Proceedings of the 7th Symposium of the Hellenic Society for Archaeometry

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Archaeology Archaeometry: 30 years later

Edited by

Eleni Filippaki
in collaboration with
Y. Bassiakos, G. Facorellis, A. Oikonomou, M. Papageorgiou,
P. Loukopoulou and M. Kaparou

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Cover images:

Upper left side: Egyptian blue grain (Βιβτένκο, Σ., Τζαναβάρη, Α. και Βασιλειάδου, Α., this volume). Upper right side: X-ray diffraction pattern of the powder obtained from a casting mould (Iliopoulos, I. and Soura, K., this volume). Lower left side: Backscattered electron image of the ceramic body of a cooking pot in cross section (Oikonomou, A., Marabea, Ch., Papachristodoulou, Ch. and Palles, D., this volume). Lower right side: Strongly tectonized marble with relics of bigger grains decaying into a groundmass of small calcite grains (Anevlavi, V., Prochaska, W. and Ladstätter, S., this volume).

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Preface

The 7th Symposium of the Hellenic Society for Archaeometry was held in the premises of the Byzantine and Christian Museum in Athens in Autumn 2019 (October 9-12) and managed to bring together well- respected members of the archaeometric community from Greece and abroad.

The Hellenic Society for Archaeometry (HSA), founded in 1982, constitutes one of the oldest associations of the field in Europe, encompassing hundreds of members, Greeks and foreigners. HSA, as a scientific association dedicated to promoting the interdisciplinary field of Archaeometry, aims at enhancing this discipline scientific field, which applies Science and Technology on Archaeology, History of Art and, generally, on any field related to Cultural Heritage. Active members of the HSA are academics, researchers and students, from related institutions- scientific and academic-, the Archaeological Service and the private sector in Greece.

Since its establishment, the HSA has organized seven Symposia on Archaeometry, all of them with intense international character, as well as numerous seminars and public lectures, promoting Archaeometry in the country and abroad. Additionally, HSA is one of the founding bodies of the prestigious international Archaeometry journal "Archaeological and Anthropological Sciences" established in 2009 https://www.springer.com/earth+sciences+and+geography/journal/12520.

The 7th Symposium entitled "*Archaeology-Archaeometry: 30 years later*", commemorated the organization of the 1st Symposium of HSA back in 1990, which bore the emblematic title "*Linking Archaeology and Archaeometry*". During the 3-day Symposium, more than 100 original papers were delivered in oral and poster presentations, all of which served as springboard for intriguing and stimulating discussions.

The Organizing Committee of the 7th Symposium consisted of Y. Bassiakos, Y. Facorellis, E. Filippaki, M. Kaparou, P. Loukopoulou, A. Oikonomou, M. Papageorgiou and G. Theodorou. The Members of the international Scientific Committee were E. Aloupi-Siotis, S. Boyatzis, H. Brekoulaki, J. Buxeda i Garrigós, A. Dellaporta, R. Jones, P. Karkanas, A. G. Karydas, V. Kassianidou, V. Kilikoglou, D. Kontopoulou, A. Kouli, I. Lyritzis, Y. Maniatis, E. Margariti, S. Pavlidis, E. Photos-Jones, Th. Rehren, C. Renfrew, M. Roumbou, A. Sarris, Z. Stos-Gale, G. Tsokas and N. Zacharias.

This volume of proceedings comprises a representative collection of the contributions presented in the Symposium, covering a wide range of fields in archaeological science, such as provenance and technology of archaeological and historical materials, geo-archaeology and bio-archaeology, dating methods and applications, landscape studies, as well as papers presenting the origins of Archaeometry in Greece.

The Organizing Committee would like to acknowledge the valuable support and the hospitality provided by The Byzantine and Christian Museum in Athens. We are also very grateful to the sponsors of the Symposium, namely NCSR "Demokritos" and Arte Solutions. Importantly, we remain indebted to the referees in Greece and abroad, as well as to the Members of the Scientific Committee who reviewed and commented on the scientific papers submitted. Finally, we cordially thank all those whose contributions have been essential in organizing the Symposium and publishing these Proceedings.

On behalf of the Editorial Committee

Eleni Filippaki, Researcher
Lab. of Archaeometry, NCSR "Demokritos"

Progressive Sea Transgression during the Late Holocene in Vatika Bay (Laconia, Peloponnese, Greece): Just When Was the Prehistoric Town of Pavlopetri Drowned by the Sea?

Eleni Kolaiti[1] and Nikos Mourtzas[2]

[1]Dr. Mining Engineer NTUA, External Collaborating Researcher, Institute of Historical Research/National Hellenic Research Foundation (IHR/NHRF); Honorary Research Fellow, Department of Classics and Archaeology, University of Nottingham; Society for the Study of Ancient Coastlines - AKTES NPO, kolaitieleni@gmail.com; Eleni.Kolaiti@nottingham.ac.uk; info@aktes.gr (corresponding author)

[2]Dr. Geologist NTUA, Independent Research Scholar; Honorary Research Fellow, Department of Classics and Archaeology, University of Nottingham; Society for the Study of Ancient Coastlines - AKTES NPO, nikosmourtzas@gmail.com; Nikolaos.Mourtzas@nottingham.ac.uk

Abstract: Geomorphological and archaeological sea level indicators, historical evidence and comparison with past sea levels identified along the eastern coast of the Peloponnese enabled us to track the relative sea level changes in Vatika Bay, the consequent sea transgression, and its impact on the coastal landscape during the last 5500 years. Five distinct beachrock generations stretching for 4 km all along the coast of Vatika Bay and now submerged between 5.10 m and 0.80 m below mean sea level (bmsl), a tidal notch, and several marine terraces submerged up to 4.60 m bmsl, formed around the submerged rocky ridge that bounds on the east the prehistoric town of Pavlopetri on the Pounta coast, allowed us to determine five former sea levels. When the sea level was at 5.00 ± 0.25 m bmsl, Elafonisos Island was joined to the Laconic coast by an isthmus. A rocky ridge offered a protected location for the first inhabitants of the Early Bronze Age. The relative sea level rise to 4.50 ± 0.25 m during the Late Bronze Age did not affect the town: only the coastal part of the cemetery and parts of the isthmus were flooded. At this sea level, a tidal notch, today submerged at 4.60 m bmsl, formed along the ridge.

The subsequent sea transgression that occurred between 1190 BC and 700 BC caused further flooding of the isthmus, although Elafonisos was still connected to the mainland, and shifted the sea level to 3.60 ± 0.10 m bmsl. It remained relatively stable until Late Roman times (AD 4th or probably 6th century). At this sea level, the prehistoric town was still protected by the now-lowered ridge. Elafonisos was detached from the Peloponnese by the end of AD 14th century, when the sea level rose to 1.50 ± 0.15 m bmsl, inundating the isthmus, the town, and most of the ridge, by now a reef, with only its higher elevated part now constituting Pavlopetri Island. The sea level remained at this height from 1389 until at least 1840. Over the following 160 years, the sea transgression that gradually shifted the sea level to 0.75 ± 0.05 m bmsl and then to its present stand further inundated the coastal landscape.

KEYWORDS: VATIKA BAY; ELAFONISOS ISLAND; ELAFONISOS STRAIT; POUNTA COAST; PAVLOPETRI; ANCIENT TOWN; EARLY BRONZE AGE; LATE BRONZE AGE; LATE ROMAN TIMES; BEACHROCK; RELATIVE SEA LEVEL CHANGE; SEA TRANSGRESSION; GEOMORPHOLOGICAL INDICATORS; ARCHAEOLOGICAL MARKERS; PALAEOGEOGRAPHIC RECONSTRUCTION; COASTAL LANDSCAPE

Introduction

The Bay of Vatika or Voion is located at the SW edge of the Elos (previously Laconic) Peninsula, NW of Cape Maleas, and belongs to the wider Laconic Gulf (Figures 1A, B). It opens toward the SSW onto the Aegean Sea. In the shape of an inverted ‘U’, it is approximately 8 km long N-S and 5 km wide E-W in its northernmost narrowest part. The entrance of the bay, approx. 8 km wide, is bounded on the east by Tsoumala Peninsula and on the west by Fragos Peninsula, at the southernmost tip of Elafonisos Island. The main port of the bay is Neapolis, where the ruins of the ancient Laconic polis of *Boeae* are located (Figure 1C).

The northern shore of the bay, at its apex, is fed by the Agioi Apostoloi and Agios Georgios streams. The sandy barrier of coastal dunes that develops all along the northern beach of the bay prevents surface runoff from flowing into the sea and entraps rainwater upstream, thus forming swampy areas parallel to the shoreline. The largest of these is Lake Strongyli, which during high-water periods occupies an area of maximum length and breadth 1200 m and 250 m, respectively (Figure 1C).

A channel, ranging from around 600 m in length in its narrowest part to as much as 1000 m in its widest part, and with a depth of up to 3.50 m, separates Pounta on the Peloponnesian coast from the opposite coast of Elafonisos (Figure 1C). Within Vatika Bay, some 300 m ESE off the Pounta shore and 800 m NE of Elafonisos, the island of Pavlopetri is situated, covering an area of approximately 2500 m^2. At a distance of 380 m NE

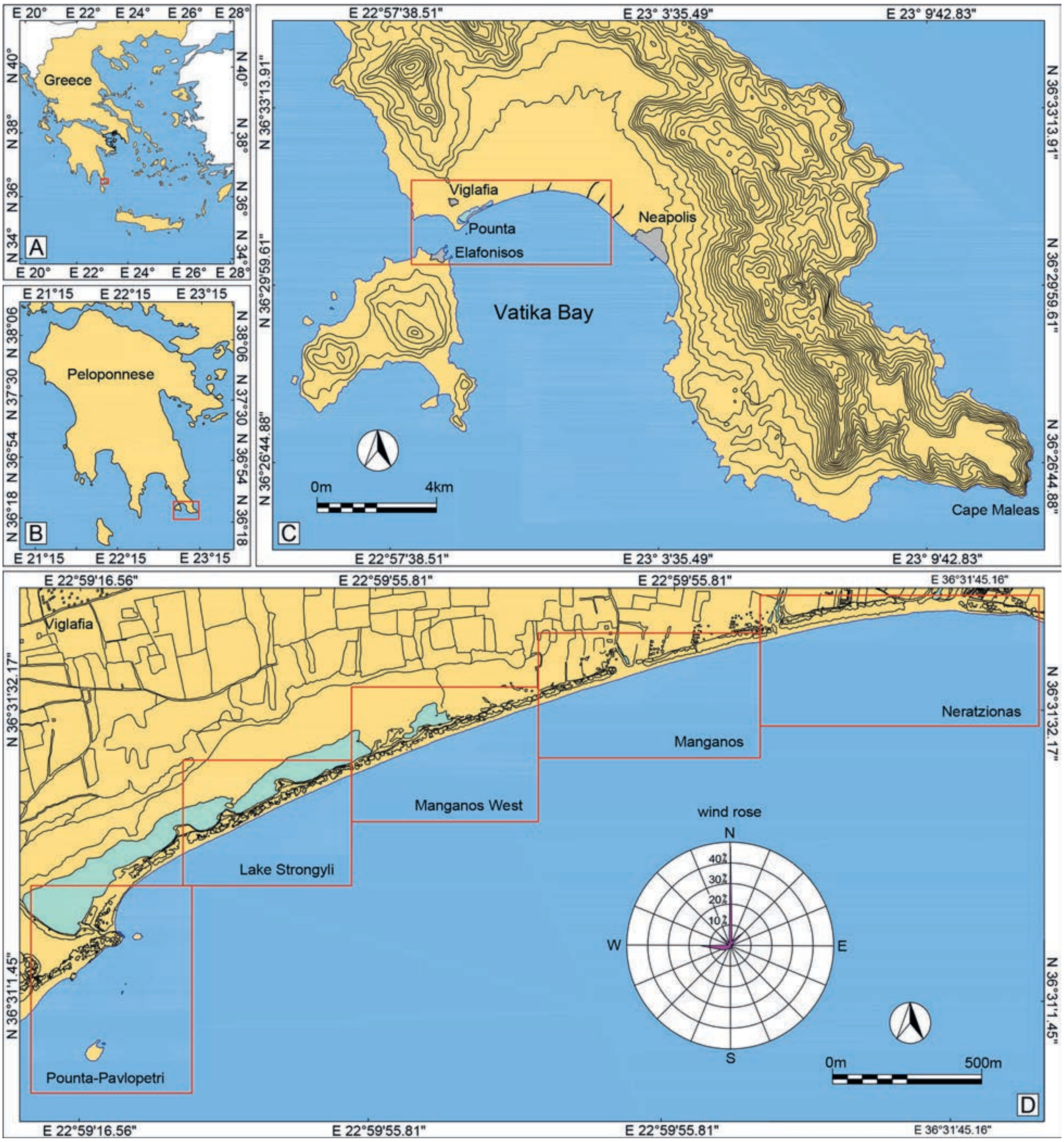

Figure 1. Location maps of: Cape Maleas in the Peloponnese, S Greece **(A)**, Vatika Bay in S Peloponnese **(B)**, the north coast of Vatika Bay and the Elafonisos Strait. **(C)** and the five sections of the north coast of Vatika Bay **(D)** as described in the text. A wind rose diagram showing the average daily wind speed and direction frequencies is presented.

of Pavlopetri Island, and just 30 m off the easternmost tip of Pounta, a second smaller islet (called Chamokelo by the locals) is situated, approximately 500 m^2, henceforth referred to as the 'NE Islet'. Between the two islets, which constitute the NE and SW edges of a submerged sandstone ridge that bounds the submerged prehistoric town of Pavlopetri on the east, two more tiny islets emerge above sea level.

