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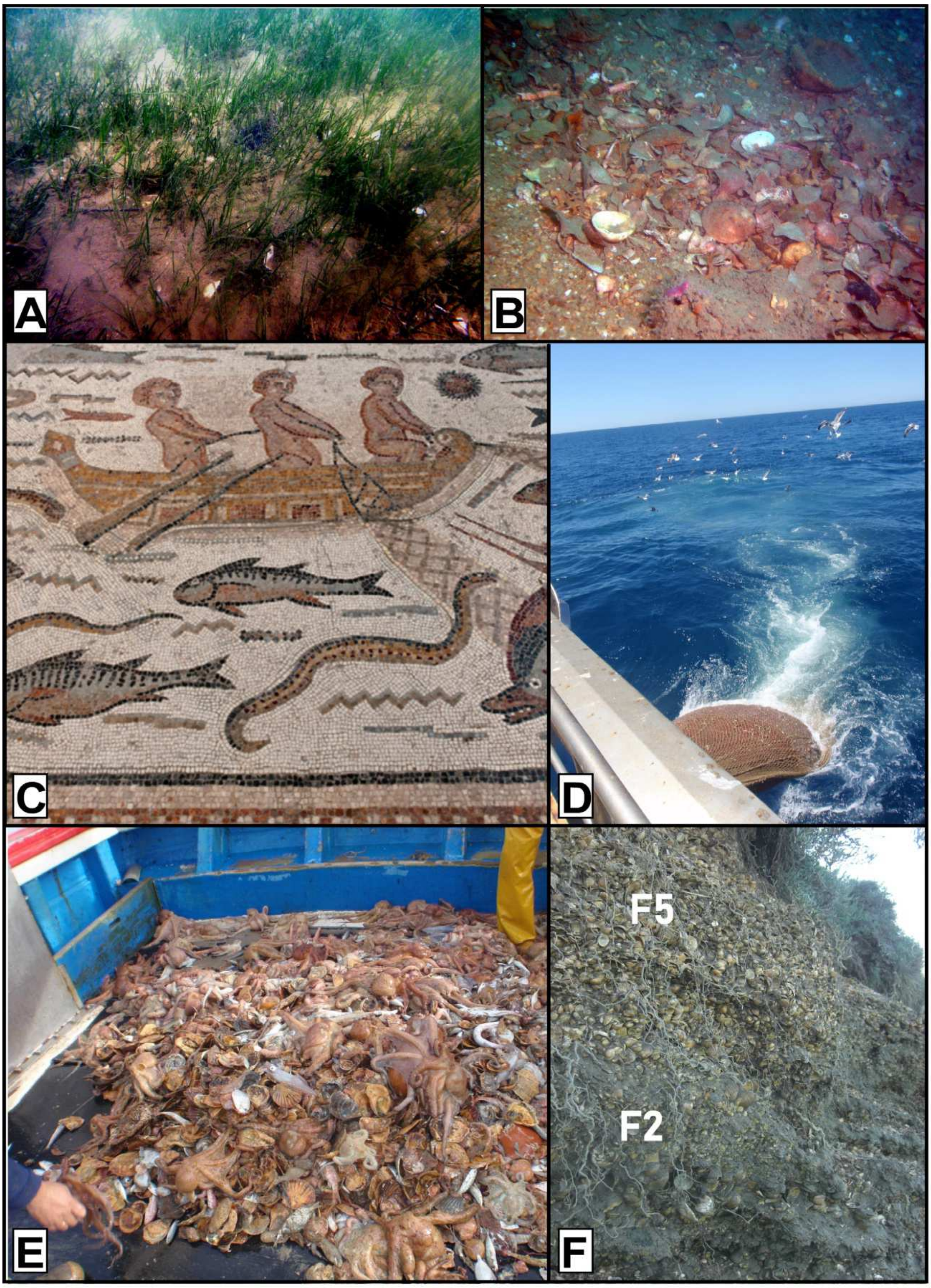
GRAPHICAL ABSTRACT



A multidisciplinary analysis of shell deposits from Saltés Island (SW Spain): the origin of a new Roman shell midden

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ABSTRACT

The analysis of shell deposits eroded by a ebb-tide channel on Saltés Island (Tinto-Odiel estuary, SW Spain) resulted in the identification of a new shell midden, associated with the activity of a nearby Roman factory over the 4th-5th centuries CE. This midden differs from other old shell deposits (sandy tidal flats, cheniers, washover fans) in several features: a) its malacological content, dominated by edible species (mainly the bivalve *Glycymeris nummaria*) and differentiated by statistical analysis; b) a partial selection and better conservation of *Glycymeris nummaria* (Linnaeus), its most abundant species; c) the absence of microfauna, which implies a previous washing to its final deposit; and d) an age concordant with the one deduced from the Roman amphoraic remains found in this area and subsequent to the washover fans on whom it was deposited. All these features, together with the absence of both anthropic fractures or cooking, would indicate that this Roman shell midden was the end result of a trawling on subtidal *Glycymeris*-rich sandy bottoms with adjacent grasslands, where the gastropod *Bittium reticulatum* (da Costa) was the most abundant mollusc. This gastropod is the dominant species in the remaining shell deposits.

Keywords: molluscs; taphonomy; statistics; microfauna; archaeology; Roman period.

1. Introduction

The prehistoric and historical evidences of mollusc consumption are very abundant and started as far back as the Lower Palaeolithic (ca. 300 ka; Colonese et al., 2011). One of the most widespread results are coastal shell middens, characterized by massive concentrations of mollusc shells that also contain frequent bone remains, charcoal and ash that denotes collection, hunting and food processing (e.g. Álvarez et al., 2011; Thompson et al., 2016). These shell accumulations are present in numerous coastal environments around the world (see Fig. 1 for examples).

The species richness of each coastal shell midden depends on the disponibility and paleobiogeographical distribution of edible species in a certain area for a defined period of time. Among bivalves, some of the most commonly reported groups are oysters (Lewis, 2011; Lulewicz et al., 2017), mussels (Jerardino et al., 2008; Erlandson et al., 2009a, b), clams (Bailey, 1977; Hallmann et al., 2009) or cockles (Dupont et al., 2007; López-Dórigal et al., 2019). The gastropod record includes marine, brackish and even terrestrial species, such as strombids, muricids or helicids (Schapiera et al., 2006; Douka et al., 2014; Magee et al., 2017). In an individual shell midden, the most consumed species may vary with time due to anthropogenic overexploitation, climatic effects, sea-level oscillations or geomorphological changes (Branch et al., 2014; García-Escárzaga et al., 2017).

In the geological record of these littoral scenarios, shell middens coexist with natural shell deposits, such as beach ridges, cheniers, washover fans or bioclastic tidal facies. An important body of research has focused on the differences between them, from which it can be deduced that middens shells are mainly characterized by: 1) Texture: absence or very low percentages of matrix and grain size selection in edible species; 2) Stratigraphy: no evidence for internal stratification; 3) Fossil record: low diversity, dominant edible species of macrofauna (e.g. bivalves, gastropods, crustaceans, bones of various groups) and absence or scarcity of microfossils in relation to natural formations; 4) Taphonomy: dominant disarticulation, selection of adults, acute fractures of shell margins, rupture of the last turn of the loop or presence of burnt evidences; 5) Archaeology: presence of hearth stones or artefacts in some cases; and 6) Chronology: consistent with the human history in most cases. This general overview should be treated with caution, because numerous problems have been described in the individual study of each shell midden (Bailey, 1977; Gill et al., 1991; Attenbrow, 1992; Carter, 1999; Saunders and Russo, 2011; Betts and Hrynick, 2017 and references therein).

In southern Spain, evidence of the mollusc exploitation has been highlighted at around 150-120 ka during the Last Interglacial and continued until the Holocene (Fa, 2008; Cortés et al., 2011; Jordá et al., 2011). During the Roman period (3rd century BCE-5th century CE), numerous halieutic sites (so-called *cetariae*) were present along the southwestern Atlantic coast of Spain (Bernal et al., 2014; Campos et al., 2015a). Associated shell middens are still poorly studied (e.g. Ramos et al., 2011) and require extensive future research.

(FIGURE 1)

This paper analyzes the main faunistic characteristics of the sedimentary facies present in the northwestern sector of Saltés Island (Fig. 2, A-B: Tinto-Odiel estuary, SW Spain) to define their main assemblages and to detect possible shell middens based on a multidisciplinary analysis (macrofauna, microfauna, taphonomy, statistics, chronology) of them.

2. Regional setting

2.1. The Tinto-Odiel estuary

In southwestern Spain, the Tinto and Odiel Rivers make up a large joint estuary, with two main channels (Fig. 2, B-C: Padre Santo channel and Punta Umbría channel) and numerous ebb-tide channels that delimit a set of islands and marshes (Fig. 2, C: Saltés, Bacuta, Enmedio). This geomorphological architecture is protected by two sandy spits (Fig. 2, B-C: Punta Umbría and Punta Arenillas). Hydrodynamic processes are controlled by the tidal regime, waves and, to a lesser extent, the fluvial dynamics. Tidal regime is mesotidal (mean range: 2.15 m; Borrego et al., 1993) and the dominant waves come from the southwest (Borrego, 1992). Fluvial inputs are limited during most of the year due to the scarce flow of the Tinto and Odiel Rivers, but they are very polluted by heavy metals (Cu. Pb, Zn) owing to millenial mining activities (Nieto et al., 2007).

2.2. Saltés Island

This small island (37º6′28′′-37º13′12′′N; 6º50′30′′-6º58′30′′W) has an elongated morphology in NW-SE direction and includes a set of cheniers (Fig. 2, C: El Almendral, El Acebuchal, La Cascajera) separated by extensive marshes and tidal channels (Fig. 2, D: e.g. Estero de Los Difuntos). These cheniers and some adjacent washover fans have been formed by the action of the equinoxial tides of spring and autumn and winter storms, with a migration towards the north of these bioclastic ridges on a previous tidal sandy plain (Morales et al., 2014; Cáceres et al., 2018).

(FIGURE 2)

In the last decades, the tidal action of the Estero de los Difuntos ebb-tide channel has caused the erosion of La Cascajera chenier, the most important of this island (Fig. 2, D). Several multidisciplinary studies on the materials now exposed has made it possible to differentiate five main sedimentary facies in this area (Fig. 3; modified from Cáceres et al., 2018; González-Regalado et al., 2019a, b), with a relatively well developed overlying edaphic profile. Synthetically, its main characteristics are the following: a) facies 1 (F1: silty tidal flat: 0.5-1 m a.s.l.): sandy blue-gray silts, intensely bioturbated by annelids; b) facies 2 (F2: washover fan: 0.7-2.5 m a.s.l.): alternating medium to coarse bioclastic sands, with N-NO orientation and avalanche faces dipping more than 30º, derived from the storm action; c) facies 3 (F3: sandy tidal flat: -0.5-0.5 m a.s.l): fine to medium sands with an abundant bioclastic record and reddish intercalations rich in organic matter; and d) facies 4 (F4: chenier; 0.5-1 m a.s.l.): well selected bioclastic gravels with planar cross-stratification; and e) facies 5 (F5: high-energy deposits; 0.75-2.25 m a.s.l.): massive shell-supported accumulations of molluscs (mainly bivalves), locally arranged on facies 2 (Fig. 3, section C) and initially attributed to storms (Cáceres et al., 2018).

2.3. Geological evolution of Saltés Island and human occupation

The archaeological record of Saltés Island presents an evolution linked to its own geological formation, which began with the emersion of the first northern cheniers on a previous sandy tidal plain (Fig. 2, C-E: El Almendral). This emersion occurred approximately 3,200 years ago (Suárez Bores, 1971) and a Roman salting factory (*cetaria*) was built later on this chenier (2nd century BCE), with the presence of pools and massive accumulations of bivalves (mainly *Glycymeris*; Ponsich, 1988). It was part of a significant number of coastal settlements distributed along the entire southern Iberian Atlantic coast (Fig. 2, E).

New cheniers subsequently emerged to the south (Fig. 2, C: La Cascajera), which were partially eroded by the action of storms that caused the deposit of washover fans between the 1st century BCE and the 3th century CE (González-Regalado et al., 2018). Recently, a new Roman *cetaria* has been discovered in the northern end of this chenier, very close to the study area (Campos et al., 2015). Its first evidence of occupation occurred during the 4th century CE and they lasted until the end of the 5th century CE or early 6th century CE. Consequently, this occupation occurred between two and three centuries after the deposit of washover fans.

3. Material and methods

3.1. Field methods

The erosive action of the Estero de los Difuntos ebb-tide channel on the northwestern sector of La Cascajera chenier has allowed the current exposure of various profiles. One of them was selected due to the presence of all the facies defined above (facies 1-5; Cáceres et al., 2018) and three sections about 3.5 m in height were sampled (Fig. 2, D), with the extraction of forty-one samples (Fig. 3).

(FIGURE 3)

Samples were selected from the different vertical sedimentary units that make up the facies mentioned above (Fig. 3). Before taking each sample, the surface was cleaned and a small vertical profile was made, to avoid possible contamination of overlying or adjacent areas. Samples were collected with a spatula and placed in self-sealing plastic bags.

In addition, an underwater exploration of the adjacent littoral has been carried out to find the possible origin of the molluscs present in these facies.

3.2. Laboratory methods

3.2.1. Macrofauna

In each sample, two hundred grams of sediment were separated for the malacological analysis, which were sieved through a 2 mm mesh sieve. The residue was dried in an oven at a constant temperature of 40 °C for a period of not less than one day. Once dry, they were weighed and all mollusc specimens were extracted, weighed and counted. A valve of a bivalve was considered as a specimen if it retained the hinge and at least half of the valve, and as a fragment if this element had disappeared. On the other hand, the vast majority of gastropods have remained almost complete and they have only been considered as fragments if they did not keep the last body whorl. Complete and fragmentary specimens of identified species or genera has been counted (e.g. NISP: Number of Identified Specimens), a common way of quantifying faunal remains in shell middens (Heritage New Zealand Pouhere Taunga, 2014; Lambacher et al., 2016).

