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Marine seismic investigation of the ancient Kane harbour bay, Turkey

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ABSTRACT

The ancient city of Kane, situated at the NW corner of the Kane Peninsula (NW Anatolia, Turkey), is known from ancient literary sources as a local harbour place in the area of the Pergamenian kingdom, which hosted a Roman fleet in winter 191/190 BC. Its precise location could not be determined so far. In search of evidences of the ancient Kane harbour, a marine seismic reflection survey in the bay west of the presumed Kane city area was performed together with an archaeological survey. The objectives of these surveys were to map remains of ancient harbour installations, thereby to distinguish between anthropogenic and geological structures and to derive clues from geological aspects influencing the interpretation of ancient harbour installations in the Kane Bay. From the seismic data we determined depth maps of the seafloor and of major layer interfaces of the marine subsoil. Based on this data, a possible harbour basin bounded by a submarine bedrock promontory and by a coastal bulge can be identified. For the harbour this bedrock promontory had the effect of a breakwater. Rock accumulations at the inner harbour side of the breakwater indicate that it was probably enhanced and fortified by construction work. Offshore archaeological findings such as an ancient bollard and a quay wall in the possible harbour basin support this interpretation. In Hellenistic times, the sea level was about 2 m lower than today, revealing that the top of the breakwater was above sea level then. From seismic sediment markers a minimum accumulation rate of ~1 mm/a was calculated in the transition zone between breakwater and centre parts of the Kane Bay, indicating a previous basin depth of 4 m. The local bedrock, consisting of weathered limestone could be recognized in the seismic data all over the Kane Bay.

1. Introduction

For solving archaeological questions, information on the historical landscape development and climate development is required in most cases. This applies in particular to coastal regions where sea level fluctuations and sedimentation rates play an important role (e.g. Marriner and Morhange, 2007; Vött, 2007). Especially for the investigation of ancient harbours, coastline shifts are essential (e.g. Seeliger et al., 2014). The major natural conditions for ancient harbours are a protected location, a good access to the land and an easy way to enter the port. Geophysical methods, especially marine reflection seismics, can help to verify these conditions because they allow to determine large-scaled images of the sea bottom and the underlying stratigraphy along the coastline in dm-to m-scale resolution (e.g. Vardy et al., 2008; Müller et al., 2009).

In 2014, the archaeological site of Kane was investigated for the first time. (Laufer, 2015; Seeliger et al., 2016). Due to Kane's location at the Aegean coast and its proximity to the Hellenistic kingdom of Pergamon, possible harbour facilities and a political and economical connection of Kane to the regional harbour-network and its connections to the hinterland are subjects of special interest. The survey included classical archaeological surveys, which were extended to water depths of 1.5 m below mean sea level (MSL) and marine reflection seismic investigations. Since only little information on the ancient settlement was available at the beginning of the project, no detailed archaeological underwater survey was planned.

In this paper we report on the results of this marine seismic prospection of the ancient Kane Bay focussing on the following two issues:

(i) Identification of possible harbour installations in the Kane Bay.
(ii) Understanding the geological context of the possible ancient harbour.

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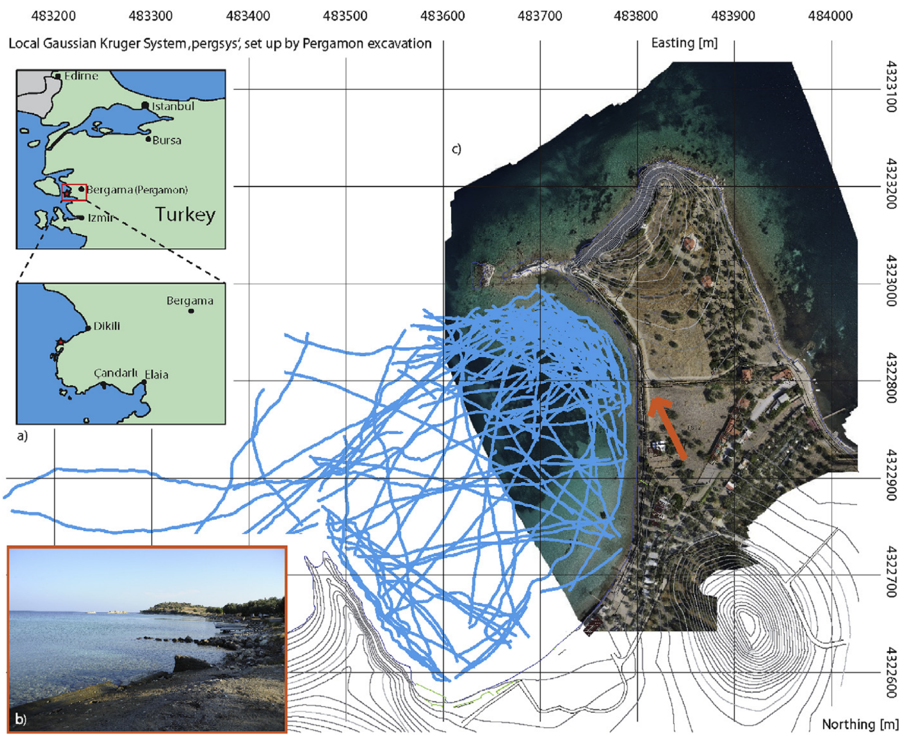

