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Geoarchaeology of the Burmarrad ria and early Holocene human impacts in western Malta

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ABSTRACT

Holocene sediments from the ria of Burmarrad (western Malta) provide a record of changing geomorphology, relative sea-level rise and human impacts. Chronostratigraphic evidence attests to a fluvial-dominated upper estuarine environment between ~7500 cal. BP and ~7000 cal. BP, with increasing salinity linked to rising post-glacial sea level. The shift to a marine setting is dated to ~7000 cal. BP, characterized by a wave-dominated coastline that accreted up until ~4000 cal. BP. During the maximum marine ingression, the Burmarrad floodplain formed a vast 1.8 km^2 marine bay, ~3000 m long by ~650 m wide, whose environmental potentiality presented western Malta's early societies with a multiplicity of coastal, terrestrial, and fluvial resources, in addition to a low-energy context favourable to the anchoring of boats. New palynological data show intensified human impact on the landscape beginning ~7300 cal. BP, which is broadly consistent with the earliest archaeological traces. Western Malta was already void of a significant vegetation cover by the mid-Holocene. Rapid human-induced sedimentation means that by the Bronze Age, the palaeobay had been reduced by ~40% compared to its mid-Holocene maximum. The final morphogenetic phase constitutes fluvial silts and sands that began accreting after 2700 cal. BP. During Punic/Roman times, the ria bay was ~1 km^2, and was flanked to the south by a well-developed deltaic plain providing fertile land for agriculture. Today, the ria is ~60% smaller than it was 7000 years ago.

1. Introduction

The Maltese islands (Malta, Gozo and Comino) constitute a group of small, low islands (highest point 246 m asl) situated in the Central Mediterranean, some 90 km south of Sicily and 350 km north of Libya (Schembri et al., 2009; Fig. 1). With a surface area of just 246 km^2, the archipelago's largest island, Malta, provides a unique laboratory to explore the geo-environmental problems linked to the evolution of civilizations in a Mediterranean island context (Guilaine, 1994, 2003). The island has a long and complex history of human use, stretching back at least ~7400 years cal. BP, when it was first occupied by societies from the island of Sicily (Bonanno, 1994). These settlers formed communities, developed agriculture and domesticated animals (Cassar, 1997). The island developed a rich Neolithic culture, most enduringly expressed by its megalithic architecture, and played an important role during the metal ages, Punic, Roman and Medieval times (Moscati, 1993; Sagona, 2002; Bonanno, 2005; Vella, 2005; Dalli, 2006; Bruno, 2009).

Despite Malta's rich archaeological record, very few environmental studies have been undertaken to probe the island's diverse sedimentary archives (Hunt, 1997; Gambin, 2005; Fenech, 2007), and our understanding of human land-use changes, climate and vegetation is poor. The prehistoric period in particular has been a source of vastly contradictory speculations (Guilaine, 1994), notably with regards to diffusionist versus autochthonous theories of cultural development. In this paper, we present new high-resolution data from the ria of Burmarrad, a ~1 by 2.5 km alluvial plain presently situated south of Salina Bay, where research has elucidated deep Holocene records conducive to high-resolution palaeoenvironmental study (Gambin, 2005).

1.1. Geomorphological context

Burmarrad is a 38.5 km^2 catchment situated on the western side of Malta (Fig. 2A). After Marsa, it constitutes the second largest watershed on the Maltese islands, with a 1.8 km^2 deltaic plain fed by three valley tributaries. The geology of the catchment is dominated by shallow marine carbonates of mid-Tertiary age (Hyde, 1955; Vossmerbäumer, 1972; Pedley et al., 1976) that are dissected by an intricate system of widiens, short Mediterranean-type watercourses that carry water during the wet season and flash-flood events (Anderson, 1997). The upland

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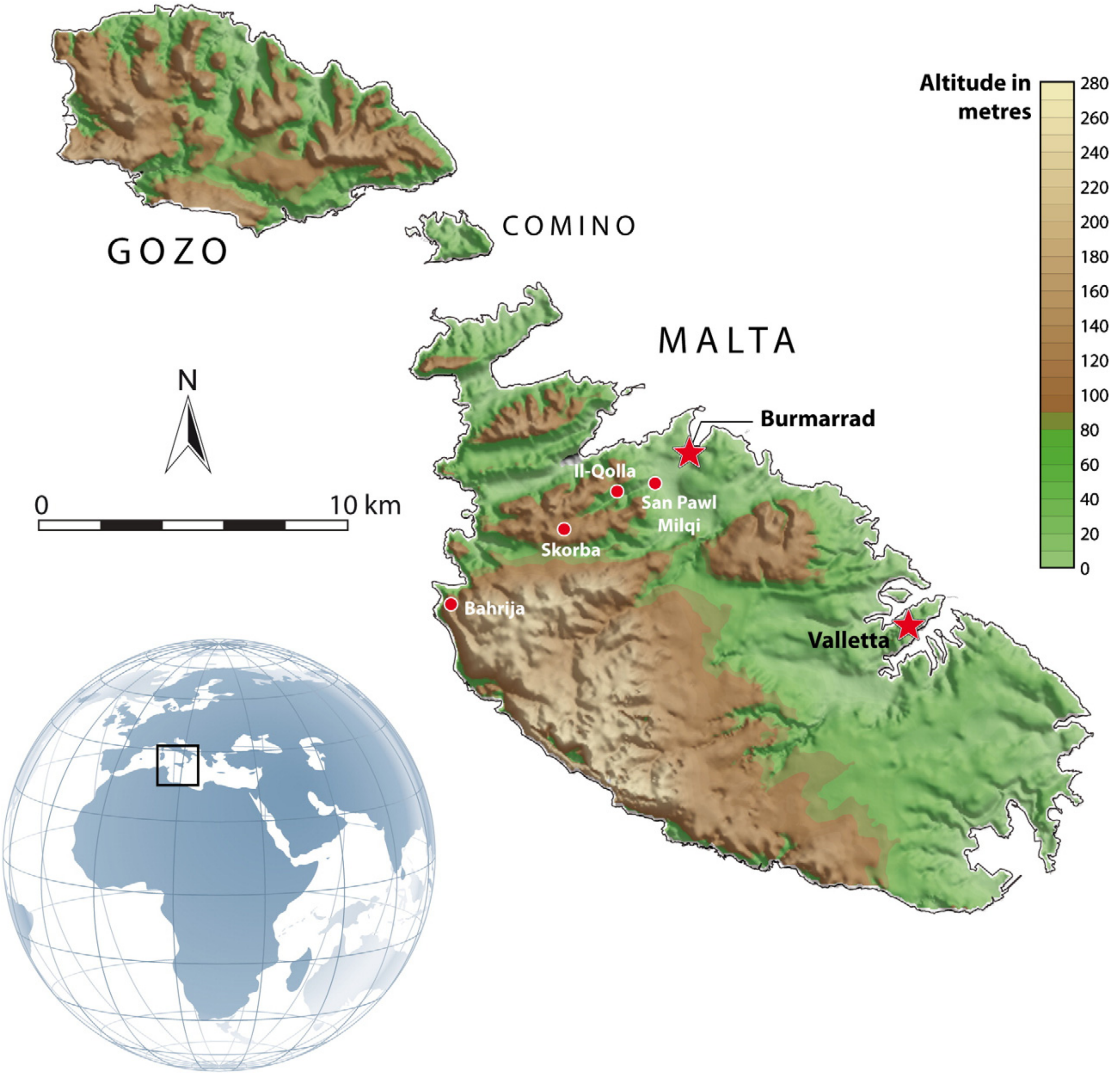

Fig. 1. Location map.

plateau (230 m amsl) is made up of the more competent beds of Coralline limestone while the lower reaches comprise Lower Coralline limestones, Greensand and Blue Clay Formations (Dart et al., 1993). This succession of limestone strata, interstratified with calcareous clay facies, is characterized by extensive faulting (Illies, 1981), with particularly high strain zones attested in the upland areas of the Burmarrad catchment (Putz-Perrier and Sanderson, 2010). Karstic phenomena, including small-scale lapis, solution features and cave systems are common (Guilcher and Paskoff, 1975; Paskoff and Sanlaville, 1978; Alexander, 1988).

The Burmarrad floodplain lies at the head of Salina Bay, a wave-dominated ria coastline governed by a micro-tidal wave regime of ~50 cm. The dominant longshore drift derives from the WNW (Paskoff and Sanlaville, 1978). At present the bay is particularly well sheltered by two limestone promontories that flank the eastern and western sides; the entrance to the embayment faces north-east. The permanently flooded marine basin area is presently 0.69 km² (Fig. 2B). The wind climate shows that only ~8% of the year is calm (Fig. 2A). The predominant wind is WNW, which on average blows on 16% of windy days (Schembri, 1997). The other wind directions, generally inferior to 6%, are nearly all equally represented. Severe winter storms arrive from the northeast (fetch of ~570 km). The maximum wave heights are >6 m and storms with waves above 4 m occur approximately eight times a year.

The overall geometry of Burmarrad's SW–NE trending valley has been governed by tilting and subsidence, leading to a submerged outer ria around Salina Bay. This contrasts with the pronounced elevation of the southern catchment area (Alexander, 1988; Putz-Perrier and Sanderson, 2010). Bed load sediment is supplied by three major fluvial systems: (i) the Wied il-Ghasel; (ii) the Wied Ghajn Rihana; and (iii) the Wied Qannotta. These watersheds are today heavily artificialized, with a shallow soil cover (20–60 cm) made-up of terra rosa soils, xerorendzinas and carbonate raw soils (Lang, 1960). In natural conditions, the soils are easily eroded under a climatic regime of long dry summers and a wet season in which rain frequently falls in heavy showers. At present rainfall averages 529.6 mm per annum and is characterized by a marked seasonal distribution, with ~70% of the total falling between October to March (Chetcuti et al., 1992). In many areas, the valley sides and floors have been eroded to bare rock.