The rocky ridge that apparently protected the prehistoric town, the basin where the town was located, and part of the coastal zone, consists of Upper Pliocene-Pleistocene marine and lacustrine clastic and biogenic sediments, mainly sandstones and calcarenites. These overlay the Jurassic limestone and dolomitic limestone of the Tripolis zone that structure the wider elevated area of Viglafia and the major part of Elafonisos Island.

The extended low area consists of unconsolidated alluvial deposits, eluvial mantle materials, and clastic river and torrent deposits, ending in the coastal zone where coastal dunes and sandy beach deposits also accumulate.

Three active fault zones, the Kountourianika-Viglafia fault zone in the east, the Neapolis-Palaikastro fault zone in the west (both in a N-S direction and dipping to the east and west, respectively), and the Kontrafourianika-Adiakopos fault zone in the north, running NW-SE to WNW-ESE, bound the Neogene basin of Neapolis Voion. The staircase morphology shaped by the successive marine terraces of Viglafia and Elafonisos reflects the long-term uplift of South Laconia during the Late Quaternary (Karymbalis *et al.* 2022).

The first occupation of the site goes back to the Late Neolithic (3500 BC) and continues throughout the Bronze Age until the end of the Mycenaean period and the fall of the Myceanean Palaces (1100 BC), when it was abandoned (Harding *et al.* 1969). Extensive evidence of pottery from the Early to the Late Helladic period with a noticeable Late Minoan IB influence clearly indicates that Pavlopetri had established links with the Cyclades, Crete and mainland Greece since the Early Bronze Age (Henderson *et al.* 2011; Gallou and Henderson 2012). However, its geographical position, in a sheltered bay with sandy beaches east and west of the settlement, favoured the approach of light boats that had already sailed the dangerous Cape Maleas, thus rendering Pavlopetri an important harbour town (Gallou and Henderson 2012). The site was repopulated to a lesser extent, probably during the Geometric and certainly in the Classical and Hellenistic periods (4th-3rd century BC). The Roman and Byzantine pottery at the site is associated with a later, limited occupation of the area mainly related to purple dye production and trading of local stone and iron ore from the nearby haematite mines of Agios Elissaios at the foot of Mount Voion (Henderson *et al.* 2011; Gallou and Henderson 2012).

The submerged remains of the prehistoric town were first reported by Negris (1904), who provided some measurements of depths of the ancient remains, which in his view constituted a town built on the isthmus that connected Elafonisos with the Peloponnese with only two islets protruding from the sea. Over half a century later, in 1967, N.C. Flemming from the National Institute of Oceanography (UK) visited the site in the context of a pioneering geoarchaeological survey in the South Aegean aimed at determining the eustatic and tectonic components of the relative sea level (henceforth 'rsl') change based on archaeological evidence (Flemming 1968; Flemming *et al.* 1973). It was then that the archaeological survey in Pounta-Pavlopetri was begun by the Ephorate of Antiquities of the Peloponnese and the British Archaeological School at Athens (Ministry of Culture – www.culture.gov.gr). In 1968, the "Cambridge Underwater Exploration Group" from the University of Cambridge conducted a more systematic underwater survey and recorded in a first drawing the sunken ruins of the ancient town (Harding *et al.* 1969).

Forty-one years later, in 2009, interest in Pavlopetri resumed and the five-year program "The Pavlopetri Underwater Archaeology Project" was instigated by the University of Nottingham in collaboration with the Ephorate of Underwater Antiquities of the Greek Ministry of Culture. The aim was to conduct digital underwater recording of the site and funerary remains, the architectural remains of both the building complexes originally surveyed in 1968 (Harding *et al.* 1969) over an area of 30,000 m^2, and the new building and rock-cut tombs to the north of the settlement and at the eastern side of the ridge, over an area of more than 9000 m^2 (Mahon *et al.* 2011; Henderson *et al.* 2011).

Flemming (1968) suggested a rsl change of 3 m for Elafonisos during the last 3.5 millenia (with a rate of 0.9 mm/yr). Of this, 0.50 m was attributed to net eustatic change during the last 2000 years, the rest representing a general depression across the margins of the Peloponnese with areas of faulting in the Mani Peninsula. Harding *et al.* (1969, 140), taking into account that the maximum observed depth (3 m) of the ancient remains in the basin was the minimum rsl change, suggested that a "realistic" change was 4 m to 5 m, based on the reasoning that "the buildings are not likely to have stood actually at sea level". They further suggested that the life of the prehistoric town ended in the Late Helladic IIIB period, when it was either destroyed or abandoned, and assumed that Elafonisos was disconnected from the Peloponnese by a local tectonic event in the AD 2nd century. Thereafter, small-scale tectonic events caused the gradual subsidence of the site, as the Elafonisos Strait was fordable until at least AD 1677. They also mentioned the lack of a prehistoric harbour there, while the harbour shown in their plan (Harding *et al.* 1969, *Fig. 11*) on the north side of Pavlopetri Island is actually a quarryscape. In a subsequent study, Flemming *et al.* (1973) argued that the foundations of the Helladic buildings do not exceed the depth of 3 m, thus suggesting a rsl change of 3-3.50 m, with Elafonisos Island having been connected to the Peloponnese until the AD 2nd century and the Elafonisos Strait fordable until the AD 17th century. After his involvement in the 2009 Pavlopetri Project, Flemming reconsidered the theory of the existence of a fordable isthmus in 1677—a theory formulated by the misreading of the diaries of John Covel (1670-1679), first by Bent in 1893, and by subsequent authors. This was briefly presented in a later co-authored publication (Henderson *et al.* 2011, 217 and references therein), but was also explained in detail in a personal communication that we had with him. Henderson *et al.* (2011) suggest a rsl change of 4-5 m during the last 5000 years, and of this attribute 0.50-1 m to eustatic rise and the rest (3-4.50 m) to gradual co-seismic subsidence with a rate of 0.80-1 mm/yr. They do not, however, determine the causative faults or paroxysmal events that caused it. Moreover, they assume a 2-3 m subsidence "by *c.*2000 cal BP" (Henderson *et al.* 2011, 216) and suggest—in the absence of concrete evidence—that the prehistoric town was most likely inundated "by the time of the Roman Empire" (Henderson *et al.* 2011, 217).

The systematic recording of various geomorphological sea level indicators and their dating using archaeological markers, all of which were identified in Vatika Bay, along with their correlation with the past sea levels identified throughout the eastern coast of the Peloponnese, enabled us to track the rsl changes in Vatika Bay, the consequential sea transgression, and its impact on the coastal landscape during the last 5500 years. As a consequence, this study aims to decode the past sea levels in Vatika Bay based on both the analysis of the observed rsl change indicators and their synthesis to reconstruct the palaeogeography of the coast from the Early Bronze Age to the present. The ultimate goal is to answer the question of precisely when the prehistoric town of Pavlopetri was drowned by the sea and whether the sea transgression was the causative factor in its demise.

Methods

The determination of the several sea level stands was based on geomorphological indicators, i.e. marine tidal notches, marine terraces, and various beachrock generations (e.g. Kolaiti and Mourtzas 2023). An underwater geological snorkel survey in Vatika Bay revealed many geomorphological indicators of past sea levels, which were mapped using satellite images (Google Earth Pro, v. 7.3.2) and high-resolution orthophotos at a scale of 1:500 (Ktimatologio SA). During the survey, their features were recorded and depths at selected points were measured. In particular, the morphometric features (opening, inward depth, base width) and elevation of the base of the tidal notch, which represents or is slightly below the mean sea level (e.g. Kelletat 1997, 2005; Antonioli *et al.* 2015; Kolaiti 2019 and references therein), were measured. The length, gradient, and elevations of the inner shoreline angle (landward end) and outer edge (seaward end) of each marine terrace were also measured (e.g. Kolaiti 2019). During snorkel surveys, the length, width and thickness, as well as the depth of the seaward and landward end of the top and base of each beachrock generation, were measured according to the methodology initially suggested by Kolaiti (2019). Correspondingly, the seaward base of a beachrock slab in well-preserved parts that have not undergone erosion or fragmentation, represents the mean low tide of a former sea level. Different sea level stands form distinct beachrock slabs at various elevations that correspond to different generations of a fossilized palaeoshoreline (e.g. Vousdoukas *et al.* 2007; Desruelles *et al.* 2009; Mauz *et al.* 2015 and references therein; Mourtzas and Kolaiti 2023). The loose, unconsolidated, sandy/sandy-gravel sediments on the sea bottom between two different beachrock generations represent a period of rsl change (e.g. Desruelles *et al.* 2009). To determine the former sea level stands, the depth of the seaward base of each beachrock generation representing the low tide of a former sea level is used. Fossils, organic material, or archaeological remains embedded in a beachrock offer a *terminus post quem* for the beachrock formation, which postdates the embedded material (Kolaiti 2019; Kolaiti and Mourtzas 2023).

Various ancient coastal constructions now submerged were related to the sea level at the time they were in use and can therefore be used as precise archaeological indicators for the determination and dating of the former sea level stands inferred along the coast of Vatika Bay. The measurement of the elevations/depths of particular functional features of the ancient structures can lead us to the determination of their functional elevation with sufficient accuracy. The archaeological interpretation and age of ancient structures enable us either to define the time period when the change in sea level occurred or to determine at least a maximum dating limit (*terminus post quem*) after which the structures could not have been in use according to their initial design, or a minimum dating limit (*terminus ante quem*) prior to which the sea level could not have changed since the structures were in use (e.g. Kolaiti and Mourtzas 2023).

All measurements of depths were collected during calm sea conditions using mechanical methods (namely, a tape measure equipped with a stabilizer system on the measurement surface and a circular metallic ranging rod with conical shoe fitted at bottom and fully painted with 10 cm long colour bands in red and white), and repeated during three different survey periods (June 2015, May 2016, October 2017). An accuracy of ±1 cm along the vertical is routinely estimated (e.g. Antonioli *et al.* 2007). To account for tides, observational data were reduced for tide values at the time of the surveys with respect to mean sea level, using tidal data from the Hellenic Navy Hydrographic Service (HNHS) for the closest tide-gauge station, i.e. that at Piraeus. The effect of atmospheric pressure on the sea level was corrected using the meteorological data for the site at the time of the surveys that were retrieved from the web site meteo.gr managed by the National Observatory of

Athens (NOA) or from a portable station measuring the atmospheric pressure in the field. Therefore, all depths reported herein correspond to depths below mean sea level (bmsl).

