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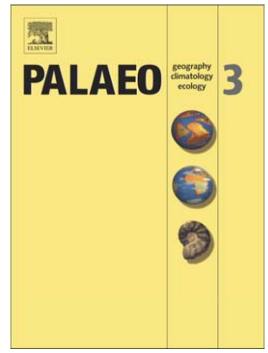

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In search of *Pollentia*'s southern harbour: geoarchaeological evidence from the bay of Alcúdia (Mallorca, Spain)

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Keywords

Ancient harbour, geoarchaeology, palaeogeography, lagoonal harbour, *Pollentia*, Mallorca, Balearic Archipelago, dredging, sea-level, Holocene, Mediterranean

Abstract

The Roman city of *Pollentia* was founded on the north-eastern coast of Mallorca (Balearic archipelago) after the Roman conquest of the island in 123 BC. There is evidence that the city had two harbours, a small harbour located to the north, whereas the main harbour was located to the south of *Pollentia*. Our study focuses on the southern harbour, on a coastal plain in proximity to the ancient city. Four sedimentary cores were taken and bio-sedimentological analysis were performed. Here, we describe the palaeogeographical changes in this area, evolving from an open lagoon environment between ca. 3200 and ca. 500 cal. years BC to a semi-enclosed lagoon during Roman times. Progressively, the lagoon became silted and was isolated from the sea by the development of a large sand spit, probably during the second half of the first millennium AD. We also discuss the water depth, linked to the palaeo sea level, which is important in defining the possible ancient harbour location.

1. Introduction

The Balearic Archipelago held a strategic position at the centre of maritime shipping routes in the western Mediterranean (Mascaró, 1971; Ruiz de Arbulo, 1990; Guerrero 1993, 2004, 2006; Arnaud, 2005; Carayon, 2008; Colom, 2013) (**Fig. 1A**). The importance of the Balearics in maritime navigation routes implied the existence of a series of harbours and ports for shelter. In Mallorca, there is evidence that many bays and inlets along the coast provided refuge for the boats crossing the Western Mediterranean during different historical periods. Examples in Fig. 1.B, include Palma and its port of Porto Pí (Cerdà, 1999; Cau, 2004) in the West; Pollença (Cerdà, 2002) and Cala Sant Vicenç (e.g. Nieto et al., 2002; Nieto and Santos 2008) in the North; Porto Colom (VVAA, 2007; Riera and Martín, 2009) and Porto Cristo (Frey, 1970; Manera, 1983; Puig Palerm, 2011, 2015) on the East side; or in the southern part of the island the Colònia de Sant Jordi and the islet of Na Guardis (e.g. Cerdà, 1979, 1980; Guerrero, 1984, 1985, 1987, 1997; Colls, 1987) and the archipelago of Cabrera as attested by the shipwrecks found in the area (e.g. Guerrero and Colls, 1982; Colls et al.,1986; Bost et al., 1992; Pons et al., 2001). The coast of Mallorca provides a contrasting and paradoxical environmental context. It is both attractive – with broad bays – and challenging – with the steep cliffs of the Serra de Tramuntana exposed to the northern wind.

The Roman city of *Pollentia* probably had two ports: one to the south of the city opening onto the Bay of Alcúdia, and the second to the North of the settlement on the southern part of the Bay of Pollença (**Fig. 1C**). The first bay is cited in Mediaeval documents as *Portus Maior* while the second is often called *Portus Minor* (Domingo and Druget, 2004). Concerning the southern part of the city, there is already enough evidence and oral tradition to support the presence of an anchorage in the present port of Alcúdia (Munar and Sastre, 2010) in a marshland area that is presently silted and urbanised.

The main objective of our study is to reconstruct the coastal environments and the palaeogeography of the shoreline of *Pollentia* since the end of the Holocene marine transgression. More specifically, our research is focused on the environmental potentiality and vulnerability of the site during Roman times in order to ascertain whether or not the environment was favourable for a harbour, south of the ancient city.

2. Geomorphological context and possible harbour location

2.1. Geological setting (**Fig. 2**)

The island of Mallorca is composed of four main geomorphological units resulting from a complex geological structure characterised by a set of horst and grabens that trend in a SW-NE direction (Ginés et al., 2012). The horst forms the mountain ridges, with the Serra de Tramuntana to the north and the Serres de Llevant to the south and some of the central relief of the island. The central depression, called Es Pla, consists of an extensive area located between the two main ridges. Three stages can be noted in the evolution of the geological structure of Mallorca (Sàbat et al., 2011), i) an extensional Mesozoic pre-orogenic stage; ii) a contracting Oligo–Miocene orogenic stage and iii) a relative quiescent mainly extensional, Late Miocene to Recent post-orogenic stage. These tectonic movements, that occurred during the Tertiary period, have created the central hills and the two mountain ridges at the periphery (horst). The rest of the island is formed of Pliocene and Pleistocene deposits undulating on a Miocene carbonate platform (Sàbat et al., 2011). Nowadays, Mallorca is subject to low seismic activity. Instrumental records show that the current seismicity is surficial (<10km depth) and of low magnitude (mb<4). Only three major seismic events (MSK >= VII – mb = 6.1) are reported in 1660, 1721 and 1851 AD (Silva et al., 2001). At the western Mediterranean basin scale, relative sea-level rose continuously during the whole Holocene. A sudden slowdown began around 7500 years BP and a more pronounced deceleration has occurred during the last 4000 years (Stewart and Morhange, 2009; Vacchi et al., 2016).

2.2. Coastal geomorphology of Mallorca (**Fig. 3**) and of the bay of Alcúdia (**Fig. 4**)

The Mallorcan coastline is, for the most part, composed of rocky coasts (80%) (Balaguer, 2005) illustrated by steep rocky coasts on the seaward limits of the two mountain ridges and the low cliffs of the platform of Migjorn. The second type of coast, represented by the large bays of Palma, Pollença and Alcúdia is characteristic of the grabens adjoining the sea, to the west and the east of the island. These provided excellent natural mooring areas for the ancient populations. Alcúdia bay is an important part of the island's coastal lowlands, comprising large sandy beaches largely formed of biogenic sand (Basterretxea et al., 2007). The seabed is covered with *Posidonia oceanica* meadows extending from depths of 6 to 30 m (Servera et al., 2006). These seagrasses could be a source of biogenic sediments for the nearby beaches as proposed by Jeudy de Grissac and Boudouresque (1985), De Falco et al. (2003) and Fornós and Ahr (2006). The bay has a structural origin and is delimited by two Mesozoic scarps along normal faults (Servera et al., 2009). From a tectonic point of view, Alcúdia bay can be divided in two subsections (Muntaner, 1980; Goy et a., 1997): (i) a stable southern part, characterised by an alternation of sandy beaches and Pliocene rocky coasts (eolianites) surrounding a dune field partially stabilised by a pine forest, while (ii) the northern part is supposed to be subsiding and is formed by a beach-dune system, protecting leeward-side wetlands, in particular the marshy area of s'Albufera (Servera et al., 2009). This north-south distinction is also observed in the hydrodynamics of the bay. Indeed, although sediment transport around the bay is mostly controlled by longshore drift (Servera et al., 2009), there are two sedimentary cells (**Fig. 4**): (i) the larger northern cell drives sediments northwards; and (ii) the smaller southern cell pushes them to the south. The bay is generally washed by calm waves coming from the north-northeast (32%), with a significant height of <1 m almost three-quarters of the time (**Fig. 1C**).

The wetland of s'Albufera (ca. 25 square km), situated between the two main ridges (**Fig. 4**), is a relic of a vast lagoon formed following the Holocene marine transgression (Fornós et al., 1996; Goy et al., 1997). This palaeo-lagoon, separated from the sea by a coastal spit, developed between 6500 and 2400 cal. years BP (Goy et al., 1997), extended up to the Roman city. This wetland is currently fed by the Sant Miquel and Muro streams (up to 0.5 m^3/s and 0.2 m^3/s respectively) and by groundwater inputs (up to 0.8 – 0.95 m^3/s) (Canyelles et al., 2003).

3. *Pollentia*: historical and archaeological contexts

The Roman city of *Pollentia* was founded at the base of a rocky isthmus (**Fig. 1C** and **Fig.2**) in a strategic position. It was created following the Roman military intervention of the Balearics (Mallorca and Menorca) by the consul *Quintus Caecilius Metellus,* later named the *Balearicus* in 123 BC. The city was founded in an area where a previous indigenous

(Talayotic) settlement was installed. Although the written sources are clear with regards to the foundation of the city in 123 BC, from an archaeological point of view, the earliest structures in the *Forum* date to the 70s/60s BC (e.g., Orfila et al., 1999; Orfila et al., 2006). There was a period of Augustan monumental construction. A major restructuration of the city took place at the end of the second century AD or at the beginning of the third century AD. After a period of trouble at the end of the third century AD, around 270-280, several parts of the city were partially destroyed by a fire well recognised for instance in the *insula* 1 of *tabernae* in the *forum*. However, after this traumatic event, the city continued to be occupied but was transformed during the Late Roman, Vandal (AD 455-534) and Byzantine (AD 534-902/903) periods, probably gradually moving from a Roman Imperial and Pagan city to a Christian one (Cau, 2012). There is also evidence of a Muslim occupation (AD 902/903-1229) in several parts of the city including the *forum* area (Orfila and Riera, 2002). Overlying the *forum*, a large necropolis was found that dates to the medieval period (Cau et al., 2016). The medieval city of Alcúdia started to develop on the northern side of the old Roman city and in 1300 it was protected by strong fortifications by order of the king Jaume II of Aragon.

4. Methods

4.1. Biosedimentology

Our work is based on four continuous cores, between 410 and 453 cm length, drilled close to the limits of the Roman city (**Fig. 5**). The coring campaign was undertaken using a mechanical rotary corer and benchmarked relative to MSL using a GPS. Core descriptions (texture, macrofauna, organic remains) and sampling were undertaken during fieldwork. Bio-sedimentological analyses were undertaken using the methodology detailed in Marriner and Morhange (2007) and Marriner (2009). In the laboratory, the general sediment texture including the coarse fraction (>2 mm), sand fraction (50µm - 2mm) and silty-clay fraction

(<50µm) was determined by wet sieving and laser granulometry using a Malvern mastersizer. Ostracods were picked from the fraction >150µm and identified to species level (Athersuch et al., 1989; Lachenal, 2000). Macrofossils >1mm were also identified and assigned to assemblages according to the Mediterranean classification system (D'angelo and Garguilo, 1978; Poppe and Gotto, 1991, 1993; Doneddu and Trainito, 2010). Loss on Ignition (LOI) was used to quantify organic matter and the $CaCO_3$ content of the sedimentary sequences (Bengtsson and Enell, 1986; Heiri et al., 2001; Santisteban et al., 2004).

4.2. Chronology

The chronology is based on twenty-three AMS radiocarbon determinations performed at the Poznan Radiocarbon Dating Center (**Table. 1**). We calibrated the dates using Calib 7.1 (Stuiver and Reimer, 1993) and IntCal13 and Marine13 curves (Reimer et al., 2013). For the marine shells, we used a local ΔR of 75.9 with an uncertainty of 40.5, based on the average of ten published dates of marine shells from around the site (http://calib.qub.ac.uk/marine/). 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.

4.3. Statistics

Principal components analyses (PCA) were performed to test the ordination of samples by assessing major changes in palaeoenvironmental proxies. In this statistical analysis, faunal records (ostracod ecology, mollusc ecology) were included for each core. Ostracods and molluscs have been grouped according to species ecology. PCA ordination was chosen because it is a non-parametric method that extracts the most important information from complex datasets (e.g. Kaniewski et al., 2008, 2015; Marriner et al., 2014). Most of the variance is accounted for by the first PCA-Axis, hence, the PCA-Axis1 scores were plotted on a linear depth-scale for each core. The statistical analyses were performed using the paleontological statistics software PAST (Version 2.14, Hammer et al., 2001).

4.4. Modelling sea-level position during the Roman period

The sea-level position during the Roman period in the Balearic archipelago is essential in reconstructing the water-column depth of the harbour basin. Presently, there is a paucity of archaeological and geological data constraining late Holocene (i.e. last 4.0 ka) RSL in the Balearic archipelago. For this reason, we used numerical models to predict the RSL position during the Roman period. We used an improved version of the open source code SELEN (Spada and Stocchi, 2007) that, at the western Mediterranean scale, has been shown to be robust in predicting RSL position during the Holocene (Vacchi et al., 2016). For the purposes of this study, we used the ICE-5G glacio-isotatic adjustment (GIA) model of Peltier (2004) to predict a nominal RSL curve, based on a three-layer approximation of the multi-layered viscosity profile VM2. To account for the uncertainties in the viscosity profiles (see Vacchi et al., 2016), we performed further runs varying the viscosity profiles in each layer within a reasonable range: the minimum and maximum viscosity. At the western Mediterranean scale, the palaeo sea-level position is typically constrained between the nominal and the minimal RSL curves predicted by the ICE-5G (VM2) model (Vacchi et al., 2016).

5. Results

The soundings undertaken on the coastal plain have elucidated the stratigraphy. We first present the litho- and biostratigraphic results obtained for the core POL6/b because it is the most representative of the lagoon's evolution and because this core reaches the pre-transgressive substratum composed of Miocene marls. Then, we compare the evolution of the palaeo-lagoon recorded in the different cores, using a PCA. The synthetic results for the core POL3 are presented in order to highlight differences with the reference core POL6/b. The study of POL10 highlights the specificity of facies on the lagoon shore.