Fig. 1. a) Geographical location of the archaeological site of Kane, Turkey. b) Photography of the western Kane Bay. Orange arrow: direction of the photography. c) Topographical contour map (© DAI-Pergamongrabung) and octocopter photography (created by Andreas Bolten, University of Cologne) of the Kane promontory. Blue lines: seismic profile coverage in the western Kane Bay. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

2. Archaeological and geological settings of Kane Peninsula

The ancient city of Kane is located on a promontory on the ancient Kane Peninsula (Fig. 1a). Today, the peninsula is called Karadag Peninsula and is located in Western Anatolia in Turkey, 40 km from the ancient city of Pergamon. The Kane Bay lies about 20 km NW of Pergamon's major harbour city Elaia (Pirson et al., 2015).

2.1. Archaeological background of Kane Peninsula

The ancient site of Kane is considered as an important element within a regional harbour-network facing Pergamon's micro-region towards the Aegean Sea (Laufer, 2015, 2016).

From historical sources only few information is available. In 191/190 BC a Roman fleet overwintered near Kane in a fortified camp with the ships pulled onto the beach (Livy 36, 45, 8). The existence of harbour facilities in the city is not attested explicitly by the sources but can be postulated based on the city's maritime topography. Due to the proximity to the Greek island Lesvos and to Elaia, Kane is located in a strategic position in NS as well as in EW direction (Laufer, 2015).

Archaeological finds prove that Kane flourished at the same time as Pergamon, during Hellenistic and early Roman times (Laufer, 2015). During Roman Imperial times, the number of archaeological finds decreases and only increases again in the Byzantine era. The size of the intra-urban archaeological site is about 8 ha, which is limited by a hill and a necropolis to the south and by the sea to the other three directions. Due to its geographically isolation through the Karadağ mountains and the lack of suitable agricultural plains, the small city could never reach major importance. Trade connections to Pergamon are not known; however, some economic relationship might have existed. Remains of a city wall are preserved today, an agora (central public square) can be assumed based on geomagnetic indication, other public buildings like temples or a theatre cannot be proved (Laufer, 2015, 2016).

Nowadays, most archaeological finds are concentrated along the coastline and in the shallow water. Most of them belong to housing areas. Some walls of post-Roman date are located in higher levels according to the natural increase of the settlement's stratigraphy. In a pre-site survey a shallow submarine bedrock promontory, partly covered by artificial rock accumulation had been discovered underwater near the western shoreline. It was tentatively addressed as a possible breakwater and formed the major target of the seismic survey. Building remains show that the main construction materials are limestone and andesite blocks, which do not differ in their physical parameters from the naturally occurring rocks and boulders on the seafloor.

2.2. Geological settings of Kane Peninsula

The Karadağ Peninsula was formed by volcanic processes in the Tertiary and belongs to the formerly volcanic active Karadağ mountains, separating the coastal zone from the Bergama Graben and Pergamon in the hinterland (Radt, 1999; Karacik et al., 2007). Western Anatolia is a tectonically highly active region (e.g. Erkül and Erkül, 2010). Earthquakes and hot springs show that the region remains still tectonically active today. Therefore, the marine seismic sections could be expected to show tectonic structures besides sedimentary layering and possible harbour installations might be affected by tectonic events.

Kane is situated close to the seismically active Bergama Graben. Expressions of the extensional tectonic activity are subsidence and faulting (e.g. Altunkaynak and Yılmaz, 1998. According to Aksu et al. (1987), the Bergama Graben subsides 1m in 1000 years, a very high rate which was moderated by Seeliger et al. (2017). The subsidence also affects the regional sea level curve (RSL curve). Since no sea level curve is available for Kane Bay we apply RSL of the nearby Bay of Elaia, located only 20 km SE of Kane. This is justified by Kane's and Elaia's geographical proximity. For Elaia a sea level rise of about 2 m since 2800 BP has been found (Seeliger et al., 2017), which is consistent with the existence of submerged building remains in Kane. According to Altunkaynak and Yılmaz (1998), the Kane promontory consists of volcanic rocks and Neogene sediments. Onshore drillings in the campaign showed that the local bedrock consists of weathered limestone (Seeliger et al., 2016).

