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Environmental evidence of Valencia Lagoon coastal barrier stabilization from 8500 BP to Present. Climate and eustatic variations

--Manuscript Draft--

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Abstract:	The Albufera de Valencia is one of the largest lagoon in the Spanish Mediterranean. Two continuous borehole cores reaching depths of 8 and 14 m in the northern part of the lagoon underwent sedimentological, micropaleontological and biological study. The organic content was also analysed, and 14 C radiometric dating and amino acid racemization were performed. Study of the content of benthic foraminifera and n-alkanes and alkanoic acids in the lagoon sedimentary record identified several periods. The core records showed seven different environments: alluvial; freshwater marsh; brackish marsh; brackish lagoon; brackish lagoon with marine connection, backbarrier flat, and backshore. These environments changed due to eight phases associated with the transgression and regression of the barrier system, which caused the shift from exposed environments as the backshore with washover, to the typical low-energy lagoon and marsh deposition. The paleoenvironmental evolution described above is interpreted as a response to global climate changes. The shift from an alluvial setting to a brackish lagoon is probably related to the late of Early Holocene sea level rise ending at the Holocene Climate Optimum, when the highest sea level was reached. The persistence of the brackish lagoon, with no marine connection, is probably synchronous with dry conditions in the area (Booth et al., 2005) at the time of Bond event 3 (i.e., 4.2 ka) in the North Atlantic region (Bond et al., 2001). Finally, the arrival of large amounts of sediment triggered the accretion of the barrier, also enhancing coastal progradation until the present day. These results allow an evaluation of the impact of anthropic action on the Valencia lagoon, especially since the eighteenth century, and a short- and medium-term projection of the consequences of present-day climate change.
Response to Reviewers:	STOTEN Editor-in-Chief Ms. Ref. No.: STOTEN-D-20-27702R1 Title: Environmental evidence of Valencia Lagoon coastal barrier stabilization from 8500 BP to Present. Climate and eustatic variations. Journal: Science of the Total Environment Dear Editor-in-Chief,

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	7.A paragraph has been included with the impact of the port of Valencia in its southern area in lines 683-685. 8.Only a single comment has been included in the conclusion in response to this request. We prefer not to include bibliographic references in the conclusions. 9/10: A new graphical abstract has been proposed.

Science of the Total Environment
Special Issue Editor

Ms. Ref. No.: STOTEN-D-20-27702
Title: Environmental evidence of Valencia Lagoon coastal barrier stabilization from 8500 BP to Present. Climate and eustatic variations.
Journal: Science of the Total Environment

Dear Prof. Verlicchi

Here enclose the paper "**Environmental evidence of Valencia Lagoon coastal barrier stabilization from 8500 BP to Present. Climate and eustatic variations**", written by López-Belzunce, M. Blázquez, A.M., Sánchez Palencia, Y., Torres, T and Ortiz J.E.

This research is carried out in one of the most important humid areas of the western Mediterranean. In this paper we study two cores that allow us to reconstruct the evolution of the Valencia lagoon during the Holocene. Eustatic rise of the MIS 1 is the main agent responsible for the formation of this coastal system. Climatic changes related to contemporary climatic phenomena occurring in the Northern Hemisphere, which allowed in cold and arid episodes the greatest sedimentary contribution to the coastal system. As a consequence, the coast prograded through the formation of island bars and brackish lagoon were developed in at least four different moments. The knowledge of the behavior of this coast during the holocene eustatic rise (registered between 7000 and 5300 cal yr BP) will allow to predict the effect of the rise in sea level related to the current global change.

This paper shows a direct relationship between the ocean, the atmosphere, the coastal geosphere and human action, since the alteration of this space will favor a greater impact of the marine invasion linked to climate change.

The authors have made the modifications suggested by the referees. Some of them have not been able to carry out and we think that these have been duly justified. If not, please do not hesitate to indicate it. The authors are very grateful for this much appreciated opportunity.

Sincerely

Dra. Ana Blázquez
Environmental and Marine Sciences Research Institute
Catholic University of Valencia
C/ Guillem de Castro, 94
46003. Valencia
España

Environmental evidence of Valencia Lagoon coastal barrier stabilization from 8500 BP to Present. Climate and eustatic variations.

ABSTRACT

The Albufera de Valencia is one of the largest lagoon in the Spanish Mediterranean. Two continuous borehole cores reaching depths of 8 and 14 m in the northern part of the lagoon underwent sedimentological, micropaleontological and biological study. The organic content was also analysed, and ^{14}C radiometric dating and amino acid racemization were performed. Study of the content of benthic foraminifera and n-alkanes and alkanoic acids in the lagoon sedimentary record identified several periods.

The core records showed seven different environments: alluvial; freshwater marsh; brackish marsh; brackish lagoon; brackish lagoon with marine connection, backbarrier flat, and backshore. These environments changed due to eight phases associated with the transgression and regression of the barrier system, which caused the shift from exposed environments as the backshore with washover, to the typical low-energy lagoon and marsh deposition.

The paleoenvironmental evolution described above is interpreted as a response to global climate changes. The shift from an alluvial setting to a brackish lagoon is probably related to the late of Early Holocene sea level rise ending at the Holocene Climate Optimum, when the highest sea level was reached. The persistence of the brackish lagoon, with no marine connection, is probably synchronous with dry conditions in the area (Booth et al., 2005) at the time of Bond event 3 (i.e., 4.2 ka) in the North Atlantic region (Bond et al., 2001). Finally, the arrival of large amounts of sediment triggered the accretion of the barrier, also enhancing coastal progradation until the present day. These results allow an evaluation of the impact of anthropic action on the Valencia lagoon, especially since the eighteenth century, and a short- and medium-term projection of the consequences of present-day climate change.

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1. Introduction

Due to its contrasting climate, the Western Mediterranean region is particularly sensitive to climate change. The Intergovernmental Panel on Climate Change (IPCC) predicts the advance of aridity and high temperatures in the area in the near future (IPCC, 2019). This contrasting climate has been recorded in the area since the middle Holocene, specifically since the dry event 4.2 cal ka BP. Since that episode, a progressive aridification accompanied by the development of typical Mediterranean low-land vegetation (Schröder et al., 2018) has continued until the present day. The IPCC forecasts that it will persist in the medium term, reinforced by the intensification of human activity.

Numerous sedimentary records have made it possible to determine the main Holocene climate changes in the Spanish Mediterranean region, located both in continental areas and in marine and coastal environments (Goy et al., 2003; Blázquez, 2005; Zazo et al., 2008; Ortiz et al., 2010; Ferrer and Blázquez, 2012; Marco-Barba et al., 2013a, 2013b; Torres et al., 2014; Carmona et al., 2016; Mediato, 2016; Blázquez et al., 2018; Rodríguez Pérez et al., 2018; Torres et al., 2018; Ortiz et al., 2020). Multiproxy analyses of mechanical boreholes carried out in lagoon, lake and estuary basins, based on sedimentary, geochemical, micropaleontological, bioindicator and chronological studies have identified conditions of aridity during the Late Early Holocene. These climatic characteristics coincide with the spread of a shrubby vegetation throughout the European Mediterranean, defined by Blytt-Sernander and related to the Boreal phase (9 ka-8 ka), and whose maximum aridity is located in the 8.2 ka event (Bond 5 event). Jones et al. (2018) report an increase in solar insolation after 9 ka cal BP, which saw the re-establishment of pine forests.

According to Morellón et al. (2018), in the Mediterranean areas prolonged arid conditions are recorded after the Younger Dryas, followed by a sudden increase in humidity until 10-9 cal yr BP. The insufficient humidity in the summer led to the retreat of the mesophyte forest and the fall in the water level in the lakes, in contrast to the areas influenced by the Atlantic. Schröder et al. (2018) recorded warm conditions in Lake Medina from around 9.5 to 7.8 cal ka BP, with a desiccation event at 8.8 cal ka BP as well as tentative evidence of the regional expression of a cold and abrupt arid climate event centering on 8.2 cal ka BP. At the paleoenvironmental level, the Early Holocene and especially the cold dry event of 8.2, led to the descent of the water levels in lake basins (Morellón et al., 2018), hyper-salinity and low lake levels (Jones et al., 2018) and even its desiccation (Blázquez et al., 2017). In many cases the sedimentary records studied corresponding to this age are deposited on fluvial gravels associated with a period characterized by high rainfall. These gravels are also related to the change in the position of the mouth of the rivers as a consequence of the sea level rise of the MIS 1 (Amorosi et al., 2009). After a first episode of fluvial deposits (gravels), bars appeared in estuaries and river mouths and migrated to the mainland (Dabrio et al., 2000; Bruneton et al., 2001; Bellotti et al., 2004; Boyer et al., 2005; Amorosi et al., 2009; Carmona and Ruiz, 2011).

A humid trend is identified between 8.2 and 4.2 dry events in the Mediterranean basin, corresponding to a humid and warm climate. The dry 5.9 event (Bond 4) is not clearly recorded in the Western Mediterranean. However, several authors identify vegetation changes (Burjachs et al., 2017) and calcretes (Silva et al., 2020) in this period, though less notable than those found in the 8.2 and 4.2 events. As a consequence of the humidity, the level of the inland lakes rose (Morellón et al., 2009; Aranbarri et al., 2014) and the Mediterranean deltas began to evolve, especially between 8500 and 6500 cal yr BP (Vella et al., 2005; Cearreta et al., 2016). Jones et al. (2018) indicates a continued trend towards increasing dryness at 7 ka cal BP but with continued freshwater input, feeding powerful littoral aquifers capable of stopping the marine influence corresponding to the sea level rise (Blázquez et al., 2018; Rodríguez-Pérez et al., 2018). The Holocene Climate Optimum, dating from around 7.8 to 5.5 cal ka BP, is characterized by a humid climate and maximum lake levels with anoxic bottom water condition (Schröder et al., 2018). In the coastal systems, after the stabilization of the sea level in MIS 1, the current island-barrier lagoon systems were formed; this maximum level of marine flooding is recorded around 5500 cal yr BP (Rodríguez-Pérez et al., 2018). When the rate of sea level rise slowed during MIS 1 (7000 and 6000 cal yr BP), spit systems, barriers, and deltas were formed (Carmona and Ruiz, 2011; Fanget et al., 2014), especially between 4000 and 3000 cal yr BP. The geomorphological results are the complex associations of floodplains, lagoons and deltas from the rivers that developed during this period (Bellotti et al., 2004; Rossi et al., 2011).

This humid phase coinciding with the sea level rise in MIS 1 is recorded in coastal systems through different paleoenvironments: in tectonically stable coastlines, aquifers play a key role feeding these lagoons by contributing fresh water (Almenara; Blázquez et al 2017, 2018; Rodríguez-Pérez et al., 2018), while on tectonic coasts with a negative sign there are lagoons that are connected to the sea, as seen in the Albufereta (Ferrer and Blázquez, 2012), Albufera de Valencia (Carmona et al., 2016; López-Belzunce, 2020), Bajo Segura (Blázquez, 2005; Blázquez and Ferrer, 2012), Pego (Torres et al., 2014), allowing the highest increase in sea level during the Holocene transgression. Towards 5900 cal yr BP an increase in sclerophyllous open woody vegetation and increasing humidity is represented in the lake records (Jones et al., 2018) which lasted until 3000 cal yr BP.

From 4200 cal yr BP (Bond cold event 3 at 4.2 ka, Bond et al., 1997, 2001 and Wanner cycle 4.8-4.5 cal yr BP, Wanner et al., 2011), at the beginning of the Meghalayan, a gradual cooling down to 2800 cal yr BP (Bond Event 2, cold) is recorded, where 1500 cycle patterns are observed from 4.4 cal yr BP to present. Several studies (Jalut et al., 2000; Carrión, 2002; González-Samperiz et al., 2006; Magny et al., 2007, 2009, 2011;

Moreno et al., 2008; López-Blanco et al., 2011; Anthony et al., 2014; Jimenez-Moreno et al., 2015), report changes in vegetation dynamics, prominent peaks of xerophytes and, particularly, water level fluctuations which have been related with global climatic oscillations in the Holocene. The abrupt climatic changes (8.2 and 4.2 cal yr BP) are marked by the cold climatic pulse and by a severe reduction in rainfall that coincided with a period of global reorganization of the oceanic and atmospheric circulation (Walker et al., 2018). Since 2.5 ka (the end of the Meghalayan) the response seems to have been conditioned both by Holocene climatic variability and by human action (Burjachs et al., 1997; Riera et al., 2004; Butzer, 2005; Pérez-Obiol et al., 2011).

In this Mediterranean context, the main aims of this paper, based on the Holocene record of the Valencia lagoon, are as follows: (a) to determine the paleoenvironments recorded since the early Holocene, b) to infer the most significant changes in sea level and climate in the basin configuration, c) to interpret the results in the context of global change. To do so, we carry out a detailed geomorphological study of the coastal barrier–lagoon and analysis of the sedimentology and foraminifera of a well-dated record (^{14}C) obtained in the northern sector of the lagoon, the area of maximum sedimentation.

2. Study Area

The coastal barrier lagoon system of Valencia is one of the largest in the Spanish Mediterranean. This wetland zone has been designated a protected area by both national and international organizations. Due to the anthropic activity of the last centuries, since 1970 or so it has presented characteristics of hypertrophy (Del Barrio-Fernández et al., 2012).

The present-day coastal barrier that closes the lagoon begins at the mouth of the River Turia and extends to the south (Fig. 1). In the north of the lagoon (the delta of the

Turia) the barrier is a single deposit, only 330m wide and with an elevation of 2 m a.s.l. Southwards, this barrier continues with a width of 980 m and an elevation of up to 5 m a.s.l. provided by the dune formations. According to Sanjaume (1985), sedimentary and geomorphological studies indicate the existence of two prograding barriers, the older of which provided the material for the formation of dunes in the more recent one.

To date, several multidisciplinary studies have been carried out on the margins of the lagoon near the coast (Santisteban et al., 2009; Marco-Barba et al., 2013b, 2019; Carmona et al., 2016, Ruiz and Carmona 2019). According to Santisteban et al. (2009) and Marco-Barba et al. (2013b, 2019) the evolution of the barrier comprised two phases. In the first, there was a rapid rise in sea level from the beginning of the Holocene to 6500 BP; in the second, the rise was more moderate, and a sandy group was deposited containing the six different progradation units (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 Ebro delta. Four periods of barrier formation were identified by these authors the first between 6250 BP and 4700 BP in the northern sector; the second between 4400 BP and 2700 BP (2300 m from the modern-day coastline), which reaches further south; the third between 2500 BP and 1200 CE and, finally, the present-day barrier, formed since 1200 CE. Carmona and Ruiz (2011) found a barrier formed by beach sand in the northernmost area of the lagoon, dated at 7500-7300 cal yr BP, underlying gray silts dated to 3360-3150 cal yr BP and interpreted as a backbarrier flat deposit. Ruiz and Carmona (2019) indicate the growth of prograding sand bars in the northern part of the study area, as a consequence of the greater availability of sediments linked to the southward migration of the mouth of the River Turia around 1650 cal yr BP. The result was the total isolation of the lagoon from the open sea at that time (Carmona et al., 2016).

3. Methodology

Two cores were analysed in positions close to the current barrier: SAL 3, 14 m thick with geographical coordinates 39° 23' 29.16” N; 0° 20' 43.80" W; and SAL 4, 8 m thick with geographical coordinates 39° 22' 20.35” N, 0° 20' 11.53” W. Coring was carried out in this area using a mechanical drill, and optimal preservation of the core was ensured.

One hundred and ninety samples underwent sedimentological study, 114 underwent micropaleontological study (especially in search of benthic foraminifera) and 69 were assessed for biomarkers. In the sedimentological study, the sandy fraction was separated from the clay silt using wet sieving through a 63 mm screen. The proportion of each fraction was calculated on the basis of the total weight of the sample used. The sedimentological information was completed with binocular stereomicroscope observations of sand grains and the color was evaluated on dry samples with the help of the Munsell charts. The calcimetry method (gas-volumetric determination), using a Bernard calcimeter, was followed to obtain the calcium carbonate (CaCO3) content in each sample. The amount of organic matter was determined by the calcination technique (loss of ignition), based on the weight loss of the sample resulting from the total calcination of the organic matter (Walkley and Black, 1934).

The micropaleontological study focused mainly on benthic foraminifera shells. 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 species with proportions above 5% are well represented in a sample size of 100 shells, while Patterson and Fishbein (1989) suggest that if the species under study account for almost 50% of the assemblages, then only 50 individuals are needed. 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 (1988) and Hayward et al. (2017) for generic attributions. The data obtained were quantitatively analysed, and the diversity index (Shannon and Wiener, 1949), dominance, equitability, density and Fisher's alpha (Fisher et al., 1943), were calculated. The alpha index is unreliable in samples of fewer than 100 individuals (Murray, 2006).

Finally, the characterization of organic compounds makes it possible to infer environmental changes from variations in their lipid composition in various media, such as seawater (Mingram et al., 2004; Sabel et al., 2005; Vegas et al., 2010; Németh et al., 2008), lakes (Hanisch et al., 2003; Muri and Wakeman, 2006; Pearson et al., 2007; Routh et al., 2007) and peat bogs (Zhou et al., 2005; Ortiz et al., 2009, 2010; Bingham et al., 2010). To this end, the terrestrial-aquatic ratio of hydrocarbons (TAR_{HC}) and the relative percentage of the n-alkanes n-C_{27}, n-C_{29} and n-C_{31} were calculated since, according to Cranwell (1973) and Maffei (1996), herbaceous plants present a predominance of C_{31}, while C_{27} and C_{29} alkanes are more abundant in trees. For their part, according to Herbin and Robins (1968) and Cranwell (1973), pines also have a high concentration of C_{31}.

In these cores, eight ^{14}C dates were obtained on shells and five via amino acid racemization on ostracod shells of the species *Cyprideis torosa* (Jones) (Table 1). These calibrated ages allowed an extrapolation of the core's accretion ratios. In core SAL 4, one dating was interpreted as anomalous, the one for the height of 2.85 m b.s.l (1127 ± 93 cal yr BP), since it gave an older age than the one recorded in the sample immediately below it.

A set of 70 samples from SAL-3, and 38 samples from SAL-4 were used. Around 5 g of dried sample was ground, and biomarkers extracted using accelerated solvent extraction (Dionex ASE 200). Free lipids were extracted with dichloromethane DCM/MeOH (2:1) at 1500 psi and 175 ºC. The heating phase lasted 8 min and the static extraction time 5 min.

The extract was concentrated using a rotating evaporator. Prior to analysis with gas chromatography-mass spectrometry (GC-MS), samples were methylated with trimethylsilyl diazomethane and methanol. Samples were injected into an HP 6890 gas chromatograph equipped with a selective mass detector (HP 5973) and an ATM-5 column (25 m x 0.25 mm; 0.20 µm). He was the carrier gas and decafluorobiphenyl an internal standard. The oven temperature was programmed from 60 to 300 ºC (maintained for 20 min) at 6ºC/min, and the injector was maintained at 275ºC. Components were identified with the Data Analysis programme and the Wiley Library. Although other compounds were identified in the samples, we focused on *n*-alkanes whose distributions were obtained from the *m/z* 57 in the chromatograms (base peak).

4. Results and Discussion

The sedimentary and micropaleontological study and the analysis of the biomarkers has allowed the identification of eight paleoenvironmental units in core SAL 3 and four in core SAL 4 which correlate with each other. Details of each one are presented below.

4.1 Foraminifera

In core SAL 3 a total of 16,516 individuals were obtained, grouped into 43 species of three different orders (Miliolida, Rotaliida, and Textulariida). Seven dominant species were identified, representing 97.05% of all the organisms identified: *Ammonia tepida* (Cushman) (72.7%), *Haynesina germanica* (Ehrenberg) (13.58%), *Cribroelphidium excavatum* (Terquem) (3.82%), *Pseulochanella eburnea* (d'Orbigny) (3.18%), *Miliolinella circularis* (d'Orbigny) (1.67%), *Ammonia beccarii* (Linné) (1.49%) and *Adelosina longirostra* (d'Orbigny) (0.59%). The dominant orders were Rotaliida

(92.46%) and Milioliida (7.54%). Table 2 shows the associations of dominant species throughout the core that allow us to identify a sequence of paleoenvironmental units. Some of these specimens are represented in figure 2.

