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Palaeogeography of Ancient Lasaia (SE Crete, Greece)

The Evolution of a Harbour from the Minoan Palatial Period to Roman Times

Paléogéographie de Lasaia l'antique (Crète du sud-est, Grèce). L'évolution d'un port de la période palatiale minoenne à l'époque romaine

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Abstracts

English Français

The remains of the Hellenistic-Roman harbour-town of Lasaia are situated in southeastern Crete on a headland at the NE end of the bay of Kaloi Limenes, while at a short distance from the shore lies the island of Traphos. The application of a geoarchaeological method allowed us to reconstruct the palaeogeography of the coast and track the evolution of the ancient harbour of Lasaia from the Minoan palatial period to Hellenistic-Roman times to the 17th century AD.

The palaeogeography of the seafront of ancient Lasaia followed the relative sea level changes that occurred during the last 4,000 years along the coast of central and eastern Crete: from a tied island connected to the mainland by a strip of land when the sea level was at 4.15 ± 0.30 m between ca. 1900 BC and ca. 1600 BC, and 2.50 ± 0.20 m bmsl between ca. 1600 BC and ca. 1200 BC, to a low promontory jutting out into the sea within a short distance from the coast of Traphos when the sea level was at 1.20 ± 0.10 m bmsl between ca. 1200 BC and AD 1604, and finally to a narrow shore opposite the island, when the sea level rose to 0.55 ± 0.05 m bmsl during the AD 1604 earthquake, which remained there for a significant period of time within the last 400 years.

During the Minoan palatial period, an artificial outer breakwater at the SW end of Traphos Island appears to have formed a protected harbour basin. In Hellenistic-Roman times, the outer breakwater had been submerged and an inner breakwater was constructed, leaving a channel between it and the island that allowed mariners to pass from the western to the eastern basin depending on the weather. In the early 17th c., the island was isolated from the mainland and provided shelter for Cretan refugees.

Les vestiges de la ville portuaire antique de Lasaia sont situés dans le sud-est de la Crète sur un promontoire à l'extrémité nord-est de la baie de Kaloi Limenes, à proximité de l'île de Traphos. Nous avons pu reconstruire la paléogéographie de la côte et reconstituer l'évolution de l'ancien port de Lasaia de la période minoenne jusqu'au 17e siècle après J.-C. La paléogéographie du front de mer a suivi les changements relatifs du niveau de la mer qui se sont produits au cours des 4 000 dernières années. Le niveau de la mer était à -4,15 ± 0,30 m vers 1900-1600 avant J.-C., -2,50 ± 0,20 m vers 1600-1200 ans avant J.-C., -1,20 ± 0,10 m entre vers 1200 av. J.-C. et 1604 après J.-C., et enfin vers -0,55 ± 0,05 m lors du tremblement de terre de 1604 après J.-C. Pendant la période minoenne, un brise-lames à l'extrémité sud-ouest de l'île Traphos semble avoir protégé un bassin portuaire. À l'époque hellénistique et romaine, le brise-lames a été submergé et un deuxième brise-lames intérieur a été construit, permettant la circulation des navires du bassin ouest au bassin oriental en fonction de la météorologie marine. Au début du XVIIe siècle, l'île était finalement séparée du continent, offrant un abri à des réfugiés crétois.

Index terms

Mots-clés : Lasaia antique ; Crète ; Grèce ; port minoen ; Port hellénistique-romain ; changement relatif du niveau de la mer ; paléogéographie

Keywords : Ancient Lasaia; Crete; Greece; Minoan harbour; Hellenistic-Roman harbour; relative sea level change; palaeogeography

Full text

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Introduction

1 The Kaloi Limenes Bay ('Fair Havens'), sheltered from the northern and western gales, lies below the southern foothills of the Asterousia mountain range, between the ancient town of Lebena (now Lendas) and the stormy coast of Cape Lithino. It would have been known to Minoan mariners heading towards or sailing from the harbour-town of Minoan Kommos "in the great days of Minoan sea dominion" (Evans, 1928, p. 85) (Fig. 1).

