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Holocene coastal environmental changes and human occupation of the lower Hérault River, southern France

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A R T I C L E I N F O

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A B S T R A C T

Sea-level rise, human impacts and climate change have deeply affected coastal environments during the Holocene. These forcing factors are studied using the Lower Hérault valley, which constitutes a very representative Mediterranean case study because of (i) its very early, intense and continuous land use since Neolithic times, and (ii) its sensitivity to sea-level rise and Mediterranean climate changes over a relatively small watershed. 34 cores and 61 AMS radiocarbon dates, associated with biological and geochemical analyses, have allowed us to precisely reconstruct the Holocene evolution of the lower valley. Until 6500 cal yr BP, a wave-dominated morphology and retrogradational dynamics were reconstructed. During this phase, ephemeral channels and successive river mouths formed and were rapidly submerged by sea-level rise. The progradational phase began after 6500 cal yr BP, and the alluvial plain gradually built seawards with the formation of a beachridge system outside the valley. Growth of the fertile alluvial plain was coeval with the development of Neolithic agriculture. This alluvial progradation gradually filled the estuary with advances of the mouths, several shallow lagoons and sandbar. The high density of information collected allows us to recognize, for the first time, a pronounced fluvial-dominated deltaic morphology, especially 3000 years ago, during the Bronze Age. Lagoonal and coastal shores were continually inhabited. Human land use continually adapted to geomorphological and environmental changes. Around 300 years ago, the delta shifted to a wave-dominated system.

1. Introduction

Between the Last Glacial Maximum (ca. 22 ka BP) and ca. 6 ka BP, sea level rise (SLR) displaced Mediterranean shorelines inland by transgressive dynamics. At a wide scale, the pace and distance of shoreline migration was mainly mediated by the morphology (geomorphological heritage) of the transgressive surfaces which were narrow in active margins and/or mountainous areas (Dubar, 1988), or large in passive continental margin (Aloisi et al., 1978; Labaune et al., 2008). At a smaller geographical scale, fluvial valley incision is also an important factor. In such a geomorphological fluvial context, the maximum flooding surface can be more than 13 km from the current coastline (Dubar and Anthony, 1995; Dubar, 2004; Garcia-Garcia et al., 2005; Devillers, 2008; Traini et al., 2013). These flooded valleys or rias (Goudie, 2018), were subsequently filled by alluvial deposits because of the slowing of sea level rise, attested in almost all of the geological contexts of the Mediterranean from around 7000 BP (Pirazzoli, 1991; Bard et al., 1996; Vacchi et al., 2016), in a context of low accommodation space. The rate and timing of the progradation phase is sensitive to variations in sediment supply, related to human and/or climatic events (Devillers, 2008; Anthony et al., 2014). For large river systems, these dynamics led to deltaic construction from the narrow valley to the open sea (Aloisi, 1986; Stanley and Warne, 1994; Vella et al., 2005; Vött et al., 2006; Amorosi et al., 2004, 2013). For smaller valleys with lower sediment supply, the flooded fluvial valley topography (ria) was progressively silted but did not exceed the mouth of the valley as illustrated by the present shorelines of most Mediterranean fluvial embayments (Anthony et al., 2014). Depending on

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climate, human history and geomorphological heritage, sedimentation in some systems has not reached yet the downstream valley, as for example for some small watersheds in the Northern part of the Black Sea (Dolukhanov et al., 2009).

Based on these trends, we can formulate the following hypotheses. During the transgressive period (between ca. 18 ka BP and 7 ka BP), the retrogradational coastal system track could produce a wave-dominated delta morphology (Galloway, 1975; Anthony, 2015) because of the lack of sedimentation, the great accommodation space and the rapid sea-level rise.

During the first progradation phase (before ca. 7 ka BP), the river-dominated delta morphology (Galloway, 1975; Anthony, 2015) was favoured by a low accommodation space in the narrow valley (Homewood et al., 2000). Wave energy was low, because of the distance from the offshore zone, which concentrated sediment deposition near the river mouth (Allen, 1993). It often resulted in a deltaic morphology dominated by fluvial channels and lagoon systems (Fig. 1).

During the second progradation phase, siltation shifted to offshore areas, and the accommodation space became more significant, leading to wave-dominated delta morphology. The active delta front was also more exposed to wave energy, dispersing sediments over wider areas (Allen, 1990, 1993; Anthony and Héquette, 2007). Much like the present morphology of deltas, the shorelines were regularized into large concave curves punctuated by the rocky capes. The lagoons were infilled by sediment supply. For these wave-dominated deltas (Galloway, 1975), offshore dynamics were the main geomorphological agent.

Sediment accumulation of river systems at base level, linked to the relative stability of sea level from 7500 cal yr BP (Lambeck and Bard, 2000; Vacchi et al., 2016), led to the formation of fertile soils and a constant freshwater supply. These environmental conditions were conducive to human settlement and to the emergence of structured societies and trades along the coast (Day et al., 2007; Guilaine and Verger, 2008; Garcia and Sourisseau, 2009). Several studies have shown a direct relationship between the development of deltaic areas and the sedentarization of human societies between 8500 and 6500 yr BP (Stanley and Warne, 1994; Kennett and Kennett, 2006; Hu et al., 2013). Before 5000 yr BP, many archaeological sites were located close to deltaic areas. These rapidly evolving environments were inhabited by societies that derived their livelihood from the agricultural, fisheries and tradding potentialities (Fokkens and Harding, 2013; Guilaine, 2003; Brückner et al., 2002, 2005; Devillers, 2008; Bertoncello et al., 2014). In these areas, the environmental and human dynamics are closely intertwined, in both space and time (Carozza et al., 2012; Brisset et al., 2018).

Although our understanding of human-environment interactions and coastal changes in deltaic areas has advanced significantly in recent years, many questions remain and can only

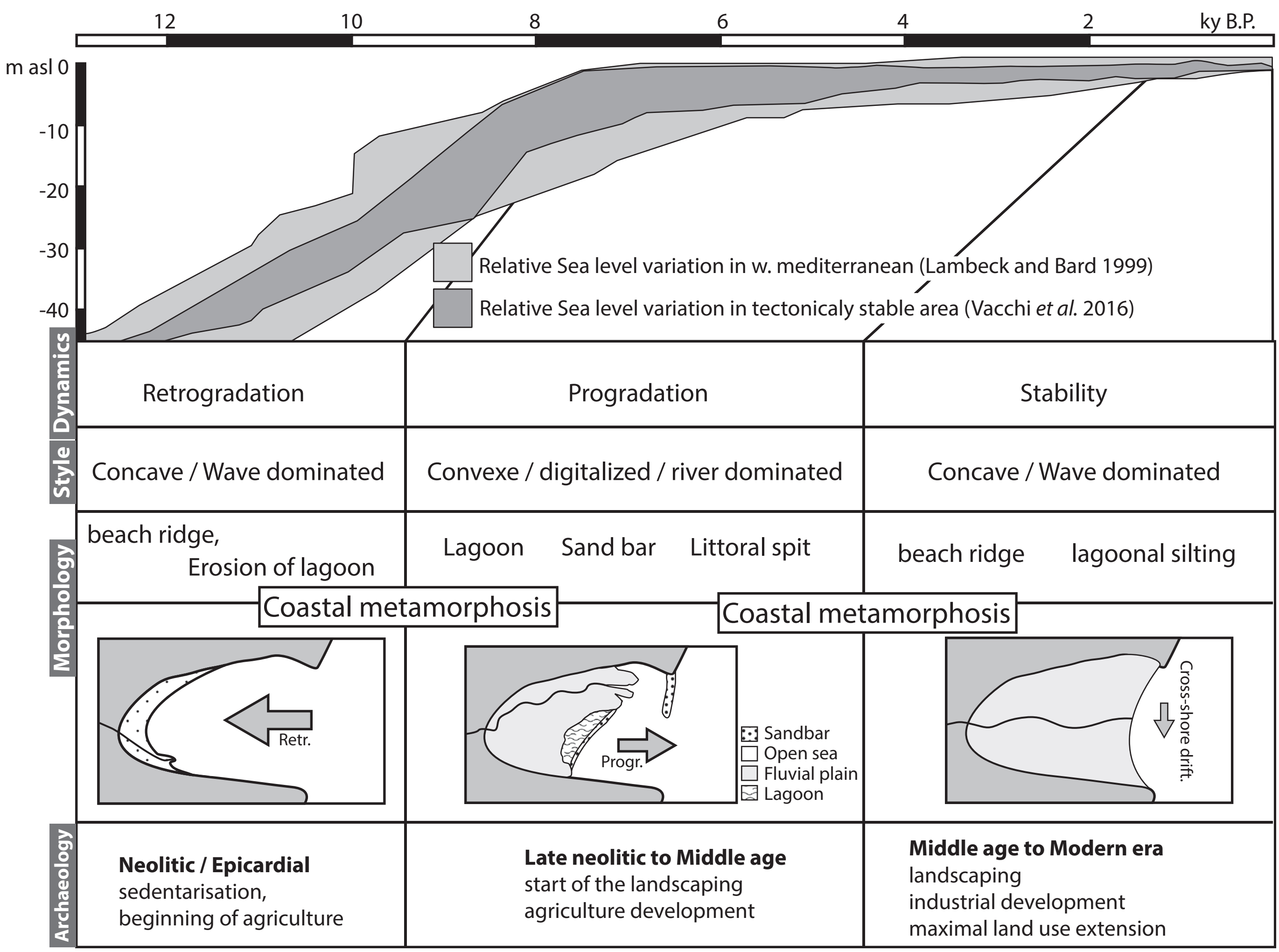

Fig. 1. Coastal metamorphosis during the Holocene.

be answered by the multiplication of coring. What was the chronology of these changes? Beyond the simple change of shoreline, is the coastal metamorphosis, namely changes in the nature of the coastal environment, could be proved and measured? Were coastal changes observable at human time-scales? How did environmental changes affect the economic and agricultural systems until the Neolithic?

The landscape changes at Agde area, due to the construction and evolution of the Hérault deltaic plain, favoured the installation of ancient societies, especially during the early phase of Neolithization in southern France (Guilaine et al., 2007; Briois and Manen, 2009; Guilaine, 2017). But this area also attests to a dense, continuous and rich occupation history for all the archaeological periods of the Bronze Age, Iron Age and Antiquity (Lugand and Bermond, 2002; Ugolini et al., 2002; Gomez, 2011; Gascó et al., 2012; 2015). Archaeological remains of these ancient settlements are sporadically detected in the Hérault catchment and on the rocky volcanic promontory of Agde. By contrast, our understanding of the settlement history of the lower Hérault plain is poor due to the significant sediment accumulations in these areas (Ambert *in* Lugand and Bermond, 2002; Ambert, 2001; Ropiot, 2009; Gomez, 2011; Gascò et al., 2012; 2015).

