

## TWO TYRRHENIAN TRANSGRESSIVE CYCLES IN COASTAL DEPOSITS OF THE CAP BON PENINSULA, TUNISIA

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### RÉSUMÉ

A sedimentological and fauna analysis of Quaternary deposits at two sites located on the south-eastern littoral of the Cap Bon peninsula (Tunisia) provides new details about sea-level changes. Two shallowing-upward sequences separated by an erosion surface occur above the present sea level at several locations along the south-eastern shoreline of Cap Bon peninsula. Each sequence has a distinctive sedimentology and fauna content. The older one is especially rich in quartz grains and lithic fragments and is associated with shallow marine fauna in the lower member which would indicate a high relative sea level. The younger sequence is dominated by carbonates such as pellets, oolites and mollusk fragments. The fauna of its lower marine member is rich in "Senegalian fauna" such as the *Strombus bubonius* LAMARCK. This biomarker, revealed at other locations in Tunisia (e.g., Sahel region, Jorf and Jerba Island) and at many sites around the Mediterranean Basin (Spain, France, Italy, Greece, Lebanon, and Egypt), indicates warm sea water. Both units include paleosols, colluviums and dunal members indicating respectively a wet phase followed by a drier phase. The vertebrate fauna discovered in the dunal deposits of the carbonate unit provides more information on the development of a savannah occurring with trees in the Cap Bon land at the post-Tyrrhenian.

**Keys-words:** Tunisia, Cap Bon peninsula, Quaternary, Upper Pleistocene, littoral deposits, lithostratigraphy, fauna content.

### ABSTRACT

#### DEUX CYCLES TRANSGRESSIFS TYRRHÉNIENS DANS LES DÉPÔTS CÔTIERS DE LA PÉNINSULE DU CAP BON, TUNISIE

Une analyse sédimentologique et faunistique détaillée des dépôts quaternaires de sites situés sur le littoral oriental de la péninsule du Cap Bon (Tunisie) fournissent de nouvelles informations sur les environnements et les variations du niveau marin au Tyrrhénien à l'échelle de la région et à l'échelle de la Méditerranée. Ces dépôts sont organisés en deux séquences de type « shallowing-up », débutant par un terme marin et se terminant par un terme continental. Ces deux séquences sont séparées par une discontinuité majeure caractérisée par une surface d'érosion. Elles sont toutefois distinctes par leur cortège lithologique et faunistique. Ainsi, la séquence la plus ancienne est nettement plus riche en éléments détritiques (grains de quartz, lithoclastes, ...). Son terme marin contient une riche faune marine littorale peu profonde dominée par *Cardium edule* LINNE, *Cardium tuberculatum* LINNE et *Cardium exiguum* GMELIN. Son terme continental, peu développé, est représenté par des dépôts dunaires. La séquence la plus récente est composée essentiellement d'éléments carbonatés tel que les oolites, les pellets et les débris de mollusques variés. Son terme marin est riche en faune sénégalaise de mer chaude caractérisée par *Strombus bubonius* LAMARCK. Son terme continental est représenté par des dépôts dunaires remarquablement développés et riches en oolites et en pellets. Ce contraste bio-sédimentaire est déterminé par un réchauffement climatique permettant l'expansion de la faune sénégalaise à strombes en Méditerranée dont les traces sont retrouvées notamment en Espagne, France, Italie, Grèce, Egypte, Liban et en Tunisie dans l'ensemble de son littoral de Bizerte à Jerba. Dans le secteur de Menzel Temime, les séquences comportent dans leurs termes continentaux des paléosols, des colluvions et des dunes nous renseignant sur le développement dans ce secteur d'épisodes humides entrecoupant une période à climat chaud et sec. Dans le secteur de Qorba, la partie sommitale des dépôts dunaires oolithiques contient une riche faune de vertébrés présentant une adaptation à des biotopes ouverts et particulièrement secs et indiquant ainsi que le climat vers la fin du Tyrrhénien est encore chaud. La série quaternaire étudiée est coiffée par une croûte calcaire de type zonal.

**Mots-clés :** Tunisie, Cap Bon, Quaternaire, Pléistocène supérieur, dépôts littoraux, lithostratigraphie, faune.

### 1 - INTRODUCTION

Quaternary coastal deposits are well studied at many localities around the Mediterranean Basin, especially in Spain (Zazo & Goy, 1989), France (Malatesta & Zarlenga, 1988), Italy (Balescu *et al.*, 1997; Kindler *et al.*, 1997; Antonioli *et al.*, 1999), Greece (Collier & Thompson, 1991; Caron *et al.*, 1998; Keraudren *et al.*, 2000), Lebanon (Sanlaville, 1980), Israel (Sivan *et al.*, 1999), Egypt

(Hegab *et al.*, 1995) and Tunisia (Castany, 1954; Paskoff & Sanlaville, 1983; Oueslati *et al.*, 1994). The deposits include the biomarker *Strombus bubonius* LAMARCK and other species of the "Senegalian fauna" attributed to the transgressive Tyrrhenian phase (Gignoux, 1911; Issel, 1914). Such a "Senegalian fauna" indicates a warm shallow marine environment (Moret, 1958).

In Tunisia, Quaternary littoral deposits outcrop parallel to the present shoreline, overlain Miocene, Pliocene and

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Villafranchian deposits and their base underlines a major unconformity. Many authors have been interested in these deposits, especially those exposed along the shoreline from the Sahel (Central Tunisia) through Jerba Island (Castany, 1955, 1956; Paskoff & Sanlaville, 1976, 1977, 1978; Mahmoudi, 1986, 1988; Jedoui, 2000; Jedoui *et al.*, 2001; Le Guern, 2005).

Paskoff and Sanlaville (1976, 1977) first defined three main Formations in Central Tunisia, based on the lithology:

- the Douira Formation, outcrops locally near the village of the Douira in the Sahel area at 15-20 m above the present sea level. It is made up of coarse to fine shelly sands and conglomerate.

- the Rejiche Formation well exposed 10 m above the present sea level is made up of two members. The lower member contains coarse-grained calcareous sandstone, rich in shallow marine fauna, especially the Tyrrhenian biomarker *Strombus bubonius* LAMARCK species. The upper member is composed of consolidated carbonate sand rich in oolites and pellets.

- the Chebba Formation, composed of conglomerates and broken mollusk shells, including *Strombus bubonius* LAMARCK.

Mahmoudi (1986, 1988) subsequently subdivided the Quaternary deposits outcropping in the Sahel region into three lithological units (tab.1):

- the Douira Unit, which corresponds to the Douira Formation;

- the Khniss Unit subdivided into three members: the lower member characterized by coarse sand rich in shallow marine shells, the medium member consisting of

fine sand rich in mollusks and the upper member composed of consolidated quartzous sediments.

- the Rejiche Unit in which he associated the Rejiche Formation and the Chebba Formation previously defined by Paskoff and Sanlaville (1976).

