Quaternary International 312 (2013) 57–69

Contents lists available at SciVerse ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

In search of the harbours: New evidence of Late Roman and Byzantine harbours of Ephesus

Friederike Stock[a,*], Anna Pint[a], Barbara Horejs[b], Sabine Ladstätter[b], Helmut Brückner[a,*]

[a] Institute of Geography, University of Cologne, Albertus-Magnus-Platz, Zülpicher Str. 45, 50923 Köln, Germany
[b] Austrian Archaeological Institute, Franz Klein-Gasse 1, 1190 Wien, Austria

ARTICLE INFO

Article history:
Available online 14 March 2013

ABSTRACT

Ephesus (Greek name: Ephesos) in Western Turkey was an important harbour city during Antiquity. The progradation of the Küçük Menderes delta has continuously shifted the coastline westwards. Thus, along with the delta progradation, new harbour sites had to be established in a western direction. Historical sources refer to different harbours. While much is known about the Roman and older ones, the exact location of the ports and the coastline in late Roman and Byzantine times is still an open question.

This article presents the results of geoarchaeological research in the area located along the southern flank of the Küçük Menderes graben near Ephesus. Sediments from cores were examined with geochemical, sedimentological, and microfaunal analyses. These data were combined with the study of ancient maps and satellite images. The chronological framework was rendered by AMS-^{14}C ages and diagnostic ceramics. The farthermost inland shoreline dates from 5000 BC; since then, delta progradation has continuously shifted the shoreline westwards. Çanakgöl, today a little lake to the west of the city of Ephesus is identified as the harbour site in late Roman and Byzantine times. This harbour persisted at least until the 16th century AD. Further, a landing site with a pier was discovered west of Çanakgöl, presumably dating to the late Byzantine–Ottoman times.

1. Introduction

The Aegean coastal zone of Anatolia has a long settlement history. In particular, within the fertile alluvial plains and deltas of rivers, often situated in tectonic grabens, such as the Büyük Menderes, Gediz and Küçük Menderes, were favourable settlement areas (Kayan, 1999). Situated approximately 70 km south of Izmir, Ephesus is located on the southern flank of the Küçük Menderes graben (Fig. 1). During the last six millennia, the surroundings of the ancient city experienced major palaeogeographical changes. These were caused by the progradation of the Küçük Menderes (ancient name: Kaystros) delta and the resulting shoreline changes which fundamentally affected the development of the city of Ephesus and in particular of its harbour (Kraft et al., 2000). The advancing delta progressively silted the harbour areas. Thereafter, new harbours were built further to the west. Although literary sources mention "Panormos" and "Pygela" (Fig. 1) as late Roman and Byzantine harbours to the west of the city (Foss, 1979; Hess, 1985; Meriç, 1985; Kraft et al., 2000; Steskal, in press), their exact locations remained unknown. The research presented herein investigated the areas along the foot of the southern flank of the Küçük Menderes graben, and thus identified the ever changing ancient harbour sites. Methods encompassed satellite image interpretation, physiography, vibracoring, sedimentological, geochemical, and microfaunal (foraminifers, ostracods) analyses, as well as AMS-^{14}C and diagnostic ceramic dating.

2. Description of the study area

2.1. Physical setting

Stretching in a west–east direction of about 80 km, the Küçük Menderes graben ends in the Aegean Sea approximately 70 km south of Izmir (Fig. 1). It is surrounded by the Menderes Massif, a 300 km by 200 km mountain range with elevations up to 2000 m. The mountains around the Selçuk plain at the western end of the graben reach up to 700 m (Bozdağ mountains to the north and Aydındağ mountains to the south) (Philippson, 1918; Güldali, 1979; Erol, 1983; Bozkurt and Satir, 2000; Bozkurt, 2001).

Within the regional setting, the graben system of the Küçük Menderes is part of the Aegean–Anatolian microplate. Due to the northward drift of the Arabian plate, it was pushed into a southwestern direction (Polat et al., 2008). During the Pleistocene,

* Corresponding authors.
E-mail addresses: stockf@uni-koeln.de (F. Stock), h.brueckner@uni-koeln.de (H. Brückner).

1040-6182/$ – see front matter © 2013 Elsevier Ltd and INQUA. All rights reserved.
http://dx.doi.org/10.1016/j.quaint.2013.03.002

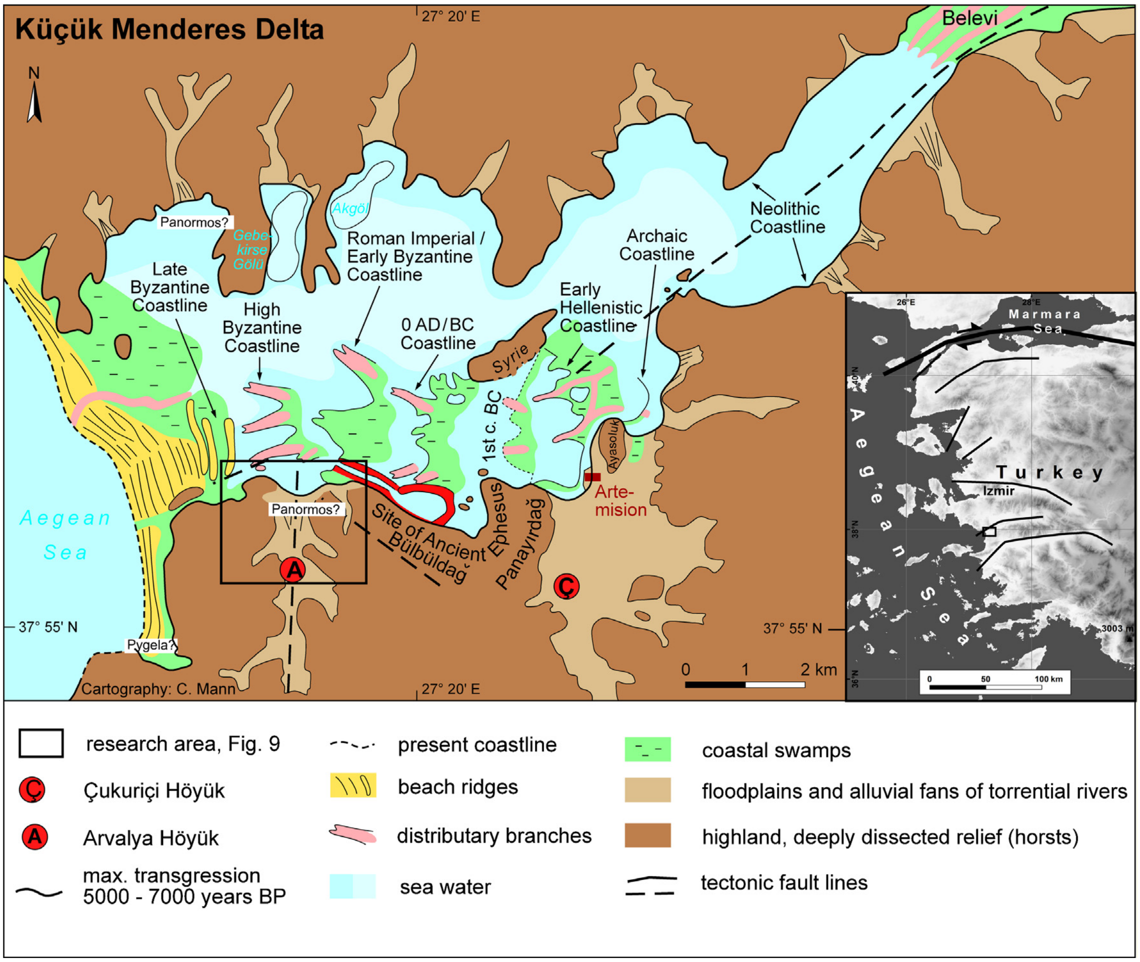

Fig. 1. Geographical setting of the research area and scenario of the delta progradation since Neolithic times. The scenario is based on historical sources and geoarchaeological research (Brückner, 2005, modified). The presumed harbour sites of "Panormos" and "Pygela", discussed in literature, are indicated. The research area is consistent with Fig. 9. The tectonic fault lines are based on Brückner et al. (2010).

the tensions led to the development of the fault system striking SW–NE (Doutsos and Kokkalas, 2000; Hütteroth and Höhfeld, 2002; Taymaz et al., 2007). The river Küçük Menderes follows this faulted structure and flows through the Selçuk plain into the Aegean Sea (Gulf of Kuşadası). Nowadays the floodplain of the Küçük Menderes, situated at the western end of the graben, has a west–east length of about 11 km and a width varying between 2 and 5 km (Fig. 1) (Güldali, 1979). Due to the presence of secondary N–S oriented faults, drained tributary valleys (Derbent, Selinus, Klaseas and Kenchrios) cut the southern flank of the graben (Derbent and Arvalya valleys) (Güldali, 1979; Crouch, 2004). The bedrock bordering the alluvial plain is dominated by marble, mica schist, carbonaceous schist, quartzitic schist, quartzitic paragneiss, quartzite and gneiss of the Menderes Massif (Philippson, 1912; Vetters, 1989).

During the Flandrian transgression, the sea level rose rapidly by about 120 m (Stanley and Warne, 1994) until the middle of the Holocene (Erinç, 1954; Kayan, 1999). A large marine embayment extended into the Küçük Menderes graben as far east as the area of Belevi, today some 18 km inland (Fig. 1) (Brückner et al., 2008). When sea level rise decelerated, the delta of the Küçük Menderes started to form around Belevi and then continuously prograded westwards. As a consequence, the formation of alluvial fans took place in the transition zone between the graben flanks and the developing floodplain (Erinç, 1954; Brückner, 1997) (Fig. 1). The floodplain is currently dominated by the former islands of Syrie and the former Ayasoluk peninsula (Philippson, 1912; Kraft et al., 2007).

The Küçük Menderes river was freely meandering until its regulation in 1934 (Eisma, 1962; Güldali, 1979). Since then, the Menderes debouches into the sea further north and a new delta was formed. However, little sediment has accumulated because of the building of barrages and the influence of the marine longshore drift (Eisma, 1978; Güldali, 1979). Former meander loops and oxbow lakes have persisted until today, as did the lakes Gebekirse Gölü and Akgöl (Fig. 1).

The ~9 km^2 research area is located at the confluence of the Kenchrios and the Küçük Menderes rivers. The valley floors are filled with Holocene alluvium, colluvium, and Pleistocene slope debris whereas the bordering mountains are mainly composed of mica schist and marble on the eastern side and Miocene sediments (red breccia) on the western side (Vetters, 1989; Brückner, 1997).