The shallow-water area to be investigated extends about 400 m E-W at the western slope of a promontory forming the NW edge of the Karadağ Peninsula (Fig. 1b and c). The promontory is up to 20m high and flanked by two bays to the east and west with a maximum water

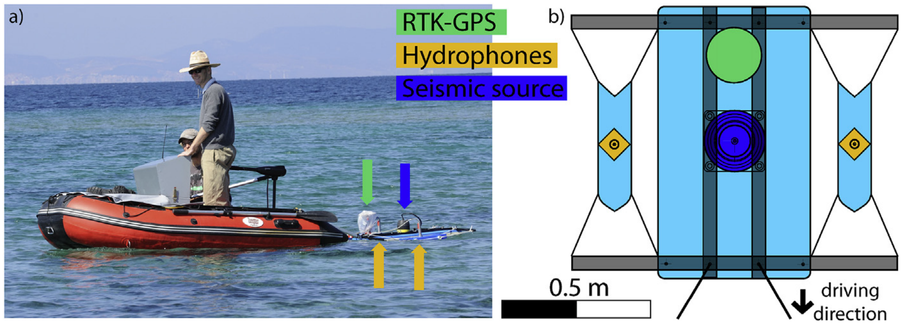

Fig. 2. a) Reflection seismic acquisition system used during the Kane survey. b) Detailed view of the seismic acquisition system consisting of pinger, two hydrophones and a DGPS.

depth of ~15 m.

3. Methods

3.1. Seismic data acquisition

A two channel reflection seismic acquisition system, developed at the Kiel University (Fig. 2a), was chosen for the marine investigations of the western Kane Bay (Fig. 2b), consisting of a sound transducer ("Pinger" coloured in blue) and two acoustic sensors ("hydrophones" coloured in orange) towed behind a boat and a recording unit on the boat. Technical details of the acquisition system are summarized in Table 1.

The system enables an efficient mapping of possible remains of ancient harbour installations and the stratigraphy with 10 cm-to 1 m-scale resolution down to 30 m depth.

The transducer sends short acoustic pulses in the audio range. The positioning is performed by differential GPS (coloured in green) with about < 5 cm nominal accuracy in the lateral dimension. Due to the chosen signal frequency band the principle structural resolution of this system is of the order of 10–20 cm in the vertical direction and 0.5–1.5 m horizontally. The horizontal resolution was improved by digital processing ("migration") to the order of vertical resolution. The horizontal data sampling depends on the signal repetition rate and travel speed of the boat, which led in this case to a spacing of about 16 cm per data point along the boat track.

Table 1
Technical details of the seismic and DGPS acquisition system.

Seismic source	Pinger (Elac Nautik Gmbh, Type TL-444)
Seismic source cycling rate	3 Hz
Seismic source signal	Fuchs-Mueller-Wavelet 4 kHz, bandwidth 2–6.5 kHz)
Receiver	2 Hydrophones (Innomar)
Lateral resolution (v = 1450 m/s, along-track)	10 cm (migrated along-track)
Lateral resolution (v = 1450 m/s, across-track)	> 60 cm (Fresnel zone across-track)
Vertical resolution (v = 1450 m/s)	10 cm, no significant chance with depth
Depth penetration in the Kane Bay	30 m
Data coverage along-track (boat speed 0.5 m/s)	16 cm
Data coverage across-track (inverse mean amount of shots per area)	50 cm
Positioning	Leica DGPS 500. RTK (real time kinematic), usage of a base station & mobile rover.
DGPS nominal accuracy	horizontal < 5 cm, vertical < 10 cm
DGPS Cycle rate	5 Hz
Local Datum PERGSYS05	"local Gaussian-Krueger system", set up by Pergamon excavation
Number of profiles	143 profiles in 7 days
Total profile length	49 km profile length
Covered area	34 ha.

To reach this high spatial sampling rate, a maximum velocity of 0.5 m/s was not exceeded. However, due to the slow driving, the boat got drifted by strong winds, swell (> 15 cm) and currents. Due to that, it was not possible to drive a predefined grid in the bay. The total tracks recorded in the western Kane Bay are shown in Fig. 1c. This high data coverage enabled a 3D interpolation of horizon depth at a later stage of data processing.

Tidal and swell variations were estimated from long-term and short-term DGPS variations during the surveys. The variations of waves (5 cm) and tides (17 cm) did not exceed the vertical seismic resolution (10 cm) and vertical DGPS resolution (10 cm). Therefore, a tidal correction of the seismic data (Wardell et al., 2002) was not necessary.

3.2. Data processing

The data was pre-processed with the open-source software *Seismic Unix* (Stockwell, 1999). The following steps were applied:

1. Editing of noisy records.
2. Resampling of recording length to 0.04 s, wave travel time corresponding to 30 m depth.
3. Trapezoidal band pass filter (frequency range 1.5–2.0-6.0–7.0 kHz) to suppress noise from waves and boat torsion.
4. A spike deconvolution (Wiener filter) to suppress reverberations of the acquisition system.
5. A normal-moveout correction for correcting effects of the horizontal distance between transducer and hydrophone (20 cm). Since the propagation velocity of the generated compressional waves is nearly the same in water and water saturated near-surface marine sediments a constant (depth-independent) wave velocity of 1450 m/s was applied.
6. Positioning: DGPS coordinates were spatially smoothed along the tracks and assigned to the seismic data.
7. Determination of depth sections along tracks by Stolt-Migration (Stolt, 1978). For this process again a constant compressional wave velocity of 1450 m/s was applied.
8. Suppression of Migration artefacts caused by swell and wave motion were reduced by a notch filter (frequency range 1.8–2.0 kHz).
9. Determination of depth maps of the sea floor and geological interfaces: the reflection signals of the sea floor and major geologic horizons were "picked" along the migrated seismic sections. Horizontal and depth coordinates were then interpolated to determine depth maps. A by-product of the seismic survey is the bathymetric map of the Kane Bay (Fig. 3), which reveals already important structural features. The layer interfaces directly underneath the seafloor were analysed in the same way, taking care of crossing and neighbouring profiles. The picking, interpolation and displaying was performed with the programme *Kingdom Suite*.