Given that the great majority of samples (> 85%) did not exceed 160 shells, the sample size (NISP: 50 individuals/sample) was calculated for this number with a confidence level of 95% and an accuracy of 5%, assuming that p=0.5 (50%). These levels are similar to others applied in the study of these organisms (eg, Paolucci, 2010). The study of 50 shells per sample is the basis of this work.

To select them randomly, the content of each sample was spread on a tray subdivided into nine squares. The shells were collected by grids. The order of choice of the grids was established for each sample by random numerical series from 1 to 9. In the samples with less than 50 shells the total of these were taken into account.

If possible, specimens were identified to the species level, according to Gómez (2015) and the World Register of Marine Species (WoRMS). We established: a) the percentage by weight of the molluscs, the number of molluscs per sample and the species richness; b) the total percentages of each species in each sample; and c) the range and mean percentages of the main species in the different facies and the upper soil.

3.2.2. Edible species

The percentages of the edible species in all the samples were also calculated, as well as their minimum, maximum and average for the facies and the upper edaphic profile. They are exclusively bivalves, such as *Glycymeris*, *Acanthocardia*, *Cerastoderma*, *Chamelea*, *Donax*, *Ruditapes*, *Spisula* and the family Ostreidae, in accordance with current standards. These genera are frequently consumed today in southwestern Spain (Junta de Andalucía, 2001) and they are also some of the most abundant in numerous shelf middens of southwestern Spain (e.g. Martín and Campos, 1995; Bernal et al., 2014; Campos et al., 2015b; Bernal et al., 2015). Consequently, it is reasonable to assume that these species were also appreciated by the Romans.

3.2.3. Statistical analysis

A statistical analysis was applied to the percentages of the eighteen most abundant species. In a first phase, the correlation coefficient matrix between them was calculated to obtain a global view of the main groups of taxa. In addition, a Q-mode cluster analysis was applied to: a) the percentages of these eighteen main species; and b) the percentages of edible species in each sample. Five methods were initially applied (complete linkage clustering; single; average;

Mcquitty; Ward) and the first one was selected since it reflects the number of groups that are deduced in most of the others.

3.2.4. Taphonomy

To define the state of preservation of the valves, a classification composed of four categories was made: perfect condition (A); small erosions (B); perforations and umbo/broken apex (C); and fragments (D). In a later step, the percentage of each category in the samples was calculated, as well as their minimum, maximum and average percentages in each facies and the upper edaphic profile.

Some additional taphonomical features have been tested: a) the percentages of bioeroded valves and the types of bioerosion; b) the fractures of the bivalve margins or the gastropod shells with a possible anthropic origin; and c) evidence of cooking.

A morphometric analysis of *Glycymeris nummaria*, the most abundant species among bivalves, has been made. The anterior-posterior axis of all its valves was measured and four intervals or growth stages were established with equal amplitude from 12.1 to 52.8 mm. Next, the percentage of each stage was calculated in fourteen samples selected and representative of the different facies and the upper edaphic profile, as well as its minimum, maximum and average in each sedimentary facies.

3.2.5. Microfauna

Forty samples were selected for microfaunistic analysis. In each sample, ten grams of sediment were separated, an adequate amount according to other microfaunal studies in archaeological sites (Lilley et al., 1999). These samples were levigated through a 125 μm mesh sieve. The residue was dried in an oven at a constant temperature of 40 °C for a period of not less than one day. The total populations of foraminifera and ostracods were extracted and the average abundance of the main species of both groups was calculated in each facies.

3.3. Archaeology

The archaeological survey surface focused on the border areas of the sections studied, with the delimitation of eight sectors (Fig. 11, I-VIII) with a variable area between 6,500 m^2 (sector III) and 13,000 m^2 (sector I). The recovered objects were classified, accounted for and divided into ceramic or construction material (Tab. 10).

3.4. Dating

The age of the different facies were extracted from Cáceres et al. (2018) and González-Regalado et al. (2019b), with the application of the reservoir effect correction (-108 ± 31 ^{14}C yr) calculated by Martins and Soares (2013) in this area. Results are presented as calibrated ages for 2σ intervals (Tab. 11). In addition, the time interval of production of different amphoras found in the upper soil has been taken into account.

4. Results

4.1. Malacofauna

4.1.1. Global analysis

Malacofauna constitutes an important percentage of the total sediment weight in most of the studied samples, with a facies average that ranges from 2.5% (F1) to 73.8% (F5) (see supplementary data). Mollusc shells are abundant in F3 (M: mean; M: 84 specimens/sample), F4 (M: 80 specimens/sample) and especially F5 (50-404 specimens/sample; M: 156 specimens/sample). Species richness is also greater in these three facies, with 8-11 species in most of their samples. On the contrary, molluscs are rare in F1 (2 species/sample) and in some sandy, non-bioclastic levels of F2 (2-3 species/sample).

(TABLE 1)

(FIGURE 4)

In total, 3,566 specimens were collected and 1,724 of the projected 2,050 have been studied, because in 12 of the samples the number of shells was less than the calculated sample size (50). Forty-eight taxa have been identified, reaching the specific level for thirty-two of them (Table 1). Bivalves (Fig. 4; 50.96%) dominates slightly over gastropods (Fig. 5, except R; 48.81%), whereas scaphopods are poorly represented (Fig. 5, R; 0.23%). The former are represented by twenty-two species, although the most abundant are *Glycymeris nummaria* (Fig. 4, M; M: 22.81%), *Chamelea gallina* (Linnaeus) (Fig. 4, G; M: 10.21%), *Ostrea* sp. (Fig. 4, O; M: 5.46%), *Glycymeris glycymeris* (Linnaeus) (Fig. 4, L; M: 3.89%) and *Loripes orbiculatus* Poli (Fig. 4, X; M: 3.83%).

(FIGURE 5)

Gastropods have a lower diversity with twelve identified species, among which *Bittium reticulatum* (Da Costa) (Fig. 5, B) constitutes almost half of the studied specimens (45.39%). The rest of gastropods appear very sporadically and do not exceed 0.65% in any case. *Calyptraea chinensis* (Linnaeus) (Fig. 5, E; M: 0.64%) and *Rissoa* sp. (Fig. 5, N; M: 0.58%) approach this value.

4.1.2. Species richness and sedimentary facies

The percentages of the species present vary considerably depending on the sedimentary facies that contain them (Table 2 and supplementary data). Silty tidal flat (F1) is characterized by the smaller number of individuals (2) and taxa (2), with scarce specimens of the bivalve *C. gallina* and the gastropod *B. reticulatum*. The faunal abundance of washover fans (F2) varies remarkably between the medium, non-bioclastic sands (6-25 specimens/200 g) and the bioclastic levels (45-195 specimens/200 g), although the dominant species are similar. *B. reticulatum* is the dominant species (M: 61.3%), with the bivalves *G. glycymeris* (M: 10.2%) and *C. gallina* (M: 9.2%) as main secondary species.

Bioclastic sands of sandy tidal flats (F3) differ from the previous facies in a higher average percentage of bivalves, as well as by the replacement of *G. nummaria* (M: 17.6%) by *G. glycymeris* as dominant bivalve. The total percentage of bivalves slightly increases, although *B. reticulatum* continues to be the most abundant mollusc in most samples (M: 52.8%). On the other hand, the bioclastic cheniers of La Cascajera (F4) have similar percentages of bivalves and gastropods. Among the former, *C. gallina* (M: 19.5%) and *G. nummaria* (M: 15.7%) are dominant, although their average percentages are much lower than those of *B. reticulatum* (M: 46.7%).

(TABLE 2)

F5 presents a singular malacological content, being the bivalves (> 60%) dominant over the gastropods in all the samples. The main species is *G. nummaria* (M: 47.6%), which can represent up to 78% of all molluscs. It is followed in abundance by *B. reticulatum* (M: 20.2%), while ostreids and *C. gallina* appear frequently represented (M> 6.5%). Occasionally, the bivalves *Anomia ephippium* Linnaeus, *Cerastoderma glaucum* (Bruguière) and *L. orbiculatus* can reach 10% or more. The two studied samples of the edaphic profile closely resemble this facies in their faunal composition, with high percentages of *G. nummaria* (35-66%) and *B. reticulatum* (14-40%). *C. gallina* (2-10%) is the main secondary species in these samples.

4.1.3. Statistical analysis

The correlation matrix allows to distinguish three groups of species (Table 3). The first group (*A. ephippium -Cerastoderma edule -C. glaucum -Ostrea* sp.) is positively correlated with *G. nummaria*, while these species have negative correlations with *B. reticulatum*. This group and *G. nummaria* are abundant in F5 (40-84%), the upper edaphic profile (35-72%) and some basal samples of F4 included in section C (24-64%). Their percentages are low in F3 (4-12%). A second group (*C. gallina-Corbula gibba-Dentalium* sp.) shows a very irregular distribution, reaching 50% in some samples of F1 and F4 and not exceeding 32% in F2. The third group (*L. orbiculatus-Calyptraea chinensis-Rissoa* sp.) is scarcely represented in F2 (<10% in most samples), F3 (M: 6%), F4 (M: 5.4%) and F5 (<8% in most samples), although it reaches 24% in sample C-10 (F5).

(TABLE 3)

Cluster analysis allows us to differentiate two large groups of samples (Fig. 6, A: groups 1 and 3) and detects an outlier (group 2: sample B-3), identified by the predominance of *G. glycymeris* (52%) on *B. reticulatum* (26%) and ostreids (8%). Group 1 (16 samples) includes all samples of F5 and some samples of F4 below them in section C, as well as the soil samples and two samples of F2 located below it in sections A and B (Fig. 6, B). The majority of these samples are characterized by the predominance of *G. nummaria*, although three subgroups can be distinguished. Subgroup 1.1 (5 samples) is characterized by the highest percentages of *G. nummaria* (Fig. 6, C: 54-78%; M: 61.2%), with *B. reticulatum* (12-30%; M: 18%) and *C. gallina* (2-20%; M: 8.4%) as main secondary species. Subgroup 1.2 (3 samples) is exclusively represented in F5, with *G. nummaria* as the most representative species but with lower percentages than in the previous subgroup (38-44%; M: 42%). Other differentiating characters of this group are the high percentages de ostreids (16-26%; M: 22.67%), as well as the highest values of *A. ephippium* (4-12%, M: 7.33%) and *C. glaucum* (2-10%, M: 5.33%) of all the differentiated subgroups. Subgroup 1.3 (8 samples) shows very similar percentages of *G. nummaria* (24-42%, M: 33.32%) and *B. reticulatum* (28-41.3%, M: 34.83%), together with moderate percentages of *C. gallina* (4-22%, M: 12.17%).

Group 3 (24 samples) consists of samples from F1 to F4, all dominated by the gastropod *B. reticulatum*. Four subgroups can be distinguished, defined mainly by the decreasing abundance of this taxon. The main feature of subgroup 3.1 (7 samples) is the extremely abundance of *B. reticulatum*, the highest amongs all the subgroups determined (74-86.7%; M: 79.5%). *C. gallina*

(0-10%; M: 5,06%) is the main secondary species in these samples, the majority of which belong to F2. Subgroup 3.2 (9 samples) includes seven samples of F2 and one sample of both F3 and F4. Their percentages of *B. reticulatum* are lower than the previous subgroup (52-70%; M: 64.29%), being accompanied by *C. gallina* (0-14; M: 7.86%), *L. lucinalis* (0-17%; media: 5.83%) and *G. glycymeris* (0-16%; M: 5.36%). Subgroup 3.3 (2 samples) presents similar percentages of *B. reticulatum* (44.44-50%; M: 47,22%) and *C. gallina* (38.89-50%; media: 44.44%). The last subgroup (6 samples) includes samples of F2, F3 and F4, which are distinguished from the previous three subgroups by the lower percentages of *B. reticulatum* (27.3-54%; M: 45.87%), as well as by the moderate values of *C. gallina* (10-30%; M: 18.79%), *G. nummaria* (2-20%; M: 12.18%) and sometimes appreciable values of *L. orbiculatus* (up to 12%).

(FIGURE 6)

4.1.4. Facies and edible species

The most representative edible species are *G. glycymeris*, *G. nummaria*, *C. gallina* and oysters. In the sandy tidal flat (F3), these edible species represent an average of 35% of the malacofauna (range: 18-66%), with *G. glycymeris* (M: 17.6%) and *C. gallina* (M: 10%) as the most representative species and very low percentages or absence of *G. nummaria* (0-4%). In F2 (washover fans) and F4 (chenier), *C. gallina* also has moderate percentages (M: 10-19.6%), while *G. nummaria* (M: 10-15.7%) replaces *G. glycymeris* as main low-quality culinary species.

The highest percentages of edible species are found in F5 (M: 68.4%) and in soil (M: 62.5%). F5 includes the largest number of edible species of all the facies studied (Table 4: 11 species), some of them exclusively present in this facies (e.g. *Acanthocardia* spp. -3 species-, *P. maximus*, *R. decussatus*). In section C, the vertical evolution of this facies allows to differentiate three horizons: a) basal horizon (samples C-5 and C-6), with high percentages of *G. nummaria* (54-78%); b) intermediate horizon (samples C-7 to C-10), with lower percentages of *G. nummaria* (38-54%); and c) upper horizon (samples C-11 and C-12), with an important diversification, significant percentages of oysters (up to 26%) and the highest percentages of cockles (4-10%) of all the samples studied. The upper edaphic profile resembles F5, with a high percentage of edible species (M: 62.5%) dominated by *G. nummaria* (M: 50.5%).