2.2. Location of the successive harbours of Ephesus: A historical perspective

Archaeological work in the Ephesus area started in 1863 with the British engineer J. T. Wood. He searched for the ruins of the Artemision temple that he finally unearthed in 1869 (Wiplinger and Wlach, 1996). Systematic research has been carried out in Ephesus since 1895 by the Austrian Archaeological Institute (Knibbe, 1998) and it has always been accompanied by geographical and geological investigations (Grund, 1906; Philippson, 1912, 1918, 1920; Darkot and Erinç, 1954; Erinç, 1954, 1978; Eisma, 1962, 1978; Vetters, 1985, 1989). Since the 1990s, numerous geoarchaeological studies have been carried out in the vicinity of Ephesus (Brückner, 1997, 2005; Kraft et al., 1999, 2000, 2001, 2005, 2007, 2011; Brückner et al., 2005, 2008).

Throughout its settlement history, the city had different centres and associated harbour sites. During the Archaic period, one settlement was situated on top of the Panayırdağ (Kerschner et al., 2008). The respective harbour site was possibly located on the northern side of the hill in a natural embayment. Palaeogeographic research (Kraft et al., 1999) as well as our field investigations carried out in 2012 in this area proved the existence of a marine embayment at that time. Many ceramic findings embedded in marine sediments date back to this Archaic period. The most important and most well-known settlement was situated between the mountains Bülbüldağ (northern side) and Panayırdağ (western side), directly next to the sea.

Ephesus was founded by Lysimachos around 300 BC and persisted for more than 1000 years as the main settlement site (Wiplinger and Wlach, 1996). During Hellenistic time, the harbour was situated at the foot of the Bülbüldağ and Panayırdağ. Ephesus became the most important city of the Roman province of Asia; in 133 BC the city was declared its capital. As a consequence of the ongoing siltation process during Roman time, the Roman harbour basin was created to the west of the city (Scherrer, 1995; Zimmermann and Ladstätter, 2011).

Already by the end of the 2nd century BC, prodelta silts were deposited in the harbour (Kraft et al., 2011). As the shoreline continued to advance into western direction, the harbour basin was infilled with sediments. It had to be dredged several times and a harbour canal had to be constructed in order to maintain the connection to the sea. From the 2nd century AD on, only small ships could enter the canal. When the Roman harbour basin and canal silted up, Ephesus had lost direct access to the sea, although anchorage sites to the west of the city were still utilised (Foss, 1979). It is not known how long the harbour basin was still in use, and when additional outer ports were constructed. Undoubtedly Ephesus could be reached by smaller boats until the medieval ages, at latest until the 14th century AD. In literature, different later ports are mentioned, but without an exact location.

The location of the Late Roman–early Byzantine harbour, also called "Panormos", is discussed by several authors. Strabo (2007 ed., 14, 1, 20), during the 1st century AD, places it on the southern side of the Küçük Menderes floodplain, between Pygela and Ephesus (Fig. 1), Foss (1979) and Hess (1985), however, presumed its location at the northern flank of the Küçük Menderes graben. Other possible sites were suggested at the northern end of the Kenchrios floodplain (Foss, 1979; Hess, 1985; Kraft et al., 2000), with later sites (from the 11th century AD onwards) at Pamucak and Kuşadası (Hess, 1985). Meriç (1985) locates the Panormos harbour on the northern flank of the marine embayment close to the village Zeytinköy, based on the fact that a paved road had been discovered under the alluvial sediments.

Kraft et al. (2000) are of the opinion that the area around Çanakgöl might have been a suitable harbour site from late Byzantine

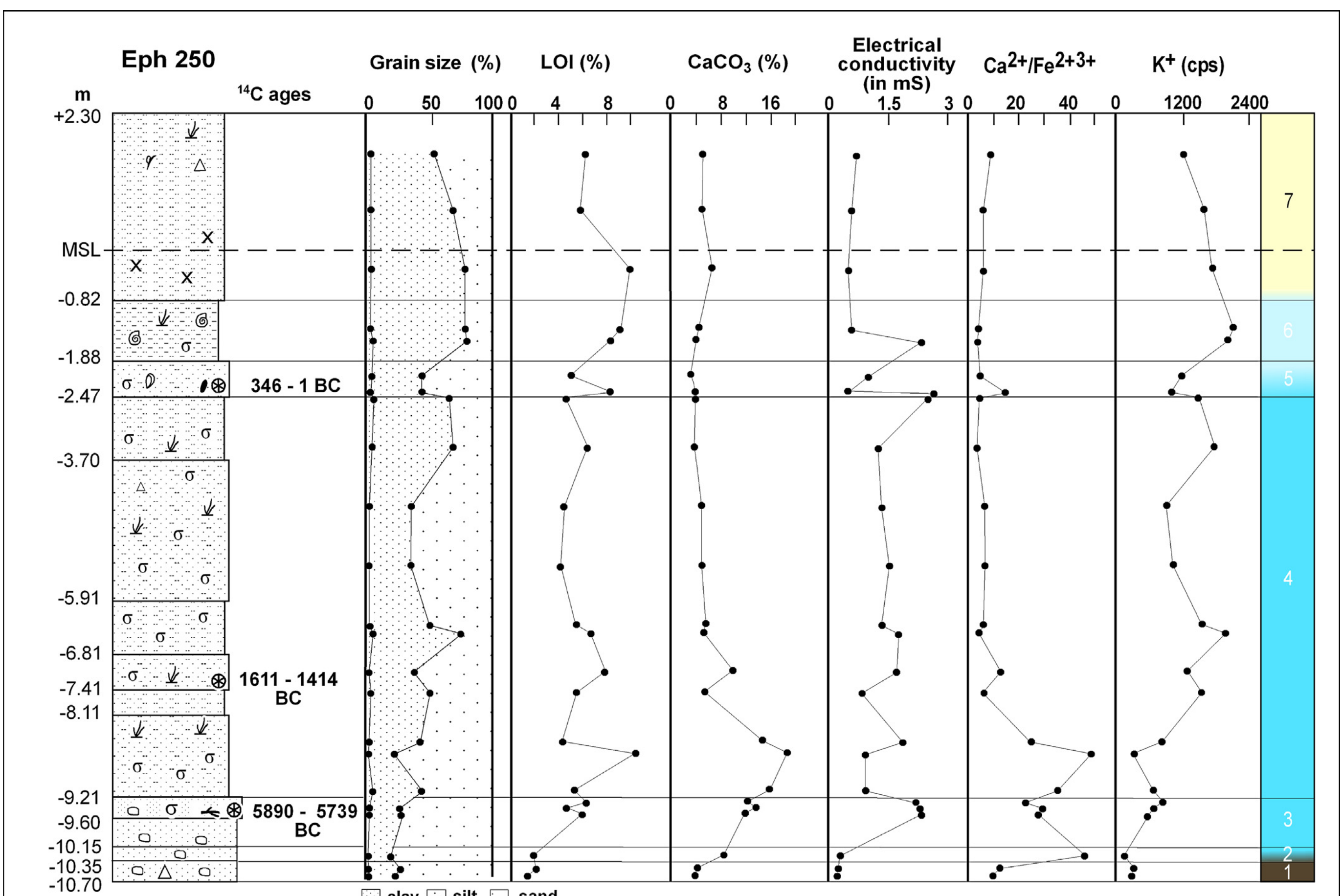

Fig. 2. Sediments and geochemical results of core Eph 250 to the north of the Arvalya valley. Points represent the depth of the measured samples, horizontal lines the boundaries of the units and dashed horizontal line the present sea level. Matrix and components are described in Fig. 5. K was analyzed semi-quantitatively using Itrax core scanner (cps = counts per second). Facies: 1) underlying stratum (late Pleistocene), 2) transgression facies, 3) and 4) shallow marine, 5) transition unit, 6) brackish, 7) alluvial.

to Turkish times. After the 16th century, no harbour is mentioned in literature (Steskal, in press).

3. Methods

In the northern Arvalya valley and around Çanakgöl, twelve half open vibracores were retrieved (diameters of augerheads: 6, 5, and 3.6 cm, maximum depth: 14 m). The work is based on the geo-archaeological research design published by Brückner et al. (2005), and Brückner and Gerlach (2011). Drill cores were carried out with the vibracorer Cobra mk1 (Atlas Copco Co.) and a hydraulic lifting device. The sediment cores were photographed. In order to establish a facies stratigraphy, colour (with Munsell Soil Color Charts), grain size, carbonate content and texture, as well as other characteristics were determined in the field according to AG Boden (2005). During fieldwork, ceramics, macro-fauna and -flora (bivalves, gastropods, plant remains, seeds, olive stones etc.) were sampled for determination and radiocarbon dating. Drill cores were sampled for geochemical and sedimentological analyses. The positions of the coring sites were measured with differential GPS (Topcon–Hiper Pro; accuracy: 2–3 cm in all three dimensions).

In the geo-laboratory at the University of Cologne, the samples were dried and pestled. Every sample (<2 mm) was measured with a laser diffraction particle sizer after removing the organic material with H_2O_2 (Beckmann Coulter LS13320 Mikro). The statistical analyses were done with Gravistat (Blott and Pye, 2001). Electrical conductivity was determined after Barsch et al. (2000). For loss on ignition (LOI), 5 g of sediment were dried at 105 °C overnight and heated for 4 h at 550 °C in an annealing furnace (Schlichting et al., 1995). $CaCO_3$ content was determined with the Scheibler apparatus (0.5 g of sediment was moistened and reacted with 10% HCl). X-ray fluorescence (XRF) analysis was done with an Itrax Core Scanner (Cox analytic system). It has an exposure time of 10 s; elements being measured reach from Al to Pb (Croudace et al., 2006). Usually it has a resolution of 2 mm. Due to the fact that the entire core was not available, only single samples were measured for cores Eph 250 and 266.

In four cores, detailed microfaunal analysis was accomplished in order to reconstruct the milieu of deposition. Ostracods and foraminifers are excellent indicators for the interpretation of palaeoenvironments due to well-known ecological requirements. Foraminifers live in marine and rarely in brackish habitats, ostracods in all aquatic ones. The species distribution depends on factors such as salinity, temperature and water depth (Frenzel and Boomer, 2004; Frenzel et al., 2006). After sieving (mesh size: 100 μm) the samples of foraminifers and ostracods were determined after Meriç (2004). All individuals per sample were counted for the qualitative and quantitative analyses.

The determination of diagnostic ceramic fragments and AMS-^{14}C dating of plant remains, charcoal, olive stones and seagrass also helped to establish a chronostratigraphy. Marine samples were corrected with 390 ± 85 years (reservoir effect of the Eastern Mediterranean region; cf. Siani et al., 2000) (Table 1).

Table 1
Radiocarbon data of cores Eph 250, 266 and 268.

