Quaternary beach deposits in Mallorca: paleontological and geomorphological data

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1. Research on Quaternary shorelines from Mallorca. Historical background

Many researchers have worked on the Quaternary deposits scattered along the littoral zones of Mallorca Island. As a consequence, there are a significant number of publications on this topic, being almost impossible to assemble a comprehensive review in a general chapter like this one. Therefore, the present paper exclusively provides a historical background on the knowledge of Mallorcan Quaternary shorelines, along with their paleontological remains and chronology.

La Marmora (1834) was the first geologist writing about Quaternary deposits on Mallorca Island. This author reports the presence of sandstones (with modest fossil content) in the southern flat areas of the island and conglomerates with marine shells, resembling those of present-day beaches, in just a few places.

Haime (1855) dedicates only a paragraph in his study on the Quaternary paleontology, citating 12 species. Hermite (1879) distinguishes two levels within the marine raised beaches existing to the east of Palma Bay. The lower level is composed of some conglomerates previously mentioned by Haime, containing *Acanthocardia tuberculata*, along with other species currently living in the Mediterranean Basin, except for the thermophilous species *Strombus bubonius*. The upper level, abundant on fragments of small-sized marine shells and foraminifera, is correlated with the deposits cited by La Marmora.

Hermite (1879), Hoernes (1905), and Collet (1909) described some calcareous deposits containing *Helix*. However, it was Gignoux (1913), who indicated the real origin of these formations, i.e., they are ancient hardened dune materials. This author also establishes the synchronism of the Mallorcan deposits containing *Strombus bubonius* with those from other sites in the Western Mediterranean Basin, but he

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considers quite difficult to resolve the precise elevation of the sea level at the time when the sedimentation of these materials took place.

When referring to the Quaternary of Mallorca, Fallot (1922) focuses his attention on the alluvial sediments but when discussing the marine formations, he simply reproduces the previous observations of Hermite.

Beginning with 1950, Andreu Muntaner and Joan Cuerda started to publish some notes on the Quaternary from Palma Bay, in the *Bolletí de la Societat d'Història Natural de les Balears*. As a result of these investigations, in 1952, two levels situated at +4 and +2 m ASL, respectively, were distinguished within the Eutyrrhenian (or Tyrrhenian II). In addition, their studies are citing a total of 110 marine species (Cuerda & Muntaner, 1952). The researches continued over the next years, culminating with two major papers: one by Joan Cuerda on the paleontology of marine Tyrrhenian deposits in the Bay of Palma (Cuerda, 1957), and the other by Andreu Muntaner devoted to the Tyrrhenian stratigraphy in the same area (Muntaner, 1957). The scientific expertise of the two authors, as well as their abundant publication record and the paleontological collections assembled by them, prompted the Organizing Committee of the *V International Quaternary Congress (INQUA)* to develop a fieldtrip in Mallorca in September 1957 (Figure 1).

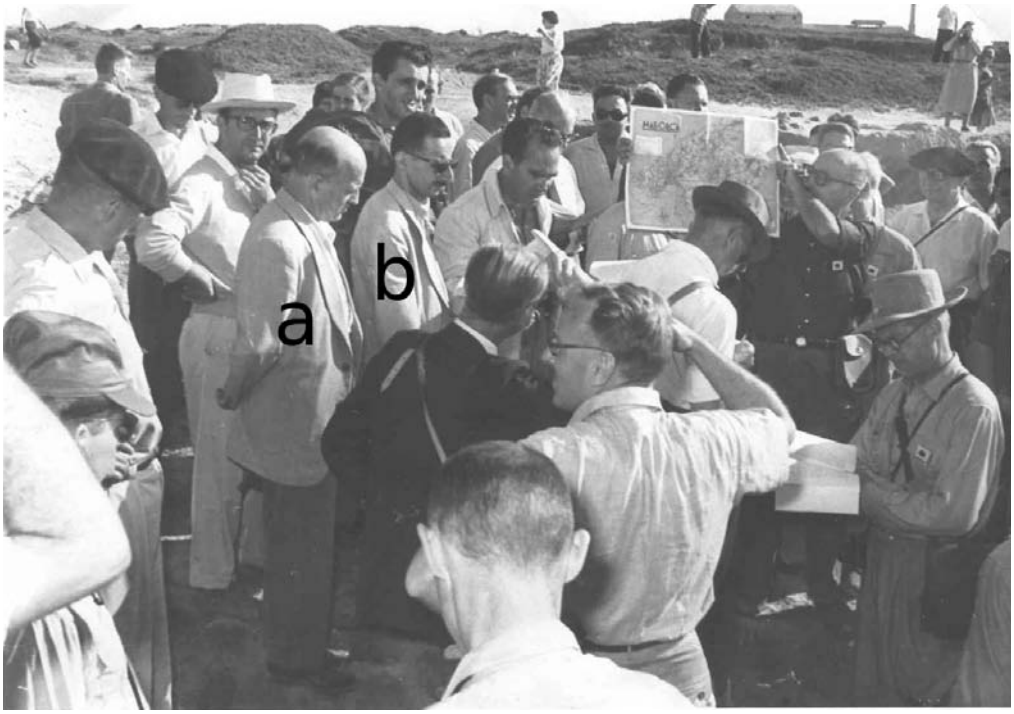

Figure 1. A visit to Es Carnatge site (known in most of the papers as "Campo de Tiro") in September 1957, during the 5th INQUA Congress fieldtrip to Mallorca. Joan Cuerda (a) and Andreu Muntaner (b), two remarkable local Quaternary researchers, were part of the committee organizing the Mallorca fieldtrip (Photographic archive of Andreu Muntaner).

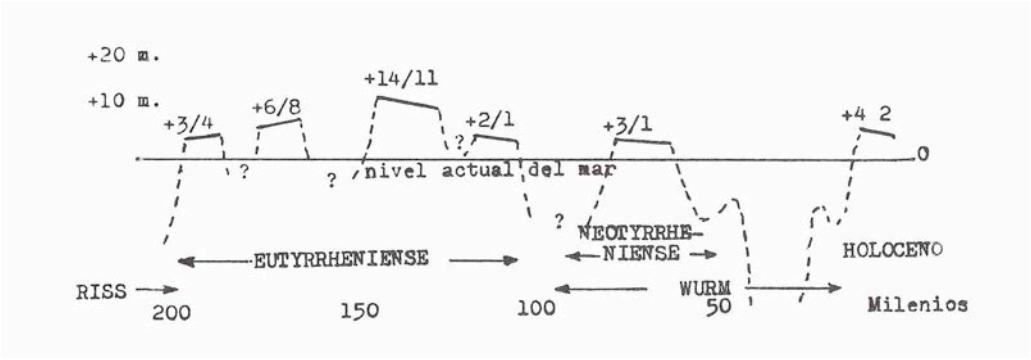

Figure 2. Eustatic sea-level curve proposed by Cuerda (1975) based on the elevation of Mallorcan marine deposits and the U/Th datings of shells published by Stearns & Thurber (1965).

Between 1950 and 1962, Karl W. Butzer and Joan Cuerda conducted three research campaigns in the Balearic Islands revealing a large number of Middle and Upper Pleistocene shorelines and marine deposits. Their investigations on marine erosion platforms and the paleontological remains in the littoral deposits, pointed out to a multitude of ancient sea levels recorded along the Mallorcan coasts (Butzer & Cuerda, 1960, 1962a, b).

Also, the paper by Solé-Sabaris (1962) is remarkable in that it reviewed the marine Quaternary deposits in the Balearics and attempted to elucidate their relationships with the shorelines of the Iberian Peninsula. Furthermore, of special significance was the first U/Th age determinations conducted by Stearns & Thurber (1965) on molluscs from Mallorcan marine deposits, belonging to the Upper Pleistocene. These age-data allowed Cuerda (1975) and Butzer (1975) to generate tentative eustatic sea-level curves (Figure 2), exclusively based on the elevation and chronology of the studied sites.

Certainly, the year 1975 represents a milestone for the Quaternary studies in the Balearic Islands due to the publication of the monograph compiled by Joan Cuerda. In this outstanding work (Cuerda, 1975), apart from some general concepts about the Quaternary, the author focuses his attention on the marine deposits of the Balearics both from the stratigraphic and paleontological points of view. Another publication synthesizing the information that became available for the Quaternary in Mallorca was elaborated by Pomar & Cuerda (1979).

A few years later, a stimulating book edited by Rose (1978) is published on the Quaternary of Mallorca. A large part of the information provided is based on the earlier works of Cuerda, but new data supplied by researchers from the United Kingdom were also included. Richards (1985) made some contributions to the topic using previous publications and his own personal data; the author suggested that the highest raised beaches of the Eutyrrhenian were affected by tectonic movements. Stearns (1985) presented some criticisms on their own pioneer U/Th dating work.

In 1987, another important monograph resulting from Cuerda's continuous dedication was published. The work contains a complete catalogue of marine and

brackish water molluscs collected from Pleistocene littoral deposits of the Balearic Islands (Cuerda, 1987). The very same year, Hearty (1987) published a paper that presents the dating of 15 Mallorcan sites using amino acid racemization technique; the obtained data are presented in the context of aminostratigraphic studies carried out around the world.

Cuerda & Sacarés (1992) published a book that compiles all their investigations on the Quaternary deposits from Llucmajor municipality. Also in the 90s, two more relevant studies which provide new absolute ages for the Pleistocene littoral deposits from Mallorca were published by Hillaire-Marcel *et al*. (1996) and Rose *et al*. (1999).

In an extensive investigation of the phreatic overgrowths on speleothems (POS) in the coastal caves of Mallorca, Ginés (2000) critically reviewed the sea-level and the chronological data emerging from the stratigraphic study of raised beaches. Using the POS record, Ginés's PhD dissertation suggests some preliminary eustatic sea-level curves rather different to those of Cuerda (1975) and Butzer (1975). More detailed and updated contributions to sea level history in Mallorca have been recently published by Tuccimei *et al*. (2006) and Dorale *et al*. (2010), both based on the investigation of phreatic speleothems.

Several papers –some relatively recent– deal specifically with stratigraphic, paleontological, or chronologic aspects of the Pleistocene sites from Mallorca; the following are worth to mention: Cornu *et al*. (1993), Goy *et al*. (1997), González-Hernández *et al*. (2000), Vicens *et al*. (2001), Zazo *et al*. (2005), Vicens & Pons (2007), and Muhs *et al*. (2010). All these papers include extensive reference lists that give readers access to more information on those specific topics. Significant to the Western Mediterranean domain are also the publications of Hearty *et al*. (1986), Zazo *et al*. (2003, 2004), and Bardají *et al*. (2009). Even the paper of Meco (2008) on Canary Islands is of great interest from a paleontological point of view, because during MIS 5e the Mediterranean Sea shared species of thermophilous fauna with this Atlantic archipelago.