(TABLE 4)

Cluster analysis dendrogram in Q-mode allows to differentiate five groups of samples, according to their percentages of edible species (Fig. 7, A). Group E.1 (2 samples) is characterized by the highest percentages of *G. nummaria* of all the samples studied (66-78%, average: 72%). These samples belong to F5 and to the soil of section B.

Group E.2 (14 samples) have lower percentages of *G. nummaria* than group E.1. This species is usually accompanied by *C. gallina* and ostreids. Two subgroups can be differentiated, each of them composed of seven samples. Subgroup E.2.1 includes samples from F4, F5 and the soil of section C, as well as samples of the upper part of the three sections belonging to F2 (Fig. 7, B). They have moderate percentages of edible species (45-66.7%), with dominance of *G. nummaria* (24-38%; M: 32.08%) and *C. gallina* (10-16.67%; M: 13.34%). Most of these samples included in subgroup E.2.2 belong to F5 and contain percentages of *G. nummaria* higher than those of the previous subgroup (38-54%; M: 47.14%). Ostreids (4-26%; M: 12.57%) and *C. gallina* (2-20%; M: 7.71%) are well represented in this subgroup.

Group E.3 (one sample) is distinguished by the domain of *G. glycymeris* (Fig. 7, C: 52%), with ostreids (8%) and *C. gallina* (4%) as main secondary species. This group coincides with the outlier detected in the previous cluster analysis (see section 4.1.3). This last species is the dominant edible species of group E.4 (30-50%; M: 39.63%), which includes three samples from F4 (section B) and F1 (section A).

(FIGURE 7)

Group E.5 (21 samples) includes samples from F2, F3 and F4 separated in three subgroups, whose common character is the absence or the very low to moderate percentages of edible species (0-50%). Subgroup E.5.1 (sample A-4: F2) presents a very low number of specimens (see supplementary data), with isolated valves of *G. nummaria* and *Ostrea* sp. The common characteristic of subgroup E.5.2 (14 samples) is a percentage of edible species lower than 25% in all cases. These samples from F2, F3 and F4 have very low to low percentages of *C. gallina* (0-14%, M: 6.44%) and *G. glycymeris* (0-16%; M: 4.39%). Subgroup E.5.3 is constituted by six samples from facies 2, 3 and 4 with intermediate percentages of edible species (30-50% of the total malacofauna). Its main components are *C. gallina* (10-22.73%, M: 16.46%) and *G. nummaria* (2-20%; M: 11.85%).

4.1.5. Taphonomy and sedimentary facies

4.1.5.1. Preservation

The defined taxonomic categories are represented unequally in the different facies. The largest number of well-preserved specimens (category A) is found in F5 (Table 5; M: 27.97%), which also contains another 50.87% of specimens with small erosions (category B). F3 and soil are as follows in order of conservation, with 67-71% of shells between categories A and B.

On average, the facies with the worst conserved specimens are, in descending order, F2 (C + D ~ 36.8%) and, above all, F4 (C + D > 39%). In addition, the first one has the smallest number of specimens in category A (<10%).

(TABLE 5)

Bioerosion is very rare in all facies studied, affecting 1.75% of all specimens (7 of 400) in F5 and 1.74% of them (23 of 1,324) in the remaining facies. It is mainly represented by traces of predatory gastropods (Fig. 8, A: *Oichnus*) or branching networks of galleries formed by sponges (Fig. 8, B: *Entobia*).

(FIGURE 8)

Numerous bivalves and gastropods present fractured margins and broken shells, but the fracture surfaces are rounded and no evidence of human manipulation has been found. In addition, no vestiges of cooking have been observed.

4.1.5.2. *Morphometric analysis of* Glycymeris nummaria

According to the length of the antero-posterior axis of the valves, a predominance of the smallest sizes (4.4-28.6 mm) over the larger sizes (28.6-52.8 mm) is observed. However, a more detailed analysis allows to differentiate three groups of facies (see supplementary data files for percentages). Group M1 (F3-F4) is characterized by a significant dominance of sizes smaller than 16.5 mm ($\geq$ 61%), while specimens with an anterior-posterior length greater than 28.6 mm are on average between 5.5% and 9%. Group M2 (F2) presents the highest percentages of the 16.5-28.6 mm interval (59.75%) and almost the entire population of *G. nummaria* (>95%) has an antero-posterior length lower than 28.6 mm. In the remaining facies (group M3: F5-soil), the approximate half of the population is between 16.5 mm and 28.4 mm, while the sizes greater than 28.6 mm are more abundant than in the previous group (26-36%). The largest average size is found in F5, which also has the smallest percentages of sizes below 16.5 mm (M: 10.67%). The differences between these groups are reflected in Fig. 9.

(FIGURE 9)

4.2. Microfauna

Both density and diversity of microfauna are very variable in the selected samples, even within the same sedimentary facies (see supplementary data). Foraminifera and ostracods are frequent in F3 (26-114 specimens/sample; M: 66.4 specimens/sample) and the basal samples of section C belonging to F4 (up to 166 specimens/sample), which also have the greatest diversity (30 species/sample). Conversely, both groups dissapear in all samples of F5 and soil and an isolated sample of F4. In total, 1,116 specimens belonging to 60 species were collected from twenty-nine samples. In these samples, foraminifera (68.19%) dominates clearly over ostracods (31.81%). The former are represented by thirty-three taxa, with *Ammonia beccarii* (17.2%), *Elphidium crispum* (9.5%), *Ammonia tepida* (7.08%), and *Elphidium advenum* (4.12%) as main benthic species. Planktonic species are very rare (4 species; 0.63%).

(FIGURE 10)

Ostracods have a lower diversity (27 species), with *Urocythereis britannica* (11.11%) as most representative species. Only other four species of this group surpass 2% of the total microfauna (*Bairdia mediterránea*, *Cytherois fischeri*, *Paracypris polita*, *Xestoleberis communis*).

The benthic foraminiferal population of F1 to F4 is very similar, being composed mainly of *Ammonia beccarii*, *Ammonia tepida* and *Elphidium crispum* (Table 6). The first species is dominant in F2 (M: > 6 specimens/sample) and F3 (M: ~10 specimens/sample), while the second has its largest number of individuals in F4 (M: >5 specimens/sample).

(TABLE 6)

4.3. Archaeology

A total of 840 fragments have been recovered in the eight sectors studied (see supplementary data), almost all of Roman times. Two main types of Roman materials have been recognized, according to their functionality and tipology: a) construction material, including complete copies and fragments of bricks (pedalis, semipedalis), imbrices, tegulae and plates (Fig. 11, D-E-F); and b) ceramic material, which includes several types of amphoras (e.g. III/Keay 25-X, LRA1, Keay XIX-C, Keay XXXV) and fine tableware (76-type and 91-type of African Red Slipe Ware-ARSW).

(FIGURE 11)

Density of construction materials is higher in the north-western sectors closer to the sections studied (Fig. 11, A-B: sectors I-II) and decrease towards the southeast. On the contrary, the highest concentrations of ceramic materials were found in the central sectors (IV-V). Both types of materials are rare in the southeast sectors (VII-VIII).

4.3. Dating

According to Cáceres et al. (2018), age of washover deposits (F2) is between the 1st century BCE and the 2nd century CE (Table 7). A dating obtained in F5 (sample C-10) has provided a more recent age (370 CE-510 CE).

(TABLE 7)

The amphoric materials of La Cascajera provides an additional dating on the soil covering the three sections studied. Some of them were produced from the middle of the 3rd century CE until the 5th century CE (e.g. Keay XIX-C), while the production of others are restricted to the 5th century CE (e.g. Keay XXXV, LRA1, ARSW-types) (Keay, 1984).

5. Discussion

5.1. Facies 5: a coastal shell midden?

According to the previous results, F5 has a series of distinctive features in relation to the rest of facies although very similar to those of the upper edaphic horizon:

1. Faunal content. It presents the highest percentages in total weight of malacofauna, as well as the largest average number of specimens per sample (Tab. 1). It is composed overwhelmingly of shells with a very scarce sediment matrix. This facies and the upper soil stand out for the abundance of the *Glycymeris nummaria* and other edible species associated with it (see correlation matrix and cluster analysis), whereas the malacofauna of the remaining facies are mainly dominated by the gastropod *Bittium reticulatum*. This characteristic points to a shell deposit created by human activity, similar to those observed in northern Australia (SMD, *sensu* Holdaway et al., 2017). In addition, it does not include non-molluscan food remains. These features are frequent in numerous coastal middens as opposed to other shells deposits like cheniers (e.g. Beaton, 1985; Sullivan and O'Connor, 1993).

Glycymeris nummaria is very common in coastal middens of southwestern Spain in Roman *cetariae*. These factories also processed other edible species of bivalves (*Ruditapes*, *Chamelea*, *Ostrea*) or very specific species of gastropods that were dedicated to the production ofI mperial purple, such as *Bolinus brandaris* (Campos et al., 2014; Bernal et al., 2015). The presence of some samples of F2 and F4 with similar abundances of *Glycymeris nummaria*

(Fig. 6, B: group 1) may be due to the dropping of valves into the lower sedimentary layers from F5 or the soil.

2. Edible species. F5 is also differentiated by the statistical analysis of edible species (Fig. 7: group E1 except sample C-6), because it has the highest percentages and diversity of these species (see supplementary data files). This characteristic differentiates F5 from the soil, which also has contents higher than 60% in edible species. This high abundance is one of the most widespread features among shell middens (Bailey, 1977; Rosendahl, 2005).

3. Taphonomy. Valves found in both F5 and soil have have a better state of conservation than those of the other facies, which have undergone an important transport by traction derived from the action of storms (F2: washover fans) or fair-weather refracted waves (F4: cheniers; Morales et al., 2014). However, the absence of both acute fractures and warming evidence rule out direct consumption of the molluscs found in both F5 and soil. Therefore, the abundance of edible species must be explained by an alternative accumulation mechanism (see next chapter).

4. Population size of *G. nummaria*. The populations of *Glycymeris* in F5 and soil are larger than those found in other facies. This population distribution implies a selective process stronger than tides, waves or high-energy events can perform (e.g. F1 to F4). It is a typical feature of many coastal middens, which denotes a selective anthropic action (Baker, 1981).

5. Microfauna. The absence or extreme shortage of the marine microfauna in relation to other shell deposits has been cited in several coastal middens (Lilley et al., 1999; Rosendahl et al., 2007), although it has not been studied in most of them. In this case, this absence of foraminifera and ostracods can point to a wash prior to its subsequent accumulation.

6. Geological setting. Facies 5 overlaps the rest of facies in the northwest sector of La Cascajera (Fig. 3: section C; Fig. 12, E) and manifests as a malacological accumulation that follows the slope towards the Estero de los Difuntos ebb-tide.

7. Age. The datings obtained from an isotopic dating of F5 and the deduced from the ceramic materials show a high degree of coincidence (e.g., 5th century CE) and they are concordant with the oldest ages obtained in the underlying materials (F2: 1st century BCE-2nd century CE).

These results reveal that F5 meets the characteristics of a midden shell, according to the main criteria normally used to distinguish them from natural shell deposits (see reviews in Bailey, 1977; Gill et al., 1991; Attenbrow, 1992; Szabó, 2017, among others)

5.2. The origin of F5

For all the above, it is considered that F5 has an anthropic origin, as a consequence of the industrial activity of the next Roman *cetariae*. The taphonomic features and the absence of microfauna point to: a) a wash of the valves; b) a partial selection by size; and c) its accumulation and the creation of a landfill in favor of the slope of the ebb-tide channel (Fig. 12, E). Other similar landfills in haleutic contexts have been described in southwestern Spain, associated with Roman *cetariae* (Bernal, 2011). It is classified as a bivalent shell midden, since it does not include molluscs dedicated to the production of Imperial purple (Bernal, 2011).

In Mediterranean and Atlantic shell middens of Spain, the abundant presence of *Glycymeris* has been attributed to: a) its direct consumption, with different levels of previous cooking; b) the preparation of sauces, mixed with viscera and unappreciated parts of fishes (e.g. garum); c) discards and shellfish remains, product of the use of non-selective fishing gear type nets; d) an ornamental use; e) weight for fishing nets; or f) bait fishing, in archaeological sites where this genus is in low proportions (Campos et al., 2002; Álvarez et al., 2011; Bernal et al., 2015; Nadal et al., 2015; Pascual and García, 2015; Valente and Martins, 2015).

The abundance of *B. reticulatum* and *G. nummaria*, the different taphonomical features mentioned above and a review of the recent underwater environments of the Huelva littoral point to a discard produced by a non-selective trawling as the origin of F5. *B. reticulatum* feeds by grazing on small algae and grasslands of phanerogams (Fig. 12, A; Borja, 1986; Augier 2007). It feeds on the organic matter that covers the beam of the leaves and the soil of these meadows (Luque and Templado, 2004). In these meadows, *G. nummaria*, the main species of F5, is a frequent infaunal filtering species that inhabits the sandy bottoms of these areas (Fig. 12, B), usually associated with other bivalves, such as *Acanthocardia* spp., *C. gallina*, *Donax* spp., *Dosinia lupinus*, *Loripes lucinalis*, *Ruditapes decussatus* , *Spisula* spp. or *Tellina* spp. (Péres and Picard, 1964; Pérès, 1982; D'Amico et al., 2013).

In the Huelva littoral, these vegetated sandy sediments with this mollusc assemblage are mainly found at depths between 2 and 20 m, although some of these species can occupy a wider bathymetric range (Gómez, 2015). These areas would be the main sources of shells for the deposit of the sedimentary facies that constitute La Cascajera barrier, with the transport of *B. reticulatum* and, to a lesser extent, of *G. nummaria,* to the tidal plains and the inner areas of the Tinto-Odiel estuary due to waves, tides or storms. This tractive transport of these and other species of molluscs would explain the worst state of shells in F2, F3 and F4 than in F5 or the soil (see chapter4.1.5.1.).