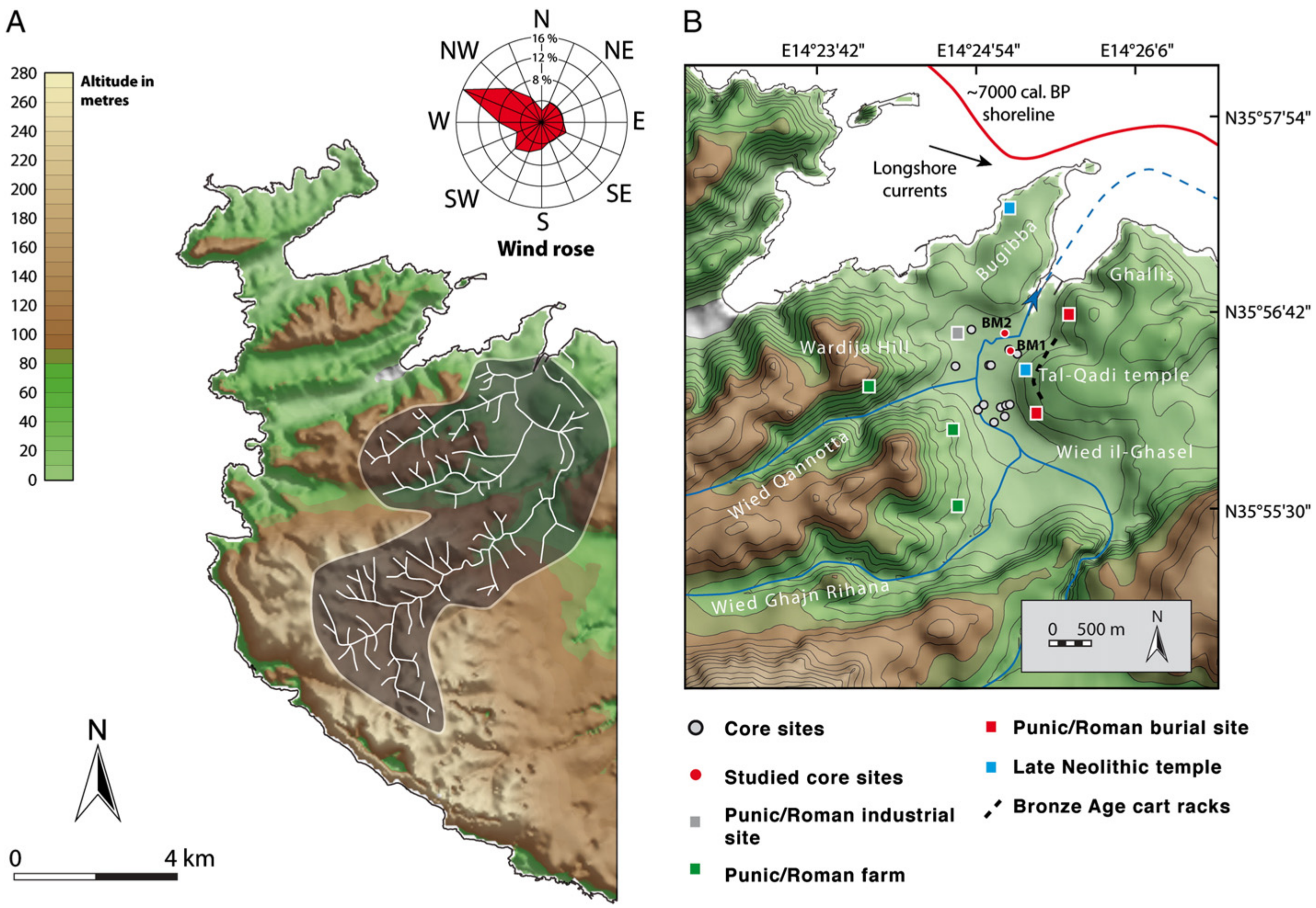

Fig. 2. A. Burmarrad catchment. B. Location of core sites (20 m contour lines). Studied core sites are denoted in red. Cores from Gambin (2005) are depicted in grey.

1.2. Archaeological background

Early settlement of Malta is set in the context of early post-glacial maritime voyages (Guilaine, 1994, 2003). The maritime importance of Malta is significant because it occupies a highly strategic position in the Mediterranean, controlling the narrow straits of Sicily and Tunisia. Accordingly, it has solicited considerable interest from human societies, as attest both its contemporary landscapes and archaeological finds (Gambin, 2004; Atauz, 2008). The great antiquity of human occupation within the Burmarrad valley has been retraced back to the Neolithic period (Gambin, 2005). It was a particularly attractive site for prehistoric human occupation as it provided, for instance, transport routeways, a source for food and a line of defence. Numerous archaeological sites from the Neolithic to Middle Ages overlook the present floodplain and evoke changing Holocene palaeogeographies (Gambin, 2004, 2005; Fig. 2B). Neolithic, Bronze Age and Punic-Roman finds are particularly well documented and consist of evidence for temples, farms and industry, in addition to burial sites. The environmental potentiality of the former embayment yielded all-weather protection for the anchoring of boats of all sizes. The earliest archaeological traces in the catchment area derive from Skorba that has yielded radiocarbon levels dated to 6040 ± 160 BP (6533–7267 cal. BP; Guilaine, 2003). It seems probable that these colonizers came from Sicily in search of fertile land. It is the only site on the island to manifest continuous occupation throughout the period (Guilaine, 2003).

This paper investigates the Holocene evolution of the Burmarrad coastal plain. Burmarrad is of particular importance, as it shows undisturbed sediment sequences spanning much of the Holocene (Gambin, 2005), including the earliest phases of human occupation of the island during the Neolithic. A multi-proxy sedimentological and palaeoecological approach is used to probe human–environment interactions since prehistoric times. Our aims are to:

- examine the general Holocene evolution of a fluvio-marine ria system in a Mediterranean island context, including its response to the Holocene marine transgression and subsequent infilling after ~6000 cal. BP. Particular attention is given to changes in sediment supply that caused fundamental modification of the ria's morphology;
- investigate the impact of human activities on the evolution of this base-level depocentre (deforestation, early pastoralism, agriculture, coastal response to catchment erosion); and
- better understand how and when the ria's anchorages evolved.

2. Methods

A series of four cores (BM 1–4) was drilled in spring 2008 and 2010, using a Baretta percussion corer. These stratigraphic data are complemented by previous soundings undertaken by Gambin (2005; Fig. 2). The position of each logged section was located using GPS and benchmarked relative to present mean sea level. These targeted boreholes provided the framework for identifying major stratigraphic units across the study area. Sections were extracted in metal tubes (diameter 10 cm) and subsequently stored in cold rooms at the University of Malta.

Two of the cores (BM1 and BM2) were sampled at regular 5 to 10 cm intervals. Initial facies descriptions (e.g. colour, petrofacies) were undertaken under standardized laboratory conditions. Samples were oven dried at 40 °C before being described using the Munsell colour scheme. Dry sediment aggregates were weighed and washed through two mesh sizes, 2 mm and 50 μm, to separate out the gravels (>2 mm), sands (2 mm to 50 μm) and silts and clays (<50 μm) fractions. In most cases, >150 g of dry aggregate were washed through to ensure the statistical validity of the results. The dried fractions were weighed and data plotted against stratigraphic logs in percentages.

Identification of mollusc shells was undertaken upon the retained gravels fraction and assigned to assemblages according to the Pérès and Picard (1964), Pérès (1982), Poppe and Goto (1991, 1993), and Doneddu and Trainito (2005) classification systems. Both *in situ* and *extra situ* taxa have been identified on the basis of core lithology and shell taphonomy. This approach aids in establishing the degree of environmental confinement/exposure. Ostracods were picked from the dried sands fraction and assigned to five ecological groups: freshwater, lagoonal, marine lagoonal, coastal and marine (Lachenal, 1989; Nachite et al., 2010). A minimum of 100 valves was picked and mounted on micropalaeotological slides.

Pollen extractions were performed following the classic method described by Moore et al. (1991). Sediments were treated by 10% HCl to remove the carbonate fraction, HF to remove the siliciclastic fraction, and concentrated HCl to remove the silicofluorides produced during HF treatment. The remaining material containing pollen grains was then subjected to acetolysis to remove organic material and to outline the wall structure of pollen grains for identification. Lycopodium tablets were also added to calculate the pollen concentrations (Stockmarr, 1971).

Chronological control is provided by eleven radiocarbon dates, calibrated using IntCal09 and Marine09 (Reimer et al., 2009; see Table 1). We constructed an age model using the dedicated R-code Clam (Blaauw, 2010), which uses repeated random sampling of the dates' calibrated distributions to derive a robust age-depth model through the sampled ages.

3. Results

The soundings undertaken on the floodplain have elucidated the sedimentary sequence. Here we describe the litho- and biostratigraphical data based on two representative cores: BM1 and BM2 (Figs. 2B and 3). Previous research has demonstrated that similar sediments can be traced several kilometres inside the ria (Gambin, 2005). The facies have been categorized into units A–E and are described from oldest to youngest.

3.1. Unit A

Unit A comprises a dark grey clay unit dated between ~7500 cal. BP and ~7000 cal. BP. The sediment color includes various shades of grey, typical of waterlogged gley-like conditions. The facies is dominated by silts and clays (47–98%). The molluscan faunal density is low at 3–52 tests per 500 g of the sediment aggregate (Figs. 4 and 5, Supplementary Figs. 1 and 2). Dominant species derive from the lagoonal (*Cerastoderma glaucum*, *Abra segmentum*) and the upper muddy-sand assemblage in sheltered areas (*Cerithium vulgatum*). There is a general increase in molluscan species diversity and density, from ~1 to 2 species at the base to 8 at the top of the unit. The ostracods are dominated by brackish water (*Cyprideis torosa*) and freshwater (*Candona* cf. *lactea*, *Candona* cf. *compressa*, *Potamocypris variegata*, *Darwinula stevesoni*, *Illyocypris gibba*) species (Figs. 6 and 7, Supplementary Figs. 3 and 4). Statistical biozonations (total sum of squares) of the macrofauna and ostracod datasets are in broad agreement with the lithostratigraphic data. A Principal Components Analysis (PCA) was calculated to help define and illustrate the main direction of variation in the ostracod assemblages. For core BM1, PCA axis 1 explains 90% of the variation in the data, essentially a salinity gradient between estuarine and freshwater species. PCA axis 1 scores are significantly correlated ($p<0.01$) with species diversity ($r^2=0.94$). The lagoonal taxa and low faunal densities support an early to mid-Holocene upper estuarine environment that began accreting in a context of rising post-glacial sea level.

Table 1
Radiocarbon dates and calibrations (Reimer et al., 2009). 'Poz' denotes Poznan (Poland) and 'Sac' denotes Saclay (France).