2. The Pleistocene littoral fossil assemblages

There are a series of taxa that are extremely useful with respect to the chronology of marine deposits in the Balearic Islands. In particular, those species corresponding to the Upper Pleistocene are the best known due to the abundance of sites allowing the study of their paleontological records. The Lower- and Middle Pleistocene-related taxa are really scarce and not well-documented up to now.

The taxonomic nomenclature used in this paper are not updated, but suggested instead those habitually used in the marine Quaternary of Mallorca reference. However, the correspondence between the used taxonomy and the alternative equivalence of Appeltans *et al*. (2011) is listed in Table I.

Currently, the institution in the Balearic Islands that hosts the most extensive collection of Pleistocene littoral fossils is the *Societat d'Història Natural de les Balears*. This collection was assembled thanks to a number of donations from different local

researchers, among which the late Joan Cuerda. The majority of the available collections (Figure 3) are partially catalogued; nowadays the paleontological register includes nearly 8,000 entries and the number of specimens exceeds 28,000 fossils (Table II).

2.1. Marine fossils from the Lower and Middle Pleistocene

There are few known marine fossil taxa reported from the Lower and Middle Pleistocene of Mallorca (Cuerda, 1987). Among the most representative, *Saccostrea virleti* and *Purpura gallica* (nowadays extinct molluscs) are attributed to the Plio-Quaternary limit.

Two species from the Lower Pleistocene are cited: *Saccostrea cucullata* and *Purpura pleissi*. The first one lives today along the Red Sea and African inter-tropical coasts, whereas the second one is an extinct taxon.

Table I. Marine and brackish-water species having stratigraphic significance after Cuerda (1987), and their correspondence with the nomenclature by Appeltans *et al*. (2011). (♦): correspondence proposed by the authors of this paper. (●): doubtful correspondence that needs further in-depth revision. (♥): the type-species is banal, but a variety (var. *nodulosa*) and a subspecies (ssp. *consul*) have stratigraphic significance. (---): the correspondence has not been established, perhaps because there are mainly brackish-water species and no strictly marine ones. (♠): Cited by Cuerda (1975).

Class	Cuerda (1987)	Appeltans *et al*. (2011)
Bivalvia	*Barbatia plicata* (Chemnitz, 1870)	*Barbatia plicata* (Dillwyn, 1817)
	Anadara geissei (Dunker, 1891)	*Mosambicarca hians* (Reeve, 1844)
	Brachidontes senegalensis (Lamarck, 1819)	*Brachidontes puniceus* (Gmelin, 1791) ♦
	Hyotissa hyotis (Linné, 1758)	*Hyotissa hyotis* (Linnaeus, 1758) ●
	Ungulina rubra Roisy, 1802	*Ungulina cuneata* (Spengler, 1798) ♦
	Cardita senegalensis Reeve, 1843	*Cardita senegalensis* Reeve, 1843
	Eastonia rugosa (Chemnitz, 1782)	*Eastonia rugosa* (Helbling, 1779)
Gastropoda	*Patella ferruginea* Gmelin, 1790	*Patella ferruginea* Gmelin, 1791
	Monodonta lineata (da Costa, 1778)	*Osilinus lineatus* (da Costa, 1778)
	Mathilda granosa (Borson, 1821)	----------
	Melania tuberculata (Müller, 1773)	----------
	Pirenella conica (Blainville, 1826)	*Potamides conicus* (Blainville, 1829)
	Thericium minutum (De Serres, 1822)	----------
	Strombus bubonius Lamarck, 1822	*Persististrombus latus* (Gmelin, 1791)
	Polinices lacteus (Guilding, 1831)	*Polinices lacteus* (Guilding, 1834)
	Naticarius turtoni (E.A. Smith, 1890)	*Natica turtoni* E.A. Smith, 1890
	Cymatium costatum (Born, 1780)	*Monoplex parthenopeus* (Salis-Marschlins,1793) ♦
	Bursa scrobiculator (Linné, 1758)	*Bursa scrobilator* (Linnaeus, 1758)
	Thais haemastoma (Linné, 1767)	*Stramonita haemastoma* (Linnaeus, 1767) ♥
	Cantharus viverratus (Kiener, 1834)	*Gemophos viverratus* (Kiener, 1834)
	Arcularia gibbosula (Linné, 1767)	*Nassarius gibbosulus* (Linnaeus, 1758)
	Mitra fusca Swainson, 1833	*Scabricola fusca* (Swainson, 1824)
	Conus testudinarius Martini, 1773	*Conus ermineus* Born, 1778
Crustacea	*Ocypoda cursor* (Linné) ♠	*Ocypode cursor* (Linnaeus, 1758)

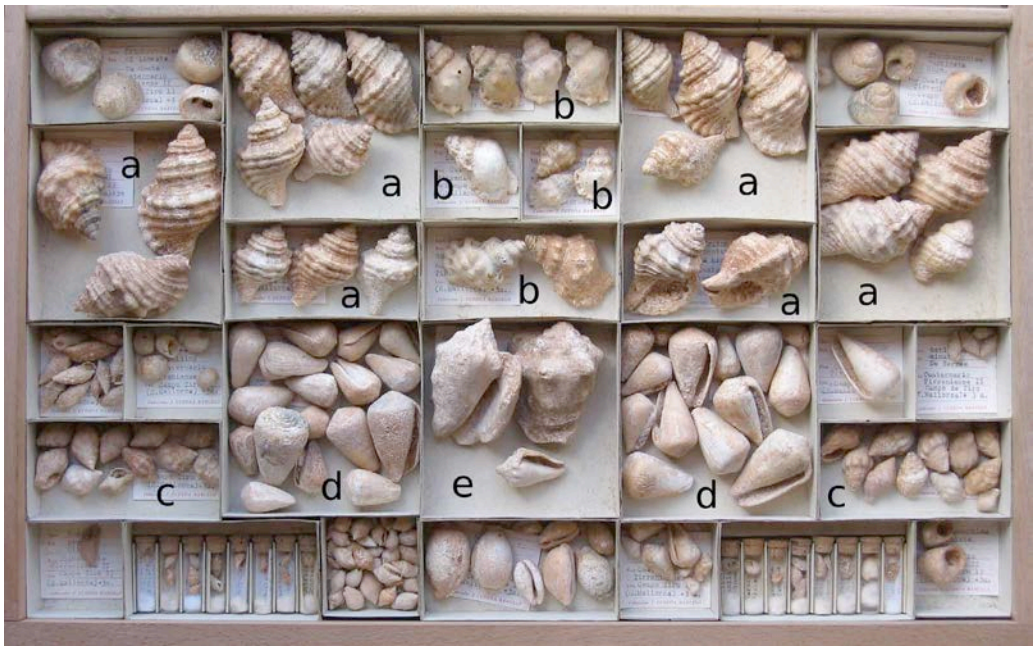

Figure 3. Fossils from the Palma Bay (collection Joan Cuerda-SHNB) shown as they were stored at the original collection (Archive SHNB). a- *Cymatium costatum*. b- *Bursa scrobiculator*. c- *Cantharus viverratus*. d- *Conus testudinarius*. e- *Strombus bubonius*.

Patella longicosta and *Patella* cf. *ambroggii* can be found –though with some taxonomic doubts– in Plio-Quaternary and Lower Pleistocene deposits. They are currently extinct species in the Mediterranean Basin, living only in South Africa.

Patella ferruginea, according to Cuerda (1975, 1987), is a characteristic taxon in the Paleotyrrhenian of Mallorca (Middle Pleistocene) and fairly abundant in deposits belonging to this stage.

2.2. Marine fossils from the Upper Pleistocene

Among the taxa found in the Upper Pleistocene deposits of the island, there are species living today in the Western Mediterranean waters, which are referred in the

Table II. An estimate of the number of paleontological registers (RP) and the amount of specimens (NS) within the collections of *Societat d'Història Natural de les Balears*, coming from Upper Pleistocene marine deposits at the Balearic archipelago. About 99% of the specimens are from Mallorca Island.

SHNB collections	Marine fossils		Terrestrial fossils	
	RP	NS	RP	NS
Col. Joan Cuerda	3,700	16,000	350	1,600
Col. Andreu Muntaner	850	1,800	50	100
Col. Damià Vicens	2,000	7,000	500	1,000
Col. F. Gràcia- D. Vicens	350	1,600	3	10
Col. Gabriel Fornés	61	277	-	-
TOTAL	6,961	25,077	903	2,710

literature as "banal fauna" due to their lack of stratigraphic interest. Besides, other taxa do not live today in the Balearics although they were common during some Quaternary stages (Figure 4). Within this second group of species –that have stratigraphic interest– one can distinguish two categories based on whether they are nowadays present or not, in different regions of the Mediterranean Basin.

2.2.1. Taxa that are extinct in the Balearics, but living in Southern Mediterranean waters or neighboring Atlantic areas

Fossils corresponding to this category have been reported from the Last Interglacial marine deposits. According to Cuerda (1987), the most representative taxa are:

Bivalvia: *Ungulina oblonga* and *Eastonia rugosa*.

Gastropoda: *Patella ferruginea*, *Monodonta lineata*, *Thericium minutum*, *Bursa scrobiculator*, *Arcularia gibbosula*, and *Mitra fusca*.

Exceptionally, some of these species can be found alive in the Western Mediterranean, as is the case of *Bursa scrobiculator*, whose presence may be considered accidental since it is a typical Atlantic species (Verdejo, 2001). Cuerda (1987) gave stratigraphic value to *Eastonia rugosa*, a slightly thermophilous taxon, which currently is missing from the Balearic waters. Recently, La Valle *et al*. (2007) and López *et al*. (2010) found this taxon living in the littoral regions of Catalonia (Spain) and Rome (Italy), where apparently was introduced not long ago.

A fossil crab currently extinct in the Balearics, *Ocypoda cursor*, was reported living in the Eastern Mediterranean and the Atlantic inter-tropical coasts of Africa (Via, 1966).