On the other hand, the abundance of *G. nummaria* in F5 would be explained as the final result of trawling on these grasslands, associated with the activity of the next Roman *cetaria*. Different features support this claim:

1. Mollusc assemblages. The very high percentages of *G. nummaria* and the secondary presence of *B. reticulatum* and other bivalve species are consistent with an extraction method of this type in these environments. Other edible species (*P. maximus*, *R. decussatus*) are also collected with *G. nummaria* in these subtidal sandy bottoms and consumed on this coast currently (Junta de Andalucía, 2001). However, other edible species of F5 come from other habitats, involving a secondary collection in other sedimentary environments. Edible species also include cockles and inhabitants of hard substrates, such as oysters. Among the cockles, the lagoon cockle *C. glaucum* inhabits small, often isolated euryhaline non-tidal basins (Tarnowska et al., 2012), while the common cockle *C. edule* is widely distributed on tidal flats of estuaries and bays (Dabouineau and Ponsero, 2009).

2. Taphonomy. This type of fishing involves at least four types of selection in relation to the remaining facies:

a. First selection, derived from the action of the fishing nets on a certain type of bottom with abundant shells of *G. nummaria* and an important proportion of *B. reticulatum* coming from the adjacent meadows. This action favors the preservation of thick shells like *G. nummaria* in comparison with other thinner species. This differential preservation or fragmentation possibility has been revealed in the study of shell middens (Muckle, 1985).

b. Second selection, caused by the drag of the fishing nets on the bottom, which would cause a first wash of the sandy matrix, as well as the loss of specimens with a length or diameter less than its mesh diameter. In this selection, the larger size of *G. nummaria* is a positive collection factor in relation to *B. reticulatum*. This selection would also explain the largest average size of *G. nummaria* in this facies.

(FIGURE 12)

c. Third selection, as a consequence of the traction of the net for a new cleaning of the catches (Fig. 12, D). These last two selections explain the absence of foraminifera and ostracods in F5, since the elimination of the sands that contained them has taken place. This absence or a very pronounced shortage has been tested in different shell middens in comparison with other shell deposits, as mentioned above (see review in Rosendahl, 2005).

d. Fourth selection, which eliminates empty valves and shells, non-edible species or those edible species that are not subject to industrial activity (Fig. 12, E). These four selections explain the mollusc assemblage extracted from F5 (Fig. 12, F), as well as the best conservation of the valves and shells in relation to the rest of the facies.

3. This type of fishing has been described during this period (3rd-5th centuries CE) in the Roman factories, with the use of mobile networks to which clay and lead weights were associated (e.g. Fig. 12, C; Oliver, 1982; Campos and Vidal, 2004). In addition, the ages of both shells and archaeological remains are coincident and point to a creation of F5 as a landfill of the next Roman factory (see chapter 4.3).

6. Conclusions

1. The study of shell deposits exposed in the northern sector of Saltés Island has allowed to determined thirty-three species of mollucs, with a predominance of the gastropod *Bittium reticulatum* in old sandy tidal flats (F3), cheniers (F4) and washover fans (F2). Other two facies (F5 and soil) are dominated by the bivalve *Glycymeris nummaria*, while molluscs are poorly represented in the old muddy tidal flats (F1).

2. A multidisciplinary analysis of F5 allows to classify it as a shell midden, according to its very high percentages and diversity of edible species (clams, oysters, cockles), a partial selection by size, a better state of conservation of the *Glycymeris* valves and the absence of both foraminifera and ostracods.

3. This facies represents a bivalent shell midden, with a mollusc content derived from waste of a next Roman factory (*cetariae*). Soil of this factory has similar features to those observed in this shell midden. Age of this midden (4th-5th centuries CE) is similar to that deduced from the amphoric archaeological remains extracted in this soil.

4. The autoecological analysis of mollusc species and the revision of littoral environments of the adjacent areas indicate a process of collecting malacofauna (mainly *Glycymeris nummaria*) in shallow sandy bottoms of the Iberian Atlantic shelf with phanerogam meadows. The presence of oysters or common cockles also means an additional collection in rocky environments or tidal flats, respectively.

5. This shell midden comes from trawling carried out on these environments, with up to four selective processes involved in the final result.

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FIGURE CAPTIONS

Figure 1. Examples of coastal shell middens, their most abundant species (B: bivalve; G: gastropod) and their ages. 1: Hallmann et al. (2009); 2: Erlandson et al. (2009a); 3: Erlandson et al. (2009b); 4: Carbotte et al. (2004); 5: Lulewicz et al. (2017); 6: Herrera and Solís (2011); 7: Schapiera et al. (2006); 8: Belknap and Sandweiss (2014); 9: Latorre et al. (2017); 10: Vasconcellos et al. (2014); 11: Zubimendi (2017); 12: Hood and Grovdal (2016); 13: Waddington et al. (2003); 14: Lewis (2011); 15: Dupont et al. (2007); 16: García-Escárzaga et al. (2017); 17: López-Dórigal et al. (2019); 18: Wijnen (1981); 19: Douka et al. (2014); 20: Barusseau et al. (2010); 21: De Sapir (1971); 22: Bar-Yosef and Beyin (2009); 23: Martínez (1976); 24: Jerardino et al. (2008); 25: Sivan et al. (2006); 26: Bailey et al. (2013); 27: Magee et al. (2017); 28: Biagi (2014); 29: Cooper (1997); 30: Tieng (2013); 31: Cassidy and Vostretsov (2007); 32: Habu et al. (2011); 33: Jing and Liang (2002); 34: Thiel (1986-1987); 35: Morse (1993); 36: Ward et al. (2016); 37: Bailey (1977); 38: Frankland (1990); 39: Flores (2009); 40: Puch (1974).

Figure 2. A-B: location of Saltés Island (courtesy: Google maps); C: geomorphological map of Saltés Island and the adjacent areas of the Tinto-Odiel estuary; D: Photograph of the study area, with situation of the three sections analyzed; E: Location of the main Roman *cetariae* along the south-western Iberian coast (courtesy: Google maps).

Figure 3. Sedimentary logs of the three studied sections, including the forty-one selected samples and details of the different facies.

Figure 4. Class Bivalvia. A-B: *Acanthocardia* sp.; C: *Acanthocardia tuberculata* (Linnaeus, 1758); D: *Anomia ephippium* Linnaeus, 1758; E: *Cerastoderma glaucum* (Bruguière, 1789); F: *Cerastoderma edule* (Linnaeus, 1758); G: *Chamelea gallina* (Linnaeus, 1758); H: *Clausinella fasciata* (da Costa, 1778); I: *Donacilla cornea* (Poli, 1791); J: *Donax trunculus* Linnaeus, 1758; K: *Donax venustus* Poli, 1795; L: *Glycymeris glycymeris* (Linnaeus, 1758); M: *Glycymeris nummaria* (Linnaeus, 1758); N: *Limaria tuberculata* (Olivi, 1792); O: *Ostrea* sp.; P: *Panopea glycymeris* (Born, 1778); Q: *Pecten maximus* (Linnaeus, 1758); R: *Ruditapes decussatus* (Linnaeus, 1758); S: *Spisula*

solida (Linnaeus, 1758); T: Family Cardidae; U: Family Cardiidae; V: *Corbula gibba* (Olivi, 1792); W; *Dosinia lupinus* (Linnaeus, 1758); X: *Loripes orbiculatus* Poli, 1795: *Striarca lactea* (Linnaeus, 1758); Z: *Tellina* sp.

Figure 5. Class Gastropoda (A-Q)-Class Scaphopoda (R). A: *Bela* sp.; B: *Bittium reticulatum* (da Costa, 1778); C: *Calliostoma* sp.; D: *Calliostoma zizyphinum* (Linnaeus, 1758); E: *Calyptraea chinensis* (Linnaeus, 1758); F: *Steromphala umbilicalis* (Linnaeus, 1758); G: *Steromphala varia* (Linnaeus, 1758); H: *Jujubinus striatus* (Linnaeus, 1758); I: *Mangelia* sp.; J: Family Nassaridae; K: *Tritia nitida* (Jeffreys, 1867); L: *Ocenebra erinaceus* (Linnaeus, 1758); M: *Peringia ulvae* (Pennant, 1777); N: *Rissoa* sp.; O: *Tritia incrassata* (Strøm, 1768); P: *Tritia pfeifferi* (Philippi, 1844); Q: *Tritia pygmaea* (Lamarck, 1822); R: *Dentalium* sp.

Figure 6. A: Q-mode cluster analysis applied to the eigtheen main species; B: distribution of groups and subgroups in the sections studied; C: Mean percentages of the main species in the different subgroups obtained.

Figure 7. Statistical analysis of edible species. A: Q-mode cluster analysis applied to the edible species (see Tab. 4); B: distribution of groups and subgroups in the sections studied; C: Mean percentages of the edible species in the different subgroups obtained. Bold: main species of each subgroup.

Figure 8. Evidences of bioerosion. A: *Oichnus*; B: *Entobia*. Scale: 1 cm.

Figure 9. *Glycymeris nummaria*: mean percentages of the valve sizes in the different sedimentary facies.

Figure 10. Foraminifera (A-H)-Ostracoda (I-K). A: *Ammonia beccarii* (Linnaeus, 1758); B: *Ammonia tepida* (Cushman, 1926); C: *Elphidium crispum* (Linnaeus, 1758); D: *Elphidium advenum* (Cushman, 1922); E: *Haynesina germanica* (Ehrenberg, 1840); F: *Planorbulina mediterranensis* D'Orbigny, 1826; G: *Quinqueloculina seminulum* (Linnaeus, 1758); H: *Triloculina oblonga* (Montagu, 1803); I: *Urocythereis britannica* Athersuch, 1977; J: *Cytherois fischeri* (Sars, 1866); K: male of *Loculicytheretta pavonia* (Brady, 1866).

Figure 11. Archaeology. A-B: location of the eight sectors studied. C: Shore of section C (sector II) with ceramic remains; D: Fragment of brick (sector I; scale: 5 cm); E: Fragment of brick (base of section C, sector II); F: Semipedalis (sector I).

Figure 12. The formation of a shell midden (F5). A-B-D-E: Huelva littoral. A. Phanerogam meadows; B: Adjacent sea bottom with numerous valves of *G. nummaria*; C. Roman Mosaic,

Hippolytus Museum, Alcalá de Henares (Spain); D: Drag net cleaning; E: Discard from a trawl; F. Shell midden of La Cascajera (F5) located on washover fans (F2).

TABLE CAPTIONS

Table 1. Total percentages and sample distribution of mollusc species. ES: edible species. If possible, 50 individuals were studied in each sample (NISP).

Table 2. Distribution of the main species of molluscs (in %) in the different sedimentary facies: mean and range of each species in each facies. White numbers: most abundant species. See the total number of specimens per sample in the supplementary data files.

Table 3. Coefficient correlation matrix of the most abundant species. Bold: $p<0.01$; Underlined: $p<0.05$.

Table 4. Percentages of edible species in each facies: mean and range.

Table 5. Mean percentages and range of each taphonomic category in each facies. White numbers: average maximum values of each taphonomic category.

Table 6. Main species of foraminifera and ostracods in each facies: mean and range (number of individuals per sample). See the total number of specimens counted per sample in the supplementary data files.

Table 7. Database of ^{14}C and U/Th samples and results. Reservoir effect corrected (-108 ± 31 years BP; Martins and Soares, 2013).

SUPPLEMENTARY DATA FILES: CAPTIONS

File 1. General data of the malacofauna, including its total percentage by weight, the total number of individuals collected and studied and the number of species per sample.

File 2. Percentages of the determined valve sizes in selected samples of the different sedimentary facies and mean percentages of each valve size in each facies.

File 3. Total percentages of foraminifera and ostracod species and number of individuals in each sample. *: reworked Neogene species.

File 4. Archaeology. Distribution of archaeological remains in the eight sectors studied.