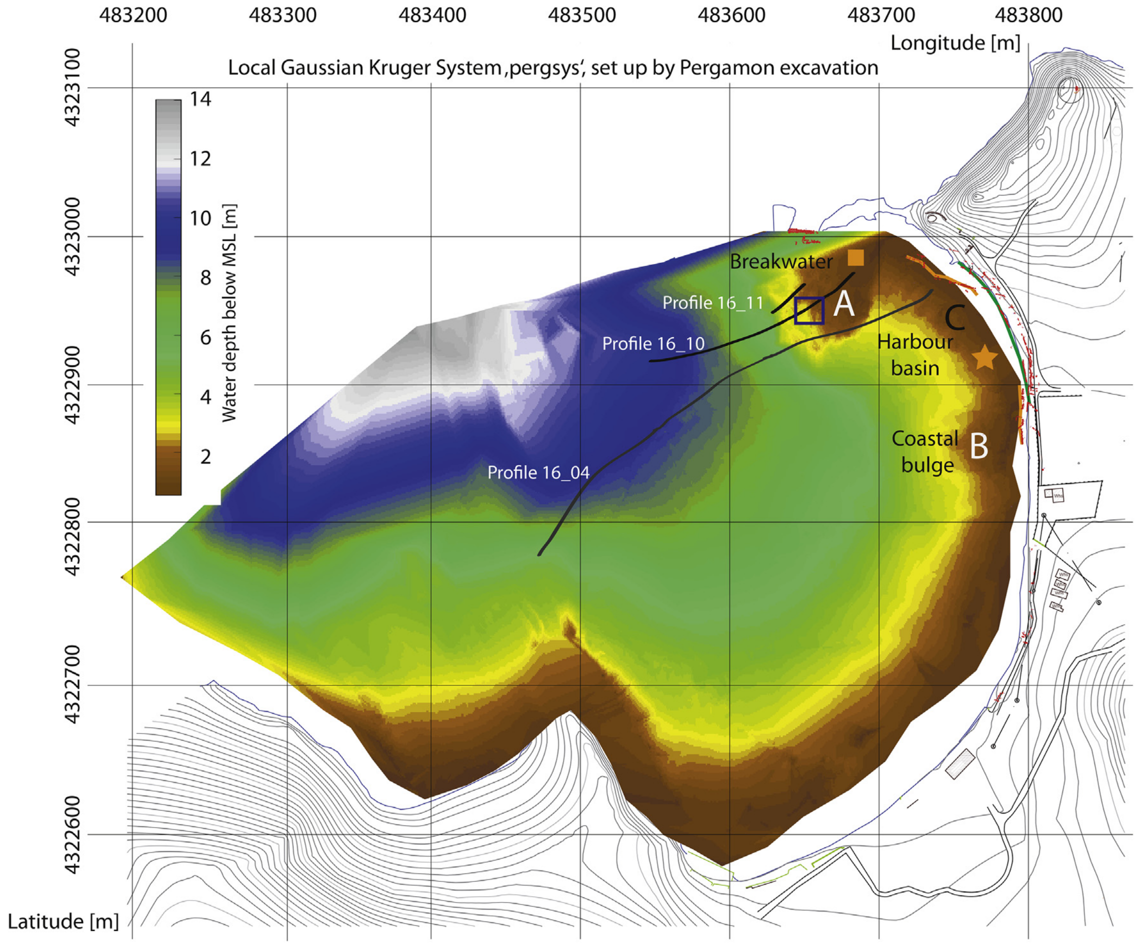

Fig. 3. Contour map of the Kane promontory including archaeological findings (© DAI-Pergamongrabung) and bathymetric chart of the western Kane Bay (colour plot). A and B: Location of the breakwater and the coastal bulge. Black lines: Location of four profiles described in section 4.2. Orange star: Location of an ancient bollard. Orange square: Location of anthroponegical blocks on the breakwater. Orange lines: First wall row. Green line: Second wall row. Blue box: Location of accumulation rate estimation. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

4. Results

4.1. Bathymetry and relevant archaeological findings

The water depth of the western Kane Bay ranges from 0.6 to 13m below MSL (Fig. 3). In the northern part, the eye-catching bathymetric height of the submarine bedrock promontory previously identified by underwater surveys is visible (A in Fig. 3). The bedrock promontory is today 80 m wide, its rocky surface reaching 0.6–2m below MSL. At the SW edges, the bedrock promontory slopes from 2 to 5 m below MSL towards the open sea with average slope angles of 7°. The SE edge of the bedrock promontory is almost perpendicular to the coastline and has a steep, rocky slope of about 9°. In this part of the bedrock promontory, artificial rock accumulations differing from the surrounding material consisting of limestone and andesite were found during snorkelling surveys.

