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Human impact on Holocene sediment dynamics in the Eastern Mediterranean – the example of the Roman harbour of Ephesus

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ABSTRACT: During the past millennia, many erosion and accumulation processes have been modified by anthropogenic impact. This holds especially true for the environs of ancient settlements and their harbours along the Mediterranean coasts. Our multi-proxy investigations in the Roman harbour and the harbour canal of Ephesus (western Turkey) reveals that humans have significantly triggered soil erosion during the last three millennia. Since the eighth century BC, and especially since the Hellenistic period, a high sedimentation rate indicates fast alluviation and delta progradation of the Küçük Menderes. Deforestation, agriculture (especially ploughing) and grazing (especially goats) were the main reasons for erosion of the river catchment area. One consequence was significant siltation of the Hellenistic/Roman harbour basin. This sediment trap archives the human impact, which was strongly enhanced from Hellenistic/Roman to Byzantine times (second/first centuries BC to the sixth/seventh centuries AD), evidenced by high sedimentation rates, raised values of heavy metal contaminations [lead (Pb), copper (Cu)], the occurrence of fruit tree pollen and of intestinal parasites. From the middle to the end of the first millennium AD, the influence of Ephesus declined, which resulted in a decrease of human impact. Studies of several ancient settlements around the Mediterranean Sea tell a comparable story. They also confirm that during their most flourishing periods the human impact totally overprinted the climatic one. To detect the latter, geo-bio-archives of relatively pristine areas have to be investigated in detail. Copyright © 2016 John Wiley & Sons, Ltd.

KEYWORDS: geochemistry; human impact; sediment dynamics; eastern Mediterranean; harbour geoarchaeology

Introduction

Anthropogenic impacts upon sediment processes have been occurring for several millennia. Especially with the beginning of a sedentary lifestyle and the practise of agriculture, sediment processes were directly affected by humans through soil erosion and floodplain deposition (Broothaerts *et al.*, 2014; Lewin and Macklin, 2014). This period of strong and global human impacts on the environment especially since the Industrial Revolution has been called 'the Anthropocene' (Crutzen and Stoermer, 2000; Crutzen, 2002; Steffen *et al.*, 2007). Humans have become a geological factor. Their impact can be studied in many geo-bio-archives (e.g. floodplains, colluvial deposits, lakes, deltas, soils, ice caps; Dusar *et al.*, 2011). However, there are many discussions about the processes, the stratigraphy, the onset, the spatial scales of recorded impacts and hence its precise definition (Ehlers, 2008; Zalasiewicz *et al.*, 2008, 2015; Brown *et al.*, 2013a, 2013b; Lewin and Macklin, 2014). We follow those authors who take the term 'Anthropocene' in the widest possible sense: the period of strong human–environment interactions.

The impact of humans was already proven during the Neolithic period when small farming communities started to practise agriculture (Ruddiman and Thomson, 2001; Ruddiman *et al.*, 2008; Ruddiman and Ellis, 2009; Derin, 2012; Lichter and Meriç, 2012; Foley *et al.*, 2013; Anthony *et al.*, 2014; Stock *et al.*, 2015). However, by then, only some examples are known where extensive deforestation took place (Marriner *et al.*, 2012; Kaniewski *et al.*, 2013). Enhanced soil erosion has been observed since the Bronze age with a larger population and agricultural activities (Zolitschka *et al.*, 2003; Zalasiewicz *et al.*, 2010; Dusar *et al.*, 2011; Broothaerts *et al.*, 2014; Lewin and Macklin, 2014; Wilkinson *et al.*, 2014). Especially with a higher population density during the Hellenistic and Roman periods, land-use changes and deforestation led to intensified erosion processes (Casana, 2008; Dusar *et al.*, 2011; Broothaerts *et al.*, 2014).

In the Mediterranean coastal areas, human–environment interactions have been studied intensively in the environs of ancient settlement sites and their harbours through a wide range of approaches. The investigations focused on landscape and coastline changes during the Holocene, often correlated to shoreline migration due to the advance of river deltas or the evolution of coastal barriers (e.g. Kraft *et al.*, 2000; Brückner *et al.*, 2002, 2006; Goiran *et al.*, 2011; Bini *et al.*, 2012; Flaux *et al.*, 2013). Recently, ancient harbours have been investigated in detail with sedimentological, geochemical, macrofaunal and microfaunal analyses since they serve as sediment traps in an anthropogenic context (e.g. Frenzel and Boomer, 2005; Marriner and Morhange, 2006a, 2007; Bernasconi *et al.*, 2010). Study sites include Alexandria (Bernasconi *et al.*, 2006; Véron *et al.*, 2006), Elaia (Seeliger *et al.*, 2013; Pint *et al.*, 2014), Ephesus (Kraft *et al.*, 2000, 2007, 2011; Brückner, 2005; Brückner *et al.*, 2008; Stock *et al.*, 2013, 2014), Magdala (Sarti *et al.*, 2013), Marseille (Morhange *et al.*, 2003; Le Roux *et al.*, 2005), Miletus (Brückner *et al.*, 2006, 2014, 2015), Luna (Bini *et al.*, 2012), Portus (Mazzini *et al.*, 2011; Salomon *et al.*, 2012; Delile *et al.*, 2014a, 2014b, 2014c), Sidon (Marriner *et al.*, 2006), Troy (Kraft *et al.*, 2003), Tyre (Marriner and Morhange, 2006b), Utica (Delile *et al.*, 2015a), and İstanbul/Yenıkapı (Algan *et al.*, 2011). For this paper, we used a multi-proxy approach by applying sedimentological, geochemical, palynological, parasitological, microfaunal and macrofaunal as well as archaeobotanical tools for deciphering the intensity of the human impact recorded in the harbour archive, and thus test the concept of the Anthropocene *sensu lato* for the Küçük Menderes graben and the Roman harbour of Ephesus.

Study Area

The study area is located on the Aegean coast of Turkey in the east–west (E–W) striking Küçük Menderes graben. The still active graben has formed within the pre-Miocene basement during the Neogene, and contains a Miocene-Quaternary sediment fill (Rojay *et al.*, 2005). The Küçük Menderes follows the graben structure. Nowadays it debouches into the Aegean Sea 6 km to the west of Ephesus (Figure 1). The river was

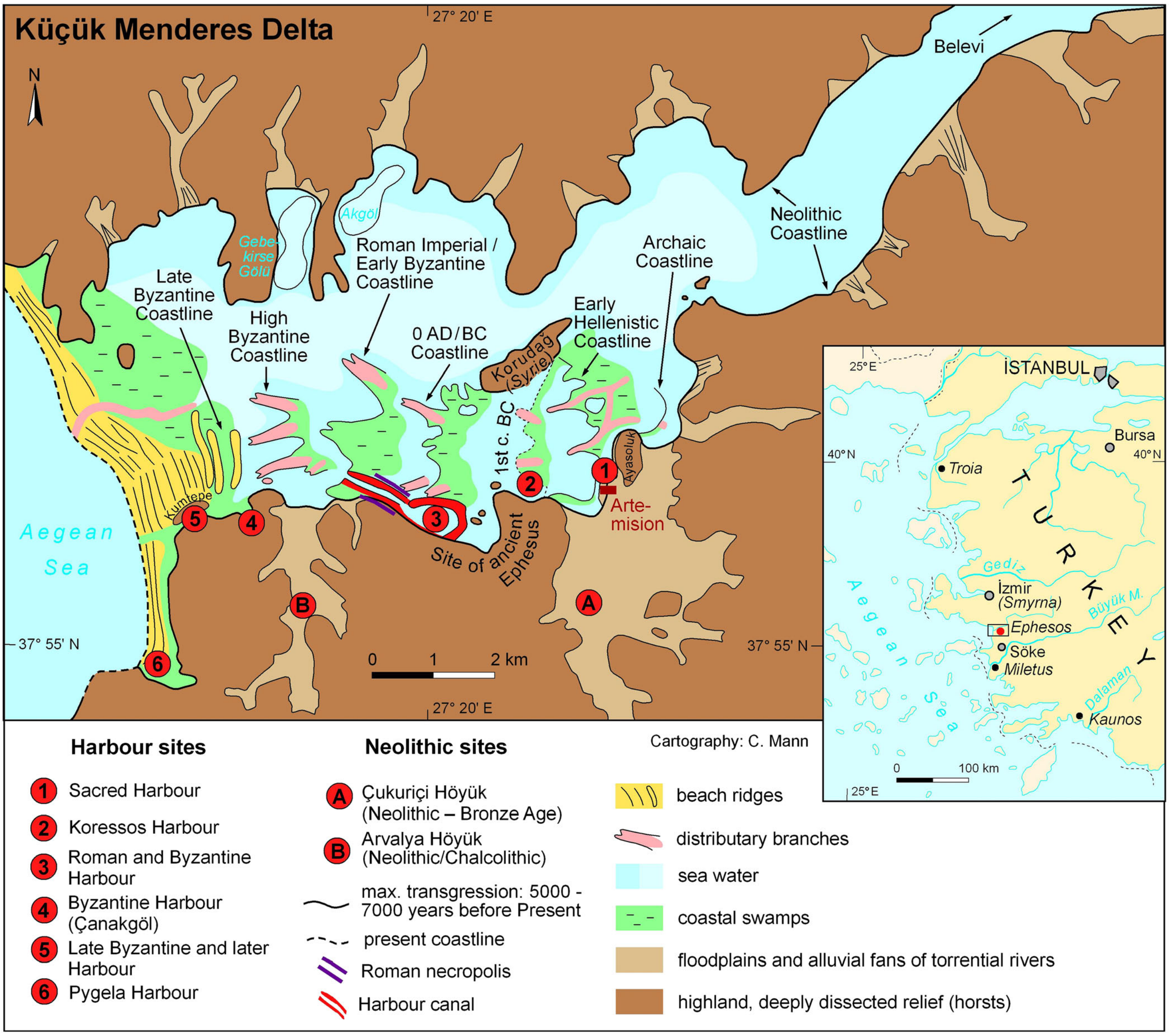

Figure 1. Scenario of the progradation of the Küçük Menderes (Cayster) delta since Neolithic times (after Brückner, 2005, modified).

characterized by the highest denudation rates in Turkey with 660 m^3/m^2 (Eggeling, 1973) until it was regulated during the twentieth and twenty-first centuries AD (Güldali, 1979; Figure 1). The drainage basin of the Küçük Menderes River (100 km) as well as the mountain ranges to the south and east of the study area mostly consist of erosion-prone mica schist, quartzite schist, gneiss and marl (Vetters, 1989; Brückner, 1997; Çakmakoğlu, 2007; Rantitsch and Prochaska, 2011) whereas the mountains to the north of the Küçük Menderes graben (marble, partly dolomitic) are more resistant to weathering processes.

