The palaeogeography of Mesolithic settlement-subsistence and shell midden formation in the Muge valley, Lower Tagus Basin, Portugal

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Submitted for: a *Holocene* research paper. Words abstract: 246; Words from abstract to references: 6090. Number of references: 98.

Abstract

This paper reports the first detailed palaeogeographical analysis of the environmental context of late Mesolithic shell midden sites in the lower Tagus area and focuses on the lower Muge valley, which contains an internationally significant Mesolithic record. The lower Muge valley fill comprises buried estuarine and fluvial environments contemporary with Mesolithic settlement. Holocene environmental and palaeogeographic changes influenced Mesolithic settlement-subsistence and midden accumulation. The sudden appearance of large late Mesolithic shell middens throughout Portugal represents a process of increased visibility and preferential preservation of the archaeological record. Prior to ~6100 cal BC, aggrading valley floor environments did not occupy the entire width of the present lower Tagus floodplain and any sites located in the early Holocene valley are currently deeply buried. Shell midden occupation on terrace levels followed the establishment of aggrading estuarine environments, containing productive shell beds, near the mouth of the lower Muge valley at ~6100 cal BC. The critical factors in site choice appear to have been the nearby presence of i) rich shell resources and, ii) freshwater environments. Long-term site occupation and (semi-)sedentary behaviour was favoured by the local presence, for over 2000 years, of rich resources from estuarine, freshwater and open woodland environments. Site abandonment (~5300-4800 cal BC) coincided with the regional establishment of an open landscape (~5000 cal BC) and the contraction of local estuarine environments (~5555-3800 cal BC). The associated gradual decrease in resources and cultural interaction with the expanding early Neolithic communities may have influenced Mesolithic site abandonment.

Keywords: palaeogeography, Mesolithic, shell midden, preferential preservation

(A) Introduction

The role of marine and aquatic resources in prehistoric economies has received relatively little attention in past archaeological research. However, recent interpretations suggest that coastal environments may have been a primary focus for human settlement, dispersal, population growth and cultural interaction (e.g. Deacon and Schuurman, 1992; Erlandson 2001; Mannino and Thomas, 2001). The most visible prehistoric use of marine resources is recorded during the Holocene in the form of coastal shell middens (e.g. Bailey, 1999; Luby and Gruber, 1999). Prehistoric records in Europe do not register an extensive use of aquatic and marine resources until the beginning of the Mesolithic period (Bailey and Craighead, 2003). Large Mesolithic shell middens appeared in great numbers around 6000 cal BC along the coastlines of Denmark, Brittany, Portugal and Scotland, and have been associated with conditions of resource abundance, large sedentary populations and social complexity (e.g. Rowley-Conwy, 1983; Richard and Hedges, 1999). The Mesolithic shell midden communities persisted for perhaps a thousand years before they were transformed into, or displaced by, early Neolithic agricultural societies with much less emphasis on marine resources. The Mesolithic record has been interpreted to reflect a genuine trend of resource diversification and intensification of marine exploitation, culminating in a sudden increase of specialised coastal economies strongly dependent on marine resources (e.g. Zilhão, 1993; Bicho, 1994; Emili Aura *et al.*, 1998). An alternative hypothesis suggests that the increased representation of marine resources and especially molluscs in Late Pleistocene to Holocene coastal sites represents a process of increased visibility and preferential preservation of the youngest part of the archaeological record (Bailey and Craighead, 2003). However, important questions remain to be answered. Why did large shell middens only appear during the late Mesolithic, and even then in quite restricted geographical areas? Why were these sites suddenly abandoned if coastal resources were so attractive and capable of supporting large, sedentary populations?

A factor, independent of economic reliance, which influences the potential formation and growth of shell middens is the local presence of productive shell beds (O'Connor, 1999). The presence of coastal shell beds is variable in space and time due to environmental changes. A critical question is: how did the contemporary palaeogeography, topography and distance of available marine resources affect Mesolithic shell midden formation? Published geoarchaeological studies have reconstructed positions of former (rocky) coastlines using sea-level curves and bathymetric data, while palaeoclimatic and substrate-lithological data were compared to modern analogues to infer the resource availability (e.g. Van Andel, 1989; Bailey and Craighead, 2003). However, this method cannot be used for reliable reconstructions of coastlines in unconsolidated sediments and, in particular, near river mouths where the coastal configuration and topography may change substantially over time due to sediment deposition and erosion.

This study presents one of the most detailed palaeogeographical analyses of valley floor evolution yet undertaken in relation to coastal shell middens. Detailed investigations have focused on the Mesolithic shell middens along the Lower Tagus River (central Portugal) and, in particular, on the intensively studied cluster of sites along the lower Muge valley. This paper is the third in a series concentrating on the lower Muge tributary, located ~60 km upstream of Lisbon (Fig. 1). Previous papers have described the Holocene palaeoecology and stratigraphy of the fine-grained valley fill in detail, and established sea-level change as the predominant infill control (van der Schriek *et al.*, *in press* a, b). The present paper reports new palaeogeographic data and evidence concerning i) preferential preservation and visibility of the Mesolithic shell midden record, and ii) the dynamic link between midden formation, resource availability and palaeoenvironmental changes.

FIGURE 1

(A) Portuguese Mesolithic shell middens

The well-preserved Mesolithic shell midden record of central-southern Portugal is internationally significant in European prehistory (Straus *et al.*, 1990; Zilhão, 1993, 2000; Vierra, 1995). Small early Mesolithic shell middens (~11000 to 6200 cal BC) are mainly found along the present coastline. Around 6200 cal BC the settlement focus shifted to locations with significantly larger midden development along the lower reaches of central-southern Portuguese river systems (Fig. 1). Late Mesolithic shell midden formation (~6200 to 4800 cal BC) is commonly linked to the establishment and subsequent cessation of inner estuarine conditions in the immediate vicinity of the sites (e.g. Morais Arnaud 1987, 1989). These estuarine environments are thought to have constituted a rich resource base, containing productive shell beds. The final disappearance of the last Mesolithic societies in Portugal, 500 to 700 years after the arrival of Neolithic culture (Zilhão, 1993, 2000), was perhaps influenced by environmental change and constraining resources (e.g. Bicho, 1994). Published interpretations of the contemporary environmental context are, to date, mainly based on faunal analyses at site level or regional palynological records (e.g. Morais Arnaud, 1989; Bicho, 1993, 1994; Vierra, 1995). Independent reconstructions of the changing environmental conditions and the specific palaeogeographical setting of the sites during occupation are unavailable. Therefore, archaeological interpretations relating the shell midden record to environmental changes are currently not sustained by evidence.

Particular importance is attributed to the shell midden cluster in the lower Tagus valley which has been intensively studied over the past 140 years (Roche, 1977). The middens are located on Quaternary fluvial terraces along the lower reaches of the Magos, Muge and Vale da Fonte da Moça tributaries (Fig. 1). The principal mollusc species in the middens are the common cockle (*Cardium edule*) and the estuarine clam (*Scrobicularia plana*). The four largest middens, Cabeço dos Ossos (Fig. 1), Moita do Sebastião, Cabeço da Amoreira and Cabeço de Arruda (Fig. 2a), are up to 5 m thick and ~100 m in diameter. These middens are characterised by rich faunal and artefact assemblages, abundance of human burials and residential structures (Morais Arnaud, 1989; Rolão, 1994; Cunha and Cardoso, *in press*). Faunal and isotope studies testify to the mixed marine-terrestrial resources exploited, with marine resources accounting for ~50% of the diet (Veiga Ferreira, 1954; Lentacker, 1986; Lubell *et al.,* 1994; Richards and Hedges, 1999; Detry, 2001). This evidence has been interpreted as reflecting a successful broad-spectrum economy with high population densities and a high degree of sedentism (e.g. Gonzales Morales and Morais Arnaud, 1990). Local isotope and skeletal studies have also yielded critical information on population continuity and change at the Mesolithic-Neolithic transition (Mendes Correa, 1933;

Lubell and Jackes, 1988; Lubell *et al.,* 1994; Jackes *et al.,* 1997a, 1997b; Bamforth *et al.,* 2000).

Mid-points of published age-estimates for the lower Tagus middens range between 6375 and 3900 cal BC (Table 1a). Some age-estimates have large error margins and the stratigraphic integrity of the dated samples (Sa-194 and Sa-196 in particular) is often questionable (Zilhão, 2000) or even unknown. Dates on human bone collagen have to be interpreted with care due to the marine diet and the associated (variable) reservoir effect which renders dates too old. Finally, it is uncertain if these dates represent the entire occupation period as shell accumulation itself has not been dated. Stratigraphic reliable radiocarbon dates for late Mesolithic sites throughout Portugal fall all within the period 6200-4800 cal BC (Zilhão, 2000). Most of the lower Tagus dates with reasonable error margins (i.e. ~100 years) fall within this age-range. Therefore, this period is assumed to correspond with Mesolithic site-occupation in the study area.

TABLES 1a AND 1b

(A) Environmental setting of the study area

The River Tagus is ~1,100 km long, drains a catchment of ~81,947 km^2 in central Iberia and is characterised by extreme seasonal (monthly averages: 30 to 2050 m^{3}s^{-1}) and annual (inter-annual discharge: 96 to 680 m^{3}s^{-1}) flow variability (Benito *et al.*, 1998, 2003). The course of the lower Tagus River is determined by a series of NNW-SSE orientated faults that are part of a half-graben structure believed to have been uplifting since the Late Tertiary (Barbosa, 1995; Cabral, 1995). The valley floor is inset in Tertiary sediments and Quaternary alluvial deposits, while Jurassic limestone hills up to 600 m above sea level border the valley floor to the west (Fig. 1) (Zbyszewski, 1946; Mozzi *et al.*, 2000). The Holocene lower Tagus valley fill is poorly described (Breuil and Zbyszewski, 1942; Zbyszewski, 1946, 1958) and lacks a chronostratigraphic framework.

The Muge River is an east-bank tributary of the lower Tagus River with a length of ~55 km and a catchment of ~616 km^2 which drains the central part of the Tertiary Lower Tagus Basin (Fig. 1). The E-W course of the lower Muge River is probably determined by a minor fault perpendicular to the Tagus valley (Barbosa, 1995). The present tidal limit of the Tagus estuary is located ~28 km downstream of Muge. The shallow (mean depth ~5 m) inner estuary has a surface area of ~320 km^2 and semi-diurnal tides, with tidal range varying from 1-4 m between neap and spring tides (Brotas and Plante-Cuny, 1998; Cabrita *et al*., 1999). A fault-controlled, bedrock-confined outlet near Lisbon connects the inner estuary with the outer estuary and the Atlantic Ocean (Fortunato *et al*., 1997).

(A) Methodology

Geomorphological mapping was achieved using aerial photographs, geological and topographical maps and field survey. Lithostratigraphic field description was conducted on ~90 sedimentary sequences in the lower Muge valley (Fig. 2a) exposed by river bank sections, machine excavation or sediment coring using Eijkelkamp hand-augers. Selected sediment cores were re-taken with a Cobra/Stitz percussion corer, allowing continuous recovery of sediment, and returned to the laboratory for sampling. Selected samples were analysed, using standard techniques, for molluscs (Barret and Younge, 1958; Tucker Abbot, 1990; Peacock, 1993), diatoms (Battarbee, 1986; p. 528-531) and foraminifera (Brasier, 1980; p. 162-168). Foraminifera were examined under a reflected light microscope with a 100x magnification. Pollen was extracted using conventional pollen preparation techniques including acetolysis and treatment with hydrofluoric acid (Moore *et al.*, 1989); pollen types were identified at 400x magnification. Total pollen sum was always above 300 grains.

Dating control is provided by fourteen ^{14}C dates on samples from representative sediment cores (Table 1b). Two bulk samples (beta 111010 and beta 111011) were obtained during reconnaissance survey (Passmore and Stevenson, 1999). The remaining radiocarbon samples were extracted at diagnostic levels from the centre of Cobra/Stitz core sections. Samples for AMS radiocarbon dating were deflocculated with analytical grade sodium hexametaphosphate and wet sieved (125µm mesh) with de-ionised water; recognisable plant fragments were collected for dating. Throughout this paper, analysed dates are expressed as mid-points of calibrated calendar ages (cal BC/AD) with age spans at the 2σ range. Calibrated ages were calculated with the OxCal 3.5 program (Bronk Ramsey, 1995), using the terrestrial calibration data set (INTCAL98; Stuiver *et al.*, 1998a). One sample (MUG-4), consisting of estuarine *Scrobicularia Plana* shell fragments, has been calibrated against the marine calibration data set (Marine98; Stuiver *et al.*, 1998b) with ΔR = 253+/-29 (Monges Soares, 1993).

FIGURES 2a AND 2b; TABLE 2

(A) Lower Muge valley fill

The presently canalised and cultivated low relief alluvial floodplain of the lower Muge River is underlain by a wedge of fine-grained clastic sediments and peat that overly impenetrable coarse sand and gravel deposits. The fine-grained valley fill lacks distinct erosive boundaries and reaches its greatest thickness of >11 m near the Tagus confluence. The greater part of the sedimentary record is permanently waterlogged with groundwater levels at ~2 m MdC (Marégrafo de Cascais, Portuguese datum level). Ten allostratigraphic units have been recognised in the lower Muge valley fill (Fig. 2b, Table 2). Units are defined on the basis of laterally traceable bounding surfaces and may contain one or several textures, while boundaries do not represent time-lines.