About 100 m SE of the breakwater a second striking bathymetric feature, a coastal bulge, was found. It is a triangular shaped corner with NE-W-SE orientated edges (B in Fig. 3). The coastal bulge was also noticed during snorkelling surveys, the rock accumulations are comparable to those occurring at the submarine bedrock promontory. Between the bedrock promontory and the coastal bulge an almost rectangular 100*50 m wide area extends. Its sea floor shows a low, almost continuous slope of only ~5° towards the sea (C in Fig. 3).

Relevant archaeological findings in this area include an ancient bollard in the rectangular area (Fig. 3, orange star) as well as large anthropogenical blocks on the bedrock promontory (Fig. 3, orange square) (Laufer, 2016). Additionally, two rows of walls following the coastline between the submarine bedrock promontory and the coastal bulge are visible. One row is located in the shallow water (Fig. 3, red items along two orange lines) and one follows the present coastline (Fig. 3, red items along green line).

4.2. Stratigraphy of the seismic profiles

Due to favourable recording conditions we are able to map the sedimentary strata down to the top of consolidated rocks ("basement") in the entire Kane Bay, partly even deeper. In the investigated area basement depth varies between 3 and ~25 m below MSL (Fig. 4). Exemplary seismic profiles, from which Figs. 3 and 4 have been derived are shown and discussed below. Comparing Figs. 3 and 4 it can already be noted that the bathymetry is closely related to basement depth.

Profile 16_04 (Fig. 5) is a SW-NE orientated transect through the Kane Bay, across the submarine bedrock promontory ending in the rectangular area identified in the bathymetry (C in Fig. 3). Accordingly, the transect is divided in three sections: a) the deep part of the bay, b) the submarine bedrock promontory and c) the near-shore shallow part of the bay.

From top to bottom the first impedance contrast is related to the sea bottom. In the centre of the bay the seafloor appears smoothly because of its sedimentary cover. It changes to a rough and discontinuous chaotic surface on the submarine bedrock promontory caused by

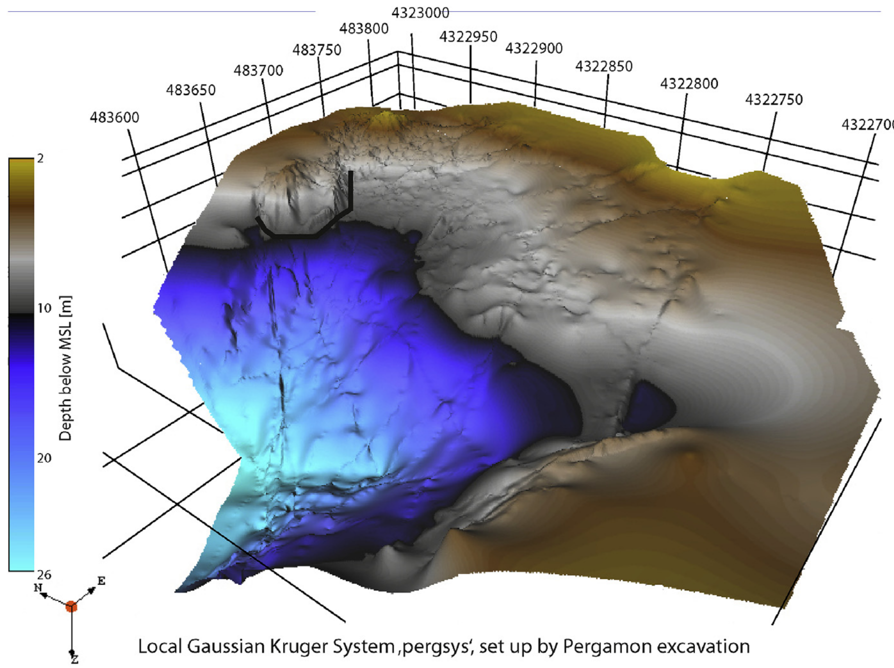

Fig. 4. 3D model of the bedrock of the western Kane Bay. Black circle: Location of the bedrock promontory.

boulders and debris. Behind the bedrock promontory, in the near-shore part of the bay, the seafloor gets smoothly again, though locally disturbed by small-scale deflection.

The deeper part of the bay consists of sedimentary layers overlying a seismic basement.

The seismic basement consists of a layer of strong and chaotic amplitudes, which can be attributed to the local bedrock (Fig. 5). Offshore, the bedrock can be traced until 26 m below MSL, from where it raises steadily towards the coast. Its continuation below the bedrock promontory is unclear because the near-surface boulders scatter all seismic energy at shallow levels. It can be tracked again in the near-shore shallow part of the bay where it is found in depths of 8 m below MSL. Below, other seismic horizons are still visible (Fig. 5).

Examining the bedrock promontory in detail, we find that the surface of the bedrock promontory slopes down from 1.8 to 2.5 m below MSL. In profile 16_04 the seafloor reflection continues below the present bedrock promontory for about 3 m (Figs. 5 and 6a, yellow box), meaning that the seafloor of the Kane Bay is partly overlain by debris from the bedrock promontory. The impact on the original width of the bedrock promontory in Antiquity is analyzed in section 5. The zooming into profile 16_11 (Fig. 6b) highlights this feature as well as the steep slope of the bedrock promontory in some areas.