2.2.2. Taxa that are currently extinct in the Mediterranean

Among the fossil marine molluscs there is a group of taxa traditionally referred as "Senegalese" species, which are nowadays extinct in the Balearics but today they are living along the coasts of Senegal and other neighbor African countries. Favored by a warm climate, they invaded the Mediterranean during the Eutyrrhenian (MIS 5e), but became extinct over the Last Glacial period (Cuerda, 1987). The "Senegalese" species are the following:

Bivalvia: *Anadara geissei*, *Brachidontes senegalensis*, *Hyotissa hyotis*, and *Cardita senegalensis.*

Gastropoda: *Strombus bubonius, Polinices lacteus*, *Naticarius turtoni*, *Cantharus viverratus*, and *Conus testudinarius.*

In the Balearic Islands, this molluscs assemblage is characteristic for the marine stage known as Eutyrrhenian. Normally, two additional taxa, also from the Atlantic coasts of Africa (*Cymatium costatum* and *Bursa scrobiculator*) accompany the "Senegalese" species. Because of the warm climate that characterized the Eutyrrhenian, these species flourished along the Mallorcan coasts (Cuerda, 1987), but are completely extinct nowadays from the Balearic Islands.

The most characteristic and emblematic species is *Strombus bubonius*. Comprehensive and interesting information on this taxon are available in Meco *et al*. (1977) and Torres *et al*. (2006). Based on chronological criteria –established from Es Carnatge site by Hillaire-Marcel *et al*. (1996)– Bardají *et al*. (2009) suggest that *Strombus bubonius* vanished from Mallorca at the end of MIS 5e. However, this species populated the Iberian Peninsula coasts throughout the entire MIS 5. We think this topic deserves further attention.

Barbatia plicata is another taxon, currently extinct in the Mediterranean Sea, which does not belong to the "Senegalese" species and is found at the Balearics in deposits corresponding to the Last Interglacial. Today is living in the Red Sea region.

Within the Neotyrrhenian (MIS 5a) deposits from the Balearics, not all the characteristic species of the "Senegalese" group are present. Among them, only *Brachidontes senegalensis*, *Cantharus viverratus*, and *Conus testudinarius* are found. Furthermore, *Barbatia plicata*, a thermophilous taxon (not belonging to the "Senegalese" group) is also present. In this respect, the Neotyrrhenian deposits as a whole are characterized by an "impoverished thermophilous fauna" (Cuerda, 1987).

Moreover, is worth mentioning *Thais haemastoma* var. *nodulosa*, a variety of gastropod that is no longer living in the Balearic Islands. This taxon is present within the Eutyrrhenian raised beaches from Mallorca, but was not reported from the Neotyrrhenian deposits (Cuerda, 1987). There are no valid information on this variety, likely because authors could not distinguish it from the type-species (Vicens, 2010). Within this taxon, there is another sub-species –*T. haemastoma* ssp. *consul*– never found in the taphocoenosis of present-day beaches, although it has been collected alive in the Palma Bay from depths between 20 and 40 m; this sub-species is present in the Eutyrrhenian deposits from Mallorca, but it is rather rare in the Neotyrrhenian sediments (Cuerda, 1987).

2.2.3. Additional paleontological data

When speaking on the percentages of specimens found in the marine Upper Pleistocene sites, molluscs (Bivalvia, Scaphopoda, and Gastropoda) are the most common ones. Statistical analyses are useful to gain a general view over this issue, although not all of them refer to the entire island of Mallorca. On one hand, Cuerda *et al*. (1989-1990) described 1,003 specimens from a Neotyrrhenian site named by the authors "Sa Tanca de sa Torre II". These specimens belong to the following 9 classes: Rhodophyceae, Anthozoa, Bryozoa, Echinoidea, Bivalvia, Scaphopoda, Gastropoda, Malacostraca, and Acninopterygii; molluscs, with 952 individuals, represent 94.9% of all specimens found at this site.

On the other hand, 153 marine taxa belonging to the Upper Pleistocene and Holocene (the latter being very scarce) have been identified from fossil remains collected over a large area of Mallorca (Vicens 2010). Molluscs from Bivalvia, Scaphopoda, and Gastropoda classes, with 46, 2, and 87 taxa determined respectively, represent as a whole the 88.23% of taxa located in the selected area, comprising Pollença, and Alcúdia bays. The rest of classes, like Rhodophyceae, Anthozoa, Malacostraca, Chondricthyes, Actinopterygii, and Mammalia have fewer taxa identi-

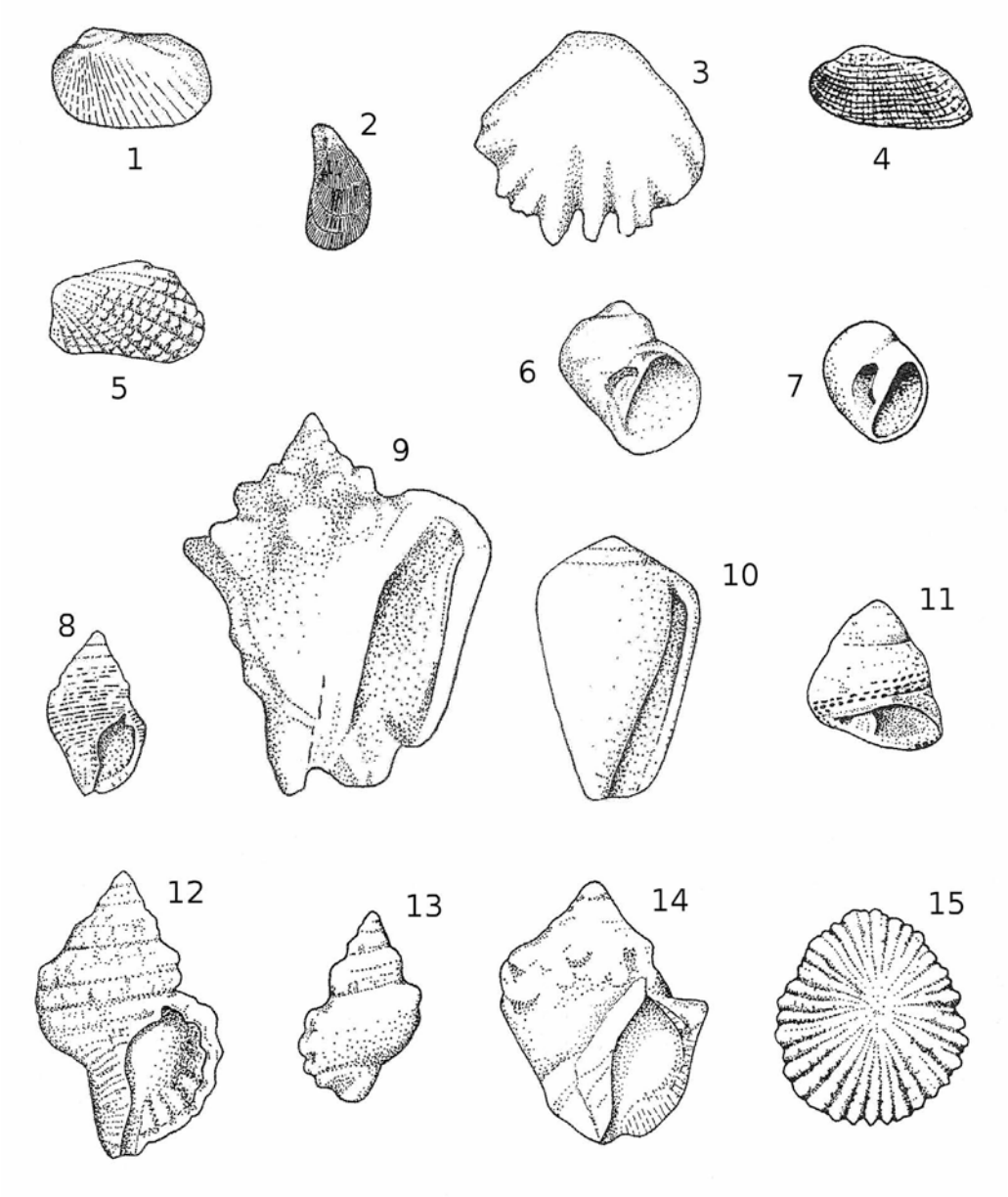

Figure 4. Marine fossils with stratigraphic significance from Mallorca, corresponding to MIS 5. Within brackets, the major axis length of each specimen is indicated. 1- *Anadara geissei* (28 mm). 2- *Brachidontes senegalensis* (23 mm). 3- *Hyotissa hyotis* (55 mm). 4- *Barbatia plicata* (20 mm). 5- *Cardita senegalensis* (28 mm). 6- *Naticarius turtoni* (22 mm). 7- *Polinices lacteus* (19 mm). 8- *Cantharus viverratus* (32 mm). 9- *Strombus bubonius* (70 mm). 10- *Conus testudinarius* (55 mm). 11- *Monodonta lineata* (33 mm). 12- *Cymatium costatum* (80 mm). 13- *Bursa scrobiculator* (55 mm). 14- *Thais haemastoma* ssp *consul* (57 mm). 15- *Patella ferruginea* (70 mm).

identified in the paleontological record of the area. If instead of using the taxa above, an inventory is compiled based on the specimens present in the *Societat d'Història Natural de les Balears* collections (col. Joan Cuerda, col. Andreu Muntaner, and col. Damià Vicens), the percentages will vary considerably. This is mainly because the poorest classes, such as Chondricthyes, Actinopterygii, and Mammalia, are each represented by just one specimen.

The total number of specimens from the above-mentioned collections is of 1,269 individuals, and the percentage of molluscs (Bivalvia, Scaphopoda, and Gastropoda) is 94.3%. The marine vertebrate fossils are unusual in the Quaternary littoral deposits, being most of them fish teeth (Vicens & Gràcia, 1999; Vicens 2010).

2.3. Continental fossils

The Quaternary littoral-continental deposits basically consist of eolianites, reddish silts, and paleosols that mainly yield molluscs fossils (Figure 5). In particular, faunal differences can be found in each of the islands, but is the greatest between those from Gimmèsies (Mallorca, Menorca, and Cabrera) and Pitiüses islands (Eivissa and Formentera) (Gasull, 1966; Cuerda, 1975). It seems that extinctions have occurred in both groups of islands, probably during or before the Last Glacial period. The present malacological fauna of native molluscs would be the survivors of that stage (Pons & Palmer, 1996).

The nomenclature and the systematic position of continental molluscs remain controversial. In this light, the work of Beckmann (2007) is very useful as provides synonymies and descriptions of all current Balearic molluscs along with excellent photographs.