Wind data were acquired by the website meteo.gr (NOA), for the closest weather station to the study area, at Cape Maleas (LGB5) (Lat: 37°36'00"N Long: 22°06'00" E, location: Agios Nikolaos Voion, elevation: 161 m). Wind data cover the period from August 2008 to May 2020 sequentially, with only brief interruptions of usually no more than three days, the longest lasting 14 days. Statistical analyses of raw data and the wind rose diagram of average daily wind speed and direction frequencies (Figure 1D, inset) were performed by the authors. The wave parameters were calculated to close approximate by the Sverdrup-Munk-Bretschneider (SMB) empirical model as described in the Shore Protection Manual (CERC, 1977).

Results

Geomorphological indicators of the rsl change in Vatika Bay

The northern shore of Vatika Bay, stretching WSW-ENE for about 4 km from Pounta to Neratzionas, comprises plenty of geomorphological sea level indicators, i.e. five distinct beachrock generations, one tidal notch, and several marine terraces now lying below water, as well as a beachrock formation that is now cementing on the contemporary coastline. By way of illustration, the shore was divided into five sections, namely from E to W (Figure 1D): Neratzionas (length: 940 m), Manganos (length: 720 m), Manganos West (length: 775 m), Lake Strongyli (length: 950 m) and Pounta-Pavlopetri (length: about 600 m). The plan of each section is given in Figure 2, except for Pounta-Pavlopetri, which is given in Figures 3 and 4. The measured depths and the average values are summarized in Table 1. It should be mentioned that for a better understanding of the sequence between sea level stands and geomorphological indicators, the labelling of the beachrock generations, tidal notch, and marine terraces corresponds to that of the sea level stands observed for the eastern Peloponnese (as presented below in the 'Interpretation and Discussion' section).

Neratzionas (Figures 1D and 2A)

On the eastern side of Vatika Bay along the Neratzionas coast, four out of five beachrock generations were recorded. The deepest generation (I), running parallel to and along almost the entire length of the shoreline, has an average width of 15 m (range: 10-38 m). It appears moderately-to-very fragmented, without the blocks having moved from their original position. The seaward top is at 4.30-4.45 m bmsl, its seaward base at 4.90-5.25 m bmsl.

The next beachrock generation (II) develops parallel to (I), at an average distance of 5 m towards the shore, separated from it by a sandy strip. It also appears moderately-to-very fragmented, but with its blocks in the original position. Its breadth varies between 11 m and 33 m, the seaward top is at 3.95-4.10 m bmsl, and its seaward base at 4.60-4.75 m bmsl.

In the central part of the Neratzionas section, after 120 m of sandy bottom from beachrock (II) towards the shore, and 10-15 m offshore, lies the beachrock generation (V). It extends parallel to the shoreline for a length of about 145 m and a total width of 30 m. It is solid to slightly fragmented, with its seaward top and base at 1-1.35 m bmsl and 1.25-1.55 m bmsl, respectively.

Between beachrock (V) and the beach, 5 m offshore, the youngest beachrock generation (VI) runs parallel to the shoreline for 550 m. It is solid, 3-5 m wide and its seaward top is at 0.30-0.45 m and seaward base at 0.85-0.90 m.

Manganos (Figures 1D and 2B)

Along the Manganos coast, the two deepest of five beachrock generations are developing extensively, and only two limited occurrences of beachrock generation (V) were observed at the easternmost side of this section with the seaward top and base at 1.15 m and 1.50 m, respectively. The deepest beachrock generation (I) starts 220 m offshore and runs parallel to it for about 700 m, with an average width of 25 m (range: 12-30 m). It appears moderately-to-very fragmented, without the blocks having moved from their original position. The seaward top is at 3.90-4.30 m bmsl and its seaward base at 4.80-5 m bmsl.

The next beachrock generation (II) develops parallel to (I), at a varying distance of 2-10 m offshore, separated from it by a sandy strip. It also appears moderately-to-very fragmented, but with its blocks in the original position. Its breadth varies between 12 m and 30 m, the seaward top is at 3.95-4.10 m bmsl and its seaward base at 4.80-4.75 m bmsl.

Manganos West (Figures 1D and 2C)

In the central part of the Vatika coast, just after the previous section ends, two out of five beachrock generations are developing westward as far as the area of Lake Strongyli, with the contemporary one now cementing on the beach. The deepest beachrock generation (I) starts 230 m offshore and runs parallel to the shore for about 750 m, with an average width of

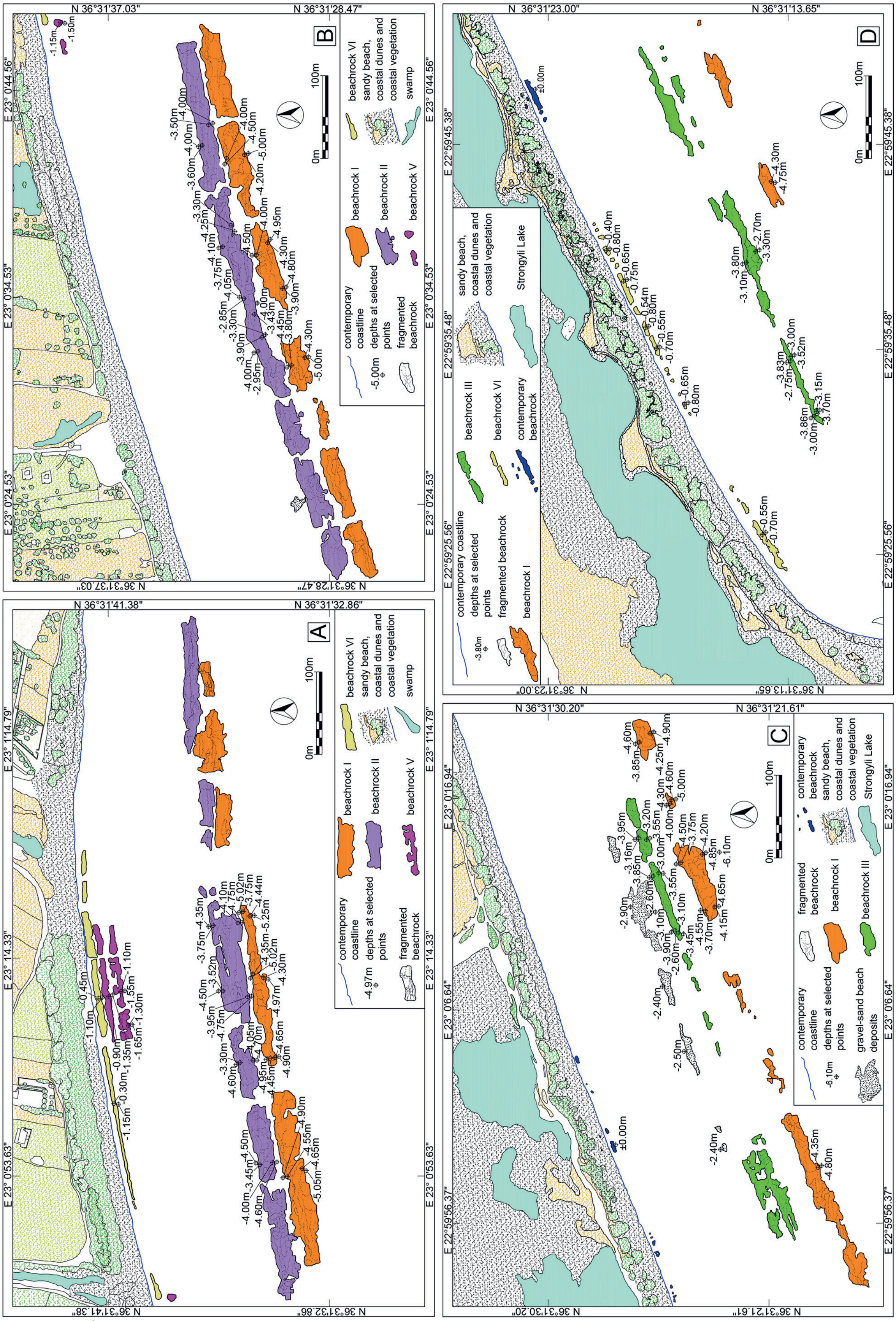

Figure 2. Schematic plans of the various beachrock generations recorded on the coast of Vatika Bay. **(A)** Neratzionas section. **(B)** Manganos section. **(C)** Manganos West section. **(D)** Lake Strongyli section.

Table 1 Depths of the various beachrock generations recorded and measured in Vatika Bay. The locations are shown in Figures 1D, 2 and 3. The depths were measured at the top and base of the seaward end of each beachrock generation (see 'Methods'). All measurements have been corrected for tide and pressure at the time and date of survey and correspond to depths below mean sea level (bmsl) or elevation above mean sea level. In the last row, the average depth of multiple measurements and the depth uncertainty are provided.

Location	depth (m) bmsl										elevation (m)
	beachrock (I)		beachrock (II)		beachrock (III)		beachrock (V)		beachrock (VI)		contemporary beachrock
	top	base	top	base	top	base	top	base	top	base	
Neratzionas	4.50 ± 0.20	5.10 ± 0.15	4.0 ± 0.10	4.65 ± 0.10			1.20 ± 0.10	1.60 ± 0.05	0.35 ± 0.10	0.85 ± 0.05	
Manganos	4.20 ± 0.15	5.00 ± 0.10	3.40 ± 0.10	4.25 ± 0.10			1.15	1.50			
Manganos West	4.30 ± 0.15	4.90 ± 0.10			3.10 ± 0.10	3.55 ± 0.05					±0.00 ÷ +0.50
Lake Strongyli	4.30 ± 0.05	4.75			2.95 ± 0.20	3.60 ± 0.10			0.55 ± 0.10	0.75 ± 0.05	±0.00 ÷ +0.50
Pounta-Pavlopetri								1.50			
average depth (m)	**5.00 ± 0.25**		**4.45 ± 0.30**		**3.60 ± 0.10**		**1.55 ± 0.10**		**0.80 ± 0.10**		**±0.00**

12 m (range: 4-30 m). It appears moderately-to-very fragmented, without the blocks having moved from their original position. The seaward top is at 4.15-4.60 m bmsl and its seaward base at 4.80-5 m bmsl.

At a landward distance of 30-40 m from beachrock (I), separated from it by a sandy strip, beachrock generation (III) is developing for 550 m parallel to it but more sporadically and to a smaller extent than beachrock generation (I). Its breadth varies from 5 m to 12 m and shows a moderate to high fragmentation, but with its blocks, in the well-preserved parts, in their original position. The seaward top of beachrock generation (III) is at 3-3.20 m bmsl, the seaward base at 3.45-3.55 m bmsl. In the central part of this section, and for a length of 300 m toward the west, parallel to, and at a distance of 10-26 m behind beachrock (III) toward the coast, sand-gravel beach deposits are laid on the sandy bottom along the isobath of 2.40 m.

In the swash and backwash zone of the contemporary shoreline, for a length of about 330 m westward, beachrock seems to be cementing. Sporadic occurrences were also found in the spray zone of the modern sandy beach. The average width of the beachrock is 5 m, with a visible trace on the beach extending to a maximum distance of 10 m from the shoreline. These observations clearly demonstrate that the beachrock is cemented concurrently in the intertidal and supratidal zone, and that its seaward end is the most reliable point for measuring the depth as it represents the low tide of the sea level at the time of formation.

Lake Strongyli (Figures 1D and 2D)

This coastal section comprises the coast in front of Lake Strongyli; in its final western part this turns to the south and ends at the Pounta shore. Three out of five beachrock generations were recorded, along with the contemporary beachrock. Two sizeable slabs of the deepest beachrock generation (I) are located 215 m off the coast, growing parallel to it for 72 m in the east and 58 m in the west, with an average width of 10 m and 14 m, respectively. They appear moderately fragmented but have not been dislocated from their original position. The seaward top and base of the western slab are at 4.30 m bmsl and 4.75 m bmsl, respectively.

At a landward distance about 40 m from beachrock (I), separated from it by a sandy strip, beachrock generation (III) runs parallel to the shoreline for 500 m. Its breadth varies from 5 m to 20 m and is slightly-to-moderately fragmented. The seaward top of beachrock generation (III) is at 2.70-3.15 m bmsl and the seaward base at 3.30-3.70 m bmsl. Located at a distance 3-5m off the coast, the younger beachrock generation (VI) is developing parallel to the coast for 480 m from the central part toward the west. It appears solid, with a width of 3-8 m, and its seaward top and base is at 0.40-0.65 m bmsl and 0.70-0.80 m bmsl, respectively.