Laboratory code	Sample code	Material	Date BP	Calibrated age BP
SacA 11658	BM1/4	Charcoal	1650 ± 30	1418–1553
SacA 11663	BM1/64A	Charcoal	4565 ± 30	5056–5249
SacA 11665	BM1/74	2 *Loripes lacteus*	5445 ± 30	5731–5816
Poz-42441	BM1/80	Charcoal	5410 ± 40	6027–6295
SacA 11668	BM1/93	Peat	6115 ± 30	6899–7029
SacA 11669	BM1/100	Charcoal	6500 ± 30	7277–7349
Poz-42439	BM1/121	Charcoal	6650 ± 60	7434–7608
Poz-42682	BMII/42	Wood fragments	3655 ± 35	3888–4086
Poz-42443	BMII/28	Grain	3810 ± 30	4090–4347
Poz-42442	BMII/16	Charcoal	4010 ± 35	4416–4568
Poz-42444	BMII/4	Charcoal	6055 ± 35	6797–6995

In core BM1, the top of unit A grades from minorgenic sediments into a 15-cm long humified peat unit dated to 6115 ± 30 BP (6899–7029 cal. BP). The colour spans 3/1 7.5Y to 3/1 2.5Y. Silts and clays dominate (74–77%) with minor percentages of sands (14–23%) and gravels (3–9%). Slow moving water and associated muddy areas were particularly conducive to the accumulation of plant debris. The palynological data suggest that this peat accreted in a marginal freshwater environment, just before the mid-Holocene marine flooding of the ria and transition to lower estuarine conditions. It suggests the local development of a minor freshwater event; perhaps pool formation at the valley margins linked to a rising water table. The peat layer does not appear to be laterally extensive because it is not attested in other cores.

3.2. Unit B

Unit B is a silt-rich unit (72–97%) with minor percentages of sands (8–28%) and gravels (1–13%). In core BM1, it is dated from ~6800 to ~6000 cal. BP, in contrast to ~6800 to ~4300 cal. BP in core BM2. The color ranges between various shades of grey (4/1 7.5Y; 5/1 5Y; 5/1 7.5Y). There is a sharp rise in molluscan faunal densities (31–740/500 g) consistent with the marine transgression of the ria. Average species number in the unit is 7 compared to just 2 in unit A. Dominant molluscan species include *Cerastoderma glaucum* (lagoonal), *Bittium reticulatum* and *Rissoa ventricosa* (infralittoral sands assemblage), and *Cerithium vulgatum* and *Loripes lacteus* (upper muddy–sand assemblage in sheltered areas). Secondary species include *Parvicardium exiguum* (lagoonal) and *Pirenella conica* (upper clean-sand assemblage). Microfossil analysis indicates that, through much of the sequence, assemblages are dominated by brackish (*Cyprideis torosa Leptocythere lagunae*, *Leptocythere* cf. *lacertosa*) and coastal (*Loxoconcha rhomboidea*, *Hiltermannicythere* sp., *Costa batei*, *Aurila convexa*, *Loxoconcha stellifera*) species, with high faunal densities of 700–3450 tests/10 g. An increase in coastal ostracod taxa corroborates an opening up of the ria to marine dynamics. Gradually increasing marine conditions are confirmed by the PCAs of the molluscan datasets. The fine-grained sedimentology and palaeoecological data evoke a lower estuarine environment.

3.3. Unit C

Unit C is a shelly sands unit that accreted between 6000 and 4000 cal. BP. These deposits vary from poorly to well-bedded sands (22–49%) and silts (28–85%) with a rich biological fraction that includes posidonia fibres, molluscan shells and microfossils. *Cerithium vulgatum* and *Loripes lacteus* continue to dominate the molluscan suite with numerous secondary species from the lagoonal, upper muddy-sand assemblage in sheltered areas, infralittoral sands and upper clean-sand

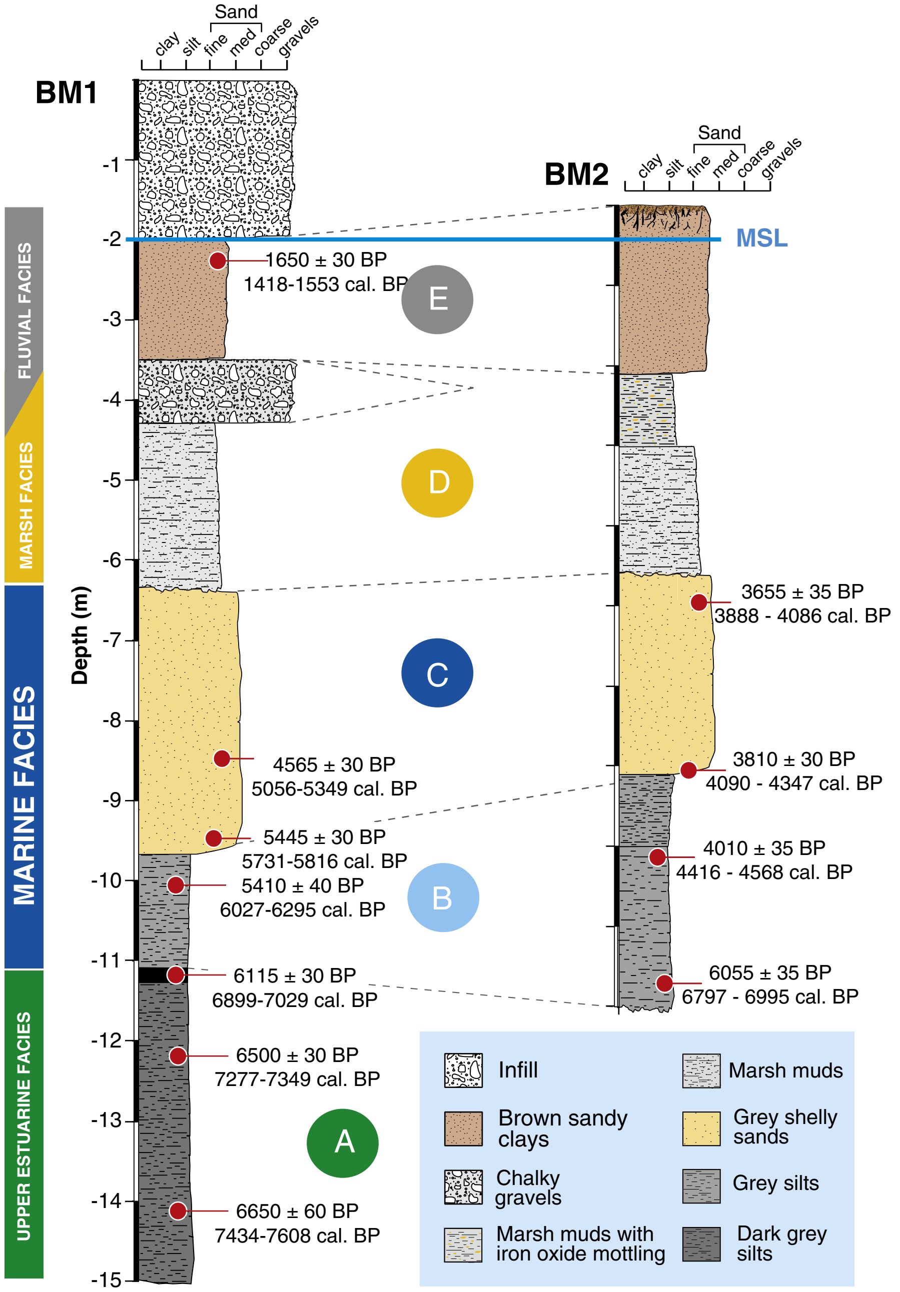

Fig. 3. Stratigraphy of cores BM1 and BM2.

assemblages. Unit B has the highest faunal density of the cores, with a mean of 298/500 g. Juvenile to adult tests are represented, consistent with the development of an *in situ* biocenosis, typical of a low-energy marine context. The ostracods, with faunal densities of ~800–5300 tests/10 g sand, are dominated by lagoonal (*Xestoleberis dispar*, *Xestoleberis communis*) and coastal taxa (*Leptocythere lagunae*, *Cytherelloidea sordida*, *Aurila woodwardii*, *Loxoconcha rhomboidea*, *Aurila convexa*, *Echinocythareis* sp. and *Loxoconcha stellifera*). This unit attests to the gradual progradation of a wave-dominated shoreface in a context of relative sea-level stability.

3.4. Unit D

Unit D is a light yellow (7/4 2.5Y) to light grey (7/2 5Y) silty sands unit, made-up of 55–86% silts and clays, 11–45% sands and 1–6% gravels. It began accreting after ~3900 cal. BP. Iron mottling and blue/grey colours indicate poor drainage. The sedimentological and biostratigraphical indicators are typical of brackish marsh deposits. A sharp fall in molluscan faunal densities (mean: 21/500 g) and species number (mean: 3) attests to decreasing marine influence and an infilling of the ria with fluvial sediments. Molluscan fauna is dominated by marsh species including *Peringia salinasi*, *Hydrobia ventrosa*, *Truncatella subcylindrica* and *Ovatella myosotis*. Freshwater (*Illyocypris gibba*, *Darwinula stevesoni*, *Potamocypris variegata*, *Candona* cf. *lacteal*, *Candona* cf. *compressa*) taxa dominate the ostracofauna, with minor abundances of brackish and coastal (*Leptocythere lagunae*, *Acantocythereis hystrix*, *Cytherelloidea sordida*, *Loxoconcha rhomboidea*, *Aurila convexa* and *Echinocythareis* sp.) species. There is a sharp fall in ostracod faunal densities to <100 tests/10 g sand (mean: 90). These assemblages indicate accumulation under freshwater/low brackish water conditions. The top of the unit is void of marine shells, consistent with a gradual isolation of the environment from marine dynamics. Cessation of sequence formation is radiocarbon dated to ~2700 cal. BP.