Among molluscs with significance for warm periods, *Rumina decollata* has been found in the Lower Pleistocene levels of the Balearics (Cuerda, 1975). Vicens & Pons (2011) questioned its presence because only one specimen was found at Cala Pudent within a Eutyrrhenian beach. Recently, another specimen was discovered in the Eutyrrhenian beach from Cala Murada. This fact signifies that *Rumina decollata* likely lived during the Last Interglacial period in Mallorca. In spite of intensive search conducted by Vicens & Pons (2007), this species has not been found in the most recent Upper Pleistocene deposits from Mallorca. Currently, it dwells in Mallorca as a consequence of its Holocene introduction by humans.

Chondrula gymnesica (Figure 5), known until recently as *Mastus pupa*, was part of the endemic malacological fauna of Mallorca and Menorca, but vanished during the Würm glaciation (Quintana, 2006). It has always been considered a warm climate species (see Cuerda, 1975), although it likely survived the Riss glaciation; otherwise it would be difficult to justify its presence in the Eutyrrhenian silts, unless it was a newcomer. This mollusc is mentioned by Vicens & Pons (2007) at Caloscamps at a level dated by Rose *et al*. (1999) as 62.8 ±8.5 ka BP.

Oestophora cuerdai is another extinct taxon that is only found as a fossil in the Upper Pleistocene of Mallorca (Quintana *et al*., 2006).

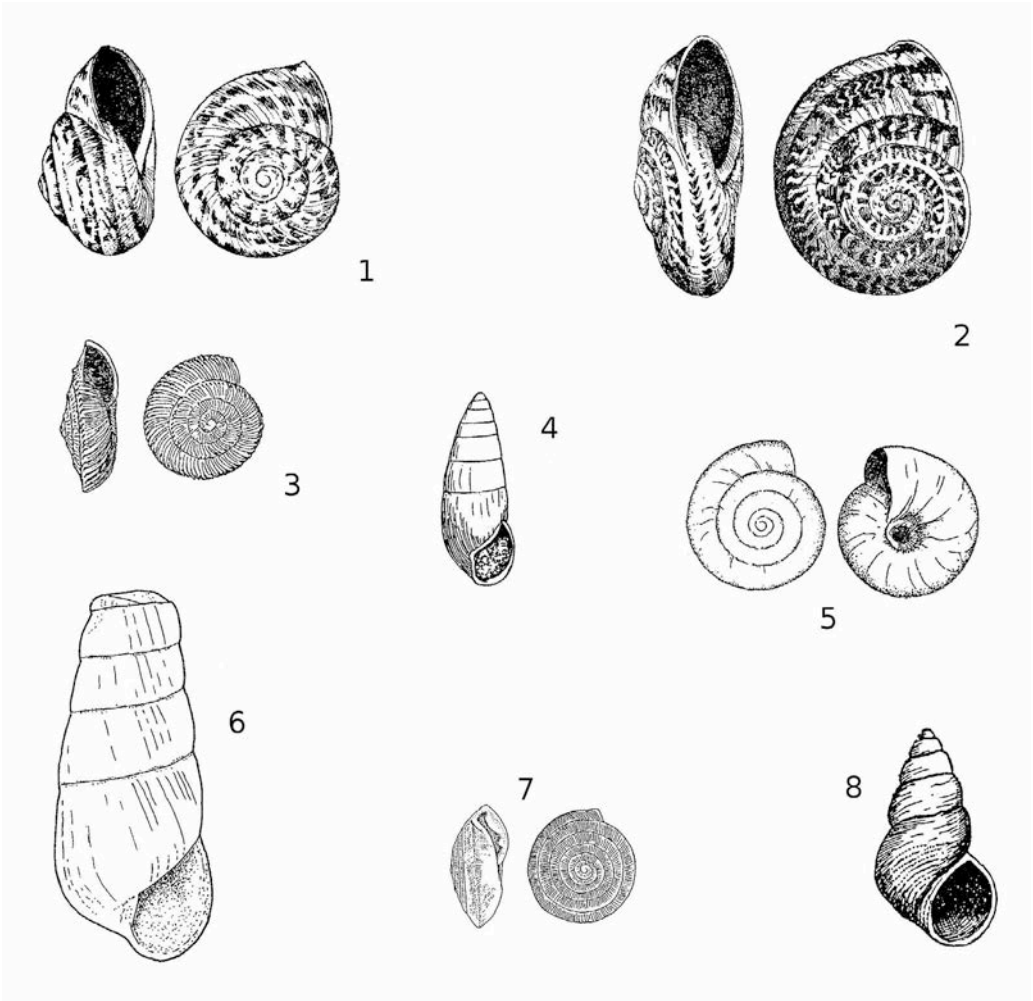

Figure 5. Continental molluscs from the Upper Pleistocene of Mallorca. Within brackets, the major axis length of each specimen is indicated. 1- *Iberellus companyonii* (20 mm). 2- *Iberellus balearicus* (25 mm). 3- *Xerocrassa frater* (11 mm). 4- *Chondrula gymnesica* (extinct) (16 mm). 5- *Oxychilus lentiformis* (11 mm). 6- *Rumina decollata* (35 mm). 7- *Oestophora cuerdai* (extinct) (9 mm). 8- *Tudorella ferruginea* (19 mm). Drawings 1, 2, 3, and 5 after Colom (1957), 4 and 8 after Colom (1987), and 6 and 7 by D. Vicens.

Apart from the former mentioned molluscs, in the Upper Pleistocene sediments of Mallorca *Iberellus* sp., *Tudorella ferruginea*, *Oxychilus lentiformis*, and *Xerocrassa frater* are commonly found; all of them are part of the current native fauna of Mallorca.

Throughout the Quaternary, in Mallorca and Menorca, an assemblage of vertebrates genus, such as *Myotragus, Hypnomys, Nesiotites* and *Podarcis*, yielded different endemic species (Alcover *et al*., 1981). Most of the fossils belonging to these taxa are found in sedimentary traps, like some littoral caves (Soondar *et al*., 1995; Bover, 2011). Myotragus tracks discovered on littoral eolianites are rather common (Fornós *et al*., 2002). Remains of fossil birds like *Puffinus mauretanicus, Columba* sp. (Vicens *et al*., 1998), and *Phalacrocorax aristotelis* (McMinn & Vicens, 2007) have also

been found in Upper Pleistocene littoral deposits. The former is an endemic marine bird from the Balearics, whereas the last one is a bird with large distribution range. The vertebrate sites different to those in caves are particularly scarce in the Balearics (Alcover & Bover, 2002).

Coprolites are highly interesting trace fossils found both outside and in caves (Alcover & Bover, 2002). Excluding the sites of karstic origin, Cuerda *et al*. (1969) and Servera *et al*. (2001) described them from subaerial outcrops but, however, it is highly possible they are not coprolites but nests of some sort of insects. The deposits between Cala Figuera and el Toro (Calvià) and the ones from Es Bancals and Vallgornera, formed by weathering of eolianites and red silts of assumed Pliocene or Lower Pleistocene age, contain a great deal of these nests (Vicens, 2010). They have also been identified in some Upper Pleistocene deposits from southern Mallorca (personal obs.).

To conclude this section, it should be said that deposits of pedo-diagenetic carbonate surrounding plant roots (rizhocretions) are abundant in the littoral eolianites; the taxa that generated them is unknown.

3. The Quaternary raised-beaches

Pomar & Cuerda (1979) counted 70 Pleistocene marine sites in the littoral of Mallorca, but a few years later Cuerda (1987) mentioned 75. This figure has constantly increased year after year as new sites were discovered and studied. Presently, based on our own data we estimate that in Mallorca are about 130 such locations. The vast majority of sites are from the Upper Pleistocene and only a few of them belong to the Middle or Lower Pleistocene. The coast of Serra de Tramuntana is very poor in Pleistocene marine deposits, probably owing to active uplift and intense erosion. Not all sites are exactly ancient beaches; many of them are fissure infillings, occasional accumulations of beach sands caused by storm events, lagoon deposits, etc.

3.1. Lower Pleistocene

Lower Pleistocene deposits have been found in southern Mallorca, at sites located on littoral cliffs. Cuerda & Sacarés (1970) studied an outcrop discovered at Vallgornera (+12 m ASL) and claimed it represents the Lower Pleistocene, possibly the Pliocene-Pleistocene boundary. Other younger locations compared to the previous one was discovered at Es Pas des Verro at +70 m, and at Can Xarpa at +50 m ASL, respectively (Butzer & Cuerda, 1962b).

3.2. Middle Pleistocene

References to the Middle Pleistocene fossil deposits are scarce in the island, and like the older horizons, the deposits are found in southern Mallorca. Marine erosion platforms and notches have been located at Punta de Sa Plana area, between +16 and +34 m ASL, with no marine fossils. Butzer & Cuerda (1962a) assigned the level located at +5 m ASL at Sa Torre de s'Estelella and another deposit at Es Bancals (+16 m ASL), where *Patella ferruginea* is abundant, to the Middle Pleistocene (Tyrrhenian I = Paleotyrrhenian). Besides, at the latter site, a level scarce in fossils exists at +22 m ASL (Cuerda & Sacarés, 1966).

3.3. Upper Pleistocene

In the Mediterranean region, the following terms have been used to refer to the Upper Pleistocene stages: Tyrrhenian II (Eutyrrhenian), Tyrrhenian III (Neotyrrhenian), and the Würm glaciation. The Neotyrrhenian was chronologically placed at the end of the Last Interglacial *sensu lato* (MIS 5) and just before the onset of the Würm glaciation (Cuerda, 1975, Pomar & Cuerda, 1979). This nomenclature has been in use in Mallorca until very recently (mainly the terms Eutyrrhenian and Neotyrrhenian). The relative chronology derived from these terms is somewhat useful because allows to distinguish between the sites containing the so-called "Senegalese" fauna (Eutyrrhenian) and those with impoverished thermophilous fauna (Neotyrrhenian). When correlating these periods with those defined as marine isotope stages, a consensus seems was reached for the Neotyrrhenian, which would correspond to the MIS 5a. The Eutyrrhenian period is much more controversial. For example, Cuerda (1975) located the early Eutyrrhenian within today's MIS 7 –based on Stearns & Thurber (1965) absolute datings– but overall, he considered the Eutyrrhenian positioned within the Upper Pleistocene. According to Ginés (2000) the Eutyrrhenian, as defined by Cuerda (1975), encompasses the MIS 7 and MIS 5e deposits.

The Eutyrrhenian sites are usually found between +2 and +5 m above the current sea level and yield, among other fossils, species that imply a warmer than present climate; these thermophilous species are not currently living in the Mediterranean Sea, but live today in the inter-tropical region of the Atlantic African coasts and nearby islands. The Neotyrrhenian localities are found at lower elevations, generally less than +3 m ASL, and show impoverished thermophilous fauna, lacking the majority of the so-called "Senegalese" species (Pomar & Cuerda, 1979).