Another archaeologically relevant observation is the occurrence of strong and disordered amplitudes in a narrow band at the seaward foot of the bedrock promontory at depths of 6–8 m below MSL in profile 16_04 (Fig. 6a, red box), as well as in profile 16_10 (Fig. 7, red box). This feature is consistently found on other profiles crossing the SE slope of the bedrock promontory (Fig. 8, black stars). Profile 16_10 runs almost parallel to profile 16_04 (Fig. 5) at a place where the seafloor is not overlain by debris from the bedrock promontory. The narrow band of disordered amplitudes is discussed in section 5 with regard to the question whether or not the bedrock promontory is of anthropogenic or

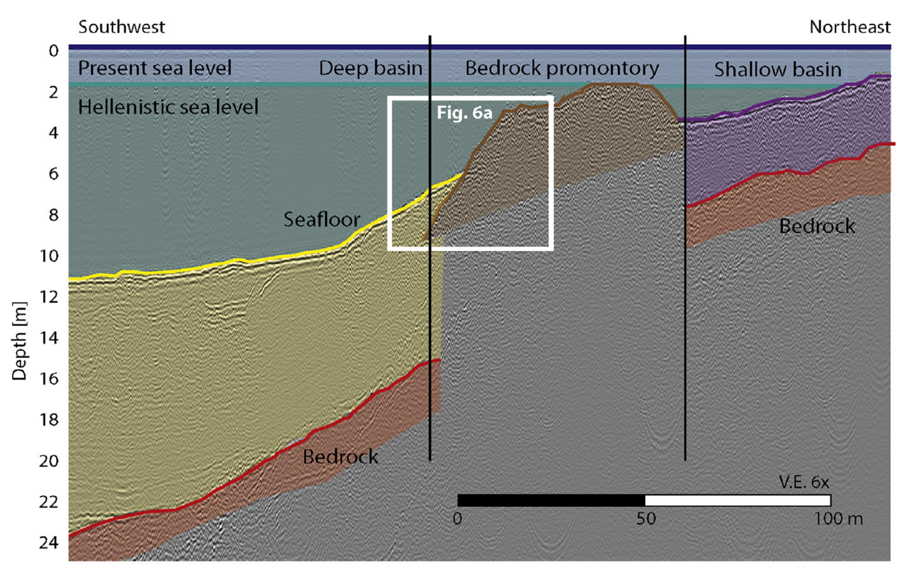

Fig. 5. Seismic profile 16_04 with coloured horizons. White box: Area with detailed view in Fig. 6a. Location of profile is in Fig. 3.

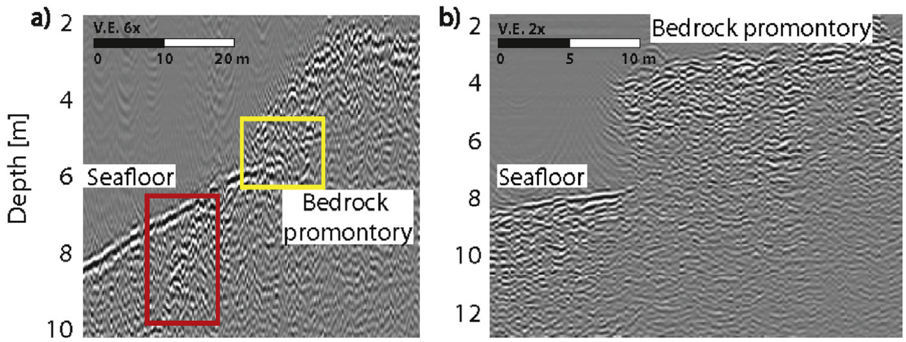

Fig. 6. a) Detailed view of the with box in Fig. 4, profile 16_04. Red box: Narrow seismic reflection band. Yellow box: Continuation of the seabed horizon in the breakwater. b) Zooming into the breakwater slope of profile 16_11. Location of zoom is in Fig. 3. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

natural origin.

4.3. Sea level changes

For reconstructing the ancient harbour situation in the Kane Bay also sea level changes have to be considered. According to section 2.2 we assume that the sea level rose continuously 2 m from Hellenistic times until today. To visualize the shape of possible harbour installations in the ancient landscape, we highlight the shape of the ancient coastline in the bathymetric map (Fig. 8). The submarine bedrock promontory and the coastal bulge were located clearly above the ancient sea level, flanking an U-shaped rectangular basin with an average water depth of 3.5 m.

5. Discussion

5.1. Possible harbour installations in the Kane Bay

From bathymetry and seismic reflection measurements, we found the following evidence for a harbour at Kane Bay:

Firstly, the bathymetric maps show a rectangular basin in the NE part of the bay (C in Figs. 3 and 8). Its western edge extends into a NE-SW trending bedrock promontory (A in Figs. 3 and 8) which has the effect of a breakwater and may have protected the harbour or landing site. Its eastern edge extends into a coastal bulge (B in Figs. 3 and 8), which has the effect of a harbour boundary. This suggests interpreting that both edges are harbour moles (A and B in Figs. 3 and 8) bounding a harbour basin (C in Figs. 3 and 8) of the size of 0.5 ha.

