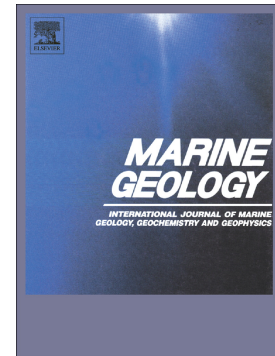


Accepted Manuscript

8000 years of coastal changes on a western Mediterranean island:
A multiproxy approach from the Posada plain of Sardinia

Rita T. Melis, Federico Di Rita, Charles French, Nick Marriner,
Francesca Montis, Giovanni Serreli, Federica Sulas, Matteo
Vacchi



PII: S0025-3227(17)30532-7
DOI: doi:[10.1016/j.margeo.2018.05.004](https://doi.org/10.1016/j.margeo.2018.05.004)
Reference: MARGO 5794
To appear in: *Marine Geology*
Received date: 1 November 2017
Revised date: 23 April 2018
Accepted date: 14 May 2018

Please cite this article as: Rita T. Melis, Federico Di Rita, Charles French, Nick Marriner, Francesca Montis, Giovanni Serreli, Federica Sulas, Matteo Vacchi , 8000 years of coastal changes on a western Mediterranean island: A multiproxy approach from the Posada plain of Sardinia. The address for the corresponding author was captured as affiliation for all authors. Please check if appropriate. Margo(2017), doi:[10.1016/j.margeo.2018.05.004](https://doi.org/10.1016/j.margeo.2018.05.004)

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

8000 YEARS OF COASTAL CHANGES ON A WESTERN MEDITERRANEAN ISLAND: A MULTIPROXY APPROACH FROM THE POSADA PLAIN OF SARDINIA

Rita T. Melis^{1*}, Federico Di Rita², Charles French³, Nick Marriner⁴, Francesca Montis¹, Giovanni Serreli⁵, Federica Sulas⁶, Matteo Vacchi⁷

¹Dipartimento di Scienze Chimiche e Geologiche, Università di Cagliari, Via Trentino 51, 02127 Cagliari, Italy, rtmelis@unica.it

²Dipartimento di Biologia Ambientale, Sapienza Università di Roma, Piazzale Aldo Moro 5, 00185 Roma, Italy, federico.dirita@uniroma1.it,

³Department of Archaeology, University of Cambridge, Downing Street Cambridge CB2 3DZ, UK, caif2@cam.ac.uk

⁴CNRS, Laboratoire Chrono-Environnement UMR 6249, MSHE Ledoux, USR 3124, Université de Bourgogne-Franche-Comté, UFR ST, 25030 Besançon, France, nick.marriner@univ-fcomte.fr.

⁵Istituto di Storia dell'Europa Mediterranea ISEM CNR, Via Giovanni Battista Tuveri, 128, 09129 Cagliari, serreli@isem.cnr.it

⁶School of Culture and Society - Centre for Urban Network Evolutions (UrbNet), Aarhus University, Moesgård Allé 20, 8270 Højbjerg, Denmark, sulas@cas.au.dk

⁷Geography, College of Life and Environmental Science, University of Exeter, EX4 4RJ, Exeter, UK M.Vacchi@exeter.ac.uk

Keywords: Coastal evolution, Palaeoenvironmental reconstructions, sea-level changes, Pollen, eastern Sardinia, Mediterranean Sea

Abstract

A multi-proxy palaeoenvironmental investigation was conducted to reconstruct the Holocene history of coastal landscape change in the lower Posada coastal plain of eastern Sardinia. In the Mediterranean region, coastal modifications during the Holocene have been driven by a complex interplay between climate, geomorphological processes and human activity. In this paper, millennial-scale human-sea level-environment interactions are investigated near Posada, one of the largest coastal plains in eastern Sardinia. Biostratigraphic and palynological approaches were used to interpret the chrono-stratigraphy exhibited by a series of new cores taken from the coastal plain. This new study elucidates the main paleoecological changes, phases of shoreline migration and relative sea-level change during the last 8000 years. These results indicate the major role of sea-level stabilization and high sediment supply in driving major landscape changes, especially during the Neolithic period (6th-4th millennia BC), and the long-term settlement history of this coastal valley area. It is concluded that human occupation of the coastal plain, from prehistoric to historical times, was most likely constrained by the rapid and constant evolution of this coastal landscape.

1. Introduction

Coastal plains contain key sediment archives to determine environmental change. In the Mediterranean region, such modifications are controlled by both natural processes and human impacts. Moreover, these river valley coastal areas have always been ideal locations for settlements due to their strategic position in relation to food availability, proximity to hinterland valleys and the sea, and the control of major trading routes (Walsh, 2013; Fontana et al., 2017; Ghilardi et al., 2017a).

Along the Mediterranean coastline, coastal plains have usually developed through the combined effects of the slowing of post-glacial sea-level rise over the last six millennia (Amorosi et al., 2008; Vacchi et al., 2016) and the increase of sediment input caused by both natural and anthropogenic factors (Maselli and Trincardi, 2013; Anthony et al., 2014). This progradation trend has often resulted in the formation of large coastal plains that became densely settled from the prehistoric times onwards, as for example at the mouth of the Arno, Po and Tiber rivers in Italy (Amorosi et al., 2008; Rossi et al., 2011, Fontana et al., 2017; Milli et al. 2013), the Rhone River in France (Vella et al., 2005), and the Llobregat and Turia rivers in Spain (Carmona and Ruiz, 2011; Daura et al., 2016).

However, multi-disciplinary studies looking at human-environment interactions on Sardinia, the Mediterranean's second largest island, are still scarce and to date have concentrated on the western side of the island (Ratto et al., 2016; Melis et al.; 2017, Pascucci et al., 2018).

The large coastal plains mainly located along the western and southern sectors of the island were densely settled, especially from the Neolithic to Late Antiquity (Lilliu, 2002; Antonioli et al., 2007; Di Rita and Melis, 2013; Melis et al., 2017). In contrast, along the eastern side of the island, where the coastal plain areas are bordered by a mountainous hinterland, there are fewer known prehistoric sites. Even where the archaeological records indicate continuous settlement since the Neolithic period elsewhere in the region (Fadda 1984; Dyson and Rowland, 2001, 2007; Sanciu 2011), investigations of past human-environment interactions are absent for this eastern part of the island. For this reason, the environmental modifications of the Posada coastal plain raise important questions about the landscape context of human settlement in this part of Sardinia, its evolution in space and time, and its wider relevance for understanding environmental and cultural developments at regional scales.

The present study aims to provide new stratigraphic and chronological insights into the palaeoenvironmental evolution of the Posada coastal plain, one of the largest base-level depocenters on the eastern side of the Sardinian coastline (Fig. 1a). We assess its potential influence on human

settlement in the area, and compare and contrast these records with those of other Mediterranean coastal plains during the Holocene.

2. Study area

2.1. Geology and geomorphology

The morphology of the study area is influenced by the geological and structural contexts. Gentle hills, on Palaeozoic metamorphic rocks, and rugged and steep hills, on Mesozoic limestone-dolomitic rocks, surround the Posada alluvial-coastal plain (Carmignani et al., 2001) (Fig. 1b). A limestone-dolomitic complex outcrops on the plain, forming an elongated hill with steep slopes. The village of Posada, located on the east side of the hill, is topped by the medieval castle. The alluvial plain, deposited by the Santa Caterina river and Posada fluvial system during the Quaternary, lies along a structural E-W depression (Ardau et al., 1999). Pleistocene alluvial terraces and alluvial fans, composed of sands and well-cemented pebbles, are present along the edge of the alluvial coastal plain. Holocene floodplain deposits consist mainly of clay-sand sediments, deposited in channel fills, crevasse splays, overbank deposits, as well as shallow, reed-fringed marshy sediments. The coast is characterized by long sandy beaches, which develop between the promontories of Torre S. Giovanni and Mt. Orvili. Sand dunes and relict channels of Posada and Santa Caterina rivers mainly characterized the backshore area. Analysis of MIS 5e shoreline elevations indicates the general tectonic stability of Sardinia since the last interglacial at ca. 125,000 years ago (Ferranti et al., 2006). Furthermore, GPS-derived vertical velocities indicate minimal on-going vertical motion of the island, in a similar vein to Corsica (Serpelloni et al., 2013).

2.2. Archaeological setting

The presence of settlements in the area surrounding the Posada coastal plain (Fig. 1 b) dates back to at least the Middle Neolithic (ca. 6500 BP or 4500 BC) as evidenced by the remains found in the Posada village and by the several tombs (named “Domus de Janas”) in the territory (Fadda, 1984, 2001). The density of settlements increased during the Bronze Age with the Nuragic civilization (ca. 3600-2500 cal. BP or 1600-500 BC) with several structures found on the hillsides overlooking the floodplain (Lo Schiavo, 1978; Fadda 1984). However, the lack of specific archaeological investigations precludes a detailed chronological assessment on the use and evolution of the area during the Bronze Age. Little is known about the next period of Punic-Roman occupation of the area (Sanciu, 2011), but historical sources (Ptolemy, 1st century AD) indicate the existence of an ancient Roman city, Feronia, most likely located within the Posada coastal plain. This is further corroborated by the presence of a Byzantine church and a Roman bridge on the coastal plain

(Sanciu, 2011). In the Middle Ages, the town of Posada reached its maximum socio-political and economic development, as testified by Castle della Fava built atop a limestone hill (Castellaccio, 1990). This was mainly due to its strategic position between the middle of the two large medieval kingdoms of Gallura and Arborea (D'Oriano, 1999; Serreli, 2014).

3. Methods

The stratigraphic record was elucidated using five continuously-cored boreholes (cores P3, P4, P5, P6, P7, Fig. 1c) drilled down to a maximum depth of 12 m. These were located between the alluvial plain of the lower Posada River and the shoreline of San Giovanni, following a roughly west–east orientation, in order to obtain chronostratigraphic information about the palaeo-environments of the coastal plain system. The elevations of the boreholes with respect to the msl were derived from a Digital Elevation Model (DEM) with a final vertical accuracy of ± 0.5 m. Lithofacies description included colour, mean grain size, sorting, skewness, sedimentary structures and biogenic components (i.e. molluscan shells and fragments, macro-fossils, plant remains, wood fragments). These cores were sub-sampled for sedimentary, palynological and molluscan analyses and a series of AMS radiocarbon dates.

The palaeo-environmental reconstruction was based on a multi-disciplinary analysis of the dated sedimentological parameters, palaeoecological data (marine molluscs and microfauna) and pollen assemblages of the cores, based on a widely used methodology (Mazzini et al., 1999; Di Rita et al., 2011; Amorosi et al., 2013; Milli et al., 2013; Di Rita and Melis, 2013; Pieruccini et al., 2016). This multiproxy approach provided the framework for identifying major stratigraphic units as well as for defining the palaeoecological and palaeoenvironmental changes across the study area.

3.1 Sampling, description and methodological techniques

Preliminary facies descriptions (e.g. colour and lithofacies) were carried out under standardized laboratory conditions (see Marriner et al., 2012). Each core was split lengthwise, and described in terms of mean grain size and colour. The five cores were sampled at intervals of between 0.3 and 0.8 m. Dry sediments were weighed and washed through two mesh sizes, 2 mm and 63 μm , to separate out the gravel (>2 mm), sand (2 mm to 63 μm) and silt and clay (<63 μm) fractions. The coarse fraction was mechanically sieved using 15 mesh sizes descending in size from 5.6 mm to 0.063 mm, spaced at $1/2$ phi (ϕ) per unit. The different fractions were plotted against stratigraphic logs in percentages.

Samples were prepared for palaeoecological analyses including pollen, peat, plant and wood fragments, molluscan shells and bioclasts. A biostratigraphic analysis of the cores' molluscan

assemblages, as well as the identification of microfossils (foraminifera and ostracods), was undertaken. For the macro- and micro-fauna analysis, a total of 22 samples was collected from the most significant litho-stratigraphic levels. Samples were washed through 2 mm and 50 μ m sieves to separate out the gravels, sands and silts fractions. The gravels and sands fractions were subsequently oven dried at 40 °C. Malacological identification was undertaken on shells present in the gravels fraction (cf. Poppe and Goto, 1991, 1993; Doneddu and Trainito, 2005). These were assigned to ecological assemblages based on the classification systems of Pérès and Picard (1964), Pérès (1982), Doneddu and Trainito (2005). All macro-fauna in the samples were counted and are expressed as a percentage of total shells, with the distribution of the molluscan taxa identified in Units B and Unit C described as abundant (>30 individuals), common (10-30%), scarce (3-10%) or rare (1-3%).

The micro-fauna was hand-picked from the sand fraction of the washed sediment, using a stereo-microscope. Species determination of foraminifera and ostracods was mainly based on studies concerning the Mediterranean benthic fauna (cf. Sgarrella and Moncharmont Zei, 1993; Fiorini and Vaiani, 2001; Fiorini, 2004). The palaeoenvironmental significance of the different assemblages was defined using the methodology developed for central Mediterranean coasts (Donnici and Serandrei Barbero, 2002; Carboni et al., 2002; Frezza and Carboni, 2009). On the basis of species ecology outlined by Lachenal (1989), ostracods were attributed to three groups: freshwater, lagoonal and coastal. The species identified are listed in the World Register of Marine Species (WoRMS) (<http://www.marinespecies.org>).

3.2. Chronology of the stratigraphic units

The chronological framework was established by a series of 11 new AMS radiocarbon dates taken from organic-rich sediment samples collected from all the cores (P3-7) (Table 1). AMS radiocarbon analyses were performed by the Innova Laboratory of Caserta, Italy. As the production of atmospheric radiocarbon has varied through geological time, radiocarbon ages were calibrated to provide dates in calendar years before present with a 2σ range. All samples were calibrated using the software CALIB 7.1 (Stuiver et al., 2016). In calibrating the samples of sediment, we considered that the original depositional environment was a transitional zone in the back-coastal area, influenced by fluvial processes as well as marine inputs. Therefore, for some dates a mixed IntCal13/Marine13 calibration method was applied according to the methods proposed in Di Rita et al. (2011) and Di Rita and Melis (2013). Local deviations in the marine reservoir effect were taken into account using a ΔR value of 43 ± 38 , which is the average of the ΔR values available for the Tyrrhenian Sea in the Marine13 dataset (Stuiver et al., 2016).

For P3 and P7 cores an age-depth model was calculated (Fig. 2). This was based on a linear interpolation between the midpoints of the 2σ calibration ranges of each ^{14}C date. In addition, six modelled ages per core, provided by the function ‘Age Depth Model’ of CALIB 7.04 software (<http://calib.org/calib/>) (Stuiver and Reimer, 1993) were used to build the models.