Sample	Sampled material	Depth (m) [a]	Lab ID (UGAM)	$\delta^{13}C$ (‰)	^{14}C age	Age cal BC/cal AD (2 σ)
Eph 250/10F	Olive stone	−2.24	11437	−14.9	2100 ± 40	346–1 BC
Eph 250/22Sg	Seagrass	−7.32	11436	−26.5	3570 ± 25	1611–1414 BC
Eph 250/29P	Plant remain	−9.54	11438	−25.3	6940 ± 30	5890–5739 BC
Eph 266/4P	Plant remain	−0.93	11082	−27.3	140 ± 20	AD 1671–1953
Eph 266/10H	Plant remain	−3.18	11086	−27.4	2060 ± 20	164–1 BC
Eph 266/15H	Grape seeds	−4.20	11084	−26.9	2160 ± 20	354–117 BC
Eph 266/21Sg	Seagrass	−6.80	11085	−16.9	5680 ± 25	4269–3939 BC
Eph 268/2HK	Charcoal	−1.76	11089	−24.8	2030 ± 25	152 BC–AD 51
Eph 268/14H	Plant remain	−6.34	11088	−27.2	2050 ± 20	164–1 BC
Eph 268/15H	Charcoal	−6.94	11083	−26.3	2110 ± 20	195–55 BC
Eph 268/24K	Olive stone	−11.14	11087	−26.9	2000 ± 25	48 BC–AD 60

The samples were dated in the Center for Applied Isotope Studies, University of Georgia, Athens (USA). All ^{14}C ages were calibrated with Calib 6.0 (Reimer et al., 2009) and are calculated with a standard deviation of 2 σ (probability of 95.5%).
[a] Depth reference is mean sea level.

4. Results and facies identification

Twelve cores were drilled around Çanakgöl and in lower alluvial plains of the Arvalya and Arap Derç valleys, in order to discover the Late Roman and Byzantine harbour sites (Fig. 9). A representative example for the general stratigraphy of the investigated area is core Eph 250, described in detail below.

4.1. Core Eph 250

Eph 250 was drilled north of Arvalya valley, 160 m south of the old course of the Küçük Menderes. A depth of 13 m below surface (b.s.) and 10.70 m below present sea level (b.s.l.) was reached. Seven different stratigraphic layers were differentiated (Figs. 2 and 3).

From the base up to 10.35 m b.s.l. dark yellowish brown medium sand with angular stones occurs (unit 1), void of micro- and macrofossils and with low values of electrical conductivity, LOI, $CaCO_3$, K and Ca/Fe ratio. The stratum was deposited under terrestrial conditions, probably during late Pleistocene or early Holocene times (Fig. 2).

It is overlain by 20 cm of brown coarse sand and pebbles containing marine foraminifers (*Elphidium crispum*, *Ammonia tepida*, *Ammonia compacta* and *Lobatula lobatula*). Most probably, these are the first transgressive sediments encountered (unit 2).

Up to 9.21 m b.s.l., this unit is overlain by poorly sorted grey medium sand with pebbles at the base (unit 3). The increased values of electrical conductivity, carbonate content, LOI, K and Ca/Fe ratios are indicators of a facies change. Plant remains at the base date to 5890–5739 cal BC. Marine gastropods and bivalves as well as the marine foraminifers *L. lobatula*, *E. crispum*, *Rosalina bradyi*, and *Rosalina floridensis* are present.

Unit 4 from 9.21 to 2.47 m b.s.l. is evidence of low energy marine sedimentation with a high variety of microfauna dominated by *L. lobatula*, *R. bradyi*, *R. floridensis*, *Rosalina globularis* and *A. tepida*, and macrofauna characterized by echinoid spines and gastropods. Seagrass is intercalated from 8.50 to 6.81 m b.s.l. and dated to 1611–1414 cal BC. This sequence has abundant plant remains and a coarser matrix than above. The Ca/Fe ratio as well as LOI, K and

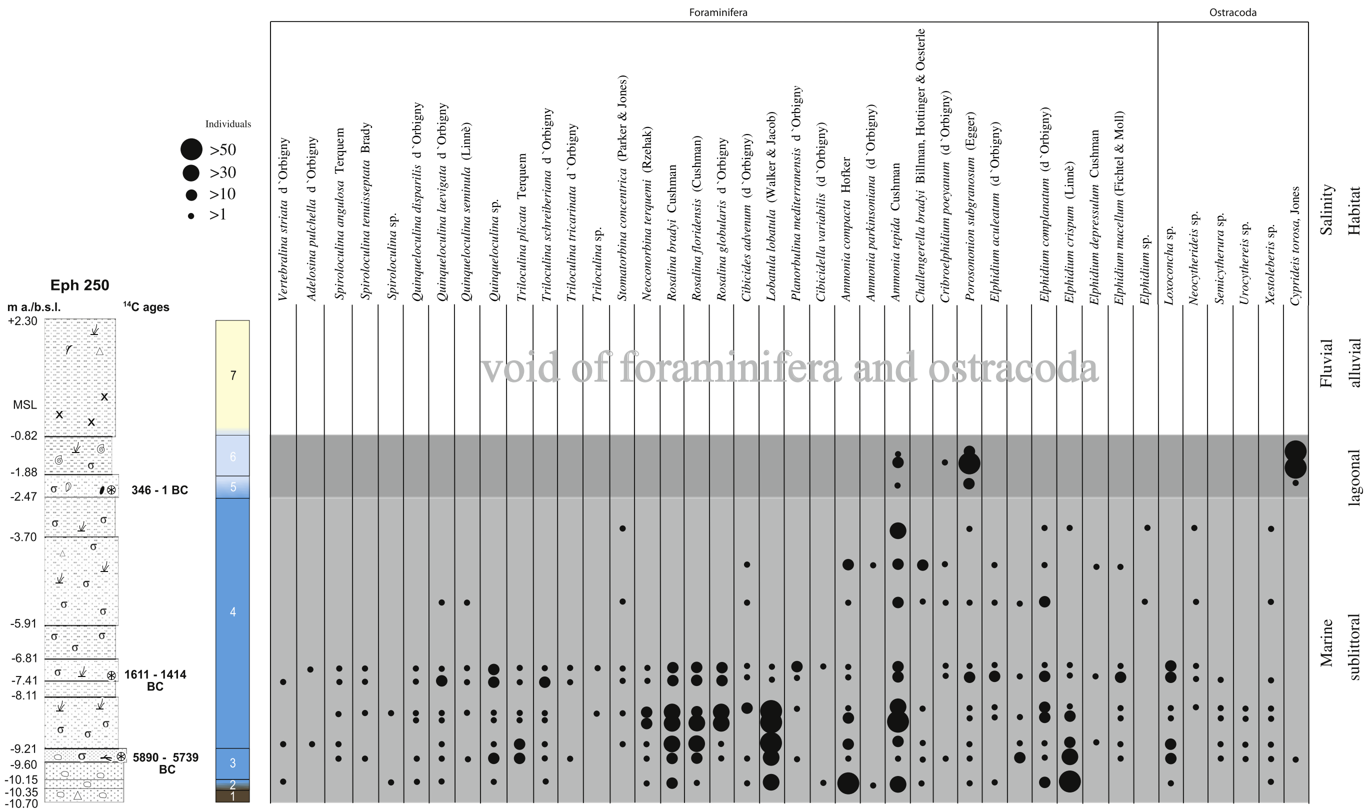

Fig. 3. Distribution of foraminifera and ostracoda of the sediment core Eph 250.

electrical conductivity show higher values. Fine sands dominate from 5.91 m b.s.l. upwards. Lesser organic material was deposited in the upper metres.

In unit 5 from 2.47 to 1.88 m b.s.l., grain size increases and *Balanus* sp. and *Cerastoderma glaucum* are present. Electrical conductivity declines upwards. An olive stone at 2.47 m b.s.l. was ^{14}C-dated to 346–1 cal BC. Angular and subangular clasts are more common. Geochemical and sedimentological data suggest a higher energetic environment with increased terrestrial input.

The following stratum (unit 6) up to 0.82 m b.s.l. is characterized by a sharp contrast, where dark grey clayey silts represent less-energetic sedimentation. Organic content and the K values rise. While most of the marine species disappear, the brackish foraminifers *Porosononion subgranosum*, *Cribroelphidium poeyanum* and *A. tepida* are present. The brackish water ostracod *Cyprideis torosa* also occurs in high numbers indicating a decreasing salinity as evidence of the development of a temporary lagoonal system. From 1.11 m b.s.l. upwards, dark yellowish brown sand layers indicate the terrestrial influence.

A transition layer up to 0.53 m b.s.l. indicates the process of siltation. From 0.53 m b.s.l. to 2.30 m a.s.l. (above present sea level) the colour changes to brown and yellowish brown (unit 7). Angular mica schist, limestone and quartz stones as well as carbonate concretions occur in the silt dominated matrix.

4.2. Cross section in Arap Derç valley

Two drillings (Eph 246 and 247) were carried out west of Kaleburun Tepe and north of Kara Tepe in a north–south striking valley called Arap Derç (maximum width: 200 m). The alluvial plain is surrounded by hills with an altitude of 73 m (Kaleburun Tepe) and 71 m (Kara Tepe), respectively (Fig. 5).

The base of Eph 247 (max. depth: 2.81 m b.s.l.) is characterized by strong brownish sandy loam with many angular stones similar to the alluvial fan of the lower Derbent valley to the south of the Artemision. The loam is overlain by compact clayey silt to silty clay, most probably a freshwater environment close to the river. Eph 246 is located 118 m northwest of Eph 247, 7.39 m b.s.l. It displays a different stratigraphy. At the bottom of the drill core appear mostly dark grey silty micaceous fine sands. Intercalations of seagrass with marine microfauna *A. compacta, E. crispum*, *R. bradyi*, as well as marine gastropods and echinoid spines occur, typical for a marine environment close to the coast. Geochemical analyses indicate a high value of electrical conductivity, and a high content of $CaCO_3$ due to the calcareous fauna. A transitional layer up to 1.54 m b.s.l. with sand and pebbles was interpreted as a regressive beach deposit. It is overlain by medium sand-dominated dark yellowish brown sediments up to 0.81 m b.s.l. containing many subangular stones (mainly limestone, mica schist and quartz up to 5 cm). The absence of macro- and micro-fauna and decreasing geochemical values, especially electrical conductivity, indicate a different milieu of deposition. In both cores, alluvial fan deposits continue up to the surface, in Eph 247 with rockfall debris (quartz, limestone, mica schist) in the upper 3 m. In Eph 246, ceramic fragments, burnt clay and charcoal occur at 0.04 m b.s.l. and 0.34–0.38 m a.s.l. Kitchen ware and a skyphos/kantharos fragment date back to the Hellenistic–early Roman period, i.e. 3rd–1st century BC. The cores show that at the mouth of the Arap Derç valley a harbour site in Roman times can be excluded.