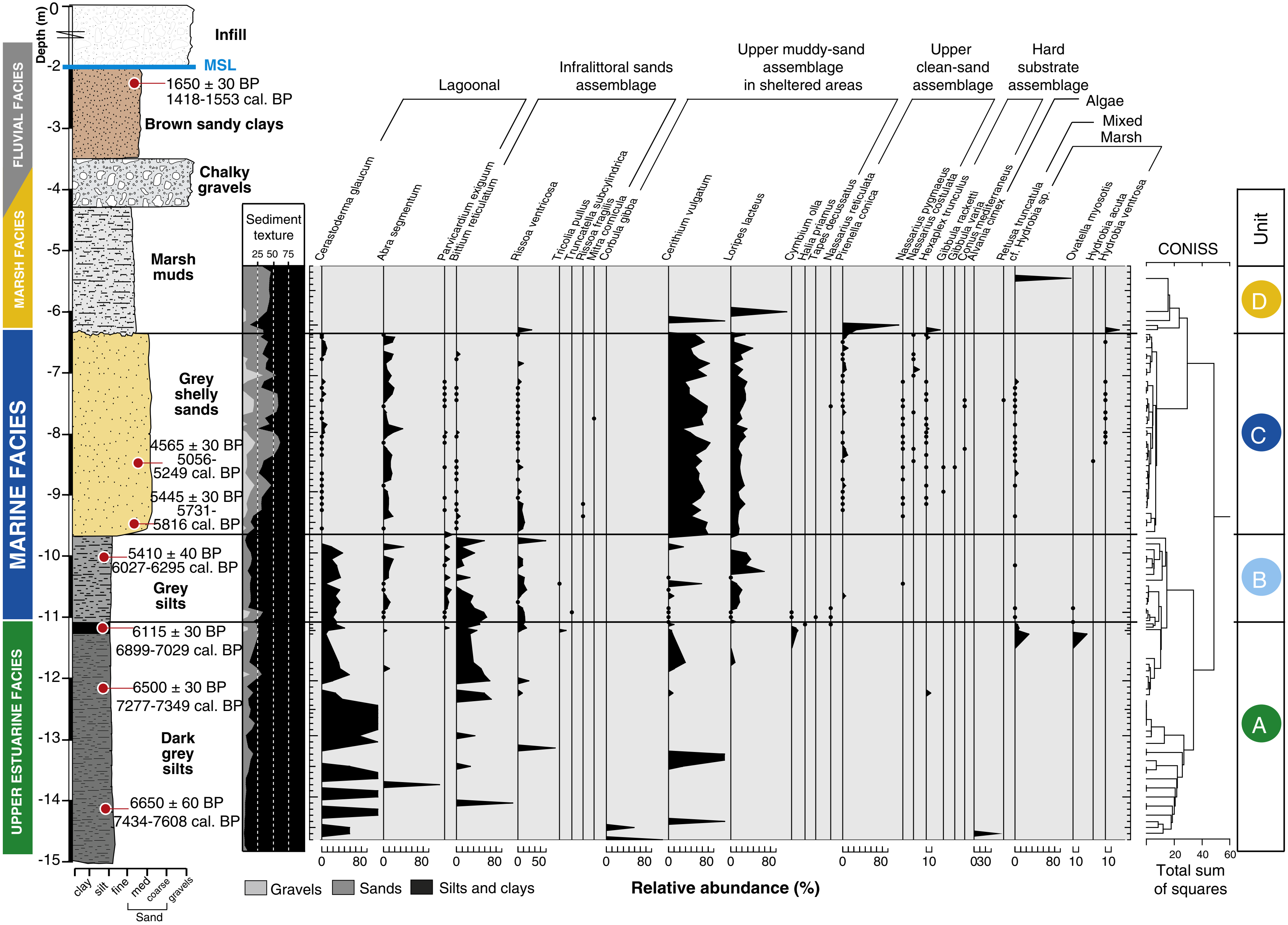

Fig. 4. Molluscan biostratigraphy of core BM1 (relative abundances).

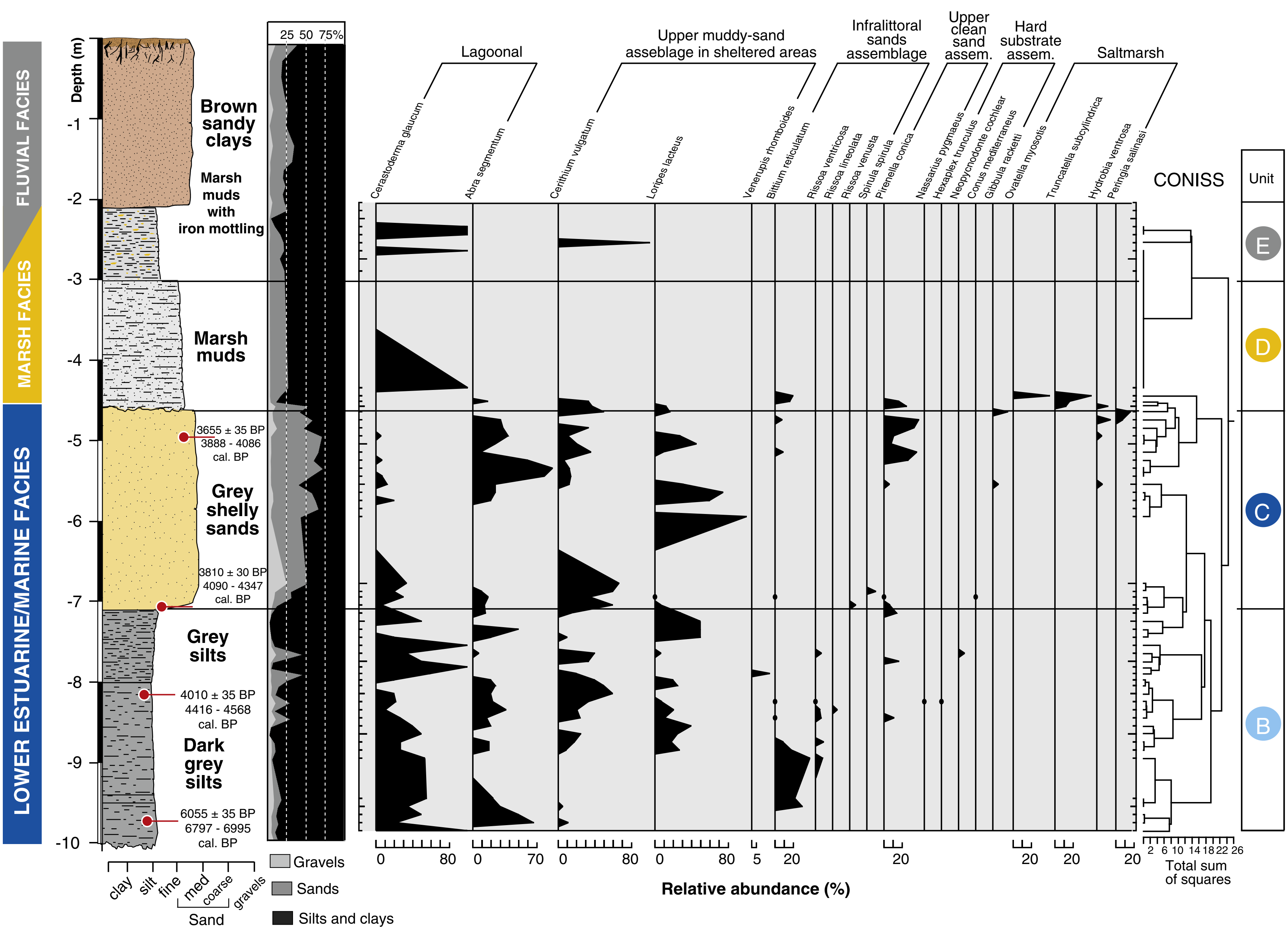

Fig. 5. Molluscan biostratigraphy of core BM2 (relative abundances).

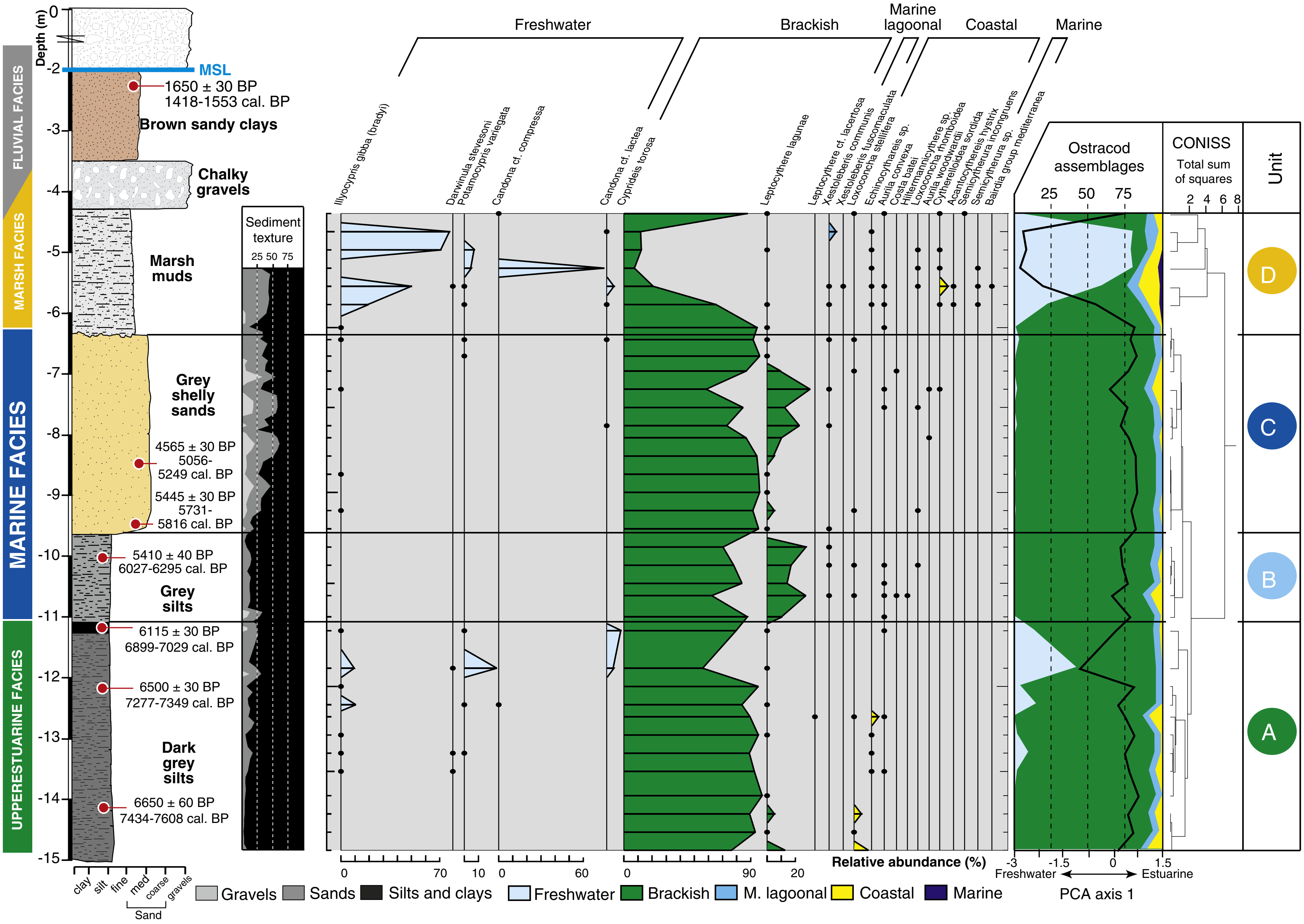

Fig. 6. Ostracod biostratigraphy of core BM1 (relative abundances).