Recently, Jedoui (2000), working on Jorf Peninsula and Jerba Island, identified two distinct lithostratigraphic units (tab.1) in the Quaternary deposits, separated by an erosion surface:

- the lower quartzous unit is fine-grained bioclastic quartz-rich sand, locally overlain by thin maerl layers containing benthic foraminifera and ostracods. These deposits locally display a well-developed aeolian facies that ends the sedimentary sequence. Jedoui correlated this quartzous unit with the Khniss unit defined by Mahmoudi (1988).

- the upper unit is carbonate-rich and is more widespread than the underlying quartzous unit. It consists of slightly consolidated carbonate sand, rich in oolites and pellets, where the “Senegalian fauna”, including *Strombus bubonius* LAMARCK, is well preserved. This unit displays a remarkable shallowing-upward sequence from shoreface to aeolian dunes. It is considered to be the lateral equivalent of the stratigraphic unit of Rejiche in Central Tunisia.

The Cap Bon area forms a peninsula trending NE-SW which is 35 km wide and 64 km long and is located in north-eastern Tunisia (fig. 1). It is approximately 140 km from Sicily. These two neighbouring lands are separated by the Sicilian strait, allowing the present communica-

(Paskoff & Sanlaville, 1976 ; 1977)	Mahmoudi, 1988	Jedoui, 2000	Present paper	
Chebba Formation	Rejiche unit	Upper unit Carbonate unit	Carbonate unit	Paleosol B <sub>V</sub>
Rejiche Formation				Calcrete B <sub>IV</sub>
				Coastal dune B <sub>III</sub>
				Colluvium B <sub>II</sub>
				Marine member B <sub>I</sub>
	Khniss unit	Lower unit Quartzous unit	Quartzous unit	Coastal dune A <sub>III</sub>
Douira Formation	Douira unit			Paleosol A <sub>II</sub>
				Marine member A <sub>I</sub>

**Tab. 1: Correlation between the different formations and units identified in the Quaternary of Tunisia.**

Tab. 1 : Corrélation entre les différentes formations et unités sédimentaires identifiées dans le Quaternaire tunisien.

tion between the southern Mediterranean sea and the Tyrrhenian sea.

The Quaternary deposits of the Cap Bon Peninsula remain poorly investigated (Fournet, 1981; Kchouk, 1982; Bonvallot & Paskoff, 1983). The last interglacial (Tyrrhenian, isotopic stage 5) deposits are widespread along all the south-eastern and the eastern shoreline of the Cap Bon peninsula. The aim of the present work is to provide additional sedimentological and palaeontological data, to describe their stratigraphical succession, to reconstitute the environmental conditions under which the deposits were formed and to compare them with contemporaneous coastal deposits described in the Mediterranean Basin.

This study focuses on Quaternary deposits present on the eastern (NE- SW) shoreline of the Cap Bon peninsula. Among the sections, five are detailed at Qorba and Menzel Temime regions.

## 2 - LITHOLOGY AND FAUNA CONTENT

Deep quarries recently excavated in the Quaternary deposits offer good outcrop conditions. Several lateral and vertical profiles were studied, although Tyrrhenian

deposits were rather complex and required serial stratigraphical logging.

### 2.1 - MENZEL TEMIME OUTCROPS

In the Menzel Temime area, quarries excavated near Sidi Salem Necropolis allow for the analysis of the Quaternary series along one kilometre length parallel to the present shoreline. Three serial sections (MT1, MT2 and MT3) provide a clear idea on the spatio-temporal lay-out of the different facies (fig.2).

#### 2.1.1 – Menzel Temime section 1 (MT1)

The Quaternary series exposed on the north-eastern side of the quarry is composed of two main units (fig. 2) unequally developed: the quartzous and the carbonate units.

#### *The quartzous unit*

This unit is made up of three members ( $A_1$  to  $A_{III}$ ).

– The lower member  $A_1$  is locally observed on the northern side of the quarry. It consists of pale brown quartzous sands including thin shelly layers rich in

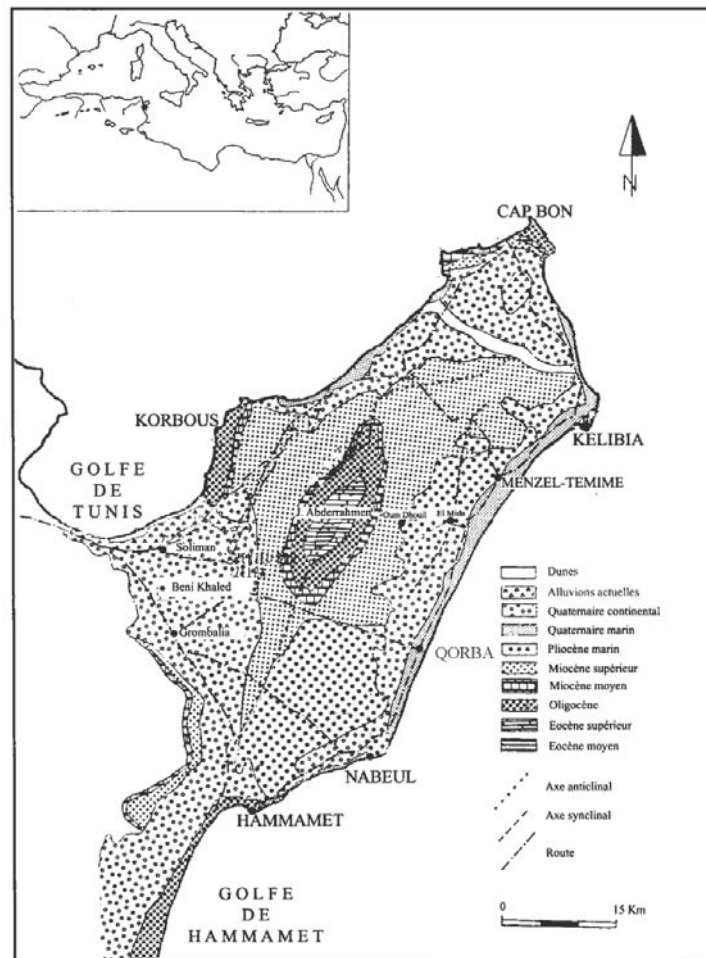


Fig. 1: Geological setting of the Cap Bon area from the geological map data of Tunisia (scale 1/500000; ONM Publisher, 1987).

Fig. 1 : Cadre géologique de la péninsule du Cap Bon établi à partir de la carte géologique de la Tunisie (échelle 1/50000 ; ONM Editions, 1987).