During the maximum ingression of the sea, a marine embayment had extended for about 20 km inland (Brückner, 2005). Since 6000–5000 BC, an alluvial plain has formed due to the progradation of the deltas of the Küçük Menderes River and its tributaries, which has led to a continued regression of the shoreline towards the west (Kraft *et al.*, 2000; Brückner, 2005). Many decametres of sediment have been deposited on top of the pre-Holocene strata (Kraft *et al.*, 2005). Evidence of the former embayment are two remaining lakes at the northern side of the graben, and the fact that Korudağ had formerly been the island of Syrie (Figure 1).

The ancient Hellenistic–Roman city of Ephesus is located on the southern flank of the graben. It is surrounded by the mountain ranges of Bülbüldağ to the south (356 m) and Panayırdağ to the east (157 m) which form the southern hanging wall of the graben and mostly consist of dolomitic marble, limestone, and phyllite (Figure 2a; Vetters, 1989; Çakmakoğlu, 2007; Rantitsch and Prochaska, 2011). The Roman harbour is nowadays located 5 km east of the present coastline. During the summer it almost dries out (Figure 2b).

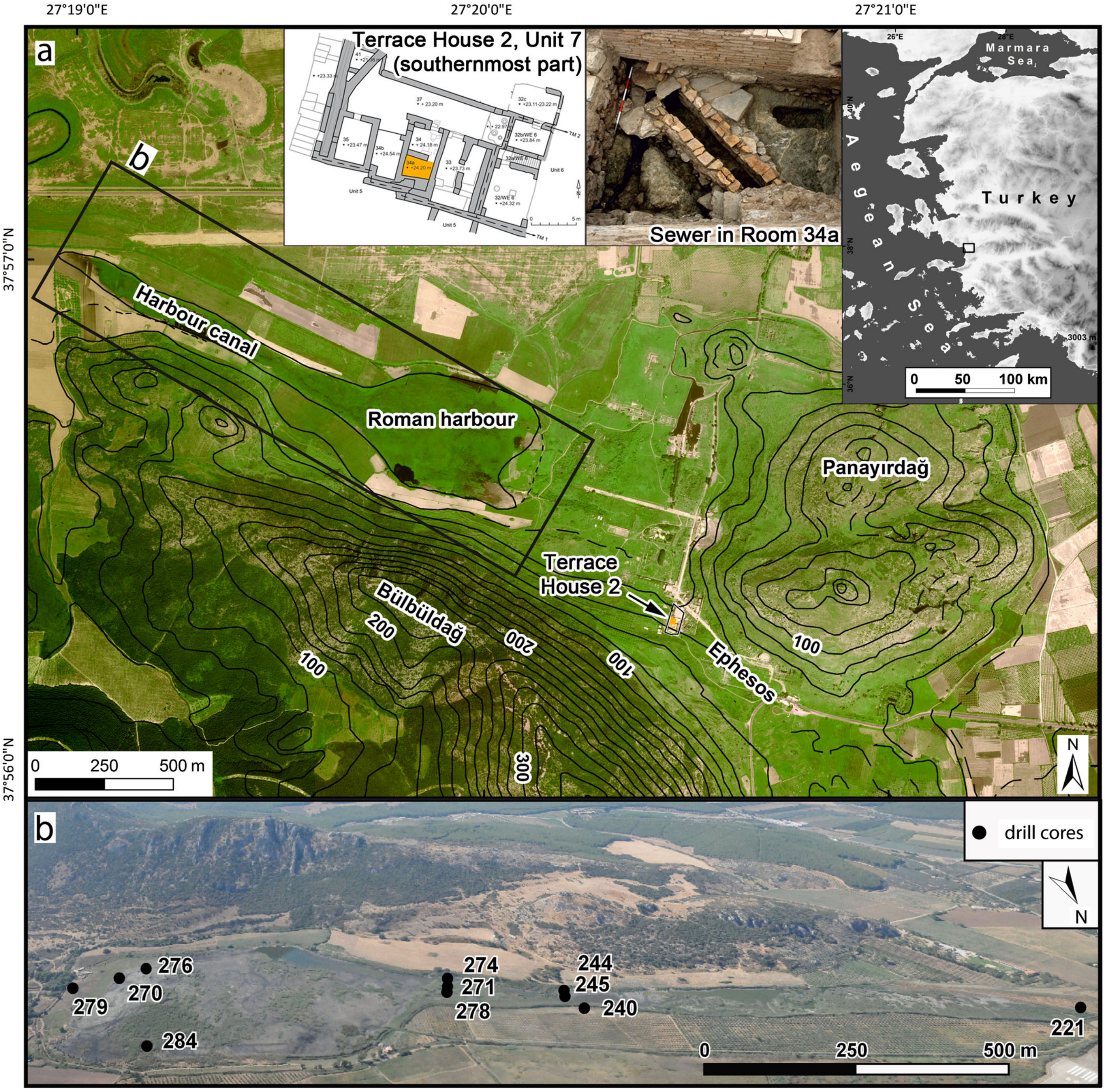

Figure 2. (a) Study area within the city of Ephesus with the surrounding mountains of Bülbüldağ and Panayırdağ. The sewer is from Room 34a of Terrace House 2, a Roman agglomeration (*insula*) (stratigraphical units SE 1014 and 1024). Conversion of the aerial image from miscolour to natural colour. Sources: Austrian Archaeological Institute, University Vienna Institute of Photogrammetry and Remote Sensing, İstanbul Technical University Department of Photogrammetry, 1997, modified. (b) Location of drill cores in the Roman harbour basin and the harbour canal. View during summer time.

Methodology

Nine sediment cores up to a depth of 12 m and with diameters of 6 and 5 cm were retrieved from geo-bio-archives of the harbour basin and the canal using the percussion coring device Cobra pro of Atlas Copco. Coring positions and elevations were levelled with a Topcon HiPer pro GPS (global positioning system with a precision of 2 cm); they refer to the present mean sea level. The focus was set on two master cores from the basin and the canal (Eph 276 and 244) which were analysed in detail.

In the laboratory, magnetic susceptibility (MS) was measured with a Bartington MS2B sensor. Elemental analyses were conducted in 2 mm resolution using an energy-dispersive X-ray fluorescence (XRF) Itrax Core Scanner (Cox Analytical Systems, Sweden; Croudace *et al.*, 2006) equipped with a 1.9 kW chromium (Cr) X-ray tube set to a voltage and current of 30 kV and 30 mA, and an exposure time of 20 seconds. For grain size analysis (111 samples from Eph 276, 39 samples from Eph 244), the fractions < 2 mm were measured with a laser diffraction particle sizer (LS 13320, Beckman Coulter Ltd.); the results were statistically processed with GRADISTAT (Blott and Pye, 2001). Loss-on-ignition (LOI) was measured for both cores in a muffle furnace (*c.* 5 g of sediment heated for 12 hours at 105 °C, and 4 hours at 550 °C), calcium carbonate ($CaCO_3$) (Eph 244) was determined with the Scheibler apparatus [0.5 g of sediment reacted with hydrochloric acid (HCl) (10%)].

Thin sections were carried out on samples from characteristic layers of Eph 276. The micromorphological interpretation is according to van der Meer and Menzies (2011).

A detailed microfaunal investigation was carried out for drill core Eph 276 (98 samples). About 4 cm^3 of sediment were sieved with 100 µm mesh size, and determined following Meisch (2000) and Handl *et al.* (1999) for ostracods and Meriç *et al.* (2004) for foraminifers.

For pollen analysis, samples from Eph 244 (25 samples; 2–4 cm^3) were treated as described in Eisele *et al.* (1994) and cleaned by ultrasonic sieving with a 7 µm mesh. For pollen and spore identification, the collection of recent pollen and spores at the Institute of Botany, University of Hohenheim (Stuttgart, Germany) was used together with Beug (2004); Moore *et al.* (1991) and Reille (1992). Calculation of the results and plotting of the pollen diagram were done using the software FAGUS (University of Innsbruck, Austria).