(B) *Units 1 and 1c*

Basal unit 1 comprises well-sorted bedded coarse sand and gravel with little organic material and no foraminifera. The texture and sorting suggests deposition near, or in, a channel system. The surface of unit 1 grades towards the Tagus confluence and contains buried knickpoints. The morphology of this surface suggests the presence of an entrenched channel in the central reach (Fig. 2b).

Unit 1c has been distinguished from unit 1 on the basis of its geometry which consists of narrow, tabular sand and gravel bodies in a fine-grained matrix. The geometry, texture and sorting of this unit suggests deposition in, or near, narrow channel systems in a fine-grained floodplain. This interpretation is supported by bank exposures, which reveal the presence of sand and gravel bodies (interpreted as paleaochannel fills) inset in fine-grained deposits.

(B) *Units 2 and 2α*

The discontinuous beds of unit 2 contain laminated sandy silt and bedded silty sand with frequent organic material; foraminifera are absent. These characteristics indicate a depositional environment with low energy flow conditions. The sediments are interpreted as a suite of (fluvial) channel proximal deposits. The gradual lower boundary with unit 1 has been dated to 4510+/-170 cal BC and 5005+/-205 cal BC, respectively, in cores 51 and 64 (Fig. 2b). The bounding surface in downstream core 51 is younger, despite its greater absolute depth, while both basal dates are younger than equivalent stratigraphic levels in core 20 (Fig. 2b). These apparent age-inversions may be explained by the specific depositional environments of the sediment cores. The base of core 51 is ~1 m above the basal gravel in adjacent cores, while core 64 is located in an entrenched basal channel structure. This suggests that the cored sediments in both cases infill local palaeochannels and that the dates represent local channel abandonment.

Unit 2α is found near the confluence with the Tagus River and contains estuarine shells and foraminifera; its lithology is identical to unit 2. The shells and foraminifera are characteristic for deposition in a (lower) tidal flat environment (Figs. 3a and 3b). The upper part of unit 2α has been dated to 5910+/-120 cal BC in core 11 (Table 1b).

FIGURES 3a AND 3b

(B) *Units 3, 3α and 3β*

Units 3, 3α and 3β form a thick depositional wedge in the lower Muge valley fill, pinching out near the Lamarosa tributary (Figs. 2a and 2b), and share the same lithology. The maximum thickness of the combined units is ~8 m near the Tagus confluence. The plastic silty clay of unit 3 contains infrequent sandy lamination and frequent organic material, while foraminifera are absent. These characteristics indicate deposition in a low energy fluvial environment, most likely in an overbank setting. The disappearance of regional tidal conditions in the lower Muge valley, based on the disappearance of saltwater indicators such as *Chenopodiaceae* and *Isoetes* in the pollen record (Fig. 4), has been dated to 3795+/-155 cal BC in the upper part of unit 3 in core 20.

Unit 3α, distinguished on the basis of estuarine shell and foraminifera presence (Table 2), is found in discontinuous basal beds near the Tagus confluence (Fig. 2b). The (micro-)fossils reveal saltwater presence and diurnal tidal flooding (Figs. 3a and 3b), suggesting deposition in a (lower) tidal flat environment. Unit 3β forms a basal wedge pinching out upstream of core 40, and is differentiated from unit 3 on the basis of foraminifera presence (Table 2). The foraminifera reveal regular tidal flooding by saltwater (Figs. 3a and 3b) indicating deposition in an estuarine saltmarsh environment. The abrupt lower boundary with unit 1 has been dated to 6150+/-90 cal BC in core 20; the gradual lower boundary with unit 3α has been dated to 6120+/-100 cal BC in core 11 (Fig. 2b). Maximum tidal influence is revealed by the peak in foraminifera numbers between ~5.2-4.7 m in core 20 (Fig. 3a): relatively low numbers of foraminifera are normal in saltmarsh environments and peak numbers suggests increased tidal flooding (Boomer, 1998). The upper limb of this foraminifera peak has been dated to 5555+/-75 cal BC.

An organic-rich clayey bulk sample (MUG-2) in core 20 has dated the upper bounding surface of unit 3β to 6325+/-425 cal BC (Table 1b). However, two lower samples (MUG-5 and MUG-6) in core 20 and the basal samples in core 11 yield younger age-estimates. The large error margins and age-inversions suggest this date to be unreliable. The older than expected age may be caused by old (radioactive "dead") carbon that is present in estuarine organic-rich mud (e.g. Soter *et al.*, 2001; Colman *et* *al.*, 2002); this date has been rejected. In upstream core 40, this upper bounding surface was dated to 1240+/-160 cal BC (Table 1b). Stratigraphic cross-correlation with core 20 indicates that this age-estimate is anomalously young. Furthermore, the overlying soil is well-developed and dated to 3200+/-170 cal BC in core 64. These considerations suggest that the radiocarbon sample was contaminated during coring and extraction; accordingly, this date is rejected.

FIGURE 4

(B) *Unit 4*

Unit 4 consists of discontinuous peat, silty peat and peaty silt beds with frequent large wood fragments in the central reach of the lower Muge valley fill (Fig. 2b). The habitat preferences of the main plant species (*Scirpus cf. lacustris* and *Hypericum tetrapterum*) found within core 51 depict a freshwater marsh with a silty substrate (Dr Cotton, *pers. com.*). Organic material was degraded, suggesting surface exposure prior to waterlogging and burial. Alluvial peat formation indicates a high contemporary groundwater table and a low clastic sediment input; these conditions are characteristic for backswamp settings. The lower boundary with unit 2 has been dated to 4415+/-85 cal BC in core 64, while a sample near the upper boundary of this unit has been dated to 3200+/-170 cal BC (Table 1b).

(B) *Unit 5*

Unit 5 forms a distinct black bed in the upper part of the valley fill (Fig. 2b) consisting of oxidised peaty clayey silt with lamination and cm-scale beds of grey inorganic silty clay. There are occasional white lenses of freshwater diatomite, while the bed has a blocky structure with calcite concretions. Dark vertical stripes, probably representing root penetration, extend into units 2 and 3. The diatomite lenses and pollen indicators such as *Myriophyllum alterniflorum*, *Typha* and *Nymphaea* (Fig. 4) suggest shallow, standing freshwater conditions at the floodplain surface. These characteristics are typical for an alluvial floodplain soil with a low clastic sediment input and a high groundwater table (USDA, 1975).

A sample of degraded wood fragments (MUG-8) at the lower bounding surface yielded a date of 4815+/-125 cal BC in core 20 (Table 1b). This age-estimate is older than the lower date of 3795+/-155 cal BC in core 20 and the date of 3200+/-170 cal BC for the boundary of units 4 and 5 in core 64. Published dates for soil formation in Atlantic Iberian estuaries date from ~2000 cal BC onwards (Devoy *et al.*, 1996; Goy *et al.*, 1996; Granja and De Groot, 1996). Without further evidence supporting floodplain stabilisation and soil formation around 4815+/-125 cal BC, this age-estimate has been rejected. The older than expected age of the sample may have been caused by the dating of reworked wood fragments. Finally, samples near the upper boundary of unit 5 have been dated to 230+/-180 cal BC in core 20, and to cal AD 1805+/-155 in core 64 (Table 1b).

(B) *Unit 6*

Unit 6 caps the fine-grained lower Muge valley fill (Fig. 2b) and consists of reddish mottled clayey silt to sandy silt with occasional lamination and cm-scale sand beds. There is frequent degraded organic material present within the unit; foraminifera are absent. These characteristics indicate a low energy depositional environment and a fluctuating groundwater table. The sediments have been interpreted as a suite of fluvial overbank deposits.

FIGURE 5

(A) Mesolithic palaeogeography and settlement

An entrenched fluvial channel system occupied the non-aggrading lower Muge valley floor prior to ~6100 cal BC. Inner estuarine tidal mudflat and saltmarsh environments were abruptly established in the tributary valley, up to ~3.5 km inland, around ~6100 cal BC (Fig. 5a). Estuarine environments displayed high rates (~7 mm/yr) of fine-grained sedimentation (Fig. 6) and their upstream limit was initially confined by the inherited valley floor topography (Fig. 2b). The valley floor upstream of the first basal knickpoint was occupied by entrenched, non-aggrading fluvial systems (Fig. 5a). The age-depth relationship of the earliest estuarine deposits in the lower Muge valley is in good agreement with regional estuarine records that link initiation of fine-grained deposition to early Holocene sea level rise (e.g. Goy *et al.*, 1996; Rodriguez Ramirez *et al.*, 1996; Zazo *et al.*, 1996; Morales, 1997; Borja *et al.*, 1999; Dabrio *et al.*, 2000; Psuty and Moreira, 2000; Cearreta *et al.*, 2003; Freitas *et al.*, 2003; Santos and Sánchez Goñi, 2003). At ~6100 cal BC, pine forests occupied the free-draining sandy soils of the terrace levels, while semi-deciduous oak occupied more moisture-rich soils along the freshwater valley floor (Fig. 5a). The presence of *Erica arborea*, *Calluna, Genista* (Fabaceae), Lamiaceae and *Cistus ladanifer* point towards an open woodland environment (Fig. 4). Occasional agglutinating foraminifera at the base of core 20 indicate that the site was at the margins of tidal influence (Fig. 3a). Freshwater indicators (e.g. *Alnus*, *Salix, Cyperaceae*, *Ranunculus* and *Equisetum*) suggest that upstream parts of the floodplain supported marshy woodland.

Regional shell midden occupation started probably ~6000 cal BC (Table 1a), following the establishment of estuarine conditions in the lower valley floor. The sites were located on the edge of terrace levels adjacent to saltmarsh environments near, or at, the upstream limit of tidal influence. Springs along the valley edge probably provided freshwater and the nearest productive shell beds, containing the shell species *Cardium edule* and *Scrobicularia plana* which dominate the middens, were located 1-2 km downstream of the sites. Faunal evidence from the middens shows the wide range of resources exploited besides shells, including fish, deer and birds (e.g. Veiga Ferreira, 1954; Detry, 2001). All of these resources were probably nearby available: molloscs and fish in the estuary, and birds, mammals and plants on the terrace levels and in the fluvial valley floor.

FIGURE 6

(B) *Maximum tidal influence*

Upper mudflat and saltmarsh environments were present in the lower Muge valley from ~6100-3800 cal BC. These environments occupied the same position in the upper part of the tidal framework for over 2000 years, suggesting that the rate of sediment accumulation kept pace with the rate of sea level rise. Peak numbers of agglutinating foraminifera species between 5.2 to 4.7 m in core 20 (Fig. 3a) probably indicate the period of maximum tidal influence as foraminifera numbers in high saltmarsh environments are closely related to flooding frequency (Boomer, 1998). Linear extrapolation between radiocarbon dates in core 20 (Fig. 6) suggests that the lower limb of this peak dates to ~5800 cal BC; the upper limb dates to ~5555 cal BC. These dates are consistent with regional estuarine records registering a maximum transgressive surface around 5700-4100 cal BC (Zazo *et al.*, 1994, 1996; Goy *et al.*, 1996; Rodriguez Ramirez *et al.*, 1996; Morales, 1997; Borja *et al.*, 1999; Dabrio *et al.*, 1999, 2000; Psuty and Moreira, 2000; Cearreta *et al.*, 2003; Freitas *et al.*, 2003; Santos and Sánchez Goñi, 2003). Stratigraphic cross-correlation between the base of the valley fill and core 20 (Fig. 6) suggests that sea level had risen sufficiently by ~5800 cal BC to cause rapid fine-grained backfill up to the second basal knickpoint ~7.5 km inland. Tidal saltmarshes expanded ~4 km upstream into the lower Muge valley and were bordered by an aggrading lowland alluvial floodplain (Fig. 5b). The upstream limit of tidal environments was no longer determined by the inherited valley floor topography, but became a function of the balance between the rates of sea level rise and sediment supply from this period onwards. More than 7.5 km upstream, the non-aggrading Muge River still occupied the entrenched floodplain which supported Alder woodland. Regional pine woodland suffered progressive losses from ~5800 cal BC, while oak forest was maintained (Fig. 4). The major shell middens were all occupied from ~5800-5555 cal BC (Table 1a) and situated adjacent to saltmarsh environments with tidal mudflats and shell beds in close proximity (Fig. 5b). Due to the creation of a freshwater alluvial floodplain upstream of the saltwater limit, the variety of potential resources increased over this period.

(B) ***Estuarine contraction***

The rate of sediment supply began to balance the decreasing rates of sea level rise after ~5555 cal BC, and tidal influence gradually declined until ~3800 cal BC, when estuarine environments in the lower Muge valley disappeared. Saltwater indicators (e.g. *Chenopodiaceae* and *Isoetes*) are abruptly lost near the base of zone PZ 4 (~3800 cal BC) and replaced by indicators of shallow open water conditions, notably

Myriophyllum alterniflorum, *Typha* and *Nymphaea* (Fig. 4), suggesting rapid deterioration of the floodplain drainage. Depth cross-correlation between core 64 and the base of the valley fill (Fig. 6) indicates that the entire lower Muge valley experienced base level induced sedimentation at ~4400 cal BC. Peat formation started ~4400 cal BC in the central lower Muge floodplain (Fig. 2b), suggesting high contemporary groundwater levels, low rates of base level rise and a low clastic sediment input. Reliable dates indicate that the Muge shell middens were still occupied by ~5300 cal BC. Some stratigraphically insecure dates on bulk charcoal samples from the top of the shell accumulations (Roche and Veiga Ferreira, 1973) may suggest occupation until ~5000-4000 cal BC (Table 1a). Occupation until ~4800 cal BC is considered likely given the existence of stratigraphic reliable dates indicating Mesolithic presence up to this time in Portugal (Zilhão, 2000). Neolithic ceramics have been reported in the uppermost part of the midden strata (Ferreira, 1974) and may indicate cultural interaction with the earliest agricultural communities (cf. Zilhão, 2000) rather than Neolithic occupation of the midden sites. Isolated finds of lithics and pottery throughout the area reveal a late Neolithic, Bronze- and Iron Age presence (Cruz and Oosterbeek, 1993; Lucas and Ferrarri, 1993). However, the first definite evidence of renewed settlement in the area dates from the Roman period (Batata and Gaspar, 1993).