5.1. General evolution of the lagoon

5.1.1. Stratigraphic evolution of the lagoon recorded in core POL6/b (**Fig. 6** and **Fig. 7**)

The depositional facies have been divided into units, A-C for the core POL6/b, and are described from oldest to youngest. The base of the core, between 445 and 420 cm depth is composed of middle Miocene marls incorporating silts and gravels.

Unit A: Open lagoon between 3200 and ca. 1200 cal. yr BC

Unit A, located between 420 cm and 220 cm depth, is characterized by poorly sorted silty-sands (mode ≈ 150 µm and sorting values between 1.2 and 1.6). The coarse fraction, representing 15% of the total weight of the sediment, is only composed of shells and plant remains. The organic matter content is between 3% and 11% and the sediments are very calcareous ($CaCO_3$ = 73%). A radiocarbon date obtained from a marine shell (*Loripes lacteus*; 400 cm depth) indicates that this unit was deposited beginning around 4900 ± 35 yr BP (3350 - 3035 cal. yr BC; Poz-69457). The age of the top of the unit is unclear due to two age reversals. Nonetheless, we believe that the date of 3395 ± 35 yr BP (1375 - 1054 cal. yr BC; Poz-69099) can be accepted because it is conventional that in such instances, the youngest age is the most reliable.

The base of the unit is characterised by an important species richness. More than 100 individuals (gastropods or bivalves) were found in each sample (in around 20 g of sediment). The lagoonal assemblage is dominant (50%). It is composed of the group *Hydrobia* spp. associated with other species such as *Abra segmentum*, *Cerastoderma glaucum*, *Loripes lacteus* and *Parvicardium exiguum*. The remaining species are specimens living on marine upper-muddy sand substratum (10%) like *Cerithium vulgatum* and *Lucinella divaricata* or in infratidal sands (≈20%) such as *Alvania* spp., *Bittium reticulatum*, or *Rissoa ventricosta*. Some species living on marine rocky substratums are also present in the unit (*Cythara* sp., *Gibbula albida* and *Gibbula varia*).

The ostracod ecological groups are similar to those of the macrofossils. The lagoonal (*Cyprideis torosa* and *Cytherois fischeri*) and marine lagoonal (*Loxoconcha elliptica* and *Xestoleberis* spp.) species are dominant with respectively 31% and 49% of the total assemblages. Coastal species, dominated by *Leptocythere psammophila*, represent 14% of the assemblage. Marine species are sporadically represented by some individuals of *Callistocythere* sp. or *Hiltermannicythere emaciata*. This association of species, based on both the macrofauna and ostracod assemblages, is typical of an open lagoon (Salel et al., 2016).

<u>Unit B:</u> Gradual transition/closure of the lagoon around the beginning of the present era

Unit B, situated between 220 and 160 cm depth, is characterised by an increase in the sediment grain size (the mode doubles to 200 μm). The coarse fraction, that represents 7% of the total weight, is composed of shell debris and small sub-rounded gravels. The sediment of the unit is mostly composed of $CaCO_3$ (>70%). The quantity of organic matter decreases relative to the previous unit and represents just 2%.

In this unit, the relative abundance of the lagoonal assemblage increases considerably. It accounts for 45% of the total assemblage at the base of the unit, increasing to more than 95% of the individuals at the top. This domination of the lagoonal species is accompanied by an important decrease in species diversity, which is typical of partially closed lagoon contexts. In fact, the macrofauna is almost monospecific, characterised by *Hydrobia* spp. Coastal species dominated by *Rissoa ventricosa* and *Bittium reticulatum* are present at the base of the unit, then they disappear. Like in the previous unit, the ostracofauna closely mirrors the evolution of the macrofauna. Progressively, a monospecific environment, comprising *C. torosa*, appears.

The presence of ceramics, probably Roman, in this unit, shows that this facies was contemporaneous with *Pollentia*. In addition, some trenches opened in the port area in 2015 reveal the presence of a larger number of Roman ceramics (not studied in depth yet) immediately near the core POL6/b.

<u>Unit C:</u> closed lagoon after the 6th century AD.

Unit C, between 160 and 130 cm depth, is a silty-sand unit. The mode, starting near 400µm at the base of the unit decreases to less than 100µm at the top and the sediment is increasingly less well sorted. The coarse fraction, most important at the top of the unit, is again composed of shell debris. A radiocarbon date, performed on a *Cerastoderma glaucum* shell at the base of the unit, yielded an age of 1840 ± 30 BP (573 – 663 cal. yr AD; Poz-69098). A monospecific assemblage comprising *Hydrobia* spp. prevails. A few individuals of *Cerastoderma glaucum* (lagoonal) and *Bittium reticulatum* (coastal) are however present in the unit. The ostracod assemblage is also monospecific, with *Cyprideis torosa* throughout the whole unit. There are a few species that prefer fresh to oligohaline waters (*Darwinula stevensoni*, *Ilyocypris gibba*). The closure of the lagoon is further underscored by a decrease in the faunal density. A similar trend was identified by Flaux et al. (2013) in the Holocene stratigraphy of the Maryut lagoon (Egypt). Using strontium isotopes in *Cyprideis torosa* shells, they demonstrated that the abundance of lagoonal species was positively correlated with marine inputs into the lagoon's water budget. According to the Mediterranean classification of paralic environments by Guelorguet and Perthuisot (1983), this biofacies is consistent with protected conditions, with limited seawater renewal.

The upper 130 cm of the core is composed of coarse sediments from modern filling of the lagoon for health and sanitary reasons during the 1960s.

5.1.2. Comparison of the cores POL3, POL6/b and POL9 (**Fig. 8** and **Fig. 10**)

The results of the Principal Components Analyses (PCA) show the gradual closure of the lagoon. The assemblages are the same for the three cores and are detailed for the core POL6/b (**Fig. 9**). The core shows positive scores for the lagoonal species which are correlated with a closure of the lagoon. Conversely, species preferring marine waters and less variability in salinity, present negative scores consonant with an open lagoon exposed to marine influence. The PCA of core POL6/b is dominated by negative scores in unit A, consistent with an open lagoon phase. Subsequently, we observe an increase in the scores linked to the closure of the lagoon (Unit B). Finally, a stabilisation of the PCA scores translates the transition to a semi-enclosed lagoon (Unit C).

The results highlight the progressive closure of the lagoon that started before the present era (**Fig. 8**). The core POL3 shows that this phenomenon started between 3200 ± 30 yr BP (1521 – 1417 cal yr BC; Poz-69460) and 2425 ± 30 yr BP (162 cal yr BC – 101 cal yr AD; Poz-72246).

5.2. Core POL3: harbour basin core (**Fig. 10** and **Fig. 11**)

As highlighted by the results of the PCA, the biostratigraphic results of core POL3 show the same general palaeoenvironmental evolution of the lagoon. The same units as POL6/b have been identified (**Fig. 10**). The silty-sand unit (Unit A), deposited between ca. 2000 yr cal. BC and ca. 1470 yr cal. BC is the open lagoon stage, characterised by the same assemblages as core POL6/b (Unit A) but with a lower proportion of lagoonal species. The sharp transition is also clear in this core, especially in the ostracod record but occurs at a greater depth than in

POL6/b (Unit B) (**Fig. 8**). The "lagoonal unit" is thicker in POL3 (≈ 100 cm) than in POL6/b (≈ 70 cm). Unit B's faunal record is similar, characterised by the abundance of *Cyprideis torosa* and *Hydrobia* spp in the upper part. In this unit, a sub-unit formed by finer sediment bearing shells is observed (silts and clay >50%; **Fig. 10** and **Fig. 11**). The closure of the lagoon is translated by a decrease in the molluscan species diversity and the absence of ostracods after 841-1092 cal. yr AD in POL3 (529 – 746 cal. yr AD in POL6/b).

From a geoarchaeological perspective, the association of bio-sedimentological data with chronological results allows us to divide the stratigraphic sequence of the core into three general units described in Marriner and Morhange (2006) as the "Ancient Harbour Parasequence" (AHP) (**Fig. 11**). Within this framework, the silty-sand unit at the base of the core corresponds to the pre-Roman harbour phase, identified as an open lagoon environment increasingly protected, from a faunal perspective, by the growth of a sand spit. The silt unit that begins to develop at the onset of the present era is identified as the harbour phase. It is followed by the harbour abandonment phase, consistent with a shallow lagoon gradually disconnected from the sea. This succession constitutes a classic progradational sequence.

The strata formed by fine-grained sediments only appear in this core, the others being characterised by sand at the same depth. Three radiocarbon dates at the base of this unit yielded an age between ca. 30 cal. yr BC and 960 cal. yr AD. A gap exists between the dates obtained in the cores POL3 and POL6/b. In fact, at the same depth, POL3 is dated to 162 cal. yr BC - 101 cal. yr AD at 139 cm depth b.s.l. and POL6/b is at least a thousand years older and displays several age reversals (**Fig. 8**). We will discuss this finding in section 6.1.3.

5.2.1. Results of core POL10: a marginal lagoonal environment

Core POL10 presents chrono-stratigraphic differences when compared to the cores taken from the palaeo-lagoon. It provides specific information concerning the evolution of the eastern shore of the lagoon during Roman times. For core POL10, the facies have been divided into units A to D and are described from oldest to youngest (**Fig. 5**, **12** and **13**). This core is then presented alone, with no direct connection with the cores taken from the palaeo-lagoon.

Unit A: Monospecific marginal lagoon facies before 3400 cal. yr BC

Unit A, dated in its centre to 5060 ± 30 yr BP (≈ 3954 – 3791 cal. yr BC; Poz-69473) comprises very poorly sorted fine sediments (sorting >2 and mode <50µm); silts and clays represent around 80 % of the total weight of sediment. The proportion of $CaCO_3$ is lower than 10% and the quantity of organic matter is negligible. The depth of this unit is between 370 and 425 cm (200-255 cm below present sea level), this fact shows that the depositional environment was probably situated in an area of higher elevation because it is not clearly linked to the lagoon at that time. In this unit, the fauna is mostly composed of lagoonal species (molluscs = *Hydrobia* spp. (80%); ostracods = *Cyprideis torosa* (90%)). At the base of the unit, a few individuals of the mollusc *Myosotella myosotis*, that can support periods emerged, testify to the proximity of the shore. In this unit, the molluscan density is low (2) as is the ostracod density (≈15 valves /20grams). This unit is interpreted as a protected brackish water body with probable episodic seawater input, possibly during storms and high-swell episodes.

Unit B: Coastal sand deposition between 3400 and 2500 cal. yr BC

This unit develops between ca. 4570 ± 30 yr BP (3493 – 3110 cal. yr BC; Poz-69472) and ca. 4395 ± 30 yr BP (2655 – 2328 cal. yr BC; Poz-69470). The unit differs from the previous one in terms of the sediment texture. In this unit the sediment is coarser (two peaks in the mode at 1200 µm) and better sorted (sorting ≈ 1.4). The coarse fraction represents 50% of the total sediment in the centre although the relative proportion of the sand fraction is not greater than in unit A. The coarse fraction is essentially composed of shells, mostly broken, as confirmed by the important increase in the $CaCO_3$ values. Regarding the fauna, there is an important increase in the diversity of the assemblages associated with an increase in the faunal density. Moreover, it is in this unit that the molluscs and the ostracods are the most abundant and varied. Seven ostracod species were found with an average faunal density of 1300 valves per 20 grams of sediment. The ostracods show assemblages from lagoonal (56%), marine lagoonal (42%) and from coastal environments (2%). This combination of species is also visible in the macrofaunal assemblage and reflects the same type of environment. We interpret this unit as being coastal sands deposited close to sea level during the third millennium BC at the end of the littoral cell.

<u>Unit C:</u> Semi-enclosed lagoon between ca. 2500 cal. yr BC and 0 cal. yr AD

Contrary to the other cores, the texture of this unit is very fine (mode <100 µm). Silts and clays represent more than 75% of the total sediment. Fine sands represent around 80% of the total sand fraction. The faunal assemblage of this unit is typical of a very shallow water body disconnected from the main lagoon. The ostracods are dominated by *Cyprideis torosa* and a few individuals of *Sarcypridopsis aculeata*. The macrofauna is composed of *Hydrobia* spp. and some specimens of *Myosotella myosotis*. This unit probably reflects the inland part of the lagoon.

<u>Unit D:</u> Marshland from Roman times onwards

The sedimentary texture of this unit is the same as in unit C. Fine sands represent 65% of the total sand fraction. The molluscan assemblage is dominated by the snail species *Myosotella myositis.* This taxon is well adapted to supratidal coastal fringes and can tolerate fresh to polyhaline waters. The association of this mollusc with the ostracod species *Sarcypridopsis* *aculeata* reveals an environment that is not permanently inundated. A radiocarbon date of a *Myosotella myosotis* shell in this unit yielded an age of 1725 ± 30 yr BP (245 - 388 cal. yr AD; Poz-72249). ^{14}C dating on terrestrial shells is not commonly used because large taxa are known to incorporate dead carbon from carbonate rocks when building their shells. This phenomenon can create age offsets of up to 3000 years (Pigati et al., 2010). The same authors suggest, however, that the fossil shells could sometimes yield ^{14}C ages statistically indistinguishable from ^{14}C ages of well-preserved plant macrofossils from the same stratum. On this basis, we can only assume that this layer is younger than 245 - 388 cal. yr AD. This part of the coastal plain was largely silted in Roman times. Presence of these species also attests to freshwater inputs. These inputs could be linked to the proximity of a spring or to the everyday use of inhabitants possibly released in the lagoon by a sewer.