Ancient parasite analysis (nine samples of Eph 244) was performed at the University of Cambridge, UK. Following disaggregation, 1 g samples were passed through sequential microsieves (300, 160 and 20 µm) (Anastasiou and Mitchell, 2013a). Due to their size, intestinal parasite eggs are trapped on the 20 µm mesh; they were determined according to their shape, colour, dimensions and other characteristics (Garcia, 2009).

On-site macro-charcoal of Terrace House 2 was recovered from archaeobotanical flotation samples, dated by pottery and numismatic typologies. Samples were processed from Dwelling Unit 1 (Popovtschak, 2010), Dwelling Unit 2 (Thanheiser, 2010), and from the Rooms 32c (one sample, 18.6 l from a secondary chalk pit filling, second quarter of the first century AD; Ployer, in press), and 34a in Dwelling Unit 7 (three samples, 45 l, from the stratified filling of a sewer, second century BC–third century AD; Ployer, in press). Due to their precise numismatic dating the sewer layers in particular allowed a high-resolution interpretation of the data. The material was floated and searched for plant macro-remains and charcoal (Heiss and Thanheiser, in press); this was carried out on a minimum of 50 randomly picked charcoal fragments per sample. Its identification is based on standard literature (Schweingruber, 1990; Heiss, 2000–2009; Heiss and Marinova, 2009).

In total, 23 accelerator mass spectrometry radiocarbon (AMS-^{14}C) age estimates of organic material and enriched pollen plus fragments of diagnostic ceramics constrain the chronostratigraphy (Table I).

Table I. Radiocarbon data set

Sample code	Laboratory code	Unit	Material	Depth (cm) b.s.	Depth (cm) b.s.l.	$\delta^{13}C$ (‰)	^{14}C age	Age cal BC/ cal AD (2σ)
Eph 270/12H	UGAMS 11910	3a	wood	3.77	-4.41	-26.5	1520±20	cal AD 432–600
Eph 270/14 Sg	UGAMS 13571	3a	echinoid spins	4.88	-5.52	1	2100±25	cal AD 173–363
Eph 276/186/113P	Lyon-9957 37622	6a	plant fragment	1.86	-2.32	-26.6	665±30	cal AD 1276–1391
Eph 276 362H	Lyon-9959 37624	4a	wood	3.62	-4.08	-30.8	1455±30	cal AD558–649
Eph 276 460	Lyon-9960 37625	3a	seeds	4.6	-5.06	-31.3	2020±30	104 BC– cal AD 57
Eph 276 680-690	UGAMS 17652	2a	enriched pollen	6.85	-7.31	-27.8	2000±40	111 BC– cal AD 83
Eph 276 1080-1090	UGAMS 17352	1a	seeds	10.85	-11.31	-25.9	1990±25	43 BC– cal AD 62
Eph 276 1189pl.	Lyon-9962 37627	1a	plant fragment	11.89	-12.35	-31.9	2040±30	162 BC– cal AD 47
Eph 284/13H	UGAMS 11913	2a	plant fragment	4.6	-5.21	-28.9	2090±25	179–45 cal BC
Eph 284/21P	UGAMS 11912	2a	olive stone	9.4	-10.01	-26.3	1980±25	40 BC– cal AD 68
Eph 278/285	Lyon-9955 37620	8a	plant fragment	2.85	-3.52	-33.1	475±30	cal AD 1409–1453
Eph 278/660	Lyon-9958 37623	2a	shell fragment	10.5	-11.17	-6.2	3195±30	1159–930 cal BC
Eph 271/7	UGAMS 11909	1a	charcoal	0.9	-1.77	-24.5	390±20	cal AD 1445–1617
Eph 271/79Pf	UGAMS 11908	2a	plant fragment	9.87	-10.74	-22.9	2270±25	399–212 cal BC
Eph 271/95H	UGAMS 11906	2a	plant fragment	11.68	-12.55	-29.8	2020±25	91 BC– cal AD 52
Eph 244 B1 137-138	UGAMS 8222	2b	plant fragment	1.37	-2.11	-29.0	650±35	cal AD 1279–1396
Eph 244 B5S 377	UGAMS 8223	5b	seeds	3.77	-4.51	-22.5	1700±25	cal AD 256–402
Eph 244 B8 575-577	UGAMS 8224	4b	plant fragment	5.76	-6.5	-27.3	2120±25	334–53 cal BC
Eph 244 B12 859-860	UGAMS 8225	2b	plant fragment	8.59	-9.33	-13.8	2520±25	792–545 cal BC
Eph 245 B4 77-78	UGAMS 8226	7b	plant fragment	1.27	-2.02	-29.5	1490±25	cal AD 539–637
Eph 245 B4 77-78	UGAMS 8227	4b	charcoal	7.88	-8.63	-25.9	2270±25	399–212 cal BC
Eph 221/8H	UGAMS 13072	8b	wood	2.51	-27.4	-19.9	240±20	cal AD 1642–1950
Eph 221/16Cg	UGAMS 13071	2a	shell fragment	5.52	-0.8	-21.8	2360±25	129 BC– cal AD 57

Note: Samples were calibrated with Calib 7.1 (Reimer *et al.*, 2009). Marine samples were corrected using the reservoir age for the Eastern Mediterranean region, i.e. 390 ± 85 years (Siani *et al.*, 2000). b.s. below surface, b.s.l. below sea level. Radiocarbon age estimates with two sigma (2σ) standard deviation (95.5% probability). The six radiocarbon ages from drill core Eph 276 have already been published in Delile *et al.* (2015b).

Results

The study is based on nine drill cores from the harbour basin and the harbour canal (Figure 3). Eph 276 represents the typical stratigraphy of the harbour basin, Eph 244 the one of the harbour canal, wherefore they are described in detail. The archived time span reaches from the end of the second millennium BC to the twentieth century AD. We used the multi-proxy approach by applying sedimentological, geochemical, palynological, parasitological, microfaunal and macrofaunal as well as archaeobotanical tools for a detailed knowledge about (i) the stratigraphy and evolution since pre-Hellenistic times; (ii) the landscape changes; and (iii) the intensity and dynamic of the human impact.

Overview of the stratigraphy in the harbour and the harbour canal

In the harbour basin, Eph 276 reveals laminations of clayey silts at the base (unit 1a in Figure 4a). The drill cores from the harbour basin and the transition to the canal (Eph 279, 270, 276, 284, 278, 271) are characterized by silts with intercalations of fine sand from the base to *c.* 5 m b.s.l. (metre below present sea level), dating from the end of the second millennium BC to the first century AD (Figure 3, unit 2a). Different ages occur at the same level (e.g. 1172–932 cal BC and 43 cal BC–62 cal AD at 11 m b.s.l.). This may be due to the fact that the harbour basin had once been dredged (Kraft *et al.*, 2000, 2011; Kirbihler, 2013).

Unit 3a of core Eph 276 is a stratified silty layer of pale yellow to brown colour; it yielded ages between the first century BC to the sixth/seventh centuries AD. The overlying greyish silts (units 4–5a) seem to have been deposited after the seventh century AD. Eph 271 and 279 are dominated by a brown layer rich in organic matter with angular stones, mortar and ceramic fragments spanning from Roman Imperial times to Late Antiquity.

All drill cores reveal a silty to sandy pale yellow layer (unit 6a), deposited until the fourteenth century AD. Peat occurs after the fourteenth century AD (units 7–8a). Brown silts (unit 9a) with ceramic sherds (Late Antiquity) dominate Eph 279, 270 and 276 to the top.

In the harbour canal (Eph 244, 245, 221), the base of Eph 244 and 245 is formed of sandy silts and overlain by mica-rich sands, deposited before the eighth–sixth centuries BC (units 1–2b) and between the fourth and the first centuries BC (units 3–4b) (also Eph 221). A sharp contact separates the mica-rich sands from silts (unit 5b), dated between the first centuries BC/AD until at least the fifth century AD. Units 6b and 7b reveal the same silty to sandy pale yellow layer as units 5–7a, poorly dated with a ^{14}C age estimates of the sixth/seventh centuries AD (Eph 245). On top follow peat (unit 8b, thirteenth–twentieth centuries AD), and in Eph 221 brown silts rich in ceramic fragments and edged stones.

Chronology and stratigraphy of the harbour basin

Master core Eph 276 (E 27°19′59.32″, N 37°56′32.89″) from the harbour basin can be differentiated into nine lithostratigraphical units (Figures 2, 4a and 5).