The environmental context of the middens changed over the final period of occupation, although the same mix of habitats remained present in the lower valley until ~3800 cal BC. Saltmarshes gradually contracted after ~5555 cal BC; linear extrapolation between radiocarbon dates in core 20 indicates that foraminifera, and therefore saltwater influence, disappeared ~4700 cal BC at this site (Fig. 6). Around this time, the upstream middens would fringe a freshwater alluvial floodplain, while the middens closer to the confluence would still border saltmarsh (Fig. 5c). From 4400-3800 cal BC marshy (aggrading) floodplain environments expanded to the upstream limit of the lower floodplain. Saltmarsh and tidal mudflats with shell beds finally disappeared ~3800 cal BC near the mouth of the Muge valley and the floodplain converted into a freshwater marsh with standing water bodies. The regional vegetation changed significantly: the gradual decline of open Pine woodland ended in sustained deforestation ~5000 cal BC (Figs. 4 and 6). This decline is mirrored in pollen sequences throughout southern Iberia (~5500-4000 cal BC) and suggests a regional drying trend (e.g. Mateus, 1985; Van Leeuwaarden and Janssen, 1985; Carrion and Dupré, 1996; Carrion and van Geel, 1999; Yll *et al.*, 1999; Mateus and Queiroz, 2000; Carrion *et al.*, 2001; Santos and Sánchez Goñi, 2003).

(B) ***Late Holocene environments***

From ~3800-3200 cal BC the lower Muge tributary experienced progressive infill of the accommodation space. The loss of oak woodlands and their replacement by prominent shrub communities dominated by *Erica arborea*, *Calluna, Cistus* and *Genista*, and ruderals like *Rumex* and *Plantago* indicate major anthropogenic disturbance of the catchment vegetation starting ~3800 cal BC (Fig. 4). Peat formation ended ~3200 cal BC in core 64 and an alluvial floodplain soil developed, suggesting a stable Tagus base level and improved drainage conditions. Downstream, at the locality of core 20, the base of the floodplain soil has not been accurately dated. Soil formation took place between ~3200-1600 cal BC based on linear extrapolation of sedimentation rates between ~5500-3800 cal BC and ~3800-230 cal BC, respectively, to the base of the soil (Fig. 6). Alder woodland invaded the valley floor around the time of soil formation (Fig. 4). Alluvial soil formation was probably related to a stable base level and low flooding frequencies; a contemporary decrease in suspended sediment load is unlikely given the major catchment disturbance since ~3800 cal BC. The absence of a soil in the NW part of the valley fill (Fig. 2b) reflects continued sedimentation, probably near the contemporary Muge River mouth.

By ~230 cal BC, renewed sedimentation had buried the alluvial soil up to ~3.5 km inland from the confluence zone (Fig. 2b); this bed is currently found up to 2 m below base level. There is no evidence for contemporary soil-burial further upstream in the Muge valley where the soil is located above current base level. This suggests that aggradation of the trunk river induced backfill near the tributary mouth. Rapid soil-burial (~5 mm/yr; Fig. 6) in the central-upstream reaches of the lower Muge valley floor started ~200 years ago. The greatest overburden depth is found at the upstream limit of the lower floodplain (Fig. 2b), indicating an increased sediment input from the Muge catchment. Increased fluvial activity is also indicated by fan-toe incision at this locality: the fine-grained infill of the incised fan-toes does not contain a buried soil, suggesting recent incision. This phase of local fluvial activity is most likely related to the documented clearance and agricultural intensification at the end of the 19th century (Vilar, 1993) which may have increased sediment supply, run-off and flooding frequency.

(A) Environmental change and Mesolithic settlement-subsistence

The Portuguese early Mesolithic record has been interpreted to reflect resource diversification and intensification of marine exploitation (e.g. Bicho, 1993, 1994). However, older prehistoric communities may have exploited marine resources to an unknown degree. Existing interpretations do not acknowledge that the distribution of early Mesolithic sites appears to be an artefact of preferential preservation created by sea level rise and geomorphic processes. The oldest Mesolithic middens are preserved on steep-gradient rocky shores, where coastline retreat under influence of Holocene sea level rise was relatively limited. Even so, the early Holocene coastline would have been positioned several km's away from these sites. Contemporary sites which were located closer to the shore, and older sites constructed when sea level was even lower, must have been drowned by sea level rise (Bailey and Craighead, 2003). No early Mesolithic sites have been found in lower Portuguese river valleys. However, any sites near the contemporary shore in these localities would have been drowned entirely, due to the high rates of early Holocene coastline retreat in these low-gradient settings (e.g. Rodriguez Ramirez *et al.*, 1996).

Regional records indicate that estuarine environments occupied the incised valley floors of lower Iberian river systems from ~9800 cal BC onwards (e.g. Dabrio *et al.*, 2000; Boski *et al.*, 2002; Freitas *et al.*, 2003). High rates of early Holocene relative sea level rise caused the low-gradient estuarine environments to shift rapidly inland (e.g. Morales, 1997; Borrego *et al.*, 1999; Lobo *et al.*, 2001). The mid Holocene slow-down in relative sea level rise allowed the rate of sediment input to balance the creation of accommodation space, which led to expansion of estuaries (~6000 cal BC) including tidal flats and productive shell beds (Dabrio *et al.*, 1999, 2000; Boski *et al.*, 2002). The increasing availability of estuarine resources and stability of valley floor environments allowed (semi-) sedentary occupation of specific areas along the lower valleys of the Tagus, Sado, Mondego and Mira rivers. Long-term occupation of sites, in turn, favoured the accumulation of large shell middens.

The specific variables influencing site-choice are illustrated in the lower Tagus area, where Mesolithic shell middens cluster ~50-68 km upstream of Lisbon (Fig. 1). The founding of these sites (~6000 cal BC) on the edge of fluvial terrace levels appears to have followed the establishment of aggrading estuarine environments in the lower Muge valley (~6100 cal BC) and across the entire width of the present Tagus valley. The palaeogeographic context of the sites did not change significantly from ~6100-3800 cal BC. The prime consideration for site-establishment along this specific reach of the Tagus valley appears to have been the local presence of extensive tidal flats, containing accessible estuarine shell beds. More open estuarine conditions dominated the valley downstream of the Magos tributary, while extensive saltmarshes probably surrounded the limit of tidal influence near Santarem (Dias *et al.*, 2000). In addition, the sites shows a preference for sheltered settings along lower tributary valleys which could offer freshwater resources and probably attracted wildlife in this dry region. The tidal Muge tributary allowed quick access by boat to various parts of the Lower Tagus estuary, while the surrounding open woodlands contained a variety of supplementary resources.

Early Neolithic settlements expanded between ~5500-4750 cal BC into central Portugal and along the coastline, bypassing the late Mesolithic communities (Fig. 1). Abandonment of the Lower Tagus shell middens, between ~5300-4800 cal BC, coincided with the slow contraction of estuarine habitats (from ~5500 cal BC onwards) and with the gradual establishment of an open landscape (ending ~5000 cal BC). These environmental changes altered the resources available in the vicinity of the sites and may, perhaps, have constrained local food resources. However, estuarine environments did not disappear near the Muge confluence until ~3800 cal BC and even later downstream, at the lower Magos confluence. Environmental changes, therefore, were probably not solely responsible for site abandonment. The encroachment of Neolithic settlements limited the area available for migration or adjustment in response to the environmental changes, while cultural interaction may have introduced agricultural practise. These multiple cultural and environmental factors may have induced, perhaps over several generations, a change from a hunter-fisher-gatherer society to an agricultural one.

(A) Conclusion

The founding of late Mesolithic shell middens in the lower Tagus valley is related to environmental changes. Estuarine environments were contained within the lower Tagus valley up to ~6100 cal BC, when aggrading estuarine environments expanded into the mouth of the Muge valley. Shell midden occupation (~6000 cal BC) followed the local establishment of tidal conditions in the tributaries closely. The middens were located along a specific reach of the lower Tagus valley which supported extensive tidal flats with productive estuarine shell beds. Sites were constructed on the edge of fluvial terraces, high above the flood level, near the upstream limit of tidal influence in the adjacent aggrading valley floor. This location gave direct access to resources from saltmarsh, tidal flat, fluvial and open woodland environments, while the open estuary in the lower Tagus valley was easily reached by boat. The setting suggests that site-choice was primarily based upon the local availability of shell resources, while the nearby presence of freshwater environments also played a significant role. The latter may have been important in attracting wildlife in this dry region.

The stable range of valley floor environments between ~6100-3800 cal BC and the increased availability of shell resources, due to expansion of estuarine environments (~6100-5555 cal BC), favoured (semi-)sedentary behaviour, long-term site occupation and high population densities which led to the accumulation of large (highly visible) shell mounds over time. Cultural and environmental factors probably interacted to cause the end of the Mesolithic way of life. Site abandonment (~5300-4800 cal BC) coincided with the gradual contraction of estuarine habitats (~5500-3800 cal BC) and with the regional establishment of an open landscape around ~5000 cal BC. These environmental changes altered the resources available in the vicinity of the sites and, perhaps, constrained local food resources. Furthermore, Neolithic expansion (~5500-4700 cal BC) and cultural interaction may have stimulated abandonment by limiting the area available for migration in response to environmental change, while simultaneously introducing agricultural practise and offering an alternative way of life.

The explosion of late Mesolithic shell midden sites in Portugal does not reflect the culmination of resource diversification and intensification of marine exploitation since the Late Pleistocene. Instead, both the age and the distribution of Mesolithic shell middens are artefacts of differential preservation, while midden size varied according to environmentally-influenced differences in occupation length. The age of local Mesolithic records depends on their setting: Holocene sea level rise forced low-gradient coastlines to retreat inland over greater distances than high-gradient rocky coastlines. Geomorphic processes changed the coastal configuration and topography, in particular of unconsolidated shorelines. Consequently, the earliest Mesolithic middens are found along steep rocky coastlines, while shell middens along lower river valleys have a late Mesolithic age. However, it is likely that marine resources were exploited prior to the early Mesolithic although any evidence will be buried. In the Lower Tagus area, it became only necessary to locate the middens on higher ground around 6100 cal BC, when aggrading estuaries occupied the entire width of the present valley; accordingly these sites were not buried. These findings have wider implications for Mesolithic shell midden research. This study shows that detailed palaeogeographic reconstructions in relation to coastal shell middens are essential for a balanced interpretation of their records. In particular, the sudden occurrence of late Mesolithic shell midden sites in quite restricted geographical areas of W Europe may be explained by increased visibility and preferential preservation of the youngest part of the archaeological record, as well as to the local presence of stable, productive shell beds.

Acknowledgements

The authors wish to thank the Camara Municipal de Salvaterra de Magos for much appreciated logistical support and Dona Teresa for fieldwork permission and providing accommodation. This research was undertaken while in receipt of a studentship of the Department of Geography, Newcastle University. Twelve radiocarbon dates (laboratory codes starting with AA and SRR) were granted by the

NERC radiocarbon laboratory (radiocarbon dating allocation No. 923.0501): their support is gratefully acknowledged. Finally, we would like to thank two anonymous referees for their helpful and constructive comments.

References

Bailey, G. N. 1999: Shell mounds and coastal archaeology in northern Queensland. In J. Hall and I. McNiven, editors, *Australian Coastal Archaeology*, Canberra: ANU Publications, 105-112.

Bailey, G. N. and Craighead, A. S. 2003: Late Pleistocene and Holocene Coastal Palaeoeconomies: a Reconsideration of the Molluscan Evidence from Northern Spain. *Geoarchaeology: An International Journal* 18, 175-204.

Bamforth, F., Jackes, M. and Lubell, D. 2000: Mesolithic-Neolithic population relationships in Portugal: the evidence from ancient mithochondrial DNA. In L. Larsson, H. Kindgren, K. Knutsson, D. Loeffler and A. Åkerlund, editors, *Mesolithic on the move: papers presented at the Sixth International Conference on the Mesolithic in Europe, Stockholm 2000*, Oxford: Oxbow, 581-587.

Barbosa, B. P. 1995: Alostratigrafia e litostratigrafia das unidades continentais da Bacia Terciaria do Baixo Tejo-Relaçóes com o eustatismo e a tectonica. *Unpubl. PhD thesis*. Lisbon: Universidade de Lisboa.

Barret, J., and Younge, C.M. 1958: Collins pocket guide to the sea shore. Collins, London.

Batata, C. and Gaspar, F. 1993: Novos dados sobre a estação arqueológica de Porto do Sabugueiro (Muge, Salvaterra de Magos). *O Foral*, 24-33.

Battarbee, R.W. 1986: Diatom analysis. In: B.E. Berglund, editor, *Handbook of Holocene Palaeoecology and Palaeohydrology*, Chichester: Wiley, 527-570.

