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Holocene coastline evolution in the northern area of the Guadalquivir palaeoestuary

Evolución de la línea de costa holocena en la zona norte del paleoestuario del Guadalquivir

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Abstract

In this article the theoretical framework and the results of my doctoral thesis *La Transgresión Flandriense en la Vega de Sevilla. El paleoestuario del río Guadalquivir (The Flandrian Transgression in the alluvial plain near Seville. The Guadalquivir River palaeoestuary)* (Barragán Mallofret, 2016a; 2016b) are presented, as well as a brief synthesis of the immediate research precedents about the Holocene evolution of the Guadalquivir estuary. The work includes the cartography of the palaeoestuary generated by the Holocene (Flandrian) transgression circa 6500 BP in the Guadalquivir valley, as well as a proposal about its siltation process. Moreover, the historical contextualization of this coastal landscape in the transition between the Neolithic tribal society and the initial classist society is also discussed.

Key words: Guadalquivir estuary, geoarchaeology, Holocene (Flandrian) transgression, Neolithic

Resumen

En este artículo se presentan el marco teórico y los resultados de mi tesis doctoral *La Transgresión Flandriense en la Vega de Sevilla. El paleoestuario del río Guadalquivir* (Barragán Mallofret, 2016a; 2016b), así como una breve síntesis de los inmediatos precedentes de investigación sobre la evolución holocena del estuario del Guadalquivir. Este trabajo incluye la cartografía del paleoestuario generado por la transgresión holocena (flandriense) en el valle del Guadalquivir *circa* 6500 BP, así como una propuesta acerca de su proceso de colmatación. Además, la contextualización de este paisaje costero en la transición entre la sociedad tribal neolítica y la sociedad clasista inicial también es discutida.

Palabras clave: estuario del Guadalquivir, geoarqueología, transgresión holocena (flandriense), Neolítico

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1. Introduction

This work is an updated and expanded English version of the article "La línea de costa flandriense en el paleoestuario del río Guadalquivir (c. 6500 BP)", published in 2016 in *Revista Atlántico-Mediterránea de Prehistoria y Arqueología Social*, 18 (Barragán Mallofret, 2016b). We present the results of more than 20 years of investigation about the Holocene coastline evolution in the Guadalquivir estuary. The main part of the research comes from my doctoral thesis *The Flandrian Transgression in the alluvial plain near Seville. The Guadalquivir River palaeoestuary* (Barragán Mallofret, 2016a; 2016b), which included the mapping of the coastline of the palaeoestuary generated by the Holocene (Flandrian) transgression circa 6500 BP in the Guadalquivir valley in the area of Seville, north of the present-day marshlands. I also obtained data which allowed making approaches and producing work hypothesis about the fill process of the palaeoestuary.

This article also includes the analysis of the published results of the preceding *Proyecto Geoarqueológico Puerto de Itálica* (*Port of Italica Geoarchaeological Project*) (Arteaga et al., 2015; 2016b), in which I participated as a member of the scientific team, and the *Proyecto Geoarqueológico de las Marismas del Guadalquivir* (*Guadalquivir Marshes Geoarchaeological Project*), carried out in the 1990s by an international team led by Professor Oswaldo Arteaga (University of Seville) and Professor Horst D. Schulz (Bremen University) (Schulz et al., 1992; 1995; Arteaga and Roos, 1992; 1995; 2007; Arteaga, Schulz and Roos, 1995).

Some of the data and conclusions of the previous works have been corrected and refined with the help of new data obtained in field works realized after 2016, especially the campaign accomplished in 2022 in the context of the collaboration between the *"Valencina-Nord" Project*, led by Professor Thomas X. Schumacher (German Archaeological Institute of Madrid), Professor Alfredo Mederos (Autonomous University of Madrid) and Professor Frank Falkenstein (Würzburg University), and the project *F1: "Climate Constraints of Western Mediterranean Socio-environmental Transformation and Potential Implications for Central Europe"* led by Professor Mara Weinelt (Kiel University) as part of the *Scales of Transformation Project*.

Thereby, starting from the application of the methodology of the Dialectic Geoarchaeology (Arteaga and Hoffmann, 1999; Arteaga and Schulz, 2008; Arteaga and Roos, 2012), through diverse observation techniques, from space (satellite pictures), air (aerial photographs), land surface (pedestrian surveys) and subsoil (geoarchaeological boreholes) (Arteaga et al., 1988; Arteaga and Ménanteau, 2004), the results thus obtained allow to make a proposal of delimitation of the coastline of the maximal level reached by the Holocene transgression in the alluvial plain of Seville (*Vega de Sevilla*).

The current research has as precedents, as we have already indicated, the results obtained by the aforementioned *Guadalquivir Marshes Geoarchaeological Project*, continuing, upstream, the delimitation of the maximum extension of Holocene aquatic sediments deposited under a permanent water coverage under current mean sea level. To achieve this objective, 37 geoarchaeological boreholes were carried out expressly for my doctoral thesis project, combining the mechanical sampler with the manual one when necessary. These boreholes were made in the contact zones between the sediments of the Holocene floodplain and the pre-Holocene reliefs bordering it, except in the urbanized areas and in the southern section of the east bank, due to budgetary constraints. In addition, data from the 20 geoarchaeological boreholes realized in the *Port of Italica Geoarchaeological Project* (Arteaga et al., 2015), where I participate as researcher, have been used. Apart from the boreholes carried out for my doctoral thesis project or in collaboration with the team of the *Port of Italica Geoarchaeological Project*, we have used and interpreted the stratigraphic data of the geotechnical boreholes and archaeological sections published by the team of Francisco Borja Barrera, compiled, among other publications, in the doctoral thesis of Mª Ángeles Barral (Barral, 2009).

This global eustatic sea level rise, occurred after the end of the last glacial period, reached its transgressive maximum circa 6500 years BP (Schulz et al., 2004; Goy et al., 1996, Brückner and Radtke, 1990),

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generating a fluvial-marine estuary whose headwaters were in the east border of the Alcalá de Río municipal district, in the vicinity of the Cortijo del Vado, where the Guadalquivir river flowed into it. This estuary was 30 km long and had a maximal width of 5 km near the town of La Algaba. It emptied into a large marine gulf (the current Guadalquivir marshes) 50 km long and 50 km wide. In total, the gulf and the estuary extended 80 km into the mainland.

In addition to the proposal of delimitation of the 6500 BP coastline, the obtained data allowed to pose some hypothetical approximations about the evolution of the fill process occurred after the transgressive maximum, although these hypotheses must be contrasted with the realization of further research that includes more boreholes and analytics.

2. Theoretical framework

Our theoretical position is Dialectic Materialism, holistic theory developed by Karl Marx and Friedrich Engels in the second half of the 19th century, with the later contributions applied to Archaeology by the Latin American Social Archaeology current (Lumbreras, 1974; Lorenzo, 1976; Vargas, 1990; Gándara, 1993; Arteaga and Nocete, 1996; Bate, 1998). From Dialectic Materialism as holistic theory of reality (both natural and social) would derivate the methodological development of the Dialectic Geoarchaeology that we apply (Arteaga and Hoffmann, 1999; Arteaga and Schulz, 2000; Arteaga and Roos, 1992; 1995; 2012; Arteaga and Schulz, 2008; Arteaga, Schulz and Roos, 2008), rather than from Historical Materialism, substantive theory referred traditionally only to social reality.

Dialectic Geoarchaeology shares the valuative area (*área valorativa*, the "*what for*" of the research) of Social Archaeology, focused, following Manuel Gándara, on the inequality and exploitation produced by global capitalism, regarding not only social inequality and very different qualities of life among the different social classes, but also the damage that this predative economic system produce in the natural environments within human life takes place (Gándara, 1993: 12-13).

Our reasons for investigating are both ethical-political and scientific, because we assume that the explication of History is a condition for the modification of the present and for the prediction of the future, and that many processes occurring today have an historical depth that goes back to periods where only archaeological documentation is available. With the explication as our cognitive objective, we can contribute as archaeologist to elucidate the historical processes that lead to the nowadays situation, and help to understand and change our present (Gándara, 1993: 13).

The cognitive objective of this work is to contribute to the explication, in the south of the Iberian Peninsula, of the causes of the historical development of the double dialectic among the social systems and the natural systems in the transition from the Neolithic tribal socio-economic formation and initial classist socio-economic formation, between the 4th and the 3rd millennium BC. In order to achieve this objective, the landscape generated by the Holocene Transgression (circa 6500 BP) in the alluvial plain of Seville was investigated by the delimitation of the coastline of the palaeoestuary of the Guadalquivir River.

Regarding the theory of reality, Dialectic Geoarchaeology defends, unlike determinist ambientalism and adaptationist and possibilist contextualism, "a non-passive and much more contradictory vision of the anthropic concept, in line with the evaluation of its social content […]", "questionable from the social relationships" that humans establish among them and the actual societies with nature "not precisely in ecological terms: no anthropic effect can be ecological" (Arteaga and Schulz, 2000: 20. The translation is mine).

Therefore, a holistic analysis of reality is postulated. Reality is one only and exists independently of the subject that intends to know it. Reality is also material (Gándara, 1993; Bate, 1998), starting from a double dialectic that is established, the first one, based on the relationships among men and women that integrate the socio-economic formations, and the second one between those socio-economic formations, which are historical and dialectically changing, and the natural systems, which also have an internal dialectical dynamic.

We consider, consequently, that it is up to socio-economic formations, rather than adaptative functions, to play the promoting role of the "anthropic" effects, which in nature have been reflected in various practices of use and exploitation, and which have had an unequal impact on the transformations of landscapes. So, productive work is proposed as the engine of history instead of adaptative capacity. A productive work whose development took place during Pleistocene in modes of life conditioned by what nature provided, characteristic of the pre-tribal socio-economic formation (hunter-fisher-gatherer mode of production) and which, from the emergence of the tribal socio-economic formation (tribal agricultural and livestock farming mode of production) in Holocene, changed into "increasingly varied and unequal modes of life, and because of that dialectically more complex." (Arteaga and Hoffmann, 1999: 36. The translation is mine).

Referring to the theory of knowledge, our theoretical position adopts, according to Gándara:

> […] a materialist, gnostic (reality is knowable), dialectic (knowledge is a product of transformative action on the world and is always dynamic), social (the subject who knows is a product of his/her society) and historical (subject and reality are changing constantly, and the process of knowledge is limited by the historical context) epistemology; a notion of truth is maintained as correspondence, whose criterion is praxis; and a non-fundamentalist, fallibilist position regarding the status of knowledge: knowledge is fallible, but perfectible. This position will translate […] into a falsificationist methodology: […] there is no refutation without an alternative that improves what it refutes. Scientific change is, at least on a larger scale, subject to growth via rational criticism. (Gándara, 1993: 17. The translation is mine).

This methodology will command the application of reality observation techniques, which will transform the theory of knowledge (and in the last instance the theory of reality) into work hypotheses subjected to the falsification principle and subordinated to the observed reality.

3. Applied techniques

3.1. Cartographic analysis and photo-interpretation techniques

To investigate Holocene stratigraphy, it is first necessary to map the surface extent of the Holocene soft sediments corresponding to the alluvial or alluvial-colluvial plains of the valleys, as well as the pre-Holocene slopes that surround them. To do this, we have used the online geological cartography viewer (InfoIGME Viewer) at a scale of 1:25 000 of the Geological and Mining Institute of Spain (IGME), which also allows it to be included as a layer in the vector cartographies generated for GIS (Geographic Information System) software that we have used to elaborate our own cartographies of the coastline of the Holocene transgressive maximum (6500 BP) in the Vega de Sevilla. One of these maps is the vector digital cartography at a scale of 1:10 000 (2007), available from the Institute of Statistics and Cartography of Andalusia (Ministry of Economy and Knowledge of the Junta de Andalucía). We have also used the digital colour raster cartography of the same Institute, at a scale of 1:10 000 (2007), visualizable through the Mulhacén program and also insertable as a layer in the GIS.

As for photointerpretation, it is a very useful tool, together with geological and topographic cartography, to complete the delimitation of Holocene sediments in the valleys to be studied. In the present work it has been done from digital or digitized photographs, taking advantage of the tool, also produced by the Institute of Statistics and Cartography of Andalusia, called *Historical Digital Orthophotography of Andalusia 1956-2007. Half a century of changes in Andalusia*, which makes it possible to combine the observation of the 2007 Landsat satellite image, the digitized orthophoto of the 1956 U.S. Air Force aerial flight and the 2007 colour orthophoto, also including a digital terrain model. All images are georeferenced in the coordinate system of the UTM European Datum 1950 projection (ED50), unified to zone 30, since the area under study is divided between zone 30, to the east, and zone 29, to the west. We have also followed this criterion and all

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the coordinates of the boreholes carried out by us, both those of the Port of Italica Geoarchaeological Project and those realized exclusively for the doctoral thesis whose results are summarized in this article, have been referenced to zone 30 of the UTM ED50 system.

3.2. Field techniques

3.2.1. Pedestrian survey

The pedestrian survey of the edges of the Holocene plains to be investigated, as well as of their interior, especially in territories as wide as the object of research of this work, is also fundamental. By means of the survey, the accuracy of the information collected in the geological and topographic cartography, as well as our interpretation of the aerial and satellite photographs, are checked beforehand. Possible modifications to the terrain that occurred after the cartographies and photographs were made, such as constructions, debris dumping, etc., as well as accessibility to them, are also found out.

Archaeological survey is one of the main techniques of geoarchaeological methodology, with the aim of detecting material evidence of historical settlement in the areas to be investigated. In the research of the Holocene transgression, special emphasis must be placed on the areas where it is assumed as hypothesis that the ancient coastline of the transgressive maximum was developed, and where the presence and dispersion of archaeological materials can give us indications of possible advances in the coastline, as well as the possibility of detecting hillside layers with archaeological materials or directly archaeological layers interspersed with Holocene sediments (Arteaga and Hoffmann, 1999).

Many archaeological sites located in the vicinity of the contact zones between the Holocene alluvial plains and the pre-Holocene reliefs have been used to search for stratigraphic relationships interspersed between the alluvial sediments (long-distance) and the eroded archaeological layers (short-distance), which has facilitated the obtaining of geoarchaeological sequences of great explanatory potential in the investigated river basins (Schulz, 1983; 1988; 1993; Schulz, Jordt and Weber, 1988; Schulz et al., 1992; 1995; Arteaga and Schulz, 1997). The comparison of different stratigraphic sequences obtained from several boreholes made at the foot of various archaeological sites from different periods, but belonging to the same river basin or maritime palaeoinlet, can provide the researcher with a sequential scale of sedimentation, usually better dated than sediments formed by long-distance transport, since the latter often provide absolute chronologies referring to more distant soils. The eroded materials from these older soils do not usually correspond to the time of deposition of the sediment (Arteaga and Hoffmann, 1999: 23).

3.2.2. Geoarchaeological boreholes

The drilling techniques that we are applying in the geoarchaeological investigation of the Guadalquivir alluvial plain (Arteaga et al., 2015) include the Eijkelkamp (the Netherlands) Edelman-type manual sampler, with which most of the boreholes have been performed, combined with the Stitz (Germany) open-chamber percussion sampler (*Rammkernsonde*) when the sediments were covered by contemporary debris, were too compacted, were layers with gravel or rock, or were sandy layers in combination with groundwater. In total, we drilled 57 boreholes for the research we are presenting in this article. The following is a detailed description of the samplers used.

Manual drilling

For the stratigraphic analysis of soft Holocene sediments, especially in estuarine and marsh environments, a manual Edelman-type sampler from the firm Eijkelkamp (the Netherlands) is used. This sampler consists of a 0.5 m long T-shaped handlebar, augers of the same length with diameters of 10 and 7 cm and 1 m long steel extension tubes. The different pieces are assembled very easily and quickly with a bayonet lock.

Depending on the granulometric spectrum and water content of the sediment to be drilled, different augers are applied. As a general rule, it can be said that the thicker the granulometric fraction of the sediments to be drilled, the closer the auger to be

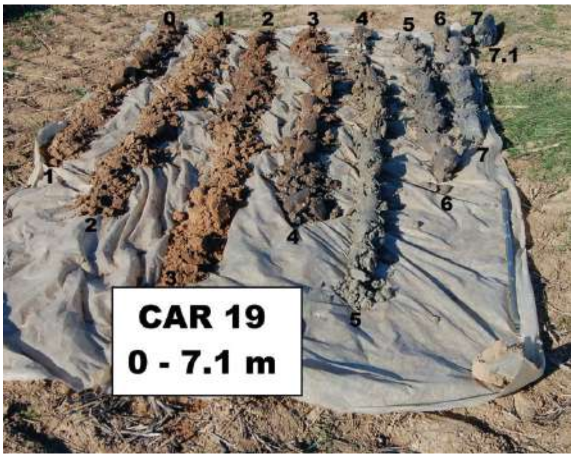

Figure 1. Example of a stratigraphic column obtained in a manual drilling. The numbers indicate the depth in meters

Figura 1. Ejemplo de columna estratigráfica obtenida en una perforación manual. Los números indican la profundidad en metros

used. The Eijkelkamp sampler is ideal for sampling loose clayey, silty and, in areas without groundwater, also sandy sediments. It is simple and easily assembled, lightweight, robust and usable even in the smallest space. The difficulties arise when drilling sandy layers with groundwater and layers of gravel and rock.

By using the device by two people, depths of 12-13 m can be reached, although greater depths can be reached with a three people team. The 10 cm diameter augers fill about 700 cm^3 of sediment, a sufficient amount of sample material for both sedimentological and paleontological research. With this diameter, which is relatively large for a sedimentological sampler, the possibility of obtaining significant fragments of anthropogenic material, especially ceramic fragments, in the sample increases (Schulz, 1988; Hoffmann, 1988; Arteaga and Hoffmann, 1999) (figure 1).

Mechanical drilling

This technique is used to drill archaeological layers, harder sediments and sediments under anthropic layers, when these are too hard to penetrate with the manual sampler, as is the case of historic urban centres (Arteaga et al., 2001a and b) or, in our study area, the areas affected by contemporaneous debris dumping.

Figure 2. Example of mechanical drilling in progress

Figura 2. Ejemplo de perforación mecánica

This sampler is also used when it is necessary to drill into sandy sediment combined with groundwater, layers with gravel or rock, or relatively soft pre-Holocene layers. In these cases, we have used a percussion window sampler (*Rammkernsonde*) from the firm Stitz (Germany), powered by a gasoline or an electric hammer, that allows us to obtain samples from 1 to 2 m long, with diameters ranging from 36 to 80 mm. As a general rule, the harder the sediment to be drilled, the smaller the diameter of the sampler to be used, starting the drilling with the widest possible diameter. On the other hand, if the sediment is too loose due to the presence of water and sand, it is also advisable to use a small diameter (figure 2).

Borehole Location Criteria

After surface delimitation of the Holocene sediments of the alluvial plains, boreholes are located, as much as possible, in areas that are assumed to have been low-energy water bodies in the past. Drilling in the vicinity of rivers is avoided due to the coarse materials that appear there. Drilling coarse

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sediments of ancient river meanders cannot, in general, be avoided, as ancient meanders cannot always be detected on the surface. Fossil meander terraces are rarely shown in alluvial plains, as these are covered by alluvium and erosive sediment from palaeoterraces (Hoffmann, 1988: 18). Satellite and aerial photographs can sometimes help locate these buried palaeomeanders.

Of particular interest are the lateral sinuosities of the river valleys. From a morphological point of view, ideal conditions for the formation of peatlands exist there, separated by sand bars or river sediments, and the analysis of changes in the vegetal landscape that can be provided by the pollen contained in the peat profiles is of primary interest. Apart from that, these side valleys, which are not normally crisscrossed by any streams, usually do not hide any obstacles to drill in the form of river gravels and are therefore good for drilling (Hoffmann, 1988: 19).

Based on the comparison of the stratigraphies obtained in several boreholes grouped in profiles parallel and perpendicular to the valley or bay investigated, it is possible to begin the reconstruction of the siltation process of the basin under study, thus establishing "the objective bases for the progressive monitoring of changes in the coastline" (Arteaga and Hoffmann, 1999: 24. The translation is mine).

Another criterion for the location of boreholes is the location of archaeological sites, with the aim of analysing the interspersion of layers produced by slope erosion and potentially containing archaeological material with marine, estuarine, marsh or alluvial sediments. Archaeological materials transported by slope erosion and interspersed between Holocene sediments are of great importance in dating the stratigraphic sequence of siltation (Schulz, 1988; Hoffmann, 1988; Arteaga and Hoffmann, 1999).

After drilling, the longitude, latitude and height coordinates of the boreholes are measured with a precision GPS with respect to a reliable topographic point, with the objective of ordering and comparing the extracted sediments in relation to sea level. This measurement in extent and depth is of great importance, since it allows us to distinguish the subsidence and uplift of the land for seismic and tectonic causes from the eustatic variations of sea level (Schulz, 1988; Hoffmann, 1988; Arteaga and Hoffmann, 1999). The batimetries of the permanent water coverage facies (identified as such from the reducing colour of the sediments) are calculated in relation to the current sea level, since this has not varied substantially in the study area with respect to the Holocene transgressive maximum (Schulz et al., 2004; Goy et al., 1996; Brückner and Radtke, 1990), including the bay of Cádiz (Dabrio et al., 1999).

Furthermore, no evidence of Holocene tectonic uplift of subsidence has been documented in the available literature on the Guadalquivir alluvial plain north of Coria del Río. As a contrast, a strong neotectonic subsidence has been proposed between around 4000 and 2000 cal BP in a sector of the palaeoestuary near the present-day Guadalquivir mouth in the Gulf of Cádiz (Rodríguez Ramírez et al., 2014).