The aim of this paper is to investigate the Holocene geomorphological evolution of the Lower Hérault valley, in order to establish a dynamic model for coastal changes since 10 000 y. BP. The Lower Hérault valley and the Agde area constitute interesting case studies to probe coastal changes in and around archaeological contexts (Garcia, 1995). It could be used as a model for the Holocene morphogenesis and human-society co-evolution.

To refine the landscape evolution in the Hérault lower valley and improve our understanding of the environmental context of the site of La Motte, a multidisciplinary research project was initiated. The main objectives of this project were notably to determine the extension of the lagoonal-marine domain inside the palaeo-ria, the position of the coastal sandbars and barrier beaches, and the palaeogeography of the floodplain and palaeochannels of the Hérault River. This study is the first one to be undertaken in the Hérault valley, and complements previous research on western Mediterranean deltas and coastal geosystems during the Holocene (Dubar and Anthony, 1995; Blanchemanche et al., 2002; Dubar, 2004; Arnaud-Fassetta, 2002, 2003; Vella et al., 2005; Devillers et al., 2007; Bertoncello et al., 2014; Faïsse et al., 2015; Dolez et al., 2015). The originality of this work is the highly detailed geomorphological evolution provided by numerous cores and the better understanding of the relation between societies and environment in Agde territory. This paper focuses on the palaeogeographical evolution of the lower Hérault valley and is based on the bio-sedimentological study of 36 sedimentary cores from the coastal plain.

2. Study area, a mediterranean coastal floodplain

2.1. Geomorphic setting

The Hérault River is located on the Languedoc plain, in South of France. It is a Mediterranean coastal river and its source is Mount Aigoual in the Cevennes area. Its geomorphology begins at the end of the Eocene. The Pyrenean-Alpine orogeny created the Villeveyrac syncline, north of the Etang de Thau, and the anticline of Castelnau-de-Guers, northeast of Nézignan-l'Evêque (Fig. 2), which forms the very large structure of the Hérault valley. After the Late Miocene, a regression associated with the Mediterranean Messinian salinity crisis (Clauzon et al., 1987; Ambert et al., 1998) incised the area between the current Orb (west of the Hérault valley) and Hérault rivers (Ambert et al., 1998; Larue, 2009). The discordant Pliocene series shows a succession of marine sediments and continental deposits filling the deeply incised Messinian palaeovalley and exceeding it up to 100 m NGF.

Volcanic activity occurred in the lower Hérault valley from the late Lower Pleistocene to the early Middle Pleistocene (Berger et al., 1978; Féraud and Campredon, 1983; Gastaud et al., 1983). It was characterized by effusive, strombolian, and hydromagmatic eruptions that respectively created the basaltic plateaus of Agde and Saint-Thibéry, the scoria cones of Mount Saint-Loup and Mount Ramus, and the tuff-ring of Cape d'Agde. The creation of these volcanic landscapes associated with an eustatic lowstand sea level led to a new incision of the present course of the Orb and Hérault valleys. Thereafter, during Pleistocene times, a system of stepped alluvial terraces was deposited over the Pliocene sediments.

The Holocene sequence is spatially restricted to the coastal area and the active flood plain of the present rivers (Ambert, 2001). Along its lower part beyond Saint-Thibéry, it flows in meanders on the plain. The slope of the river is low, leading to the formation of a low and flat coastal plain from Florensac, as well as a reduction in sediment grain-size (Berger et al., 1978). The low topography also contributes to the development of secondary networks located at the limit of the floodplain, such as the current Ardaillon River (Fig. 2). The Hérault River flows into the Mediterranean, and its watershed is around 2550 km^2. The present average river flow is ca. 50 m^3/s, but the river witnesses strong rain storms (the so-called Cevenol events). These strong rainfall events lead to brutal flood events (up to 1500 m^3/s) on the Hérault lower valley (Gest'eau, 2005). River flow has been significantly mediated by Holocene rapid climate changes (Degeai et al., 2017).

2.2. Archaeological context and human occupation of the Hérault lower valley

The west of the valley attests to the earliest documented Neolithic settlements in the western Mediterranean, dating to ca. 7600 BP. These sites provide evidence of the exploitation of the environment with new imported farming and crops techniques (Manen and Guilaine, 2007; Briois and Manen, 2009). The impact of these Neolithic societies on the forest cover and soil erosion, consequently, on fluvial sediment supply is attested by pollen (Court-Picon et al., 2010) and geoarchaeological (Devillers and Provansal, 2003) analysis. Furthermore, sites suggest the existence of docking and anchorage areas further inland, consistent with the maximum flooding stage of the Languedoc coast (Gascó et al., 2015). The coastal plain and the most fertile lands at this time occupied a small area because of the ending of the transgressive phase.

At the beginning of the Bronze Age (ca. 4250 cal yr BP), landscape clearance can be attributed to several small settlements. They probably benefited from the stabilization of mean sea level and the progradation phase which contributed to create a lagoonal system and alluvial plain. Nonetheless, the paleogeography and the coastline, as well as the deltaic, lagoonal and fluvial (i.e. channels) systems are unclear.

Until 2011, underwater archaeological surveys undertaken by UMR5140 ASM and IBIS association in the Hérault riverbed led to the discovery of a protohistoric dwelling dating to the late Bronze Age (Bronze final IIIb, between ca. 3000 and 2700 cal yr BP). This archaeological site, called La Motte, is located north of Agde, in the middle part of the coastal plain, at −5 m NGF. The site comprises ceramics and organic deposits, wood-pile alignments and accumulations of basalt blocks, interpreted as a managed lagoon-river bank in the vicinity of the habitat (Gascó et al., 2015). This pile-

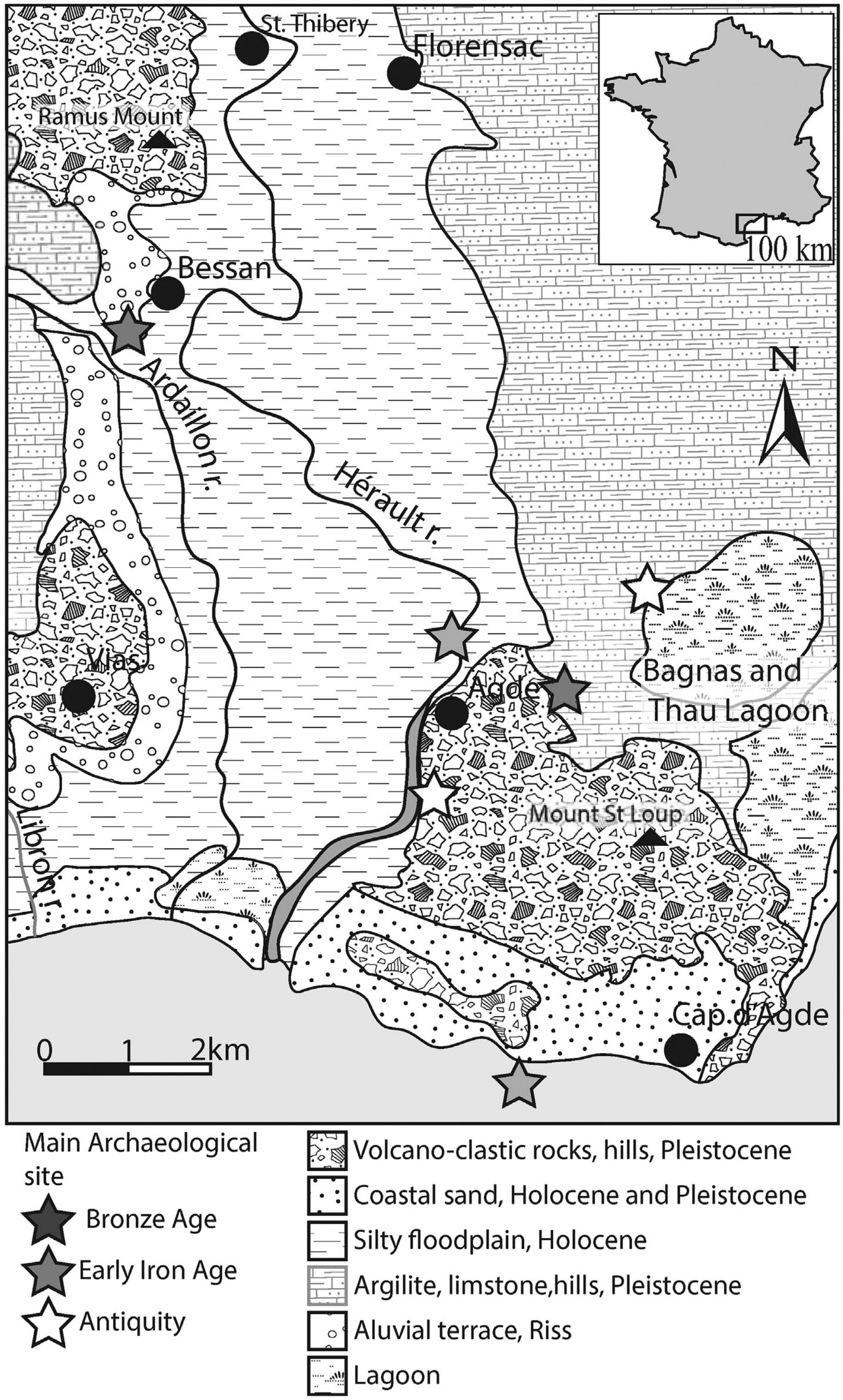

Fig. 2. Geological map of the lower Hérault region.

dwelling settlement lies near lagoonal clay layers and river-mouth deposits, which demonstrate that this Bronze Age settlement was located between a palaeolagoon and a river mouth. Understanding the environmental evolution of deltaic plain is therefore key to contextualizing the archaeological data.

Downstream, close to the sea, the Cap d'Agde harbour excavation has unearthed many metal objects consistent with human societies (Mazière, 2013). The populations of the end of the Bronze Age have invested the Hérault lower valley and the Mediterranean coastline.