3.3. Pollen analysis

Pollen analysis was carried out on 26 samples, selected as follows: 15 samples between 1.3 and 7.85 m from core P3; 4 samples between 8.5 and 9.5 m from core P6; and 7 samples between 7.15 and 11.65 m from core P7. These samples were chosen in order to obtain a temporally continuous composite pollen record of the site, taking into account both the chronology of the cores and the sandy levels presenting problems of pollen preservation. Subsequently, the preliminary pollen analysis revealed that there were several intervals without pollen. The samples were treated with HCl (37%), HF (40%) and NaOH (10%) following standard procedures for pollen extraction summarized in Magri and Di Rita (2015). Pollen concentration values were estimated by adding *Lycopodium* tablets to known weights of sediment. Pollen grains were identified under a microscope at x400 and x640 magnifications, with the help of both pollen morphology atlases (Reille, 1992a; Beug, 2004) and the reference collection of the Laboratory of Palaeobotany and Palynology at Sapienza University of Rome. The main percentage sum is based on terrestrial pollen excluding the aquatic pollen, fern spores and other non-pollen palynomorphs. The computer program Psimpoll 4.27 (Bennett, 2009) was used to plot the pollen diagrams.

3.4. Relative sea-level reconstruction

Results of the paleo-environmental reconstructions revealed facies typical of marine, fluvial and lagoonal environments (see section 4.1). Lagoonal facies found in cores have been widely used for RSL reconstructions in the Mediterranean (e.g., Pavlopoulos et al., 2006; Vacchi et al., 2016; Chelli et al., 2017). However, there is need for caution when defining the relationship of the dated facies and the palaeo-msl (i.e. the indicative meaning, Shennan, 1986; Rovere et al., 2016) that can only be defined using a multiproxy analysis of lithostratigraphy, faunal assemblages and, when available, corroborated by pollen data (Primavera et al., 2011; Currás et al., 2017; Melis et al., 2017).

In this paper, a new suite of RSL index points (cf. Engelhart et al., 2015; Edwards, 2007; Shennan, 2007) was created by combining grain size analysis with the molluscan, foraminifera and ostracod assemblages found in the five cores.

The protocol developed by Vacchi et al., (2016) was followed. This methodology has recently been applied to a number of studies focused on Mediterranean RSL reconstructions (Currás et al., 2017;

Fontana et al., 2017; Karkani et al., 2017; Melis et al., 2017; Ruello et al., 2017; Vacchi et al., 2017). We attributed an indicative range of 0 to -2 m msl to samples found in open lagoonal facies, with a high diversity of faunal assemblages comprising taxa dominated by marine brackish molluscs, and foraminifera and ostracod assemblages dominated by marine brackish littoral taxa (Rossi et al., 2011; Marriner et al., 2014; Salel et al., 2016).

Due to the difficulty in establishing a direct relationship with the former msl, samples deposited in marine (i.e. infralittoral sands) or freshwater (fluvial sediments or freshwater marsh) environments were used as marine and terrestrial limiting points, respectively. Reconstructed RSL must fall above marine limiting points and below terrestrial limiting points (Vacchi et al., 2014; Rovere et al., 2015). To each of these index and limiting points, we added the additional vertical errors: (1) an error associated with calculating the sample's altitude (± 0.5 m, i.e. the accuracy of the Digital Elevation Model); and (2) a core stretching/shortening error of 0.15 m typically associated with mechanical cores (Hijma et al., 2015).

4. Results

4.1. Litho- and bio-stratigraphy

A detailed lithostratigraphic description of the cores in the Posada alluvial-coastal plain allowed different units or depositional environments to be distinguished, indicated by the letters **A to E**. The radiocarbon dating of the units yielded ages comprised between 7583 ± 91 and 1462 ± 108 cal. BP (Table 1). Unit characterization of the Holocene deposits in the Posada River alluvial-coastal plain is based upon the detailed biostratigraphic and sedimentological study of five cores (P3 to P7). A synthetic view of litho-stratigraphic, palaeoenvironmental and chronological data was obtained from the cores P3 to P7.

The sequence in which each unit is described and interpreted reflects their order of occurrence in the stratigraphic record, from bottom to top. The grain-size analysis datasets are provided in Supplementary Figs. P3, P4, P5, P6 and P7. The faunal assemblage used to define the different units is provided in Supplementary Table A.

Detailed facies description (including sedimentological features, palaeontological content) and interpretations of the depositional environments are reported below.

4.1.1 Alluvial deposits (Unit A)

This unit (A) marks the bottom of the stratigraphic record in the P5 and P6 cores, located about 2 km inland from the present shoreline (Fig. 3). It is characterized by dark gray, 'muddy' sandy

gravels and gravelly ‘muddy’ sands. These sediments are located below the finer organic sediments of unit B. These coarse sediments suggest that this facies was formed in a fluvial environment.

4.1.2 Open lagoon deposits (Unit B)

This unit (B) represents the lowest part of the stratigraphic succession in the core P7 (Fig. 4). In the cores P5 and P6 it is above unit A at a depth of 10.95 m and 9.7 m respectively, while in the core P3 it is interleaved with Unit C. The thickness is greater than 3 m in core P7. It comprises a succession of greenish gray/very dark gray sands, with interbedded centimetre-thick layers rich in seagrass remains. These deposits are underlain by the medium-coarse sandy sediments of Unit D or are interbedded with shallow marine sands of Unit C (P3 core).

The particle size analysis shows the presence of predominantly fine deposits, with variable sediment texture. Moderately well sorted fine silty sands and very fine sands alternate with muddy sands and/or, in some cases, gravels. A large number of samples have a unimodal distribution, only some are bimodal, with mean grain sizes varying from fine sand to very fine sand. Sorting is mainly poor, but varies from poor to moderately sorted due to the variable content of the silty clay matrix. Skewness is mainly positive, ranging from symmetrical to very finely skewed. The mineralogical composition is dominated by quartz and micaceous minerals.

The fossiliferous content is characterized by very abundant bioclasts, marine bivalves and gastropod shells, plant fibers of seagrasses (*Posidonia oceanica*) and benthic microfossils (foraminifera and scarce ostracod valves). The unit shows the concomitant presence of taxa typical of the upper muddy sands in sheltered areas biocoenosis dominated by *Loripes lacteus*, *Abra alba*, *Cerithium vulgatum*, *Tellina tenuis* and brackish lagoonal molluscan taxa mainly represented by *Abra segmentum*, *Hydrobia* sp., *Parvicardium exiguum*, *Cerastoderma glaucum* (see Supplementary Tab. A).

The occurrence of *P. exiguum* indicates high organic matter content in the sediment (Lastra et al., 1993) as suggested by the presence of *Loripes lacteus* (Tebble, 1966). Other species such as *Bittium reticulatum*, *Pusillina lineolata*, *Pusillina radiata*, *Tricolia* sp. and *Rissoa* sp., typical of the *Posidonia oceanica* meadows (HP) and Photophilous Algae (AP) biocoenoses, are present discontinuously in the sandy and muddy sands levels.

The micro-fossil assemblages include Rotalidae and Miliolidae, with foraminifera species of the genera *Quinqueloculina*, *Elphidium*, *Spiroloculina* and *Adelosina* genus occurring commonly. The most abundant species is *Quinqueloculina seminula*, a widely distributed species occurring in marshy to coastal environments (Albani and Serandrei Barbero, 1990; Sgarrella and Moncharmont Zei, 1993; Frezza and Carboni, 2009). Unfortunately, ostracod faunal densities were too low for

robust palaeoecological reconstructions. Nonetheless, some rare valves of *Cyprideis torosa* (lagoonal), *Xestoleberis* spp. (marine lagoonal), *Aurila convexa* (coastal), *Callistocythere mediterranea* (coastal) and *Bairdia* sp. were observed in this unit.

Sedimentological features and the peculiar fossil content indicate that this facies association was formed in a lagoonal environment with marine influence (Marriner et al., 2012; Giaime et al., 2017; Salel et al., 2016). The faunal assemblage is consistent with marine-brackish lagoonal environments subject to salinity changes. No archaeological remains were found within this facies. Several radiocarbon dates were determined for Unit B, revealing an age between 7583 ± 91 cal. BP (5583 ± 91 cal. BC) for the bottom (at 12.25 m core depth in P7 core) and 5451 ± 130 cal. BP (3451 ± 130 cal. BC) for the upper part of the unit (at 4.30 m core depth in P3 core). This last date in core P3 marks the transition between the lagoonal environment and the fluvial deposit above. Deposition of this unit is thus constrained between ca. 7500 cal. BP and 5400 cal. BP (5500-3400 BC).

4.1.3 - Shallow marine deposits (Unit C)

This unit marks the bottom of the stratigraphic record of P3 and P4 cores (Fig. 5), but is also present in the core P7 above unit B at a depth of between 8.4 m and 6.6 m. It consists of mainly gray and dark gray sandy sediments with a minor silt component, abundant bioclasts and scattered shells of marine bivalves and gastropods. It is present from 10 to 8.4 m and from 7.45 to 6 m in P3, as well as 7.4 to 3.8 m in core P4. The grain size analysis of 11 samples indicated that they were composed mainly of well-rounded quartz and feldspar grains, ranging from medium sand to very fine gravel in size. The sediments vary from moderately well sorted to poorly sorted, with a mean grain-size range of medium sand to very coarse sand. Distributions are mainly unimodal, with some bimodal and skewness ranges from symmetrical to fine skewed but rarely coarse skewed.

The faunal assemblage of unit C is characterized by different species of molluscs, generally more diversified than unit B. Furthermore a large presence of echinoid spines was observed as well as benthic microfossils (foraminifera and rare ostracod valves) and unidentifiable shell fragments. Molluscan assemblages include different species of *Rissoidae*, *Cerethidae*, *Cardidae* and the *Tellinidae* family, typical of marine infralittoral biocenoses (Supplementary Tab. A). *Bittium reticulatum*, the dominant species, is a soft bottom epifaunal and microherbivore species (Rueda et al., 2009), typically associated with *Posidonia oceanica* meadows, but occurring in a wide range of infralittoral environments (Pérès and Picard, 1964; Pérès, 1982). Small gastropods such as *Alvania cimex*, *Alvania discors*, *Pusillina radiata*, *Rissoa lineolata*, *Tricolia tenuis* and *Tricolia pullus* belong mainly to infralittoral algae associated with sub-tidal sands (Pérès and Picard, 1964; Pérès, 1982).

Bivalve and gastropod taxa occurring in Unit C (Table 1) can be divided into four main ecological groups. These include the upper clean sand assemblage (*Pirenella conica*, *T. nitida*, *D. semistriatus*, *Nassarius pygmaeus*, *A. tuberculata*, *C. gallina*), the upper muddy-sand assemblage in sheltered areas (*L. lacteus*, *C. vulgatum*, *Hydrobia* sp., *T. decussatus*), the sub-tidal sands and hard substrates assemblage (*Bittium reticulatum*, *Vermetus triqueter*, *R. lineolata*, *Tricolia pullus*) and the algae assemblage (*A. cimex*, *A. discors*, *P. radiata*).

The foraminifera of unit C are represented by euryhaline marine species that live on sandy and vegetated bottoms of shallow depth, as demonstrated by diverse taxa such as *Quinqueloculina* spp. (some *Quinqueloculina seminula*), *Triloculina* sp., *Elphidium crispum*, *Planorbulina mediterraneensis*, *Rosalina bradyi*, *Lobatula lobatula* and *Ammonia beccarii*. These taxa are all typical of shallow coastal waters and Mediterranean marine environments (Cearreta et al., 2016). Ostracod faunal densities are extremely low for this unit. Some broken valves of coastal species (e.g. *Aurila* spp.) are consistent with a coastal environment.

The sedimentological features and faunal assemblages suggest that Unit C formed in a shallow marine environment, not far from the shoreline. In particular, deposition took place in a medium to high-energy coastal environment, probably between the upper shore-face and the foreshore. This is shown by the presence of well-rounded and clean fine sands. The molluscan and micro-fossil content is mainly composed of taxa belonging to a shallow marine environment with variable energy (i.e. from the shoreface to a marginal marine environment). A radiocarbon date from this unit provided an age of 6348 ± 56 cal. BP (4348 ± 56 cal. BC) at -7.05 m in core P7. Another date constrains the transition between Units B and C, 6905 ± 118 cal. BP (4905 ± 118 cal. BC) at -7.45 m in core P3.

4.1.4. Fluvial deposits (Unit D)

Unit D is present in all cores, ranging in thickness from 2 m to 4.5 m. It mainly consists of grayish brown and gray coarse-grained sandy sediments, which overlie finer-grained lagoonal deposits (Unit B), with the exception of the stratigraphic record in cores P3 and P4 which overlie coastal sands (Unit C).

On the basis of the particle size analysis, the deposits consist mainly of medium-coarse sands that alternate with slightly gravelly sands and gravelly 'muddy' sands with very few pebbles. The sediments show unimodal and bimodal distributions with a mean grain size ranging from coarse sand to medium sand up-profile, and moderate to poor sorting. The skewness is generally symmetrical, it also varies according to the content of coarser or finer size fractions. There are no recognizable sedimentary structures, but organic remains (wood and other plant debris) are present

and shell fragments are scarce. The sediments include rare and poorly preserved transported bioclasts in a few samples. The mineralogical composition comprises a significant proportion of quartz as well as micas and feldspars with common lithic fragments of metamorphic rocks. In cores P3 and P4, and in the upper part of the Unit D in cores P6 and P7 core, medium sands and slightly 'muddy' sand deposits occur. These sediments show a unimodal grain size distribution, with poor to moderate sorting and a mean grain size ranging from medium to fine sand. Skewness is mostly symmetrical, and sometimes very finely skewed. Scattered plant debris and wood fragments are encountered, while no microfossils are found. The sandy sediments are mainly composed of micaceous quartz. In all cores, Unit C displays a characteristic fining-upwards trend. The diagnostic sedimentological features (mineralogical composition, grain-size distribution, scarce and reworked fossiliferous content) suggest that Unit D was deposited in a medium to high-energy alluvial environment. The presence of a sandy succession with a fining upward trend can be interpreted as deposits within a deltaic or fluvial depositional system. In particular, the deposits consisting of coarse-medium sands and gravelly sands represent channel fill deposits, while medium-fine sands can be interpreted as levee or crevasse splay deposits related to channel avulsion.

4.1.5. Floodplain deposits (Unit E)

Unit E represents the top of the Holocene succession in the Rio Posada alluvial-coastal plain and reaches a maximum thickness of 3 m (i.e. in core P6). The transition between Unit E and the underlying Unit D is gradual. We performed grain-size analyses on 15 samples. Unit E is composed of dark brown/dark yellowish brown fine and very fine sands showing an upwards transition to silty sands or silty clayey sands. The sediment texture is mainly sandy loam and loamy sand. No molluscan shells and microfossils were found within this unit, while plant debris, wood fragments, roots and charcoal specks are generally present. The occurrence of yellow-brown mottles, due to iron and manganese oxides, suggests fluctuating redox conditions most likely related to oscillations in the groundwater table. In core P3, Unit E exhibits two different deposits. The deepest deposit (at 2 m depth) consists of black 'muddy' sands with vegetal, woody remains and charcoal fragments, passing upward (at a depth of 1 m) to yellowish-brown clayey silty sands.

No archaeological remains were found within these deposits. Two radiocarbon dates yielded an age of 2244 ± 89 cal. BP (224 ± 89 cal. BC) from the lower portion of this unit (at 1.75 m in P3) and of 1462 ± 108 cal. BP (488 ± 108 cal. AD) at 1 m in core P4.