4.3. A tell in Arvalya valley

In order to reconstruct the maximum landward position of the shoreline and its spatiotemporal shifts while trying to find potential

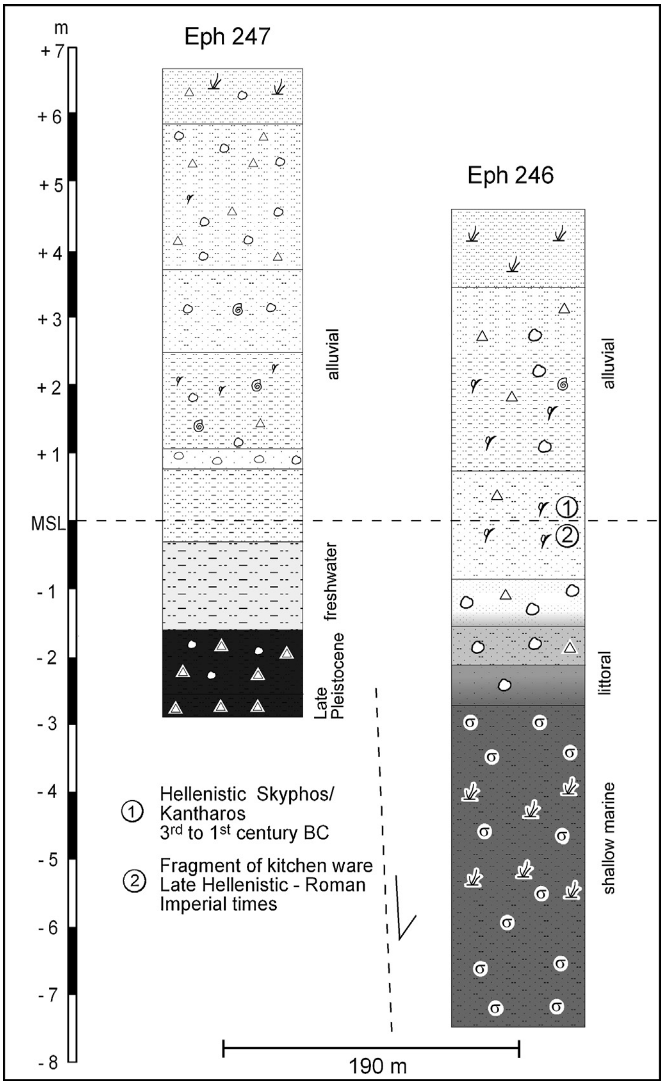

Fig. 4. Synopsis of Eph 246 and 247, cored in the Arap Derç valley. Sedimentology and facies are described in Fig. 5, position of coring sites in Fig. 9.

harbour sites, four cores with a maximum depth of 13 m b.s. were performed in the Arvalya valley (Fig. 5). Eph 346 was cored in the top of a small elevation 1.5 km south of Eph 308, and the other coring sites are located in the lower floodplain of the Kenchrios (Fig. 9).

Working in this area offered the opportunity to investigate a possible prehistoric site in September 2012 and to clarify its principal stratigraphy. The so-called Arvalya Höyük or Gül Hanım (Figs. 6 and 9) is known as a prehistoric site, with surface finds in the mid-1990s published by Evren and İcten (1998). Due to the massive destruction of the area in recent times, the definition of its size, function and dating remain vague (Horejs et al., 2011).

The strata in Eph 346 identified this apparently small hill as a distinct settlement mound composed of cultural layers. From 6.00 to 3.50 m b.s., alluvial sediments were deposited. They are covered by 3.50 m of settlement layers with ceramic flitters, charcoal, fragments of flint tools and even fragments of painted plastering material. Additional new surface finds around the Arvalya tell revealed a spectrum comparable to Çukuriçi Höyük, the second known tell in the Ephesos region, intensively excavated since 2007 (e.g. Horejs, 2008; Horejs et al., 2011). A few pottery sherds, fragments of tools and flakes of local flint and imported obsidian as well as fragments of polished stone axes of different raw materials show strong similarities with the assemblages of the neighbouring Çukuriçi Höyük in its Neolithic and Chalcolithic layers (phases ÇuHö IX-VII: Horejs et al., 2011; Galik and Horejs, 2011). Both tells are situated in similar palaeographic settings, in the plains of neighbouring valleys open to the sea and about one to two kilometres away from the former coastline (Horejs et al., 2011). With the drilling Eph 346 and additional archaeological material studies of surface finds in 2012 a distinct tell site can be defined in the Arvalya valley, presumably dating to Neolithic and Chalcolithic periods. To date, nothing is known about a potential harbour site during that time. It can only be said that, if it existed at all, it was not directly adjacent to the tell.

4.4. *Cross section in Arvalya valley*

Summarizing the cross-section, the vibracores Eph 308, 248 and 250 are dominated by terrestrial sands and silts with pebbles and angular stones at the base, whereas Eph 249 (drilling progress was stopped at 2.58 m b.s.l. due to a massive log) is characterized by silts and sands. The first marine transgressive facies – medium sand with pebbles and marine microfauna – appears in Eph 250; it was dated to the 6th millennium BC. The continuously rising of the sea level created a marine embayment. A layer of Eph 250 with an abundant marine microfauna dates to the middle of the 2nd millennium BC. During Hellenistic time, clayey silts dominate with *C. glaucum*, small plant remains and a ceramic fragment. Eph 248 revelaed terrestrial strata with land snails. Clayey silts may be evidence of the existence of a small water basin close to the coast. It silted up due to the prograding river. Later, fine-grained freshwater and lagoonal sediments accumulated over terrestrial sediments in Eph 248 as well as in Eph 250. The rising potassium content in Eph 250 and 249 characterises the fluvial facies of the Kenchrios and Küçük Menderes. After the formation of a sand barrier, brackish stillwater sediments were deposited. The lagoon in Eph 250 turned to freshwater, but was still influenced by the sea, maybe during storm events. Eph 249 is dominated by fluvial silts of the Küçük Menderes up to the surface. It was drilled only 60 m south of the river. Alluvial fine-grained sediments (alternating clayey and sandy silts) of the Küçük Menderes form the upper metres of the cores, often with ceramic and brick fragments.

4.5. *Vibracores around Çanakgöl*

Çanakgöl, a residual lake, is situated west of the Arvalya valley (Figs. 8a and 9e) in an area surrounded by small hills – Çanakgöl Tepe (36 m) in the north and Ideli Tepe (50 m) in the west. To the east a small elevation separates the area from the Arvalya valley. On this elevation, a 10,000 m^2 villa was discovered during geophysical research in October 2012 (Österreichisches Archäologisches Institut, 2012). Five cores to a maximum depth of 12 m b.s. were drilled to decipher the palaeo-geographic evolution.

On Schindler's (1897) map, Çanakgöl still had a connection to the ancient Küçük Menderes river. Eph 267 and Eph 266 are located in the east of the lake, only 27 m and 70 m west of the hill slope. The sediments of Eph 266 and 267 differ from those of Eph 268, 282 and 283 (carried out in the north of the lake). In the deepest layers of the latter, homogeneous silts with microfauna of marine origin occur. At the base of Eph 266 and 267 well-rounded pebbles of a beach environment dominate (transgression facies). With the rising sea level, coarse sand with gravel was accumulated; seagrass with marine shells and gastropods are intercalated. Geochemical analyses (low K and high LOI and $CaCO_3$ values as well as elevated Ca/Fe ratios) show a changing environment. Ca/Fe ratio and $CaCO_3$ value are good indicators for a foraminifer or shell rich layer as shown at

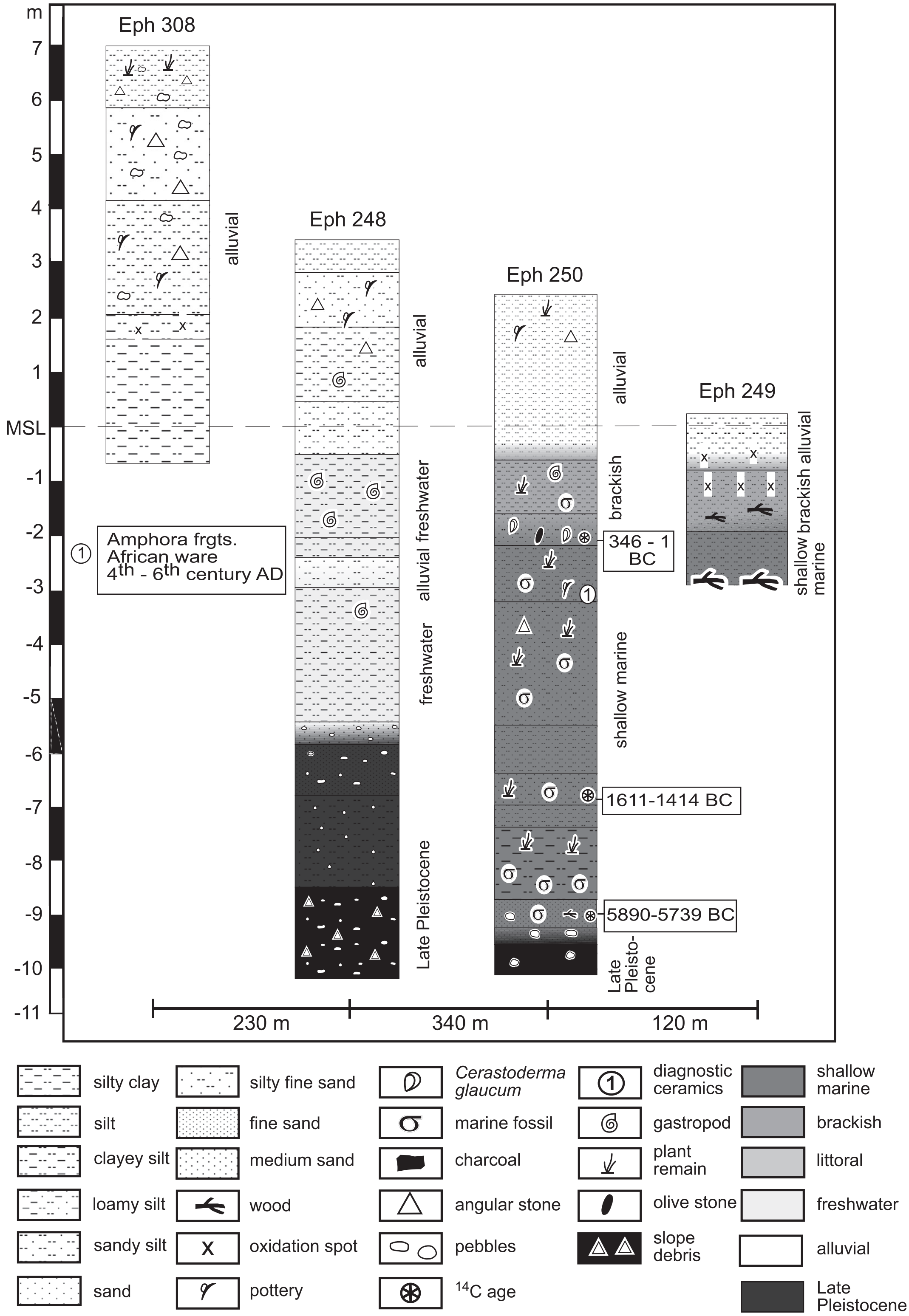

Fig. 5. Cross section through Arvalya valley from south to north. The legend also applies for Figs. 2, 4, 7 and 8. Position of coring sites in Fig. 9.

the base of Eph 250 (Vött et al., 2002; Rothwell and Rack, 2006; Croudace et al., 2006). Foraminifers (*Elphidium complanatum*, *E. crispum*, *A. compacta*, *R. bradyi*, *Rosalina globulosa*, *Cibicides advenum*, *Spiroloculina angulosa*, *L. lobatula*, *Vertebralina striata* and *Triloculina* sp.) and ostracods (*Aurila* sp. and *Loxoconcha* sp.) are evidence of a marine environment close to the coast. Seagrass at the transition to the bottom layer dates to 4269–3939 cal BC. This sublittoral milieu ended during Hellenistic times (354–117 cal BC). The marine transgression reached Eph 267 as well.