Most of the sites are formed by cemented beach sands with pebbles and marine fossils. In many outcrops, a mixture of sands and silts of continental origin is present, fact that causes the matrix to be reddish in color (Cuerda, 1975). The sand of the fossil beaches is mainly bioclastic, similar to the present one in the Mallorcan beaches (Jaume & Fornós, 1992). Mallorca has about 120 Upper Pleistocene sites with marine fauna (personal obs.). Many of the deposits are found over paleosols or eolianites. The raised-beaches can be covered with paleosols, eolianites, other beach deposits, or sometimes with none.

Cuerda (1975) and Pomar & Cuerda (1979) pointed out the existence of early Eutyrrhenian fossil beaches at ~ +3 m ASL in the Palma Bay (Cala Pudent, Es Carnatge, etc.); more recent deposits are found at +7.5 m (S'Illot), +11 m (Torre de S'Estelella; see detailed discussion in the next section 4.2), and +13 m (Es Bancals), with ages of about 130 ka BP (the last two) according to former datings from Stearns & Thurber (1965), later questioned in Stearns (1985). The data provided by Cuerda, could indicate the existence of a transgressive maximum at +13 m ASL, about 130 ka BP (MIS 5e). This interpretation does not agree with the study of Hillaire-Marcel *et al*. (1996), which pointed out that the Eutyrrhenian deposits existing at Es Carnatge (located at +3 and +2 m ASL) have ages between 135 and 117 ka (MIS 5e) and 100 ka BP (MIS 5c), respectively. It seems likely that the elevations assumed by Cuerda (1975) for some Eutyrrhenian beaches of Mallorcan coasts, situated between +6 m and +13 m ASL, are

not confident (Ginés, 2000), perhaps owing to inconsistency of the absolute datings available on these deposits; moreover, they could have been affected by recent tectonic deformations.

The Neotyrrhenian is present in Mallorca by means of deposits situated at elevations close to +2 m ASL. One of the most paradigmatic site is Es Carnatge, which can be correlated to the MIS 5a.

Around mid-Holocene the sea level reached a maximum, with some fossil beaches belonging to the Flandrian located up to +2 m ASL.

According to Morey & Cabanellas (2007-2008), approximately 33% of the Upper Pleistocene sites have disappeared as a consequence of anthropic impacts. In another paper, Morey (2008) states that half of the known sites are in bad preservation conditions or have already disappeared. Unfortunately, these percentages reflect a number of fundamental mistakes that were made when the conservation of the sites was checked. In our view, the estimated percentage of disappeared sites is much lower than the one established by these authors. Morey (2008) in his paper, evaluated the Upper Pleistocene Mallorcan deposits, based on different aspects (status of the investigations, conservation of the deposits, etc.). On the other hand, his inventory list includes sites that have never been studied from a paleontological point of view; this fact, along with other mistakes existing in his table of checked sites, make us question its reliability.

4. Main Quaternary marine sites from Mallorca

Throughout this section, few of the most relevant raised-beaches in Mallorca Island (Figure 6) will be described, emphasizing on their stratigraphy, paleontological records, as well as the chronology of each deposit.

4.1. Cala Pudent - Es Carnatge

Without a doubt, internationally, the most well-known sites on the island are those from Cala Pudent and Es Carnatge –both located in Palma Bay– also referred as "Campo de Tiro" in many of the previous papers. This last toponym, introduced by Joan Cuerda and Andreu Muntaner, relates to a military area dedicated to gunshot training. The first author to publish a stratigraphy of these marine sites was Muntaner (1957) whereas the paleontological study was conducted by Cuerda (1957).

The Cala Pudent site shows two superposed Eutyrrhenian (MIS 5e) raised-beaches with thermophilous "Senegalese" fauna, observable exclusively at the western part of the small bay (Figure 7C); at its eastern part, only one Eutyrrhenian fossil beach is recognized (Cuerda, 1979). At its base, the deposit starts with Riss eolianites (MIS 6) showing a marine erosion platform developed on it. The eolianite are covered by reddish to yellowish paleosols with terrestrial mollusca, including the extinct species *Chondrula gymnesica*. Cuerda (1979) presents a faunal list corresponding to the raised-beach from the eastern part of the bight, which is correlated to the more ancient beach occurring in its western part. There is a large number of fossils cited from this site,

among which the most characteristic are: *Barbatia plicata*, *Hyotissa hyotis*, *Cardita senegalensis*, *Patella ferruginea*, *Monodonta lineata*, *Strombus bubonius*, *Polinices lacteus*, *Cymatium costatum*, *Bursa scrobiculator*, *Cantharus viverratus*, and *Conus testudinarius*. Stearns & Thurber (1965) reported U/Th ages of ~200 ka BP for these deposits; but in a later paper (Stearns, 1985) these ages were questioned. The exact location (which of the two beaches) where the authors collected their samples is furthermore unknown.

The site of Es Carnatge (Figure 7A) is located 170 m to the SSE from Cala Pudent. Cuerda (1975) describes four different levels with marine fauna. According to Zazo *et al*. (2003), the four marine units are separated by reddish continental deposits or by erosive surfaces, extending between the present-day sea level and +3 m. The lower two levels (units 1 and 2) contain the oldest fossils and were correlated with the Eutyrrhenian levels from Cala Pudent. They consist of beach-rock deposits with thermophilous fauna including the characteristic *Strombus bubonius*. The unit 3, composed of rock blocks from the lower units (mean diameter between 0.5 and 1 m) along with rounded clasts embedded within a clayey-silty matrix of a red coloration, overlies an erosion surface that cut across units 1 and 2. According to Cuerda (1975), *Cantharus viverratus* and *Conus testudinarius* were recovered from unit 3. The most recent marine deposit, the unit 4, is represented by beach-rock conglomerates and covers an erosion surface affecting unit 3 (Zazo *et al*., 2003). From unit 4, Cuerda (1975)

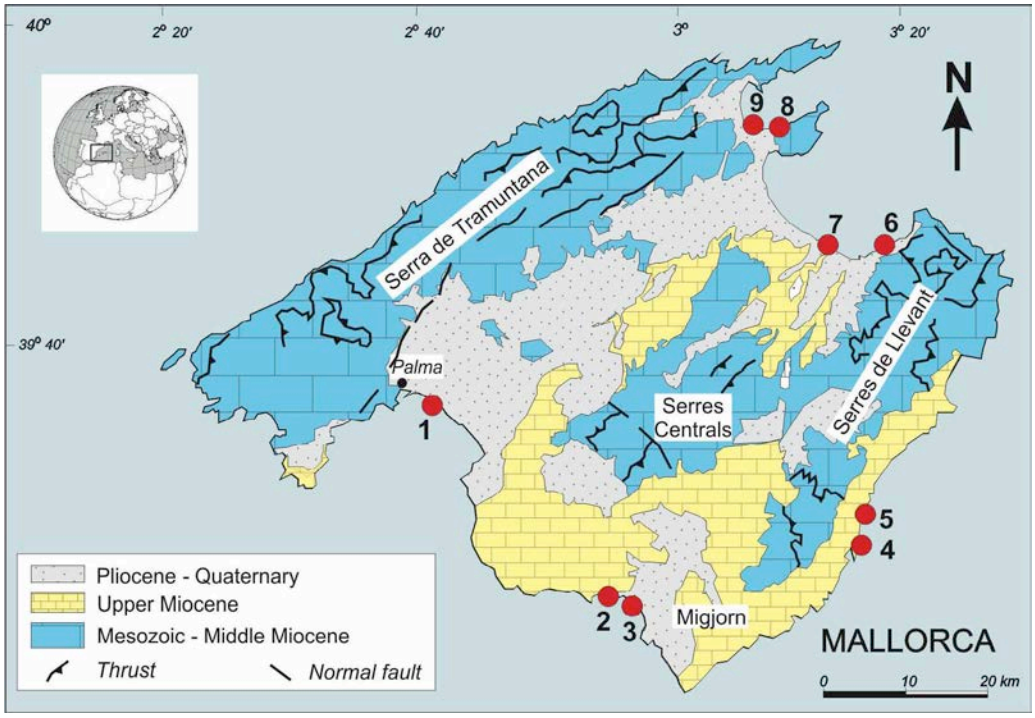

Figure 6. Locations referred throughout the text. 1- Cala Pudent-Es Carnatge (also known as "Campo de Tiro" in most publications). 2- S'Estelella. 3- Rentador de ses Egos. 4- Sa Tanca de sa Torre II. 5- Cala Murada. 6- Caloscamps. 7- Torrent de Son Real. 8- Platja de la Font de Sant Joan. 9- Sa Marina.

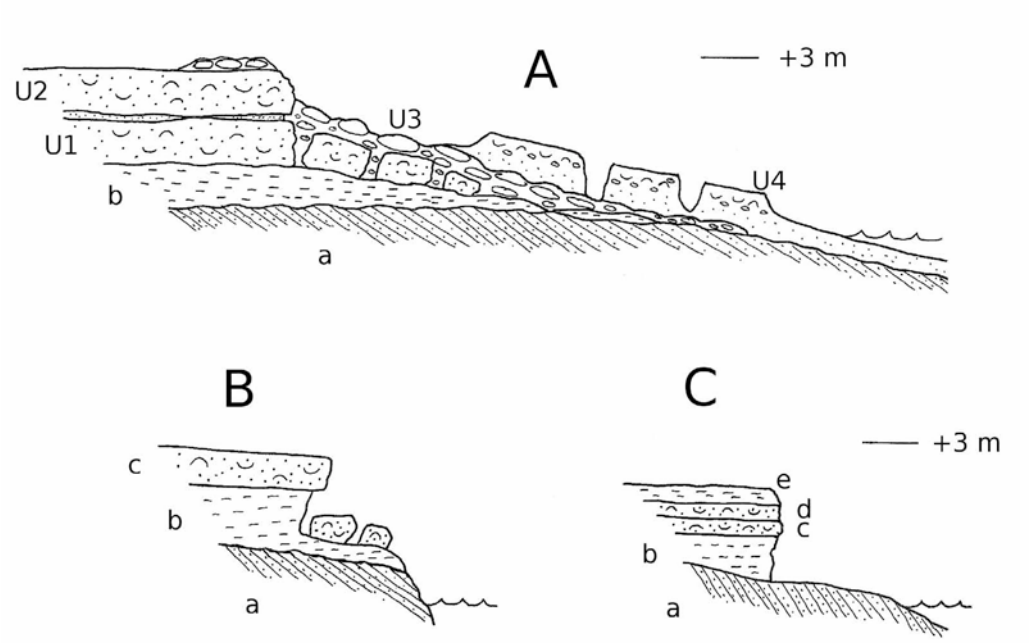

Figure 7. A- Es Carnatge: a- Riss dune (MIS 6). b- Reddish-yellow silts with *Chondrula gymnesica*. U1- Beach with Senegalese species (MIS 5e). U2- Beach with Senegalese species (MIS 5e). U3- Displaced blocks of lower levels cemented altogether (MIS 5a?). U4- Fine beach sands which pass upwards into coarse sands and gravels (MIS 5a?). B- Cala Pudent (East) according to Cuerda (1979): a- Riss dune (MIS 6). b- Reddish-yellow silts with *Chondrula gymnesica*. c- Beach with Senegalese species (MIS 5e). C- Cala Pudent (West) according to Cuerda (1979): a- Riss dune (MIS 6). b- Reddish-yellow silts with *Chondrula gymnesica*. c- Beach with Senegalese species (MIS 5e). d- Beach with Senegalese species (MIS 5e). e- Reddish-yellow silts.

reports the presence of *Barbatia plicata*, *Cantharus viverratus* (only fragments), and *Conus testudinarius*. The author emphasizes important differences concerning the paleontological content of units 3 and 4 when compared with units 1 and 2. The abundant thermophilous fauna characterizing units 1 and 2, is not fully represented in the upper 3 and 4 units. These differences apply to some sedimentological aspects of the discussed levels as well.