In core SAL 4, a total of 9,038 individuals were analysed, grouped into 48 species of four different orders (Lagenida, Miliolida, Rotaliida and Textulariida). Eleven dominant species were identified that represent 96.64% of the total, of which 87% were from the order Rotaliida, and 12.8% from the order Miliolida. The dominant species were *Ammonia tepida* (70.93%), *Haynesina germanica* (8.03%), *Pseulochanella eburnea* (4.71%), Miliolinella circularis (2.93%), Criboelphidium excavatum (2.73%), *Ammonia beccarii* (2.29%), *Adelosina bicornis* (Walker and Jacob), (1.34%), *Adelosina longirostra* (1.28%), *Massilina secans* (d'Orbigny) (1.07%), *Triloculina trigonula* (Lamarck) (0.72%) and *Rosalina globularis* (0.61%). Table 3 shows the associations of dominant species throughout the core that allow us to distinguish a series of paleoenvironmental units.

A. tepida, *H. germanica* and *C. excavatum* are species present in brackish waters and are found recurrently in estuaries and marshes (Usera et al., 2002; Murray, 2006). *P. eburnea* and *M. circularis* are frequent in the Mediterranean and colonize silty substrates (Usera and Blázquez, 1997) and fine sand (Alejo et al., 1999). The rest of the species are stenotopic and live only in coastal and marine environments, and in different types of substrate up to depths of 100 m (Murray, 1991, 2006; Usera and Blázquez, 1997; Alves-Martins and Ruivo Dragão Gomes, 2004; López-Belzunce et al., 2014). In addition, some of them like A*. longirostra*, *R. globularis* and *M. secans* are epiphytes, frequently of *Posidonia oceanica*, and are stenotopic, inhabiting littoral marine environments and colonizing sandy substrates (Ribes et al., 1992; Usera and Blázquez, 1997; López-Belzunce et al., 2014).

4.2 n-Alkanes

n-Alkane profiles were used to distinguish the origin of the organic matter (OM), that is, the contribution from algae, aquatic macrophytes or terrigenous plants. Each sample was characterized by the predominant n-alkane chain length. n-Alkane distribution in phytoplankton and algae is dominated by LMW forms, lower than C_{21}, with C_{17} maximum in algae and C_{19} in cyanobacteria (Gelpi et al., 1970; Blumer et al., 1971; Cranwell et al., 1987).

Submerged/floating macrophytes maximize at C_{21}, C_{23} and C_{25} (Ogura et al., 1990; Viso et al., 1993), while emergent macrophytes have a composition similar to that of terrestrial plants, peaking at C_{27} and C_{29} (Cranwell, 1984). Terrigenous plants contain a high proportion of HMW n-alkanes, higher than C_{25} (mainly C_{27}, C_{29} and C_{31}) in their epicuticular wax (Eglinton and Hamilton, 1967; Nott et al., 2000; Pancost et al., 2002). Deciduous trees typically maximize at C_{27}, whereas in marsh plants and possibly grasses C_{31} is dominant (Cranwell et al., 1987; Schwark et al., 2002; Ortiz et al., 2011). All the samples showed a predominance of odd n-alkanes, with a distribution ranging from C_{15} to C_{33}. The logs of the different indexes appear in figures 3, 4 and 5.

Predominant n-alkane chain: In SAL 3 and SAL 4, most of the samples maximized at C_{25} or C_{31} (Fig. 3), indicating two sources of the OM. The ACL (Average Chain Length; Poynter, 1989), calculated as $[(C_i \times i + C_{i+1} \times (i+1) + C_{i+2} \times (i+2) \ldots + C_n \times n))/(\sum C_{n+1} + C_{n+2} + \ldots + C_n)]$, with i = 13, n = 33], is a good proxy for distinguishing between the predominance of low vs. high MW n-alkanes (Pancost et al., 2002; Rommerskirschen et al., 2003). In SAL 3, considerable oscillations were present in the ACL profile, with values varying between the marked minimum at 135 cm (24.70) and the maximum at 90 cm (29.70). In SAL 4 the values oscillated between 24.4 at 4.3 m and 28.0 at 1.7 m and were higher in the upper part of the record.

The TAR_{HC} ratio (Silliman et al. 1996), calculated as $(C_{31} + C_{29} + C_{27})/(C_{15} + C_{17} + C_{19})$ is very useful for distinguishing between land plants and algal input. In SAL 3, its values were between 2.9 (140 cm) and 69.0 (90 cm), in SAL 4 between 1.3 at 5.3 m and 28.4 at (3.3 m).

The P*aq* index, calculated as $(C_{23} + C_{25})/(C_{23} + C_{25} + C_{29} + C_{31})$ ratio (Ficken et al., 2000), reflects the relative contribution of emergent and submerged/floating aquatic macrophytes, which typically maximize at C_{23} and C_{25}, and that of terrigenous plants. In SAL 3, the values ranged from 0.1 at 9 m to 0.8 at 13.5 m, being higher in the lower part of the record. According to Ficken et al. (2000), values < 0.1 are linked to a dominant contribution from land plants, while values between 0.1 and 0.4 indicate a significant input from emergent macrophytes. Values > 0.4 are typical of a major n-alkane input from submerged/floating macrophytes. In SAL 4 the lowest values appeared in the upper part of the record (0.3 at 2.9 m) and the maximum was 0.8 at 4.3 m

4.3. Paleoenvironmental interpretation of the cores

Changes in the sedimentary sequence are detected from the dominant associations of foraminifera, the abundance of shells and their state of conservation (well-preserved shells being considered autochthonous), as well as the sedimentary characteristics and biomarkers. The sedimentological and micropaleontological characteristics of core SAL3 distinguished eight units that reflect different paleoenvironments (Figs. 4 and 6, Tables 2 and 4). Most stratigraphic contacts between units are gradual.

Unit I is an alluvial pack (A) characterized from the sedimentary point of view by a mixed texture of silts, clays and sands, with abundant signs of hydromorphism especially at the top. There is no micropaleontological evidence, and organic matter is scarce. The alkane C_{25} indicates the significant input of OM from aquatic macrophytes. The Paq index recorded oscillations between 0.5 (12.3 m) and 0.8 (13.1 m), thus corroborating the contribution of submerged/floating macrophytes (Ficken et al., 2000), and showing a good inverse correspondence with ACL values and the alkane predominant chain index. The TAR_{HC} values also indicate a significant input of OM from terrestrial plants. Thus, during this unit aquatic macrophytes dominated, alongside the contribution of land plants.

Unit II is interpreted as a brackish lagoon (BL) with processes that indicate a restrictive environment. The dominant association characterizing this paleoenvironment comprises the brackish species *Ammonia tepida, Criboelphidium excavatum, Haynesina germanica, Pseulochanella eburnea, Miliolinella circularis* and *Aubignyna perlucida* (Heron-Allen and Earland). At 9.4 m b.s.l, there is an increase in the proportion of carbonates and a decrease in the content of organic matter. As regard the granulometric content, an increase in sand and a decrease in silts and clays were observed. The importance of C_{29} and C^{31} alkanes and of ACL shows the dominance of terrestrial plants. In this regard, the TAR_{HC} ratio confirms the predominance of OM from land plants over algae. The variation in the granulometric content at the top of the unit is interpreted as a change to a more restricted environment, with precipitates of calcium carbonate and many fauna remains, associated with a period of saturation and descent in the water column. Well-preserved shells indicate a lower-energy event. Inside the unit, ^{14}C dating obtained at 11.3 m b.s.l. gave an age of 8418 ± 77 cal yr BP, and another at 9 m b.s.l. an age of 7870 ± 75 cal yr BP.

In Unit III (BL) the lagoon continues to be closed but shows conditions of greater restrictions compared to the previous unit, since only three species of brackish water are recorded: *Ammonia tepida, Haynesina germanica* and *Criboelphidium excavatum*. The absence of a sandy fraction and the increase in organic inputs indicate the most restrictive and lowest-energy conditions in the environment. C_{29} and C_{31} were also the predominant alkanes. ACL values, low *P*aq index together with the TAR_{HC} ratio, indicate the predominance of OM from land plants and the reduced contribution of aquatic macrophytes or algae, and thus a shallow water depth.

In Unit IV the lagoon has a clear connection with the open sea (BLM), inferred from the micropaleontological and sedimentological evidence. An erosive contact with respect to Unit III is verified in this unit, characterized by the abundance of hyaline quartz sands, calcite and bioclasts of marine origin. In the foraminifera associations species typical of more marine environments appear (although they do not dominate) mixed with species from brackish waters. The high rates of diversity, the presence of mixed association and the marine fauna corroborate this connection. Towards the top of the unit, the more rounded marine shells indicate a change in environmental conditions. C_{29} was again the predominant alkane although at the end C_{25} was also abundant. ACL values and *P*aq index reflect an increased contribution of OM from aquatic macrophytes, and greater water depth.

Unit V again shows the isolation of the open sea lagoon (BL), with a brackish lagoon paleoenvironment that is much more restrictive even than in Unit II. It is characterized by an association of well-conserved brackish species and an absence of more marine species. The decrease in the proportion of carbonates and the increase in the proportion of silts and clays, together with the micropaleontological evidence, could be indicative of a trend towards a lower-energy environment. Also, the alkane C_{29} is dominant although some samples maximized at C_{25} and C_{31}. ACL is slightly lower than in Unit IV and indicative of land plant input with the influence of aquatic macrophytes. The *Paq* index and TAR_{HC} ratio indicate the predominance of terrestrial plants input over algae. Thus, during this unit, the contribution from aquatic macrophytes increased slightly, although land plants were dominant. In this unit, several dates were obtained with the following ages: 4776 ± 683 cal yr BP (AAR), 4706 ± 106 cal yr BP and, at the top, 4550 ± 442 cal yr BP (AAR) (Table 1).

The recovery of the connection with the marine environment is recorded in Unit VI (BLM). An erosive contact with respect to the underlying unit marks the change towards a sediment rich in calcite and hyaline quartz sand. This communication with the open sea is more marked than in unit IV, as indicated by the remains of *Posidonia oceanica* and the greater importance of marine species. Species such as *Rosalina globularis* (d'Orbigny), *Planorbulina mediterranensis* (d'Orbigny) or *Asterigerinata mamilla* (Williamson) stand out, with well-preserved shells, indicating a continuous communication not associated with specific storm episodes. The diversity of these samples is high and reflects an environment that is very rich in organisms of both marine and brackish origin.

In Unit VII the brackish lagoon (BL) communicating with the sea gradually becomes isolated (subunit VIIa). This paleoenvironment is inferred from the dominant association formed by brackish species, similar to the one identified in Unit II. The high proportion of fine grain sizes (silt and clay), close to 90%, indicates a lower-energy environment where settling dominates. At 3.8 m b.s.l, a dating reflects the age of 1922 ± 92 cal yr BP. In subunit VIIb, the micropaleontological content, with a more restricted association (*Ammonia tepida, Haynesina germanica* and *Criboelphidium excavatum*) and the presence of a high content of organic matter and plant remains, indicate redox conditions, and has been interpreted as a brackish water swamp (BM).

Finally, Unit VIII reflects an oligohaline marsh environment (FM), as inferred from the progressive disappearance towards the top of the foraminifera and the presence of charophytes. At the base of this unit are facies with rhizotubule precipitates that are interpreted as reflecting moments of saturation and descent of the water column. At the top of the unit, sand levels are detected that may be due to fluvial or silting processes.

At 2.3 m b.s.l there is a dating of 1575 ± 32 cal yr BP. In the uppermost part of the record, the dominant n-alkane was C_{29} with ACL values denoting a predominance of land plant inputs. *P*aq index reflects the contribution of emergent macrophytes, and the TAR_{HC} indicates the predominance of terrestrial plants over algae.

In core SAL4, from the paleoenvironmental point of view, the sedimentological and micropaleontological characteristics allow us to distinguish four paleoenvironmental units (Figs. 5 and 7, Tables 3 and 5). The base (Unit I) is related to a backshore environment (B), identified by the importance of the pebbles and flattened and rounded gravels, originating from the River Turia and nearby ravines. Well sorted fine sands are observed with hardly any biogenic content. In this unit C_{25} was the dominant n-alkane with ACL values characteristic of the input of aquatic macrophytes. The *P*aq index indicates the contribution of submerged/floating macrophytes, and the TAR_{HC} ratio reflects a significant terrestrial contribution to OM. Therefore, this unit marked a dominance of submerged/floating macrophytes, with low input of terrestrial plants and algae.

Towards the top, this paleoenvironment changes to partially flooded facies, where species of marine and brackish origin are observed with a poor state of preservation. This area is interpreted as a backbarrier flat (BB) environment (Unit II). The dominant association of subunit IIa is formed by brackish and marine species. The marine species that appear are characteristic of infralittoral zones (*Ammonia beccarii, Asterigerinata mamilla, Rosalina globularis* and *Adelosina bicornis*), epiphytes of *Posidonia oceanica* and sandy substrates (Ribes et al., 1992). Specifically, this association bears similarities to the one found in the 5 m isobath in the present-day infralittoral zone of Valencia (López-Belzunce et al., 2014). Therefore, despite the scarcity of organic matter, the presence of these species with poorly preserved shells that mix with brackish species, in a medium dominated by quartz sands, allows us to interpret this deposit as a backbarrier flat.

As in the previous unit, C_{25} was the predominant *n*-alkane, although at the end, C_{29} was dominant. ACL and *P*aq values indicated the input of submerged/floated macrophytes, and the TAR_{HC} ratio reflected the predominance of land plants over algae. These results were indicative of the presence of OM from aquatic macrophytes during most of this period while towards the end, land plants became predominant. In subunit IIb, the increase in grain size (greater presence of gravel and coarse sand), indicates a higher-energy environment. From the stratigraphic point of view an erosive contact is recorded with respect to subunit IIa. No associations of brackish foraminifera are observed. The signs of erosion of the marine shells confirm the drag. This unit containing poorly sorted material can be associated either with a specific energetic storm event or washover fan, very frequent at this time (Sabatier et al., 2008; Amorosi et al., 2009; Sacchi et al., 2014) or with a rollover translation of the barrier. These environments are usually identified by the presence of an overwash, formed by beach sediment and nearshore sand, which interdigitates with low-energy deposits typical of coastal lagoons (Switzer and Jones, 2008). It is also characterized by a marine assemblage, with frequent signs of transport, in the sediments from the coastal environment and a brackish assemblage, better preserved, from the autochthonous record of the lagoon. In this deposit, the absence of foraminifera may be due to environmental stress deriving from the changes in the conditions of the lagoon (e.g., hypoxia, and the dissolution of carbonates) or due to transport conditions and the erosion of the shells (Pilarczyk et al., 2014). This means that we cannot clearly associate this event with a washover fan episode, although it coincides with the increase in storm activity analysed by Sabatier et al. (2012) around 5,400 years BP. In this unit, two dates have been obtained: 6727 ± 671 cal yr BP (AAR) and 5683 ± 152 cal yr BP (AAR).

In subunit IIc, the backbarrier flat environment returns with a mixture of brackish species and stenotopic species from littoral marine environments. This episode shows the maximum influence of the marine environment on the barrier, corroborated by the abundance of marine species. The lagoon facies are reflected in the high proportion of silts and clays, although organic matter is scarce. Finally, subunit IId indicates a more restricted backbarrier flat environment than the one identified in the underlying subunit; this is inferred from the decrease in the presence of marine species and their poorer conservation, as well as the dominance of brackish species towards the top.

After this unit, which encompasses different subenvironments of the barrier, Unit III is identified as a brackish water lagoon environment (BL), as can be inferred from a well-conserved association of restricted-water foraminifera and the high proportion of the clay silt content, organic matter and the presence of charophytes. C_{29} is dominant and ACL records a change with regard to the previous unit, with higher values indicative of the presence of terrestrial plants. The *P*aq index indicates emergent macrophytes. The TAR_{HC} ratio shows a predominance of land plants over algae. This unit is dated at the base at 2212 ± 90 cal yr BP.

Finally, Unit IV is interpreted as a brackish marsh at the base which evolves into an oligohaline paleoenvironment (FM). The presence of the high content of organic matter, the high proportion of silts and clays and of plant remains indicate the change towards a marsh facies. Foraminifera only appear at the base of the unit and are characteristic of brackish waters. The presence of the species *Discorinopsis aguayoi* (Bermúdez), typical to Mediterranean marshes, stands out (Guillem 2008; Sanjuán and Blázquez, 2017). Towards the top, no foraminifera are recorded and freshwater ostracods and gastropods are observed. At the bottom, C_{25} is the predominant n-alkane chain coinciding with falls in ACL values and *P*aq values indicative of the presence of submerged/floating macrophytes. In this regard, the TAR_{HC} values indicate a predominance of land plants over algae. In contrast, in the upper 1.8 m the dominant n-alkane is C_{31} and ACL values are higher, indicating the presence of land plants. The *P*aq index reflects the presence of OM from emergent and submerged/floating macrophytes, and TAR_{HC} values show the predominance of land plants over algal input. This unit presents a greater influence of fluvial processes, it is dated at 1340 ± 44 cal yr BP and, towards the top, at 588 ± 170 cal yr BP (AAR).

4.4. The lagoon and eustatic pulse of the MIS 1

The correlation of the two series allows us to propose the following paleoenvironmental evolution for the lagoon (Fig. 8). An alluvial paleoenvironment is identified around 8500 cal yr BP responding to warm and arid conditions in alluvial plain facies (unit I, SAL 3), which is also identified at other points of the study area (López-Belzunce et al., 2020). Biomarkers indicate the existence of water bodies within the alluvial environment. On top of this reservoir, a brackish water lagoon is recorded, formed in response to the onset of the sea level rise in MIS 1 (unit II, SAL3) with a major input of land plants with a fringe of emergent macrophytes. Carbonate sands at 10.8 m b.s.l indicate water saturation episodes, probably contemporary to the 8.2 event, also identified at other sites in the study area (Carmona et al., 2016). The establishment of a brackish lagoon with a marine connection between 7000 and 5300 cal yr BP (interpolated dates, unit IV, SAL3), allows the extension of the marine communication of the lagoon paleoenvironment to a large part of the study area, where biomarkers indicate aquatic macrophytes and greater water depth.

The record of the rise in sea level of MIS 1 in the Valencia lagoon is similar in terms of facies to that identified in other nearby coastal lagoons (Blázquez et al., 2017, 2018; Brisset et al., 2018). In the Valencia lagoon the maximum marine invasion during the Holocene is found at least 3 km from the present-day coastline, in lagoon facies that communicated with the sea (Carmona et al., 2016; López-Belzunce et al., 2020). In nearby lagoons, such as Albufereta de Alicante (Ferrer and Blázquez, 2012) and the Bajo Segura basin (Blázquez, 2005, Blázquez and Ferrer, 2012) the same facies is identified during this episode. Other facies (foreshore, shoreface, backshore) also show this Holocene marine maximum in similar nearby systems, such as the Almenara marsh (Blázquez et al., 2018; Rodríguez-Pérez et al., 2018) and in the Pego-Oliva marsh (Brisset et al., 2018). These differences in facies reflect the variations in the access of the Holocene sea level rise to different stretches of the coast, which is attributed to regional tectonics, since coastal subsidence leads to the marine invasion of these lagoon systems. Several authors report high subsidence rates in the Valencia lagoon. According to Zazo et al. (1993) the subsidence of this coastal section is 0.12 mm yr-1 in the last 200 ka; for Serpelloni et al. (2013), it is less than 2 mm yr-1 and according to Rey and Fumanal (1996) it is 0.45 mm yr-1. Assessing paleobarriers conserved in the internal platform, Albarracín et al. (2013) report a subsidence of 0.3 mm yr-1 in the last 22 ka BP.