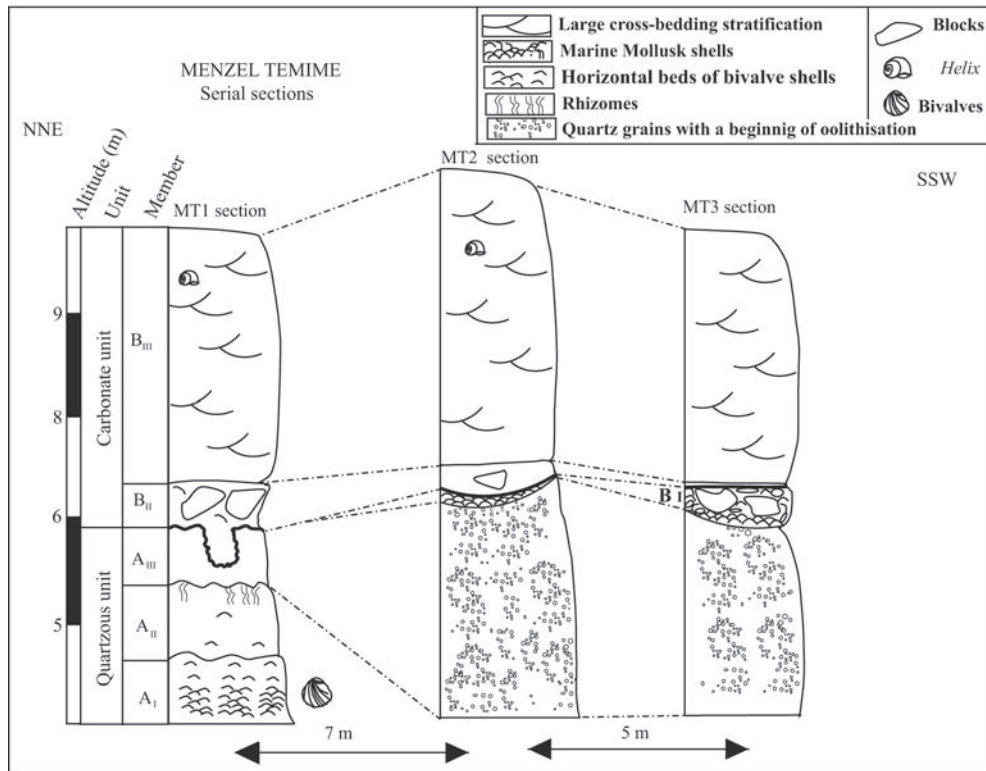


Fig. 2: Menzel Temime sections (MT1, MT2 and MT3).

Fig. 2: Coupes de Temime Menzel (MT1, MT2 et MT3).

marine fauna. The sandy fraction is very homogeneous and contains predominantly quartz (80 %) associated with a biogenic fraction of echinoids (isolated plates and spines) and mollusk debris. The quartzous sands are very well sorted, the modal grain size being 160  $\mu\text{m}$ . The total carbonate content does not exceed 20 % and is originated from the rare shell debris. The quartz grains morphoscopy shows a predominance of sub-angular and blunt grains. The fauna is diversified with the most dominant species being endobenthic such as: *Cardium edule* LINNE, *Cardium tuberculatum* LINNE, *Cardium exiguum* GMELIN, *Loripes lacteus* LINNE, *Tellina planata* LINNE, *Donax trunculus* LINNE. The less frequent endobenthic fauna are composed of bivalves *Glycymeris violacescens* LAMARCK, *Glycymeris insubricus* BROCCHI, *Meretrix subnitidula* D'ORBIGNY, *Meretrix rudis* POLI, *Dosinia lactea*, *Solen ensis* LINNE, *Solencurtus strigialitus* LINNE, *Donax trunculus*, LINNE, *Tapes rhomboides* PEN, *Venus galina* LINNE, *Venus multilamella* LAMARCK, *Venus verrucosa* LINNE and endobenthic gastropods (*Nassa mutabilis* LINNE, *Nassa reticulata* LINNE, *Cyclonassa neritea* LINNE) and Echinoids (*Echinocardium cordatum*). This endofauna is associated with the rare epifauna of gastropods (*Cerithium vulgatum* BRUG), bivalves (*Pecten jacobaeus* LINNE) and Crustacea (*Balanus* sp.). The epibenthic species, which correspond to coarse, sandy and gravely or rocky edaphic conditions, show their allochthonous character and the reworking of these deposits. The fact that the major bivalve shells have closed valves and also have a horizontal bed distribution demonstrates the presence of a calm marine environ-

ment-far from wave action. All of these criteria are characteristic of a protected shallow marine bay. In fact, the high frequency of joined valves and complete mollusk shells is typical of autochthonous fauna rather than a storm shell accumulation.

These marine deposits identified in the large quarry located between Sidi Salem and Sidi Ahmed at Menzel Temime may be correlated to the lower part of the Khniss Unit as defined by Mahmoudi (1988) and with the Douira Formation defined by Paskoff & Sanlaville (1976).

– The middle member, A<sub>II</sub>, contains yellow-red limono-quartzous deposits, in which the sandy grains are slightly cemented. The upper part is rich in tubular rhizomes. This member is interpreted as a palaeosol showing pedobioturbation of its uppermost bed by rhizomes and demonstrates the presence of wet environmental conditions. Of the three samples successively gathered from the base, the middle and the top of this member were analyzed. In each of them, the sandy particles are homogeneous. However, there is a progressive decrease in shell debris from the bottom to the top.

– The upper member, A<sub>III</sub>, is also observed in the eastern part of the quarry. It consists of a pink (5 YR 8/1) quartzous sand that is moderately consolidated and contains no fossils. This member is affected by a very irregular erosion surface corresponding to an important unconformity.

#### The carbonate unit B

Between the quartzous unit and the carbonate unit, an irregular erosion unconformity is observed. Such an



unconformity is well developed in the section (MT1) where the carbonate unit starts from the second member B<sub>II</sub>. Towards the SW section of the quarry, in the other sections (MT2, MT3), the unconformity is poorly expressed and the complete carbonate unit is composed of three members.

– In the MT1 section, the second member, B<sub>II</sub> consists of a yellow- red sandy matrix linking angular white blocks originating from the underlying member A<sub>III</sub> of the lower quartzous unit. The angular blocks are heterometric in size (15-20 cm) and illustrate a chaotic orientation. This matrix is less rich in quartz grains than the blocks and contains in its uppermost part a few pellets and oolites. With a carbonate content reaching 80 %, such deposits with their grain sizes and organization and their inherited material and colour suggest colluvium.

– The B<sub>II</sub> member is overlain by 3 m thick B<sub>III</sub> member composed of a white (2,5 YR 9/0) carbonate sandy deposit rich in oolites and pellets. This upper member records dense, well-preserved and large-scale cross-stratifications. These stratifications testify the eolian origin of these deposits.

### 2.1.2 – MENZEL TEMINE section 2 (MT2)

Half way into the quarry toward the southwest and 7 m far from MT1 section, the MT2 section is incompletely exposed and shows some lateral changes within the Quaternary series (fig.2).