Stearns & Thurber (1965) obtained U/Th ages of 75 ka BP for samples collected within unit 3. Hearty (1987) attributes the deposits of Es Carnatge to the amino-zone E, corresponding to MIS 5e, and suggests that probably the deposits from unit 3 are younger (MIS 5c or 5a). This author identifies only three marine units, which correspond to units 1, 2, and 3 after Zazo *et al.* (2003). Based on Hearty's drawings, in our opinion, these levels are related, however, to units 1, 2, and 4 of Zazo *et al*. (2003).

Hillaire-Marcel *et al*. (1996) performed U/Th TIMS datings on molluscs shells from all four units. The data suggest an age of 135 ka BP in the case of unit 1; units 2 and 3 yielded ages of 117 ka BP; for unit 4 ages cluster around 100 ka BP. These chronological data point towards an interpretation that correlates the oldest three units with two sea-

level high-stands occurred during MIS 5e; however, the stratigraphic, sedimentological, and faunistical data suggest the existence of even a third high sea stand within the MIS 5e. The unit 4 represents a well-defined high-stand that reasonably correlates with MIS 5a (Zazo *et al*., 2003). Bardají *et al*. (2009) also discuss this location so important for the Western Mediterranean region.

Although the ages reported for units 2 and 3 are the same (117 ka BP), in our opinion is very probable that unit 3 contains reworked fossils coming from the lower two units, since unit 3 erosionally cuts these older levels. This could be a possible explanation for the MIS 5e age obtained for the third unit.

Within the current state of the knowledge on this site, and considering valid the eustatic curve of Tuccimei *et al*. (2006), it seems the most feasible interpretation to consider the units 1 and 2 as corresponding to MIS 5e and units 3 and 4 belonging to MIS 5a.

4.2. S'Estelella

Butzer & Cuerda (1960) are the first authors to report at S'Estelella, in southern Mallorca, an Upper Pleistocene marine level at +10.5 m ASL, based on its paleontological content. According to their study, over the Riss eolian complex, 30 cm of consolidated fine sands are observed up to a maximum elevation of +10.5 m ASL, along with red silts, sharp clasts and fossils. They proposed a chronology that corresponds to the early Eutyrrhenian (Tyrrhenian II). Butzer & Cuerda (1962a) revised their study and added a much more accurate stratigraphic profile compared to their initial description of the site (Figure 8B). The following species described by Cuerda 1975) from this level have stratigraphic significance: *Barbatia plicata*, *Brachidontes senegalensis*, *Hyotissa hyotis*, *Strombus bubonius*, *Cymatium costatum*, *Cantharus viverratu*s, *Mitra fusca*, and *Conus testudinarius*. Stearns & Thurber (1965) dated this level, by means of the U/Th method, using samples collected by Cuerda; the obtained age was 135 ka ±10 ka BP.

Zazo *et al.* (2003) suggest that the unusual high elevation of this deposit might have been affected by recent tectonic movements. These authors believe that units 1, 2, and 3 from Es Carnatge (referred in the original paper as "Campo de Tiro") located at elevations of +3, +1.5, and +1 m ASL, respectively, are represented at S'Estelella at higher altitudes. Hearty (1987) considers that the presence of marine specimens at this high elevation could be explained by strong storm events with high waves. If the sedimentological characteristics of the deposit at +10.5 m ASL are taken into account, one can observe marine sands mixed with continental silts, hence, these deposits cannot be considered genuine beach formations. Although tectonics cannot be completely ruled out, Hearty's suggestion seems more feasible. In this respect, 2.3 km to the west of this location, an Upper Pleistocene marine deposit has been found –at an elevation of +2 m ASL– at the base of a 20 m high coastal cliff (personal obs.); this finding argues for a tectonic stability of the area, at least since the Upper Pleistocene.

(Butzer & Cuerda (1962b) described another Eutyrrhenian deposit at +4.5 m ASL. The marine materials represented by beach sands, are overlying reddish-yellowish sandy-silty deposits (Figure 8C). The thermophilous fauna described by Ginard *et al*.

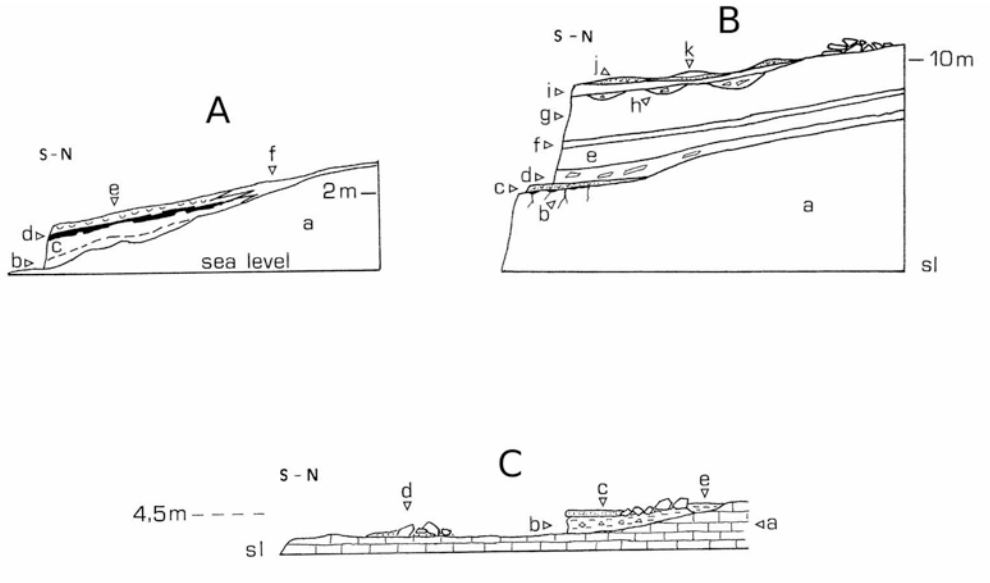

Figure 8. Stratigraphy of selected Upper Pleistocene marine deposits. A- Rentador de ses Egos (in the original paper cited as "Punta de Son Bieló") according to Butzer & Cuerda (1962a): a- Miocene limestones. b- Colluvial silts. c- Colluvial silts. d- Beach rock. e- Fossiliferous marine sand. f- Terrestrial silts. B- Torre de s'Estelella, level +10.5m ASL (Butzer & Cuerda, 1962a): a- Miocene calcarenite. b- Terra rossa soil in situ. c- Tyrrhenian I beach. d- Silt and colluvium. e- Eolianite. f- Silt and colluvium. g- Eolianite. h- Silt and colluvium. i- Eolianite. j- Eutyrrhenian (Tyrrhenian II) beach containing *Strombus bubonius*. k- Terrestrial silts. C- Torre de s'Estelella, level +3m/+4.5m ASL (Cuerda, 1975): a- Miocene calcarenite. b- Breccia with silts. c- Late Eutyrrhenian marine sediments. d- Cemented blocks with sandy silts and marine fossils. e- Würmian silts.

(2008) from this marine layer consist of: *Barbatia plicata, Hyotissa hyotis*, *Strombus bubonius*, *Bursa scrobiculator*, *Cantharus viverratus*, and *Conus testudinarius*.

Later on, Cuerda (1975) reported yet another Quaternary deposit located between the coastline and the one situated at +4.5 m ASL. In this case, sandy and silty materials are cementing a set of rocks disposed parallel to the coast, at an elevation of +3 m ASL (Figure 8C). *Patella ferruginea* was the only fossil bioindicator found in this deposit. Taking into account its elevation and the scarce presence of thermophilous species, the deposit was assigned to the end of Eutyrrhenian stage, thus, younger than the two other higher levels. More recently, Cuerda & Sacarés (1992) proposed a Neotyrrhenian age for this deposit. Also assigned to Neotyrrhenian is the presence of *P. ferruginea* in this site (Cuerda, 1987). However, in the very same study, when referring to *Conus mediterraneus* var. *vayssieri* (within the same deposit) the authors proposed an Eutyrrhenian age. It is evident from the above discussion that there is much confusion concerning the chronology of the lowest deposit.