Benito, G., Machado, M. J., Pérez-González and Sopeña, A. 1998: Palaeoflood Hydrology of the Tagus River, Central Spain. In G. Benito, V.R. Baker and K.J. Gregory, editors, *Palaeohydrology and Environmental Change*, Chichester: John Wiley, 317-333.

Benito, G., Sopena, A., Sanchez-Moya, Y., Machado, M. J. and Perez-Gonzalez, A. 2003: Palaeoflood record of the Tagus River (Central Spain) during the Late Pleistocene and Holocene. *Quaternary Science Reviews* 22, 1737-1756.

Bicho, N. 1993: Late Glacial prehistory of central and southern Portugal. *Antiquity* 67, 761-775.

Bicho, N. 1994: The end of the Paleolithic and the Mesolithic in Portugal. *Current Anthropology* 35, 664-674.

Boomer, I. 1998: The relationship between meiofauna (Ostracoda, Foraminifera) and tidal levels in modern intertidal environments of North Norfolk: a tool for palaeoenvironmental reconstruction. *Bulletin of the Geological Society of Norfolk* 46, 17-29.

Borja, F. Zazo, C., Dabrio, C.J., Diaz del Olmo, F., Goy, J.L. and Lario, J. 1999: Holocene aeolian phases and human settlements along the Atlantic coast of southern Spain. *The Holocene* 9, 333-339.

Borrego, J., Ruiz, F., Gonzalez-Regalado, M.L., Pendon, J.G. and Morales, J.A. 1999: The Holocene transgression into the estuarine central basin of the Odiel River mouth (Cadiz gulf, SW Spain): lithology and faunal assemblages. *Quaternary Science Reviews* 18, 769-788.

Boski, T., Moura, D., Veiga-Pires, C., Camacho, S., Duarte, D., Scott, D. B. and Fernandes, S. G. 2002: Postglacial sea-level rise and sedimentary response in the Guadiana Estuary, Portugal/Spain border. *Sedimentary Geology* 150, 103-122.

Brasier, M.D., 1980. Microfossils. London: George Allen and Unwin, 193 pp.

Breuil, H. and Zbyszewski, G. 1942: Contribution a l'etude des Industries Paleolithiques du Portugal et de leurs Rapports avec la Geologie du Quaternaire. *Comunicações dos Serviços Geológicos de Portugal*, 219-225.

Bronk Ramsey, C. 1995: Radiocarbon Calibration and Analysis of Stratigraphy: The OxCal Program. *Radiocarbon* 37, 425-430.

Brotas, V. and Plante-Cuny, M. R. 1998: Spatial and temporal patterns of microphytobenthic taxa of estuarine tidal flats in the Tagus Estuary (Portugal) using pigment analysis by HPLC. *Marine Ecology Progress Series* 171, 43-57.

Cabral, J. 1995: *Neotectónica em Portugal Continental. Memórias, 31*. Lisbon: Instituto Geológico e Mineiro.

Cabrita, M. T., Catarino, F. and Vale, C. 1999: The effect of tidal range on the flushing of ammonium from intertidal sediments of the Tagus estuary, Portugal. *Oceanologica Acta* 22, 291-302.

Carrion, J. S. and Dupré, M. 1996: Late Quaternary vegetational history at Navarrés, eastern Spain. A two core approach. *New Phytologist* 134, 177-191.

Carrion, J. S. and Van Geel, B. 1999: Fine-resolution Upper Weichselian and Holocene palynological record from Navarrés (Valencia, Spain) and a discussion about factors of Mediterranean forest succession. *Review of Palaeobotany and Palynology* 106, 209-236.

Carrion, J. S., Andrade, A., Bennett, K. D., Navarro, C. and Munuera, M. 2001: Crossing forest thresholds: inertia and collapse in a Holocene sequence from south-central Spain. *The Holocene* 11, 635-653.

Cearreta, A. 1988: Distribution and ecology of benthic foraminifera in the Santoña estuary, Spain. *Revista Española de Paleontología* 3: 23-38.

Cearreta, A. 1998: Holocene sea-level change in the Bilbao estuary (north Spain): foraminiferal evidence. *Micropaleontology* 44, 265-276.

Cearreta, A., Cachão, M., Cabral, M.C., Bao, R. and Jesus Ramalho, M.d. 2003: Lateglacial and Holocene environmental changes in Portuguese coastal lagoons 2: microfossil multiproxy reconstruction of the Santo André coastal area. *The Holocene* 13, 447-458.

Colman, S.M., Baucom, P.C., Bratton, J.F., Cronin, T.M., McGeehin, J.P., Willard, D., Zimmerman, A.R. and Vogt, P.R. 2002: Radiocarbon Dating, Chronologic Framework, and Changes in Accumulation Rates of Holocene Estuarine Sediments from Chesapeake Bay. *Quaternary Research* 57, 58-70.

Cruz, A. R. and Oosterbeek, L. M. 1993: A Arqueologia de Salvaterra. *O Foral*: 1-5.

Cunha, E. and Cardoso, F. *in press*: New data on Muge shell middens: a contribution to more accurate numbers and dates. *O Mesolítico Português*, Universidade Autónoma e Câmara Municipal de Salvaterra de Magos.

Dabrio, C.J., Zazo, C., Lario, J., Goy, J.L., Sierro, F.J., Borja, F., Gonzalez, J.A. and Flores, J.A. 1999: Sequence stratigraphy of Holocene incised-valley fills and coastal evolution in the Gulf of Cadiz (southern Spain). *Geologie en Mijnbouw* 77, 263-281.

Dabrio, C. J., Zazo, C., Goy, J. L., Sierro, F. J., Borja, F., Lario, J., González, J. A. and Flores, J. A. 2000: Depositional history of estuarine infill during the last postglacial transgression (Gulf of Cadiz, Southern Spain). *Marine Geology* 162, 381-404.

Deacon, H. J. and Schuurman, R. 1992: The origins of modern people: the evidence from Klasies River. In G. Brauer and F. H. Smith, editors, *Continuity or Replacement: controversies in Homo Sapiens evolution* Rotterdam: Balkema, 121-129.

Detry, C. 2001: Arqueozoologia em concheiros de Muge. *Unpubl. MSc Thesis*. Lisbon: Autonomous University of Lisbon.

Devoy, R.J.N., Delaney, C., Carter, R.W.G. and Jennings, S.C. 1996: Coastal Stratigraphies as Indicators of Environmental Changes upon European Atlantic Coasts in the Late Holocene. *Journal of Coastal Research* 12, 564-588.

Dias, J. M. A., Boski, T., Rodrigues, A. and Magalhães, F. 2000: Coast line evolution in Portugal since the Last Glacial Maximum until present-a synthesis. *Marine Geology* 170, 177-186.

Emili-Aura, J. V., Villaverde, M., Gonzales-Morales, C., Gonzales-Sainz, J., Zilhão, J. and Straus, L. G. 1998: The Pleistocene-Holocene Transition in the Iberian Peninsula: Continuity and Change in Human Adaptations. *Quaternary International* 49/50, 87-104.

Erlandson, J. M. 2001: The archaeology of aquatic adaptations: paradigms for a new millennium. *Journal of Archaeological Research* 9: 287-350.

Ferreira, O. V. 1974: Acerca das cerâmicas neolíticas na parte superior dos concheiros da região de Muge. *Comunicações dos Serviços Geológicos de Portugal* 57, 191-197.

Fortunato, A. B., Baptista, A. M. and Luettich Jr, R. A. 1997: A three-dimensional model of tidal currents in the mouth of the Tagus estuary. *Continental Shelf Research* 17, 1689-1714.

Freitas, M. d. C., Andrade, C., Rocha, F., Tassinari, C., Munhá, J. M., Cruces, A., Vidinha, J. and Marques da Silva, C. 2003: Lateglacial and Holocene environmental changes in Portuguese coastal lagoons 1: the sedimentological and geochemical records of the Santo André coastal area. *The Holocene* 13, 433-446.

Gonzales Morales, M.R. and Morais Arnaud, J.E. 1990: Recent Research on the Mesolithic in the Iberian Peninsula: Problems and Perspectives. In Vermeersch, P. M. and Van Peer, P., editors, *Contributions to the Mesolithic in Europe*, Leuven: Leuven University press, 451-461.

Goy, J.L., Zazo, C., Dabrio, C.J., Lario, J., Borja, F., Sierro, F.J. and Flores, J.A. 1996: Global and regional factors controlling changes of coastlines in southern Iberia (Spain) during the Holocene. *Quaternary Science Reviews* 15, 773-780.

Granja, H.M. and De Groot, T.A.M. 1996. Sea-Level Rise and Neotectonism in a Holocene Coastal Environment at Cortegaça Beach (NW Portugal): A Case Study. *Journal of Coastal Research* 12, 160-170.

Haslett, S.K., Strawbridge, F., Martin, N.A. and Davies, C.F.C. 2001: Vertical Saltmarsh Accretion and its Relationship to Sea-level in the Severn Estuary, U.K.: An Investigation using Foraminefera as Tidal Indicators. *Estuarine, Coastal and Shelf Science* 52, 143-153.

Jackes, M., Lubell, D. and Meiklejohn, C. 1997a: Healthy but mortal: human biology and the first farmers of Western Europe. *Antiquity* 71, 639-658.

Jackes, M., Lubell, D. and Meiklejohn, C. 1997b: On Physical Anthropological Aspects of the Mesolithic-Neolithic Transition in the Iberian Peninsula. *Current Anthropology* 38, 839-846.

Lentacker, A. 1986: Preliminary results of the fauna of "Cabeco de Amoreira" and "Cabeco de Arruda" (Muge, Portugal). *Trabalhos de Antropologia e Etnologia* 24, 9-26.

Lobo, F.J., Hernández-Molina, F.J., Somoza, L. and Díaz del Río, V. 2001: The sedimentary record of the post-glacial transgression on the Gulf of Cadiz continental shelf (Southwest Spain). *Marine Geology* 178, 171-195.

Lubell, D. and Jackes, K. 1985: Mesolithic-Neolithic continuity: evidence from chronology and human biology. *Actas da I Reunião do Quaternário Ibérico* 2, 113-133. Lisbon.

Lubell, D. and Jackes, K. 1988: Portuguese Mesolithic-Neolithic subsistence and settlement. *Rivista di Antropologia* 66, 231-248.

Lubell, D., Jackes, M., Schwarcz, H. and Meiklejohn, C. 1986: New Radiocarbon dates for Moita do Sebastião. *Arqueologia* 14, 34-36.

Lubell, D., Jackes, M., Schwarcz, H., Knyf, M. and Meiklejohn, C. 1994: The Mesolithic-Neolithic transition in Portugal: isotopic and dental evidence of diet. *Journal of Archaeological Science* 21, 201-206.

Luby, E. M. and Gruber, M. F. 1999: The dead must be fed: symbolic meanings of the shellmounds of the San Francisco Bay area. *Cambridge Archaeological Journal* 9: 95-108.

Lucas, M. M. and Ferrari, M. 1993: Relatórios dos trabalhos realizados na área da Pré-História da região. *O Foral*, 8-23.

Mannino, M. A. and Thomas, K. D. 2001: Intensive Mesolithic Exploitation of Coastal Resources? Evidence from a Shell Deposit on the Isle of Portland (Southern England) for the Impact of Human Foraging on Populations of the Intertidal Rocky Shore Molluscs. *Journal of Archaeological Science* 28, 1101-1114.

Mateus, J. 1985: The coastal lagoon region near Carvalhal during the Holocene; some geomorphological aspects. *Actas da I Reunião do Quaternário Ibérico* 2, 237-249.

Mateus, J. and Queiroz, P. 2000: Lakelets, lagoons, and peat-mires in the coastal plane South of Lisbon - Palaeoecology of the Northern Littoral of Alentejo. In *Excursion guide of the 2nd workshop of the Southern European working group of the European Lake Drilling Program (ELPD - ESF)*, Sintra: 33-37.

Mendes Correa, A. A. 1933: Les migrations préhistoriques. *Revue anthropologique* 7-9, 1-26.

Monges Soares, A. M. 1993: Isotope techniques in the Study of Past and Current Environmental Changes in the Hydrosphere and the Atmosphere. In *Proceedings, International Atomic Energy Agency - SM - 329/49*, Vienna: 471-485.

Moore, P.D., Webb, J.A. and Collinson, M.E. 1989: Pollenanalysis. Oxford: Blackwell publishers.

Morais Arnaud, J. 1987: Os concheiros mesolíticos dos vales do Tejo e Sado: semelhanças e diferenças. *Arqueologia* 15, 53-64.

Morais Arnaud, J. 1989: The Mesolithic Communities of the Sado Valley, Portugal, in their Ecological Setting. In Bonsall, C., editor, *The Mesolithic in Europe*, Edinburgh: John Donald, 614-631.

Morales, J.A. 1997: Evolution and facies architecture of the mesotidal Guadiana River delta (SW Spain-Portugal). *Marine Geology* 138, 127-148.

Mozzi, P., Azevedo, M. T., Nunes, E. and Raposo, L. 2000: Middle Terrace Deposits of the Tagus River in Alpiarça, Portugal, in Relation to Early Human Occupation. *Quaternary Research* 54, 359-371.

O'Connor, S. 1999: A diversity of coastal economies: shell mounds in the Kimberley region in the Holocene. In J. Hall and I. McNiven, editors, *Australian Coastal Archaeology*, Canberra: ANU Publications, 37-50.

Passmore, D. G. and Stevenson, A. C. 1999: *Geoarchaeology of the lower Muge valley, west-central Portugal*. Newcastle upon Tyne: Universities of Durham and Newcastle upon Tyne Archaeological Reports 1998, 12-16.

