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Facies and fauna proxies used to reconstruct the MIS 5 and MIS 7 coastal environments in eastern Tunisia

Amel CHAKROUN[1,] * and Dalila ZAGHBIB-TURKI[1]

[1] University of Tunis El Manar, Department of Geology, Faculty of Sciences of Tunis, University Campus, 2092, El Manar II, Tunisia

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This study is based on the analysis of the sedimentology and the fossil assemblages of Pleistocene deposits in Eastern Tunisia. It uses different fauna assemblages to help infer palaeoenvironments and in particular discusses the importance of the distribution of *Persististrombus latus*, especially as regards MIS 5e deposits around the Mediterranean Basin. The stratigraphic succession has been divided into two main units. The lower unit is quartz-rich. Its basal part contains a marine fauna that includes well-preserved bivalves, gastropods, echinoids and cirripedes dominated by *Acanthocardia, Cerastoderma, Parvicardium, Arca, Donax, Glycymeris, Loripes, Tellina* and *Cerithium.* This fauna represents a typical association/biocenosis typically developed in a sheltered bay, of moderate to low wave/current action and rapid post-mortem burial. The upper unit is carbonate-dominated. Its basal part also contains a rich marine fauna that includes the extant tropical West African species *Persististrombus latus*. The occurrence of *Persististrombus latus* in this unit compared to its presence in the whole Mediterranean basin in the Late Pleistocene leads us to question its importance in the interpretation of climate warming during the Late Pleistocene, and to suggest its Atlantic origin.

Key words: MIS 5 and MIS 7, Tunisia, malacofauna, palaeoecology, *Persististrombus latus*, palaeoclimate.

INTRODUCTION

Pleistocene deposits of the eastern coast of Tunisia correlative to marine isotope stage (MIS) 5, MIS 7 and MIS 9 have been the subject of several studies (Allemand-Martin, 1923, 1924; Castany, 1954, 1955, 1956; Barrot, 1972; Paskoff and Sanlaville, 1976, 1977, 1978, 1980, 1983; Oueslati, 1980; Oueslati et al., 1982; Blanc, 1982; Bernat et al., 1985; Miller et al., 1986; Mahmoudi, 1986, 1988; Oueslati, 1994; Jedoui, 2000; Jedoui et al., 2001, 2002, 2003; Bouaziz et al., 2003; Le Guern, 2005; Chakroun et al., 2005, 2009a, b, 2016; Chakroun, 2006; Mauz et al., 2009; Mejri et al., 2012). This succession, containing a marine fauna, has been documented as transgressive. In eastern Tunisia, it is underlain by a major unconformity. It can directly overlie continental as well as marine Miocene deposits or the marine Pliocene, or even continental Villafranchian deposits.

In the present work we detail the fossil content of the MIS 5e and MIS 7 deposits outcropping along the Cap Bon Peninsula and farther towards the south in the Hergla area. The faunal species distribution and taphonomy are analysed. The main ecological characteristics of the different invertebrate species communities help to reconstruct their depositional environments or biotopes developed along the eastern coast of Tunisia.

MATERIAL AND METHODS

Along the eastern Tunisian coast, from the Cap Bon to Hergla areas, the Pleistocene (MIS 5e and MIS 7) succession, outcropping at the cities of Menzel Temime, Qorba and Hergla (Fig. 1), is investigated. Five sections across this succession are detailed (Fig. 2). In the study, the stratigraphy was documented, and samples were collected from the carbonate and the quartz-rich units (MT, Q2 and Hg1 sections) composing this succession.

We collected a range of species present within the different units. Additionally, we processed (1) by extraction of large specimens of all taxa (larger than 2 mm in size) taking into account their stratinomy and position within the sediment, (2) by extracting 500 g of dry deposits and gathering small specimens from their residues obtained in sieves (using a 1 mm mesh screen). All specimens that remained on the screen were picked and identified and counted (Tables 1 and 2). Typical species assemblages are also defined and any change in their assemblages composition is detected and commented on.

For taxonomic identification and ecological assignation, we referred to Abbott (1960), Perrier (1954), Fekih (1975), Meco (1977) and Sessa et al. (2013). Taxonomic attributions were updated by using the World Register of Marine Species Data-

*Corresponding author, e-mail: chakroun_amel@yahoo.fr

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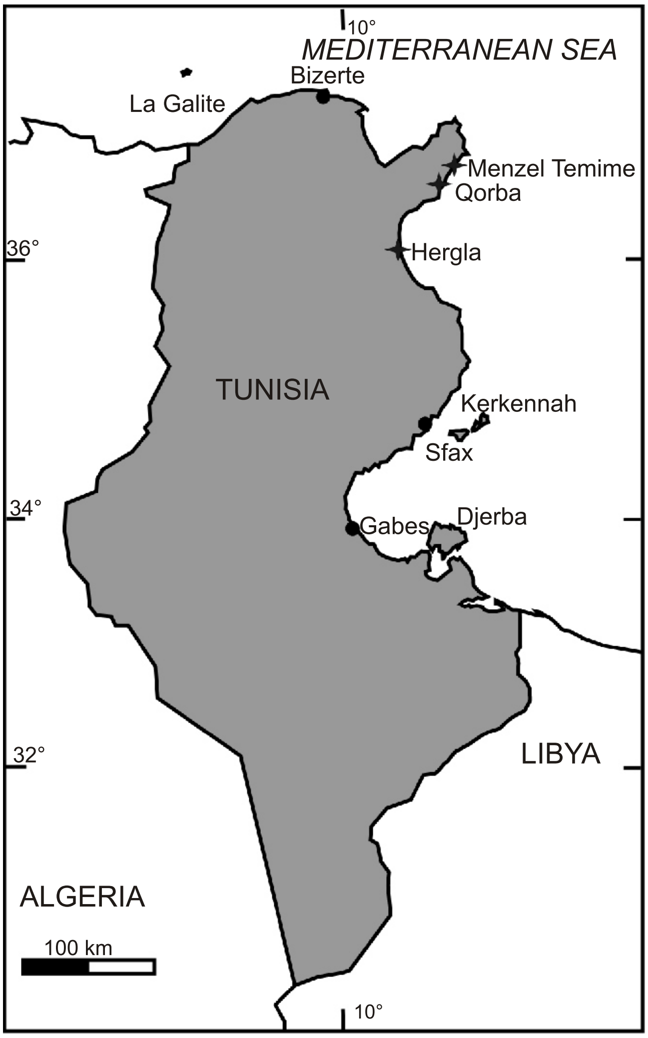

Fig. 1. Location map of the Tyrrhenian sites studied: Menzel Temime, Qorba and Hergla

base (http://www.marinespecies.org) and the Paleobiology Database (https://paleobiodb.org/#/).

FACIES AND GEOLOGICAL SETTING

Along the eastern coast of Tunisia the Pleistocene succession analysed (MIS 5e and MIS 7) are far from homogeneous. In our previous studies based on the detailed analysis of stratigraphy, lithofacies, morphoscopy, exoscopy, and palaeontological content (vertebrates and invertebrates), we recognized two main Middle to Late Pleistocene units, each one defining a complete transgressive cycle (Chakroun et al., 2005, 2009a, b; Chakroun, 2006). These two units are distinguished by their sedimentological and their palaeontological characteristics (Fig. 2). Below, a concise description of these units in the Menzel Temime and Qorba sections is given.

The lower unit, rarely developed, is characterized by quartz-rich deposits. It is composed, from base to top, of (1) thin layers of fine sands rich in entire shells of marine molluscs such as *Glycymeris nummaria*, *Loripes lucinalis*, *Ceratoderma edule*, *Parvicardium exiguum*, *Acanthocardia tuberculatum, Donax trunculus*, *Tellina planata* and *Cerithium vulgatum*; (2) lenticular green clay layers observed only at Menzel Temime and (3) coarse sandy deposits with dune cross-bedding or densely packed root structures. Thus, towards the top of this lower part a continental character is developed.

The carbonate unit is significantly better developed in the Cap Bon area as well as along the eastern coast of Tunisia. It consists of 12 m of carbonate deposits, outcropping at various altitudes ranging from 5 to 10 m above the present sea level. It is composed of two parts:

1. Centimetre- to metre-scale chalky sands rich in altered marine mollusc shells. These deposits are organized into four normally graded bedding sequences underlain by an erosive surface. This basal part records the action of local episodic storms along this northeastern coastal area. In this part are preserved the main species characterizing the Senegalese fauna, *Persististrombus latus,* a proxy of warm tropical marine water.

2. Decimetric-scale carbonate deposits rich in ooliths and pellets with dune cross-bedding. This part contains a continental invertebrate fauna composed mainly of helicid gastropods including *Helix* spp. and *Rumina decollata*. Locally, close to Qorba city, these helicids are associated with large mammal species: *Phacochoerus aethiopicus*, *Gazella atlantica*, *Alcelaphus buselaphus*, *Equus mauritanicus*, *Ceratotherium simum* and *Hystrix cristata* (Chakroun et al., 2005).

Towards the south of Cap Bon, in the Sahel region close to the village of Hergla (Fig. 1), there is an Upper Pleistocene succession that was studied by Mahmoudi (1988). This author distinguished two formations: the Kniss Formation and the Rejiche Formation, and he attributed this succession to the Tyrrhenian on the base of the occurrence of *Persististombus latus* (a senior synonym of *Strombus bubonius*).

The basal part of the quartz-rich unit in the Hergla area (Hg1 and Hg2 sections) is equivalent to the Khnis Formation (Fig. 2). It is composed from base to top of (1) fine sands, with rare crustacean pellets and ooliths, the fauna being represented either by debris and small entire bivalve shells, especially cardiids and lucinids; (2) green clay and silts and (3) sandy deposits with densely packed root structures.

The carbonate unit that is equivalent to the Rejiche Formation is composed of two parts: the lower part consists of less or more consolidated carbonate sands rich in molluscs and including *Persististrombus latus*. The upper part is made up of sands rich in helicids and root structures.

CHRONOLOGICAL BACKGROUND

The best developed Pleistocene deposits outcropping in eastern Tunisia have been attributed to the Tyrrhenian and were characterized by the occurrence of *Persististombus latus* (Paskoff and Sanlaville, 1978).