In Eph 268, an olive stone at 11.14 m b.s.l. (48 BC–60 cal AD), a diagnostic piece of pottery at 10.04 m b.s.l. (1st–2nd century AD) as well as plant remains (195–55 cal BC) and charcoal (164–1 cal BC)

Fig. 6. Settlement mound called Arvalya Höyük or Gül Hanım in the Arvalya valley. Position of mound in Fig. 9. (a) View of Arvalya Höyük. (b) Sediment core of Eph 346, drilled in the top of the mound. (c) Finds of a surface survey. (d) Painted plaster from core Eph 346 encountered at a depth of 2.26–2.28 m b.s.

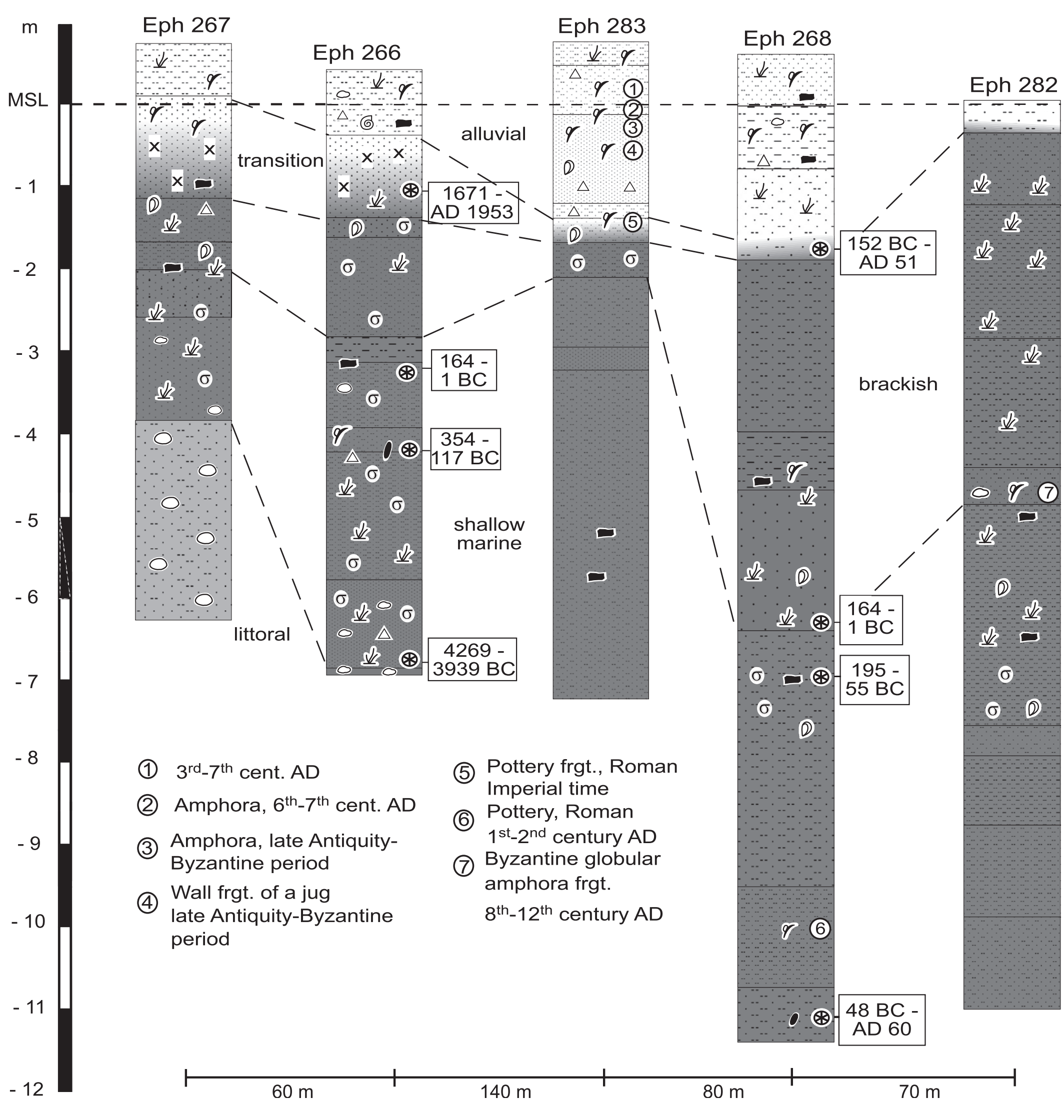

Fig. 7. Five cores around Çanakgöl. Legend for sedimentology and facies in Fig. 5. Position of coring sites in Fig. 9.

at 6.34 and 6.94 m b.s.l., respectively, all date to Hellenistic and/or Roman times.

In Eph 266, nearly 1 m of silty and sandy sediments was deposited from the beginning until the end of the Hellenistic period. The advancing foreset beds of the delta – in Eph 268 from 6.29 to 4.83 m b.s.l. – are characterised by very homogeneous, sterile sand and silt layers with a thickness of up to 0.5 cm each. The granulometry and geochemical analysis led to the assumption that sediments were deposited in a stillwater environment at the coring sites Eph 268 and 266, probably due to the building of a sand barrier from the river (levee) which cut off the area from the open sea. During high floods, the river overflowed, thus depositing coarser sediments in the low energy environment. Geochemistry shows decreasing values of carbonate content and Ca/Fe and a rising value of LOI, Pb and K.

The first area where people could settle was at the sites Eph 268 and 282. The oldest artefacts in Eph 283 date from the Roman era; they are followed by Byzantine ceramics. During this period, Eph 282 was still under the influence of the Küçük Menderes. In this coring, a ceramic fragment at a depth of 3.94 m b.s.l. dates to Byzantine time. Fluvial sediments characterised by sterile olive brown medium sands with very little shell debris were deposited at Eph 266 and 267 between the 17th and 20th centuries AD (^{14}C age in Eph 266, Figs. 7 and 8). In the upper metres alluvial sediments consistent of clayey and sandy silt with ceramics and mortar dominate. As the LOI, Ca/Fe and the $CaCO_3$ contents increase, the Pb value decreases.

5. Discussion

5.1. *Ancient landscape reconstructions on the southern flank of the Küçük Menderes graben*

The cores around Arvalya valley and Çanakgöl revealed the shifts in the coastline during the last eight millennia. Therefore, palaeogeographic scenarios can be sketched (Figs. 9a–e).

The marine transgression dates to the beginning of the 6th millennium BC. The maximum landward shoreline is shown between Eph 246 and 247 as well as 250 and Eph 248 (Fig. 9a). The question why no marine sediments were found in drill cores Eph 248 and 247 and the sea did not ingress into this area still remains unclear. At Çanakgöl, the deepest marine sediments (at a depth of −6.84 m b.s.l., Eph 266) were deposited at the beginning of the 5th millennium BC, post-dating the even deeper transgression facies, which was not reached at this site. When people started to settle the Arvalya valley, the coastline was situated about 2 km to the north. The sedimentation rate in the marine embayment was very low during this period (5 cm per century in core Eph 250) (Fig. 9b).

During the Hellenistic period (3rd–1st centuries BC), marine conditions still prevailed around Çanakgöl. Eph 246 had already been silted up. In the Arvalya valley, a freshwater lake developed in Eph 248 and a lagoon in Eph 250 (Fig. 9c). This can be explained by a developing sand barrier (levee) of the prograding Kenchrios river. The sedimentation rate increased from 6 cm (from the end of the 4th millennium BC) to 68 cm per century in Hellenistic–early Roman times at Çanakgöl, and to 37 cm per century in the Arvalya valley. This is in accordance with the proposed position of the Küçük Menderes delta front during that period (Brückner et al., 2008). At the end of Hellenistic–early Roman times, the first prodelta silts of the Küçük Menderes were deposited at Eph 268. Three ^{14}C ages and one diagnostic ceramic fragment at depths between 6.39 and 11.39 m b.s.l. date back to the Roman period. One possibility for this unusually rapid deposition of 4 m sediments may reflect a rapid sedimentation of the foreset beds of the approaching delta front in the marine embayment. Nevertheless, dredging and the deposition of sediments in this environs is more probable. During the Hellenistic period, Eph 266 and 267 were located closer to the coast in a more wave-dominated environment.

In Byzantine times, the area of the lower floodplain of the Kenchrios had been silted up as well as Eph 283 and 268 (Fig. 9d). A charcoal at 1.74 m b.s.l. in Eph 268, dated to the Roman age, was

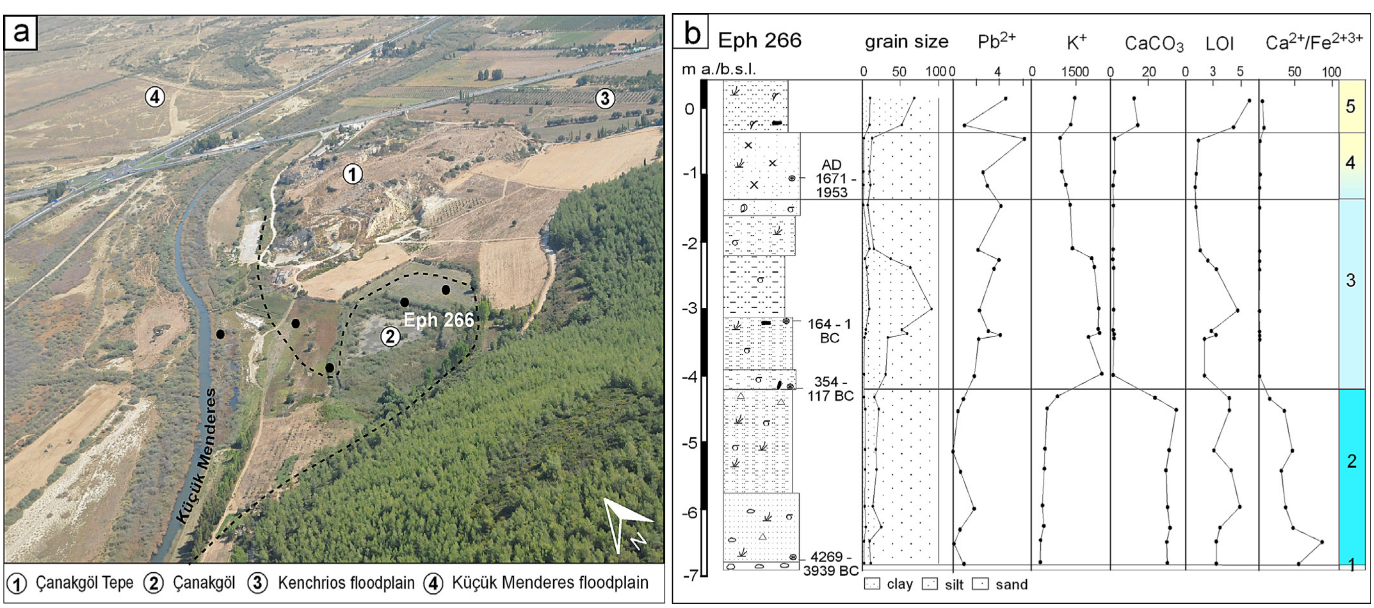

Fig. 8. The area around Çanakgöl. (a) View towards northeast (oblique aerial photography) on the remnant lake Çanakgöl and the former harbour basin (area consistent with rectangle in Fig. 9). It is situated in a natural embayment at the foot of the southern flank of the Küçük Menderes graben. b) Core Eph 266 with grain size, Pb, K, $CaCO_3$, LOI and Ca/Fe. Pb and K were analyzed semiquantitatively using Itrax core scanner (cps = count per second). Grain size, $CaCO_3$ and LOI are indicated in percent. Points represent the depth of the measured samples, horizontal lines the boundaries of the units. Matrix and components are described in Fig. 5. Facies: 1) littoral, 2) shallow marine, 3) brackish, 4) transition layer, 5) fluvial.

