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Sedimentology; coastal evolution; Pergamum; Elaia; geoarchaeology; Hellenistic harbour.

An archaeological survey organised by the German Archaeological Institute (DAI) has been carried out since 2005 in the Bay of Elaia (see Fig. 2a), situated 26km south-east of Pergamum (modern Bergama). Among others, it discovered ancient cemeteries and remains of submerged stonewalls. Together with literary evidence from ancient sources, the findings led to the conclusion that the Bay of Elaia once had hosted the harbour of Pergamum. Further investigations aimed at deciphering the spatial and temporal changes of the coastal area, especially during the Classical and Hellenistic epochs. Palaeogeography is essential for understanding the function and characteristics of the archaeological evidence.[1] Incorporated into the network of the SPP 1209 "The Hellenistic Polis as a Living Space", funded by the German Research Foundation, we have studied the area under geoarchaeological aspects since 2008, based on a total of 68 terrestrial and semi-aquatic corings (see Fig. 1). As for the geoarchaeological research design, see Brückner and Vött.[2]

First results have been published by Brückner and Seeliger,[3] Brückner[4] and Seeliger;[5] they are partly also described in Seeliger[6] and Bartz.[7] Tab. 1 is a compilation of the AMS-^{14}C ages.

In this abstract, we present the history of the central harbour basin that today is the most visible relict of ancient Elaia. The closed harbour basin, situated in the central northern part of the Bay of Elaia, has almost totally been silted up by sediments from the surrounding hills (see Fig. 2b). The present aspect makes it hard to imagine that water depth was deep enough for ships to anchor here as described by ancient authors. The main aim to study the basin was to determine the dynamics and the timing of the siltation process.

Coring ELA 13, with a total depth of 10m b.s. (below present surface) was carried out 37m to the east of the closed harbour's western pier (see Figs. 2b, 2c). Up to 7,00m b.s., well-sorted, dark greenish grey clayey silt occurs (see Fig. 2d). The fine grain size and the homogeneity indicate a calm sedimentary environment. The granulometry and the geochemical parameters suggest a marine formation of the lowermost three metres of ELA 13.

At approximately 7,00m b.s., the marine facies is covered by a lagoonal one, reaching up to 3,10m b.s. and showing remarkable differences in the geochemical and sedimentological parameters as compared to the substratum. These changes originate from the

1 Pirson 2004.
2 Brückner and Vött 2008.
3 Brückner and Seeliger 2009.
4 Brückner, Seeliger, and Knipping 2010.
5 Seeliger, Bartz, and Brückner (in press).
6 Seeliger 2010.
7 Bartz 2011.