Radiometric age determination has been made on the *Persististrombus latus*-bearing deposits at different localities in eastern Tunisia. U-series dating yielded reliable ages (Table 3). These ages (126 ± 7 Ky: Miller et al., 1986; 120 Ky: Jedoui et al., 2003) attribute the marine carbonate member of the Rejiche Formation to MIS 5e. This marine member is overlain by deposits with eolian cross-stratification attributed to MIS 4 (Mauz et al., 2009).

At Qorba and Hergla the outcrops (Fig. 2) host the marine warm-water gastropod *Persististrombus latus* in the carbonate unit, attributing it to the Rejiche Formation (MIS 5e). The absence of *Persististrombus latus* in the carbonate marine level of Menzel Temime make us less certain about the age of this latter deposit. However, the presence of the amphi-Atlantic species

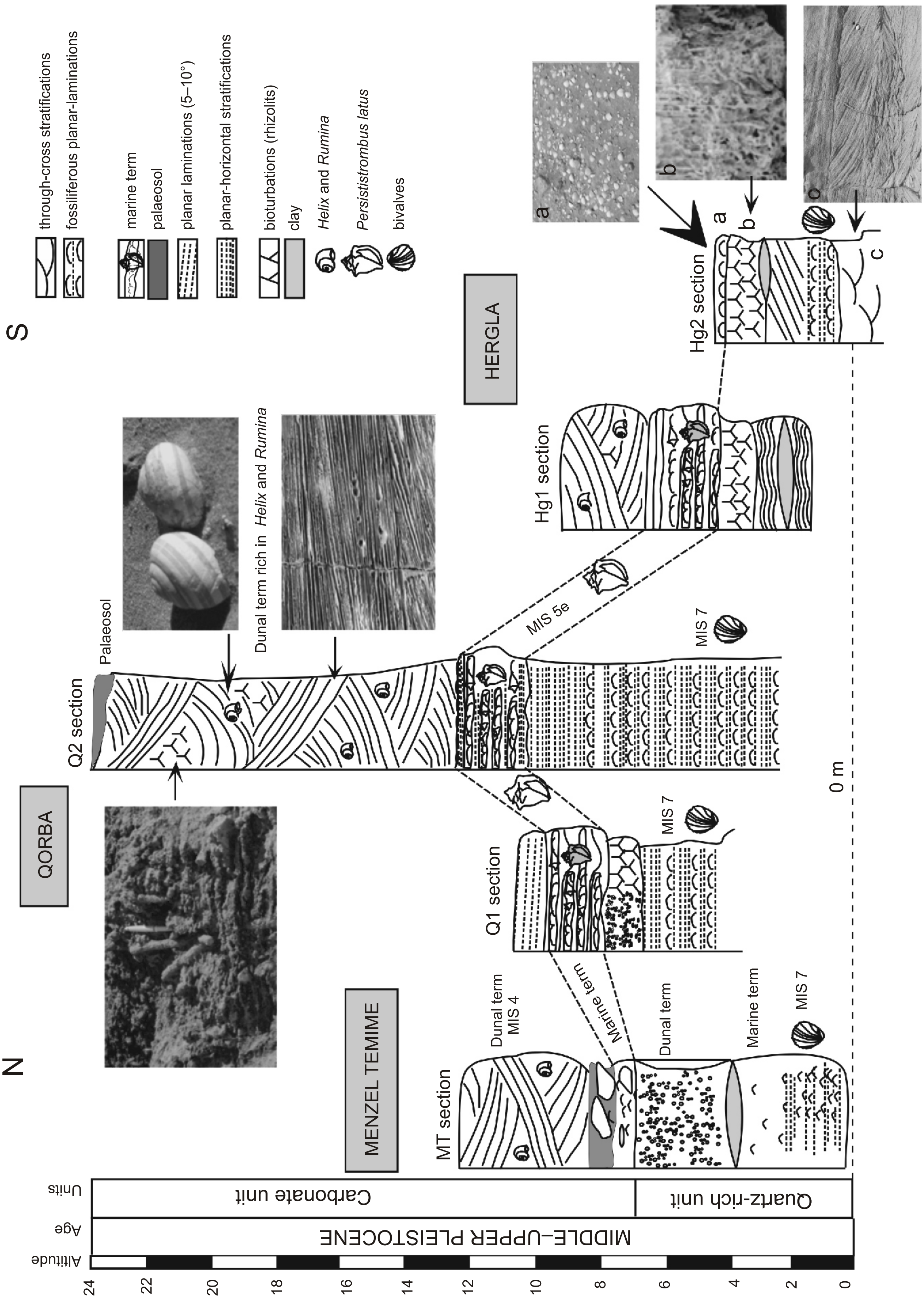

Fig. 2. The Menzel Temime, Qorba and Hergla sections, showing correlation between carbonate marine members

Table 1

Taxonomic composition and frequency of specimens identified in the Mid-Upper Pleistocene quartz-rich unit of Tunisia

QUARTZ-RICH UNIT SPECIES	MENZEL TEMIME		QORBA		HERGLA		KHNIS (a)
	NI	[%]	NI	[%]	NI	[%]	
Acanthocardia tuberculata Linne	17	7	22	20	24	24	*
Cerastoderma edule Linne	18	8	25	23	20	20	*
Parvicardium exiguum Gmelin	22	10	23	21	20	20	
Barbatia barbata Linne							*
Arca noae Linne	*		17	16	2	2	***
Arca tetragona Poli					2	2	***
Pseudochama gryphina Lamarck	*				2		
Dosinia exoleta Linne	*						*
Dosinia lupinus Linne	2	1					
Donax trunculus Linne	31	14					
Eastonia rugosa Helbling	*						*
Gastrana fragilis Linne	*						***
Glycymeris nummaria Linne	12	5	17	16	2	2	
Loripes lucinalis Lamarck	28	12			18	18	*
Mactra stultorum Linne	*						*
Mactra glauca Born	*						*
Callista chione Linne	*						
Pitar rudis Poli	2	1					
Modiolus barbatus Linne					*		*
Solecurtus strigilatus Linne	*						
Pecten jacobaeus Linne	4	2					
Ensis ensis Linne	5	2					
Solecurtus strigilatus Linne	5	2					*
Ruditapes decussatus Linne					2	2	
Polititapes rhomboides Pennant	4	2			2	2	
Tellina planata Linne	33	14			*		*
Venus verrucosa Linne	5	2			3	3	
Chamelea galina Linne	4	2			3	3	
Bolma rugosa Linne	*						
Neverita josephinia Risso	*						
Hexaplex trunculus Linne	*						
Semicassis granulata undulata Gmelin	*		4	4			
Cerithium vulgatum Bruguiere	19	8			*		*
Nassarius sufflatus Gould	5	2	*				
Nassarius reticulatus Linne	6	3					
Cyclope neritea Linne	6	3					
Balanus sp.	*						
Echinocardium cordatum Pennant	*						
Bulk sample richness = 38 taxa	228	100	108	100	100	100	

(a) – additional data from (Mahmoudi, 1986); * – species identified from field survey of the quartz-rich unit: * – common; ** – very common; *** – abundant; NI – number of individuals (for bivalve taxa, this is the valve with higher frequency)

Stramonita haemastoma, which is generally associated with *Persististrombus latus* at this level and its stratigraphic position above the quartz-rich Douira Formation (MIS 7), suggests that the deposits can be correlated with Rejiche Formation (MIS 5e). Further dating may yield a more precise age of this carbonate unit at Menzel Temime.

The marine quartz-rich deposit lacking *Persististrombus latus*, richly fossiliferous, is attributed to the Douira Formation. This latter formation has long been thought to date to MIS 5 (Tyrrhenian). Based on U/Th dating, Miller et al. (1986) correlated the marine quartz-rich Douira Formation with MIS 7. New IRSL analysis of the Douira Formation, in the Cap Bon Peninsula, support the manty previous works (Miller et al., 1986; Mauz et al., 2009; Mejri et al., 2012; Balescu et al., 2015).

At the Khnis locality, the Khnis unit has an age of 121 ± 10 Ky (Mauz et al., 2009).

Table 2

Taxonomic composition and frequency of specimens identified in the Mid-Upper Pleistocene carbonate unit of Tunisia

CARBONATE UNIT SPECIES	MENZEL TEMIME		QORBA		HERGLA		KHNIS (a)
	NI	[%]	NI	[%]	NI	[%]	
Acanthocardia tuberculata Linne	2	3	22	19	36	20	*
Cerastoderma edule Linne	3	4			34	19	
Parvicardium exiguum Gmelin	2	3			25	14	
Glycymeris nummaria Linne	12	17	24	24	29	16	*
Arca noae Linne			4	4	29	16	*
Arca tetragona Poli					*		*
Pecten jacobaeus Linne	10	14	4	5			
Spondylus gaederopus Linne			*		*		*
Ostrea edulis Linne	9	12	1	1			
Loripes Lucinalis Lamarck			1	1	6	3	*
Pseudochama gryphina Lamarck			*				
Chama gryphoides Linne			*		*		*
Callista chione Linne			*				*
Dosinia exoleta Linne			*				
Dosinia lupinus Linne			*				
Ruditapes decussatus Linne			*				
Polititapes rhomboides Pennant			*				
Chamelea gallina Linne			*				
Venus verrucosa Linne			1	1	*		*
Donax trunculus Linne			1	1			
Eastonia rugosa Helbling			1	1			
Mactra glauca Born			*		6	3	
Mactra stultorum Linne			*		*		
Callista chione Linne			*		*		
Gastrana fragilis Linne			1	1			
Tellina planata Linne			1	1	6	3	*
Diodora italica Defrance			2	2	*		
Diodora graeca Linne			1	1			
Patella ferruginea Gmelin			1	1			
Patella vulgata Linne			*				
Patella caerula Linne			1	1			
Naticarius stercusmuscarum Gmelin			*				
Rissoa membranacea Adams			*				
Tarantinaea lignaria Linne			*				
Turritella communis Risso			3	3	*		*
Hexaplex trunculus Linne	14	20	2	2	*		*
Stramonita haemastoma Linne	12	17	2	2	*		
Cerithium vulgatum Bruguiere			10	10			
Bittium reticulatum Da Costa			3	3			
Monophorus perversus Linne			1	1			
Cerithiopsis minima Brusina			*				
Cerithiopsis tubercularis Montag			*				
Persististrombus latus Gmelin			*		*		*
Semicassis granulata undulata Gmelin	7	10	10	10	*		*
Nassarius sufflatus Gould			*		*		*
Nassarius reticulatus Linne			10	10			
Cyclope neritea Linne			*				
Columbella rustica Linne			4	4	*		*
Conus ventricosus Gmelin					6		*
Neverita josephinia Born					*		*
Vermetus triquetrus Bivona Bernardi	*	*					
Thylacodes arenarius Linne			*				
Bulk sample richness = 52 taxa	71		100	100	181	100	