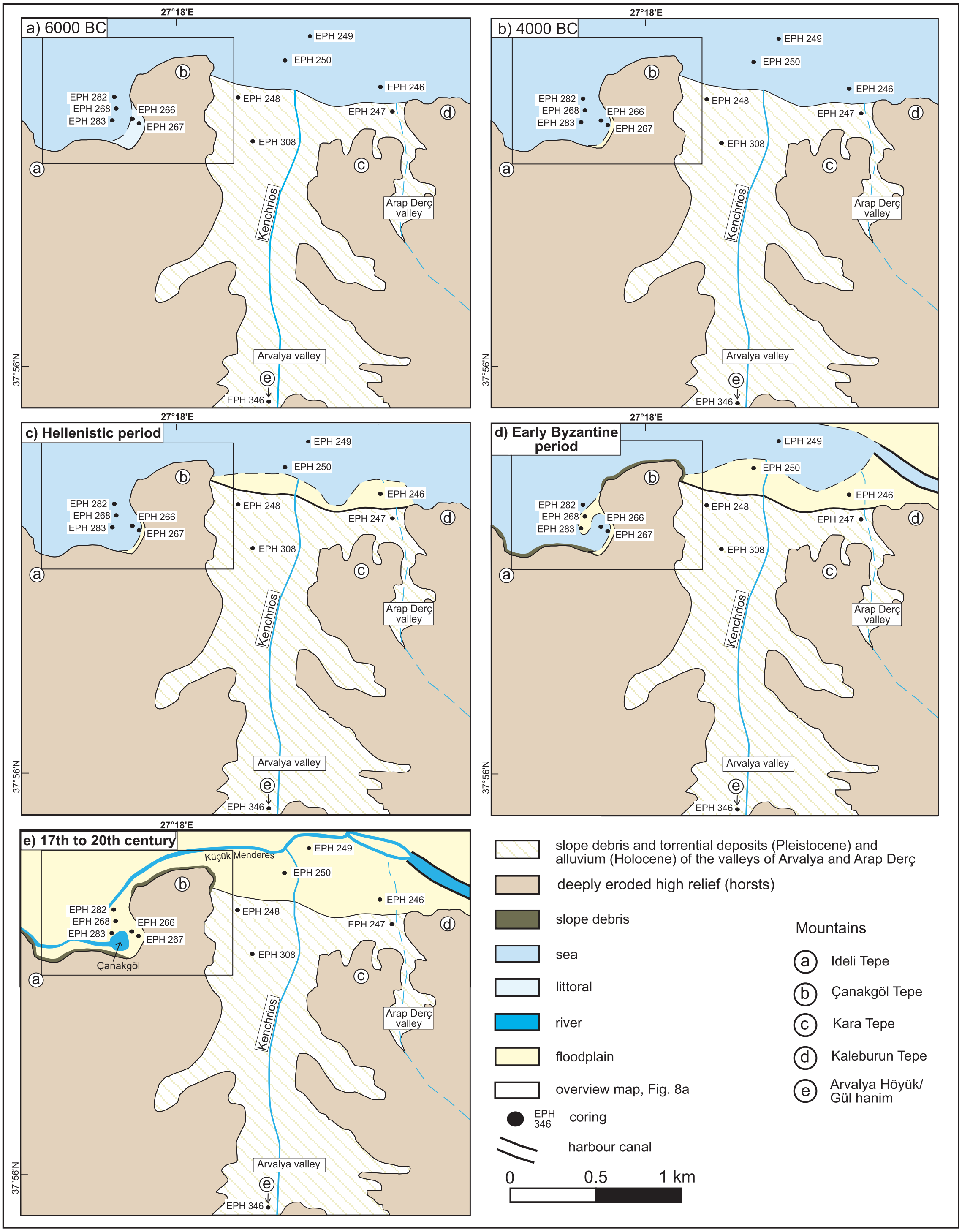

Fig. 9. Scenarios of the landscape evolution of the northern Kenchrios valley and the area of Çanakgöl for 6000 BC, 4000 BC, Hellenistic period, early Byzantine period, 17th–20th century.

most probably redeposited. The southern cores around Çanakgöl still represented a marine environment with connection to the sea. The barrier was sometimes breached by floods or storm events, so that fluvial silts were deposited.

Between the 17th and 20th centuries AD, fluvial sediments dominate Eph 266 and 267 (Fig. 9e). The sedimentation rate from Hellenistic to early Roman times until the 17th century decreased to 18 cm per year. The coastline was further west, probably near the remnant lake Çanakgöl. During this period, the bay was still connected to the sea (Schindler, 1897). At the latest after the regulation of the Küçük Menderes in 1934 with its redirection to the north of the floodplain, the lake lost its connection to the river and therefore to the sea (Güldali, 1979).

5.2. Late Roman and Byzantine harbours of Ephesus

An ideal harbour site should be located in a marine embayment or indentation, which is protected against the open sea so that a low-energy wave environment is present. One of the best examples is the famous Lion Harbour of Miletus (Brückner et al., 2006). An example from Ephesus is the Roman harbour, bordered by Bülbüldağ and Panayırdağ after the city centre had been shifted around 300 BC. The research presented herein focused on three areas which are one to three kilometres to the west of the ancient city centre at the southern flank of the graben.

The Roman harbour canal was flanked on both sides by a necropolis. The oldest objects in the necropolis area date to the end of the 1st century AD. At this time, the Roman harbour had to be connected with the canal to the sea (Österreichisches Archäologisches Institut, 2011). At least since that time, new anchorages farther to the west were needed.

One possible harbour site is located to the west of Kaleburun Tepe. It can be concluded that the sea never ingressed into this valley. The core inside the valley does not show any marine influence. To the north of the valley, however, close to the connection with the Küçük Menderes alluvial plain, core Eph 246 shows the existence of marine sediments. The area silted up in Hellenistic or Roman Imperial times at the latest, probably due to the vicinity to the surrounding mountains (colluviation) and a small river building up its delta (alluviation). As siltation started early and the site was not well protected, it could not have hosted a harbour.

In the Arvalya valley, Schindler (1897) and other authors had presumed the existence of a so-called Panormos harbour. However, coring revealed that the coastline did not reach far into the valley. Only the northern core, Eph 250, shows marine strata (Fig. 2). Thus, a small marine embayment was present, merely protected on the western side by Çanakgöl Tepe (Fig. 9). It persisted in Hellenistic time, but turned into a brackish residual lake, sometimes connected to the sea, thereafter. As in Hellenistic time sea level was about one metre lower than today, according to the sea level curve of Müllenhoff (2005), water depth was ~1.50 m in this area. In Antiquity, the Kenchrios built its delta into the marine embayment. Due to its steep gradient and the Mediterranean climate with torrential rains, the river occasionally carried coarse–grained sediment. As a consequence, a potential harbour would continuously have been threatened by siltation.

In principle, a site for a harbour in the north of the Arvalya valley is conceivable, protected by small hills to the west (Fig. 9). However, major problems caused by the delta progradation of the Kenchrios and the siltation processes by the Küçük Menderes are obvious. As pro-delta sediments were deposited in the area of Eph 268 in Roman times, this would have also affected coring site Eph 250 and the water depth in this area. If a harbour site existed, it could not have been used for a long period of time. However, in this area it seems more probable that there have been platforms further north (closer to the harbour canal entrance) for transferring goods into smaller boats. Thus, a much better harbour site is the area around Çanakgöl (Fig. 8).

The southern area around the remnant lake which represents the former harbour basin, silted up before the 16th–19th century, while the northern part did so in the Roman, or at the latest in the Byzantine period. At least until the end of the 19th century, the lake had a connection to the Küçük Menderes river. In Byzantine and also Venetian–Turkish times, when most probably the harbour at Çanakgöl was (still) in use, the area around Eph 283 was already silted up. The oldest dated ceramics reach to the Roman Imperial period. They are overlain by several pieces of amphora and a fragment of a pitcher dating to late Antique/Byzantine times. This site was accessible to people in late Antiquity. In this period, the area around core sites Eph 266 and 267, as well as Çanakgöl and the western part of the embayment, was still a brackish water environment and probably connected to the sea. Despite the silting process of the eastern part of the embayment (not later than 16th century AD around Eph 266 and 267), the area to the west and the east of the lake was still reachable by boat. As the delta sediments also influenced this site, it is probable that the harbour was dredged to maintain the function as a port. From the Roman harbour, it is known that it was dredged a couple of times (Kraft et al., 2000). Today, the ancient Küçük Menderes river course is very close-by, and still navigable; thus, it could have been used for a long time as a harbour or a landing site. The place fits very well for the proposed late Byzantine to Venetian harbour because it was navigable for a long time and easy to reach even after the coastline had prograded further west. The present lake seems to be the former harbour basin.