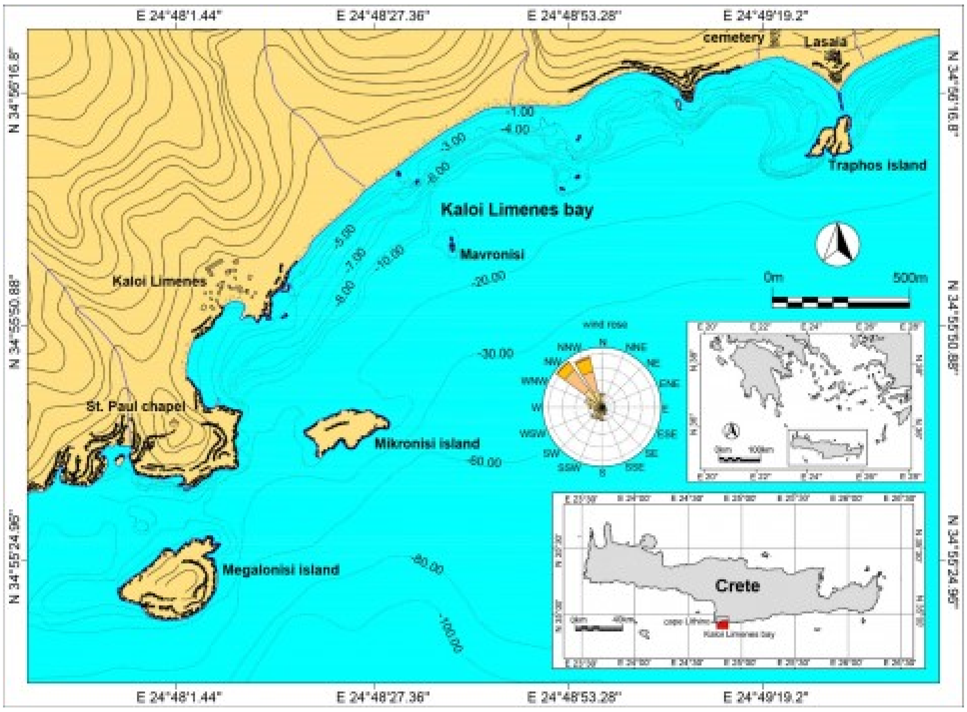
Fig. 1 - Map of the southern coast of central Crete

Place and location names as mentioned in the text

Source: Evans, 1928

2 The very location of harbours and anchorages on the southernmost coast of Crete compelled seafarers to find alternative, well sheltered places to the east and the west (Evans 1928). Shelter from most points of the compass is provided by the offshore islands of Megalonisi, Mikronisi and Traphos, and by the high and steep cliff running towards the Lithino headland at the southernmost tip of the island (Figs. 1, 2). Flat areas and low slopes immediately surround the steep coastline on the landside. Furthermore, at all times, the barrier formed by the coastline should offer effective protection from the NW strong winds descending from the highlands of Mount Ida. However, the coast is exposed to eastern gales, although in such cases small vessels could still anchor, directly protected by the small islands (Evans, 1928) (Figs. 1, 2).