Unit 1a (12.46–11.26 m b.s.l.) is composed of clayey silt with laminations of greyish and dark greyish brown colour (cf. thin section in Figure 4a); it shows low LOI values (3–9%), variations of titanium (Ti) and relatively high strontium/calcium (Sr/Ca) ratios. In the upper part few specimens of ostracods (especially *Cyprideis torosa*, *Darwinula stevensoni* and *Limnocythere*

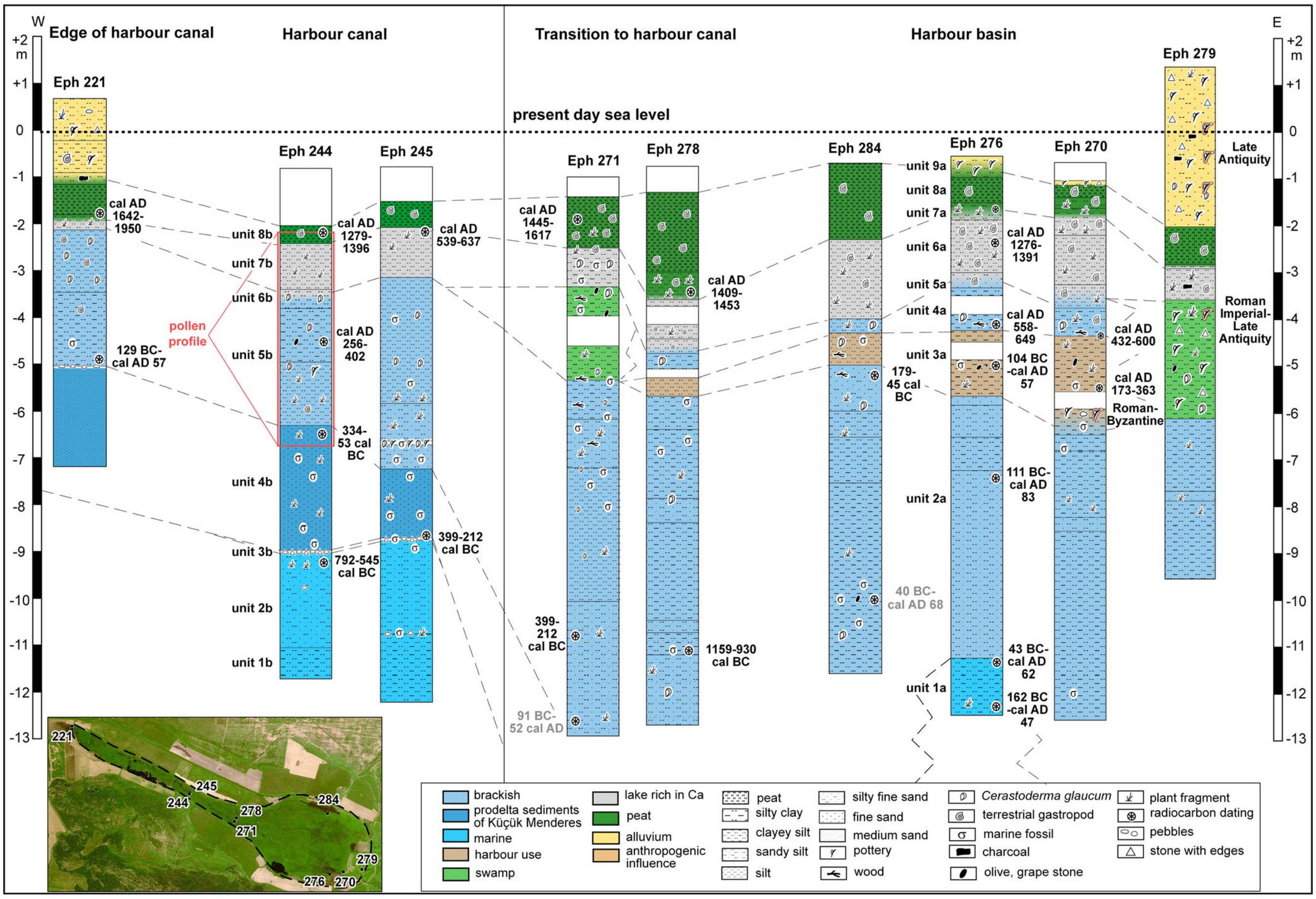

Figure 3. Geological profiles and cross-sections from the harbour basin to the edge of the harbour canal (see Figure 2b for core positions). Please note that Eph 271 and 284 reveal an age inversion. The improbable ages are shown in grey colour.

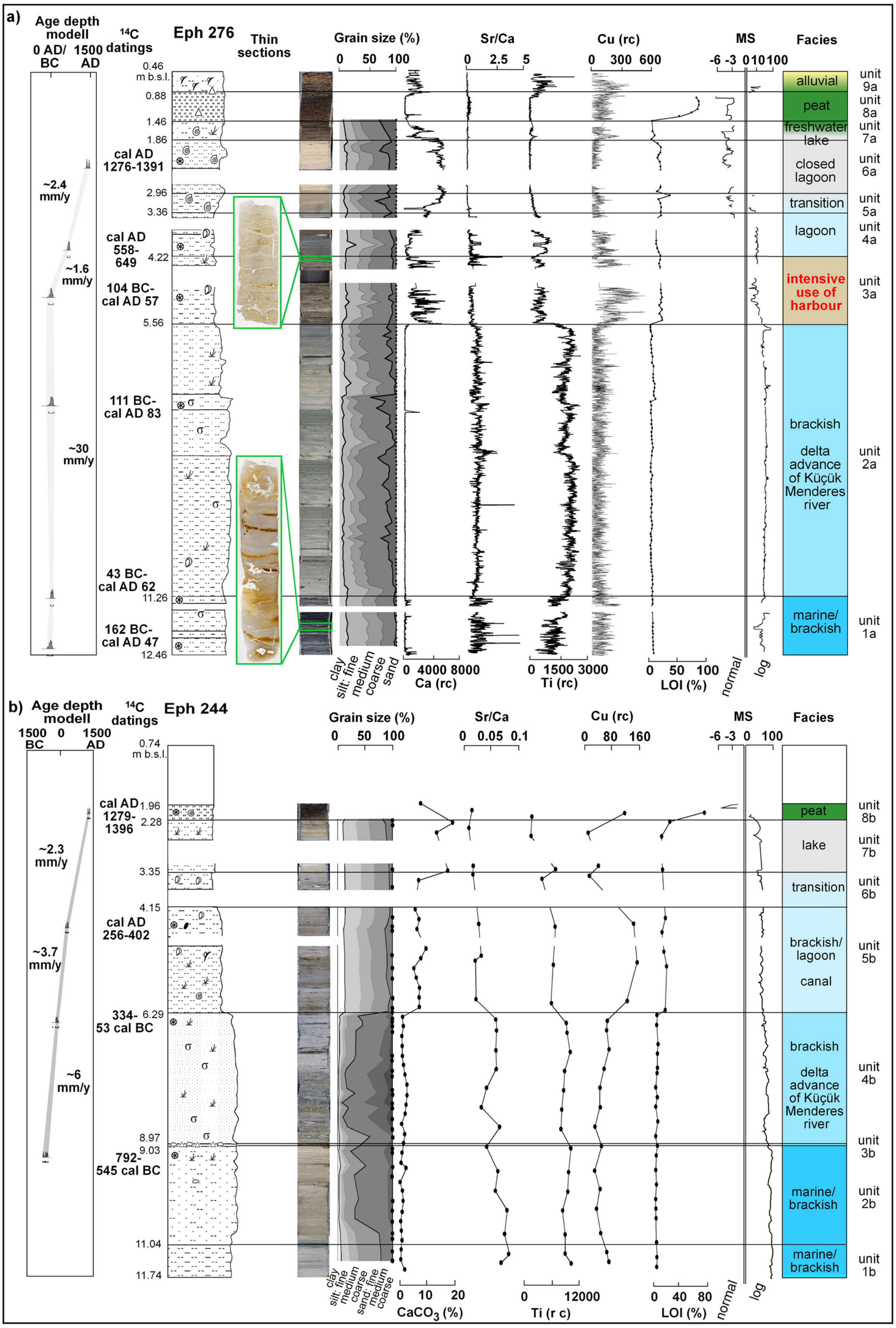

Figure 4. Stratigraphy of vibracores Eph 276 in the Roman harbour basin (a), and Eph 244 in the harbour canal (b), together with age/depth model, ^{14}C ages, granulometry (except for peat), geochemical data (Ca and $CaCO_3$, respectively, Sr/Ca, Ti, Cu), LOI, magnetic susceptibility (MS), and facies interpretation. Position of cores in Figure 2b, legend for the granulometry and fauna content in Figure 3. Photographs of thin sections reveal the detailed stratification at two important sections of the core. rw = raw counts, magnetic susceptibility in normal and logarithmic scales. Magnetic susceptibility, grain size and ^{14}C ages for core Eph 276 are already published in Delile *et al.* (2015b).