Peacock, J.D. 1993: Late Quaternary marine mollusca as palaeo-envirironmental proxies: a compilation and assessment of basic numerical data for Atlantic species found in shallow waters. *Quaternary Science Reviews* 12, 263-275.

Psuty, N.P. and Moreira, E.S.A. 2000: Holocene Sedimentation and Sea Level Rise in the Sado Estuary, Portugal. *Journal of Coastal Research* 16, 125-138.

Richards, M. P. and Hedges, R. E. M. 1999: Stable Isotope Evidence for Similarities in the Types of Marine Foods Used by Late Mesolithic Humans at Sites Along the Atlantic Coast of Europe. *Journal of Archaeological Science* 26, 717-722.

Roche, J. 1977: Les amas coquilliers mésolithiques de Muge (Portugal). Chronologie, milieu naturel et leurs incidences sur le peuplement humain. Approche écologique de l'homme fossile. *Supplémant au Bulletin de l'Association Française pour l'Étude du Quaternaire* 47, 353-359.

Roche, J. and Veiga Ferreira, O. d. 1973: Seconde datation par le C 14 de l'amas coquiller mésolithique de Moita do Sebastião (Muge). *Comunicaçoes dos Serviços Geológicos de Portugal* 56, 471-474.

Rodríguez Ramírez, A., Rodríguez-Vidal, J., Cáceres, L., Clemente, L., Belluomoni, G., Manfra, L., Improta, S. and Ramón de Andrés, J. 1996: Recent coastal evolution of the Doñana national park (SW Spain). *Quaternary Science Reviews* 15, 803-809.

Rolão, J. M. F. 1994: Uma Nova Abordagem da Necrópole da Moita do Sebastião. *Anais Serie História (Universidade Autónoma de Lisboa)* 1: 9-16.

Rowley-Conwy, P. 1983: Sedentary hunters: the Ertebølle example. In G. N. Bailey, editor, *Hunter-Gatherer Economy in Prehistory* Cambridge: Cambridge University Press, 111-126.

Santos, L. and Sánchez Goñi, M. F. 2003: Lateglacial and Holocene environmental changes in Portuguese coastal lagoons 3: vegetation history of the Santo André coastal area. *The Holocene* 13, 459-464.

Scott, D.B. and Medioli, F.S., 1978: Vertical zonations of marsh foraminifera as accurate indicators of former sea-levels. Nature 272, 528-531.

Soter, S., Blackwelder, P., Tziavos, C., Katsonopoulou, D., Hood, T. and Alvarez-Zarikian, C. 2001: Environmental Analysis of Cores From the Helike Delta, Gulf of Corinth, Greece. *Journal of Coastal Research* 17, 95-106.

Straus, L. G., Altuna, J. and Vierra, B. 1990: The Concheiro at Vidigal: a Contribution to the Late Mesolithic of Southern Portugal. In Vermeersch, P.M. and Van Peer, P., editors, *Contributions to the Mesolithic in Europe*, Leuven: Leuven University press, 463-474.

Stuiver, M., Reimer, P. J., Bard, E., Beck, W. E., Burr, G. S., Hughen, K. A., Kromer, B., McCormac, F. G., Van de Plicht, J. and Spurk, M. 1998a: INTCAL98 radiocarbon age calibration 0-24,000 BP. *Radiocarbon* 40, 1041-1083.

Stuiver, M., Reimer, P. J. and Braziunas, T. F. 1998b: High-precision radiocarbon age calibration for terrestrial and marine samples. *Radiocarbon* 40, 1127-1151.

Tucker Abbott, R. 1990: Seashells of the northern hemisphere. Surrey: Dragon's World.

USDA 1975: Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys. Washington D.C.: United States Soil Conservation Service.

Van Andel, T. 1989: Late Quaternary sea-level changes and archaeology. *Antiquity* 63, 733-745.

van der Knaap, W. O. and van Leeuwen, J. F. N. 1997: Late Glacial and early Holocene vegetation succession, altitudinal vegetation zonation, and climatic change in the Serra da Estrela, Portugal. *Review of Palaeobotany and Palynology* 97, 239-285.

van der Schriek, T., Passmore, D. G., Franco Mugica, F., Stevenson, A. C., Boomer, I. and Rolão, J. *in press*: Holocene palaeoecology and floodplain evolution of the Muge tributary, Lower Tagus Basin, Portugal. *Quaternary International*.

van der Schriek, T., Passmore, D. G., Rolão, J., and Stevenson, A. C. *in press*: Estuarine-fluvial floodplain formation in the Holocene Lower Tagus valley (central Portugal) and implications for Quaternary fluvial system evolution. *Quaternary Science Reviews*.

van Leeuwaarden, W. and Janssen, C. R. 1985: A preliminary palynological study of peat deposits near an Oppidum in the Lower Tagus Valley, Portugal. . *Actas da I Reunião do Quaternário Ibérico* 2, 226-236.

Veiga Ferreira, O. d. 1954: Faune malacologique: crustaces et poissons-Muge (Moita do Sebastião). *Comunicaçoes dos Serviços Geológicos de Portugal*, 339-352.

Vierra, B. J. 1995: Portuguese Mesolithic Research, Subsistence and stone tool technology: an old world perspective. *Anthropological research papers (Arizona State University)*, 1-19.

Vilar, H.V. 1993: Em torno do foral de Salvaterra de Magos: a genese dum concelho. *O Foral*, 34-38.

Yll, E. I., Pérez-Obiol, R., Pantaleon-Cano, J. and Roure, J. M. 1999: Palynological evidence for climatic change and human activity during the Holocene on Minorca (Balearic Islands). *Quaternary Research* 48, 339-347.

Zazo, C., Goy, J.-L., Somoza, L., Dabrio, C.-J., Belluomini, G., Improta, S., Lario, J., Bardaji, T. and Silva, P.-G. 1994: Holocene Sequence of Sea-Level Fluctuations in Relation to Climatic Trends in the Atlantic-Mediterranean Linkage Coast. *Journal of Coastal Research* 10, 933-945.

Zazo, C., Goy, J.L., Lario, J. and Silva, P.G. 1996: Littoral Zone and Rapid Climatic Changes during the Last 20,000 Years. The Iberian Study Case. *Zeitschrift für Geomorphologie*, Suppl.-Bd. 102, 119-134.

Zbyszewski, G. 1946: Etude Geologique de la region d'Alpiarça. *Comunicações dos Serviços Geológicos de Portugal* 27, 145-268.

Zbyszewski, G. 1958: Le Quaternaire de Portugal. *Boletim da Sociedade Geologica de Portugal* 12, 1-227.

Zilhão, J. 1993: The Spread of Agro-Pastoral Economies across Mediterranean Europe: A View from the Far West. *Journal of Mediterranean Archaeology* 6, 5-63.

Zilhão, J. 2000: From the Mesolithic to the Neolithic in the Iberian peninsula. In Price, T.D., editor, *Europe's First Farmers*, Cambridge: Cambridge University Press, 144-182.

FIGURE CAPTIONS

Figure 1

Map of Mesolithic shell middens and approximate areas of early Neolithic settlement in central-southern Portugal (after Zilhão 1993, 2000; Vierra 1995) and simplified geological map of the Lower Tagus valley including location of Mesolithic shell middens (black dots). VdFdM stands for Vale da Fonte da Moça tributary, while 1. indicates the Cabeço dos Ossos shell midden.

Figure 2a

Schematic geomorphological map of the lower Muge valley, including Mesolithic shell midden sites and sediment observations. Labelled cores are discussed in the text. Altitudes are given in meters above Marégrafo de Cascais (MdC, Portuguese datum level). For location in the Lower Tagus valley see Figure 1.

Figure 2b

Allostratigraphic model of the lower Muge fine-grained valley fill, including accepted radiocarbon dates (Table 1b). The model is based on correlation between the deepest sedimentary sequences along transect lines (Fig. 2a); allostratigraphic units are summarised in Table 2.

Figure 3a

Graphic representation of lithology, foraminifera and mollusc species recorded in analysed cores. Foraminifera sample weight varied from 1.5-4 grams of sediment; each sample contains less than 250 specimens and is thus statistically not significant (Haslett *et al.*, 2001). Foraminifera data are therefore displayed as raw count diagrams; raw count curves are not an artefact of variances in sample weight (van der Schriek *et al., in press* a) and are sufficiently accurate to characterise particular depositional environments and saltwater influence. See Table 2 and Fig. 3b for explanation biofacies assemblages. Underlined radiocarbon dates are rejected.

Figure 3b

Foraminifera and mollusc assemblages in the lower Muge valley fill and associated estuarine environments. Palaeoenvironmental interpretations are based on established relationships between modern foraminifera (Scott and Medioli, 1978; Cearreta, 1988, 1998; Boomer, 1998; Freitas *et al.*, 1999; Haslett *et al.*, 2001) and shell assemblages (Barret and Younge, 1958; Tucker Abbot, 1990; Peacock, 1993), and their habitat. Dashed lines indicate the tidal range in which species are rare (HAT: Highest Astronomical Tide, MHWST: Mean High Water Spring Tide, MHW: Mean High Water, MHWNT: Mean High Water Neap Tide, LHWNT: Lowest High Water Neap Tide, MTL: Mean Tidal Level).

Figure 4

Summary pollen diagram of core 20 in the lower Muge valley floor (analysed by F. Franco Mugica) including raw foraminifera counts (*Jadammina macrescens*). Dates are given in years cal BC and underlined dates are rejected. For legend of graphic log see Figure 3a.

Figure 5

Palaeogeographic maps of the lower Muge valley floor around the time of Mesolithic shell midden occupation. Palaeogeographic reconstructions are based on allostratigraphic data and detailed palaeoecological analyses; individual maps represent an age-range, rather than a precise date.

A) Environments at the beginning of tidal and saltwater influence (~6200 cal BC) in the lower Muge valley floor.

B) Environments around the period of maximum tidal and saltwater influence (~5800-5500 cal BC) in the lower Muge valley floor.

C) Late estuarine environments in the confluence zone of the lower Muge valley floor (~4700-3800 cal BC).

Figure 6

Age-depth curves for cores 20 and 64, based on accepted radiocarbon dates (Table 1b). Basal dates of cores 11 and 51 are included. Dashed lines indicate the depth of specific levels (mentioned in the text) relative to core 20 or core 64.

TABLE CAPTIONS

Table 1a

Published radiocarbon age-estimates of the Mesolithic record in the Lower Tagus Basin (Ch: charcoal; Hbc: human bone collagen). Calibrated ages BC contain unknown error margins due to the variable reservoir effect in bone samples of individuals with a mixed marine-terrestrial diet. See Figures 1 and 2 for location of sites.