– The MT2 section starts with the upper member A<sub>III</sub> of the quartzous unit composed of quartzous sand in which the quartz grains show a beginning of oolithisation. It contains rare shell debris.

– The upper member of the quartzous unit is overlain by a well developed carbonate unit where a thin layer of reddish sand is observed at its base rich in mollusk shells, especially *Purpura haemastoma* BRUG, *Cardium tuberculatum* LINNE, *Murex trunculus* LINNE, *Cassidulinia undulata* GMELIN and *Solen ensis* LINNE. This thin layer corresponds to the relict of the B<sub>I</sub> member which is better developed towards the southwest. Its shallow marine fauna nature makes it similar to the marine member of the Rejiche Formation (Paskoff & Sanlaville, 1980).

– The medium member of the carbonate unit B<sub>II</sub> consists of reddish sands including some blocks of lithified sand material originating from the underlying unit. These blocks are similar to those observed in the medium member of the carbonate unit in the MT1 section. The blocks are angular and mainly quartzous and are often surrounded by a thin layer of altered material. Their angular shape confirms their brief transport. This member is more reduced toward the southwest where it became block free and consists of thin shelly sandy layers. It also contains a diversified marine fauna such as *Cardium tuberculatum* LINNE, *Glycymeris violaceus* LAMARCK, *Pecten jacobaeus* LINNE, *Ostrea sp.*, *Solen ensis* LINNE, *Purpura haemastoma* BRUG.

– The upper member, B<sub>III</sub>, of the carbonate unit is 3 m thick and contains sands that show good sorting (S<sub>0</sub>=1.2).

These deposits are rich in pellets, oolites and quartz grains where large cross bedding stratifications are frequent. This member is the most laterally expanded in the quarry and has high carbonate content (80 % in average). These oolites and pellet-rich sands are weakly cemented. Their large scale cross bedded stratification is typical of an eolianite backshore environment. Moreover they also contain a few well preserved shells of continental gastropods such as *Helix melanostoma* Draparnaud.

### 2.1.3 – MENZEL TEMINE section 3 (MT3)

Further to the southwest, the MT3 section exhibits an incomplete Quaternary series as well (fig.2). Only the upper member, A<sub>III</sub>, of the quartzous unit is preserved and is similar to that observed at the MT1 and MT2 sections (fig.2). The carbonate unit is better exposed and it exhibits the B<sub>I</sub>, B<sub>II</sub> and B<sub>III</sub> members.

– The lower member, B<sub>I</sub>, is composed of rounded and flattened pebbles varying from a few centimetres to 10 cm in size, that are commonly perforated by saccate mollusks. It contains several white blocks produced by the demolition of the underlying sandy deposits. The blocks have a chaotic orientation and their size varies from 10 to 20 cm. Therefore, they are similar to those observed in the member B<sub>II</sub> towards the NE in the MT1 and MT2 sections. This pebble rich member preserves diversified marine mollusk species such as *Cardium tuberculatum* LINNE, *Glycymeris violaceus* LAMARCK, *Pecten jacobaeus* LINNE, *Ostrea sp.*, *Solen ensis* LINNE and *Purpura haemastoma* BRUG.

– The pebble member is overlain by a thin, fine sandy layer which substitutes the colluvial deposits of the B<sub>II</sub> member in a lateral formation, observed at the MT1 and MT2 sections.

– The upper member, B<sub>III</sub>, of the carbonate unit is well-developed in the Menzel Temime area. It is also rich in oolites and pellets- preserving large scale cross stratifications.

Globally in the Menzel Temime area, the Quaternary deposits are composed of two lithostratigraphical units: the lower unit which is better exposed towards the south-east of the quarry is quartzous. Its lower member is rich in marine mollusks and contains no Senegalian species. The matrix of this member is mainly composed of highly fragmented shells. The upper unit is carbonated and rich in oolites and pellets. Its lower member has no *Strombus bubonius* LAMARCK, but it is rich in other species of the “Senegalian fauna” such as *Purpura haemastoma* BRUG and *Cassidulinia undulata* GMELIN.

## 2.2 - QORBA OUTCROPS

At about 25 km southwest of Menzel Temime, the Quaternary deposits of Qorba are well-exposed in the quarries. Their facies show lateral changes and two out of eight sections are investigated in this study (fig.3). The Q1 section exhibits a complete Quaternary series; the Q2 section is displayed near the national road Qorba-Menzel Temime.

### 2.2.1 - QORBA section 1 (Q1)

The quarry exhibiting the Q1 section of the Quaternary series is 1 km away from Qorba towards Menzel Temime. The oldest bed of this series is 3 m above the present sea level. This bed is part of the quartzous unit which contains two members.

– The lower member, A<sub>I</sub>, about 7 m thick, is composed of pale-brown quartzous and well-sorted cemented sands where the frequent quartz grains (78 %) are associated with rare carbonate biogenic debris, consisting of Echinoids and mollusks. The morphoscopic analysis of quartz shows a predominance of sub-angular and blunt grains. It contains thin shelly layers which are slightly cemented and rich in marine fossils-preserving sets of plane parallel laminae. The well preserved and weakly diversified fauna is mainly composed of bivalves: *Cardium tuberculatum* LINNE, *Cardium exiguum* LINNE, *Cardium edule* LINNE, *Glycymeris violascens* LAMARCK, *Donax trunculus* LINNE, *Arca noe* LINNE and gastropods: *Purpura haemastoma* BRUG, *Nassa mutabilis* LINNE and *Cassis undulata* GMELIN. Some of these bivalve shells are closed valves, while the others show convexity upward. In the lower part of this member the shells are small in size and

well sorted. They may be organized in centimetric sub-horizontal layers in which the shells are agglomerated or sparse, but often well preserved with complete shells. Therefore, their pattern and well preserved nature suggests that a shallow marine biocoenose has been weakly transported; the waves occur in a calm, shallow marine environment which prevails in a protected coastal bay. The shallow marine character of the member, A<sub>I</sub>, recalls the lower part of the Khniss unit that occurs towards the south (Mahmoudi, 1988; Jedoui, 2000; Jedoui *et al.*, 2001).

– However, the palaeosol developed in the Menzel Temime area is absent. Hence, the marine member is immediately overlain by uncemented quartzous sand, devoid of oolites and pellets which is similar to the A<sub>III</sub> member developed at the Menzel Temime area. The calcimetric analysis and endoscopic observation of these sand types reveal the predominance of quartzous grains over bioclastic fragments (mollusks, echinoid). This sedimentary facies suggests that a coastal dune was developed in the Qorba area during a regressive event.