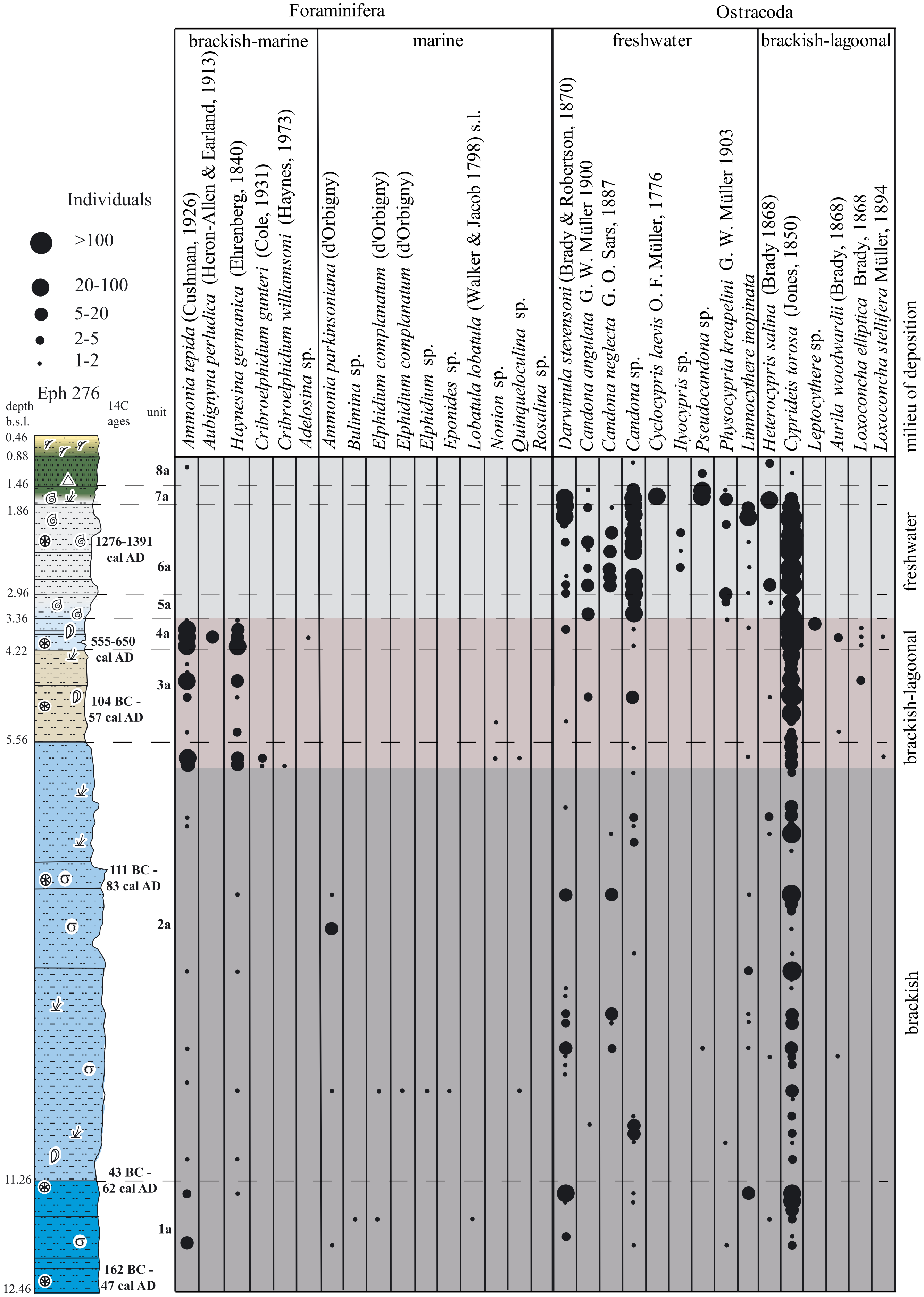

Figure 5. Microfossil analysis of foraminifera and ostracoda (with frequencies) of drill core Eph 276 from the Roman harbour basin, with stratigraphic units and depositional environments. Four different habitats were detected which may overlap to some degree: marine, brackish-marine, brackish-lagoonal, and freshwater. The dashed lines represent the boundaries between lithological units 1a–8a.

inopinata) and foraminifers (especially *Ammonia tepida*) are present. Unit 1a was deposited between 162 cal BC and 62 cal AD.

Slightly coarser sediments build up unit 2a (11.26–5.56 m b.s.l.), which consists of homogeneous, grey to dark greyish silts (up to 75%). Subsections rich in fine sand and void of microfossils show an increased MS. High Ti and low Ca values, low Sr/Ca ratios, frequent *Pinus* pollen and *Isoetes* spores (at 9.31 m b.s.l.) occur. In this unit, the ostracods *Cyprideis torosa*, *Darwinula stevensoni*, and *Candona* sp. dominate whereas towards the top the foraminifer species *Ammonia tepida* and *Haynesina germanica* appear. Units 1a and 2a both reveal similar ages and were deposited with a high sedimentation rate of ~30 mm/yr from the end of the second century BC to the first century AD.

Unit 3a (5.56–4.22 m b.s.l.) is characterized by alternations of greyish brown silts and pale yellow silts with a lower amount of sand and increased values of Ca. The facies change is demonstrated by raised values of organic matter (up to 25%), declined Sr/Ca ratios, low Ti values, and the highest copper (Cu) peaks in the core. Ostracod *Cyprideis torosa* as well as foraminifers *Ammonia tepida* and *Haynesina germanica* are frequent. The age of this unit is sandwiched between 104 cal BC–57 cal AD and 555–650 cal AD.

Unit 4a (4.22–3.36 m b.s.l.) consists of homogeneous, very dark greyish clayey silts. Geochemical values are similar to those of unit 2a. The layer contains shell fragments of the bivalve *Cerastoderma glaucum*, abundant specimens of the foraminifers *Ammonia tepida* and *Haynesina germanica* as well as the ostracod *Cyprideis torosa*. The sedimentation rate significantly decreases to 1.6 mm/yr from the first to the seventh centuries AD (555–650 cal AD).

Unit 5a (3.36–2.96 m b.s.l.) is composed of sandy silts, with an elevated amount of sand, lower Cu values and Sr/Ca ratios, and Ti values decreasing upwards. No foraminifers are present anymore, however a rich ostracod fauna.

Unit 6a (2.96–1.86 m b.s.l.), a silty layer of very pale brown colour, contains laminae rich in sand towards the top of the unit, plant remains (LOI up to 25%), and the highest Ca values of the core. The gastropods *Gyraulus* sp. and *Radix* sp., as well as ostracods such as *Cyprideis torosa*, *Candona* sp. and *Darwinula stevensoni* are present. The sedimentation rate rises to 2.4 mm/yr.

Unit 7a (1.86–1.46 m b.s.l.) is characterized by dark brown silts, low Ca content, the dominance of *Gyraulus* sp. and the same ostracods as in unit 6a. Moreover, *Pseudocandona* sp. and *Cyclocypris laevis* occur.

Unit 8a (1.46–0.88 m b.s.l.) consists of peat (LOI rises up to 87%) that is marked by a strong decrease of microfossils. The stratigraphy is terminated by unit 9a (0.88–0.46 m b.s.l.), brown sandy silts with ceramic fragments.

Chronology and stratigraphy of the harbour canal

Master core Eph 244 (E 27° 19′29.372″, N 37° 56′47.795″) from the harbour canal comprises eight units (Figures 2 and 4b). Unit 1b (11.74–11.04 m b.s.l.). It is dominated by olive to dark olive grey sandy silts with intercalations of sandy laminae of up to 1 cm thickness. The sedimentary unit is void of plant remains and shell fragments. LOI and $CaCO_3$ show low, Sr/Ca, Ti and MS high values.

Unit 2b (11.04–9.03 m b.s.l.), a homogeneous sand-dominated deposit, contains a few remains of plants and mollusc shells. While MS exhibits the highest values of the entire core, the values of other geochemical parameters are low. Seagrass (*Posidonia* sp.) at a depth of 9.34 m b.s.l. dates to 775–556 cal BC.

Unit 3b is a 6 cm layer of stones (quartz and mica schist, mostly angular), sandwiched with sharp contrast between units 2b and 4b.

Unit 4b (8.97–6.29 m b.s.l.) is mostly composed of olive grey fine and medium mica-rich sands, with seagrass, fragments of mollusc shells and barnacles. The geochemistry shows minor changes, with low Sr/Ca ratios and Ti values. The MS peaks correlate with horizons of increased grain size. This unit was deposited between the eighth/sixth and the fourth/first centuries BC.

The boundary to unit 5b is marked by a sharp contact at 6.29 m b.s.l. Up to 4.15 m b.s.l. the sediments consist of silts with many mollusc shell fragments (including *Cerastoderma glaucum*) and a pottery sherd. The geochemistry reveals an environmental change, with raised values of $CaCO_3$ and LOI, highest Cu contents of the core, and decreased values of Ti, MS and Sr/Ca. A grape seed at 4.51 m b.s.l. dates to 257–410 cal AD.

A transition stratum (unit 6b, 4.15–3.35 m b.s.l.) consists of similar sediments as before, with *Cerastoderma glaucum* and declined Cu values. The overlying unit 7b (3.35–2.28 m b.s.l.) is composed of homogeneous dark olive grey silts with intercalations of organic-rich layers, high $CaCO_3$ values and low Sr/Ca ratios; it was deposited after the third/fifth centuries AD. The top part is enriched in organic matter (up to 25%). Towards the uppermost sediment of the core (unit 8b) consists of peat (organic matter up to 80%). Macrofossils are represented by the freshwater gastropod *Gyraulus* sp. One date of the compacted unit dates to the thirteenth/fourteenth centuries AD.

Palynological and parasitological studies of drill core Eph 244

In total, five pollen assemblage zones (PAZs) were differentiated (Figure 6a, see Figures 3 and 4b for depths in Eph 244). PAZ 1, 6.71–6.35 m b.s.l., contains a high level of indeterminate pollen, *Isoetes* spores and burnt plant remains. The quantity of deciduous oak (*Quercus*) remains low and declines towards the top of the unit, while *Olea* pollen increases. Cerealia-type, *Plantago lanceolata*-type, *Cannabis* and a high amount of Fabaceae are present.

PAZ 2, 6.29–5.32 m b.s.l., is characterized by a sudden change in the pollen spectrum: discontinuation of *Isoetes* spores and a rapid decline of indeterminates. Typical of this unit are high amounts of *Sarcopoterium*-type and Brassicaceae (crucifers) partly occurring in clusters and anthers. A further differentiation between Brassicaceae in wild plants or crops is not possible. *Sarcopoterium*-type pollen appears as thorny burnet (*Sarcopoterium spinosum*) and/or small burnet (*Sanguisorba minor*), which cannot be distinguished accurately. Characteristic for PAZ 2 are pollen grains of fruit trees (*Olea*, *Juglans*, *Castanea*, *Vitis*), Cerealia-type, *Cannabis*, Fabaceae, eggs of the intestinal parasites whipworm (*Trichuris* sp.; cf. Figure 6b) and roundworm (*Ascaris* sp.), as well as *Cucumis melo* (muskmelon) (cf. Beug, 2004) towards the top.