For the late 7th century BC, the excavation of the Peyrou Necropolis shows the presence of an indigenous community (Figs. 2 and 3) on the basaltic promontory of Agde. At that time, local

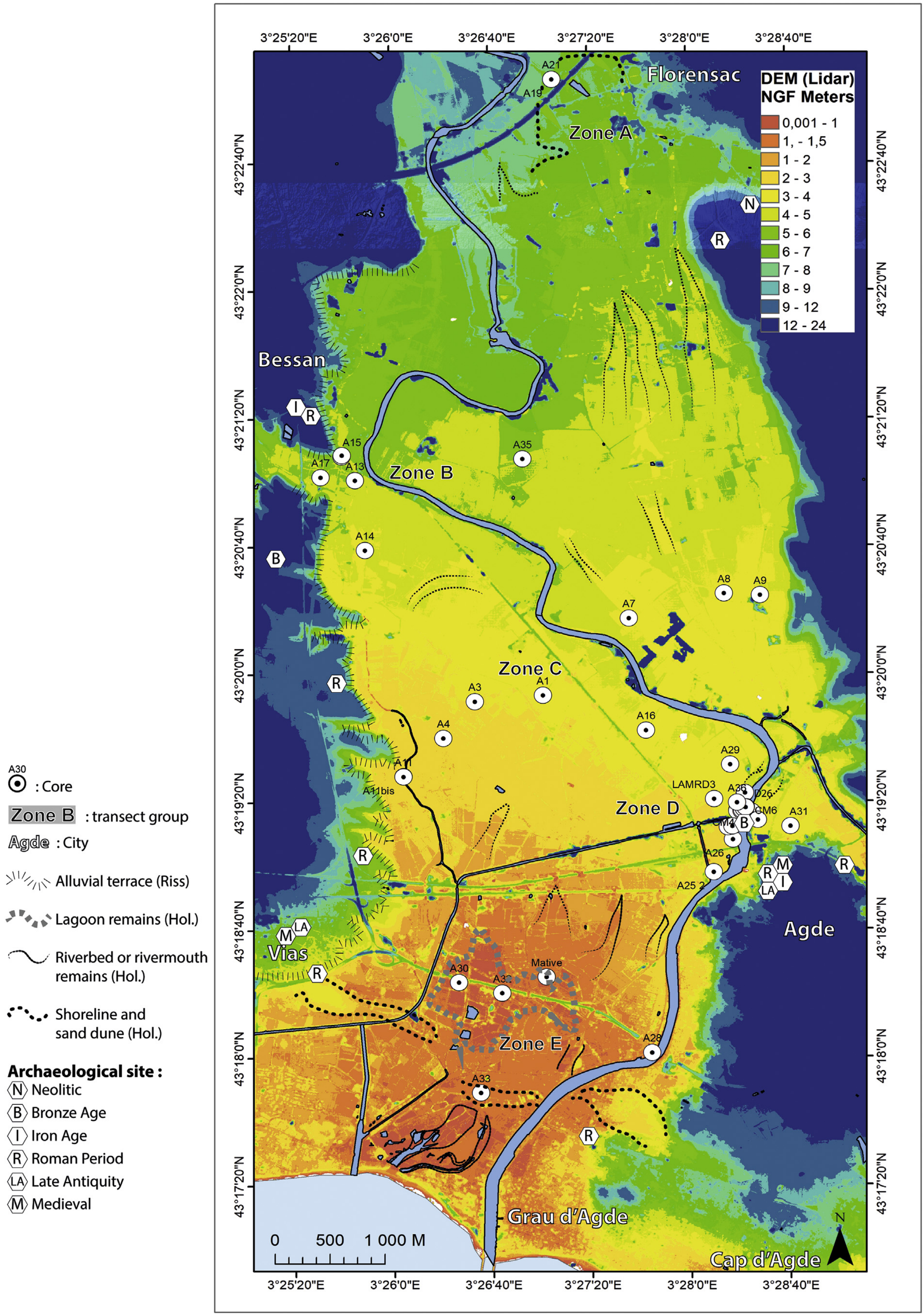

Fig. 3. Lidar, morphological and archaeological map of the lower Hérault valley.

people had already established contacts with the Mediterranean world (Ugolini, 2010), as demonstrated by the Greek vases from the necropolis of Peyrou (Nickels et al., 1981; Dedet and Schwaller, 2017). At about 4.4 km from the current mouth of the Hérault River, a shipwreck cargo (Garcia, 2002) or more likely votive deposit (Gascó et al., 2012) dated to the 6th century BC was discovered and confirms maritime activity and long-distance trade in the Agatois area.

The foundation of the ancient Greek city of Agde dates to 550-525 BC. It will remain active until about 50 AD (Nickels et al., 1989; Nickel et al., 1989; Ugolini et al., 2002). The city is installed on a volcanic promontory overlooking the left bank of the Hérault River. Lower draught shipwrecks went up the river to trade with the native populations. The location of the Greek harbour is still not known, due to the progradation and avulsions of the Hérault delta, and thus this work could greatly help to find it.

During the early Roman Empire, Agde became a key town. Numerous sites were mentioned, and trade on the river, related to the export of wine, is attested (Lugand and Bermond, 2002). At this time, the progradation of the Hérault delta led to the infilling of lagoons and an extension of fertile land conducive to human activities. Nonetheless, the environment of the city of Agde is not known during this period.

3. Materials and methods

3.1. Coring

The Holocene palaeoenvironments of the Hérault lower valley have been reconstructed using sedimentological, palaeobiological and chronostratigraphic data. Thirty-four cores were drilled on the alluvial plain, all of them yielding precise stratigraphic information. The lithological, geochemical and biological content were analysed for ten stratigraphic cores. These cores formed a transversal transect to the deltaic plain (Fig. 3). This transect is particularly useful to reconstruct palaeoenvironments of the alluvial plain, and to spatially constrain the palaeo-channels of the Hérault River and its palaeocoastline. The coring campaign was undertaken in April and October 2014 using an Atlas Copco Cobra TT percussion corer. The sampling interval depends on the nature of the sediment, and varied between 5 and 10 cm. The multiplication of coring is favoured in this work compared to pollen or geophysical approaches for example. Indeed, the large number of coring is the better approach to reach the objective which is to better characterize the environments and the littoral morphology.

3.2. Lithological and sedimentological studies

In the ASM laboratory (UMR5140 Paul-Valéry Montpellier 3 University) and Geosciences laboratory (Montpellier University), the sediment texture was determined using wet sieving and laser grain sizing with a Beckman Coulter LS13320 Particle Size Analyser (Fig. 4). A Passega diagram was drawn to determine the hydrodynamic conditions of the depositional environments (Passega, 1964). To characterize the depositional environment in relation to the hydrodynamic conditions (i.e. fluvial, coastal, lagoonal environments), we used the grain-size limits observed in similar coastal environments on the Tiber delta (Salomon, 2013). The results are consistent with other palaeoenvironmental markers.

3.3. Biological studies

The palaeo-ecology of the different environments was probed using species determination of mollusc shells (macrofauna) present in the sedimentary fraction > 2 mm (Figs. 5–7) and ostracodes present in the dry sand fraction >150 μm. 47 samples were analysed. 176 specimens of macrofauna covering 10 taxa were picked and identified using the following references: Clanzig (1987), D'Angelo and Garguillo (1978), Doneddu and Trainito (2005). The ecological groups were defined according to Peres and Picard (1964), a molluscan classification system for Mediterranean species, and on the basis of the salinity gradient. For the ostracodes, 6081 specimens covering 10 taxa were picked and determined. For each sample we normalised the ostracoda density to a standard dry sample weight (10 g). The ecological groups are based on the salinity gradient between freshwater species and brackish species (Salel et al., 2016).

3.4. Mineralogical analyses

Optical mineralogical analyses of the sand fraction were performed on nine samples of an E-W core transect. The objective was to determine the influence of the Hérault River on depositional environments. Minerals of biotite and muscovite along with clasts of carbonates and Permian sandstones are indicators of the Hérault watershed, whereas quartz, feldspars, pyroxenes, amphiboles, olivines and lithic fragments of granite and metamorphic rocks are more widespread minerals or clasts.

3.5. Geochronology

The chronological framework is provided by 61 radiocarbon dates performed at Poznan (Poland) and Saclay (France). Dates performed on charcoal and organic matter have been corrected for atmospheric ^{14}C variations using the calibration curve IntCal13 (Reimer et al., 2013) (Table 1). Marine shells were calibrated using the Marine13 calibration curve (Reimer et al., 2013). For lagoonal species a Δr correction of 245 years was applied (Degeai et al., 2015). Sixty AMS ^{14}C were produced. Dated samples were rejected in three cases: (i) if a dated coastal shell was collected from sediment of a fluvial or continental environment (which has been determined with post-dating analysis); (ii) if the ^{14}C result of a marine material was significantly higher than the expected sea level at the time of deposition, indeed a marine organism collected substantially above the sea level of its time can only be reworked; and (iii) if a single date departed significantly from the age-depth model made up of a large group of reliable dating. We assume that these precautions associated with the large number of available dates is the only method to minimize error caused by reworking.

3.6. Facies catalogue

The palaeogeographic results are based on two different methods. Different facies were studied in detail in cores A4 and A8 and subsequently extrapolated to other cores in the valley. On the basis of these results, the other cores are summarized and presented on the basis of the depositional environments (Fig. 8). Palaeogeomorphological maps are based on these analyses, the radiocarbon chronology and the interpretation of present floodplain landforms revealed by Lidar DEM mapping (Fig. 3).

4. Results

4.1. Facies study in the lower Hérault valley: cores A4 and A8

Palaeobiological analyses were performed on three cores from the Zone C transect (A11, A4 and A8). A11 and A8 are located at the

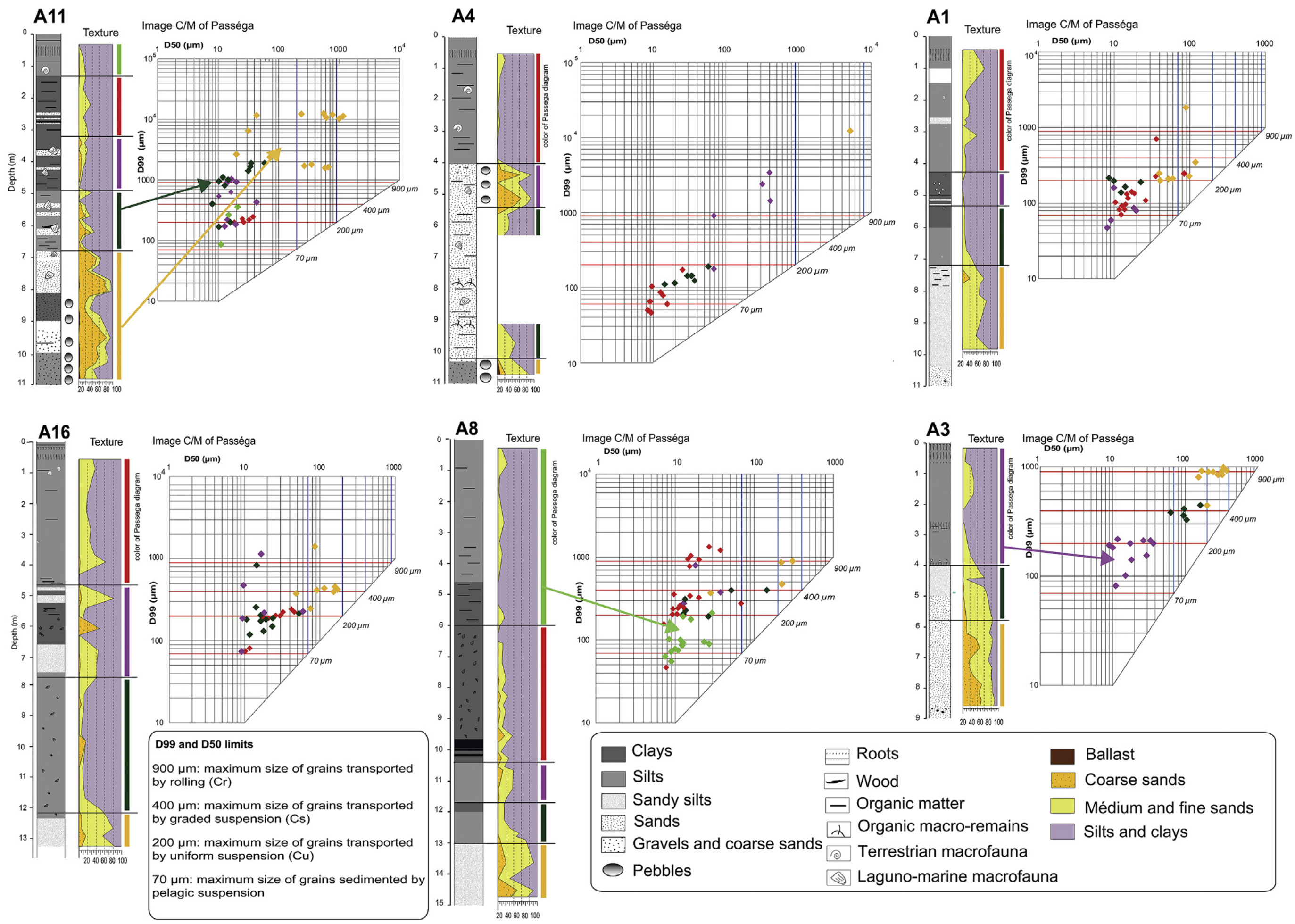

Fig. 4. Sedimentological analysis of the A1, A3, A4, A8, A11 and A16 cores.

extremities of the lower valley, on either side of the Hérault river bank (Figs. 4–8). The core A11 is also located on the right flank of the Ardaillon river.