Explanations as in Table 1

Table 3

Dating result summary of the Pleistocene littoral deposits of the Tunisian coast

Formations (Paskoff and Sanlaville, 1983)	Mahmoudi (1988)	Present work	Terms	Locality	Dating technique	Age (Kys)	MIS	References
Rejiche	Rejiche unit	Carbonate unit	Aeolian		OSL	68–122	4	Mauz et al. (2009)
			Marine	Monastir	Th/U	126 ± 7	5e	Miller et al. (1986)
				Djerba Island	Th/U	120	5e	Jedoui et al. (2003)
	Khnis unit	Quartz-rich unit	Lagoonal	Khnis	OSL	121 ± 10	5e	Mauz et al. (2009)
Douira	Douira unit		Marine	Menzel Temime	Amino-acid data	–	7	Miller et al. (1986)
				Douira	OSL	138 ± 9	7	Mauz et al. (2009)
				El Hajeb	IRSL	216	7	Mejri et al. (2012)
				El Hajeb	IRSL	333	9	Mejri et al. (2012)
				Hergla	IRSL	–	?	Mejri et al. (2012)
			Lagoonal Cap Bon		IRSL	182 ± 21	7	Balescu et al. (2015)
				Cap Bon	IRSL	205 ± 16	7	Balescu et al. (2015)

RESULTS

The fauna studied from the Pleistocene successsion is very diverse, differing from one unit to another and being distinguished by assemblage species composition and frequency. The Upper Pleistocene fossils collected in the different units in eastern Tunisia allow the determination of different faunal assemblages and the coastal sedimentary environments that they reflect.

ASSEMBLAGES FROM THE MARINE PART OF THE QUARTZ-RICH UNIT

MENZEL TEMIME SECTION (MT)

In the thin shelly layer, the sandy basal part of the quartz-rich unit (Fig. 3A), has been attributed to MIS 7 (Miller et al., 1986). The marine mollusc fauna identified here (Fig. 4) is abundant and includes 34 species. It contains mainly *Acanthocardia tuberculata, Cerastoderma edule, Parvicardium exiguum, Arca noae*, *Donax trunculus, Loripes lucinalis*, *Tellina planata and Cerithium vulgatum*. Less abundant species are *Dosinia lupinus, Glycymeris nummaria*, *Pitar rudis*, *Solecurtus strigilatus*, *Pecten jacobaeus*, *Ensis ensis, Polititapes rhomboides*, *Venus verrucosa*, *Chamelea gallina, Nassarius mutabilis, N. reticulatus*, *Cyclope neritea* and *Balanus* sp. (Table 1).

The shells of bivalves, especially those of *Loripes lucinalis, Tellina planata* and *Donax trunculus* are often well-preserved, in life position, with their two contiguous valves. In this assemblage, the dominant marine species are euryhaline. The stenohaline species such as those belonging to *Neverita* and *Hexaplex* are rare. Moreover, in these shelly sands the species diversity is high. This indicates stable and favourable environmental conditions.

The dominance of entire and well-preserved shells of many bivalves belonging to diverse genera (e.g., *Loripes, Acanthocardia, Polititapes, Venus, Donax, Tellina*) demonstrates that they have not undergone long transportation. Thus, they are indubitably fossilised in or close to their appropriate biotope. Furthermore, the shells of these molluscs are never encrusted by algae or bryozoans or perforated by cliones or lichens; this suggests that they were quickly buried where they lived.

Besides, the faunal assemblage mentioned above, from the quartz-rich unit of the MT section consisting mainly of endobenthic species, was capable of being buried in soft sand or mud. Therefore, such an assemblage suggests a shallow-marine environment, though quiet and little affected by currents (e.g., tides, waves, swells, storms), far from wave action, e.g., in sheltered bay. The preponderance of molluscs confined to soft substrate is consistent with the grain size distribution within the basal part of the quartz-rich unit outcropping in the Cap Bon Peninsula (Chakroun, 2006).

Among the stenohaline species, echinoids are rare, though represented by many dissociated elements, e.g., spines and plates such as those attributed to *Echinocardium cordatum*, an endobenthic species. Today this taxon lives buried in sandy or silty substrates, like most of the marine fauna recognized in the marine part of the quartz-rich unit of the Menzel Temime section. Globally this endobenthic fauna may be considered as autochthonous/subautochthonous and representative of biota characterizing shallow but quiet marine-water.

QORBA SECTIONS (Q1 AND Q2)

In the Qorba region, behind the present-day shoreline, near the cave of El Geffel (Fig. 2, Q1 and Q2 sections), to the west, the MIS 7 sand deposits from the base of the succession studied is rich in fossils representative of a biotic community dominated by *Acanthocardia tuberculata, Parvicardium exiguum*, *Cerastoderma edule, Glycymeris nummaria* and *Arca noae* (Table 1). Indeed, in this basal part of the quartz-rich unit the fauna is abundant but less diverse (7 species) and smaller than in the Menzel Temime section. Besides, the entire shells and scarce debris are not sorted but form regular subhorizontal thin layers without any graded bedding (Fig. 3B). The well-preserved shells suggest little lateral transportation of the fauna. The assemblage of this basal part of the quartz-rich unit contains abundant euryhaline molluscs (e.g., *Cerastoderma edule*). The stenohaline species, e;g., *Semicassis granulata undulata* are represented by few specimens (4%). In addition most of them are endobenthic, living buried in soft substrate.

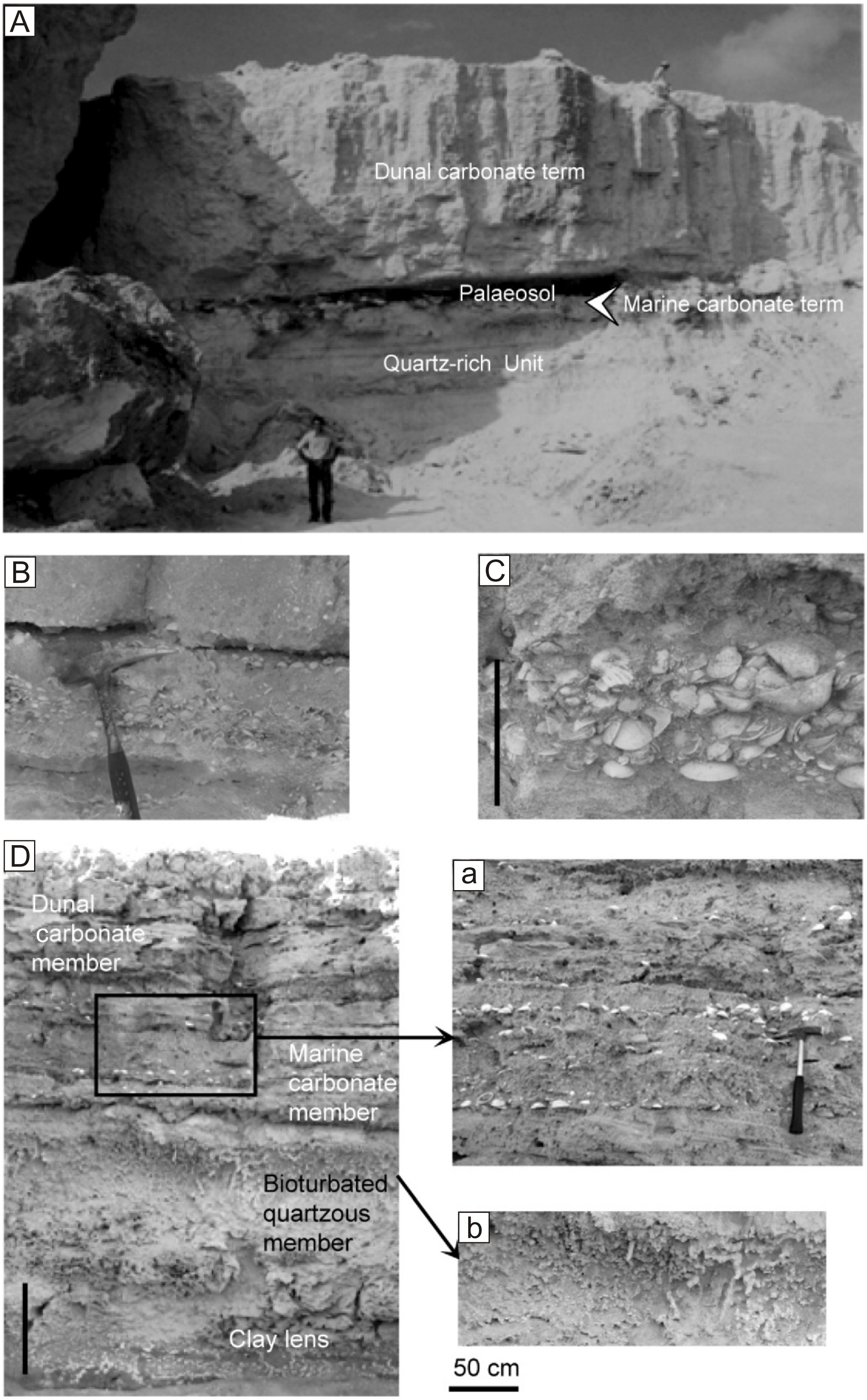

Fig. 3A – general view of the MT section; B – fossiliferous plane laminations of the quartzose marine member (Qorba); C – conglomeratic deposit of the carbonate marine member (Qorba); D – general view of Hg1 section

