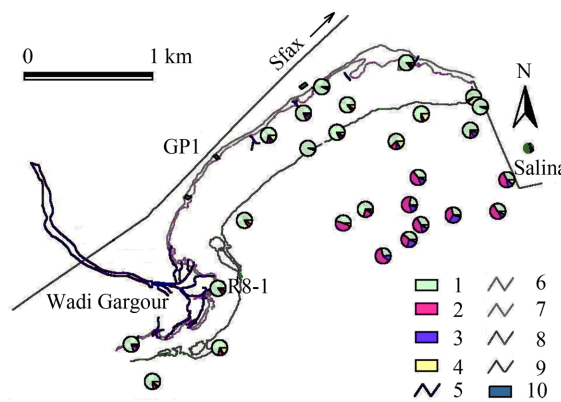

Fig. 10. Mineralogy and distribution of surface samples from the tidal flat of Nakta. 1. Quartz (%); 2. calcite (%); 3. dolomite (%); 4. feldspath (%); 5. network hydrographic; 6. limit of the zone supratidal; 7. limit enters the intertidal zone and supratidal zone; 8. limit of the zone infratidal; 9. Road GP1; 10. treatment plants of the product of the sea.

The argillaceous fraction is composed of kaolinite (31%–37%), illite (23%–37%) and smectite (23%–35%). The maximum level of smectite is determined in the infratidal zone. In contrast illite and kaolinite are concentrated in the intertidal zone (Fig. 11).

3.2.7 Facies distribution

Four cores cover all sector of study [(C_1) in the supratidal zone, (C_2, C_3) in the intertidal zone and (C_4) infratidal zone]. The examination of these cores allowed the recognition of five distinct subfacies (H_1, H_2, H_3,H_4, and H_5) and a varied fauna (Table 1).

H_1 is composed of fine sand and containing lamellibranches and gastropods fragments.

H_2 is present in all cores at the depth ranging to 20 cm to 1 m and is composed of sand and bioclast and associated with lithoclast near the continent. The fauna is composed of marine species according to the ^{14}C dating, approximately 2000 a B.P.

Table 1. Faunistic associations in various cores

Species	*C_{1-1}*	*C_{1-2}*	*C_{1-3}*
Lamellibranchiata	-Remains of Loripes lucinalis	-Loripes lucinalis -Cerastroderma glaucum - Rhuditapes -Jagonia	-Remains of Tapes rhomboedes
Gasteropoda	-Turritella communis	-Conus -Cerithuim vulgatum -Turritella communis	-Turritella communis

Species	*C_{2-1}*	*C_{2-2}*	*C_{2-3}*	*C_{2-4}*
Lamellibranchiata		-Loripes lucinalis	-Loripes lucinalis	-Loripes lucinalis -Cerastroderma glaucum
Gasteropoda	-Remains of Rissoa -Remains of Turritulla communis	-Remains of Eratocyres cypracolo -Remains of Turritulla communis	-Cyclope -Turritella communis	-Cerithuim vulgatum -Territella communis -Nitida

Species	*C_{3-1}*	*C_{3-2}*	*C_{3-3}*
Lamellibranchiata	-Cerastroderma glaucum	-Cerastroderma glaucum -Tapes Rhomboedes	-Remains of Tapes Rhomboedes -Remains of cerastroderma glaucum -Loripes lucinalis
Gasteropoda	-Cerithopsis -Cyclopes cyclonassa -Remains of cerithuim	-Eratocyprea cyproeola -Turritella communis -Conus -Rissoa	-Cerithuim vulgatum -Cerithopsis -Lomida -Conus -Rissoa -Cyclope cyclonassa
Scaphopoda		- Dentalium	-Dentalium