4.1.1. Core A8

4.1.1.1. Core A8 Unit A: Facies 1. The basal unit (Unit A) between 13 and 15 m depth consists of an accumulation of ca. 70% of brown sands (50% of medium and fine sands and 20% of coarse sands) in a clayey silt matrix. The gravels fraction is virtually absent (Fig. 4). However, the C/M Passega diagram indicates that these sediments were transported by bed load (at the base) to graded suspension with rolling (at the top) (Fig. 4). This depositional environment is characteristic of open high-energy environment. This interpretation is consistent with the grain-size of the C/M image of Passega diagram limits used by Salomon (2013) to determine palaeoenvironments.

The sand fraction is composed of ca. 15% of minerals derived from the Hérault watershed (ca. 7% of Permian sandstone clasts, 5% of biotite and muscovite, and 3% of carbonates). 85% of sands correspond to minerals like quartz (78%) and to clasts of granite and metamorphic rocks (7%). The presence of minerals from the Hérault river watershed suggests fluvial inputs into this environment. The microfauna is dominated by euryhaline species such as *Loxoconcha elliptica* and *Cyprideis torosa* at very high faunal population densities (Fig. 5). This association is characteristic of lagoonal environments. This is confirmed by the presence of *Loxoconcha tamarindus,* which is present in the sandy silts of the Thau lagoon (Kurc, 1961). *Hydrobia ventrosa* is the only macrofauna species present, attesting to a brackish depositional environment.

This highly hydrodynamic environment is characterized by fluvial inputs from the Hérault River. The brackish water salinity indicates a distal connection of the lagoon to the sea. The different proxies are consistent with a riverbed in connection with a lagoon.

4.1.1.2. Core A8 unit B: Facies 2. Unit B is located between 13 and 11.8 m depth and is dated at the base to 7819 ± 114 cal yr BP (Table 1). The sedimentary texture corresponds to silty sands characterised by ca. 15% of medium and fine sands. Coarse sands are virtually absent (Figs. 4 and 5). The Passega diagram indicates a pure deposit related to uniform suspension transport and a mixed deposit due to uniform suspension with the injection of graded suspension (Fig. 4). This reduction in grain size is typical of a constant and progressive environmental protection. These grain size characteristics evoke the onset of a less hydrodynamic and more protected environment, with only minor inputs of fine sands (Figs. 4 and 5). Eight ostracoda species with relatively high faunal population densities were identified. The following lagoonal species are dominant: *Cyprideis torosa*, *Loxoconcha elliptica* and *Loxoconcha tamarindus*. These are found in association with the lagoonal species *Cytherois fischeri* and the littoral species *Leptocythere lacertosa* (Fig. 5). This suggests the onset of a calm lagoonal environment in distal connection with the sea. The

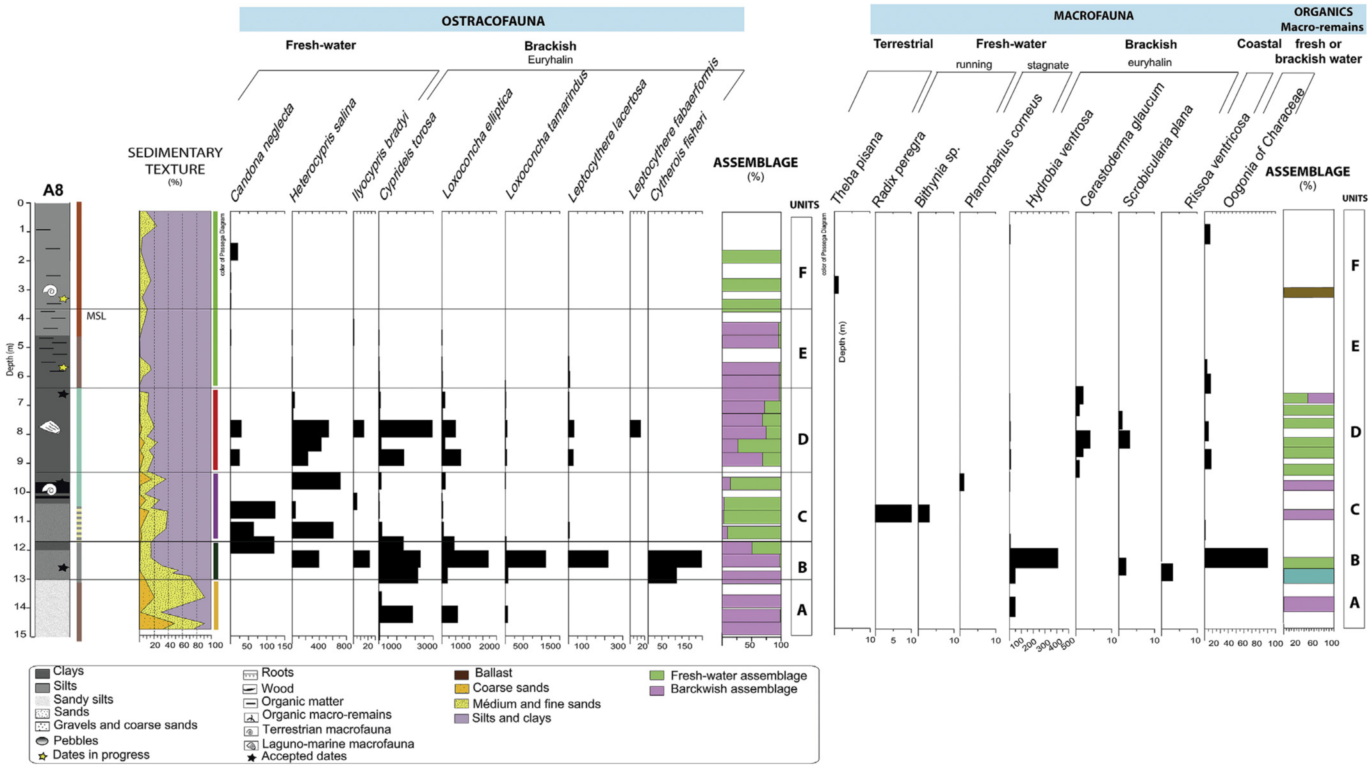

Fig. 5. Ostracod analyses of the core A8.

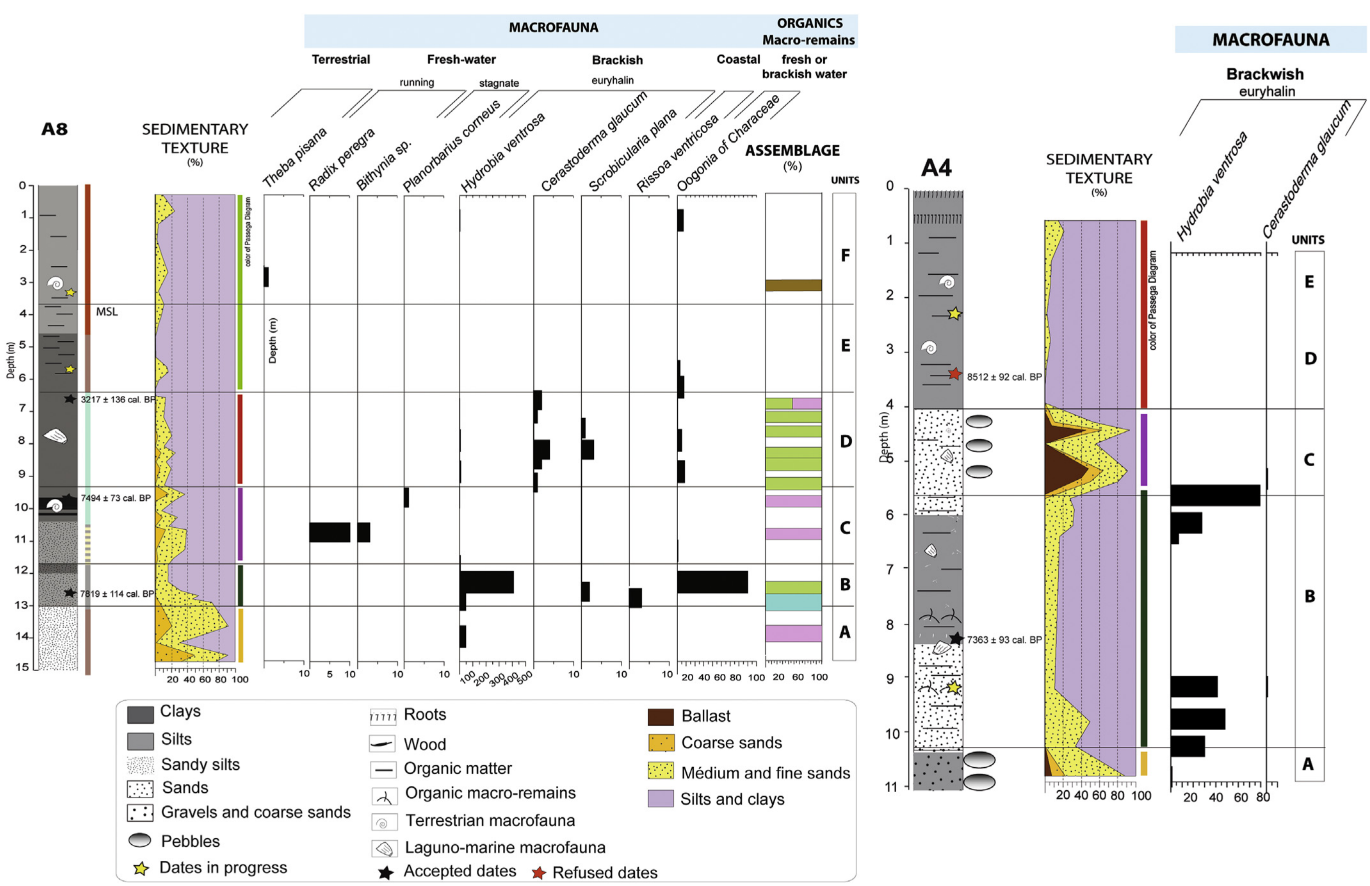

Fig. 6. Benthic macrofauna analyses of cores A4 and A8.