PAZ 3, 5.22–4.21 m b.s.l., still reveals *Cucumis melo*, *Trichuris* sp. and *Ascaris* sp. parasite eggs and *Papaver rhoeas*-type pollen (poppy) during the third–fifth centuries AD. Whipworm eggs were much more common than roundworm in all of the analysed samples. The distinction between opium poppy and wild species is not possible. More burnt plant remains occur towards the top.

In PAZ 4, 3.72–3.50 m b.s.l., the amount of *Pinus* pollen increases, *Olea* decreases while *Quercus ilex*-type and *Pistacia* rise. Eggs of *Trichuris* sp. and *Ascaris* sp. are lacking in this zone while more aquatic algae occur. Flax pollen (*Linum*

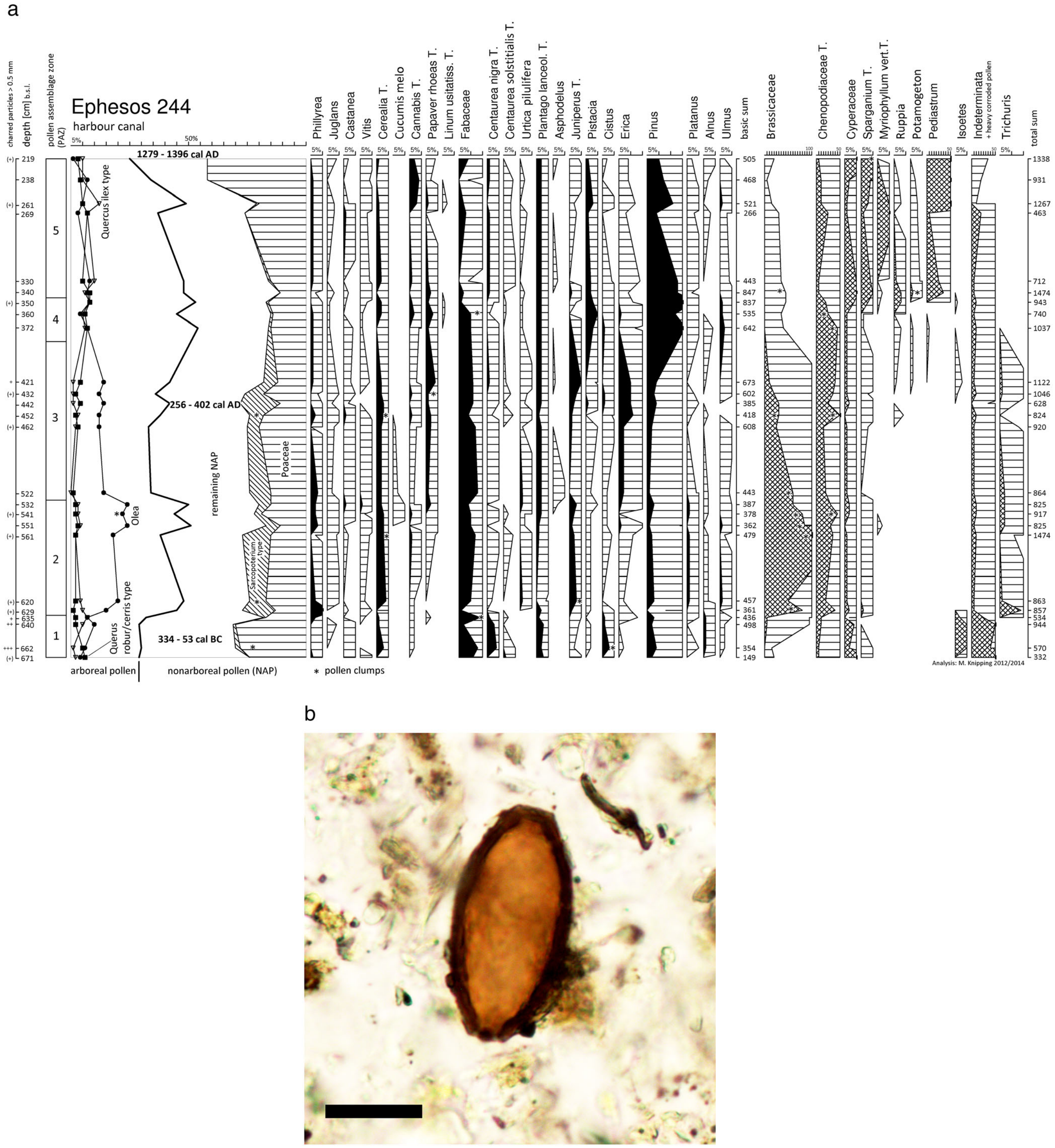

Figure 6. (a) Pollen diagram of sediment core Eph 244 from the harbour canal. The input of pollen in the sediment derives from different sources. Therefore, the preservation of pollen grains is extremely variable, which was accounted for by clustering them into different preservation groups during counting. All terrestrial taxa are included in the basic sum, whereas *Brassicaceae* and *Chenopodiaceae* (as possibly overrepresented elements), pollen clumps and anther remains, wetland plants (Cyperaceae, *Sparganium*-type, *Typha latifolia*-type, *Lythrum*), indeterminable and heavily corroded grains as well as spores and algae are excluded. The scale is always 5% with a magnification of 10. Only the most frequent taxa are shown in the pollen diagram. In total, 22 468 palynomorphs and algae were counted from 25 samples of drill core Eph 244. (b) Egg of the intestinal parasite *Trichuris* sp. (scale bar: 20 µm).

usitatissimum-type) is still present. PAZ 5, 3.40–2.19 m b.s.l., is characterized by abundant aquatic and swamp plants during the thirteenth–fourteenth centuries.

Finds of plant macro-remains in terrace house 2

Several of the pollen grains and especially the intestinal parasite eggs seems to originate from the city area; they were washed into the Roman harbour and the canal. Therefore, it is interesting to study the source area of these sediments. In the following section, the plant macro-remains in Terrace House 2, a Roman agglomeration (*insula*) built upon Hellenistic structures, and spanning the first until the third centuries AD, are described (Figure 7, Table II).

The mineralized finds are dominated by *c.* 20 000 fig pips (*Ficus carica*) and nine muskmelon seeds in the canal (SE 1016) of Dwelling Unit 7; they are dated to the third century AD (Figure 2). Grapevine (*Vitis vinifera* ssp. *vinifera*), one of the most significant cultivated woody plants in antiquity (also

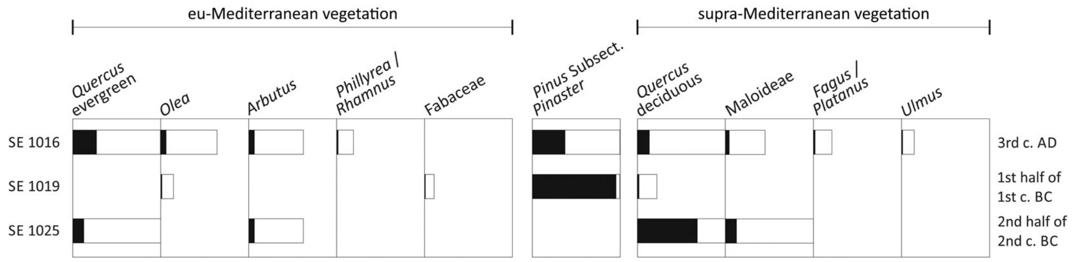

Figure 7. Charcoal percentages by weight from the sewer in Room 34a (cf. Figure 2a).

documented in the pollen profile), is present in mineralized form throughout the sewage layers from the first century BC to the third century AD. The presence and use of olive (*Olea europaea*) is proven by charred olive stones in all previously analysed Dwelling Units (Popovtschak, 2010; Thanheiser, 2010; Heiss and Thanheiser, in press). The charcoal spectrum is dominated by oak (*Quercus*, mainly deciduous taxa) and some species from the cluster pine group (*Pinus* subsect. *Pinaster*), to varying extents. Woody plants representative of a maquis shrubland, and high-altitude woodland from elevated altitudes are found in minor quantities.

Discussion

Interpretation of the stratigraphy of the harbour basin

The base of Eph 276 (unit 1a), a distinct lamination, probably in the form of varves (see thin section). The preservation of the laminated texture implies the sediments to be deposited in a non-bioturbated embayment at a water depth of *c.* 10 m from the second century BC to the first century AD (Figure 4a). Ostracods represent changing environments: brackish-lagoonal (*Cyprideis torosa*), freshwater to a slightly salinity (*Darwinula stevensoni* and *Limnocythere inopinata*), and brackish-marine (*Ammonia tepida*) ones. While variations of Ti may be linked to the beginning of detrital input from catchment erosion due to fluvial activity (Haug *et al.*, 2001; Yancheva *et al.*, 2007; Panizzo *et al.*, 2008), the increased Sr/Ca ratio may indicate a strong salinity (Wünnemann *et al.*, 2006). We interprete the basal sediments to be deposited in a very low-energy environment, probably under marine-brackish conditions with seasonal input of freshwater from the direct environs.