In the field work that constitutes the empirical basis of this research, the measurements have been made with a Trimble precision GPS. These measurements refer to the geographical 0 of the Andalusian Positioning Network, whose accuracy has also been verified by measuring the coordinates of Barros geodesic point, located at the coordinates X: 229498, Y: 4152809, Z: 36.813 m (European Datum 1950, zone 30S), which coincided exactly with the GPS measurement, with an error of less than 3 cm.

Sediment description

During each drilling, the extracted sediments are arranged in the same order on a plastic sheet spread on the ground. Thereby, the stratigraphical sequence is reconstructed on the surface. This allows, after each drilling, the photograph and observation of the stratigraphic column. Apart from the macroscopic analysis of the sediments, they are described and sampled for further sedimentological and micro-palaeontological analysis in the laboratory. Along with the granulometry, the colour of the sediment is also recorded, which is the decisive key that informs both about the geochemical environment at the time of deposition and about the geochemical transformation processes that have taken place since then. In addition, chemical precipitation such as calcium carbonate and gypsum are recorded in the field, as well as fragments of charcoal, plant remains, shells of bivalves and snails, pottery sherds, construction material, wood, etc. (Schulz, 1988; Hoffmann, 1988; Arteaga and Hoffmann, 1999).

3.3. Laboratory techniques

3.3.1. Palaeontological techniques

For the reconstruction of the depositional milieu of Holocene sediments, the biogenic components of the sediment are analysed. Since the living environment of many inhabitants of marine, brackish and fresh waters is known, conclusions can be drawn from its presence about the depth, temperature, salinity, amount of oxygen and transparency of the water. The conservation status of fossils also provides information on sedimentation conditions, especially the energy of currents. Of particular interest is the criterion of the autochthony or allochtony of the sediment investigated, since redeposited sediments can be interpreted only in a very vague way (Hoffmann, 1988: 21; Arteaga and Hoffmann, 1999: 27).

In our study area we have decided to collect in the field selected samples of 700 cm^3, depending on the colour of the sediment and, sometimes, on the presence of macrofossils observable to the naked eye, especially from the permanently submerged and intertidal transition facies, which were the ones that most interested us in order to know the ecological conditions of the aquatic environments and, through the fragments of biogenic remains (preferably wood and charcoal), date the evolution of the aggradation and progradation processes.

Thus, 22 samples of 700 cm^3 from 11 boreholes have been sieved in a column with 4-, 2-, 1- and 0.5- mm mesh sieves, detecting the following mollusc taxa: bivalves of the *Cardiidae* family and the species *c.f. Scrobicularia plana,* and the gastropods *Hydrobia* sp., *Bulinus* sp., *Radix balthica, Melanopsis* sp., *Cecilioides c.f. acicula* and *Vertigo* sp.

The taxonomic classification of macrofossils has been carried out on the basis of specialized literature and reference websites such as <http://species-identification.org/> (not available any more), <http://www.marinespecies.org/ and http://www.animalbase.org/>.

Some fragments of a bivalve mollusc detected in permanently submerged sediment at -0.1 m a.s.l. in borehole CAR 21, in front of the settlement of Cerro Macareno (founded at the Phoenician-Tartessian period), could not, due to their degree of fragmentation and erosion, be identified taxonomically, so they were sent for analysis to the Stable Isotope Laboratory of the Faculty of Sciences of the Autonomous University of Madrid. The values of 0.81 for $\delta^{13}C$ and 1.83 for $\delta^{18}O$, based on the international marine standards V-PDB (Vienna Pee Dee Belemnite) for carbon-13 and V-SMOW (Vienna Standard Mean Ocean Water) for oxygen-18, whose δ value is 0, clearly indicate a marine origin for this bivalve.

Half of the fragments of the same bivalve was sent for AMS dating to the Beta laboratory (Miami, USA), which yielded a result of 3197-2829 cal BP at 2 sigma range (1248-880 cal BC). The mean radiocarbon date is intercepted by the calibration curve at 1050 cal BC. The marine reservoir effect has been calculated, according to the recommendations of Soares, 2015, in −108 ±31. The calibration was made with the program Calib. Rev. 8.1., with the calibration dataset Marine 20.14c. Due to the excessive margin of error of this date, it should be taken as a mere guideline while waiting for new dating to be made.

No microfossil analyses have been carried out for this work due to budgetary constrains, although in future research this technique will have to be applied where it is necessary to refine the data provided by macrofossils. Thus, selected samples have been reserved for this purpose.

Finally, both macro- and microfossils must be photographed, the latter using the electron microscope.

For the photograph of the smallest macrofossils, from sub-centimetre to millimetre size, we used a USB digital microscope of up to 500x magnification. For the observation of the samples once they have been sieved and dried, we have used a binocular optical microscope of up to 40× magnification, through which photographs have also been taken.

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Figure 3. Sample of plant matter at −5.05 m a.s.l. (borehole CAR 8)

Figura 3. Muestra de materia vegetal a −5,05 m s.n.m. (perforación CAR 8)

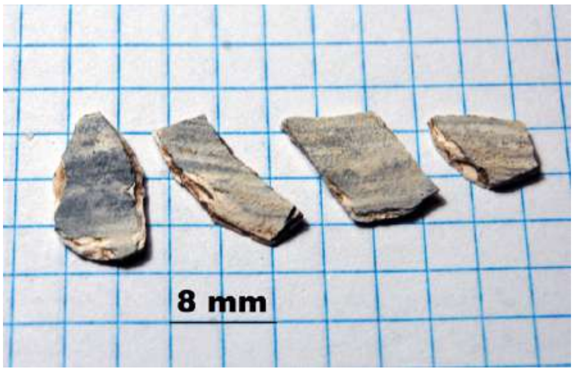

Figure 4. Marine bivalve shell fragments documented at −0.1 m a.s.l. in borehole CAR 21

Figura 4. Fragmentos de conchas de bivalvos marinos documentados a −0,1 m s.n.m. en la perforación CAR 21

3.3.2. Dating techniques

Radiocarbon dating

5 dates have been obtained with the AMS technique (accelerator mass spectrometry) for my doctoral thesis project in the area under study, in the laboratories Beta Analytic (Miami, USA) and Leibniz Labor für Altersbestimmung und Isotopenforschung (Kiel University, Germany) (figures 3 and 4).

Archaeological dating

Archaeological dating is usually much more precise, based on the materials provided by lateral erosion, which would cause the fall of these archaeological materials from sites near the coastline, especially at those points where the sediments eroded from the archaeological sites are deposited interspersed with marine, estuarine or alluvial sediments. The comparison of the archaeological evidence obtained in the boreholes realized in the contact zones between the alluvial sediments and the archaeological layers is decisive, since it is possible to analyse, as we have seen, the direct stratigraphic relationship between the historical soils and the sediments, with the aim of interpreting the relationships between natural and historical processes (Arteaga et al., 1985; Arteaga, 1988; Schulz, 1988; Arteaga and Hoffmann, 1999).

Archaeological dating has been used to precise the chronology of the stratigraphic sequence off the coastline of Italica, based on the record of ceramic materials included in the sediments of the permanently submerged, intertidal transition and alluvial plain facies, combined with radiocarbon dating of a wood fragment, which gave a result of 167-36 cal BC (Arteaga et al., 2015).

However, this date must be corrected with the new dating of the samples obtained in a long borehole (19 m deep) that we made in collaboration with the German Archaeological Institute, the Autonomous University of Madrid and the University of Kiel, whose results, still unpublished, indicates an even more recent date (Late Roman Empire) for the sediments dated in the previous works. The occurrence of older eroded materials in younger sediments can lead to wrong dating (which is what happened here). To solve this problem, numerous dates must be obtained throughout the stratigraphy.

In front of Cerro Macareno, the erosive presence of pottery and mortar has helped to contextualize the radiocarbon date of the intertidal transition facies (105 cal BC-65 cal AD) at a time probably after the abandonment of the site, archaeologically dated around the end of the 1st century BC (García Fernández, 2020; García Fernández et al., 2022).

4. Geographical and geological context

The study area, the Holocene alluvial plain of the Guadalquivir River at Seville (*Vega de Sevilla*), is included, together with the Guadalquivir valley, in the so-called Ibero-Moroccan Gulf, defined by the French geographers Jean-René Vanney and Löic Ménanteau (Vanney and Ménanteau, 2004), where clear parallelisms, produced largely by the Alpine orogeny, are observed between the two shores of the Strait of Gibraltar. The Guadalquivir valley constitutes a Cenozoic foreland sedimentary basin, with an ENE-WSW orientation, delimited to the north by the Palaeozoic massif of Sierra Morena and to the south by the Baetic mountain ranges (specifically olistostromes with chaotically disposed Mesozoic and Cenozoic materials from the Sub-Baetic system) (Sierro and Zazo, 2004). The Guadalquivir valley presents many similarities with the Sebou river basin, in Morocco.

The sediments of the Holocene transgressive palaeoestuary under study are below the deposits of the Guadalquivir River Holocene alluvial plain: the Vega or Ribera.

The geomorphological units bordering the Holocene alluvial plain and, therefore, the palaeoestuary, are, to the west, the littoral and marine tertiary formations of the Aljarafe Plateau and El Campo de Gerena, which present, especially the Aljarafe, a very steep slope in the limit with the alluvial plain.

The Aljarafe Plateau, which reaches 185 m a.s.l. as maximal height (between 40 and 100 m a.s.l. in the vicinity of the palaeoestuary), is formed mostly by calcareous sandstones, sands, yellow silts and marls: sedimentary formations characteristic of a coastal environment dated between the Messinian (last age of the Miocene epoch) and the Lower Pliocene. At the lowers heights of the eastern flank of this plateau, a fringe of blue marls, indicative of a deep marine environment (basin) emerges, also dated towards the Miocene-Pliocene transition, according to the Spanish Geological Survey (Instituto Geológico y Minero de España, IGME), although stratigraphically prior to the coastal formations (Mayoral and González, 1986-1987). South of the Aljarafe, on the northern limit of the Guadalquivir marshes and west of the Strait of Coria, calcarenites, sands and yellow silts characteristic of the continental shelf are recorded. These formations are dated between the Upper Pliocene and the Lower Pleistocene, as well as the deltaic fans, coastal bars and estuaries composed by gravels, sands, silts and locally marls which also appear in this area.

El Campo de Gerena, north of the Aljarafe, constitutes a landscape formed by gentle hills that do not usually exceed 40 m a.s.l. near the palaeoestuary, where erosion (Drain, Lhénaff and Vanney, 1971) has exposed the basin blue marls of the Messinian (figure 5).

To the north and east the alluvial plain is delimited by Pleistocene fluvial terraces, whose contact surface with the Holocene alluvial plain is much smoother and sometimes imperceptible. The terrace that forms this shore of the Holocene transgressive palaeoestuary is the low terrace T13 (Upper Pleistocene), defined by professor Rafael Baena (Baena, 1993; Baena et al., 2014) and studied by this researcher in the locations of "Los Rosales", "Brenes" and "San José de la Rinconada". A first approximation to the contact between the outcrop of this terrace and the Holocene sediments of the alluvial plain can be obtained from the analysis of the colour aerial photography (the soils of the Pleistocene terrace are usually of a typical red colour and the ones of the Holocene alluvial plain are of a greyish brown colour) and from the analysis of topography.

The T13 terrace, where the left bank of the Guadalquivir River practically fits from the toponym "Cerrado del Río", about 3 km north from the urban area of San José de la Rinconada, emerges from 13 m a.s.l. and reaches, according to Baena et al., up to 18 m a.s.l., having a thickness of more than 8 m and being made up of cemented gravel pavements covered at the top by sands and fine sediments 1.5 to 2 m thick (Baena et al., 2014: 113). Near the palaeoestuary, lithic industry of the Middle Palaeolithic has been documented in this formation in the profiles "Brenes" and "San José Cuartelillo" (Baena et al., 2014: 113).

The area under study itself, the Holocene alluvial plain, constitutes a territory of about 30 km long and between 4 and 5 km wide, which has as its main vertices, from south to north and from west to east, the towns of Coria del Río, San Juan de Aznalfarache, Camas, Santiponce, Torre de la Reina (La Algaba), Alcalá del Río, San José de la Rinconada, Sevilla and the ancient city of Orippo (Torre de los Herberos, in the municipal area of Dos Hermanas).

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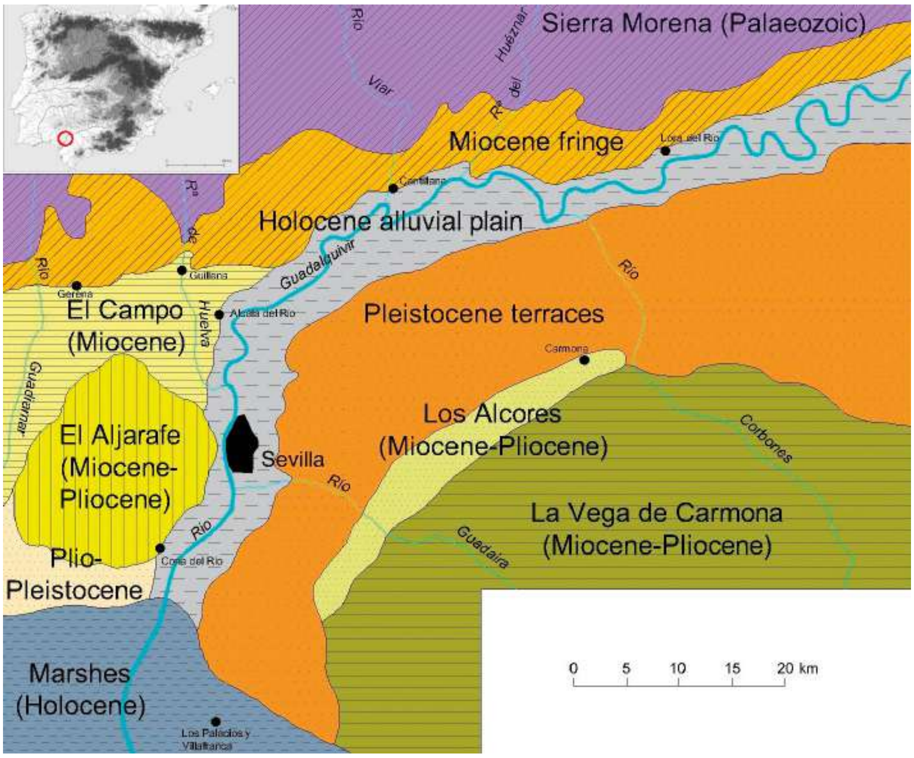

Figure 5. Geomorphological units of the Lower Guadalquivir, modified after Drain, Lhénaff and Vanney, 1971: fig. 10

Figura 5. Unidades geomorfológicas del Bajo Guadalquivir, modificado a partir de Drain, Lhénaff y Vanney, 1971: fig. 10

5. Research precedents

The most important precedent of my doctoral thesis is the *Proyecto Geoarqueológico de las Marismas del Guadalquivir* (*Guadalquivir Marshes Geoarchaeological Project*) (Arteaga and Roos, 1992; 1995; 2007; Schulz et al., 1992; 1995; Arteaga, Schulz and Roos, 1995; Arteaga et al., 2016a). This project, in addition to delimitate the huge inner marine gulf (*The Guadalquivir Gulf*) that was generated by the Holocene transgression in the territory currently occupied by the Guadalquivir marshes, obtained records of the transformation of the natural environment on a regional scale, due to the role as collector of this ancient gulf in relation to the Guadalquivir basin. Other authors (Zazo et al.,1994; Goy et al., 1996; Zazo et al., 2008; Rodríguez Ramírez et al., 1996; Ruiz et al., 2010; Rodríguez Ramírez et al., 2014) prefer to call it estuary or palaeoestuary. We prefer to call it gulf because of its huge size (around 50 km from west to east and 57 km from northeast to southwest) and greater depths, in order to diferenciate it from the much narrower palaeoestuary (4-5 km wide) northeast from Coria del Río, which is the object of this article.

The analysis of the sediments that silted up this palaeogulf (see figure 5) documented incipient erosive processes from the 4th millennium BC (dated circa 3300 BC from a sample of wood found in marine sediments documented 3.5-3.6 m deep in borehole SEV-115, located in the shore near Lebrija), intensified in the 3rd millennium BC as a consequence of the agricultural and livestock farming exploitation processes of the soils of the basin by the initial classist society (Arteaga, Schulz and Roos, 1995: 111-115).

This erosion, according to Arteaga, Schulz and Roos, resulted in the gulf in the accumulation of sediments in an inner delta that was forming in front of the *Strait of Coria* around the 3rd millennium BC. This inner delta was detected in borehole SEV-410, located around 5 km far from the shore and dated circa 2680 BC from a vegetal remains sample found in intertidal sediments at a depth of 2.1-2.2 m (Arteaga, Schulz and Roos, 1995: 111-114). In borehole SEV-610, located much closer to the ancient shore (around 100 m) near Los Morenos (10 km southwest from La Puebla del Río), marine sediments documented 4.4-4.8 m deep were dated circa 2380 BC from a shell sample (*Cardium* sp.) (Arteaga, Schulz and Roos, 1995: 114-115). Another 2 shell samples (*Cardium* sp. and *Ostrea* sp.) found in marine sediments from borehole SEV-308 (8-8.3 m) provided 3rd millennium BC dates (2390-2380 BC) too, in a location also close to the ancient shore of the gulf near Los Palacios y Villafranca (Arteaga, Schulz and Roos, 1995: 115).

2 more samples from intertidal and marine sediments yielded dates of the second half of the 2nd millennium BC. The first one was a shell sample (*Cardium* sp.) obtained from an intertidal layer documented 0.5-0.8 m deep in a profile (Perfil A) of the east bank of the Guadalquivir River at the *Strait of Coria* (northeast from borehole SEV-410). This sample gave a date of circa 1280 BC (Arteaga, Schulz and Roos, 1995: 115). The second dating was made on several shells found in marine sediments recorded 4.3-4.4 m deep in borehole SEV-318, located in a very closed palaeobay near Las Cabezas de San Juan, around 380 m far from the ancient shore. This sample gave a date of circa 1220 BC.

All these dates of the 3rd and 2nd millennium BC are only consistent with each other if an interior delta was forming in front of the *Strait of Coria* short after the Holocene transgressive maximum, and would indicate that marine conditions continued in a great part of the gulf at least until the end of the Bronze Age. However, most of these dates are isolated in the sediment cores (except 2 from SEV-308, almost from the same layer), so it could be objected that some of the materials, like wood and vegetal remains, could have been eroded from older soils, transported and redeposited in younger sediments. I think that the shells of marine species collected from these cores are less likely to have been transported over a long distance (they were documented in primary position in very low energy sedimentation contexts), but obtaining well-dated new sediment cores (dating the different layers of each core) would help to correct the effects of possible reworked material, and therefore to test this interpretation of the fill process of the gulf, which seems correct and plausible to me.

In regard to the territory of the present-day Guadalquivir marshes, we must also mention the important works carried out since the 90s by the research teams led by Caridad Zazo Cardeña (Department of Geology of the Museo Nacional de Ciencias Naturales (CSIC)) and Antonio Rodríguez Ramírez (Huelva University), respectively. These teams focused in the area of the Doñana National Park, which includes the west bank of the mouth of the Guadalquivir River in the Atlantic.

The main results of the team led by Caridad Zazo were the identification and dating of a series of Holocene sand spits that closed the gulf generated by the Holocene transgression (these authors prefer to call it estuary or palaeoestuary) (Zazo et al.,1994; Goy et al., 1996; Zazo et al., 2008) and the investigation of the fill process of the palaeoestuary and of the landscape changes based on 2 long cores: Mari López (ML7) (Zazo et al., 1999) and Casa del Lobo (CL-S1) (Lario et al., 2002), drilled near the northern limit of the Doñana National Park. The Mari López core was the one analized with more detail, providing a date for the beginning of the Holocene transgressive formation of 5650 cal BP at 11 m deep. In the same core, a date of 3827 cal BP was obtained at 7.3 m deep, thus indicating a water depth for the Bronze Age of 4.8 m at this point.

The team led by Antonio Rodríguez Ramírez has also made very valuable contributions to the research of the Guadalquivir palaeoestuary, but, as we said, their data concentrate on the west bank of the Guadalquivir River within the limits of the Doñana National Park.

Some of their results include the indentification and dating of 6 progradation phases in the spits of Doñana and La Algaida (Rodríguez Ramírez et al., 1996), as well as the study of a long core (PNL) (Ruiz et al., 2010; Rodríguez Ramírez et al., 2014), drilled a bit further south, where the Holocene transgression was dated circa 6500-7000 BP at a depth of more than 20 m, being the oldest date for the Holocene estuarine formation 6543-6789 cal BP at 26.1 m deep (Rodríguez Ramírez et al., 2014: 130).

They have also identified emerged formations (sandy and shelly ridges, called *chéniers*) in the northwest area of the palaeoestuary (Rodríguez Ramírez and Yáñez Camacho, 2008; Rodríguez Ramírez et al., 2014), being the oldest ones in the

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Carrizosa-Vetalarena system (4071-4706 cal BP), and in the Mari López system (3534-4047 cal BP), also located at the northwest area of the palaeoestuary, but a bit more central than Carrizosa-Vetalarena. The rest of the emerged formations documented by these teams within the palaeoestuary (Las Nuevas and Vetalengua systems), located closer to the present-day mouth of the Guadalquivir in the Atlantic Ocean, were dated in the Middle Ages (from 7th century AD to 12th century AD), except a littoral strand detected in the Doñana spit and dated 1883-2152 cal BP (Rodríguez Ramírez et al., 2014: 130, 134).

Another important contribution of this team is the detection of a strong neotectonic subsidence south of the Torre Carbonero-Marilópez fault (its orientation coincides grosso modo with the Carrizosa-Vetalarena sandy and shelly ridges), dated from circa 4000 to circa 2000 cal BP. Since this date onwards the subsidence appears to have been dormant (Rodríguez Ramírez et al., 2014).