6. Discussion

6.1. The lagoon 2000 years ago: geomorphological and biological evidence for a possible harbour area

After the conquest of Mallorca in 123 BC, the first Romans found a coastal lagoon suitable for a harbour in the northern part of the bay of Alcúdia. This area was protected from the prevailing winds and waves, coming from the North, by the rocky promontory of *Cap des Pinar*. Part of the harbour activities of Roman *Pollentia* may have taken place inside the palaeo-lagoon identified in our geoarchaeological drillings. This harbour environment shows features common to many harbours in lagoonal contexts that generally evolved towards the complete closure of the lagoonal water body over time (regressive sequence *sensu* Morhange et al., 2015). It shares some geomorphological traits with the ancient lagoon of Kition in Cyprus, that hosted the Hellenistic port of the city. Morhange et al. (2000) showed that the leaky lagoon was partially closed by a gravel spit and used as a military harbour (Bamboula) for Kition, capital of a Phoenician kingdom, during the first millennium BC. Another harbour was possibly located in the same context to the northwest at Kathari (Bony et al., 2016). The lagoonal harbour of Cumae-Licola, situated down-drift from the Volturno river was a protected mooring area during Archaic times. The combined formation of offshore sand bars, rendering access to the lagoon difficult, and of silting, explain why it was abandoned in early Roman times (Stefaniuk et al., 2003; Stefaniuk and Morhange, 2010). The specificity of lagoonal harbours compared to artificial harbours (Marriner and Morhange, 2006), is that lagoons do not show important anthropogenic impacts in the sedimentary facies due to the absence, in most cases, of protective harbour structures.

6.1.1. Spatial extent of the lagoon

Our research has highlighted that this lagoon, separated from the sea by a coastal sand spit, extended to the foot of the Roman city (**Fig. 14**). Several archaeological test pits made in the area in 2015 (Cau et al., 2015) show the presence of several finds, including some walls or their foundations, a human incineration contained in an italic cooking pot (see **Fig. 14**, labelled as necropolis) and several Roman ceramic finds mainly amphorae. The ceramics were encrusted with marine organisms showing that sea water was present near this edifice. Another Roman structure, probably linked to the exploitation of the lagoon, was found in the north-east and confirms its limit in this direction, as shown by the presence of a coastal marsh in the core POL10 that translates the shoreline of the lagoon.

Such a morphology is typical of coastal lagoons used as harbours (Morhange et al., 2015). A map drawn in 1851 (**Fig. 15**), representing the northern shore of the bay of Alcúdia shows that this morphology persisted in part until the 19th century before the lagoon was drained and artificialized a century later. During Roman times, the lagoon that hosted the harbour of *Pollentia* was connected to the sea by a channel probably south of our drilled zone because of the low density of coastal species discovered in the faunal assemblage of the lagoonal unit. According to the classification of Kjerfve (1986), this lagoon could correspond to a restricted lagoon connected by the modern channel linking the pond "Estany dels Ponts" to the sea, identified on the 1851 map (**Fig. 15**).

The northern shore of the lagoon was situated near the theatre, at the foot of a rocky coast formed by Quaternary aeolianites discovered during archaeological excavations near this zone. The proximity between the lagoon and the city is an essential aspect in the choice of harbour installations. During Antiquity, coastal lagoons close to settlements were, in many cases, chosen as natural anchorages by coastal populations because of their favourable environmental conditions, such as Orgame on the margin of the Danube delta in present-day Romania (Bony et al., 2015), in order to avoid carrying goods over long distances and for the defence of the harbour.

6.1.2. Evolution of the harbour's water column (POL3)

As demonstrated by Boetto (2010), the nautical dimensions of a harbour basin, in terms of its volume and geometry, are essential. Thus it is necessary to consider the accessibility of docks, and boat traffic in the different areas of the harbour (Salomon et al., 2016). The relative sea-level (RSL) position 2000 years ago is crucial because, together with the sedimentary budget, it determines the water depth of the lagoon and consequently the thresholds for the accessibility of ships. There is a paucity of geological sea-level data constraining the RSL position in Roman times in the Balearic Islands. Following the protocol proposed by Vacchi et al., (2016), our lagoonal data indicate that the sea-level position was within 1 m above -1.39 m at ~30 BC cal. yr and above -1.29 m at ~380 cal. yr AD. These values match estimates predicted using the ICE-5G (VM2) GIA model (Spada and Stocchi, 2007; see section 4) which constrain the RSL position during Roman times to -35±15 cm below the present MSL (**Fig. 16**).

According to these data, the reconstructed water column in the harbour basin (core POL3; **Fig. 11**) can thus be estimated at 100±15 cm in the 1st century AD. The core POL3 was drilled in proximity to the lagoon's shoreline, so it can be reasonably assumed that the depth increases seawards. Such a water column is sufficient for a harbour basin, allowing the navigation of ships (Section 6.2).

6.1.3. Hiatus in the sedimentary record of POL3

The comparison of cores POL3 and POL6/b highlights chronological gaps. For POL3, the chronology obtained is consistent, age increases with depth. The unit identified as the "harbour facies", sensu Marriner et Morhang (2006), is dated between 162 cal. yr BC to 101 cal. yr AD and 841 to 1092 cal. yr AD (**Fig. 11**). However, an important chronological shift occurred between the top of the "pre-harbour" unit (1521 – 1417 cal. yr BC) and the bottom of the harbour unit (162 cal. yr BC and 101 cal. yr AD). Furthermore, the top of the open lagoon unit (Unit A) of core POL6/b presents important age reversals (**Fig. 8**).

The chronological gap encountered in POL3 could be explained by a sedimentary hiatus. One explanation for this hiatus is ancient dredging. Such harbour maintenance practises have, for example, been identified in several ancient harbours in the Mediterranean (Morhange and Marriner, 2010b), in Marseille (Morhange et al., 2003), in Naples (Giampaola et al., 2004) and in Tyre (Marriner and Morhange, 2006b). Calculation of sedimentation rates for POL3 (**Fig. 11**) shows important differences between the pre-harbour unit and the harbour unit. In fact, the sedimentation rate obtained for the pre-harbour facies (<2.5 mm. yr^{-1}) is the highest rate encountered in the core. The base of the unit identified as the harbour phase, only recovered in POL3, is dated to around 30 cal. yr BC consistent with the city's foundation.

Furthermore, the sedimentation rate shows limited sediment accumulation in this unit (sedimentation rate ≈ 0.17 mm. yr^{-1}) which could indicate sediment removal from the harbour basin. If dredging practises took place in the lagoon, they probably began in the first century BC and could explain the hiatus recorded between the end of the pre-harbour unit and the harbour unit, such as for the harbour of Lechaion (Corinthos gulf) which was dug into the loose substrate during the Iron Age (Stiros et al., 1996; Morhange et al., 2012; Mourtzas et al., 2014). In this case, the harbour could also present similarities with the Greek harbour of Naples, where excavations in the ancient harbour basin have shown that the harbour bottom was completely reshaped by extensive dredging between the fourth and the second centuries BC (Giampaola et al., 2004; Carsana et al., 2009). Dredging activities may have caused the re-suspension of sediments and could explain the age reversals in POL6/b.

Regarding these results, we can estimate that the harbour could have been used between ca. 30 cal. yr BC (162 cal. yr BC – 101 cal. yr AD) and 966 cal. yr AD (841 – 1092 cal. yr AD) if we take into account the date obtained from the core POL3 (**Table. 1**). But the date of the abandonment of the harbour could be shortened to ca. 637 cal. yr AD (529 – 746 cal. yr AD) because it is the date of the lagoon closure recorded in the core POL6/b.

6.2. Navigation inside the lagoon

As demonstrated by the estimates of the lagoon's water column, the circulation of large ships linked to interregional trade would have been difficult within the lagoon during Roman times. Based on the work of Charlin et al. (1978), Boetto (2008, 2010), Carre and Roman (2008) and Poveda (2012), the harbour basin could however accommodate ships with a deadweight of around 20 tons for a draught of ca. 1m (**Table. 2**). Shipwrecks excavated in Naples (Napoli A and B) and Portus near Rome (Fiumicino 1), are associated with coastal navigation and were used as lighter vessels in order to carry goods transported by large commercial vessels

(Boetto, 2008, 2010). Our data assume that the depth of the lagoon was adequate for such boats and even for larger ones in other parts of the lagoon.

A large amount of archaeological remains, located near the Alcanada islet (**Fig. 1**) and in the present commercial port of Alcúdia (Munar and Sastre, 2010), allows us to hypothesize a deep water anchorage or outer harbour for large commercial vessels. Such a scenario has been envisaged for the harbour of Sidon (Lebanon), where the outer harbour was located on the leeward side of Zire island, 800 meters from the inner harbour (Frost, 1973; Carayon, 2003; Marriner et al., 2006). Goods could be safely unloaded and transported to the mainland port by smaller ships such as lighters. An important source of freshwater in the immediate vicinity of the islet of Alcanada (Gràcia et al., 2001) was then available for sailors, making this area a possible mooring zone for transiting ships.

Conclusions and perspectives

Infilled lagoonal harbours in deltaic contexts are the best represented type of lagoonal harbours (see Morhange et al, 2015, 2016). The lagoon of *Pollentia*, situated on the margin of the vast palaeo-lagoon of s'Albufera, has undergone the same geomorphological evolution as deltaic lagoons. In fact, sediment supply and low accommodation space invariably leads to the infilling of these basins during historical times due to the stabilisation of sea level during the last 7000 years (Stewart and Morhange, 2009; Vacchi et al., 2016) and coastal progradation driven by sediment supply at base-level (Stanley and Warne, 1994; Anthony et al., 2014).

Our geoarchaeological work reveals the presence of a lagoon near the Roman city of *Pollentia*. This water body, separated from the sea by a sand spit accomodating constructions of Roman age, was well protected from winds and waves and could accommodate shallow-draft vessels, which were commonly used at this time. The other boats, larger and probably in transit, had the possibility to anchor offshore in a quiescent area close to the Alcanada islet. We assume that human activities, and possible harbour activities, took place around the area where our core POL3 was drilled due to possible evidence for dredging around 2000 years ago. Such lagoonal harbours, situated in a naturally protected basin made possible, by means of reduced infrastructure (landing stage) and the possible beaching of small boats, a logical development of harbour activities.

Further investigations in *Pollentia* should consider the extension of the lagoon to the south of the bay in order to better understand the geomorphology of the water body and to try to locate an area where the lagoon was less confined, in order to find the possible location of the channel which permitted access to the lagoon. Geophysics could be an interesting tool for a better cartography of the ancient lagoon and to help pinpoint the location of possible harbour structures. These results should also be validated by further archaeological excavations.

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Fig.1

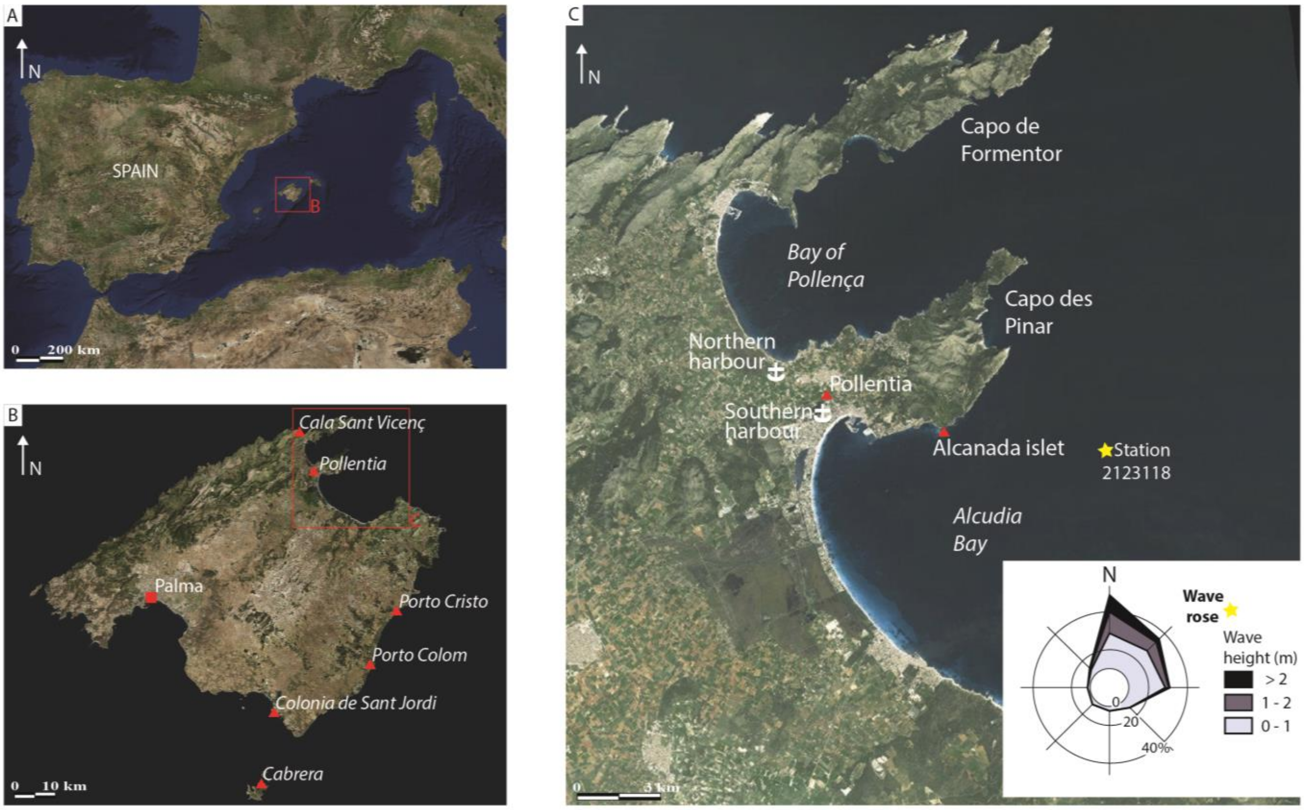

A
N
SPAIN
B
0 200 km
B
N
Cala Sant Vicenç
Pollentia
C
Palma
Porto Cristo
Porto Colom
Colonia de Sant Jordi
Cabrera
0 10 km
C
N
Capo de Formentor
Bay of Pollença
Capo des Pinar
Northern harbour
Pollentia
Southern harbour
Alcanada islet
Station 2123118
Alcudia Bay
N
Wave rose
Wave height (m)
> 2
1 - 2
0 - 1
0
20
40%
0 3 km