Unit 2a, also encountered in Eph 279, 270, 284, 271 and 278 (Figure 3), seems to reflect a very fast sedimentation of silts (~30 mm/yr), with some thin sand intercalations, from the second century BC to the first century AD; these are probably harbour muds (Marriner and Morhange, 2006a) deposited after the construction of a mole on the northern side of the harbour (159–138 BC). It was built in order to maintain the harbour's function for trade and communication and as a protection against the deposition of river sediments (Kraft *et al.*, 2000, 2001; Zabehlicky, 1995, 1999; Steskal, 2015; Strabo, 2007; 14.1.24). It may also reflect a dredging dump site; from ancient literature we know that the harbour and canal had been cleaned and dredged several times between the first to the third centuries AD (Zabehlicky, 1995; Kraft *et al.*, 2000, 2011). Despite the very high sedimentation rate, a natural deposition is likely since the sediments at the base reveal stratifications under natural conditions. In Eph 278 and 271, the silts were deposited earlier, between 1172–932 cal BC and 397–211 cal BC. Obviously, they represent the natural deposition prior to the harbour and canal construction. The age inversions in Eph 284 and 271 may derive from dredging activities close to the assumed quay on the northern and southern side of the basin/canal. The presence of *Isoetes* spores in the lower part of unit 2b is typical of fluvial transport, as proven in the Büyük Menderes graben (Knipping *et al.*, 2008). Moreover, it is supported by the brackish-lagoonal ostracod *Cyprideis torosa*, and few freshwater ostracods (*Darwinula stevensoni*, *Candona* sp.). Low Sr/Ca ratios are characteristic for a brackish water environment with low salinity probably due to the regular freshwater inputs (Delile *et al.*, 2015b). High MS values in the sandy intercalation reflect the terrigenous flux derived from fluvial input (Dearing, 1999), as proven in Portus, the harbour of Ostia (Salomon *et al.*, 2012). On top of the unit, the occurrence of the brackish-marine foraminifer species *Ammonia tepida* and *Haynesina germanica* indicate a facies change to a brackish-lagoonal milieu.

A sharp contact separates unit 2a from unit 3a, also encountered in Eph 270, 284 and 278 (Figure 3). The 0.40–2 m thick alternations of greyish brown and pale yellow silts may have been caused by seasonal variations in the hydrological conditions in a protected harbour basin (as for similar examples see Marriner *et al.*, 2006, 2010; Algan *et al.*, 2011; Salomon *et al.*, 2012; Sarti *et al.*, 2013): the pale yellow layer may result from epilimnic calcification during summer, with terrestrial clastic input occurring during the rainy winter season. In this section Cu attains the highest values in the core, most probably due to human impact (Sakan *et al.*, 2013). A significantly decreasing sedimentation rate to 1.6 mm/yr may indicate a decreased fluvial input, but also dredging operations explaining the sharp contact to the underlying unit. Microfossils suggest once more a lagoonal environment with brackish ostracod *Cyprideis torosa* and brackish-marine foraminifers *Ammonia tepida* and *Haynesina germanica*. In core Eph 279 unit 2a is overlain by swampy material deposited during Roman Imperial times which suggests siltation in the eastern part of the basin. Eph 271 reveals a similar environment on the southern side.

Unit 4a (Eph 276, 270, 284, 278) reveals a decreasing grain size, similar to unit 1a. The layer was deposited in a low-energy environment with declining human impact in a lagoon-like environment with abundant brackish-marine foraminifers *Ammonia tepida* and *Haynesina germanica* and the brackish-lagoonal ostracod *Cyprideis torosa*. The change in sedimentation may have been caused by dredging activities of the harbour or a subsidence caused by an earthquake. It was deposited from the sixth/seventh centuries AD onwards; the top is poorly dated. Decreasing Ti values towards the top of the core indicate the recession of fluvial and marine input (unit 5a). High Ca values and lower Sr/Ca ratios in units 5a and 6a (Eph 279, 270, 276, 284, 278, 271) can be explained by a higher biogenic calcite production during the thirteenth/fourteenth centuries AD (Bayon *et al.*, 2007) related to the decrease of the harbour water depth (Delile *et al.*, 2014c, 2015b). While brackish-marine foraminifers disappear, abundant freshwater gastropods (*Gyraulus* sp. and *Radix* sp.), brackish and freshwater ostracods (brackish: *Cyprideis torosa*; freshwater: *Candona* sp., *Darwinula stevensoni*) indicate the ecology of a permanent

Table II. Anthracological data from Terrace House 2, unit 7 (cf. Figure 2a)

Context	Room 34a, sewage canal layers						Room 32c, chalk pit filling	
Layer/sample	SE 1025		SE 1019		SE 1016		99/640	
Period	Second half of second century BC		First half of first century BC		Third century AD		Mid-first century AD	
Volume (l)	10		10		15		18.6	
Total charcoal content (g)	6.22		10.53		37.16		17.6	
Identified charcoal	68%		53%		42%		26%	
	Number	Weight (g)	Number	Weight (g)	Number	Weight (g)	Number	Weight (g)
eu-Mediterranean vegetation								
Arbutus sp.	2	0.26	—	—	3	0.90	—	—
Fabaceae	—	—	1	0.05	—	—	—	—
Olea europaea s.l.	—	—	1	0.09	3	0.40	—	—
cf. *Olea europaea* s.l.	—	—	—	—	1	0.60	—	—
Phillyrea sp./*Rhamnus* sp.	—	—	—	—	2	0.30	—	—
Quercus sp. evergreen	8	0.54	—	—	14	4.20	3	0.23
anthropogenic woodland								
Pinus subsect. *Pinaster*	—	—	31	5.31	17	5.80	15	1.71
supra-Mediterranean vegetation								
Fagus sp. / *Platanus* sp.	—	—	—	—	1	0.30	—	—
Fraxinus sp.	—	—	—	—	—	—	9	0.67
Maloideae	4	0.54	—	—	2	0.70	—	—
Quercus sp. deciduous	16	2.87	2	0.10	6	2.10	4	0.37
Ulmus minor	—	—	—	—	1	0.20	—	—
traded timber								
Abies sp./*Cedrus* sp.	—	—	—	—	—	—	14	1.33
Tilia sp.	—	—	—	—	—	—	5	0.22
Total	30	4.21	35	5.55	50	15.50	50	4.53

lacustrine system, which was likely fed by karstic springs (Somay *et al*., 2008; Somay and Gemici, 2009; Delile *et al*., 2015b).

The organic rich layer in all drill cores (units 7a and 8a) with a thickness of 0.50 to 2.50 m together with low Ca contents and the dominance of freshwater fauna (gastropod: *Gyraulus* sp.; ostracods: *Pseudocandona* sp., *Candona* sp.) indicate a swampy environment and the gradually siltation of the area. Radiocarbon age estimates prove the peat development after the fourteenth century. The uppermost part of Eph 276 and 279 represent the final siltation of the area (unit 9a).

Interpretation of the stratigraphy of the harbour canal

Facies interpretation

In contrast to Eph 276, the base of Eph 244 and 245 (units 1b and 2b) is dominated by high-energy conditions in a marine environment until the eighth–sixth centuries BC, probably even until the fourth–third centuries BC (^{14}C age at the base of unit 4b, Eph 245) with detrital input from the environs.

The overlying layer of stones (unit 3b) may derive from slope debris or have been dumped there intentionally after dredging activities of up to 6 m (see also Bony *et al*., 2011). The mica-rich sand (3–4 m thick) with peaks in MS correspond to a coarse-grained fluvial material and point to a prograding advancing river delta from the fourth to the first centuries BC, in Eph 221 until the first century AD (unit 4b in Eph 244, 245, 221).

A sudden change to a low-energy environment with silts in all three drill cores represents sediments of the canal (unit 5b); its time of operation is dated from the first century BC onwards. In this unit, Cu shows the highest amounts of the drill core; it declines after the fifth century AD (unit 6b). It indicates human influence in the sediments as it is not linked to a changing grain size. The uppermost units also represent the development of a lake and its siltation from the thirteenth century AD onwards.

Interpretation of palynological and parasitological analyses

At the base (PAZ 1), the pollen diagram reveals many indeterminate pollen grains which show signs of decay during transport and *Isoetes* spores from the hinterland, probably transported by the Küçük Menderes River in Hellenistic times. This zone is characterized by a strong anthropogenic influence (*Olea*, Cerealia-type, *Plantago lanceolata*-type, *Cannabis*, high amount of Fabaceae). From Late Hellenistic to the Early Byzantine period, PAZ 2 and PAZ 3 represent the canal sediments with a discontinuation of *Isoetes* spores and a rapid decline of indeterminates. *Sarcopoterium spinosum* hints at a higher grazing pressure whereas *Sanguisorba minor* is more likely to have been used as lettuce. With the appearance of eggs of the intestinal parasites whipworm (*Trichuris* sp.) and roundworm (*Ascaris* sp.), *Cucumis melo*, and pollen grains of fruit trees, the anthropogenic impact rises. *Papaver rhoeas*-type pollen as a predictor of poppy use is abundant. The high amounts of Brassicaceae during this period also point to the use of some species of this family as vegetable like cabbage or radish (Russo Ermolli *et al*., 2014). Between the third and the fifth centuries AD, the amount of eggs of the intestinal parasite *Trichuris* sp. decreases. In the overlying PAZ 4, the increasing amount of *Pinus* indicates fallow land with pines as pioneer trees. The decreasing indicators for human impact (less *Olea*, discontinuation of intestinal parasites) may reflect the declining population in Ephesus after the seventh century AD. However, settlement activities still continue (e.g. flax pollen *Linum usitatissimum*-type). It also persists during the thirteenth–fourteenth centuries AD (PAZ 5). Abundant aquatic and swamp plants indicate the beginning of the siltation of the canal.