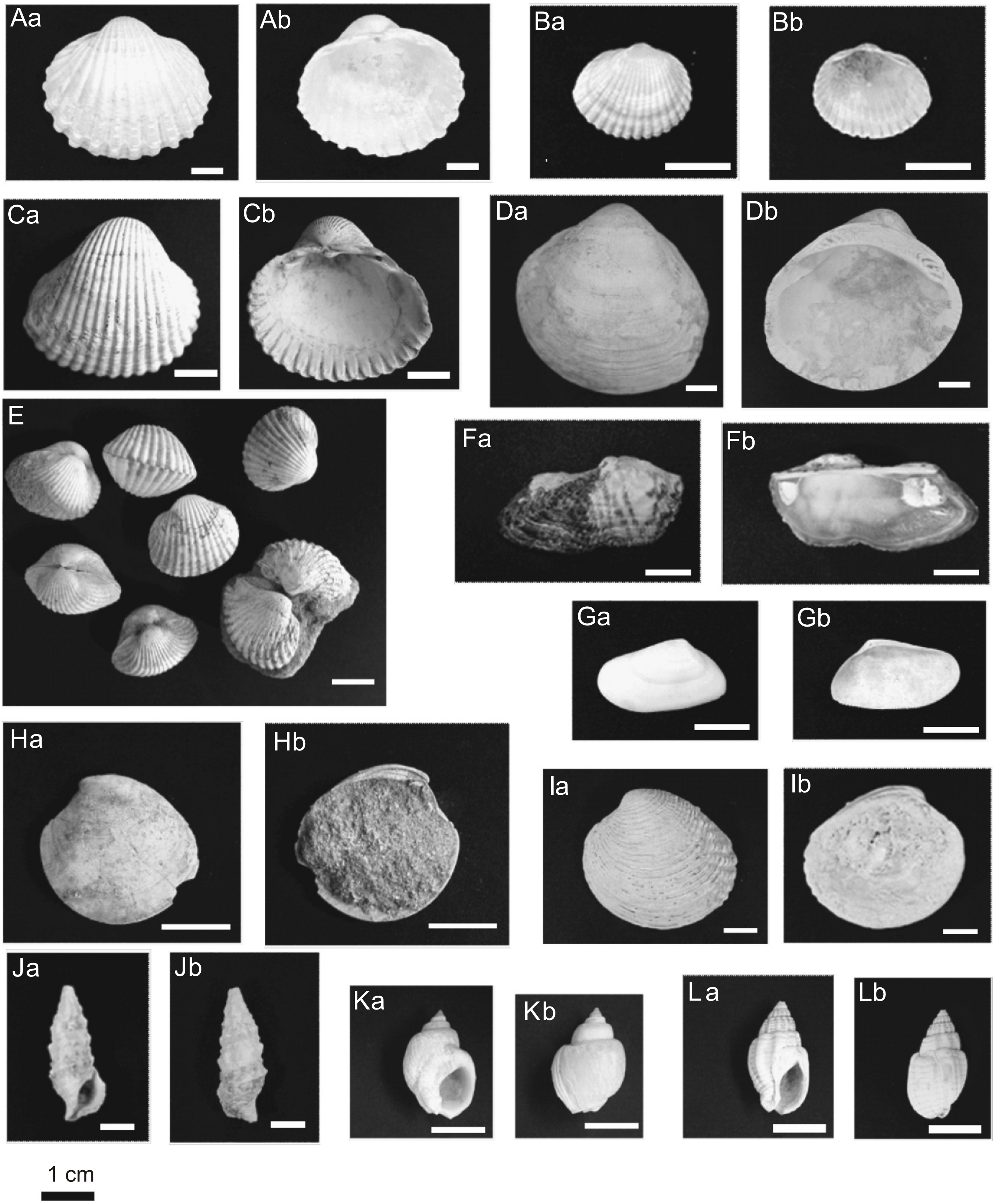

Fig. 4Aa, b – ***Acanthocardia tuberculata***, **Ba, b** – ***Parvicardium exiguum***, **Ca, b** – ***Cerastoderma edule***, **Da, b** – ***Glycymeris nummaria***, **E** – ***Parvicardium exiguum***, **Fa, b** – ***Arca noae***, **Ga, b** – ***Donax trunculus***, **Ha, b** – ***Dosinia exoleta***, **Ia, b** – ***Venus verrucosa***, **Ja, b** – ***Cerithium vulgatum***, **Ka, b** – ***Nassarius sufflatus***, **La, b** – ***Nassarius reticulatus***

HERGLA SECTIONS (HG1 AND HG2 SECTIONS)

In the Hg1 and Hg2 sections the basal part of the quartz-rich unit (Fig. 2) is composed of fine sands, with rare crustacean pellets and ooliths, the faunal assemblage being represented either by debris or by small bivalve shells. It is dominated by *Acanthocardia tuberculata, Ceratoderma edule, Parvicardium exiguum* and *Loripes lucinalis* (Table 1). Other species are rare, and include *Arca noae*, *A. tetragona*, *Pseudochama gryphina*, *Glycymeris nummaria*, *Ruditapes decussatus*, *Polititapes rhomboides, Venus verrucosa* and *Chamelea gallina.*

This facies of this basal part is overlain by a sandy level with planar laminations then by lenticular clay with rare *Cerastoderma edule*.

ASSEMBLAGES FROM MIS 6 OR/AND MIS 4 AEOLIAN QUARTZ-RICH UNIT

The deposits of the upper part of the quartz-rich unit, outcropping sporadically along the eastern coast of Tunisia, are not very fossiliferous. In the Menzel Temime sections, they consist of sands which are very bioturbated by roots. In the Qorba sections this deposit is 1 to 2 m thick and it contains both marine and continental fossils (e.g., *Helix* spp., *Rumina decollata*). This assemblage indicates a lagoon linked to the sea.

In the Hergla area, the continental quartz-rich deposits (with an average thickness of 1 m) are composed of fine sands and preserve cross-bedding commonly destroyed by intense bioturbation. They contain only a very few helicid shells. Locally the top of the quartz-rich unit is marked by intense root structures and may be otherwise unfossiliferous.

ASSEMBLAGES FROM THE MARINE PART OF THE CARBONATE UNIT

The faunal assemblages in the lower term of the carbonate unit are different from those of the underlying unit.

MENZEL TEMIME SECTION

The basal term of the carbonate unit outcropping in the Menzel Temime area (Fig. 2; MT section, Fig. 3A) is rich in marine fossils. The fauna is dominated by *Glycymeris nummaria, Hexaplex trunculus*, *Stramonita haemastoma, Semicassis granulata undulata*, *Pecten jacobaeus* and *Ostrea edulis* (Table 2). The bivalve valves are often stacked one above the other to form a coquina with an average thickness of 50 cm. The shells are often poorly preserved (worn, corroded, rolled and broken). In these deposits, the <2 mm sized fraction consists mainly of very fine debris of these shells, ooids and pellets. Isolated quartz grains are rare; these grains as well as shell debris form the ooid nuclei. Benthic foraminifera are rare; they are composed mainly by *Ammonia beccarii* and *Elphidium crispum*. The abundant ooliths and the poor preservation of shells reflect more intense marine dynamics than those characterizing the marine part of the quartz-rich unit. All the characteristics of the assemblage from the basal term of the carbonate unit suggest that the biota was not fossilised *in situ* but underwent substantial transport by waves and storms. Thus this assemblage represents a shallow fauna thanatocenosis accumulated close to the coastal line. This is corroborated by the occurrence in this deposit of angular blocks of decimeter size, and rounded pebbles. In the Menzel Temime area the marine part of the carbonate unit seems to be devoid of *Persististombus latus*. However, *Stramonita haemastoma* is frequent. This species is still alive in the shallow Mediterranean sea and along the western coast of Africa from Morocco to Senegal (Clench, 1947; Weisrock et al., 1999), in shallow seas around the Canary Islands (Ramirez et al., 2009) and the Azores (Spence et al., 1990). In the Mediterranean this species seems to inhabit similar habitats to that of *Persististrombus latus* (Rilov et al., 2001). The abundance of *Stramonita haemastoma* on tropical coasts of Africa and America shows that this species requires warm coastal marine waters (Butler, 1985; Brown and Richardson, 1987). Near the coast of Senegal it is associated with strombids and defines the Senegalese fauna living in shallow warm marine waters. Besides, the abundance of *Stramonita haemastoma* on tropical and subtropical coasts of Africa and America additionally indicates that this species requires warm shallow-marine waters (Butler, 1985; Brown and Richardson, 1987).

Secondly, the preservation state of this fauna (disarticulated valves, shell debris, worn shells) reflects strong coastal dynamics, with wave and swell activity. This is corroborated by the presence in this marine part of the carbonate unit of angular blocks of decimetre size and rounded pebbles.

QORBA SECTIONS

Towards the west, in the Q2 section (Fig. 2) behind the El Geffel cave, the fauna of the marine part of the carbonate unit is both very abundant, very diverse (46 species) and marked by the occurrence of *Persististrombus latus*, *Semicassis granulate, Stramonita haemastoma*, *Conus ventricosus* (Fig. 5). The assemblage is dominated by *Acanthocardia tuberculata* and *Glycymeris nummaria*.

The associated species are numerous (Table 2): *Arca noae*, *Pecten jacobaeus*, *Spondylus gaederopus*, *Ostrea edulis*, *Loripes lucinalis, Pseudochama gryphina, Chama gryphoides*, *Callista chione*, *Dosinia exoleta*, *Do. lupinus*, *Ruditapes decussatus*, *Polititapes rhomboides*, *Chamelea galina*, *Venus verrucosa*, *Donax trunculus*, *Eastonia rugusa*, *Mactra glauca*, *M. stultorum, Callista chione, Gastrana fragilis*, *Tellina planata*, *Diodora italica*, *D. graeca*, *Patella ferruginea*, *P. vulgata, P. caerula*, *Naticarius stercusmuscarum*, *Rissoa membranacea*, *Tarantinaea lignaria*, *Turritella communis*, *Hexaplex trunculus, Stramonita haemastoma, Cerithium vulgatum, Bittium reticulatum, Monophorus perversus, Cerithiopsis minima*, *C. tubercularis*, *Persististrombus latus*, *Semicassis granulata undulata*, *Nassarius mutabilis, N. reticulatus*, *Cyclope neritea, Columbella rustica* and *Thylacodes arenarius.*

Among gastropods, species *Cerithium vulgatum*, *Semicassis granulata undulata* and *Nassarius reticulatus* are the most common.

This very diverse assemblage (46 species) likely reflects a marine palaeoenvironment corresponding to the photosynthetic zone, in which Ca^{++} and CO_3 ions were sufficiently available to allow formation of thick calcareous shells. The components of this biocenosis would be dependent on sufficient primary producers and hence sufficient nutrients.