Obviously, the very few bioindicator taxa had a crucial impact in separating this level from the one at +4.5 m ASL, which abounds in thermophilous taxa. Reviewing

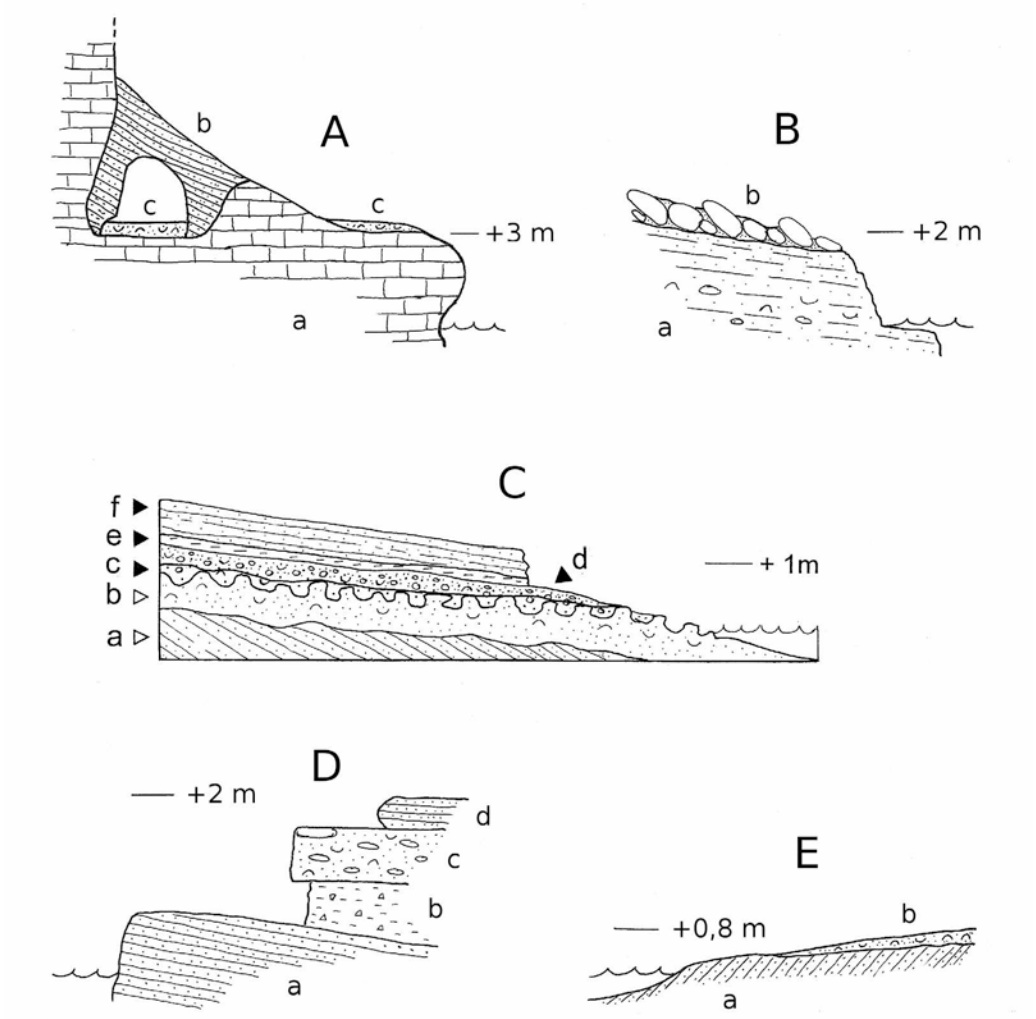

Figure 9. Upper Pleistocene marine sites from Mallorca. A- Sa Tanca de sa Torre II (Cuerda *et al.*, 1989-90): a- Miocene calcarenite. b- Eolianite. c- Beach with marine species (MIS 5a). B- Cala Murada: a- Beach with Senegalese species (MIS 5e). b- Cemented blocks with silts and terrestrial fossils. C- Torrent de Son Real (Vicens, 2010): a- Riss dune (MIS 6). b- Beach with Senegalese species (MIS 5e). c- Sandy silts with Senegalese species (MIS 5e). d- Beach with marine species (MIS 5a). e- Terrestrial silts. f- Eolianite. D- Platja de la Font de Sant Joan (Vicens, 2008): a- Riss dune (MIS 6). b- Reddish silts. c- Beach with Senegalese species (MIS 5e). d- Eolianite. E- Sa Marina according to Vicens (2008): a- Riss dune (MIS 6). b- Beach with marine species (MIS 5a).

the Vicens-SHNB collection, two additional bioindicator species have been found: *Cantharus viverratus* and *Bursa scrobiculator*. According to Cuerda (1987), the latter species has been reported in the Balearics exclusively from Eutyrrhenian deposits. Thus, the +3 m level hosts four bioindicator taxa. Taking into consideration its geomorphological context and its faunal content, we propose an Eutyrrhenian age (MIS 5e) for this lower deposit (personal obs.).

4.3. Rentador de ses Egos

Rentador de ses Egos, also referred as Punta de Son Bieló by Butzer & Cuerda (1960, 1962a), is a site located at a maximum elevation of +2 m ASL in southern Mallorca (Figure 8A). It comprises a unique, thin, marine level with abundant fossils. Although 38 different taxa from this location were cited by Butzer & Cuerda (1960) and Ginard *et al*. (2008), none of them reported the presence of any thermophilous species or even fragments. For this reason, and also considering the stratigraphic and geomorphological context, Butzer & Cuerda (1960) attributed this site to Neotyrrhenian (Tyrrhenian III), a chronology that is fully supported by Ginard *et al*. (2008) and Vicens *et al*. (2011) studies.

4.4. Sa Tanca de sa Torre II

This location was described and studied by Cuerda *et al*. (1989-1990), showing a unique marine deposit, located over a littoral erosion platform that develops at +3 m ASL (Figure 9A) in the eastern coast of the island. A total amount of 1,003 specimens were determined, including 3 valves of *Barbatia plicata* and 2 fragments of *Cantharus viverratus*. According to the fauna present in this site, the authors placed the deposit within the Neotyrrhenian (MIS 5a).

4.5. Cala Murada

Cala Murada is a site that contains a Quaternary deposit, first mentioned by Pomar & Cuerda (1979) but not yet described. Morey & Cabanelles (2007-2008) and Morey (2008) mistakenly stated that this locality is today totally destroyed.

In this location there is only a marine level characterized by the presence of a raised-beach deposit (Figure 9B) containing the "Senegalese" species *Strombus bubonius*. Within this outcrop, the terrestrial gastropod *Rumina decollata* has been collected. It is a thermophilous mollusc never documented in more recent sediments from the Upper Pleistocene of Mallorca. Based on its faunal content, the deposit belongs to Eutyrrhenian. Above the marine sediments there are reddish silts, from which the terrestrial gastropod *Chondrula gymnesica* has been recovered. The contact between these sediments and the lower marine layer is erosional. It is difficult to propose a chronology for this upper level, but according to its stratigraphic position may correspond to the Neotyrrhenian (MIS 5a)

4.6. Caloscamps

Located in the eastern part of the Alcúdia Bay, Caloscamps site is without a doubt the most studied locality in that area, being first investigated by Cuerda & Galiana (1976). There are two marine units. The oldest level lies over the Riss eolianites, and is represented by a wide marine erosional platform located +0.5/+1 m ASL (Figures 10 and 11). This horizon consists of well-cemented clasts, sands, and silts, including thermophilous fauna such as *Barbatia plicata*, *Brachidontes senegalensis*, *Cardita senegalensis*, *Cantharus viverratus*, and *Conus testudinarius*. Chronologically, this layer corresponds to the Eutyrrhenian. The upper level, a mixture of sands, reddish silts, and abundant marine fauna, appears to be an erosional deposition of materials over

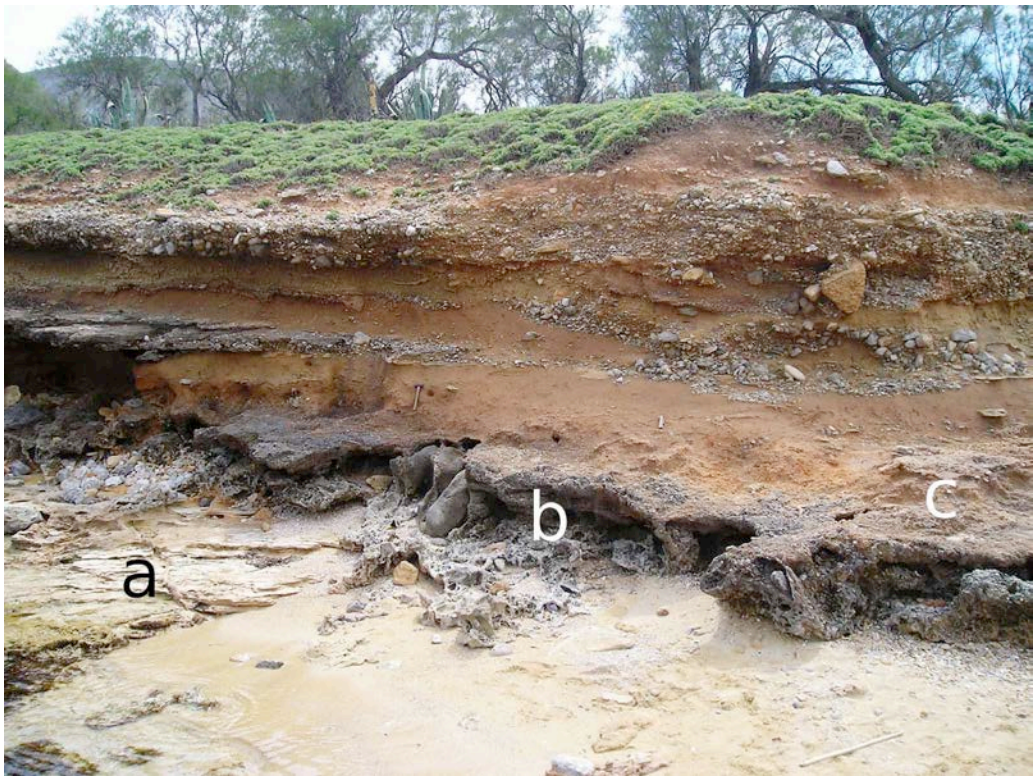

Figure 10. Caloscamps: a- Calcarenite (MIS 6). b- Beach with Senegalese species (MIS 5e) c- Sandy silts with marine species (MIS 5a).

the lower unit. No thermophilous fauna has been recovered from this level; therefore, Cuerda & Galiana (1976) placed the upper level to the end of the Eutyrrhenian stage.

The horizons existing over the marine units have significant lateral variation, which lead to different stratigraphic profiles even in very close locations; this fact is shown in Figure 10.

Rose *et al*. (1999) studied and dated three stratigraphic columns from this location. In the light of their age data, the lower eolianite unit corresponds to MIS 6. Above it, the ages cover the time interval from MIS 5e to MIS 1. Using the data from Rose *et al*. (1999) and taking into account the lack of thermophilous species, Vicens *et al*. (2001) consider that the upper marine unit (level "c" from Cuerda & Galiana, 1976) was deposited during MIS 5a.

Unlike Cala Pudent site, the silty level existing between the Riss eolianite and the Eutyrrhenian unit is not visible at this locality.