SECTION		SECTION A											SECTION B																SECTION C													
SPECIES	% TOTAL	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9	A-10	A-11	B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8	B-9	B-10	B-11	B-12	B-13	B-14	B-15	B-16	C-1	C-2	C-3	C-4	C-5	C-6	C-7	C-8	C-9	C-10	C-11	C-12	C-13	C-14
BIVALVIA (TOTAL: 50.96%)																																										
Acanthocardia aculeata (ES)	0.06																																			2						
Acanthocardia tuberculata (ES)	0.12																																							2		
Acanthocardia sp. (ES)	0.06																																	2		2						
Anomia ephippium	1.51									2			2	2	2	2							2			2				2	4	2	2		2	6			12	4	4.35	
Cardium sp.	0.06										4.55						2																									
Cerastoderma edule (ES)	0.23		2																													2	2						2			
Cerastoderma glaucum (ES)	0.64																												2		2	2				2			4	10		
Chamelea gallina (ES)	10.21	50	8	2			4	8	8	20	22.73	16.67	6	20	4	16	4	30	38.89	3.23	12.77	8	14	10	2.22	14	10	2	22	10	20	4	10	4	12	6	6	10	6	2	8.7	10
Clausinella fasciata	0.17			2														2																							2.17	
Corbula gibba	0.75										4.55		2			2	2		5.56		4.26	4							2	4									1			5
Donacilla cornea	0.06														2																											
Donax trunculus (ES)	0.12								2						2																											
Donax venustus (ES)	0.06																													2												
Dosinia lupinus	0.06																											2														
Glycymeris glycymeris (ES)	3.89			2				6		2	9.09	16.67	10	10	52	6	10	4	5.56	3.23	4.26	16	4	4		12	6	6	2			2	2	2								
Glycymeris nummaria (ES)	22.81		2	2	16.67		6	6		18	9.09	33.33		2		4	2	6			2.13		4	20	2.22	24	2	66	30	18	54	42	54	78	38	44	54	36	38	44	28.26	35
Limaria tuberculata	0.06																																						2	6		
Loripes orbiculatus	3.83		2	12		16.67	10	6		2	4.55		12	6	4		2	2			8.51		4	4	2.22	4		2	6	12	2		2		4	4		16				
Ostrea sp. (ES)	5.46		8	8	16.67		6	4	6	4	9.09		2	8	8	4	2	2		3.23			2			4		6	6	4	4	6	6			16	4		26	26	8.7	
Panopea glycimeris	0.06																	2																								
Pecten maximus (ES)	0.06																																							2		
Ruditapes decussatus (ES)	0.06																																						2	2		
Spisula solida (ES)	0.23			2				2					4																													
Spisula sp. (ES)	0.12																							2	2.22																	
Striarca lactea	0.06		2																																							
Tellina sp.	0.06												2																													
Indeterminated	0.06			2																																						
GASTROPODA (TOTAL: 48.81%)																																										
Bittium reticulatum	45.39	50	74	66	66.67	83.33	66	66	80	50	27.27	33.33	52	50	26	62	74	52	44.44	80.65	65.96	64	70	54	86.67	36	78	14	30	42	12	36	20	14	34	14	30	28	4	2	41.3	40
Calliostoma zizyphinum	0.29																							2			2				2		2					2				
Calliostoma sp.	0.06								2																																	
Calyptraea chinensis	0.64						2						2								2.13									2		2			2	2		6	2			
Gibbula sp.	0.23						2	2																													2				2.17	
Mangelia attenuata	0.29																					8				4																5
Ocenebra erinaceus	0.06																															2										
Peringia ulvae	0.17																																								4.35	5
Rissoa sp.	0.58			2			2						4							3.23				4	2.22										2			2				
Steromphala cineraria	0.12													2																2												
Steromphala umbilicalis	0.23						2									2									2.22					2												
Tritia incrassata	0.12									2																									2							
Tritia nitida	0.06																																			2						
Tritia pfeifferi	0.06																			3.23																						
Tritia pygmaea	0.12												2																								2					
Tritia sp.	0.12		2													2											2										2					
Family Calliostomidae	0.06																			3.23																						
Family Nassaridae	0.06																																		2							
Indeterminated	0.17										4.55																	2							2							
SCAPHOPODA (TOTAL: 0.23%)																																										
Dentalium sp.	0.23								2		4.55						2		5.56																							
FACIES		1	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	4	4	4	4	2	2	2	2	2	2	SOIL	4	4	4	4	5	5	5	5	5	5	5	5	2	SOIL

FACIES	1		2		3		4		5		SOIL	
SPECIES	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**
BIVALVIA												
Anomia ephippium	0	0	0.61	0-4.35	1.6	0-2	0.85	0-4	3.11	0-12	0	0
Chamelea gallina	50	50	9.2	0-22.73	10	4-20	19.55	3.23-38.89	6.67	2-12	6	2-10
Cerastoderma glaucum	0	0	0	0	0	0	0.57	0-2	2	0-10	0	0
Corbula gibba	0	0	0.5	0-0.5	1.2	0-2	2.26	0-5.56	0.11	0-1	2.5	0-5
Glycymeris glycymeris	0	0	4.57	0-16.67	17.6	6-52	2.72	0-5.56	0.67	0-2	3	0-6
Glycymeris nummaria	0	0	10.21	0-33.33	1.6	0-4	15.73	0-54	47.56	36-78	50.5	35-66
Loripes orbiculatus	0	0	3.97	0-16.67	4.8	0-12	4.36	0-8.51	2.89	0-16	1	0-2
Ostrea sp.	0	0	4.5	0-16.67	4.8	2-8	2.75	0-6	9.33	0-26	3	0-6
GASTROPODA												
Bittium reticulatum	50	50	61.33	27.27-86.67	52.8	26-74	46.72	12-80.65	20.22	2-36	27	14-40
Calyptraea chinensis	0	0	0.12	0-2	0.4	0-2	0.59	0-2.13	1.56	0-6	0	0
Rissoa sp.	0	0	1.46	0-4	0.4	0-2	0.46	0-3.23	0.44	0-2	0	0
SCAPHOPODA												
Dentalium sp.	0	0	0.39	0-4.55	0.4	0-2	0.79	0-5.56	0	0	0	0

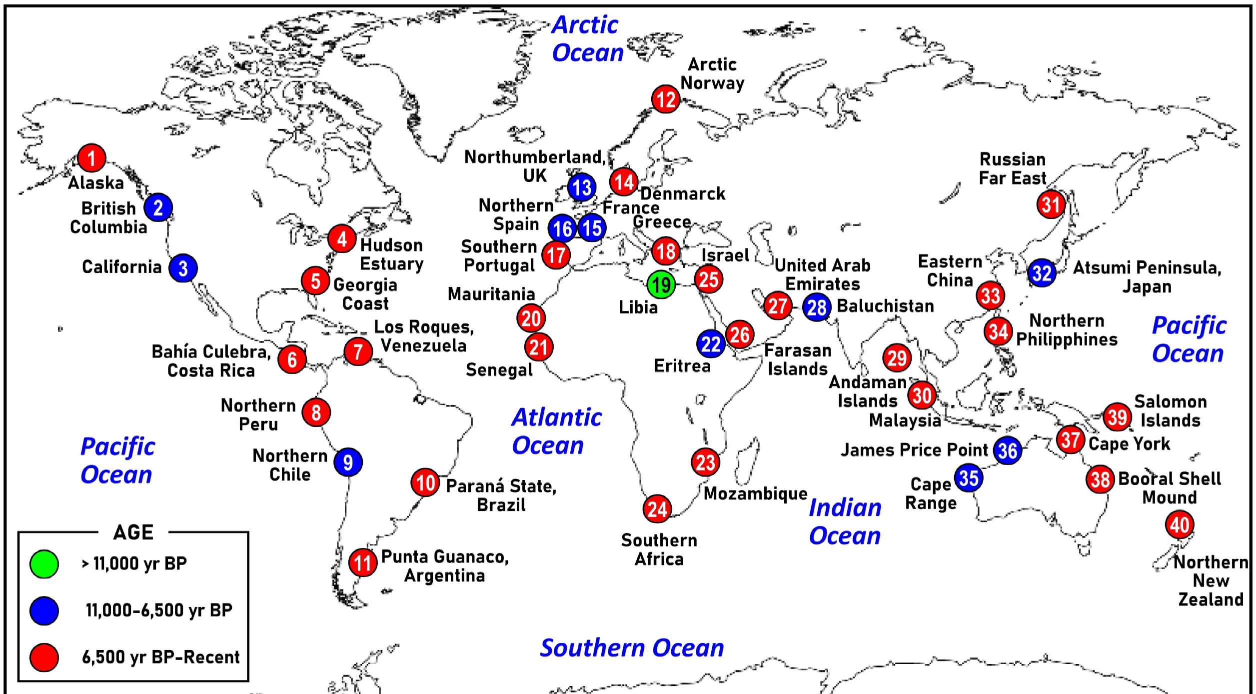
		AE	CH	CE	CG	CO	GG	GN	Lo	OE	BT	CZ	CC	GI	NA	RI	SU	TP	DS
BIVALVIA	*Anomia ephippium* (AE)	1																	
	Chamelea gallina (CH)	0.106-	1																
	Cerastoderma edule (CE)	0.397	0.140-	1															
	Cerastoderma glaucum (CG)	**0.531**	0.142-	0.185	1														
	Corbula gibba (CO)	0.121-	0.269	0.127-	0.099-	1													
	Glycymeris glycymeris (GG)	0.064-	0.030-	0.144-	0.160-	0.061	1												
	Glycymeris nummaria (GN)	0.301	0.199-	0.215	0.327	0.222-	0.253-	1											
	Loripes orbiculatus (LO)	0.142-	0.179-	0.192-	0.177-	0.039	0.033-	0.228-	1										
	Ostrea sp. (OE)	**0.687**	0.280-	0.338	**0.723**	0.178-	0.077-	0.223	0.177-	1									
GASTROPODA	*Bittium reticulatum* (BT)	**0.526-**	0.089-	0.189-	**0.497-**	0.008	0.072-	**0.796-**	0.157	**0.434-**	1								
	Calliostoma zizyphinum (CZ)	0.013-	0.024	0.129	0.030-	0.200-	0.103-	0.230	0.094	0.187-	0.135-	1							
	Calyptraea chinensis (CC)	0.219	0.138-	0.129	0.050	0.043	0.175-	0.145	**0.535**	0.023	0.207-	0.209	1						
	Gibbula sp (GI)	0.018-	0.149-	0.108-	0.103-	0.177-	0.126-	0.056	0.019	0.033	0.054	0.122-	0.014-	1					
	Nassarius sp. (NA)	0.159-	0.092-	0.223	0.088-	0.151-	0.091-	0.009-	0.185-	0.050-	0.168	0.182	0.129-	0.217	1				
	Rissoa sp. (RI)	0.148-	0.229-	0.153-	0.145-	0.145-	0.081-	0.182-	0.354	0.220-	0.243	0.224	0.302	0.010-	0.130-	1			
	Steromphala umbilicalis (SU)	0.044-	0.111-	0.108-	0.103-	0.114	0.126-	0.193-	0.166	0.090-	0.254	0.122-	0.121	0.156	0.092-	0.164	1		
	Tritia pfeifferi (TP)	0.090-	0.126-	0.052-	0.050-	0.085-	0.029-	0.148-	0.127-	0.048-	0.230	0.059-	0.073-	0.052-	0.044-	**0.380**	0.052-	1	
SCAPHOPODA	*Dentalium* sp. (DS)	0.169-	0.380	0.098-	0.093-	**0.552**	0.060	0.234-	0.125-	0.050-	0.017	0.111-	0.137-	0.098-	0.084-	0.138-	0.098-	0.047-	1

EDIBLE SPECIES/FACIES	1		2		3		4		5		SOIL	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Acanthocardia aculeata	0	0	0	0	0	0	0	0	0.22	0-2	0	0
Acanthocardia echinata	0	0	0	0	0	0	0	0	0.22	0-2	0	0
Acanthocardia sp.	0	0	0	0	0	0	0	0	0.44	0-2	0	0
Chamelea gallina	50	50	10.42	0-22.7	10	4-20	19.56	10-38.9	6.67	2-12	6	2-10
Cerastoderma edule	0	0	0.12	0-2	0	0	0	0	0.67	0-2	0	0
Cerastoderma glaucum	0	0	0	0	0	0	0.57	0-2	2	0-10	0	0
Donax trunculus	0	0	0.12	0-2	0.4	0-2	0	0	0	0	0	0
Donax venustus	0	0	0	0	0	0	0.29	0-2	0	0	0	0
Glycymeris glycymeris	0	0	4.57	0-16.7	17.6	6-52	2.72	0-5.56	0.67	0-2	3	0-6
Glycymeris nummaria	0	0	10.21	0-33.33	1.6	0-4	15.73	0-54	47.46	36-78	50.5	35-66
Ostrea sp.	0	0	4.5	0-16.7	4.8	2-8	2.74	0-6	9.33	0-26	3	0-6
Pecten maximus	0	0	0	0	0	0	0	0	0.22	0-2	0	0
Ruditapes decussatus	0	0	0	0	0	0	0	0	0.44	0-2	0	0
Spisula solida	0	0	0.24	0-2	0.4	0-4	0	0	0	0	0	0
Spisula sp.	0	0	0.26	0-2.22	0	0	0	0	0	0	0	0
% TOTAL EDIBLE SPECIES	50	50	29.2	0-66.67	35.2	18-66	41.61	19.2-80	68.44	50-88	62.5	45-80
NUMBER OF EDIBLE SPECIES	1		8		6		6		11		4	

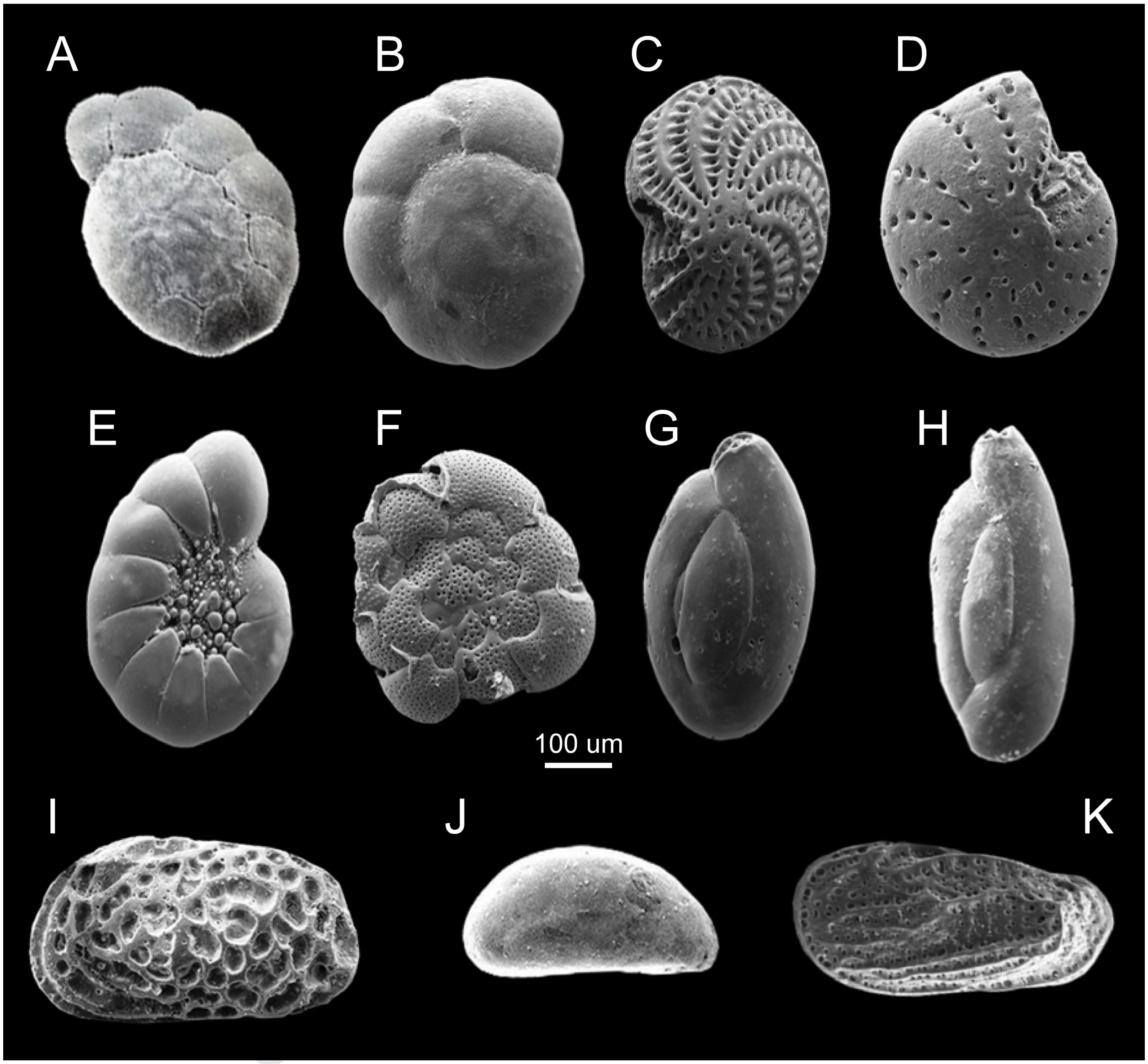
FACIES/CATEGORY	A		B		C		D	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
2	9.92	0-20	53.27	28-72.72	24.69	8-38	12.11	0-33.33
3	17.39	10.2-29.41	50.54	40.81-64.58	27.65	18.75-40.81	4.42	0-10
4	11.29	0-23.91	49.36	30-74.19	21.2	15.22-28	18.16	3.22-38.89
5	27.97	7.84-50	50.87	38.46-60.78	14.57	3.85-21.57	6.58	0-10
SOIL	4.99	3.85-6.12	65.22	61.22-69.23	15.19	3.85-26.53	14.6	6.12-23.08