Fig. 2 - Location map of the bay of Kaloi Limenes and site wind rose diagram

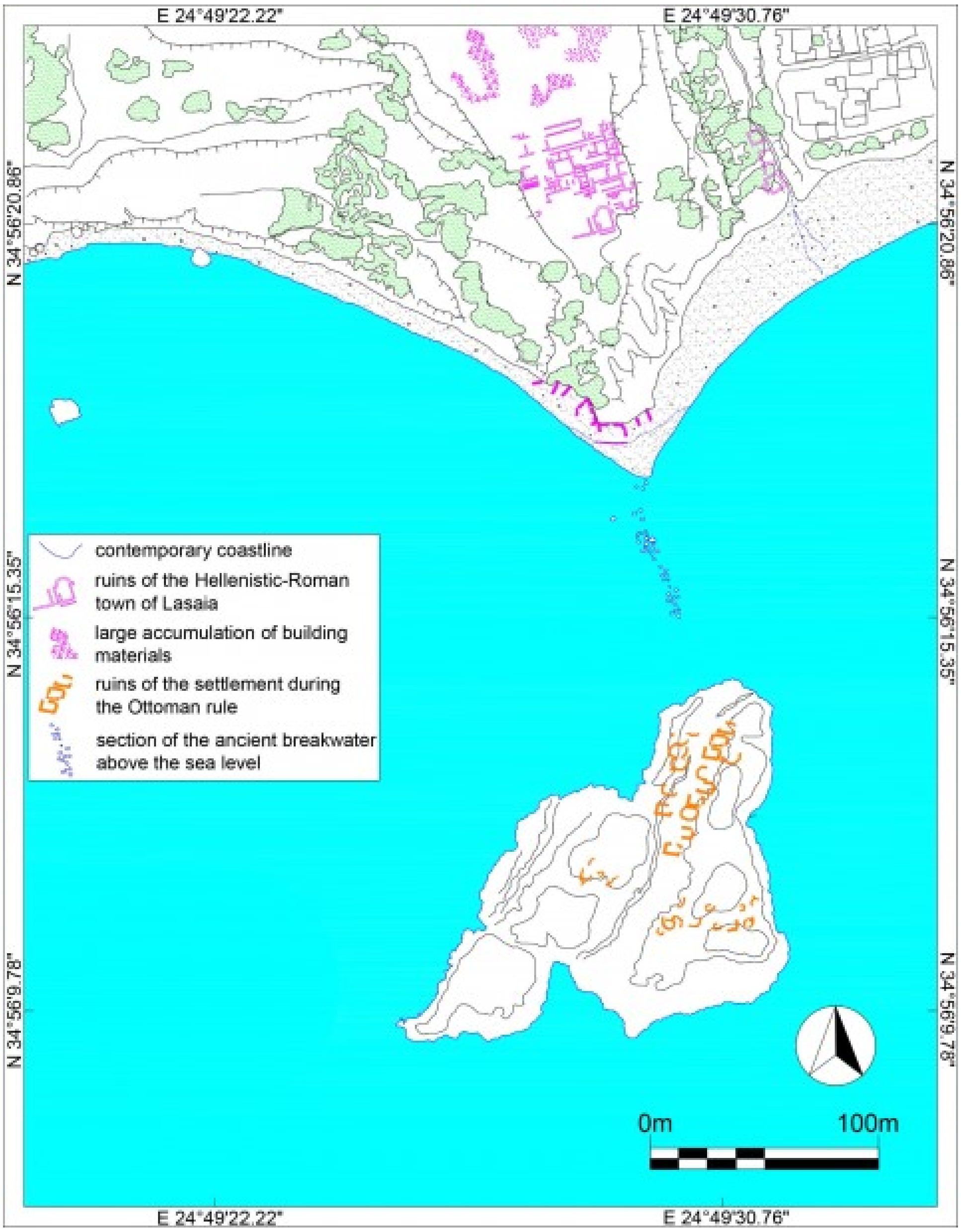


Isobaths in metres

Credit: Authors

3 At the NNE end of the bay, behind the steep cliff, on the ridge that follows an (imaginary) rectilinear trajectory towards the island of Traphos, lie the ruins of the ancient town of Lasaia (Figs. 1, 2, 3, 4, 5). Epigraphic evidence suggests that Lasaia had become a dependent *polis* of Gortyn by the late 2nd c. BC (Chaniotis, 2000). Lasaia flourished during Roman times, serving as one of Gortyna's harbours. The town had a Roman coin assigned to it as *'Thalassea'* (Spratt, 1865) or *'Thalassa'* or *'Alasa'* and elsewhere as *'Alas'* (Vassilakis, 2000), which underlines its importance as a hub for seafaring.