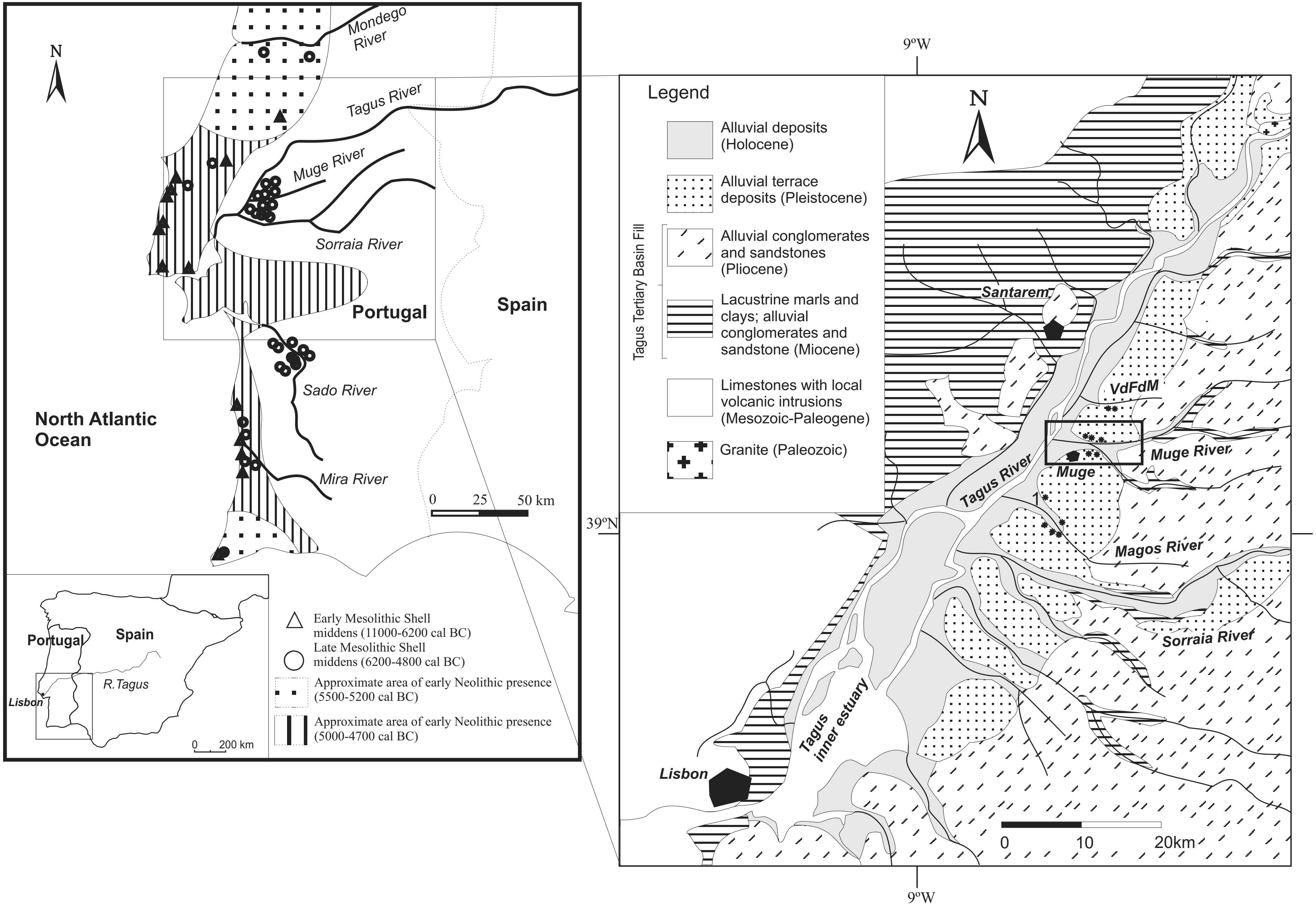
Table 1b

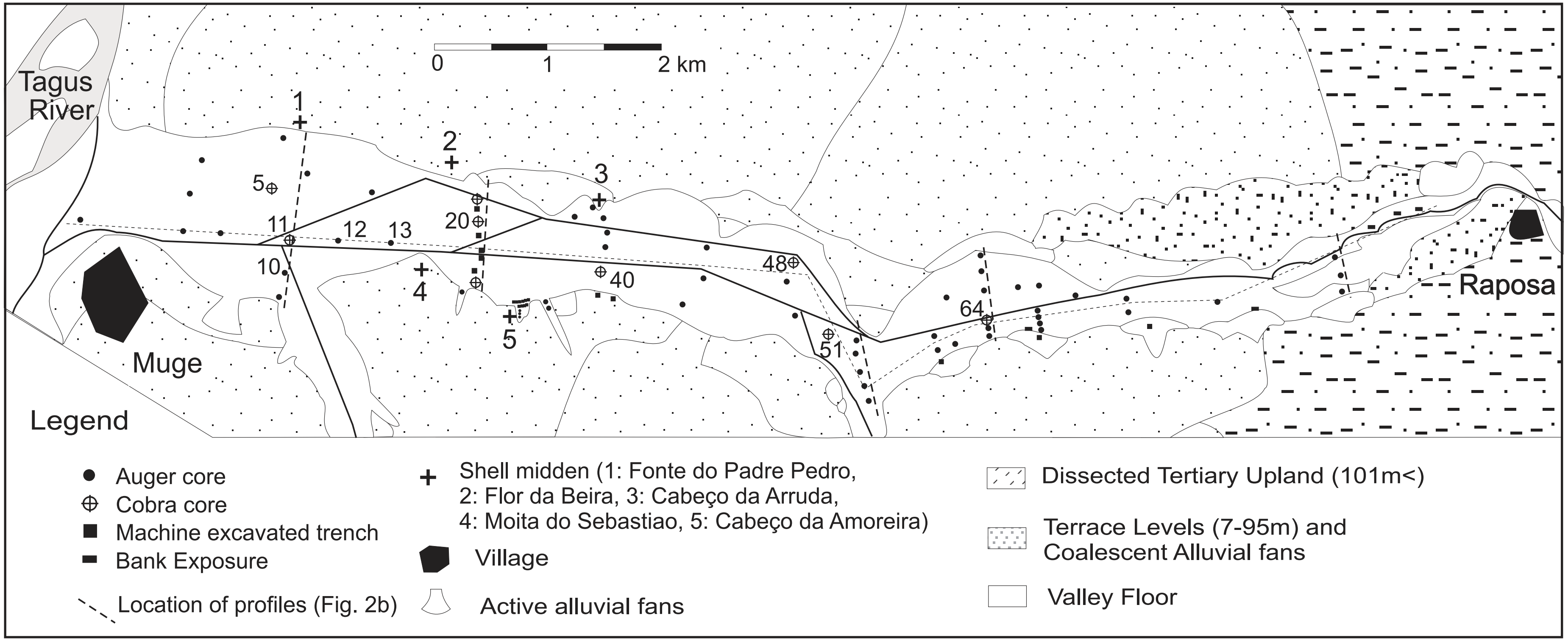
Radiocarbon age-estimates for samples from the lower Muge valley fill. Rejected dates are underlined; see text for reasons of rejection.

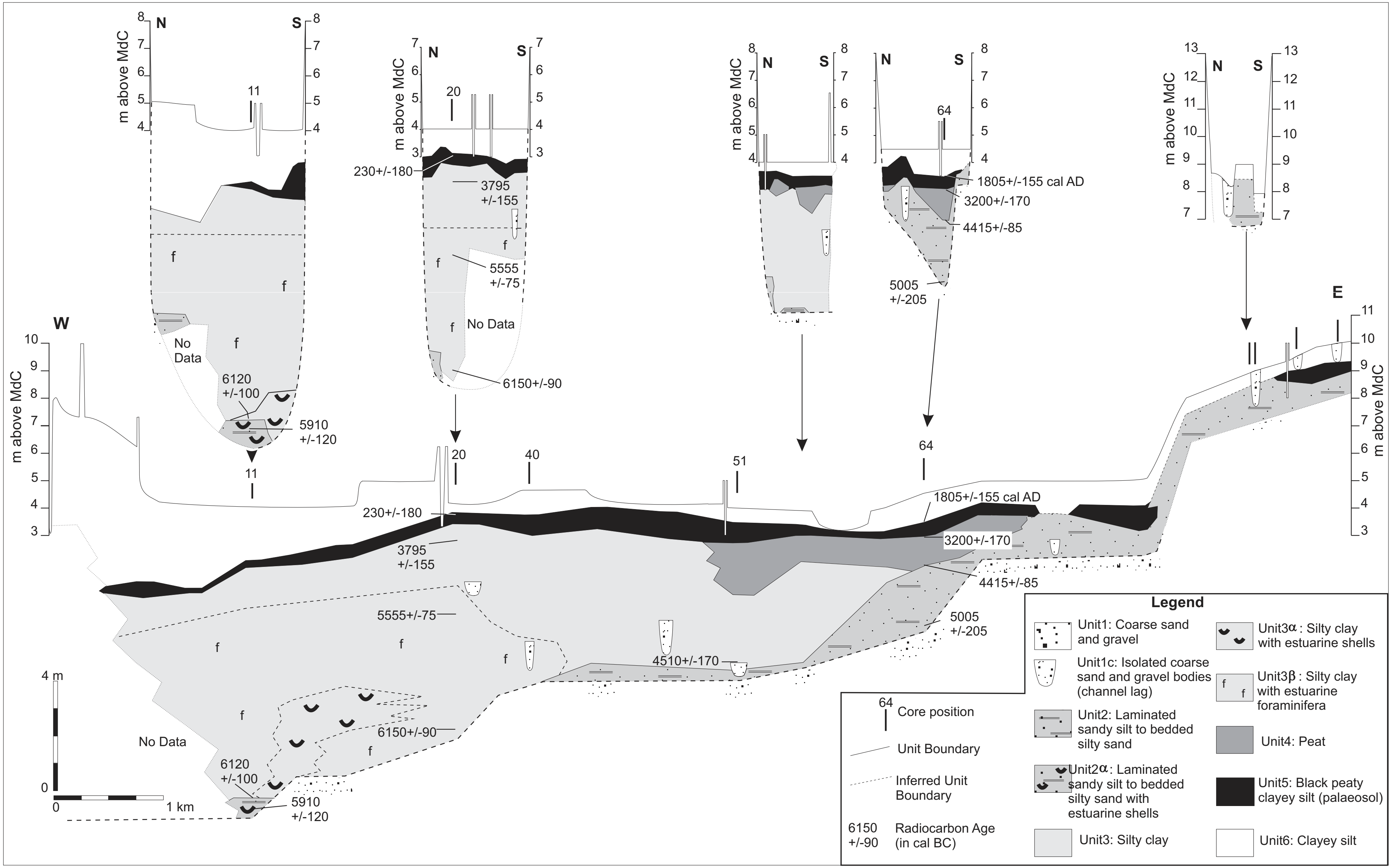
Table 2

Allostratigraphic units in the lower Muge valley fill and their inferred depositional environment. Unit codes consist of a number, based on the lithology, sometimes followed by a second symbol that subdivides the units on the basis of biofacies (α, β) or geometry (c).

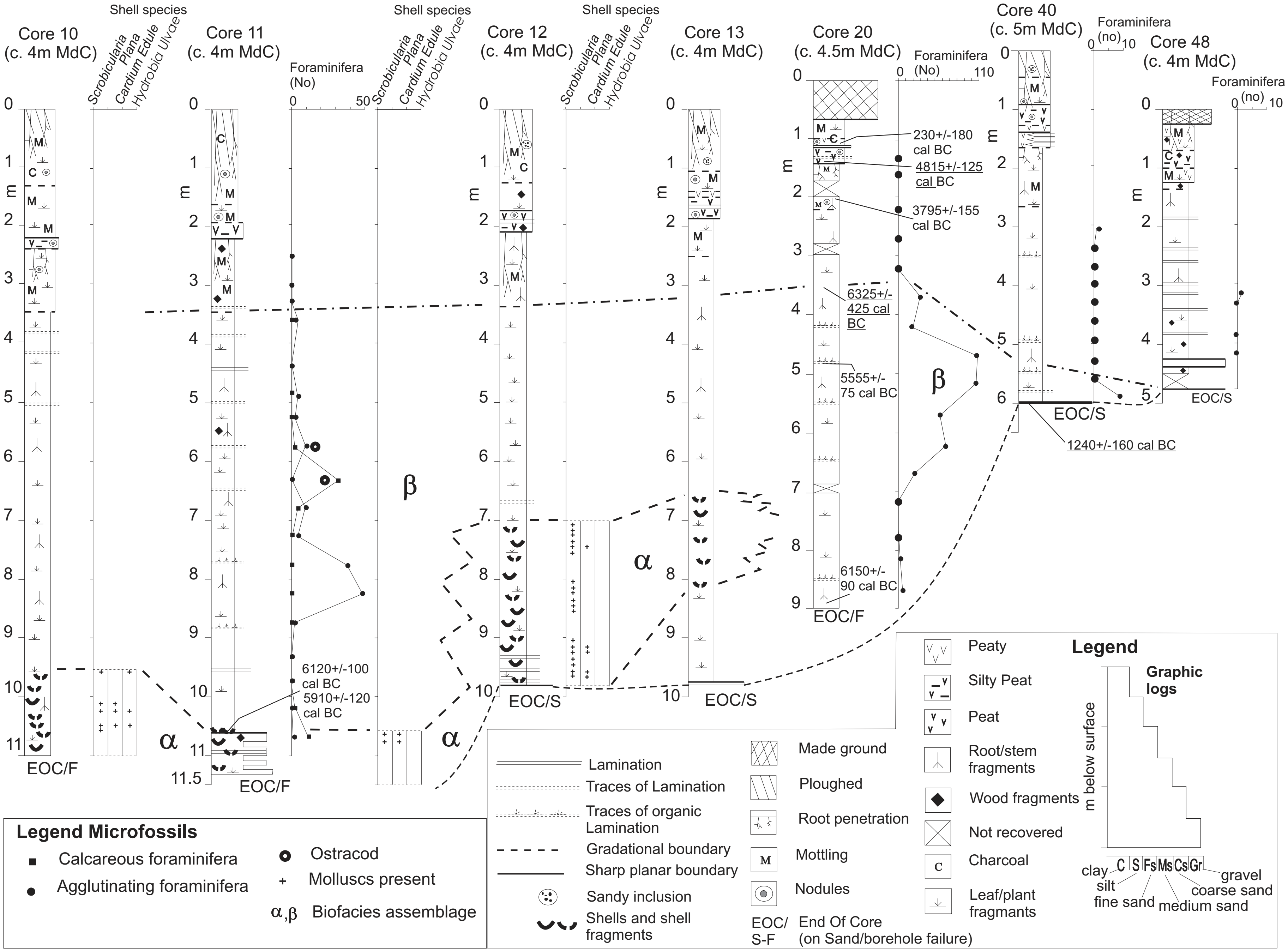
Biofacies α: shell assemblage with *Scrobicularia plana* and, occasionally, *Cardium edule/exiguum* and/or *Hydrobia ulvea* and a calcareous foraminifera assemblage of *Haynesina germanica*, *Haynesina depresula*, *Ammonia beccarii* with rare agglutinating species *Jadammina macrescens* and *Trochammina inflata.* Biofacies β: a foraminifera assemblage dominated by agglutinating species *Jadammina macrescens* and *Trochammina inflata,* and sometimes containing calcareous species *Haynesina germanica*, *Haynesina depresula* and *Ammonia beccarii*.