Fig.2

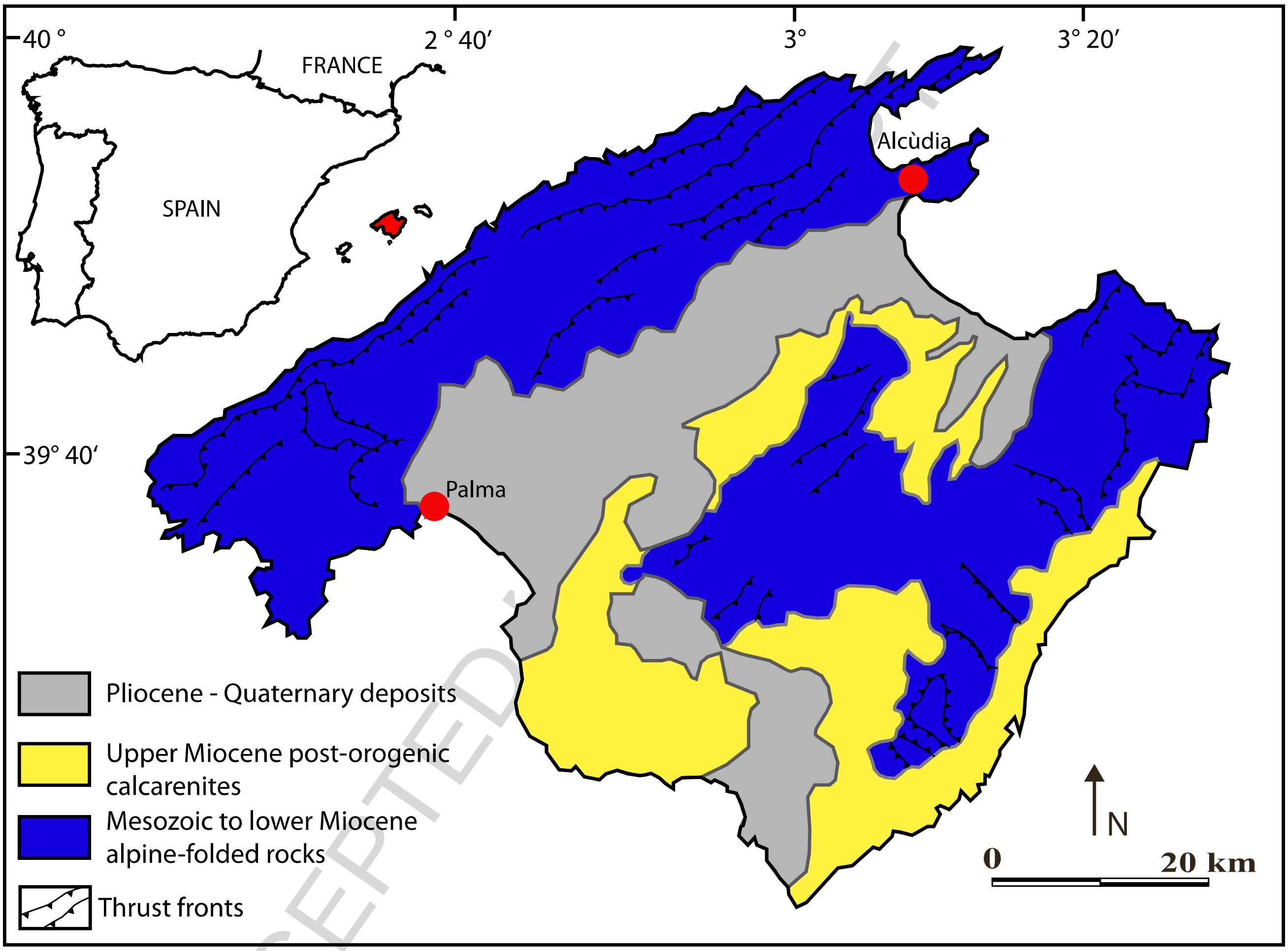

40 °
2 ° 40′
3°
3° 20′
39° 40′
FRANCE
SPAIN
Alcùdia
Palma
Pliocene - Quaternary deposits
Upper Miocene post-orogenic calcarenites
Mesozoic to lower Miocene alpine-folded rocks
Thrust fronts
N
0
20 km

Fig.3

Fig.4

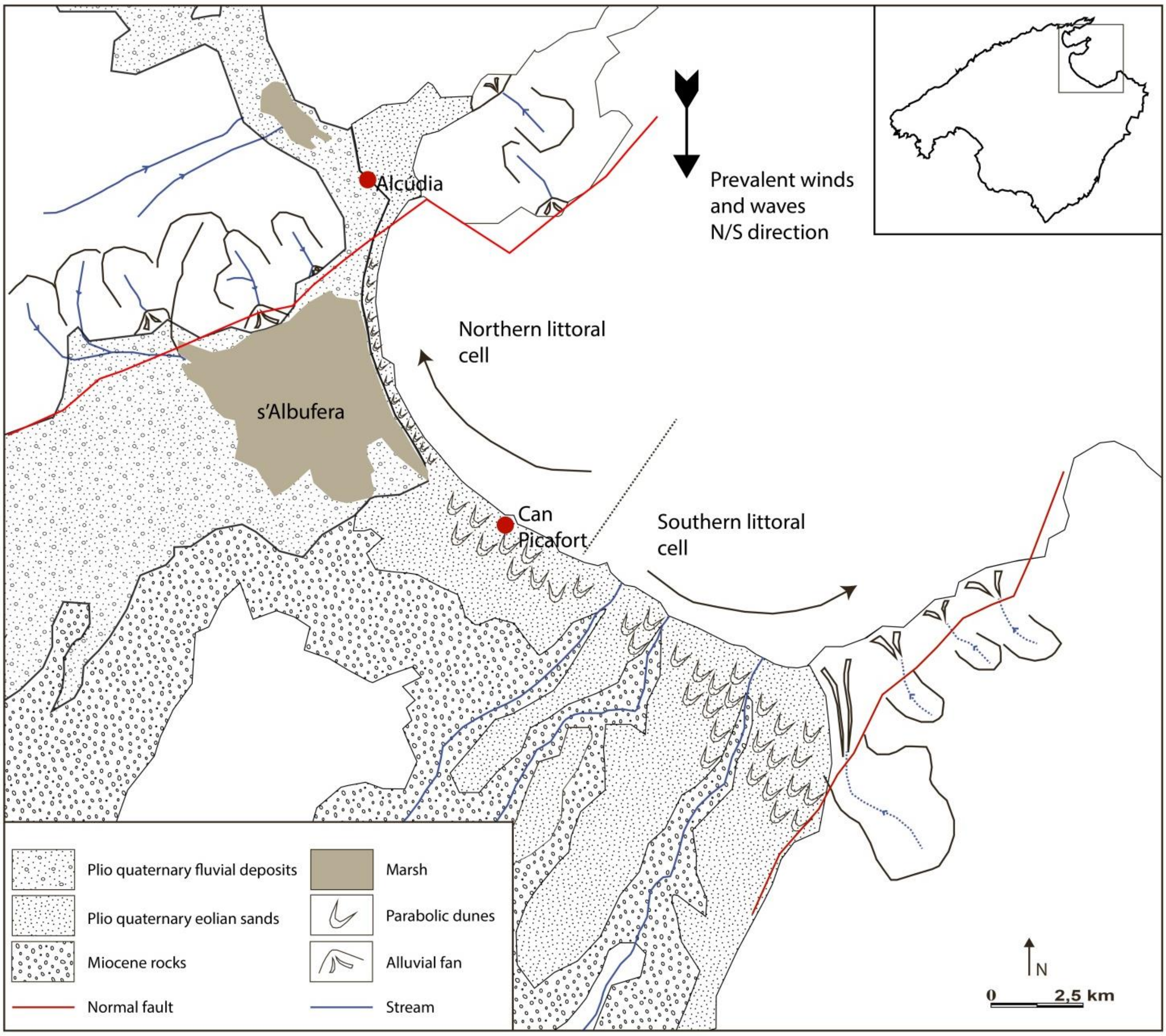
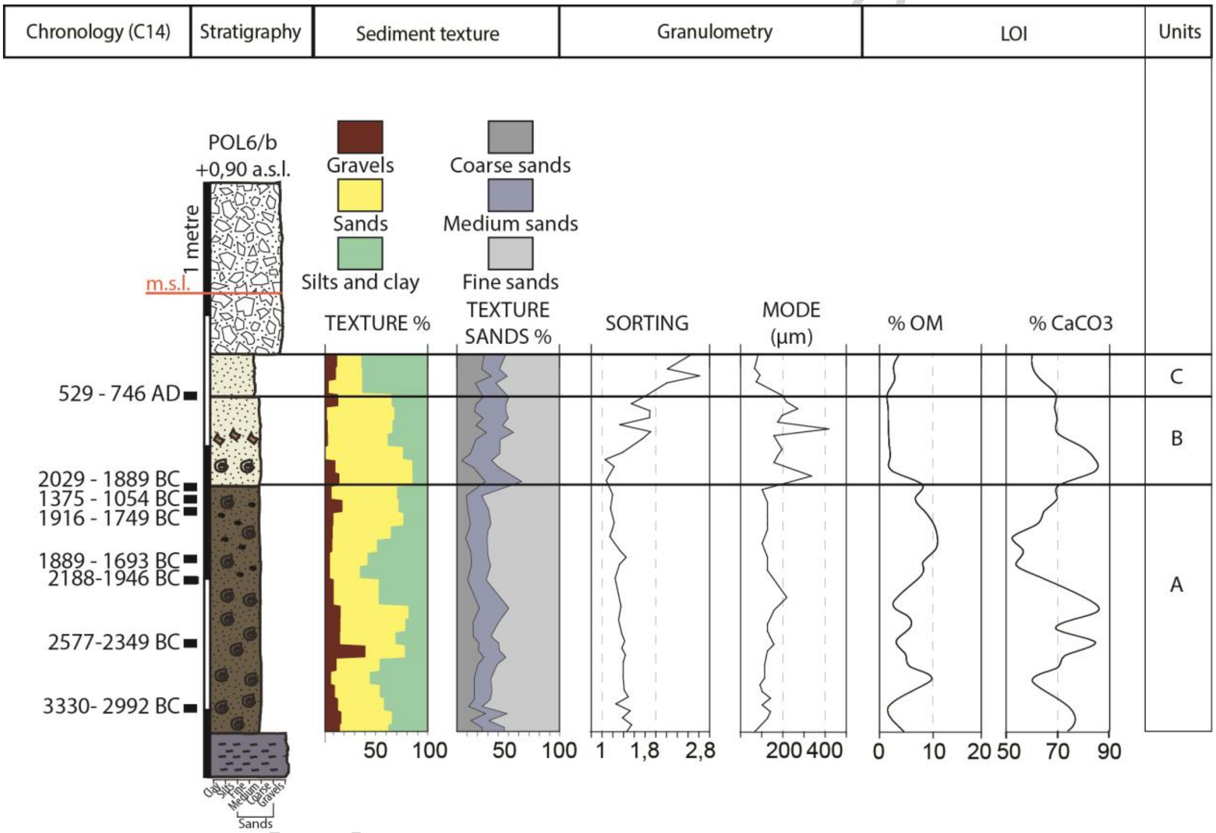

Alcudia
Prevalent winds
and waves
N/S direction
Northern littoral
cell
s'Albufera
Can
Picafort
Southern littoral
cell
Plio quaternary fluvial deposits
Plio quaternary eolian sands
Miocene rocks
Normal fault
Marsh
Parabolic dunes
Alluvial fan
Stream
N
0
2,5 km