Fig. 3 - Ancient Lasaia



Plan of the seafront as it now stands

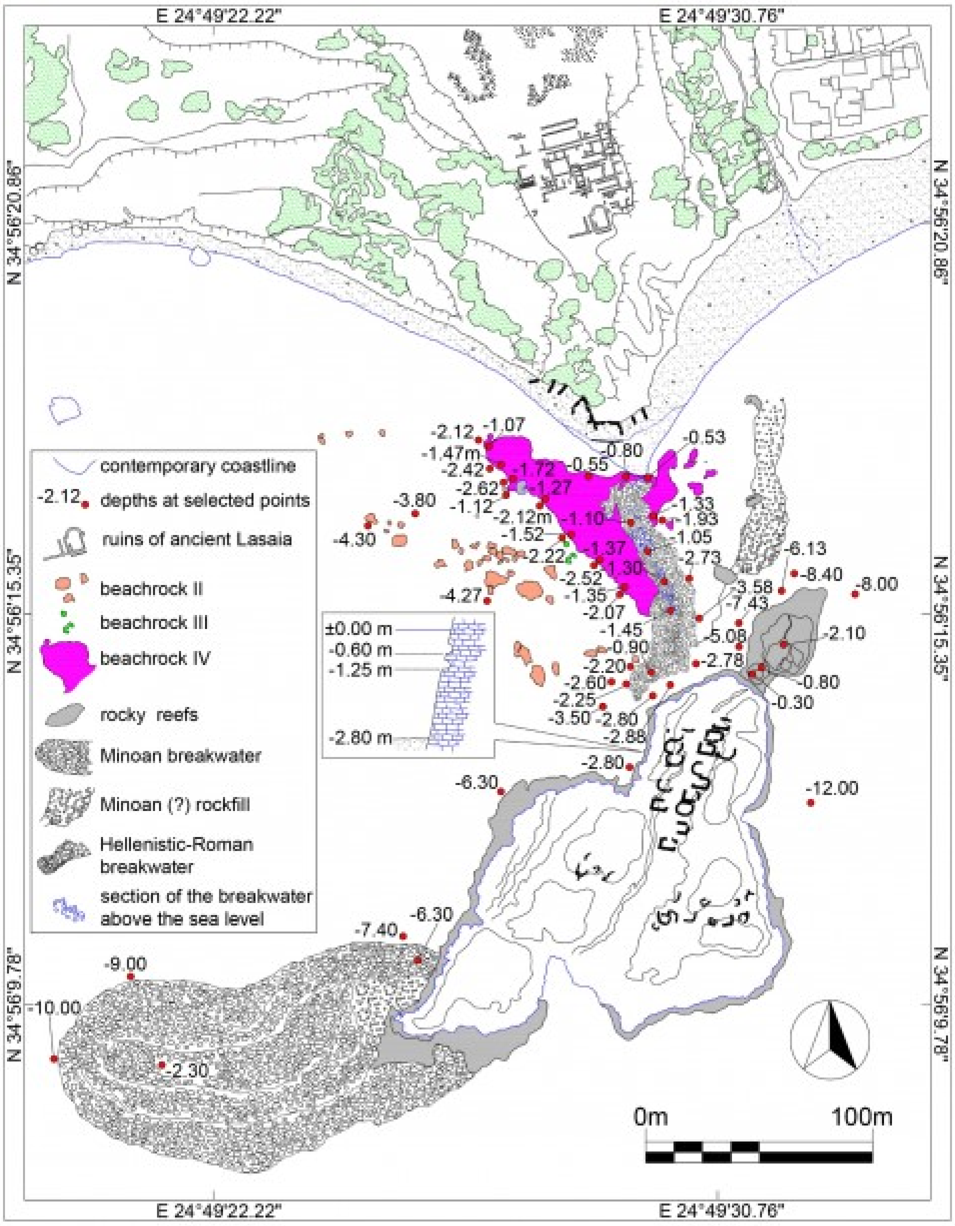
Credit: Authors

Fig. 4 - Ancient Lasaia and the island of Traphos

Lithographic print depicting the bay of Kaloi Limenes

Source : Spratt, 1865

Fig. 5 - **Detailed mapping of the submerged geomorphological and archaeological sea level indicators with depths below mean sea level (bmsl) in metres**



Credit: Authors

4 In AD 59, the ship carrying on St. Paul the Apostle on his journey to Rome, experiencing tough sailing conditions off the coast of Crete in the November storms, approached the bay of Kaloi Limenes. *"We moved along the coast with difficulty and came to a place called Fair Havens, near the town of Lasea"* (Acts 27.8). Yet, the harbour of Kaloi Limenes ultimately proved unsuitable for waiting out the winter, and it was decided they would make for Phoenix, a harbour better suited to their purpose. However, on their way, they were unable to cope with the extremely strong north-easterly wind blowing off the land, and *"were driven along"* (Acts 27.12-27.15).

5 In the mid-19th c., between 1851 and 1853, Thomas Spratt travelled around Crete. He described Kaloi Limenes as an anchorage open to the east and southeast, and safe only in summer, suggesting that its name (Fair Havens) could be attributed to its sheltered position in comparison with other more exposed locations on the southern coast of Crete (Spratt, 1865). It was here that he came across the ruins of ancient Lasaia and an ancient causeway, stretching towards Traphos from the mainland but ultimately unconnected to it, with a passage allowing craft to transfer to either side of the bay depending on wind and sea conditions (Fig. 4). On the island, he also discovered many temporary residences of the Cretan Greeks in the area who had sought shelter there during the revolution for independence, and, close to shore on the mainland, a considerable chunk of a Roman brick wall, which he interpreted as "*part of a sea defence or facing to support the embankment there"* (Spratt, 1865, p. 8).