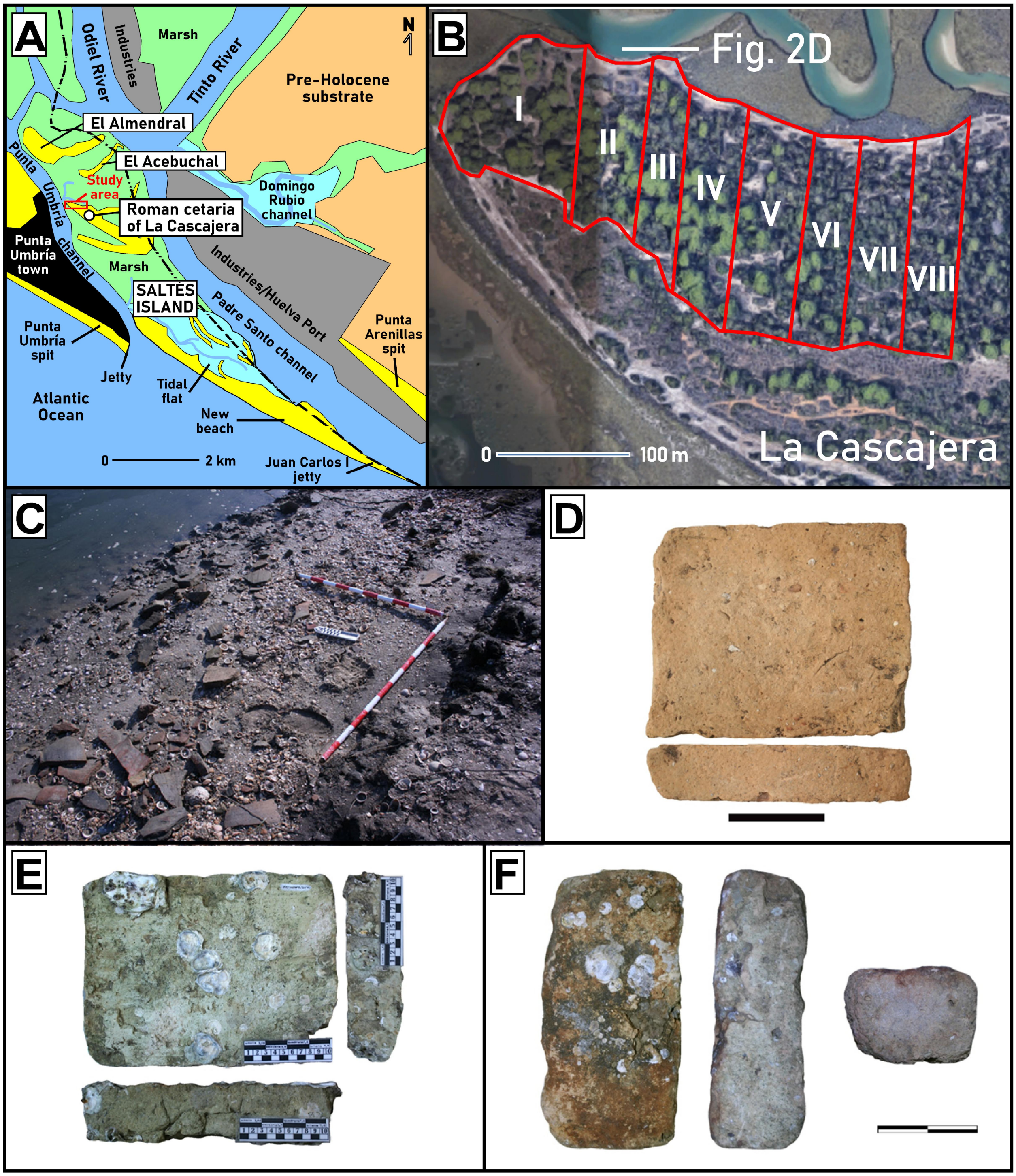
GROUP		SPECIES (FACIES)	1 Mean	1 Range	2 Mean	2 Range	3 Mean	3 Range	4 Mean	4 Range	5 Mean	5 Range	SOIL Mean	SOIL Range
FORAMINIFERA	BENTHIC FORAMINIFERA	*Ammonia beccarii*	6	6	6.35	0-13	9.8	5-14	4.14	0-11				
		Ammonia inflata	3	3	0.94	0-8	2	0-4	0.14	0-1				
		Ammonia tepida	3	3	0.53	0-3	5.8	0-10	5.43	0-20				
		Elphidium advenum	4	4	0.82	0-8	4.2	2-8	1	0-4				
		Elphidium complanatum	4	4	0.53	0-3	2	0-6	1.29	0-7				
		Elphidium crispum	7	7	3.35	0-9	4.8	1-7	2.57	0-7				
		Haynesina germanica	3	3	0.59	0-4	1.8	0-2	1.43	0-9				
		Neoconorbina orbicularis	0	0	0	0	0.8	0-4	3	0-9				
		Planorbulina mediterranensis	0	0	0.29	0-3	1.6	0-5	2.57	0-13				
		Rosalina globularis	1	1	0.41	0-4	1.6	0-8	2	0-4				
OSTRACODA		*Bairdia longivaginata*	0	0	0	0	0	0	2	0-8				
		Bairdia mediterranea	0	0	0	0	0.4	0-2	3.7	0-21				
		Cytherois fischeri	3	3	0.65	0-4	1.2	0-4	1	0-7				
		Hiltermannicythere sphaerulolineata	0	0	0.06	0-1	0.8	0-4	0.71	0-3				
		Palmoconcha laevata	0	0	0	0	0.6	0-3	0.71	0-3				
		Paracypris polita	3	3	0.71	0-5	0.8	0-2	0.86	0-3				
		Pontocythere elongata	0	0	0	0	0.8	0-4	1.43	0-4				
		Semicytherura sulcata	0	0	0.18	0-2	0.4	0-2	0.57	0-3				
		Urocythereis britannica	6	6	2.65	0-9	6.8	0-25	5.57	0-25				
		Xestoleberis communis	1	1	0.12	0-2	0	0	4.14	0-19				

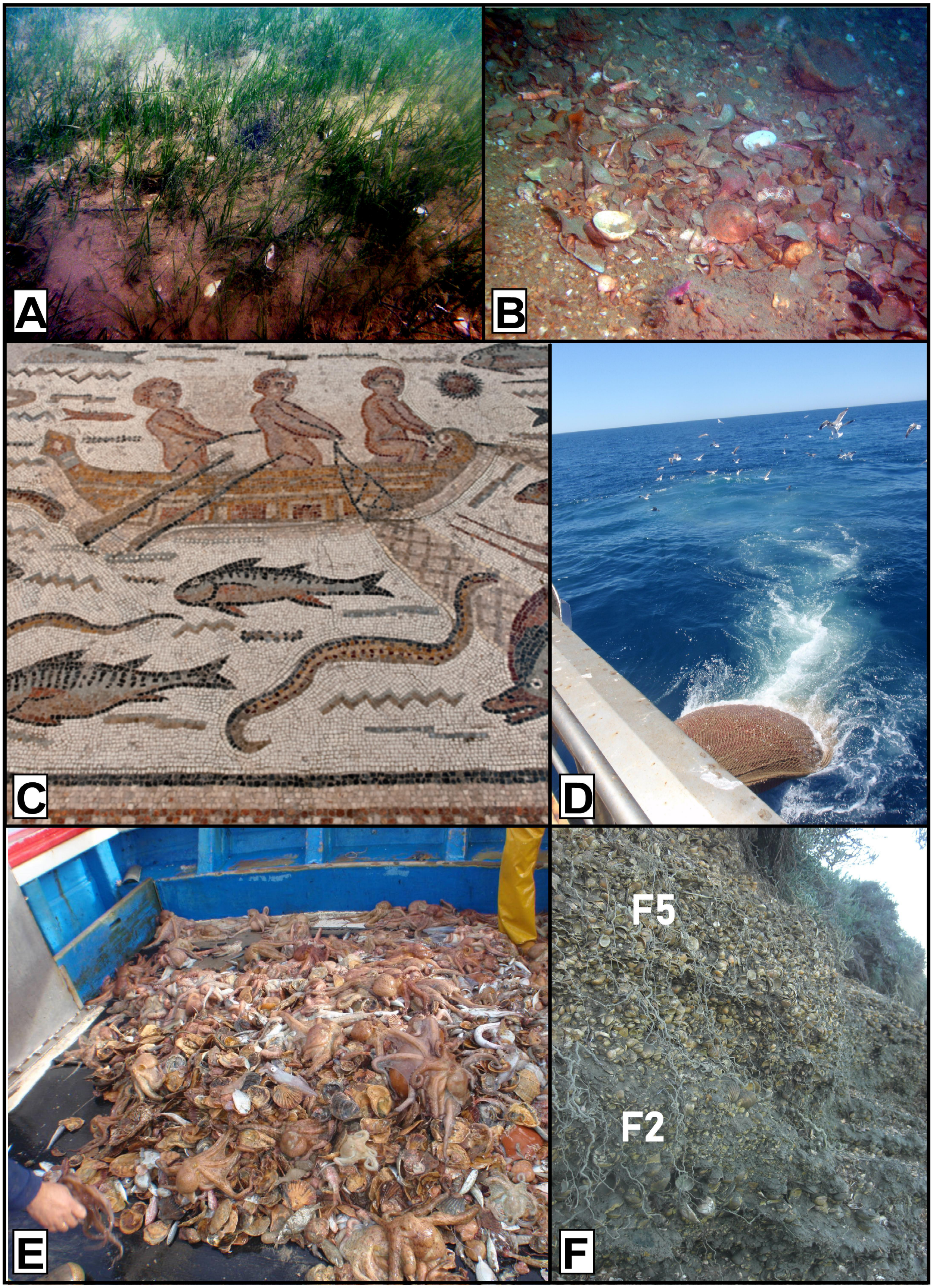
Facies	Sample code	Material (*Glycymeris*)	Laboratory code	^{14}C age	Error	^{14}C Calibrated age	Median probability	U/Th	References
F2	HUCA-1301	Shell	CNA-2817	2263	31	170 BCE - 70 CE	48 BCE		Cáceres et al. (2018)
F2	HUCA-1401	Shell	CNA-2820	2210	32	110 BCE - 130 CE	15 CE		Cáceres et al. (2018)
F2	HUCA-1303	Shell	CNA-2819	2189	31	85 BCE - 150 CE	40 CE		Cáceres et al. (2018)
F2	HUCA-1405	Shell	CNA-2823	2172	32	65 BCE - 180 CE	59 CE		Cáceres et al. (2018)
F2	HUCA-1407	Shell	CNA-2825	2170	32	60 BCE- 185 CE	61 CE		Cáceres et al. (2018)
F2	HUCA-1406	Shell	CNA-2824	2150	33	30 BCE - 200 CE	85 CE		Cáceres et al. (2018)
F5	C-10	Shell	CNA-2818					370 CE - 510 CE	This paper