Fig.5

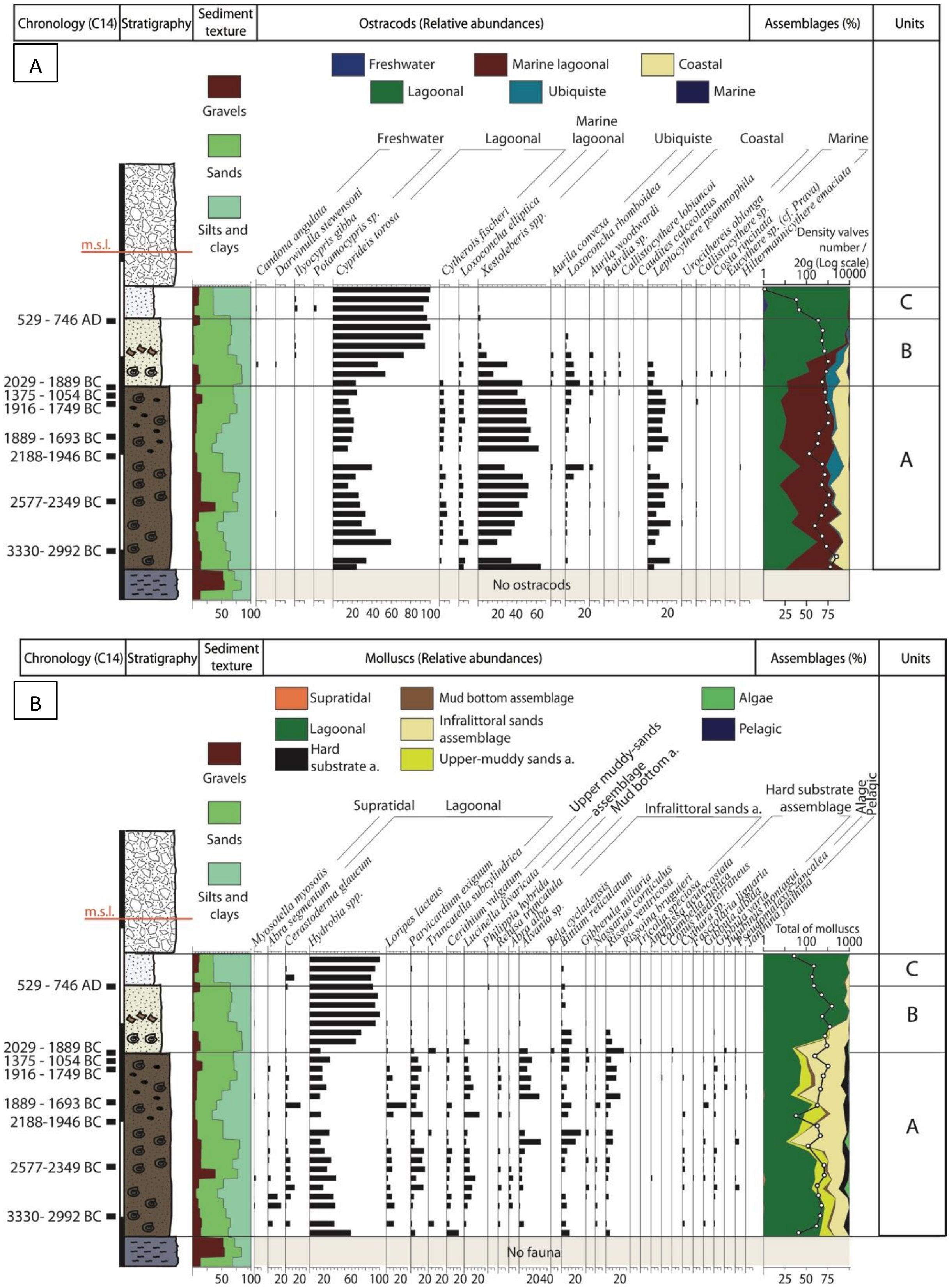

POL 3
POL 6/b
POL 9
POL 10
0
3 km
N
0
300 m
Roman theatre
Cores
Archaeological area

Fig.6



Chronology (C14)
Stratigraphy
Sediment texture
Granulometry
LOI
Units
POL6/b
+0,90 a.s.l.
1 metre
m.s.l.
Gravels
Sands
Silts and clay
Coarse sands
Medium sands
Fine sands
TEXTURE %
TEXTURE SANDS %
SORTING
MODE (µm)
% OM
% CaCO3
529 - 746 AD
2029 - 1889 BC
1375 - 1054 BC
1916 - 1749 BC
1889 - 1693 BC
2188-1946 BC
2577-2349 BC
3330- 2992 BC
C
B
A
50
100
50
100
1
1,8
2,8
200
400
0
10
20
50
70
90
Sands

Fig.7



Chronology (C14)
Stratigraphy
Sediment texture
Ostracods (Relative abundances)
Assemblages (%)
Units
A
Freshwater
Marine lagoonal
Coastal
Lagoonal
Ubiquiste
Marine
Gravels
Sands
Silts and clays
m.s.l.
No ostracods
Density valves number / 20g (Log scale)
529 - 746 AD
2029 - 1889 BC
1375 - 1054 BC
1916 - 1749 BC
1889 - 1693 BC
2188-1946 BC
2577-2349 BC
3330- 2992 BC
B
C
Molluscs (Relative abundances)
Supratidal
Mud bottom assemblage
Algae
Infralittoral sands assemblage
Pelagic
Hard substrate a.
Upper-muddy sands a.
Total of molluscs
No fauna

Fig.8

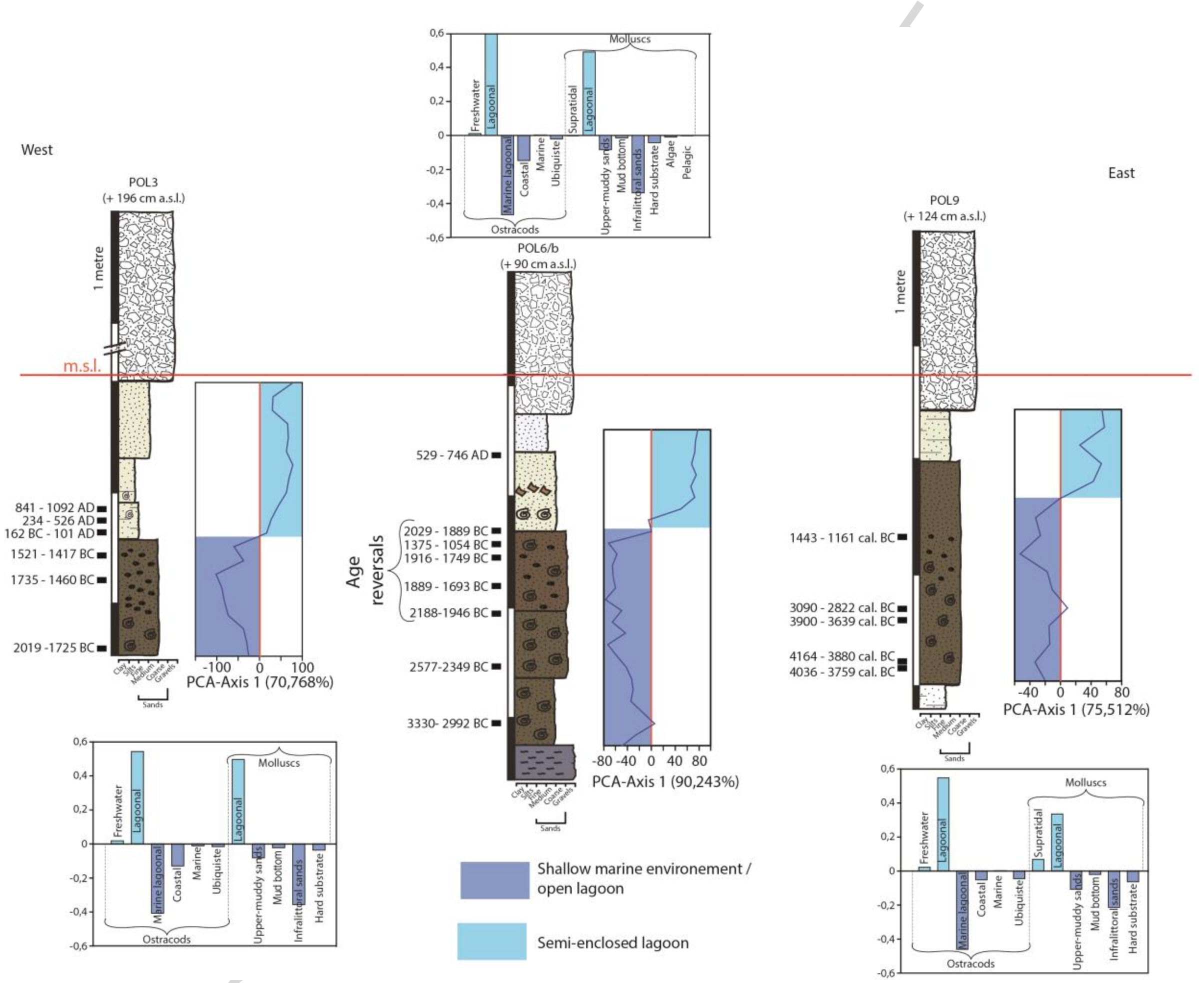
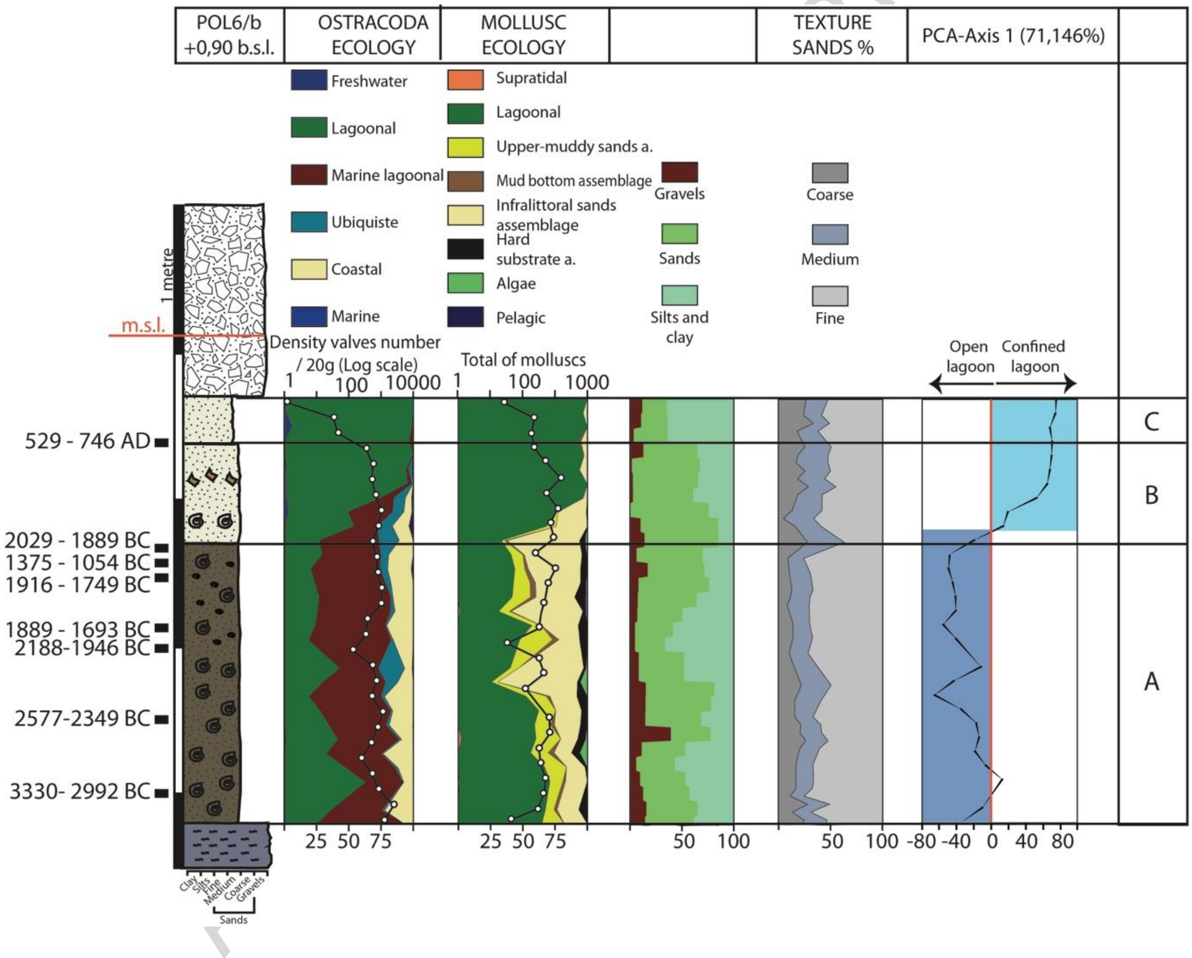
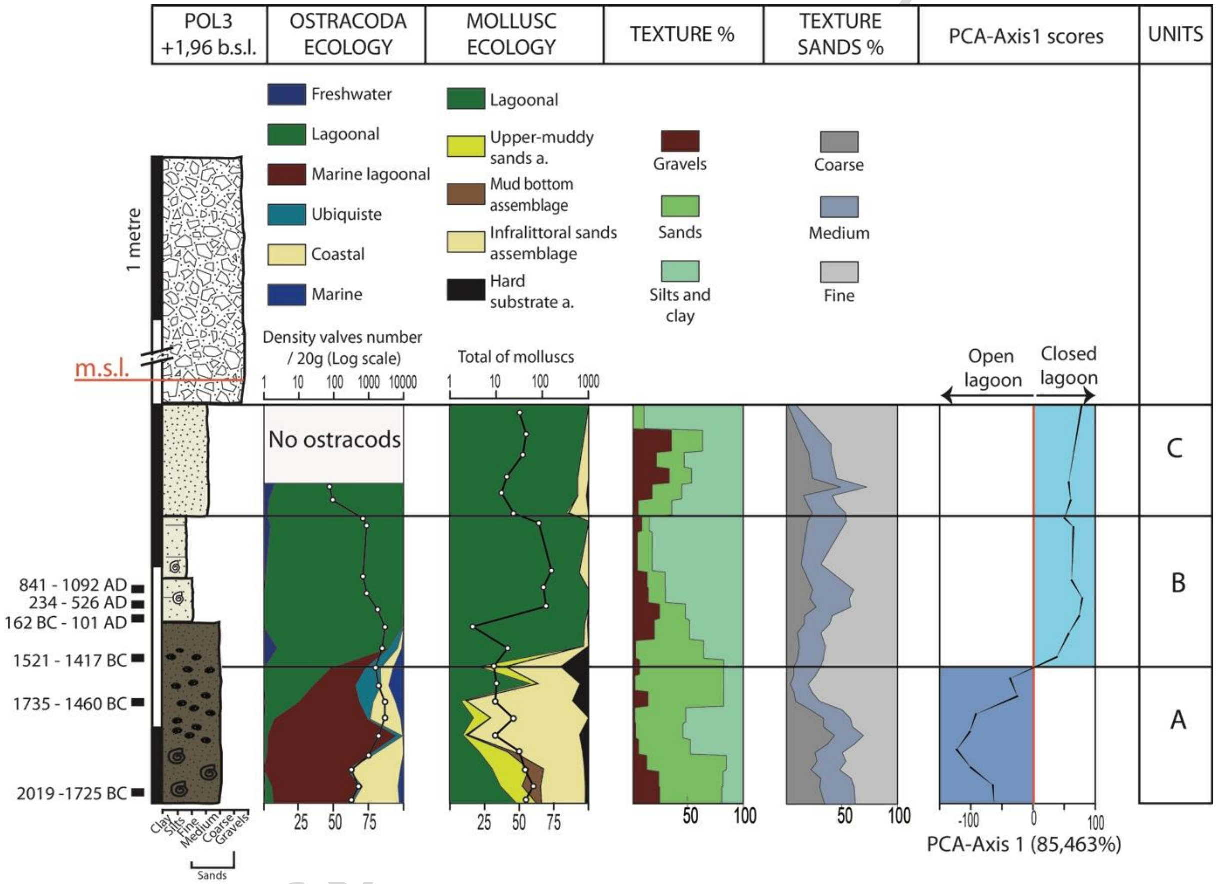