As regards the substrate, the bivalves of the Veneridae family, e.g., *Venus* and *Donax* indicate a soft substrate composed of fine sands, silt or mud. The rare attached gastropods, e.g., *Diodora graeca*, *D. italica*, *Patella ferruginea* and *P. caerula*, suggest the occurrence of sporadic gravel and rocky blocks in this shallow-marine biotope. The extreme scarcity of vermetids suggest the dispersion of rock blocks and pebbles on which these gastropoda may build large reefs in areas with permanent active waves and swell as in a few present-day Mediterranean localities (Fevret and Sanlaville, 1966; Safriel, 1974;

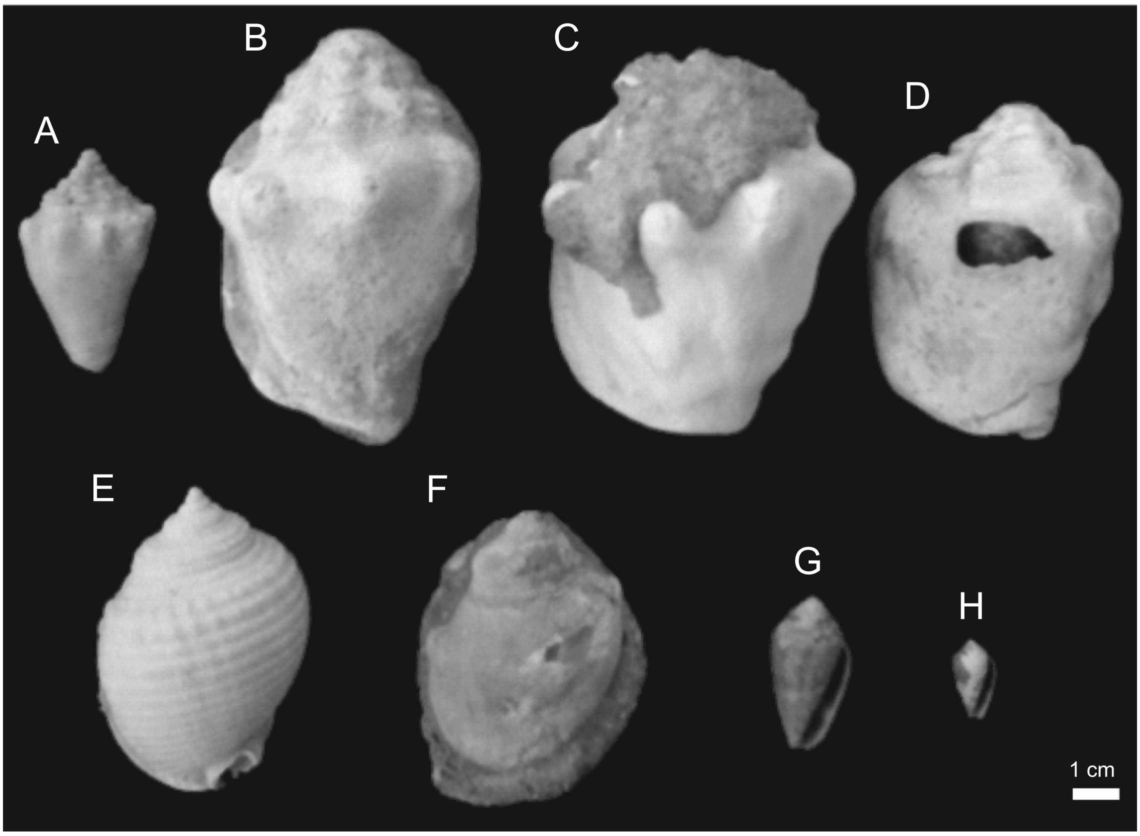

Fig. 5A – *Persististrombus* sp., B–D – *Persististrombus latus*, E – *Semicassis granulata undulata*, F – *Stramonita haemastoma*, G – *Conus ventricosus*

Dalongeville, 1995, 1996; Vescogni et al., 2008). However, the occurrence of *Persististrombus latus* Gmelin (a senior synonym of *Strombus bubonius* Lamarck) and *Stramonita haemastoma* (originally attributed to the genus *Thais*) indicates that this Upper Pleistocene fauna inhabited shallow warm marine waters (Bard et al., 1994; DeTurck et al., 1999; Rilov et al., 2001; Meco, 2002; Torres et al., 2006; 2010; Ramirez et al., 2009; Harding and Harasewych, 2007; Harzhauser and Kronenberg, 2013; Sessa et al., 2013; Muhs et al., 2014).

In the Q1 section (Fig. 2), bordering Chiba Wady, close to the bridge and few metres from the road leading to Menzel Temime, the faunal assemblage of the lower part of the carbonate unit is also very diverse with many of the same species observed in the marine carbonate unit Q1. This reflects a diverse and productive biocenosis, fossilised near its original biotope. Accumulation was in channels where the speed of currents close to the sea-floor enabled rapid transportation (Fig. 3C). Consequently, the bivalves comprise exclusively separate valves or debris; entire shells being absent.

In addition, among the gastropods, the species *Persististrombus latus* is omnipresent over the whole Qorba area, where many entire shells of this marine gastropod are preserved. Depending on the age of the animal the respective shells are more or less large and thick. Their size varies from 8 to 15 cm in height and 7 to 9 cm in width, without any modification of specific characters. This indicates that all these shells (small or large) belong to one and the same population of *Persististrombus latus*. Compared to those living today on the shallow-marine biotopes of Senegal, Gabon, Angola as well as around the Cape Verde islands and the Gulf of Guinea, which can be reach 100 m in depth, the Upper Pleistocene specimens from Qorba area are also large (Meco, 1977; Garcia-Talavera, 1990, 1999; Zazo et al., 1993a, b, 2006; De Turk et al., 1999; Avila, 2000; Goy et al., 2003, 2006; Ardovini and Cossignani, 2004; Rolan, 2005; Meco et al., 2011; Montesinos et al., 2014). This species requires warm marine waters (with an average temperature of 16°C in February and of 27°C in September). Meco (1977) noted that current strombids live in quiet marine biotopes located near the mouths of rivers. Various modes of life characterizing these diverse molluscs are recognized in this part of carbonate unit: (1) carnivores, e.g., those belonging to *Semicassis, Stramonita* and *Hexaplex*; (2) herbivorous grazers, e.g., those of *Persististrombus*, *Bittium*, *Cerithium*, *Rissoa* and *Patella* (3) suspension feeders, e.g., those of *Turritella*, *Donax, Pecten*, *Ostrea* and *Chama* (Perrier, 1954). The occurrence of suspension feeders requires that the waters were constantly renewed at the bottom. The herbivore taxa, as at present, were likely related to a mat of seaweed and/or seagrass of *Zostera* and *Posidonia* the traces of which are not fossilised. In their absence of the latter, these animals are able to swallow large amounts of sand to ingest dispersed cyanobacteria (Goiran, 1990).

Analysis of this marine sands part of the carbonate unit in the Q1 section shows that bioclasts which are abundant are mainly of bivalve and gastropod shells. As in the Upper Pleistocene deposits of Qorba, the microfauna is scarce and of low diversity. A few specimens of benthic foraminifera are recognized, e.g., *Ammonia beccarii* and *Elphidium crispum*.

In sum, the sedimentary facies of the carbonate unit of the Qorba sector is characteristic of channelized marine deposits (relatively coarse and well-sorted sands). Thus they correspond, in all likelihood, to storm deposits accumulated in abandoned channels and hollows within the subtidal zone in which water was warm and favourable to diverse bivalve and gastropod populations, especially strombids.

HERGLA SECTIONS

The basal part of the carbonate unit (Fig. 2, Hg1 and Hg2 sections) is composed of sands rich in mollusc shells with ooids and rare quartz grains. These sands are intercalated with thin coquina beds (Fig. 3Da, b) in which some bivalve species are dominant, e.g., *Acanthocardia tuberculata, Ceratoderma edule*, *Parvicardium exiguum*, *Glycymeris nummaria* and *Arca noae*.

In this assemblage the other bivalves are rare (e.g., *Arca tetragona*, *Chama gryphoides*, *Loripes lucinalis*, *Mactra glauca*, *Mactra stultorum, Callista chione*, *Spondylus gaederopus*, *Tellina planata* and *Venus verrucosa*. Gastropoda are also rare: *Semicassis granulata undulata*, *Columbella rustica*, *Conus ventricosus*, *Hexaplex trunculus*, *Neverita josephinia*, *Persististrombus latus, Turritella communis* and *Stramonita haemastoma* (Table 2).

The taphonomy indicates less turbulent shallow-marine water than in the Cap Bon area. However, the organization of deposits in four sequences with graded bedding suggests distant storm episodes still affected the Hergla area.

ASSEMBLAGE FROM THE MIS 4 AEOLIAN CARBONATE UNIT

In the Qorba as well as in the Hergla area (Fig. 2), the upper part of the carbonate unit is well-developed. It is composed of eolianites made of carbonate sands rich in ooids and pellets. These dunal oolitic sands are rich in various continental gastropods composed of *Helix* spp. and *Rumina decollata*. However in the Menzel Temime area these coastal dunal deposits are less well-developed or absent.

PALAEOENVIRONMENTAL RECONSTITUTION

The diverse assemblages from the areas studied, by their structure, the ecological significance of species content and their preservation, inform about their habitats and their depositional environment (Table 4).

In the Menzel Temime area, the fauna within the lower part of the quartz-rich unit is very diverse. This biodiversity reflects optimal environmental conditions characterizing their biotope. The preservation of many disarticulated bivalve valves demonstrates that the biocenosis did not undergo postmortem transport. The assemblage is dominated by endobenthic species, living in a loose substrate composed of sands or mud. It is also characteristic of a moderately agitated shallow-marine biotope.

Farther south in the Qorba area, the assemblage from the lower part of the quartz-rich unit, attributed to MIS 7, is dominated by cardiids and glycymerids, e.g., *Acanthocardia tuberculata*, *Parvicardium exiguum*, *Ceratoderma edule* and *Glycymeris nummaria*. By contrast *Nassarius sufflatus* and *Semicassis granulata undulata* are less frequent. Most of these mollusc species (Table 4) are of a shallow-marine biotope, living buried in fine sand and mud substrates.

Shells are commonly preserved entire, and debris is rare. These shells are regularly arranged in planar laminae. This suggests that the biota was affected by little or no transport from its biotope. This biotope may be compared to that of a sheltered bay, characterized by calm-water.

In the Qorba area, the marine part of the quartz-rich unit is overlain by fine sands with abundant root traces (Fig. 3Db). These sands, suggest that an exposed barrier along the beach had formed and adjoined the shallow-marine environment.