In the swash and backwash zone of the eastern part of the contemporary shoreline, for a length of about 55 m, beachrock now appears to be cementing. Three sporadic occurrences were also found in the spray zone of the modern sandy beach. The average width of the beachrock is 5 m, with a visible trace on the beach extending to a maximum distance of 8 m from the shoreline.

Pounta-Pavlopetri (Figures 1D, 3 and 4)

At the westernmost final part of the northern coast of Vatika Bay, just opposite the island of Elafonisos, between the 'NE Islet' and Pavlopetri Island to the SW, the prehistoric settlement lies on the seabed. On the rocky Peloponnesian coast bounding the basin of the prehistoric town on the north, there are remains of an ancient quarry in the sandstone bedrock and the terrestrial part of the prehistoric cemetery, while on the north-easternmost side of the coast a channel is cut into the sandstone.

Only a limited occurrence of beachrock generation (V) was observed north of the northernmost edge of the prehistoric town. It lies just 7 m off the Peloponnesian shore and develops for 70 m parallel to it with a maximum width of 20 m. It appears highly fragmented, with most blocks having moved from their original position. In the few intact parts, the seaward base was measured at 1.50 m bmsl.

During the snorkel survey, a now submerged sandstone ridge was observed, with an average width of about 50 m, developing in a NE-SW direction for a length of 600 m, and bounding the prehistoric settlement on the east. The ridge projections from the sea are the 'NE Islet' (about +1 m) and Pavlopetri Island to the SW (+3.60 m). The submerged ridge forms an elongated reef, its upper surface at 0.60-0.80 m bmsl, with sporadic parts reaching the mean sea level. The reef has a stepped morphology, formed by marine terraces underlying and on either sides of the upper surface, from 1.50 m to 30 m wide, separated from each other by small cliffs. The depths of each marine terrace reported below represent the landward and outer seaward edges (see 'Methods' above).

On the east seaward side of the reef, two marine terraces were observed: the higher between 2.40 m and 2.80 m bmsl and the lower from 3.60 m to 4.25 m bmsl, with the seafloor being between 4.20 m and 5.10 m bmsl. On the inner west landward side of the reef, a terrace is formed between 1.50 m and 2 m bmsl with the seafloor at 2.50 m bmsl. The SW part of the reef and its projection above sea level constitutes Pavlopetri Island. Surrounding it, three marine terraces have formed, the highest between 1.80 m and 2.30 m bmsl, the intermediate between 2 m and 2.70 m bmsl, and the deepest between 3.25 m and 3.45 m bmsl. The greatest depths were measured on the seaward side, and the seafloor is at 4.65 m bmsl (Figure 4, cross-section C). The NE part of the reef and its projection above sea level constitutes the 'NE Islet'. Three marine terraces have also formed around it, the highest between 0.25 m and 0.60 m, the second between 1.30 m and 1.90 m, and the deepest between 3.40 m and 3.45 m, with the seabed being at 3.97 m bmsl (Figure 4: cross-section A). The reef section between the two underwater stepped morphologies around the two islets inclines smoothly toward the sea and ends at the seafloor (Figure 4, cross-section B). On this flattened surface, many chamber-tombs were cut into the rock (see below 'Archaeological indicators of the rsl change').

On the seaward side of the reef, east of Pavlopetri Island, a well-preserved tidal notch is incised on the sandstone bedrock and visible for a length of 40 m. Its base is at 4.60 ± 0.05 m bmsl and its opening is 0.30-0.40 m (Figures 3, 4: cross-section C, 5A, B).

Archaeological indicators of the rsl change

The largest depth recorded in 2018 within the basin between the reef and the Pounta coast that once hosted the prehistoric town of Pavlopetri and now hosts its remains is 2.70 m bmsl. The published plans of Harding *et al.* (1968), Flemming *et al.* (1973) and Henderson *et al.* (2011) clearly show that the remains do not extend beyond the isobath of 3 m. Although this depth is indicative of the rsl rise since the Early Bronze Age, it does not suffice to determine its size accurately.

The internal depth of the largest southernmost of two chamber-tombs, carved on the uppermost surface of the ridge and now submerged, is 2.70 m bmsl. An almost equivalent depth (-2.50 m) was provided by Harding *et al.* (1969), who also assigned the tombs to the Late Bronze Age, probably the Mycenaean period. This is clear evidence that, until the late 12th century BC, the sea level was at least 3 m lower than at present.

During the geomorphological snorkel survey, on the surface of the reef between the stepped morphologies of the two islets, at a distance of about 40 m south of the 'NE islet' and a short distance NE of the northernmost edge of the settlement, a large number of man-made circular holes were found. They are carved on the now submerged sandstone bedrock that slopes smoothly toward the sea. Round-shaped, 1.20-1.50 m in diameter, and of an internal depth of 0.50-0.80 m, they resemble the sixty or more chamber-tombs located NE of the prehistoric town on land between Lake Strongyli and

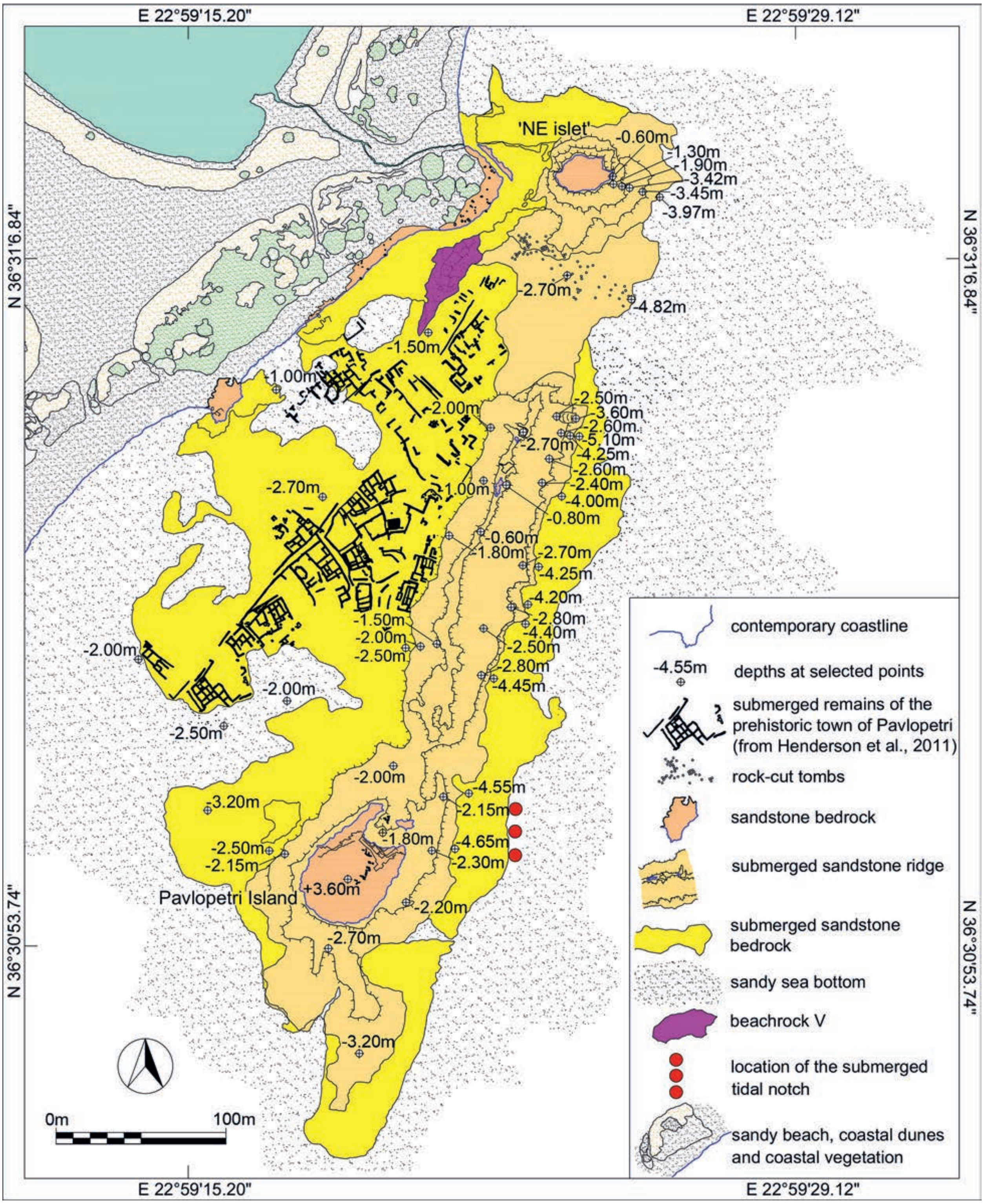

Figure 3. Schematic plan of the Pounta-Pavlopetri section. The outline of the visible submerged ruins of the prehistoric town from Henderson *et al.* (2011).

the sea, which belong to the Early Helladic period (3000-2000 BC) (Harding *et al.* 1969; Henderson *et al.* 2011; Gallou and Henderson 2012). The deepest hole (probably tomb) was found at 4.82 m bmsl (Figure 3). This depth represents a minimum depth limit when this area was occupied and in use, and therefore the coastline would have been at a greater depth than this.

Another archaeological indicator of the rsl change are the carvings found on the eastern seaward side of the

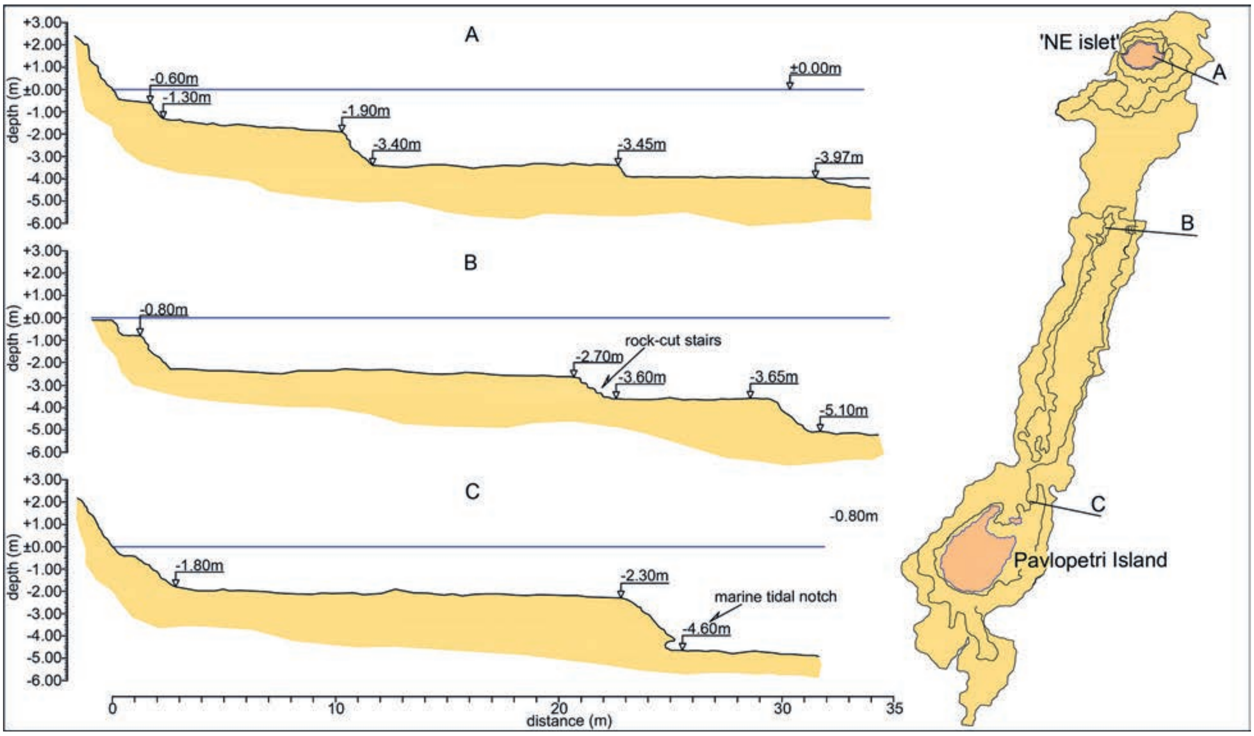

Figure 4. Plan of the ridge bounding on the east the prehistoric town and cross-sections at selected positions along it.

reef, between the depths of 2.70 m and 3.60 m bmsl. They point to a set of five stairs, which lead from the upper marine terrace at 2.50 m bmsl to the underlying terrace at 3.60 m bmsl (Figures 3, 4, 6A). Neither the submerged Early Helladic rock-cut tombs nor the rock-cut stairs were illustrated in the previously published plans of 1968, 1973 and 2011.

The extensive quarrying traces of unidentified age reported by Harding *et al.* (1969), and submerged at 1 m bmsl on the eastern side of Pavlopetri Island, only provide evidence of the rsl rise since the period that the quarry was in use.

During this survey, traces of cart tracks were found incised on the sandstone bedrock along the Peloponnesian coast of the isthmus, at a distance of 440 m west of the modern dock of Pounta (36°31'15.89"N, 22°58'28.25"E). Starting from land at the elevation of +1 m and observed for a length of 27 m up to a depth of 0.80 m bmsl, these are parallel grooves up to 0.20 m deep and 1.30 m to 1.50 m apart (Figure 6B). Two pairs of cart tracks were observed on site, beginning on land 12 m apart and heading towards the sea in a SE and SW direction, respectively. They intersect underwater 21 m off the coast, and then follow a common path toward the south. Apparently, this was the entrance to a road that served the traffic of carriages during the period that the Elafonisos Strait was fordable along its entire length, when the sea level was lower than the greatest observed depth in the strait (now up to 3.50 m in its central part, according to the depths provided by the Hellenic Navy Hydrographic Service, HNHS).

At the eastern end of the sandstone bedrock on Pounta coast, just opposite the 'NE islet', a rectangular channel was cut, with a width of 2.80 m and a visible length of 30 m— today mostly silted. It connected Lake Strongyli with the sea and was probably used to allow seawater to enter the lagoon, although it was also properly blocked to prevent the lagoon from draining into the sea (Harding *et al.* 1969). It was probably built during the Late Roman or Byzantine period and certainly later than the Early Helladic cemetery on the coast, as it has been cut through three tombs (Harding *et al.* 1969). Its current position does not provide evidence of the rsl change.

Was the prehistoric town of Pavlopetri protected from waves?

The prehistoric settlement of Pavlopetri was protected to the N, NE, and NW by the mainland, as is the case today, but it was also protected to the W throughout its occupation and later during the period when the Elafonisos Strait was still land. The only direction in which there is a significant fetch (120-150 km) is SE toward the NW coast of Crete, while in a southerly direction there is a significantly shorter fetch of 25-30 km toward the NE coast of Kythera, and an even shorter fetch in an easterly direction, not exceeding 10 km toward the west coast of the Maleas Peninsula.

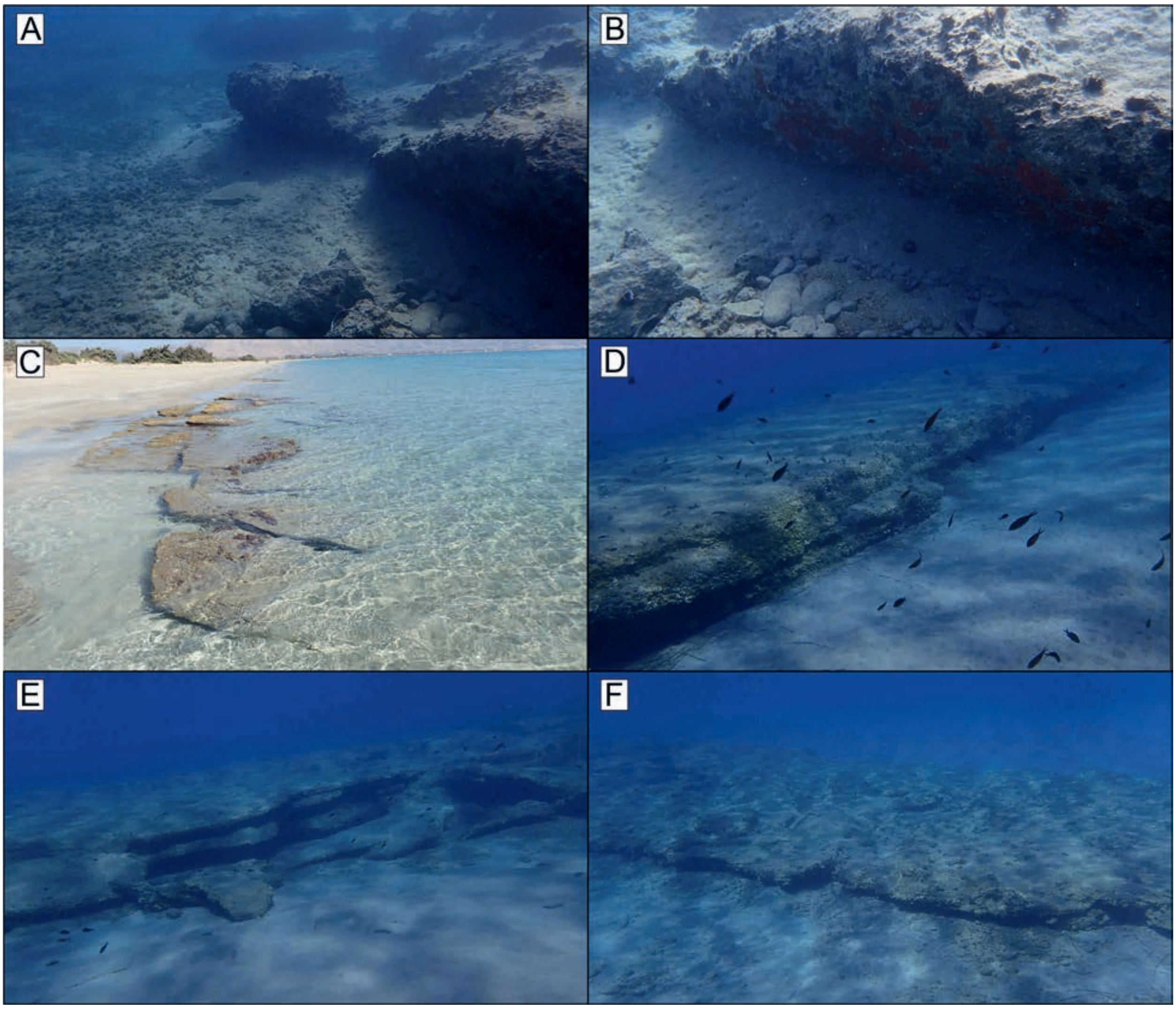

Figure 5. **(A)** Underwater view of the submerged tidal notch to the east of Pavlopetri Island at -4.60 ± 0.05 m bmsl and **(B)** detail of it. **(C)** View of the contemporary beachrock. **(D, E, F)** Underwater views of the submerged beachrock generations (V) **(photo D)**, (III) **(photo E)** and (I) **(photo F)** (photos authors).

The location and orientation of the coast of the prehistoric settlement indicate that the waves are generated by S and SE winds, which create the longest fetch. The wave features generated by E winds were also examined, given the proximity of Pavlopetri to the west coast of the Maleas Peninsula. The analyses of the time series wind data for average and high wind speed and direction along with the corresponding wind rose diagram (Figure 1D, inset) reveal that NW winds are more frequent, representing 68.5% of the total, with the strongest reaching 114 km/h. W winds represent 20.51%, with an observed maximum wind speed of 82.10 km/h. S and E winds are less frequent, with 8.66 % and 2.34%, respectively.

The wind-wave analysis for the study period of 3904 days concluded that SE winds prevailed for 35 days. Of these, there were two days with a maximum wind speed of 91.7 km/h and 83.7 km/h, which generated on the coast of the prehistoric settlement a wave height of 4.20 m and 4 m, respectively, three days with a maximum wind speed of 62.8-69.2 km/h, generating a wave height of 3-3.30 m, twelve days with a maximum wind speed of 43.5-59.5 km/h, generating a wave height of 2.20-2.90 m, and eighteen days with a maximum wind speed of 19.3-59.5 km/h, generating a wave height of 0.30-1.90 m. S and SSE winds were dominant for 106 days with a maximum speed of 20.9-70.8 km/h, generating a wave height of 0.40-1.80 m. Finally, E winds prevailed for 79 days with a maximum speed of 17.70-78.9 km/h, generating a wave height of 0.10-0.90 m.

In conclusion, the wave height very rarely (twice in a twelve year-period) exceeds 4 m, with a maximum observed wave height of 4.20 m produced by SE winds. Therefore, if the ridge that bounded the

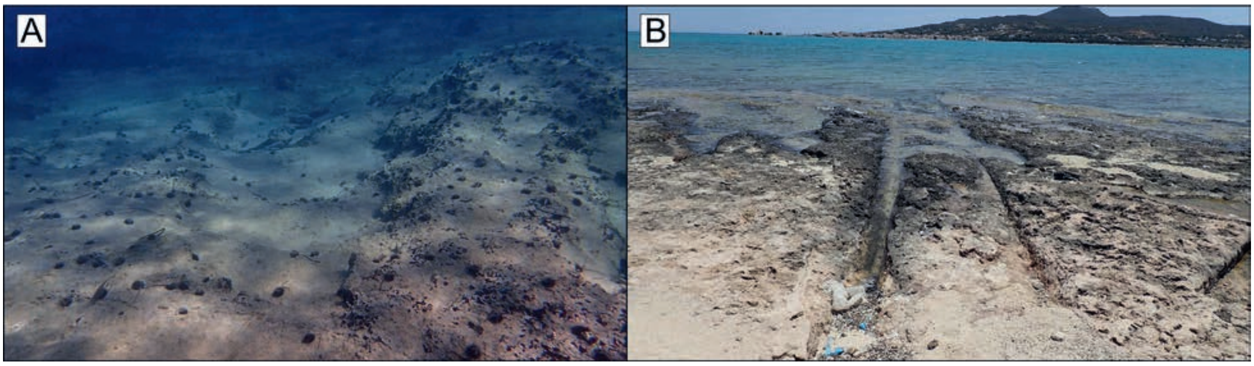

Figure 6. **(A)** Underwater view of the rock-cut stairs at the eastern seaward side of the sandstone reef. **(B)** View of the partly submerged traces of cart tracks on the Viglafia coast, consisting of two pairs of parallel grooves deeply incised on the sandstone (photos authors).

prehistoric town on the east side had a minimum equivalent elevation, then the town would have been fully protected from the waves. Given that the upper surface of the ridge is now at 0.60-0.80 m bmsl—with the exception of Pavlopetri Island (+3.60 m) and the 'NE Islet' (+2 m)—it follows that with a minimum sea level 5 m lower than at present, the town, or even its remains, would not have been affected by waves, even extreme storm waves, whatever the weather conditions.

Interpretation and Discussion

Correlation of the geomorphological indicators in Vatika Bay

Along the entire coast of Vatika Bay, five distinct beachrock generations were observed, mapped and measured, with the average depths of their seaward base at 5.00 ± 0.25 m bmsl (I), 4.45 ± 0.30 m bmsl (II), 3.60 ± 0.10 m bmsl (III), 1.55 ± 0.10 m bmsl (V), 0.80 ± 0.10 bmsl (VI), together with the contemporary beachrock (±0.00). The deepest generations (I) and (II) are developing along almost the entire coast of Vatika Bay, while generations (III), (V), (VI) and the contemporary beachrock appear to a lesser extent. All the beachrock generations distinguished along the coast of Vatika Bay from Neratzionas to the Pounta-Pavlopetri area and the respective coastline during their formation are shown in Figure 7. All depth measurements of the various beachrock generations are presented in Table 1. Depth diagrams of each beachrock generation and the combined depth diagram of all beachrock generations are shown in Figures 8A to 8F. An indicative cross-section of the various beachrock generations is illustrated in Figure 8G. Views of the contemporary and submerged beachrocks (V), (III), and (I) are shown in Figures 5C to 5F.

Comparing the depths of the distinct beachrock generations (seaward base) with those of the marine terraces (inner shoreline angle, landward edge) and the tidal notch (base), a good correlation between them can be deduced. This suggests the same sea level stands during their formation. Beachrock generation (II) at 4.45 ± 0.30 m bmsl is consistent with the tidal notch at 4.60 ± 0.05 m bmsl. The marine terrace between 3.40 m and 4.25 m matches beachrock generation (III) at 3.60 ± 0.10 bmsl. The marine terrace between 1.30 m and 1.90 m agrees with beachrock generation (V) at 1.55 ± 0.10 bmsl. The shallowest marine terrace between 0.60 m and 0.80 m bmsl matches beachrock generation (VI) at 0.80 ± 0.10 m bmsl.

Pizzaro *et al.* (2012) carried out side-scan sonar mapping, sampling, and radiocarbon dating, and used stereo imagery to create a 3D photomosaic of the beachrock formations in a very limited area between the Manganos and Neratzionas sections, of seaward length 140 m and width of 40 m out of 4 km occurrence. They reported that the beachrock bands closest to the shore are 150 m offshore at depths of 3-4 m, provided some depths for three bands (2.50-3 m, 2.60-3.50 m and 3.90-4.80 m)—without defining at which part of the formation they measured depths—and yielded four samples from these bands for preliminary dating. The conventional radiocarbon age of the deepest band is 1850 ± 90 BP (cal. age AD 480-650) while that of the intermediate band is 1520 ± 50 BP (cal. age AD 1030-1150). The shallowest and youngest beachrock band recorded radiocarbon ages older than the two deeper bands. Since these ages do not match the stratigraphic position of the bands, doubt is automatically cast over the ages of the deeper bands.

RSL change history along the eastern coast of the Peloponnese

The rsl change history along the eastern coast of the Peloponnese (Kolaiti 2019) begins in the Early Bronze Age (3500-2200 BC) with a sea level stand at 5.10 ± 0.20

Figure 7. Schematic plan of the entire coast of Vatika Bay from Neratzionas to Pounta-Pavlopetri area. All the beachrock generations and the respective coastline during their formation are distinguished. The 'NE islet', Pavlopetri Island, the submerged ridge and the submerged ruins of the prehistoric town (from Henderson *et al.* 2011) are also shown.

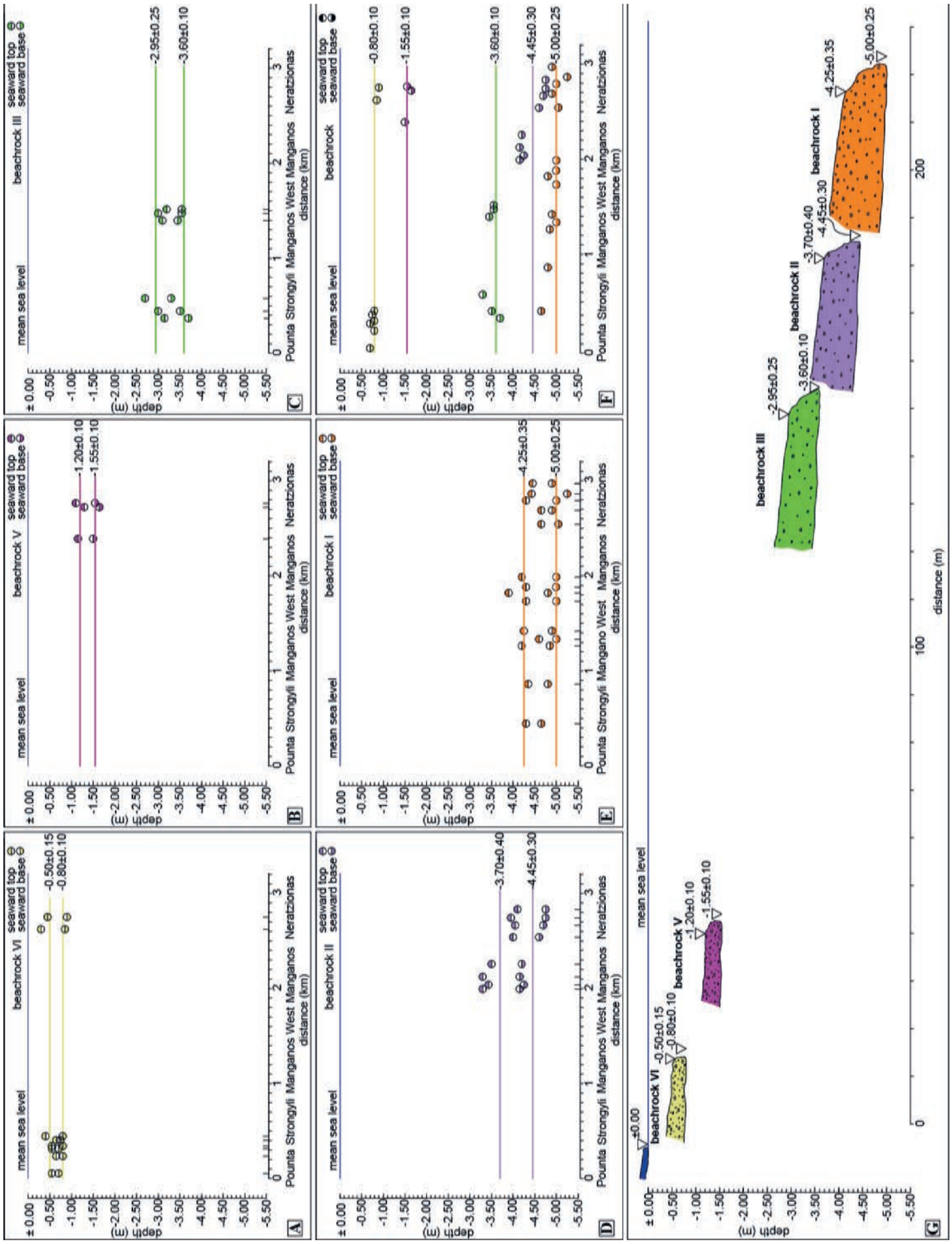

Figure 8. Depth diagrams of each beachrock generation recorded in Vatika Bay. **(A)** beachrock generation (VI). **(B)** beachrock generation (V). **(C)** beachrock generation (III), **(D)** beachrock generation (II) **(E)** beachrock generation (I), **(F)** combined depth diagram of all beachrock generations along the north coast of Vatika Bay. All depth measurements of the various beachrock generations are presented in Table 1. **(G)** Indicative cross-section of the various beachrock generations.

m bmsl (sea level I). The sea level at 4.40 ± 0.20 m bmsl (sea level II) is dated to the Late Bronze Age (1500-1190 BC) and seems to have shifted to the next sea level stand at some time between 1190 BC and 700 BC. Sea level III at 3.60 ± 0.20 m bmsl, repeatedly found to be associated with robust archaeological evidence throughout the eastern coast of the Peloponnese, ranges from the Archaic period to Late Roman times (700 BC to AD 4th or probably 6th century), thus indicating a long period of sea level stability, a period of at least 1000 or 1200 years. Sea level stand IV at 2.40 ± 0.20 m bmsl dates to after AD 13th century and seems to have been short-lived, as its succession by sea level V at 1.45 ± 0.15 m bmsl occurred at some time before the First Venetian occupation. Sea level V dates to between 1389 and *c.*1840. The next sea level stand at 0.80 ± 0.10 m bmsl (sea level VI) dates to Modern times and seems to have lasted for a few decades until the early 20th century, when the sea level rose to 0.35 ± 0.15 m bmsl (sea level VII) and then shifted to its current position. The curve of the mean rsl change during the last 5500 years for the eastern coast of the Peloponnese is illustrated in Figure 9 (red line), along with the inferred periods of the rsl stability and change (Kolaiti 2019).

Determination and dating of former sea level stands in Vatika Bay

On the basis of the geomorphological indicators of the rsl change and their correlation, five distinct sea levels can be determined for Vatika Bay: 5.00 ± 0.25 m (I), 4.50 ± 0.25 m (II), 3.60 ± 0.10 m (III), 1.50 ± 0.15 m (V) and 0.75 ± 0.10 m (VI) bmsl. The sand-gravel beach deposits found in the Manganos West section for a significant length of 300 m at a depth of 2.40 bmsl seem to have accumulated along a former shoreline and might determine a sixth sea level stand at 2.40 m bmsl. The diagram in Figure 9 depicts both the observed mean sea level stands in Vatika Bay and those along the entire eastern coast of the Peloponnese, which are remarkably consistent in terms of depth. In the case of those stands for which evidence of dating is not provided in the study area, we can safely adopt the dating of the respective sea level stands determined for the eastern Peloponnese (Kolaiti 2019) (Figure 9).

The deepest sea level stand (I) at 5.00 ± 0.25 m bmsl is determined by the depth of the seaward base of beachrock (I) at 5.00 ± 0.25, the depth of the reef at its eastern seaward side at 5.10 m, and the deepest trace of the rock-cut Early Helladic tomb at 4.82 bmsl, which certainly dates this sea level stand (I) to the Early Helladic period (3000-2000 BC, 5000 years before present). What is important, the depth and dating of this sea level stand (I), inferred from local rsl change data, is consistent with the predicted rsl 5 ka BP, which is provided by Lambeck (1995) for the Laconic Gulf . In the same diagram, the predicted rsl curve resulting from the Lambeck's (1995) glacio-hydro-isostatic model for the Laconic Gulf since 5 ka BP is also illustrated (Figure 9).

The depth of the seaward base of beachrock (II) at 4.45 ± 0.30 m and tidal notch carved on Pavlopetri Island at 4.60 ± 0.05 m bmsl determines the sea level stand (II) at 4.50 ± 0.25 m bmsl. The tomb of the Late Helladic period carved on the reef, now at a depth of 2.70 m bmsl, as well as the maximum recorded depth of 3 m in the basin of the prehistoric town, reasonably suggest a sea level lower than 3 m during the Late Bronze Age occupation of the area. Moreover, based on evidence of the entire eastern coast of the Peloponnese, the 4.50 ± 0.25 m sea level stand is robustly dated to the Late Bronze Age, between 1500 BC and 1190 BC.

Sea level (III) at 3.60 ± 0.10 m is identified by the seaward base of beachrock (III) at 3.60 ± 0.10 m, the depths of the marine terrace formed around the 'NE Islet', and the marine terrace and the rock-cut stairs on the eastern seaward side of the reef at 3.60 m bmsl. Based on strong evidence pertaining to the entire eastern coast of the Peloponnese, this falls within the range of the Archaic period to Late Roman times, i.e. from 700 BC to AD 4th or probably the 6th century.

Although not adequately documented on the coast of Vatika Bay, sea level (IV) identified on the eastern coast of the Peloponnese at 2.40 ± 0.20 m bmsl also points to a short sea level stand in Vatika Bay, which dates to after AD 13th century and until before the First Venetian occupation (AD 14th century).

The depth of the seaward base of beachrock (V) at 1.55 ± 0.10 and the marine terrace around the 'NE Islet' determine a sea level stand at 1.50 ± 0.15 m, which, based on relevant evidence pertaining to the entire eastern coast of the Peloponnese, dates to the period between the end of AD 14th century (1389) and 1840.

The sea level stand at 0.75 ± 0.05 m is determined by the depth of the seaward base of beachrock (VI) at 0.80 ± 0.05 m, the upper surface of the reef, and the uppermost marine terrace around 'NE Islet', both at 0.60-0.80 m bmsl. It dates to Modern times, after 1840 according to relevant data on the eastern coast of the Peloponnese.

The mean sea level stands observed in Vatika Bay with respect to the curve of the mean rsl change during the last 5500 years for the eastern Peloponnese is shown in Figure 9, along with the inferred periods of the rsl stability and change.

Changes in the coastal anthropogenic landscape

When the sea level was at 5.00 ± 0.25 m lower than at present (Figure 10A), Elafonisos was connected to the Peloponnesian coast by a sandy isthmus about 2.2 km wide, which protruded from the sea by 1.50 m to 4.20 m in its central part. Between the eastern end of the isthmus and the western end of the shore of Vatika Bay, on the coastal zone in front of the westernmost end of Lake Strongyli, sandstone bedrock appears. On its seaward side, an elongated ridge developed in a NE-SW direction, protruding 4.20 m above the sea with occasional local elevations (i.e. the 'NE Islet' +6 m, Pavlopetri Island +8.60 m). On the west side of the ridge towards the isthmus, a depression of the rocky bedrock (+1.80 m to +2.30 m) formed a sheltered basin for the settlement of the first inhabitants of the Early Bronze Age. On the NE side of the settlement, outside its boundaries and at a higher elevation where the bedrock sloped smoothly towards the sea, the chamber-tombs of the Early Helladic period were cut into the rock. The lowermost of these, which is now at 4.82 m bmsl, was

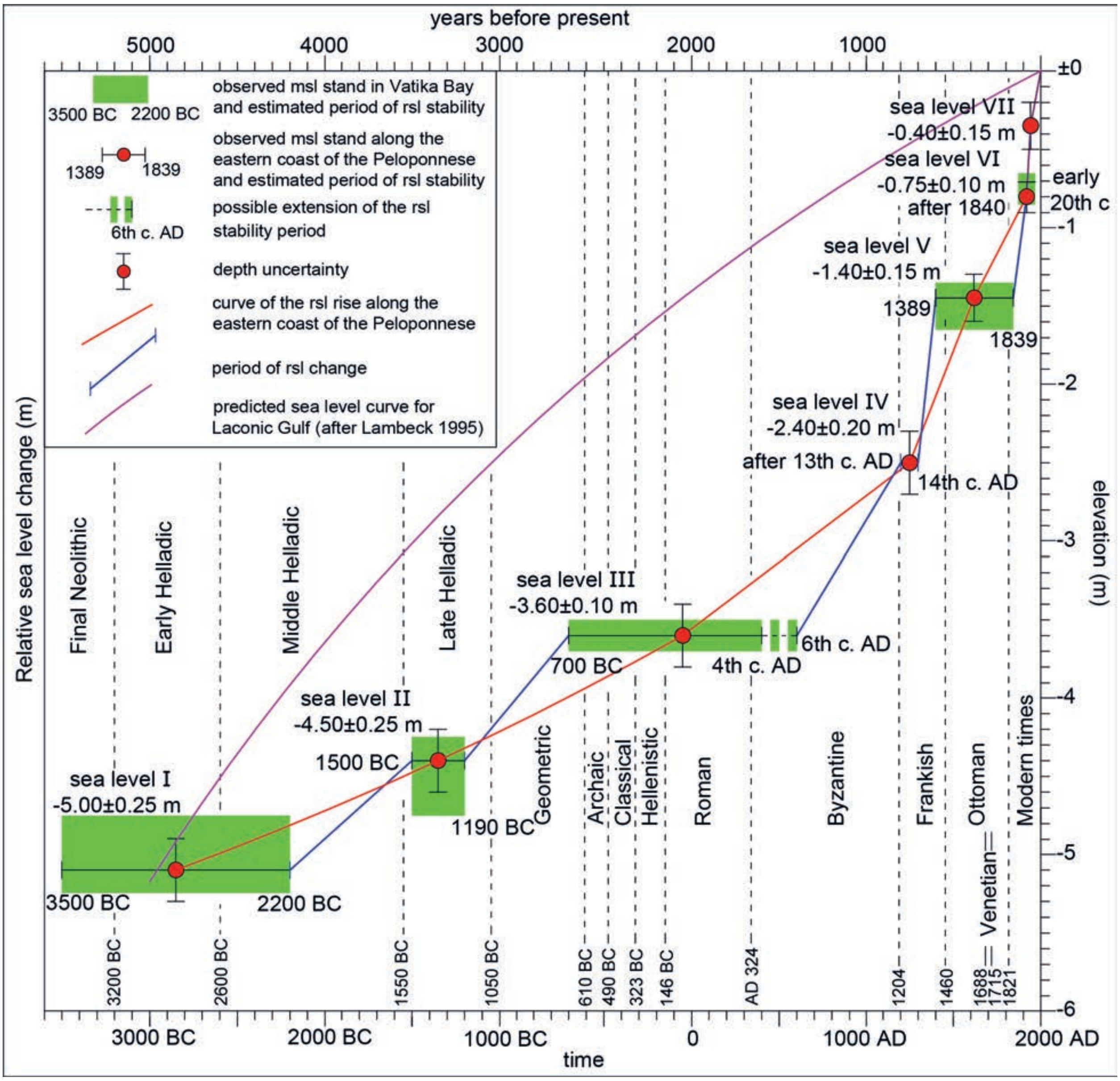

Figure 9. The mean sea level stands observed in Vatika Bay with respect to the curve of the mean rsl change during the last 5500 years for the eastern coast of the Peloponnese and the predicted rsl curve for the Laconic Gulf by Lambeck (1995). The main archaeological periods are shown. (msl: mean sea level, rsl: relative sea level)

at that time just above sea level (+0.50 m). Its position determines the boundary of the usable land area during the Early Bronze Age. At this sea level, the sandy beach deposits were cementing to form beachrock generation (I) on the coast of Vatika Bay. The small boats of that time would have been dragged onto the sandy beach of the bay NE of the settlement or SW onto the sandy beach of the isthmus (Figure 10A, right).

When the sea level was at 4.50 ± 0.25 m lower than at present (Figure 10B), Elafonisos Island was still connected to the mainland by the sandy isthmus, by now inundated on its lower western side up to about 80-100 m inland, yet still protruding from the sea by 1 m to 3.70 m in its central part. The ridge protruded from the sea at least 3.90 m with occasional local elevations (i.e. the 'NE Islet': +5.50 m, Pavlopetri Island: +8.10 m). The life of the Early Bronze Age settlement was not affected by the slight rsl rise, since it was still protected by the rocky ridge in the east. However, the coastal part of the Early Bronze Age cemetery was now inundated. Two chamber-tombs were then carved on the ridge. The internal depth of the southernmost was at an elevation of +1.80 m. Given that the tombs date to the Late Bronze Age, probably to the Mycenaean period (Harding *et al.* 1969), a sea level of 4.50 ± 0.25 m bmsl is assigned to this period. With this sea level, the tidal notch was incised on the ridge (today at 4.60 m bmsl), the beachrock

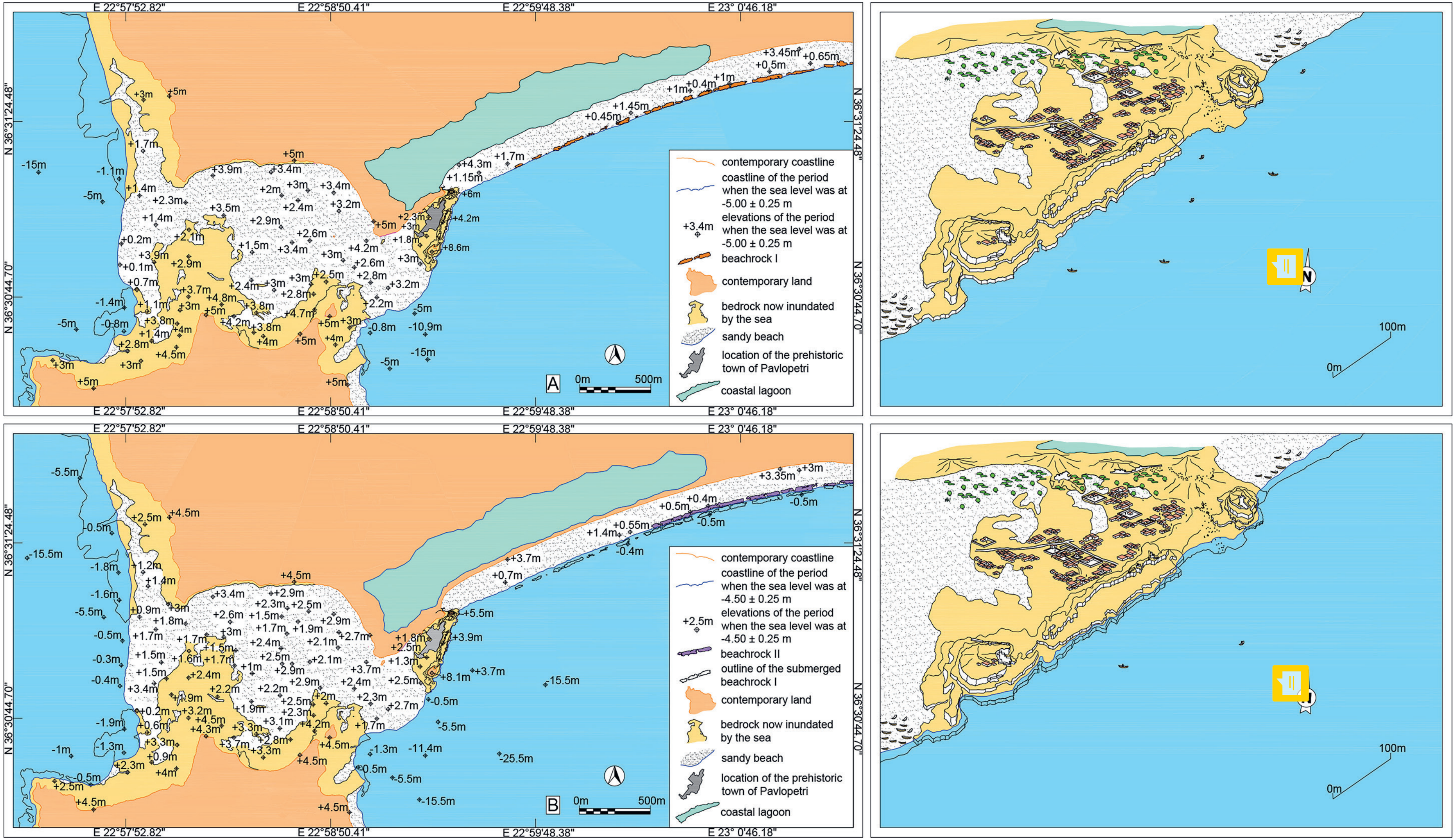

Figure 10. **(A)** Palaeogeographic reconstruction of the shoreline of Elafonisos Strait when the sea level was at 5.00 ± 0.25 m bmsl and a 3D sketch of the prehistoric town of Pavlopetri during the same period (top right). **(B)** Palaeogeographic reconstruction of the shoreline of Elafonisos Strait when the sea level was at 4.50 ± 0.25 m bmsl and a 3D sketch of the prehistoric town of Pavlopetri during the same period (right bottom).

(I) submerged, and a new beachrock generation (II) formed. The small boats of that time would have been dragged onto the sandy beach of the bay NE of the settlement or SW onto the sandy beach of the isthmus (Figure 10B, right).

The rsl rise of 1.10 m that followed shifted the sea level to 3.60 ± 0.10 m bmsl (Figure 11A), further inundating the sandy isthmus up to about 200 m inland. Yet it still protruded from the sea by 0.50 m to 2.80 m in its central part, leaving Elafonisos still connected to the mainland. The ridge protruded from the sea at least 3 m with local occasional elevations (i.e. the 'NE Islet': +4.50 m, Pavlopetri Island: +7.20 m). The Early Bronze Age cemetery was further inundated, although the Late Bronze Age tombs were not affected, since the floor of the southernmost tombs was now at +0.90 m. It was then that the set of five stairs descending to the then shoreline was probably carved on the seaward side of the ridge. At this sea level, the tidal notch and beachrock (II) were submerged, while a new beachrock generation (III) formed on the sandy beach. The boats of that time would have been dragged onto the sandy beach of the bay NE of the settlement or SW onto the sandy beach of the isthmus (Figure 11A, right). The life of the settlement could have continued despite the sea level rise, since it was still protected by the rocky ridge in the east, notwithstanding the rare SE storm waves. After all, the lack of sea defense works on the seafront of the settlement indicates that the habitants never had concerns about the risk of flooding. This sea level stand is evidenced to have lasted from the Archaic period to Late Roman times (700 BC to AD 4th or probably 6th century). Therefore, the assumption of Henderson *et al.* (2011) that the town was inundated during Roman times is open to question. Even if the town had been abandoned during this period, the reasons would have been other than sea transgression. Besides, ancient sources confirm that Elafonisos had not detached from the Peloponnese during the Classical period and in Roman times. It remained connected to the mainland as a low-lying peninsula certainly until the late AD 2nd century (Thucydides, *History of the Peloponnesian War*, VII.26; Strabo, *Geography*, 8.5.1; Pausanias, *Description of Greece*, 3.22.10).

