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Article Type: Research Paper

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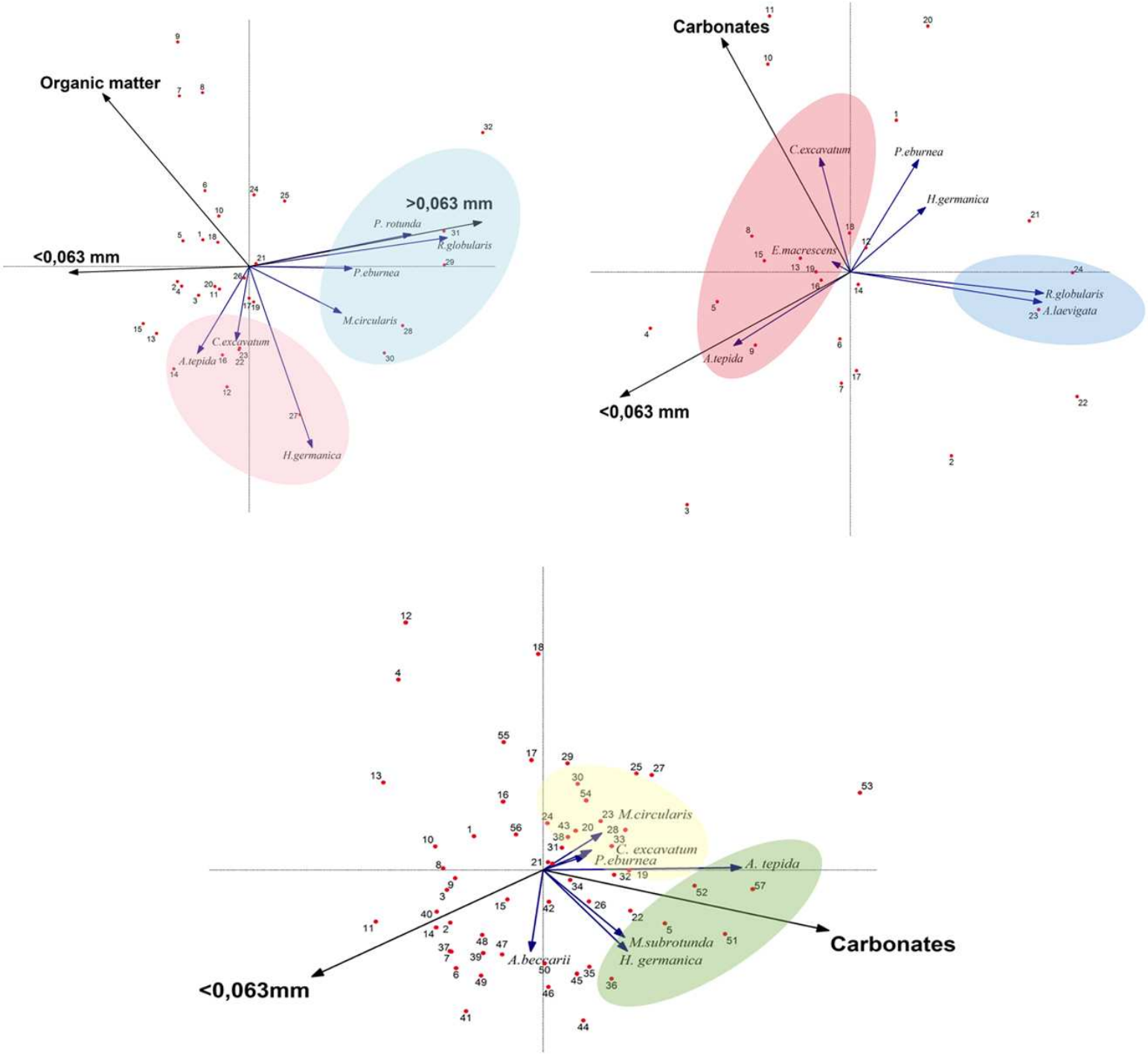
Graphical Abstract



Highlights

- The type of substrate and the content in calcium carbonate is the key role in the evolution of the foraminiferal assemblages in the study area.
- Three phases of the paleoenvironment evolution during the late Holocene in Albufera de Valencia by eustatic and geomorphological causes were reconstructed.
- Paleoenvironments of brackish lagoon were developed during the cold events Bond II (2.8 ka) and Bond I (1.4 ka).

Keywords: Foraminifera, Sediment, Lagoon, Paleoenvironment, Geomorphology, Western Mediterranean.

MULTI PROXY ANALYSIS IN THE LATE HOLOCENE EVOLUTION OF A MEDITERRANEAN COASTAL LAGOON: ENVIRONMENTAL VARIABLES WITHIN FORAMINIFERAL ASSEMBLAGES.

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ABSTRACT

The evolution of foraminiferal assemblages and the environmental variables (type of substrate, content in calcium carbonate and content in organic matter) at the Valencia lagoon (western Mediterranean) in response to climate changes in the late Holocene were rebuilt in this study. In this area of low tidal range, several multiproxy analyses were carried out to determine which environmental variables influence the distribution of the fossil assemblage, and its association with global, regional or local climatic phenomena. The statistical results show that in environments with higher exposure to marine conditions, the calcium carbonate content is the significant factor, whereas in more restricted environments the type of substrate (grain size) is determinant. Three phases were identified in the evolution of this area from 2800 cal yr BP to the present: Phase I, corresponding to a brackish lagoon connected to the sea, characterized by an assemblage of brackish and sea water foraminifera species evolving towards a brackish lagoon without marine connection at the top. Phase II (1232 ± 74 cal yr BP - 791 ± 104

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1. INTRODUCTION

The paleontological content of lagoons of low coastal areas, especially those of low tidal range, have been widely studied in attempts to determine changes in climate and variations in the sea level throughout the Holocene (Bartels-Jónsdóttir et al., 2006, Leorri et al., 2012, Pérez-Asensio et al., 2012, Di Bella and Casieri, 2013, Benito et al., 2015, Cosentino et al., 2017). On the Mediterranean coasts, several authors have established the paleoenvironmental evolution of these environments during the Holocene (Blázquez et al., 1999, Magny et al., 2007, Delgado et al., 2012, Ferrer and Blázquez, 2012, Mauz et al., 2012, Burjachs et al., 2015, Degeai et al., 2015, Mensing et al., 2015, Vacchi et al., 2016). The maximum flooding of the sea during the Holocene in the western Mediterranean was recorded around 6000-5000 BP (Pirazzoli, 2005, Zazo et al., 2008, Blázquez and Usera, 2010, Rodríguez-Perez et al., 2018); the rise and subsequent stabilization of the sea level caused the formation of deltas (Carmona and Ruiz, 2011; Cearreta et al., 2016) and barrier island systems (Marco-Barba et al., 2013; Fanget et al., 2014; Carmona et al. , 2016; Blázquez et al., 2017). The study of fossil

assemblages also allows inferences to be made about other environmental conditions, such as the degree of energy, nutrient supply, salinity and temperature (Di Bella et al., 2013, Dolven et al., 2013).

The main mechanisms responsible for paleoenvironmental changes are difficult to identify, since the sea level is largely determined by other factors such as tectonic or marine dynamics. In these areas, the tectonic factor is significant (Carmona and Ruiz, 1999, Albarracín et al., 2013), since subsidence rates of 12.8 cm/kyr have been recorded in the last 200 ka (Zazo et al., 1993). The sedimentary record contains other signs such as fluvial flood events (Barriendos and Martin-Vide, 1998, Benito et al., 2015, Carmona et al., 2016, Sospedra et al., 2017), storms (Sabatier et al., 2012; Pardo-Pascual et al., 2014) and, in recent centuries, the increasing effects of anthropic action (del Barrio Fernandez et al., 2012). Identifying the mechanisms that play the greatest role in the stabilization of coastal environments would provide essential information for improving the prediction of the range of changes in sea level in the short and medium term. The Mediterranean basin may be one of the areas most affected by the effects of current climate change, given its high sensitivity to the variations in the climate (Fletcher and Zielhofer., 2013) and the increasingly intense impact of human activity (Bellin et al., 2013: Filip and Gousan., 2014; Pascual-Aguilar et al., 2015).

The scope of this study is the Albufera de Valencia, one of the most important wetlands in the Spanish Mediterranean. It is recognized as a wetland of international importance (according RAMSAR Convention) and is protected by several European environmental protection programs (Site of Community Importance, Special Bird Protection Area). Currently, the protected area occupies an approximate surface area of 21,000 ha, of

which 3,000 ha comprise the current lagoon. It is communicated with the sea through three artificial drainage channel systems (known as *golas*) which have sluice gates installed for water regulation purposes.

This coastal system was formed from the sedimentary deposits of the Júcar and Turia rivers and the ravines of Catarroja and Poyo (Sanchis 2001, Ruiz and Carmona 2005). From the dynamic perspective, coastal processes are controlled by waves, wind and longshore drift (N-S). The tidal influence, with an average daily oscillation around 15 cm, is negligible. Barrier-island formation extends between the Turia river delta and the cape of Cullera. At the northern end (Turia river delta) the barrier has been taken over by the Valencia city port installations. To the south, the barrier presents different morphologies closely related with Pleistocene calcarenite outcrops and neotectonics (Carmona and Ruiz, 1999). At present, the main use of the wetland area is rice cultivation, whose point of greatest expansion coincided with the largest reduction in the lagoon during the 19th century (Garcia-Labrandero, 1959).

In this area, multidisciplinary studies (micropaleontological, sedimentary, chronostratigraphic, etc.) have been carried out on the margins of the lagoon near the coast (Santisteban et al., 2009; Marco-Barba et al., 2013; Ruiz and Carmona, 2017). According to Santisteban et al. (2009) and Marco-Barba et al. (2013) the evolution of the barrier presents two phases: the first corresponding to a rapid increase in sea level from the beginning of the Holocene to 6500 BP, and a second, with a more moderate ascent, with a sandy deposit in which the six units of progradation (H1-H6) described by Goy et al. (2003) in the Gulf of Almería, by Dabrio et al. (2000) in the Gulf of Cádiz and by Somoza et al. (1998) in the delta of the Ebro can be differentiated. Four periods

of formation of the barrier are identified (Santisteban et al., 2009), the first between 6250 BP and 4700 BP in the northern sector; the second between 4400 BP and 2700 BP, which reaches further south; the third between 2500 BP and 1200 AD and the fourth, between 1200 AD and the present day, until the formation of the current barrier. Carmona and Ruiz (2011) identified a barrier formed by beach sand in the area to the north of the lagoon dated from 7500-7300 cal yr BP and underlying a coastal backbarrier (3360-3150 cal yr BP). In addition, Ruiz and Carmona (2017) dated the prograding sandbars of the north zone of the Albufera indicating the closure of the barrier lagoon during the High Medieval Period as a result of the migration of the mouth of the Turia river towards the south around 1650 cal yr BP. The sandbar is dated 1373±173 cal yr BP.

The study by Carmona et al. (2016) compared a core from the interior of the wetland with six less thick cores located around the Turia mouth. These authors identified four phases in the evolution of the lagoon. The first was dated around 8240 ± 80 BP and corresponded to a brackish lagoon culminating with a deposit associated with the Holocene transgression maximum. A second phase, between 6450 cal yr BP and 3710 ± 130 cal yr BP, reflects a lagoon connected to the sea. Between 3710 ± 130 cal yr BP and 820 ± 90 cal yr BP (third phase) the open sea lagoon was progressively isolated until a freshwater lagoon emerged, coinciding with the increase in the frequency and magnitude of flooding in the Turia alluvial plain during the Little Ice Age (Ruiz and Carmona, 2011). Finally, this freshwater lagoon environment changed to a flood plain environment, related to the sedimentary flood deposits.