West
East
POL3
(+ 196 cm a.s.l.)
POL6/b
(+ 90 cm a.s.l.)
POL9
(+ 124 cm a.s.l.)
1 metre
m.s.l.
841 - 1092 AD
234 - 526 AD
162 BC - 101 AD
1521 - 1417 BC
1735 - 1460 BC
2019 -1725 BC
529 - 746 AD
Age reversals
2029 - 1889 BC
1375 - 1054 BC
1916 - 1749 BC
1889 - 1693 BC
2188-1946 BC
2577-2349 BC
3330- 2992 BC
1443 - 1161 cal. BC
3090 - 2822 cal. BC
3900 - 3639 cal. BC
4164 - 3880 cal. BC
4036 - 3759 cal. BC
PCA-Axis 1 (70,768%)
PCA-Axis 1 (90,243%)
PCA-Axis 1 (75,512%)
Freshwater
Lagoonal
Marine lagoonal
Coastal
Marine
Ubiquiste
Supratidal
Upper-muddy sands
Mud bottom
Infralittoral sands
Hard substrate
Algae
Pelagic
Ostracods
Molluscs
Shallow marine environement / open lagoon
Semi-enclosed lagoon

Fig.9



POL6/b
+0,90 b.s.l.
OSTRACODA ECOLOGY
MOLLUSC ECOLOGY
TEXTURE SANDS %
PCA-Axis 1 (71,146%)
Freshwater
Lagoonal
Marine lagoonal
Ubiquiste
Coastal
Marine
Supratidal
Lagoonal
Upper-muddy sands a.
Mud bottom assemblage
Infralittoral sands assemblage
Hard substrate a.
Algae
Pelagic
Gravels
Sands
Silts and clay
Coarse
Medium
Fine
1 metre
m.s.l.
Density valves number / 20g (Log scale)
Total of molluscs
Open lagoon
Confined lagoon
529 - 746 AD
2029 - 1889 BC
1375 - 1054 BC
1916 - 1749 BC
1889 - 1693 BC
2188-1946 BC
2577-2349 BC
3330- 2992 BC
C
B
A
Clay
Silts
Fine
Medium
Coarse
Gravels
Sands

Fig.10



POL3 +1,96 b.s.l.
OSTRACODA ECOLOGY
MOLLUSC ECOLOGY
TEXTURE %
TEXTURE SANDS %
PCA-Axis1 scores
UNITS
Freshwater
Lagoonal
Marine lagoonal
Ubiquiste
Coastal
Marine
Lagoonal
Upper-muddy sands a.
Mud bottom assemblage
Infralittoral sands assemblage
Hard substrate a.
Gravels
Sands
Silts and clay
Coarse
Medium
Fine
1 metre
m.s.l.
Density valves number / 20g (Log scale)
Total of molluscs
Open lagoon
Closed lagoon
No ostracods
C
B
A
841 - 1092 AD
234 - 526 AD
162 BC - 101 AD
1521 - 1417 BC
1735 - 1460 BC
2019 -1725 BC
Clay Silts Fine Medium Coarse Gravels
Sands
PCA-Axis 1 (85,463%)

Fig.11

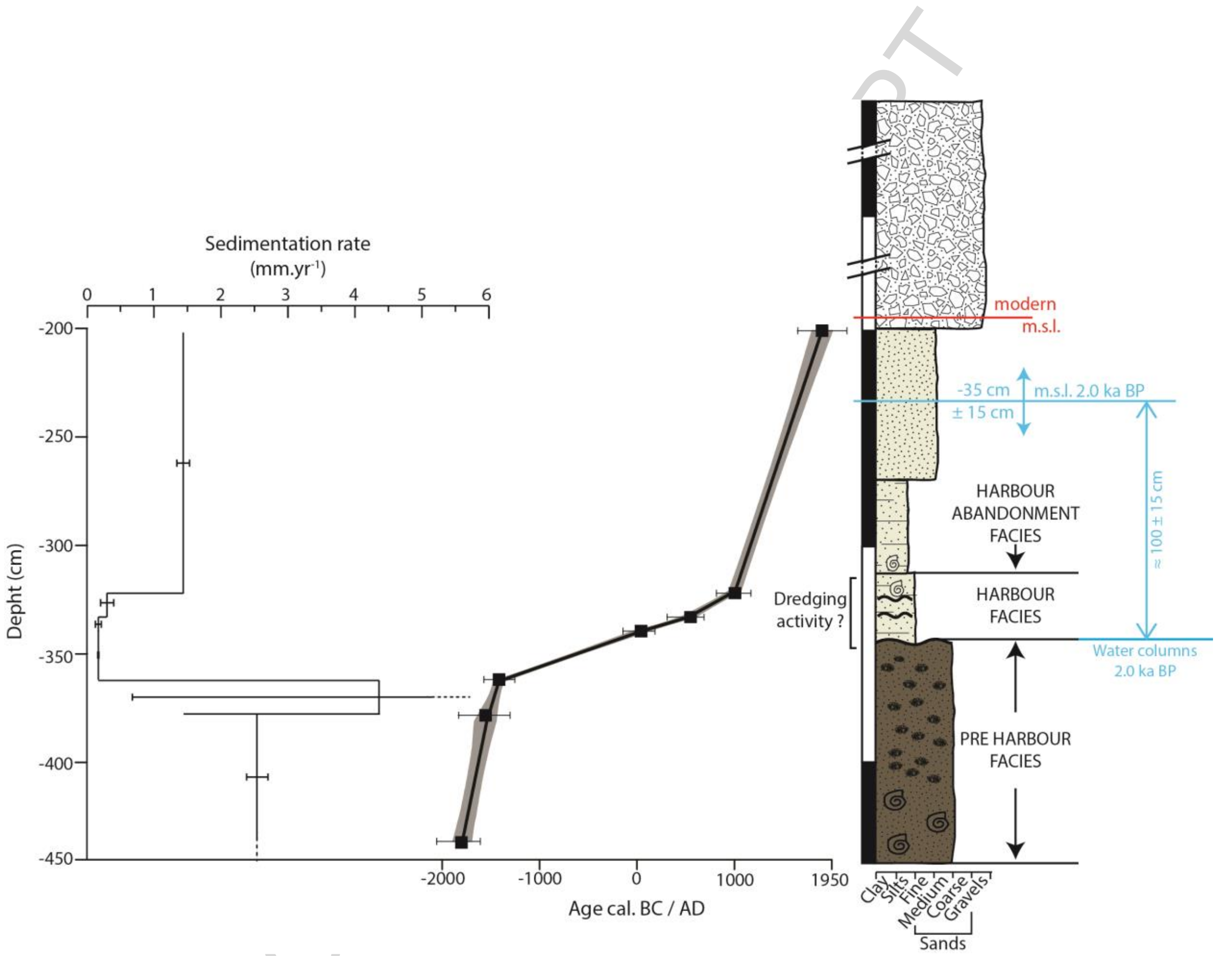

Sedimentation rate
(mm.yr-1)
0 1 2 3 4 5 6
-200
-250
-300
-350
-400
-450
Depht (cm)
-2000 -1000 0 1000 1950
Age cal. BC / AD
Dredging activity ?
modern
m.s.l.
-35 cm
± 15 cm
m.s.l. 2.0 ka BP
≈ 100 ± 15 cm
HARBOUR ABANDONMENT FACIES
HARBOUR FACIES
Water columns
2.0 ka BP
PRE HARBOUR FACIES
Clay
Silts
Fine
Medium
Coarse
Gravels
Sands

Fig.12

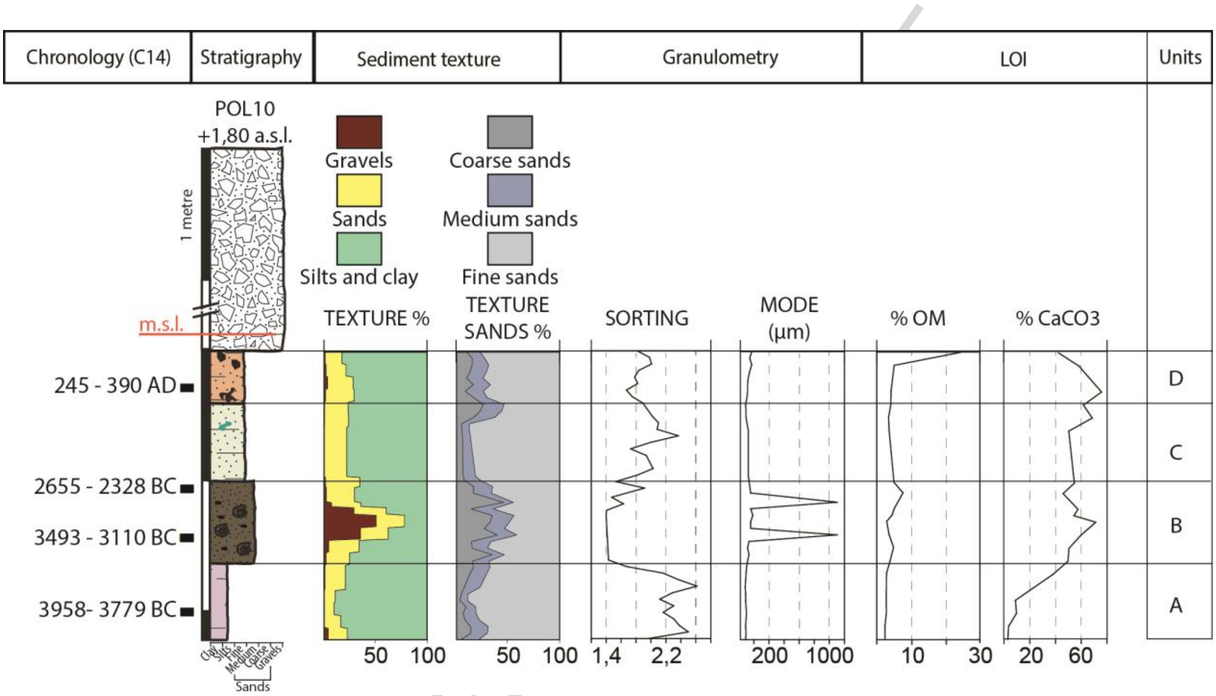
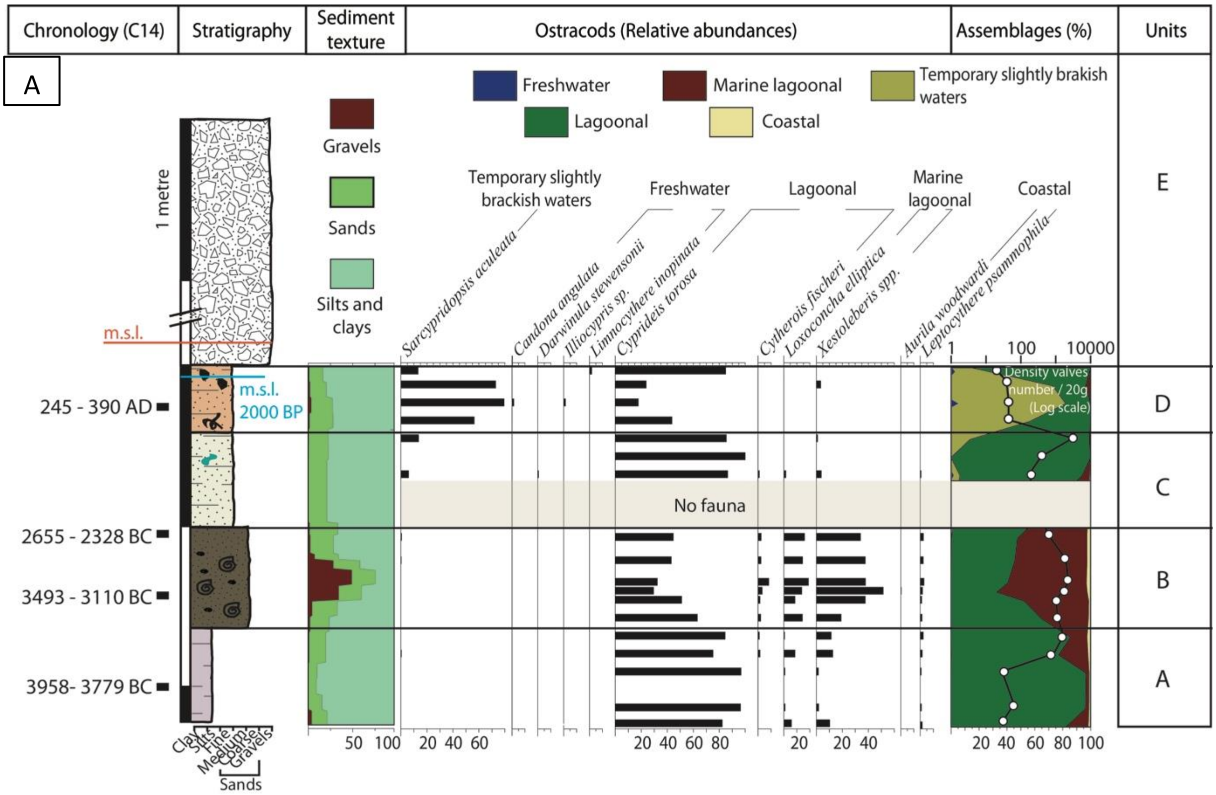