Sedimentological features suggest that this unit formed in an alluvial depositional setting, subject to subaerial exposure, such as a well-drained floodplain occasionally affected by river flooding. Silty sand and silty clayey sand sediments represent typical deposits of areas inundated by the low-

energy floodwaters. Unit E represents overbank sedimentation, including minor crevasse/levee sandy-silty deposits, which often occur at the bottom of channels and at the transition to the underlying Unit D. Floodplain deposits are predominantly fine grained, and may be charcoal bearing if developed in humid environments. In fact, muddy sandy sediments with organic matter and charcoal in core P3 can be interpreted as backswamp deposits underlying overbank deposits.

4.2. Vegetation history

Pollen analysis was successfully performed on 18 out of 26 samples, because 8 samples of the core P3 were barren, probably due to problems of pollen preservation in sandy sediments. The pollen records presented in Figure 6 include: a percentage diagram of selected taxa, the Arboreal Pollen (AP)/Non Arboreal Pollen (NAP) percentage diagram and the total pollen concentration (number of pollen grains/gram of sediment). The results are also presented in a composite percentage diagram including all the samples analysed plotted against the age and the micro-charcoal concentrations measured according to the procedure reported in Clark et al. (1989), which can be a indicator of fire incidence in the area (Fig.7). The total pollen concentration varies between 900 and 83,000 terrestrial pollen grains/g. Pollen preservation was good, since the number of indeterminable grains (degraded, corroded and broken) never exceeds 5%. The palynological richness is represented by 70 pollen taxa of terrestrial and aquatic plants and 16 non-pollen taxa including fern spores and algae, and other palynomorphs, most of which are reported in Fig. 7. These ecological indicators contribute to define both the vegetation characteristics and the aquatic conditions of the Posada coastal plain at different time intervals.

The pollen record of core P3 (7.85-1.45 m; ca. 7030-2000 cal. BP; ca. 5030-0 cal. BC) is composed of seven samples. The lower part of the diagram (7.85-5 m; 7030-5800 cal. BP; ca. 5030-3800 cal. BC) suggests a landscape with semi-wooded to scrubby vegetation (AP=60-70%). This was characterized by widespread *Erica*-dominated evergreen shrubs (*Erica* type: 44%) accompanied by significant frequencies of evergreen *Quercus* (10%), *Cistus* (6%), *Pistacia* (4%), *Olea* (3%) and *Arbutus* (2%). Both broadleaved deciduous trees and conifers show low percentages, testifying to their sparse presence in the region. Among the deciduous trees, *Quercus* (deciduous oak) and *Corylus* (hazel) are the most representative taxa, while conifers are only represented by *Pinus* (pine). The herbaceous vegetation was mainly composed of Cichorioideae, Poaceae, Apiaceae, Asteroideae, Cyperaceae/Juncaceae and *Carduus* type. Among the herbs, a peak of *Asphodelus* (14%) at around 6900 cal. BP (ca. 4900 cal. BC) deserves special mention, as it suggests a phase of intense environmental degradation related to grazing and/or fire activity (Rhizopoulou et al., 1997). In several regions of the Mediterranean, including Sardinia, *Asphodelus ramosus* and other species

of the same genus form plant coenoses which dominate areas particularly degraded by overgrazing and fire (e.g. Asphodel-geophyte deserts in Israel or asphodel-semi-deserts in Greece) (Pignatti 1982; Pantis and Margaris, 1988).

The central part of the P3 diagram (5-3.65 m) shows complex vegetation dynamics. A rapid decline in *Erica* type (down to 15%) is paralleled by an increase in evergreen *Quercus* (up to 25%) and *Myrtus* (5%), pointing to a clear floristic turnover in this Mediterranean maquis scrubland. This marked change in the main woody taxa is also reflected in a clear decline in total pollen concentrations (Fig.6). A contemporary increase in *Alnus* (alder) frequencies (38%) can be related to the development of riparian vegetation, probably as a result of dramatic geomorphic changes in the Posada river coastal plain. This increase in *Alnus* contributes to keeping the AP values high (80%). The upper part of the diagram, represented by the sample at 1.45 m, dated to ca. 2000 cal. BP (ca. 0 cal. BC), shows an open landscape (AP=47%), with Chenopodiaceae and Cichorioideae as the dominant herbs. Within the arboreal-scrub vegetation, there is a decline in evergreen *Quercus*, and a slight increase in *Erica* type, suggesting an overall degradation of the Mediterranean maquis. In the upper part of P3, the pollen record shows an increase in *Juniperus* (juniper; 5%), consistent with the development of thermophilous coastal dune vegetation.

The pollen records of core P6 and P7 highlight vegetation patterns similar to the lower part of the P3 pollen record, but with a better time-resolution. They elucidate the vegetation history of the lower Posada valley between 7550 and 6400 cal. BP, a time-interval with vegetational characteristics only roughly highlighted by the two lowest samples of the P3 record. The P6 pollen record of P6 core is represented by four samples dated between 7500 and 7300 cal. BP. It is characterized by a semi-open scrubland (AP=74-57%) dominated by *Erica* type (56%), with *Cistus* (7%), *Pistacia* (6%), evergreen *Quercus* (3%), *Olea* (2%) and *Arbutus* (2%) as companion taxa of this Mediterranean scrubland. The seven samples of the P7 pollen record, which spans the time-interval 7550-6400 cal. BP, confirm the extensive *Erica*-dominated shrubland, rich in Mediterranean thermophilous trees and shrubs, with arboreal pollen frequencies varying between 78% and 58%. The vegetation composition does not show any marked changes over the recorded time-interval.

5. Discussion

5.1. Landscape evolution of Posada coastal plain during the last 8000 years

The multi-proxy analysis (i.e. lithostratigraphy, palaeoecology) of the depositional environment observed in the five cores has allowed the landscape evolution of the Posada coastal plain to be reconstructed, including the main phases of shoreline development during the last 8000 years. The

stratigraphic data testify to the presence of a transitional coastal environment linked to the interaction between coastal and river processes. Cumulatively, these factors have controlled the evolution of the lower Posada river valley. Later in the sequence, there is a clear transition from brackish lagoon facies or shallow-marine deposits (shore-face and foreshore deposits) to an alluvial floodplain regime. The age of this transition is chronologically consistent with the main progradation processes affecting Mediterranean coasts following a major slowdown in sea-level rising rates after ca. 6000 cal BP (Amorosi et al., 2017; Anthony et al., 2014; Vacchi et al., 2016) and already recorded in the coastal plains of western Sardinia (Melis et al., 2017) and Corsica at about the same time (Ghilardi et al., 2017a; Currás et al., 2017, Vacchi et al., 2017).

Between ca. 7500 and 7000 cal. BP, a large portion of the Posada coastal plain was characterized by a lagoonal environment intermittently connected to the open sea by one or multiple inlets (Fig. 8a). The faunal assemblage is consistent with marine-brackish lagoonal environments subject to salinity changes. The molluscs in Unit B indicate a marine-lagoonal ecosystem, with common species belonging to euryhaline and eurythermal (LEE) biocenosis, typical of brackish water, and to the biocenosis of superficial muddy sands in sheltered water (SVMC), both typical of a marginal marine environment (Pérès, 1967; Augier, 1982). A sand bar, subject to seasonal storm surges, was probably close to core P3 as testified to by the presence of allochthonous and transported micro-gastropods belonging to the photophile algae (AP) and *Posidonia oceanica* meadows (HP) biocenoses of the infra-littoral marine environment. The analysis of core P3 shows an interesting periodicity in the palaeoecological data. Peaks in species numbers may be coincident with periods of either higher-energy coastal dynamics (e.g. storms) or wider inlet channels characterized by species reworking from diverse biocenoses (Kaniewski et al., 2016) and their deposition in this well-protected environment. The foraminifera associations confirm a transitional environment from a lagoonal to continental shelf environment.

The presence of coarse fluvial deposits (Unit A) at the bottom of P5 and P6 suggests that before ca. 7500 cal. BP (ca. 5500 cal. BC), the present inland area was characterized by a wide palaeo-channel, subsequently filled by lagoonal deposits composed of sandy organic muds.

From ca. 7000 to 6000 cal. BP (ca. 5000-4000 cal. BC), stratigraphic records (cores P3 and P4), faunal assemblage and radiocarbon dating confirm that shallow marine environments extended up to a maximum of 1.5 km inland from the present shoreline. While inland, near cores P5 and P6, the lagoonal area begins to be affected by fluvial sedimentation after ca. 7000 cal. BP (ca. 5000 cal. BC) (Fig. 8b). The stratigraphic record of core P7 shows that between ca. 6900 and 6300 cal. BP (ca. 4900- 4300 cal. BC) there was a shallow marine environment (near a beach), as confirmed by the bivalve and gastropod taxa occurring in Unit C which mainly belong to infralittoral algae, the *P.*

oceanica meadows biocenosis and the sub-tidal sands assemblage (Pérès and Picard, 1964; Pérès, 1982).

The end of a transgressive trend occurs at ca. 6000-5500 cal. BP consistent with the significant slowing in sea-level rise rates recorded throughout the Mediterranean (Anthony et al., 2014; Vacchi et al., 2016). The presence of an open lagoon environment (Fig. 8c) is documented by muddy sands (at core P3) up to about ca. 5500 cal. BP (ca. 3500 cal. BC) at the top of the deposit, above a shallow marine unit (shoreface and/or beach environment deposits). Medium-coarse sand deposits, characterized by a mixed malacofauna of small gastropods belonging to the HP and AP biocenosis, as well as molluscs living in the littoral and infralittoral area, indicate that the marine ingression occurred with a discontinuous sea-level rise rate. This is also highlighted in the stratigraphic record of P3, by the alternation of sandy littoral and marine-lagoonal deposits. Fluvial sedimentation with channel fill deposits is only dominant in this area after ca. 5500 cal. BP (ca. 3500 cal. BC), according to the age attributed to the upper part of the marginal marine deposits in the core P3.

From ca. 5500 to 4200 cal. BP (ca. 3500-2200 cal. BC, or the Eneolithic period) and until ca. 2400 cal. BP (ca. 400 cal. BC, or towards the end the Iron Age), fluvial activity increased dramatically. It triggered intense lateral and vertical sedimentation linked to river channel migration, as documented by the accumulation of medium-coarse sand bodies on the lagoonal deposits (Fig. 8d).

Subsequently, a progradational trend started, causing the seaward migration of the shoreline and, later, the formation of a barrier-lagoon system, as observed elsewhere along the western coast of Sardinia (Melis et al. 2017). Finally, overbank deposition of fine-grained material in the floodplain as alluvium, associated with seasonal low-energy river flows, dominated the Posada coastal plain from the Late Punic period (ca. 2300 cal. BP; 300 cal. BC) until recent times.

In Posada, as already observed in other western Mediterranean coastal plains (e.g., Currà et al., 2017; Fontana et al., 2017; Melis et al., 2017) continuous landscape changes seem to have played an important role in the long-term settlement history of the area. For instance, there is a significant difference between the number of archeological settlements found on the Posada floodplain and those found on the hillsides (see figure 1a). In particular, none of the numerous Nuragic archeological structures (ca. 3600-2500 cal. BP or 1600-500 BC) was found within the coastal plain (Lo Schiavo, 1978; Fadda 1984) and the sole the presence of a Byzantine church and a Roman bridge is reported in the area (Sanciu, 2011).

Furthermore, our cores did not provide stratigraphic evidence (see Marriner and Morhange, 2011) for an ancient harbour serving the ancient Roman city of Feronia (Ptolemy, 1st century AD). This

does not exclude the existence of the city but future investigations should be carried out in other areas of the coastal plain.

5.2. Vegetation evolution

The composite pollen diagram of Posada is particularly useful in probing the vegetation history of the area and to compare the recorded vegetation changes with those described for Sardinia and Corsica.

Between ca. 7550 and 5800 cal. BP (ca. 5550-3800 cal. BC), the pollen record of Posada points to a landscape characterized by a widespread *Erica*-dominated shrubland, rich in other evergreen Mediterranean elements such as *Cistus*, and evergreen *Quercus*, *Pistacia*, *Olea* and *Arbutus*. This type of vegetation, still widely recorded in Sardinia today, had a much wider distribution on the island, as well as in Corsica, during the middle Holocene, as documented by pollen records (Reille, 1992b; Beffa et al., 2016; Poher et al., 2017; Curràs et al., 2017). In particular, between 8100 and 5300 cal. BP (ca. 6100-3300 cal. BC), the pollen and plant macrofossil record of Sa Curcurica, ca. 10 km from Posada, presents very similar vegetation suites, pointing to dense stands of *Erica scoparia* and *E. arborea*, and a high fire incidence testified by high microcharcoal frequencies (Beffa et al., 2016). According to Beffa et al. (2016), the prolonged dominance of *Erica* was related to warmer/drier summers and cooler/moister winters than today, in turn determining high fire activity, an environmental stress to which *Erica* species are extremely well-adapted, being able to regenerate biomass after frequent and intense fires (Ojeda et al., 2000; Keeley et al., 2012). The scarcity of palaeoclimatic data for Sardinia makes it difficult to explain the dominance of *Erica* at Posada in climatic terms, however also in our study the development of the *Erica*-dominated shrubland matches high concentrations of micro-charcoal indicating high fire activity. In Corsica, *Erica*-dominated shrubland are interpreted as primeval woody vegetation, which almost completely disappeared during the late Holocene (Reille, 1992b).

Between ca. 5800 and 4600 cal. BP (ca. 3800-2600 cal. BC), the Posada pollen record suggests that evergreen *Quercus* forest formations with *Myrtus* communities rapidly replaced part of the *Erica*-dominated shrubland. This vegetation turnover is also clearly recorded at Sa Curcurica (Beffa et al., 2016), where the development of evergreen oaks is accompanied by an increase in mesophilous taxa, while the decline of *Erica* parallels a decrease in fire frequency. These vegetation changes and fire dynamics are probably related to climate change, specifically to the establishment of moister/cooler summers and drier/milder winters after ca. 5300 cal. BP (ca. 3300 cal. BC) (Beffa et al., 2016), and possibly human impacts in terms of clearance and agriculture. At Posada, the development of the evergreen oak scrub woodland does not appear to be accompanied by a clear

development of mesophilous tree communities, excluding very slight increases in deciduous *Quercus* and *Corylus* trees. However, indicators of fire activity decreased, as at Sa Curcurica. A similar vegetation pattern is also highlighted in Corsican pollen records (Reille 1992b; Poher et al., 2017). Reille (1992b) states that the Atlantic period (ca. 7500-5000 cal. BP; ca. 5500-3000 cal. BC) corresponds to the maximal expansion of *E. arborea* in Corsica, the only climax shrub present at middle elevation, whilst during the Sub-boreal (from ca. 5000 cal. BP; 3000 cal. BC) *Quercus ilex* replaced *E. arborea* vegetation everywhere in Corsica.