127 The main aim of the present study is to determine the paleoenvironmental changes of
128 the Albufera de Valencia in its northern zone, where the deposits of the Turia river have
129 a greater influence, on the basis of a multidisciplinary analysis of sedimentary cores and
130 their relationship with the SAL 1/2 core (Carmona et al., 2016). The relationship with
131 global and regional climatic phenomena and with local factors (i.e., the influence of the
132 nearby paleochannels) offers the possibility of establishing a more complete model of
133 the evolution of this space since the Middle Holocene, especially in the northern area
134 closest to the coast.

135 FIG1. Location of study area and the sampling stations. Geomorphological map of the coastal barrier–lagoon of
136 Valencia through time. (Spain).

137

138 ## 2. MATERIAL AND METHODS

139 In 2016 two new sedimentary cores were drilled as part of a project that aims to
140 reconstruct the situation of the Valencia lagoon during the Holocene. The methodology
141 used in this study combines geomorphological, stratigraphic, sedimentological and
142 micropaleontological techniques (foraminifera, charophytes, ostracods, etc.) and ^{14}C
143 dating. A manual core was collected in the north of the Valencia lagoon, called
144 Tremolar 2 (TRE2), with geographical coordinates 39°24'21"N, 0° 21'18"W, at 0.65 m
145 a.s.l and 3.5 m thick and Tremolar 3 (TRE3), with geographical coordinates
146 39º24'40''N, 0º21'15"W at 0.75 m a.s.l and 3 m thick. Coring was carried out in this
147 area using a 50 cm x 5 cm "Russian" corer. TRE3 and TRE2 are 0.6 km apart, and are
148 3.5 km from the SAL1/2 core (Fig.1)
149 Systematic sampling involved collection of the sediments at intervals of 10 cm
150 interspersed between the micropaleontological and sedimentological samples. The
151 texture was characterized sedimentologically (assessing percentages of silt and clay

sand). The colour was checked with dry samples and the Munsell charts. From the chronological perspective, eight radiocarbon dates were obtained from material from both cores, whose upper extreme was considered to correspond to a contemporary date (Fig.2).

FIG2. Upper: Table with radiocarbon dates. Lower: Composite time–altitude (cm) model based on ^{14}C dating and calibration curve following Reimer et al. (2013) of TRE2 and TRE3 cores.

2.1 Study of foraminifera

The micropaleontological analysis of the core was carried out by the Geology Laboratory at the Catholic University of Valencia. As mentioned above, there is a high level of human activity in this lagoon today, and so the present-day foraminifera distribution would not serve as a reliable reflection of the natural environment. The foraminiferal assemblages of present-day wetlands and lagoons can be extrapolated from the study of nearby wet areas (Usera and Blázquez, 1997, Guillem, 2008, López-Belzunce et al., 2014, Sanjuán and Blázquez, 2017), although none of them are free from the impact of human activity.

The determination of the paleoenvironment is based above all on the fossil content, especially of benthic foraminifera. For this, systematic sampling was carried out at intervals of 10 cm along the cores. A total of 56 samples were collected. Whenever possible, 300 specimens were counted: several authors (Buzas, 1990; Murray, 1991) state that this sample size is sufficient in order to identify foraminiferal assemblages. Fatela and Taborda (2002) consider that a sample of 100 shells is enough, because they represent all species with proportions above 5%, while Patterson and Fishbein (1989)

suggest that if the species under study represent almost 50% of the assemblages, then only 50 individuals are needed.

The percentage of allochthonous species is calculated according to the auto-ecology of the species and its conservation status, and especially according to the association of living foraminifera found in the inner shelf in adjacent sectors (Usera and Blázquez, 1997; López-Belzunce et al., 2014). The autochthonous taxa come from the association studied in the present-day marshes and in Holocene sedimentary records of similar or nearby lagoons such as Torreblanca (Guillem, 2008), Peñíscola (Usera et al., 2006), Oliva-Pego (Torres et al., 2014), Javea (Fumanal et al., 1993), Albufereta (Ferrer and Blázquez, 2012) and Elx (Blázquez and Usera, 2010).

The samples were wet sieved through a 63 mm screen. Foraminifera shells were picked (under a binocular stereomicroscope) using reflected light until a representative number of 300 individuals per sample was obtained. The foraminifera were classified following Loeblich and Tappan (1987) and Hayward et al. (2017) for generic attributions.

The data obtained were quantitatively analysed, and the diversity index (Shannon and Wiener, 1949), equitability and Fisher's alpha (Fisher et al., 1943) were calculated. The alpha index is unreliable in samples of fewer than 100 individuals (Murray, 2006). It was estimated in order to establish the composition and proportional abundance of the species identified and the dominance of the species in the samples. Diversity values were computed with the PAST (Paleontological statistics) software (Hammer et al., 2001, 2008).

For the classification of paleoenvironments of different salinity, the Venice System (1958) was used, especially in order to distinguish oligohaline, euhaline and hypersaline waters. However, this classification is more suitable in environments with significant

tides. Other classifications such as the EU Water Framework Directive define transitional waters as "bodies of surface water in the vicinity of river mouths which are partially saline in character as a result of their proximity to coastal waters but which are substantially influenced by freshwater flows" (European Communities, 2000). For McLusky and Elliott (2007), these transitional waters are largely assimilated to estuaries, which are associated with brackish water (Table 1), both on tidal and microtidale coasts. Therefore, in this study the term "transitional waters" refers to non-tidal brackish water lagoons. The term "lentic non-tidal lagoons" covers environments depending on the species of foraminifera, the geomorphological characteristics, and the classifications used in other similar studies of adjacent zones. The characteristics of the environments defined are shown in Table 1.

TAB1. Paleoenvironments classification using Venice System, McLusky and Elliot (2007) and taking in consideration the characteristics of the Mediterranean area.

2.2 Sedimentary analysis

The sedimentary analysis of the core was carried out by the Geomorphology Laboratory at the Geography Department of Valencia University. Texture was determined by dry sieving (sand fraction > 4 phi) and the pipette method (silt and clay fractions). Grain size was calculated with the Gradistat software package (Blott and Pye, 2001). The sedimentological information was completed with binocular stereomicroscope observations of sand grains.

Organic matter was determined using the Walkley Black method (Walkley and Black, 1934) and the proportion of calcium carbonate was calculated using a Bernard calcimeter.

2.3 Statistical analysis

Numerous methods have been developed to quantitatively reconstruct paleoenvironmental variables. These methods differ in terms of the numerical assumptions made regarding the data used: for instance, whether the taxon-environment response is unimodal (Gaussian) or linear (Sejrup et al., 2004).

First, Principal Component Analysis (PCA) was carried out to extract the most important foraminiferal assemblages. Due the high variability of the study area, with a mean value of 27 foraminiferal taxa per sample, we had to represent the benthic foraminifera taxa with a relative abundance ≤1% in the samples collected. This left us with five species, representing around 95% of the total analysed.

A Detrended Correspondence Analysis (DCA) was calculated to determine whether the distribution of species was linear or unimodal (Leps and Smilauer, 2005). A linear response was observed, so we performed Redundancy Analysis (RDA), which relates the species to the environmental parameters considered (depth, grain-size, organic matter content and calcium carbonate).

Square root transformation of the percentages was carried out prior to statistical analysis. The foraminiferal content percentages were transformed into square roots. The sample was standardized by error variance, as this procedure indicates how much of this variance is not explained by the environmental variables. The inverse of this value is used as the weight of each species: the better the description of the species by the environmental parameters, the greater their weight at the end of the analysis. The Monte Carlo permutation was used to obtain the p value, and the environmental parameter test was performed by forward selection to determine the variables that best explain the data distribution (Table 2). For this analysis we used the software Canoco 4.5 (Ter Braak and

Smilauer, 2002; Leps and Smilauer, 2005).

In order to determine whether there is an association between the samples in the three surveys, a cluster analysis hierarchical classification was performed. This analysis consists of locating the samples in groups, so that the degree of association/similarity between samples of the same cluster is stronger than that between samples of different cluster analyses. In this case the measurement of the Euclidean distance was chosen, since it is the most suitable when the variables are homogeneous and are measured in similar units. For its representation a dendrogram was created, a tree-type graphic representation summarizing the grouping process in a cluster analysis.

TAB2. Statistical results of redundancy analyses (RDAs).

3. RESULTS

Several distinct paleoenvironments were determined on the basis of the sedimentary variables, the main foraminiferal assemblages and the relationship between the two, through statistical correlations. Textural distribution, carbonate content and the percentage of organic matter in 114 samples were analysed. A total of 27,653 benthic foraminifera were collected, grouped into 58 species and three different orders: Miliolida, Rotaliida and Textulariida.

TAB3. Main micropalaeontological results and dominant assemblages in each unit of samples collected (TRE2 and TRE3 core).

For the statistical analysis of RDA, the following environmental variables were included: sand content, silt and clay content, organic matter content and carbonate

content. All of them were related to the benthic foraminiferal assemblage recorded. The results of these core analyses are presented below.

3.1 Core Tremolar 2 (TRE2)

In the TRE2 core (Fig.3), a change in trend of the environmental variables was seen from sample 28 (elevation 2.3 m b.s.l) upwards, with an increase in carbonate and organic matter content. The carbonate distribution recorded a reduction at 1.5 m b.s.l and an increase at 1.2 m b.s.l; from this latter level upwards, the organic matter content began to decrease, although between 0.5 m b.s.l. and 0.6 m b.s.l. the trend reversed, since the carbonate content fell and the percentage of organic matter (peat) rose. Six ^{14}C datings were carried out in this core (Fig.2). The resulting ages were consistent with other results of ^{14}C dating in the study area (Carmona et al., 2016). However, an anomalous dating was observed at 2.15 m b.s.l (2797±50 cal yr BP).

Five species were identified in the whole of the core, representing 96% of the foraminifera shells studied. The foraminifera identified corresponded to three different orders: by far the most abundant was Rotaliida (94.5%) followed by Miliolida (5.24%) and Textulariida (0.25%). Table 3 shows the dominant assemblages in each unit, on the basis of the micropaleontological and sedimentological results.