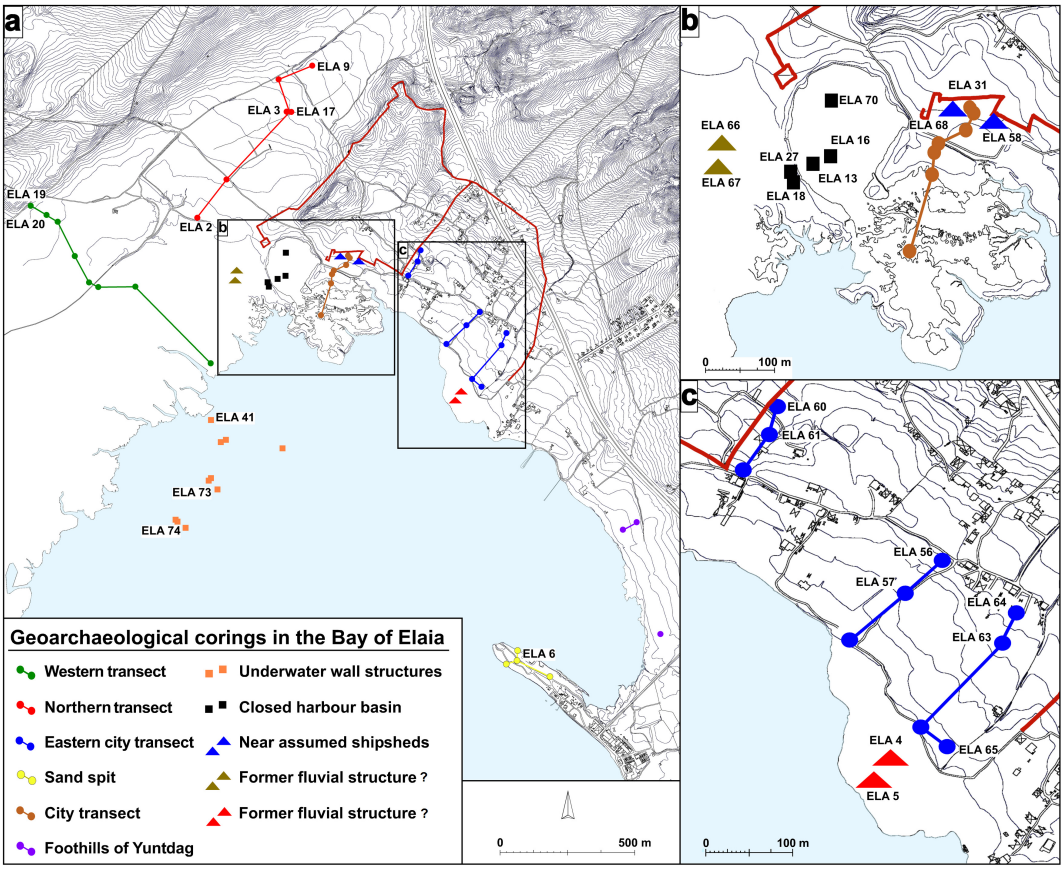


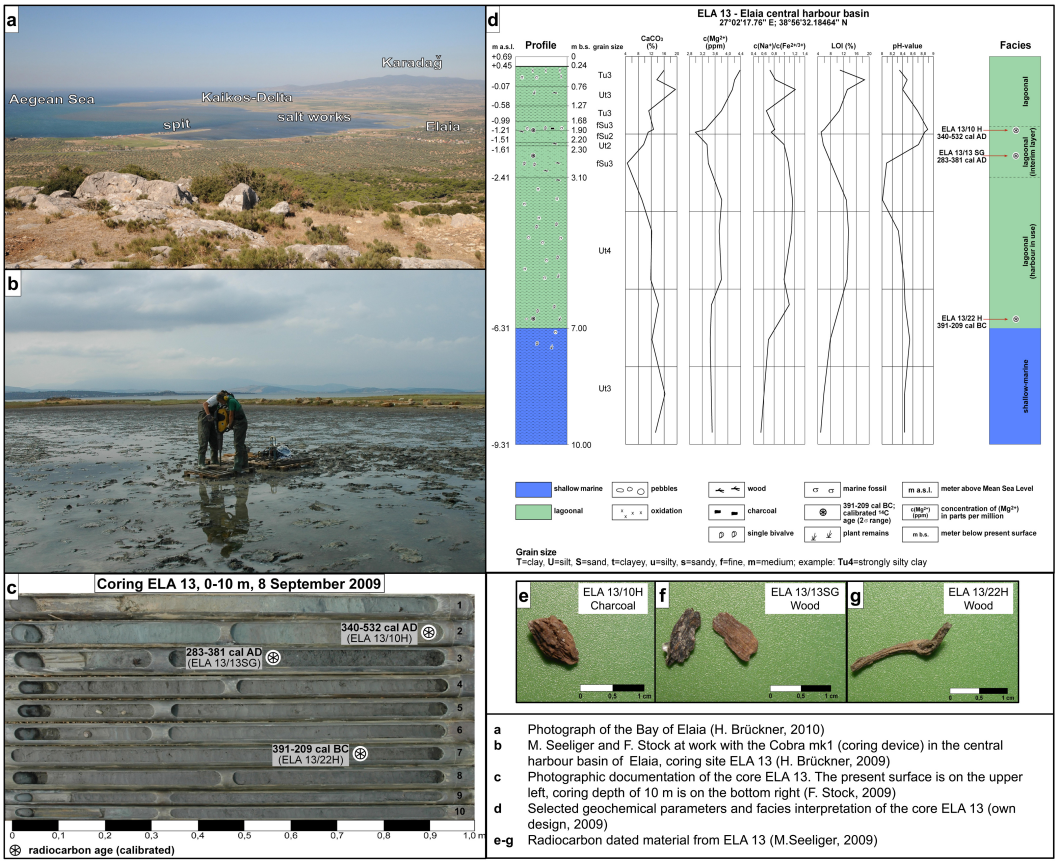
Fig. 1 | Position of the corings in 2008–2011, organised in geological transects and/or different topics. 1a: total overview, 1b: area of the central harbour basin, 1c: area east of the "Diateichisma." Source: own design, 2012.

Sample ID	Laboratory ID (UGAMS)	Material	δ^{13}C (‰)	Libby-Age	cal BC/AD (2σ)
ELA 13/10H	6038	charcoal	-26,4	1640±25	340-532 cal AD
ELA 13/13SG	6037	charcoal	-27,5	1750±25	283-381 cal AD
ELA 13/22H	6036	wood	-27,4	2250±25	391-209 cal BC
ELA 18/09	6030	charcoal	-24	1730±25	245-384 cal AD
ELA 18/07SG	6031	charcoal	-24,5	1740±25	240-381 cal AD

Tab. 1 | Table of ^{14}C ages. Dating laboratory: Center for Applied Isotope Studies (CAIS), University of Georgia (USA); calibration with Calib 6.01; marine reservoir effect: 390±85 years, ΔR: 75±60 years Siani et al. 2004. All ages are noted with a 2σ-standard deviation in calibrated years BC (before Christ) and AD (Anno Domini, after Christ), respectively.

construction of the harbour pier which dates back to Hellenistic times.[8] As a consequence, the area of the closed harbour basin was connected with the open Aegean Sea only through a narrow port entrance. A piece of wood at 6,75m b.s. dates to 391–209 cal BC (ELA 13/22H, see Figs. 2d, 2g). This age links the building time of the harbour pier to the depth of the sediment core at 6,75m b.s., nearly marking the marine/lagoonal transition. Thus, the postulated Hellenistic construction time of the harbour is verified