They have also detected 4 extreme wave events (EWEs) from the 3rd to the 2nd millennia cal BC, which have also played a role in the evolution of the palaeoestuary and in the human activities in this territory (Rodríguez Ramírez et al., 2015; López-Sáez et al., 2018). The younger of these high energy events (EWE-4), dated ~3185-3140 cal BP, coincides roughly with the date (3197-2829 cal BP) of the marine shell fragments documented in our borehole CAR 21. These shell fragments were registered in a high energy facies, made up of sandy silt and medium gravel. López-Sáez et al. consider EWE-4 as tsunamigenic. In their own words: "EWE-4 must have brought about large and catastrophic geomorphological changes throughout the southwest of the Iberian Peninsula" (López-Sáez et al., 2018: 72; Rodríguez Ramírez et al., 2015: 37).

We must also mention the multi-proxi palaeoenviromental study carried out by this team on the S1 core, drilled southwest of the Carrizosa-Vetalarena ridge system (López-Sáez et al., 2018). In this core the oldest date (4891-4347 cal BP) was obtained at 11 m deep. The results of the different analysis applied to the sediments of this core evidenced the beginning of anthropic influence from ~4900 cal BP onwards, during the Copper Age, and the interruption of human activities in this territory from ~4200 cal BP to ~3100 cal BP (Early and Middle Bronze Age). The anthropic impact resumed from ~3100 cal BP onwards (Late Bronze Age).

The Proyecto Geoarqueológico Puerto de Itálica (*Port of Itálica Geoarchaeological Project*; Arteaga et al., 2015), whose data are part of the original corpus of the research presented here, was carried out between 2010 and 2011 (with a pilot borehole in 2003) by the interdisciplinary team formed by Oswaldo Arteaga, Daniel Barragán, Anna-Maria Roos and Horst D. Schulz. The project had the collaboration of the archaeologist Daniel Arsenio Lara Montero in the pilot borehole from 2003 and the students Cristina Ávila Giménez and Antonio Rodríguez Santos in the field work in 2010 and 2011.

In this project, 20 boreholes were done in a stretch of coast about 3 km long, making a high-resolution map of the coastline of the Holocene transgressive maximum and also confirming the existence of a permanently submerged area in front of Italica, with water depths of more than 2.3 m by the time of the founding of the city (206 BC) (Arteaga et al., 2015). The chronology of the permanently submerged sediments in this area has turned out to be even younger within the Roman age at the depths documented in this project, due to the dates obtained in a deep borehole (19 m) made in 2022 in collaboration with the German Archaeological Institute, the Autonomous University of Madrid and the University of Kiel (these results will be published in another article). This area has been delimited through the field work that serves as the empirical basis for the doctoral thesis whose results are presented here, constituting the North sector of the Guadalquivir palaeoestuary generated by the Holocene transgression.

Taking the results of the *Guadalquivir Marshes Geoarchaeological Project* as a starting point, the research presented in this article focuses on the alluvial plain of the Guadalquivir River near Seville, whose sediments cover the ancient estuary that emptied into the *Guadalquivir Gulf* through the *Strait of Coria*. In this area another 37 boreholes were made between 2011 and 2013 for my doctoral thesis project in order to complete the delimitation of the Guadalquivir River palaeoestuary (figures 6, and 7).

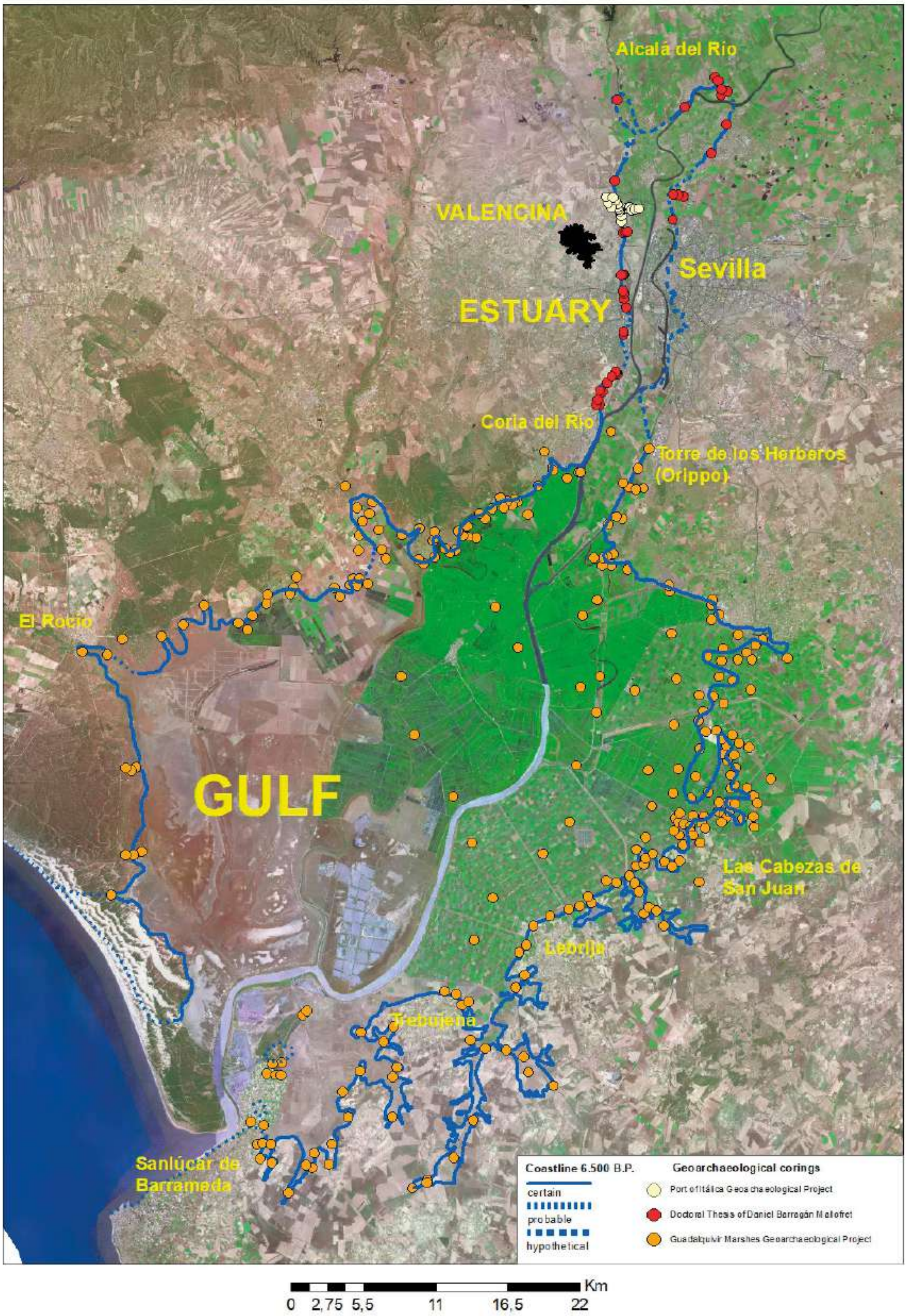

Figure 6. Guadalquivir palaeogulf and palaeoestuary c. 6500 BP on 2014 satellite image from Spot 5 (modified after Arteaga et al., 2016a: fig. 2)

Figura 6. Paleogolfo y paleoestuario del Guadalquivir c. 6500 BP sobre imagen de satélite de 2014 del Spot 5 (modificado a partir de Arteaga *et alii*, 2016a: fig. 2)

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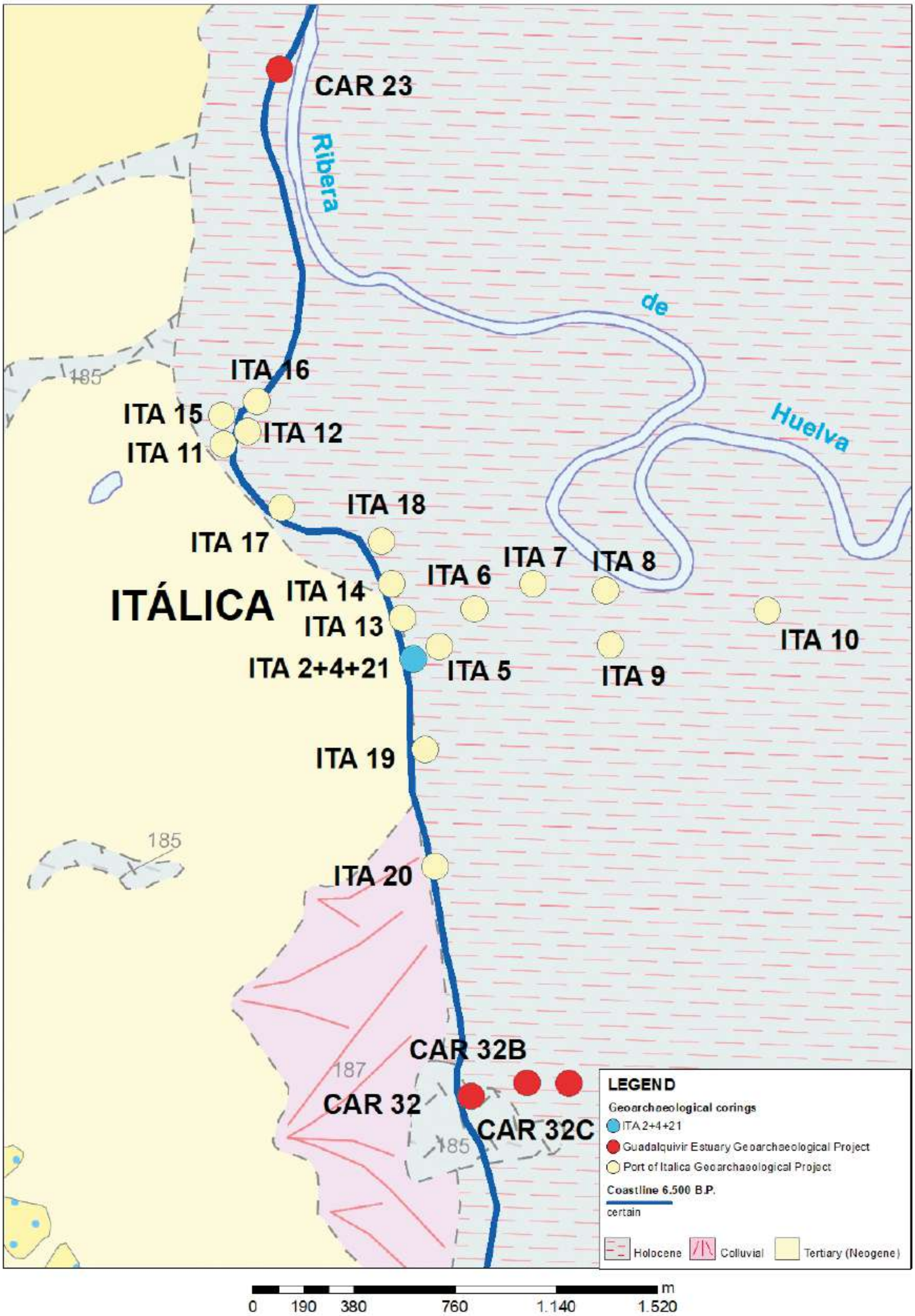

Figure 7. Coastline of c. 6500 BP off Italica (modified after Arteaga et al., 2016b: fig. 2)

Figura 7. Línea de costa *c.* 6500 BP frente a Itálica (modificado a partir de Arteaga *et alii*, 2016b: fig. 2)

6. Results

6.2. Sectorization of the Guadalquivir Estuary

6.2.1. Differences between the west and east shores

The palaeoestuary has been analytically divided into west shore and east shore, based on the different geological formations where the pre-Holocene reliefs that constitute them are modelled (figure 8).

The west shore is formed by the Tertiary (Neogene) slope of the Aljarafe plateau to the south, between Coria and the Pie de Palo stream (Santiponce) and, at a much lower height and with a much less steep slope, by the hills formed by blue marls of Campo de Gerena to the north, between Santiponce and the small alluvial plain of the Ribera de Huelva. At the eastern limit of this small alluvial plain there is a middle terrace of Pleistocene age, with blue marls resurfacing in the area around Alcalá del Río, to the northeast (figures 9 and 10).

The headwaters of the Guadalquivir palaeoestuary (Arteaga, Schulz and Roos, 1995; Arteaga and Ménanteau, 2004; Arteaga and Roos, 2007) have been located to the east of Alcalá del Río and they would be delimited by low Pleistocene terraces, similar to Rafael Baena's T13 (Baena and Díaz del Olmo, 1994; Baena et al., 2014). In this area, the Guadalquivir would flow into its estuary, we do not know if through a single channel or through several simultaneous channels at some point. We have detected possible palaeochannels to the northwest of this sector, in the stratigraphic profile formed by boreholes CAR 28, CAR 36 and CAR 37. In the interpretation of this profile, we can observe that the Pleistocene terrace (including a pre-Holocene palaeosol) has been eroded by 2 possible palaeochannels (maybe before the Holocene transgression), from which the one detected in borehole CAR 28 has a coarser filling. In the one detected in borehole CAR 37, a permanently submerged facies of medium-low energy was registered (figures 11 and 12).

The slope of the Aljarafe, as indicated above, is made up at the base of blue marls from the Messinian-Lower Pliocene transition and, above them, of calcareous sandstones, sands and yellow silts of the same chronology. This slope forms a cliff coastline where the greatest water depths have been documented in our boreholes, based on the thickness of the sediments of the low-energy permanently submerged facies, which we have not been able to cross in most of the boreholes with our light equipment.

Thus, more than 7 m of minimum water depth has been recorded east of Palomares del Río (CAR 13), more than 4 m south of San Juan de Aznalfarache (CAR 8), more than 3.6 m in front of El Carambolo (CAR 1B), and more than 4.7 m in front of Italica (ITA 2+4+21), to give a few examples (figures 13, 14 and 15).

The relief of the Messinian blue marls, which have emerged due to intense erosion perhaps since the Pliocene or Lower Pleistocene in the Campo de Gerena (according to Drain, Lhénaff and Vanney, 1971), is much less pronounced, although we can also observe, both in the field and in aerial photographs (especially those taken by the US Air Force in 1956), traces of possible palaeocliffs both southwest and northeast of Alcalá del Río. In the borehole carried out on the alluvial plain in front of this particular locality (CAR 25), the combination of sand and groundwater prevented us from reaching great depths below sea level (−0.45 m a.s.l.) with our drilling equipment, as the walls of the borehole began to collapse from a depth of 11 m below the surface. However, based on the calculated difference in height from the top of the possible cliff, at +18 m a.s.l. and about 100 m away, it is very likely that there was a great depth of water at this point. Until deeper boreholes are carried out, we can only propose this at the level of hypothesis (figure 16).

In the Headwaters sector, the sediment thickness of the permanently submerged facies documented in the boreholes decreases rapidly as we move to the northeast, going from 1.65 m (CAR 37) to 0.95 m (CAR 38) in 185 m distance, parallel to the rise in the height of the Pleistocene gravels at the bottom (from 0 to +0.7 m a.s.l.). These layers of gravel are reached in almost all boreholes of this subsector, indicating the proximity of the coastline and the palaeomouth of the Guadalquivir River, whose location we estimate to be about 250 m to the east of the CAR 38 borehole (figures 17 and 18).

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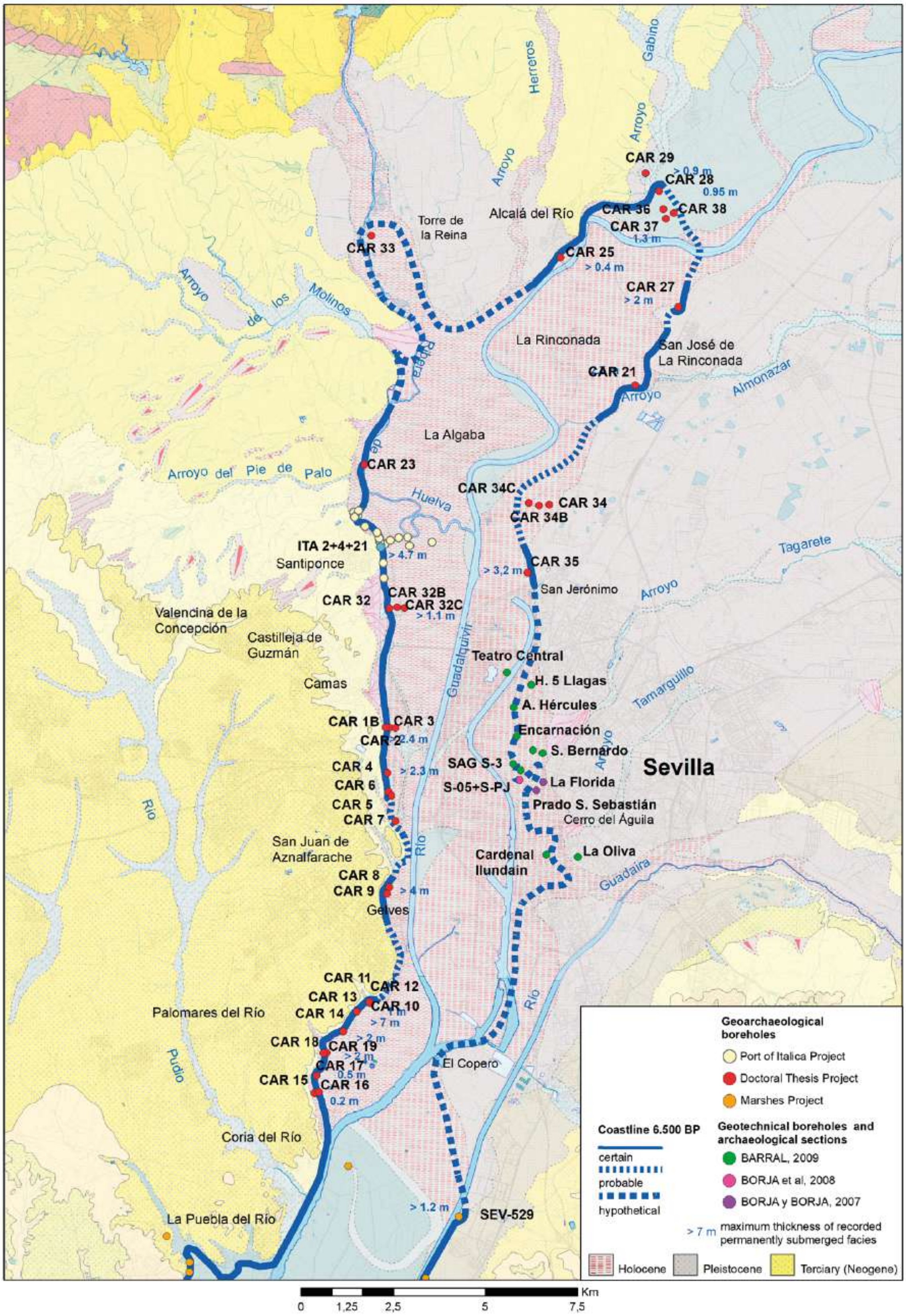

Figure 8. Coastline of the study area (c. 6500 BP) on the IGME geological map

Figura 8. Línea de costa de la zona de estudio (c. 6500 BP) sobre el mapa geológico del IGME

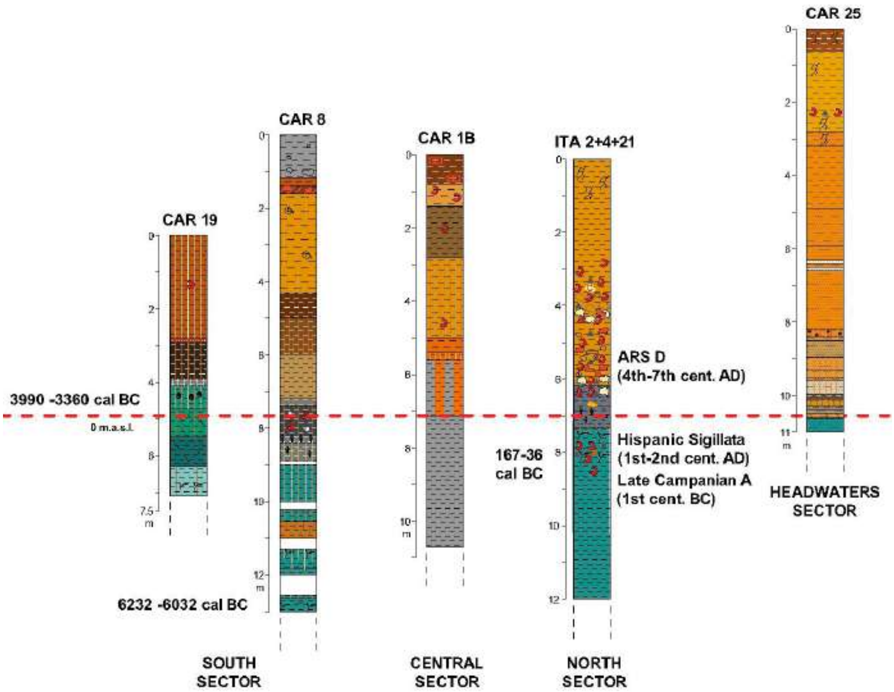

Figure 9. Borehole profile of the west shore of the palaeoestuary

Figura 9. Perfil de perforaciones de la orilla oeste del paleoestuario

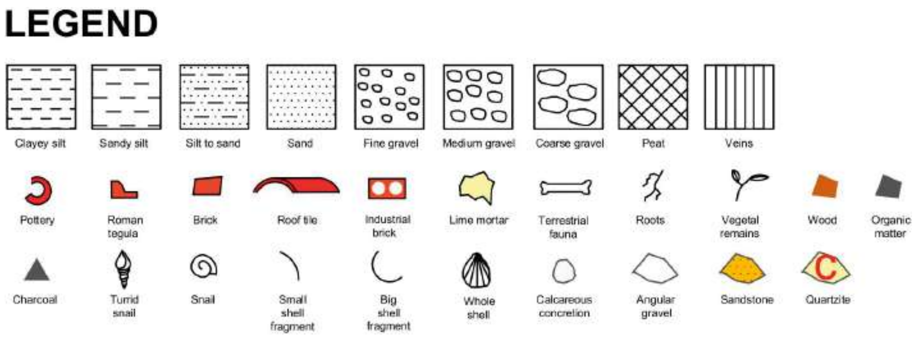

Figure 10. Legend of the simbols used in the stratigraphic diagrams

Figura 10. Leyenda de los símbolos utilizados en los diagramas estratigráficos

On the east shore of the palaeoestuary, the relief is formed by the lower Pleistocene terrace T13, whose contact with the alluvial sediments is much softer than on the west shore, making the delimitation of the coastline of the Holocene transgressive maximum more difficult.