When the sea level rose to 2.40 ± 0.20 m bmsl (Figure 11B), the rocky ridge protruded from the sea by at least 1.80 m with occasional local elevations (i.e. the 'NE Islet': +3.40 m, Pavlopetri Island: +6 m). The isthmus was further inundated leaving only a narrow causeway on its eastern side slightly protruding from the sea by 0.20 m to 1.60 m. The basin where the remains of the prehistoric town was located was partly inundated (Figure 11B, right), while the floor of the tomb carved on the ridge was flooded by sea water to an internal depth of 0.30 m. Beachrock (III) was then submerged and sand-gravel deposits accumulated along the subtidal zone of the then shore of Vatika Bay.

The next rsl rise to 1.50 ± 0.15 m occurred by the end of AD 14th century (after 1389) and caused the flooding of the isthmus with 0.70-1.30 m of water in its eastern part. Elafonisos was cut off from the Peloponnese and now became an island, while on the opposite Laconic coast, the cape of Pounta was shaping. The rocky ridge (along with the tombs on it) was entirely submerged up to a depth of 1 m, with the exception of its SW part, which now protruded from the sea by +5 m, forming Pavlopetri Island, and its elevated NE part that was still connected to the mainland (i.e. the 'NE Islet': +2.5 m). The prehistoric town that had already been abandoned and ruined was now entirely submerged to a maximum depth of 1.50 m. At this sea level, beachrock (V) formed on the eastern coast of Vatika Bay and the eastern side of Cape Pounta (Figure 12A). Therefore, the isthmus of Elafonisos was not fordable by the end of AD 14th century, having become the Elafonisos Strait. This is also attested by historical sources: (a) John Covel in his diaries of 1670-1679 (Covel 1893, as cited in Simopoulos 2007, 115-116) writes that, when English sailors from three warships anchored in Elafonisos, the crew, in search of water and supplies, travelled to the opposite shore in boats. There, people from Mani captured many of them and demanded a ransom for their return. After a meeting of the masters, a fundraiser was held to raise the amount and the Admiral sent his boat to deliver it, while another boat with a white truce flag sailed around the island. (b) W. Leake, who visited the area in 1806 (Leake 1830, as cited in Harding *et al.* 1969) wrote that the strait between Elafonisos and the mainland was 300-400 yd (= 275-365 m) and so shallow that only small boats could pass. Both reports confirm that since at least 1670/1677 Elafonisos had already detached from the Peloponnese and that the strait was not fordable without the use of boats.

The isthmus, the remains of the prehistoric town, and the ridge were further inundated when the sea level shifted to 0.75 ± 0.10 m around 1840. The NE edge of the ridge was now cut off from the mainland and the 'NE Islet' had shaped. At this sea level, beachrock (V) submerged and a new generation (VI) was formed on the coast of Vatika Bay (Figure 12A).

The recent rsl rise of 0.75 m shifted the sea level to its current stand and the remains of a once thriving town lying on the sandy bottom were further covered by the sea (Figure 12B). In the early 20th century, Negris (1904), who showed great interest in the submersion of the Greek coast and the consequential sea level changes, reported the submerged ruins of a town built on the isthmus that connected Elafonisos with the Peloponnese, of which only two islets now protrude

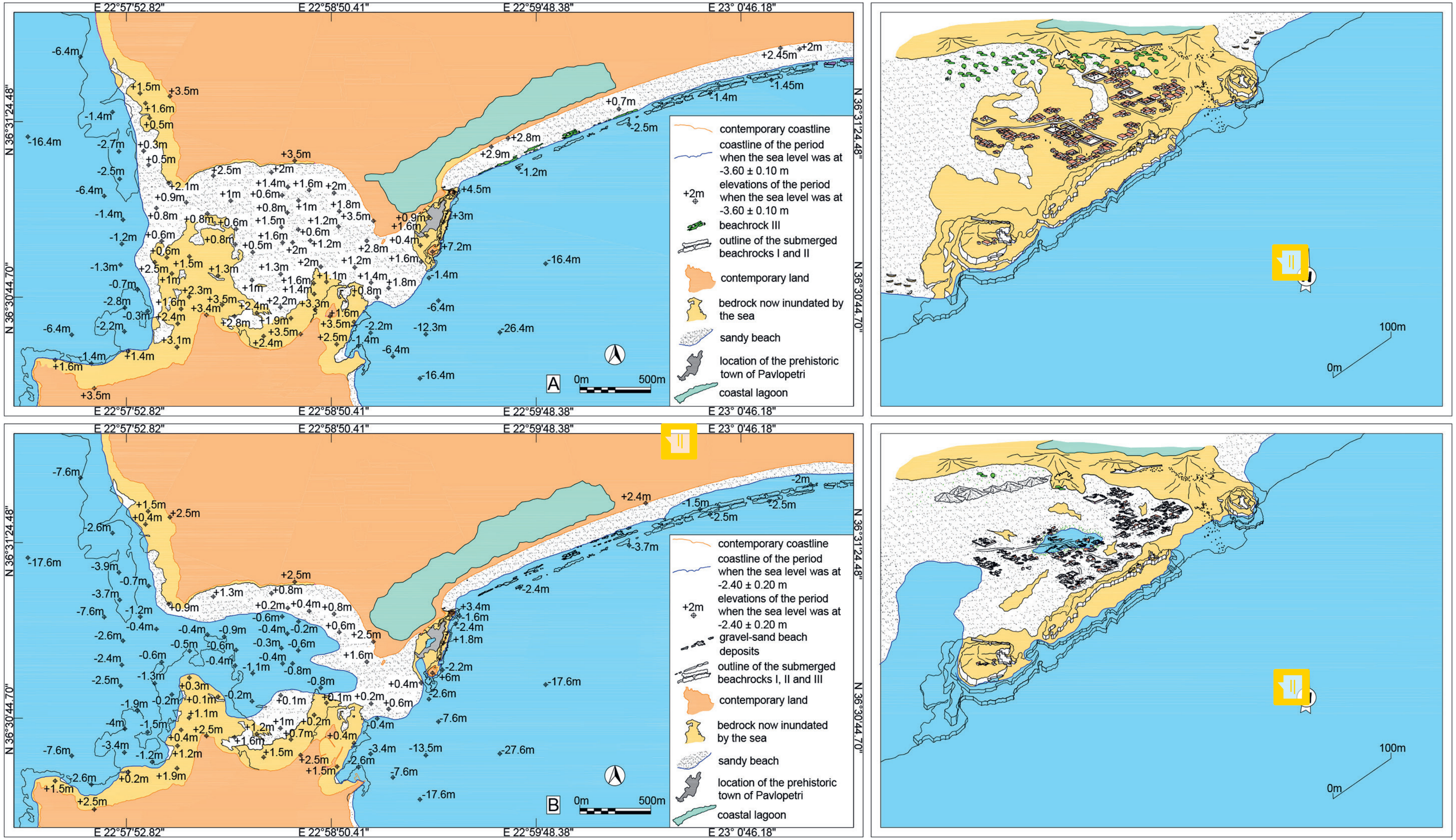

Figure 11. **(A)** Palaeogeographic reconstruction of the shoreline of Elafonisos Strait when the sea level was at 3.60 ± 0.10 m bmsl and a 3D sketch of the prehistoric town of Pavlopetri during the same period (top right). **(B)** Palaeogeographic reconstruction of the shoreline of Elafonisos Strait when the sea level was at 2.40 ± 0.10 m bmsl and a 3D sketch of the prehistoric town of Pavlopetri during the same period (bottom right).

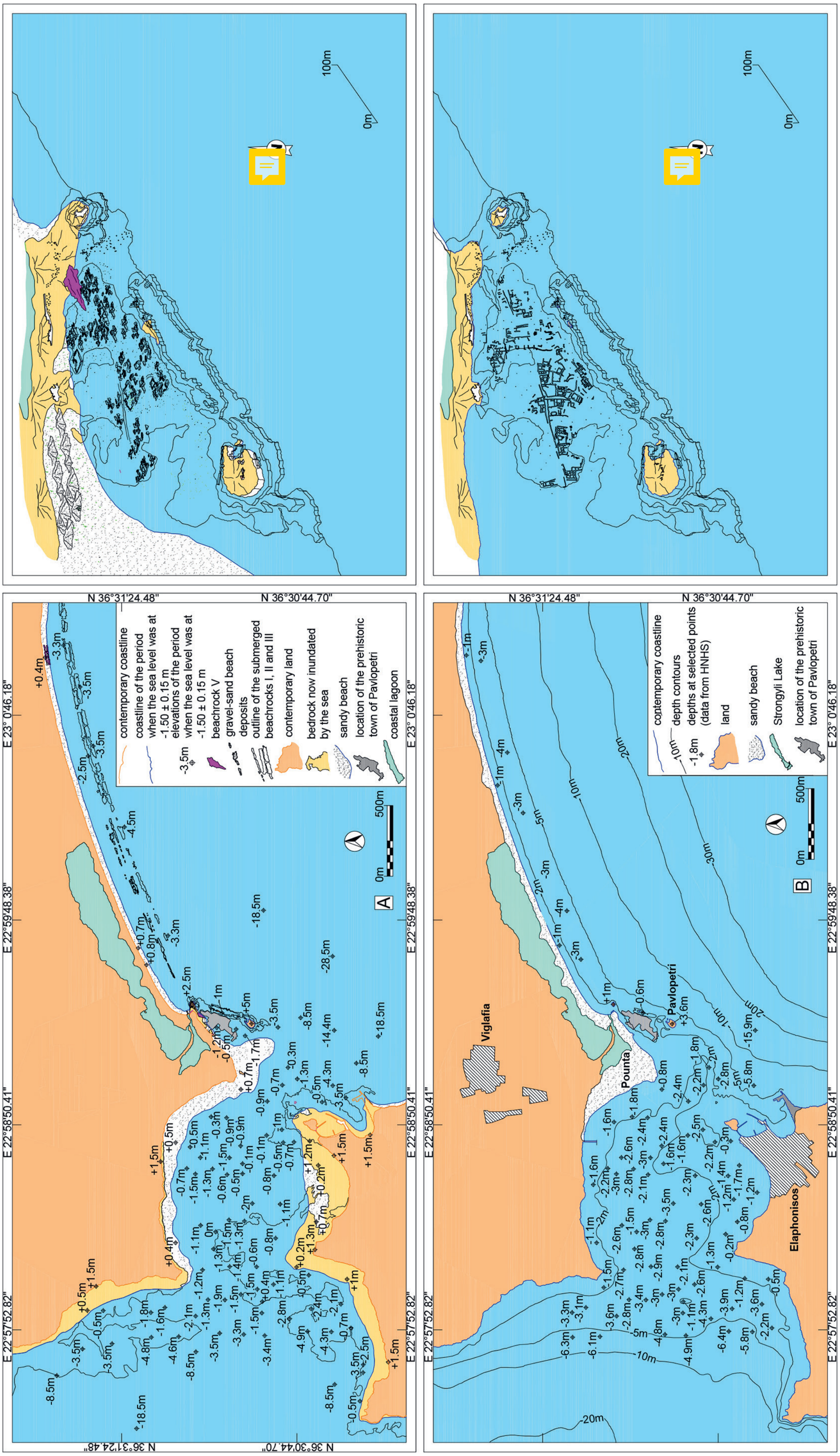

Figure 12. **(A)** Palaeogeographic reconstruction of the shoreline of Elafonisos Strait when the sea level was at 1.50 ± 0.15 m bmsl and a 3D sketch of the prehistoric town of Pavlopetri during the same period (right top). **(B)** The contemporary shoreline of Elafonisos Strait and a 3D sketch of the prehistoric town of Pavlopetri as it now stands (bottom right).

from the sea. In this way, the prehistoric town of Pavlopetri emerges from the shallows into the light.

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