In the Hergla area, the quartz-rich unit is characterized by the same species (*Acanthocardia tuberculata*, *Parvicardium exiguum*, *Ceratoderma edule* and *Glycymeris nummaria*) in the same frequencies. Its lithological and faunal characteristics make it the lateral equivalent of the MIS 7 quartz-rich deposits at Menzel Temime and Qorba. However, Mauz et al. (2009) defined it as the lower member of the Khnis unit and attributed it to MIS 5e. Later, Mejri et al. (2012) dated this level at two localities in the Sahel (El Hajeb and Hergla) by IRSL and attributed it to MIS 7 in El Hageb whereas no chronological data have been obtained for the Khnis locality.

At Hergla, this quartz-rich deposit is overlain locally by lenticular clay suggesting a lagoon with brackish stagnant-water and continental deposits.

In the Qorba and Hergla areas, the lower part of the carbonate unit is rich in molluscs. The assemblage is very diverse and dominated by *Acanthocardia tuberculata, Glycymeris nummaria, Parvicardium exiguum*, *Ceratoderma edule and Arca noae. Nassarius sufflatus* and *Semicassis granulata undulata* are less frequent. The occurrence of ecological markers such as *Stramonita haemastoma* and *Conus ventricosus* (Fig. 5), especially the thermophilic species *Persististrombus latus*, indicate shallow warm marine water similar to that known in the present tropical zone.

Particularly in the Qorba area, the lower deposits of the carbonate unit are organized in three to four sequences filling submarine channels. In each sequence, bounded by an erosive base, sedimentary clastic and shell elements (disarticulated, rolled, altered and even finely broken) are arranged in positively graded layers. Each of these sequences suggests that in the subtidal abandoned channels intermittently accumulated shells and debris during storms as transgression proceeded (Chakroun et al., 2009a, b). In Hergla area storms effect was minor.

The upper part of the carbonate unit, rich in ooids, pellets, terrestrial gastropoda and root structures, corresponds to MIS 4 coastal dunal deposits (Chakroun, 2006; Mauz et al., 2009; Chakroun et al., 2009a, b). These dunal deposits are consistent with strong winds acting on an exposed platform during the Late Pleistocene. They are deposited during low stand conditions (Le Guern, 2005; Frébourg et al., 2008).

PERSISTISTROMBUS LATUS DISTRIBUTION

In Tunisia, the marine part of the carbonate unit containing *Persististrombus latus* Gmelin is commonly attributed to the isotopic substage 5e or MIS 5.5 (Dubar et al., 2008; Torres et al., 2010). This biomarker is frequent and often associated with *Stramonita haemastoma* and *Nassa circumcincta* at many localities near the north eastern coast line of the Cap Bon Peninsula (Fig. 6B), e.g., near Qorba, Tazaraka and Lebna beach. However, in the Menzel Temime area, it is absent but *Stramonita haemastoma* and *Nassa circumcincta* persist (Chakroun, 2006). Near the northwestern coast line of this peninsula the Upper Pleistocene deposits are different. They are composed of consolidated sands in which molluscs are absent but decapod burrows (e.g., *Callianassa* sp.) are common. These latter suggest a supratidal environment.

In the northeast locality of the Cap Bon Peninsula in the El Haouaria area, the carbonate unit is composed of sands rich in *Acanthocardia tuberculata* and *Glycymeris nummaria* overlain by soil, in which present-day ploughing exhumes rare specimens of *Persististrombus latus* (Fournet, 1981; Chakroun,

Table 4

Taxonomic composition and ecology of specimens identified in the Upper Pleistocene deposits

TAXA	MT	QRB	HRG	KN(a)	ECOLOGICAL CHARACTERISTICS
BIVALVIA					Substrate/tiering/mobility/feeding
*Acanthocardia tuberculata (*Linnaeus, 1758)	■	■	■	■	Sand, mud or gravel/epifaunal/facultatively mobile/suspension feeder
Barbatia barbata Linnaeus, 1758					Hard/epifaunal/stationary, attached/suspension feeder
Arca noae Linnaeus, 1758	■	■	■	■	Hard/epifaunal/stationary, attached/suspension feeder
Arca tetragona Poll, 1795			■	■	Hard/epifaunal/stationary, attached/suspension feeder
Ceratoderma edule (Linnaeus, 1758)	■	■	■	■	Sand, mud and gravel/endobenthic/mobile/suspension feeder
Callista chione (Linnaeus, 1758)	■	■		■	Sand/infaunal/facultatively mobile/suspension feeder
Chama gryphoides Linnaeus, 1758		■	■	■	Hard/epifauna/stationary, attached/suspension feeder
Chamelea gallina (Linnaeus, 1758)	■	■	■		Sand and mud/infaunal/facultatively mobile/suspension feeder
Dosinia exoleta Linnaeus, 1758	■	■		■	Sand/infaunal/facultatively mobile, creeping/suspension feeder
Donax trunculus Linnaeus, 1758	■	■			Sands and mud/infaunal/facultatively mobile/suspension feeder
Dosinia lupinus (Linnaeus, 1758)	■	■			Sand/infaunal/facultatively mobile, creeping/suspension feeder
Eastonia rugosa (Helbing, 1779)	■	■		■	Sand and mud/ infaunal/ facultatively mobile/ suspension feeder
Ensis ensis Linnaeus, 1758	■				Sand or mud/infaunal/stationnay/suspension feeder
Gastrana fragilis (Linnaeus, 1758)	■	■		■	Sand/ infaunal/facultatively mobile/deposit feeder
Glycymeris nummaria (Linnaeus, 1758)	■	■	■	■	Sand or gravel/semi-infaunal/creeping/suspension feeder
Loripes lucinalis (Lamarck, 1818)	■	■	■	■	Sand and gravel/deep infaunal/facultatively mobile/chemosymbiotic
Mactra stultorum (Linnaeus, 1758)	■	■	■	■	Sand/infaunal/facultatively mobile/suspension feeder
Mactra glauca Born, 1778	■			■	Sand/infaunal/facultatively mobile/suspension feeder
Pitar rudis (Poli, 1795)	■				Sand/infaunal/facultatively mobile/suspension feeder
Modiolus barbatus (Linnaeus, 1758)			■	■	Hard/semi-infaunal/stationary/suspension feeder
Ostrea edulis Linnaeus, 1758	■	■			Hard/epifaunal/immobile attached/suspension feeder
Parvicardium exiguum Gmelin, 1791	■	■	■		Sand/epifaunal/facultatively mobile/suspension feeder
Pecten jacobaeus (Linnaeus, 1758)	■	■			Sand/epifaunal/facultatively mobile/suspension feeder
Polititapes rhomboides (Pennant, 1777)	■	■	■		Mixed/infaunal/facultatively mobile/suspension feeder
Pseudochama gryphina (Lamarck, 1819)	■	■	■		Hard//epifaunal/immobile attached/suspension feeder
Solecurtus strigilatus (Linnaeus, 1758)	■			■	Sand/infaunal/facultatively mobile/suspension feeder
Spondylus gaederopus Linnaeus, 1758		■	■		Hard/epifaunal/immobile attached/suspension feeder
Ruditapes decussatus (Linnaeus, 1758)		■	■		Sand, muddy gravel and clay/infaunal/facultatively mobile/suspension feeder
Tellina planata Linnaeus, 1758	■	■	■	■	Sand, muddy gravel and clay/infaunal/facultatively mobile/suspension feeder
Venus verrucosa Linnaeus, 1758	■	■	■	■	Sands, muddy gravel or clay/ infaunal/ facultatively mobile/suspension feeder
GASTROPODA					
Bittium reticulatum (Da Costa, 1778)		■			Seagrass system/epibenthic/mobile/grazer, deposit feeder
Cerithiopsis minima (Brusina, 1865)		■			Hard/epifaunal/mobile/ectoparasite and carnivore
Cerithiopsis tubercularis (Montagu, 1803)		■			Live and gaze on sponge/epifaunal/mobile/deposit feeder, carnivore
Cerithium vulgatum Bruguiere, 1792	■	■	■	■	Mixed/epifaunal/mobile/herbivore
Columbella rustica (Linnaeus, 1758)		■	■	■	Hard/ epifaunal/creeping/omnivore-grazer, Herbivore
Conus ventricosus Gmelin, 1791			■	■	Mixed/epifaunal/creeping/scavenger, predator
Cyclope neritea (Linnaeus, 1758)	■	■			Sands and mud/epifauna/slow-moving/carnivore
Diodora italica (Defrance, 1820)		■			Hard/epifaunal/attached, facultatively mobile/ectoparasites and carnivore, herbivore
Diodora graeca (Linnaeus, 1758)		■			Hard/epifaunal/attached, facultatively mobile/ectoparasites and carnivore, herbivore
Hexaplex trunculus (Linnaeus, 1758)	■	■	■	■	Mixed/epifaunal/creeping/carnivore, predator,scavenger
Monophorus perversus (Linnaeus, 1758)		■			Mixed/epifaunal/mobile/ectoparasites and carnivore
Nassarius reticulatus (Linnaeus, 1758)	■	■			Sandy and gravels/epifaunal/ slow-moving low-level/carnivore, scavenger
Nassarius sufflatus (Gould, 1860)	■	■	■	■	Sandy and gravels/epifaunal/slow-moving low-level/carnivore, scavenger

Tab. 4 cont.