The species *Ammonia tepida* (Cushman) was dominant throughout the TRE2 core (Fig.3), though with a reduced abundance from sample 17 (1.2 m b.s.l.) onwards, with an increase in *Haynesina germanica* (Ehrenberg) until its disappearance coinciding with the peat level (samples 9,8 and 7, from the levels 0.6 m b.s.l. to 0.4 m b.s.l.). *Cribroelphidium excavatum* (Terquem) is associated with brackish lagoon environments (Debenay, 2000, Debenay and Guillou, 2002, Gregory et al., 2015). The vertical

297 distribution of the core shows how the increase in *C. excavatum* (sample 18, level 1.4 m
298 b.s.l) coincides with the change from a brackish lagoon with low marine connection to a
299 brackish marsh.
300
301 The diversity and richness indices show a downward trend from the base to the top of
302 the core. The Shannon index had low values (scores > 2 indicate conditions of normal
303 marine diversity) with higher values in unit I, and Fisher's alpha indicated that the
304 greatest richness was found in Unit I. In samples 15 and 7 (1.2 b.s.l. to 0.6 b.s.l.)
305 Fisher's alpha values were lower, possibly indicating a change in environment.
306
307 Although the dominant assemblage was quite homogeneous, along the core four groups
308 were identified by the cluster analysis (Fig.3). One group (samples 31 and 32), with a
309 higher proportion of sands, presented the greatest diversity of species in the core,
310 remains of *Posidonia oceanica* (Delile) and a mixed assemblage of stenohaline species
311 such as *Rosalina globularis* (D'Orbigny), and euryhaline species (*H. germanica* and *A.*
312 *tepida*), with the occasional presence of species associated with *Posidonia oceanica*
313 such as *Nubecularia lucifuga* Defrance, *Lobatula lobatula* (Walker & Jacob), *Massilina*
314 *secans* (D'Orbigny) and *Planorbulina mediterranensis* D'Orbigny. A second group
315 comprised samples 30-21, characterized by a lower presence of sands, the presence of
316 marine species and the progressive dominance towards the top of euryhaline species
317 (samples 25, 24, 23, 22, 21). Samples 18-16 presented a significant increase in *C.*
318 *excavatum* and contained the miliolide *Miliolinella circularis* (D'Orbigny), which is
319 more common in more brackish waters (Gregory et al., 2015); in these samples the silt
320 and clay fractions increase. Finally, in the fourth group (samples 15-1), *A. tepida. H.*
321 *germanica* and *C. excavatum* predominate, with the occasional appearance of species

such as *Discorinopsis aguayoi* (Bermúdez), and *Trochammina inflata* (Montagu). These euryhaline and eurythermic species are frequent in lagoons of hyposaline waters and muds or silts rich in organic matter (Scott and Medioli, 1980, Zaninetti, 1984, Albani et al., 1984, Murray, 1991).

FIG3. TREMOLAR 2 core, Upper: Composite diagram including key selected variables. Lower: Multivariate analyses based in benthic foraminifera: Correlation between Cluster Q-type analysis of samples and distribution of species according the environmental variables, in the analysis by redundancy analysis (RDA).

According to the RDA analysis (Fig.3, Table 2) the variables that best describe the variance of the data are, first, the grain size (sands), followed by the organic matter content and silt and clay content. Carbonates do not play an important role in the foraminiferal distribution and the typical species of marine habitats are best described by environmental variable, sand content. The sand distribution accounted for 58.4% of the variance of the data and organic matter 28.3%; together, they accounted for 86.7% of the variance.

At the base of the core the sedimentation rates were around ~ 0.10 cm per year up to 2797 ± 50 cal yr BP. They then declined at a rate of ~ 0.04 cm y^{-1} to around 1073 ± 240 cal yr BP; from that point they rise to the values at the base of the core (by 0.17 cm y^{-1}, 0.09 cm y^{-1}) and reaching maximum increases of ~ 0.72 cm y^{-1} from 144 ± 159 cal yr BP onwards (Fig. 2).

3.2 Core Tremolar 3 (TRE3)

In core TRE3 (Fig.4) the carbonate distribution is highly variable, while the organic matter is more constant. The organic matter content rises at 0.9 m b.s.l. (presence of

plant remains); from that point onwards until the top, the carbonate and organic matter decrease, with a recovery at the top between 0.2 m b.s.l. and 0.1 m a.s.l. The proportion of silts and clays increases considerably from 1.7 m b.s.l. upwards, with a maximum of 0.1 m b.s.l. The presence of sands is greater at the bottom of the core. Two ^{14}C dates were recorded, one at 1.75 m b.s.l, with an age of 2401 ± 69 cal yr BP, and another at 0.85 m b.s.l, with an age of 1232 ± 74 cal yr BP.

Five dominant species were identified throughout the core, accounting for more than 96% of the shells analysed (Fig. 4). The most abundant order is *Rotaliida* (94.2%) followed by *Miliolida* (1.58%) and *Textulariida* (0.5%).

In the analysis of the assemblage (Table 3), *A. tepida* dominates to 1.5 m b.s.l; at this point it begins to descend until 1 m b.s.l, coinciding with the maximum abundance of *C. excavatum* and *H. germanica*. From 0.9 m b.s.l *A. tepida* predominated once again, being practically the only species. The presence of the following species stands out: *Adelosina laevigata* (D'Orbigny) epiphytes of *Posidonia oceanica* seagrass (Colom, 1974), associated with sandy sediments (Mateu, 1970), sands with biodetrites (Mateu, 1981), coarse sand, muddy sand and sandy mud (Planelles, 1996), on loose substrates of different textures (Usera and Blázquez, 1997), on coralligenous, muddy and maërl bottoms (Alberola, 1997) and *Pseudolachlanella eburnea* (D'Orbigny) eurytopic, able to withstand the significant variations in temperature and salinity associated with estuaries and marshes, both species disappears upwards of 1.5 m b.s.l; Some authors consider it to be a euryhaline species, interpreting it as autochthonous in marsh sediments (Usera et al., 1996). *E. macrescens,* typical of marsh environments (Guillem, 2008), appears at the top of the core.

372

373 Three units were distinguished on the basis of the species studied, the sedimentological
374 analysis and the statistical variables, which are described in detail in Table 3.

375

376 Regarding the diversity and richness indices, the highest values of the Shannon and
377 Fisher's alpha indices are located at the bottom of the core. The highest values of the
378 dominance index (Equitability) were located at the top of the TRE3 core (from 0.8 m
379 b.s.l.), due to the abundance of *A. tepida*. Between 1.30 m b.s.l. and 0.9 m b.s.l. the
380 density of foraminifera is extremely high, coinciding with a high organic matter content;
381 in contrast, in the samples located between 0.7 m b.s.l. and 0.2 m b.s.l., the minimum
382 number of individuals was not reached after analysing all the sediment.

383

384 Regarding the Cluster analysis, the dominant association presents few variations. Unit
385 III was clearly differentiated in the cluster (samples 1-8) (Fig.4). Another grouping of
386 samples (13-9) dominated by the presence of *D. aguayoi* species is also notable; this
387 euryhaline species is very common in the marshes and lagoons of the Mediterranean
388 area, in warm waters (Bermúdez, 1935), and in muddy bottoms (Scott et al., 1979,
389 Lévy, 1982, 1989, Gasse et al., 1987). These samples also present sediments rich in
390 rhizotubules, related to events of saturation. Finally, another grouping of samples with
391 greater diversity is recorded (samples 23-21) in which the dominant assemblage is a
392 mixture of stenotopic and euritopic species. The typical brackish water species (*A.*
393 *tepida, C. excavatum, P. eburnea, H. germanica*) are mixed with marine water species;
394 particularly abundant among the latter are *R. globularis*, an epiphyte on seaweed and
395 seagrass, especially in the leaves (Blanc-Vernet, 1984, Langer, 1993, Ribes et al., 1992),
396 and *A. laevigata*.

The RDA (Fig.4, Table 2) indicates that the silt and clay fraction is the variable that best explains the distribution of the various species throughout the core (81.9%), followed by carbonates (18.1%). However, *C. excavatum* is associated with carbonates, while it is the silts and clays that best describe the variability of distribution of *A. tepida*.

FIG4. TREMOLAR 3 core, Upper: Composite diagram including key selected variables. Lower: Multivariate analyses based in benthic foraminifera: Correlation between Cluster Q-type analysis of samples and distribution of species according the environmental variables, in the analysis by redundancy analysis (RDA).

As regards sedimentation rates, the minimum values are located at the base of the core (~ 0.068 cm y-1), reaching a maximum of ~ 0.133 cm y-1 from 1232 ± 74 cal yr BP.

3.3 Core SAL 1/2

The paleoenvironmental interpretation of this core indicates the presence of a lagoon which was well communicated with the sea but was isolated after the construction of a coastal barrier (Carmona et al., 2016). Analyses of percentages of silt and clays, sands, carbonates, organic matter and statistical studies were carried out in this study and compared with the results of the TRE2 and TRE3 cores.

Carbonate content present a highly variable pattern between 2.9 m b.s.l. and 0.9 m b.s.l. The percentages are very high, with a downward trend from 0.9 m b.s.l. to 0 m a.s.l; there is a rebound at 0.30 m a.s.l. The organic matter content presents high values from 4.1 m b.s.l upwards. The dominance of the silt and clay fraction is observed throughout the core, except at the bottom where the sandy fraction dominates until 4.1 m b.s.l.

Five species account for 97% of the foraminiferal assemblages, which are described in detail in Carmona et al. (2016). Up to the level of 2.9 m b.s.l., marine habitat species such as *Ammonia beccarii* (Linné) and *Miliolinella subrotunda* (Montagu) stand out, and from there up until 0.9 m b.s.l. the most frequent are *P. eburnea*, *M. circularis* and *H. germanica*, species that are abundant in brackish lagoons and estuarine environments (Murray, 1991). The presence of *C. excavatum* is not very significant but its dominance coincides with a high carbonate saturation of the environment (Fig.5).

Cluster analysis identifies the two paleoenvironmental units interpreted as Unit A and Unit B. Unit A comprises brackish-influenced samples, and unit B samples from an environment identified as a freshwater lagoon (Carmona et al., 2016). The most disparate samples correspond to periods of drying with the presence of rhizotubules and more anoxic environments.

FIG5. SAL1/2 core, Upper: Composite diagram including key selected variables. Lower: Multivariate analyses based in benthic foraminifera: Correlation between Cluster Q-type analysis of samples and distribution of species according the environmental variables, in the analysis by redundancy analysis (RDA).

The RDA shows the dominant variable in the foraminiferal assemblage to be the calcium carbonate content, explaining 98% of the distribution, followed by organic matter content and finally grain size. *C. excavatum* is associated with the presence of calcium carbonate while *A. beccarii* is more frequent in samples with low organic matter content.

4. DISCUSSION

4.1 Paleoenvironmental interpretation

From the paleoenvironmental point of view, the sedimentological, micropaleontological and statistical characteristics distinguish three environments in the Tremolar 2 core (Fig.6).

The oldest recorded paleoenvironment is a brackish lagoon with marine connection (2.8 to 2.2 m b.s.l.), containing an assemblage comprising a mixture of organisms adapted to brackish water (*A. tepida, H. germanica, C. excavatum* and *P. eburnea*), and another less frequent assemblage comprising stenohaline foraminifera (*R. globularis* and *M. circularis*). In addition, epiphyte species of *Posidonia oceanica* appear, such as *P. mediterranensis* and *N. lucifuga*. The diversity values are the highest in the core (especially Fisher's Alpha) although they remain low given the restricted nature of the environment. ^{14}C dating at the depth of 2.50 m b.s.l gives an age of 2941 ± 268 cal yr BP at the base of the unit. The cluster analysis distinguishes two subgroups in this unit: the first dominated by *R. globularis* and the presence of epiphyte species of *Posidonia oceanica*, and with high biodiversity values, and the second less dominated by marine species and with a lower species diversity.

FIG6. Upper: Foraminiferal interpretation, geomorphological processes, chronology and succession of paleoenvironmental phases throughout the lagoon record from TRE2 and TRE3 core. Lower: Correlation between TRE2. TRE3 and SAL1/2 paleoenvironmental phases of the lagoon.