Moreover, reflection seismic and snorkelling surveys show that there are partly instable, stony slopes in the SE of the breakwater towards the possible harbour basin suggesting an anthropogenic origin (Figs. 5, 6a and 7).

Finally, both the surface of the breakwater, the landward rim of the rectangular basin or ramp and the surface of the coastal bulge were more than 1 m above MSL in Hellenistic times (Fig. 8).

The interpretation of the geophysical measurements was confirmed by archaeological finds, in particular, an ancient bollard situated in the possible harbour basin (Fig. 3, orange star) and blocks detected on the breakwater's surface (Fig. 3, orange square) which indicate remains of anthropogenic dam crests (Laufer, 2016). There are two types of walls situated in the possible harbour area. The one close to the harbour basin was interpreted as a quay wall (Fig. 3, orange line). The wall following the coastline (Fig. 3, green line) is Kane's reconstructed city wall fitting to the geophysical interpretation of harbour facilities. Its position justices that the city wall probably separated the harbour area from the town centre (Laufer, 2016). Due to its simple construction, the rock accumulation is probably dated to the Hellenistic period (Laufer, 2015).

The harbour basin of Elaia is 4.8 ha in size (Seeliger et al., 2017), compared to that the size of the harbour basin of Kane of 0.5 ha is small. This can be explained by Kane's minor importance in the Pergamenian Kingdom (see also section 2.1.).

In many aspects, the harbour installations of Kane are comparable to those of Phaselis, an ancient city near Antalya, Turkey (Schäfer, 1981). Phaselis also has a natural bedrock promontory covered by anthropogenic accumulations with the effect of a breakwater. Its size is 136*75 m, which is larger compared to the breakwater of Kane with 80 *80 m in size. Both breakwaters show different kinds of slopes of similar inclination angles. In Phaselis, the surface of the breakwater was more than 1 m above the ancient sea level and there are indications of dam crest remains, too.

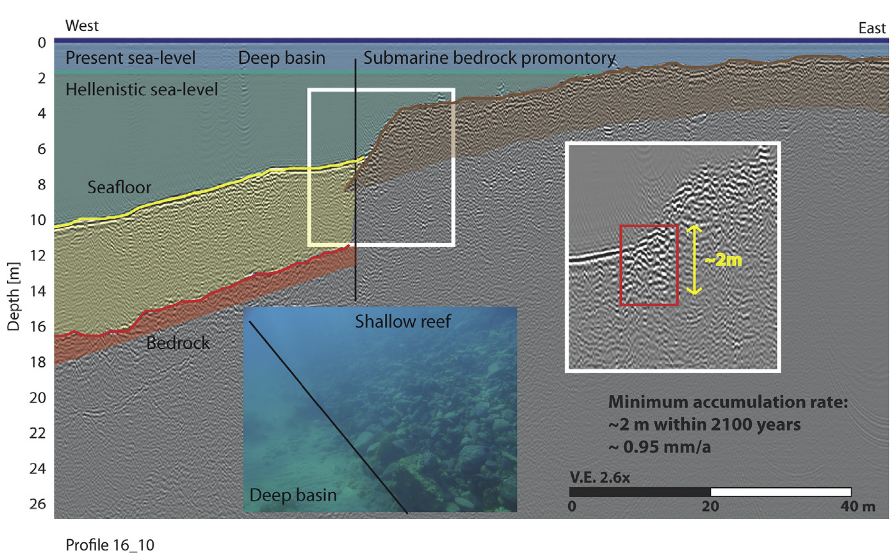

Fig. 7. Seismic profile 16_10 with coloured horizons. White box: Detailed view of anthropogenic structures and estimation of the sediment rates of the bay. Red box: Narrow seismic reflection band. Location of profile is in Fig. 3. Right: Underwater photography of the breakwater (© DAI-Pergamongrabung). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