– The lowest member of the carbonate unit, B<sub>I</sub>, never exceeds 2m in thickness and is composed of carbonate oolitic-pelloidal sands, rich in diversified shallow marine mollusks with the typical senegalian marker

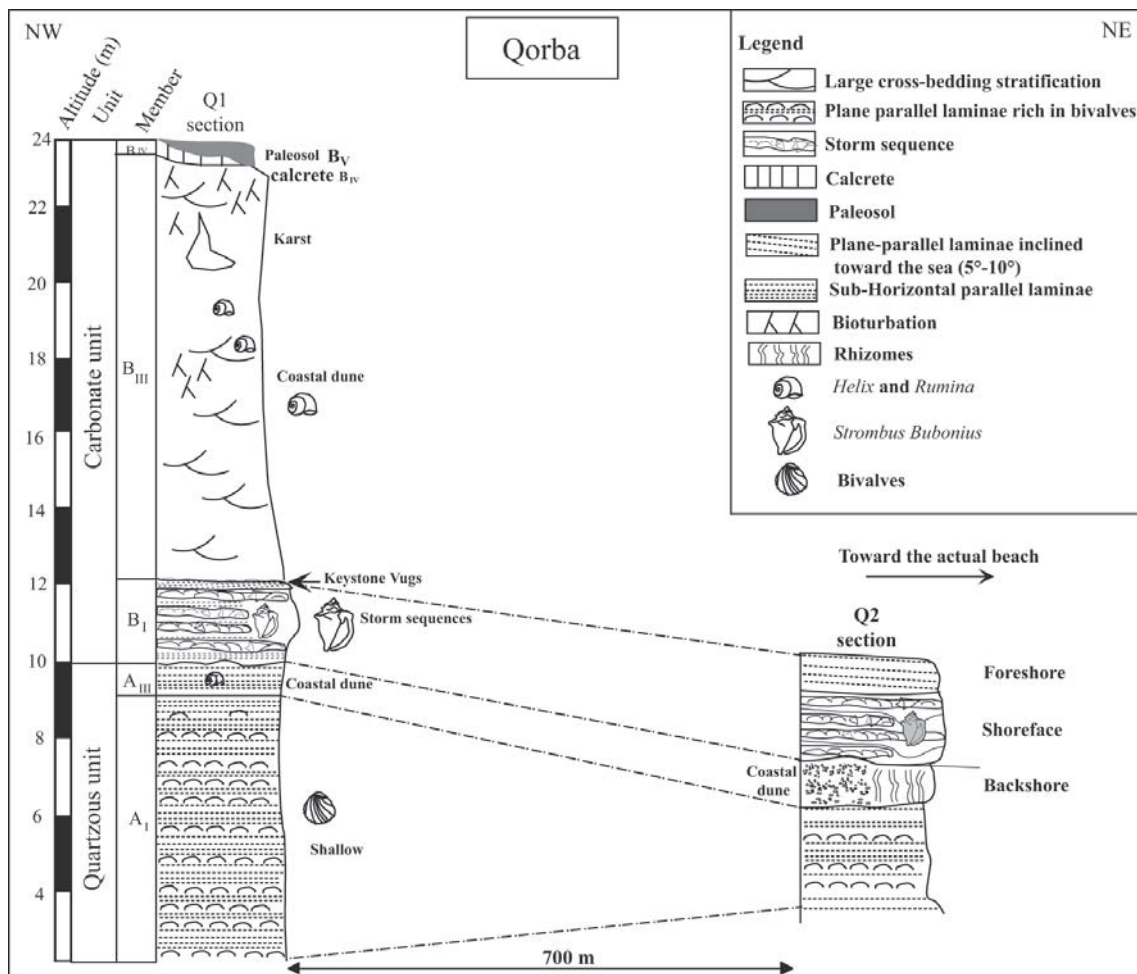


Fig. 3: Qorba sections (Q1 and Q2).

Fig. 3 : Coupes de Qorba (Q1 et Q2).



species such as *Strombus bubonius* LAMARCK and *Purpura haemastoma* BRUG (fig. 4 A). This widespread marine member is well-exposed at many sites parallel to the eastern shoreline (e.g., Tazerka, Qorba, Lebna and Menzel Temime). There the bioclastic elements are mainly composed of algae, echinoids isolated plates and spines, bryozoans and mollusk debris. These bioclasts range from sparse to agglomerate and are more abundant than the quartz grains. The marine-green (e.g. Caulerpale) and red algae (e.g. Corallinaceae) (fig. 4 B) are frequent in this member. The  $\alpha$  typed oolites (Purser, 1980) are dominant (fig. 4 C) and are associated with pellets, pelletoids and aggregates with the presence of few lithoclasts. They are composed of quartzous material and carbonate grains with oolites and pellets.

At Qorba, the lower member of the carbonate unit may be organized into four distal storm sequences topped by sets of plane-parallel laminae inclined weakly towards the sea. Laterally, 1 km inland from the coastline and 10 m above the present sea level, cemented calcarenites preserving beach fenestral porosity (keystone vugs) are found in the top of the lower member, suggesting upper foreshore deposits. Moreover, subtidal Crustacea burrows are locally preserved in this lower member where the deposit laminations are clearly disturbed by crabs. Based on the large occurrence of *Strombus bubonius* LAMARCK shells, this member is attributed to the Eu-Tyrrhenian (isotopic substage 5e). This member has been affected by a few syndimentary normal faults, which generated lateral facies changes.

– This shallow marine member is overlain by carbonate rich sand containing oolites and pellets of the B<sub>III</sub> member, which outcrops up to 12 m above the present sea level. It is 12 m thick and is composed of ooid-peloid particles, associated with detrital grains (heavy minerals and quartz). These sandy deposits preserve large and well-developed cross bedding laminations and contain continental gastropods of *Helix* and *Rumina* species. Laterally, the cross-stratification of these coastal dune deposits has been partially destroyed by insect burrows and root bioturbations. Moreover, the upper part is excavated by a karst. This latter contains higher mammals with the vertebrates being composed of at least six species: *Equus mauritanicus* POMEL, *Alcelaphus buse-laphus* PALLAS, *Gazella atlantica* BOURGUINAT, *Phacochoerus aethiopicus* PALLAS, *Ceratherium simum* BURCHELL (Chakroun *et al.*, 2005).

– These dune deposits are overlain by a zonal calcrete, B<sub>IV</sub>, that was developed during a warm and dry climate. Reddish sands, B<sub>V</sub>, end the Quaternary series at the Q1 section. They are rich in ferruginous carbonate concretions and quartz grains, and may contain helicidae (*Helix* and *Rumina*). Such deposits invoke palaeosol developed during the post-Tyrrhenian sea level low stand (glacial period) and rainy climate. The palaeosol is correlated to the Nahlieli member observed in Israel which overlies the Yasaf member rich in *Strombus bubonius* LAMARCK (Sivan *et al.*, 1999). This kind of palaeosol is called Hamra which is equivalent to Terra Rossa.