In western Sardinia, the past vegetation dynamics are still difficult to define at a regional scale due to the scarcity of pollen records. However, considering the records of the Mistras Lagoon (Di Rita and Melis, 2013) and the Tirso Coastal Plain (Melis et al., 2017), which discontinuously span the last ca. 6000 years, they indicate that *Erica* was not as abundant as in eastern Sardinia, while a similar increase in evergreen oaks is recorded after ca. 5000 years BP. This result contrasts with other central Mediterranean coastal and marine records, where a general decline in the evergreen oak-dominated vegetation is recorded (Di Rita and Magri, 2009; Magri et al., 2015; Tinner et al., 2009; Margaritelli et al., 2016). This suggests that at least parts of Sardinia and the Italian Peninsula had vegetation and climate histories marked by different dynamics during the last ca. 6000 years. These different patterns probably also involved the centennial scale climate changes recognized in the central Mediterranean, as reported for the 4.2 ka BP climate event (Di Rita et al., 2018).

At Posada, the time interval between ca. 5800 and 4600 cal. BP (ca. 3800-2600 cal. BC) is also characterised by the development of *Alnus* (alder) woodland, especially along the margins of the floodplain and around marshy areas just inland from the coastal dunes. This is also consistent with the development of *Alnus*-dominated woodland occurring between ca. 6000 and 5000 cal. BP (ca. 4000-3000 cal. BC) in many coastal estuarine areas elsewhere in the central Mediterranean (Reille, 1992; Di Rita et al., 2010; Melis et al., 2017). This probably results from the interplay between complex environmental dynamics triggered by a decrease in the rate of sea-level rise. This process produced deep geomorphic, sedimentological and palaeoecological changes in the river floodplains, including dune formation, river-mouth modification and the establishment of freshwater environments with alder communities (Di Rita et al., 2015). In the Posada pollen record, these changes are also corroborated by other ecological indicators. They include the drop of foraminiferal faunal densities, indicating a change from a brackish to a freshwater environment, and the increase in both *Juniperus* and coastal thermophilous woody taxa which is consistent with the accumulation of dune deposits and the spread of coastal thermophilous vegetation, as documented in pollen records from other coastal sites during the Holocene (Di Rita et al., 2010, 2011; Poher et al., 2017).

The pollen record of Posada ends with a sample dated to around 2000 cal. BP, showing a decline in scrub woodland vegetation mostly related to an important decrease in evergreen *Quercus*. By contrast, the increase in *Juniperus* may point to a further stabilization of the dunes with a further development of thermophilous coastal vegetation. The increase in Chenopodiaceae and Cichorioideae, accompanied by the increase in *Pseudoschizaea* and the lack of foraminiferal tests, suggests sediment erosion and selective preservation of local, resistant pollen grains in a freshwater environment rather than the development of halophilic communities as recorded at other coastal sites (Bellotti et al., 2011; Di Rita 2013; Currás et al., 2017; Melis et al., 2017).

Regarding human impacts, pollen indicators of arable farm activities are observed throughout the record, mostly represented by low frequencies of cereal-type pollen. These findings appear to occur in an early Neolithic phase, during the 6th/5th millennia BC. It is unclear if there was cereal cultivation on Sardinia at this time. It is possible that these pollen grains belong to wild species of Poaceae, with a pollen-grain morphology similar to cereals. The few records of *Vitis* are probably related to wild grapes, since clear evidence for cultivation is only attested on the island from the Bronze Age onwards (Ucchesu et al., 2015a, 2015b). In general, the palynological evidence suggests a modest use of the land for arable crops. Conversely, the presence of significant frequencies of *Carduus*, *Asphodelus*, *Rumex*, and other taxa with species living in meadows exploited by cattle (e.g. Cichorioideae, Fabaceae, *Plantago*, Apiaceae), may indicate livestock grazing. In particular, a striking peak in *Asphodelus* at ca. 6900 cal. BP (ca. 4900 cal. BC) may indicate a phase of intense pastoralism during the early Neolithic. Although direct evidence for local human activities is still absent, it is likely that these existed in the area during the early mid-Neolithic periods, as hypothesized by others (Beffa et al., 2016; Lilliu, 2002).

5.3. Relative Sea-level evolution

A new suite of seven RSL index points and four RSL limiting points was produced in this study to provide new data to assess the RSL evolution of this part of the Sardinian coast, an area which had previously suffered from a paucity of data. Previous sea-level reconstructions had mainly focused on the southern (Orrù et al., 2004; Antonioli et al., 2007), western (Melis et al., 2017; Palombo et al., 2017) and northern coasts (Demuro and Orrù, 1998; Lambeck et al., 2004).

Along the eastern Sardinian coast, a beachrock sample (crf Mauz et al., 2015) was sampled at ca. 33 m near Cala Liberotto, less than 20 km south of the Posada coastal plain (Demuro and Orrù, 1998). The radiocarbon dating of the intertidal beachrock cement yielded a calibrated age of ca. 10,000 BP (Demuro and Orrù, 1998; re-calibrated by Vacchi et al., 2016) providing an insight into the RSL position in the early-Holocene (Figure 9). However, caution should be used with this RSL indicator

because problems in the radiocarbon age of Sardinian beachrocks were previously reported (Vacchi et al., 2016).

The newly produced RSL data are mainly clustered in the mid-Holocene, documenting the progressive RSL rise to -9.7 ± 1.2 m msl at ca. 7581 ± 95 cal. BP and to -5.3 ± 1.25 m msl at ca. 6905 cal. BP (Figure 9). The remaining part of the mid-Holocene is only constrained by two marine limiting points which place the RSL above -5.2 and -3.1 m msl at ca. 6348 and ca. 5380 cal. BP, respectively. For the late Holocene, the record is poor. Two terrestrial limiting points constrain the RSL to below -0.6 m msl at ca. 2253 cal. BP and below the present msl at ca. 1461 cal. BP.

In figure 8, we plotted the new RSL datapoints together with the RSL record reconstructed along the western coast of Sardinia (Melis et al., 2017, figure 9). The two datasets, reconstructed using the same methodology, are in very good agreement and provide new insights into the mid-Holocene RSL evolution for Sardinia.

The reconstructed RSL history shows an offset with the Glacio-hydro isostatic (GIA) predictions proposed for the area by Lambeck et al. (2011, figure 9). Between ca. 7500 and 7000 cal. BP, RSL was at least ca. 5 m above the position predicted by the model. Furthermore, at ca. 5300 cal. BP, a marine limiting point demonstrates that the RSL was at least ca. 3 m above the predicted position. Neo-tectonics are probably not responsible for this offset, especially as Sardinia is recognized as one of the most tectonically stable areas of the Mediterranean (Ferranti et al., 2006; Antonioli et al., 2007; Anzidei et al., 2014). In particular, elevations of the MIS 5.5 shoreline near the Posada coastal plain indicate negligible vertical movements (± 0.01 mm a⁻¹) during the last ca. 125,000 years (Ferranti et al., 2006). Aging effects in the lagoonal sequence, resulting in apparent older age of the samples, cannot be excluded. However, our new radiocarbon dataset forms a very coherent age-depth model and do not show evidence of age inversions (Fig. 2); furthermore, both the age and the elevation of the lagoons are not only consistent with those of southeastern Sardinia (Melis et al., 2017) but also for those from mid to southern Corsica (Poher et al., 2017; Vacchi et al., 2017; Ghilardi et al., 2017a,b).

For these reasons, with some cautions related to the age of the samples, the newly assembled dataset represents an advance in the definition of the mid-Holocene RSL evolution of the eastern coast of Sardinia. The total sea-level variation that was within ca. 11 m during the last ca. 7600 years and within 3.6 m during the last ca. 5400 years. This new dataset shows agreement with the recently published ICE-6G GIA model (Roy and Peltier, 2018) at least for this portion of the Holocene. However, new data are necessary to further confirm our record and to better constrain the RSL evolution in this portion of Sardinia. This is particularly important for the last 5000 years during which time the record is only composed of RSL limiting points.

6. Conclusions

The multi-proxy analysis of a new dataset of boreholes in the lower Posada valley of eastern Sardinia has provided insights into the palaeoenvironmental evolution of a large coastal plain during the last ca. 8000 years. The complex interplay between sea-level rise, sediment supply at base level and river progradation resulted in a very dynamic coastal environment during the mid- to late Holocene. In Posada, landscape dynamics played an important role in the long-term settlement patterns of the area. In fact, the low density and discontinuous nature of human occupation of the plain, from prehistoric to historic periods, was most likely related to the rapid and constant evolution of the coastal landscape. The area gradually changed from one of marine-lagoonal conditions during the earlier Neolithic period into a large alluvial plain with gradual seaward progradation of the shoreline during the later Neolithic period. This is consistent with complex environmental dynamics triggered by a decrease in the rate of sea-level rise and high sediment supply at base level that occurred during the 4th millennium BC. These data are consistent with geomorphic, sedimentological and ecological changes from other central Mediterranean river floodplains, including dune formation, river-mouth changes and the development of freshwater environments (cf. Amorosi et al., 2008; Anthony et al., 2014; Maselli and Trincardi, 2013; Vacchi et al., 2016, 2017).

Evidence of these changes are also documented in the stratigraphic and palynological records of the lower Posada river valley, which furnishes new data on vegetation development on the eastern side of Sardinia. In the sixth-fifth millennia BC, the landscape was dominated by *Erica* evergreen scrub woodland in the hinterland and brackish water lagoonal environments along the river mouth and coastline. The first major change that followed was marked by a change from a brackish to a freshwater environment that had occurred by the middle of 4th millennium BC. This was coincident with a partial replacement of the *Erica* scrub by evergreen oak scrub woodland (*Quercus ilex*) and *Myrtus* shrub communities, and then an increase in *Juniperus* (juniper), which is consistent with the accumulation of dune deposits, and a rapid increase in *Alnus* (alder) pollen testifying to the development of scrubby woodland on the damp riparian margins of floodplain. As for clear evidence for human impacts, the pollen data suggest only a modest use of the land in the catchment for arable crops during prehistoric times. Instead, the presence of significant frequencies of *Carduus*, *Asphodelus*, *Rumex* and other taxa, including species living in meadows exploited by cattle, are mostly consistent with livestock grazing activities, although other corroborative evidence of human activities in the locality is still largely lacking for the Neolithic period. Nonetheless, from the later Neolithic, the aggradation of the alluvial floodplain of the lower Posada valley suggests

increasing human impacts in the catchment, with clearance and agricultural activities leading to soil erosion and its entrainment and re-deposition downstream in overbank flooding events.

ACCEPTED MANUSCRIPT

Acknowledgments

This work was supported by the LR/7 2010 Regione Sardegna (project TENDER CRP-7704 Sa massaria), RTM is grateful to UNICA for FdS-RAS funding F72F16003080002. MV thanks the MOPP-Medflood (INQUA CMP 1603P) community for fruitful discussions. We also thank Donatella Magri for her precious comments.

ACCEPTED MANUSCRIPT

References

- Albani, A., Serandrei Barbero, R., 1990. I foraminiferi della Laguna e del Golfo di Venezia. *Mem. Sc. Geol. Univ. Padova*, 42, 271-331.
- Amorosi, A., Sarti, G., Rossi, V., 2008. Anatomy and sequence stratigraphy of the late Quaternary Arno Valley fill (Tuscany, Italy). *Geodin. Acta (Special publication)* 1, 1–14.
- Amorosi, A., Bini, M., Giacomelli, S., Pappalardo, M., Ribecai, C., Rossi, V., Sammartino, I., Sarti, G., 2013. Middle to late Holocene environmental evolution of the Pisa coastal plain (Tuscany, Italy) and early human settlements. *Quat. Int.* 303, 93-106.
- Amorosi, A., Bruno, L., Campo, B., Morelli, A., Rossi, V., Scarponi, D., Hong, W., Bohacs K.M., Drexler, T. M., 2017. Global sea-level control on local parasequence architecture from the Holocene record of the Po Plain, Italy. *Mar. Petr. Geol.* in press
- Anthony, E.J., Marriner, N., Morhange, C., 2014. Human influence and the changing geomorphology of Mediterranean deltas and coasts over the last 6000 years: from progradation to destruction phase? *Earth Sci. Rev.* 139, 336–361.
- Antonioli, F., Anzidei, M., Lambeck, K., Auriemma, R., Gaddi, D., Furlani, S., Orrù P., Solinas E., Gaspari, A., Karinja, S., Kovac, V., Surace L., 2007. Sea-level change during the Holocene in Sardinia and in the northeastern Adriatic (central Mediterranean Sea) from archaeological and geomorphological data. *Quat. Sci. Rev.* 26, 2463-2486.
- Anzidei, M., Lambeck, K., Antonioli, F., Furlani, S., Mastronuzzi, G., Serpelloni, E., Vannucci, G., 2014. Coastal structure, sea-level changes and vertical motion of the land in the Mediterranean. *Geol. Soc. Lond., Spec. Publ.* 388 (1), 453–479.
- Arda, F., Barbieri, G., Vernier, A., Vernier, E., 1999. Salinisation phenomena in the Posada coastal aquifer (North-East Sardinia). In: De Breuck, W. (Ed.), *Proceedings of the 15th Salt-Water Intrusion Meeting Ghent (Belgium), 25–29 May 1998*, pp. 79.
- Augier, H., 1982. Inventory and classification of marine benthic biocenoses of the Mediterranean. *Nature and Environment Series 25*, Council of Europe, Strasbourg.
- Beffa, G., Pedrotta, T., Colombaroli, D., Henne, P.D., van Leeuwen, J.F.N., Süssstrunk, P., Kaltenrieder, P., Adolf, C., Vogel, H., Pasta, S., Anselmetti, F.S., Gobet, E., Tinner, W., 2016. Vegetation and fire history of coastal north-eastern Sardinia (Italy) under changing Holocene climates and land use. *Veg. Hist. Archaeobot.* 25, 271–289
- Bellotti, P., Calderoni, G., Di Rita, F., D'Orefice, M., D'Amico, C., Esu, D., Magri, D., Preite Martinez, M., Tortora, P., Valeri, P., 2011. The Tiber river delta plain (central Italy): coastal evolution and implications for the ancient Ostia Roman settlement. *Holocene* 21, 1105–1116.