The second unit corresponds to a brackish lagoon (2.2-1.2 m b.s.l), without marine connection, dominated by brackish species such as *A. tepida, C. excavatum* and *H. germanica*. The high abundance of *C. excavatum* and episodes of massive carbonate precipitation (1.6 m, 1.7 m, 1.3 m, 1.2 m b.s.l.) characterize the top of this unit. These sediments, together with the micropaleontological evidence, indicate the saturation of

the environment. The change in trend of carbonates and organic matter at the 2.3 m b.s.l. level reflects an alteration in the environmental conditions, which is corroborated by the micropaleontological content. The diversity values decrease in this unit and the dominance of brackish species increases. Two ^{14}C dates were obtained at 2.2 m b.s.l. (bottom of the unit), from 2648 ± 185 cal yr BP and another at 2.1 m b.s.l. from 2797 ± 50 cal yr BP, which differ by only ~100 years. As was pointed before, this date was identified as anomalous date, therefore, was dismissed, due that the original material was different from the others calibrated dates and that could be misled in the interpretation of the other dates obtained in this core. At 1.5 meters b.s.l., the third ^{14}C dating indicates an age of 1073 ± 240 cal yr BP.

In this second unit it is also worth noting the identification of two drying periods at 1.7-1.6 m b.s.l. and at 1.3-1.2 m b.s.l. In the first period, we note the presence of euryhaline species such as *M. circularis, P. eburnea* and *M. rotunda* and the fall in values of *A. tepida* and *H. germanica*: and in the second, *C. excavatum* presents a significant increase. In the cluster analysis, samples 16, 17 and 18, which are grouped separately from the samples in the brackish lagoon, correspond to moments of saturation with reduced sand content and increased silt and clay fractions, and significant increases in the presence of *C. excavatum*.

Finally, the most recent paleoenvironment is a brackish marsh (1.2 b.s.l. to 0.3 a.s.l.) with two distinct subunits separated by a layer of peat. The first subunit presents low species diversity, with a predominance of *A. tepida, H. germanica* and *C. excavatum*, and plant structures. The high values of organic matter and peat in the middle of this unit are indicative of the marsh environment. Subunit II contains hyposaline species such as *E. macrescens, D. aguayoi, T. inflata* (occasionally) and pyrite concretions

typical of anoxic environments. The ^{14}C dating reveals ages of 791 ± 104 cal yr BP (1 m b.s.l.) and 144 ± 159 cal yr BP (-0.4 meters b.s.l.). In this paleoenvironment, a river flooding event at a level of 0.5-0.3 m b.s.l. is identified with the absence of foraminifera, the appearance of highly reworked shells and the emergence of a layer of peat with resulting increases in organic matter content and decreases in the carbonate values throughout the core.

In Tremolar 3 (TRE3), the sedimentological and micropaleontological characteristics indicate the presence of three paleoenvironments (Fig.6):

The oldest is a brackish lagoon with marine connection (2.2 m b.s.l. to 1.8 m b.s.l.), characterized by the mixed assemblage of brackish-water foraminifera (*A. tepida, H. germanica, C. excavatum*) and marine foraminifera (*R. globularis, A. laevigata*), a dominant sandy sediment, with abundant rounded quartz, and high Fisher's alpha and Shannon indexes.

A second unit interpreted as a brackish lagoon (1.8 m b.s.l. to 0.8 m b.s.l.), is defined by an assemblage of *A. tepida, H. germanica, C. excavatum* and *P. eburnea*. From the 1.3 m b.s.l. level up to 0.9 m b.s.l. a greater density of foraminifera and many carbonate and rhizotubule precipitates is observed, especially at the top of the unit, in addition to a significant increase in the organic matter content. Diversity indices show a much more restricted environment, which indicates the presence of a brackish lagoon without a marine connection. The base of this unit is dated around 2041 ± 69 cal yr BP and the top around 1232 ± 74 cal yr BP.

Finally, between 0.8 m b.s.l. and 0.10 m a.s.l., the most recent paleoenvironment is identified and interpreted as a brackish marsh, due to a dominant euryhaline assemblage (*A. tepida, H. germanica* and *C. excavatum*) and a clearly lower density and diversity of species with respect to the previous unit. The subunits are differentiated by the predominance of *D. aguayoi* in the base and by *E. macrescens* in the top. At the sedimentological level, plant remains are observed at the base of the unit (dated at 1232 ± 74 cal yr BP). Diversity indexes decrease significantly, with some samples presenting a total absence of shells. The presence of silt could be related to the sedimentary deposits of large scale floods of the Turia river around the tenth century A.D. (Carmona and Ruiz, 2011). In subunit II the increase in organic matter, together with the species identified, reflects a decrease in the water level of the lagoon and a change to more marshy environments in transition towards a flood plain.

The data provided by statistical analysis obtained in this study from the SAL1/2 core, continue to support the paleoenvironmental inferences presented in Carmona et al. (2016). The sedimentological and environmental results indicate that the high content of sand in the deeper samples is due to a higher energy environment caused by the marine connection, which gradually decreases towards the top. The precipitated carbonates rise with the isolation from the marine environment. At the height of 0.9 m b.s.l., the increase in organic matter is assumed to reflect the increased isolation of the environment.

4.2 Evolution during the Upper Holocene

The data obtained in the three cores studied and the paleoenvironmental interpretation of the deposits suggests the presence of three phases of development in the northern area of the Albufera de Valencia (Fig.6).

Phase I: 2797 ± 50 cal yr BP -1232 ± 74 cal yr BP. From the 2.8 ka cold event to 1232 ka: evolution from a brackish lagoon, connected with the sea, to an isolated brackish lagoon.

In the Tremolar 3 (TRE3) core, located further north, a brackish lagoon with marine connection is identified from the base of the core up to 2401 ± 69 cal yr BP. From this date onwards, a brackish lagoon is established (without connection with the sea). In the Tremolar 2 (TRE2) core, further south, the brackish lagoon paleoenvironment with a marine connection lasts until about 2648 ±185 cal yr BP/2797 ± 50 cal yr BP, coinciding with the start of the 2.8 ka cold event (Bond et al., 1997, 2001) and with a phase increased coastal storms in the North-Western Mediterranean (Sabatier et al., 2012), and high magnitude flood events (Benito et al., 2015).

From that time (2797 ± 50 cal yr BP) until 1232 ± 74 cal yr BP a brackish lagoon is registered, coinciding with an increase in aridity (Ejarque et al., 2016) and the development of coastal barriers isolating the coastal lagoons from the open sea (Dabrio et al., 2000; Goy et al., 2003;); these authors report the depositing of H4 and phases of coastal progradation between 2700 cal yr BP and 1900 cal yr BP (Somoza et al., 1998). In the SAL1/2 core, a brackish lagoon is also recorded at the same time, in which the influence of the Catarroja ravine and other freshwater contributions is also observed (Fig. 1). As in other areas studied, the data in this phase associated with the Bond 2.8 reflect the drying of lakes (Schroder et al., 2018) and brackish environments in more coastal areas (Ejarque et al., 2016).

The sedimentation rates are good indicators of the stability of the wetlands (Day et al., 2011). For Fletcher and Zielhofer (2013), the terrigenous deposits on the eastern coasts of the Iberian Peninsula are the highest during this Holocene phase. Nonetheless, in the three cores analysed, sedimentation rates are low, especially when compared with the records in southern estuaries (Dabrio et al., 2000, Zazo et al., 2008,). These low rates may be due to the high subsidence recorded in the area, with an average of 30 cm/kyr (Albarracín et al., 2013) or 12.8 cm/kyr (Zazo et al., 1993). Assuming an annual subsidence of a maximum of ~ 0.03 cm/yr, the accretion rates in the study area are even higher than those calculated in other Mediterranean wetlands (Ejarque et al., 2016). In the Palmar core, between 8300 and 6200 BP, Marco-Barba et al. (2013) report a maximum sedimentation rate of 12 cm/yr, which shows the rapid accretion of this coastal sector.

Phase II: 1232 ± 74 cal yr BP - 791 ± 104 cal yr BP. From brackish lagoon to brackish marsh, and migration of the mouth of the Turia river.

In the TRE3 core, saturation processes have been identified due to the increase in carbonate content and the presence of carophytes and plant remains. This micropaleontological record indicates a constant trend towards a less brackish environment to the top of the core. These data suggest the evolution of a brackish lagoon towards a brackish marsh, around 1232 ± 74 cal yr BP, results in the combination between the increase in the impact of agriculture (Ejarque et al., 2016, Schroder et al., 2018), in response to the 1.4 ka cold event (Bond et al., 1997, 2001), and the migration of the Turia river further south from its previous position, which may have occurred in the Late Roman Period, around 1650 cal yr. BP (Ruiz and Carmona, 2017). In the TRE 2 core, the change from a brackish lagoon to a brackish marsh occurs later; it is attributed to the formation of the coastal barriers linked to the southward

596 migration of the mouth of the Turia river in the TRE3 core (before TRE2) and the
597 growth of the sand bar dated to 1373 ± 173 cal yr BP (Ruiz and Carmona, 2017),
598
599 In the SAL1/2 core the brackish lagoon endures, but is evolving progressively into a
600 more restricted environment, as indicated by the micropaleontological content. The
601 Medieval Climate Anomaly (MCA) is characterized by a marked aridity and an increase
602 in temperature (Martín-Puertas et al., 2009, Moreno et al., 2012, Schroder et al., 2018);
603 so the arid conditions detected at the top of this phase may correspond to this moment
604 (1.05 and 0.65 cal yr BP).
605
606 In contrast to Phase I, in Phase II the accretion rates in all cores present increases.
607 During this phase the accretion rates of the TRE2 and TRE3 cores are higher than those
608 in the more northern ones, due perhaps to the contribution of the Turia river after its
609 southward migration.
610 *Phase III: 791 ± 104 cal yr BP- Present. From a brackish marsh to freshwater/low*
611 *brackish environment.*
612 The TRE3 core indicates a less brackish marsh in this phase, marked by processes of
613 saturation. The freshwater conditions have not yet been established in the northern area
614 of the Albufera, but they do appear in cores from the southern part of the lagoon (Ruiz
615 et al., 2014, Carmona et al., 2016). As for the chronology of the shift from brackish to
616 freshwater lagoon, these cores suggest dates from 1050 to 920 cal. yr BP (1.25 m b.s.l.)
617 and 960 to 770 cal. yr BP (1.75 m b.s.l.) for the change.
618
619 However, the fluvial influence is indicated by the abundance of silt deposits (Fig.4). In
620 TRE2 also the brackish marsh identified in the previous phase persists throughout this

period, and its subunits indicate two different environments: the first (whose base is dated at 791 ± 104 cal yr BP) is freshwater, and the second is interpreted as a brackish marsh. This second subunit presents a layer of peat dated 144 ± 159 cal yr BP which may coincide with the end of the Little Ice Age (LIA), 150 cal yr BP.

The appearance of pyrite at the top of the TRE2 and TRE3 cores indicates anoxic conditions that reflect the total isolation of the lagoon. As in the SAL1/2 core, this isolation occurs at approximately 820 ± 90BP, when the paleoenvironment changes from a brackish lagoon to a freshwater lagoon. The isolation of lagoon occurs at the same time as other Mediterranean wetlands (Ejarque et al., 2016). This unit associated with the MCA and LIA (0.7 -0.15 kcal yr BP) presents a continuous increase in sedimentation rates towards the top, where the influence of human activity in the form of agriculture is significant (Soria, 2006)

The statistical analyses corroborate the variability of the environment in the three cores, in spite of the short distance between them. Differences are observed between the environmental variables that influence the distribution of benthic foraminifera: the key variable in TRE3 is the silt clay fraction, in TRE2 the sandy fraction and in SAL1/2 the calcium carbonate content. The importance of silt grain size and clays in the TRE3 core (in contrast to TRE2, where sand grain size is the decisive variable), reflects a greater fluvial influence (i.e., the presence of silt), associated with the migration of the Turia (Ruiz and Carmona, 2017). Previous studies of present-day foraminifera carried out near the study area found that two factors that determine the distribution of living assemblages of benthic foraminifera are carbonate content and organic matter in areas with high hydrodynamism (López-Belzunce et al., 2014).