In addition, the incision of fluvial channels hidden under the alluvial sedimentation has probably eroded the oldest estuarine sedimentation at several points (CAR 27, CAR 34C boreholes), depositing coarse materials that cannot be drilled with our light samplers, including the mechanical percussion samplers. Thus, the minimum depths of water documented (based on the thickness of the permanently submerged sediments) are much shallower than on the west shore, although sufficient for ancient navigation, such as the 2.7 m of CAR 21 (in front of Cerro Macareno), where gravels of the Pleistocene terrace were reached at −0.6 m a.s.l. (figures 19, 20 and 21).

The depth where Holocene sediments below sea level have been documented in CAR 27, which would reach more than −2 m a.s.l., cannot simply be extrapolated to the depth of the palaeoestuary, since it most likely corresponds to the incision of a later palaeochannel. At the Cortijo de Tercia (CAR 35),

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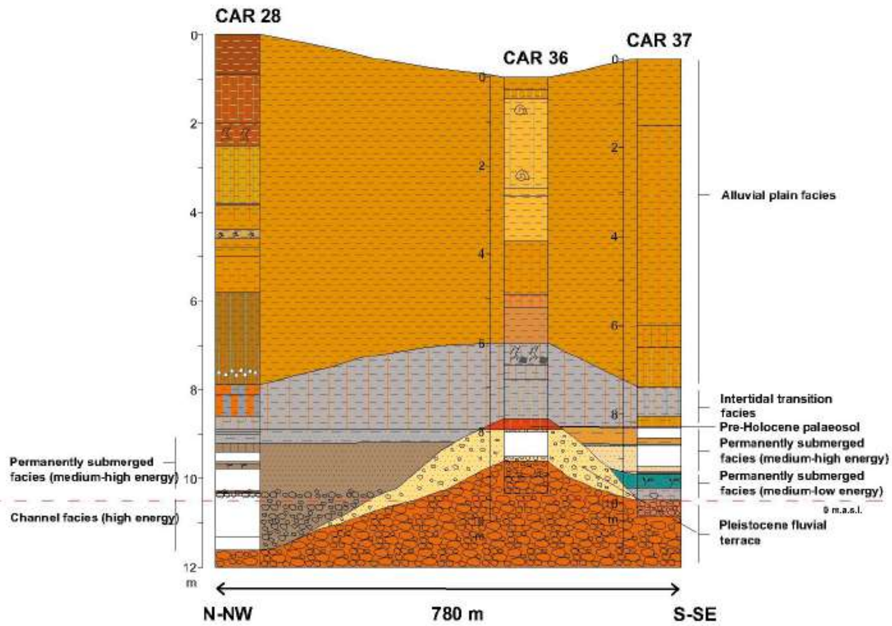

Figure 11. Stratigraphic profile formed by boreholes CAR 28, CAR 36 and CAR 37

Figura 11. Perfil estratigráfico formado por las perforaciones CAR 28, CAR 36 y CAR 37

north of the Sevillian district of San Jerónimo, we have documented a minimum water depth of more than 3.2 m (−2.9 m a.s.l.), which could indicate an increase in depth to the south on the east shore of the palaeoestuary, as has also been recorded in the geotechnical boreholes published by Francisco Borja and M.ª Ángeles Barral, among others, and carried out in the urban area of Seville. To give some examples, in the plaza de la Encarnación a stratigraphy of high-energy Holocene sediments (sands with fine gravel) was documented, reaching −12 m a.s.l., changing to clays with lamination at −1.65 m a.s.l. (Barral, 2009: 411) ; in the surroundings of the Cathedral of Seville there are also fine-grained Holocene sediments of reducing colour (bluish grey, grey) between −9 and +2 m a.s.l. (Barral, 2009: 192, 197, 198, 206-208, 210), as well as in calle San Fernando, where the depth of Holocene sediments reaches at least −5.5 m a.s.l., with reducing colours documented from that depth to 0 m a.s.l. (Borja et al., 2008: 91, 94) (figure 22).

Finally, at the southern limit of our study area, at the foot of the probable palaeocliff where the ancient city of Orippo stood, Rebecca von Lührte and Jan Schubert carried out the geoarchaeological borehole SEV 529 for the Guadalaquivir Marshes Geoarchaeological Project. In this borehole they documented a low-energy permanently submerged facies, composed of grey-blue silt with layers of fine sand between −1.2 and 0 m a.s.l., approximately, without reaching the bottom of the facies. This borehole would therefore delimit the coastline of the Holocene transgressive maximum at this point (Lührte, 1993; Schubert, 1993; Schulz et al., 1992; 1995).

6.2.2. South, Central, North and Headwaters Sectors

In addition to the differentiation between west and east shores according to the pre-Holocene relief and water depths, we have divided the palaeoestuary into 3 sectors based on the fossils detected in the samples collected in the boreholes, which provide an approximation to the ecological conditions of the sedimentation milieu, especially in terms of salinity percentages. With this criterion as a reference, we have differentiated 3 sectors: South, Central and North. In addition, we have differentiated a Headwaters sector between the meander of La Rinconada and the mouth of the Guadalquivir River in the palaeoestuary, based mostly on the height differences at the top of the permanently submerged facies between this sector and the North, Central and

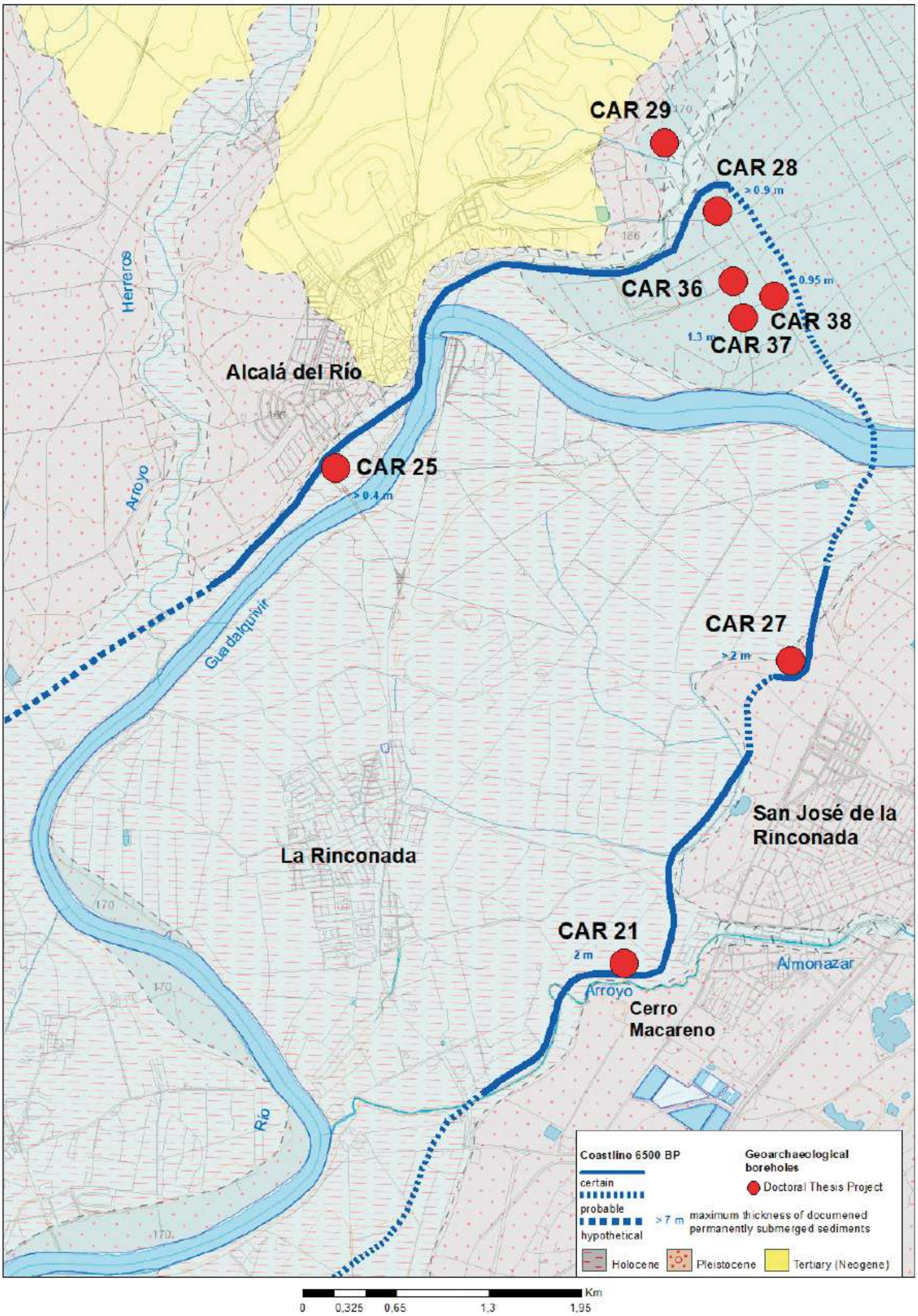

Figure 12. Headwaters sector on the IGME geological map

Figura 12. Sector de cabecera sobre el mapa geológico del IGME

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Figure 13. Probable palaeocliff at the northeast border of the Palaeocove of Coria-Gelves

Figura 13. Probable paleoacantilado en el límite noreste de la paleoensenada de Coria-Gelves

Figure 14. Samples of borehole CAR 1B (0 to 10.7 m deep)

Figura 14. Muestras de la perforación CAR 1B (0 a 10,7 m de profundidad)

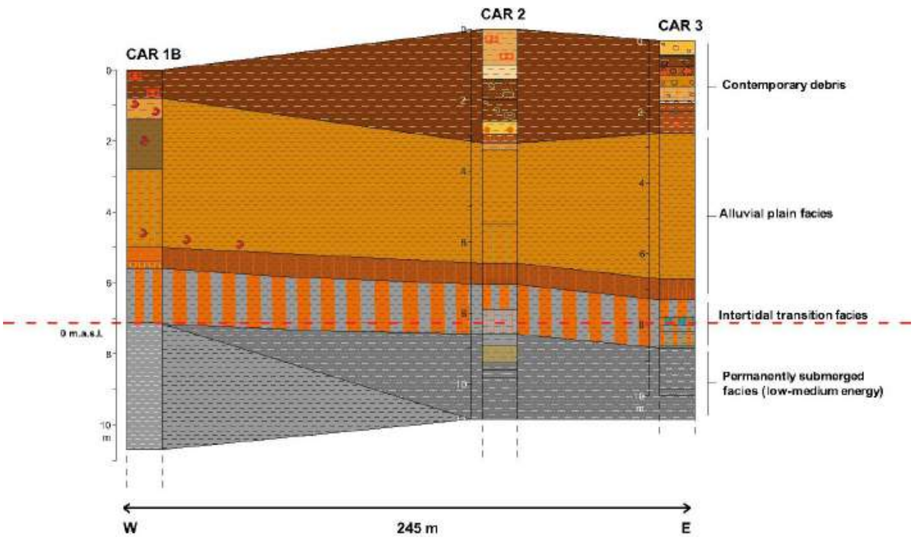

Figure 15. Profile formed by boreholes CAR 1B, CAR 2 and CAR 3

Figura 15. Perfil formado por las perforaciones CAR 1B, CAR 2 y CAR 3

Figure 16. Traces of possible palaeocliffs east of Alcalá del Río from the location of borehole CAR 38

Figura 16. Huellas de posibles paleoacantilados al este de Alcalá del Río desde la localización del sondeo CAR 38

South sectors. The meander of La Rinconada is most likely delimiting an island or deltaic formation at the confluence with the Ribera de Huelva, where the town of La Algaba is located (figures 23, 24 and 25).

On the west shore of the South sector, from Coria del Río to Cape of San Juan de Aznalfarache, marked by the elevated spur where the ancient settlement of OSSET (Cerro Chavoya or Cerro de los Sagrados Corazones) is located, we have detected, in the intertidal transition facies (between −1.5 and +0.8 m a.s.l.) of CAR 16, CAR 19 and CAR 8, fragments and whole shells of bivalves (*Cardiidae* and *c.f. Scrobicularia plana*) and microgastropods (*Hydrobia* sp.). These species are typical of brackish contexts and their size (especially that of bivalves, together with the thickness of their shells) decreases towards the north, which may be an indicator of the decrease in salinity in that direction. This west shore of the southern sector would be divided, from south to north, into *Palaeocove Coria-Gelves* and *Palaeocove of San Juan de Aznalfarache*, separated by the *Cape of Gelves*.

In the stratigraphic sequences from the city of Sevilla published by Borja and Barral (Borja and Barral, 2003, 2005; Borja et al., 2007, 2008; Barral, 2009), reference is also made to the presence of gastropods (often micro) and bivalves, especially in those located further south, between the Cathedral and San Fernando Street, which could indicate similar conditions also on the east shore (figures 26 and 27).

The western shore of the central sector, between the aforementioned Cape de San Juan de Aznalfarache and the industrial estate located between Camas and Santiponce, is characterized, in the samples collected in our boreholes, by the almost total absence of molluscs, both from brackish or fresh water environments, with the exception of one specimen of the gastropod *Bulinus* sp., a freshwater species with relative tolerance to slightly brackish waters, documented in the permanently submerged facies of CAR 32C (figure 28).

In the North sector, between this industrial estate and the meander of La Rinconada, freshwater gastropods with tolerance to slightly brackish waters, such as *Radix balthica,* are recorded in the intertidal transition facies of the ITA 2+4 borehole, and others typical of totally fresh and clean waters, such as the genus *Melanopsis*, on a high-energy permanently submerged facies from the ITA 8 borehole. Regarding this genus, we have doubts about the chronology of the sedimentation milieu where it is documented, since it could correspond to a channel incised in the alluvial plain much later than the Holocene transgression. Unfortunately, we do not have any AMS date from this borehole.

Finally, terrestrial gastropods from humid environments near flooded areas have been detected in the Headwaters sector, specifically *Cecilioides c.f. acicula* and *Vertigo* sp., presumably carried by the waters and deposited in a permanently submerged layer of the CAR 38 borehole (figure 29).

The exception to the predominantly freshwater panorama of the Headwaters sector is constituted by several fragments of a bivalve shell somewhat eroded on its dorsal face, documented at −0.1 m a.s.l. in the CAR 21 borehole (northeast shore, in front of the settlement of Cerro Macareno, founded around the 8^{th} century BC). This shell has been identified as marine in the analysis of stable isotopes $\delta^{13}C$ and $\delta^{18}O$ and dated by AMS between 1248 and 880 cal BC. These results could indicate brackish to marine conditions for this period in that area, although we prefer to be cautious, as this is an isolated datum.

Moreover, the date presents the problems of the marine reservoir effect and the strong variations in atmospheric ^{14}C in the first half of the

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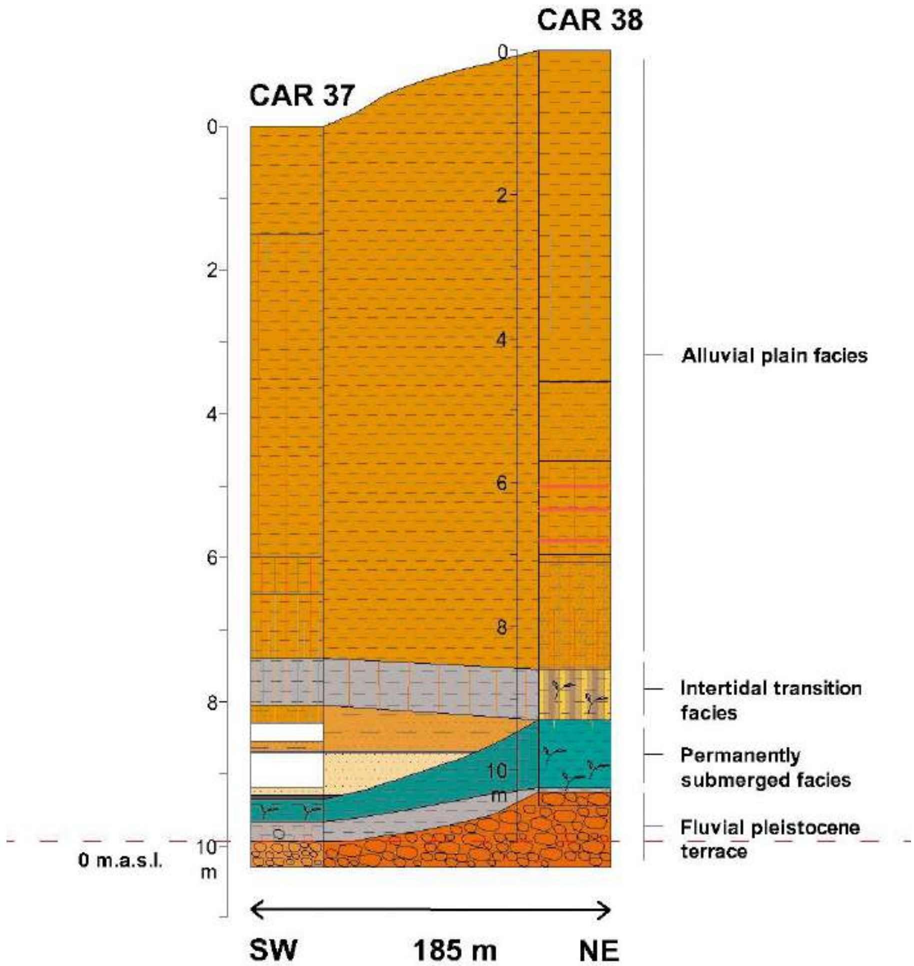

Figure 17. Stratigraphic profile formed by boreholes CAR 37 and CAR 38

Figura 17. Perfil estratigráfico formado por las perforaciones CAR 37 y CAR 38

1st millennium BC. The mean of the measured date curve crosses the calibration curve at 1050 cal BC, but it is a result we cannot trust, although the following date in that same core (1 m above), gives a result of 515-390 cal BC, so the shell would have been deposited at least before the beginning of the 4th century BC. Another doubt is raised by the erosion of its dorsal face, which could indicate the transport of the shell, which may have been dragged into the water from an archaeological layer (a context of consumption, for example) of the nearby settlement, but there is no evidence so far of occupation of the site before de 8th century BC. Besides, this date coincides roughly with the date of an extreme wave event detected in the Doñana National Park (EWE-4) and interpreted as a tsunami (Rodríguez Ramírez et al., 2015; López-Sáez et al., 2018). Could this shell and the sediment where it was found (sandy silt with fine to medium gravel) have been transported by this tsunami? Another possibility would be the existence of saline to brackish conditions on that shore of the palaeoestuary in the Late Bronze Age, which seems strange to me, considering the proximity of the mouth of the Guadalquivir River. However, an estuary is a very complex environment, where synchronous variations in salinity can occur, as well as daily and seasonal oscillations. Additionally, the freshwater gastropods from the ITA 2+4 borehole dated on the basis of the ceramic fragments and the C14 date obtained 1.1 m below (167-36 cal BC) would correspond to a post-high Roman imperial period context, well after the 5th century BC, which is the ante quem term for the bivalve age of CAR 21.