- Bennett, K.D., 2009. Documentation for Psimpoll 4.27 and Pscomb 1.03: C Programs for Plotting Pollen Diagrams and Analysing Pollen Data. Queen's University of Belfast, Department of Archaeology and Palaeoecology.
- Beug, H.J., 2004. Leitfaden der Pollenbestimmung für Mitteleuropa und angrenzende Gebiete. Verlag Friedrich Pfeil, Munich.
- Cearreta, A., Benito, X., Ibáñez, C., Trobajo, R., Giosan, L., 2016. Holocene palaeoenvironmental evolution of the Ebro Delta (Western Mediterranean Sea): Evidence for an early construction based on the benthic foraminiferal record. *Holocene*, 26(9), 1438-1456.
- Carboni, M.G., Bergamin, L., Di Bella, L., Iamundo, F., Pugliese, N., 2002. Palaeoecological evidences from foraminifers and ostracods on Late Quaternary sea-level changes in the Ombrone river plain (central Tyrrhenian coast, Italy). *Geobios* 35, 40-50.
- Carmona, P., Ruiz, J.M., 2011. Historical morphogenesis of the Turia River coastal flood plain in the Mediterranean littoral of Spain. *Catena* 86(3), 139–149.
- Carmignani, L., Oggiano, G., Barca, S., Conti, P., Salvadori, I., Eltrudis, A., Funedda, A., Pasci, S., 2001. Geologia della Sardegna; Note Illustrative della Carta Geologica della Sardegna in scala 1:200.000. Memorie Descrittive della Carta Geologica d'Italia, , Servizio Geologico d'Italia, 60, Roma, pp. 283.
- Castellaccio, A., 1990. Note sul castello della Fava. Medioevo saggi e rassegne. Fossataro, Cagliari 15, pp. 55-83.
- Chelli, A., Pappalardo, M., Bini, M., Brückner, H., Neri, G., Neri, M., Spada, G. 2017. Assessing tectonic subsidence from estimates of Holocene relative sea-level change: An example from the NW Mediterranean (Magra Plain, Italy). *The Holocene*, 27(12), 1988-1999.
- Currás, A., Ghilardi, M., Peche-Quilichini, K., Fagel, N., Vacchi, M., Delanghe, D., Dussouillez P., Vella C., Bontempi J.M. Ottaviani, J.C., 2017. Reconstructing past landscapes of the eastern plain of Corsica (NW Mediterranean) during the last 6000 years based on molluscan, sedimentological and palynological analyses. *J. Archaeol. Sci. Rep.*, 12, 755-769.
- D'Angelo, G., Gargiullo, S., 1978. Guida alle conchiglie mediterranee. Fabbri (MI)
- Daura, J., Sanz, M., Ramos, J., Riera, S., Miras, Y., Allué, E., Picornell-Gelabert, L., López-Reyes, D., Albert, R.M., Macià, L. and Domènech, R., 2016. Palaeoenvironmental record of the Cal Maurici wetland sediment archive in Barcelona (NE Iberian Peninsula) between c. 6000 and 4000 cal. yr BP. *The Holocene*, 26(7), 1020-1039
- Demuro, S., Orrù, P., 1998. Il contributo delle beach-rock nello studio della risalita del mare olocenico. le beach-rock post-glaciali della Sardegna Nord-Orientale". *Italian Journal Quat. Scienc.*, 11(1), 19-39.

- Di Rita F., Magri D., 2009. Holocene drought, deforestation and evergreen vegetation development in the central Mediterranean: A 5500 year record from Lago Alimini. Piccolo, Apulia, southeast Italy. *Holocene*: 19, 295-306.
- Di Rita, F., Celant, A., Magri, D., 2010. Holocene environmental instability in the wetland north of the Tiber delta (Rome, Italy): sea-lake-man interactions. *J. Palaeolimnol.* 44, 51-67.
- Di Rita, F., Simone, O., Caldara, M., Gehrels, W.R, Magri, D., 2011. Holocene environmental changes in the coastal Tavoliere Plain (Apulia, southern Italy): a multiproxy approach. *Palaeogeogr., Palaeocl.* 310, 139–151.
- Di Rita, F., 2013. A possible solar pacemaker for Holocene fluctuations of a salt-marsh in southern Italy. *Quatern. Int.* 288, 239–248.
- Di Rita, F., Melis, R.T., 2013. The cultural landscape near the ancient city of Tharros (central West Sardinia): vegetation changes and human impact. *J. Archaeol. Sci.* 40, 4271-4282.
- Di Rita, F., Celant, A., Milli, S., Magri, D., 2015. Late glacial early Holocene vegetation history of the Tiber delta (Rome, Italy) under the influence of climate change and sea level rise. *Rev. Palaeobot. Palyno* 218, 204-216.
- Di Rita, F., Lirer, F., Bonomo, S., Cascella, A., Ferraro, L., Florindo, F., Insinga, D.D., Lurcock, P.C., Margaritelli, G., Petrosino, P., Rettori, R., Vallefucio, M., Magri, D. 2018. Late Holocene forest dynamics in the Gulf of Gaeta (central Mediterranean) in relation to NAO variability and human impact. *Quaternary Science Reviews*, 179, 137–152.
- Doneddu, M., Trainito E., 2005. Conchiglie del Mediterraneo. Il Castello, Cornaredo (MI).
- Donnici, S., Serandrei Barbero, R., 2002. The benthic foraminiferal communities of the northern Adriatic continental shelf. *Mar. Micropaleont.* 44 (3), 93-123.
- D’Orlando, R., 1999. La Sardegna Settentrionale nel VI sec. A.C. Bernardini, P., Spano P.G., Zucca, R., (Eds.), *MAXH la battaglia del Mare Sardonio*. Catalogo delle Mostre, Cagliari-Oristano, pp. 96-103.
- Dyson, S.L., Rowland, R.J., 2007. *Archaeology and History in Sardinia from the Stone Age to the Middle Ages. Shepherds, Sailors, and Conquerors*. University of Pennsylvania Press., Philadelphia, pp. 248.
- Edwards R.J., 2007. Sea levels: resolution and uncertainty. *Prog. Phys. Geog.*, 31, 621.
- Engelhart, S.E., Vacchi, M., Horton, B.P., Nelson, A.R., Kopp, R.E., 2015. A sea-level database for the Pacific coast of central North America. *Quat. Sci. Rev.* 113, 78–92.
- Fadda, M.A., 1984. Il Nuraghe di Monte Idda di Posada e la ceramica a pettine in Sardegna. *B.A.R.* 229, 2, 671-702.
- Fadda, M.A., 2001. Posada: preistoria sarda all’ombra di un castello. *Archeologia Viva*, 85, 88-93.

- Ferranti, L., Antonioli, F., Mauz, B., Amorosi, A., Dai Pra, G., Mastronuzzi, G., Monaco, C., Orrù, P.E., Pappalardo, M., Radtke, U., Renda, P., Romano, P., Sansò, P., Verrubbi, V., 2006. Markers of the last interglacial sea-level high stand along the coast of Italy: tectonic implications. *Quat. Int.* 145, 30-54.
- Fiorini, F., Vaiani, S.C., 2001. Benthic foraminifers and transgressive–regressive cycles in the Late Quaternary subsurface sediments of the Po Plain near Ravenna (Northern Italy). *Boll. Soc. Paleont. It.*, 40, 357–403.
- Fiorini, F., 2004. Benthic foraminiferal associations from Upper Quaternary deposits of southeastern Po Plain, Italy. *Micropaleontology* 50, 45–58.
- Fontana, A., Vinci, G., Tasca, G., Mozzi, P., Vacchi, M., Bivi, G., Salvador, S., Rossatto, S., Antonioli, F., Asioli A., Bresolin, M., 2017. Lagoonal settlements and relative sea level during Bronze Age in Northern Adriatic: Geoarchaeological evidence and palaeogeographic constraints. *Quat. Int.* <http://doi.org/10.1016/j.quaint.2016.12.038>
- Frezza, V., Carboni, M.G., 2009. Distribution of recent foraminiferal assemblages near the Ombrone River mouth (Northern Tyrrhenian Sea, Italy). *Revue de micropaléontologie* 52, 43-66.
- Ghilardi, M., Istria, D., Currás, A., Vacchi, M., Contreras, D., Vella, C., Dussouillez, P., Crest, Y., Guiter, F., Delanghe, D., 2017a. Reconstructing the landscape evolution and the human occupation of the Lower Sagone River (Western Corsica, France) from the Bronze Age to the Medieval period. *J. Archaeol. Sci. Rep.* 12, 741–754.
- Ghilardi, M., Delanghe, D., Demory, F., Leandri, F., Pêche-Quilichini, K., Vacchi, M., Robresco, S., 2017b. Enregistrements d'événements extrêmes et évolution des paysages dans les basses vallées fluviales du Taravo et du Sagone (Corse occidentale, France) au cours de l'âge du Bronze moyen à final: une perspective géoarchéologique. *Géomorphologie: relief, processus, environnement*, 23(1), 15-35.
- Giaime, M., Morhange, C., Ángel Cau Ontiveros, M., Fornós, J. J., Vacchi, M., Marriner, N., 2017. In search of Pollentia's southern harbour: Geoarchaeological evidence from the Bay of Alcúdia (Mallorca, Spain). *Palaeogeogr. Palaeoclimatol.*, 466, 184-201.
- Hijma, M., Engelhart, S.E., Tornqvist, T.E., Horton, B.P., Hu, P., Hill, D., 2015. A protocol for a Geological Sea-level Database. In: Shennan, I., Long, A., Horton, B.P. (Eds.), *Handbook of Sea Level Research*. Wiley, pp. 536–553.
- Jorissen, F.J., 1987. The distribution of Benthic Foraminifera in the Adriatic Sea. *Mar. Micropaleontol.* 12, 21–48.

- Jorissen, F.J., 1988. Benthic foraminifera from the Adriatic Sea: principles of phenotypic variation Utrecht micropaleontol. Bull. 37
- Kaniewski, D., Marriner, N., Morhange, C., Faivre, S., Otto, T., Van Campo, E., 2016. Solar pacing of storm surges, coastal flooding and agricultural losses in the Central Mediterranean. Scientific Reports, 6, 25197.
- Karkani, P. A., Evelpidou, N., Vacchi, M., Morhange, C., Tsukamoto, S., Frechen, M., Maroukian, H., 2017. Tracking shoreline evolution in central Cyclades (Greece) using beachrocks. Mar. Geol., 388, 1, 25-37.
- Lachenal, A.M., 1989. Écologie des ostracodes du domaine méditerranéen : application au Golfe de Gabès (Tunisie orientale). Les variations du niveau marin depuis 30,000 ans. Documents des laboratoires de géologie de Lyon 108, 1-239.
- Lambeck, K., Antonioli, F., Purcell, A., Silenzi, S., 2004. Sea-level change along the Italian coast for the past 10,000 yr. Quat. Sc. Rev., 23(14), 1567-1598.
- Lambeck, K., Antonioli, F., Anzidei, M., Ferranti, L., Leoni, G., Scicchitano, G., Silenzi, S., 2011. Sea level change along the Italian coast during the Holocene and projections for the future. Quat. Int. 232 (1), 250–257.
- Lastra, M., Sa´nchez, A., Mora, J., 1993. Population dynamics and secondary production of *Parvicardium exiguum* (Gmelin, 1790) in Santander Bay (N of Spain). J. Mollus. Stud. 59, 73-81.
- Keeley, J.E., Bond, W.J., Bradstock, R.A., Pausas, J.G., Rundel, P.W., 2012. Fire in Mediterranean ecosystems. Ecology, evolution and management. Cambridge University Press, Cambridge
- Lilliu, G. 2002. La civiltà preistorica e nuragica in Sardegna. Accademia Nazionale dei Lincei, Serie IX, vol. XV/3), pp. 42 Roma.
- Lo Schiavo, F., 1978. Le fibule della Sardegna. Studi Etruschi, 46 (3), 25-46.
- Magri, D., Di Rita, F., 2015. Archaeopalynological preparation techniques. In: Yeung, E.C.T., Stasolla, C., Sumner, M.J., Huang, B.Q. (Eds.), Plant Microtechniques and Protocols. Springer International Publishing, Cham, pp. 495e506.
- Magri, D., Agrillo, E., Di Rita, F., Furlanetto, G., Pini, R., Ravazzi, C., Spada, F., 2015. Holocene dynamics of tree taxa populations in Italy. Rev. Palaeobot. Palynol. 218, 267-284.
- Margaritelli, G., Vallefucio, M., Di Rita, F., Capotondi, L., Bellucci, L.G., Insinga, D.D., Petrosino, P., Bonomo, S., Cacho, I., Cascella, A., Ferraro, L., Florindo, F., Lubritto, C., Lurcock, P.C., Magri, D., Pelosi, N., Rettori, R., Lirer, F., 2016. Marine response to climate changes during the last five millennia in the central Mediterranean Sea. Global Planet. Change, 142, 53–72.

- Marriner, N., Morhange, C. 2007. Geoscience of ancient Mediterranean harbours. *Earth-Sci. Rev.*, 80(3-4), 137-194.
- Marriner, N., Gambin, T., Djamali, M., Morhange, C., Spiteri, M., 2012. Geoarchaeology of the Burmarrad ria and early Holocene human impacts in western Malta. *Palaeogeogr. Palaeocl.* 339, 52-65.
- Marriner, N., Morhange, C., Faivre, S., Flaux, C., Vacchi, M., Miko, S., Boetto, G., Rossi, I. R. 2014. Post-Roman sea-level changes on Pag Island (Adriatic Sea): Dating Croatia's "enigmatic" coastal notch?. *Geomorph.*, 221, 83-94.
- Maselli, V., Trincardi, F., 2013. Man made deltas. *Sci. rep.*, 3.
- Mauz, B., Vacchi, M., Green, A., Hoffmann, G., Cooper, A., 2015. Beachrock: a tool for reconstructing relative sea level in the far-field. *Mar. Geol.* 362, 1–16.
- Mazzini, I., Anadon, P., Barbieri, M., Castorina, F., Ferreli, L., Gliozzi, E., Mola, M., Vittori, E., 1999. Late Quaternary sea-level changes along the Tyrrhenian coast near Orbetello (Tuscany, Central Italy): palaeoenvironmental reconstruction using ostracods. *Mar. Microp.* 37, 289-311.
- Melis, R.T., Depalmas, A., Di Rita, F., Montis, F., Vacchi, M., 2017. Mid to Late Holocene environmental changes along the coast of western Sardinia (Mediterranean sea). *Glob. Planet. Change.* doi:10.1016/j.gloplacha.2017.06.001
- Milli, S., D'Ambrogio, C., Bellotti, P., Calderoni, G., Carboni, M.G., Celant, A., Di Bella, L., Di Rita, F., Frezza, V., Magri, D., Pichezzi, R.M., Ricci, V., 2013. The transition from wave-dominated estuary to wave-dominated delta: the Late Quaternary stratigraphic architecture of Tiber River deltaic succession (Italy). *Sediment. Geol.* 284–285, 159–180.
- Ojeda, F., Arroyo, J., Marañón, T., 2000. Ecological distribution of four co-occurring Mediterranean heath species. *Ecography* 23, 148–159
- Orrù, P.E., Antonioli, F., Lambeck, K., Verrubbi, V., 2004. Holocene sea-level change in the Cagliari coastal plain (southern Sardinia, Italy). *Quat. Nova* 8, 193–212.
- Palombo, M. R., Antonioli, F., Presti, V. L., Mannino, M. A., Melis, R. T., Orru, P., Stocchi, P., Talamo, S., Quarta G., Calacagnile, L., Deiana, G., Altamura S., 2017. The late Pleistocene to Holocene palaeogeographic evolution of the Porto Conte area: Clues for a better understanding of human colonization of Sardinia and faunal dynamics during the last 30 ka. *Quat. Int.* <http://doi.org/10.1016/j.quaint.2016.06.014>
- Pantis J.D., Margaris NS 1988. Can systems dominated by asphodels be considered as semi-deserts? *Int. J. Biometeorol.* 32, 87-91