5. CONCLUSIONS

From this study of foraminifera, the following conclusions can be drawn with regard to the paleoenvironmental evolution of the northern area of the Albufera de Valencia:

1) According to the statistical results, the variable with the strongest influence on the distribution of the assemblages of benthic foraminifera recorded in the three cores is the substrate, especially the grain size, which is closely related to the sedimentary environment. The statistical correlation of the environmental variables with the dominant assemblage has been particularly useful for characterizing environments in lagoons where the influence of the tides is barely perceptible. In addition, throughout the Holocene the coastal dynamics and fluvial processes played a decisive role in the evolution of this area.

2) The assemblages of foraminifera that predominate in the cores comprise *A. tepida, C. excavatum* and *H. germanica*, which indicate restricted environments. The appearance of marine habitat species (*A. laevigata, A. beccarii, R. globularis)* reveals the direct influence of the marine environment. Towards the top, species characteristic of more marshy environments (*E. macrescens*) are recorded. *C. excavatum* predominates in all the cores studied, particularly in sediments rich in calcium carbonates.

3) Three distinct paleoenvironments are recorded in the three cores: a brackish lagoon with marine connection at the base, followed by a thicken deposit of brackish lagoon, culminating in a brackish marsh in transition to a flood plain. The micropaleontological content reveals the evolution from a saline paleoenvironment with a clear marine influence towards the hyposaline (TRE2 and TRE3) or freshwater conditions (SAL1/2)

671 that are recorded at the top. Coastal processes are mainly responsible for the evolution
672 of this area during phase I, while the influence of fluvial processes is significant towards
673 the top, especially in phase III.
674
675 4) From 2800 cal yr BP to the present, three phases are identified in the evolution of this
676 area: Phase I, corresponding to a brackish lagoon with marine connection characterized
677 by an assemblage of brackish and marine foraminifera species. Around 2800 cal yr BP
678 there is an episode of saturation of the enviroment and disconnection from the sea that
679 gives rise to a brackish lagoon. The formation of a more efficient barrier island on the
680 coast is probably responsible for this paleoenvironmental change in the lagoon. Phase II
681 (1232 ± 74 cal yr BP - 791 ± 104 cal yr BP) indicates the evolution of a brackish lagoon
682 towards a brackish marsh, in correlation with the Bond I event and with the migration of
683 the Turia mouth, which favored the development of the barrier from north to south. The
684 top of this phase is characterized by more arid conditions, which may be associated with
685 the Medieval Climate Anomaly (MCA) (1.05 and 0.65 cal BP). Finally, Phase III (791 ±
686 104 cal yr BP to present) shows a much more restricted but still brackish environment,
687 with river flood events related to the LIA.
688
689 5) The northern part of the Albufera of Valencia maintains the paleoenvironment of a
690 brackish lagoon with marine communication (TRE 3 and TRE2) for longer than the
691 (SAL1/2). This suggests that the closure of the northern part occurred at a later date.
692 Brackish marsh facies appear earlier in the most northern core (TRE3) than in TRE2.
693
694 6) The cold events Bond II (2.8 ka) and Bond I (1.4 ka) in the Upper Holocene are
695 manifested in the barrier island lagoon systems of the Mediterranean coast, with

paleoenvironments of brackish lagoons. These were produced by high levels of coastal sedimentation and the closure of the environments communicating with the open sea due to the thickening of the coastal barriers.

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966 IMAGES AND TABLES

967 FIG1. Location of study area and the sampling stations. Geomorphological map of the coastal barrier–lagoon of
968 Valencia through time. (Spain).

969 FIG2. Upper: Table with radiocarbon dates. Lower: Composite time–altitude (cm) model based on ^{14}C dating and
970 calibration curve following Reimer et al. (2013) of TRE2 and TRE3 cores.

971 FIG3. TREMOLAR 2 core, Upper: Composite diagram including key selected variables. Lower: Multivariate
972 analyses based in benthic foraminifera: Correlation between Cluster Q-type analysis of samples and distribution of
973 species according the environmental variables, in the analysis by redundancy analysis (RDA).

974 FIG4. TREMOLAR 3 core, Upper: Composite diagram including key selected variables. Lower: Multivariate
975 analyses based in benthic foraminifera: Correlation between Cluster Q-type analysis of samples and distribution of
976 species according the environmental variables, in the analysis by redundancy analysis (RDA).

977 FIG5. SAL1/2 core, Upper: Composite diagram including key selected variables. Lower: Multivariate analyses based
978 in benthic foraminifera: Correlation between Cluster Q-type analysis of samples and distribution of species according
979 the environmental variables, in the analysis by redundancy analysis (RDA).

980 FIG6. Upper: Foraminiferal interpretation, geomorphological processes, chronology and succession of
981 paleoenvironmental phases throughout the lagoon record from TRE2 and TRE3 core. Lower: Correlation between
982 TRE2. TRE3 and SAL1/2 paleoenvironmental phases of the lagoon.

983 TAB1. Paleoenvironments classification using Venice System, McLusky and Elliot (2007) and taking in
984 consideration the characteristics of the Mediterranean area.

985 TAB2. Statistical results of redundancy analyses (RDAs).

986 TAB3. Main micropalaeontological results and dominant assemblages in each unit of samples collected (TRE2 and
987 TRE3 core).

Table 1

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Venice System		
Salinity (ppt)	**Salinity term**	**Typical Environment**
0-0.5	Limnetic	Freshwater
0.5-5	Oligohaline	Near mouth of river or stream
5.0-18	Mesohaline	Upper estuary (influenced by marine environment- more restricted)
18-30	Polyhaline	Middle to lower estuary (influenced by marine environment- more open)
30-40	Euhaline	Marine
> 40	Hypersaline	Shallow bodies of saltwater, subjected to significant evaporation
McLusky and Elliott (2007) Transitional waters		
	Type	**Characteristics**
	Classical estuary	Tidally dominated at the seaward part; salinity notably reduced by freshwater river inputs; riverine dominance inward
	Fjord	Land freshwater seepage or markedly seasonal riverine inputs; limited tidal influence; stratified; long narrow, glacially eroded sea inlet, step sided, sill at mouth
	Lentic non-tidal lagoon	Limited exchange with coastal area through a restricted mouth, separated from sea by sand or shingle banks, bars, coral, etc.., shallow area, tidal range ≤ 50 cm
	Lentic microtidal lagoon	As above but with tidal range ≥ 50 cm
	Ria	Drowned river valley, some freshwater inputs; limited exchange
	Fjard	Glacially carved embayment, sea inlet, smaller than fjord; limited freshwater inputs
	River mouth	River outlet as well-defined physiographic coastal feature
	Delta	Low energy, characteristically shaped, sediment dominated, river mouth area, estuary outflow
	Coastal freshwater/brackish water plume	Outflow of estuary or lagoon, notably diluted salinity and hence differing biota than surrounding coast
Lentic non-tidal lagoon		
	Type	Characteristics
	Brackish lagoon with marine connection	Exchange with coastal area, limited by sand barrier
	Brackish lagoon (without marine connection)	Early closing of the lagoon by the sand barrier, permeable barrier
	Brackish marsh	Middle closing, more dissconected from the coastal area and with shallow bodies with significant evaporation (hypersaline)
	Brackish marsh with fluvial influence	Late closing from the coastal area, more influenced from the fluvial inputs (oligohaline)
	Freshwater lagoon	Totally isolated from the open sea, controlled by fluvial inputs (limnetic)
	Swampy environment	High levels of organic matter from vegetal origin

Table 2

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RDA				
Tremolar 2	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.281	0.136	0.064	0.160
Species-environment correlations	0.873	0.759	0.643	0.000
Cumulative percentage variance of species data	28.1	41.7	48.1	64.1
of species-environment relation	58.4	86.7	100.0	0.0
Correlation				
>0.063 mm	0.8263	0.1368	0.1730	0.0000
Organic matter	-0.5217	0.5332	-0.2488	0.0000
<0.063 mm	-0.6403	-0.0189	0.4373	0.0000
Tremolar 3	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.283	0.063	0.295	0.195
Species-environment correlations	0.748	0.505	0.000	0.000
Cumulative percentage variance of species data	28.3	34.6	64.1	83.6
of species-environment relation	81.9	100.0	0.0	0.0
Correlation				
<0.063mm	-0.3708	0.4389	0.0000	0.0000
Carbonates	-0.5217	-0.2347	0.0000	0.0000
Sal1/2	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.324	0.005	0.000	0.591
Species-environment correlations	0.595	0.320	0.180	0.000
Cumulative percentage variance of species data	32.4	32.9	32.9	92.0
of species-environment relation	98.3	99.9	100.0	0.0
Correlation				
Carbonates	0.5096	-0.0639	0.0000	0.0000
<0.063mm	-0.4127	-0.1127	0..0000	0.0000