With regard to its chronology, the sediments studied in the Valencia lagoon (unit IV, SAL3; subunit IIa SAL4) suggest that the maximum sea level rise is synchronous with the beginning of the Holocene Climate Optimum and is recorded between 7000 and 5300 cal yr. BP. This age is corroborated in nearby areas (Blázquez and Usera, 2010; Ferrer and Blázquez, 2012; Blázquez et al., 2018; Rodríguez-Pérez et al., 2018).

Later, around 5300 cal yr BP (SAL3), dated at 4706 ± 106 cal yr BP and 4776 ± 683 cal yr BP (AAR) a brackish lagoon facies was established. The paleoenvironment of the restricted lagoon indicates a lower energy than in the underlying environments communicated with the sea. Probably a patchy environment (terrestrial + “aquatic ponds") occurred, which explains the mixed input of submerged/floating macrophytes and land plants. These facies are recorded synchronously in other sedimentary media, such as deltaic fill (Stefani and Vicenzi, 2005; Carmona and Ruiz, 2011; Anthony et al., 2014; Cearreta et al., 2016) and the formation of barrier island systems (Fanget et al., 2014). Near the barrier (SAL4), backbarrier flat facies are preserved, which shows the importance of the material available for coastal constructions; this material is associated with a more arid climate in which the slopes are exposed, and an increase in torrential rainfall, with greater transport capacity. This environment corresponds to extensive water mass, in which submerged/floating macrophytes are dominant, but this water mass presents a continuous decrease with higher input of terrestrial plants.

From 2800 cal yr BP onwards, the lagoon becomes more isolated from the open sea and, according to the biomarkers, presents a major reduction in the flooded area and water depth. There is an increase in aridity in the coastal areas (Sacchi et al., 2014; Dolez et al., 2015) and the development of barriers that isolate coastal lagoons from the open sea in the western Mediterranean (Dabrio et al., 2000; Goy et al., 2003).

Next, the decrease in the water table involves an increase of terrestrial patches in the context of the flooded area. At the end there was a shrinkage of the flooded area, denoting a terrestrial moment, in accordance with arid conditions in the western Mediterranean and the development of wetlands (Mensing et al., 2015).

The definitive closure of the lagoon is interpreted from the marked decrease of water mass, although some temporary ponds remained active. This may respond to the reduction of vegetation as a consequence of aridity and to the increase in the exploitation of resources, which increases the input sediment to the littoral system, strengthens the barrier, and favors the definitive closure of the lagoon (López-Belzunce et al., 2020).

4.5 The barrier-islands and paleo lagoons

According to several authors (Bellotti et al., 1994; Adlam, 2005; Anderson et al., 2014), the most important factors affecting the development and conservation of the coastal barriers are the subsidence of the basin, compaction, the source of sediments, the sea level rise and coastal currents (swell and tides). The continuity of the sedimentary input in the coast is fundamental in the preservation of the barriers. Tidal ranges also control the position of these barriers, and even their very existence. Finally, rises in sea level have a notable influence, since the rate of eustatic increase can lead to the submergence or preservation of the barriers. Taking these factors into account, the transgressive and regressive phases identified in the cores have been listed in Figure 8 and a model of evolution, based on the synchrony of the deposits with the barriers preserved on the surface, is proposed in Figure 9. These barriers which have been studied by several authors (Santisteban et al., 2009; Carmona et al., 2016; Ruiz and Carmona, 2019).

In SAL3, located 1600 m away from the current coastline, the brackish lagoon that remained until 7870 ± 75 cal yr BP (Unit II) was isolated from the open sea (unit III) due to the formation of a very effective barrier, at least in the vicinity of the core. The slowing of the sea level rise from 7500 BP (Vacchi et al., 2016) allowed the development of barriers both on the coast and on the internal continental shelf of the Gulf of Valencia (Albarracín et al., 2013; Alcántara-Carrió et al., 2013). This barrier may be contemporaneous with the infralittoral sands identified in 6980 - 6780 cal yr BP (Carmona and Pérez-Ballester, 2011) and may be associated with the backshore facies with gravels and flattened pebbles from the Turia, which are identified in positions closer to the present-day barrier (unit I, SAL4). This backshore environment evolves into a backbarrier flat towards 6727 ± 671 cal yr BP, coinciding with prograding phases also identified in the Gulf of Almería (H1: 7,400-6000 BP) by Goy et al. (2003), although according to Santisteban et al. (2009), it is only recorded in the northernmost area of the barrier.

Up to 5300 BP (interpolated date) SAL3 indicates greater exposure of the lagoon, consistent with its connection to the sea, and reflecting the Holocene transgression maximum. These eustatic fluctuations influence the sedimentation of the beach/dune system and, therefore, the formation of the barrier, as can be seen on other Mediterranean coasts (Goy et al., 2003; Zazo et al., 2008).

According to Davis and Stevenson (2007), the North Atlantic Oscillation has a manifest influence on the development of Mediterranean barriers. The effect of cooling in high latitudes associated with the 8.2 event reinforced the latitudinal temperature gradient, causing the Hadley cell to recede towards the Equator and bringing the subtropical anticyclone back to more southerly positions, which resulted in an intense drought in the Mediterranean. Further, around 5.3 ka cal BP the results show a new change towards arid climatic conditions in the transit between the Northgrippian and the Meghalayan (Tallón-Armada et al., 2014). In the study area, this change was associated with an increase in fires, which in turn led to increased soil erosion, greater availability of sediments, and increased transport capacity due to the rise in seasonal torrential rains. This evidence is in agreement with poorly sorted sand-size deposits (SAL4) that may coincide with a paleostorm event around 5683 ± 152 cal yr BP (AAR), and periods of increased storm activity (5650-5400 BP) in the western Mediterranean (Sabatier et al., 2012). These results bear witness to the coast's rapid adaptation to climate variability in the recent Holocene.

From 5300 BP (interpolated date) (SAL 3) a marine regressive phase is recorded, marked by a brackish lagoon and dated to 4706 ± 106 cal yr BP. The determination of this environment implies that the wide communication with the marine environment is clearly closed. In more coastal zones (SAL 4), the backbarrier flat deposit recorded on a backshore indicates a relative regression, implying the prograding of the Holocene barrier dated as ~4400 BP (Santisteban et al., 2009). The richness in silts and clays may indicate a more protected position, which confirms the progradation of the barrier and, therefore, the marine regression. Probably this is a consequence of the arid conditions established by the 4.2 ka Bond event; aridity involves less vegetation cover, an increase of fluvial sedimentary load and consequently a higher sedimentary availability for coastal constructions. Furthermore, they correlate with the H2 phase identified by Goy et al. (2003) (5400-4200 cal yr BP), which is interpreted as a phase of coastal progradation. Next, a transgressive phase identified in the SAL3 core between 4550 ± 442 cal yr BP is recorded, which lasts until approximately 3220 BP (interpolated date; López-Belzunce, 2020).

According to previous tectonic studies carried out in the study area (Zazo et al., 1993; Rey and Fumanal, 1996; Albarracín et al., 2013; Serpelloni et al., 2013) the tectonic factor is significative in this coastal section. In this context, this phase may be related to the subsidence of the barrier and the degree of compaction rather than to the sea level rise; nonetheless, in the Gulf of Almería an erosive episode (3155 cal yr BP) was interpreted as a consequence of the rise in sea level not compensated by the entry of sediments (Goy et al., 2003). This sea level rise has also been identified in the Almenara marsh (Rodríguez-Pérez et al., 2018). However, this facies change is not recorded in the paleoenvironment of the backbarrier flat, which may corroborate the formation of an intermittently emerged and submerged barrier open in the northern zone, in line with a second Holocene barrier identified in 3360-3150 cal yr BP with a backbarrier flat and associated dune environments (Carmona et al., 2016). Nevertheless, this transgressive signal may simply indicate a lagoon more effectively connected with the sea, thus permitting to maintain the same position of the SAL4 backbarrier. However, the records of marine deposits in more interior cores (Carmona et al. 2016) indicate a marine entrance of at least 3 km at this time, with significant sedimentary thickness, which could favor the tectonic hypothesis.

Between 2800-2200 BP, an increase in the amount of sediment in the River Turia is identified when tongues of sand, gravel or submerged bars reach the open lagoon (Ruiz and Carmona, 2019). This may be related to the beginning of wind accumulations in coastal areas around 2700 years BP (Borja et al., 1999). The thickening of the barrier produces a change in the lagoon environments, with a greater influence from the river, evidencing the greater power and stabilization of the Holocene coastal barriers. In this period a third barrier dating from 2300-2200 years BP is identified, characterized by cross-stratification sands (Carmona y Pérez-Ballester, 2011), and at 2500 BP by Santisteban et al. (2009), described as medium sands. This deposit corresponds chronologically in the cores analysed to a brackish lagoon (2212 ± 90 cal yr BP, in SAL4); 1922 ± 92 cal yr BP (SAL3)). This progradation of environments towards the sea is similar to the prograding unit described by Goy et al. (2003) (H4, 2700-1900 cal yr BP). The progressive isolation of the lagoon coincides chronologically with the sandy barriers that closed other Mediterranean lagoons (Dolez et al., 2015; Dezileau et al., 2016) and the progradation of Mediterranean deltas (Stefani and Vincenzi, 2005; Amorosi et al., 2013). This progressive closure of the Mediterranean lagoons also coincides with Bond event 2.8.

The displacement of the mouth of the River Turia from 1600 BP onwards (Carmona et al., 2016), produces an even more significant development of the coastal barrier that allows the evolution of environments from lagoon to freshwater marsh, passing through the brackish marsh phase (unit VIIb and VIII; SAL3). A last prograding sand barrier dated to 1373 ± 137 cal yr BP (Ruiz and Carmona, 2019) is identified with the formation of the most recent barrier (1200 BP) also cited by Santisteban et al. (2009). The action of this barrier is reflected in the change in the salinity of the marsh water. The stabilization and progradation of the coastal barrier system and the change towards a brackish lagoon isolated from the sea was favored by the greater sedimentary availability produced by the arid conditions recorded in the Iberian Peninsula at that time (Schröder et al., 2018) and by the high-magnitude floods identified in the River Turia (Carmona and Ruiz, 2011).

The littoral system is very sensitive to climatic changes, since they are reflected in the availability of sediment that reaches the coast. In other areas of the Mediterranean there are deposits on the coast linked to the characteristic dry climatic episodes of the Holocene (Goy et al., 2003; Zazo et al., 2008). In the study area, the 8.2 event is observed discretely in SAL3 (and other nearby areas) in the abundant carbonaceous sands, while the 4.2 and 2.9 events are more clearly appreciable from the record of a brackish lagoon environment, which implies the isolation of the open sea lagoon and the further development of the barrier.

Finally, the study of these Holocene facies allows us to extrapolate the behavior recorded in the barriers to future scenarios. The predictions of the International Panel on Climate Change (IPCC) suggest an indicative range of sea level rise from 0.26 to 0.77 m by the end of the twenty-first century, as a consequence of a temperature rise of 1.5°C. This would imply a global rise in sea level, in the most conservative scenario, of 2.6 mm/yr. These levels are very similar to those identified in the Valencia lagoon between 8500 and 6500 cal yr BP, where an annual sea level rise of around 2 mm/yr is inferred (López-Belzunce, 2020). In the present-day context, the sea level rise is expected to produce a response in the barrier similar to that recorded in the Holocene maximum, that is, its partial disappearance, and the entry of the marine environment into the area occupied by the lagoon.

The high level of human activity in the vicinity of the current barrier weakens its feeding and its natural protection, since urbanization has eliminated the dunes and their contributions (Sanjaume and Pardo, 2019; Sanjaume et al., 2019). The coastal dynamics is altered by the construction of the harbor, which restricts sediments to the area north of the port of Valencia and has meant that no sediment is available to the south (Sanjaume, 1985). Some studies indicate rates of retreat of up to 10 m / year at the beginning of the 20th century on the coast located south of the Valencia Harbour (Pardo and Sanjaume, 2001). In addition, these sediments are already scarce compared to other historical periods, since they are retained by the construction of reservoirs (Pardo and Sanjaume, 2001). Therefore, these anthropic factors harm the preservation of the barrier and its ability to respond to the rise in sea level linked to global change. In the north, the barrier is notably narrower and more recently formed (López-Belzunce et al, 2020), and so, in all probability, the consequences of the rise in sea level of the twenty-first century will first be noted here.

5. Conclusions

From the analysis of the benthic foraminifera, biomarkers, and sediments in two cores drilled in the Valencia lagoon, as many as seven different paleoenvironments have been determined. These paleoenvironments are: alluvial, brackish lagoon, brackish marsh, brackish lagoon with marine communication, backshore, backbarrier flat and freshwater marsh. This sequence responds mainly to eustatic and climatic changes, as recorded in nearby similar areas.

The rise in sea level in MIS 1 has made it possible to record transgressive and regressive paleoenvironmental facies in the cores. This rise is recorded in the study area in brackish lagoon facies with marine communication, and reached its maximum flooding around 5300 cal yr BP. The eustatic signal was modulated by the climatic changes recorded in the study area after 7000 cal yr BP. The influence of the 8.2 ka, 4.2 ka and 2.8 ka cold cycles has been verified, in which arid conditions are recorded causing specific changes (the 8.2 ka event) such as carbonaceous sands in the brackish lagoon, or lasting paleoenvironmental changes (the 4.2 ka and 2.8 ka events), which produced the isolation from the open sea lagoon of a brackish lagoon with marine communication, which is attributed to the growth and progradation of the barrier. In addition, negative phases in the North Atlantic Oscillation triggered episodes of storms that may have caused instability in the barrier. A paleostorm is recorded in the most coastal core around 5600 cal yr BP.

The paleo-lagoons identified in the cores can be correlated with four different phases of the formation of the Holocene barrier, which are preserved on the surface and have been attributed by other authors to 7000 cal yr BP, 3360-3150 cal yr BP, 2300-2200 cal yr BP and 1200 cal yr BP.

Today, faced with climate change and the associated rise in sea level, a behavior similar to that recorded in the maximum of MIS 1 is expected: that is, the invasion of the Valencia lagoon by the sea, especially in the northern area where the barrier is narrower. However, as a consequence of human activity – which has retained the sediment in the rivers, altered the coastal dynamics, and destroyed the barrier through urbanization – the effect on this protected area of a sea level rise similar to that recorded between 7000 cal yr BP and 5300 cal yr BP will be much greater.

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FIGURE INDEX

Figure 1: Study area (Modified of López Belzunce et al., 2020)

Figure 2. Foraminifera species found in Sal 3 and Sal 4 cores. *1. Miliolinella circularis 200 μm x 220; 2. Triloculina trigonula 400 μm x 130; 3. Pseudolachlanella eburnea 200 μm x 200; 4. Adelosina longirostra 500 μm x 90; 5. Ammonia beccarii 300 μm x 150 vista ventral; 6. Ammonia beccarii 500 μm x 70; 7. Adelosina bicornis 100 μm x 350; 8. Ammonia tepida 300 μm x150; 9. Haynesina germanica 100μm x 300; 10. Massilina secans 1mm x 50; 11. Rosalina globularis 100 μm x 300; 12. Rosalina globularis 300 μm x 1 80; 13. Cribroelphidium excavatum 300 μm x150.*

Figure 3. Chromatograms from selected samples. Samples maximized: (A) at C_{25} n-alkane with a bimodal distribution; (B) at C_{31} n-alkane.

Figure. 4. Profiles of lithology, predominant *n*-alkane chain, ACL, P_{aq} index and TAR_{HC} in SAL3 core. M: mud, S: sand, G: gravel. Colors of the sediment represent the original ones.

Figure 5. Profiles of lithology, predominant *n*-alkane chain, ACL, P_{aq} index and TAR_{HC} in SAL4 core. M: mud, S: sand, G: gravel. Colors of the sediment represent the original ones.

Figure 6. Dominant foraminifera species, diversity and richness indices and sedimentological variables from core SAL3. A: Alluvial, BL: Brackish lagoon, BLM: Brackish lagoon with marine communication, BM: Brackish marsh, FM: Freshwater marsh.

Figure 7. Dominant foraminifera species, diversity and richness indices, and sedimentological variables from core SAL4. *A*. *laevigata=A*. *longirostra*. B: Backshore, BB: Backbarrier flat, BL: Brackish lagoon, FM: Freshwater marsh.

Figure 8. Correlation of the cores SAL3 and SAL4

Figure 9. Transgressive and regressive phases in the coastal barrier zone (SAL 3 and SAL4).

TABLES INDEX

Table 1. Numerical datings: Amino acid racemization (AAR; and C^{14}).

Table 2. Paleoenvironments in core SAL 3. A: Alluvial, BL: Brackish lagoon, BLM: Brackish lagoon with marine communication, BM: Brackish marsh, FM: Freshwater marsh

Table 3. Paleoenvironmental data of core SAL 4. B: Backshore, BB: Backbarrier flat, BL: Brackish lagoon, FM: Freshwater marsh.

Table 4. Indices of diversity and dominant species in core SAL 3. A: Alluvial, BL: Brackish lagoon, BLM: Brackish lagoon with marine communication, BM: Brackish marsh, FM: Freshwater marsh.

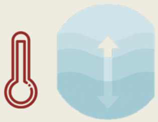
Table 5. Indices of diversity and dominant species in core SAL 4. B: Backshore, BB: Backbarrier flat, BL: Brackish lagoon, FM: Freshwater marsh.

Graphical Abstract

OBJECTIVES

A) Determine the paleoenvironments recorded since the early Holocene

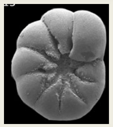
B) Changes in sea level and climate in the basin configuration



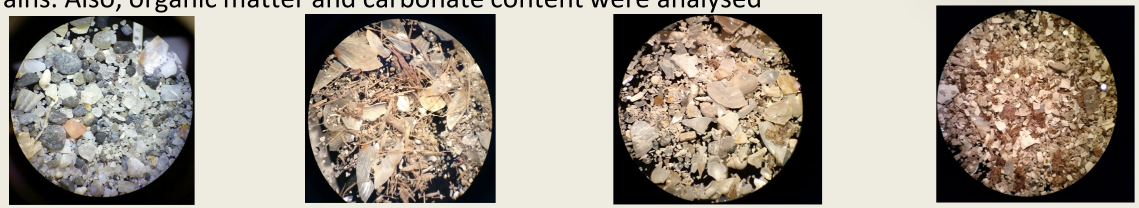
A) Interpret the results in the context of global change

MULTIPROXY METHODOLOGY

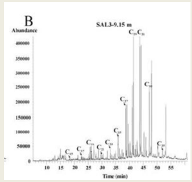
A) In the micropaleontological study, 114 samples of benthic foraminifera were studied



B) In the sedimentological study, the sandy fraction was separated from the clay silt using wet sieving through a 63 mm screen. These was completed with binocular stereomicroscope observations of sand grains. Also, organic matter and carbonate content were analysed

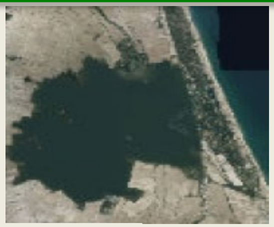


C) 108 samples were assessed for biomarkers



MAIN OUTCOMES

-Seven different paleoenvironments have been determined in the Albufera. These paleoenvironments are: alluvial, brackish lagoon, brackish marsh, brackish lagoon with marine communication, backshore, backbarrier flat and freshwater marsh



-The eustatic signal was modulated by the climatic changes recorded in the study area after 7000 cal yr BP. The influence of the 8.2 ka, 4.2 ka and 2.8 ka cold cycles has been verified, in which arid conditions are recorded causing specific changes

-The paleo-lagoons identified in the cores can be correlated with four different phases of the formation of the Holocene barrier, which are preserved on the surface and have been attributed by other authors to 7000 cal yr BP, 3360-3150 cal yr BP, 2300-2200 cal yr BP and 1200 cal yr BP

Highlights (for review : 3 to 5 bullet points (maximum 85 characters including spaces per bullet point)

Highlights

- Several phases indicate the evolution of the Holocene paleoenvironment in the Valencia lagoon.
- In this area the Holocene record is determined by eustatic and climatic changes.
- The lagoon was isolated from the sea during the Bond cold events (4.2 and 2.8).
- The current eustatic rise invaded this area at least 5300 years ago.