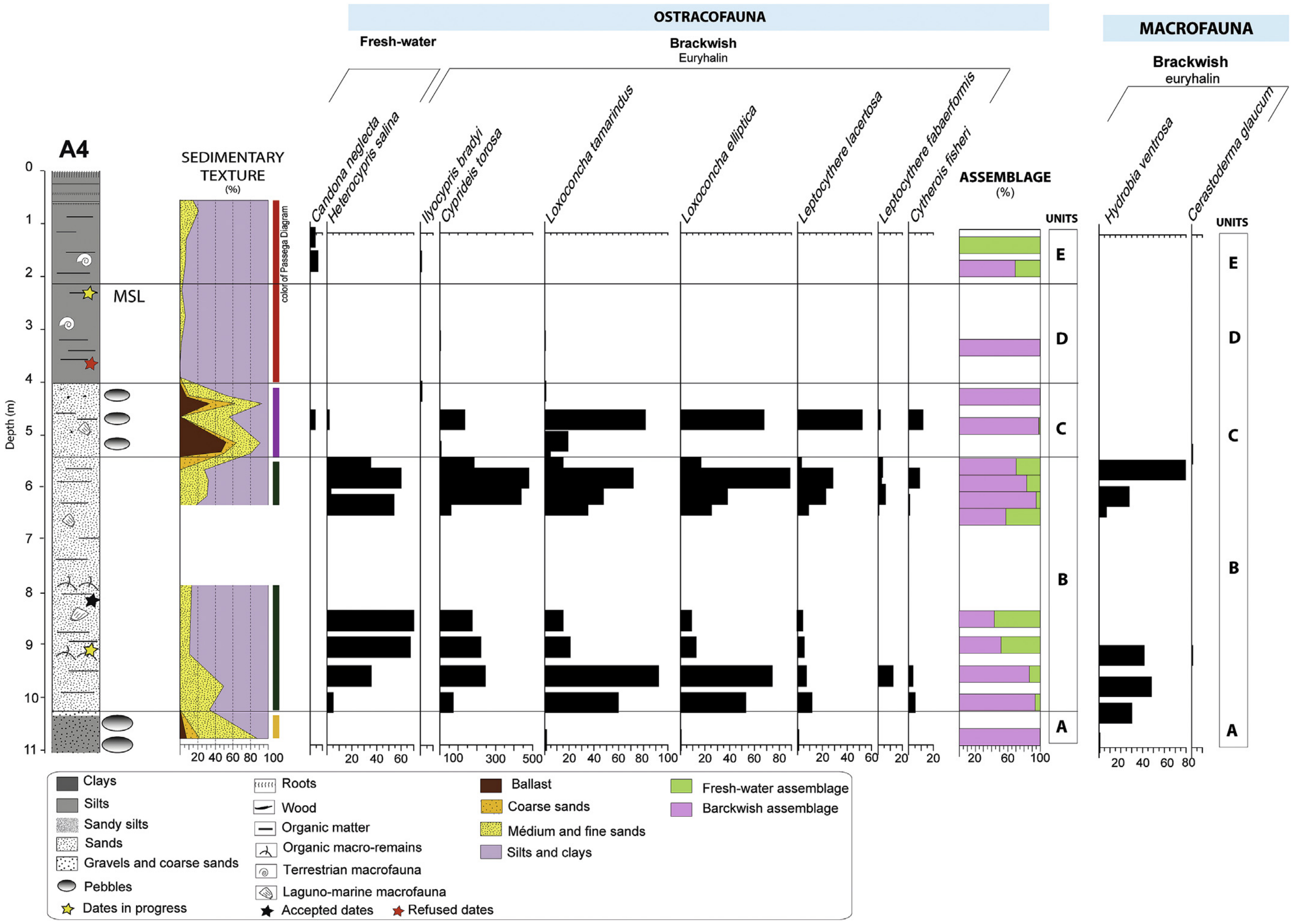

Fig. 7. Ostracod analyses of the core A4.

presence of freshwater species at high faunal densities (*Candona neglecta*, *Heterocypris salina*, *Ilyocypris bradyi*; Fig. 5) attests to the presence of a river mouth in a deltaic context. This interpretation is confirmed by some coastal (*Rissoa ventricosa*) and lagoonal (*Hydrobia ventrosa* and *Scrobicularia plana;* Fig. 6) macrofauna. Charophyte gyrogonites are present in abundant quantities (Figs. 5 and 6). They are indicative of fresh to low salinity environments (Soulié-Märsche et al., 2008) and support the hypothesis of a river mouth with hydro-sedimentological injections in a protected lagoon.

4.1.1.3. Core A8 unit C: Facies 3. Unit C is located between 11.8 and 9.2 m depth. It consists of an accumulation of silty sand (ca. 20% of medium and fine sand and ca. 10% of coarse sand; Figs. 4 and 5). Between 11.6 and 10.3 m depth, the sediment comprises an alternation of greyish silty sand with whitish sandy-marls. The sand percentage is higher than in the rest of the unit (ca. 35%). Between 9.8 and 10.1 m depth, the sediment comprises an organic deposit. This peat deposit has been dated to 7494 ± 73 cal yr BP (Table 1). The Passega diagram places the sandy-marl sub-unit in mixed deposit due to uniform suspension with the injection of rolling deposit (Fig. 4). The environment is calm and protected but records some sandy-marl injections. Lagoonal ostracods decrease in favour of freshwater ostracods dominated by *Candona neglecta* and *Heterocypris salina* (Fig. 4). The environment corresponds to a freshwater swamp or a frequently flooded fluvial plain. Macrofauna species point to a hydrodynamic environment (Fig. 6). The presence of *Radix peregra* and *Bithynia* sp. in the sandy-marly sub-unit indicates a running freshwater environment. The specie of *Planorbarius corneus* indicates a stagnant freshwater pond (Fig. 6). In light of these data, unit C comprises a fluvial environment, such as a floodplain or a riverbed margin.

4.1.1.4. Core A8 unit D: Facies 4. Unit D is located between 9.2 and 6.4 m depth. The sedimentary texture corresponds to silty sand characterised by ca. 15% of medium and fine sand and 5% of coarse sand (Figs. 4 and 5). The Passega diagram indicate pure uniform suspension deposits and some sedimentary lens corresponded to uniform suspension with injection of graded suspension (Fig. 4). The ostracod diversity is high and lagoonal species reappear with the dominance of *Cyprideis torosa* (Fig. 5). The environment corresponds to a lagoon. The permanence of freshwater ostracods indicates a closed deltaic mouth. The low salinity of this lagoonal environment is attested by Charophyte gyrogonites. *Cerastoderma glaucum* and *Scrobicularia plana* are euryhaline species that can tolerate low salinities (D'Angelo and Garguillo, 1978) (Fig. 6). The proxies from this unit are consistent with lagoonal conditions.

4.1.1.5. Core A8 units E and F: Facies 3bis. These two units show similar sedimentary textures consistent with the accumulation of silts. The medium and fine sand fractions are very low (ca. 10%) (Fig. 4). The Passega diagram shows a pelagic suspension for these

Table 1
AMS 14C radiocarbon date.