Table 3

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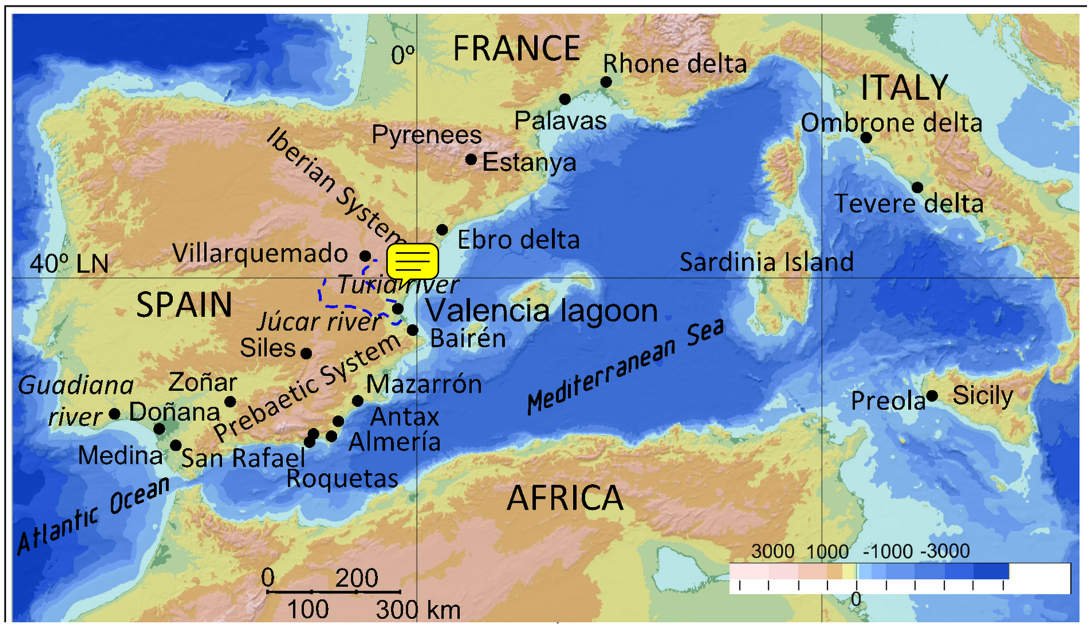
Tremolar 2			
Paleoenvironmental unit	**Overview**	**Foraminifera assemblages**	**Other fossils**
III UNIT (Samples 1-16)(0.3 a.s.l to 1.2 m b.s.l)	**Subunit I**: (samples 16- 7)(1.2 m to 0.3 m b.s.l. Low diversity indexes (only 3 taxa)	*Ammonia tepida* *Haynesina germanica* *Cribroelphidium excavatum*	Broken shells, rhizotubule precipitates is observed.
	Subunit II:(samples7 to 1) (0.3 m b.s.l a 0.3 m a.s.l) Dominance of species from hyposaline conditions, still remains the association from Subunit I	*Discorinopsis aguayoi* *Entzia macrescens* *Trochammina inflata*	Sediment with pyrite concretions typical of anoxic environments and emergence of a layer of peat.
II UNIT Samples 17 to 26. (1.2 m b.s.l to 2.2 m b.s.l)	Lower diversity indeces in the shallower samples of the unit, the brackish species remains.	*Haynesina germanica* *Ammonia tepida* *Cribroelphidium excavatum* *Miliolinella circularis*	Fragments of molluscs: bivalves, marine ostracods and gastropod and plant structures, the typical marine species dissapears. Significant increase of *Cribroelphidium excavatum.*
I UNIT Samples 27 to 32. (2.8 m b.s.l to 2.2 m b.s.l)	In the deepest samples of the unit, well preserved species typical from marine open enviroments. Increase the dominance of species from more restricted environments at the top of this unit.	*Rosalina globularis* *Haynesina germanica* *Ammonia tepida* *Pseudolachlanella eburnea* *Cribroelphidium excavatum*	Many molluscs: bivalves, marine ostracods and gastropod, fragments of *Posidonia oceanica.* Species typical from marine environments as *Planorbulina mediterranensis* . the ostracod *Cyprideis torosa* (Jones) in live position.
Tremolar 3			
Paleoenvironmental unit	**Overview**	**Foraminifera assemblages**	**Other fossils**
UNIT III (samples 10 a la 1)(0.8 m b.s.l to 0.1 a.s.l)	**Subunit I** (samples 10-4) (0.9 m b.s.l-0.3 m b.s.l). Total absence of foraminifera at 0.7 m b.s.l	*Ammonia tepida.* *Trichoyalus aguayoi* (occasional appearance)	Fragments of shells and rhizotubule precipitates is observed.
	Subunit II (samples 4-1) (0.3 m b.s.l to 0 m a.s.l). The association is only composed by two species.	*Ammonia tepida* *Entzia macrescens* (ocasional to the top)	Pyrite concretionsand peat fragments abundant to the top of the unit.
UNIT II (samples 19 to 10) (1.8 m b.s.l to 0.8 m b.s.l)	Brackish species and low diversity indexes.	*Pseudolachlanella eburnea* *Ammonia tepida* *Cribroelphidium excavatum* *Haynesina germanica*	Shells poorly preserved, high presence of rhizotubule precipitates and gastropods.
UNIT I (samples 23 to 19) (1.8 m b.s.l to 2.2 m b.s.l)	Presence of species from open marine enviroments mixed with brackish species.	*Adelosina laevigata* *Pseudolachlanella eburnea* *Ammonia tepida* *Cribroelphidium excavatum* *Haynesina germanica* *Rosalina globularis*	High presence of brackish and marine gastropods and ostracods like *Cyprideis torosa* , The shells typical from marine environments highly eroded like *Adelosina colomi, Planorbulina variabilis, Lobatula lobatula.*

Figure 1


0º
FRANCE
Rhone delta
ITALY
Palavas
Ombrone delta
Pyrenees
Estanya
Iberian System
Tevere delta
Ebro delta
40º LN
Villarquemado
Sardinia Island
Turia river
SPAIN
Valencia lagoon
Júcar river
Bairén
Siles
Mediterranean Sea
Guadiana river
Zoñar
Doñana
Prebaetic System
Mazarrón
Antax
Almería
Preola
Sicily
Medina
San Rafael
Roquetas
Atlantic Ocean
AFRICA
3000 1000 -1000 -3000
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0 200
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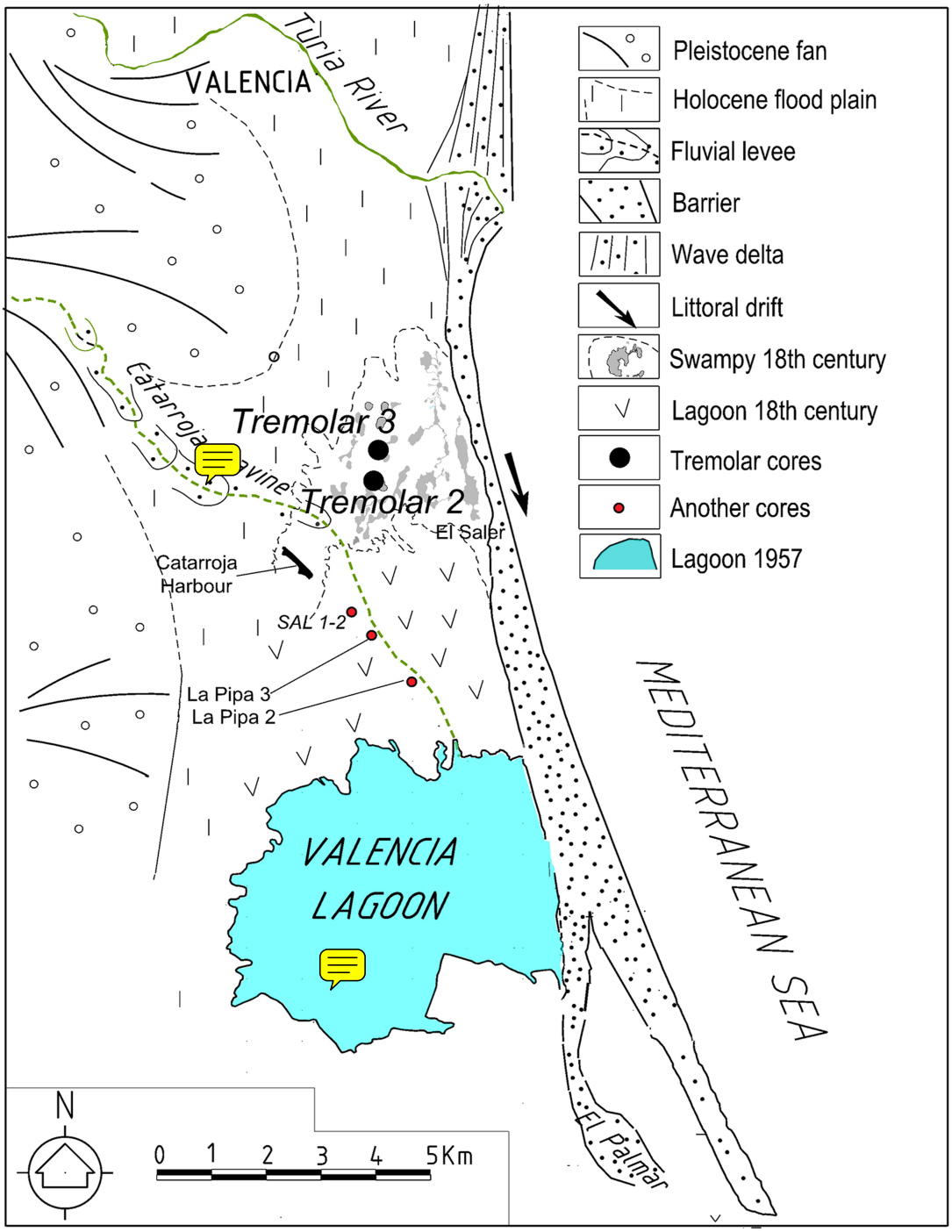

VALENCIA
Turia River
Pleistocene fan
Holocene flood plain
Fluvial levee
Barrier
Wave delta
Littoral drift
Swampy 18th century
Lagoon 18th century
Tremolar cores
Another cores
Lagoon 1957
Tremolar 3
Tremolar 2
El Saler
Catarroja Harbour
SAL 1-2
La Pipa 3
La Pipa 2
VALENCIA LAGOON
MEDITERRANEAN SEA
El Palmar
N
0 1 2 3 4 5Km

Figure 2

Corer	Code	Material	Depth	Cal years BP
TRE2	Tremolar 2 310-320	She	2.55 m b.s.l	2941 ± 268
TRE2	Tremolar 2 280-290	Shell	2.25 m b.s.l	2648 ± 185
TRE2	Tremolar 2 270-280	Organic matter	2.15 m b.s.l	2797 ± 50
TRE2	Tremolar 2 220	Shell	1.55 m b.s.l	1073 ± 240
TRE2	Tremolar 2 170	Organic matter	1.05 m b.s.l	791 ± 104
TRE2	Tremolar 2 112	Peat	0.45 m b.s.l	144 ± 159
TRE3	Tremolar 3 230-240	Shell	1.65 m b.s.l	2401 ± 69
TRE3	Tremolar 3 158	Peat	0.85 m b.s.l	1232 ± 74