1. Introduction

Due to its contrasting climate, the Western Mediterranean region is particularly sensitive to climate change. The Intergovernmental Panel on Climate Change (IPCC) predicts the advance of aridity and high temperatures in the area in the near future (IPCC, 2019). This contrasting climate has been recorded in the area since the middle Holocene, specifically since the dry event 4.2 cal ka BP. Since that episode, a progressive aridification accompanied by the development of typical Mediterranean low-land vegetation (Schröder et al., 2018) has continued until the present day. The IPCC forecasts that it will persist in the medium term, reinforced by the intensification of human activity.

Numerous sedimentary records have made it possible to determine the main Holocene climate changes in the Spanish Mediterranean region, located both in continental areas and in marine and coastal environments (Goy et al., 2003; Blázquez, 2005; Zazo et al., 2008; Ortiz et al., 2010; Ferrer and Blázquez, 2012; Marco-Barba et al., 2013a, 2013b; Torres et al., 2014; Carmona et al., 2016; Mediato, 2016; Blázquez et al., 2018; Rodríguez Pérez et al., 2018; Torres et al., 2018; Ortiz et al., 2020). Multiproxy analyses of mechanical boreholes carried out in lagoon, lake and estuary basins, based on sedimentary, geochemical, micropaleontological, bioindicator and chronological studies have identified conditions of aridity during the Late Early Holocene. These climatic characteristics coincide with the spread of a shrubby vegetation throughout the European Mediterranean, defined by Blytt-Sernander and related to the Boreal phase (9 ka-8 ka), and whose maximum aridity is located in the 8.2 ka event (Bond 5 event). Jones et al. (2018) report an increase in solar insolation after 9 ka cal BP, which saw the re-establishment of pine forests.

According to Morellón et al. (2018), in the Mediterranean areas prolonged arid conditions are recorded after the Younger Dryas, followed by a sudden increase in humidity until 10-9 cal yr BP. The insufficient humidity in the summer led to the retreat of the mesophyte forest and the fall in the water level in the lakes, in contrast to the areas influenced by the Atlantic. Schröder et al. (2018) recorded warm conditions in Lake Medina from around 9.5 to 7.8 cal ka BP, with a desiccation event at 8.8 cal ka BP as well as tentative evidence of the regional expression of a cold and abrupt arid climate event centering on 8.2 cal ka BP. At the paleoenvironmental level, the Early Holocene and especially the cold dry event of 8.2, led to the descent of the water levels in lake basins (Morellón et al., 2018), hyper-salinity and low lake levels (Jones et al., 2018) and even its desiccation (Blázquez et al., 2017). In many cases the sedimentary records studied corresponding to this age are deposited on fluvial gravels associated with a period characterized by high rainfall. These gravels are also related to the change in the position of the mouth of the rivers as a consequence of the sea level rise of the MIS 1 (Amorosi et al., 2009). After a first episode of fluvial deposits (gravels), bars appeared in estuaries and river mouths and migrated to the mainland (Dabrio et al., 2000; Bruneton et al., 2001; Bellotti et al., 2004; Boyer et al., 2005; Amorosi et al., 2009; Carmona and Ruiz, 2011).

A humid trend is identified between 8.2 and 4.2 dry events in the Mediterranean basin, corresponding to a humid and warm climate. The dry 5.9 event (Bond 4) is not clearly recorded in the Western Mediterranean. However, several authors identify vegetation changes (Burjachs et al., 2017) and calcretes (Silva et al., 2020) in this period, though less notable than those found in the 8.2 and 4.2 events. As a consequence of the humidity, the level of the inland lakes rose (Morellón et al., 2009; Aranbarri et al., 2014) and the Mediterranean deltas began to evolve, especially between 8500 and 6500 cal yr BP (Vella et al., 2005; Cearreta et al., 2016). Jones et al. (2018) indicates a continued trend towards increasing dryness at 7 ka cal BP but with continued freshwater input, feeding powerful littoral aquifers capable of stopping the marine influence corresponding to the sea level rise (Blázquez et al., 2018; Rodríguez-Pérez et al., 2018). The Holocene Climate Optimum, dating from around 7.8 to 5.5 cal ka BP, is characterized by a humid climate and maximum lake levels with anoxic bottom water condition (Schröder et al., 2018). In the coastal systems, after the stabilization of the sea level in MIS 1, the current island-barrier lagoon systems were formed; this maximum level of marine flooding is recorded around 5500 cal yr BP (Rodríguez-Pérez et al., 2018). When the rate of sea level rise slowed during MIS 1 (7000 and 6000 cal yr BP), spit systems, barriers, and deltas were formed (Carmona and Ruiz, 2011; Fanget et al., 2014), especially between 4000 and 3000 cal yr BP. The geomorphological results are the complex associations of floodplains, lagoons and deltas from the rivers that developed during this period (Bellotti et al., 2004; Rossi et al., 2011).

This humid phase coinciding with the sea level rise in MIS 1 is recorded in coastal systems through different paleoenvironments: in tectonically stable coastlines, aquifers play a key role feeding these lagoons by contributing fresh water (Almenara; Blázquez et al 2017, 2018; Rodríguez-Pérez et al., 2018), while on tectonic coasts with a negative sign there are lagoons that are connected to the sea, as seen in the Albufereta (Ferrer and Blázquez, 2012), Albufera de Valencia (Carmona et al., 2016; López-Belzunce, 2020), Bajo Segura (Blázquez, 2005; Blázquez and Ferrer, 2012), Pego (Torres et al., 2014), allowing the highest increase in sea level during the Holocene transgression. Towards 5900 cal yr BP an increase in sclerophyllous open woody vegetation and increasing humidity is represented in the lake records (Jones et al., 2018) which lasted until 3000 cal yr BP.

From 4200 cal yr BP (Bond cold event 3 at 4.2 ka, Bond et al., 1997, 2001 and Wanner cycle 4.8-4.5 cal yr BP, Wanner et al., 2011), at the beginning of the Meghalayan, a gradual cooling down to 2800 cal yr BP (Bond Event 2, cold) is recorded, where 1500 cycle patterns are observed from 4.4 cal yr BP to present. Several studies (Jalut et al., 2000; Carrión, 2002; González-Samperiz et al., 2006; Magny et al., 2007, 2009, 2011;

Moreno et al., 2008; López-Blanco et al., 2011; Anthony et al., 2014; Jimenez-Moreno et al., 2015), report changes in vegetation dynamics, prominent peaks of xerophytes and, particularly, water level fluctuations which have been related with global climatic oscillations in the Holocene. The abrupt climatic changes (8.2 and 4.2 cal yr BP) are marked by the cold climatic pulse and by a severe reduction in rainfall that coincided with a period of global reorganization of the oceanic and atmospheric circulation (Walker et al., 2018). Since 2.5 ka (the end of the Meghalayan) the response seems to have been conditioned both by Holocene climatic variability and by human action (Burjachs et al., 1997; Riera et al., 2004; Butzer, 2005; Pérez-Obiol et al., 2011).

In this Mediterranean context, the main aims of this paper, based on the Holocene record of the Valencia lagoon, are as follows: (a) to determine the paleoenvironments recorded since the early Holocene, b) to infer the most significant changes in sea level and climate in the basin configuration, c) to interpret the results in the context of global change. To do so, we carry out a detailed geomorphological study of the coastal barrier–lagoon and analysis of the sedimentology and foraminifera of a well-dated record (^{14}C) obtained in the northern sector of the lagoon, the area of maximum sedimentation.

2. Study Area

The coastal barrier lagoon system of Valencia is one of the largest in the Spanish Mediterranean. This wetland zone has been designated a protected area by both national and international organizations. Due to the anthropic activity of the last centuries, since 1970 or so it has presented characteristics of hypertrophy (Del Barrio-Fernández et al., 2012).

The present-day coastal barrier that closes the lagoon begins at the mouth of the River Turia and extends to the south (Fig. 1). In the north of the lagoon (the delta of the

Turia) the barrier is a single deposit, only 330m wide and with an elevation of 2 m a.s.l. Southwards, this barrier continues with a width of 980 m and an elevation of up to 5 m a.s.l. provided by the dune formations. According to Sanjaume (1985), sedimentary and geomorphological studies indicate the existence of two prograding barriers, the older of which provided the material for the formation of dunes in the more recent one.

To date, several multidisciplinary studies have been carried out on the margins of the lagoon near the coast (Santisteban et al., 2009; Marco-Barba et al., 2013b, 2019; Carmona et al., 2016, Ruiz and Carmona 2019). According to Santisteban et al. (2009) and Marco-Barba et al. (2013b, 2019) the evolution of the barrier comprised two phases. In the first, there was a rapid rise in sea level from the beginning of the Holocene to 6500 BP; in the second, the rise was more moderate, and a sandy group was deposited containing the six different progradation units (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 Ebro delta. Four periods of barrier formation were identified by these authors the first between 6250 BP and 4700 BP in the northern sector; the second between 4400 BP and 2700 BP (2300 m from the modern-day coastline), which reaches further south; the third between 2500 BP and 1200 CE and, finally, the present-day barrier, formed since 1200 CE. Carmona and Ruiz (2011) found a barrier formed by beach sand in the northernmost area of the lagoon, dated at 7500-7300 cal yr BP, underlying gray silts dated to 3360-3150 cal yr BP and interpreted as a backbarrier flat deposit. Ruiz and Carmona (2019) indicate the growth of prograding sand bars in the northern part of the study area, as a consequence of the greater availability of sediments linked to the southward migration of the mouth of the River Turia around 1650 cal yr BP. The result was the total isolation of the lagoon from the open sea at that time (Carmona et al., 2016).

3. Methodology

Two cores were analysed in positions close to the current barrier: SAL 3, 14 m thick with geographical coordinates 39° 23' 29.16” N; 0° 20' 43.80" W; and SAL 4, 8 m thick with geographical coordinates 39° 22' 20.35” N, 0° 20' 11.53” W. Coring was carried out in this area using a mechanical drill, and optimal preservation of the core was ensured.

One hundred and ninety samples underwent sedimentological study, 114 underwent micropaleontological study (especially in search of benthic foraminifera) and 69 were assessed for biomarkers. In the sedimentological study, the sandy fraction was separated from the clay silt using wet sieving through a 63 mm screen. The proportion of each fraction was calculated on the basis of the total weight of the sample used. The sedimentological information was completed with binocular stereomicroscope observations of sand grains and the color was evaluated on dry samples with the help of the Munsell charts. The calcimetry method (gas-volumetric determination), using a Bernard calcimeter, was followed to obtain the calcium carbonate (CaCO3) content in each sample. The amount of organic matter was determined by the calcination technique (loss of ignition), based on the weight loss of the sample resulting from the total calcination of the organic matter (Walkley and Black, 1934).

The micropaleontological study focused mainly on benthic foraminifera shells. 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 species with proportions above 5% are well represented in a sample size of 100 shells, while Patterson and Fishbein (1989) suggest that if the species under study account for almost 50% of the assemblages, then only 50 individuals are needed. 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 (1988) and Hayward et al. (2017) for generic attributions. The data obtained were quantitatively analysed, and the diversity index (Shannon and Wiener, 1949), dominance, equitability, density and Fisher's alpha (Fisher et al., 1943), were calculated. The alpha index is unreliable in samples of fewer than 100 individuals (Murray, 2006).

Finally, the characterization of organic compounds makes it possible to infer environmental changes from variations in their lipid composition in various media, such as seawater (Mingram et al., 2004; Sabel et al., 2005; Vegas et al., 2010; Németh et al., 2008), lakes (Hanisch et al., 2003; Muri and Wakeman, 2006; Pearson et al., 2007; Routh et al., 2007) and peat bogs (Zhou et al., 2005; Ortiz et al., 2009, 2010; Bingham et al., 2010). To this end, the terrestrial-aquatic ratio of hydrocarbons (TAR_{HC}) and the relative percentage of the n-alkanes n-C_{27}, n-C_{29} and n-C_{31} were calculated since, according to Cranwell (1973) and Maffei (1996), herbaceous plants present a predominance of C_{31}, while C_{27} and C_{29} alkanes are more abundant in trees. For their part, according to Herbin and Robins (1968) and Cranwell (1973), pines also have a high concentration of C_{31}.

In these cores, eight ^{14}C dates were obtained on shells and five via amino acid racemization on ostracod shells of the species *Cyprideis torosa* (Jones) (Table 1). These calibrated ages allowed an extrapolation of the core's accretion ratios. In core SAL 4, one dating was interpreted as anomalous, the one for the height of 2.85 m b.s.l (1127 ± 93 cal yr BP), since it gave an older age than the one recorded in the sample immediately below it.

A set of 70 samples from SAL-3, and 38 samples from SAL-4 were used. Around 5 g of dried sample was ground, and biomarkers extracted using accelerated solvent extraction (Dionex ASE 200). Free lipids were extracted with dichloromethane DCM/MeOH (2:1) at 1500 psi and 175 ºC. The heating phase lasted 8 min and the static extraction time 5 min.

The extract was concentrated using a rotating evaporator. Prior to analysis with gas chromatography-mass spectrometry (GC-MS), samples were methylated with trimethylsilyl diazomethane and methanol. Samples were injected into an HP 6890 gas chromatograph equipped with a selective mass detector (HP 5973) and an ATM-5 column (25 m x 0.25 mm; 0.20 µm). He was the carrier gas and decafluorobiphenyl an internal standard. The oven temperature was programmed from 60 to 300 ºC (maintained for 20 min) at 6ºC/min, and the injector was maintained at 275ºC. Components were identified with the Data Analysis programme and the Wiley Library. Although other compounds were identified in the samples, we focused on *n*-alkanes whose distributions were obtained from the *m/z* 57 in the chromatograms (base peak).

4. Results and Discussion

The sedimentary and micropaleontological study and the analysis of the biomarkers has allowed the identification of eight paleoenvironmental units in core SAL 3 and four in core SAL 4 which correlate with each other. Details of each one are presented below.

4.1 Foraminifera

In core SAL 3 a total of 16,516 individuals were obtained, grouped into 43 species of three different orders (Miliolida, Rotaliida, and Textulariida). Seven dominant species were identified, representing 97.05% of all the organisms identified: *Ammonia tepida* (Cushman) (72.7%), *Haynesina germanica* (Ehrenberg) (13.58%), *Cribroelphidium excavatum* (Terquem) (3.82%), *Pseulochanella eburnea* (d'Orbigny) (3.18%), *Miliolinella circularis* (d'Orbigny) (1.67%), *Ammonia beccarii* (Linné) (1.49%) and *Adelosina longirostra* (d'Orbigny) (0.59%). The dominant orders were Rotaliida

(92.46%) and Milioliida (7.54%). Table 2 shows the associations of dominant species throughout the core that allow us to identify a sequence of paleoenvironmental units. Some of these specimens are represented in figure 2.

In core SAL 4, a total of 9,038 individuals were analysed, grouped into 48 species of four different orders (Lagenida, Miliolida, Rotaliida and Textulariida). Eleven dominant species were identified that represent 96.64% of the total, of which 87% were from the order Rotaliida, and 12.8% from the order Miliolida. The dominant species were *Ammonia tepida* (70.93%), *Haynesina germanica* (8.03%), *Pseulochanella eburnea* (4.71%), Miliolinella circularis (2.93%), Criboelphidium excavatum (2.73%), *Ammonia beccarii* (2.29%), *Adelosina bicornis* (Walker and Jacob), (1.34%), *Adelosina longirostra* (1.28%), *Massilina secans* (d'Orbigny) (1.07%), *Triloculina trigonula* (Lamarck) (0.72%) and *Rosalina globularis* (0.61%). Table 3 shows the associations of dominant species throughout the core that allow us to distinguish a series of paleoenvironmental units.

A. tepida, *H. germanica* and *C. excavatum* are species present in brackish waters and are found recurrently in estuaries and marshes (Usera et al., 2002; Murray, 2006). *P. eburnea* and *M. circularis* are frequent in the Mediterranean and colonize silty substrates (Usera and Blázquez, 1997) and fine sand (Alejo et al., 1999). The rest of the species are stenotopic and live only in coastal and marine environments, and in different types of substrate up to depths of 100 m (Murray, 1991, 2006; Usera and Blázquez, 1997; Alves-Martins and Ruivo Dragão Gomes, 2004; López-Belzunce et al., 2014). In addition, some of them like A. *longirostra*, *R. globularis* and *M. secans* are epiphytes, frequently of *Posidonia oceanica*, and are stenotopic, inhabiting littoral marine environments and colonizing sandy substrates (Ribes et al., 1992; Usera and Blázquez, 1997; López-Belzunce et al., 2014).

4.2 n-Alkanes

n-Alkane profiles were used to distinguish the origin of the organic matter (OM), that is, the contribution from algae, aquatic macrophytes or terrigenous plants. Each sample was characterized by the predominant n-alkane chain length. n-Alkane distribution in phytoplankton and algae is dominated by LMW forms, lower than C_{21}, with C_{17} maximum in algae and C_{19} in cyanobacteria (Gelpi et al., 1970; Blumer et al., 1971; Cranwell et al., 1987).

Submerged/floating macrophytes maximize at C_{21}, C_{23} and C_{25} (Ogura et al., 1990; Viso et al., 1993), while emergent macrophytes have a composition similar to that of terrestrial plants, peaking at C_{27} and C_{29} (Cranwell, 1984). Terrigenous plants contain a high proportion of HMW n-alkanes, higher than C_{25} (mainly C_{27}, C_{29} and C_{31}) in their epicuticular wax (Eglinton and Hamilton, 1967; Nott et al., 2000; Pancost et al., 2002). Deciduous trees typically maximize at C_{27}, whereas in marsh plants and possibly grasses C_{31} is dominant (Cranwell et al., 1987; Schwark et al., 2002; Ortiz et al., 2011). All the samples showed a predominance of odd n-alkanes, with a distribution ranging from C_{15} to C_{33}. The logs of the different indexes appear in figures 3, 4 and 5.

Predominant n-alkane chain: In SAL 3 and SAL 4, most of the samples maximized at C_{25} or C_{31} (Fig. 3), indicating two sources of the OM. The ACL (Average Chain Length; Poynter, 1989), calculated as $[(C_i \times {}_i + C_{i+1} \times_{(i+1)} + C_{i+2} \times_{(i+2)} \ldots + C_n \times {}_n))/(\sum C_{n+1} + C_{n+2} + \ldots + C_n)]$, with i = 13, n = 33], is a good proxy for distinguishing between the predominance of low vs. high MW n-alkanes (Pancost et al., 2002; Rommerskirschen et al., 2003). In SAL 3, considerable oscillations were present in the ACL profile, with values varying between the marked minimum at 135 cm (24.70) and the maximum at 90 cm (29.70). In SAL 4 the values oscillated between 24.4 at 4.3 m and 28.0 at 1.7 m and were higher in the upper part of the record.

The TAR_{HC} ratio (Silliman et al. 1996), calculated as $(C_{31} + C_{29} + C_{27})/(C_{15} + C_{17} + C_{19})$ is very useful for distinguishing between land plants and algal input. In SAL 3, its values were between 2.9 (140 cm) and 69.0 (90 cm), in SAL 4 between 1.3 at 5.3 m and 28.4 at (3.3 m).