Chronology (C14)
Stratigraphy
Sediment texture
Granulometry
LOI
Units
POL10
+1,80 a.s.l.
1 metre
m.s.l.
Gravels
Sands
Silts and clay
Coarse sands
Medium sands
Fine sands
TEXTURE %
TEXTURE SANDS %
SORTING
MODE (µm)
% OM
% CaCO3
245 - 390 AD
2655 - 2328 BC
3493 - 3110 BC
3958- 3779 BC
D
C
B
A
50 100
50 100
1,4 2,2
200 1000
10 30
20 60
Sands

Fig.13


Chronology (C14)
Stratigraphy
Sediment texture
Ostracods (Relative abundances)
Assemblages (%)
Units
A
Freshwater
Marine lagoonal
Temporary slightly brakish waters
Lagoonal
Coastal
Gravels
Sands
Silts and clays
1 metre
m.s.l.
m.s.l. 2000 BP
Temporary slightly brackish waters
Freshwater
Lagoonal
Marine lagoonal
Coastal
Sarcypridopsis aculeata
Candona angulata
Darwinula stewensonii
Illiocypris sp.
Limnocythere inopinata
Cyprideis torosa
Cytherois fischeri
Loxoconcha elliptica
Xestoleberis spp.
Aurila woodwardi
Leptocythere psammophila
Density valves number / 20g (Log scale)
No fauna
245 - 390 AD
2655 - 2328 BC
3493 - 3110 BC
3958- 3779 BC
E
D
C
B
A
Clay
Silts
Fine
Medium
Coarse
Gravels
Sands

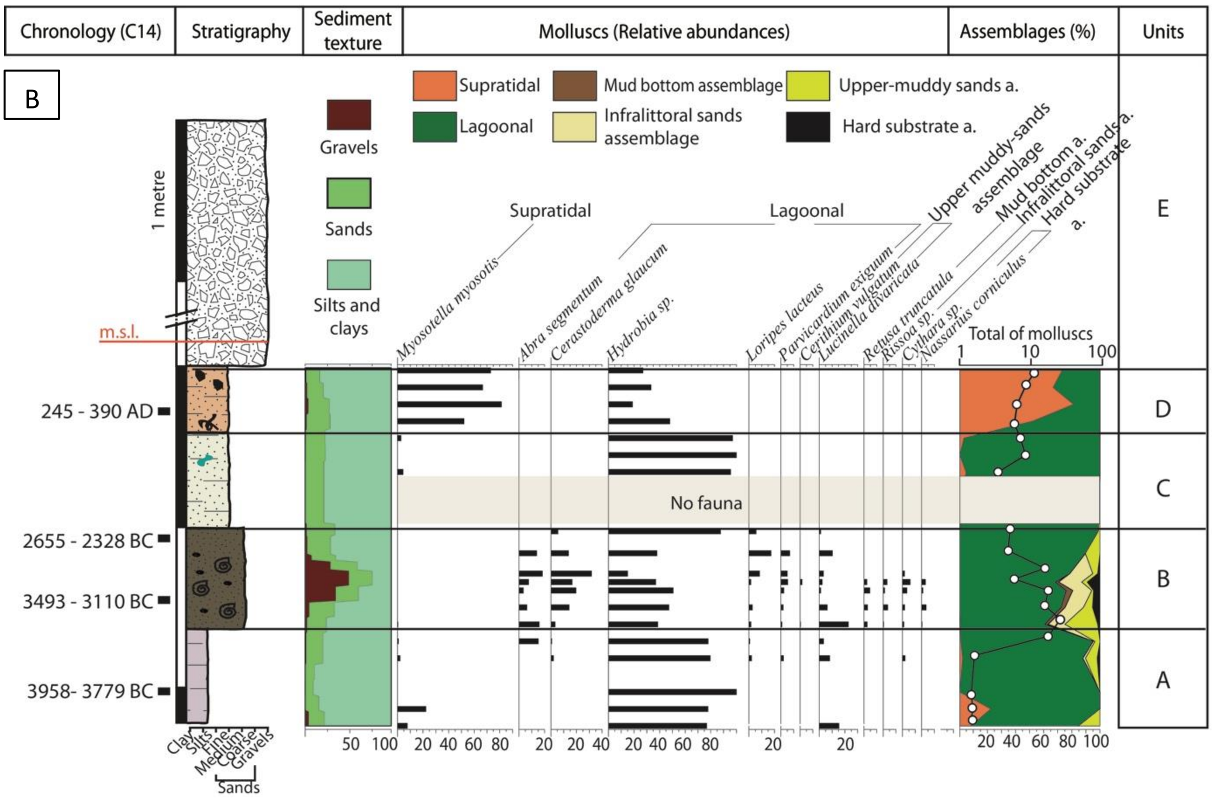

Chronology (C14)
Stratigraphy
Sediment texture
Molluscs (Relative abundances)
Assemblages (%)
Units
B
Supratidal
Mud bottom assemblage
Upper-muddy sands a.
Lagoonal
Infralittoral sands assemblage
Hard substrate a.
Gravels
Sands
Silts and clays
1 metre
m.s.l.
Supratidal
Lagoonal
Upper muddy-sands assemblage
Mud bottom a.
Infralittoral sands a.
Hard substrate a.
Myosotella myosotis
Abra segmentum
Cerastoderma glaucum
Hydrobia sp.
Loripes lacteus
Parvicardium exiguum
Cerithium vulgatum
Lucinella divaricata
Retusa truncatula
Rissoa sp.
Cythara sp.
Nassarius corniculus
Total of molluscs
No fauna
245 - 390 AD
2655 - 2328 BC
3493 - 3110 BC
3958- 3779 BC
E
D
C
B
A
Clay
Silts
Fine
Medium
Coarse
Gravels
Sands

Fig.14

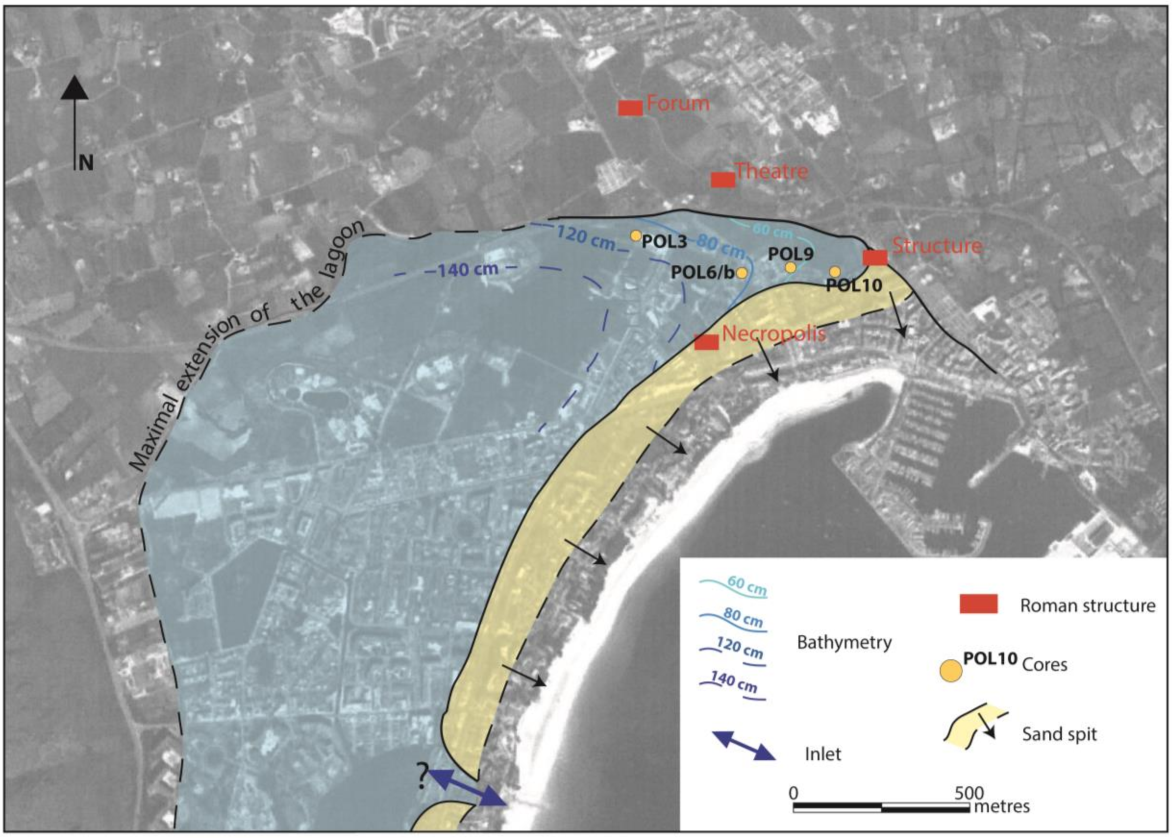

Forum
Theatre
N
Structure
Necropolis
POL3
POL9
POL6/b
POL10
120 cm
80 cm
60 cm
140 cm
Maximal extension of the lagoon
?
60 cm
80 cm
120 cm
140 cm
Bathymetry
Roman structure
POL10 Cores
Sand spit
Inlet
0
500
metres