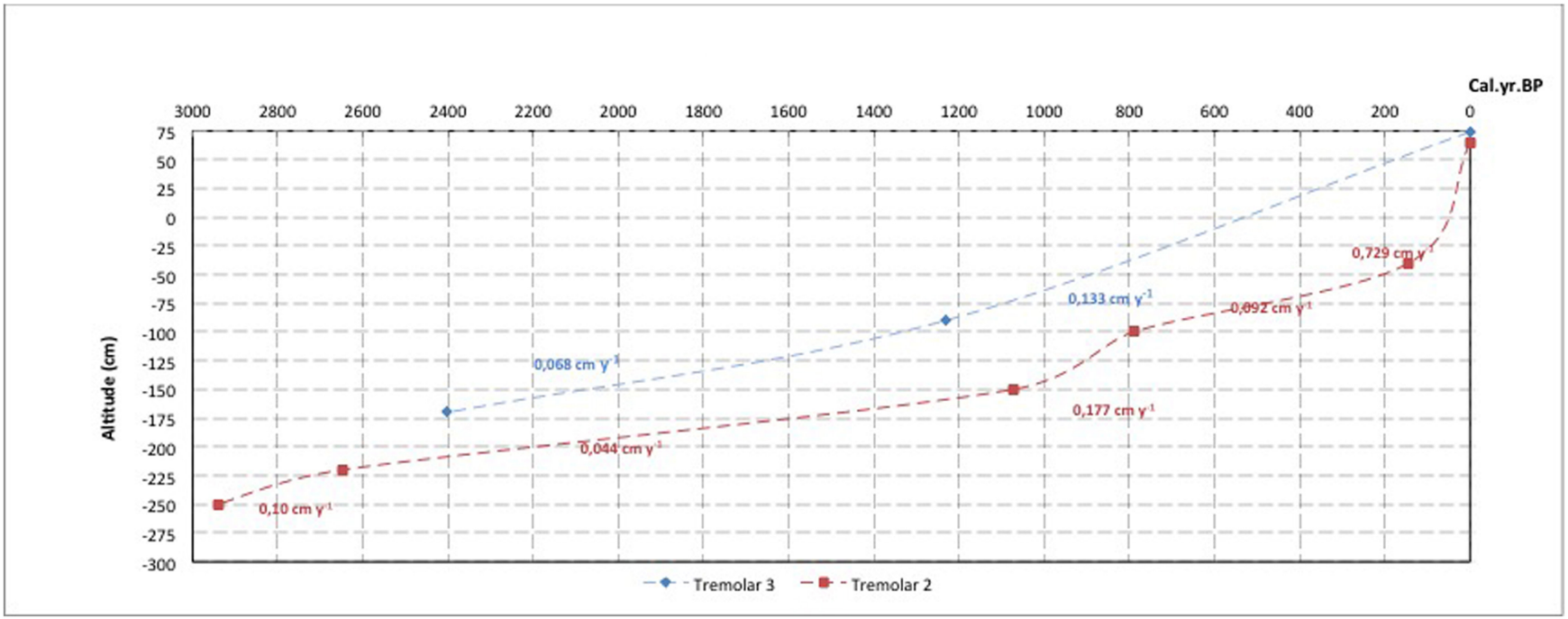
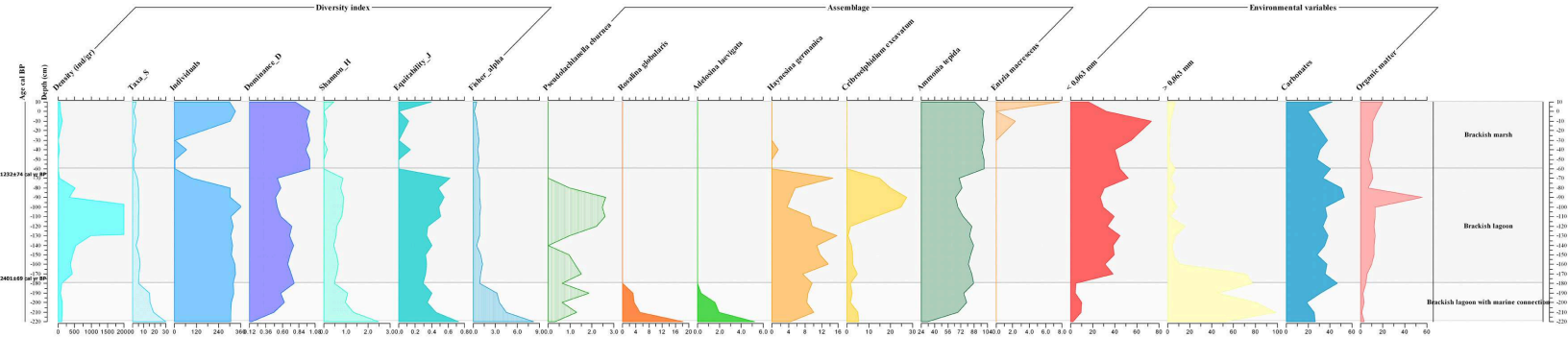
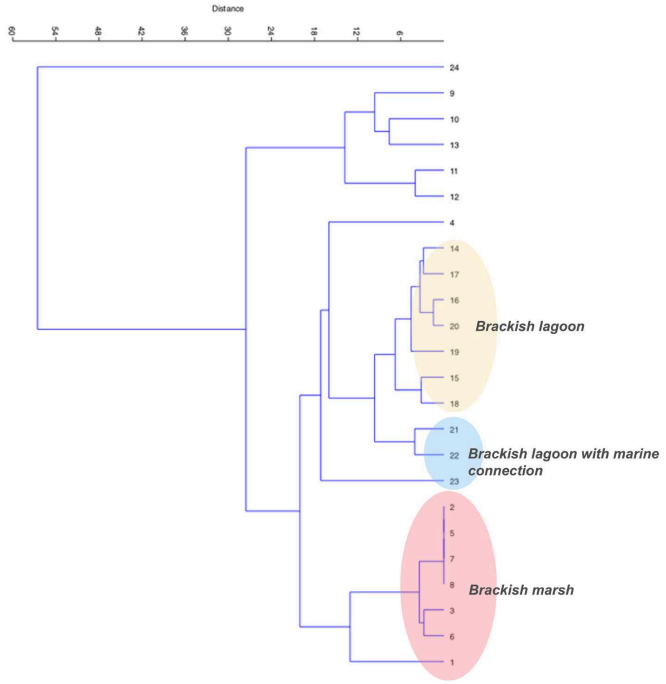


Figure 4


Diversity index
Assemblage
Environmental variables
Age cal BP
Depth (cm)
Density (ind/gr)
Taxa_S
Individuals
Dominance_D
Shannon_H
Equitability_J
Fisher_alpha
Pseudolabiella ebumea
Rosalina globularis
Adelosina laevigata
Hyrrenina germanica
Cribroelphidium excavatum
Ammonia tepida
Entzia macrescens
< 0,063 mm
> 0,063 mm
Carbonates
Organic matter
Brackish marsh
Brackish lagoon
Brackish lagoon with marine connection


Distance
Brackish lagoon
Brackish lagoon with marine connection
Brackish marsh

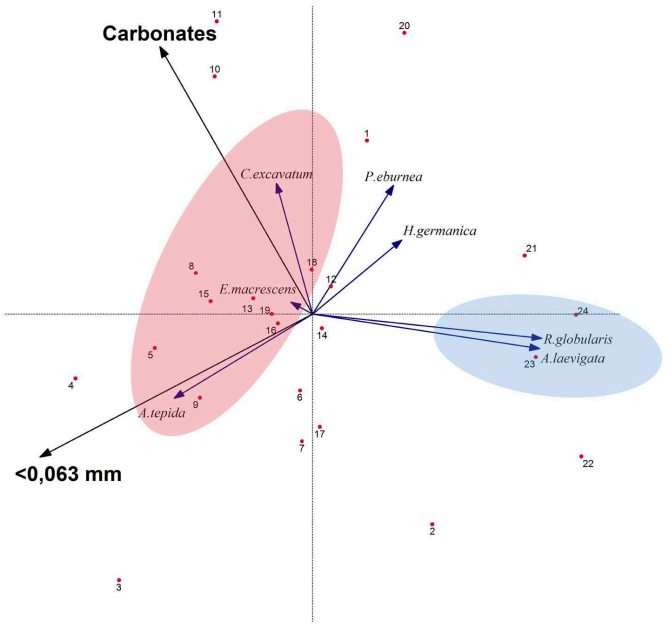
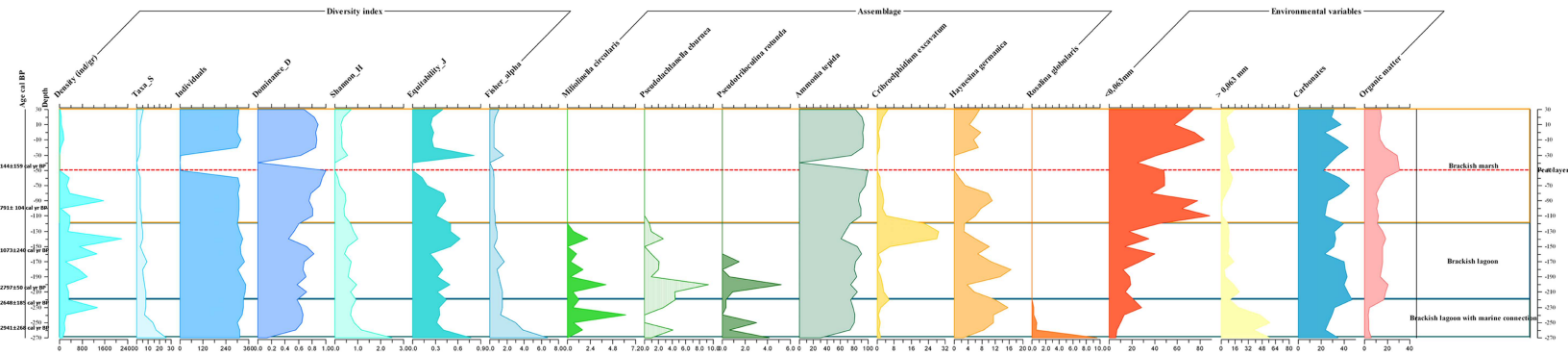
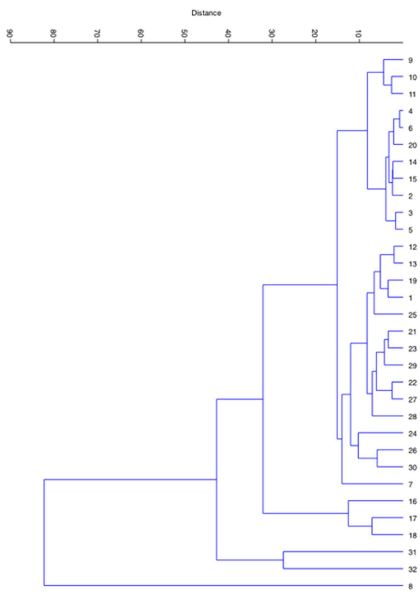

Carbonates
<0,063 mm
C.excavatum
P.eburnea
H.germanica
E.macrescens
A.tepida
R.globularis
A.laevigata

Figure 3


Diversity index
Assemblage
Environmental variables
Age cal BP
Depth
Diversity (Hill/gr)
Taxa_S
Individuals
Dominance_D
Shannon_H
Equitability_J
Fisher_alpha
Miliolinella circularis
Pseudolachlanella eburnea
Pseudotriloculina rotunda
Ammonia tepida
Cribroelphidium excavatum
Haynesina germanica
Rosalina globularis
<0,063mm
> 0,063 mm
Carbonates
Organic matter
Brackish marsh
Brackish lagoon
Brackish lagoon with marine connection