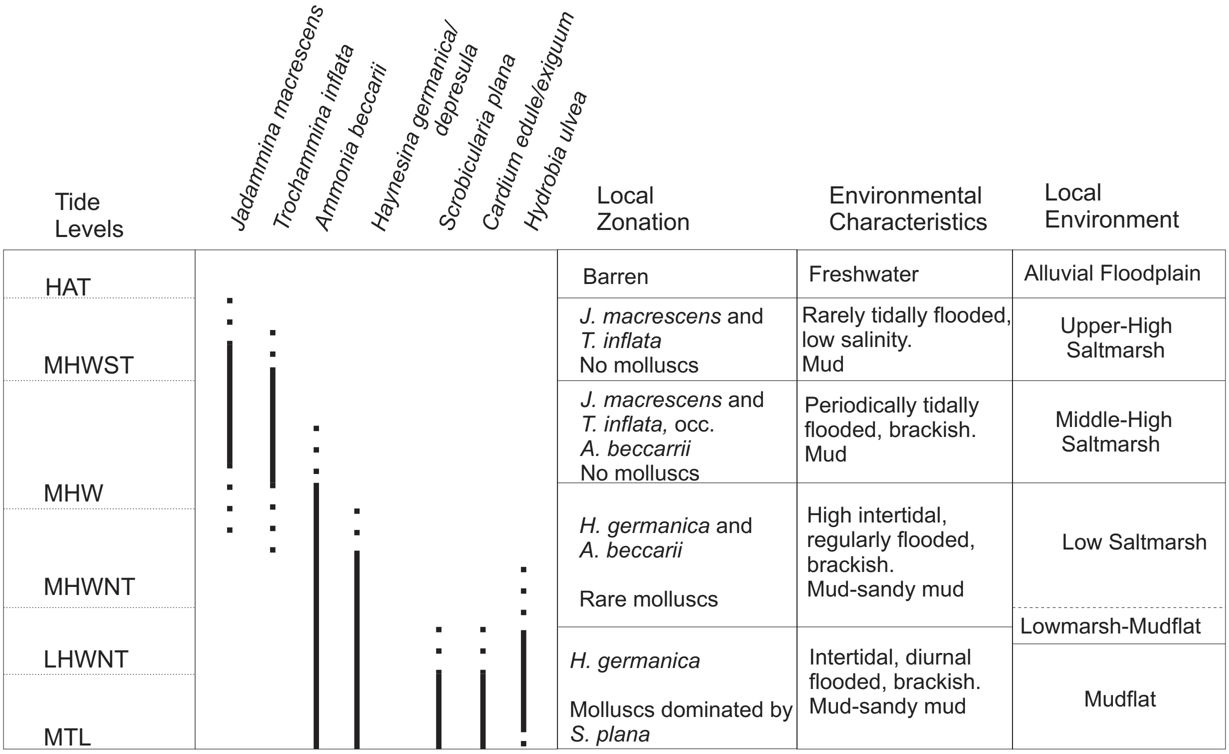

N
Mondego River
Tagus River
Muge River
Sorraia River
Portugal
Spain
Sado River
North Atlantic Ocean
Mira River
0 25 50 km
Portugal
Spain
R.Tagus
Lisbon
0 200 km
Early Mesolithic Shell middens (11000-6200 cal BC)
Late Mesolithic Shell middens (6200-4800 cal BC)
Approximate area of early Neolithic presence (5500-5200 cal BC)
Approximate area of early Neolithic presence (5000-4700 cal BC)
9ºW
Legend
Alluvial deposits (Holocene)
Alluvial terrace deposits (Pleistocene)
Tagus Tertiary Basin Fill
Alluvial conglomerates and sandstones (Pliocene)
Lacustrine marls and clays; alluvial conglomerates and sandstone (Miocene)
Limestones with local volcanic intrusions (Mesozoic-Paleogene)
Granite (Paleozoic)
N
Santarem
VdFdM
Muge River
Muge
Tagus River
39ºN
39ºN
Magos River
Sorraia River
Tagus inner estuary
Lisbon
0 10 20km
9ºW


Tagus River
0
1
2 km
1
2
3
4
5
5
10
11
12
13
20
40
48
51
64
Muge
Raposa
Legend
● Auger core
⊕ Cobra core
■ Machine excavated trench
▬ Bank Exposure
Location of profiles (Fig. 2b)
+ Shell midden (1: Fonte do Padre Pedro, 2: Flor da Beira, 3: Cabeço da Arruda, 4: Moita do Sebastiao, 5: Cabeço da Amoreira)
Village
Active alluvial fans
Dissected Tertiary Upland (101m<)
Terrace Levels (7-95m) and Coalescent Alluvial fans
Valley Floor

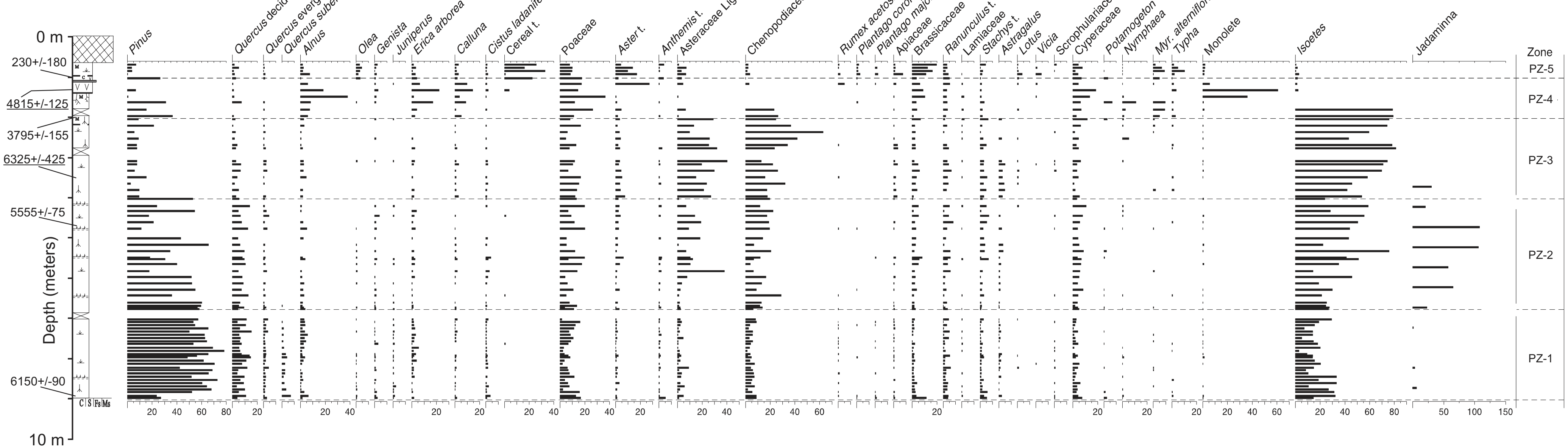


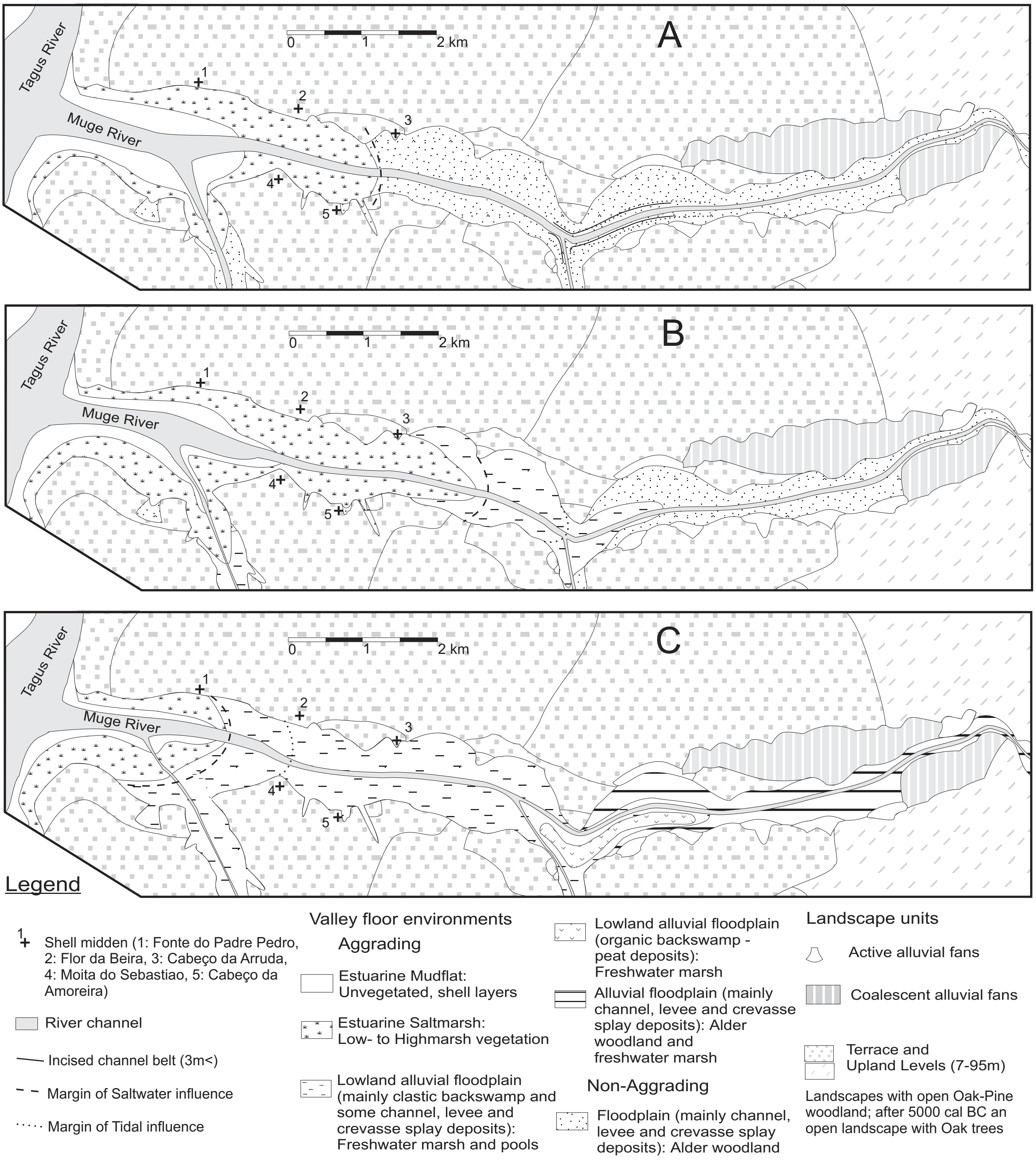
W
E
N
S
m above MdC
11
20
40
51
64
230+/-180
3795 +/-155
5555+/-75
6150+/-90
6120 +/-100
5910 +/-120
1805+/-155 cal AD
3200+/-170
4415+/-85
5005 +/-205
4510+/-170
f
No Data
4 m
0
1 km
Legend
Unit1: Coarse sand and gravel
Unit1c: Isolated coarse sand and gravel bodies (channel lag)
Unit2: Laminated sandy silt to bedded silty sand
Unit2α: Laminated sandy silt to bedded silty sand with estuarine shells
Unit3: Silty clay
Unit3α: Silty clay with estuarine shells
Unit3β: Silty clay with estuarine foraminifera
Unit4: Peat
Unit5: Black peaty clayey silt (palaeosol)
Unit6: Clayey silt
64 Core position
Unit Boundary
Inferred Unit Boundary
6150 +/-90 Radiocarbon Age (in cal BC)

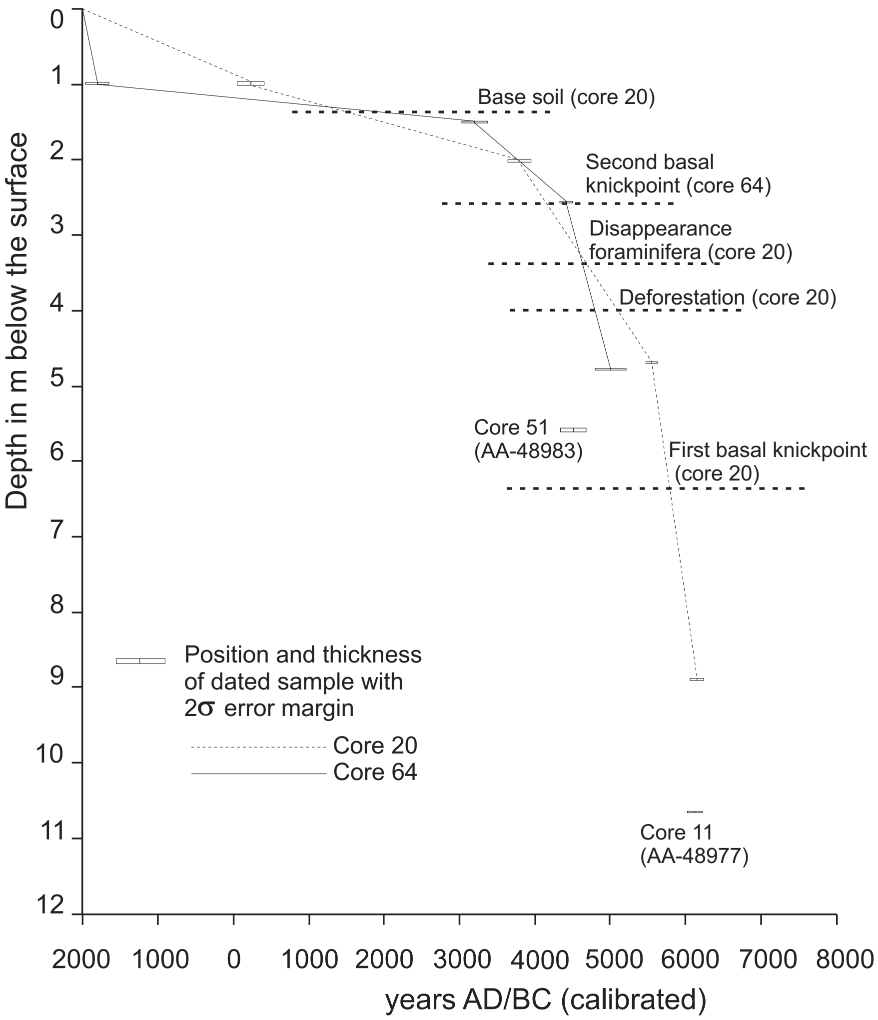

Core 10 (c. 4m MdC)
Shell species
Scrobicularia Plana
Cardium Edule
Hydrobia Ulvae
Core 11 (c. 4m MdC)
Foraminifera (No)
0
50
Core 12 (c. 4m MdC)
Core 13 (c. 4m MdC)
Core 20 (c. 4.5m MdC)
Foraminifera (No)
110
Core 40 (c. 5m MdC)
Foraminifera (no)
10
Core 48 (c. 4m MdC)
m
11.5
230+/-180 cal BC
4815+/-125 cal BC
3795+/-155 cal BC
6325+/-425 cal BC
5555+/-75 cal BC
6150+/-90 cal BC
6120+/-100 cal BC
5910+/-120 cal BC
1240+/-160 cal BC
α
β
EOC/F
EOC/S
M
C
Legend Microfossils
Calcareous foraminifera
Agglutinating foraminifera
Ostracod
Molluscs present
α,β Biofacies assemblage
Lamination
Traces of Lamination
Traces of organic Lamination
Gradational boundary
Sharp planar boundary
Sandy inclusion
Shells and shell fragments
Made ground
Ploughed
Root penetration
Mottling
Nodules
EOC/S-F End Of Core (on Sand/borehole failure)
Peaty
Silty Peat
Peat
Root/stem fragments
Wood fragments
Not recovered
Charcoal
Leaf/plant fragmants
Legend
Graphic logs
m below surface
clay
silt
fine sand
medium sand
coarse sand
gravel
C S Fs Ms Cs Gr