Palaeoenvironmental changes and their consequences

Development from the end of the second millennium BC to the second century BC

The results presented here clearly reveal the siltation of Ephesus' harbour and its environs in response to the advance of the Küçük Menderes delta. Until the first millennium BC, a dynamic marine embayment with detrital input from the adjacent drainage area was in existence. From the fourth–third centuries BC onwards, the influence of the Küçük Menderes became dominant. The high sedimentation rate of ~6 mm/yr in comparison to earlier low values (i.e. 1 mm/yr from the sixth to the first millennia BC; Stock *et al*., 2013) can be explained by an increase in erosion in the drainage basin, triggering a faster advance of the Küçük Menderes delta. This phenomenon was probably linked to the rise of several settlements (Stock *et al*., 2013). A fast delta progradation was described for the Küçük Menderes delta by Eisma (1978); Erinç (1978); Meriç (1985); Hess (1989); Brückner (2005) and other Mediterranean rivers (Grove and Rackham, 2001; Vella *et al*., 2005; Kaniewski *et al*., 2013). All of them start their advance during the mid-Holocene when sea level stabilized following its rapid rise after the Last Glacial Maximum (LGM) (Stanley and Warne, 1994; Kraft *et al*., 1999). For the first millennium BC, human influence is evidenced in the vegetation association by the presence of Fabaceae, *Cannabis*, Cerealia-type and *Plantago lanceolata*-type pollen present; this is confirmed by other pollen records from the Mediterranean (e.g. Casana, 2008; Bellotti *et al*., 2011; Broothaerts *et al*., 2014).

Strong human influence from the second century BC to the seventh century AD

After the second century BC, laminated silts at the base of the harbour basin are overlain by homogeneous silts of the open harbour with a particularly high sedimentation rate of 30 mm/yr. A similar high value was determined for the protected harbour of Marseille (22 mm/yr; Marriner and Morhange, 2006b). Besides the human impact the high value was caused by the proximity of the delta front. The deposition of laminae between the second/first centuries BC and the sixth/seventh centuries AD in the harbour of Ephesus suggests seasonal deposition. The changing geochemistry (e.g. elevated Cu values) points to the construction of a protected harbour basin and its intensive use. This corresponds to the most prosperous phase of the city. Similar laminites composed of mineral-rich and biogenic sediments, deposited during winter and summer seasons, have been described, e.g. for the Santa Barbara Basin, California (Schimmelmann *et al*., 2006). The same is also visible in core Eph 244: a sudden change to low-energy conditions indicates the man-made development of a canal around the end of the first century BC to the beginning of the first century AD. Eggs of intestinal parasites, typical for latrines (Mitchell *et al*., 2008; Anastasiou and Mitchell, 2013b), muskmelon, macro-remains in a dwelling of Ephesus as also found in Portus (Pepe *et al*., 2013; Sadori *et al*., 2014), and *Cannabis*, and fruit tree pollen in combination with raised lead (Pb) (Delile *et al*, 2015b) and Cu concentrations confirm the strong human influence (Sarti *et al*., 2013).

Evidence for the footprint of human impact is also seen from the on-site charcoal record from the city area. The role of cluster pines (dominant from the 1st century BC onwards) may be an anthropogenic indicator: only two species from the group are likely to have occurred in the region during antiquity, and both are fostered by anthropogenic action – either through the degradation of natural forests as in the case of *Pinus brutia* (Axelrod, 1975; Knipping *et al*., 2008) or by planting as for *P. pinea* (Kislev, 1988). High quantities of *Pinus* in the charcoal record during the Roman period may result from the overuse of woodland resources in the vicinity (Heiss and Thanheiser, 2014). In a synopsis of all data from the Roman period (Table II), it becomes apparent that throughout there is a noticeable presence of plants from woodland in the Ephesian hinterland: *Fraxinus* (ash), *Ulmus* (elm), and *Fagus*/*Platanus* (beech/plane) point to a considerable amount of wood gathering – be it for fuel, tool-making or construction timber. *Olea* appears from the beginning of the first century BC, which indicates that this species was also used for its wood, not only its fruits (see for instance older evidence of this kind from Sicily: Stika *et al*., 2008; Mercuri *et al*., 2013; Sadori *et al*., 2013).

Taking all these data into account they clearly provide many indications for a fast delta advance during the Roman and Byzantine periods (so called 'man-made deltas'; Maselli and Trincardi, 2013). This is in line with evidence from other deltas around the Mediterranean: the Büyük Menderes (Brückner *et al*., 2002), the Po (Simeone and Corbau, 2009), the Tiber (Bellotti *et al*., 2011) and the Rhône (Arnaud-Fassetta, 2002) – just to mention a few examples. Human impacts also occur during the Hellenistic/Roman to Byzantine periods, as e.g. in Tyre and Alexandria (Marriner *et al*., 2008a). These results prove once more that humans had a strong impact on the environment.

There has been an ongoing debate about climate forcing (Vita-Finzi, 1969; Grove and Rackham, 2001) *versus* human forcing (Zolitschka *et al*., 2003; Broothaerts *et al*., 2014). Climate changes may have played a role, but the changes along the deltas of the Mediterranean seem to correlate with population dynamics, especially during the last millennia. Moreover, most of the studied geo-bio-archives are dominated by human impact, therefore it is very difficult to trace evidence of the climate. Especially from the end of the first millennium BC, the faster delta advance correlates with a higher population density. The landscape changed with a degradation of the hillslopes due to deforestation (for agriculture, fuel, construction of houses and ships) and grazing (Williams, 2000). Kaplan *et al*. (2009) calculated a significant decrease in forests on usable land between 500 BC and the turn of the era. As a consequence of a decreased forest cover, torrential rains during the winter season led to increased slope erosion and associated deposition in the floodplain and delta areas (Dusar *et al*., 2011). Thus, it seems that the anthropogenic signal clearly overprinted the climatic one.

Development since the seventh century AD

From the sixth/seventh centuries AD onwards, greyish silts were deposited in the harbour basin, probably in a lagoon-like environment. Both in the port and in the canal, a Ca-rich layer, dominated by freshwater ostracods and also characterized by a lack of foraminifera, overlies the brackish water indicating sediments. Its deposition took place between the seventh and the thirteenth centuries AD. Detrital input from the environs is missing, maybe as a result of reduced cultivation on surrounding slopes or the distal delta-mouth location. Human impact decreases considerably, most probably due to a decline of the city and a less intensive use of the harbour and the surroundings after the mid-seventh century AD. The increase in *Quercus ilex*-type and *Pistacia* points to the increased importance of pasture farming on abandoned land; higher values of pine tree pollen support this hypothesis. According to palynological results marine/brackish algae disappear; they were progressively replaced by aquatic and amphibious plants, indicating a reduced inflow of marine water due to a siltation of the canal. Settlement activities, however, are still confirmed by archaeological and historical evidence.

The decline of harbours and their cities after the Roman period is a common phenomenon in the Mediterranean (e.g. Brückner, 1986; Pranzini, 2001; Marriner *et al*., 2008a, 2008b). Along with a shrinking population, agricultural activities were diminished and the hillslopes started to recover (Pranzini, 2001). More recently and especially during the last centuries, the opposite has occurred, with dam and barrage construction serving as sediment traps, resulting in erosion along the coasts in the outer deltas (Hoffmann *et al*., 2010; Anthony *et al*., 2014). This clearly demonstrates that population dynamics strongly influences land-use changes and erosion processes.

Conclusion

Multi-proxy analyses of sediment cores from Ephesus have revealed the development of the Roman harbour and its canal since the end of the second millennium BC. The study proved that harbours are excellent geo-bio-archives for recording human impact during the last millennia and for underlining the fact that growing cities and societies in the Mediterranean had severe effects on sediment dynamics. This is especially true for the Hellenistic to Byzantine periods, thus confirming the concept of the Anthropocene *sensu lato* from this period on. From the first millennium BC on, with a peak during the Hellenistic and Roman periods, a high sedimentation rate indicates fast delta progradation which has also been proven for other Mediterranean deltas. A stratified layer attests to the development of a protected harbour basin and the construction of the canal during the first century BC/AD. The results prove strong human impacts for the period between the first century BC to the seventh century AD with elevated Cu values, high amounts of pollen from cultivated plants, and the discovery of eggs of two species of intestinal parasites. The data show that a larger population, especially during the Roman period, deforested the direct environs of the settlements as well as the hinterland, leading to increased erosion from the adjacent hillslopes. In consequence, more sediment was transported by the rivers causing a faster delta progradation. From the seventh century AD onwards, human impact diminishes. This goes along with a decrease in population and the decline of the harbour. The demise of the cities directly affected land-use changes and resulted in a decreased sediment supply due to recovered hills.

It is noteworthy that most of the research in the Mediterranean took place in the environs of settlements. For a better differentiation between climate change and human impact, geo-bio-archives relatively untouched by humans should be studied more intensively. The swamps and lake of Belevi *c*. 20 km east of the present shoreline in the Küçük Menderes graben are such an example.

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