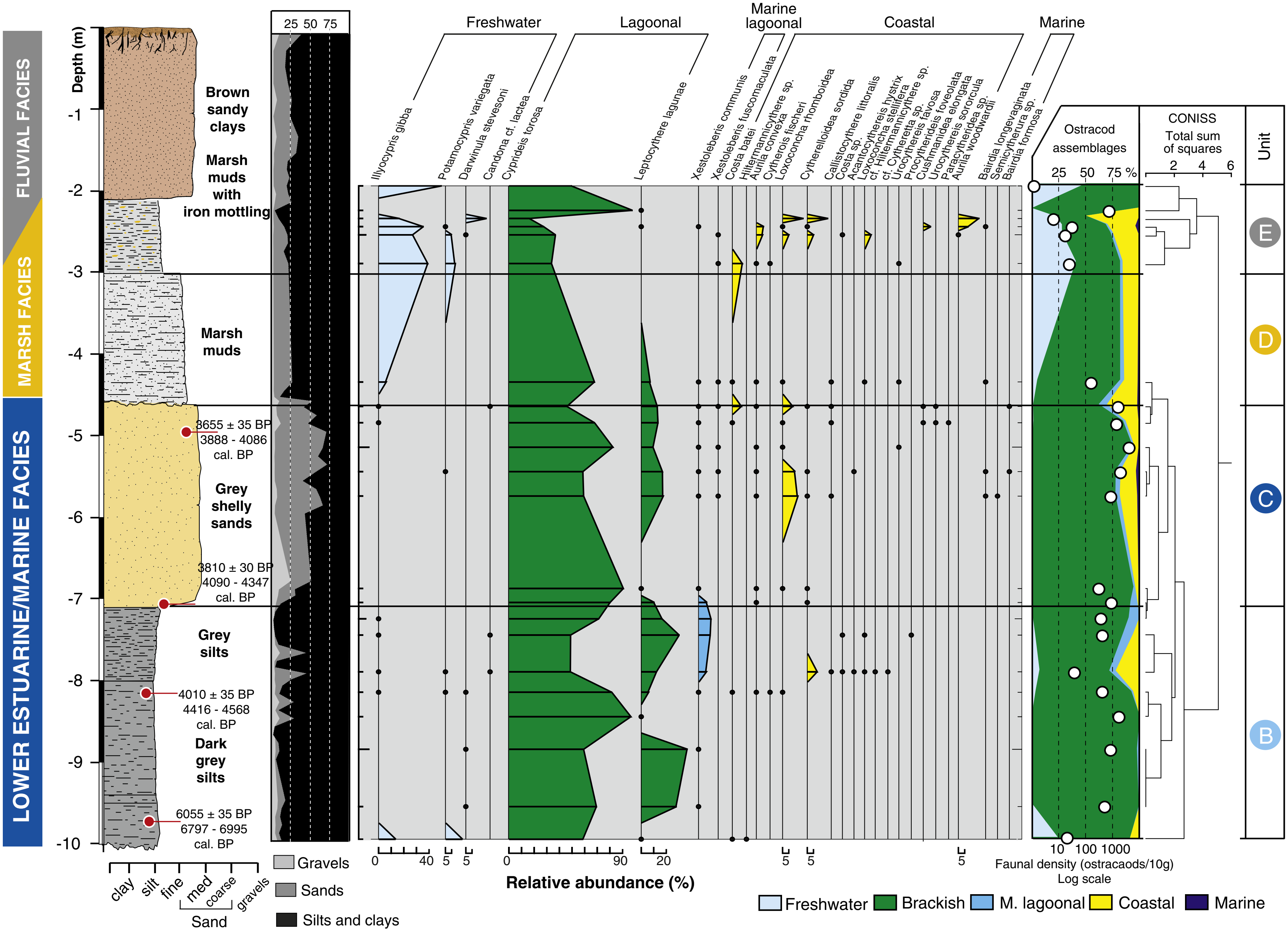

Fig. 7. Ostracod biostratigraphy of core BM2 (relative abundances).

3.5. Unit E

Unit E constitutes the final sequence of deposits in the Burmarrad valley. Pronounced red, yellow and brown colors produced by iron oxide accumulation and weathering distinguishes unit E silts. This suggests that they formed in a terrestrial, floodplain setting. The unit is rich in calcium carbonate grains and nodules, typical of a long dry season and the absence of deep leaching of the solutions in the soils. We interpret these as fluvial overbank deposits consistent with the final infilling of the valley bottom. There is an absence of biological indicators. In core BM1, this unit is dated from 2700 to 1300 cal. BP and after 2300 cal. BP in core BM2.

4. Discussion and interpretations

The ria of Burmarrad provides clear evidence for widespread landscape changes during the Holocene that can be linked to sea-level transgression, sediment forcing agents and human impacts. The first-order stratigraphy of the floodplain sequence constitutes a classic transgressive-regressive succession, ~10–15 m thick, made-up of four morphogenetic phases (Fig. 4). The sequence coarsens upwards from fine estuarine silts at the base to sandy fluvial fill at the top. In this section, we: (i) compare and contrast the chronostratigraphic data; (ii) probe the history of human impacts in the Burmarrad watershed; and (iii) discuss a series of working hypotheses regarding the ria's ancient anchorages.

4.1. Early Holocene estuary (7500–7000 cal. BP)

The earliest chronostratigraphic unit represents a continuous period of roughly five hundred years documented by basal silt deposits indicative of a low-energy environment. These sediments are concurrent with the earliest attested occupation of Malta ~7300 cal. BP (Trump, 1993; Guilaine, 1994). We interpret this facies as basal clays deposited in an estuarine setting, with terrestrial organic material deriving mainly from direct inflow by the three dominant fluvial tributaries. The faunal data support a euryhaline estuarine setting, characterized by the mixing of freshwater and seawater. The fine-grained sedimentation evokes inputs by low-energy alluvium that gradually infilled the incised limestone palaeo-valley. This unit is particularly rich in organic matter and charcoal. Although the coast is inferred to have been situated ~3 km from the core sites at this time, the incised talweg acted as a conduit for marine waters to penetrate into the lower reaches of the valley. The high amount of aquatic macrophytes (*Typha*/*Sparganium* and spores) fit closely with a brackish to freshwater environment, with dominant terrestrial rather than marine influences.

These results enable a better understanding of human activity around the Burmarrad area. The proven presence of an estuarine environment in the Neolithic period supports the working hypotheses of the potentiality for a Neolithic anchorage. The earliest human occupation of the area can be dated to ~6000 cal. BP. Although no traces of Neolithic dwellings have yet been unearthed, the presence of a tomb datable to ~4000 BC strongly points to some form of occupation of the environs (Bruno, 2009). The environmental conditions would have been ideal for the gathering of edible molluscs such as *Cerastoderma glaucum* (lagoon cockle), as well as fishing activities in sheltered waters. Late Neolithic occupation of the valley is attested by the presence of the Tal-Qadi temple situated on the eastern side of the present-day floodplain (Trump, 2002; Fig. 2B).

Some of the variability in faunal percentages and densities may be linked to the intensity of fresh and saline water inputs. Changes in the rainfall pattern, correlated with river discharge, appear to have influenced the palaeosalinity of the Burmarrad coast. High-resolution palaeoclimate studies for the Central Mediterranean are sparse (Dormoy et al., 2009; Jalut et al., 2009; Sadori et al., 2011). Nonetheless, recent research in nearby Sicily suggests that more humid conditions persisted in the region until ~4500 cal. BP, with gradually increasing relative aridity towards present underpinned by an orbitally-induced decrease in summer insolation (Magny et al., 2011).

In core BM1, the cessation of unit A is marked by a well-developed peat unit, which is securely dated to 6115 ± 30 BP (6899–7029 cal. BP). We interpret this as a swampy environment around the valley edge. This scenario is supported by the palynological data with a peak in *Cyperaceae* that corresponds to the localized choking of the estuary and the development of a pre-transgressive freshwater peat bog. Peat formation in coastal settings occurs within the upper littoral zone (Vella and Provansal, 2000). Together with the unusually high organic content, our results suggest that this short-lived environmental shift represents a decline in water salinity and increased proximity to a freshwater source (karstic spring, fluvial inputs or rising watertable). Ostracod analysis provides additional support for this interpretation of a swamp setting, with freshwater species making up ~8% of the sample (Fig. 6).

4.2. Maximum Holocene marine transgression of the Burmarrad ria (~7000 cal. BP)

The transition to unit B is characterized by a sharp rise in molluscan faunal densities (>740/500 g) and diversity (mean: 7), typical of a marine environment. The litho- and biostratigraphical data demonstrate that as sea level continued to slowly rise during the approach to the mid-Holocene, marine waters penetrated ~3 km inland, creating a large palaeobay at ~7000 cal. BP (Fig. 8). It marks a shift to lower-estuarine conditions then a wave-dominated coast, clearly supported by the physiography of the valley and a positive increase in the PCA axis 1 scores of the molluscan data. The presence of marine facies from cores further inland (Gambin, 2005) suggests that this bay had approximated dimensions of ~3000 m SN by ~650 m EW during the maximum marine ingression. A suite of archaeological remains is attested around the former bay spanning the Neolithic to Roman times (Gambin, 2005). These vestiges indicate that the ria was viewed as a desirable settlement area, with ready access to coastal resources, in addition to a low-energy context particularly favorable to the anchoring of boats. The ria would have provided year-round shelter from the dominant north-westerly winds.

The palynological data demonstrate intensified human impact on the landscape beginning ~7300 cal. BP, which is broadly consistent with the earliest archaeological traces (Trump, 1993). After this period, there is evidence for growing population size, in tandem with an increasingly elaborate material culture (Guilaine, 1994). The vegetation development reveals interesting information about early human activities, which appear to have been both prolonged and variable. The pollen spectra confirm high amounts of *Pistacia* dominating western Malta (>60% of the pollen). These strikingly elevated abundances are thus far unique in the Holocene records of the Mediterranean region, although it has also been demonstrated that *Pistacia* shrublands characterized the Sicilian coast around the same time (Tinner et al., 2009). The association of *Pistacia* with numerous anthropogenic pollen indicators (e.g. *Plantago lanceolata*-type, *Rumex*, and *Asphodelus)* suggest that the dense *Pistacia*-dominated shrublands were most probably a consequence of intensive human activities in the form of pastoralism. After 7300 cal. BP, high concentrations of charcoal are also recorded in association with the anthropogenic pollen indicators, supporting the idea that human-induced fires were employed from an early stage to promote the growth of edible plants and young shrubs for domesticated animals.