Sample	Lab code	Material	Species	Age BP	±	Calib. curve	Delta R	CAL. BP.	±	Ac/Rej
LMRD1 layer9E2	Lyon-9699(SacA-31255)	Hazelnut		2220	30	IntCal13		2237.5	85.5	Ac
LAMRD3.7	Lyon-9990(SacA 32617)	Coastal Shell	Pavicardium Exiguum	6895	35	MARINE13	245 ± 30	7166.5	119.5	Rej
LAMRD3.13	Lyon-9991(SacA 32618)	Coastal Shell	Pavicardium Exiguum	7080	160	MARINE13	245 ± 30	7138.5	147.5	Rej
LAMRD3.17	Lyon-9992(SacA 35285)	Coastal Shell	Pavicardium Exiguum	6530	35	MARINE13	245 ± 30	6748.5	119.5	
LAMRD3.15	Lyon-11182(SacA37160)	Coastal Shell	Pavicardium Exiguum	6050	40	MARINE13	245 ± 30	6216.5	116.5	Ac
LAMRD3.16	Lyon-11183(SacA37161)	Coastal Shell	Pavicardium Exiguum	6285	45	MARINE13	245 ± 30	6462	141	Ac
LAMRD3.19	Lyon-11184(SacA37162)	Coastal Shell	Pavicardium Exiguum	7880	50	MARINE13	245 ± 30	8091.5	136.5	Ac
RGM1.16	Lyon-11185(SacA37163)	Coastal Shell	Pavicardium Exiguum	3910	35	MARINE13	245 ± 30	3569.5	126.5	Ac
RGM1.19	Lyon-11186(SacA37164)	Coastal Shell	Rissoa Parva	5875	40	MARINE13	245 ± 30	6038.5	126.5	Ac
RGM1.20	Lyon-11187(SacA37165)	Coastal Shell	Pavicardium Exiguum	6155	40	MARINE13	245 ± 30	6326	107	Ac
RGM1.12	Lyon-11170(SacA37146)	Charcoal		3075	45	IntCal13		3275	105	Ac
A1 410	Lyon-12195(SacA42588)	Organic sediment		4895	35	IntCal13		5648.5	62.5	Ac
A1 620	Lyon-12196(SacA42589)	Organic sediment		6440	35	IntCal13		7358.5	68.5	Ac
A1 735	Lyon-12197(SacA43381)	Organic sediment		6200	35	IntCal13		7118.5	121.5	Ac
A3 835	Lyon-12198(SacA42989)	Organic sediment		4940	30	IntCal13		5664	61	Ac
A4 235	Lyon-12199(SacA42592)	Organic sediment		3840	30	IntCal13		4278	127	Ac
A4.370	Poz-72070	Organic sediment		7750	50	IntCal13		8512.5	91.5	Rej
A4.815	Poz-71901	Wood		6460	50	IntCal13		7363.5	92.5	Ac
A4 905	Lyon-12200(SacA42593)	Organic sediment		7005	40	IntCal13		7837.5	98.5	Ac
A7.300	Lyon-12058(sacA41945)	Wood	Possidonia sp.	modern		IntCal13		0	0	Ac
A7 620	Lyon-12201(SacA42594)	Organic sediment		7345	40	IntCal13		8164	138	Ac
A7.965	Lyon-12059(sacA41946)	Organic sediment		6860	35	IntCal13		7700.5	83.5	Ac
A7.1088	Lyon-12060(sacA41947)	Organic sediment		7460	40	IntCal13		8277.5	87.5	Ac
A8 340	Lyon-12202(SacA42595)	Organic sediment		2965	30	IntCal13		3110.5	104.5	Ac
A8 580	Lyon-12203(SacA42596)	Organic sediment		4690	30	IntCal13		5452.5	123.5	Ac
A8.665	Poz-71905	Plant deposit		3030	35	IntCal13		3222	131	Rej
A8.980	Poz-71904	Plant deposit		6570	50	IntCal13		7494.5	72.5	Ac
A8.1275	Poz-71906	Wood		6990	50	IntCal13		7819.5	113.5	Ac
A11.670	Poz-72132	Organic sediment		7000	80	IntCal13		7821.5	141.5	Ac
A11 973	Lyon-12204(SacA42597)	Organic sediment		7225	40	IntCal13		8062.5	96.5	Ac
A11.495	Poz-71903	Charcoal		7350	50	IntCal13		8169.5	141.5	Rej
A12.33	Lyon-12061(SacA42986)	Organic sediment		7520	40	IntCal13		8306	99	Rej
A12.33C	Lyon-12062(sacA41949)	coquille Pavicardium	Pavicardium Exiguum	7165	35	MARINE13	245 ± 30	7423.5	99.5	Rej
A12.39	Lyon-12063(sacA41950)	Organic sediment		7120	40	IntCal13		7936	78	Ac
A12.447	Lyon-12065(SacA42805)	Organic sediment		1450	30	IntCal13		1344	45	Ac
A12.365	Lyon-12064(sacA41917)	Wood		170	30	IntCal13		145.5	144.5	Ac
A13.33	Lyon-12066(sacA41919)	Organic sediment		7685	40	IntCal13		8476	72	Ac
A13.1065	Lyon-12067(SacA42987)	Organic sediment		6450	35	IntCal13		7361.5	68.5	Ac
A14 895	Lyon-12205(SacA42598)	Organic sediment		6710	40	IntCal13		7582	75	Ac
A16 450	Lyon-12206(SacA42599)	Organic sediment		5465	35	IntCal13		6607.5	108.5	Ac
A16 590	Lyon-12207(SacA42600)	Organic sediment		5810	35	IntCal13		6607.5	108.5	Ac
A16 1295	Lyon-12208(SacA42601)	Organic sediment		7575	40	IntCal13		8380.5	52.5	Ac
A19 1060	Lyon-12209(SacA43382)	Organic sediment		7875	40	IntCal13		8765	205	Rej
MAT01 318	GrA-68762	Wood		3950	35	IntCal13		4389	130	Rej
MAT01 414	GrA-68763	Wood		3870	35	IntCal13		4287	128	Ac
MAT01 648	GrA-68765	Organic sediment		6230	40	IntCal13		7069.5	59.5	Ac
MAT01 760	GrA-68767	Organic sediment		6225	40	IntCal13		7130.5	122.5	Ac
MAT01 1214	GrA-68768	Organic sediment		7360	45	IntCal13		8176.5	135.5	Ac
MAT01 1755-1760	GrA-68769	Organic sediment		7950	45	IntCal13		8814.5	170.5	Ac
A28 670_1750	GrA-68588	Charcoal		6675	40	IntCal13		7543	68	Ac
A28 374_414	GrA-68586	Wood		510	110	IntCal13		493	178	Ac
A28 200_223	GrA-68770	Wood		80	30	IntCal13		142.5	117.5	Ac
D26 US13	Ly 11444	Wood		2700	30	IntCal13		2804	48	Ac
D26 US16	Ly 11446	Wood		2719	30	IntCal13		2812.5	52.5	Ac
D26 US15pieu 257	Ly 11443	Wood		2730	30	IntCal13		2819.5	57.5	Ac
D26 US4	Ly 9038	Caryopse *Triticum dicoccum*		2765	30	IntCal13		2863	80	Ac
D26 US11	Ly 9039	Caryopse *Triticum dicoccum*		2705	30	IntCal13		2806	49	Ac
A30 550-575	Poz-101419	Coastal Shell	Loripes Lacteus	6070	40	MARINE13	245 ± 30	5835.5	198.5	Ac
A30 320-340	Poz-101536	Charcoal		3650	35	IntCal13		3985.5	99.5	Ac
A32 200-240	Poz-101499	Charcoal		995	30	IntCal13		931	32	Ac

two deposits consistent with decantation processes in a very protected environment typical of a filling-up lagoon or alluvial plain (Figs. 5 and 6). In unit E, the sand fraction comprises residual ostracodes from unit D. The environment is characterised by the same association as unit D but in very low abundance. The lagoonal environment is filled up and progressively transformed into an alluvial plain characterized by freshwater ostracods like *Candona neglecta* (Fig. 4). The evolution into an alluvial plain is also marked by terrestrial macrofauna such as *Theba pisana* (Fig. 6). This facies is similar to unit 3. Here, however, this fluvial environment is more distal and decantation processes are dominant. The environment is characteristic of a floodplain.

4.1.2. Core A4

4.1.2.1. Core A4 Unit A: Facies 1. The basal unit (Unit A) is located between 10.2 and 11 m depth. Like unit A of core A8, it consists of an accumulation of sands (10% of coarse sand and 60% of medium and fine sand) in a clayey matrix. The main difference is the presence of a ballast fraction (15%) comprising gravels and small pebbles (Fig. 7). The Passega diagram indicates a rolling transport processes

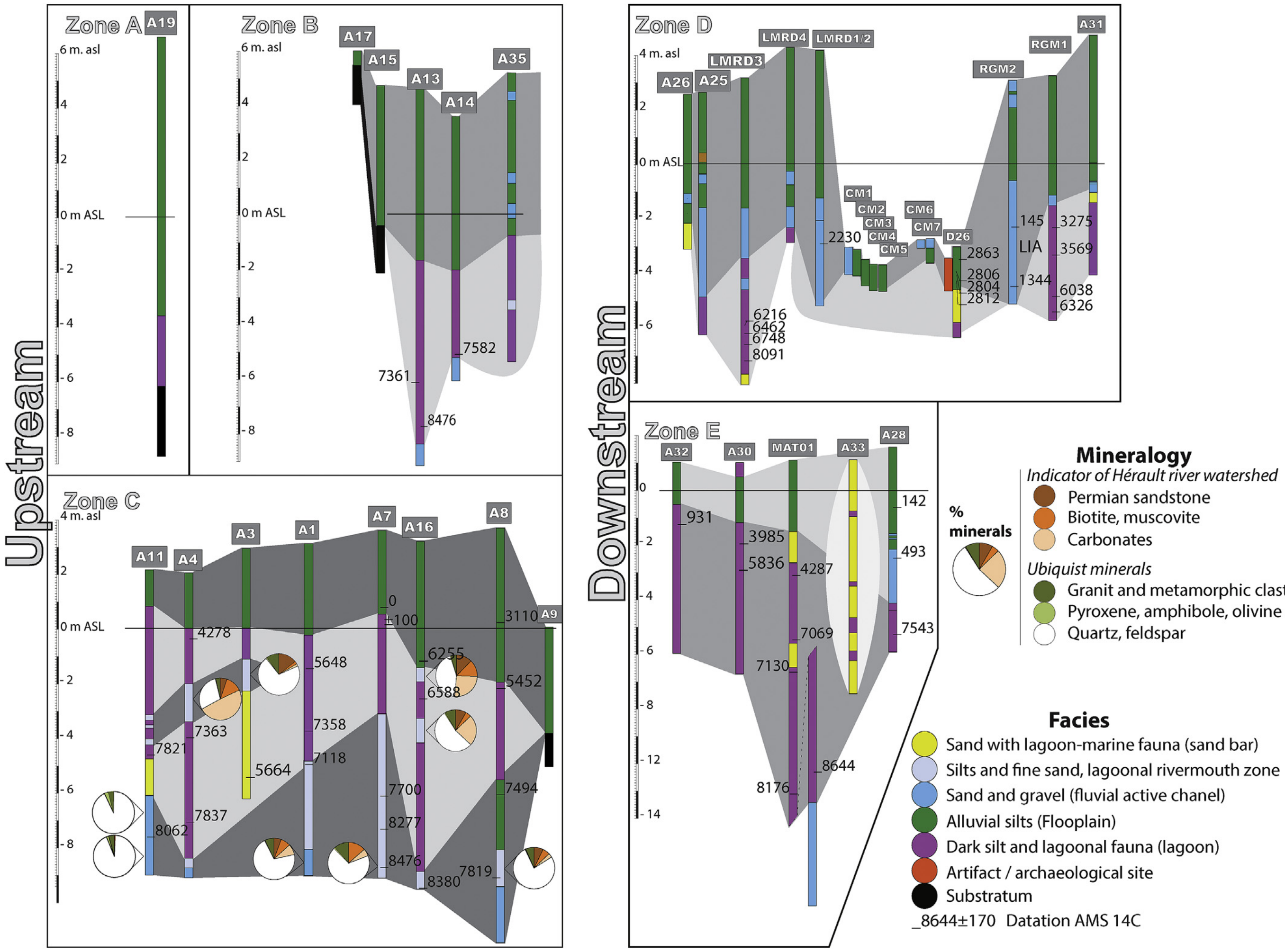

Fig. 8. Facies distribution of the Hérault's fluvio-lagoonal sedimentary body.

(Fig. 4) consistent with a very energetic depositional environment such as the bed load of a river channel. Ostracod faunal densities are low with species such as *Loxoconcha elliptica*, *Loxoconcha tamarindus* and *Leptocythere lacertosa* (Fig. 7). This association is typical of a lagoon in proximity to a fluvial mouth and connected to the sea. The presence of the macrofauna *Hydrobia ventrosa* confirms the existence of a lagoonal environment close to this riverbed (Fig. 7).

4.1.2.2. Core A4 unit B: Facies 4. Between 10.2 and 5.4 m depth, unit B is characterised by a medium and fine silty sand sedimentary texture. Coarse sand and ballast are absent. The base and the top of the unit are marked by an increase in the percentage of sands (ca. 20% vs. ca 10%; Figs. 4 and 6). The Passega diagram indicates a uniform suspension process for the deposition of this unit typical of a relatively calm and protected environment (Fig. 4). The ostracods are relatively diversified. Lagoonal species are present in high abundance. *Cyprideis torosa* is the dominant species, confirming the installation of a lagoonal environment. However, the freshwater species *Heterocypris salina* and the abundance of *Loxoconcha elliptica* indicate relatively distal fluvial inputs. The number of coastal species, such as *Leptocythere lacertosa*, decreases progressively. This is characteristic of the gradual disconnection of the environment from the sea. Variations in freshwater and lagoonal species (Figs. 6 and 7) indicate some lateral variations in fluvial inputs into the lagoon environment. Like unit A, *Hydrobia ventrosa* gastropods attest to a brackish lagoonal environment (Fig. 6).