Fig.15

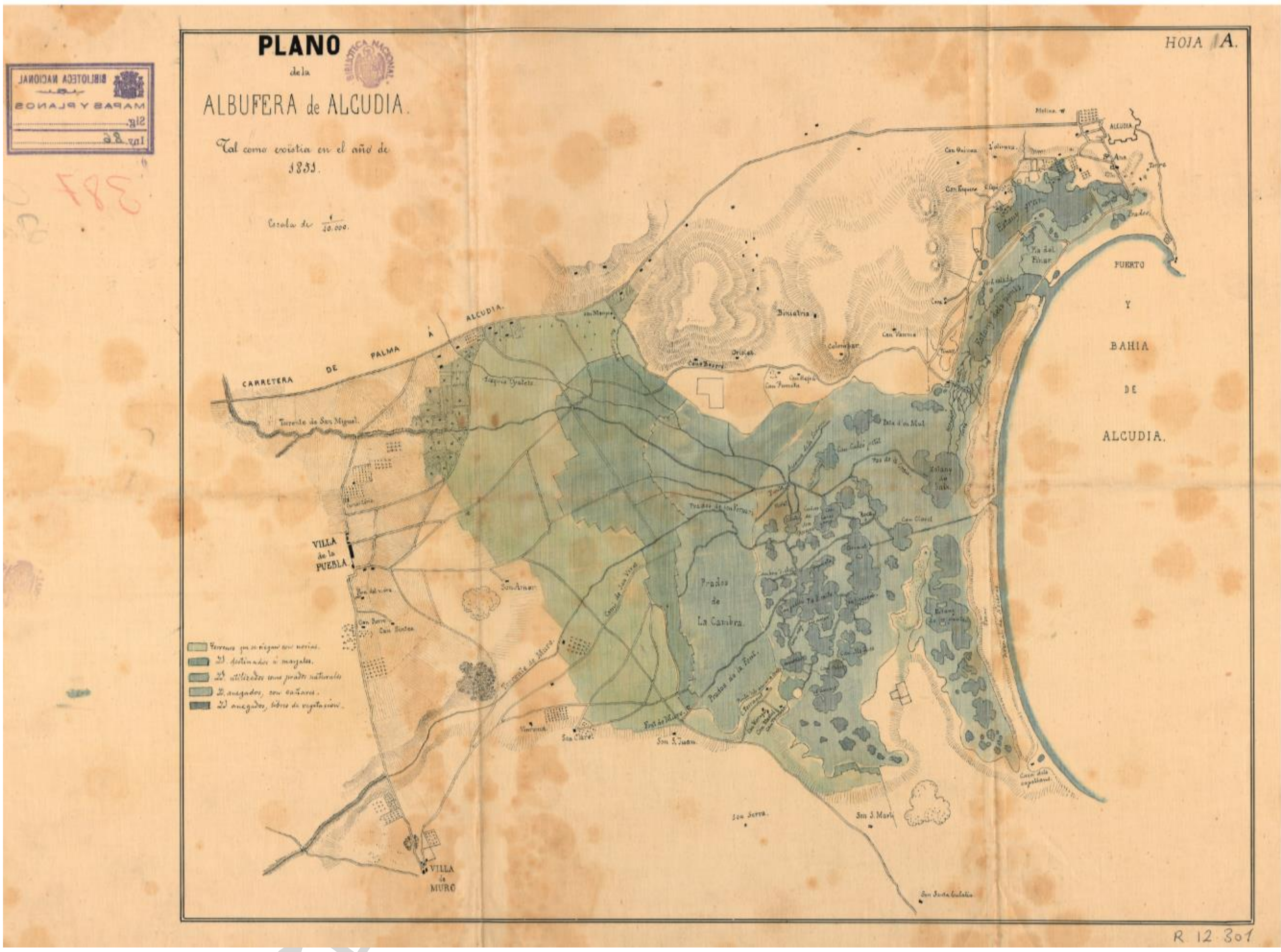

PLANO
de la
ALBUFERA de ALCUDIA.
Tal como existia en el año de
HOJA A.
CARRETERA DE PALMA A ALCUDIA.
VILLA de la PUEBLA
VILLA de MURO
ALCUDIA
PUERTO
Y
BAHIA
DE
ALCUDIA.
BIBLIOTECA NACIONAL
R 12.301

Fig.16

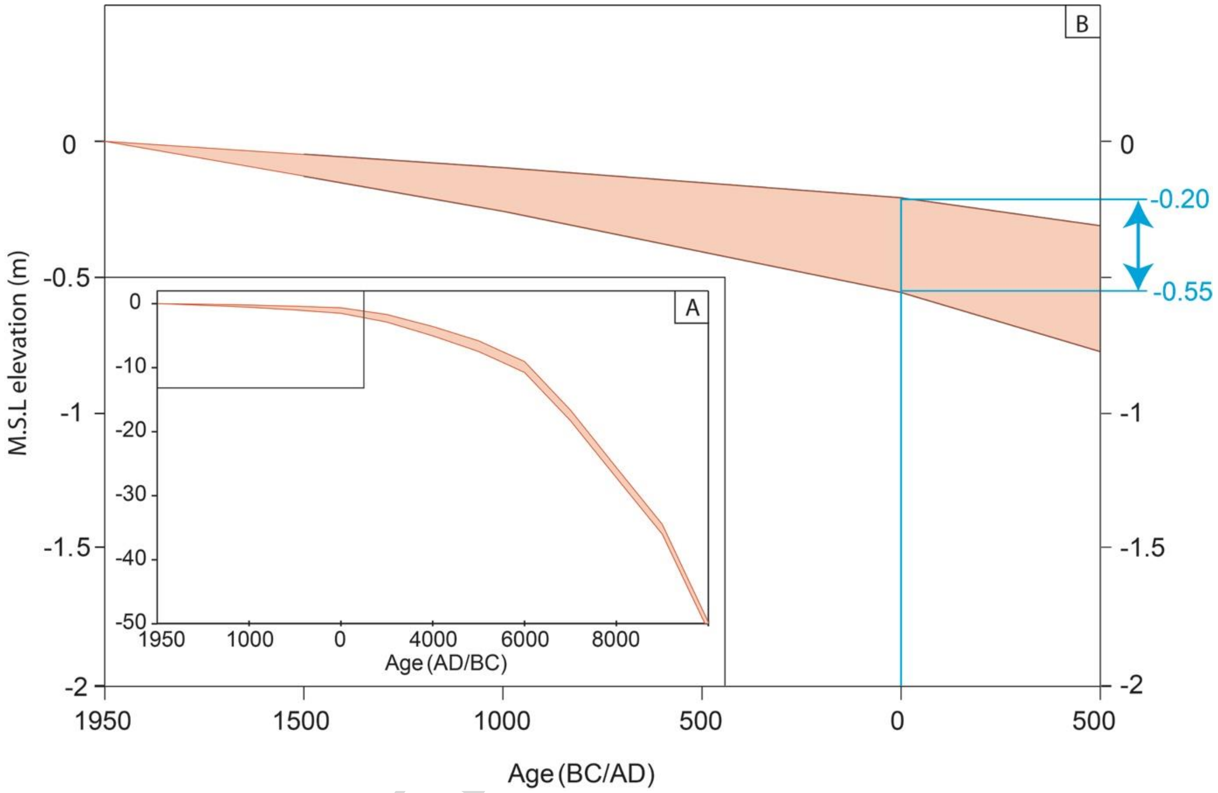

B
A
M.S.L elevation (m)
0
-0.5
-1
-1.5
-2
-0.20
-0.55
1950
1500
1000
500
0
500
Age (BC/AD)
-10
-20
-30
-40
-50
4000
6000
8000
Age (AD/BC)

Table.1

CORE	Sample	Lab number	δC^{13}	Depth (cm b.s.)	Depth (cm b.s.l.)	Material	Age C^{14}	2 σ BP min ; max	2 σ BC/AD min ; max
POL6/b	POL6b.7	Poz-69098	-8,3	160	70	Marine shell	1840 ± 30	1204 ; 1421	529 AD ; 746 AD
POL6/b	POL6b.21	Poz-69451	-7,3	230	140	Plant remains	3600 ± 30	3838 ; 3978	2029 BC ; 1889 BC
POL6/b	POL6b.23	Poz-69099	2,3	240	150	Marine shell	3395 ± 35	3003 - 3324	1375 BC ; 1054 BC
POL6/b	POL6b.25	Poz-69453	-13,1	250	160	Plant remains	3510 ± 30	3698 ; 3865	1916 BC - 1749 BC
POL6/b	POL6b.31	Poz-69454	-9,9	280	190	Plant remains	3475 ± 35	3642 ; 3838	1889 BC ; 1693 BC
POL6/b	POL6b.35	Poz-69455	-12,3	300	210	Plant remains	3670 ± 35	3895 ; 4137	2188 BC ; 1946 BC
POL6/b	POL6b.43	Poz-69456	-13	350	260	Plant remains	3975 ± 35	4298 ; 4526	2577 BC ; 2349 BC
POL6/b	POL6b.53	Poz-69457	3,6	400	310	Marine shell	4900 ± 35	4941 ; 5279	3330 BC ; 2992 BC
POL3	POL3.20	Poz-72248	-4,9	315	119	Marine shell	1500 ± 30	858 ; 1109	841 AD ; 1092 AD
POL3	POL3.22	Poz-69459	-2,3	325	129	Marine shell	2095 ± 35	1424 ; 1726	234 AD ; 526 AD
POL3	POL3.24	Poz-72246	-2,3	335	139	Marine shell	2425 ± 30	1849 ; 2111	162 BC ; 101 AD
POL3	POL3.28	Poz-69460	-16,8	360	164	plant remains	3200 ± 30	3366 ; 3470	1521 BC ; 1417 BC
POL3	POL3.32	Poz-69461	-13,3	380	184	plant remains	3310 ± 50	3409 ; 3684	1735 BC ; 1460 BC
POL3	POL3.44	Poz-69463	5,8	440	244	marine shell	3940 ± 30	3674 ; 3968	2019 BC ; 1725 BC
POL9	POL9.12	Poz-69465	3	270	146	Marine shell	3475 ± 35	3110 ; 3392	1443 BC ; 1161 BC
POL9	POL9.22	Poz-69466	0,6	330	206	Marine shell	4730 ± 35	4771 ; 5039	3090 BC ; 2822 BC
POL9	POL9.24	Poz-72246	-3,9	340	216	Marine shell	5420 ± 35	5588 ; 5849	3900 BC ; 3639 BC
POL9	POL9.29	Poz-69467	-1,4	375	251	Marine shell	5635 ± 30	5837 ; 6114	4164 BC ; 3880 BC
POL9	POL9.20	Poz-69467	-1,4	380	256	Marine shell	5560 ± 40	5710 ; 5988	4039 BC ; 3761 BC
POL10	POL10.7	Poz-72249	-9,3	230	50	Freshwater snail	1725 ± 30	1562 ; 1705	245 AD ; 388 AD
POL10	POL10.15	Poz-69470	1,4	300	120	marine shell	4395 ± 35	4277 ; 4604	2655 BC ; 2328 BC
POL10	POL10.24	Poz-69472	-27,6	345	165	charcoal	4570 ± 30	5059 ; 5442	3493 BC ; 3110 BC
POL10	POL10.35	Poz-69473	-22,6	400	220	charcoal	5060 ± 35	5728 ; 5970	3958 BC ; 3779 BC

Table.2

Wreck	Period	Type	Hull weight (tons)	Deadweight (tons)	Draught (cm)	Reference
Fiumicino1	IV - V AD	Lighter / Coastal navigation	10	50	140	Boetto (2008)
NapoliA	I AD	Lighter / Coastal navigation	6,3	16	97	Poveda (2012)
		Lighter / Coastal navigation	6,3	21	113	Poveda (2012)
NapoliC	I AD	Lighter / Coastal navigation	6,8	15	80	Poveda (2012)
		Lighter / Coastal navigation	6,8	20	98	Poveda (2012)
La Cavalière	I BC - I AD	Lighter / Coastal navigation	5	18	80	Charlin et al., (1978)
		Lighter / Coastal navigation	5	25	105	Charlin et al., (1978)
Maquette		Dolia	9	30	105	Carre and Roman (2008)

Figure 1: Location of the Roman city of Pollentia, on the eastern shore of Mallorca island. (A) Western Mediterranean basin scale. (B) Aerial photograph of Mallorca island. (C) Eastern shore of Mallorca island with Pollentia situated between the two bays and location of the Alcanada islet (source: esri). Wave rose obtained from measurements undertaken in the bay of Alcúdia in 2015 (station 2123118: Puertos del estado).

Figure 2: Main morphostructural units of Mallorca island (modified from Ginés et al., 2012).

Figure 3: Coastal geomorphology of Mallorca. (A) Serra de Tramuntana (B) platform of Migjorn (C) bay of Alcúdia (photograph Fornós).

Figure 4: Simplified geomorphological map of the bay of Alcúdia (modified from Servera et al., 2009).

Figure 5: Location of the cores drilled at the foot of the ancient city (source: ESRI and Google Earth).

Figure 6: Grain size and LOI results of the core POL6/b.

Figure 7: (A) Ostracod species and assemblages from the core POL6/b. (B) Mollusc species and assemblages from the core POL6/b.

Figure 8: Stratigraphic logs of the cores POL3, POL6/b and POL9 and results of the associated PCA.

Figure 9: Summary of the faunal and sedimentological results of the core POL6/b and PCA scores derived from faunal data.

Figure 10: Summary of the faunal and sedimentological results of the core POL3 and the PCA derived from these data.

Figure 11: Age-depth model, sedimentation rates and water column reconstructed for the core POL3.

Figure 12: Grain size and LOI results of the core POL10.

Figure 13: (A) Ostracod species and assemblages of the core POL10. (B) Molluscs species and assemblages of the core POL10.

Figure 14: Palaeogeographical reconstruction of the lagoon 2000 years ago.

Figure 15: Historical map representing the southern shore of Alcúdia (1851). Biblioteca Nacional (Madrid).

Figure 16: Model of RSL rise in Mallorca since 10000 cal. yr. BC (A). Zoom on RSL rise in Mallorca since 500 cal. yr. BC. The values on the right indicate the range of the estimated sea-level position (-0,35cm +/- 15 cm).

Table 1: AMS-^{14}C data. The radiocarbon ages are expressed in calibrated years BP and BC at the 95% confidence level (2σ). b.s. = below surface, b.s.l. = below present mean sea level. Calibration using Calib 7.1. (Stuiver and Reimer, 1993) and the IntCal13 curve (Reimer et al., 2013).

Table 2: Dimensions of several Roman ships-wreck discovered in the Mediterranean.

Highlights

A lagoon was situated near the city of *Pollentia* during Roman times.

This lagoon probably hosted one of the city's harbours.

Chronostratigraphy supports a harbour foundation between 1st c. BC and the 1st c. AD.

A chronological gap of 1000 years suggests dredging.