An indicator for the period of use is the pollutant Pb. XRF measurements of Pb revealed a rising concentration from Hellenistic time to the 17th–20th centuries (Fig. 8b). From other archaeological sites, it is known that pollutants such as Pb appear especially during the Roman period (Marriner and Morhange,

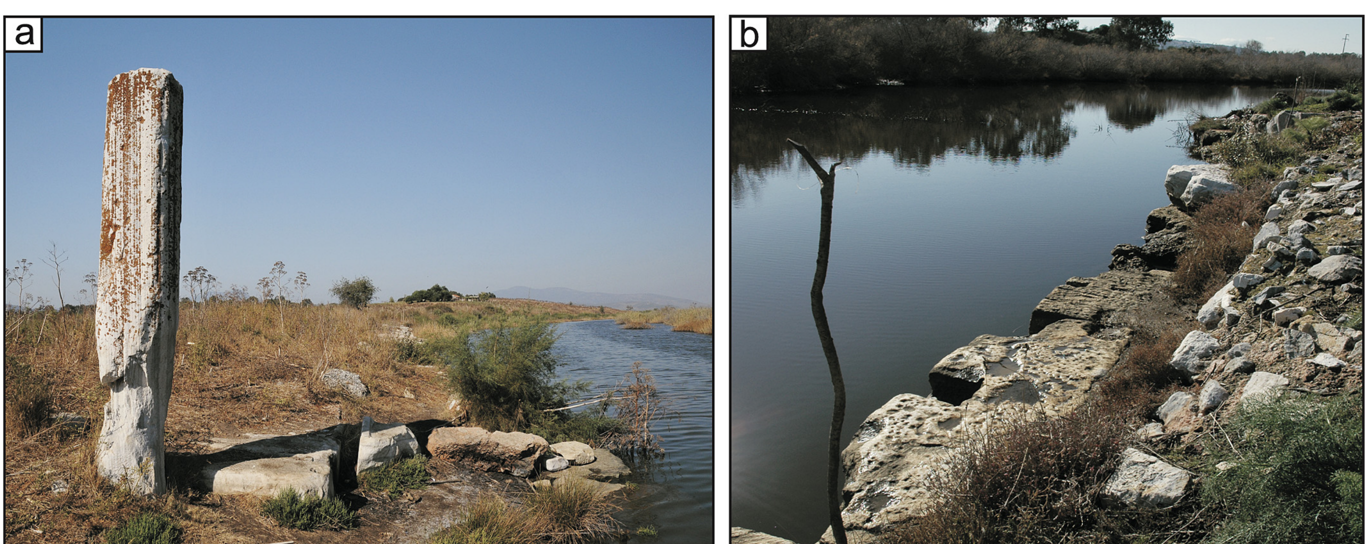

Fig. 10. Landing site discovered in January 2012. (a) Pillar at the northern side of the former channel of the Küçük Menderes. The landing site was established to the west of Çanakgöl, presumably in late Byzantine–Ottoman times. (b) View of the landing site with facilities to anchor ships.

2007). In general, a correlation exists between fine grained sediments, a high content of LOI and elevated Pb values (Pickering, 1986). The geochemical analyses show a decreasing grain size together with elevated LOI values from 3.40 to 2.20 m b.s.l. and increasing grain size (mostly sand) up to 0.45 m b.s.l. together with lower LOI values (Fig. 8b). In this area, the Pb values are not correlated to the grain size and organic content. Although grain size is coarse and low organic content consistent, the Pb values continuously increase. In sum, the elevated lead values seem to support the assumption that the site was used as a harbour during that time. More ^{14}C ages spanning the interval between the early Roman period and the 16th century have to be determined to establish a better chronostratigraphic correlation between the changing concentrations of this pollutant and the settlement history.

6. Conclusion

Geoarchaeological research in the environs of the ancient city of Ephesus leads to the conclusion that around 6000 BC, due to the transgression of the Aegean Sea, marine sediments were deposited at the southern flank of the graben. The north–south striking valleys to the east of the investigated area (valleys of Arvalya and Arap Derç) show only a minor marine influence since they were already filled with Pleistocene deposits. As a byproduct of our research, an elevated area inside the Arvalya valley could be identified as a settlement mound (tell), probably dating to the Neolithic period.

With the rising water table, the entire area around Çanakgöl became part of the marine embayment. When sea-level rise decelerated, fluvial influence became dominant, mainly the advancing delta systems of the Küçük Menderes and its tributaries from mid-Holocene times on which has permanently shifted the coastline westwards (e.g. see Brückner, 2005; Kraft et al., 2007, 2011). A major effect of the landscape changes was the siltation of the harbours. One reason for the relocation of the city of Ephesus to the area at the foot of Panayırdağ and Bülbüldağ by Lysimachos before 300 BC was the good anchoring ground there. With the advancing delta front, this area, too, was endangered by siltation. Therefore, the Romans dredged the place and turned it into a hexagonal harbour. It was the major harbour when Ephesus was the capital of the Roman province of Asia. However, the delta front continued its westward shift, thus forcing the Romans to react: a harbour canal was constructed. The latest geophysical and archaeological research indicates that on both sides of the canal tombs of a necropolis, dating from the late 1st century AD, were discovered and partly unearthed (Österreichisches Archäologisches Institut, 2011; Seren and Ladstätter, 2011). This is evidence that in late Roman times the delta front was west of the end of the harbour canal. Where then were the later harbours, especially in Byzantine times?

Çanakgöl is the best candidate since it is in the leeward position of the delta advance and the adjacent mountains do not deliver a large amount of rock debris. In Roman times, the area east of Çanakgöl was already silted in and fine-grained bottomset–foreset beds of the advancing delta front were accumulated in the direct environs of Çanakgöl. The northern part of the Arvalya valley is assumed to be accessible until (late?) Byzantine times. With the prograding deltas of Küçük Menderes and Kenchrios, the Çanakgöl also was endangered. It is possible that it was dredged to guarantee the continuation of the shipping operations. Geophysical measurements (geomagnetic – Fluxgate Magnetometer with optical distance, raster of 16 × 50 cm and georadar – Noggin with 250 MHz antenna, raster 5 × 25 cm) detected a huge villa in October 2012, but until now no harbour-related constructions of piers or storage houses (Österreichisches Archäologisches Institut, 2012). Measurements are needed in the direct environs of the remnant lake and former harbour basin. Until the end of the 20th century, Çanakgöl was connected to the river (now the former channel of the Küçük Menderes) which flows nearby.

The harbour site was in use for a long time; it even had a connection to the sea after the delta had advanced farther west. When it became too small, a new landing site with integrated spoils about one kilometre to the west was established on the right side of the Küçük Menderes as well as another harbour at Pamucak. The data suggest a Late Byzantine age of the quay. This has been confirmed by detailed research from archaeological and architectural studies. Both presumed harbour sites could have been important in Late Byzantine–Turkish times. During cleaning works in January 2012 on both sides of the ancient Küçük Menderes branch, a mole with a still-standing column was discovered on the northern side of the canalised river. It would still be a good place for landing and unloading goods (Fig. 10). Cores carried out in 2012 revealed that the southern part of the river was also rectified (core filling marble at a depth of 2–3 m b.s.).

Acknowledgements

We thank the Austrian Archaeological Institute (Österreichisches Archäologisches Institut) for funding this geoarchaeological project, and the Turkish authorities for granting the research permits. Radiocarbon dating was accomplished by the Center for Applied Isotope Studies, University of Georgia at Athens, USA. Dr. V. Wennrich, University of Cologne, carried out the XRF measurements with the Itrax core scanner. Manfred Bundschuh, Christoph Burow, Daniel Hoppe, Hannes Laermanns, Rilana Rauhut, Joel Sterzer, Ralf Urz, Florian Wilken, Ramazan Yazıcı, as well as Ibrahim Kınacı were a great help during fieldwork (2010–2012). Daniel Kelterbaum, Matthias May, Gilles Rixhon and John C. Kraft gave valuable comments on an earlier draft of this paper.

References

AG, Boden, 2005. Bodenkundliche Kartieranleitung. Schweizerbart, Stuttgart.

Barsch, H., Billwitz, K., Bork, H.-R. (Eds.), 2000. Arbeitsmethoden in Physiogeographie und Geoökologie. Klett-Perthes, Gotha.

Blott, S.J., Pye, K., 2001. GRADISTAT: a grain size distribution and statistics package for the analysis of unconsolidated sediments. Earth Surface Processes and Landforms 26, 1237–1248.

Bozkurt, E., 2001. Late Alpine evolution of the central Menderes Massif, western Turkey. International Journal of Earth Sciences 89, 728–744.

Bozkurt, E., Satir, M., 2000. The Southern Menderes Massif (western Turkey): geochronology and exhumation history. Geological Journal 35, 285–296.

Brückner, H., 1997. Geoarchäologische Forschungen in der Westtürkei – das Beispiel Ephesus. Passauer Schriften zur Geographie 15, 39–51.

Brückner, H., 2005. Holocene shoreline displacements and their consequences for human societies: the example of Ephesus in Western Turkey. Zeitschrift für Geomorphologie, N. F 137 (Suppl.), 11–22.

Brückner, H., Vött, A., Schriever, A., Handl, M., 2005. Holocene delta progradation in the eastern Mediterranean – case studies in their historical context. Méditerranée 104, 95–106.

Brückner, H., Müllenhoff, M., Gehrels, R., Herda, A., Knipping, M., Vött, A., 2006. From archipelago to floodplain – geographical and ecological changes in Miletus and its environs during the past six millennia (Western Anatolia, Turkey). Zeitschrift für Geomorphologie, N. F 142 (Suppl.), 63–83.

Brückner, H., Kraft, J.C., Kayan, İ., 2008. Vom Meer umspült, vom Fluss begraben. Zur Paläogeographie des Artemisions. In: Muss, U. (Ed.), Die Archäologie der ephesischen Artemis. Gestalt und Ritual eines Heiligtums, pp. 21–33.

Brückner, H., Kelterbaum, D., Marunchak, O., Porotov, A., Vött, A., 2010. The Holocene sea level story since 7500 BP – lessons from the Eastern Mediterranean, the Black and the Azov Seas. Quaternary International 225, 160–179.

Brückner, H., Gerlach, R., 2011. Geoarchäologie – von der Vergangenheit in die Zukunft. In: Gebhardt, H., Glaser, R., Radtke, U., Reuber, P. (Eds.), Geographie – Physische Geographie und Humangeographie. Heidelberg, pp. 1179–1186.

Croudace, I.W., Rindby, A., Rothwell, R.G., 2006. ITRAX: description and evaluation of a new multi-function X-ray core scanner. In: Rothwell, R.G. (Ed.), 2006. New Techniques in Sediment Core Analysis, vol. 267. Geological Society, London, Special Publication, pp. 51–63.