Species	*C_{4-1}*	*C_{4-2}*	*C_{4-3}*	*C_{4-4}*	*C_{4-5}*
Lamellibranchiata	-Cerastroderma glaucum -Remains of Tapes Rhomboedes	-Ceractoderma glaucum	-Loripes lucinalis -Tapes Rhomboedes -Jagonia Reticulata -Mytilus	-Tapes Rhomboedes	-Remains of Tapes Rhomboedes
Gasteropoda	-Cerithopsis -Rissoa	-Bulla striata -Cerithuim vulgatum	-Cerithopsis -Gibbulla -Patella -Bulla -Cerithuim vulgatum -Conus	-Remains of Cerithuim vulgatum -Rissoa -Cerithopsis	-Remains of Cyclope -Rissoa -Cerithopsis
Scaphopoda	-Remains of Dentalium	-Dentalium	-Dentalium	-Remains of Dentalium	-Remains of Dentalium

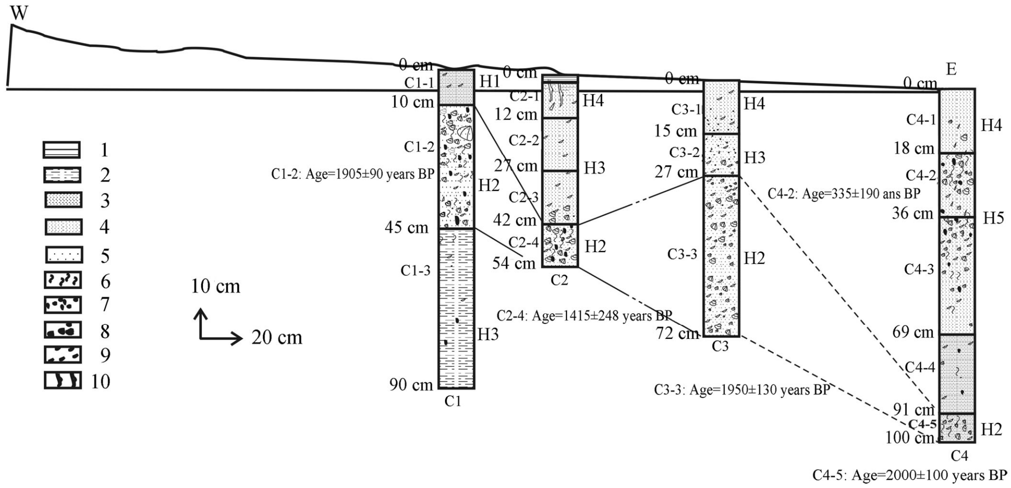

Fig. 11. Vertical and lateral distributions and approximate ages of recent sediments in the bay of Nakta. 1. Algal lamination; 2. mady sand; 3. very fine-grained; 4. fine-grained 5. medium-grained; 6. racines végétales; 7. lithoclast; 8. shell; 9. debris of shell; 10. hole testifying to the oxidation of the organic matter.

H_3 corresponds to fluvial material and is composed of clays and sand associated with lithoclast.

H_4 is composed of sand and silt associated with fine fragments of lamellibranches.

H_5 corresponds to carbonate sandy clay. The fauna included is abundant and diversified and composed essentially of gastropods, lamellibranches and scaphopoda. The age of this facies is 335±190 a B.P.

4 Conclusions

The bay of Nakta is marked by less topography and a distinct subdivision: the supratidal zone, the intertidal zone and the infratidale zone.

This zonation is marked by an increase in fine granulometry in the infratidale zone. This granulometrical evolution is controlled by hydrodynamique.

The abundance of the fine fraction in the channels is the result of decantation at low tide. The high percentages of detrital elements in this sector of study are due to:

(1) Drainage of mineral clay and quartz and feldspars by the Wadi Gargour (the principal source of detrital contribution).

(2) Mixing of detritic particles in the intertidal zone under the action of tidal courant.

The paleogeographic study of the Nakta tidal flat showed the alternation between regression and transgression periods.

Horizon H_2 corresponds to the last transgression period which attains the supratidal zone and lasts until 2 thousands years BP.

The lower horizon of the core C_1 is composed of fine sandy facies with lithoclasts, indicating continental origin and the level of the progradation of the continent.

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