Deforestation, agriculture (terracing and planting of hillsides) and animal husbandry appear to have significantly impacted upon soil erosion, with high rates of Holocene sedimentation recorded during the Neolithic period. These sediment inputs led to a rapid decrease in the ria dimensions, whose surface area was reduced by ~40% between 7000 cal. BP and the Bronze Age (Fig. 9). Archaeological evidence from

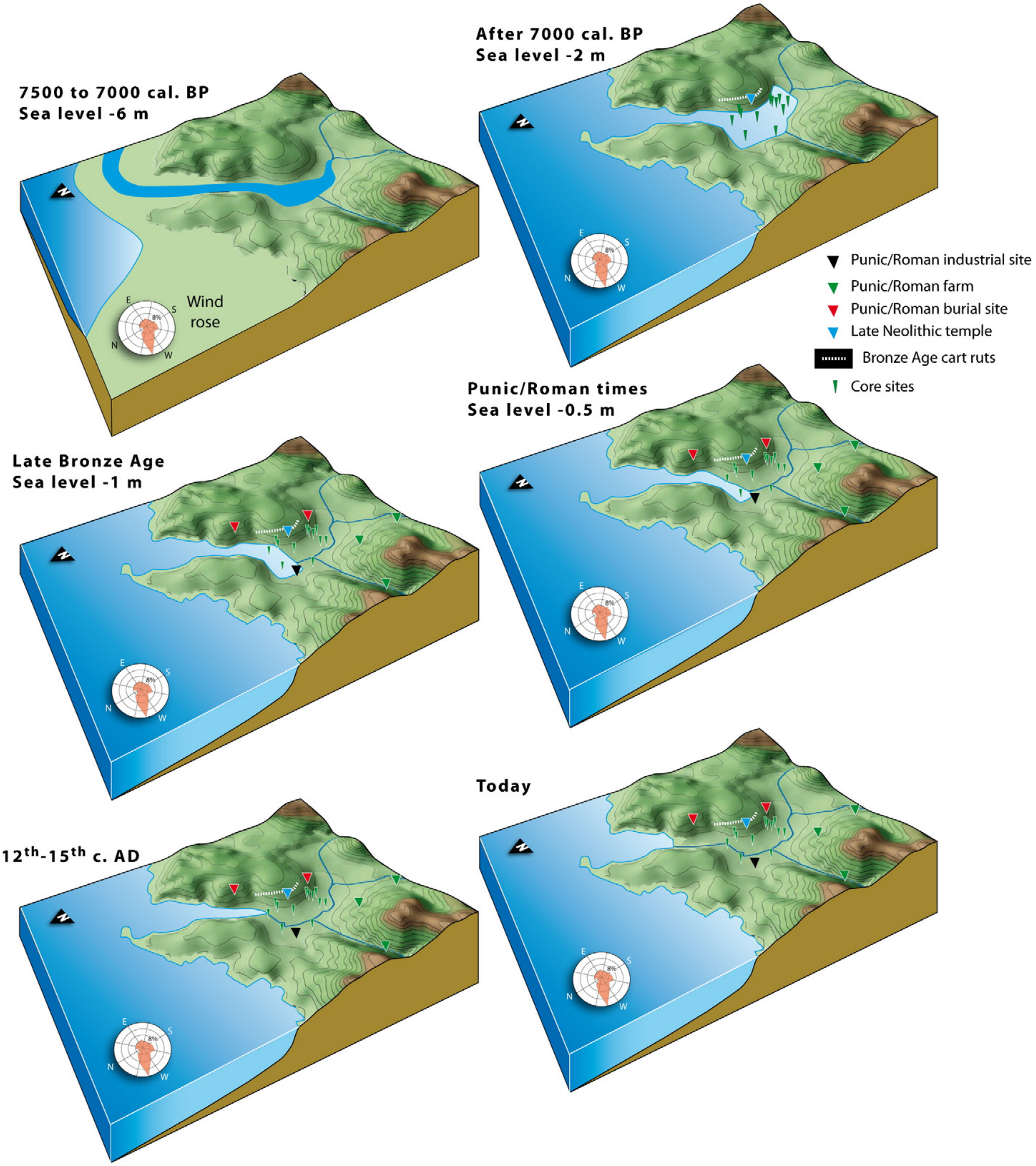

Fig. 8. Changing palaeogeographies of the Burmarrad ria. The sea-level data derive from 'global' curves (Fleming et al., 1998) and high-precision regional data from stable rocky coasts (Morhange et al., 2001).

a number of sites confirm that agricultural practices were well established by the late Neolithic (Pace, 2004). Animal reliefs at the Tarxien Temples, for example, clearly delineate the importance of animal husbandry to the prehistoric inhabitants of the islands. Our data suggest that the upland Coralline limestone areas of the Burmarrad catchment were already void of a significant vegetation cover by the mid-Holocene. Data from coastal Sicily show that humid conditions persisted in the region until around 4500 cal. BP (Tinner et al., 2009; Magny et al., 2011), which is important in explaining the flushing of sediments from upland source areas to base-level depocenters

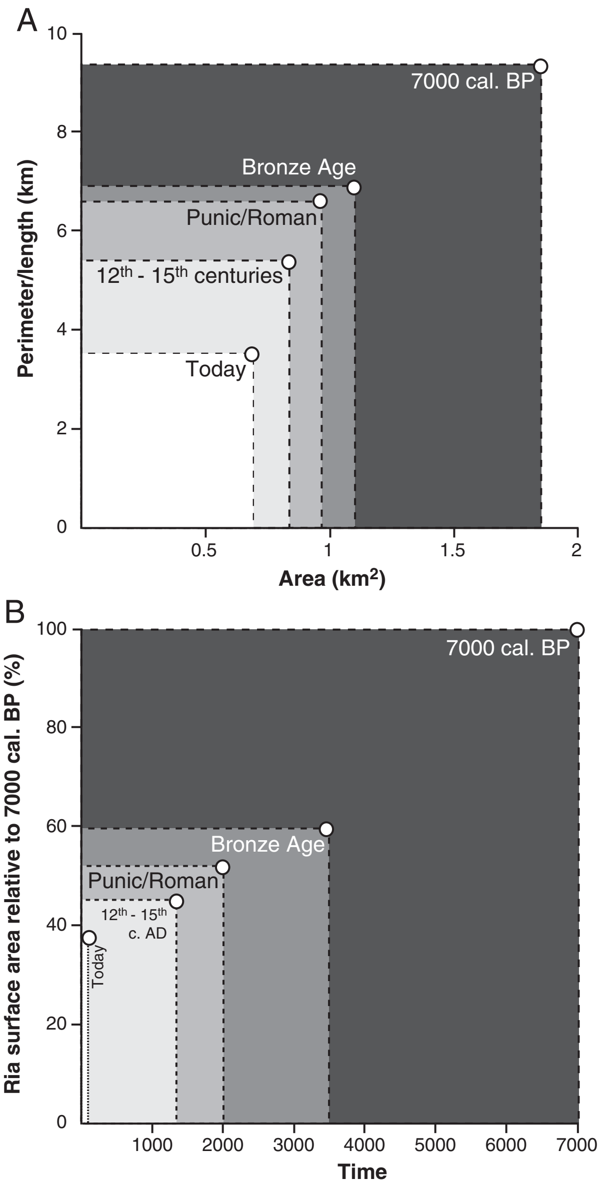

Fig. 9. A. Surface biplot of the changing dimensions of the Burmarrad ria since 7000 cal. BP. **B.** Changes in ria surface area through time, relative to 7000 cal. BP.

(Fig. 10). A sparse tree cover would have rendered the sediment-generating catchment particularly sensitive to soil erosion during the flash flood-type events that are typical of the Maltese islands.

In sum, relative sea-level stability and high sediment inputs led to the formation of a prograding delta sequence inside the transgressed ria, consistent with the coastal response in similar geomorphological contexts elsewhere in the Mediterranean (e.g. Brückner et al., 2002, 2005; Devillers, 2005; Devillers et al., 2007; Marriner and Morhange, 2007; Kazancı et al., 2009). Throughout the mid-Holocene, this sheltered marine embayment offered a multiplicity of resources (fish, shellfish) to the societies of western Malta. Of interest is the relative growth in the delta between the Late Neolithic and Bronze Age period.

4.3. Ria infilling (4000 cal. BP to present)

Full marine conditions are recorded at core site BM1 until ~4000 years ago, after which time we observe a gradual landlocking of the site, consistent with the seaward progradation of the ria coastline. The stratigraphy suggests that fluvial sediment supply rapidly overwhelmed the accommodation space. At its maximum ~7000–6000 cal. BP, the embayment was 1.8 km^2 meaning that the AD/AB index was 0.05 (AD = drainage area; AB = delta and ria area). The catchment source area was therefore large compared to the marine sink, with high potential sediment input to an area with relatively limited accommodation space, especially around the former bay's margins. During the mid-Holocene, significant sediment supply from the Wied il-Ghasel and the Wied Ghajn Rihana resulted in a northward prograding geometry along the landward flank of the ria system. Between 7000 cal. BP and ca. 3000 cal. BP, which spans the Temple period, the ria's dimensions were reduced by ~40%. By contrast, the distal systems in the western and central areas, fed by the relatively small Wied Qannotta watershed, were not infilled until the later Holocene (Fig. 8). This demonstrates that topography, watershed area and land-use history have significantly influenced the architecture of the Holocene deposits by controlling path and intensity of sediment influxes inside the ria.

The environmental modifications around the estuary, brought about by increased sedimentation, did not put a stop to human activity in the area. In the Bronze Age, it was the increased threat of seaborne raids that brought about changes. The trend in Malta was for the Bronze Age inhabitants to establish centres of habitation on high ground so as to make the most of the natural protection afforded by the topography. Some of these sites, such as Il-Qliegha Tal-Bahrija in the north-west of the island (Trump, 2002), are located in close proximity to the sea. Close to Burmarrad, underground storage pits and ceramic evidence at Il-Qolla indicate the presence of Bronze Age settlement (Gambin, 2004). This site commands a dominant view over the Burmarrad area. The extent of human activities during this period is furthermore confirmed by the numerous cart ruts incised into the limestone bedrock (Hughes, 1999). No less than 22 such networks are attested in the Burmarrad catchment (Trump, 1993; Ventura and Tanti, 1994). The tracks have been the source of intense speculation regarding vehicle technology, traction, function and chronology (Hughes, 1999) although present consensus tends to favour a Bronze Age chronology (Trump, 1993).