TAXA	MT	QRB	HRG	KN(a)	ECOLOGICAL CHARACTERISTICS Substrate/tiering/mobility/feeding
Neverita josephinia Risso, 1826		■	■		Sand/infaunal/slow-moving/carnivore, predator
Naticarius stercusmuscarum (Gmelin, 1791)		■			Sand or mud/infaunal/slow-moving/carnivore, scavenger
Patella caerula Linnaeus, 1758		■			Hard/epifaunal/facultatively mobile, attached/herbivore
Patella ferruginea Gmelin, 1791		■			Hard/epifaunal/facultatively mobile, attached/herbivore
Patella vulgata Linnaeus, 1758		■			Hard/epifaunal/facultatively mobile, attached/herbivore
Persististrombus latus (Gmelin, 1791)		■	■	■	Sand/epifaunal/creeping/herbivore, omnivore-grazer
Rissoa membranacea (Adams, 1800)		■			Mixed/epifaunal/mobile/herbivore, grazer
Semicassis granulata undulata (Gmelin, 1791)	■	■	■		Mixed/epifaunal/creeping, grazer/predatoroy, carnivore
Stramonita haemastoma (Linnaeus, 1758)	■	■	■		Hard/epifaunal/creeping, predator/scavenger, carnivore
Tarantinaea lignaria (Linnaeus, 1758)		■			Hard/epifaunal/herbiers/carnivorous.
Thylacodes arenarius (Linnaeus, 1758)		■			Hard/stationary, attached/infaunal/suspension feeder
Turritella communis Risso, 1826		■	■		Sand/epifaunal/facultatively mobile/suspension feeder
Helix spp.		■	■		Mixed (terrestrial), epifaunal/free/herbivorous
Rumina decollata Linnaeus, 1758		■	■		Mixed/terrestrial snail/carnivore/predator.
ECHINOIDEA					
Echinocardium cordatum (Pennant, 1777)	■				Sand/infaunal/slow-moving/deposit feeder-detritivore
FORAMINIFERA					
*Ammonia beccarii (*Linnaeus, 1758)			■		benthic stationary semi-infaunal/herbivore
Ammonia tepida (Cushman, 1926)			■		bentic/stationary semi-infaunal/herbivore
Asterigerinata mamilla (Williamson, 1858)			■		benthic/stationary semi-infaunal/omnivore
Elphidium crispum (Linnaeus, 1758)			■		benthic/stationary semi-infaunal/omnivore
Nonion sp.			■		benthic/stationary semi-infaunal/omnivore
Textularia sp					benthic/stationary infaunal/detritivore
MAMMELS					
Phacochoerus aethiopicus (Pallas, 1766)		■			ground dwelling omnivore
Gazella atlantica Bourguinat, 1870		■			ground dwelling grazer-browser
Alcelaphus buselaphus (Pallas, 1766)		■			ground dwelling grazer
Equus mauritanicus Pomel, 1897		■			ground dwelling grazer
Ceratotherium simum (Burchell, 1817)		■			ground dwelling grazer
Hystrix cristata Linnaeus, 1758		■			semi fossorial herbivore-frugivore

MT – Menzel Temime, QRB – Qorba, HRG – Hergla, KN – Khnis, (a) – additional data from (Mahmoudi, 1986); grey – species occurrence; for the faunal determination and the ecological characteristics, we referred to Abbott (1960), Perrier (1954), Fekih (1975), Meco, (1977) and Sessa et al. (2013); taxonomic attributions were updated by using the database: the World Register of Marine Species

2006). Farther towards the south, in the Kelibia area, this biomarker is usually associated with or replaced by *Stramonita haemastoma*.

Along the rest of the eastern coast line of Tunisia (Fig. 6C), *Persististrombus latus* is often present in the carbonate unit, especially near the beaches of Hergla, Monastir, Khnis, Mahdia, Rejiche, Chebba, Kerkennah and Djerba (Castany, 1954, 1955, 1956; Paskoff and Sanlaville, 1976; Oueslati, 1980; Kamoun, 1981; Oueslati et al., 1982; Mahmoudi, 1986; Jedoui, 2000; Chakroun, 2006; Chakroun et al., 2009a). It is represented by large specimens with large tubercles, also found by Mahmoudi (1986). Such forms are reminiscent of their counterparts living today in the Gabon coastal area to a depth of 4 to 8 m (Bernard, 1984). Farther towards the south, near the coastline of Gabes and Djerba Island, the carbonate unit is rich in strombids, ooids, pellets of crustaceans and bioclasts (Castany, 1955; Paskoff and Sanlaville, 1977). This facies indicates a warm and agitated platform (Lucas, 1955; Purser, 1980; Chakroun, 2006).

In northern Tunisia (Fig. 6A), only *Stramonita haemastoma* without strombids was reported in Pleistocene deposits of the Galite Island (Issel, 1880). Towards the south along the Mogods and Cap Blanc coastline *Persististrombus latus* species has been never reported (Solignac, 1927; Miossec, 1977; Chakroun, 2006). However, east of Bizerte city near the R'Mel beach it is sporadically present in carbonate bioclastic sands (Ben Ayed et al., 1978). In contrast, it is more frequent in the Raraf area (Chakroun et al., 2016).

Elsewhere in the Upper Pleistocene deposits situated around the Mediterranean Sea, the *Persististrombus latus* show a different distribution. In the Levant, it was reported in Lebanon (Fleisch and Gigout, 1966; Fleisch and Sanlaville, 1967; Sanlaville, 1969, 1978; Fleisch et al., 1971), in North Haifa (Issar and Kafri, 1972; Sivan et al., 1999), in Cyprus especially in Larnaca and west to Coral Bay (Poole et al., 1990). In Greece, the Senegalese fauna composed of *Loripes lucinalis*, *Conus testudinarius*, *Cantharrus viverratus* and *Stramonita haemastoma* and including *Persististrombus latus* was signaled in many localities in border of the south coast of Crete (Keraudren et al., 2000) and in Italy (Hearty et al., 1986a, b; Balescu et al., 1997). It is present in the isotopic stage 5 terraces along the southern Calabria (Dumas et al., 1988, 2002), in border of the Ionian coast and in Crotone Peninsula (Nalin et al., 2012) as well as Sicily (Gignoux, 1913; Antonioli et al.,