Crouch, D.P., 2004. Geology and Settlement. Greco-Roman Pattern. Oxford University Press, Oxford.
Darkot, D., Erinç, S., 1954. Geographical observations in the south-west of Anatolia. Review of the Geographical Institute of the University of Istanbul 1, 149–167.
Doutsos, T., Kokkalas, S., 2000. Stress and deformation patterns in the Aegean region. Journal of Structural Geology 23, 455–472.
Eisma, D., 1962. Beach ridges near Selçuk, Turkey. Tijdschrift Koninklijk Nederlandsch Aardrijkskundig Genootschap 79, 234–246.
Eisma, D., 1978. Stream deposition and erosion by the eastern Shore of the Aegean. In: Brice, W.C. (Ed.), The Environmental History of the Near and the Middle East since the Last Ice Age. Academic Press, San Diego, pp. 234–246.
Erinç, S., 1954. Über die Entstehung und morphologische Bedeutung des Tmolosschutts. Review of the Geographical Institute of the University of Istanbul 2, 55–72.
Erinç, S., 1978. Changes in the physical environment in Turkey since the end of the last glacial. In: Brice, W.C. (Ed.), The Environmental History of the Near and the Middle East Since the Last Ice Age. Academic Press, San Diego, pp. 87–108.
Erol, O., 1983. Die naturräumliche Gliederung der Türkei. Beihefte zum Tübinger Atlas des Vorderen Orients. Reihe A Naturwissenschaften 13, 1–245.
Evren, A., İcten, C., 1998. Efes Çukuriçi ve Arvalya (Gül Hanım) Höyökleri. In: Müze Kurtarma Kazıları Semineri, vol. 8, pp. 111–133.
Foss, C., 1979. Ephesus After Antiquity: a Late Antique, Byzantine, and Turkish City. Cambridge University Press, Cambridge.
Frenzel, P., Boomer, I., 2004. The use of ostracods from marginal marine, brackish waters as bioindicators of modern and quaternary environmental change. Palaeogeography, Palaeoclimatology, Palaeoecology 225, 68–92.
Frenzel, P., Matzke-Karasy, R., Viehberg, A., 2006. Zwischen Biologie, Paläontologie und Umweltforschung. Muschelkrebse als Zeugen der Vergangenheit. Biologie in unserer Zeit 36, 102–108.
Galik, A., Horejs, B., 2011. Çukuriçi Höyük – various aspects of its earliest settlement phase. In: Krauß, R. (Ed.), Beginnings. New Approaches in Researching the Appearing of the Neolithic between Northwestern Anatolia and the Carpathian Basin. Workshop at Istanbul Department of the German Archaeological Institute, April 8th–9th 2009, Istanbul, vol. 1. Menschen – Kulturen – Traditionen. Studien aus den Forschungsclustern des Deutschen Archäologischen Instituts, pp. 83–94.
Grund, A., 1906. Vorläufiger Bericht über physiogeographische Untersuchungen in den Deltagebieten des Großen und Kleinen Mäanders. Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften 115, 1757–1769.
Güldali, N., 1979. Geomorphologie der Türkei: Erläuterungen zur geomorphologischen Übersichtskarte der Türkei 1:2.000.000. Beihefte zum Tübinger Atlas des Vorderen Orients 4, 1–265.
Hess, G., 1985. Akkumulation und Erosion in westtürkischen Flüssen während des Mittelalters. Kieler Geographische Schriften 62, 199–206.
Horejs, B., 2008. Erster Grabungsbericht zu den Kampagnen 2006–2007 am Çukuriçi Höyük. Jahreshefte des Österreichischen Archäologischen Institutes in Wien 77, 91–106.
Horejs, B., Galik, A., Thanheiser, U., Wiesinger, U., 2011. Aktivitäten und Subsistenz in den Siedlungen des Çukuriçi Höyük. Der Forschungsstand nach den Ausgrabungen 2006–2009. Praehistorische Zeitschrift 86 (1), 31–66.
Hütteroth, W.-D., Höhfeld, V., 2002. Türkei: Geographie, Geschichte, Wirtschaft, Politik. Wissenschaftliche Buchgesellschaft, Darmstadt.
Kayan, I., 1999. Holocene stratigraphy and geomorphological evolution of the Aegean coastal plains of Anatolia. Quaternary Science Reviews 18, 541–548.
Kerschner, M., Kowalleck, I., Steskal, M., 2008. Archäologische Forschungen zur Siedlungsgeschichte von Ephesus in geometrischer, archaischer und klassischer Zeit. Grabungsbefunde und Keramikfunde aus dem Bereich von Koressos. Ergänzungshefte der Jahreshefte des Österreichischen Archäologischen Institutes in Wien 9, 1–192.
Knibbe, D., 1998. Ephesus. Geschichte einer bedeutenden antiken Stadt und Portrait einer modernen Großgrabung im 102. Jahr der Wiederkehr des Beginnes österreichischer Forschungen (1895–1997). Lang, Frankfurt am Main.
Kraft, J.C., Brückner, H., Kayan, İ., 1999. Palaeogeographies of ancient coastal environments in the environs of the Feigengarten excavation and the 'Via(e) Sacra(e)' to the Artemision at Ephesus. In: Scherrer, et al. (Eds.), 1999. Steine und Wege. Festschrift für Dieter Knibbe zum 65. Geburtstag, vol. 32. Österreichisches Archäologisches Institut Sonderschriften, pp. 91–100.
Kraft, J.C., Kayan, İ., Brückner, H., Rapp, G., 2000. A geological analysis of ancient landscapes and the harbors of Ephesus and the Artemision in Anatolia. Jahreshefte des Österreichischen Archäologischen Institutes in Wien 69, 175–233.
Kraft, J.C., Kayan, İ., Brückner, H., 2001. The geological and palaeogeographical environs of the Artemision. In: Muss, U. (Ed.), 2001. Der Kosmos der Artemis von Ephesus, vol. 37. Österreichisches Archäologisches Institut, Sonderschriften, pp. 123–213.
Kraft, J.C., Brückner, H., Kayan, İ., 2005. The sea under the city of ancient Ephesus. In: Brandt, B., Gassner, V., Ladstätter, S. (Eds.), 2005. Synergia, vol. 1. Festschrift F. Krinzinger, pp. 147–156.
Kraft, J.C., Brückner, H., Kayan, İ., Engelmann, H., 2007. The geographies of ancient Ephesus and the Artemision in Anatolia. Geoarchaeology 22, 121–149.
Kraft, J.C., Rapp, G., Brückner, H., Kayan, İ., 2011. Results of the Struggle at Ancient Ephesus: Natural Processes 1, Human Intervention 0, vol. 352. Geological Society, London, Special Publications. pp. 27–36.
Marriner, N., Morhange, C., 2007. Geoscience of ancient Mediterranean harbours. Earth-Science Reviews 80, 137–194.
Meriç, R., 1985. Zur Lage des ephesischen Außenhafens Panormos. In: Komitee Festschrift Hermann Vetters (Ed.), Lebendige Altertumswissenschaft. Festschrift H. Vetters, Wien, pp. 30–32.
Meriç, E., 2004. Benthic Foraminifera of Eastern Aegean Sea (Turkey) Systematics and Autoecology. Turkish marine research foundation, Istanbul, Turkey.
Müllenhoff, M., 2005. Geoarchäologische, sedimemologische und morphodynamische Untersuchungen im Mündungsgebiet des Büyük Menderes (Mäander), Westtürkei. Marburger Geographische Schriften, 141.
Österreichisches Archäologisches Institut (Ed.), 2011. Wissenschaftlicher Jahresbericht des Österreichischen Archäologischen Instituts 2011. Wien.
Österreichisches Archäologisches Institut (Ed.), 2012. Wissenschaftlicher Jahresbericht des Österreichischen Archäologischen Instituts 2012. Wien.
Philippson, A., 1912. Reisen und Forschungen im westlichen Kleinasien. In: Petermanns Mitteilungen, Ergänzungsheft, vol. 172. pp. 1–100.
Philippson, A., 1918. Handbuch der regionalen Geologie. Kleinasien. Winter, Heidelberg.
Philippson, A., 1920. Zur morphologischen Karte des westlichen Asiens. Petermanns Geographische Mitteilungen 66, 197–202.
Pickering, W.F., 1986. Metal Ion speciation – soils and sediments (a review). Ore Geology Reviews 1, 83–146.
Polat, O., Gok, E., Yilmaz, D., 2008. Earthquake hazard of the Aegean extension region (West Turkey). Turkish Journal of Earth Sciences 17, 593–614.
Reimer, P.J., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Bronk Ramsey, C., Buck, C.E., Burr, G.S., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T.J., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., McCormac, F.G., Manning, S.W., Reimer, R.W., Richards, D.A., Southon, J.R., Talamo, S., Turney, C.S.M., van der Plicht, J., Weyhenmeyer, C.E., 2009. IntCal09 and Marine09 radiocarbon age calibration curves, 0–50,000 years cal BP. Radiocarbon 51 (4), 1111–1150.
Rothwell, R.G., Rack, F.R., 2006. New techniques in sediment core analysis: an introduction. In: Rothwell, R.G. (Ed.), 2006. New Techniques in Sediment Core Analysis. Geological Society, London, Special Publication vol. 267, pp. 1–29.
Scherrer, P., 1995. Ephesos – der neue Führer; 100 Jahre österreichische Forschungen. Österreichisches Archäologisches Institut, Wien.
Schindler, A., 1897. Umgebung von Ephesus. Topographische Karte 1:25000.
Schlichting, E., Blume, H.-P., Stahr, K., 1995. Bodenkundliches Praktikum. Eine Einführung in pedologisches Arbeiten für Ökologen, insbesondere Land- und Forstwirte und für Geowissenschaftler. Blackwell, Berlin.
Seren, S., Ladstätter, S., 2011. Archaeological prospection by using geophysical methods at different field conditions and archaeological structures in Ephesos/Turkey. In: 16th International Conference on Cultural Heritage and New Technologies, Vienna, November 14–16, 2011, p. 25. Abstract.
Siani, G., Paterne, M., Arnold, M., Bard, E., Metivier, B., Tisnerat, N., Bassinot, F., 2000. Radiocarbon reservoir ages in the Mediterranean Sea and Black Sea. Radiocarbon 42, 271–280.
Stanley, D.J., Warne, A.G., 1994. Worldwide initiation of Holocene marine deltas by deceleration of sea-level rise. Science 265, 228–231.
Steskal, M. Ephesus and its harbours: a city in search of its place. In: Akten des Symposiums Häfen und Hafenstädte im östlichen Mittelmeerraum von der Antike bis in byzantinische Zeit. Neue Entdeckungen und aktuelle Forschungsansätze. Intern. Symposium in Istanbul 30.5.–1.6.2011, BYZAS.
Strabo, 2007. Geographica. Translated by Dr. A. Forbiger, Second Edition, Matrix, Wiesbaden.
Taymaz, T., Yilmay, Y., Dilek, Y., 2007. The Geodynamics of the Aegean and Anatolia: Introduction, vol. 291. Geological Society, London, Special Publications. pp. 1–16.
Vetters, W., 1985. Die Küstenverschiebung Kleinasiens: eine Konsequenz tektonischer Ursachen. In: Komitee Festschrift Hermann Vetters (Ed.), Lebendige Altertumswissenschaften. Festgabe zur Vollendung des 70. Lebensjahres von Hermann Vetters, pp. 33–37.
Vetters, W., 1989. Geologische Übersichtskarte der Umgebung von Ephesus, 1: 25.000.
Vött, A., Handl, M., Brückner, H., 2002. Rekonstruktion holozäner Umweltbedingungen in Akarnanien (Nordwestgriechenland) mittels Diskriminanzanalyse von geochemischen Daten. Geologica et Palaeontologica 36, 123–147.
Wiplinger, G., Wlach, G., 1996. Ephesus. 100 Jahre österreichische Forschungen. Böhlau, Wien.
Zimmermann, N., Ladstätter, S., 2011. Wall Paintings in Ephesus from the Hellenistic to the Byzantine Period. Ege Yayınları, Istanbul.