- Pascucci, V., De Falco, G., Del Vais, C., Sanna, I., Melis, R.T., Andreucci, S., 2018 Climate changes and human impact on the Mistras coastal barrier system (W Sardinia, Italy) *Mar. Geol.* 395, 271–284,
- Pavlopoulos, K., Karkanis, P., Triantaphyllou, M., Karymbalis, E., Tsourou, T., & Palyvos, N., 2006. Paleoenvironmental evolution of the coastal plain of Marathon, Greece, during the Late Holocene: depositional environment, climate, and sea level changes. *J. Coastal Res.*, 424-438.
- Pérès, J.M., Picard, J., 1964. Nouveau manuel de bionomie benthique de la Mer Méditerranée. *Recueil des Travaux de la Station Marine d'Endoume* 14 (23), 1-114.
- Pérès, J.M., 1967. The Mediterranean Benthos. *Oceanogr. Mar. Biol., An. Rev.*, 5: 449-533.
- Pérès, J.M., 1982. Major benthic assemblages. In: O. Kinne (Ed.), *Marine Ecology*, pp. 373-522. J. Wiley & Sons, Chichester.
- Pieruccini, P., Di Celma, C., Di Rita, F., Magri, D., Carnevale, G., Farabollini, P., Ragaini L., Caffau M., 2016. Sedimentology, faunal content and pollen record of Middle Pleistocene palustrine and lagoonal sediments from the Peri-Adriatic basin, Abruzzi, eastern central Italy. *Quaternary Res.*, 86, 13, 359-372.
- Poher, Y., Ponel, P., Médail, F., Andrieu-Ponel, V., Guiter, F., 2017. Holocene environmental history of a small Mediterranean island in response to sea-level changes, climate and human impact. *Palaeogeogr. Palaeoclimatol.* 465, 247-263.
- Poppe, G. T., Goto, Y., 1991. *European Seashells*, Vol.1, 1-352.
- Primavera, M., Simone, O., Fiorentino, G., Caldara, M., 2011. The palaeoenvironmental study of the Alimini Piccolo lake enables a reconstruction of Holocene sea-level changes in southeast Italy. *The Holocene* 21 (4), 553–563.
- Ratto, G., Montis, F., Depalmas, A., Rendeli, M., Melis, R.T., 2016. Paleoenvironmental reconstruction of the Sant’Imbenia area during the Middle Holocene (Sardinia, Italy). *Geogr. Fis. Dinam. Quat.* 39 (2016), 193-202, DOI 10.4461/ GFDQ 2016.39.18
- Regione Sardegna, 2017. Sardegna Geoportale, Digital Elevation Models. www.sardegnageoportale.it/index.html
- Reille, M., 1992a. Pollen et spores d’Europe et d’Afrique du Nord. *Laboratoire de Botanique Historique et Palynologie*. URA CNRS 1152, Marseille.
- Reille M., 1992b. New pollen-analytical researches in Corsica: the problem of *Quercus ilex* L. and *Erica arborea* L., the origin of *Pinus halepensis* Miller forests. *New Phytologist*: 122, 359-378.
- Rhizopoulou, S., Pantis, J. D., Triantafylli, E., & Vokou, D. (1997). Ecophysiological adaptations of *Asphodelus aestivus* to Mediterranean climate periodicity: water relations and energetic status. *Ecography*, 20(6), 626-633.

- Rossi, V., Amorosi, A., Sarti, G., Potenza, M., 2011. Influence of inherited topography on the Holocene sedimentary evolution of coastal systems: an example from Arno coastal plain (Tuscany, Italy). *Geomorphology* 135, 117-128.
- Rovere, A., Antonioli, F., Bianchi, C.N., 2015. Fixed Biological Indicators. In: Shennan, I., Long, A.J., Horton, B.P. (Eds.), *Handbook of Sea Level Research*. Wiley, pp. 268–280.
- Rovere, A., Stocchi, P. and Vacchi, M., 2016. Eustatic and relative sea level changes. *Curr. Clim. Ch. Rep.*, 2(4), pp.221-231.
- Roy, K., Peltier, W. R. (2018). Relative sea level in the Western Mediterranean basin: A regional test of the ICE-7G_NA (VM7) model and a constraint on late Holocene Antarctic deglaciation. *Quat. Sc. Rev.*, 183, 76-87.
- Rueda, J.L., Gofas S., Urra, J., Salas, C., 2009. A highly diverse molluscan assemblage associated with eelgrass beds (*Zostera marina* L.) in the Alboran Sea: micro-habitat preference, feeding guilds and biogeographical distribution. *Scientia Marina*, 73 (4), 669-700.
- Ruiz Muñoz, F., González Regalado Montero, M.L., Morales González. J.A., 1996. Distribution and ecology of recent foraminifera and ostracoda of the mesotidal estuary of the Guadiana River (SWSpain). *Geobios*, 29, 5, 513-528.
- Ruello, M. R., Cinque, A., Di Donato, V., Molisso, F., Terrasi, F., & Ermolli, E. R. (2017). Interplay between sea level rise and tectonics in the Holocene evolution of the St. Eufemia Plain (Calabria, Italy). *Journal of Coastal Conservation*, 21(6), 903-915.
- Salel, T., Bruneton, H., & Lefèvre, D., 2016. Ostracods and environmental variability in lagoons and deltas along the north-western Mediterranean coast (Gulf of Lions, France and Ebro delta, Spain). *Revue de Micropaléontologie*, 59(4), 425-444.
- Sanciu, A., 2011. Posada, centro storico. Recupero di materiali archeologici. *Erentzias*, 1, Delfino Carlo, Sassari, pp. 376-377.
- Sechi, N., 1982. Lo stato trofico di alcuni stagni salmastri costieri della Sardegna. *Boll. Soc. Sarda Sc. Nat.*, 21, 285-295.
- Serpelloni, E., Faccenna, C., Spada, G., Dong, D., Williams, S. D. P., 2013. Vertical GPS ground motion rates in the Euro-Mediterranean region: New evidence of velocity gradients at different spatial scales along the Nubia-Eurasia plate boundary. *J Geophys Res-Sol Ea*, 118, 6003–6024,
- Serrelli, G., 2014. I mutamenti nell’assetto insediativo del Regno di Sardegna in epoca catalana. In, Oliva A.M., Schena, O. (Eds.) *Sardegna catalana*, Institut de Estudis Catalans, Barcellona, pp. 271-284.
- Sgarrella, F., Moncharmont Zei, M., 1993. Benthic foraminifera of the Gulf of Naples (Italy): systematics and autoecology. *Boll. Soc. Palaeontol. I.* 32,145–264

- Shennan, I., 1986. Flandrian sea-level changes in the Fenland. II: tendencies of sea-level movement, altitudinal changes, and local and regional factors. *J. Quat. Sci.* 1 (2), 155–179.
- Shennan I., 2007. Overview – Sea-level studies. In Scott A.E. (Ed.): *Encyclopedia of Quaternary Science*, Elsevier, Amsterdam, 2967–2974.
- Stuiver, M., Reimer, P.J., 1993. Extended ^{14}C database and revised CALIB radiocarbon calibration program. *Radiocarbon* 35, 215–230.
- Tebble, N., 1966. *British bivalve Seashells*. Trustees of the British Museum (Nat. Hist.), London, pp. 214.
- Tinner, W., van Leeuwen, J., Colombaroli, D., Vescovi, E., van der Knaap, W.O., Henne P.D., Pasta, S., D'Angelo, S., La Mantia, T., 2009. Holocene environmental and climatic changes at Gorgo Basso, a coastal lake in southern Sicily, Italy. *Quaternary Sci. Rev.* 28, 1498–1510.
- Vacchi, M., Rovere, A., Chatzipetros, A., Zouros, N., Firpo, M., 2014. An updated database of Holocene relative sea level changes in NE Aegean Sea. *Quat. Int.* 328, 301–310.
- Vacchi, M., Marriner, N., Morhange, C., Spada, G., Fontana, A., Rovere, A., 2016. Multiproxy assessment of Holocene relative sea-level changes in the western Mediterranean: sea-level variability and improvements in the definition of the isostatic signal. *Earth-Sci. Rev.* 155, 172–197.
- Vacchi, M., Ghilardi, M., Spada, G., Currás, A., Robresco, S., 2017. New insights into the sea-level evolution in Corsica (NW Mediterranean) since the late Neolithic. *J. Arch. Sci. Rep.* 12, 783–793.
- Vella, C., Fleury, T.J., Raccasi, G., Provansal, M., Sabatier, F., Bourcier, M., 2005. Evolution of the Rhône delta plain in the Holocene. *Mar. Geol.* 222, 235–265.
- Ucchesu, M., Orrù, M., Grillo, O., Venora, G., Usai, A., Serreli, P.F., Bacchetta, G., 2015a. Earliest evidence of a primitive cultivar of *Vitis vinifera* L. during the Bronze Age in Sardinia (Italy). *Vegetation History and Archaeobotany* 24, 587–600.
- Ucchesu, M., Peña-Chocarro, L., Sabato, D., Tanda, G., 2015b. Bronze Age subsistence in Sardinia, Italy: cultivated plants and wild resources. *Veg. Hist. Archaeobot.* 24, 343–355.
- Walsh, K., 2013. *The Archaeology of Mediterranean Landscapes: Human-Environment Interaction from the Neolithic to the Roman*. Cambridge University Press, Cambridge.

Lab ID	Sample	Material	Depth (m)	Depth s.l.m.	¹⁴ C age BP	δ13C ‰	Calibration dataset	Marine%	Calibrated age yr BP (2σ) and probability
DSH6659	P3a	Organic sediment	-1.75	-0.57	2235 ± 25	-36 ± 3	Intcal13		2333-2295, 22,0% 2270-2155, 78,0%
DSH6663	P3b	Organic sediment	-4.30	-3.12	4728 ± 40	-24±4	Mixed Marine NoHem	4%	5581-5505, 29,0% 5488-5437, 23,0 % 5420-5321, 48,0%
DSH6660	P3c	Organic sediment	-7.45	-6.27	6197 ± 38	-17 ± 2	Mixed Marine NoHem	32%	7025-6788, 99,6%
DSH6669	P4	Organic sediment	-1.0	0.0	1646 ± 51	-21±3	Mixed Marine NoHem	16%	1570-1354, 99,3%
DSH6666	P5a	Organic sediment	-10.20	-7.95	6707 ± 52	-4±5	Mixed Marine NoHem	80%	7406-7167, 100%
DSH6668	P5b	Organic sediment	-7.56	-5.30	6285 ± 39	-26±2	Intcal13		7312-7156, 100%
DSH6664	P6a	Organic sediment	-8.28	-6.84	6316 ± 36	-37±2	Intcal13		7312-7168, 100%
DSH6665	P6b	Organic sediment	-9.57	-8.13	6729 ± 44	-19 ± 6	Mixed Marine NoHem	24%	7574-7436, 100%
DSH6662	P7a	Organic sediment	-7.05	-5.29	5554 ± 36	-44 ± 3	Intcal13		6404-6292, 100%
DSH6667	P7b	Organic sediment	-9.52	-7.76	6380 ± 38	-33±3	Intcal13		7418-7256, 100%
DSH6661	P7c	Organic sediment	-12.25	-10.49	7053 ± 41	-5±11	Mixed Marine NoHem	76%	7675-7492, 100%

Tab. 1. Radiocarbon dating results.

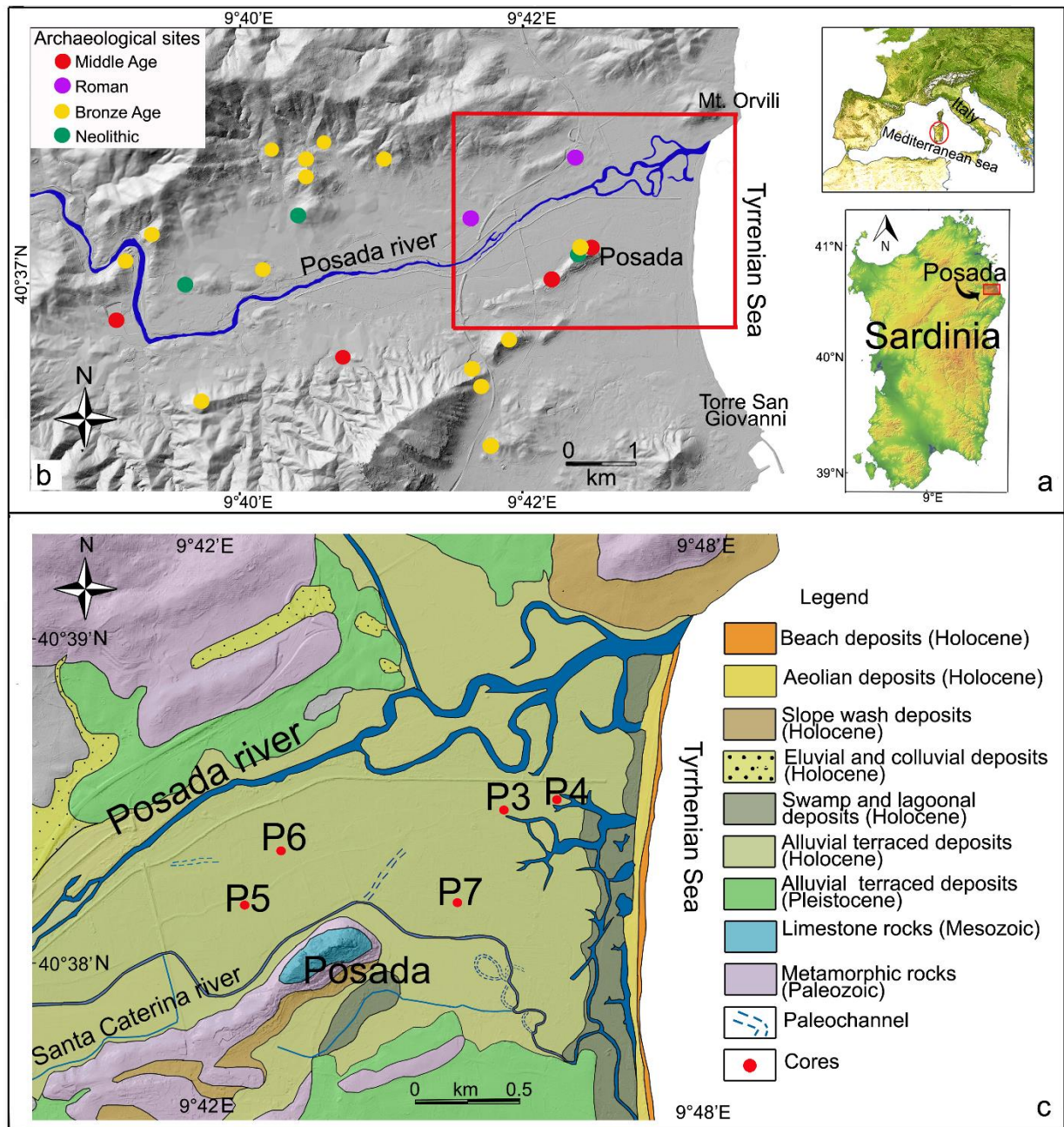


Fig. 1 a) Location of the study area on the north-east coast of Sardinia; b) distribution of archaeological sites, the box shows the location of the Posada coastal plain; c) Schematic geological map (DEM, Regione Sardegna, 2017) and location of the cores. Lat/long are provided in WGS84.