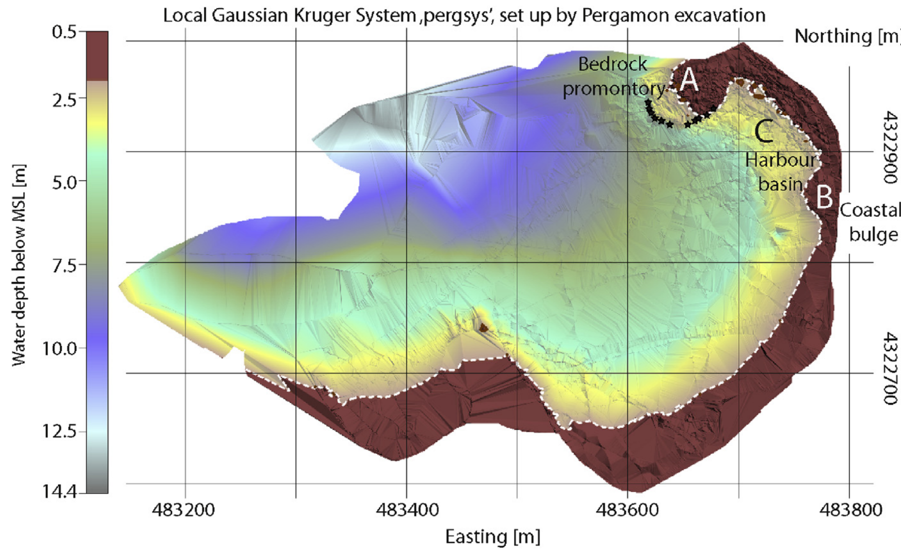

Fig. 8. Bathymetric 3D model of the western Kane Bay. The bay is submerged with the expected ancient sea level, -2m relative to the current sea-level. White dashed line: ancient waterfront. Black stars: location of the narrow band of disordered amplitudes in seismic profiles, local datum „pergsys2014".

5.2. Is the harbour of natural or anthropogenic origin?

The following observations contribute to answering this question:

The seismic reflection imaging (Figs. 5 and 6) show that the bedrock rises steeply towards the coast near the breakwater and shows indications of block-type faulting (Fig. 4). Underneath the breakwater neither sedimentary interfaces nor the top of basement were identified. This suggests that the breakwater could be essential a block of lifted basement.

Additionally, the partly continuation of the seafloor (Figs. 5 and 6b, yellow box) as well as the sloping surface of the breakwater (Figs. 5, 6b and 7) give indication of the original width of the breakwater in Antiquity. Originally, the breakwater was 50–60 m wide, about 20–30 m less than today. Still 50–60 m is a considerable width, which would have required considerable construction efforts if the breakwater was anthropogenic. Since Kane was a city of very small size and of probably little economic influence, it is most probable that the erection of such massive structures was not reasonable.

Therefore, we conclude that the breakwater is basically of geological origin and was enhanced and fortified anthropogenically. Remnants of this reworking are mainly found at the steep inner slopes in form of anthropogenic accumulations and in form of the possible dam remains. Due to erosion, tides and possible seismic events, the dam crest slumped down the slopes, which results in the seismic narrow band below the sea floor between breakwater and harbour basin (Fig. 6a, red box and 7).

The shape of the breakwater resembles the one found in Elaia (Seeliger et al., 2017), although it has larger dimensions. Elaia's breakwater shows a moderate slope towards the sea providing a natural protection of the harbour basin. The inner slope of Elaia's harbour basin is steep and suggests human stone working. This can be associated with a harbour entrance.

The bedrock promontory of the ancient harbour of Phaselis is also supposed to be of geological origin with an anthropogenically enhancement and fortification. Its former dam crest also slumped down, resulting in a sloping breakwater (Schäfer, 1981).

5.3. Accumulation rates

The accumulation rate of the possible harbour basin is of interest for determining its ancient depth. As accumulation rates from corings were not available an alternative had to be found.

For estimating the accumulation rate we assume that the bottom of the deepest known offshore anthropogenic structure represents the minimum depth of the Hellenistic seafloor level, which can be identified with the bottom of the seaward edge of the breakwater (Fig. 7, enlarged cutout). The depth difference between this point and today's seafloor level is 2 m. Assuming that this pile of sediments was accumulated continuously since the construction of the breakwater in Hellenistic times (~2300 BP) we obtain an average accumulation rate of about 1 mm/a, which indicates a previous harbour basin depth of 4 m.

This is nearly half of the accumulation rate of the Bay of Elaia for the same period. During Elaia's prime (roughly between 300 BC and AD 300) the closed harbour basin shows a sedimentation rate of ~2 mm/a (for the open harbour area 2.2 mm/a; Seeliger et al., 2017). This difference should not be overinterpreted as it may be the result of different material in the hinterland and the different grade of human impact in both areas. The environs of Elaia are mostly dominated by sandstone material while Kane's hinterland is mostly made of limestone. In addition, the importance of Elaia and Kane in their capacity as a city is not comparable while human impact in the Elaia region was more intense (Shumilovskikh et al., 2016; Seeliger et al., 2017). Low accumulation rates can be caused by currents at the sea floor causing erosion or by generally small sedimentary input. Finally, due to the specificity of both methodological approaches the comparison of sedimentation rates based on corings and on seismics may be difficult.

6. Conclusion

The objectives of the seismic survey at the Kane Bay were to search for remains of ancient harbour facilities, to distinguish between anthropogenic and geological structures and to derive clues from geological aspects influencing the interpretation of ancient harbour installations in the Kane Bay. Based on bathymetry and seismic stratigraphy the following conclusions are drawn:

a. We found evidence of a rectangular harbour basin laterally bounded by a breakwater and a quay type edge.
b. The possible harbour site is protected towards the sea by a breakwater. The breakwater has probably a natural basement but shows evidence of anthropogenic reshaping and construction.
c. From seismic markers a minimum average accumulation rate of ~1 mm/a was estimated for the area between the breakwater and the possible harbour basin. This rate is based on the assumption that the

deepest anthropogenic structure found offshore is of Hellenistic age.

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