The P*aq* index, calculated as $(C_{23} + C_{25})/(C_{23} + C_{25} + C_{29} + C_{31})$ ratio (Ficken et al., 2000), reflects the relative contribution of emergent and submerged/floating aquatic macrophytes, which typically maximize at C_{23} and C_{25}, and that of terrigenous plants. In SAL 3, the values ranged from 0.1 at 9 m to 0.8 at 13.5 m, being higher in the lower part of the record. According to Ficken et al. (2000), values < 0.1 are linked to a dominant contribution from land plants, while values between 0.1 and 0.4 indicate a significant input from emergent macrophytes. Values > 0.4 are typical of a major n-alkane input from submerged/floating macrophytes. In SAL 4 the lowest values appeared in the upper part of the record (0.3 at 2.9 m) and the maximum was 0.8 at 4.3 m

4.3. Paleoenvironmental interpretation of the cores

Changes in the sedimentary sequence are detected from the dominant associations of foraminifera, the abundance of shells and their state of conservation (well-preserved shells being considered autochthonous), as well as the sedimentary characteristics and biomarkers. The sedimentological and micropaleontological characteristics of core SAL3 distinguished eight units that reflect different paleoenvironments (Figs. 4 and 6, Tables 2 and 4). Most stratigraphic contacts between units are gradual.

Unit I is an alluvial pack (A) characterized from the sedimentary point of view by a mixed texture of silts, clays and sands, with abundant signs of hydromorphism especially at the top. There is no micropaleontological evidence, and organic matter is scarce. The alkane C_{25} indicates the significant input of OM from aquatic macrophytes. The Paq index recorded oscillations between 0.5 (12.3 m) and 0.8 (13.1 m), thus corroborating the contribution of submerged/floating macrophytes (Ficken et al., 2000), and showing a good inverse correspondence with ACL values and the alkane predominant chain index. The TAR_{HC} values also indicate a significant input of OM from terrestrial plants. Thus, during this unit aquatic macrophytes dominated, alongside the contribution of land plants.

Unit II is interpreted as a brackish lagoon (BL) with processes that indicate a restrictive environment. The dominant association characterizing this paleoenvironment comprises the brackish species *Ammonia tepida, Criboelphidium excavatum, Haynesina germanica, Pseulochanella eburnea, Miliolinella circularis* and *Aubignyna perlucida* (Heron-Allen and Earland). At 9.4 m b.s.l, there is an increase in the proportion of carbonates and a decrease in the content of organic matter. As regard the granulometric content, an increase in sand and a decrease in silts and clays were observed. The importance of C_{29} and C^{31} alkanes and of ACL shows the dominance of terrestrial plants. In this regard, the TAR_{HC} ratio confirms the predominance of OM from land plants over algae. The variation in the granulometric content at the top of the unit is interpreted as a change to a more restricted environment, with precipitates of calcium carbonate and many fauna remains, associated with a period of saturation and descent in the water column. Well-preserved shells indicate a lower-energy event. Inside the unit, ^{14}C dating obtained at 11.3 m b.s.l. gave an age of 8418 ± 77 cal yr BP, and another at 9 m b.s.l. an age of 7870 ± 75 cal yr BP.

In Unit III (BL) the lagoon continues to be closed but shows conditions of greater restrictions compared to the previous unit, since only three species of brackish water are recorded: *Ammonia tepida, Haynesina germanica* and *Criboelphidium excavatum*. The absence of a sandy fraction and the increase in organic inputs indicate the most restrictive and lowest-energy conditions in the environment. C_{29} and C_{31} were also the predominant alkanes. ACL values, low *P*aq index together with the TAR_{HC} ratio, indicate the predominance of OM from land plants and the reduced contribution of aquatic macrophytes or algae, and thus a shallow water depth.

In Unit IV the lagoon has a clear connection with the open sea (BLM), inferred from the micropaleontological and sedimentological evidence. An erosive contact with respect to Unit III is verified in this unit, characterized by the abundance of hyaline quartz sands, calcite and bioclasts of marine origin. In the foraminifera associations species typical of more marine environments appear (although they do not dominate) mixed with species from brackish waters. The high rates of diversity, the presence of mixed association and the marine fauna corroborate this connection. Towards the top of the unit, the more rounded marine shells indicate a change in environmental conditions. C_{29} was again the predominant alkane although at the end C_{25} was also abundant. ACL values and *P*aq index reflect an increased contribution of OM from aquatic macrophytes, and greater water depth.

Unit V again shows the isolation of the open sea lagoon (BL), with a brackish lagoon paleoenvironment that is much more restrictive even than in Unit II. It is characterized by an association of well-conserved brackish species and an absence of more marine species. The decrease in the proportion of carbonates and the increase in the proportion of silts and clays, together with the micropaleontological evidence, could be indicative of a trend towards a lower-energy environment. Also, the alkane C_{29} is dominant although some samples maximized at C_{25} and C_{31}. ACL is slightly lower than in Unit IV and indicative of land plant input with the influence of aquatic macrophytes. The *Paq* index and TAR_{HC} ratio indicate the predominance of terrestrial plants input over algae. Thus, during this unit, the contribution from aquatic macrophytes increased slightly, although land plants were dominant. In this unit, several dates were obtained with the following ages: 4776 ± 683 cal yr BP (AAR), 4706 ± 106 cal yr BP and, at the top, 4550 ± 442 cal yr BP (AAR) (Table 1).

The recovery of the connection with the marine environment is recorded in Unit VI (BLM). An erosive contact with respect to the underlying unit marks the change towards a sediment rich in calcite and hyaline quartz sand. This communication with the open sea is more marked than in unit IV, as indicated by the remains of *Posidonia oceanica* and the greater importance of marine species. Species such as *Rosalina globularis* (d'Orbigny), *Planorbulina mediterranensis* (d'Orbigny) or *Asterigerinata mamilla* (Williamson) stand out, with well-preserved shells, indicating a continuous communication not associated with specific storm episodes. The diversity of these samples is high and reflects an environment that is very rich in organisms of both marine and brackish origin.

In Unit VII the brackish lagoon (BL) communicating with the sea gradually becomes isolated (subunit VIIa). This paleoenvironment is inferred from the dominant association formed by brackish species, similar to the one identified in Unit II. The high proportion of fine grain sizes (silt and clay), close to 90%, indicates a lower-energy environment where settling dominates. At 3.8 m b.s.l, a dating reflects the age of 1922 ± 92 cal yr BP. In subunit VIIb, the micropaleontological content, with a more restricted association (*Ammonia tepida, Haynesina germanica* and *Criboelphidium excavatum*) and the presence of a high content of organic matter and plant remains, indicate redox conditions, and has been interpreted as a brackish water swamp (BM).

Finally, Unit VIII reflects an oligohaline marsh environment (FM), as inferred from the progressive disappearance towards the top of the foraminifera and the presence of charophytes. At the base of this unit are facies with rhizotubule precipitates that are interpreted as reflecting moments of saturation and descent of the water column. At the top of the unit, sand levels are detected that may be due to fluvial or silting processes.

At 2.3 m b.s.l there is a dating of 1575 ± 32 cal yr BP. In the uppermost part of the record, the dominant n-alkane was C_{29} with ACL values denoting a predominance of land plant inputs. *P*aq index reflects the contribution of emergent macrophytes, and the TAR_{HC} indicates the predominance of terrestrial plants over algae.

In core SAL4, from the paleoenvironmental point of view, the sedimentological and micropaleontological characteristics allow us to distinguish four paleoenvironmental units (Figs. 5 and 7, Tables 3 and 5). The base (Unit I) is related to a backshore environment (B), identified by the importance of the pebbles and flattened and rounded gravels, originating from the River Turia and nearby ravines. Well sorted fine sands are observed with hardly any biogenic content. In this unit C_{25} was the dominant n-alkane with ACL values characteristic of the input of aquatic macrophytes. The *P*aq index indicates the contribution of submerged/floating macrophytes, and the TAR_{HC} ratio reflects a significant terrestrial contribution to OM. Therefore, this unit marked a dominance of submerged/floating macrophytes, with low input of terrestrial plants and algae.

Towards the top, this paleoenvironment changes to partially flooded facies, where species of marine and brackish origin are observed with a poor state of preservation. This area is interpreted as a backbarrier flat (BB) environment (Unit II). The dominant association of subunit IIa is formed by brackish and marine species. The marine species that appear are characteristic of infralittoral zones (*Ammonia beccarii, Asterigerinata mamilla, Rosalina globularis* and *Adelosina bicornis*), epiphytes of *Posidonia oceanica* and sandy substrates (Ribes et al., 1992). Specifically, this association bears similarities to the one found in the 5 m isobath in the present-day infralittoral zone of Valencia (López-Belzunce et al., 2014). Therefore, despite the scarcity of organic matter, the presence of these species with poorly preserved shells that mix with brackish species, in a medium dominated by quartz sands, allows us to interpret this deposit as a backbarrier flat.

As in the previous unit, C_{25} was the predominant *n*-alkane, although at the end, C_{29} was dominant. ACL and *P*aq values indicated the input of submerged/floated macrophytes, and the TAR_{HC} ratio reflected the predominance of land plants over algae. These results were indicative of the presence of OM from aquatic macrophytes during most of this period while towards the end, land plants became predominant. In subunit IIb, the increase in grain size (greater presence of gravel and coarse sand), indicates a higher-energy environment. From the stratigraphic point of view an erosive contact is recorded with respect to subunit IIa. No associations of brackish foraminifera are observed. The signs of erosion of the marine shells confirm the drag. This unit containing poorly sorted material can be associated either with a specific energetic storm event or washover fan, very frequent at this time (Sabatier et al., 2008; Amorosi et al., 2009; Sacchi et al., 2014) or with a rollover translation of the barrier. These environments are usually identified by the presence of an overwash, formed by beach sediment and nearshore sand, which interdigitates with low-energy deposits typical of coastal lagoons (Switzer and Jones, 2008). It is also characterized by a marine assemblage, with frequent signs of transport, in the sediments from the coastal environment and a brackish assemblage, better preserved, from the autochthonous record of the lagoon. In this deposit, the absence of foraminifera may be due to environmental stress deriving from the changes in the conditions of the lagoon (e.g., hypoxia, and the dissolution of carbonates) or due to transport conditions and the erosion of the shells (Pilarczyk et al., 2014). This means that we cannot clearly associate this event with a washover fan episode, although it coincides with the increase in storm activity analysed by Sabatier et al. (2012) around 5,400 years BP. In this unit, two dates have been obtained: 6727 ± 671 cal yr BP (AAR) and 5683 ± 152 cal yr BP (AAR).

In subunit IIc, the backbarrier flat environment returns with a mixture of brackish species and stenotopic species from littoral marine environments. This episode shows the maximum influence of the marine environment on the barrier, corroborated by the abundance of marine species. The lagoon facies are reflected in the high proportion of silts and clays, although organic matter is scarce. Finally, subunit IId indicates a more restricted backbarrier flat environment than the one identified in the underlying subunit; this is inferred from the decrease in the presence of marine species and their poorer conservation, as well as the dominance of brackish species towards the top.
After this unit, which encompasses different subenvironments of the barrier, Unit III is identified as a brackish water lagoon environment (BL), as can be inferred from a well-conserved association of restricted-water foraminifera and the high proportion of the clay silt content, organic matter and the presence of charophytes. C_{29} is dominant and ACL records a change with regard to the previous unit, with higher values indicative of the presence of terrestrial plants. The *P*aq index indicates emergent macrophytes. The TAR_{HC} ratio shows a predominance of land plants over algae. This unit is dated at the base at 2212 ± 90 cal yr BP.

Finally, Unit IV is interpreted as a brackish marsh at the base which evolves into an oligohaline paleoenvironment (FM). The presence of the high content of organic matter, the high proportion of silts and clays and of plant remains indicate the change towards a marsh facies. Foraminifera only appear at the base of the unit and are characteristic of brackish waters. The presence of the species *Discorinopsis aguayoi* (Bermúdez), typical to Mediterranean marshes, stands out (Guillem 2008; Sanjuán and Blázquez, 2017). Towards the top, no foraminifera are recorded and freshwater ostracods and gastropods are observed. At the bottom, C_{25} is the predominant n-alkane chain coinciding with falls in ACL values and *P*aq values indicative of the presence of submerged/floating macrophytes. In this regard, the TAR_{HC} values indicate a predominance of land plants over algae. In contrast, in the upper 1.8 m the dominant n-alkane is C_{31} and ACL values are higher, indicating the presence of land plants. The *P*aq index reflects the presence of OM from emergent and submerged/floating macrophytes, and TAR_{HC} values show the predominance of land plants over algal input. This unit presents a greater influence of fluvial processes, it is dated at 1340 ± 44 cal yr BP and, towards the top, at 588 ± 170 cal yr BP (AAR).

4.4. The lagoon and eustatic pulse of the MIS 1

The correlation of the two series allows us to propose the following paleoenvironmental evolution for the lagoon (Fig. 8). An alluvial paleoenvironment is identified around 8500 cal yr BP responding to warm and arid conditions in alluvial plain facies (unit I, SAL 3), which is also identified at other points of the study area (López-Belzunce et al., 2020). Biomarkers indicate the existence of water bodies within the alluvial environment. On top of this reservoir, a brackish water lagoon is recorded, formed in response to the onset of the sea level rise in MIS 1 (unit II, SAL3) with a major input of land plants with a fringe of emergent macrophytes. Carbonate sands at 10.8 m b.s.l indicate water saturation episodes, probably contemporary to the 8.2 event, also identified at other sites in the study area (Carmona et al., 2016). The establishment of a brackish lagoon with a marine connection between 7000 and 5300 cal yr BP (interpolated dates, unit IV, SAL3), allows the extension of the marine communication of the lagoon paleoenvironment to a large part of the study area, where biomarkers indicate aquatic macrophytes and greater water depth.

The record of the rise in sea level of MIS 1 in the Valencia lagoon is similar in terms of facies to that identified in other nearby coastal lagoons (Blázquez et al., 2017, 2018; Brisset et al., 2018). In the Valencia lagoon the maximum marine invasion during the Holocene is found at least 3 km from the present-day coastline, in lagoon facies that communicated with the sea (Carmona et al., 2016; López-Belzunce et al., 2020). In nearby lagoons, such as Albufereta de Alicante (Ferrer and Blázquez, 2012) and the Bajo Segura basin (Blázquez, 2005, Blázquez and Ferrer, 2012) the same facies is identified during this episode. Other facies (foreshore, shoreface, backshore) also show this Holocene marine maximum in similar nearby systems, such as the Almenara marsh (Blázquez et al., 2018; Rodríguez-Pérez et al., 2018) and in the Pego-Oliva marsh (Brisset et al., 2018). These differences in facies reflect the variations in the access of the Holocene sea level rise to different stretches of the coast, which is attributed to regional tectonics, since coastal subsidence leads to the marine invasion of these lagoon systems. Several authors report high subsidence rates in the Valencia lagoon. According to Zazo et al. (1993) the subsidence of this coastal section is 0.12 mm yr-1 in the last 200 ka; for Serpelloni et al. (2013), it is less than 2 mm yr-1 and according to Rey and Fumanal (1996) it is 0.45 mm yr-1. Assessing paleobarriers conserved in the internal platform, Albarracín et al. (2013) report a subsidence of 0.3 mm yr-1 in the last 22 ka BP.

With regard to its chronology, the sediments studied in the Valencia lagoon (unit IV, SAL3; subunit IIa SAL4) suggest that the maximum sea level rise is synchronous with the beginning of the Holocene Climate Optimum and is recorded between 7000 and 5300 cal yr. BP. This age is corroborated in nearby areas (Blázquez and Usera, 2010; Ferrer and Blázquez, 2012; Blázquez et al., 2018; Rodríguez-Pérez et al., 2018).

Later, around 5300 cal yr BP (SAL3), dated at 4706 ± 106 cal yr BP and 4776 ± 683 cal yr BP (AAR) a brackish lagoon facies was established. The paleoenvironment of the restricted lagoon indicates a lower energy than in the underlying environments communicated with the sea. Probably a patchy environment (terrestrial + “aquatic ponds") occurred, which explains the mixed input of submerged/floating macrophytes and land plants. These facies are recorded synchronously in other sedimentary media, such as deltaic fill (Stefani and Vicenzi, 2005; Carmona and Ruiz, 2011; Anthony et al., 2014; Cearreta et al., 2016) and the formation of barrier island systems (Fanget et al., 2014). Near the barrier (SAL4), backbarrier flat facies are preserved, which shows the importance of the material available for coastal constructions; this material is associated with a more arid climate in which the slopes are exposed, and an increase in torrential rainfall, with greater transport capacity. This environment corresponds to extensive water mass, in which submerged/floating macrophytes are dominant, but this water mass presents a continuous decrease with higher input of terrestrial plants.

From 2800 cal yr BP onwards, the lagoon becomes more isolated from the open sea and, according to the biomarkers, presents a major reduction in the flooded area and water depth. There is an increase in aridity in the coastal areas (Sacchi et al., 2014; Dolez et al., 2015) and the development of barriers that isolate coastal lagoons from the open sea in the western Mediterranean (Dabrio et al., 2000; Goy et al., 2003).

Next, the decrease in the water table involves an increase of terrestrial patches in the context of the flooded area. At the end there was a shrinkage of the flooded area, denoting a terrestrial moment, in accordance with arid conditions in the western Mediterranean and the development of wetlands (Mensing et al., 2015).

The definitive closure of the lagoon is interpreted from the marked decrease of water mass, although some temporary ponds remained active. This may respond to the reduction of vegetation as a consequence of aridity and to the increase in the exploitation of resources, which increases the input sediment to the littoral system, strengthens the barrier, and favors the definitive closure of the lagoon (López-Belzunce et al., 2020).

4.5 The barrier-islands and paleo lagoons

According to several authors (Bellotti et al., 1994; Adlam, 2005; Anderson et al., 2014), the most important factors affecting the development and conservation of the coastal barriers are the subsidence of the basin, compaction, the source of sediments, the sea level rise and coastal currents (swell and tides). The continuity of the sedimentary input in the coast is fundamental in the preservation of the barriers. Tidal ranges also control the position of these barriers, and even their very existence. Finally, rises in sea level have a notable influence, since the rate of eustatic increase can lead to the submergence or preservation of the barriers. Taking these factors into account, the transgressive and regressive phases identified in the cores have been listed in Figure 8 and a model of evolution, based on the synchrony of the deposits with the barriers preserved on the surface, is proposed in Figure 9. These barriers which have been studied by several authors (Santisteban et al., 2009; Carmona et al., 2016; Ruiz and Carmona, 2019).

In SAL3, located 1600 m away from the current coastline, the brackish lagoon that remained until 7870 ± 75 cal yr BP (Unit II) was isolated from the open sea (unit III) due to the formation of a very effective barrier, at least in the vicinity of the core. The slowing of the sea level rise from 7500 BP (Vacchi et al., 2016) allowed the development of barriers both on the coast and on the internal continental shelf of the Gulf of Valencia (Albarracín et al., 2013; Alcántara-Carrió et al., 2013). This barrier may be contemporaneous with the infralittoral sands identified in 6980 - 6780 cal yr BP (Carmona and Pérez-Ballester, 2011) and may be associated with the backshore facies with gravels and flattened pebbles from the Turia, which are identified in positions closer to the present-day barrier (unit I, SAL4). This backshore environment evolves into a backbarrier flat towards 6727 ± 671 cal yr BP, coinciding with prograding phases also identified in the Gulf of Almería (H1: 7,400-6000 BP) by Goy et al. (2003), although according to Santisteban et al. (2009), it is only recorded in the northernmost area of the barrier.

Up to 5300 BP (interpolated date) SAL3 indicates greater exposure of the lagoon, consistent with its connection to the sea, and reflecting the Holocene transgression maximum. These eustatic fluctuations influence the sedimentation of the beach/dune system and, therefore, the formation of the barrier, as can be seen on other Mediterranean coasts (Goy et al., 2003; Zazo et al., 2008).