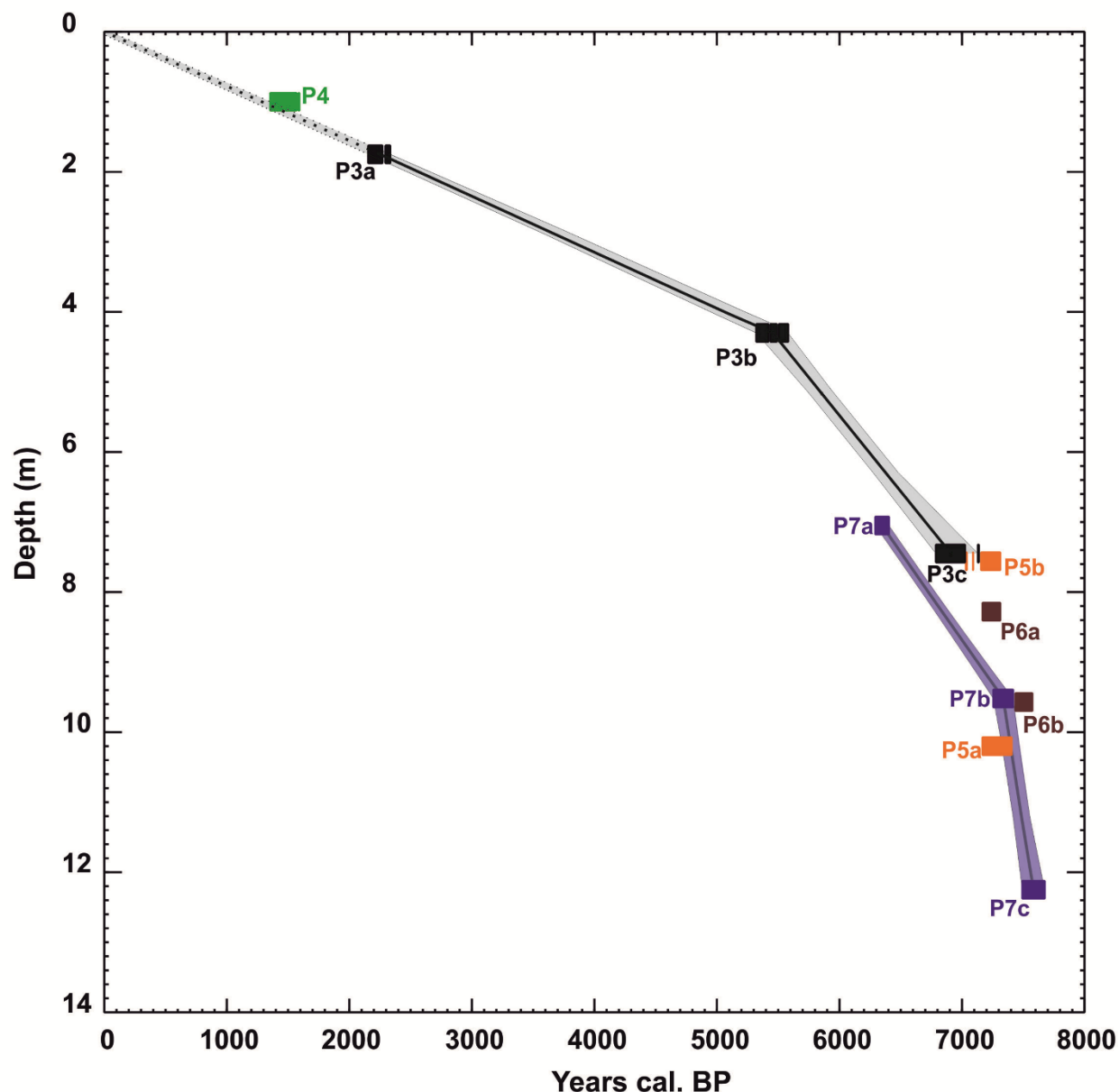


Fig. 2. Age-depth model of the cores P3 (black line) and P7 (blue line). The age-depth model is based on linear interpolation between the midpoints of 2σ calibration ranges of each ^{14}C dates (see table 1). Six modelled ages per core, provided by the function 'Age Depth Model' of CALIB 7.04 software (<http://calib.org/calib/>) (Stuiver and Reimer, 1993), were also used to build the models. The grey and violet envelopes show the final 95% confidence intervals of the calibrations for P3 and P7 cores, respectively. The diagram includes also the age-depth distribution of the dated samples of each core.

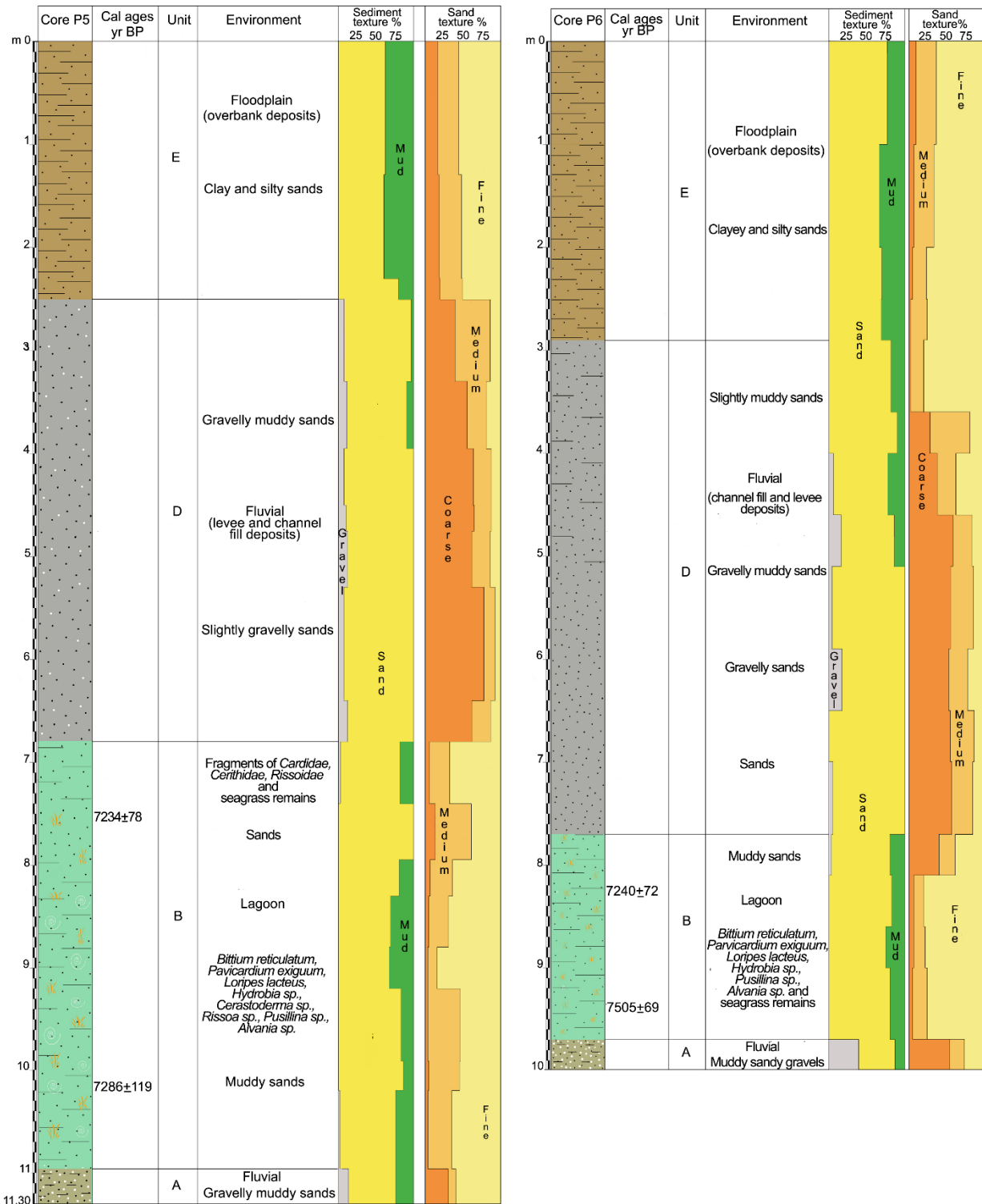


Fig. 3. Logs of P5 and P6 cores: lithostratigraphy and grain size analyses.

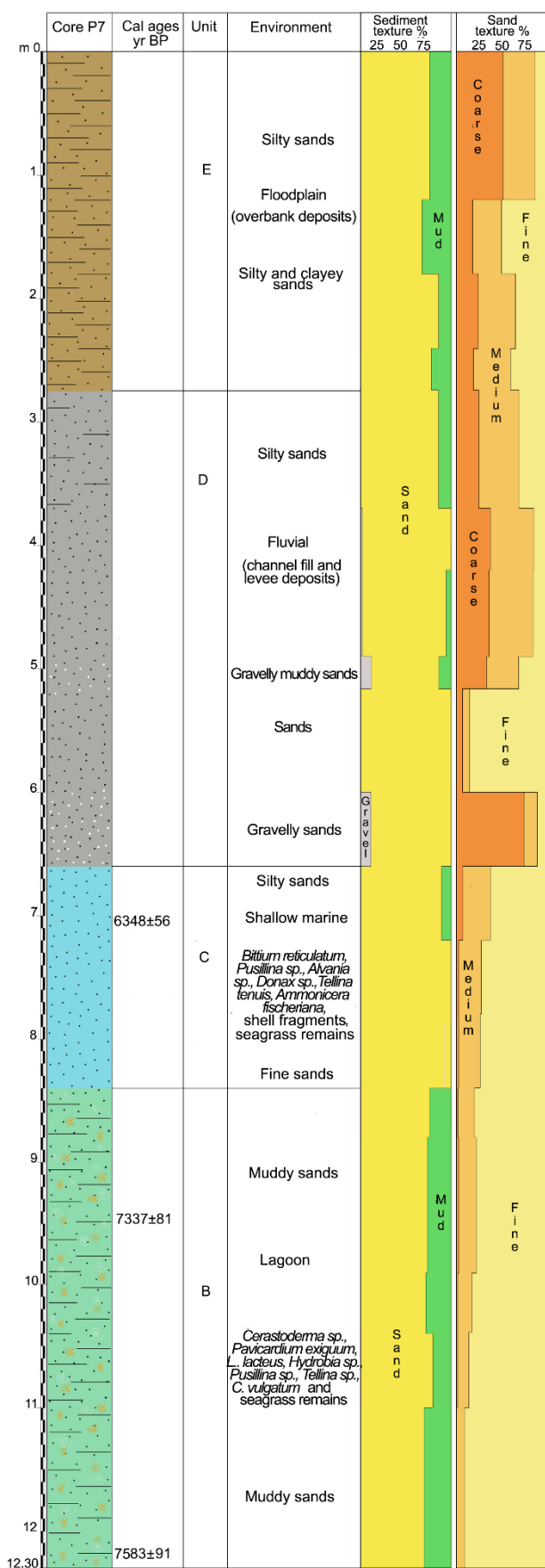


Fig. 4. Log of P7: lithostratigraphy and grain size analyses.

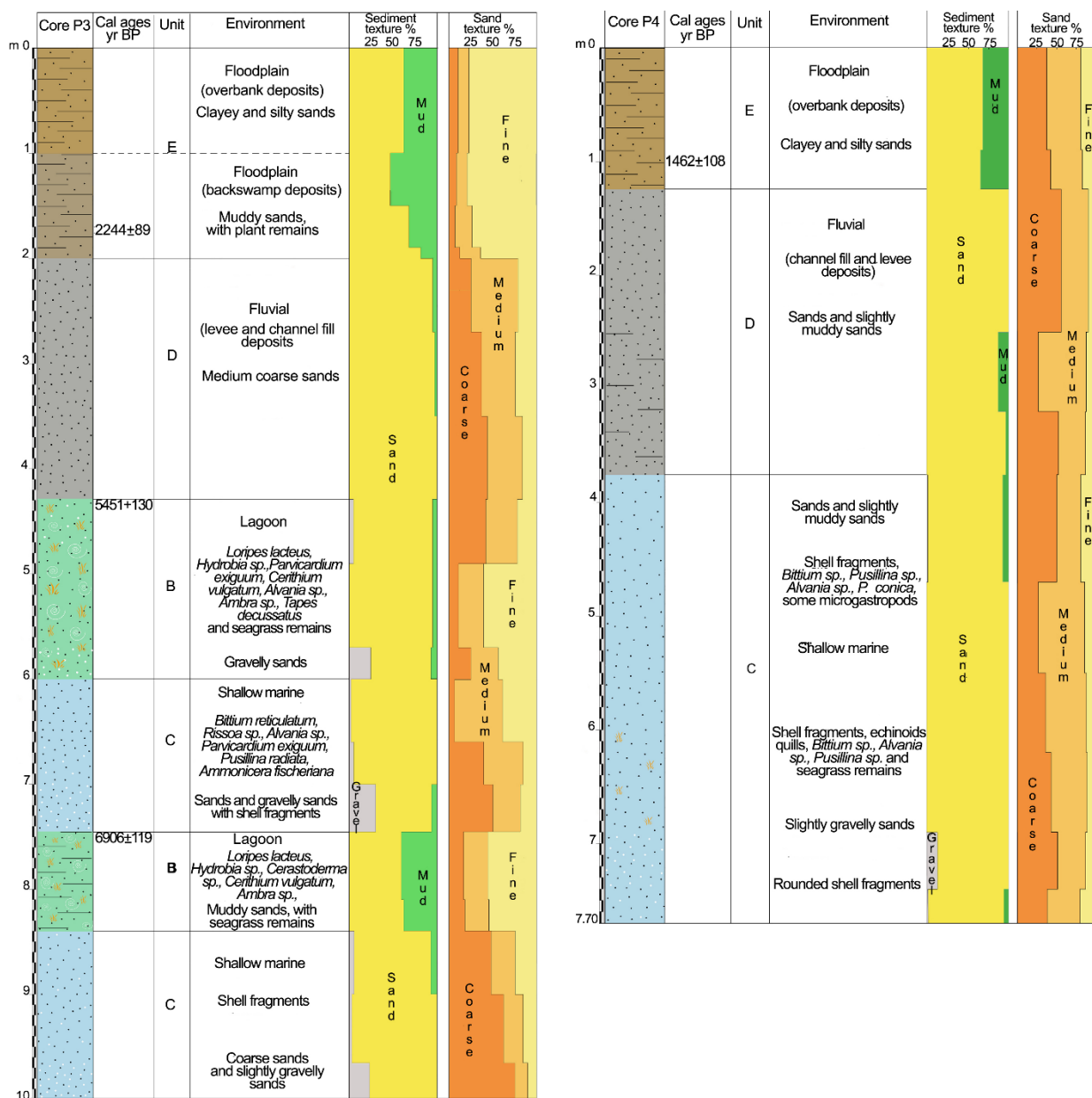


Fig. 5. Logs of P3 and P4 cores: lithostratigraphy and grain size analyses.