4.1.2.3. Core A4 unit C: Facies 2. Unit C is located between 5.4 and 4 m depth. It consists of pebbles (25%) and sands (55%) in a clayey silty matrix (Figs. 4 and 7). Like unit A, the Passega diagram indicates a very high-energy rolling transport processes typical of river channel bed load (Fig. 4). *Loxoconcha elliptica*, *L. tamarindus* and some secondary freshwater species like *Candona neglecta* and *Heterocypris salina* attest to a river mouth in a lagoonal environment (*Cyprideis torosa*) connected to the sea (*Leptocythere lacertosa*, *L. fabaeformis* and *Cytherois fisheri*). The river mouth hypothesis is also supported by the presence of Hérault River watershed minerals at 25%.

4.1.2.4. Core A4 units D and E: Facies 3. Like units E and F of core A8, these two units are characterised by the accumulation of silts (90%) (Fig. 6). They correspond to alluvial plain environment and highlight the progradation of the Hérault river.

4.1.3. Core A33: facies 5

Core A33 is almost entirely composed of bedded sand, from coarse to fine grain size. Malacofauna fragments are present is the sand fraction. Gastropods and bivalves are represented by *Cerastoderma glaucum*, *Pavicardium* sp. and *Cerithium vulgatum*. They are consistent with the coastal and lagoonal zones. These layers were deposited in a high-energy coastal zone, such as a sand bar.

4.1.3.1. Mineralogical observations. Almost all optical mineralogical counts of sand grains indicate a clear origin from the Hérault watershed (Fig. 8). Granite clasts, pyroxene, amphibole, olivine, quartz and feldspar are characteristic minerals and lithic fragments of the area, but Permian sandstone, biotite, muscovite and carbonate grains can clearly be attributed to the mid and upper Hérault valley. A marine origin for these sands can be excluded. Nonetheless, in the lower part of the core A11 (riverbed facies), mineralogical markers from the Hérault watershed are absent. We suggest that this is consistent with sediment deriving from the western tributary of the Hérault.

4.1.4. Facies model of the lower Hérault valley sedimentological records

The study of these new cores allows us to build a facies model for the lower Hérault valley (Fig. 8). Facies 1 is composed of coarse sand and gravel and it is related to the fluvial channel. Silts and fine sands are sometimes interbedded in the facies. Facies 2 contains mixed lagoonal and freshwater fauna consistent with a lagoon near a rivermouth or a rivermouth in a lagoonal environment. Facies 3 comprises brown silts associated with continental malacofauna and is indicative of a floodplain. Facies 4 is characterized by dark clays and loams associated with coastal and lagoonal macrofauna related to a lagoonal deposit. Facies 5 is made-up of shelly sands that we interpret as a shoreline or beachridge. All these facies compose the cores of this study (Fig. 8). This allows us to elucidate the geomorphological evolution of the Hérault ria since 8000 years.

5. Geomorphological evolution of the lower Hérault valley

5.1. Complex transgressive dynamics

Until ca. 5500 BP, transgressive dynamics are predominant and large lagoonal areas are elucidated in all zones (Fig. 8). In the northern part of the valley, cores A13, A14 and A35 record a relatively stable lagoonal environment between 8500 and < 7200 cal yr BP. East of the valley, a fluvial wetland rich in organic deposits began accreting around 8000 cal yr BP. The river mouth moved to the west from 8000 to 7000 cal yr BP, as shown by cores A8, A16 and A7 cores (Figs. 8 and 9). During this general transgressive period in the Hérault valley, delta-like progradation occurred, mediated by the position of the river mouth. These progradation dynamics (Fig. 9) were very restricted, mobile and transitory (ephemeral and successive river-mouth). Remnants of these channels can still be perceived by a linear morphology only revealed by a geomorphological analysis of LIDAR data (Fig. 3).

These successive fluvial environments were submerged (cores A8, A16, A7, A1, etc.) thereafter, during the maximal flooding period between 7000 and 5000 cal yr BP. (Figs. 8 and 9). Lagoonal sediments are present in almost all cores (Fig. 8). The lagoonal deposits furthest from the current shoreline are found in cores A19 and A21 (zone A, Figs. 7–8), 11.2 km inland. These constitute the farthest coastal environments known nowadays in the valley and it show the maximum extension of the Hérault palaeolagoonal system. No dates are available for the core A19, but if we assume that the first lagoonal deposits (6 m bsl) are in direct relation with sea-level rise at this depth, this maximum extension could be roughly dated to between 7000 and 6500 cal yr BP, according to regional sea-level curves (Vella et al., 2005; Vacchi et al., 2016). The main progadation phase began after 6500 cal yr BP in the middle of the valley. Beachridges and/or sandbars developed inside the lagoon, due to a slowdown in sea-level rise and the sedimentary inputs from the Hérault River and its tributaries. Until this period, the general morphological shape of this inner delta was concave, even if the river mouth could temporally prograde by siltation into small areas along the sides of the valley, where shallow depths could be more easily infilled.

Downstream, between the present-day cities of Agde and Vias, a large sandy barrier was elucidated during field surveys and mapped using the LIDAR digital elevation model (Fig. 3). The core A33, undertaken on this beach and dune ridge, is 9 m deep and composed almost entirely of sand. After 7500 cal yr BP, the aquatic environments inside the ria were brackish and therefore separated from the sea by a sandy barrier. These data demonstrate that the inner sandy barrier was in place until 7500 cal yr BP, between Agde and Vias. This barrier seems to be dynamic and discontinuous. Furthermore, it is known that a beachridge was present on the coast during the last 8000 years at least, located approximately on the current coastline (Court-Picon et al., 2010; Tessier et al., 2000; Raynal et al., 2009; Degeai et al., 2015). Once again, core BSS002KQQF (available online at: http://infoterre.brgm.fr) comprises 30 m of sand accumulation and reveals the presence of this beachridge. The beachridge was probably not continuous at this time (Court-Picon et al., 2010; Degeai et al., 2015). These natural barriers were conducive to navigation in a sheltered environment and thus promoted the appearance and dissemination of Neolithic culture in the Western Mediterranean. The Peiro Signado and Pont de Roque-Haute archaeological sites, near Vias, are the oldest Neolithic settlements in the region (Guilaine et al., 2007; Briois and Manen, 2009).

5.2. Deltaic progradation

The western route of the Hérault fluvial channel, visible in cores A4 and A3, was gradually or suddenly abandoned for a new channel to the east. Until 3000 cal yr BP, sedimentation from the Hérault river began to build a large floodplain on the western part of the valley (Figs. 8 and 9), then continued to the east of La Motte, a Bronze Age archaeological site (Gascó et al., 2015). These landscape dynamics isolated a small sub-lagoon in the eastern part of the valley. This large and fertile floodplain was attractive to human activities (navigation, agriculture, fishing) (Gascó et al., 2015) and helps to explain the importance and the long duration of La Motte settlement during this period.

From 3000 to ca. 1000 cal yr BP, the ria continued to be infilled by alluvial sediments in a lagoonal environment. Progradation dynamics were more rapid on either side of the valley, and driven by the Hérault River on the eastern side and, more slowly, by the Ardaillon tributary on the western side. Cores A30, A32 and the Lidar data (Fig. 3) show the general chronology and morphology of this lagoon, which is on the way to be filled. This lagoon, never described in previous studies, is of significant archaeological importance. Agde promontory is known to have accommodated an Iron Age Greek colony (Nickels et al., 1989; Ugolini *in* Lugand and Bermond, 2002) and such a lagoon would have been key for harbour activities and maritime trade. At this time, the Hérault valley was a major commercial route for the exportation of agricultural products throughout the Western Mediterranean (Garcia, 1995; Mauné, 2002, 2016; Ropiot, 2009). Archaeological remains have been mapped around Agde, although no harbour structures have been formally identified (Lugand and Bermond, 2002). Scholars have suggested that the Roman harbour could be close to Luno Pond, Rochelongue beach or near the present Hérault river mouth. This could be reconsidered with the knowledge of new data presented here.

The silting and infilling dynamics continued during the last

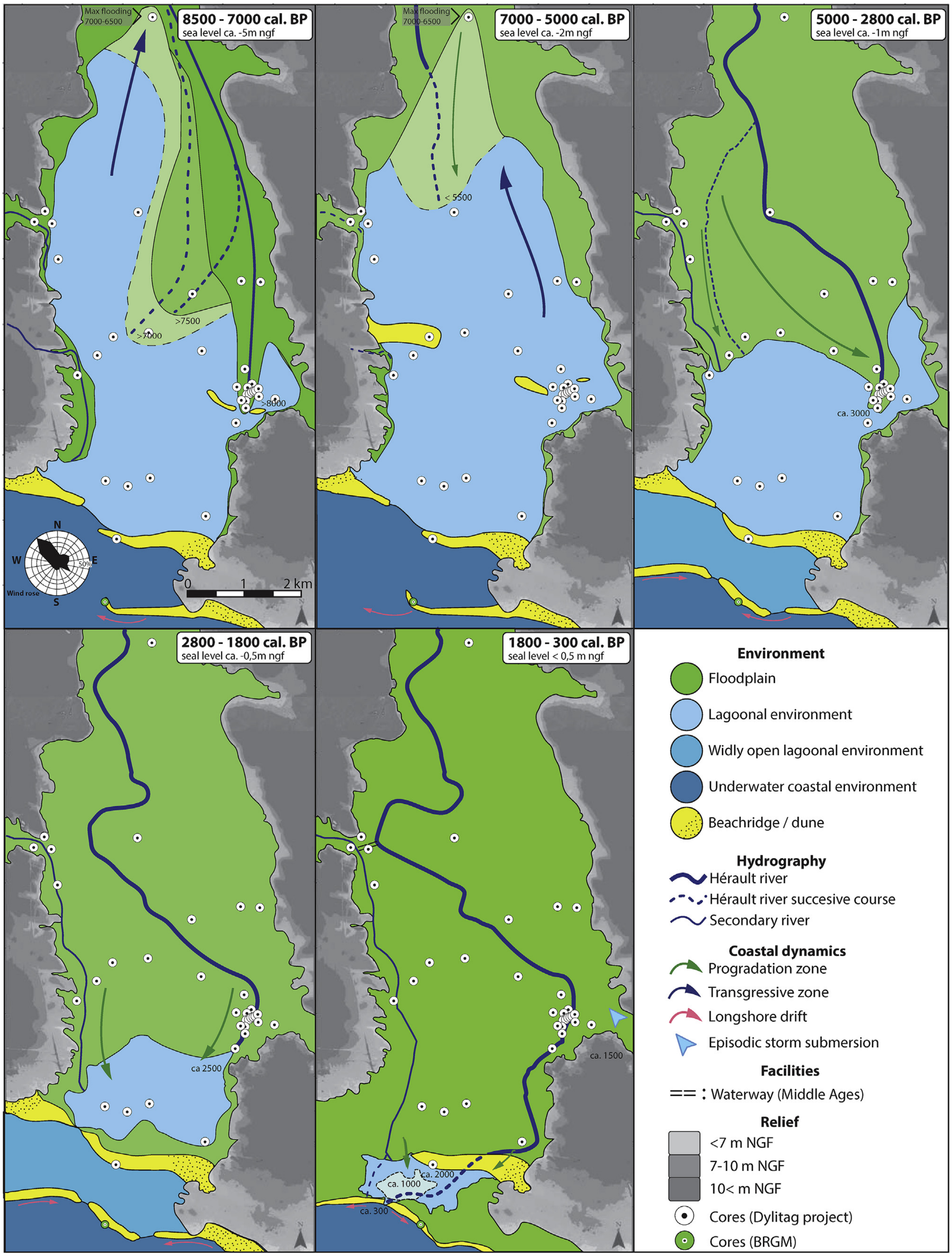

Fig. 9. Holocene geomorphological evolution of the lower Hérault valley.

evolutionary stage of the lower Hérault valley. Cores A32 and A28 suggest that the lagoon was infilled between 1000 cal yr BP (age of the last lagonal deposit) and 500 cal yr BP (riverbed dated near Agde). Further downstream, the LIDAR DEM shows a relict depression and abandoned river channel just behind the present coastline (Fig. 3). These landforms are clearly discernible in 18th century maps (Garipuy, 1774; Bourgouin et al., 1777). Likewise, the river mouth and the Grau are also mapped, supported by the geological map of the area (Berger et al., 1978) and field surveys.