The height differences at the top of the permanently submerged facies between the South, Central and North sectors and the Headwaters sector of the

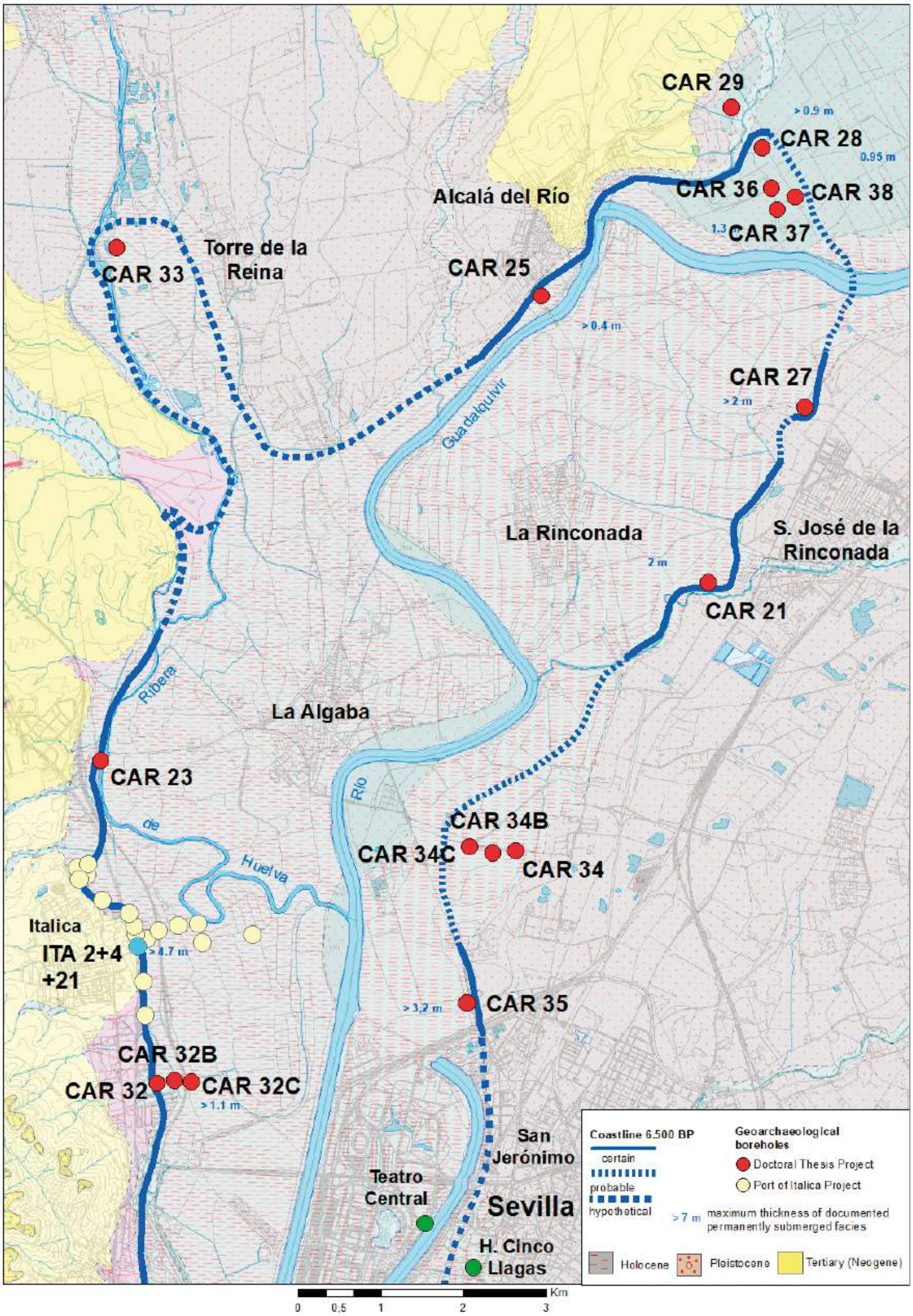

Figure 18. Coastline of c. 6500 BP in the North and Headwaters sectors on the IGME geological map

Figura 18. Línea de costa c. 6500 BP en los sectores Norte y Cabecera sobre el mapa geológico del IGME

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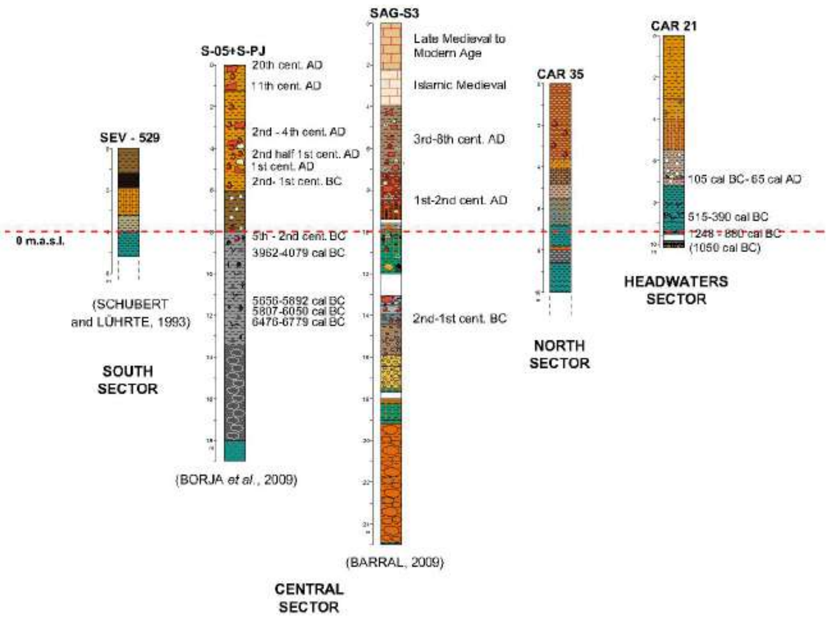

Figure 19. Borehole profile of the east shore of the palaeoestuary

Figura 19. Perfil de perforaciones de la orilla este del paleoestuario

Figure 20. Samples from borehole CAR 21 (0 –9.5 m deep)

Figura 20. Muestras de la perforación CAR 21 (0 –9,5 m de profundidad)

Figure 22. Samples from borehole CAR 35 (0 –10 m deep)

Figura 22. Muestras de la perforación CAR 35 (0 –10 m de profundidad)

Figure 21. Contact between the bottom of the Holocene permanently submerged facies (to the left) and the Pleistocene gravels (to the right) at 10 m deep in borehole CAR 21

Figura 21. Contacto entre el fondo de la facies permanentemente sumergida del Holoceno (a la izquierda) y las gravas del Pleistoceno (a la derecha) a 10 m de profundidad en la perforación CAR 21

palaeoestuary could indicate, as a preliminary hypothesis, the existence of two distinct hydrological areas and the division of the palaeoestuary into two sectors: one, to the south (South, Central and North sectors), in closer altimetric consonance with the tidal oscillations, with brackish conditions at least in the South sector based on the molluscs documented in the intertidal transition facies (*Hydrobia* sp., *Cardiidae* and *c.f. Scrobicularia plana*); and another, to the north (Headwaters sector), where the water surface is slightly raised probably due to hydrological factors where the dynamic tide and the contribution of river flows must play an important role, producing a predominantly freshwater context,

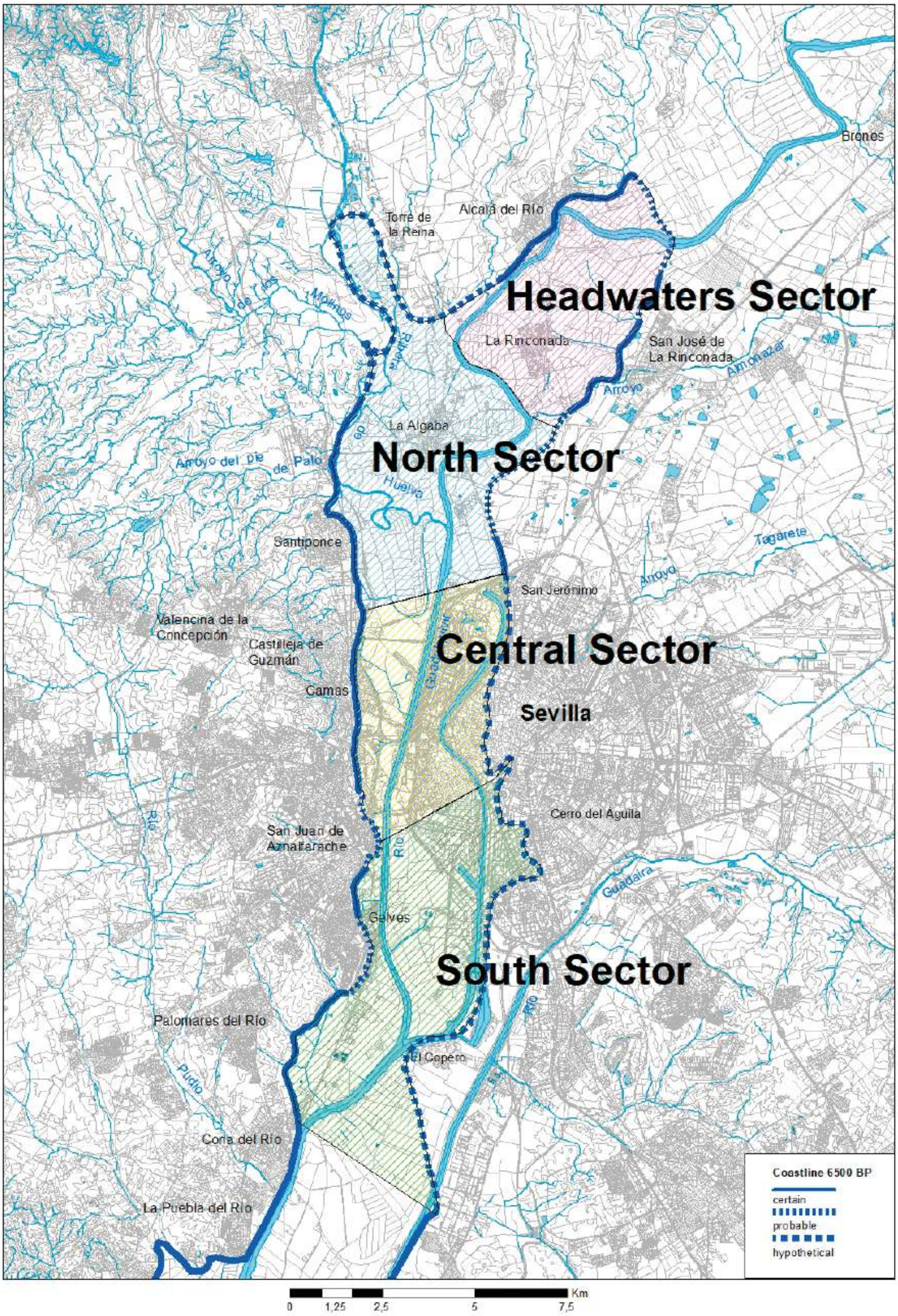

Figure 23. Sectors of the Guadalquivir palaeoestuary

Figura 23. Sectores del paleoestuario del Guadalquivir

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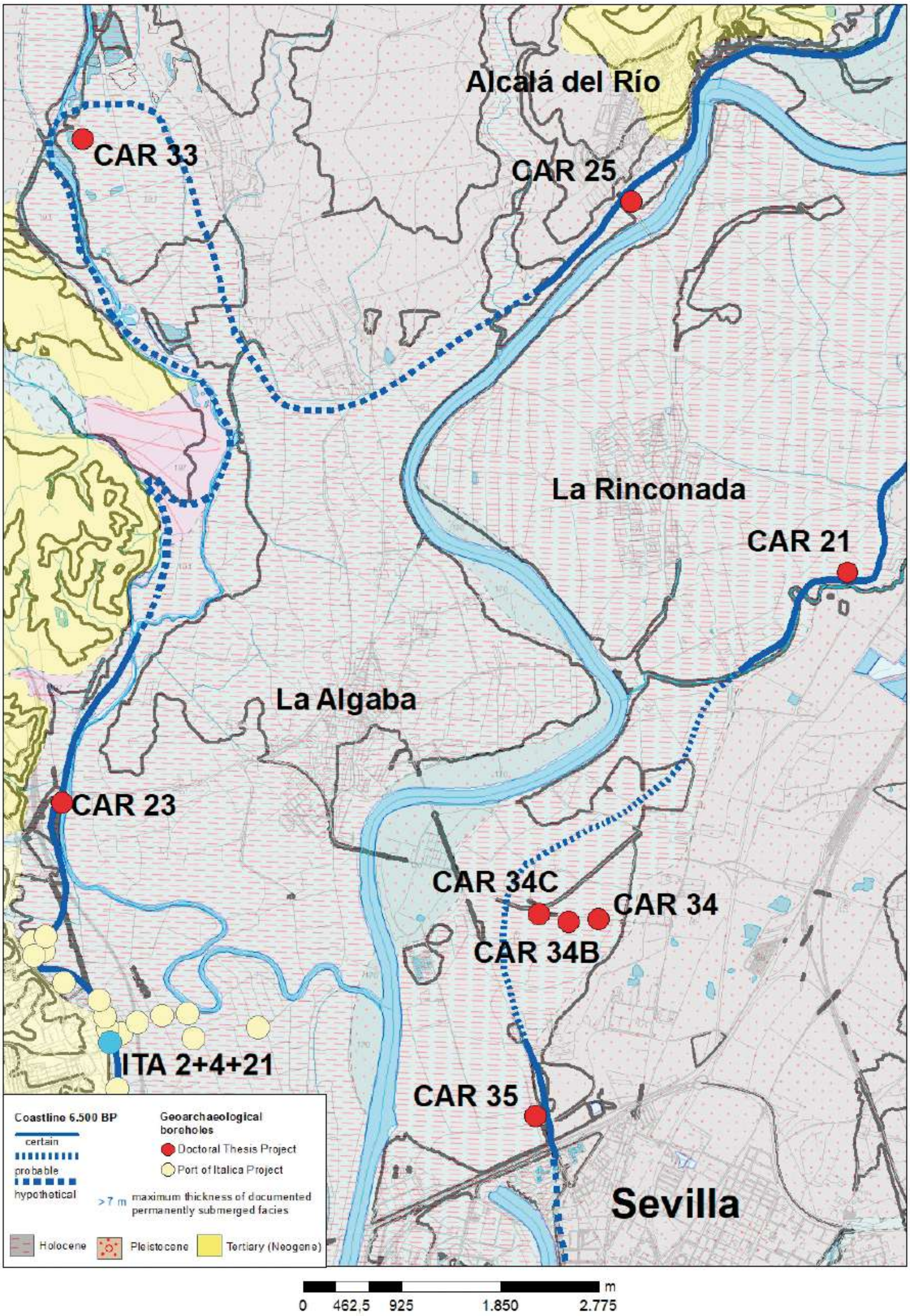

Figure 24. Meander of La Rinconada on the IGME geological map, with the main countour lines thicked

Figura 24. Meandro de La Rinconada en el mapa geológico del IGME, con las principales curvas de nivel resaltadas

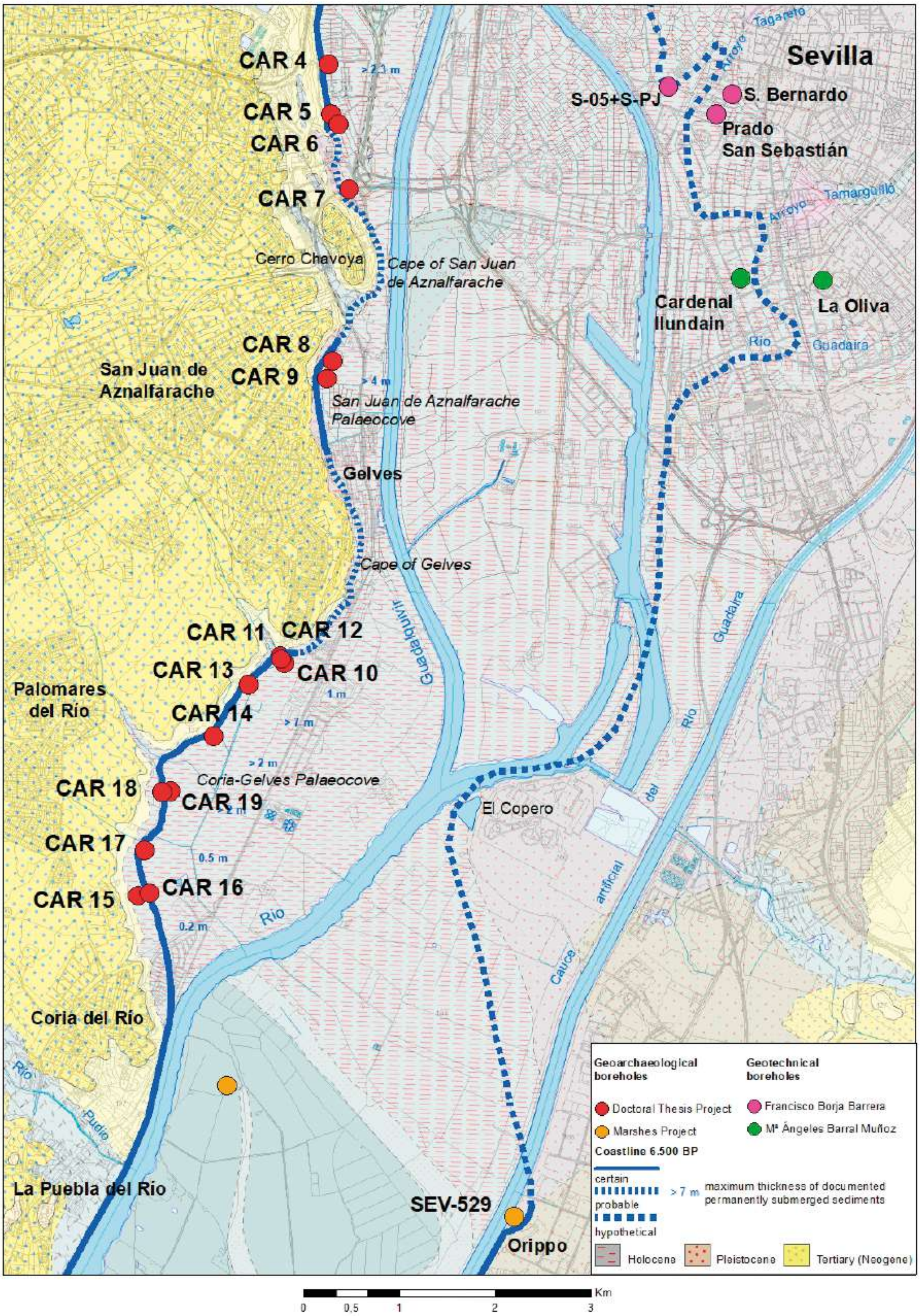

Figure 25. Coastline of c. 6500 BP in the South sector of the Guadalquivir palaeoestuary on the IGME geological map

Figura 25. Línea de costa *c.* 6500 BP en el sector sur del paleoestuario del Guadalquivir sobre el mapa geológico del IGME

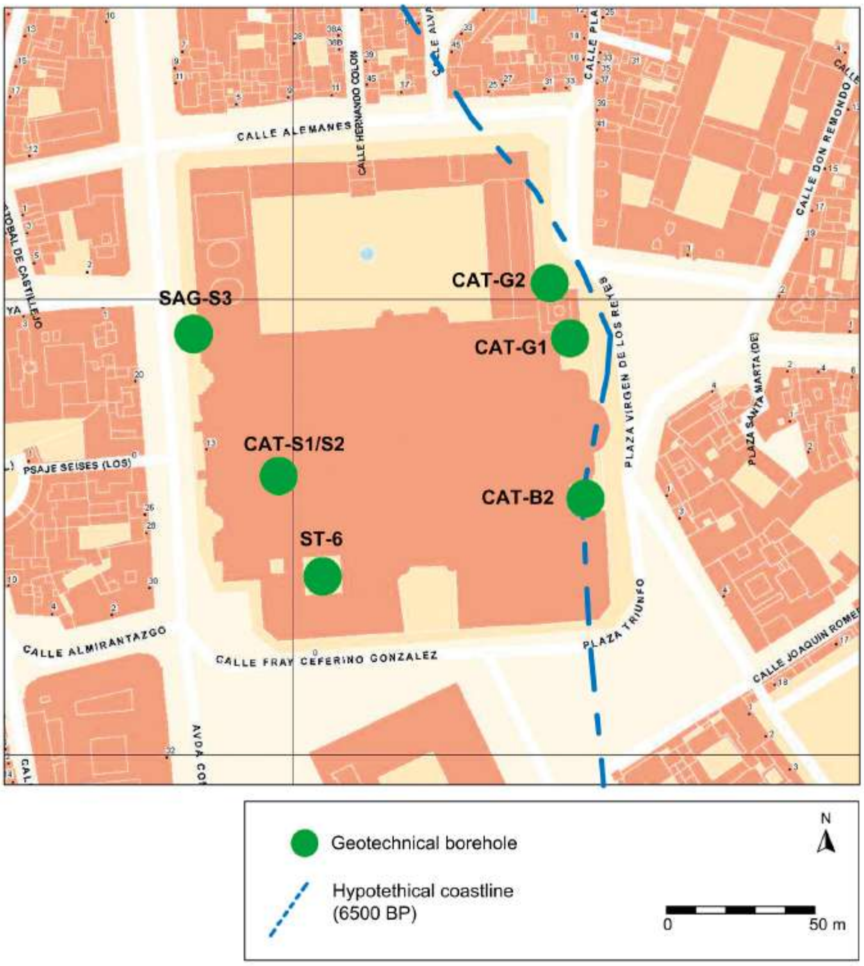

Figure 26. Hypothetical coastline of c. 6500 BP in the Cathedral of Sevilla

Figura 26. Línea de costa hipotética *c.* 6500 BP en la Catedral de Sevilla

similar to a lake (Arteaga, Schulz and Roos, 1995; Arteaga and Roos, 2007) The presence of an island or a deltaic formation around La Algaba (figure 24) could also work as a barrier between the two zones that would also contribute to the raising of the water level in the Headwaters sector. In this sector, the influence of seawater could only be argued, as we have indicated, hypothetically, at the Late Bronze Age (1248-880 cal BC), based on the analyses realized on the bivalve located in CAR 21. In any case, we must reiterate our reservations with the data provided by this bivalve in relation to its interpretation. Therefore, we consider the marine influence in the Headwaters sector for the Late Bronze Age as a mere working hypothesis, pending further data from new boreholes.

As we have said, this apparent elevation of the water surface in the Headwaters sector (1.95 m difference between CAR 38 and ITA 19, on the west shore, and 1.9 m difference between CAR 21 and CAR 35, on the east shore) could be caused by the partial enclosure of this sector after the Holocene Transgression by means of sandy bars that would form islands, creating a kind of lake (Arteaga et al., 2015) by combining the tidal influence and the fluvial contribution of the Guadalquivir and its tributaries (mainly the Ribera de Huelva). As we have already mentioned, it is likely that the meander of La Rinconada is delimiting an island or a headwaters delta formed after the transgressive maximum at the confluence with the Ribera de Huelva. From the Middle Ages onwards, the town of La Algaba was located on this ancient island or palaeodelta. Only new boreholes that include analysis of macro- and microfossils and more radiocarbon dates will be able to help testing these working hypotheses.