According to Davis and Stevenson (2007), the North Atlantic Oscillation has a manifest influence on the development of Mediterranean barriers. The effect of cooling in high latitudes associated with the 8.2 event reinforced the latitudinal temperature gradient, causing the Hadley cell to recede towards the Equator and bringing the subtropical anticyclone back to more southerly positions, which resulted in an intense drought in the Mediterranean. Further, around 5.3 ka cal BP the results show a new change towards arid climatic conditions in the transit between the Northgrippian and the Meghalayan (Tallón-Armada et al., 2014). In the study area, this change was associated with an increase in fires, which in turn led to increased soil erosion, greater availability of sediments, and increased transport capacity due to the rise in seasonal torrential rains. This evidence is in agreement with poorly sorted sand-size deposits (SAL4) that may coincide with a paleostorm event around 5683 ± 152 cal yr BP (AAR), and periods of increased storm activity (5650-5400 BP) in the western Mediterranean (Sabatier et al., 2012). These results bear witness to the coast's rapid adaptation to climate variability in the recent Holocene.

From 5300 BP (interpolated date) (SAL 3) a marine regressive phase is recorded, marked by a brackish lagoon and dated to 4706 ± 106 cal yr BP. The determination of this environment implies that the wide communication with the marine environment is clearly closed. In more coastal zones (SAL 4), the backbarrier flat deposit recorded on a backshore indicates a relative regression, implying the prograding of the Holocene barrier dated as ~4400 BP (Santisteban et al., 2009). The richness in silts and clays may indicate a more protected position, which confirms the progradation of the barrier and, therefore, the marine regression. Probably this is a consequence of the arid conditions established by the 4.2 ka Bond event; aridity involves less vegetation cover, an increase of fluvial sedimentary load and consequently a higher sedimentary availability for coastal constructions. Furthermore, they correlate with the H2 phase identified by Goy et al. (2003) (5400-4200 cal yr BP), which is interpreted as a phase of coastal progradation. Next, a transgressive phase identified in the SAL3 core between 4550 ± 442 cal yr BP is recorded, which lasts until approximately 3220 BP (interpolated date; López-Belzunce, 2020).

According to previous tectonic studies carried out in the study area (Zazo et al., 1993; Rey and Fumanal, 1996; Albarracín et al., 2013; Serpelloni et al., 2013) the tectonic factor is significative in this coastal section. In this context, this phase may be related to the subsidence of the barrier and the degree of compaction rather than to the sea level rise; nonetheless, in the Gulf of Almería an erosive episode (3155 cal yr BP) was interpreted as a consequence of the rise in sea level not compensated by the entry of sediments (Goy et al., 2003). This sea level rise has also been identified in the Almenara marsh (Rodríguez-Pérez et al., 2018). However, this facies change is not recorded in the paleoenvironment of the backbarrier flat, which may corroborate the formation of an intermittently emerged and submerged barrier open in the northern zone, in line with a second Holocene barrier identified in 3360-3150 cal yr BP with a backbarrier flat and associated dune environments (Carmona et al., 2016). Nevertheless, this transgressive signal may simply indicate a lagoon more effectively connected with the sea, thus permitting to maintain the same position of the SAL4 backbarrier. However, the records of marine deposits in more interior cores (Carmona et al. 2016) indicate a marine entrance of at least 3 km at this time, with significant sedimentary thickness, which could favor the tectonic hypothesis.

Between 2800-2200 BP, an increase in the amount of sediment in the River Turia is identified when tongues of sand, gravel or submerged bars reach the open lagoon (Ruiz and Carmona, 2019). This may be related to the beginning of wind accumulations in coastal areas around 2700 years BP (Borja et al., 1999). The thickening of the barrier produces a change in the lagoon environments, with a greater influence from the river, evidencing the greater power and stabilization of the Holocene coastal barriers. In this period a third barrier dating from 2300-2200 years BP is identified, characterized by cross-stratification sands (Carmona y Pérez-Ballester, 2011), and at 2500 BP by Santisteban et al. (2009), described as medium sands. This deposit corresponds chronologically in the cores analysed to a brackish lagoon (2212 ± 90 cal yr BP, in SAL4); 1922 ± 92 cal yr BP (SAL3)). This progradation of environments towards the sea is similar to the prograding unit described by Goy et al. (2003) (H4, 2700-1900 cal yr BP). The progressive isolation of the lagoon coincides chronologically with the sandy barriers that closed other Mediterranean lagoons (Dolez et al., 2015; Dezileau et al., 2016) and the progradation of Mediterranean deltas (Stefani and Vincenzi, 2005; Amorosi et al., 2013). This progressive closure of the Mediterranean lagoons also coincides with Bond event 2.8.

The displacement of the mouth of the River Turia from 1600 BP onwards (Carmona et al., 2016), produces an even more significant development of the coastal barrier that allows the evolution of environments from lagoon to freshwater marsh, passing through the brackish marsh phase (unit VIIb and VIII; SAL3). A last prograding sand barrier dated to 1373 ± 137 cal yr BP (Ruiz and Carmona, 2019) is identified with the formation of the most recent barrier (1200 BP) also cited by Santisteban et al. (2009). The action of this barrier is reflected in the change in the salinity of the marsh water. The stabilization and progradation of the coastal barrier system and the change towards a brackish lagoon isolated from the sea was favored by the greater sedimentary availability produced by the arid conditions recorded in the Iberian Peninsula at that time (Schröder et al., 2018) and by the high-magnitude floods identified in the River Turia (Carmona and Ruiz, 2011).

The littoral system is very sensitive to climatic changes, since they are reflected in the availability of sediment that reaches the coast. In other areas of the Mediterranean there are deposits on the coast linked to the characteristic dry climatic episodes of the Holocene (Goy et al., 2003; Zazo et al., 2008). In the study area, the 8.2 event is observed discretely in SAL3 (and other nearby areas) in the abundant carbonaceous sands, while the 4.2 and 2.9 events are more clearly appreciable from the record of a brackish lagoon environment, which implies the isolation of the open sea lagoon and the further development of the barrier.

Finally, the study of these Holocene facies allows us to extrapolate the behavior recorded in the barriers to future scenarios. The predictions of the International Panel on Climate Change (IPCC) suggest an indicative range of sea level rise from 0.26 to 0.77 m by the end of the twenty-first century, as a consequence of a temperature rise of 1.5°C. This would imply a global rise in sea level, in the most conservative scenario, of 2.6 mm/yr. These levels are very similar to those identified in the Valencia lagoon between 8500 and 6500 cal yr BP, where an annual sea level rise of around 2 mm/yr is inferred (López-Belzunce, 2020). In the present-day context, the sea level rise is expected to produce a response in the barrier similar to that recorded in the Holocene maximum, that is, its partial disappearance, and the entry of the marine environment into the area occupied by the lagoon.

The high level of human activity in the vicinity of the current barrier weakens its feeding and its natural protection, since urbanization has eliminated the dunes and their contributions (Sanjaume and Pardo, 2019; Sanjaume et al., 2019). The coastal dynamics is altered by the construction of the harbor, which restricts sediments to the area north of the port of Valencia and has meant that no sediment is available to the south (Sanjaume, 1985). Some studies indicate rates of retreat of up to 10 m / year at the beginning of the 20th century on the coast located south of the Valencia Harbour (Pardo and Sanjaume, 2001). In addition, these sediments are already scarce compared to other historical periods, since they are retained by the construction of reservoirs (Pardo and Sanjaume, 2001). Therefore, these anthropic factors harm the preservation of the barrier and its ability to respond to the rise in sea level linked to global change. In the north, the barrier is notably narrower and more recently formed (López-Belzunce et al, 2020), and so, in all probability, the consequences of the rise in sea level of the twenty-first century will first be noted here.

5. Conclusions

From the analysis of the benthic foraminifera, biomarkers, and sediments in two cores drilled in the Valencia lagoon, as many as seven different paleoenvironments have been determined. These paleoenvironments are: alluvial, brackish lagoon, brackish marsh, brackish lagoon with marine communication, backshore, backbarrier flat and freshwater marsh. This sequence responds mainly to eustatic and climatic changes, as recorded in nearby similar areas.

The rise in sea level in MIS 1 has made it possible to record transgressive and regressive paleoenvironmental facies in the cores. This rise is recorded in the study area in brackish lagoon facies with marine communication, and reached its maximum flooding around 5300 cal yr BP. The eustatic signal was modulated by the climatic changes recorded in the study area after 7000 cal yr BP. The influence of the 8.2 ka, 4.2 ka and 2.8 ka cold cycles has been verified, in which arid conditions are recorded causing specific changes (the 8.2 ka event) such as carbonaceous sands in the brackish lagoon, or lasting paleoenvironmental changes (the 4.2 ka and 2.8 ka events), which produced the isolation from the open sea lagoon of a brackish lagoon with marine communication, which is attributed to the growth and progradation of the barrier. In addition, negative phases in the North Atlantic Oscillation triggered episodes of storms that may have caused instability in the barrier. A paleostorm is recorded in the most coastal core around 5600 cal yr BP.

The paleo-lagoons identified in the cores can be correlated with four different phases of the formation of the Holocene barrier, which are preserved on the surface and have been attributed by other authors to 7000 cal yr BP, 3360-3150 cal yr BP, 2300-2200 cal yr BP and 1200 cal yr BP.

Today, faced with climate change and the associated rise in sea level, a behavior similar to that recorded in the maximum of MIS 1 is expected: that is, the invasion of the Valencia lagoon by the sea, especially in the northern area where the barrier is narrower. However, as a consequence of human activity – which has retained the sediment in the rivers, altered the coastal dynamics, and destroyed the barrier through urbanization – the effect on this protected area of a sea level rise similar to that recorded between 7000 cal yr BP and 5300 cal yr BP will be much greater.

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FIGURE INDEX

Figure 1: Study area (Modified of López Belzunce et al., 2020)

Figure 2. Foraminifera species found in Sal 3 and Sal 4 cores. *1. Miliolinella circularis 200 µm x 220; 2. Triloculina trigonula 400 µm x 130; 3. Pseudolachlanella eburnea 200 µm x 200; 4. Adelosina longirostra 500 µm x 90; 5. Ammonia beccarii 300 µm x 150 vista ventral; 6. Ammonia beccarii 500 µm x 70; 7. Adelosina bicornis 100 µm x 350; 8. Ammonia tepida 300 µm x150; 9. Haynesina germanica 100µm x 300; 10. Massilina secans 1mm x 50; 11. Rosalina globularis 100 µm x 300; 12. Rosalina globularis 300 µm x 1 80; 13. Cribroelphidium excavatum 300 µm x150.*

Figure 3. Chromatograms from selected samples. Samples maximized: (A) at C_{25} n-alkane with a bimodal distribution; (B) at C_{31} n-alkane.

Figure. 4. Profiles of lithology, predominant *n*-alkane chain, ACL, P_{aq} index and TAR_{HC} in SAL3 core. M: mud, S: sand, G: gravel. Colors of the sediment represent the original ones.

Figure 5. Profiles of lithology, predominant *n*-alkane chain, ACL, P_{aq} index and TAR_{HC} in SAL4 core. M: mud, S: sand, G: gravel. Colors of the sediment represent the original ones.

Figure 6. Dominant foraminifera species, diversity and richness indices and sedimentological variables from core SAL3. A: Alluvial, BL: Brackish lagoon, BLM: Brackish lagoon with marine communication, BM: Brackish marsh, FM: Freshwater marsh.

Figure 7. Dominant foraminifera species, diversity and richness indices, and sedimentological variables from core SAL4. *A*. *laevigata=A*. *longirostra*. B: Backshore, BB: Backbarrier flat, BL: Brackish lagoon, FM: Freshwater marsh.

Figure 8. Correlation of the cores SAL3 and SAL4

Figure 9. Transgressive and regressive phases in the coastal barrier zone (SAL 3 and SAL4).

TABLES INDEX

Table 1. Numerical datings: Amino acid racemization (AAR; and C^{14}).

Table 2. Paleoenvironments in core SAL 3. A: Alluvial, BL: Brackish lagoon, BLM: Brackish lagoon with marine communication, BM: Brackish marsh, FM: Freshwater marsh

Table 3. Paleoenvironmental data of core SAL 4. B: Backshore, BB: Backbarrier flat, BL: Brackish lagoon, FM: Freshwater marsh.

Table 4. Indices of diversity and dominant species in core SAL 3. A: Alluvial, BL: Brackish lagoon, BLM: Brackish lagoon with marine communication, BM: Brackish marsh, FM: Freshwater marsh.

Table 5. Indices of diversity and dominant species in core SAL 4. B: Backshore, BB: Backbarrier flat, BL: Brackish lagoon, FM: Freshwater marsh.

Table 1 | Click here to access/download;Table;Table 1.docx

Core	Sample	Depth	Material dated	Laboratory	D/L Asp	Conventional age	cal 2 δ	Conv. marine	Cal 2 δ marine	Age (yr)
SAL 3	SAL 3/42	5.5-5.6 m b.s.l	*Cyprideis torosa*	LEB	0.189±0.011	-	-	-	-	4550 ± 442 BP
	SAL 3/47	6.1-6.2 m b.s.l	*Cyprideis torosa*	LEB	0.192±0.016	-	-	-	-	4776 ± 683 BP
SAL 4	SAL4/7	1.7-1.8 m b.s.l	*Cyprideis torosa*	LEB	0.094±0.007	-	-	-	-	588 ± 170 BP
	SAL4/43	5.3-5.4 m b-s.l	*Cyprideis torosa*	LEB	0.216±0.004	-	-	-	-	5683 ±152 BP
	SAL 4/46	5.6-5.7 m b.s.l	*Cyprideis torosa*	LEB	0.241±0.016	-	-	-	-	6727 ± 671 BP
SAL 3	SAL_3/235	2.4-2.5 m b.s.l	Shell	Beta-463457	-	1670 ± 30 BP	374 ± 54 AD			1575 ± 32 BP
	SAL_3/379	3.7-3.8 m b.s.l	Shell	Beta-463459	-			2310 ± 30 BP	93 ± 27 BC	1922 ± 92 BP
	SAL_3/597	6-6.1 m b.s.l	Shell	Beta-463458	-			4510 ± 30 BP	2757 ± 106 BC	4706 ± 106 BP
	SAL_3/M76	9.7-9.6 m b.s.l	Shell	Beta-463456	-			7410 ± 30 BP	5921 ± 75 BC	7870 ± 75 BP
	SAL_3/M97	11.5-11.6 m b.s.l	Shell	Beta-463455	-			7950 ± 30 BP	6469 ± 77 BC	8418 ± 77 BP
SAL 4	SAL_4/M11	2.1-2.2 m b.s.l	Plant	Beta-463454	-	1440 ± 30 BP	610 ± 44 AD			1340 ± 44 BP
	SAL_4/280	2.9-2.8 m b.s.l	Shell	Beta-463453	-			1560 ± 30 BP	823 ± 93 AD	1127 ± 93 BP
	SAL_4/320	3.2-3.3 m b.s.l	Shell	Beta-463452	-			2540 ± 30 BP	263 ± 90 BC	2212 ± 90 BP

Table 2

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SAL 3				
Paleoenvironmental unit		**Foraminifera assemblages**	**Other fossils**	**Overview**
UNIT VIII (FM) Samples 11-1 (2.3 m b.s.l to 1.7 m b.s.l)		*Ammonia tepida, Haynesina germanica, Cribroelphidium excavatum, Pseudolachlanella eburnea*	Broken shells, rhizotubule precipitates are observed and carophytes remains.	Foraminifera only in samples from the bottom of the unit (11-6), increase the proportion of organic matter and decrease of relative abundance. Samples with less of 100 foraminifera test. Rhizotubule precipitates and at the top sands levels Munsell color: 5YR 5/4
UNIT VII Samples 33-12 (4.7 m b.s.l to 2.3 m b.s.l)	**UNIT VIIb (BM)** Samples 15-12 (2.8m b.s.l to 2.3 m b.s.l)	*Ammonia tepida, Haynesina germanica, Cribroelphidium excavatum*	Vegetal remains and carophytes.	More restrictive environment as a brackish marsh with low diversity. Sediments composed by the same as below level. Munsell color: 5Y 2/1
	UNIT VIIa (BL) Samples 33-17 (4.7 m b.s.l to 2.8 m b.s.l)	*Ammonia tepida, Haynesina germanica, Pseudolachlanella eburnea, Cribroelphidium excavatum, Miliolinella circularis*	Shells from marine origin poorly preserved,Fragment os ostracod, bivalves and gastropods. Also presence of carophytes.	Brackish species and low diversity indices. High proportion of fine grain sizes (silt and clay) 80-90%. Munsell color: 5Y 5/1.
UNIT VI (BLM) Samples 41-34 (5.3 m b.s.l to 4.7 m b.s.l)		*Ammonia tepida, Haynesina germanica, Pseudolachlanella eburnea, Cribroelphidium excavatum, Ammonia beccarii , Adelosina longirostra*	Fragments of bibalves (*Abra ovata*), gastropods and *Posidonia oceanica.* Marine species well preserved.	Mixed associations, increasing the dominance of marine species, the punctual presence of species such *Rosalina mediterranensis*, *Planorbulina mediterranensis*,, *Asterigerinata mamilla*, *Nubecularia lucifuga*, Lobatula lobatula. High diversity indices, the higher density of all units. From sedimentologycal point of view is formed by calcite hetermotric grains, hyaline quartz. Puntual increase of sands with high biogenic component (64%). Munsell color: 10YR 7/1
UNIT V (BL) Samples 50-42 (6.2 m b.s.l to 5.3 m b.s.l)		*Ammonia tepida, Miliolinella circularis, Haynesina germanica, Pseudolachlanella eburnea, Cribroelphidium excavatum, Ammonia beccarii*	Presence of gastropods, bivalve fragments and high proportion of post mortem valves.	More dominance of species of brackish water and less presence of marine origin. Punctual appearance of species from hiposaline environments. Higher increase of *Miliolinella circularis* and foraminifera in the smaller size. Increase of silts and clays proportion. Munsell color: 10YR 7/1
UNIT IV (BLM) Samples 65-51 (7.8 m b.s.l to 6.2 m b.s.l)		*Ammonia tepida, Haynesina germanica, Pseudolachlanella eburnea, Cribroelphidium excavatum, Miliolinella circularis, Adelosina laevigata, Ammonia beccarii*	Fragments of bivalves (*Abra ovata* and *Cerastoderma* spp.), gastropods and ostracods and vegetal remains were observed.	Mixed association, species of brackish water and marine origin. High diversity indeces and punctual presence of species such *Rosalina mediterranensis, Planorbulina mediterranensis y Massilina secans.* High proportion of biogenic sand with hyaline quartz (38%). Munsell color: 10YR 7/1.
UNIT III (BL) Samples 74-66 (8.7 m b.s.l to 7.8 m b.s.l)		*Ammonia tepida, Pseudolachlanella eburnea, Cribroelphidium excavatum, Haynesina germanica*	Fragments of bivalves and ostracods and vegetal remains were observed. High organic content.	Species from brackish water, low diversity indices, shells poorly preserved, more restrictive environment. Clay and silt fraction, in some samples high proportions (85-93%). Munsell color: 2.5Y 7/1
UNIT II (BL) Samples 100-75 (11.4 m b.s.l to 8.7 m b.s.l)		*Ammonia tepida, Pseudolachlanella eburnea, Cribroelphidium excavatum, Haynesina germanica, Miliolinella circularis*	Brackish ostracods (*Cyprideis torosa*) in live position to the top, terrestrial gastropods and vegetation fragments at the bottom. High biogenic levels in the samples.	The assemblage of foraminifera found is from brackish waters with punctual presence of eurihaline species such *Aubignyna perlucida* and the presence of most marine species at the top. Medium sands with high proportion of biogenic content (ostracoda, bivalve, gastropods) and rizhotubules. Variable colour of sediment, at the bottom (2.5Y 4/1), but increase of sand proportion at the top (50%). Munsell color: 2.5 Y 7/1
UNIT I (A) Samples 114- 100. (14 m b.s.l to 11,4 m b.s.l)		-	–	No foraminifer tests were reported,some ostracods poorly preserved were observed. Sedimentology is caracterized by sands. Munsell color: 7.5YR 7/1.