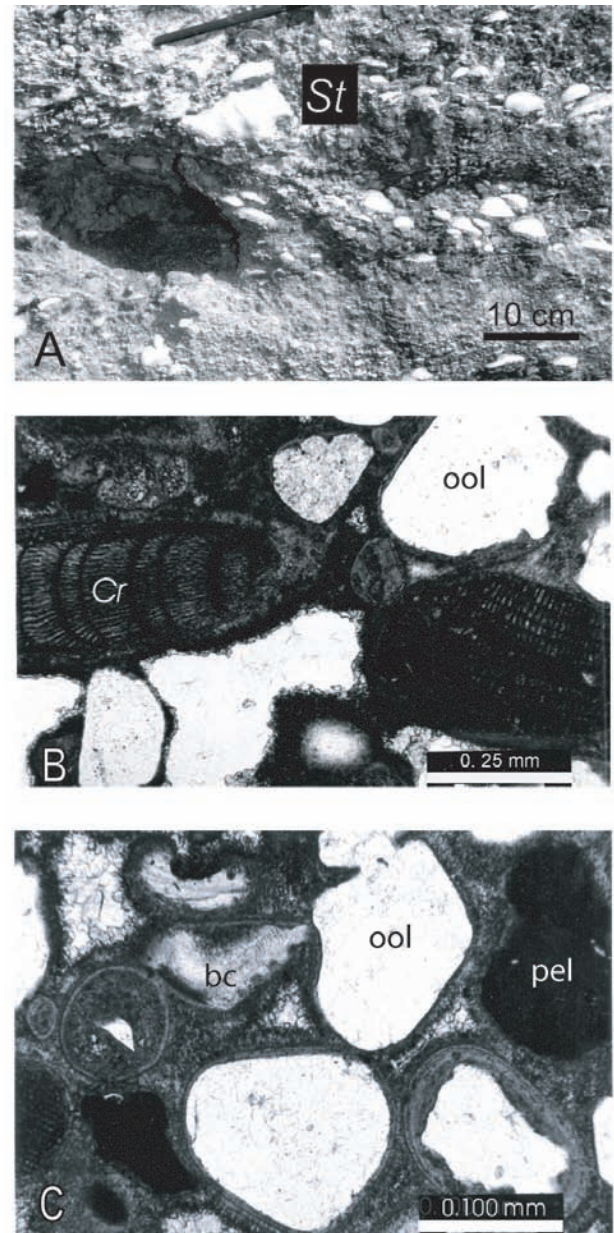


Fig. 4: A. The member B<sub>I</sub> in the field, at Qorba (section Q2), rich in diversified shallow marine mollusks with the typical senegalian biomarker species: *Strombus bubonius* LAMARCK (St). B and C. Thin sections observed by normal transmitted light from STR 14 et STR 18 gathered across the member B<sub>I</sub> of Q2 section. B. In the sample STR 14 calcarenite grainstone rich in red alga (Corallinaceae: Cr) and oolites (ool). C. In the sample STR 18 calcarenite grainstone rich in sub-spheric oolites (ool), pelletoids (pel) and bioclasts (bc) illustrates thin cortex oolites with various nucleus (quartz grains, pelletoids and bioclasts).

Fig. 4 : A. Le membre B<sub>I</sub> dans le gisement de Qorba (coupe Q2), riche en débris de mollusques variés DE MER PEU PROFONDE, incluant *Strombus bubonius* LAMARCK (St), espèce typique de la faune sénégalaise de mer chaude ; B et C. Lames minces observées en lumière naturelle des échantillons STR 14 et STR 18 provenant du membre B<sub>I</sub> de la coupe Q2 ; B. Calcarénite à texture grainstone, riche en algues rouges (Corallinaceae: Cr) et en oolites (ool) (échantillon STR 14) ; C. Calcarénite à texture grainstone, riche en oolites subsphériques (ool), en pellets (pel) et en bioclasts (bc) comportant des oolites à cortex fin et noyaux variés : grains de quartz, pellets et bioclasts (échantillon STR 18).

## 2.2.2 - QORBA section 2 (Q2)

On the ridge of the Qorba-Menzel Temime road, the Quaternary series is developed parallel to the present sea level with its two units.

– The quartzous unit is composed of two members with the lower member being exposed at 4 m above the present shoreline and consists of pale brown homogeneous quartzous sand. The carbonate particles are limited to echinoids isolated plates and spines, algae, mollusks debris and rare foraminifera tests. The sand is very well sorted and the morphoscopy of the quartz grains shows frequent sub-angular and blunt grains, with a prevalence of sparsely dispersed small, circular pebbles. The shallow marine bivalves and gastropods are frequent and diversified with the endobenthic species being dominant. The shallow marine character of this fauna allows a comparison to the lower member of the marine term of the Douira Formation (Paskoff & Sanlaville, 1977, 1980, 1983) or the Khniss unit (Mahmoudi, 1988).

– This member is overlain by homogeneous quartzous uncemented sands containing no carbonate particles (e.g. oolites and pellets) and is locally exposed towards the coastal ridge. At the top, these sands preserve abundant rhizomes and suggest the presence of a coastal dune deposit that is equivalent to the A<sub>III</sub> member developed at the Q1 section. The upward evolution throughout the quartzous unit, from its lower marine member A<sub>I</sub> to the top of its upper member A<sub>III</sub>, illustrates a regressive trend similar to that found in the Menzel Temime sections.

– Only the lower member of the upper carbonate unit is observed (B<sub>I</sub>). It is composed of a 2.5 m thick layer of shell, rich in coarse oolitic peloidal sand. Some sparse pebbles and angular blocks are observed; this material is organized into irregular thick beds, with fining up graded sequences underlined by erosion base. There are three to four sequences that are characterized as proximal tempestites. Laterally, cross-bedding lamination may also be observed. In this lower member, the fauna is abundant and dominated by broken valves of *Glycymeris violacescens* LAMARCK associated with less frequent *Cardium tuberculatum* LINNE and *Strombus bubonius* LAMARCK complete shells. Laterally, some sandy lenses are observed, where the mollusk shells are better preserved and more diversified. This fauna is dominated by Senegalian species such as *Strombus bubonius* LAMARCK, *Purpura haemastoma* BRUG and *Cardium tuberculatum* LINNE. These species indicate they were formed in warm, shallow marine water. The top of this member is marked by well-lithified, plane-parallel laminae slightly inclined toward the sea (5° to 10°). It includes mollusks debris, echinoid, pellets and oolites. These elements are thickly laminated with a sparse concentration of small bioclasts.

## 4 - DISCUSSION

The stratigraphical synthesis of the Tyrrhenian outcrops from the south-eastern coast of the Cap Bon peninsula (fig. 5) confirms that the Tyrrhenian in this area is composed of two units. The lower unit, mainly quartzous, starts with a marine member rich in shallow marine mollusks and terminates in continental deposits. The upper unit is carbonate. Its lowermost member

yields warm “Senegalian fauna” including the biomarker *Strombus bubonius* LAMARCK. Its uppermost member is also continental.

### 4.1 - DEPOSITIONAL ENVIRONMENTS: RECONSTITUTION

#### 4.1.1. The quartzous unit

At the beginning of the quartzous unit deposition, there is a predominance of quartz input and marine conditions. The presence of marine bivalves preserved in thin layers indicates rather low energy conditions which have led to a shallow protected environment.

In the Qorba-Menzel Temime area, the quartzous sands of the lower member A<sub>I</sub> of the quartzous unit are fine-grained quartz particles rich in diversified mollusks. The complete shells and especially those of bivalves preserving joint valves, indicate that the initial mollusk biocoenose is slightly disturbed by the coastal waves. Therefore, the environmental conditions continue to prevail in a protected bay.

In the Menzel Temime area, this lower member is overlain by palaeosols A<sub>II</sub> followed by dunal deposits A<sub>III</sub>. The latter are well developed along the SE shoreline and confirm the emergence of the Qorba-Menzel Temime region at the end of the quartzous unit deposition. Subsequently, towards the NNE, in the Menzel Temime area, these dune deposits are composed of well-cemented quartz grains and show a weak oolithisation that were excavated by an irregular erosion surface. In the same area, the intercalation of the reddish palaeosol between the marine member and the aeolian member indicates local wet conditions.

An equivalent quartzous unit is observed in the Sahel area (Central Tunisia). As a matter of fact, Mahmoudi (1988) reported the Khniss unit which shows similar facies. He distinguished as well a marine member rich in bivalves and a dune member. Towards the south in Jerba Island and Jorf peninsula, Jedoui (2000) described a quartzous unit composed of a shallow marine member and a dune member.

This dual composition of the quartzous unit makes it comparable to the Khniss unit and not the Douira Formation which has no dune member, according to Paskoff & Sanlaville (1977).

In the northern part of the Mediterranean Basin, the marine quaternary quartzous deposits are rich in *Cardium* and *Tapes* species. Especially along the southern coastline of France, these deposits are attributed to the Tyrrhenian stage (Barrière *et al.*, 1965; Barrière, 1966).

#### 4.1.2. The carbonate unit

The carbonate unit is well developed in the Cap Bon peninsula. It also starts by a marine member with various facies. The one at Menzel Temime is reduced in thickness and may be composed of biocalcarene rich blocks, pebbles and marine fauna. These facies suggest a high



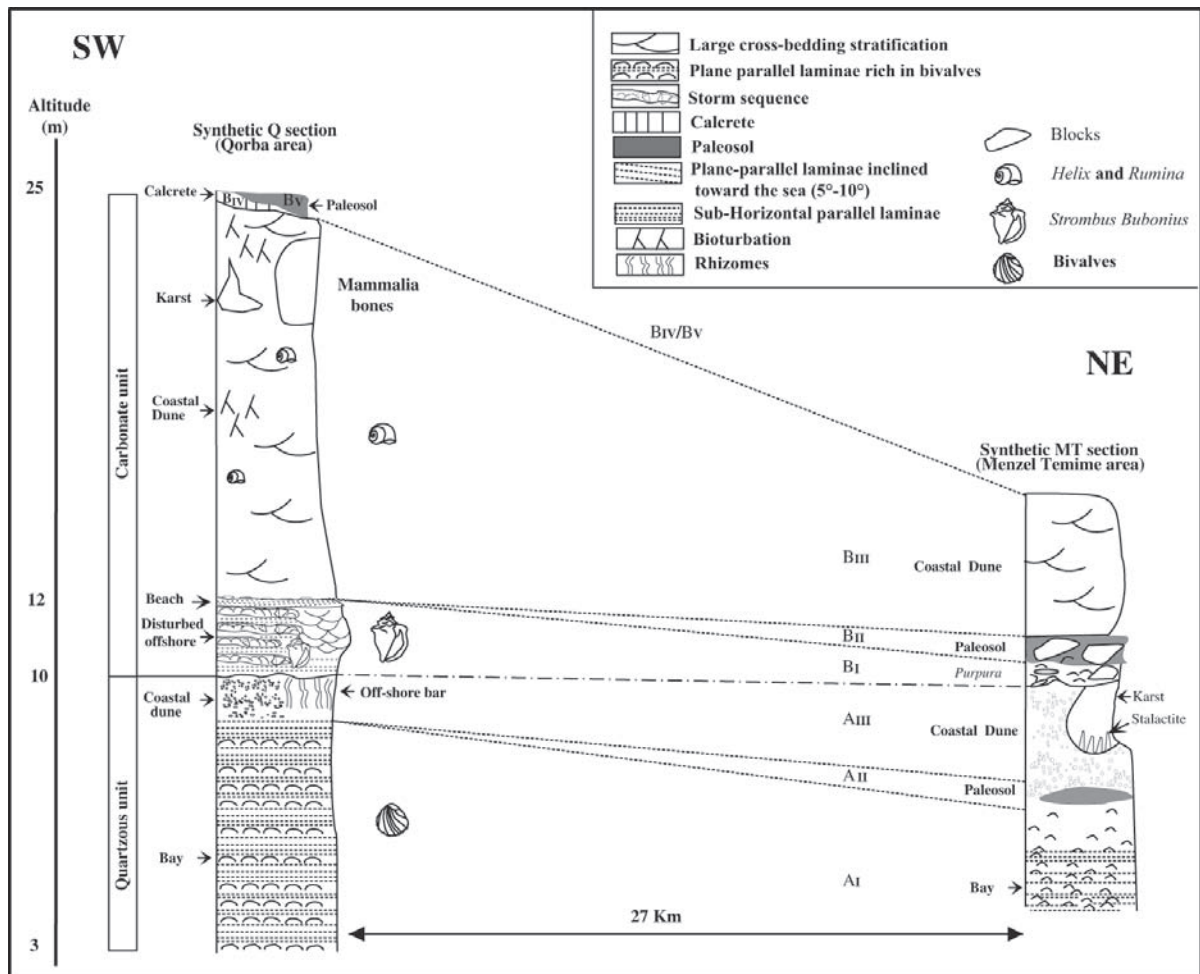


Fig. 5: Correlation between Qorba and Menzel Temime Quaternary members and units.

Fig. 5: Corrélation entre les différents membres et unités quaternaires de Qorba et Menzel Temime.

energy marine shoal. In the Qorba area, the lower member demonstrates transgressive conditions, stretching orthogonally 1 km away from the present shoreline and overlain with palaeosols. This succession displays a shallowing-upward sequence evolving from shoreface to backshore. Moreover, the abundance of broken shells, debris, pebbles in the marine member of the carbonated unit and the poor sorting of these elements, indicate a rising energy during the lower member deposition. Besides, the marine member of the carbonate unit is rich in "Senegalian fauna" which includes the marker species *Strombus bubonius* LAMARCK, thus justifying the warm shallow sea water interpretation.

The occurrence of such a marine member as the carbonate unit in the Mediterranean basin at an average level between 7 - 10 m is consistent with the evidence that the global sea level rise of 6 to 7 m during stage 5 e (Chappel & Shackleton, 1986).