6 Some 70 years later, in 1924, Sir Arthur Evans arrived at the deserted beach of the bay

of Kaloi Limenes (Fig. 1). Much impressed by the absence of Minoan relics, and the abundance of remains of Roman amphorae, he commented that the entrepreneurial folk of Lasaia must have organised wine bars by the harbour, providing bountiful entertainment for the crew of St. Paul's ship (Evans, 1928, p. 85).

7 Archaeological excavations in ancient Lasaia have never been carried out, with the exception of a systematic survey conducted by the University of Bristol in 1971 over a large area from Ayiofaraggo to Lasaia and to Chrisostomos further to the east. The remains of the Hellenistic-Roman town of Lasaia were traced and, along with the harbour installations (the breakwater and the warehouses on the shore), presented in two plans (Blackman and Branigan, 1975, p. 29, 31). Inter alia, on the western side of the breakwater, they observed a slightly submerged slab of beachrock, and concluded that, since antiquity, the sea level had risen only so much as to erode the buildings on the shore, but that this had been insufficient to cover the breakwater fully (Blackman and Branigan, 1975). Blanc (1958), Dermitzakis (1973), and Flemming and Pirazzoli (1981) adopted this view and suggested that the sea level has remained stable since antiquity and the coastal morphology relatively unchanged over the last 2000 years. After a detailed survey of the harbour installations of ancient Lasaia and on the basis of geomorphological features along the coast of the mainland and the island of Traphos, Mourtzas (1990) and Mourtzas and Marinos (1994) concluded that during the Hellenistic-Roman period the sea level was 1 m lower than at present.

8 Geoarchaeological research and study of ancient ports and anchorages in the Mediterranean area allow us to better understand the way in which societies are transformed and adapt to changing coastal environments (Marriner et al., 2016). Analysis of sediment records and AMS radiocarbon dates (e.g. Kampouroglou, 1989; Pirazzoli *et al.*, 1992; Morhange *et al.*, 2001; Kraft *et al.*, 2003; Marriner *et al.,* 2008; Pavlopoulos *et al.,* 2010; Brückner *et al.,* 2017; Carayon *et al.,* 2011; Hadler *et al.,* 2013; Stock *et al.,* 2013; Goiran *et al.,* 2014; Flaux *et al.,* 2017; Giaime *et al.,* 2017; Faisse *et al.,* 2018; Karkani *et al.,* 2018), and archaeological (e.g. Knoblauch, 1969; Scranton *et al.,* 1978; Hadjidaki, 1988; Galili *et al.,* 2002; Shaw, 2006) and geophysical (e.g. Boyce *et al.,* 2009; Keay *et al.,* 2009; Dao, 2011; Koster *et al.,* 2011; Papatheodorou *et al.,* 2014) surveys are the most common methods for the reconstruction of ancient harbour environments.

9 In this paper, as well as in a series of relevant publications on harbour morphologies and maritime installations of the prehistoric and historic periods along the coast of Crete and the entire Aegean (Mourtzas, 1988, 2010, 2012c; Mourtzas and Kolaiti, 2013, 2017a, c, 2020; Mourtzas *et al.,* 2016; Kolaiti and Mourtzas, 2016, 2020; Kolaiti *et al.,* 2018; Kolaiti, 2019), we attempt to explain the interaction between human coastal activity and the Late Holocene sea level changes, as a result of the complex glacio-hydro-isostatic impacts and vertical tectonics on the sea-land interface. Coastal features, i.e. marine tidal notches and beachrock formations, allow us to define past sea levels, and precise archaeological indicators found and recorded in the narrow and wider area (Mourtzas, 2012a, b; Mourtzas and Kolaiti, 2020; Mourtzas *et al.,* 2016) allow us to date the inferred sea levels. The palaeogeographic reconstruction of the seafront of ancient Lasaia is based on the determination of the respective sea levels and the measurement of depths of the current position of the ancient harbour installations. Finally, we demonstrate how the communities which settled in Lasaia during the Minoan and Hellenistic-Roman periods adapted the harbour installations to each specific sea level stand, and that the site was only abandoned when the sea level rise rendered the coastal morphology unfavourable for mooring and anchoring. Additionally, an important underwater find – the outer rubble mound breakwater – is presented for the first time. Its age, as inferred from the dating of the sea level during the period it was in use, reveals a unique Minoan maritime construction. It is the first Minoan harbour to be reported on the southeast coast of Crete, thus providing new evidence on the ancient seafaring and sea routes in the Aegean and, consequently, the Eastern Mediterranean.