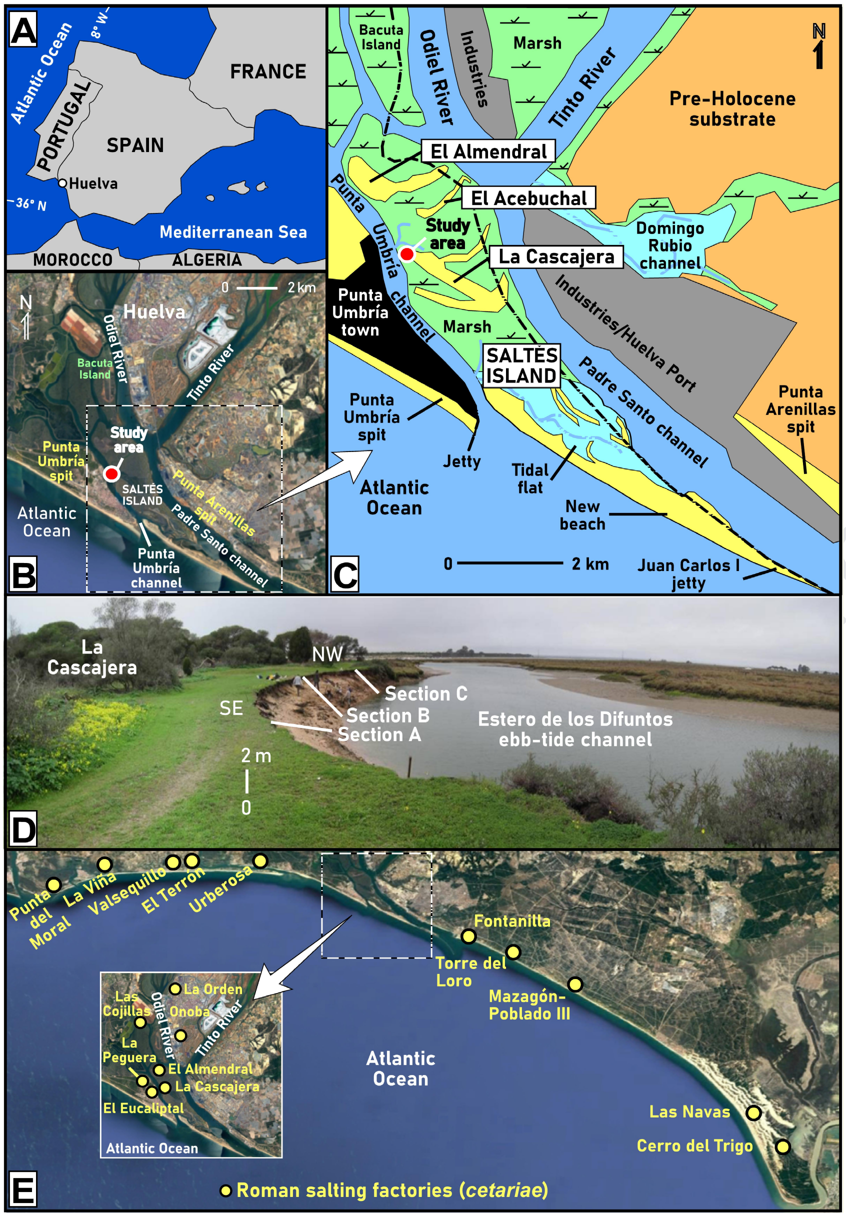


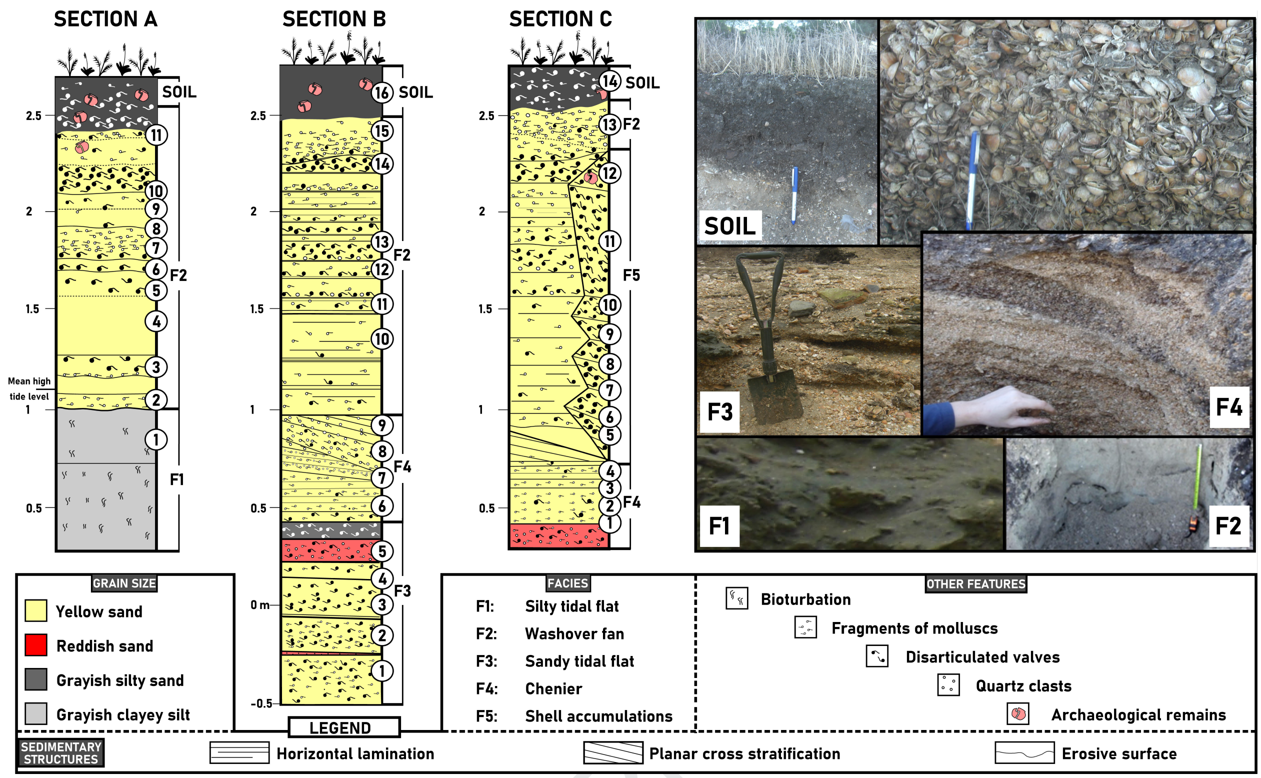
1. *Saxidomus gigantea* (B)
2. *Mytilus californianus* (B)
3. *Mytilus californianus* (B)
4. *Crassostrea virginica* (B)
5. *Crassostrea virginica* (B)
6. *Chione californiensis* (B), *Persististrombus granulatus* (G)
7. *Lobatus gigas* (G)
8. *Tivela lessonii* (B), *Donax obesulus* (B)
9. *Concholepas concholepas* (G), *Fisurella* spp.(G), *Choromytilus chorus* (B)
10. *Anomalocardia flexuosa* (B)
11. *Nacella magellanica* (G)
12. *Littorina littorea* (G), *Arctica islandica* (B), *Mytilus edulis* (B)
13. *Nucella lapillus* (G)
14. *Ostrea edulis* (B), *Cerastoderma edule* (B), *Mytilus edulis* (B)
15. *Patella* sp. (G), *Cerastoderma edule* (B), *Phorcus lineatus* (G)
16. *Phorcus lineatus* (G), *Patella* sp. (G)
17. *Scrobicularia plana* (B), *Cerastoderma edule* (B)
18. *Cardium* spp. (B)
19. *Helix melanostoma* (G), *Columbella rustica* (G)
20. *Senilia senilis* (B)
21. *Senilia senilis* (B), *Ostrea* spp. (B)
22. *Atactodea striata* (B), *Terebralia palustris* (B)
23. *Perna perna* (B)
24. *Choromytilus meridionalis* (B)
25. *Glycymeris nummaria* (B)
26. *Conomurex fasciatus* (G)
27. *Terebralia palustris* (G), *Marcia* sp. (B)
28. *Terebralia palustris* (G)
29. *Marcia recens* (G), *Tegillarca granosa* (B), Ostreids (B)-*Tridacna* (B)
30. *Meretrix meretrix* (B), *Tegillarca granosa* (B)
31. Oysters (B)
32. *Meretrix lusoria* (B)
33. *Ostrea* spp. (B)
34. *Batissa* spp. (B)
35. *Melo amphora* (G), *Conus* sp. (G)
36. *Terebralia* spp. (G), *Tegillarca* spp. (B)
37. *Tegillarca granosa* (B)
38. *Saccostrea* spp. (B), *Trichomya hirsuta* (B)
39. *Tegillarca granosa* (B), *Polymesoda* spp. (B)
40. *Perna canaliculus* (B), *Lunella smaragda* (G)

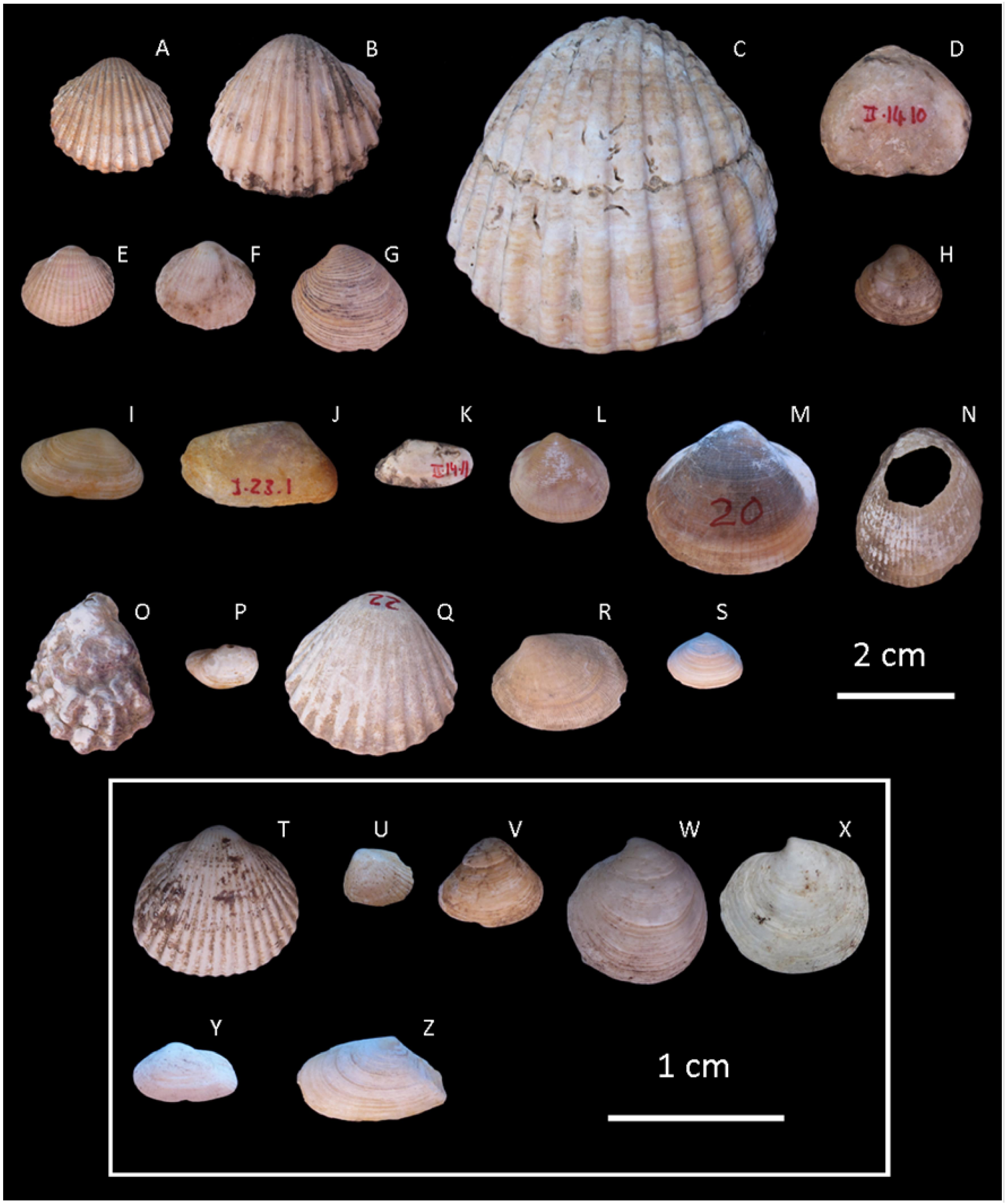

A
B
C
D
E
F
G
H
100 um
I
J
K


A
Odiel River
Industries
Marsh
Tinto River
Pre-Holocene substrate
El Almendral
El Acebuchal
Punta Umbría channel
Study area
Roman cetaria of La Cascajera
Domingo Rubio channel
Punta Umbría town
Marsh
SALTES ISLAND
Industries/Huelva Port
Padre Santo channel
Punta Umbría spit
Jetty
Tidal flat
Punta Arenillas spit
Atlantic Ocean
New beach
0 2 km
Juan Carlos I jetty
B
Fig. 2D
I
II
III
IV
V
VI
VII
VIII
0 100 m
La Cascajera
C
D
E
F


A
B
C
D
E
F
F5
F2


A
Atlantic Ocean
8° W
FRANCE
PORTUGAL
SPAIN
Huelva
36° N
Mediterranean Sea
MOROCCO
ALGERIA
B
Huelva
0 2 km
N
Odiel River
Tinto River
Bacuta Island
Study area
Punta Umbría spit
SALTÉS ISLAND
Punta Arenillas spit
Padre Santo channel
Atlantic Ocean
Punta Umbría channel
C
Bacuta Island
Odiel River
Industries
Marsh
Tinto River
N
Pre-Holocene substrate
El Almendral
El Acebuchal
Study area
La Cascajera
Domingo Rubio channel
Punta Umbría channel
Punta Umbría town
Marsh
SALTÉS ISLAND
Industries/Huelva Port
Padre Santo channel
Punta Arenillas spit
Punta Umbría spit
Jetty
Tidal flat
Atlantic Ocean
New beach
0 2 km
Juan Carlos I jetty
D
La Cascajera
NW
SE
Section C
Section B
Section A
Estero de los Difuntos ebb-tide channel
2 m
0
E
Punta del Moral
La Viña
Valsequillo
El Terrón
Urberosa
Fontanilla
Torre del Loro
Mazagón-Poblado III
La Orden
Las Cojillas
Onoba
Odiel River
Tinto River
La Peguera
El Almendral
La Cascajera
El Eucaliptal
Atlantic Ocean
Atlantic Ocean
Las Navas
Cerro del Trigo
Roman salting factories (cetariae)