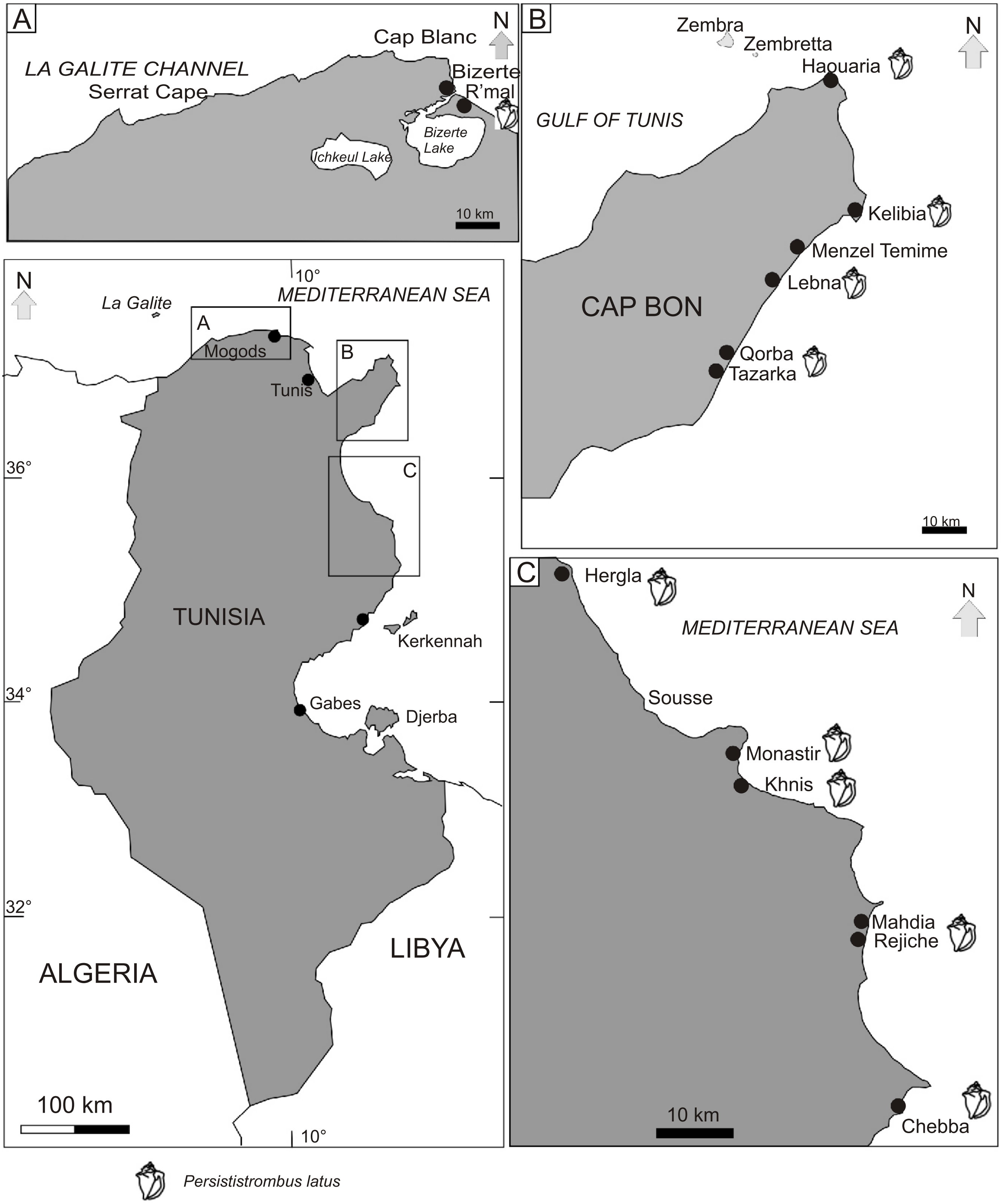

Fig. 6. Distribution map of *Persististrombus latus* on the Tunisian coast

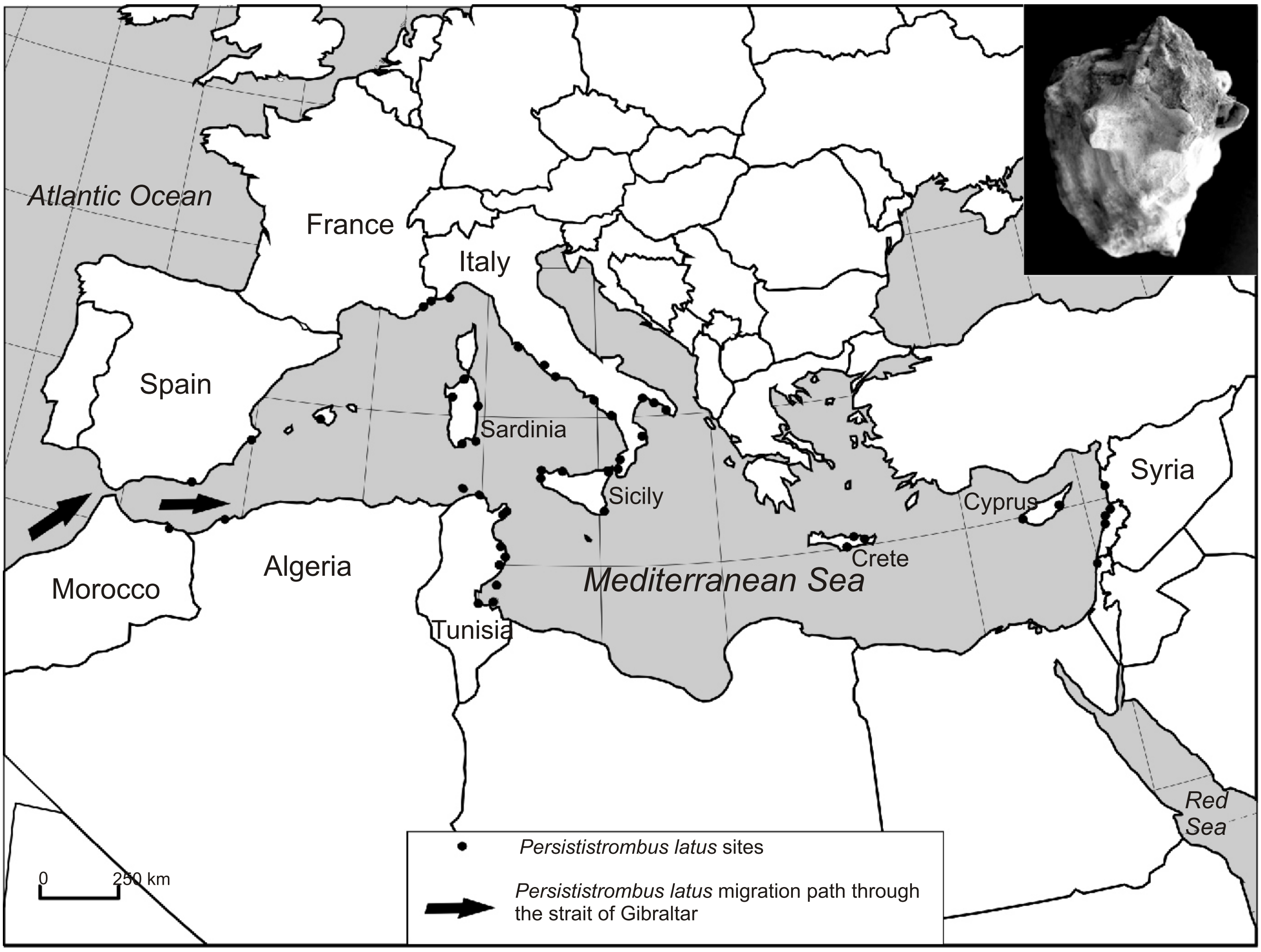

Fig. 7. Distribution map of the *Persististrombus latus* sites on the Mediterranean coast

Sources of data: Syria (Sanlaville, 1979); North Haďfa (Issar and Kafri, 1972; Sivan et al., 1999); Lebanon (Fleisch and Gigout, 1966); Cyprus (Poole et al., 1990); Greece (Keraudren et al., 2000); Italy (Gignoux, 1913; Ozer et al., 1980; Hearty et al., 1986a, b; Dumas et al., 2002; Antonioli et al., 2006; Nalin et al., 2012); Tunisia : present work; France (Valensi et al., 2007; Dubar et al., 2008); Spain (Hillaire-Marcel et al., 1996; Zazo, 1999; Zazo et al., 2003; Goy et al., 2006); Algeria (De Lamothe, 1911); Morocco (Guillemin, 1976; Hearty, 1986; Sbai, 2008; Muhs, 2015)

2006). In Sardinia strombids are rare (Ozer et al., 1980; Kindler et al., 1997; Le Guern, 2005). In this island the Upper Pleistocene assemblage is mainly composed of *Patella ferruginea* and *Conus testudinarius* (Lecca and Carboni, 2007). In Spain *Persististrombus latus* was found in Almeria, Alicante and Mallorca (Hillaire-Marcel et al., 1986; Zazo and Goy, 1989; Hillaire-Marcel et al., 1996; Zazo, 1999). Its first appearance in Almeria is associated to the MIS 7a (Zazo, 1999).

In southeastern of France, between Nice and Menton, the distribution of the Senegalese fauna including *Persististrombus latus* was used to reconstruct the palaeocoast line characterizing the Tyrrhenian period (Bonifay, 1961; Valensi et al., 2007; Dubar et al., 2008). The palaeoshore towards the south of Nice included Grimaldi caves in Italian Liguria (Cave of the Prince, Barma Grande), Monaco and Cap Ferrat (Bonifay, 1975). In northern Morocco, the *Persististrombus latus* occurs in the Pleistocene marine deposits at El Hoceima (Guillemin, 1976; Hearty et al., 1986b; Sbai, 2008; Muhs, 2015). In Algeria the most important fossil deposits of *Persististrombus latus* are located in Gulf of Oran, Gulf of Arzew and Gulf of Mostaganem (De Lamothe, 1911).

Consequently, this distribution of the Senegalese fauna especially *Persististrombus latus* (Fig. 7) in the circum-Mediterranean areas (in North Africa and Europe) allows the reconstruction of the shallow warm marine zone distribution during the Late Pleistocene. *Persististrombus latus* is a shallow-marine thermophilic species living nearby sheltered beaches.

Only while these ecological conditions are met this biomarker thrived. The species *Persististrombus latus* or its senior synonym *Strombus bubonius* were frequently signaled in many Mediterranean coastal Tyrrhenian deposits (Gignoux, 1911).

In the circum Mediterranean Sea the Senegalese Faunal Complex association including *Persististrombus latus* and other mollusc species indicates seawater warming during interglacial episodes along the Pleistocene, which corresponded to periods of high sea level. In fact, current *P. latus* is restricted to the Eastern Atlantic Region, occurring in an area from the Rio d'Oro to Angola and limited in the north by the Canary Current and in the south by the Benguela Current. Its northern distribution borders are the Cape Verde Islands (Kreipl et al., 1999). An average temperature of 25°C favours this gastropod; however, it tolerates a temperature range from 16 to 31°C. Its average lifespan of 3–5 years is characterized by a cyclic growth rate, depending on the seasonality of the sea surface temperature. *P. latus* is a gregarious species cantoned to shallow-waters (Meco, 1977; Mendes-Lopes, 2002). It is known in sandy-muddy bottoms and seagrass meadows and follows detritivorous and vegetarian feeding strategies (Lozac'hmeur and Mascarenhas, 1985), typically in waters with normal salinity (Guerreiro, 1994; Guerreiro and Reiner, 2000; Mendes-Lopes, 2002). However, in the Gulf of Guinea, Meco (1977) found *P. latus* representatives in zones with freshwater input and consequently lower salinity. Although *P. latus* inhabits soft bottoms, and may be sheltered by rocky blocks.

Comparing Pleistocene and Present distribution *of P. latus* we note that during the Late Pleistocene this warm species was cantoned to circum Mediterranean Sea. At present this species as well as its congeneric species, has become restricted to tropical seas. It is clear that this thermophilic species migrated during the glacial period succeeding the 5e substage in order to find again warm water (warmer than in current Mediterranean Sea).

SUMMARY AND CONCLUSIONS

These Pleistocene (MIS 7, MIS 5e and MIS 4) deposits exposed along the eastern coast of Tunisia, by their diverse facies and fauna contents, provide valuable information about environments prevailing during this period. Taking into account the palaeoecological requirements of different species composing the successive faunal assemblages, species richness, species relative abundance and preservation status of the different specimens, the Pleistocene palaeoenvironments are restored. These assemblages are representative of biological communities which have been affected by more or less distant transportation. In all the cases these marine communities were developed during an interglacial warm period. Any change in the assemblages traduces change in communities. These changes would be related to climate and environmental fluctuations.

Thus, facies and faunal assemblage characteristics in the basal term of the quartz-rich unit (Douira Formation), attributed to the MIS 7, indicates quite marine shallow environment in Cap Bon Peninsula. Well-preserved shells of abundant cardiids, glycymerids, arcids, lucinids and donacids suggest shallow and quite marine water characteristic of a sheltered bay or part of lagoon connected with the sea.

The quartz-rich deposits (Khnis Formation) identified in Hergla and attributed to the MIS 5e show the same species as the Cap Bon (MIS 7) deposits. Indeed, the presence of *Loripes lucinalis*, presently known to be able to live in confined biotopes in which dissolved oxygen is low and salinity is variable, may indicate lagoon with stagnant and confined water.

An upper aeolian quartz-rich term is associated to MIS 7 and MIS 5e lagoon deposits of unit deposition these marine or lagoonal environments became exposed and coastal dunes were developed. It had been fixed by more or less dense vegetation and contained continental snails (*Helix* spp. and *Rumina decollata*). The abundance of quartz grains in this aeolian part suggests relative humid conditions along the palaeoshore.

The deposition of the lower part of the carbonate unit, rich in marine fauna of MIS 5, in the Cap Bon area as well as the Hergla area indicates marine transgression. In this shallow-sea there thrived diverse shallow-marine species, e.g., bivalves: *Acanthocardia tuberculata, Ceratoderma edule*, *Parvicardium exiguum*, *Glycymeris nummaria*, *Arca noae*, *A. tetragona*, *Chama gryphoides*, *Loripes lucinalis, Mactra coralina*, *M. glauca*, *Callista chione, Spondylus gaederopus*, *Tellina planata*, *Venus verrucosa*. Gastropods are less frequent with *Semicassis granulata undulata, Columbella rustica*, *Conus ventricosus*, *Hexaplex trunculus*, *Nassarius sufflatus, Neverita josephinia*, *Persististrombus latus, Turritella communis*, *Stramonita haemastoma*. Within this assemblage thermophilic species are frequent as in the Senegalese fauna. *Persististrombus latus* is especially common. Its presence is indicative of climate warming. The grouping of deposits and fauna into four graded sequences suggests that the warmer climate included storm episodes.

As the upper part of the carbonate unit was deposited marine regression exposed the entire coastline including the previous subtidal environment. In the backshore area large dunes were developed, attributed to MIS 4, suggesting strong wind action.

In sum, the Mid-Upper Pleistocene facies and fauna suggest different environments related in space and over time: (1) a subtidal environment with sheltered bay; (2) a lagoonal environment with oligospecific fauna, (3) a subtidal environment recording storm action in submarine channels, (4) a shoreline with coastal dunes resulting from strong wind action.

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