Distance

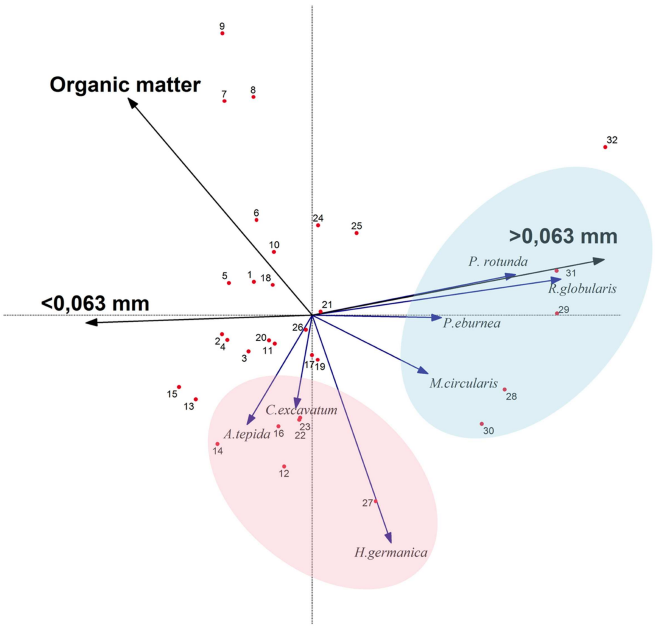
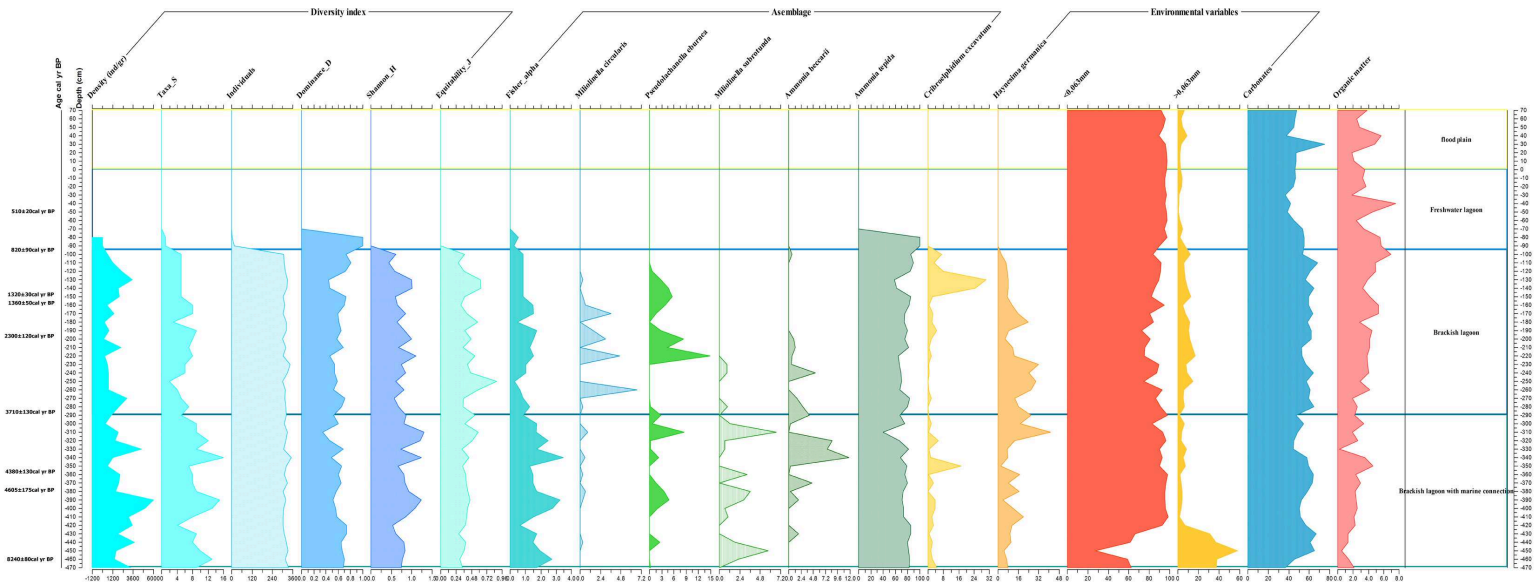
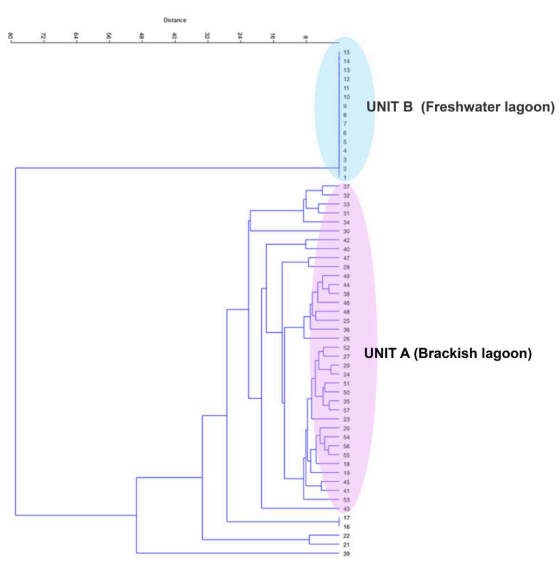

Organic matter
>0,063 mm
<0,063 mm
P. rotunda
R.globularis
P.eburnea
M.circularis
C.excavatum
A.tepida
H.germanica

Figure 5


Diversity index
Asemblage
Environmental variables
Age cal yr BP
Depth (cm)
Density (ind/gr)
Taxa_S
Individuals
Dominance_D
Shannon_H
Equitability_J
Fisher_alpha
Miliolinella circularis
Pseudoschamella obscura
Miliolinella subrotunda
Ammonia beccarii
Ammonia tepida
Cribroaphidium excavatum
Haynesina germanica
<0,063mm
>0,063mm
Carbonates
Organic matter
510±20cal yr BP
820±90cal yr BP
1320±30cal yr BP
1360±50cal yr BP
2300±120cal yr BP
3710±130cal yr BP
4380±130cal yr BP
4605±175cal yr BP
8240±80cal yr BP
flood plain
Freshwater lagoon
Brackish lagoon
Brackish lagoon with marine connection


Distance
UNIT B (Freshwater lagoon)
UNIT A (Brackish lagoon)

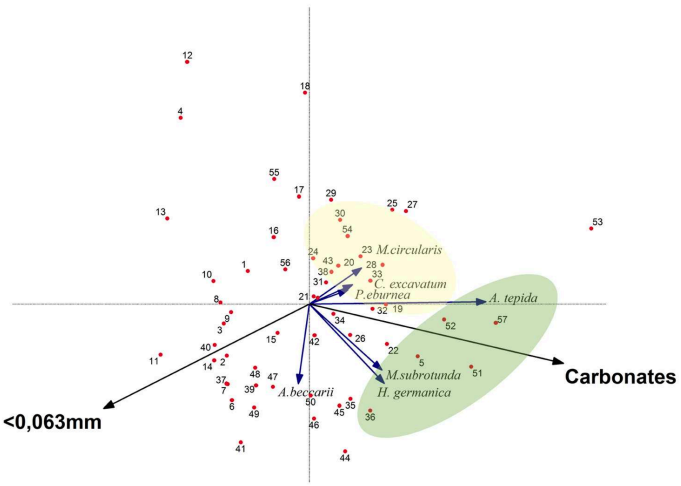
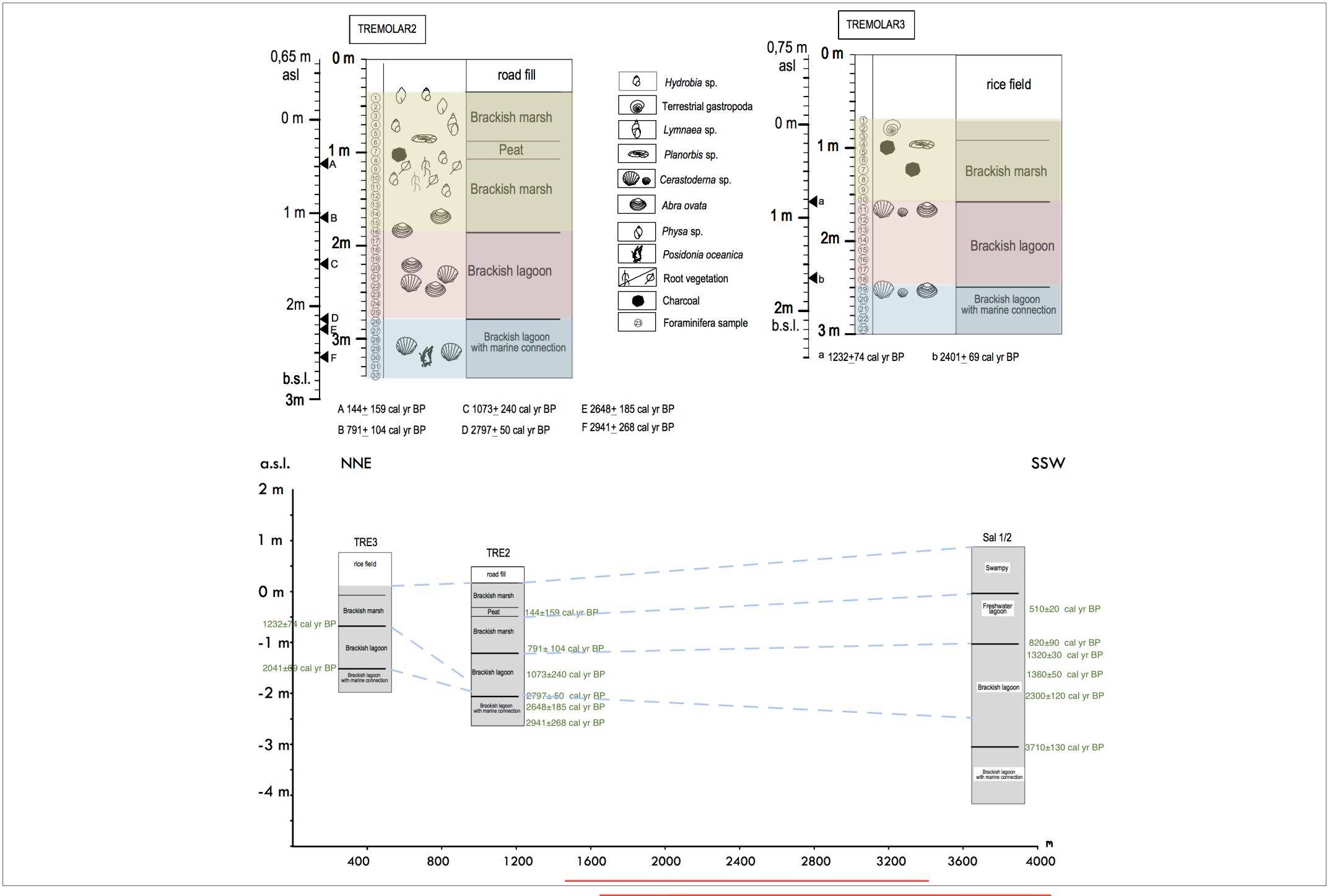

M.circularis
C. excavatum
P.eburnea
A. tepida
M.subrotunda
H. germanica
A.beccarii
Carbonates
<0,063mm

Figure 6


TREMOLAR2
0,65 m asl
0 m
1 m
2m
3m
b.s.l.
road fill
Brackish marsh
Peat
Brackish marsh
Brackish lagoon
Brackish lagoon with marine connection
A
B
C
D
E
F
Hydrobia sp.
Terrestrial gastropoda
Lymnaea sp.
Planorbis sp.
Cerastoderna sp.
Abra ovata
Physa sp.
Posidonia oceanica
Root vegetation
Charcoal
Foraminifera sample
A 144+ 159 cal yr BP
B 791+ 104 cal yr BP
C 1073+ 240 cal yr BP
D 2797+ 50 cal yr BP
E 2648+ 185 cal yr BP
F 2941+ 268 cal yr BP
TREMOLAR3
0,75 m asl
rice field
Brackish marsh
Brackish lagoon
Brackish lagoon with marine connection
a
b
a 1232+74 cal yr BP
b 2401+ 69 cal yr BP
a.s.l.
NNE
SSW
2 m
1 m
0 m
-1 m
-2 m
-3 m
-4 m
TRE3
rice field
Brackish marsh
Brackish lagoon
Brackish lagoon with marine connection
1232±74 cal yr BP
2041±69 cal yr BP
TRE2
road fill
Brackish marsh
Peat
Brackish marsh
Brackish lagoon
Brackish lagoon with marine connection
144±159 cal yr BP
791± 104 cal yr BP
1073±240 cal yr BP
2797± 50 cal yr BP
2648±185 cal yr BP
2941±268 cal yr BP
Sal 1/2
Swampy
Freshwater lagoon
Brackish lagoon
Brackish lagoon with marine connection
510±20 cal yr BP
820±90 cal yr BP
1320±30 cal yr BP
1360±50 cal yr BP
2300±120 cal yr BP
3710±130 cal yr BP
400
800
1200
1600
2000
2400
2800
3200
3600
4000
m