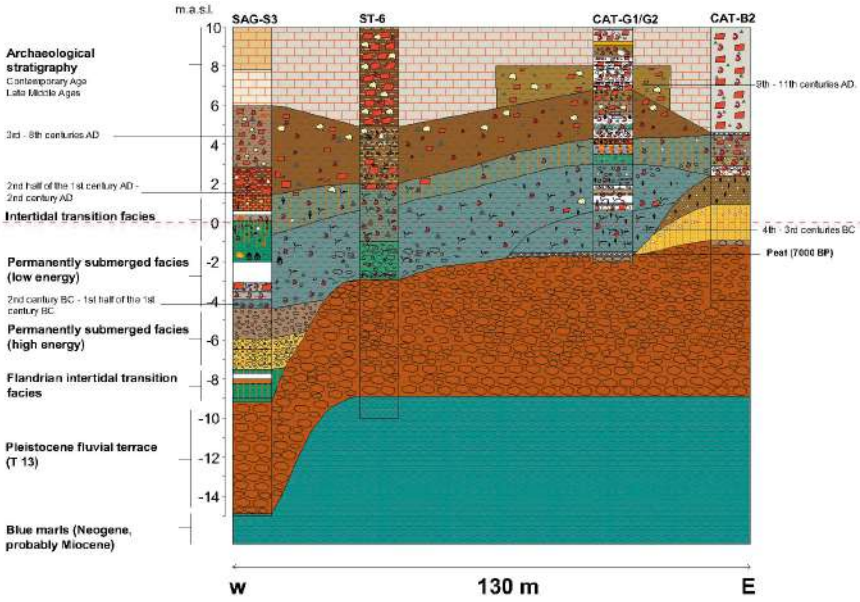

Figure 27. Stratigraphical profile formed by boreholes SAG-S3, ST-6, CAT-G1/G2 and CAT-B2 (Cathedral of Sevilla). (Modified after Barral, 2009: fig. 7.15)

Figura 27. Perfil estratigráfico formado por las perforaciones SAG-S3, ST-6, CAT-G1/G2 y CAT-B2 (Catedral de Sevilla). (Modificado a partir de Barral, 2009: fig. 7.15)

7. Discussion

7.1. Detected stratigraphic facies

The main stratigraphic facies detected in the Holocene sediments of the study area are the following:

Pre-Holocene substrates, calm (or low-energy) permanently submerged facies, moving (or high-energy) permanently submerged facies, intertidal transition facies, and alluvial plain facies.

The pre-Holocene substrates are composed of marine and coastal Tertiary (Neogene) formations, pre-Holocene palaeosoils and Pleistocene fluvial terraces, the latter detected on the east shore and at the headwaters or palaeomouth of the Guadalquivir River in the palaeoestuary.

The formations of Tertiary origin documented are made up of clayey to silty sediments of somewhat greenish grey, dark brown with grey veins and light-beige brown colour with grey veins and microlayers, from -2.05 to +0.6 m a.s.l. These layers have been detected in our boreholes CAR 15, CAR 18, CAR 11, CAR 12 in the Coria-Gelves Palaeocove (southern sector), a coast with very gentle hilly relief where the depth increases very progressively, becoming cliffier towards the north. In the deep geotechnical boreholes carried out in the urban area of Seville, the Messinian blue marls appear at the base of the sequences at different depths.

The pre-Holocene (probably Pleistocene) palaeosoils are composed of very compact sandy to silty clays of an intense red colour, which sometimes have greyish to olive-green veins due to having been under water after the Holocene transgression. They have been detected, for example, at the base of the ITA 11, ITA 12 and ITA 16 boreholes *(Puerto de Italica Geoarchaeological Project*), located northeast of the Italica amphitheatre and delimiting a salient in the coastline of 6500 BP.

The Pleistocene fluvial sediments detected are formed by medium to coarse gravels with a sandy matrix and reddish-brown colour, constituting the erosive surfaces of the lower Pleistocene terraces, specifically T13, dated to the Upper Pleistocene (Baena and Díaz del Olmo, 1994; Baena et al., 2014). These formations have been recorded at the base of the sequences of the headwaters of the palaeoestuary (between −1.1 and +0.7 m a.s.l.) and in those of the northern sector of the east shore, such as CAR 21 (−0.6 m a.s.l.), CAR 34 (+7.1 m a.s.l.) and CAR 34B (+7.92 m a.s.l.). These terrace formations are also documented in the geotechnical boreholes of the urban area of Seville (figures 30, 31 and 32).

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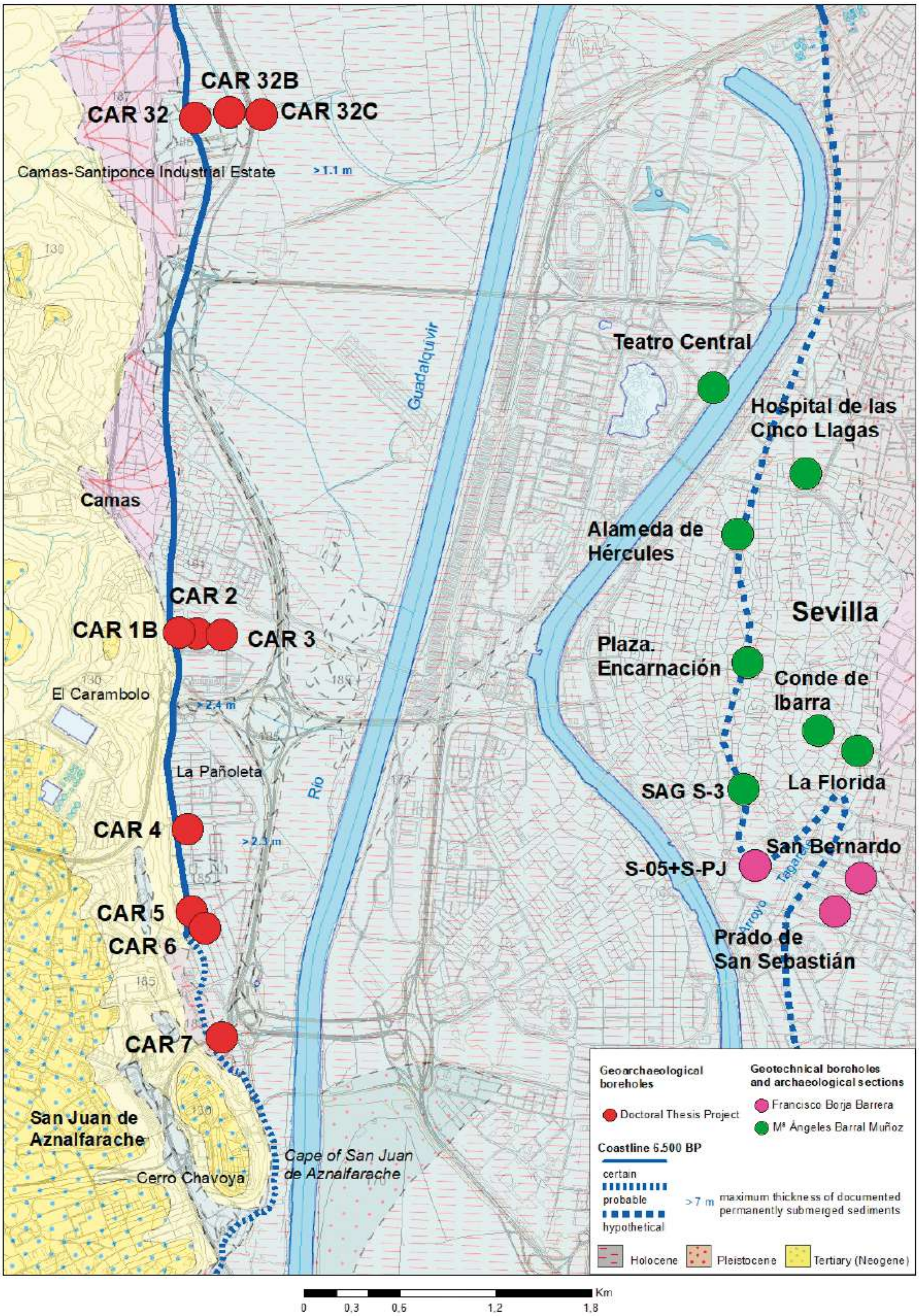

Figure 28. Central sector of the palaeoestuary on the IGME geological map

Figura 28. Sector central del paleoestuario sobre el mapa geológico del IGME

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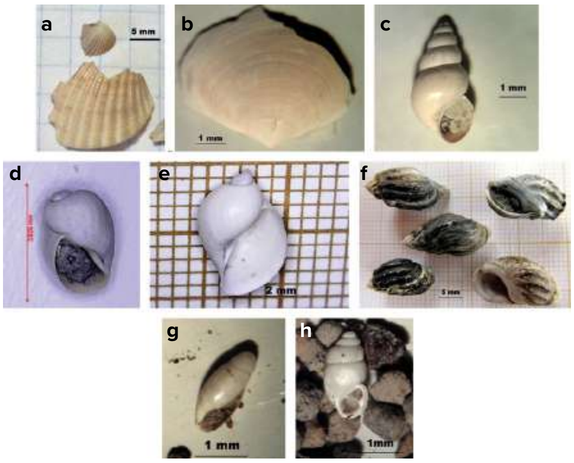

Figure 29. Molluscs identified in the analysed samples: a. *Cardiidae.* b. *c.f. Scrobicularia plana.* c. *Hydrobia* sp. d *Bulinus* sp. e. *Radix balthica.* f. *Melanopsis* sp. g. *Cecilioides c.f. acicula* and h. *Vertigo* sp.

Figura 29. Moluscos identificados en las muestras analizadas: a. *Cardiidae.* b. *c.f. Scrobicularia plana.* c. *Hydrobia* sp. d *Bulinus* sp. e. *Radix balthica.* f. *Melanopsis* sp. g. *Cecilioides c.f. acicula* y h. *Vertigo* sp.

Figure 30. Pleistocene gravel from borehole CAR 36

Figura 30. Grava pleistocena de la perforación CAR 36

Directly over pre-Holocene substrates, Holocene high-energy facies below current mean sea level are sometimes documented, with a normally sandy composition and yellowish-beige oxidizing colours, being interpreted asprobably fluvial beaches/bars contemporaneous with the Holocene sea level rise (CAR 17 and CAR 12). These tipe of non-fossiliferous yellow sands has also been documented at the beginning of the Holocene transgressive sequence in the Guadalete estuary (Dabrio et al., 2000: 387), interbedded with grey sands with marine fossils. The yellow sands were interpreted as fluvial deposits as a part of a bayhead delta.

Permanently submerged facies of calm waters (low-energy) under current mean sea level are composed of clayey to sandy silts of grey-blue to grey colours (reducing environment, due to oxygen scarcity), and are located in areas near the shore (figure 33).

Permanently submerged facies of moving waters (high-energy) under sea level are composed of light brown to greyish-beige gravel to sand (higher oxygen content), although sometimes they are also grey to grey-blue. They are usually documented in our boreholes in areas farther from the shore, towards the centre of the palaeoestuary. The facies of coarser granulometry (fine to coarse gravels) may correspond to fluvial channels incised in the alluvial plain and formed at an advanced stage of the palaeoestuary filling process. We have also recorded layers with sand and coarse gravel of reducing colour at great depth under low-energy permanently submerged facies in two boreholes of the *Port of Italica Geoarchaeological Project* (ITA 13, at −2.55 m and ITA 19, at −5.2 m). In ITA 13, wheelmade pottery fragments are documented in this layer, so we interpret it as a high-energy permanently submerged facies not older than the 1st Iron Age. In ITA 19 there are no ceramic fragments or components of biological origin, so we do not have the possibility of dating this layer, although we think, based on its reducing colour and the depth where it is documented, that it should be interpreted as a high-energy facies within the estuary formed by the Holocene transgression.

Permanently submerged facies are recorded below sea level in the South and Central sectors (from −7.35 to −0.3 m a.s.l.), but in the North and Headwaters sectors they start below current mean sea level and reach heights above current mean sea level in some boreholes, especially those located further northeast, such as CAR 21 (+2.2 m a.s.l.) and CAR 38 (+1.7 m a.s.l.) (figure 34).

Geotechnical boreholes executed in the urban area of Seville also documented permanently submerged facies above current mean sea level, such as the CAT-G1 and CAT-G2 boreholes (base of the Giralda), where bluish-grey clays are documented up to +2 m a.s.l. (Barral, 2009: 192-200). These heights would be somewhat over the current mean tidal range, although within the influence of maximum high tides.

Intertidal transition facies are formed by clayey to sandy silts of grey-blue colour with reddish-brown

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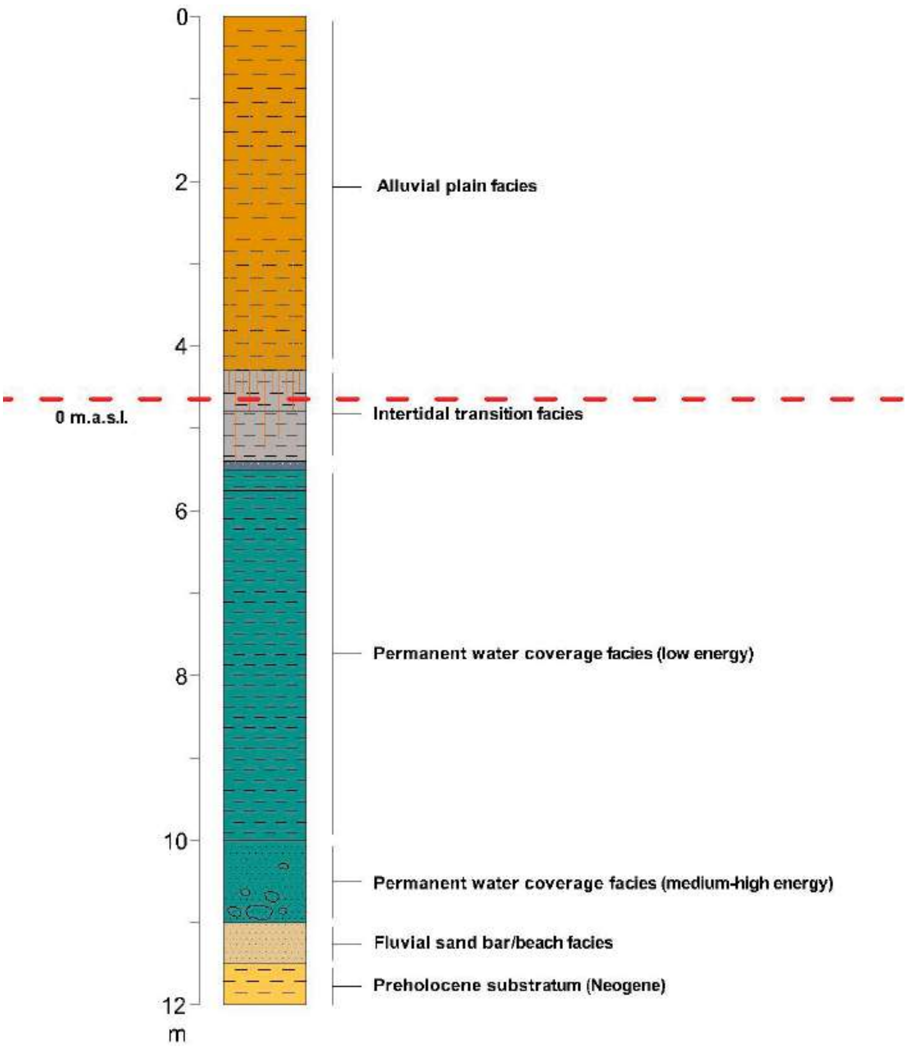

Figure 31. Type stratigraphy of the palaeoestuary (west shore)

Figura 31. Estratigrafía tipo del paleoestuario (orilla oeste)

to orange oxidizing veins, caused by the introduction of oxygen into a sediment originally deposited in a reducing environment and indicative of sediment colonization by aquatic plants, as well as partial exposure to the atmosphere. Black colours indicative of wetlands have sometimes been documented, as in our CAR 8 and CAR 9 boreholes and in the sequences studied in the palaeomouth of the Tagarete stream (Borja and Borja, 2007). The intertidal transition facies detected in our boreholes begin in the southern and central sectors below current mean sea level (−1.25 m a.s.l.) and reach +1.07 m a.s.l. In the North sector they usually start somewhat below current mean sea level (−0.5 m a.s.l.), and again in the more northeastern boreholes (Headwaters sector) they always start above current mean sea level (+1.7, +2.2 m a.s.l.), and reach +2.4 m a.s.l. in CAR 38 and +3.9 m a.s.l. in CAR 21. In the geotechnical boreholes of the urban area of Seville, the intertidal transition facies are detected between 0 m a.s.l. (SAG-S3, on the sidewalk near the Iglesia del Sagrario) and +2.8 m a.s.l. (CAT-S1, in the western third of the Cathedral of Seville) (Barral, 2009: 471) (figure 35).

The alluvial plain facies consist of usually sandy, light brown silts with isolated millimetre-sized greyish and oxidizing veins that decrease towards the surface. In the South and Central sectors, they start between +1.6 and +2 m a.s.l. and in the North and Headwaters sectors between +2.45 and +3.9 m a.s.l. On the top of the alluvial plain facies there is a height decrease from north to south of the palaeoestuary, from +11 m a.s.l. in CAR 38 (Headwaters

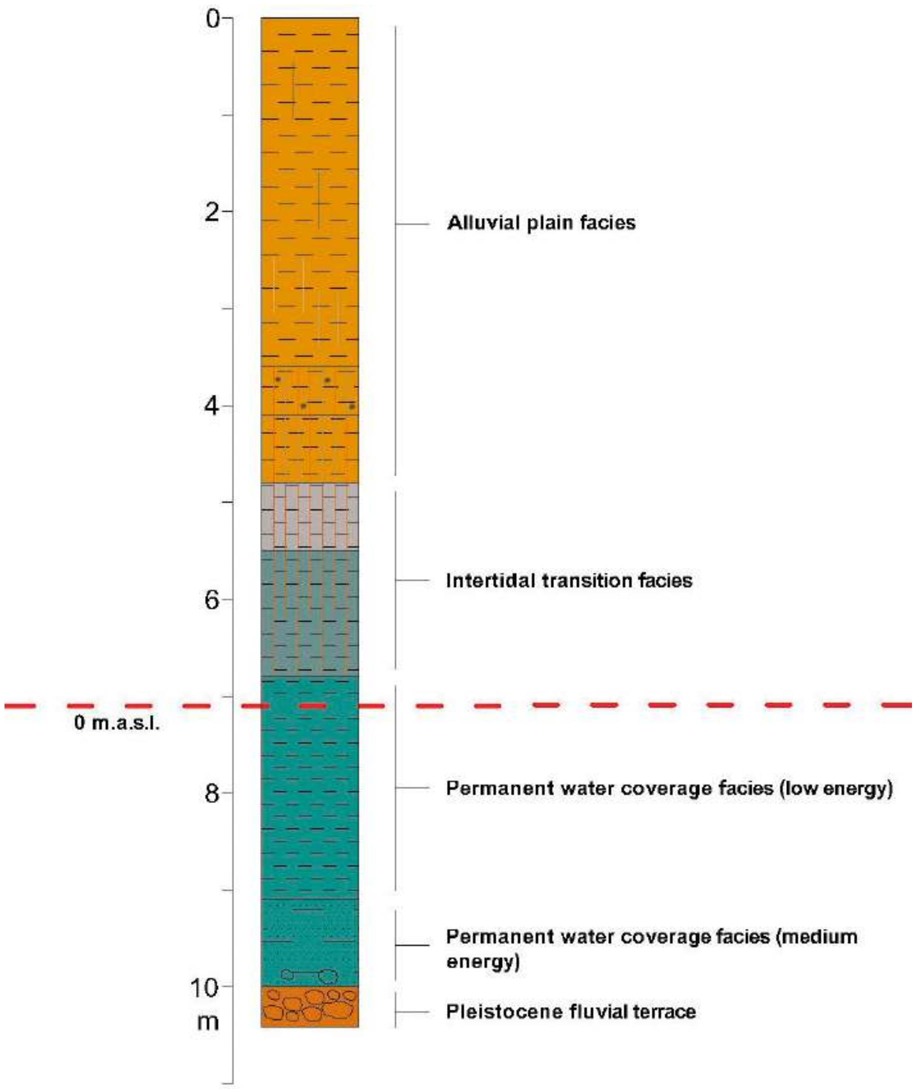

Figure 32. Type stratigraphy of the palaeoestuary (east shore)

Figura 32. Estratigrafía tipo del paleoestuario (orilla este)

sector), +9.4 m a.s.l. in CAR 21 (Headwaters sector) and +7 m a.s.l. in ITA 2+4+21 (North sector), to 6.05 m a.s.l. in CAR 8 (South sector) and 4.5 m a.s.l. in CAR 16 (South sector). This north-south drop in the surface heights of the alluvial plain that completes the filling of the palaeoestuary would be indicative of the earliest siltation of the northernmost areas.

7.2. Approach to the siltation process of the palaeoestuary

Regarding the dating of the different facies and their implications in the siltation process of the palaeoestuary, the oldest date was obtained in the low-energy permanently submerged facies of the CAR 8 borehole, in the Palaeocove of San Juan de Aznalfarache (immediately south of the Cerro de los Sagrados Corazones, that makes up the Cape of San Juan de Aznalfarache), from a plant remains sample documented at -5.05 m a.s.l. However, its old date (6232-6032 cal BC), does not coincide with the sea level rise curves, which place it at -10 m a.s.l. for that time (Delgado et al., 2012; Zazo et al., 2008), so I think that the plant remains comes from an older eroded soil and does not correspond to the age of deposition of the layer.

The next oldest date has been obtained in an intertidal transition facies on a shell of *Cardiidae* collected at +0.4 m a.s.l. in the CAR 19 borehole, in

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the Palaeocove of Coria-Gelves. The date, which has the same problem with the marine reservoir effect as that of the Cerro Macareno bivalve and for which the same ΔR value of −108 ±31 has been calculated (following the recommendations of Soares, 2015), is 4028-3685 cal BC (5510 ±30 BP without subtracting the marine reservoir effect). This sample also presents the problem of an excessive amplitude at the intersection of the radiocarbon measurements with the calibration curve (343 years). However, a prograding advance of incipient siltation in this area of calm waters and relatively sheltered from the currents would not be inconsistent with the intensification of the agricultural exploitation of the soils of the Guadalquivir basin in the first half of the 4th millennium BC, in the context of the transition from the tribal socio-economic formation to the initial classist socio-economic formation (Arteaga, 1992; Arteaga and Roos, 1992; 1995).

The next oldest date corresponds to the low-energy permanently submerged facies of the CAR 21 borehole, and was obtained from the marine mollusc recorded at −0.1 m a.s.l., whose result (1248-880 cal BC) we have already mentioned. Therefore, the first reliable date of the low-energy permanently submerged facies has been obtained from plant remains at +0.85 m a.s.l. in the CAR 21 borehole, which provided a result of 515-390 cal BC, implying the existence of a permanent water coverage in front of Cerro Macareno still at the beginning of the 4th century BC at the very least. This water body would have a minimum depth of 1.35 m and, probably, more than 2 m at high tide, based on the height reached by the intertidal transition facies at this point (+3.9 m a.s.l.). The port possibilities of Cerro Macareno are clear, in my opinion, based on these data, at least until the beginning of the 4th century BC (figures 36 and 37).

The dating of the permanently submerged facies of Cerro Macareno, in combination with that of the facies of the same type off Italica obtained from borehole ITA 2+4 (167-36 cal BC, on wood, Arteaga et al., 2015), from which a water depth of at least 2.3 m at high tide and a minimum of 1.2 m for low tide can be calculated for the end of the Roman Republic and up to 1.65 m at high tide and

Figure 33. Sediment sample of the permanently submerged facies of CAR 25

Figura 33. Muestra de sedimento de la facies permanentemente sumergida de CAR 25

Figure 34. Permanently submerged facies from borehole CAR 37

Figura 34. Facies permanentemente sumergidas de la perforación CAR 37

Figure 35. Sediment sample of the intertidal transition facies from borehole CAR 21 (small fragments of charcoal and pottery can be observed)

Figura 35. Muestra de sedimento de la facies de transición intermareal de la perforación CAR 21 (se observan pequeños fragmentos de carbón y cerámica)

Borehole	Lab. Code	Height	Facies	Material	Archaeological material	Result
CAR 21 (Cerro Macareno)	KIA48703	+2.45 m a.s.l.	Intertidal transition	Charcoal	Mortar with millimetric remains of oxidizing firing pottery	2015 ± 30 BP 105 cal BC-65 cal AD (2 sigma range)
CAR 21 (Cerro Macareno)	KIA48704	+0.85 m a.s.l.	Permanently submerged	Vegetal remains	No	2360 ± 25 BP/2380±25 BP 515-390 cal BC (2 sigma range)
CAR 21 (Cerro Macareno)	Beta-412221	-0.1 m a.s.l.	Permanently submerged	Shell (bivalve indet.)	No	3200 ± 30 BP 1248-880 cal BC (2 sigma range) 1050 cal BC (intersection with calibration curve)
CAR 19 (Palomares del Río)	Beta-412800	+0.4 m a.s.l.	Intertidal transition	Shell (Cardiidae)	No	5510 ± 30 BP 4028-3685 cal BC (2 sigma range)
CAR 8 (San Juan de Aznalfarache)	KIA48425	-5.05 m a.s.l.	Permanently submerged	Vegetal remains	No	7274 ± 54 BP 6232 -6032 cal BC (2 sigma range)

Figure 36. ^{14}C datings realized for this research

Figura 36. Dataciones ^{14}C realizadas para esta investigación

a minimum of 0.45 m for the 1st-2nd centuries AD (based on the ceramic fragments documented above the dated wood fragment), allows us to deduce the existence of a permanent water coverage in front of Italica from the Holocene transgressive maximum until the high Roman imperial period. However, the 105 cal BC-65 cal AD date of the intertidal transition facies in the borehole located off Cerro Macareno indicates the earliest siltation of this shallower sector of the northeast coast of the palaeoestuary, coinciding with the abandonment of the site, as well as an advance of the coastline to the west. The coast off Italica would not reach the same siltation stage until, at the earliest, the Late Roman Empire, based on the fragments of African Red Slip Ware type D (4th-5th centuries AD, with some productions reaching up to the 7th century AD) registered at the base of the alluvial facies of the ITA 2+4 borehole (Arteaga et al., 2015). As I mentioned above, recent and still unpublished research carried out together with the German Archaeological Institute, the Autonomous University of Madrid and the Kiel University has evidenced younger dates (Late Roman Empire) for the permanently submerged facies at the same point as borehole ITA 2+4 (figure 38).

On the east shore of the palaeoestuary, there also seems to be an advance of the coastline in the urban area of Seville since at least the 5th century BC. This progradation would allow the occupation of the port area of San Fernando Street in the 1st century AD (geotechnical boreholes S-05 and S-PJ, in Borja et al., 2008). In the same way, between the 4th-3rd centuries BC and the first half of the 1st century AD, based on the data from the analysed geotechnical boreholes, the advance of the coastline is documented in the areas of plaza de la Encarnación and the Cathedral, as well as in the old channel of the Tagarete stream in La Florida (Borja and Barral, 2003; 2005; 2007; Borja and Borja, 2007). In the geoarchaeological analysis realized in the archaeological excavations for the underground parking of avenida de Roma (south of San Fernando Street), a low-energy permanently submerged facies (greenish grey laminated clays) was recorded between +0.5 and +0.9 m a.s.l. This facies, deposited under the first anthropic occupation of the site, dated to the 1st century BC, was dated by AMS between 1685 and 1256 BC (Baena and Guerrero, 2009: 177) (figures 39 and 40).

In the second half of the 1st century AD, the prograding advance of the siltation would also allow the occupation of a strip of about 300 m of maximum width to the west, between the Pleistocene fluvial terrace (plaza de la Encarnación) and the coastline (Sierpes Street). This occupation would be related to the port and the production of salted fish, documented at the factory located in plaza de la

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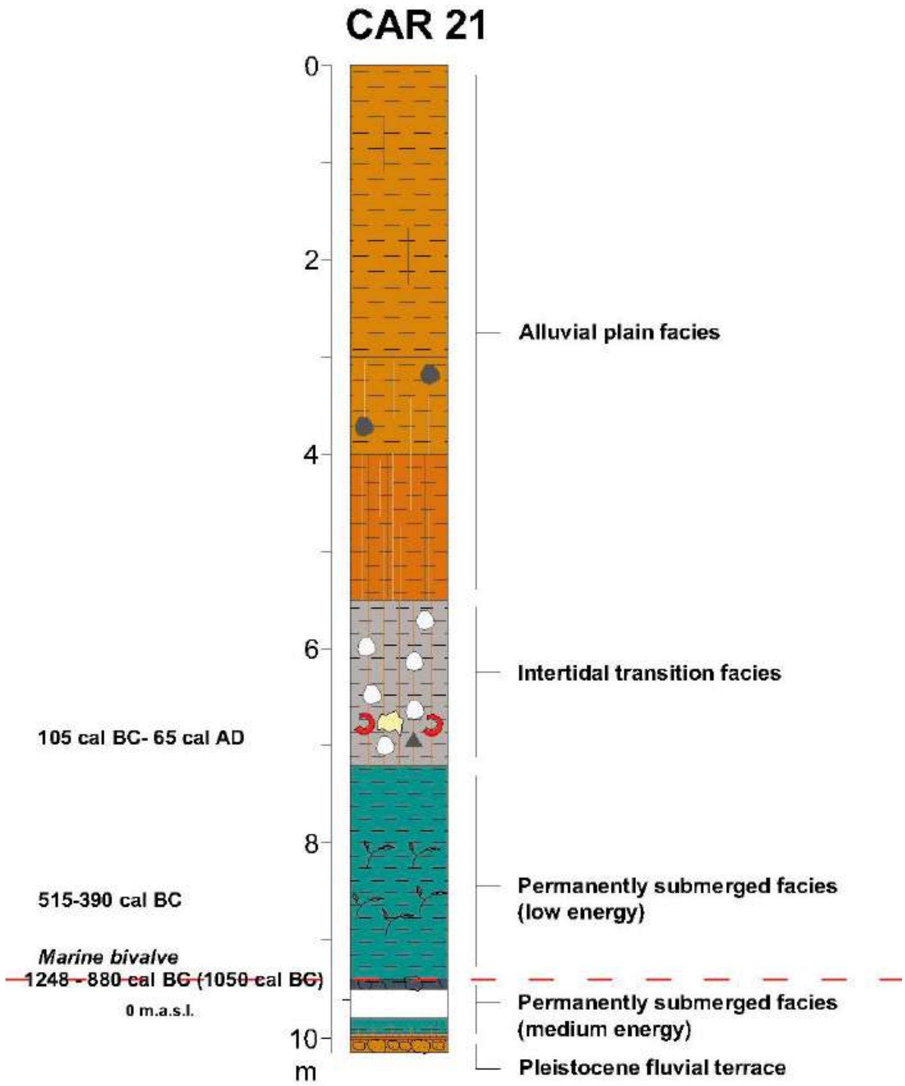

Figure 37. Stratigraphy of borehole CAR 21 (modified after Arteaga et al., 2016b: fig. 3)

Figura 37. Estratigrafía de la perforación CAR 21 (modificado a partir de Arteaga *et alii*, 2016b: fig. 3)

Encarnación (Beltrán and Rodríguez, 2014: 147-149). Thus, a first port area would be in the area of San Fernando Street and Jardines del Cristina, which, according to José Beltrán Fortes and Oliva Rodríguez Gutiérrez, became an area for burial and ceramic production in the 2nd century AD, ceding then the port prominence to the area of the Sierpes Street-Cathedral axis.

It was not until the Late Antiquity and the Early Middle Ages, as we had pointed out for the coast of Italica, that the siltation was completed in a general north-south direction and, at the level of hypothesis based on the data collected in the CAR 21 borehole, also east-west, progressively constituting a terrestrial alluvial plain over the prograding transition facies from the shores. This does not mean that the siltation process occurred in a linear and mechanical way, as we have seen with the intertidal transition facies of the 4th millennium BC of the Coria-Gelves Palaeocove, and even less so in an environment as dynamic and complex as an estuary, being more than likely the formation of a headwaters deltaic facies similar to the one documented off the Strait of Coria in the Guadalquivir Gulf (Arteaga, Schulz and Roos, 1995). Moreover, islands/bars that could strangle the palaeoestuary would very probably be formed, and fluvial and tidal channels among them. We do not have, by any means, the data to define this evolution in such detail, since many more boreholes will be necessary, with light and heavy equipment

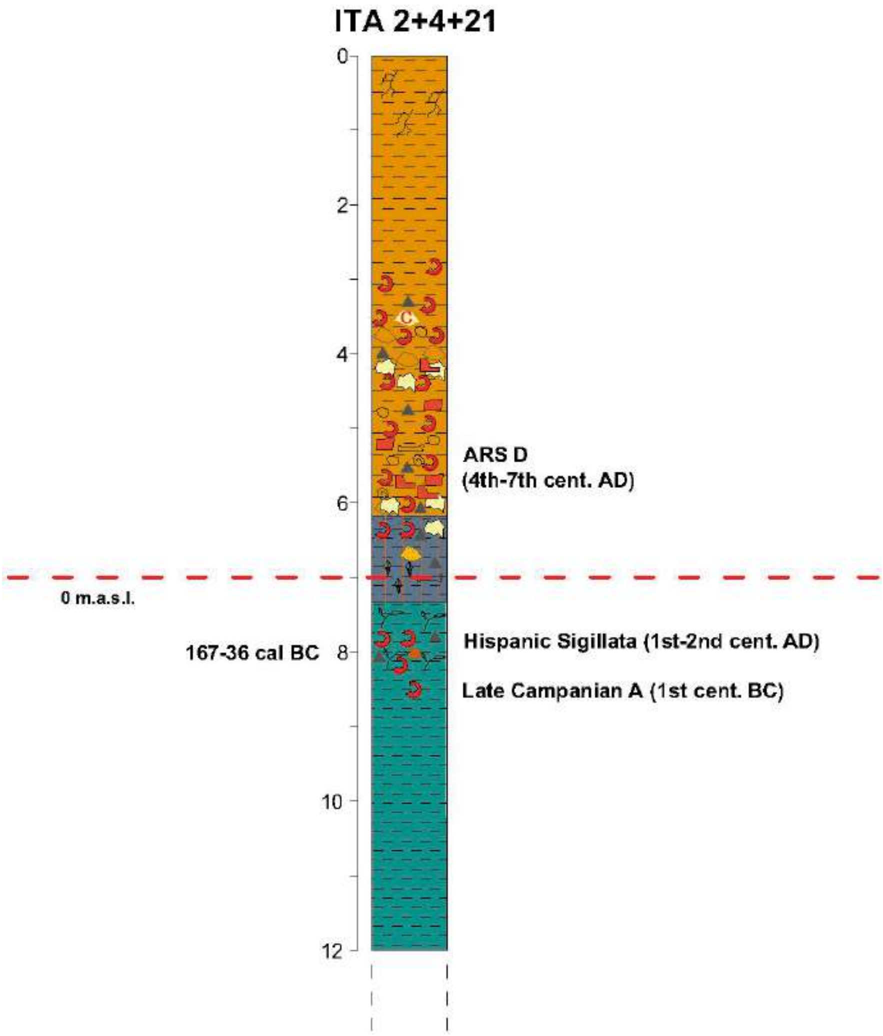

Figure 38. Synthesis stratigraphy of boreholes ITA 2+4+21 (modified after Arteaga et al., 2016b: fig. 3)

Figura 38. Estratigrafía de síntesis de las perforaciones ITA 2+4+21 (modificado a partir de Arteaga *et alii*, 2016b: fig. 3)

and grouped in profiles parallel and transversal to the Holocene transgressive coastline, other geophisycal surveys, such as seismic profiles, as well as many more dates and multi-proxy analysis, to unravel the complex structure of sedimentary facies and their stratigraphic evolution.

8. Historical contextualization of the landscape generated by the Holocene transgression

Regarding the socio-historical structure of the territory around the palaeoestuary generated by the Holocene transgression (Arteaga and Roos, 1992; 1995; Arteaga, Schulz and Roos, 1995), I have focused on the coastline that has been most surely delimited, which is the one that corresponds to the Holocene transgressive maximum, whose chronological reference is 6500 BP. This transgressive maximum coincides with a moment of fundamental transition in the historical process of the Euro-African, Atlantic-Mediterranean sphere, which is, from the Historical Materialist perspective, the transition from the tribal socio-economic formation to the initial classist socio-economic formation, produced by the internal contradiction of the appropriation of lands with dissimilar productive potentialities by tribal communities and parental segments. The ensuing productive precariousness,

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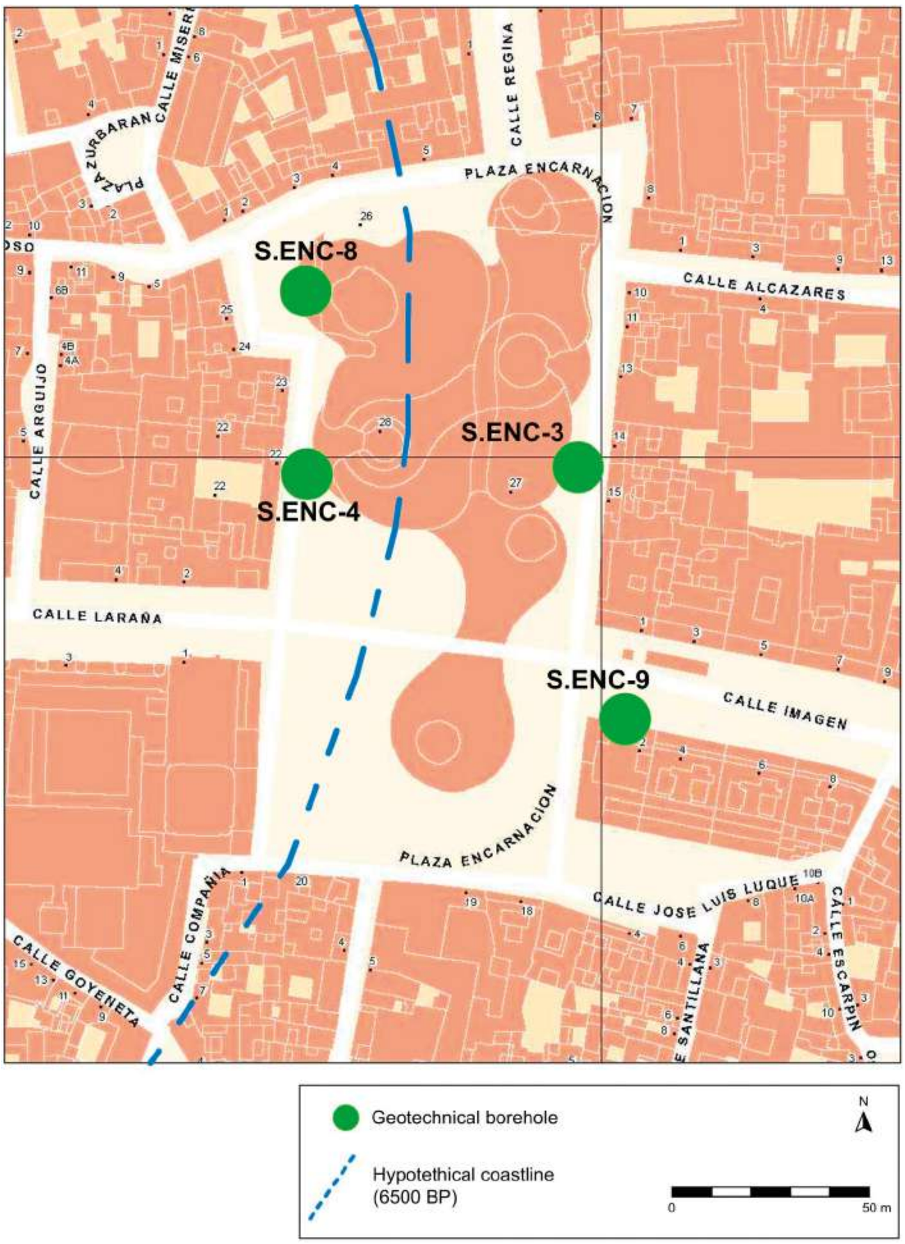

Figure 39. Hypothetical coastline of c. 6500 BP in plaza de la Encarnación (Sevilla)

Figura 39. Línea de costa hipotética *c.* 6500 BP en la plaza de la Encarnación (Sevilla)

unequally distributed among the tribal communities, would make it necessary "to create a supra-parental political organization that would have the authority required by all to guarantee productive reciprocity, including a mobilization of human labour power" (Arteaga, 2002: 263, the translation is mine). This collectivist strategy would aim to compensate for the different productive deficiencies of the lands of the different segmental communities, "under the tutelary arbitration of a parental group that would be respected for its ancestry" (and probably for the greater productivity of the lands appropriated by it), "and that would modulate the fulfilment of solidarity norms of cooperative reciprocity" (Arteaga, 2002: 264, the translation is mine).

In this way, "the Parental Society engenders within itself the contradiction of an emerging social class" (Arteaga, 2002: 263, the translation is mine), which would appropriate the human labour power of the communities, directly or in the form of consumer goods, through the tribute specified in surpluses that would be produced by the work "developed by

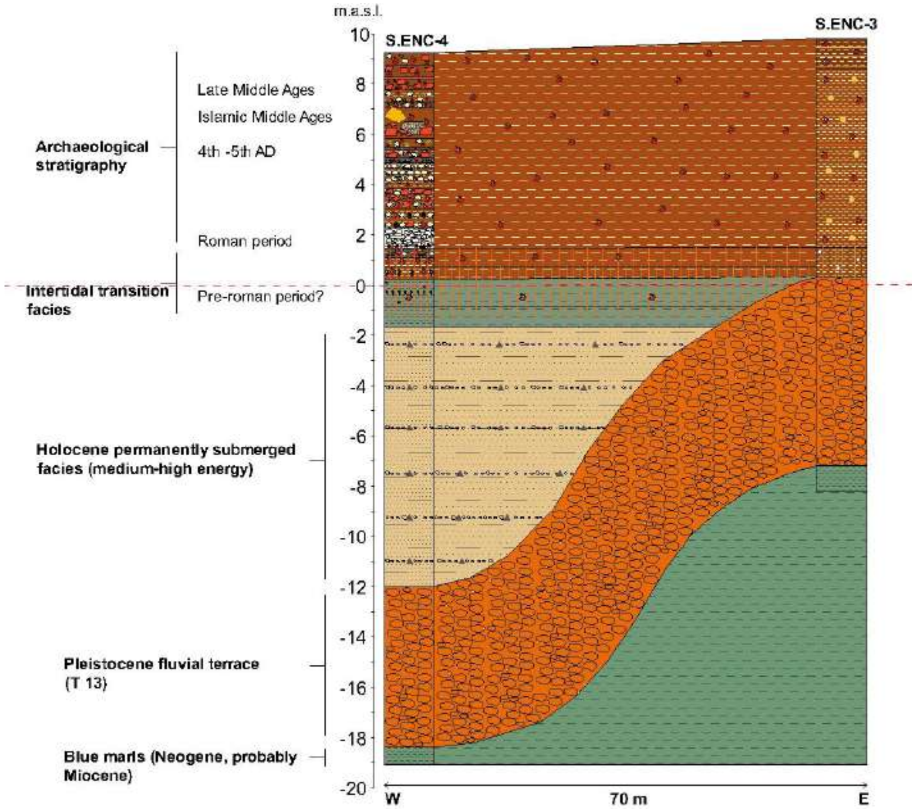

Figure 40. Stratigraphic profile formed by boreholes S.ENC-3 and S.ENC-4, at plaza de la Encarnación (Sevilla). (Modified after Barral, 2009: fig. 7.13)

Figura 40. Perfil estratigráfico formado por las perforaciones S.ENC-3 y S.ENC-4, en la plaza de la Encarnación (Sevilla). (Modificado a partir de Barral, 2009: fig. 7.13)

many others over and above their subsistence needs" (Arteaga, 2002: 263, the translation is mine), originated, at first, by the need to guarantee the subsistence of conjunctural or structurally precarious communities, and which would end up being used for the maintenance and reproduction of social and political structures controlled by the ruling or exploiting class. The creation of productive surpluses "is thus consubstantial with the consolidation of a dominant class" (Arteaga, 2002: 263, the translation is mine).

The emergence of socio-parental inequality among different patriarchal lineages during the development of the tribalization process will produce the historical conditions that will allow "the emergence of a pristine form of State" (Arteaga, 2002: 271, the translation is mine).

Therefore, from this critique of the political economy of the tribal socio-economic formation, it can be deduced that the process of tribalization carries implicit within it the contradictions that will lead to the emergence of the initial classist socio-economic formation and the pristine State as its political structure.

Regarding the territorial articulation of the pristine State, Arteaga points out that:

> Given the low technical level that would affect the precariousness of the communities, the coordination of their labour power by those who would assume the distinction of the organizational, supra-parental work, would suppose an administrative articulation to guarantee, as we have pointed out, a collective functioning; above the purely communal village areas (Arteaga, 1992). And in this circumstance, the need to create the political identification of the ruling group with a centre of power, in the territory ascribed to it as an 'urban population nucleus', would leave in the villages the tangible segregation of peasant milieus (Arteaga, 2002: 264, the translation is mine).

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In our study area, the palaeoestuary of the Guadalquivir river generated by the Holocene transgression is the territory where it is necessary to contextualize the emergence of the great regional power centre of Valencina de la Concepción-Castilleja de Guzmán (Arteaga and Roos, 1992; 1995; Arteaga and Cruz-Auñón, 1995b; Cruz-Auñón and Arteaga, 1995) from the first centuries of the 3rd millennium onwards and, probably, starting from the last third of the 4th millennium BC, based on calibrated dates obtained in the settlement (Nocete et al., 2008; García Sanjuán, 2013). In my opinion, this settlement is the true urban centre of a pristine collectivist tributary State in the Guadalquivir valley.

This power centre controlled the labour power, both directly and through the centralization of the agricultural surpluses delivered as tributes by the nearby villages that bordered the palaeoestuary, such as La Angorrilla (Alcalá del Río), the area of Cerro de la Cabeza and Santiponce, Coria del Río, Puebla del Río, on the west shore; or close to it, such as Parque de Miraflores, the promontory of the Pleistocene terrace of the primitive nucleus of Seville, Universidad Laboral, or Torre de los Herberos (Dos Hermanas), on the east shore. Other secondary centres in the Guadalquivir valley, such as El Gandul (Alcalá de Guadaira) or Carmona would very probably have relations of political dependence with Valencina and would probably pay tributes to the power centre, too.

The so called "mega-site" of Valencina de la Concepción-Castilleja de Guzmán is also considered by some authors as the capital of a territorial State centred on the Guadalquivir valley, whose political borders reached the Alta Andalucía (Nocete, 2001), centralising as well the mining and metallurgical production of both the mountainous territories of Sierra Morena (to the north) and the Subbéticas (to the southeast), and developing a true "metallurgical district" delimited by ditches within the "intermediate area" of the prehistoric urban centre, dedicated to the storage of cereal surplus in silo fields and, most likely, to the stabling of a large cattle herd, and located between the peripheral necropolis zone and the habitational area (Arteaga and Cruz-Auñón, 1995a; 1995b; Cruz-Auñón and Arteaga, 1995; 1996; Nocete et al., 2008, Queipo de llano, 2010).

There are also different interpretations of the Valencina de la Concepción-Castilleja de Guzmán mega-site. For example, Leonardo García Sanjuán proposes that Valencina "[…] may have been a place of aggregation, competitive display, and ritual performance, part of a wider European phenomenon that was replaced by different structures of social power and social practice as the 3rd millennium drew to a close." (García Sanjuán, Scarre and Wheatley, 2017: 9). His main arguments to support this hypothesis are the absence, according to the author, of enclosing walls; the presence of human remains spread around the whole site, the difficulty in identifying clear domestic structures (houses) and the absence of evidence of flint knapping (although there is evidence of manufacturing of cooper, ivory or rock cristal). As a counter-argument against these assumptions, in the recent excavations carried out in the northwest area of the site, domestic structures and workshops have been documented, as well as continuous use and reshape of lithic tools, including grinding stones. These evidences lead the excavators to defend "[…] a continuous occupation of the settlement in Valencina from 3300/3200 to 2200 cal. BC. […]" (Schuhmacher et al., 2022: 92).

Another interpretation of the site is provided by José Luis Escacena, who proposes that the site is really a "big cemetery" (Escacena, Rondán y Flores, 2018), which centralized the funerary rituals of the communities living around the Guadalquivir palaeoestuary. The arguments to support this hypothesis are similar as the ones of Leonardo García Sanjuán, such as the lack of clearly domestic structures at the site and the particular abundance of funerary records, on the one hand, and he absence of funerary records in kilometers around, on the other hand.

Since 2017, the *Valencina-Nord* Project (Schuhmacher, 2018; Schuhmacher et al., 2021; Mederos et al., 2020; 2021), focused in the northern sector of the site, has documented, among other important results (which include a phase dated to the end of the 4th millennium BC), at least 5 ditched enclosures dated from 3300-3000 BC to 2550-2450 BC. These enclosures have very different sizes, from 8.85 ha (enclosure 3, the smallest and older one, dated to

Figure 41. View of the Guadalquivir alluvial plain near Seville (with the city in the background) from the top of the archaeological site of El Carambolo

Figura 41. Vista de la llanura aluvial del Guadalquivir cerca de Sevilla (con la ciudad al fondo) desde la cima del yacimiento arqueológico de El Carambolo

3300-3000 BC) to 197.06 ha (enclosure 5, the biggest one, dated to 2800-2550 BC). Enclosure 4 is the most recent one (2550-2450 BC) covering only 20.70 ha, but it could be contemporaneous with enclosure 1, which encompasses enclosure 4 and would cover 82.28 ha (Schuhmacher et al., 2022; Mederos et al., 2023).

The recent archaeological excavations in the new municipal library and its surroundings, carried out from 2018 to 2024, have also documented non-funerary stone constructions of great size associated with three ditches, in whose fillings the remains of the adobe upper part of the constructions were registered (personal communication from Juan Manuel Vargas Jiménez, municipal archaeologist of Valencina de la Concepción and director of the works, to whom I thank the kindness).

Besides, a great number of excavations and further laboratory research has been made in the southeast part of the necropolis, especially in the Montelirio tholos area (Fernández and Aycart, 2013) and the PP4-Montelirio sector (Mora et al., 2013), where products from long-distance trade, such as African elephant ivory (García Sanjuán et al., 2013; Luciañez-Triviño, García Sanjuán and Schuhmacher, 2021) and cinnabar (Rogerio Candelera et al., 2013; Emslie et al., 2019; 2022), were recorded.

The Atlantic-Mediterranean dimension given to Valencina it by the Guadalquivir palaeoestuary, in a incipient stage of siltation in the 3rd millennium BC (evident if we take into account the geoarchaeological data obtained for later periods), through its communication with the marine Guadalquivir Gulf and the Gulf of Cadiz, allowed it to centralize, accumulate and distribute exotic products such as ivory, amber and ostrich eggs, among others. These objects, together with those made of arsenicated copper, would allow the ruling elite to apply its ideological coercion through the mystifying justifications of the patriarchal lineages (the famous tribal "chiefs"), which "hid" the true classist social relations of production, based on their collective appropriation as a class of the labour power of the members of the village communities, dependent and subordinate to the ruling class.

As for the port possibilities at the time of this pristine State, these are multiple, since enclaves such as La Angorrilla, the area of the amphitheatre of Italica, the foot of the hill of El Carambolo, Coria or Puebla del Río, on the west shore; and the

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palaeomouth of the Tagarete stream in Seville or Torre de los Herberos (Orippo in Roman times), on the east shore, have port potential.

The foot of the hill of El Carambolo is perhaps the closest and best-connected location to the power centre, only 3.3 km away. In this area, the Tertiary slope where the settlement of El Carambolo is located descends sharply to the east until it reaches a minimum water depth of more than 3.7 m (we did not cross the permanently submerged facies of borehole CAR 1B), approximately 50 m away from the Tertiary outcrop at the foot of the hill.

This settlement was occupied from the middle of the 3rd millennium BC to the beginning of the 2nd millennium BC, and a practically continuous occupation was also documented throughout the 2nd half of the 2nd millennium BC until almost reaching the period of the Phoenician-Tartessian colonial horizon, which begins between 1020 and 810 BC (Fernández and Rodríguez, 2007: 87) (figures 41 and 42).

In my opinion, with regard to the tholoi burials of Castilleja de Guzmán (Arteaga and Cruz-Auñón, 1996), the practical continuity in the occupation of El Carambolo could be related to the port function carried out on the existing coastal shore at its foot and to the control of maritime traffic in the Guadalquivir palaeoestuary, achieved from the strategic visibility granted by its high location.

Other settlements with port possibilities for the Phoenician-Tartessian colonial horizon would be Alcalá del Río, Cerro Macareno (where, as we have seen, enough water depth has been documented for ancient navigation until at least the beginning of the 4th century BC); probably the area of Italica (based on the wheelmade pottery documented at −2.55 m a.s.l. in the ITA 13 borehole); Spal (Phoenician name of Sevilla); Coria del Río, Puebla del Río (Cerro de la Albina settlement) and Orippo (Torre de los Herberos) (Escacena, Belén and Izquierdo, 1996; Escacena, Feliú and Izquierdo, 2010; Belén et al., 2014).

Finally, the port potential of Italica during the Roman republican and high imperial periods is confirmed, with a water depth in front of the theatre area (ITA 2+4) at least of 2.3 m at high tide and a minimum of 1.2 m by the end of the Republic, and at least 1.65 m at high tide and a minimum of 0.45 m for the 1st-2nd centuries AD.

The water body was probably deeper for these chronologies in front of Italica, as we have already pointed out, based on the new and still unpublished results obtained in the geological boreholes carried out in 2022 in collaboration with the *"Valencina-Nord" Project*, (German Archaeological Institute of Madrid, Autonomous University of Madrid and Würzburg University), and the project *F1: "Climate Constraints of Western Mediterranean Socio-environmental Transformation and Potential Implications for Central Europe"* as part of the *Scales of Transformation Project* (Kiel University). The AMS dates obtained from the new cores evidenced that older reworked material has been deposited in younger sediments of the permanently submerged facies, and consequently the age of the upper part of this facies is younger than we thought (Late Roman Empire) (figure 43).

8. Conclusions

We can summarize the results of this research as follows:

The delimitation of the coastline of the Guadalquivir palaeoestuary between Coria del Río and Alcalá del Río has been carried out for the time of the Holocene transgressive maximum (c. 6500 BP).

The mouth of the Guadalquivir River in this palaeoestuary has been located east of Alcalá del Río.

A brackish environment has been recorded at least in the southern third of the palaeoestuary.

An incipient progradation process has been identified on the west shore of the southern sector, in the palaeocove detected between Coria del Río and Gelves, for the 4th millennium BC.

A non-synchronous and non-homogeneous siltation process throughout the palaeoestuary is proposed, with a general trend from north to south and from east to west, with centripetal progradations such as the palaeocove between Coria and Gelves.

The coastal dimension of the settlement of Valencina de la Concepción-Castilleja de Guzmán,

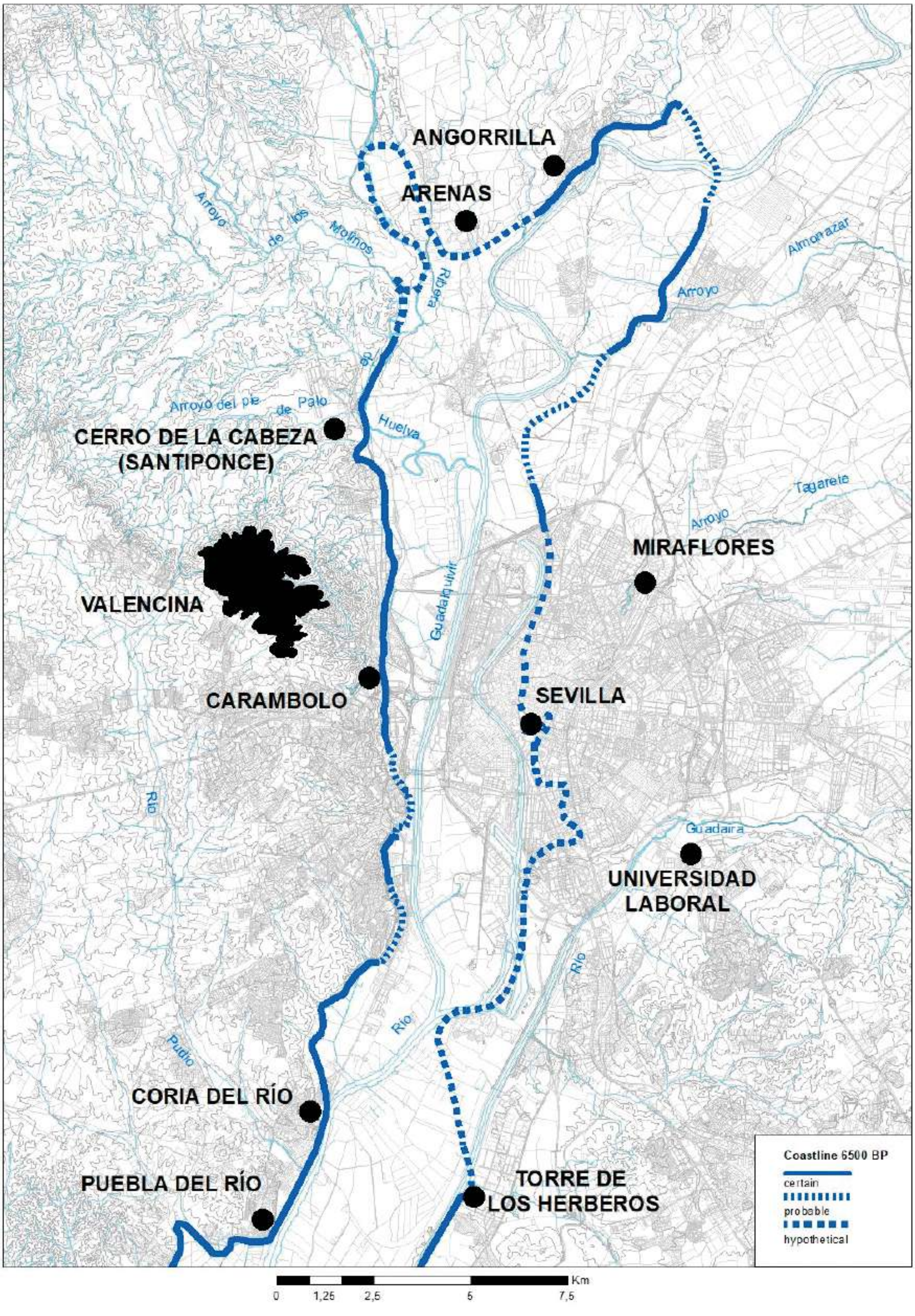

Figure 42. Coastline c. 6500 BP with the archaeological sites of the studied area occupied in the 3rd millennium BC

Figura 42. Línea de costa *c.* 6500 a. C. con los yacimientos arqueológicos de la zona estudiada ocupados en el 3er milenio a. C.

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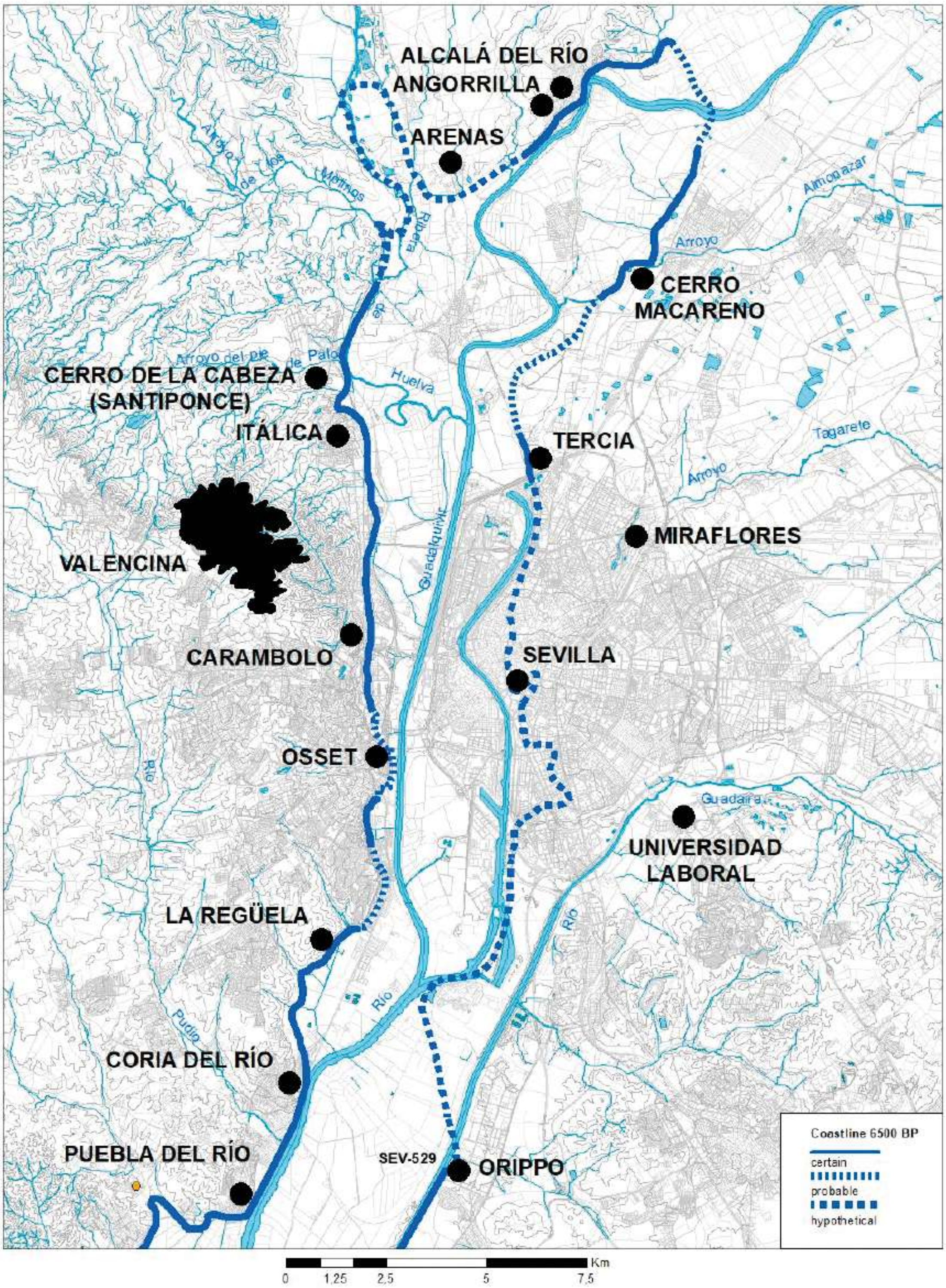

Figure 43. Coastline c. 6500 BP with the cited archaeological sites of the studied area

Figura 43. Línea de costa *c.* 6500 BP con los yacimientos arqueológicos citados de la zona estudiada the power centre of the pristine State that emerged in the transition from the 4^{th} to the 3^{rd} millennium BC in the Guadalquivir valley, has been confirmed.

The existence of a permanently submerged area between the Roman city of Italica and the settlement of Cerro Macareno (founded in the 8^{th} century BC) between 6500 BP and at least the 4^{th} century BC has been confirmed, although it is likely that bar-islands or other barriers (like a headwaters delta) formed between this two shores throughout this period.

The port possibilities of Cerro Macareno between 6500 BP and the change of era have been identified. Around that time (1^{st} century BC-1^{st} century AD), when the site was abandoned, the progress of the siltation process almost completely reduced these possibilities.

Port possibilities have been detected at the foot of the Pre- and Protohistoric settlement of El Carambolo.

Based on the data provided by the *Port of Italica Geoarchaeological Project*, port possibilities have been identified in Italica up to at least the 1^{st}-2^{nd} century AD, and probably later (Late Roman Empire), based on the new data obtained in 2022.

The coastline of the Holocene transgressive maximum in the urban area of Seville has been hypothetically delimited based on stratigraphic data from published geotechnical boreholes, mostly by Francisco Borja and M.ª Ángeles Barral.

To conclude, I hope that the results obtained in this work can serve as a basis for future research on the historical process of the Guadalquivir valley, especially with regard to the relationships between social systems and natural systems.

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