The transition to unit D after 4000 cal. BP is characterized by steep declines in marine faunal densities (mean: 21/500 g) and diversities (mean: 3). These are accompanied by an increase in typical marsh species. Iron oxide mottling of the muds translates the gradual transition to a terrestrial setting, with a seasonal wetting and drying of the marsh surface, typical of a pseudo-gley. The marsh surface gradually grades into fluvial overbank sediments dominated by freshwater ostracods and molluscs. This steady transition is confirmed by PCAs of the biostratigraphical data.

By the first millennium BC, the ria had been reduced by ~50% to ~0.9 km^2 compared to its mid-Holocene maximum (Fig. 9). At this time, a well-developed deltaic plain made the Burmarrad floodplain particularly attractive, providing fertile land for food production. Once Malta came into the orbit of Phoenician and subsequently Punic spheres of influence, the islands' inhabitants felt secure enough to establish centers of habitation and production close to the shore (Gambin, 2005). At the site of San Pawl Milqi, the Roman edifice is placed directly over Punic structures (Bruno, 2009). The exact function of this 'industrial' site during the Punic period has not yet been defined but it could well have been used for the production of some form of cloth—possibly linen. In the Roman period, the site was expanded and its function changed so as to accommodate the production of olive oil (Bruno, 2009). The sheer size of this and other farmsteads throughout Malta, point to a scale of production well beyond the needs of the local populace. The proximity to the sea of this and other oil producing villas indicates that the final destination of the product was overseas (Gambin, 2005). Ships could call in to the protected bay, to load amphorae for export. Besides the villas, an area of industrial production was excavated on the northwest coast of the current floodplain (Gambin, 2005). Furthermore, the shape of the bay as illustrated in Fig. 8 would have offered all-year protection to vessels meaning that ships of all sizes could, if necessary, winter there during the closed sailing season between October and March. The ria

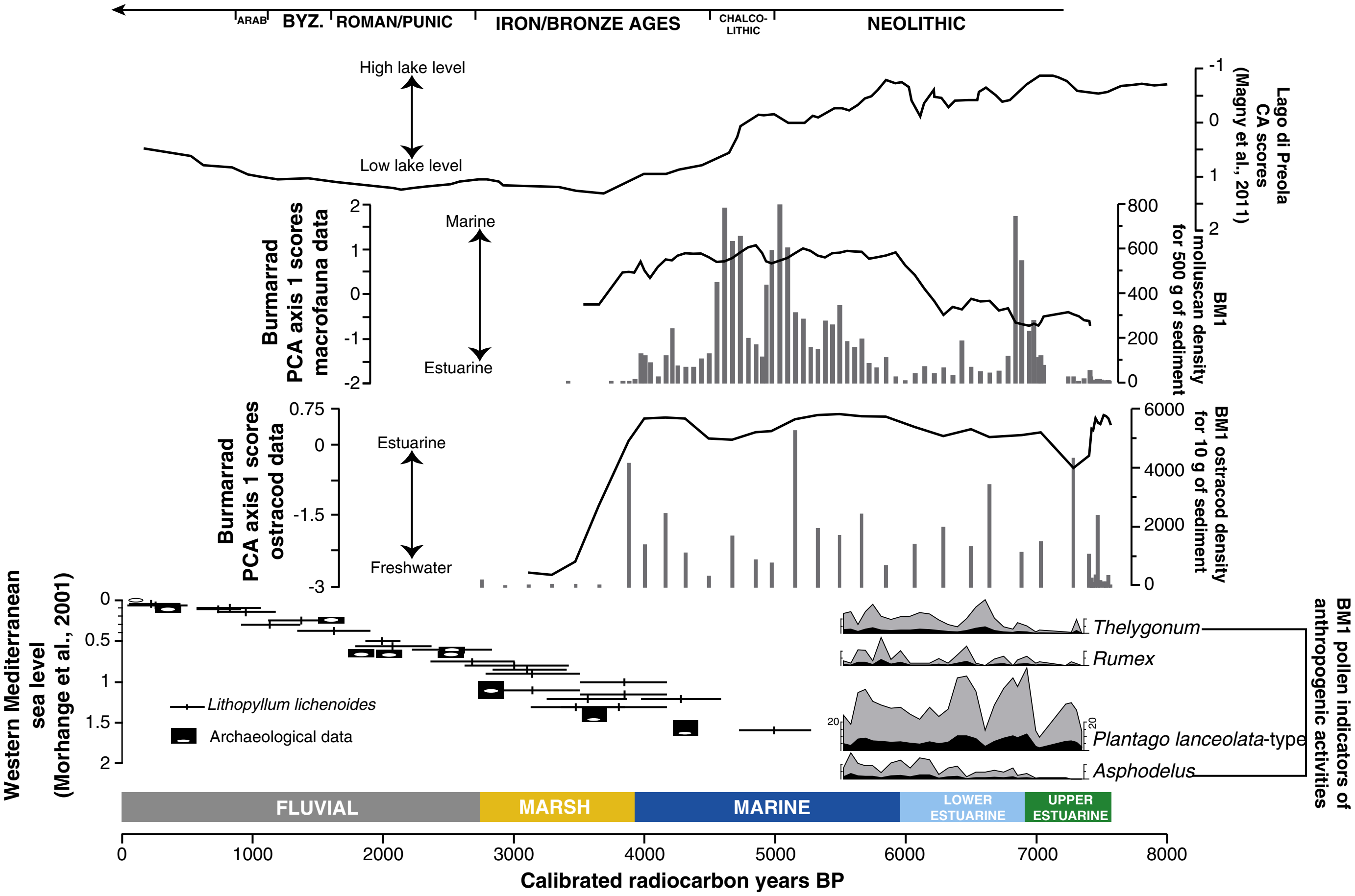

Fig. 10. BM1 chronostratigraphic data and comparison with regional proxies.

harbor complex must have been important enough to warrant the continued permanent settlement of the area into the late Roman period as is attested by the presence of hypogea datable to the 3rd and 4th centuries AD (Buhagiar, 1984).

Although these new geoarchaeological data clearly indicate that the inner bay shrank further by the Middle Ages, historical references confirm the use of the bay by medieval mariners. The inclusion of Burmarrad in medieval sailing instructions, alongside other harbors in Malta, confirms that a degree of maritime activity was maintained during the 14th and 15th centuries (Cassola, 1992). Other written sources corroborate the use of the outer bay (present day Salina Bay) by ships waiting for favorable winds. Furthermore, references to the presence of a medieval tower in the area are an indication that pirates would have used the bay as a landing place for raiding parties to go ashore. Of interest is the reaction of the inhabitants—they once again moved away from the shore and established a village (Marikatu) on what is today known as Wardija Hill (the word Wardija originating from the Italian Guardia—look out; Wettinger, 2000). In the late 16th century, the Knights of Malta, drained and paved some of the marshy area in order to construct large saltpans which are still in use today.

5. Conclusion

Evolution of the Burmarrad ria fits tightly with the general global model for Holocene deltaic development (Stanley and Warne, 1994) where deceleration in sea-level rise led to the formation of marine deltas between 8500 and 6500 BP (9500 and 7500 cal. BP). The relatively simple palaeotopography of the Burmarrad floodplain means that ria progradation and sediment architecture have been chiefly controlled by supply of riverine sediments.

Use of the bay as a natural anchorage is corroborated by archaeological finds from the seabed (Gambin, 2005) and even historical sources (Cassola, 1992; Wettinger, 2000). The coastal stratigraphy confirms an early Holocene estuarine environment between 7500 to 7000 cal. BP that would have been particularly conducive to navigation by shallow-draught Neolithic craft. The maximum marine ingression around 7000 cal. BP generated a large palaeobay whose delta system gradually began prograding seawards diminishing the size of the embayment (Fig. 8). The partially transgressed ria would have provided year-round shelter from the dominant north-westerly winds as well as the north-easterly winter storms due to the serpentine morphology of the bay. The prograding delta system, fed by watershed sediment supply, siginificantly changed the palaeogeography of this marine embayment with an inferred dislocation of the anchorages seawards. Similar scenarios played out in the rias of Ionia (Brückner et al., 2002; Kraft et al., 2006) and the Gialias of Cyprus (Devillers, 2008). By Punic/Roman times, the bay at Burmarrad had been reduced to around 0.9 km^2 whilst by the late Middle Ages, evidence suggests that the harbour lay just south of Salina Bay (Wettinger, 2000; Gambin, 2005). Despite the threat from seaborne raiding parties, people around Burmarrad took advantage of the fertile alluvial soils (Wettinger, 2000), which may be considered a classic case of 'improvement through sedimentation' from a terrestrial perspective (Horden and Purcell, 2000). Conversely, high sediment supply led to the demise of the natural anchorages inside the ria.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.palaeo.2012.04.022.

References

Alexander, D., 1988. A review of the physical geography of Malta and its significance for tectonic geomorphology. Quaternary Science Reviews 7, 41–53.

Anderson, E.W., 1997. The wied: a representative Mediterranean landform. GeoJournal 41, 111–114.

Atauz, A.D., 2008. Eight thousand years of Maltese maritime history: trade, piracy, and naval warfare in the Central Mediterranean. University Press of Florida.

Blaauw, M., 2010. Methods and code for 'classical' age-modelling of radiocarbon sequences. Quaternary Geochronology 5, 512–518.

Bonanno, A., 1994. Archaeology. In: Frendo, H., Friggieri, O. (Eds.), Malta culture and identity. Valletta, Ministry of Youth and the Arts, pp. 81–103.

Bonanno, A., 2005. Malta: Phoenician, Punic and Roman. Midsea Books Ltd., Malta.

Brückner, H., Müllenhoff, M., Handl, M., van der Borg, K., 2002. Holocene landscape evolution of the Büyük Menderes alluvial plain in the environs of Myous and Priene (Western Anatolia Turkey). Zeitschrift für Geomorphologie, Supplement Band 127, 47–65.

Brückner, H., Vött, A., Schriever, M., Handl, M., 2005. Holocene delta progradation in the eastern Mediterranean—case studies in their historical context. Méditerranée 104, 95–106.