Tide Levels	Local Zonation	Environmental Characteristics	Local Environment
HAT	Barren	Freshwater	Alluvial Floodplain
MHWST	*J. macrescens* and *T. inflata* No molluscs	Rarely tidally flooded, low salinity. Mud	Upper-High Saltmarsh
MHW	*J. macrescens* and *T. inflata,* occ. *A. beccarrii* No molluscs	Periodically tidally flooded, brackish. Mud	Middle-High Saltmarsh
MHWNT	*H. germanica* and *A. beccarii* Rare molluscs	High intertidal, regularly flooded, brackish. Mud-sandy mud	Low Saltmarsh
LHWNT MTL	*H. germanica* Molluscs dominated by *S. plana*	Intertidal, diurnal flooded, brackish. Mud-sandy mud	Lowmarsh-Mudflat Mudflat


0 m
10 m
Depth (meters)
230+/-180
4815+/-125
3795+/-155
6325+/-425
5555+/-75
6150+/-90
C S Fs Ms
Pinus
Quercus deciduous
Quercus evergreen
Quercus suber
Alnus
Olea
Genista
Juniperus
Erica arborea
Calluna
Cistus ladanifer
Cereal t.
Poaceae
Aster t.
Anthemis t.
Asteraceae Lig.
Chenopodiaceae
Rumex acetosa
Plantago coronopus
Plantago major/media
Apiaceae
Brassicaceae
Ranunculus t.
Lamiaceae
Stachys t.
Astragalus
Lotus
Vicia
Scrophulariaceae
Cyperaceae
Potamogeton
Nymphaea
Myr. alterniflorum
Typha
Monolete
Isoetes
Jadaminna
Zone
PZ-5
PZ-4
PZ-3
PZ-2
PZ-1
20 40 60 80
20
20 40
20
20
20 40
20 40
20
20 40
20 40 60
20
20
20
20
20 40 60
20 40 60 80
50 100 150


A
B
C
Tagus River
Muge River
0
1
2 km
1
2
3
4
5
Legend
1 Shell midden (1: Fonte do Padre Pedro, 2: Flor da Beira, 3: Cabeço da Arruda, 4: Moita do Sebastiao, 5: Cabeço da Amoreira)
River channel
Incised channel belt (3m<)
Margin of Saltwater influence
Margin of Tidal influence
Valley floor environments
Aggrading
Estuarine Mudflat: Unvegetated, shell layers
Estuarine Saltmarsh: Low- to Highmarsh vegetation
Lowland alluvial floodplain (mainly clastic backswamp and some channel, levee and crevasse splay deposits): Freshwater marsh and pools
Lowland alluvial floodplain (organic backswamp - peat deposits): Freshwater marsh
Alluvial floodplain (mainly channel, levee and crevasse splay deposits): Alder woodland and freshwater marsh
Non-Aggrading
Floodplain (mainly channel, levee and crevasse splay deposits): Alder woodland
Landscape units
Active alluvial fans
Coalescent alluvial fans
Terrace and Upland Levels (7-95m)
Landscapes with open Oak-Pine woodland; after 5000 cal BC an open landscape with Oak trees


Depth in m below the surface
0
1
2
3
4
5
6
7
8
9
10
11
12
2000
1000
0
1000
2000
3000
4000
5000
6000
7000
8000
years AD/BC (calibrated)
Base soil (core 20)
Second basal knickpoint (core 64)
Disappearance foraminifera (core 20)
Deforestation (core 20)
Core 51 (AA-48983)
First basal knickpoint (core 20)
Core 11 (AA-48977)
Position and thickness of dated sample with 2σ error margin
Core 20
Core 64

Site	**Provenience**	**Sample**	**Laboratory number**	**Age BP**	**cal BC (2σ-range)**	**Reference**
Cabeço da Arruda (Muge valley)	Skeleton III (stratigraphy unknown)	Hbc	TO-360	6990+/-110	6090-5640	Lubell and Jackes, 1988
	Skeleton A (stratigraphy unknown)	Hbc	TO-354	6970+/-60	5980-5650	“
	Skeleton 42 (stratigraphy unknown)	Hbc	TO-359a	6960+/-60	5980-5640	“
	Skeleton D (stratigraphy unknown)	Hbc	TO-355	6780+/-80	5810-5490	“
	Skeleton 356 (stratigraphy unknown)	Hbc	TO-356	6360+/-80	5480-5210	“
	Skeleton (stratigraphy unknown)	Hbc	Beta -?	7550+/-100	6650-6100	Cunha and Cardosa, *in press*
	Level 71-82	Ch	Sa-197	6430+/-300	6000-4600	Roche and Veiga Ferreira, 1973
	Level 3-6	Ch	Sa-196	5150+/-300	4700-3100	“
Cabeço da Amoreira (Muge valley)	Level 39	Ch	Sa-195	7030+/-350	6700-5200	“
	?	?	Hv-1349	6430+/-65	5840-5640	Vierra, 1995
	Level 3-4	Ch	Sa-194	6050+/-300	5700-4300	Roche and Veiga Ferreira, 1973
	Skeleton (stratigraphy unknown)	Hbc	Beta -?	6850+/-40	5840-5640	Cunha and Cardosa, *in press*
Moita do Sebastião (Muge valley)	Skeleton 22 (stratigraphy unknown)	Hbc	TO-131	7240+/-70	6219-5970	Lubell *et al.*, 1986
	Skeleton 29 (stratigraphy unknown)	Hbc	TO-133	7200+/-70	6180-5886	“
	Skeleton 24 (stratigraphy unknown)	Hbc	TO-132	7180+/-70	6170-5848	“
	Skeleton 41 (stratigraphy unknown)	Hbc	TO-134	7160+/-80	6170-5830	“
	Skeleton CT (stratigraphy unknown)	Hbc	TO-135	6810+/-70	5830-5540	“
	Skeleton (stratigraphy unknown)	Hbc	Beta -?	7120+/-40	6080-5880	Cunha and Cardosa, *in press*
	II base	Ch	Sa-16	7350+/-350	7100-5500	Roche and Veiga Ferreira, 1973
	II base	Ch	H2119/1546	7080+/-130	6220-5710	“
Cabeço dos Ossos (Magos valley)	Skeleton (stratigraphy unknown)	Hbc	Beta -?	7140+/-40	6160-5910	Cunha and Cardosa, *in press*

Lab. Code	**^{14}C age (years BP)**	**2σ Cal. age range (years BC/AD)**	**Sample Site**	**Sample Depth (m)**	**Sample Type**	**^{14}C Dating Method**	**Dated Event**
beta 111010	2220+/-80	cal BC 410-50	Core 20	0.94-0.96	Bulk sample peaty silt	radiometric	Last stages of soil formation
beta 111011	7490+/-180	cal BC 6750-5900	Core 20	3.57-3.60	Bulk sample clayey silt	radiometric	End local saltwater influence (indicated by disappearance foraminifera)
AA-49816	7668+/-49	cal BC 6030-5790	Core 11	10.73-10.76	Selected shell fragments (*Scrobicularia*)	AMS	Start of saltwater influence (indicated by estuarine shells) and onset of fine-grained deposition
AA-48977	7263+/-46	cal BC 6220-6020	Core 11	10.64-10.66	Selected plant fragments	AMS	Start of saltwater influence (indicated by foraminifera) and onset of fine-grained deposition
AA-48978	7318+/-44	cal BC 6240-6060	Core 20	8.88-8.905	Selected plant and wood fragments	AMS	Start of saltwater influence (indicated by foraminifera) and onset of fine-grained deposition
AA-48979	6626+/-44	cal BC 5630-5480	Core 20	4.68-4.70	Selected plant fragments	AMS	Maximum tidal influence (indicated by foraminiferan peak)
AA-48980	4985+/-73	cal BC 3950-3640	Core 20	200-202.5	Bulk sample organic clayey silt	AMS	End of regional saltwater indicators in pollen diagram
AA-48981	5929+/-52	cal BC 4940-4690	Core 20	1.365-1.38	Selected wood fragments	AMS	Initiation of soil formation and alder invasion (pollen record)
AA-48982	3006+/-46	cal BC 1400-1110, 1100-1080	Core 40	5.98-6.00	Selected plant fragments	AMS	Onset of fine-grained sedimentation
AA-48983	5638+/-71	cal BC 4680-4630, 4620-4340	Core 51	5.56-5.61	Selected plant fragments	AMS	Onset of fine-grained sedimentation
AA-48984	6096+/-54	cal BC 5210-5160, 5150-4840, 4820-4800	Core 64	4.77-4.79	Selected plant fragments	AMS	Onset of fine-grained sedimentation
SRR-6789	5578+/-51	cal BC 4500-4330	Core 64	2.55-2.57	Bulk sample peat	radiometric	Beginning of local peat formation
SRR-6790	4526+/-49	cal BC 3370-3080, 3070-3030	Core 64	1.49-1.51	Bulk sample peat	radiometric	End of local peat formation, start of peaty soil formation
AA-48985	176+/-34	cal AD 1650-1700, 1720-1820, 1830-1890, 1910-1960	Core 64	0.97-1.00	Selected plant fragments	AMS	End of local peaty silt formation, onset of mineral sedimentation

Unit	Lithology	Maximum thickness	Lower Boundary characteristics	Geometry	Interpretation
1	Bedded coarse sand and gravel	Unknown; cored to 0.3 m depth	*Not identified*	Upper boundary has a gradient towards the Tagus River.	The upper boundary surface contains entrenched channels and is eroded in the underlying fluvial deposits
1c	Bedded sand and gravel	Unknown; cored to 0.5 m depth	*Not identified*	Narrow, tabular bedded sand and gravel bodies in a silty clay matrix.	Channel lag and coarse channel fill deposits
2	Laminated-bedded sandy silt/silty sand	~2.5 m	Conformable and gradual with unit 1, based on lithological change.	Discontinuous basal beds, pinching out towards the Tagus confluence.	Levee, crevasse splay and proximal overbank deposits
2α	Laminated-bedded sandy silt/silty sand with estuarine shells	~0.7 m	Conformable and gradual with unit 1, based on lithological change.	Isolated beds at the base of the fine-grained valley fill near the confluence.	Estuarine (lower) tidal flat deposits
3	Silty clay	~5 m	Conformable and gradual with unit 2, based on lithological change. Conformable and gradual with unit 3β based on disappearance foraminifera.	Massive silty clay bed near the mouth and centre of the valley fill, pinching out upstream.	Fluvial overbank and backswamp deposits
3α	Silty clay with estuarine shells	~3 m	Conformable and abrupt (unit 1) to gradual (unit 2α), based on lithological change. Conformable and gradual with unit 3β based on appearance estuarine shells.	Basal beds near the mouth of the valley fill.	Estuarine tidal mudflat deposits
3β	Silty clay with foraminifera	~6.5 m	Conformable and abrupt (unit 1) to gradual (unit 2), based on lithological change. Conformable and gradual with unit 3α based on disappearance estuarine shells.	Massive near the mouth of the valley fill, pinching out upstream.	Estuarine tidal saltmarsh deposits
4	Peat, silty peat and peaty silt	~1.5 m	Conformable and gradual to abrupt with units 2 and 3, based on lithological change.	Beds of irregular thickness, mainly found in the central valley fill.	Peat formation in fluvial backswamp and palaeochannel settings
5	Oxidised peaty clayey silt	~0.8 m	Conformable and gradual to abrupt with units 2, 3 and 4, based on lithological change.	Thin, continuous layer, dipping towards the Tagus River.	Alluvial (layered) soil
6	Clayey to sandy silt	~3 m	Conformable and gradual (unit 2) to abrupt (unit 5), based on lithological change. No lower boundary surface with unit 3 due to the homogenous nature of the sediments.	Beds of variable thickness capping the valley fill.	Fluvial levee, crevasse splay, overbank and backswamp deposits