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SAL 4				
Paleoenvironmental unit		**Foraminifera assemblages**	**Other fossils**	**Overview**
UNIT IV (FM) Samples 16-1 (2.6 m b.s.l to 1 m b.s.l)		*Ammonia tepida, Haynesina germanica, Cribroelphidium excavatum*	Foraminifera shells well preserved, freshwater gastropods, ostracods and charophytes remains.	Brackish species dominance only three taxes. Punctual appearance of *D. aguayoi* . High density samples. Silt and clays with alternance with sand layers formed by carbonates precipitation. Munsell color: 10 YR 5/2.
UNIT III (BL) Samples 25-1 6 (3.5 m b.s.l to 2.6 m b.s.l)		*Ammonia tepida, Haynesina germanica, Pseudolachlanella eburnea, Cribroelphidium excavatum, Miliolinella circularis, Pseudotriloculina rotunda*	Brackish bivalves (*Abra ovata*), ostracods in live position (*Cyprideis torosa*) and charophytes tot the top. High proportion of organic matter.	Less diversity, dominance of foraminifera species from brackish environment. Sands formed by heterometric quartz with variable colour (Munsell color: 10YR 7/1). To the top increase of silt and clays (80%) and vegetal remains (Munsell color: 10YR 6/3).
UNIT II (BB) Samples 49-26 (5.9 m b.s.l to 3.5 m b.s.l)	**Subunit IId** Samples 37-26 (4.3 m b.s.l to 3.5 m b.s.l)	*Ammonia tepida, Pseudolachlanella eburnea, Haynesina germanica, Ammonia beccarii, Miliolinella circularis, Adelosina longirostra, Rosalina globularis, Cribroelphidium excavatum*	Gastropods and poorly preserved foraminifera shells .	Presence of species from open marine environments mixed with brackish species. Less marine foraminifera. High-energy environment. Sands with heterometric quartz. Munsell color: 10YR 7/1.
	Subunit IIc Samples 37-34 (4.7 m b.s.l to 4.3 m b.s.l)	*Ammonia tepida, Miliolinella circularis, Ammonia beccarii, Adelosina longirostra, Pseudolachlanella eburnea, Cribroelphidium excavatum, Massilina secans, Haynesina germanica, Triloculina trigonula, Rosalina globularis, Adelosina bicornis, Pseudotriloculina rotunda*	Gastropods and fragments of bivalves. Big size of foraminifera shells.	Presence of species from open marine environments mixed with brackish species. Highest proportion of marine shells and increasing the diversity index. Medium sands with hyaline quartz 90% (Munsell color: 10YR 7/1) with high presence of silts and clays in some samples (20%)
	Subunit IIb Samples 42-38 (5.2 m b.s.l to 4.7 m b.s.l)	-	Bivalves and gastropods fragments. Eroded shells form marine environment.	Absence of foraminifera shells. Sand and pebbles. Increase in grain size (greater presence of gravel and coarse sands). Munsell color: 10YR 7/1.
	Subunit IIa Samples 49-43 (5.9 m b.s.l to 5.2 m b.s.l)	*Ammonia tepida, Adelosina bicornis, Haynesina germanica, Cribroelphidium excavatum, Ammonia beccarii, Triloculina trigonula, Pseudolachlanella eburnea, Miliolinella circularis, Massilina secans, Asterigerinata mamilla, Elphidium advenum, Pseudotriloculina rotunda*	Fragment of bivalves and gastropods.Reworked and eroded shells.	Presence of species from open marine environments mixed with brackish species. Dominant litology: heterometric grains of hyaline quartz (90%) and calcite with pebbles. Munsell color: 10YR 7/1.
UNIT I (B) Samples 71- 50. (8,2 m b.s.l to 5,9 m b.s.l)		-		No foraminifera tests were reported. High proportion of platy pebbles (reach in some samples 80%) with medium and fine sands (30%) formed by hyaline quartz. Munsell color: 10YR 7/1.

Table 4

SAL3	Unit I (A)	Unit II (BL)	Unit III (BL)	Unit IV (BLM)	Unit V (BL)	Unit VI (BLM)	Unit VII		Unit VIII (FM)	
MEDIUM VALUES							Subunit VIIa (BL)	Subunit VIIb (BM)		
Taxa_S		8.94	7.40	12.29	7.4	15.75	6.08	4.5	-	
Individuals		284.58	321.6	306.29	314.8	308.5	302.75	302.5	-	
Dominance_D		0.44	0.58	0.56	0.55	0.36	0.6	0.77	-	
Shannon_H		1.17	0.90	1.05	0.94	1.57	0.78	0.48	-	
Equitability_J		.55	0.43	0.41	0.47	0.58	0.45	0.32	-	
Fisher_alpha		1.81	1.38	2.62	1.37	3.63	1.09	0.75	-	
Density ind/gr		1114.2	1739.2	1383.1	7700	8773.1	489.4	468.6	77.17	
Relative abundances %										TOTAL
Miliolida										
Adelosina longirostra	-	0.47	0.92	1.48	0.33	1.95	0.03	-	-	0.61
Miliolinella circularis	-	0.8	0.49	0.79	4.61	1.64	1.24	-	-	1.67
Pseudolachlanella eburnea	-	17.77	9.34	5.49	3.78	6.05	1.70	0.08	4.20	3.18
Rotaliida										
Ammonia beccarii	-	0.04	0.0	0.56	1.64	7.38	0.44	-	-	1.49
Ammonia tepida	-	60.17	70.38	72.67	71.07	55.79	68.61	87.42	85.76	72.7
Cribroelphidium excavatum	-	11.55	10.10	3.06	2.09	4.11	3.39	5.47	5.13	3.82
Haynesina germanica	-	6.11	6.42	9.54	15.31	14.16	15.30	6.19	4.91	13.58

Table 5

SAL4	**Unit I (B)**	**Unit II (BB)**				**Unit III (BL)**	**Unit IV (FM)**	
MEDIUM VALUES		**Subunit IIa**	**Subunit IIb**	**Subunit IIc**	**Subunit IId**			
Taxa_S	-	8.14	-	10.00	8.63	5.40	3.00	
Individuals	-	219.29	-	179.50	296.38	309.70	320.00	
Dominance_D	-	0.61	-	0.36	0.59	0.60	0.76	
Shannon_H	-	0.91	-	1.58	0.94	0.81	0.47	
Equitability_J	-	0.43	-	0.68	0.44	0.48	0.42	
Fisher_alpha	-	1.72	-	2.36	1.67	0.94	0.46	
Density ind/gr	-	11480.4	360.5	2281.2	7754.7	8507.4	15222.2	
Relative abundances %								**TOTAL**
Miliolida								
Adelosina bicornis	-	5.85	-	1.55	-	-	-	1.34
Adelosina longirostra	-	-	-	5.81	1.60	-	-	1.28
Massilina secans	-	0.80	-	2.97	-	-	-	1.07
Miliolinella circularis	-	0.92	-	11.61	2.96	2.07	-	2.93
Pseudolachlanella eburnea	-	1.91	-	4.90	7.44	4.84	-	4.71
Pseudotriloculina rotunda	-	0.55	-	0.77	-	0.51	-	-
Triloculina trigonula	-	1.23	-	1.94	-	-	-	0.72
Rotaliida								
Ammonia beccarii	-	2.53	-	7.35	3.00	-	-	2.29
Ammonia tepida	-	73.01	-	47.87	73.60	74.19	86.25	70.93
Asterigerinata mamilla	-	0.74	-	-	-	-	-	-
Cribroelphidium excavatum	-	3.45	-	4.13	0.58	3.34	5.38	2.73
Elphidium advenum	-	0.62	-	-	-	-	-	
Haynesina germanica	-	4.44	-	2.71	6.09	13.18	7.65	8.03
Rosalina globularis	-		-	1.81	0.95	-	-	0.61

Figure 1

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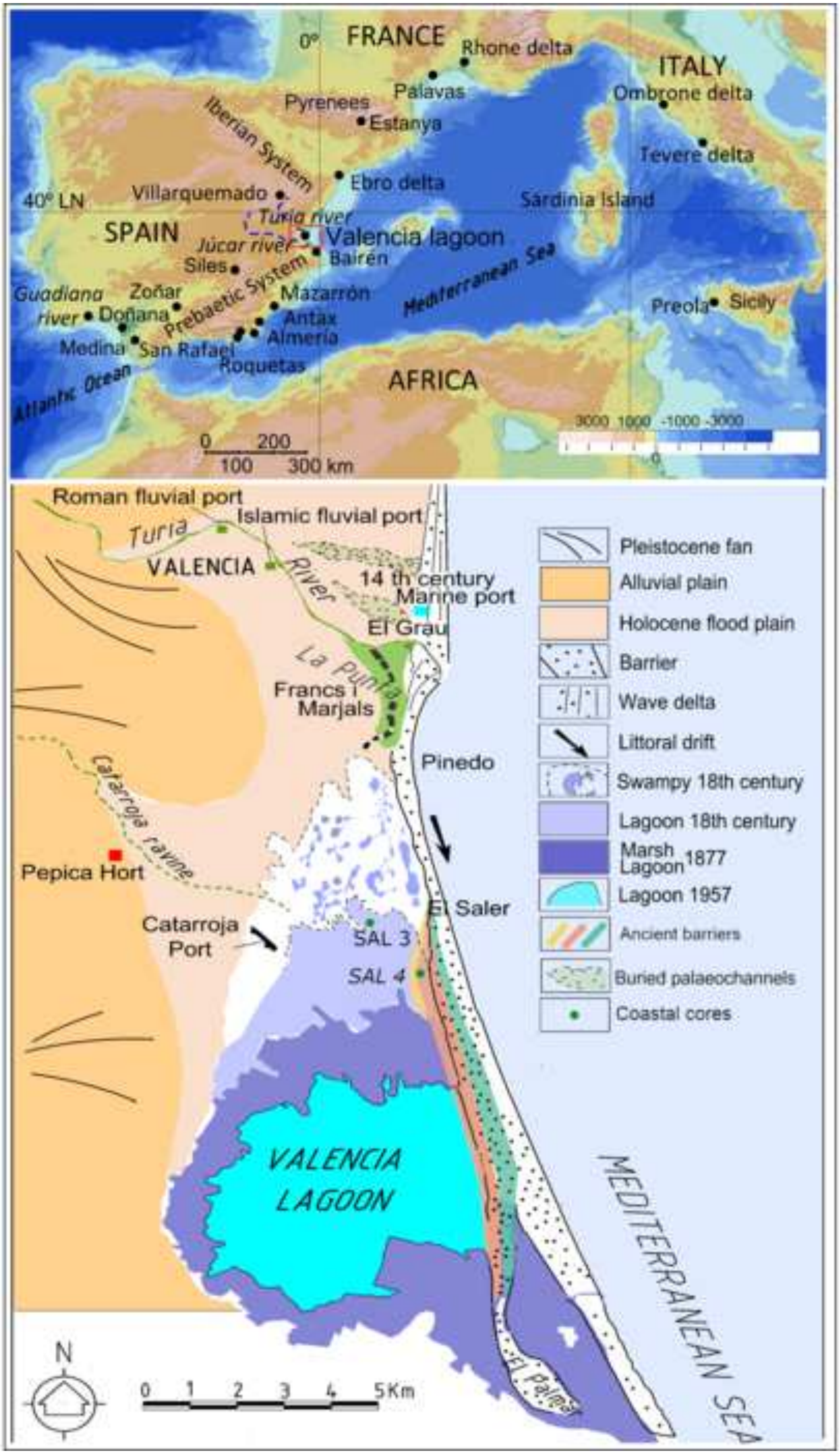

Figure 2

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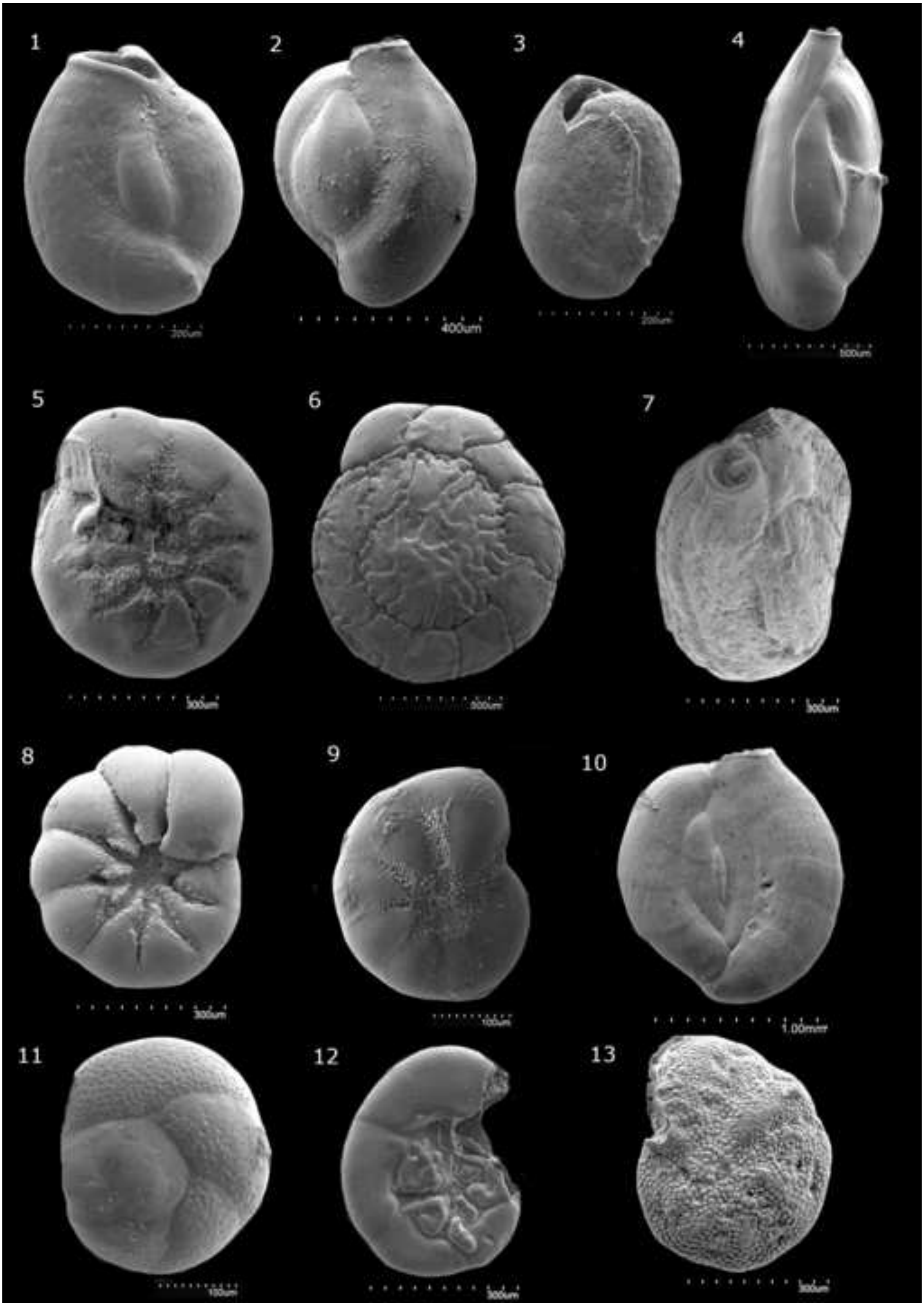

Figure 3

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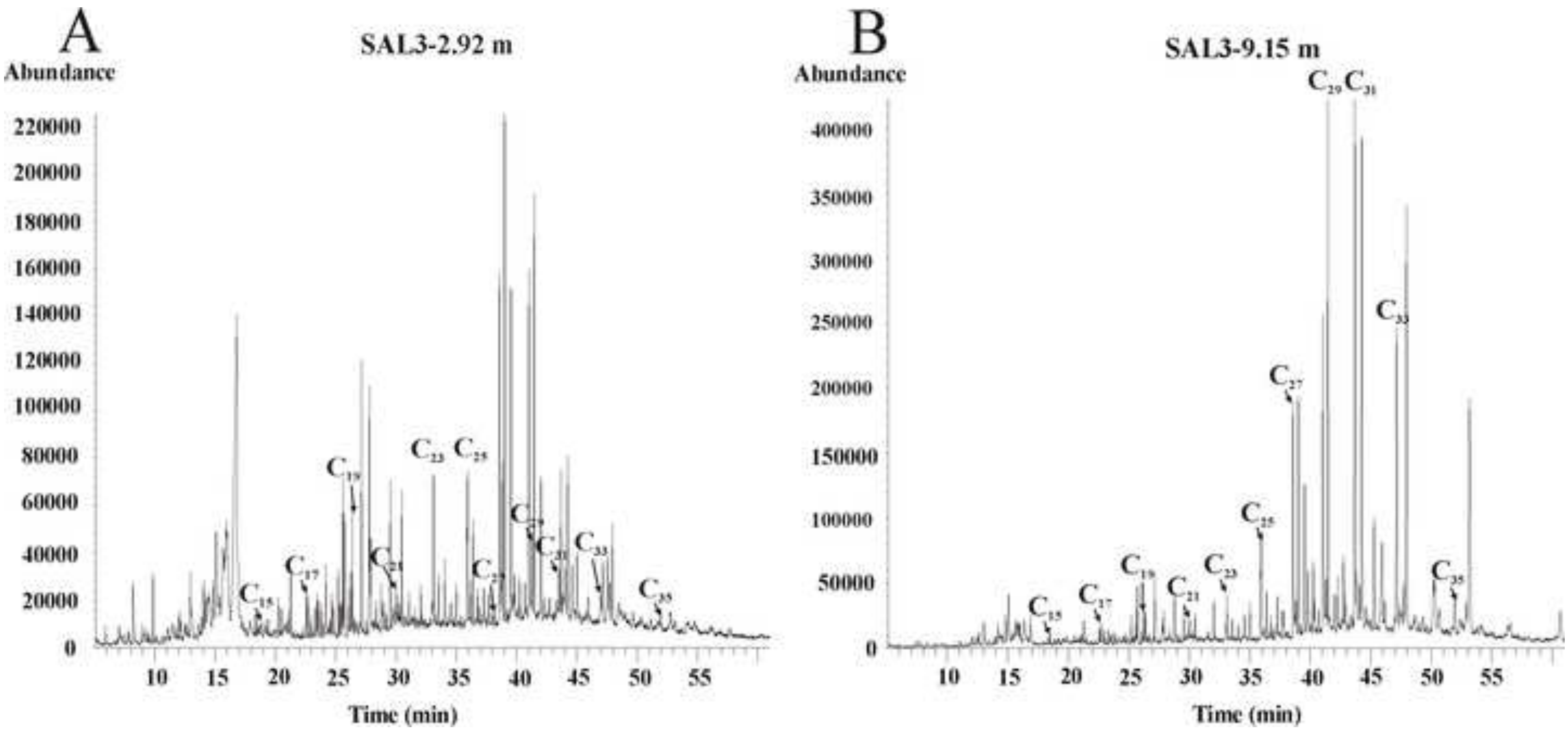