Bruno, B., 2009. Roman and Byzantine Malta—trade and economy. Midsea Books, Malta.

Buhagiar, M., 1984. The Salina Hypogea at St. Paul's Bay. Melita Historica 10, 1–18.

Cassar, L.F., 1997. Settlement patterns in the Maltese Islands: from early colonization to pre-independence. GeoJournal 41, 137–144.

Cassola, A., 1992. The Maltese Toponomy in three Ancient Italian Portulans (1296–1490). Al-Masaq Studia Arabo-Islamica Mediterranea. International Journal of Arabo-Islamic Mediterranean Studies 5, 47–64.

Chetcuti, D., Buhagiar, A., Schembri, P.J., Ventura, F., 1992. The climate of the Maltese Islands: a review. Malta University Press, Msida, Malta.

Dalli, C., 2006. Malta: the Medieval Millennium. Midsea Books Ltd., Malta.

Dart, C.J., Bosence, W.J., McClay, K.R., 1993. Stratigraphy and structure of the Maltese Graben system. Journal of the Geological Society 150, 1153–1166.

Devillers, B., 2005. Morphogenèse et anthropisation holocène d'un bassin versant semi-aride: le Gialias, Chypre, PhD thesis. Université de Provence, Aix-en-Provence.

Devillers, B., 2008. Holocene morphogenesis and anthropisation of a semi-arid Watershed, Gialias River, Cyprus. British Archaeological Reports. Archaeopress, Oxford.

Devillers, B., Excoffon, P., Morhange, C., Bonnet, S., Bertoncello, F., 2007. Relative sea-level changes and coastal evolution at Forum Julii (Frejus, Provence). Comptes Rendus Geoscience 339, 329–336.

Doneddu, M., Trainito, E., 2005. Conchiglie del Mediterraneo. Il Castello, Trezzano sul Naviglio.

Dormoy, I., Peyron, O., Combourieu-Nebout, N., Goring, S., Kotthoff, U., Magny, M., et al., 2009. Terrestrial climate variability and seasonality changes in the Mediterranean region between 15,000 and 4,000 years B.P. deduced from marine pollen records. Climate of the Past 5, 615–632.

Fenech, K., 2007. Human-induced changes in the environment and landscape of the Maltese Islands from the Neolithic to the 15th Century AD as inferred from a scientific study of sediments from Marsa, Malta. British Archaeological Reports. Archaeopress, Oxford.

Fleming, K., Johnston, P., Zwartz, D., Yokoyama, Y., Lambeck, K., Chappell, J., 1998. Refining the eustatic sea-level curve since the Last Glacial Maximum using far- and intermediate-field sites. Earth and Planetary Science Letters 163, 327–342.

Gambin, T., 2004. Islands of the Middle Sea: an archaeology of a coastline. In: De Maria, L., Turchetti, R. (Eds.), Evolución paleoambiental de los puertos y fondeaderos antiguos en el Mediterráneo occidental. Rubbettino Editore, Soveria Mannelli, pp. 127–146.

Gambin, T., 2005. The maritime landscapes of Malta from the Roman period to the Middle Ages. PhD thesis, University of Bristol.

Guilaine, J., 1994. La mer partagée. Hachette, Paris.

Guilaine, J., 2003. De la vague à la tombe : Métamorphoses en Méditerranée (8000–2000 avant J.C.). Seuil, Paris.

Guilcher, A., Paskoff, R., 1975. Remarques sur la géomorphologie littorale de l'archipel maltais. Bulletin de l'Association de Géographes Français 427 (8), 225–231.

Horden, P., Purcell, N., 2000. The Corrupting Sea: A Study of Mediterranean History. Blackwell Publishers, Oxford.

Hughes, K.J., 1999. Persistent features from a palaeo-landscape: the ancient tracks of the Maltese islands. The Geographical Journal 165, 62–78.

Hunt, C.O., 1997. Quaternary deposits in the Maltese Islands: a microcosm of environmental change in Mediterranean lands. GeoJournal 41, 101–109.

Hyde, H.P.T., 1955. The Geology of the Maltese Islands. Lux Press, Malta.

Illies, J.H., 1981. Graben formation: the Maltese Islands—a case study. Tectonophysics 73, 151–168.

Jalut, G., Dedoubat, J.J., Fontugne, M., Otto, T., 2009. Holocene circum-Mediterranean vegetation changes: climate forcing and human impact. Quaternary International 200, 4–18.

Kazancı, N., Dündar, S., Alçiçek, M.C., Gürbüz, A., 2009. Quaternary deposits of the Büyük Menderes Graben in western Anatolia, Turkey: implications for river capture and the longest Holocene estuary in the Aegean Sea. Marine Geology 264, 165–176.

Kraft, J.C., Brückner, H., Kayan, I., Engelmann, H., 2006. The geographies of ancient Ephesus and the Artemision in Anatolia. Geoarchaeology 22, 121–149.

Lachenal, A.-M., 1989. Écologie des ostracodes du domaine méditerranéen : application au Golfe de Gabès (Tunisie orientale). Les variations du niveau marin depuis 30 000 ans. Documents des laboratoires de géologie de Lyon 108, 1–239.

Lang, D.M., 1960. Soils of Malta and Gozo. Her Majesty's Stationary Office, London.

Magny, M., Vannière, B., Calo, C., Millet, L., Leroux, A., Peyron, O., Zanchetta, G., La Mantia, T., Tinner, W., 2011. Holocene hydrological changes in south-western Mediterranean as recorded by lake-level fluctuations at Lago Preola, a coastal lake in southern Sicily, Italy. Quaternary Science Reviews 30, 2459–2475.

Marriner, N., Morhange, C., 2007. Geoscience of ancient Mediterranean harbours. Earth-Science Reviews 80, 137–194.

Moore, P.D., Webb, J.A., Collinson, M.E., 1991. Pollen analysis, second ed. Blackwell Scientific Publications, Oxford.

Morhange, C., Laborel, J., Hesnard, A., 2001. Changes of relative sea level during the past 5000 years in the ancient harbor of Marseilles, Southern France. Palaeogeography, Palaeoclimatology, Palaeoecology 166, 319–329.

Moscati, S., 1993. Some reflections on Malta in the Phoenician world. Journal of Mediterranean Studies 3, 286–290.

Nachite, D., Rodríguez-Lázaro, J., Martín-Rubio, M., Pascual, A., Bekkali, R., 2010. Distribution and ecology of recent ostracods from the Tahadart estuary (NW Morocco). Revue de Micropaleontologie 53, 3–15.

Pace, A., 2004. Malta during prehistory: an overview. In: Gambin, K. (Ed.), Malta roots of a nation—the development of Malta from an island people to an island nation. Valletta, Heritage Malta, pp. 25–44.

Paskoff, R., Sanlaville, P., 1978. Observations géomorphologiques sur les côtes de l'archipel maltais. Zeitschrift für Geomorphologie 22, 310–328.

Pedley, H.M., House, M.R., Waugh, B., 1976. The geology of Malta and Gozo. Proceedings of the Geologists' Association 87, 325–341.

Pérès, J.-M., 1982. Major benthic assemblages. In: Kinne, O. (Ed.), Marine Ecology. : part 1, 5. Wiley, Chichester, pp. 373–522.

Pérès, J.-M., Picard, J., 1964. Nouveau manuel de bionomie benthique de la mer Méditerranée. Rec. Trav. Station Marine Endoume 31, Marseille.

Poppe, G.T., Goto, Y., 1991. European seashells, vol. I. Verlag Christa Hemmen, Wiesbaden.

Poppe, G.T., Goto, Y., 1993. European seashells, vol. II. Verlag Christa Hemmen, Wiesbaden.

Putz-Perrier, M.W., Sanderson, D.J., 2010. Distribution of faults and extensional strain in fractured carbonates of the North Malta Graben. AAPG Bulletin 94, 435–456.

Reimer, P.J., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Bronk Ramsey, C., Buck, C.E., Burr, G., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T.J., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., McCormac, F.G., Manning, S.W., Reimer, R.W., Richards, D.A., Southon, J., Turney, C.S.M., van der Plicht, J., Weyhenmeyer, C., 2009. IntCal09 and Marine09 radiocarbon age calibration curves, 0–50,000 years cal BP. Radiocarbon 51, 1111–1150.

Sadori, L., Jahns, S., Peyron, O., 2011. Mid-Holocene vegetation history of the central Mediterranean. The Holocene 21, 117–129.

Sagona, C., 2002. The archaeology of Punic Malta. Peeters Publishers.

Schembri, P.J., 1997. The Maltese Islands: climate, vegetation and landscape. GeoJournal 41, 115–125.

Schembri, P.J., Hunt, C., Pedley, M., Malone, C., Stoddart, S., 2009. The Environment of the Maltese Islands. In: Malone, C., Stoddart, S., Bonanno, A., Trump, D. (Eds.), Mortuary customs in prehistoric Malta. Oxbow Books, Oxford, pp. 17–39.

Stanley, D.J., Warne, A.G., 1994. Worldwide initiation of Holocene Marine Deltas by deceleration of sea-level rise. Science 265, 228–231.

Stockmarr, J., 1971. Tablets with spores used in absolute pollen analysis. Pollen et Spores 13, 615–621.

Tinner, W., van Leeuwen, J.F.N., Colombaroli, D., Vescovi, E., van der Knaap, W.O., Henne, P.D., Pasta, S., D'Angelo, S., La Mantia, T., 2009. Holocene environmental and climatic changes at Gorgo Basso, a coastal lake in southern Sicily, Italy. Quaternary Science Reviews 28, 1498–1510.

Trump, D.H., 1993. Malta: an archaeological guide. Progress Press, Valletta.

Trump, D.H., 2002. Malta: prehistory and temples. Midsea Books, Malta.

Vella, N., 2005. Phoenician and Punic Malta. Journal of Roman Archaeology 18, 436–450.

Vella, C., Provansal, M., 2000. Relative sea-level rise and neotectonic events during the last 6500 yr on the southern eastern Rhône delta, France. Marine Geology 170, 27–39.

Ventura, F., Tanti, T., 1994. The cart tracks at San Pawl tat-targa, Naxxar. Melita Historica 11, 219–240.

Vossmerbäumer, H., 1972. Malta, ein Beitrag zur Geologie und Geomorphologie des Zentraimediterranean Raumes. Wiirzburger Geographicshe Arbeiten 38, 1–213.

Wettinger, G., 2000. Place names of the Maltese Islands ca. 1300–1800. PEG, Malta.