6. Discussion

The chronostratigraphic record of the lower Hérault valley provides evidence for 7000 years of a deltaic evolution. The numerous cores have helped to elucidate a detailed image of past coastlines and lagoon morphology. Until the end of the transgressive phase, corresponding to the sea-level rise slowdown, the wave-dominated morphology led to the expansion of lagoonal systems. But this period was also characterized by the formation of several narrow deltaic lobes, which were subsequently submerged in the eastern part of the valley. Coastline are very dynamics, asymmetric and more complex than suggested in previous study or expected by models (Dubar and Anthony, 1995; Devillers, 2008; Devillers et al., 2007, 2015; Marriner et al., 2012; Ghilardhi et al., 2008; Giaime et al., 2019).

During the progradation phase, deltaic lobes developed in the middle of the valley from west to east. This was probably because of the difference in sedimentation between this part of the valley, which was a little bit lower in elevation at this time, and the eastern part of the valley, which had already gone through a long phase of fluvial sedimentation. The inner delta lagoon systems were gradually infilled. The palaeoriver channel visible on ancient maps and located in the ancient lagoon is consistent with this evolution.

Beach ridges are present until at least 7000 cal yr BP and could have two origins. The first is more inland, directly connected to the river system. In this case, the beach ridges could be linked to the displacement of the Hérault river sediments, which were reworked in the lagoon system by floods, currents and wave actions. Gravels found in core A30 support this explanation. Studies have shown that reworked sediment can form beach ridges and/or lagoonal sandbars (Brückner et al., 2017). The second explanation is linked to longshore dynamics as attested along much of the Languedoc coast (Certain et al., 2005; Raynal et al., 2009; Court-Picon et al., 2010).

These steps in ria evolution were mediated by sea-level change dynamics and sedimentary inputs, which were not linear in space or time. The successive morphological legacies make these geomorphological system dynamics not strictly reversible. The weight of each factor is difficult to quantify precisely. Indeed, each core and its associated proxies yield only a partial image of landscape changes as a whole. Nonetheless, we tentatively quantify the evolution of the surface area of the coastal plain surface inside the lower Hérault valley (Fig. 10a). From the maximum transgressive

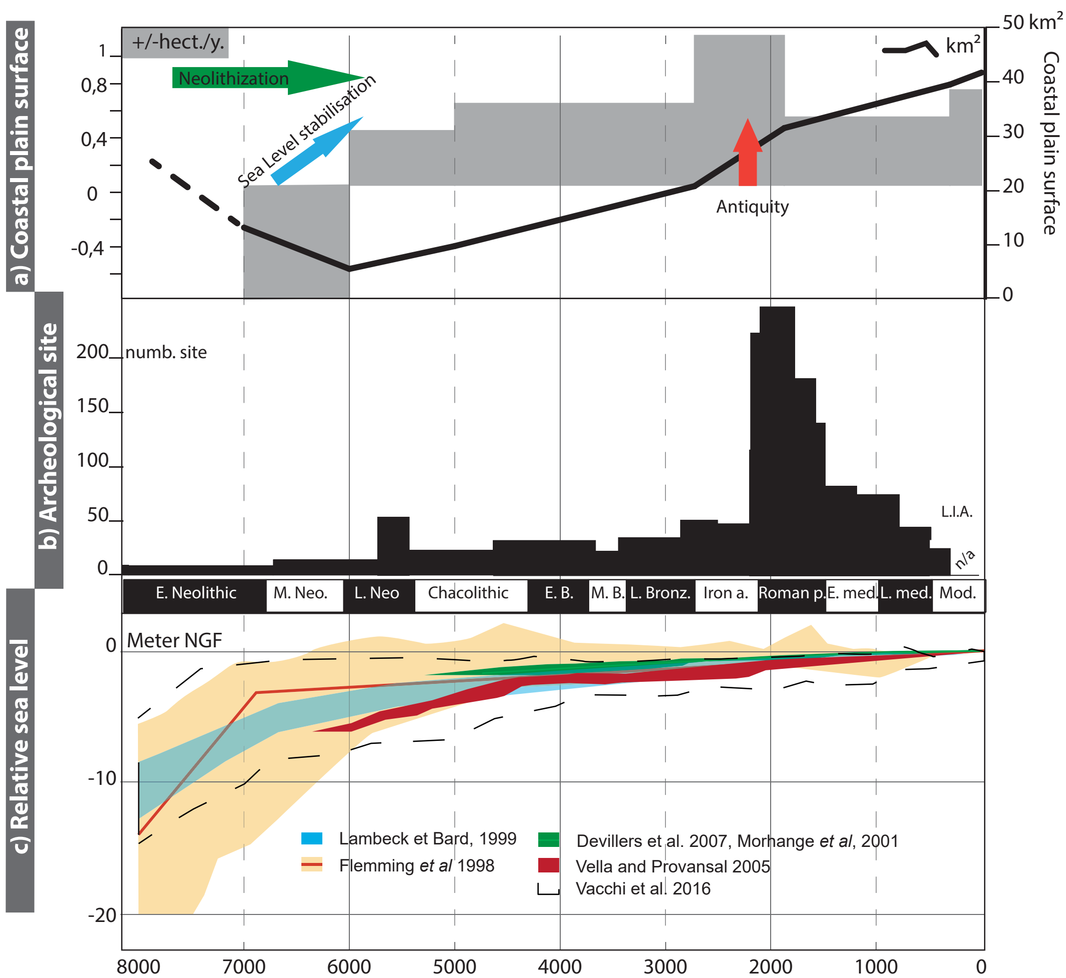

Fig. 10. Coastal evolution compared to sea-level and archaeological remains.

surface to the present landscape, the coastal plain extends from 5.6 to 43 km^2. Before 6000 cal yr BP, the submerged (or eroded) surface was about 0.7 ha/yr. Thereafter, during the ensuing 6000 years, coastal progradation expanded the plain by around 0.7 ha/yr. This rate was relatively regular except during the Roman period and late antiquity, when it was at 1 ha/yr. At present, it is not possible to compare our results with very high-resolution palaeoclimate data or the detailed land use history of the Hérault watershed. However, several key periods emerge from the data. Deceleration of sea-level rise, between 8000 and 6000 cal yr BP (Stanley, 1995; Flemmings et al., 1998; Vacchi et al., 2016), led to deltaic formation (Stanley and Warne, 1994) around 6000 cal yr BP. The progradation phase in the Hérault valley began slightly earlier, i.e. after 7000 cal yr BP. Very early Neolithization of the area is attested by Peiro Signado and Pont de Roque-Haute archaeological sites, which are the earliest Neolithic settlements known for the Western Mediterranean (Guilaine, 2003; Guilaine et al., 2007; Manen and Guilaine, 2007; Briois and Manen, 2009). This early progradation phase could have resulted from accelerated erosion (Devillers and Provansal, 2003) through Neolithic landscape clearing and agriculture. The progradation phase was mainly controlled by sea-level variations and accelerated by human impacts on local sediment budgets. Moreover, the rapid development of the coastal plain could have contributed to the successful development of the local Neolithic settlements. Another regional high-quality paper have also shown the important relationships between shoreline evolution and archaeological evolution during prehistory (Brisset et al., 2018).

A further interesting trend in the data is the acceleration of the progradation phase around 2000 cal yr BP. During the Roman period, strong economic and agricultural development is attested in the Hérault valley (Mauné, 2002, 2016; Ropiot, 2009). This development can be measured by an increase in archaeological sites in the area (Fig. 10c) and an increase in sediment supply resulting from human-induced erosion in the middle Hérault valley (Devillers and Provansal, 2003). At long time scales, an acceleration in progradation was a corollary of watershed agricultural pressures and erosion.

7. Conclusion

This work provides detailed insights into Holocene coastal evolution using chronostratigraphic data and Lidar mapping. The Hérault palaeodeltaic lobes, in both retrogradational or progradational phases, were deposited in a relatively small geographic area. This is in contrast to large deltaic systems such as the Rhone delta where the fossilized coastal forms are more spread out, visible and more easily mapped, and therefore better understood (Aloisi et al., 1978; Panin et al., 1983; Coleman et al., 1980, 1998; Amorosi and Mili, 2001). This methodological aspect may explain why small morphosedimentary systems in coastal areas have received less research attention. New techniques and approaches (LIDAR, multiplication of coring, high resolution geophysical investigation, etc.) must be used to fill this knowledge gap in the coming decades. To understand Holocene landscape dynamics, we stress the importance of a multidisciplinary approach associating (bio)stratigraphy, geomorphology and archaeology.

The large number of cores undertaken within the framework of this project has allowed us to elucidate the different stages of Holocene coastal metamorphosis. Until the late Holocene, local deltaic systems were submerged in the eastern part of the valley. The Holocene history of the landscape in the Hérault valley began with a maximum flooding surface around 12 km inland ca. 7000 years ago. Its infilling began in the western part of the valley and shifted eastwards until Late Bronze Age at least (ca. 3000 cal yr BP). The non-linearity of coastal landscape evolution inside the ria is confirmed by field data and could be taken into account in future numerical models (Dubar, 2004).

This landscape evolution must be taken in account to understand the archaeological history of the lower Hérault valley: (i) from a taphonomic point of view; (ii) because of the evolution of the most fertile agricultural lands in relation to coastal retrogradation and progradation from the Neolithic to Roman periods; (iii) for the environmental potentialities of harbours and trade routes through time; (iv) for the changing nature of environmental risks for human societies; and (v) for the relationships between economic systems and changing environments. For these reasons, the lower Hérault valley and the region of Agde is an interesting laboratory to study Holocene human-environment relationships over the long time on sensible coastal geosystems.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.quascirev.2019.105912.

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