4.7. Torrent de Son Real

Torrent de Son Real was initially investigated by Cuerda *et al*. (1991), who supplied the first stratigraphic interpretation, later modified by Vicens (2010). It is located at the mouth of an important torrential stream ending in the Alcúdia Bay. Three superposed

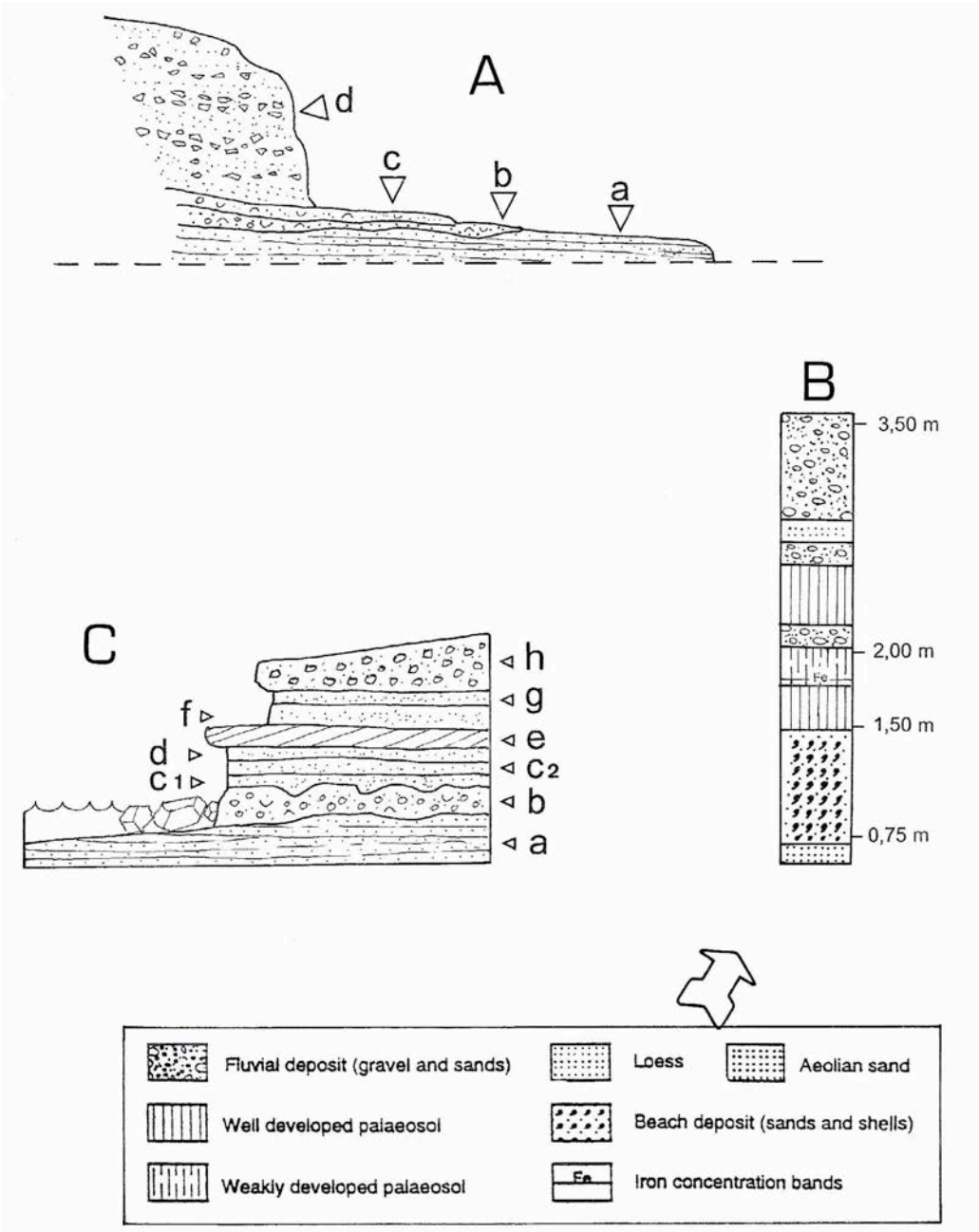

Figure 11. Some stratigraphic profiles of Caloscamps site. A- According to Cuerda & Galiana (1976): a- Basal Quaternary dune. b- Beach rock with Eutyrrhenian marine fauna. c- Sandy silts with marine fauna. d- Alluvial sediments composed by detritic elements together with silty layers containing *Chondrula gymnesica*. B- Profile B, according to Rose *et al*. (1999); the legend is in the lower part of the figure. C- Profile N-S, according to Vicens & Pons (2007): a- Eolianite (MIS 6). b- Beach deposit with marine fossils (MIS 5e). c1- Reddish silts with marine fossils (MIS 5a). c2- Reddish silts. d- Reddish silts. e- Eolianite. f- Reddish silts. g- Green-olive silts (MIS 3). h- Breccia.

marine levels can be distinguished in this outcrop (Figures 9C and 12). The oldest marine level consists of well-cemented marine sands, erosionally emplaced over a presumed Riss eolianite unit. The marine unit contains thermophilous fauna, such as *Cantharus viverratus* and *Conus testudinarius*. Above the lower level, there is another unit formed by sandy-silty deposits with marine fossils and some centimetric size pebbles; the marine fauna include thermophilous species like: *Barbatia plicata*, *Cardita senegalensis*, *Strombus bubonius*, *Cantharus viverratus*, *Conus testudinarius*, *Cymatium costatum*, and *Bursa scrobiculator*. The contact with the first level is clearly erosional. These two units are interpreted to belong to the Eutyrrhenian according to their stratigraphic, geomorphological context, and faunal content. The upper level consists of coarse marine sands, with reddish silts and centimeter-size pebbles. All taxa present in the upper unit are currently living in the Mediterranean Sea, with the only exception of a fragment of *Strombus bubonius* that Vicens (2010) interpreted as a reworked fossil coming from some of the lower levels; for this reason, the upper unit is considered Neotyrrhenian (MIS 5a).

4.8. Platja de la Font de Sant Joan

This Pleistocene site –located at Pollença Bay – is comparable to that of Cala Pudent, or even more to the Ses Covetes site described by González *et al*. (2001). The differences between Platja de la Font de Sant Joan and the two others are as follows: 1) a marine erosion platform over the Riss eolianite is not clearly visible, 2) there are no

Figure 12. Torrent de Son Real. Beach rock with marine species (MIS 5a).

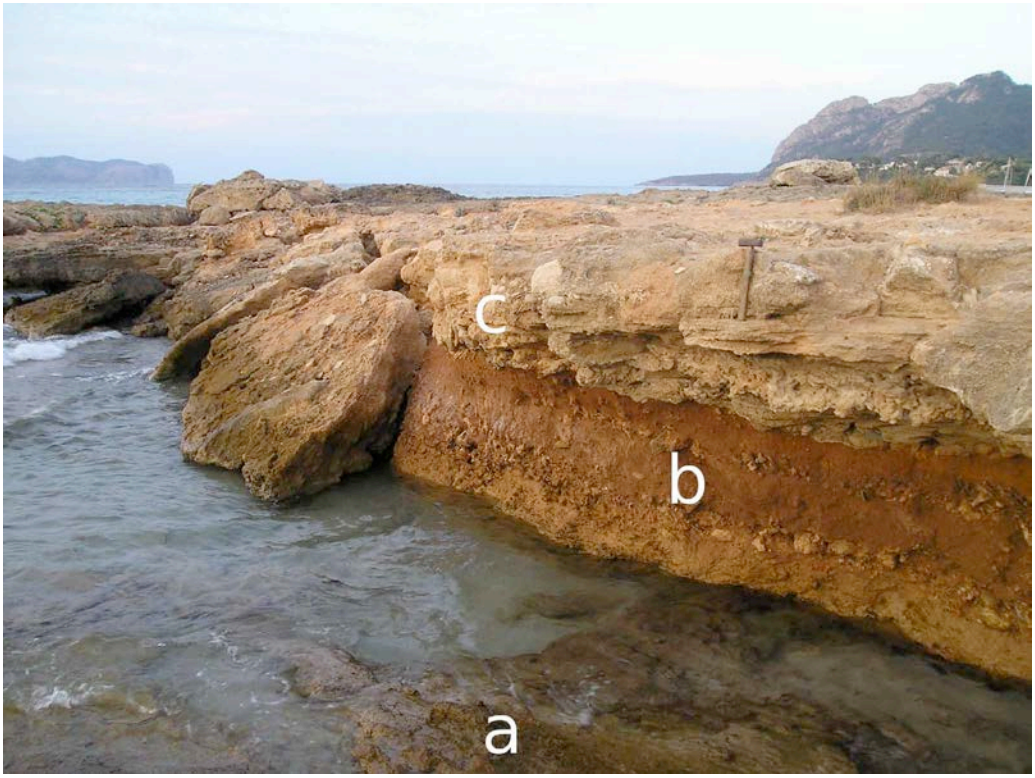

Figure 13. Platja de la Font de Sant Joan: a- Riss dune (MIS 6). b- Reddish silts. c- Beach with Senegalese species (MIS 5e).

terrestrial molluscs in the reddish silts existing below the raised-beach deposit, and finally, 3) over the Eutyrrhenian beach there are eolianite deposits instead of yellowish-reddish silts. Among the fossils collected, Cuerda *et al*. (1983) mentioned: *Barbatia plicata*, *Cardita senegalensis*, *Strombus bubonius*, and *Cymatium costatum*. The presence of *Cardita senegalensis* and *Strombus bubonius* (typical "Senegalese" fauna), denote that these deposits are from the Eutyrrhenian (MIS 5e). Moreover, *Barbatia plicata* and *Cymatium costatum* also have a clear chrono-stratigraphic significance. The same authors consider that above this beach there is another one of Neotyrrhenian age (MIS 5a). Contrary to this hypothesis, Vicens (2010) considers highly possible that in fact only one beach deposit exists (Figures 9D and 13).

Curiously, in the Canary Islands a reddish paleosol is also present beneath the beach deposits with *Strombus* corresponding to the Last Interglacial (Meco *et al*., 2007).

4.9. Sa Marina

Sa Marina is located in the Pollença Bay and is mentioned in Vicens (2008, 2010) studies as Sa Marina-1 site. At the end of the 80s, some remnants of continental reddish silts with fossil molluscs still existed between the coastline and the first line of houses. Today, this site completely disappeared. At this location it used to be a single marine level, of modest thickness (Figure 9E), made of indurated silts with marine fossils emplaced over an eolianite unit, presumably of Riss age.

The recovered fauna includes 38 taxa, none of them being thermophilous species. Based on the malacological data, Vicens (2008, 2010) placed it in MIS 5a, which could be stratigraphically correlated with some nearby outcrops at Corral d'en Bennàssar and Sa Marina-2.

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