8 Pirson 2004, 209–210.



a Photograph of the Bay of Elaia (H. Brückner, 2010)
b M. Seeliger and F. Stock at work with the Cobra mk1 (coring device) in the central harbour basin of Elaia, coring site ELA 13 (H. Brückner, 2009)
c Photographic documentation of the core ELA 13. The present surface is on the upper left, coring depth of 10 m is on the bottom right (F. Stock, 2009)
d Selected geochemical parameters and facies interpretation of the core ELA 13 (own design, 2009)
e-g Radiocarbon dated material from ELA 13 (M.Seeliger, 2009)

Fig. 2 | Compilation of coring ELA 13. Source: own design, 2011.

by geoarchaeological evidence. Abundant plant remains occur in the lagoonal part e.g., a cluster of sea grass (*Posidonia* sp.) at 6,75m and 5,65m b.s. The high LOI underlines the high percentage of organic material. Due to the closing of the harbour by a pier, the sedimentary environment turned even calmer. Due to the settling of Elaia, nutrients were flushed into the basin in the rainy season, thus supporting the plant growth. During Hellenistic times, the city of Elaia prospered and parts of the hinterland as well.

Moreover, several bivalve and gastropod species are indicative of a lagoonal environment, e.g. *Cerastoderma glaucum* which predominantly colonises muddy-sandy grounds to depths of 10m. *C. glaucum* acts as an indicator for lagoonal or shallow-marine conditions due to its high tolerance to fluctuations of temperature, oxygen concentration and salinity.[9]

The marine sediments are of similar granulometry as the lagoonal ones. This is due to the configuration of the Bay of Elaia. The central harbour basin is situated at the farthest edge of the very elongated embayment; therefore, the wave action is strongly buffered and much lower than in many other regions of the Aegean. Furthermore, the mean tidal range in this area is less than 20cm.

Between 3,10m and 1,80m b.s., the core section is dominated by silty fine sand. Two radiocarbon age estimates render a chronological framework: the lower one (wood, 2,55m b.s.: 283–381 cal AD, ELA 13/13SG, Fig. 2f) as well as the upper one (charcoal, 1,92m b.s.: 340–532 cal AD, ELA 13/10H, Fig. 2e) fit in well with the fact that Elaia had already lost its importance in Roman Imperial times. Thus, the siltation of the central harbour

9 Poppe and Goto 1993, 34.

basin started before 283–381 cal AD. Low $c(Na^{+})/c(Fe^{2+/3+})$ ratios point to an increasing terrestrial and a decreasing marine impact. This is supported by the decline of $c(Mg^{2+})$, which was quite constant in the marine and lagoonal facies. Decreased values of $CaCO_3$, correlating with low pH values, are further evidence.

The uppermost layer from 1,80m b.s. to the present surface is made up of greyish green clayey silt representing a more or less silted-up lagoon. The sedimentation pattern corresponds to the recent aquatic conditions in the central harbour basin. Today, its area is flooded by the tides, the sea level being also influenced by the intensity and the direction of the wind; from time to time, the basin even runs dry. These variations in flooding can be traced in the rise and fall of the $CaCO_3$ value and $c(Na^{+})/c(Fe^{2+/3+})$ ratio.

We can state that the bottom of the ELA 13 core represents a marine facies. The harbour pier, constructed between 391 and 209 cal BC, separated the area of the central harbour basin from the open shallow marine waters. A lagoonal facies developed between 7,00m b.s. and the ground surface. The harbour of Elaia was used in Hellenistic and Roman times. Thereafter, it was gradually given up. The strong siltation started at the end of the lagoonal facies around 3,10m b.s. and occurred before 283–391 cal AD. The recent sedimentary conditions have dominated the central harbour basin since 340–532 cal AD.

Furthermore, we decrypted the kind and the construction date of the harbour pier based on ELA 18 coring, located due west of the western harbour pier down to a maximum depth of 3m b.s. (Fig. 1). The stone basement is recognisable from the bottom of the core up to 1,83m b.s. Between 1,83m and 1,36m b.s., shallow marine sediments occurred, superimposed by laminated silty-clayey material. A ^{14}C-age (charcoal, 1,75m b.s.: 245–384 cal AD, ELA 18/9) gives a minimum age for the harbour pier. Based on archaeological and construction-engineering criteria it can be excluded that the pier was built in post-Hellenistic times. As described above, the pier can be ^{14}C-dated to 391–209 cal BC, based on the marine/lagoonal transition at about 7.00m b.s. in core ELA 13. Another ^{14}C age (charcoal, 1,38m b.s.: 240–381 cal AD, ELA 18/7SG) correlates well with the siltation sequence reconstructed from the interpretation of ELA 13 (340–532 cal AD, ELA 13/10H). The laminated material that occurred above 1,36m b.s. originated in the drying-out and flooding of this area over the past centuries. Thus, Sample ELA 18/7SG also dates the time when the area outside the central harbour basin started to silt up strongly.

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