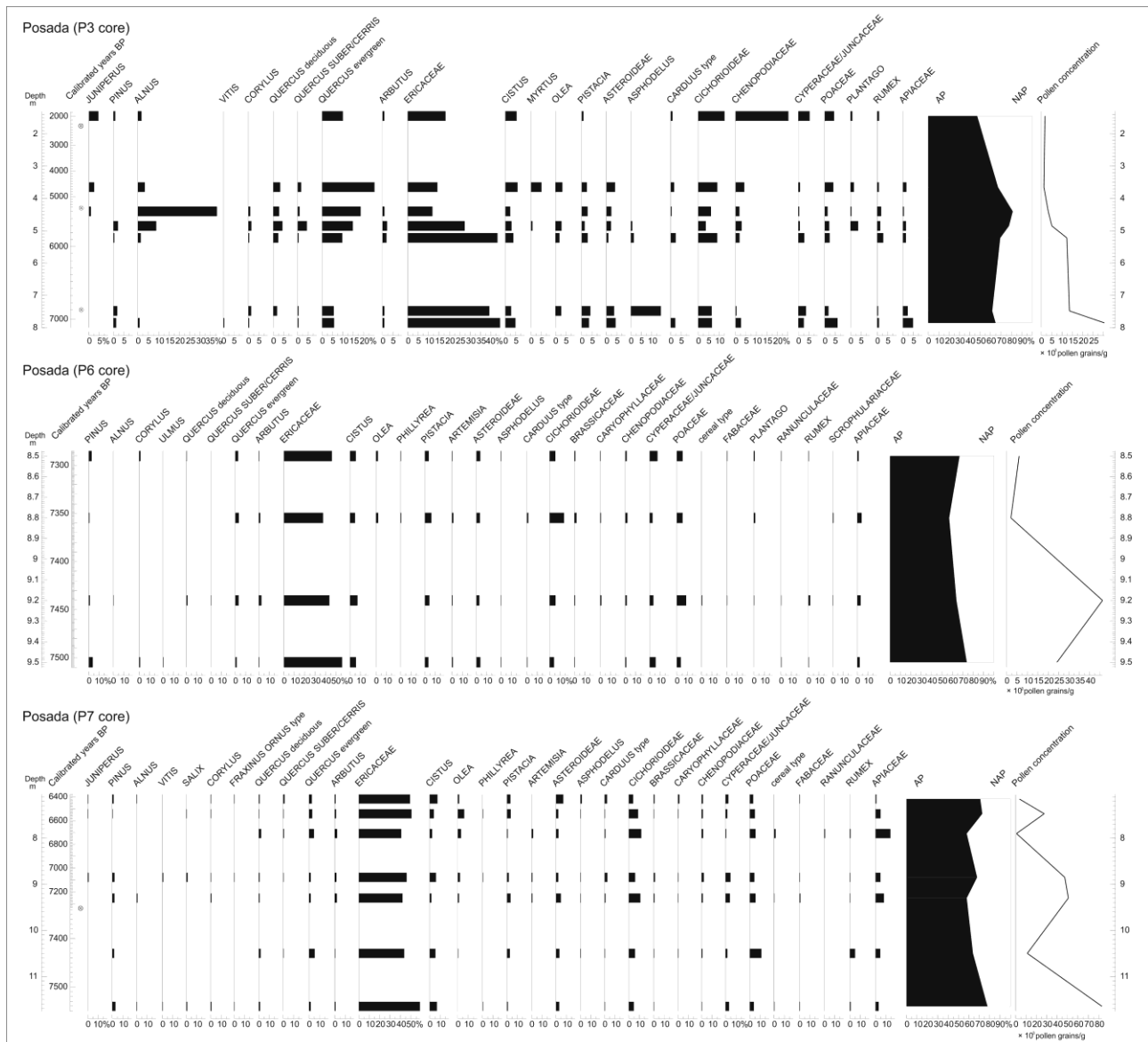


Fig.6. Percentage and Concentration pollen diagrams of cores P3, P6 and P7.

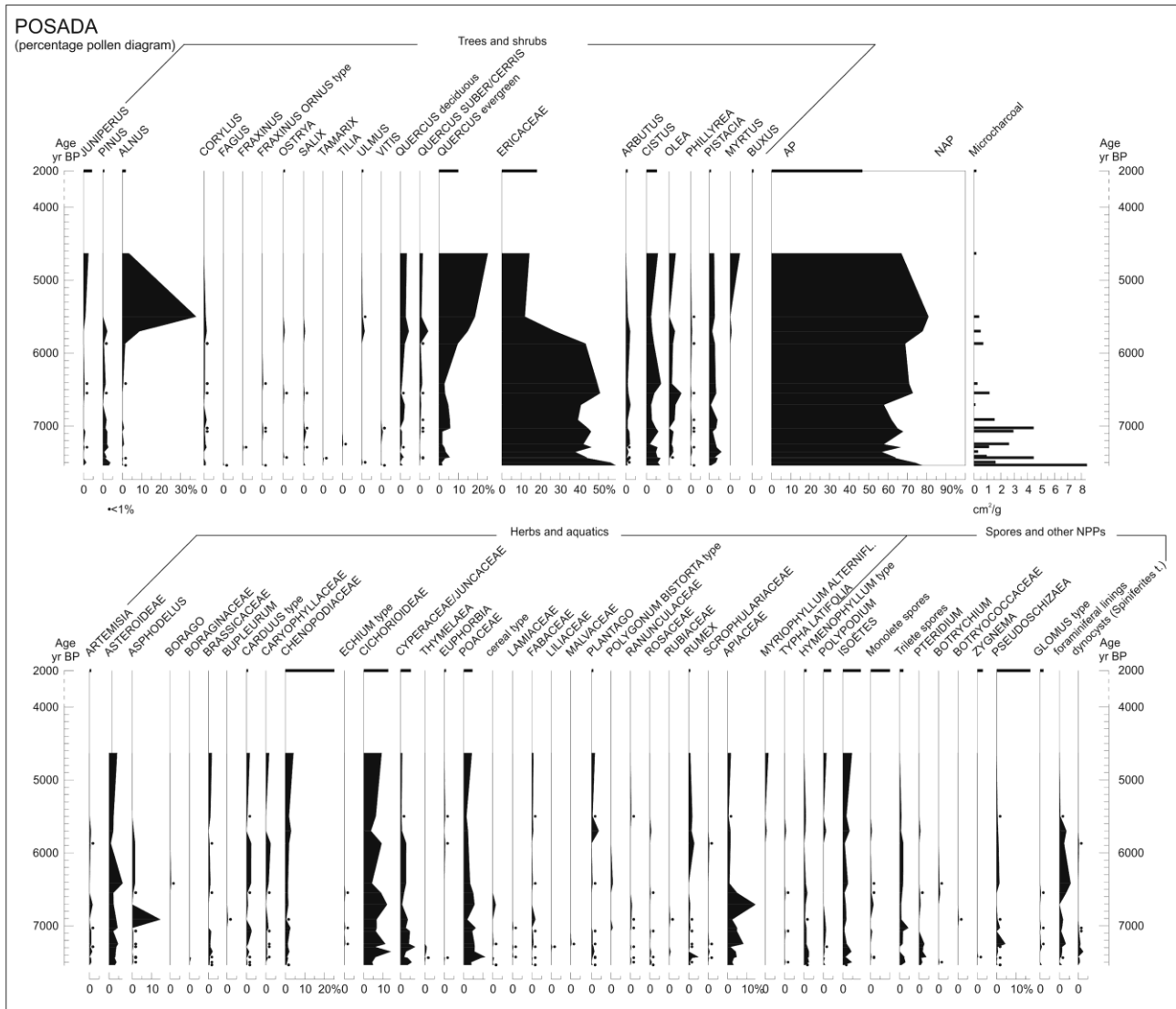


Fig 7. Percentage pollen record of Posada, including almost all the taxa and microcharcoal concentrations plotted against age.

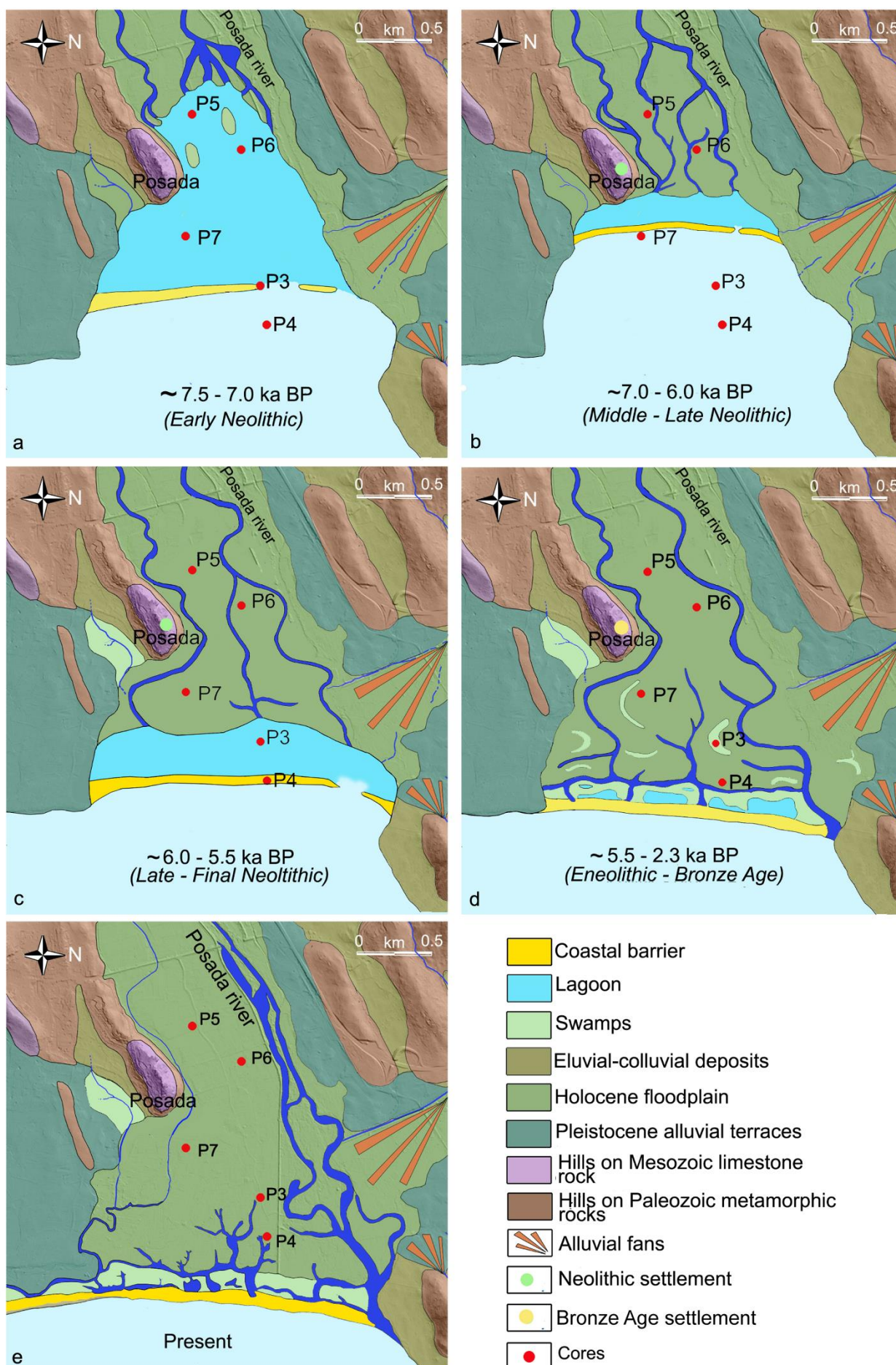


Fig.8. Schematic reconstruction of the main phases of the Posada coastal plain evolution as reconstructed by facies analysis and interpretation.

ACCEPTED MANUSCRIPT

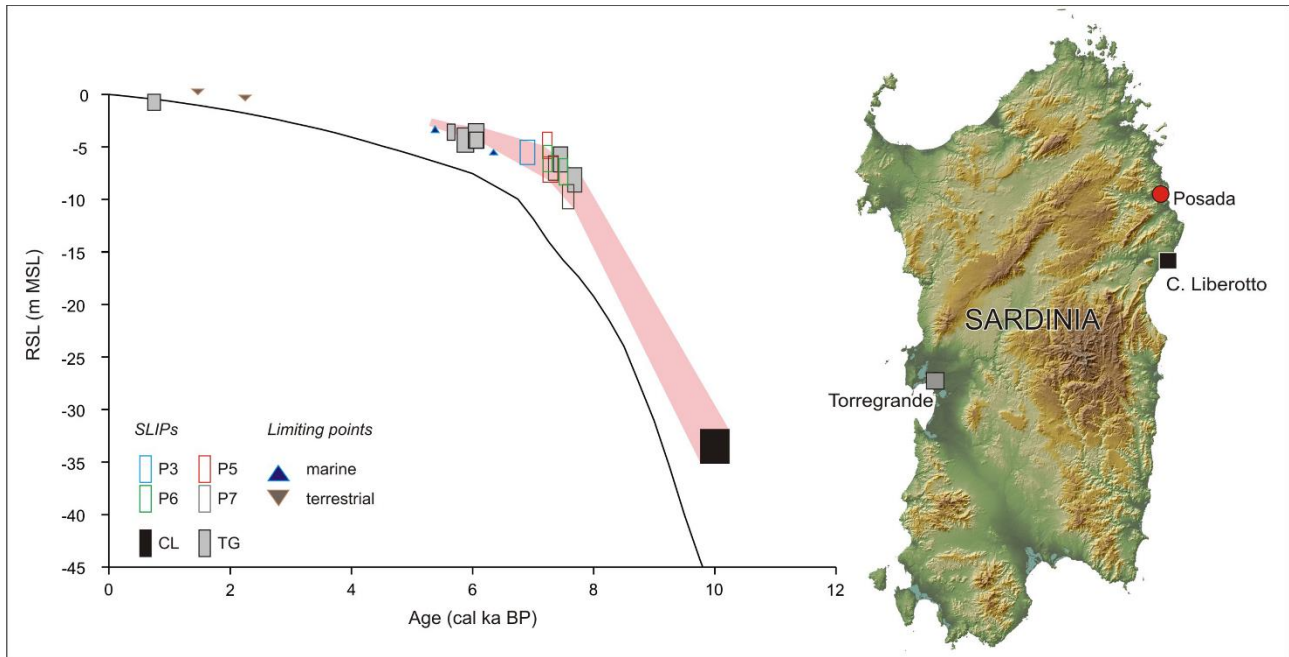


Fig.9. RSL reconstruction of the Posada coastal plains plotted against the predicted RSL curve (Lambeck et al., 2011) for eastern Sardinia. Index points (boxes) are plotted as calibrated age against the change in sea level relative to present. Limiting points are plotted as terrestrial or marine triangles. Dimensions of boxes and triangle for each point based on 2s elevation and age errors. P3, P5, P5 and P7 are the lagoonal samples from Posada coastal plains, CL is the beachrocks from Cala Liberotto (Demuro and Orrù, 1998), TG are the Torregrande lagoonal samples (western Sardinia, Melis et al., 2017). Pale red area represents the best estimate of the early to mid-Holocene RSL reconstruction.

Highlights

- 8000 years of coastal modification in a large Mediterranean coastal plain
- A multiproxy study of millennial men-environment interaction in coastal areas
- Role of sea-level stabilization and high sediment supply in the landscape evolution
- Constant changes of the coastal landscape highly influenced the human settlement
- New data on the mid-Holocene sea-level evolution in the mid-western Mediterranean

ACCEPTED MANUSCRIPT