SECTION A
SECTION B
SECTION C
SOIL
F1
F2
F3
F4
F5
Mean high tide level
0 m
2.5
2
1.5
1
0.5
-0.5
LEGEND
GRAIN SIZE
Yellow sand
Reddish sand
Grayish silty sand
Grayish clayey silt
FACIES
F1: Silty tidal flat
F2: Washover fan
F3: Sandy tidal flat
F4: Chenier
F5: Shell accumulations
OTHER FEATURES
Bioturbation
Fragments of molluscs
Disarticulated valves
Quartz clasts
Archaeological remains
SEDIMENTARY STRUCTURES
Horizontal lamination
Planar cross stratification
Erosive surface


A
B
C
D
II·14·10
E
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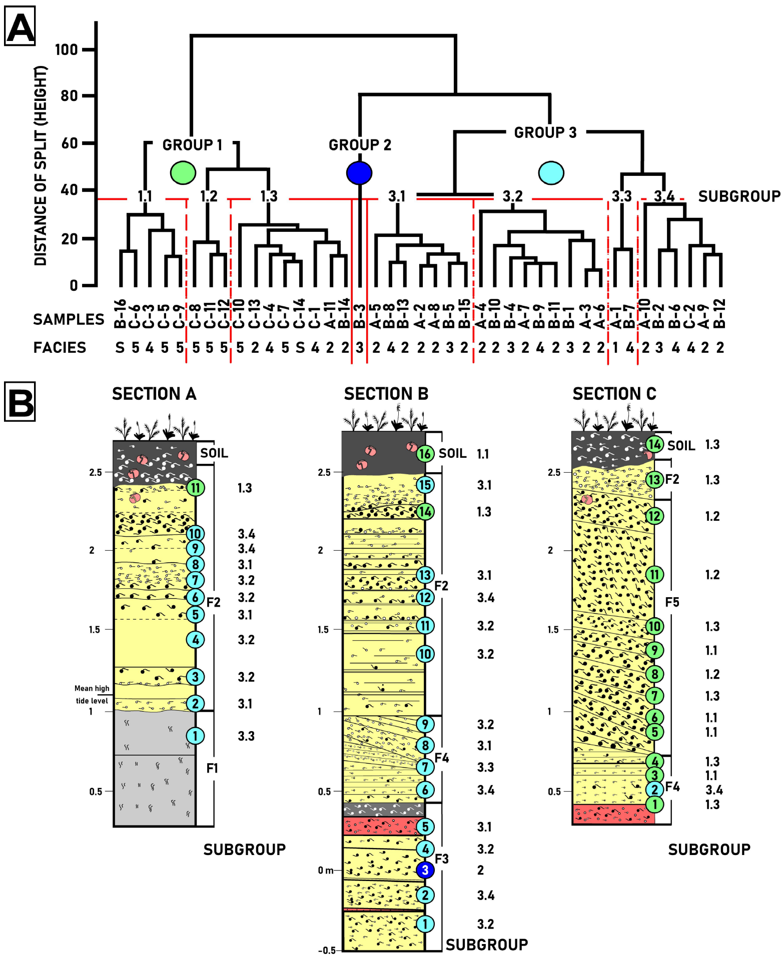
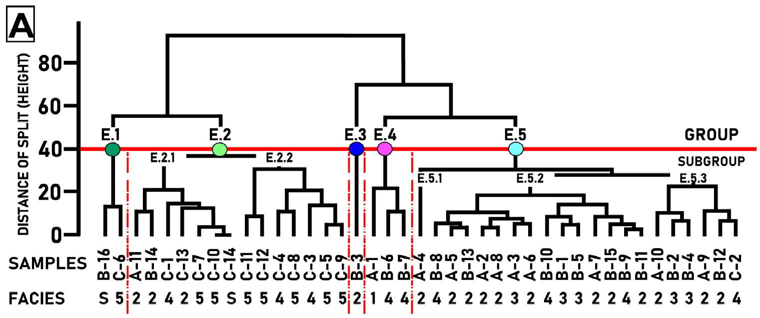
G
H
I
J
1·23·1
K
L
M
20
N
O
P
Q
22
R
S
2 cm
T
U
V
W
X
Y
Z
1 cm

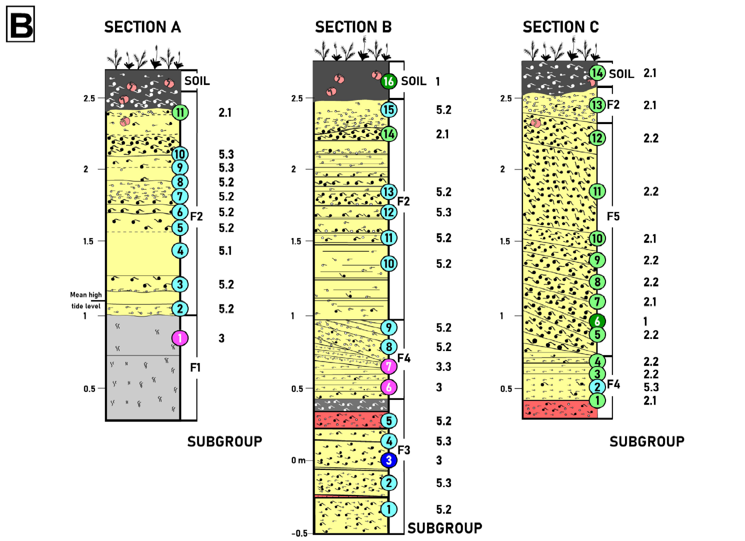

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
1 cm



C

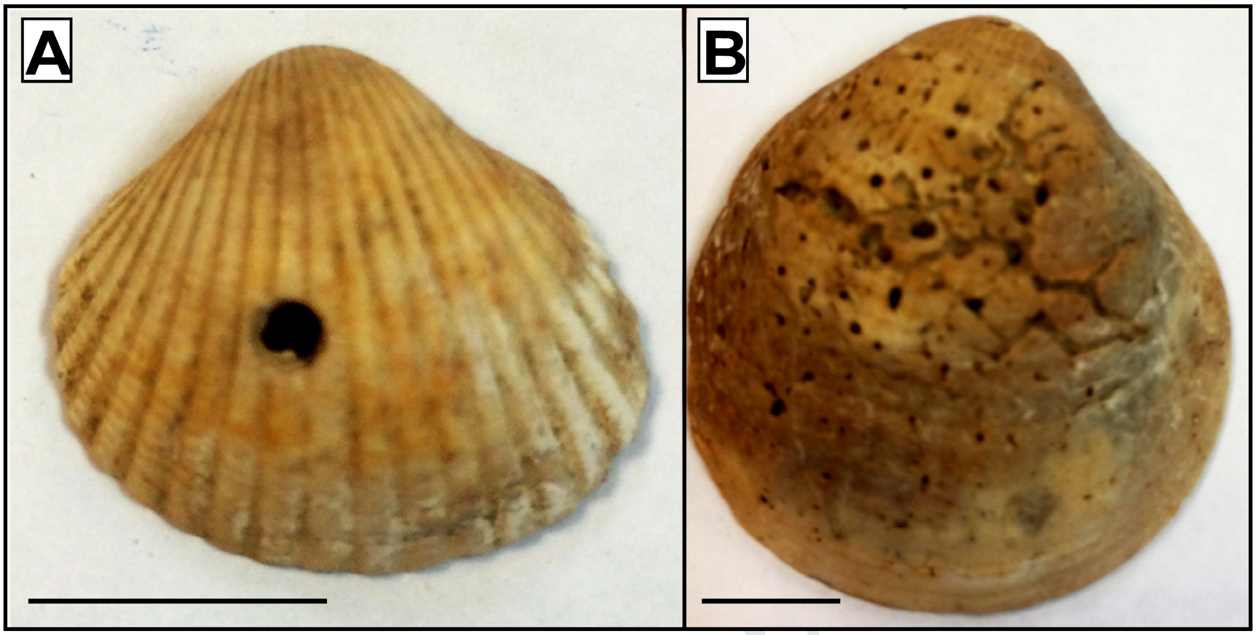
SPECIES	GROUP 1 SG. 1.1	SG. 1.2	SG. 1.3	GROUP 2	GROUP 3 SG. 3.1	SG. 3.2	SG. 3.3	SG. 3.4
Chamelea gallina	8.4	4.7	12.2	4	5.1	7.9	44.4	18.8
Glycymeris glycymeris	2	0	4.1	**52**	2.7	5.4	2.8	4.8
Glycymeris nummaria	**61.2**	**42**	33.3	0	1.2	5.5	0	12.2
Loripes orbiculatus	1.2	1.3	3	4	3.3	5.8	0	5.1
Ostrea sp.	4	22.7	3.1	8	2.7	4.7	0	4.5
Bittium reticulatum	18	6.7	**34.8**	26	**79.5**	**64.3**	**47.2**	**45.9**

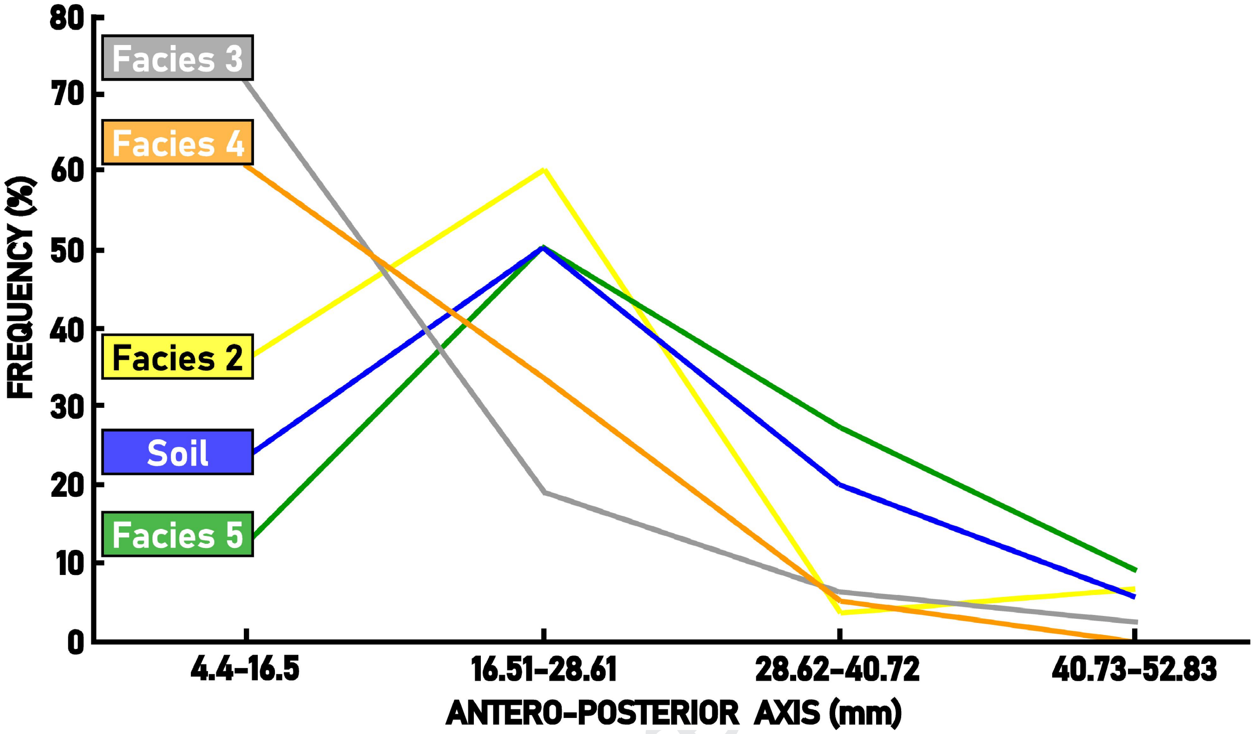




C

SPECIES	E.1	E.2: E.2.1	E.2: E.2.2	E.3	E.4	E.5: E.5.1	E.5: E.5.2	E.5: E.5.3
Acanthocardia spp.	0.3	0	0.3	0	0	0	0	0
Chamelea gallina	3	13.3	7.7	4	**39.6**	0	**6.4**	**16.5**
Cerastoderma edule	0	0	0.9	0	0	0	0.1	0
Cerastoderma glaucum	0	0.3	2.9	0	0	0	0	0
Donax spp.	0	0	0	2	0	0	0.1	0.3
Glycymeris glycymeris	4	4.4	0.6	**52**	3.2	0	4.4	5.2
Glycymeris nummaria	**72**	**32.1**	**47.1**	0	2	**16.7**	2	11.9
Ostrea sp.	3	2.7	12.6	8	0.7	**16.7**	2.9	4.8
Pecten maximus	0	0	0.3	0	0	0	0	0
Ruditapes decussatus	0	0	0.6	0	0	0	0	0
Spisula spp.	0	0	0	0	0	0	0.7	0.3


A
B



80
70
60
50
40
30
20
10
0
FREQUENCY (%)
Facies 3
Facies 4
Facies 2
Soil
Facies 5
4.4-16.5
16.51-28.61
28.62-40.72
40.73-52.83
ANTERO-POSTERIOR AXIS (mm)

HIGHLIGHTS RUIZ ET AL.

- Multidisciplinary analyzes permit to distinguish shell middens from other shell deposits.
- Percentages of edible species, taphonomy or shell size delimit shell middens.
- Statistics permits to delimitate shell middens from cheniers, washover fans or tidal flats.
- Autoecology of the species delimits the fishing spaces of a Roman factory and the the fishing techniques used.
- Age of shell midden is consistent with that of the nearby archaeological remains.

Untangling a Roman Atlantic estuary midden:

muldisciplinary analysis of shell deposits from Saltés Island (SW Spain)

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in the publication of this paper.