In the Qorba area, the lower member preserves tempestites; whereas in the Menzel Temime area, it is overlain by thick and continuous colluvial deposits with angular blocks reaching 30 cm in size. These blocks are inherited from the aeolian member of the quartzous unit and are linked by a ferruginous matrix. In addition, the colluvial material indicates the occurrence of a wetter climate. The abundant large pebbles in this colluvial

material illustrate an active drainage system, which acts on the eolian upper member of the quartzous unit. These colluviums are better developed toward the west and are overlain by an expanded aeolianite, which implies active aeolian transportation. The transition between the colluvial and the dune deposits in Menzel Temime could be explained by a climate change from wet to relatively dry conditions. These aeolian deposits, rich in oolites and pellets of the carbonate unit, are widespread along the eastern coast. They imply an expanded warm sea water platform developed previously during the marine member deposition of the carbonate unit. These aeolianites are also recognized parallel to the present shoreline towards the south (Mahmoudi, 1988; Jedoui 2000).

#### 4.2 - CLIMATE CHANGES

In the circum-Mediterranean basin, as well as in the Bahamas, marine carbonate Quaternary deposits are well documented. Their facies are similar to those of the carbonate unit lower member, developed in Qorba and characterized by their richness in the "Senegalian fauna" with *Strombus bubonius* LAMARCK; this implies a widespread warm shallow sea. Additionally, the dune deposits that overlie the lower member rich in oolites and pellets suggest that the winds have reworked a large,

exposed carbonate platform material towards the back-shore.

The zonal crust overlying the dune deposits indicates both a dry and warm climate. The warm climate generated a large carbonate production within the shallow marine environment during the carbonate unit lower member deposition. This warming was in favor of the Senegalian fauna that was thriving. The big mammal fauna preserved in the dune deposit excavation also indicates dry conditions on the land.

The palaeosols observed locally both in the quartzous unit and the carbonate unit indicate short time wet conditions. Also, the colluviums developed in Menzel Temime demonstrate a rainfall period prevailing after the *Strombus* rich deposition.

#### 4.3 - AGE ATTRIBUTION

The estimated age based on the uranium-thorium isotope content of the mollusk shells gave no coherent values. Sixteen samples of mollusk shells, coming from the type formation localities Douira, Rejiche and Chebba formations, were analyzed for Uranium and Thorium isotopes contents (Bernat *et al.*, 1985). The U-series activity ratio in bivalves for the Douira Formation yielded age ranging between 98 ka and 136 ka, for the Rejiche Formation between 37 ka and 83 ka and for the Chebba Formation between 61 ka and 92 ka. According to Bernat *et al.*, (1985) these conflicting values arise from a recent uranium contamination.

Other U-series activity ratio measured on other bivalves from the Douira formation yielded 130 ka ( $^{230}\text{Th}/^{234}\text{U}$ ) and 99 ka ( $^{231}\text{Pa}/^{235}\text{U}$ ). These estimated ages led Paskoff and Sanlaville (1983) to attribute this formation to the isotopic substage 5e.

The U-series activity ratio in a single branching coral of *Cladocora caespitosa*, taken from the Rejiche Formation exposed in Monastir, yields an absolute age of 126  $\pm$  7 ka B. P. (Miller *et al.*, 1986). This radiometric age suggests that the Rejiche Formation belongs to the isotopic substage 5e.

Since corals are largely absent in the Quaternary deposits of southern Tunisia, radiochemical age has been obtained on oyster shells by Jedoui (2000) and Jedoui *et al.*, (2001, 2002, 2003). The yielded ages range between 110 and 147 ka for the quartzous unit and 100 and 141 ka for the carbonate unit. Therefore, these estimated radiochemical ages confirm that these two units were developed during the same marine isotopic substage 5e.

Along the Mediterranean shoreline the *Strombus* palaeobeach deposits (synchronous with the carbonate unit) are well-developed and are attributed to the Tyrrhenian deposits. Their radiochemical ages, based on the associated corals, give an estimated age of about 125 Ka. Accordingly, it seems that in the Cap Bon peninsula, both marine members of the quartzous unit and the carbonate unit were developed during two distinct positive sea-level pulsations, occurring during the isotopic

substage 5e. These eustatic pulsations were recorded elsewhere in the circum Mediterranean Basin (Stearn, 1984; Hearty, 1986; Hillaire-Marcel *et al.*, 1996; Kindler *et al.*, 1997) as well as in the Bahamas (Hearty & Kindler, 1993, 1995).

Because these deposits are rich in Senegalian fauna, especially *Strombus bubonius*, and are abundant in oolites, they can be correlated with the lower terrace described in the Iberian Peninsula (Almeria and Alicante littorals) which is located at a maximum topographic elevation of +15 m. This terrace is attributed to 128 ka and it belongs to the isotopic substage 5e (Zazo, 1999). In Campo de Tiro (Mallorca, Balearis Island) another unit with abundant *Strombus* is described and is about 135 ka old (Hillaire-Marcel *et al.*, 1996).

On the Israel coastal plain, only the deposits of stage 5 (especially isotopic substage 5 e) contain *Strombus bubonius* LAMARCK and are attributed to the Yasaf member which is considered to be 122 ka old (Sivan *et al.*, 1999). As in the Cap Bon peninsula, this member is a few cm to 2 m thick. It is composed of poorly sorted biocalcarenes locally rich in skeletal fragments and complete shells of *Strombus bubonius* LAMARCK. The absence of oolites and pellets in this Israelian member can be explained by its position in the northern part of the Mediterranean Basin.

In Sardinia, Kindler *et al.* (1997) identified two sequences corresponding to distinct sea level high-stands during the isotopic substage 5e.

#### 5 - CONCLUSIONS

The Quaternary deposits bordering the SE coastline of the Cap Bon peninsula are composed of two distinct units. The lower unit is quartzous with the lower facies of this unit suggesting shallow marine conditions with a more or less protected offshore. This lower facies is succeeded by palaeosols and dune deposits. The upper unit is carbonate, rich in oolites and pellets. Its lowermost member is rich in Senegalian fauna with the Tyrrhenian *Strombus bubonius* marker indicating a warm shallow marine environment which was well exposed to coastal waves and temporary storms. This lower member is succeeded by coastal eolianites and a carbonate crust which testifies to a warm and dry period. Low-stand conditions probably favored the onshore transportation of marine particles. In contrast, the colluviums developed locally in the Menzel Temime area show the local rainfall effects. Therefore, these deposits, attributed to the isotopic substage 5e (Tyrrhenian) are clearly organized in two sedimentary shallowing up cycles. The older cycle developed during cold climate conditions; while the transgressive phase of the younger cycle corresponds to a clear climate warming, during which the carbonate production is reactivated in the shallow marine environments. Dry climate conditions have persisted during the low stand sea level favoring the development of coastal dunes.

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