Figure 4

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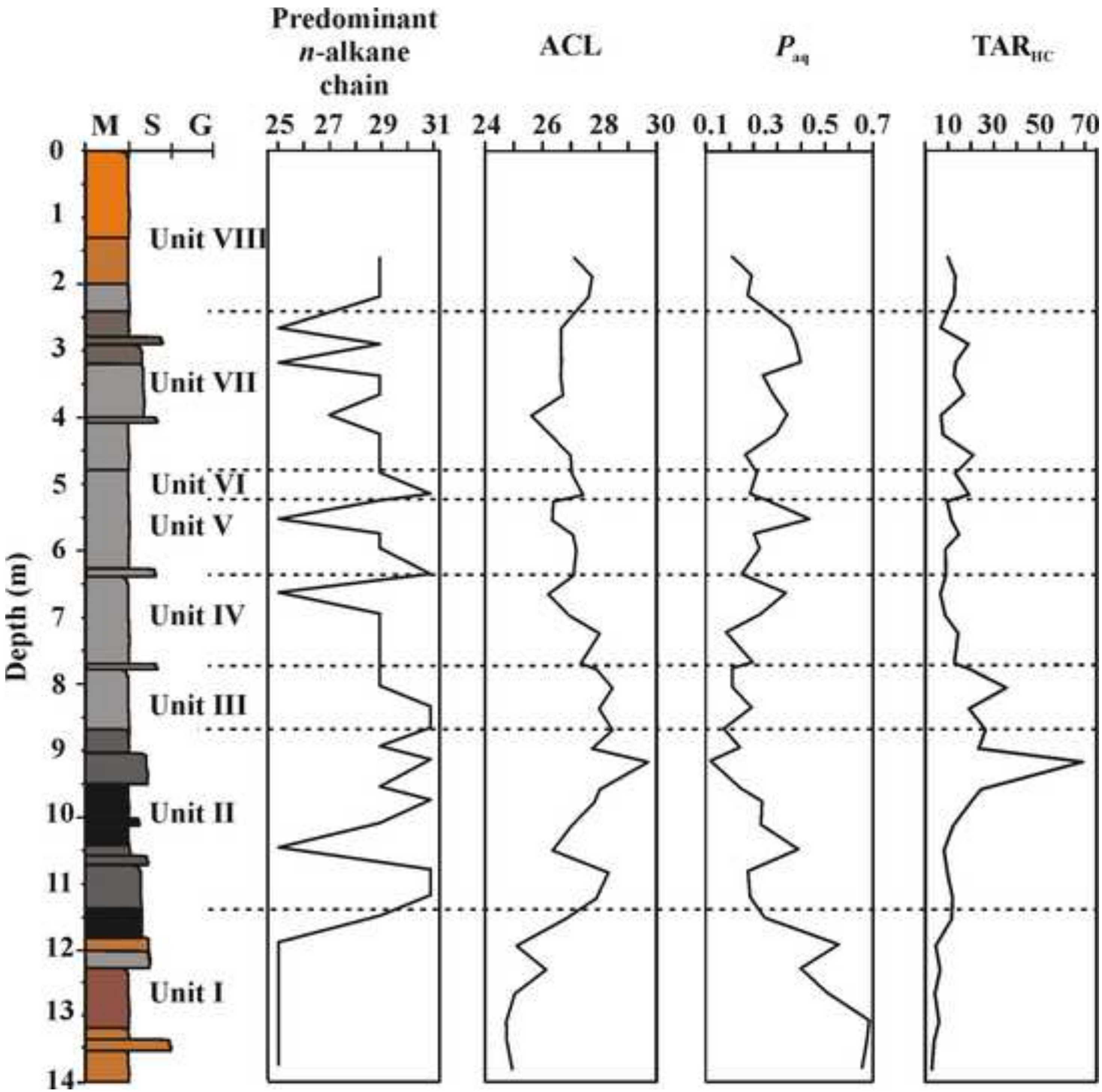

Figure 5

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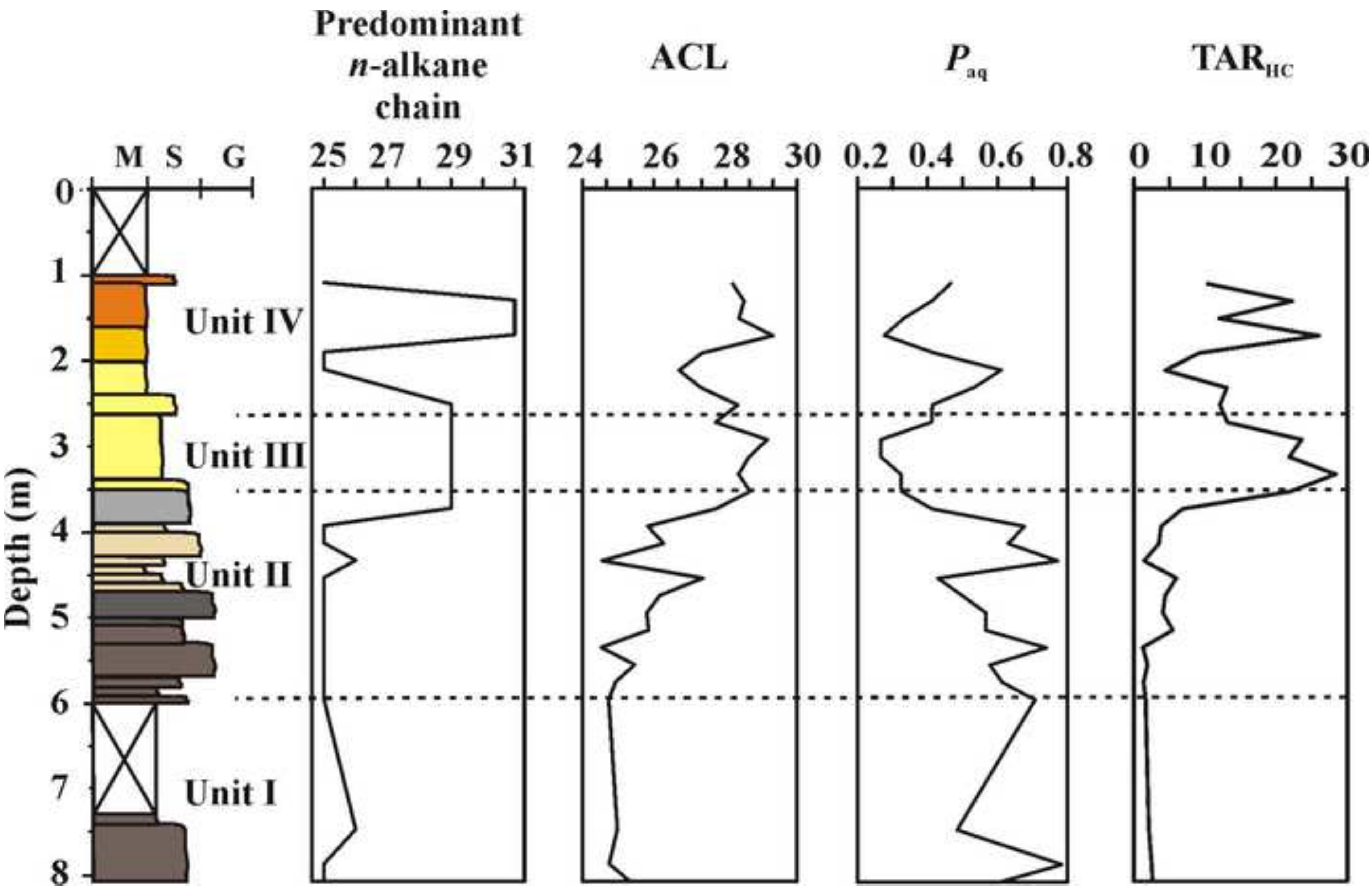

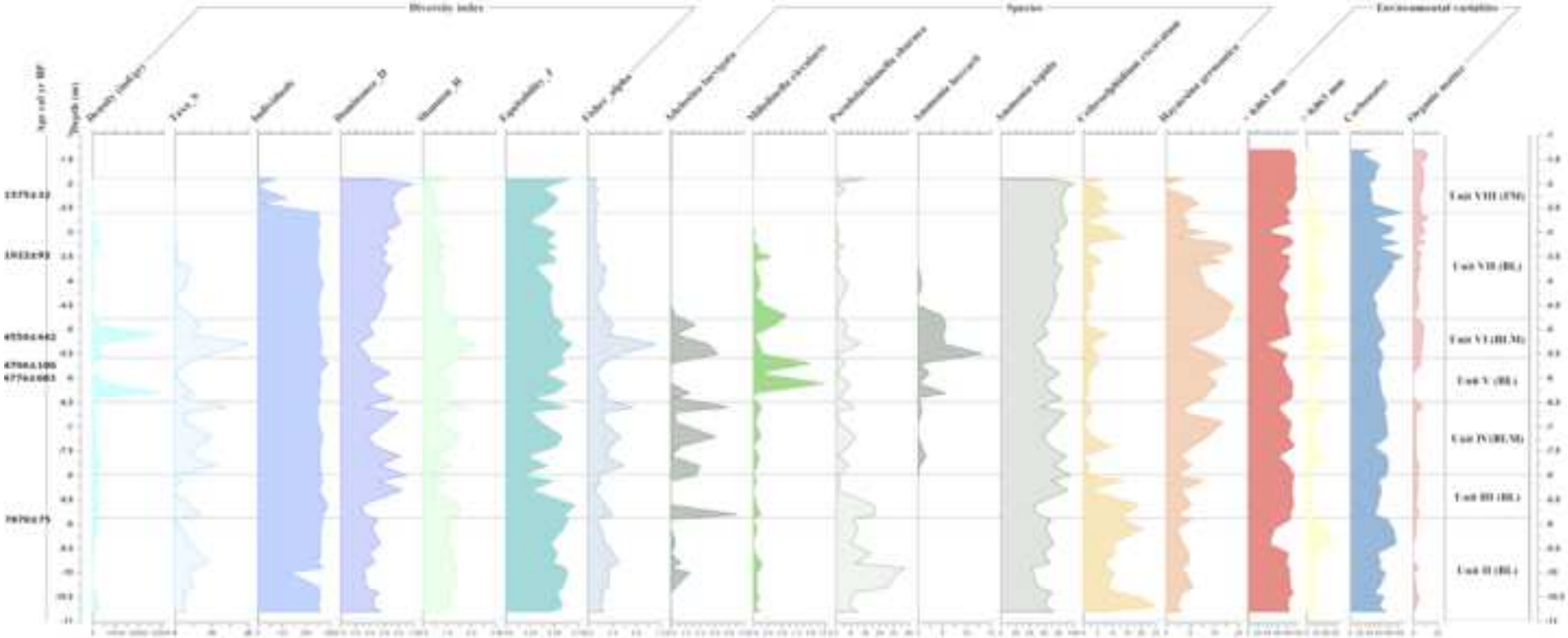
Diversity index
Species
Environmental variables

Figure 7

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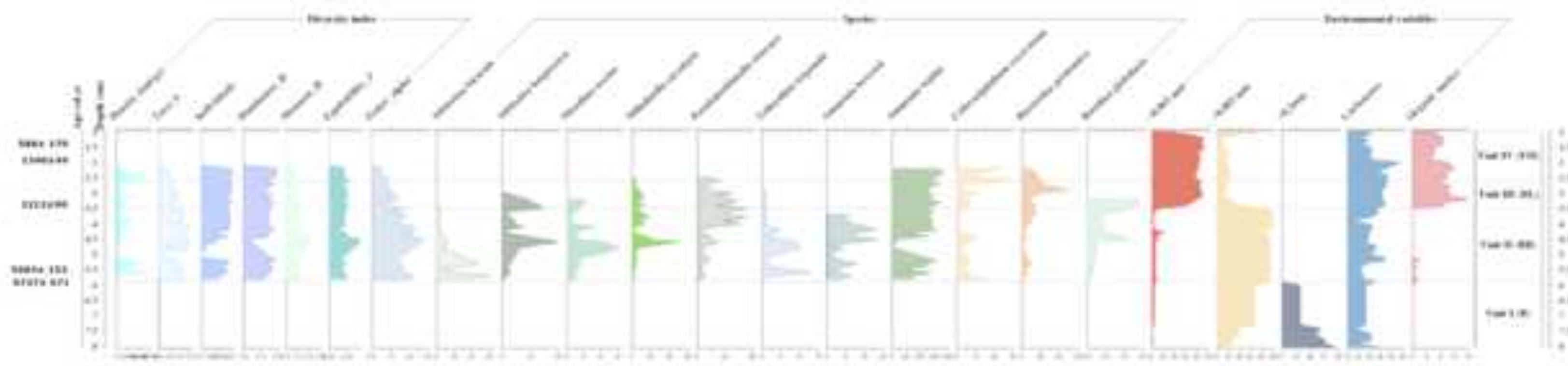
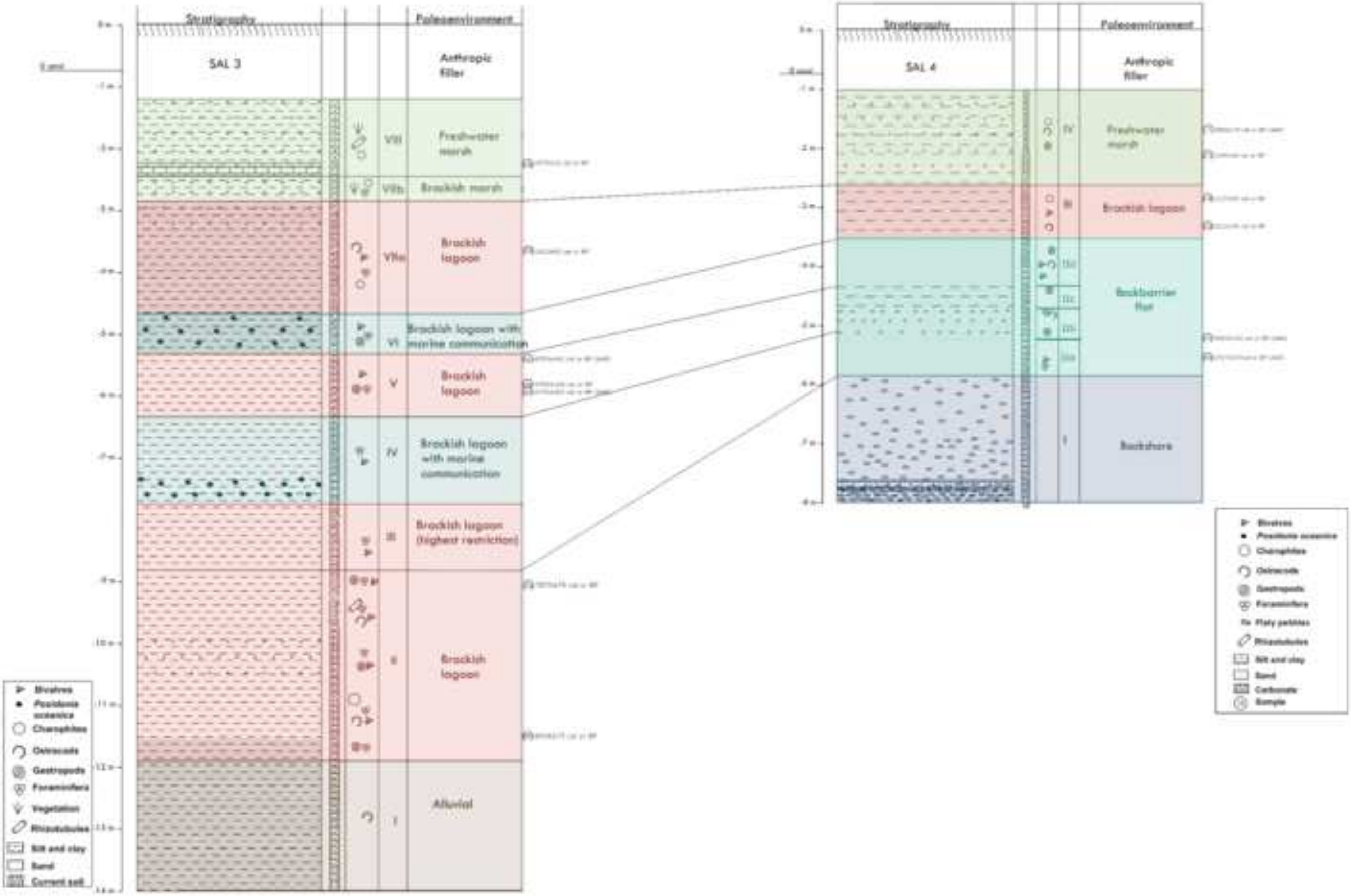
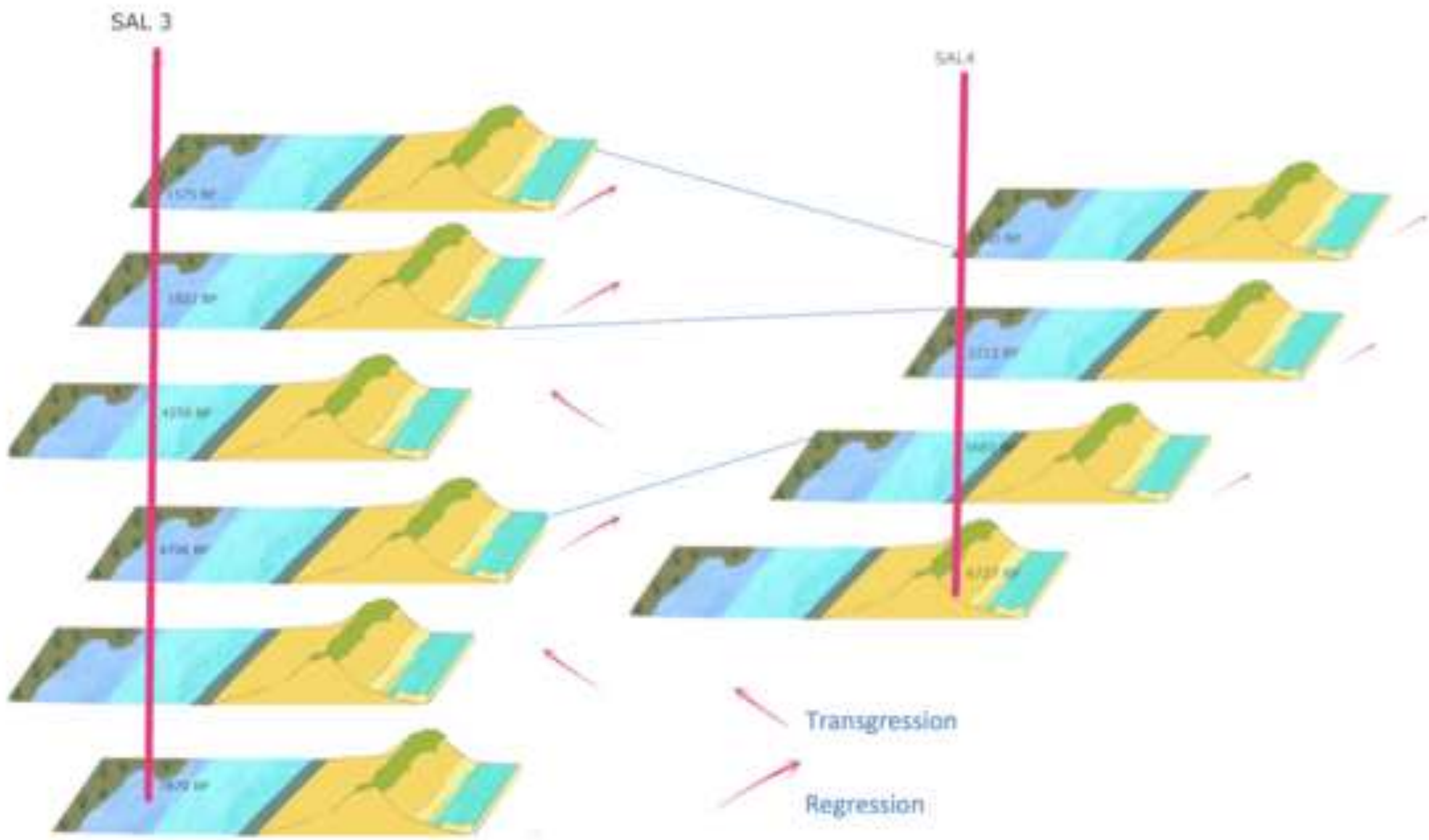


Figure 8 Click here to access/download;Figure;Figure 8.png




SAL 3
SAL 4
Transgression
Regression

López-Belzunce, M. Writing - Review, formal anaysis, Investigation

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: