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Manuel Álvarez-Martí-Aguilar
Francisco Machuca Prieto *Editors*

Historical Earthquakes, Tsunamis and Archaeology in the Iberian Peninsula

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ISSN 1613-9712
Natural Science in Archaeology
ISBN 978-981-19-1978-7 ISBN 978-981-19-1979-4 (eBook)
https://doi.org/10.1007/978-981-19-1979-4

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The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Acknowledgements

This book is the result of a line of research developed in two projects based at the University of Malaga, *The Tsunami in the Cultural Representations of the Ancient World: Gadir-Gades and the Gulf of Cádiz as a Case Study* (HAR2015-66011-P) and *Earthquakes and Tsunamis in the Iberian Peninsula: Social Responses in the Longue Durée* (PGC2018-093752-B-I00), funded by the Spanish Ministry of Science, Innovation and Universities (MCIU), the Spanish State Research Agency (AEI) and the European Regional Development Fund (ERDF).

In the framework of these projects, the International Congress entitled, "Historical Tsunamis in the Iberian Peninsula", was held in Malaga in February 2019, in collaboration with the Museum of Malaga and Malaga University. Since the Congress' keynotes and debates were the seed of this book, we, the editors, are deeply indebted to all the people and institutions that made this encounter possible: the Museum of Malaga and its director María Morente and staff; the Culture Department of Malaga City Council; and the International Campus of Excellence in Marine Science (CEI·MAR). Moreover, we would like to thank several departments and officials of the University of Malaga for their support: the Vice-Chancellor's Office for Research and the Vice-Chancellor's Office for Strategic Projects; the Dean and Vice-Dean of the Faculty of Philosophy and Literature, Juan Antonio Perles and Clelia Martínez Maza; the Director of the Strategic Chair of Leading-Edge Technologies in Humanities, José Luis Caro; the Head of the Department of Historical Sciences, Gonzalo Cruz Andreotti; and the Director of the Historiographical Studies Group, Fernando Wulff Alonso. Our heartfelt thanks also go to our colleague José Suárez Padilla, at the University of Malaga, for his invaluable collaboration in organisational tasks and, of course, to the keynote speakers and those attending the Congress.

We would also like to express our deep gratitude to the authors for their core contributions to this book. Similarly, we would like to thank the reviewers for their comments and suggestions and all those people who, in one way or another, have contributed to its production, especially Thomas MacFarlane who translated several of its chapters and revised the style of the work as a whole. Finally, thanks to Yosuke Nishida and Sridevi Purushothaman from Springer Nature for all their support in getting this book published.

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At the Mercy of the Sea—Vulnerability of Roman Coastal Settlements in the Algarve (Portugal). Boca do Rio as an Emblematic Example of a Key Maritime Industry

Florian Hermann, Lisa Feist, Felix Teichner,
João Pedro Bernardes, Klaus Reicherter,
and Helmut Brückner

Abstract

The Roman fish-salting industry in the Western Mediterranean was concentrated in a high-risk geological area as regards extreme wave events. It underwent a significant and sudden decline and reorganisation between the second and third centuries AD. The few explanations that have been hitherto offered for this abrupt transformation range from political and economic disruptions to vague speculations on natural causes. Accordingly, this chapter focuses on determining the possibility of an extreme wave event as the cause behind the restructuring of this industry. For this purpose, the results of 3 years of archaeological and geoscientific field research in Boca do Rio (Vila do Bispo, Algarve) are presented and evaluated. Although far-reaching changes in the building stock of this Roman industrial settlement have been dated to between the second and third centuries AD, and a short series of high energy events has been identified, there is no evidence of the direct influence of a single event (a flood, storm surge, tsunami, etc.) as a trigger for the changes in the settlement and the local Roman economy. Rather, medium-term environmental changes seem to have been the driving force behind them. Additionally, a previously unknown late medieval event layer is described in detail.

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M. Álvarez-Martí-Aguilar and F. Machuca Prieto (eds.), *Historical Earthquakes, Tsunamis and Archaeology in the Iberian Peninsula*, Natural Science in Archaeology,
https://doi.org/10.1007/978-981-19-1979-4_10

Keywords

Roman marine industry · Garum · Fish-salting · Third-century crisis · Tsunami · High-energy event · Coastal settlement · Environmental change

10.1 The Roman Fish-Salting Industry, Its Development and Connection to Tsunami Research

In the Hispanic and North African provinces of the Roman Empire, to the classical 'Mediterranean triad' of grain, wine and olive oil should be added preserved marine resources, above all salted fish (*salsamenta*) and fish sauces (*liquamen, garum*, etc.), as the fourth pillar on which the economy rested (Fabião 1992; Bekker-Nielsen 2002; Teichner 2014a).

Especially in the western provinces, the characteristic large vats—*cetariae*—lined with hydraulic concrete or plaster (*opus signinum* or *caementitium*) are well documented (Fig. 10.1). The lower scale production in the eastern part of the Empire employed ceramic vessels (*dolia, pithoi*) and is, therefore, less well known (Curtis 1991). The concentration of production sites on both sides of the Strait of Gibraltar and the Strait of Sicily and on the Atlantic seaboard of *Lusitania*, *Mauretania Tingitana* and *Gallia Lugdunensis*, however, is only partly true due to the difficulties in detecting sites. Rather, it is assumed to be connected with the movement of shoals of migratory fish species, such as tuna and mackerel, which regularly passed through those areas (Opp., *Hal*. III.620–648; Bekker-Nielsen 2005; Wilson 2007). The processing of catches required a complex network of facilities and manpower, including production facilities, amphora potteries, fresh water, saltworks or salt evaporation ponds, fisheries and traders (Fig. 10.2).

Since this phenomenon was systematically explored for the first time by Ponsich and Tarradell in 1965, almost 300 sites relating to fish salting have been detected in the Western Mediterranean (Fig. 10.1; <ramppa.uca.es> 01.05.2022). This impressive number should not, however, conceal the fact that large areas of the Mediterranean and Atlantic regions are still blank on distribution maps, while in view of the local topography, known fish migration routes (Fig. 10.2) and the written sources this is hardly to be expected. Furthermore, a majority of the known sites were only superficially identified or researched in rescue excavations during the first half of the twentieth century or before, namely, usually without recording stratigraphic connections. In the past, the regionally very varied state of the knowledge led to a biased representation and interpretation of the economic dominance of the *Baetica* over the *Mauretania Tingitana* (Ponsich and Tarradell 1965; Teichner and Pujol 2008; Trakadas 2015), which is now also being discussed for southern *Lusitania* during the first and second centuries AD (Fabião 2004).

The state of research allows for arriving at some basic conclusions on the distribution and organisation of fish-salting facilities, of which the most important regarding the research questions posed here are a follows:

- Settlements specialising in the 'development and processing of maritime goods' (Teichner 2008), established in areas unsuitable for agriculture, to wit, in river estuaries or bays or generally near the coast (Fabião 1992). Contrary to earlier assumptions (e.g. Trakadas 2005), both urban and extra-urban areas were involved in this maritime economy. While most of the facilities, including the largest, were still located outside cities, some of the best researched are located within or in the environs of ancient cities (Wilson 2006; Bernal Casasola 2009; Expósito Álvarez et al. 2018).
- It can be assumed that the majority of the facilities were devoted to the sale and export of their products and required a supra-regional or even Empire-wide market (Curtis 1991; Étienne et al. 1994; Martin-Kilcher 1994; Ehmig 2001).
- The majority of the identified settlements are concentrated along seismically active and, therefore, high-risk coastal areas (Lario et al. 2011; Duarte et al. 2013).

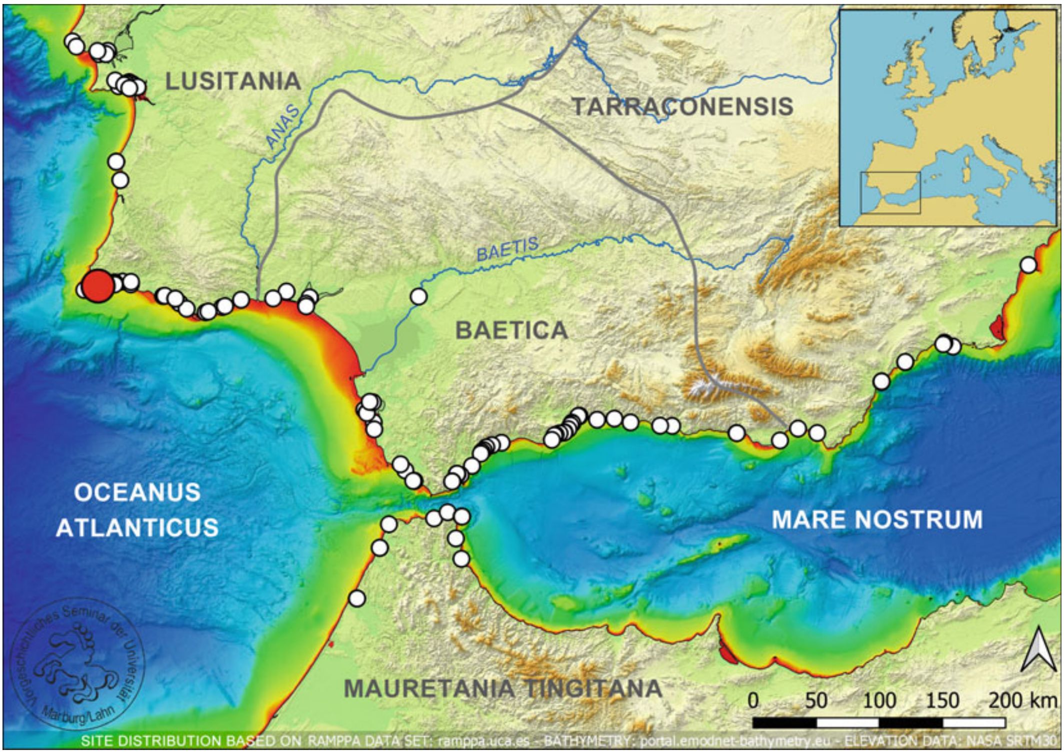

Fig. 10.1 Distribution of Roman fish-salting facilities around the Strait of Gibraltar in the southern Hispanic and North African provinces of the Roman Empire, with the red circle marking Boca do Rio's position

Possibly based on a Punic-Carthaginian tradition, the earliest evidence of fish preservation in southern Hispania in Roman times was dated to the late Republic (Bernal Casasola 2009; Bernal Casasola et al. 2018; Bernal Casasola and Vargas Girón 2019). From the first century BC onwards, the first facilities equipped with *opus signinum* lined vats—which would be subsequently commonplace during the Roman imperial period—began to appear (Bernal Casasola 2009; Trakadas 2015). After the turn of eras, numerous small and large facilities were built in the *Lusitania* province, including the supra-regional production centre of Tróia next to Setúbal (Fabião 2009; Vaz Pinto et al. 2014). The ongoing construction of new facilities and the associated growth of the aggregated vat capacities continued well into the second century AD, at the end of which a sudden upheaval can be observed (Lagóstena Barrios 2001). This is illustrated by a significant reduction in the overall vat capacity in *Hispania* due to the complete or partial abandonment of individual facilities (Wilson 2006).

Traditionally, this development is associated with the 'crisis of the third century', which is well documented for the Hispanic region, or the *bellum mauricum* and its economic and political repercussions (Reece 1981; Fabião 2008; Bombico 2015; *bellum mauricum*: Fabião 2004; Trakadas 2005).

Apart from the aforementioned anthropogenic influences, more recently natural factors have been suggested as an explanation for the changes occurring between the second and third centuries AD. On the one hand, all Roman coastal settlement were heavily dependent on the development and stability of their immediate natural environment, which has been clearly demonstrated in the settlement of Cerro da Vila in Vilamoura (Hilbich et al. 2005; Teichner 2014b, 2016, 2017; Teichner et al. 2014). On the other, Mayet and Silva (2010) suggested the possibility

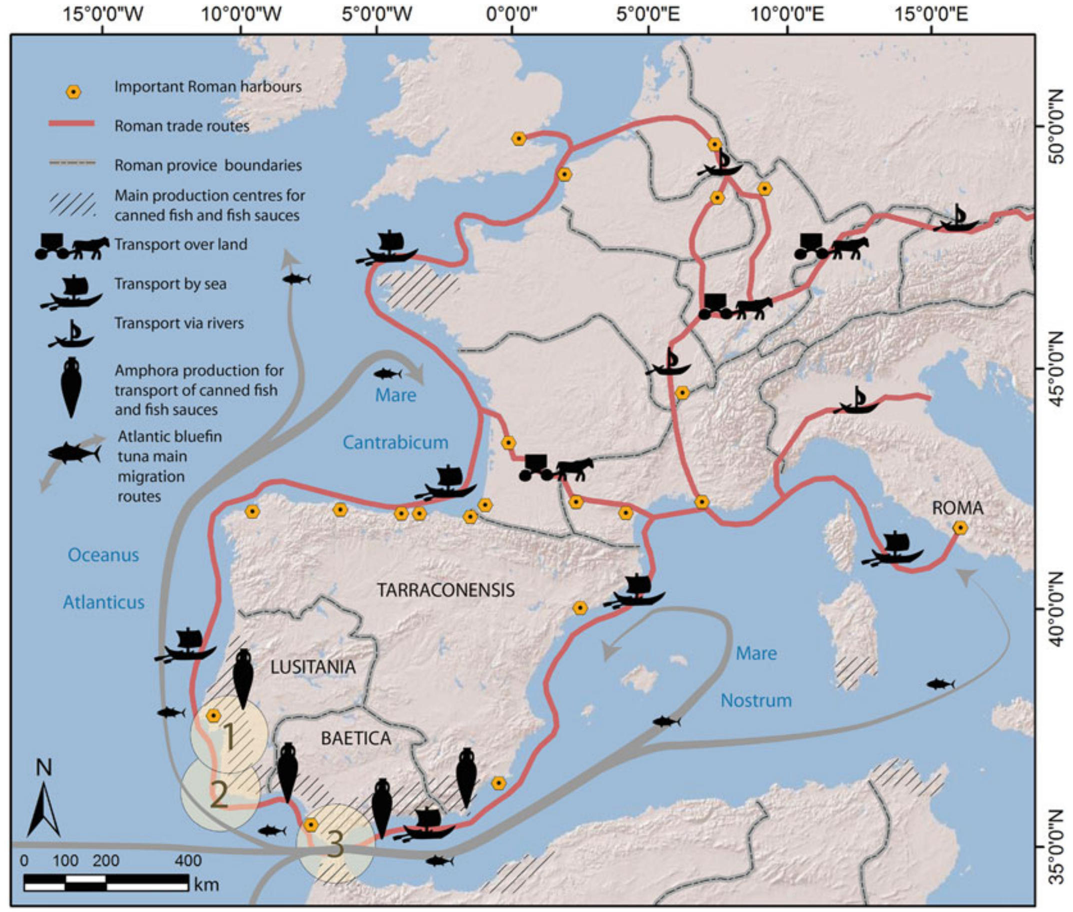

Fig. 10.2 Simplified Roman trade routes and the location of the three key regions covered by the research project: (1) the Costa Alentejana, Tróia; (2) the western Algarve, Boca do Rio (presented in this study); and (3) the Strait of Gibraltar, *Baelo Claudia* (Bolonia). Own elaboration; Atlantic bluefin tuna migration routes, after Fromentin and Powers (2005)

of a major flood or tsunami as a trigger. They based their hypothesis on destruction horizons and vat fillings in a handful of Portuguese (Tróia, Setubal, Sines and Ilha do Pessegueiro), southern Spanish (*Baelo Claudia*) and northern Moroccan (Cotta) sites which may be dated to this period. Although their hypothesis was subsequently taken up in the literature (e.g. Vaz Pinto et al. 2014), this alleged event has yet to be geologically or archaeologically evaluated. Be that as it may, it serves as a working hypothesis for the study described in this chapter.

The vats built after this change, viz. from the third century AD onwards, are usually smaller than their predecessors. Additionally, the subdivision of existing vats is often observed in the case of the continued use of facilities (Wilson 2006). However, the biggest change in *Lusitania* was the introduction of new, locally produced fish sauce amphorae (Diogo 1987; Fabião 2004) and the construction of new facilities in the previously underrepresented Algarve region. This is interpreted as a decoupling of the Lusitanian economy, in particular that of the Algarve, from that of the hitherto dominant province of *Baetica*, only made possible by this 'crisis' (Fabião 1992; Teichner 2008; Bernardes and Viegas 2017).

By the end of the fifth century AD, most of the sites had ceased production, although some continued to operate on a much smaller scale during the following centuries (Wilson 2006; Maghreb: Trakadas 2015; Hispania: Lagóstena Barrios 2001; Portugal: Teichner 2008; Fabião 2009).

10.2 Testing the Tsunami Hypothesis—'Vulnerability' of the Algarve Coast to Extreme Wave Events

In the light of new data, natural causes have yet again been put forward as an explanation for the observed breaks in coastal settlement patterns in Antiquity in general, especially in the second and third centuries AD. Particular emphasis has been placed on the possible role of single events like earthquakes or extreme wave events (hereinafter EWEs) (Étienne et al. 1994; Grützner et al. 2012; Röth et al. 2015; Gómez et al. 2015; Silva et al. 2016; Teichner 2017; Arruda, this volume; Frenken et al., this volume). This hypothesis—among other natural causes—was tested in a 3-year research project funded by the German Research Foundation (DFG). Specifically, three key regions of the fish-salting industry were identified, and in each one of them a reference site was selected and investigated: (1) the Costa Alentejana with the site of Tróia on a peninsula just outside the port of *Caetobriga* (Setúbal); (2) the western Algarve with the settlement of Boca do Rio west of Roman *Lacobriga* (Lagos); and (3) the city of *Baelo Claudia* (Bolonia) in the Strait of Gibraltar (Fig. 10.2). In this chapter, the results from Region 2 and its reference site of Boca do Rio are presented and discussed.

The Algarve coast—with Boca do Rio as the reference site—has a high potential for earthquakes and associated tsunamis due to its tectonic setting within the Gulf of Cádiz, close to the Eurasia-Africa plate boundary (Lario et al. 2011; Duarte et al. 2013). Several tsunamis hit the Algarve coast in historical times (60 BC, AD 382, 1722, 1755, 1761, 1941, 1969 and 1975—Portuguese tsunami catalogue: Baptista and Miranda 2009). It should be noted, however, that not all of the listed events affecting the Algarve region have been accepted as tsunamis in view of the sedimentary analyses performed to date. In particular, the reliability of the events dated to 60 BC and AD 382 is debatable, as their descriptions in the written sources are in all likelihood associated with events occurring at different times and places, such as the 63–65 BC Syrian and AD 365 Cretan tsunamis (Andrade et al. 2016), or their historicity is very questionable (Baptista and Miranda 2009; Álvarez-Martí-Aguilar 2020, this volume). Further east along the coast of the Spanish Gulf of Cádiz, one or more additional events occurring during the Republican period (ca. 250 ± 50 cal. BC; Lario et al. 2011; Costa et al., this volume) have been reported at several locations based on geological evidence (e.g. Bay of Cádiz: Luque et al. 2002; Guadalquivir estuary: Rodríguez-Ramírez et al. 2016). Similarly, Bermejo Meléndez et al. (this volume) and Gutiérrez-Rodriguez et al. (this volume) focus on events occurring in the areas of Huelva and Seville in Imperial times and late Antiquity, respectively. Of all events listed in the catalogues, only the devastating tsunami following the AD 1755 Lisbon earthquake has been comprehensively analysed. Along the Algarve coast, the sedimentary footprint of the AD 1755 tsunami is well preserved (e.g. Andrade et al. 2004; Kortekaas and Dawson 2007; Dinis et al. 2010; Schneider et al. 2010; Costa et al. 2011, 2012a; Trog et al. 2015; Quintela et al. 2016), especially at the site of Boca do Rio, where the AD 1755 deposit is sandwiched between finer grained floodplain strata, which has led to numerous studies focusing on various characteristics of the event deposit (e.g. Dawson et al. 1995; Hindson et al. 1996; Hindson and Andrade 1999; Oliveira et al. 2009; Cunha et al. 2010; Costa et al. 2012b; Font et al. 2013; Feist et al. 2019).

Apart from the relatively high tsunami potential, storms frequently trigger EWEs along the Algarve coast (Ferreira et al. 2008); however, only a few sedimentary imprints have been documented for the coastal lowlands of Martinhal, close to Boca do Rio (Kortekaas and

Dawson 2007), and for the Ria Formosa barrier island system of Faro further to the east (Andrade et al. 2004).

Besides this excellent setting for tsunami research, there was a Roman fish-salting settlement in the valley of Boca do Rio (Bernardes and Medeiros 2016; Bernardes et al. in press; Hermann et al. 2022, in press). The combination of these two factors led to the selection of this settlement site and its immediate surroundings for the study at hand, whose aim—as will be explained below—is to answer the following research questions:

1. Since few details are known about the industrial area of the settlement of Boca do Rio: what was its size and what role did it play in the fish-salting industry network?
2. Were there any changes and/or hiatuses in this settlement between the second and third centuries AD, as has been recorded in other coastal settlements? If so, how can they be characterised?
3. Are there traces of EWEs in the sediments of the immediate surroundings and/or in the archaeological remains? If so, can the traces of identified upheavals (no. 2) and EWEs be correlated, that is, can the former be attributed to the latter?

10.3 Topographical–Geological Environment and Archaeological Overview of the Site of Boca do Rio

Boca do Rio is located on the south-western Algarve coast, Portugal (08°48.5’W and 37° 04’N; Hindson and Andrade 1999), approximately 18 km east of Cape St Vincent (Sagres) and 15 km west of the town of Lagos (Fig. 10.1). It is a formerly V-shaped, flat-floored, sediment-filled river valley, dissecting a coast with prominent Jurassic and Cretaceous cliffs to the west and east, and bordered by the Atlantic to the south (Hindson et al. 1999). This floodplain valley, consisting of mostly fine-grained Holocene sediments (silt, clay), extends up to 1 km inland, where it is divided into three sub-valleys by the rivers Budens, Vale de Boi and Vale de Barão (Hindson and Andrade 1999). The highly variable and seasonally blocked gravelly and sandy river mouth influences the surrounding floodplain and beach, depending on the river’s water level (Costa et al. 2012b; Feist et al. 2019). A dune complex, bordered by steep terrain with an eroding cliff and a beach break with coarse gravel and boulders from the cliff, is situated to the west of the floodplain (Feist et al. 2019). This dune complex covers the Roman ruins.

At the beginning of the Roman occupation of the site in the second half of the first century AD, it is assumed that the bay was still largely open to the sea, but protected by a barrier. Identified palaeochannels of the aforementioned rivers on the western edge of the present alluvial plain, however, indicate that the estuary was practically unnavigable (Feist et al. 2019). The retreating coastline on the other hand, offered ideal conditions for the production of salt in salt gardens due to an extensive salt marsh on its edges and high evaporation during the summer months (Bernardes 2007; Fabião 2009; general prerequisites: Lagóstena and Palacios 2010; for comparison: Teichner et al. 2014).

As the siltation of the estuary progressed, it gradually lost its littoral character, while fluvial and alluvial conditions as precursors of the present geomorphology began to prevail, until the current direction of the watercourse along the eastern edge of the valley was established (Hindson et al. 1996; Allen 2003; Vigliotti et al. 2019; Feist et al. 2019). This process was greatly accelerated by the impact of the AD 1755 tsunami, which not only introduced a large amount of additional sediment but also severely restricted river discharge (Font et al. 2013).

The settlement site comprises three principal areas (Hermann et al. 2022). Firstly, a very densely built-up area to the south, divided into the *pars urbana*, or residential area with a *thermae* building and adjoining industrial complexes featuring fish-salting workshops (Fig. 10.3, between markers ‘harbour’ and ‘cliff’); and, separated from this area, a group of buildings further north-west, including ‘industrial’

Fig. 10.3 Overview of the results of the geomagnetic measurements at the site of Boca do Rio. The marked spots are mentioned in the text

structures, such as two kilns belonging to a pottery workshop (Fig. 10.3, marker 'kiln II').

The existing interpretation of Boca do Rio's building stock is based on an 1878 plan of the area on the present-day cliff (da Veiga 1910; Figs. 10.3 and 10.5 for details). Although most of the structures recorded at that time have since deteriorated due to coastal erosion (Hermann et al. 2022; Fig. 10.5), this old record has recently been reviewed and reinterpreted by Bernardes and Medeiros (2016). For these authors, they are residential and utility buildings constructed in the third century AD. The settlement's fish-salting workshops, on the other hand, have yet to be documented in detail (Alves 1997). Nevertheless, it is believed that they must have included facilities for the processing of marine resources (Bernardes 2007). So far, the dating of the site is largely based on Bernardes' stratigraphic work around the ruins of the eighteenth-century buildings of the Portuguese Royal Fishing Company (Fig. 10.4 for location), specifically, in the areas in which the residential and utility buildings of the Roman settlement were located (Bernardes et al. in press). On this basis, the earliest phase of settlement can be dated to the Flavian period (AD 69–96; Bernardes and Medeiros 2016). The area close to the beach was comprehensively reorganised as of the third century AD, which involved demolishing previous structures. Their earlier existence is only indirectly borne out by dominant levelling layers (see below section profiles for details). Thus, the majority of the building structures documented by da Veiga (1910) can be dated to this later period (Bernardes 2007; Teichner and Mañas 2018). Over its approximately 150 years of use, the building complex underwent numerous minor additions and alterations, such as repairs to the mosaics and the application of several layers of painted plaster on the walls. The last traces of the settlement's activity were reported in the form of African red slip (ARS) and Chiara C and D ware, datable to the end of the fourth or to the beginning of the fifth century AD. A vast coin hoard discovered in 1938, mostly consisting of emissions from the last third of the fourth century AD (the latest struck during the reign of Honorius), also points to this time horizon (Santos 1971; most complete coverage by Conejo Delgado 2019). Thereafter, the area was abandoned and probably only resettled in the fifteenth or sixteenth century. After the 1755 Lisbon tsunami, new short-lived buildings belonging to the aforementioned Portuguese Royal Fishing Company were constructed, the ruins of which are still visible (Bernardes and Medeiros 2016; Bernardes 2007; also Figs. 10.3 and 10.4).

10.4 Extent of the Fieldwork and applied Methodology

The campaigns conducted during the three years of fieldwork were based on a comprehensive survey of the site in the spring of 2017. This included geological drillings in the alluvial plain (Fig. 10.4; Feist et al. 2019), a geophysical measurement campaign (Fig. 10.3; Bernardes et al. in press; Hermann et al. 2022) and a detailed archaeological recording of the marine cliff's stratigraphy in 11 profiles (Fig. 10.5).

The results of the geophysical prospection (geomagnetic, resistivity and georadar) allowed for the analysis of the site as a whole, as well as the detailed identification of the individual building structures. Based on these insights, those structures whose outer shape and features ensured a heterogeneous sampling, especially as regards their chronology, and thus a representative cross-section of the history of the site's industrial area,

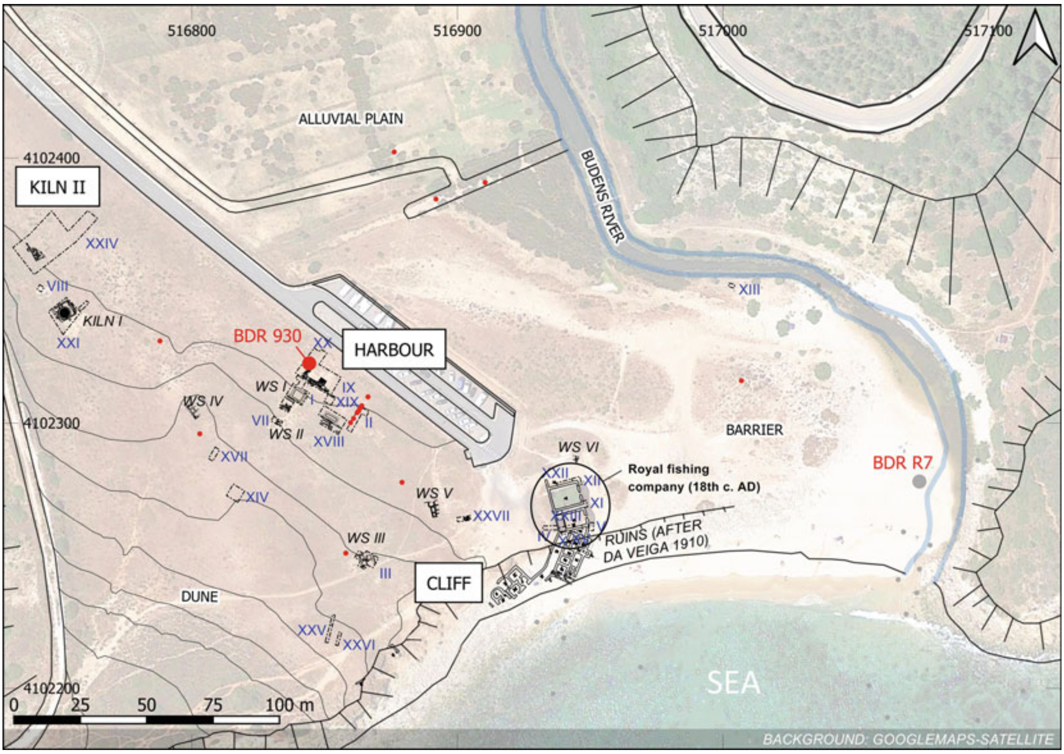

Fig. 10.4 Location of the archaeological trenches (blue, numbering after Table 10.1), sediment cores (red) and reference sites (grey), highlighting the three areas covered in this study (cliff, harbour and kiln II)

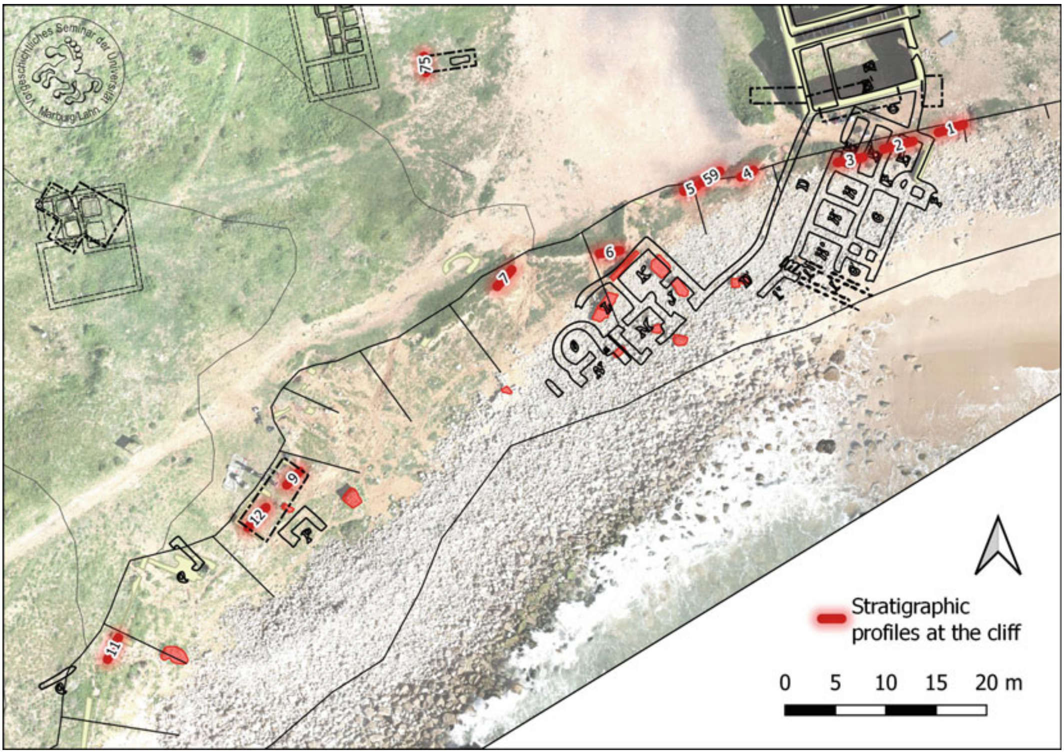

Fig. 10.5 Orthographic view of the beach area indicating the structures documented in 1878 (da Veiga 1910) and the cliff profiles mentioned in the text. Further inland, the partially excavated workshops III (west) and V (north) are shown (cf. Fig. 10.4). For the recent highly dynamic development of the cliff and its possible impact on the coastal settlement, see Hermann et al. (2022). Background image: own orthographic photograph, spring 2017

were selected systematically in 18 archaeological diagnostic trenches excavated during the subsequent campaigns (Fig. 10.4; Table 10.1). Following the excavation of first trenches during the 2017 summer campaign, three fish-salting workshops (WS I–III, Fig. 10.4) could be identified, thus supplementing the three unearthed previously in Alves' excavation (WS IV–VI, Fig. 10.4; Alves 1997). Of the first group, trenches I and II, and subsequently also IX, XVIII, XIX and XX, consecutively recorded relevant parts of workshop I and the associated harbour

Table 10.1 List and characteristics of selected trenches excavated in the industrial area, plus their connection to trench profiles and samples as mentioned in the text. For their location, see Fig. 10.4

	Campaign	Excavated structure	Investigated area (m^2)
I	Summer 2017	Workshop I, production area and harbour facilities	57.0
II	Summer 2017	Workshop I, storage rooms	12.5
IX	Summer 2018	Harbour facilities in front of workshop I	8.0
XIX	Summer 2018	Workshop I, production area	9.5
XX	Spring 2019	Harbour basin in front of workshop I **Profile 58, sediment core 930, bulk samples**	61.0
XIV	Summer 2019	Kiln II **Profile 58**	70.0

facilities (Bernardes et al. in press). In 2018, workshop II was investigated in trenches VII and XVIII, while workshop III was documented in trench III during the 2017 summer campaign (Fig. 10.4). After the promising results yielded by test trenches VI and VIII in the spring of 2018, a part of the pottery workshop to the north of the settlement was investigated in trenches XXI and XXIV in the following year. At two different locations, a Roman waste dump extending along the south-western edge of the settlement's boundary was documented in trenches XIV, XVII, XXV and XXVI.

In this study, a number of archaeological and geological features (walls, levelling layers, event layers, etc.), whose unique IDs is given in brackets (…), are addressed. This follows the excavation documentation based on stratigraphic units (UE, 'unidade estratigráfica').

10.5 Results and Interpretation

10.5.1 The Settlement

According to the geophysical measurements, the Roman settlement extended in a NW–SE direction approximately 180 m along the palaeo-estuary (Hermann et al. 2022; Fig. 10.3). Most of the remaining structures are fish-salting workshops, as demonstrated by recent excavations (Bernardes et al. in press). Their estimated accumulated vat volume distinguishes Boca do Rio as a supra-regional centre of this non-agricultural economy. Parts of these workshops, three of which have been diagnostically excavated in 2017–2019, are presented in this chapter. The northern part of the settlement is occupied by a small pottery workshop with two pottery kilns, of which kiln II will be briefly described here.

10.5.2 The Cliff

The profiles mapped along the current sandy cliff in the spring of 2017 (profiles 1–7, 9, 11–12), the spring of 2019 (profile 59) and the summer of 2019 (profile 75 in trench 27) were primarily intended to provide a stratigraphic overview (Fig. 10.5). Since numerous archaeological features (walls, debris layers, etc.) were already visible in the eroded coastal profile, a broad chronological cross section of the settlement's development on the site could be anticipated.

The connection between the stratified wall segments identified in the profiles of the active cliff, and the structures known from earlier investigations is of great importance for the interpretation of the settlement's development. Yet, the ground plans of the walls are only known with sufficient certainty in individual cases, such as profiles 9 and 12 (building P in da Veiga 1910) and profiles 2 and 3 ('*thermae*' building B/E in da Veiga 1910). Profile 11 was located directly between the two uppermost parts of the building (121) on the dune, which are only partially known ('cistern', building Q in da Veiga 1910). Of the 11 profile sections documented, profiles 2 and 3 forming the lower part, and 9 and 12, the higher part of the cliff, offer the aforementioned valuable connection with the building structures, which is why they are discussed here in detail. As the general stratigraphy observed in those profiles is similar to that of the other profiles, they are taken as representative of the cliff's general evolution.

Profiles 2 and 3 (Fig. 10.6) are located between the walls (138) to the west and (1) to the east, which belong to corridor D and rooms B/E, after da Veiga (1910) in Fig. 10.5. The archaeological features found are therefore primarily the filling of the interior of this building. The two separating walls of room E, as noted by da Veiga (1910), which divide the two profiles (71, 110), were also documented.

The oldest recorded structure in relative chronology is the remnant of a wall (97) with a preserved top at 3.70 m a.s.l. (above mean sea level), built directly on top of the boulder beach surface (Fig. 10.6). With a green compact loam band at 3.60 m a.s.l. further west (87), a loamy rammed earth floor probably associated with this wall is fragmentarily preserved.

The following levelling works (83, 85, 86; 92, 108) form a horizontal stratum covering the wall

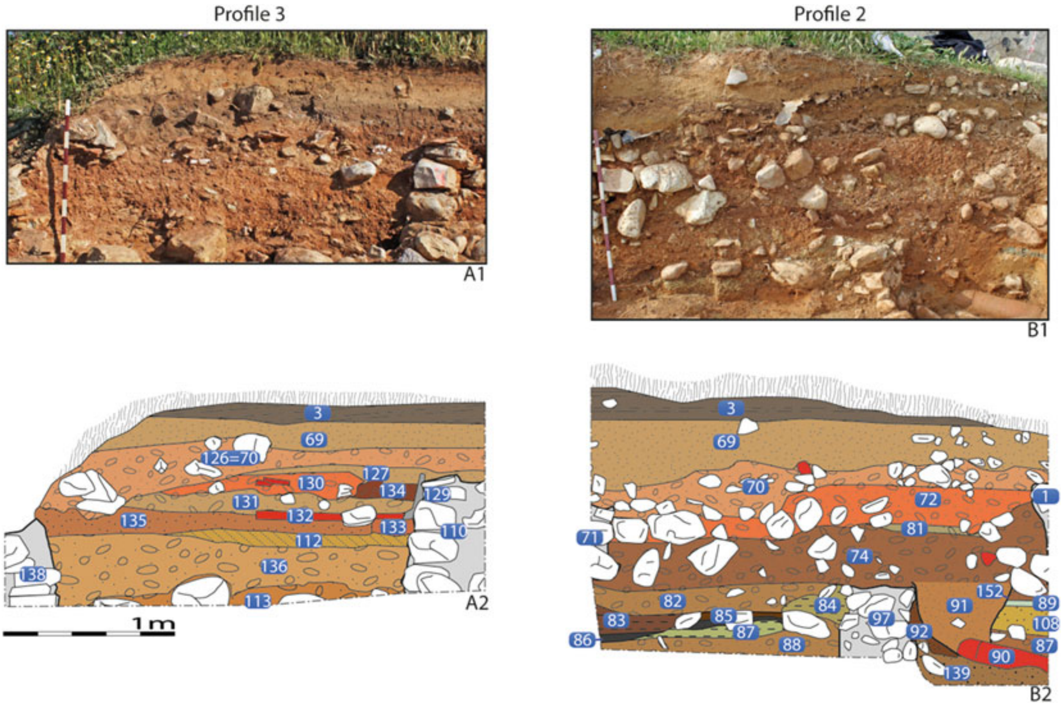

Fig. 10.6 Photograph and schematic presentation of neighbouring cliff profiles 3 (A) and 2 (B). The profiles are limited by the walls of the surrounding Roman structures; only the main features mentioned in the text are numbered. Profiles face south

(97) at 3.75 m a.s.l. In places, it can be seen that their common upper edge is terminated by a compact greenish loam layer (89 = 84). This shaped an occupation level and is only documented between the walls (1) and (110), whereas it seems to be non-existent to the west, namely, towards the wall (138). However, this wall (138) has the same depth of foundation as the walls (110) and (1), that is, directly down to the beach surface. It is possible that the floor in the area between the walls (110) and (138), which would have consisted only of rammed clay, was destroyed to such an extent in later times so as to be currently unidentifiable (see below). This, however, cannot be clarified without further archaeological interventions. On the other hand, it is certain that the floor (89 = 84) identified between the walls (110) and (1) is linked to the earliest use of those later walls.

This floor (84/89) had subsequently been affected by the digging of a pit (152) for the construction of a water pipe (90). The filling of the pit with silty sand and rubble (91), together with a further levelling layer (82), formed a new walking horizon, which was raised by 0.18 m to an absolute height of 3.93 m a.s.l. In this phase, the area between the walls (110) and (1) was also further divided by the construction of a small wall (71) above the old walking level (84). For the first time, a walking level in the form of a red rammed earth floor (132) can also now be detected to the west of the wall (110), namely, between the walls (110) and (138). At 4.40 m a.s.l., this is slightly higher than the walking level between the walls (110) and (1) and has a foundation of massive levelling of the area between the walls (138) and (110), formed by the layers (113), (136), (112), (133) and (135). The connection between the floor level (132) and these walls is marked by the corresponding plaster (129) on both faces of the wall (110). Subsequent layers indicate centuries of decay of the structures, while the uppermost layers (69) and (70 = 126) are the result of earlier archaeological interventions, like Alves' excavation in 1982 (Alves 1997).

Unfortunately, there is no stratified, datable archaeological material available in profiles 2 and 3. However, the surface formed by the red rammed earth floor (132), (89 = 84) as well as the plastering (129) on the wall (110), is the southern continuation of the features excavated in 2010 by Bernardes and Medeiros (2016), who identified a fragment of South Gaulish Samian Ware Drag. 29 found beneath the layer (87). According to their results, the second stage of construction identified in the profiles, that is, the walls (1), (110) and (138), as well as the plaster (129) and the surface (132), may therefore date, at the earliest, to the first half of the third century AD. The preceding construction, namely the wall (97), is thus of a relatively earlier date (late first / early second century AD), while the segmentation of the eastern space E'/E' by means of the wall (71) is somewhat later.

Profiles 9 and 12 (Fig. 10.7) are located in the eastern (9) and western (12) parts of two rooms visible in the cliff. In da Veiga (1910), they are documented as part of building P (Figs. 10.5 and 15.7). In profile 9, a trench was excavated to a depth of 2.50 m below the preserved floor level of the rooms at 7.65 m a.s.l, and in profile 12, to a depth of 1.60 m. In this way, it was also possible to document the deeper sand layers of the dune, namely (119, 114, 120, 117, 33), in profile 9.

The oldest identified layers are well stratified dune sands (profile 9: 119, 120, 33; profile 12: 115, 116) with up to 0.20 m thick reddish brown, slightly loamy horizontal discolourations with clear traces of bioturbation—signs of incipient soil formation on the dune surfaces (114, 117). On top of one of these surfaces (114), at 6.30 m a.s.l., the coarsely fragmented remains of a Dressel 7–11 fish sauce amphora and some quarry stones were found. In contrast, the other sand layers did not yield any archaeological finds.

The upper part of the sand (33 = 116) shows a grey humus section with clear traces of bioturbation (31 = 118). It seems to have been exposed for a long time and to have been overgrown by vegetation. Finally, clayey layers (profile 9: 28, 24, 25; profile 12: 42, 41), with inclusions of building material, in particular lime mortar (27, 34), and a layer of ash and charcoal (26), were deposited on top of it in close temporal succession—most likely the building layers associated with the surrounding structure.

In both profiles, but especially in profile 9, the change from the use of a natural, unpaved surface within the dune, i.e., the layers (114) and (117), to the construction of the building can be clearly observed. The ceramic material from the sand (115) (profile 12), samian ware of Gaulish as well as Hispanic provenance (115–006, 007, 008; 115–002), as well as the Dressel 7–11 fish sauce amphora, plainly indicate a time horizon for the use of these surfaces between the first and second centuries AD. This is supported by the ^{14}C dating of a piece of charcoal from the layer (114), which hints at a second century AD origin (BDR-17–145; Table 10.2). In the upper layers (33) and (28) in profile 9, and the layers (116), (42) and (41) in profile 12, the early ceramic material (28: 028–001; 33: 033–004, 005; 116: 116–006; 41: 041–001, 004, 42: 042–005, 009) still predominates. The presence of African kitchenware in (33), however, indicates a later date, namely, well into the second century AD or the beginning of the following one (33: 033–001, African kitchenware Hayes 181 B). The filling (42) under the later floor may then already date from the fourth century AD, as indicated by African kitchenware Hayes 196/185D shards (042–002, 003). It gives a *terminus post quem* for the overlying layers, namely, the ones linked to the building's construction horizon above the sand surfaces (31) in profile 9 and (118) in profile 12.

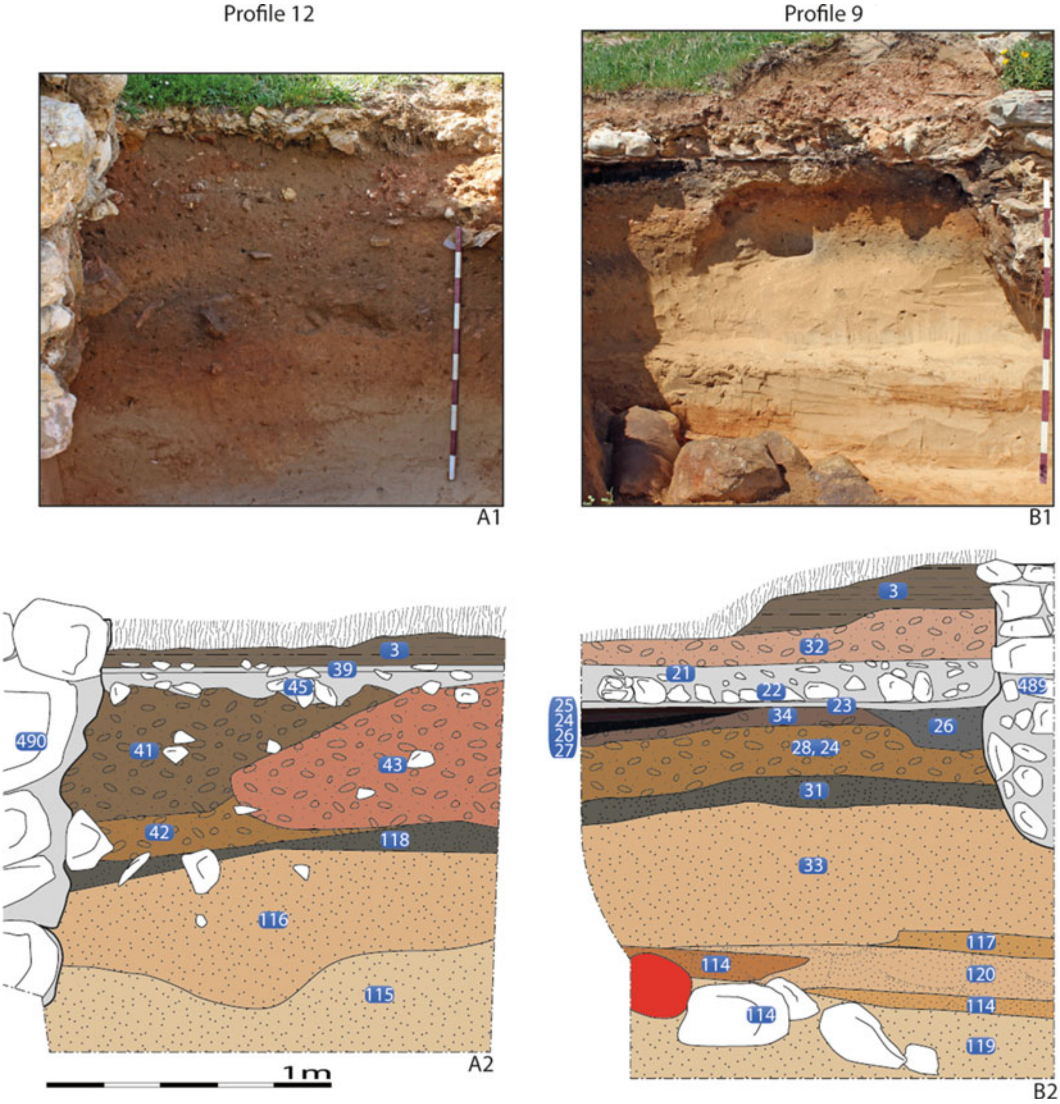

Fig. 10.7 Photograph and schematic presentation of profiles 12 (A) and 9 (B) at the cliff, limited by the Roman wall structures. Main features mentioned in the text are numbered. Profiles face south-east

10.5.3 The Harbour

The identified harbour facilities include parts of a large workshop, listed here as workshop I. A rectangular, NW-SE oriented building, 45.0 m long and 9.5 m wide, is clearly visible in the geophysical measurement data (Fig. 10.3). The regular internal division—production vats—was also evident geophysically and, thanks to the excavation results, a detailed interpretation was possible (Hermann et al. 2022, in press; Bernardes et al. in press). In front of the central segment of the complex, it was discovered that a stone quay, with direct access to the interior of the workshop, had been built.

10.5.3.1 The Quay: Harbour Front, Ramp and Platform

The building was accessible via an elevated rectangular platform measuring 1.20 m × 1.50 m

Table 10.2 Results of ^{14}C (upper part) and OSL (lower part) dating of selected samples mentioned in the text

Sample code (1)	Lab code	Material	Others	14C years (2)	Calendar years (calibrated 2σ)	
BDR-17–145	Poz-104454	Charcoal		1850 ± 30 BP	121-248 cal AD	0.944
Context	Beach profile, PR 9, UE 114					
BDR-18–853	Poz-115463	Charcoal	0.6 mg C	1785 ± 30 BP	210-265 cal AD / 272-351 cal AD	0.342 / 0.608
Context	Trench I (extension spring 2019), Unit I/harbour basin, UE 249					

Radiocarbon dating by ^{14}C-laboratory Poznan. Calibration with Calib 8.2 [calib.org]

Sample code	Lab code	Burial depth (m)	H_2O (%)	U (ppm)	Th (ppm)	K_2O (%)	Cosmic (Gy)	Dose rate (Gy/ka)	Age (ka) before sampling in 2019	Calendar years (calibrated 1σ)	Model (3)
BDR-T1-2019 35–38 cm	UNL4484	0.365	3.4	0.58	1.11	0.35	0.20	0.682 ± 0.030	0.447 ± 0.030	1572 ± 30	MAM-3
BDR-T1-2019 36–45 cm	UNL4485	0.405	3.2	0.65	0.97	0.32	0.20	0.668 ± 0.029	0.610 ± 0.036	1409 ± 36	MAM-3
BDR-T1-2019 48–51 cm	UNL4486	0.490	3.2	0.45	1.24	0.46	0.19	0.749 ± 0.033	1.05 ± 0.05	969 ± 50	CAM

OSL-dating lab: Luminescence Geochronology Laboratory of the University of Nebraska

1 = BDR + Year of sampling + internal reference number / depth

2 = rounded to closest 5-year step (T. Goslar, Poznan laboratory, 15.07.2019)

3 = Model used to calculate age, CAM = Central Age Model, MAM-3 = 3 term Minimum Age Model, after Galbraith et al. (1999)

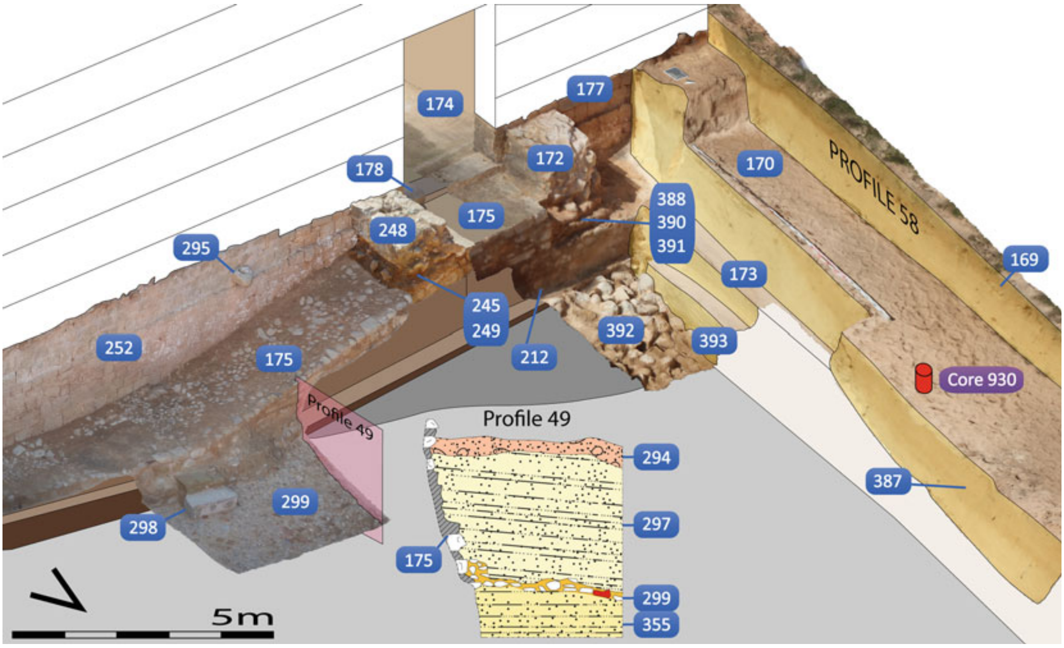

Fig. 10.8 Isometric view of the harbour facilities and the entrance to workshop I, with the position of profile 58 (Fig. 10.13), core 930's sample location and a schematic reconstruction of unexcavated features. The given view equals the proven minimal extent of the event layer (387). The inset shows profile 49 with the preceding palaeo-beach (355) and the early sedimentation layers (297) and (294)

1.30 m at its north-east façade, with a walking surface at 3.12 m a.s.l. (Fig. 10.8). Towards the north-west, this platform drops vertically down to a mat foundation (212) beneath it. To the south-east, however, a 0.15 m step connects the platform with a ramp (175), which has a gradient of around 9.1° and a minimum height of 2.1 m a.s.l. A two-stage staircase (298) built of *lateres* and a monolithic limestone ashlar is attached. Approximately 1.0 m above the level of the ramp (175), a vertically perforated mooring stone (295) protrudes 0.26 m from the façade of the wall (252) towards the former estuary. It shows clear signs of local abrasion along the edges of the inner side of its 0.10 m wide bore hole.

Typical biological markers such as barnacles (*Chthamalus* spp.) for the upper littoral zone, or limpets (Patellidae) for the middle littoral zone (cf. Laborel and Laborel-Deguen 1994, 2005), were not identified on the structures of the ramp or its foundation.

An approximately 5 cm thick layer of poorly sorted pebbles diameters of 2–6 cm (299) was found just below the bottom step of the staircase. It was mixed with medium-sized shattered and partially much worn ceramic material, broken shell fragments and traces of lime plaster. With its upper edge sloping slightly towards the north-east, this ancient surface can be interpreted as an intentional, anthropogenically reinforced beach section between 1.37 and 1.26 m a.s.l.

Beside the quay, an approximately 2.4 m-wide rampart of boulders (392) was placed in front of the walls (177 = 252) and their foundations (212) to support and protect the structures from waves and tides.

The quality of the construction, namely, the use of representative ashlar masonry in the quay wall, recalls the structure of kiln II (see below), as well as the earliest construction phase documented in the *thermae* area (Bernardes et al. in press). These structures may have formed part of the same building programme, which would have been carried out in the second century AD.

However, the decisive factor for the initial dating is the *terminus ante quem* given by the material of the subsequent modification of the quay (see below).

10.5.3.2 Changes in the Building Stock of the Quay and the Sedimentation of the Harbour Basin

In a second construction phase, roughly constructed quarry stone walls were erected on both sides of the rectangular platform (175), orthogonally adjacent to the outer wall (177 = 252). These—(248) to the south-east and (172) to the south-west—are between 0.90 and 0.95 m wide and extend over the width of the ramp (175) and the foundations (212) below. Due to their coarse type of construction, the two walls are quite distinctive in comparison to the original structure. Remarkably, both walls were erected at a distance of 0.25 m from the original platform (175), thus leaving 1.40 m long rectangular gaps, with a width of 0.25 m and a depth ranging from 0.15 to 0.20 m, between them.

They were both built on top of a more or less complex sequence of sediments and levelling layers. South-east of the ramp, on the original surface of the harbour basin, corresponding to the gravel layer (299), medium-sized sand (297) was deposited in 1–10 cm fine horizontal stratification layers (Fig. 10.8). Between these slightly NE-declining levels, isolated ceramic material and the bone fragments of small fish were found. This sediment reached the upper edge of the stairs (298) and the foundations (212). The sand layer (297) was overlaid by a light yellow, loose fine sand (294), with a thickness of about 0.60 m, which extends over the upper part of the ramp (175).

To the south-east, these naturally deposited layers (297, 393, 294) were followed by the clayey levelling layers (245) and (249), with the wall (248) resting directly on their surface. An accumulation of small to medium-sized field and quarry stones in the top levelling layer (249) served to reinforce the foundations.

To the north-west of the ramp (175), three levelling layers (391), (390) and (388), together only 0.5 m thick, were stacked on top of the foundations (212). With an irregular layer of small and medium-sized stones, the uppermost layer (388) formed the solid ground on which the wall was built (172) (Fig. 10.9).

The dating of this modification is mainly based on ceramic material from the aforementioned levelling layers. Regarding the construction of the walls built on top of them, they give a *terminus post quem*. Two fragments originate directly from the wall (248) itself (248-001: African kitchenware Hayes 23 B, 248-005; and Hispanic samian ware (TSH) base 27 or 24/25). Since the material is quite homogeneous, these works might have been carried out more or less simultaneously. In contrast, material from the sediments dating from before the modification work already contains African red slip ware (ARS-D) (236-033), which did not appear in the levelling layers below. This absence indicates that the modification took place, at the latest, in the first decades of the third century AD. A fragment of charcoal (BDR-18-853, Table 10.2) from the levelling layer (249) was ^{14}C-dated to 210-351 cal AD. In connection with the aforementioned chronological range of the ceramic finds, the overall picture of the levelling layers and the wall (248) points to the late second or the first half of the third century AD as a probable date for the modification work.

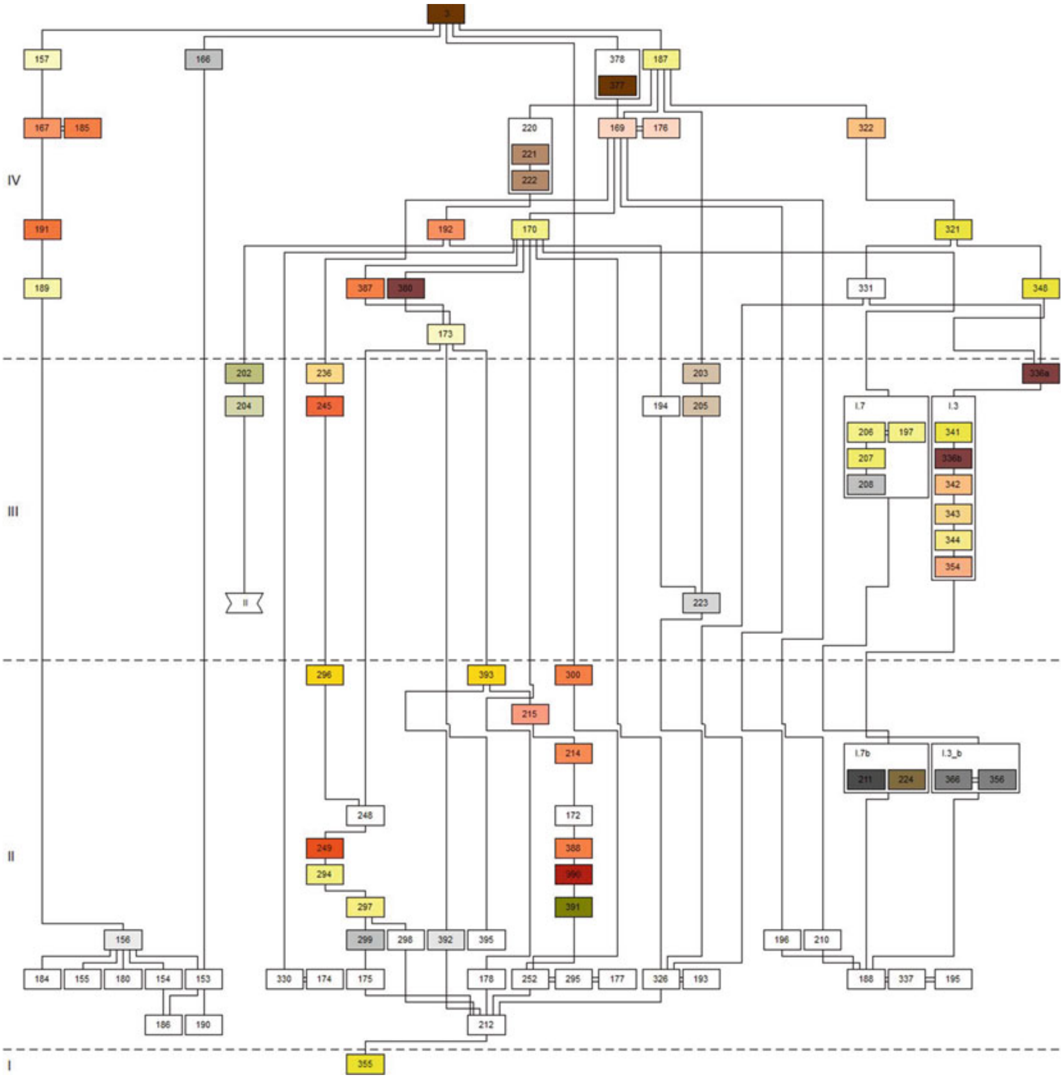

Fig. 10.9 Schematic representation of the stratigraphic units identified in sections I, IX, XVII, XVIII and XXI (see Fig. 10.4). The colours represent an approximation to the original colour of the layers. The white boxes represent construction elements (walls, floors/reinforced surfaces, etc.)

10.5.4 Kiln II

Of kiln II, located to the north of kiln I, only parts of the combustion chamber and the fire tunnel remain. As indicated in the results of the geomagnetic measurements (Fig. 10.3), the north-eastern half of these structures is lacking. It was not a stand-alone kiln, but integrated into a building made of clay pit walls with a stone base (442, 453). Parts of the rising wall structure were found to the west and south-west of the kiln in a collapsed position.

The stratigraphy around kiln II is mainly composed of undisturbed sands (457), as shown in profile 69 (Fig. 10.10). Sedimentary indicators hint at a subaerial beach environment at least for the lower part of (457). Below, a palaeo-riverbed (486) can be seen, indicating a former course very different from the river's present position in the east of the valley (Fig. 10.4). Roman tile

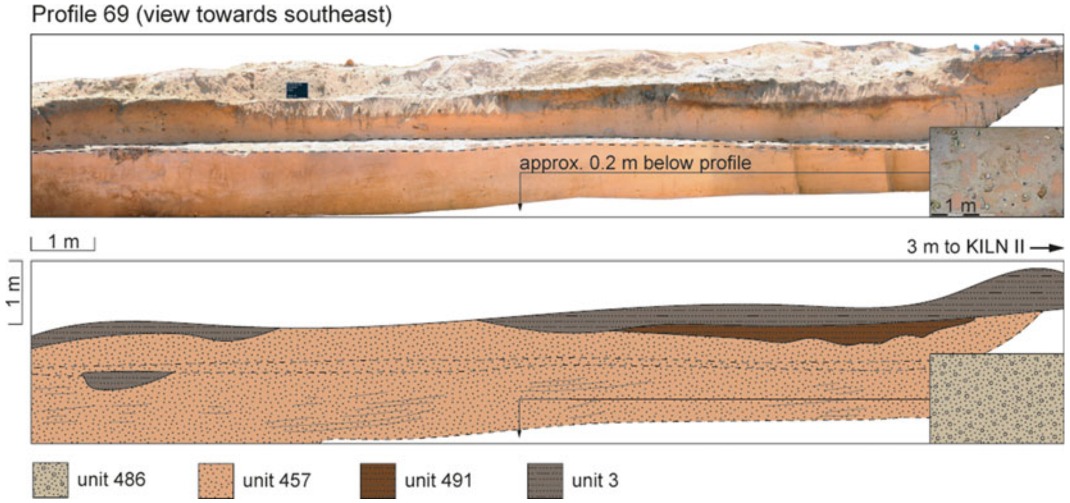

Fig. 10.10 Photo and simplified stratigraphy of profile 69. Unit 486 describes a palaeo-riverbed ca. 0.2 m below the documented profile (inlet). Unit 457 is composed of undisturbed sands, unit 491 is composed of silt and possibly part of a late Roman dirt track, and unit 3 is the uppermost top soil. The dashed lines highlight the stepped profile

fragments scattered on top of this surface already indicate an anthropogenic, that is, Roman, presence during that time. Due to the established general development of the settlement (see above), this surface should not be dated to earlier than the first century AD, the beginning of the settlement activity in Boca do Rio. The sand (457) is covered by the current top soil (3) and a silty layer, possibly a (late Roman) dirt road (491).

10.5.4.1 The Structure and Features of Kiln II

Kiln II was constructed as an updraft kiln, with the firing and combustion chambers aligned vertically. A round central column in the combustion chamber supported the perforated floor of the firing chamber (Figs. 10.11 and 10.12).

From the 1.68 m high preserved combustion chamber (435) a slightly elliptical semicircle with a width of 2.20 m is still visible. On the basis of the existing curvature, this can be reconstructed pointing to internal dimensions of 2.45 m × 2.20 m.

In the middle, there was a collapsed column of mud bricks, 0.60 m in diameter. The exterior wall (442) of the kiln building provided a representative façade and enclosed a rectangular area of at least 7.50 m × 4.0 m. Due to the massive destruction of the feature (see below), it is no longer possible to clarify its eastern extension with certainty. Only its length can be apparently established with certainty by the corner of the foundations to the north. Thus, there was an enclosed area of at least 3 m × 3 m in the apron of the fire tunnel. The contemporaneous occupation layer at 3.30 m a.s.l. consisted of a compact layer of red silty loam mixed with small fragments of limestone and sandstone (464). Due to its bad state of preservation, it was only found on a 0.40 m × 1.50 m strip west of the fire tunnel.

Inside the kiln, a single-layer floor paving of fired bricks (465) was laid out at 2.54 m a.s.l. Along its entire lower edge, and clearly less so below the fire tunnel, the sand underneath was partly vitrified. The fire tunnel to the north-west had a total length of about 1.60 m and was spanned by a round brick arch. The latter is only partially preserved, but based on the imprints of the bricks of the paving on the underlying vitrified sand, its reconstruction indicates that it would have had a width of approximately 0.70–0.80 m.

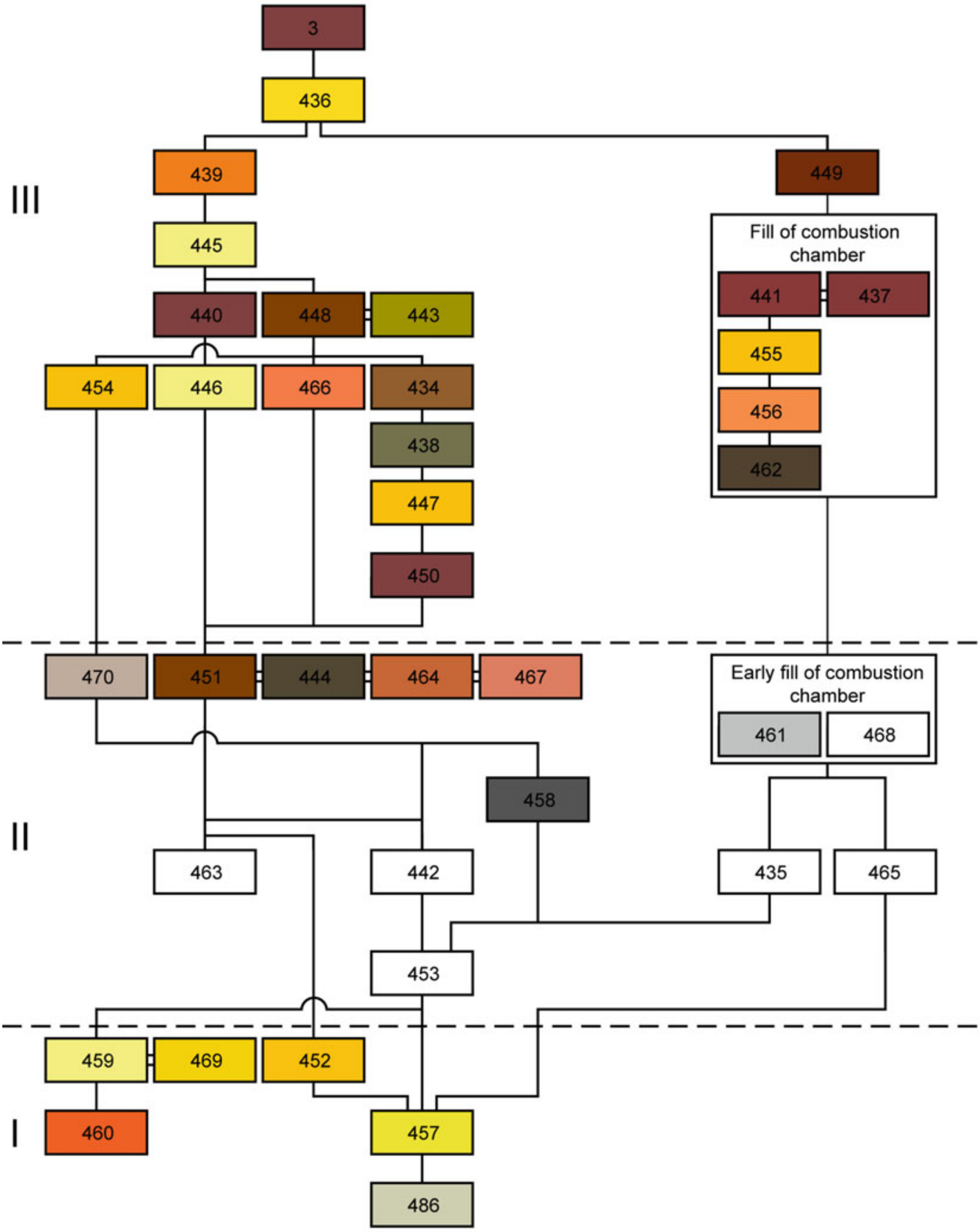

Fig. 10.11 Schematic representation of the stratigraphic units identified in trench XXIV (see Fig. 10.4) in the summer of 2019. The colours represent an approximation to the original colour of the features. Note the distribution of undisturbed (aeolian or littoral) sands in light yellow and anthropogenically influenced areas (loamy; reddish, brown). The white boxes represent architectural elements (walls, paving, etc.). Also, the three phases of the kiln (I = until construction, II = use and III = abandonment) are already visible

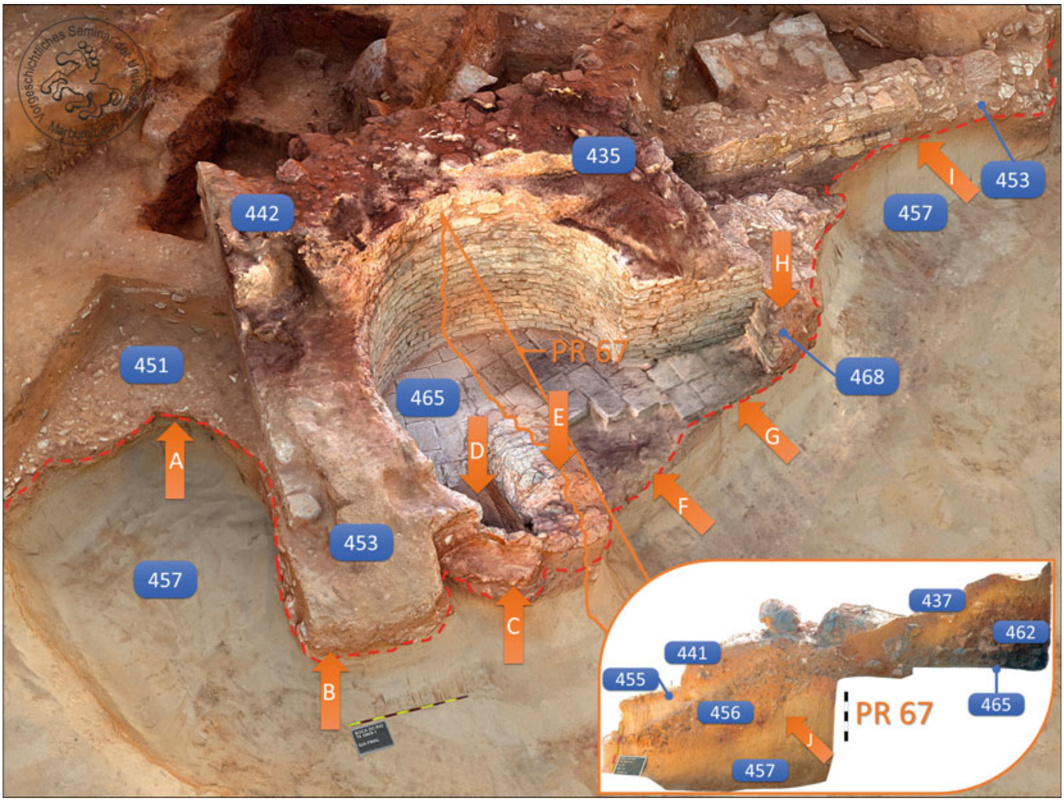

Fig. 10.12 Kiln II, highlighting the damage to the structure (orange arrows) and the limit of its conservation (red dashed line). Selected UE numbers mentioned in the text are noted in blue. Perspective from the east. Inset: NE–SW profile 67

Outside the kiln, a continuous paved surface was found to the west, south-west and south (458, 470 = 444 = 451 = 467) at about 3.30 m a.s.l. Due to its correlation to the upper edge of the foundations (453), it can be considered to have been in use at the same time as the structure.

From the area of trench XXIV, 11 datable ceramic pieces have so far been recovered and identified. The six pieces of African, three South Gaulish and two Hispanic kitchenware originate from three contexts: Post or late use waste layers (441) and (443), plus a surface used before the reinforced paving (458) around the kiln. In spite of the problems associated with their exiguousness, these pieces roughly indicate a possible period of activity of the kiln area between the second half of the first and the mid-third centuries AD.

Two of the early South Gaulish *sigillatae* (458-001: TSG Drag. 18, and 458-002: undefined base TSG) were recovered from the walking level (458), which correlates with the first usage of the kiln (see above). They provide a *terminus post quem* in the second half of the first century AD for the kiln's construction and usage. Taking into account the later deposits (434, 441), the kiln was most likely built at the end of the first or at the beginning of the second century AD.

The next datable deposit comprises the waste layers to the south-west of the kiln (434, 441). They contained organic and plentiful ceramic finds, of which the fine ceramics were chronologically quite homogeneous, with just three exceptions. Only two types of African kitchenware were found: one Hayes type 196 and five type 197. The other three pieces are Hispanic

Drag. 15 and 33, and a South Gaulish form (434-023: TSH Drag. 15, 434-024: TSH Drag. 33, 434-025: TSG, undefined base). Due to the great homogeneity of the pieces of African kitchenware, which provide a *terminus post quem* for their deposition in the last third of the second century AD, it may be assumed that the older pieces are scrap.

As later material is absent, the deposition of this settlement waste, namely, the continuous use of the exterior area of the kiln, probably took place during the circulation time of the aforementioned ceramic forms, that is, between the end of the second and the middle of the third century AD. The findings' homogeneous composition points to an abandonment of the area shortly afterwards. In fact, it might have been linked to the destruction of the kiln, whose characteristics are described in detail below.

10.5.4.2 The Destruction and Abandonment of the Kiln

The kiln and its extensions are heavily damaged along a NW–SE axis running across the structure (Fig. 10.12, red dashed line). While the parts of the structure to the west of this axis have been preserved, those to the east no longer exist.

First, the solid surface level (451) surrounding the kiln displays, especially in the southern part, a concave incision. Originally, it would have surrounded the structure (Fig. 10.12 A). At the easternmost point, the foundations are preserved only in a low-lying stone layer (B), above which only (later) collapsed material of the kiln wall (442) was found (E). A similar degradation can be observed to the north (I, H). At point C, the outer façade of the kiln wall (435) is reduced to the more stable vitrified inner half of the wall which was originally roughly 0.5 m thick; besides, the entire eastern flank of the kiln has disappeared without a trace. The debris layer (456) documented in profile 67 includes the collapsed material of the kiln's superstructure, like the firing chamber's floor, but not that of the enclosure (J, Fig. 10.12; inlet with profile 67). Inside the combustion chamber and fire tunnel, only the western part of that paving is preserved (C, D, G). Below the central column, the eastern part of the floor is also missing, which subsequently led to its collapse. Surprisingly, the underlying partially vitrified sand (= surface of 457) is still in place. The debris layers (456) and (441) deposited to the east of the kiln reach below the walking level of (465) inside. This underlines the fact that the sand (457) supporting the paving (465) had a distinct eastward slope at the time when these layers were deposited (Fig. 10.12 PR67). Originally, however, this substratum must have reached up to the lower edge of the paving (465). During or (shortly) before the destruction of the kiln, substantial parts of the sand appear to have been removed.

From these observations, the following conclusions can be drawn regarding the destruction of the kiln: it was an erosive process or an event that changed the appearance of both the building structure and the underlying sand (457). It was fast or repetitive enough to prevent sediment from being introduced to compensate for the void in the underlying sand (457), before the building material of the kiln collapsed into the created hollow. It was unsystematic, namely, it was not that certain parts of the building structure were damaged while others were spared; it took place on a broad front, affecting the entire structure and its surroundings. Ultimately, the destruction was massive enough to weaken the statics of the structure to such an extent that it disintegrated completely and a large portion of debris was carried away.

10.5.5 An Event Layer in the Harbour Basin and its Geophysical Description, UE 387

Still considered as being part of the sands (170) in the 2017 summer campaign, a very characteristic sediment layer (387) sandwiched between the deposits (173) and (170) was identified in the course of the following year's campaign (Fig. 10.13). This layer has been shown to

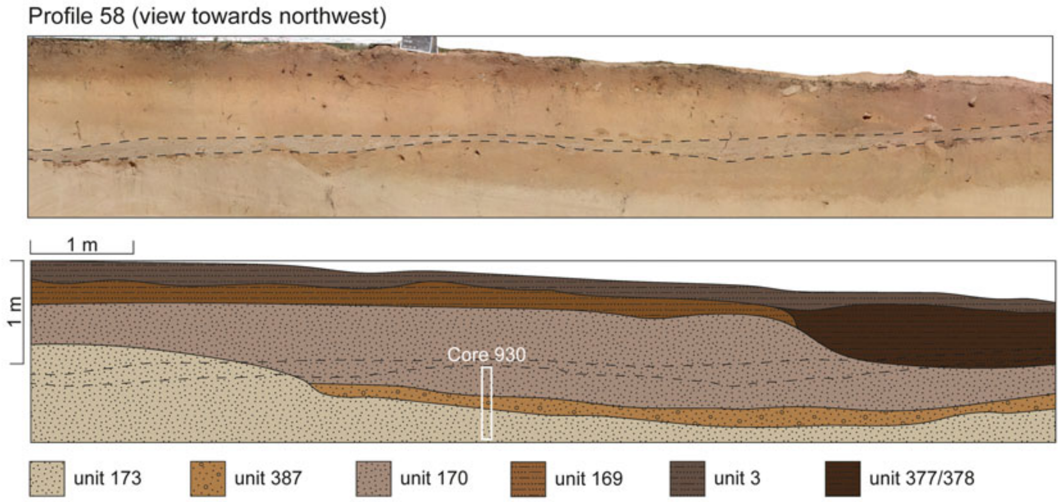

Fig. 10.13 Photograph and simplified stratigraphy of profile 58, including the location of sediment core BDR 930 (Figs. 10.4 and 10.8). The harbour facilities are located to the left. The dashed lines highlight the stepped profile

have a minimum extension over the entire harbour basin of 11 m × 9 m (=area excavated so far) (Figs. 10.8 and 10.13).

The most recent deposit in the area of the harbour basin is an approximately 0.2 m thick layer of debris (169). This layer extends up to the middle of workshop I, before slowly beginning to thin out uphill. Inclusions in this poorly sorted sediment are very often small to medium-sized stones from quarries and fields, shell fragments and mortar and plaster remains. This younger event layer (169) presumably matches that of the AD 1755 Lisbon tsunami, which has been widely preserved in the Boca do Rio floodplain and other locations along the Algarve coast.

For further analysis, a 71 cm long sediment core BDR 930 was drilled, which covered the sequence of early sedimentation of the basin (173-387-170; Fig. 10.13) (Table 10.3).

Composition of core 930

In general, the stratigraphy of the 71 cm long core BDR 930 is composed of three different sediment units. The lowermost unit (173), at a core depth of 37–71 cm (Fig. 10.14), consists of poorly sorted medium sand (1.6 Φ; Table 10.4). The upper part, until a core depth of approximately 45 cm, is slightly richer in shell fragments than the lower part of this unit. The colour is greyish orange (10 YR 7/4, Munsell Rock Color Chart 2009), while the magnetic susceptibility results give an average of $-1.4 * 10^{-5}$ SI, with $-5.0 * 10^{-5}$ SI as the lowest absolute value at the end of the core. Fe, Ca and Ca/Fe have the lowest values of the whole core (Fe: 1307 ppm, Ca: 50,685 ppm, Ca/Fe: 39). This unit is followed by 5 cm (387, 32–37 cm core depth, Fig. 10.14) of moderately sorted bioclastic medium sand (1.2 Φ; Table 10.4) which is slightly coarser than the other two units. Its colour is light brown (5 YR 5/6). The basal contact to the lowermost sediment unit (173) is clearly erosive. Magnetic susceptibility values for (387) rise to an average of $7.7 * 10^{-5}$ SI, with $12.0 * 10^{-5}$ SI being the highest absolute value at a core depth of 34.0 cm. Fe and Ca increase to 2744 ppm and 79,188 ppm, respectively, while Ca/Fe decreases to 29. The uppermost unit (170, 0–32 cm core depth, Fig. 10.14) consists of well-sorted medium sand (1.6 Φ; Table 10.4) with scattered shell fragments. At a core depth of 7.0 cm, a dark lens is visible, probably representing the remains of plant components. The colour of the uppermost sediment unit is dark yellowish orange (10 YR 6/6). The magnetic susceptibility of this unit

Table 10.3 Sampling and treatment process of the geological samples of the harbour basin

Methodologal approach		Resolution	Device
Volume-specific magnetic susceptibility		2 cm	Bartington MS2 Magnetic Susceptibility System with MS2K Sensor
Elementary composition, X-ray fluorescence (XRF)		2 cm	Hand-held Niton analytical device; exposure time of 45 s
Geochemical analysis of elements Ca, Fe and Ca/Fe ratio	Differentiation between terrestrial and marine environments (Cuven et al. 2013)	Supra	
Textural analysis by wet sieving of bulk samples from the core and its surroundings		10 cm intervals, except possible event layer (387). Idem in 4 cm intervals (29–33 cm upper contact, 33–37 cm possible event layer, 37–41 cm lower contact)	Retsch AS 200 sieve shaker; standard set of sieves in the range of −2 to 4 Φ in whole phi intervals
Micropalaeontological analysis		10 cm intervals, except possible event layer (387). Idem in 4 cm intervals (29–33 cm upper contact, 33–37 cm possible event layer, 37–41 cm lower contact); homogenised fraction of ca. 5–6 g per sample, sieved to >0.063 mm	Zeiss Stemi 2000 C microscope
Foraminifera content, qualitative and quantitative analysis	Minimum 100 benthic foraminifera for low diversity onshore assemblages (Fatela and Taborda 2002) not reached; hence, the distribution to the dominant (>10%), subsidiary (5–10%) and minor (<5%) classes should be considered with caution		

varies, with an average of $3.1 * 10^{-5}$ SI. Average Fe, Ca and Ca/Fe values for the unit (170) are 2002 ppm, 69,758 ppm and 35, respectively.

All bulk samples are mainly composed of quartz grains (>80% of all grains), with less than 5% of bioclasts. A peculiarity of the sample from a core depth of 33–37 cm (387) are charcoal fragments of different sizes up to 3 mm. The overall micropalaeontological content of all the bulk samples is predominately shell fragments (mainly bivalvia). Enchinoidea and bryozoa fragments exist in smaller amounts, as well as rare (whole or fragmented) foraminifera, ostracoda, gastropoda and whole bivalvia. The foraminifera assemblages of all the bulk samples identified at a species or, at least, genus level can be found in Table 10.5. In all the samples, *Cibicides lobatulus* (Walker and Jacob 1798) and *Elphidium crispum* (Linnaeus 1758) are dominant or at least subsidiary species. Furthermore, *Elphidium* spp. and *Quinqueloculina seminula* (Linnaeus 1758) are dominant species in the two samples from (173; 48–52 cm, 58–62 cm). However, these two samples present the lowest total number of individuals, as well as the lowest diversity in terms of the number of species

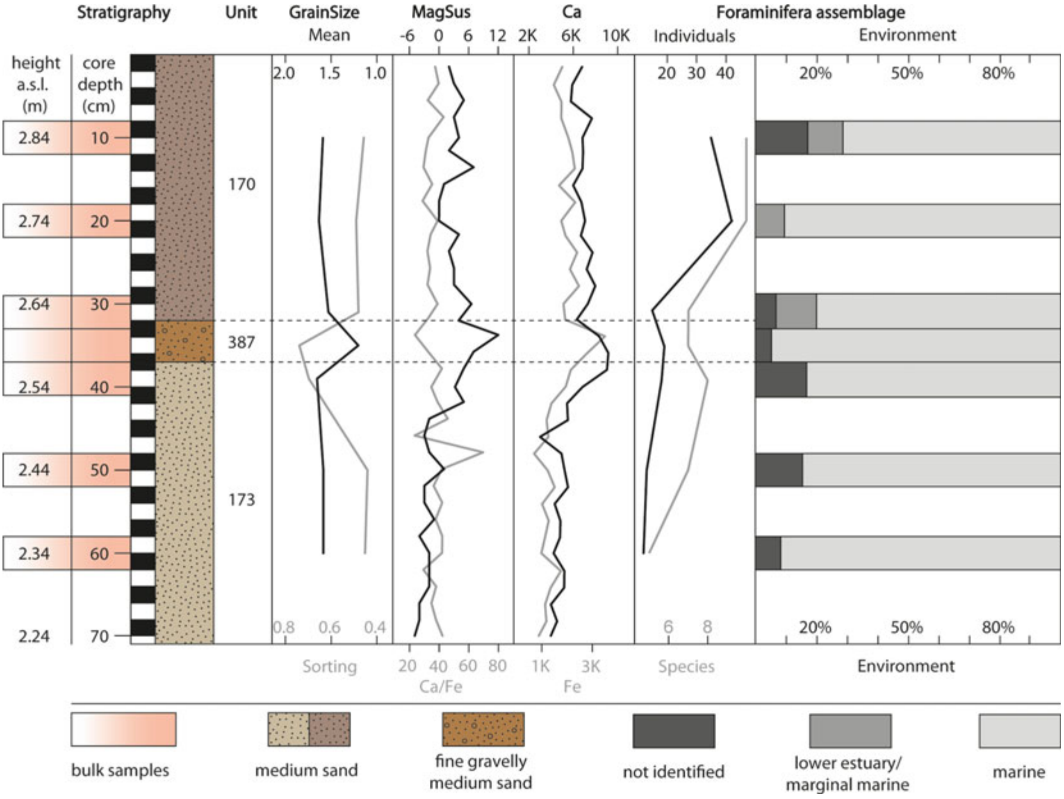

Fig. 10.14 Stratigraphy, sediment units, mean grain size (Φ), sorting (Φ), magnetic susceptibility (*10^{-5} SI) and Ca/Fe, Ca (ppm) and Fe (ppm) results, total number of individual foraminifera, total number of foraminifera species and the suitable environment of the foraminifera assemblage for sediment core BDR 930. The bulk sample depths for grain size and micropalaeontological analyses are highlighted in red

(Fig. 10.14). *Elphidium discoidale* predominates in sample 37–41 cm, the lower contact of (387) (d'Orbigny 1839). In the foraminifera assemblage of unit 387 (sample 33–37 cm), *Ammonia beccarii* (Linnaeus 1758) and *Ammonia* spp. are dominant species. The total numbers of individuals and species are still low, but slightly higher than for unit 173 (Fig. 10.14). *Elphidium williamsoni* (Haynes 1973) and *Haynesina* spp. appear exclusively in the samples from the upper contact of (387; 29–33 cm) and (170; 8–12 cm, 18–22 cm), but only as subsidiary or minor species. Furthermore, *A. beccarii* and *A.* spp. are dominant species in the uppermost sample (8–12 cm). Samples from (170) do not only present the highest numbers of individuals but also exhibit the highest species diversity (Fig. 10.14). For a better identification of palaeoenvironments, the identified foraminifera assemblages of the bulk samples were sorted into marine (*Ammonia* spp., *A. beccarii*, *Cibicides lobatulus*, *Elphidium* spp., *E. crispum*, *E. discoidale*, *Quinqueloculina* spp., *Q. seminula*) and lower estuarine (*E. williamsoni*, *Haynesina* spp.) species (Fig. 10.14). The division was made following Quintela et al. (2016), according to standard environments largely documented in micropalaeontological studies.

Sediment unit (387) consists of a medium sand deposit with an erosive basal contact and abundant shell fragments (Fig. 10.14). The granulometric results, especially a coarser mean grain size and poorer sorting (Table 10.4), differentiate it from the over- and underlying littoral sediments (units 170 and 173; Fig. 10.14). Calcium (Ca) and iron (Fe) values are also high

Table 10.4 Grain size statistics calculated after Folk and Ward (1957) for seven bulk samples from sediment core 930 and reference samples from bulk sample 855 (palaeobeach, trench 9) and the present-day beach berm R7. Sample 33–37 cm from core BDR 930 marks the possible event layer

Sample core depth (cm)	Mean (Φ)		Sorting (Φ)		Skewness (Φ)		Kurtosis (Φ)	
8–12	1.583	Medium sand	0.455	Well sorted	0.171	Fine skewed	1.12	Leptokurtic
18–22	1.631	Medium sand	0.49	Well sorted	0.215	Fine skewed	1.109	Mesokurtic
29–33	1.527	Medium sand	0.478	Well sorted	0.07	Symmetrical	1.217	Leptokurtic
33–37	1.194	Medium sand	0.74	Moderately sorted	−0.1	Symmetrical	0.86	Mesokurtic
37–41	1.643	Medium sand	0.699	Moderately well sorted	0.065	Symmetrical	1.291	Leptokurtic
48–52	1.576	Medium sand	0.44	Well sorted	0.17	Fine skewed	1.116	Leptokurtic
58–62	1.583	Medium sand	0.451	Well sorted	0.171	Fine skewed	1.12	Leptokurtic
Bulk sample (855)	1.693	Medium sand	0.527	Moderately well sorted	0.248	Fine skewed	1.089	mesokurtic
R7 Beach berm	1.578	Medium sand	0.442	Well sorted	0.169	Fine skewed	1.114	Leptokurtic

(Fig. 10.14). The coarser grain size indicates a higher energy flow regime compared to the surrounding sediment units. Elevated Ca values result from the abundance of shell fragments and other marine bioclasts in the layer (Chagué-Goff et al. 2017 and references therein). In addition to shell fragments and other marine biota, calcium also derives from detrital calcite/dolomite found in the Boca do Rio area, as well as from boulders accumulated on the upper beach (Font et al. 2013). Therefore, parts of the calcium signature can be attributed to the erosion and redistribution of these sediments. Elevated Fe concentrations can be related to siliciclastic components, especially clay minerals and iron oxides that generally correspond to the terrigenous sediment fraction of Boca do Rio's floodplain (Font et al. 2013). Thus, the sediment of unit (387) presents a mixture of marine and terrestrial signatures. The foraminifera assemblage indicates littoral conditions with all identified species deriving from shallow marine environments (Fig. 10.14). Lower estuary or even brackish species are absent in unit (387). Only *Ammonia beccarii* has typically been assigned to hyposaline lagoons and estuaries, but its natural environment is highly variable as this species also occurs frequently among sandy sediments in inner shelf environments (e.g. Murray 1971, 1991). The results of this study show that the lateral distribution of unit (387) is restricted to the area near the Roman harbour (Fig. 10.8). This may be explained by the harbour walls serving as sediment traps, leading to the accumulation of unit (387) behind them.

The sedimentary indicators discussed above lead to the conclusion that unit (387) was deposited by an as yet undocumented high-energy event. Based on micropalaeontological and compositional results, a marine origin of the sediment can be assumed, although the geochemical composition is not fully conclusive. However, the marine origin excludes river flooding as a possible generating mechanism for the event layer; deposition by an EWE, severe storm or tsunami, seems more likely. Nowadays, storms are frequent along the Algarve coast (Ferreira et al. 2008) and geological evidence of

Table 10.5 Foraminifera assemblages of seven bulk samples from sediment core BDR 930. Sample 33–37 cm marks the possible event layer. The following classes have been used to describe the foraminifera assemblage of each sample: + = dominant (>10%), o = subsidiary (5–10%), − = unidentifiable (<5%). Some foraminifera individuals were unidentifiable at a species or genus level due to broken and/or abraded tests

Sample core depth (cm)	*Ammonia* spp.	*A. beccarri*	*Cibicides* spp.	*Elphidium* spp.	*E. crispum*	*E. discoidale*	*E. williamsoni*	*Haynesina* spp.	*Quinqueloculina* spp.	*Q. seminula*	Unidentifiable
8–12	+	+	+	o	+	o	–	o	–	o	+
18–22	o	–	+	o	+	+	–	o		+	–
29–33			+		+	o	o	o	o	+	o
33–37	+	+	+		o	+			+		+
37–41		o	+	o	o	+			o	+	+
48–52		o	+	+	o	o				+	+
58–62			o	+	+					+	o

the storm-induced flooding of the coastal lowlands has been identified at Martinhal (Kortekaas and Dawson 2007) and the Rio Formosa barrier island chain (Andrade et al. 2004). The OSL age of AD 1409 ± 36 (AD 1373–1445, 1σ) matches one of the North Atlantic Holocene storm periods (HSP V: AD 1300–1650; Sorrel et al. 2012), marked by rapid global climate change, influencing the strength and location of westerly winds. Although Andrade et al. (2004) were not able to correlate their results from the Rio Formosa barrier island chain with Holocene storm periods, they identified multiple events of storm-induced overwash of different magnitudes and spatial expressions. Therefore, a storm event is likely to have caused the deposition of unit (387). A tsunami event as the generating mechanism for this unit is provisionally excluded, as there are not enough sedimentary indicators, no similar event layers have been detected in other locations of the Boca do Rio valley and there are no historical records in the Portuguese tsunami catalogue in this respect (Baptista and Miranda 2009).

10.6 Discussion

10.6.1 Size and Importance of the Fish-Salting Facilities of Boca do Rio

Due to the excellent natural conditions for processing marine resources in situ—sufficient salt and good fishing grounds—the site was interpreted early on as a hub in the tight network of the Roman maritime economy. Its connection to the sea has been stressed for a long time (Santos 1971; Alves 1997; more recently: Medeiros 2015; Bernardes and Medeiros 2016; Teichner 2016), while the most recent research has made it possible to characterise it more precisely. It can now be considered proven that the developed area roughly extended over the entire dune slope (Hermann et al. 2022) and that most of these buildings should be regarded as fish-salting facilities (Bernardes et al. in press). Because of its extensive industrial quarter and the total volume of production vats estimated at roughly 700 m^3, the complex was certainly one of the larger ones in the Hispanic provinces of the Roman world (cf. Wilson 2006; Medeiros 2015). Undoubtedly, it must have played a major role in the regional economy.

10.6.2 Identification of Major Upheavals in the Settlement's Development

In the studied sections of the cliff, stratigraphically older and younger anthropogenic alterations, such as building structures and levelling layers, are apparent. In profiles 12 and 9, thick sand deposits form a distinctive separating layer between those older (profile 9: 114, 117) and younger (profile 9: 22, 21, 32) features. Prominent levelling layers indicate the aforementioned changes inside the rooms in profiles 2 and 3. These stratigraphically separated horizons can also be distinguished from each other in absolute chronology. As shown above, the unpaved surface (114) in profile 9, and the wall (97) in profile 2 date from before the third century AD. This contrasts with the stratigraphically younger (building) features, namely the walls (1, 110, 138) in profiles 2 and 3, and the structures in profiles 9 and 12, all of which can be dated to the third or fourth century AD. Since a generally similar, although more fragmentary image also appears in the other cliff profiles (Fig. 10.5), we can assume that this was the general course of the settlement's development in the present-day cliff area.

A comparable process can be observed in kiln II, on the settlement's northern outskirts, which was built in the second half of the first century AD. The latest evidence of its use dates to the end of the second century AD—a finding that in all likelihood should be linked to its destruction. As indicated by the lack of younger ceramic material, the area seems to have been abandoned shortly afterwards. No direct parallel can be drawn between the kiln's destruction and its abandonment, as the material only provides a *terminus post quem* for its destruction.

Also, at the very heart of the settlement, in the large fish-salting facilities, a distinct change can be observed. At the beginning of the third century AD, new facilities were erected there, while the interior of early second century AD workshop I underwent a general overhaul, with its quay—i.e. the harbour facilities—being comprehensively modified.

Changes in the settlement's structures as of the third century AD have been recently reported by Bernardes and Medeiros (2016), although their dataset is only viable for the reduced area around the ruins of the halls of the Portuguese Royal Fishing Company, viz., the alleged *pars urbana*. In light of these accounts, it can now be assumed that, instead of local events or modifications, these changes point to an upheaval affecting the entire settlement and resulting in its comprehensive restructuring, including the location of the local pottery production area. A fundamental change between the high and late imperial periods can be evinced here. The conversion and extension of the settlement from the third century AD onwards seems to have been preceded by a period of relative calm, during which existing building structures or areas were abandoned and siltation became dominant, following which these buildings were demolished.

A remarkable change—especially with regard to the discussed research questions—is the replacement of the previous stone quay by a wooden structure. This measure elevated the entrance level by about 1.0 m (Fig. 10.15). While a certain amount maintenance work on the fish-salting facilities, especially the production vats, was necessary at more or less regular intervals (Driard 2014), there is a more complex reason behind the adjustment of the quay's surface level.

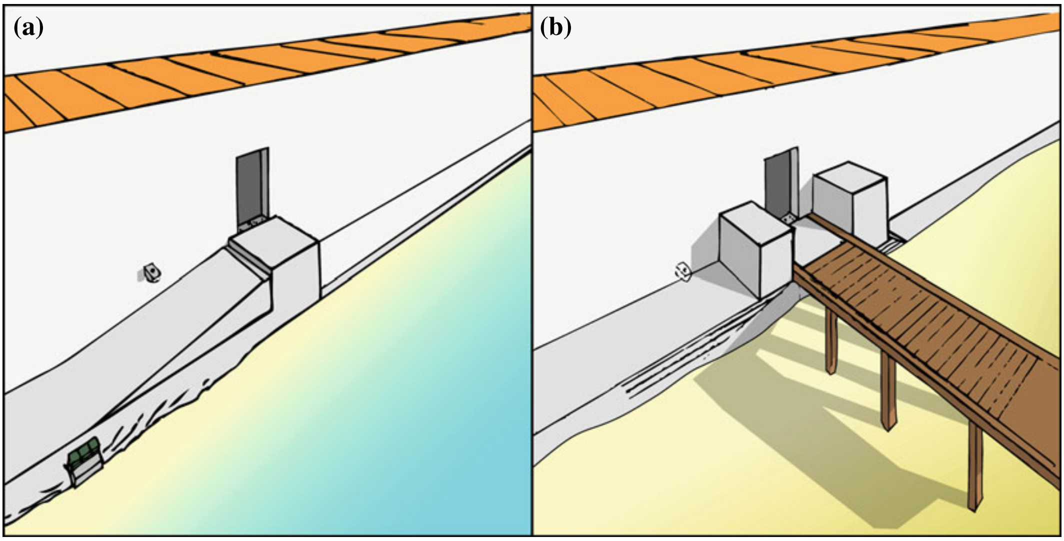

Fig. 10.15 Schematic reconstruction of the entry to workshop I before (**a**) and after (**b**) the third century AD overhaul. In the second phase, it is more than likely that a wooden quay allowed access to what was then a more distant navigable watercourse. Of the original structure, only the platform was still in use, while the former ramp was entirely covered by sediment and levelling layers

10.6.3 Identification and Correlation of EWEs and the Identified Disruption in the Settlement's Development

As yet, no tsunami deposits, apart from those generated by the AD 1755 Lisbon tsunami, have been identified in the field site of Boca do Rio. However, the aim of many previous studies (e.g. Dawson et al. 1995; Hindson et al. 1996; Hindson and Andrade 1999; Cunha et al. 2010; Costa et al. 2012b; Font et al. 2013) was to find and characterise precisely the AD 1755 deposits (and not their possible predecessors). This might explain why no further deposits of previous events have been found to date. Feist et al. (2019) were the first to detect another interesting layer, but this was restricted to one coring site and the evidence was insufficient to confirm a storm or tsunami origin. However, they definitely identified another EWE stratum.

In this study, another interesting layer associated with an EWE, tentatively interpreted as a severe storm event, was detected. The ages and foraminifera assemblages of the layers identified by Feist et al. (2019) and of those presented here do not match, whereby these layers have been interpreted as deriving from different events. This has led to the assumption that additional geological footprints of EWEs, in general, and tsunami events, in particular, may exist at Boca do Rio, but no study has so far been able to detect all of them. It is noteworthy that the tsunami catalogues (Baptista et al. 1998; Baptista and Miranda 2009; Lario et al. 2011) list other as yet geologically undocumented events on the Algarve coast and in the Spanish Gulf of Cádiz.

In this chapter, two profiles covering the entire stratigraphy of the evolution of the estuarine area since Roman times have been presented and discussed (see above, harbour and kiln II). However, only in the harbour basin, perfectly illustrated by profile 58 (Figs. 10.8 and 10.13), have two plausible events been identified. No clearly erosive layer boundaries, signalling the existence of other (earlier) erosive processes, have been found. It can be assumed that the sediments older than the layer (387) are entirely present and that an undisturbed geo-archive of the development of the immediate harbour basin during the Roman era indeed exists.

While the stratigraphically younger event layer (169) presumably corresponds to the 1755 Lisbon tsunami, geologically detected in the Boca do Rio area at many locations, the older event layer, probably the result of a severe storm (see above), was previously unknown. According to the OSL age of AD 1409 ± 36 (AD 1373–1445; 1σ), it dates to late medieval times. Based on these age estimates, both of the identified events should be considered to be irrelevant to the research question of possible EWEs in Roman times. In addition, since a coherent stratigraphic sequence of the harbour basin without any event indicator has been detected (profile 58, Figs. 10.8 and 10.13), the existence of such an event—including its theoretically associated implications for the development of the settlement and the fish-salting industry—should be rejected.

The position of the harbour and the palaeoriverbed in profile 69 indicates that the river followed a different course during the Roman occupation than today. Thus, the estuarine and littoral conditions observed by Allen (2003) and Feist et al. (2019) are supported by our findings. During the Roman age, a wide river mouth was located west of the present-day floodplain, close to the harbour and kiln II. It can be expected to have been considerably larger than it is today, with enough space for the harbour basin and related structures. Major parts of profile 58 close to the Roman harbour structures are composed of quartz-rich littoral sands typical of coastal environments (e.g. nearshore, beach and dune). This is supported by the detailed analysis of core 930 presented above, although only for a limited timeframe (as the core only comprises three units of the stratigraphy). The core's lowermost unit (173) describes the environmental conditions at least until approximately AD 969 ± 50 (OSL age: AD 919–1019, 1σ; Table 10.2). Grain size statistics reveal medium sand size (1.6 Φ) and good sorting (0.45 Φ), very similar to those of the foredunes at Martinhal (mean: 1.6 Φ, sorting: 0.3 Φ; Kortekaas and Dawson 2007) and the present-day subaerial beach berm (Table 10.3). This points to aeolian transport as the main mode for sediments in (173). The foraminifera assemblage further highlights a littoral environment for (173), exclusively containing shallow marine species (Fig. 10.14, Table 10.5). The dominant species *C. lobatulus*, *E. crispum* and *Q. seminula* all derive from the inner shelf (e.g. Murray 1971, 1991, 2006; Mendes et al. 2013), while the latter can also be found at mid-shelf depths or in the outer parts of tidal inlets (e.g. Murray 1971; Hayward et al. 1999). However, the foraminifera assemblage of this unit is severely limited, whereby further analyses are necessary to definitely classify the palaeoenvironment based on foraminifera species alone. Still, the identified environment based on foraminifera concurs with other characteristics of the unit indicating wind-blown littoral sediments. Unit (173) was abruptly covered by the possible high-energy event (387) discussed above.

The still littoral environmental conditions, featuring exclusively shallow marine species, with the ongoing aeolian sediment transport point to the gradual siltation of the harbour basin. Measures to remove these sediments, such as dredging, have not been identified.

The site of Cerro da Vila near Vilamoura (Quarteira), 60 km further east, provides a close parallel to Boca do Rio's harbour situation, and in particular to the modification of its facilities. There, at the edge of the palaeo-estuary, two differently levelled waterfront facilities have been identified. At first, a supposedly earlier wooden pier existed, which was subsequently replaced by a stone waterfront fortification, the former dating from pre-Flavian times and the latter from Flavian times onwards; in a second phase, the quay was modified in the third century AD (Teichner 2017, 2018). The confirmed gradual and strong siltation of the Vilamoura estuary, which seems to have made this necessary (Teichner et al. 2014), is striking. It should be stressed that the same researchers, although focusing on the development of the estuary, did not find any evidence of EWEs in their core-drillings either (Teichner et al. 2014).

Similarly, it can be concluded that the ongoing siltation (297, 173), following the construction of Boca do Rio's harbour facilities, produced a shift in the river course towards the north-east in the short and medium terms. Access to what was already a more distant navigable watercourse was then further ensured by modifying the quay, namely, its elevation and replacement by a wooden footbridge.

The same development, that is, the change in the river course, can be further specified based on the results for kiln II. No event layer could be detected there either—neither on the features themselves nor in the surrounding area. However, clear traces of an erosive process are documented, as this destruction was not caused by a deliberate, anthropogenically initiated event, such as the reuse of building materials. Presumably the erosive force of the watercourse was visible here, which did not move in a straight line along its entire length to the east at the time, but did so in a meandering manner. In the area of kiln II, a cut bank of this meandering river must have existed at least for a short period. As a result of this temporary, small-scale westward shift, this section of the settlement was literally milled off, namely, continuously eroded. Occasional extreme rainfall events, affecting the Algarve region in the past and at present, may have strengthened this effect (Pereira et al. 1994; Bernardes 2006). This fluvial erosion is roughly comparable to the marine erosive process in the cliff area (Carrasco et al. 2007; Bernal Casasola 2015; Hermann et al. 2022), where tides and winter storms have a highly destructive effect on the conservation status of coastal monuments.

10.7 Conclusion

There is no doubt that Boca do Rio was a major regional player in the fish-salting industry in the Roman Empire, most likely from as early as the second century AD. This is evidenced by the 'halieutic cycle', namely, that all the steps of the fish-salting process—fishing, salting, potting, etc.—were carried out in Boca do Rio.

The pottery kilns and the construction of the harbour facilities, described in detail in this chapter, were important for the functioning of the settlement. They underwent a major upheaval in the third century AD, which can also be traced in the rest of the settlement (see Sect. 10.5.2). In particular, the kilns were abandoned and even suffered, in part, from erosion. As part of the harbour, the level of the quay of one of the largest fish-salting facilities in the settlement was raised and replaced by a wooden footbridge, in order to guarantee is continued functioning.

Two high-energy events have been detected in the sediments of the harbour basin. One is the well-known AD 1755 Lisbon tsunami and the other presumably a storm event during the fourteenth century AD. While the complete stratigraphy covers the entire Roman period, no traces of an older event have been found. On the contrary, a changed sedimentation and erosion behaviour of the river bordering the settlement has indeed been detected; the modification of the harbour and the destruction of the pottery area can at least be attributed to a change in its course.

It should therefore be concluded that no definite evidence of a tsunami event during the time of the Roman occupation has been detected. The findings in Boca do Rio thus do not confirm the assumption that single events—like earthquakes or EWEs—may have led to the sudden, radical change in production.

Acknowledgements This research was conducted as part of the project 'Vulnerability of complex Roman production networks on the Atlantic coast of southern Hispania', funded by the German Research Foundation (DFG; grant nos. TE 580/8-1, RE 1361/28-1, BR 877/36-1), which is gratefully acknowledged. Special thanks are due to Pedro José Miranda da Costa (University of Coimbra) for the funding of the dating of the OSL samples used in this paper, our local partner Ricardo Soares (Câmara Municipal Vila do Bispo) for logistical support, and to Margret Mathes-Schmidt, Piero Bellanova (both from RWTH Aachen University) and Hannes Laermanns (University of Cologne) for their support during the geological fieldwork, the subsequent analyses and the discussion of the results.

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