1 - Materials and methods

10 An underwater snorkeling geological survey along the seafront of ancient Lasaia revealed many geomorphological indicators of the past sea levels, i.e. marine tidal notches and beachrocks, which were mapped using satellite images (Google Earth Pro) and high-resolution orthophotos at a scale of 1:500 (Ktimatologio S.A.). During the underwater snorkelling survey, their features were recorded and depths at selected points were measured (Fig. 5). All measurements of depths were collected during calm sea conditions using mechanical methods (measuring tape and invar rod) and were repeated in three different survey periods (in May 1987, in July 1989 and update of depth measurements in August 2014). 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 surveys with respect to mean sea level, using tidal data from the Hellenic Navy Hydrographic Service for the closest tide-gauge station of Ierapetra. The effect of atmospheric pressure on the sea level was corrected using the meteorological data for the site at the time of surveys (https://www.meteo.gr/). Therefore, all depths reported herein correspond to depths below mean sea level (bmsl).

11 Marine tidal notches are deep undercuts in rocky, mainly carbonate, cliffs. They are formed in the intertidal zone during a period of relative sea level (rsl) stability through a complex biological, physicochemical and mechanical erosional process. The mean sea level is slightly below or at the same elevation as the notch base, which statistically during much of the tidal pattern is submerged and only slightly protrudes from the mean low water. The inward depth depends on the duration of the rsl stability period, with maximum depth at mean high water (e.g. Carobene, 1972, 2015; Higgins, 1980; Pirazzoli, 1986b; Kelletat, 1997, 2005; Furlani *et al.*, 2011; Antonioli *et al.*, 2015; Kolaiti, 2019).

12 Beachrocks are formed by the cementation of coastal sediments, including anthropogenic deposits, during periods of rsl stability (e.g. Hopley 1986; Strasser *et al.*, 1989; Bernier *et al.*, 1997; Plomaritis, 1999; Turner, 2005; Vousdoukas *et al.*, 2007; Erginal and Öztürk, 2012; Mauz *et al.*, 2015; Avcioğlu *et al.*, 2016). Cementation takes place in the coastal zone that is bounded at the seaward end by the mean low water (i.e. the lowermost limit of the intertidal zone) and at the landward end by the uppermost limit of the swash and backwash zone (e.g. Vousdoukas *et al.*, 2007; Desruelles *et al.*, 2009; Vacchi, 2012; Mauz *et al.*, 2015). 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; Vacchi, 2012; Mauz *et al.*, 2015). The loose, unconsolidated, sandy/sandy-gravelly sediments laid on the sea bottom between two different beachrock generations represent a period of rsl change (e.g. Desruelles *et al.*, 2009). Fossils, organic material or archaeological remains embedded in a beachrock are a *'terminus post quem'* for the beachrock formation, postdating the embedded material (Kolaiti, 2019).

13 The intertidal diagenetic environment of beachrocks has been identified on the adjacent coast of Messara (Gifford and Reese, 1995; Neumeier, 1998), and in other coastal locations of Crete, e.g. Ierapetra, SE Crete (Dermitzakis and Theodoropoulos, 1975), Damnoni, SW Crete (Neumeier *et al.*, 2000), Platanias, NW Crete (Petropoulos *et al.*, 2016).

14 The depths of the various beachrock generations were measured following the method suggested by Kolaiti (2019). During the underwater snorkeling survey, depths at 18 selected points of the beachrock generations were obtained, covering a length of 104 m (Fig. 5). The depth of the base and top of the seaward end of each beachrock generation was measured by mechanical methods using measuring tape and invar rod. The average depth of repeated measurements in the same beachrock generation, after correction for tide and pressure, was used in the analysis and interpretation of data. 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 (Kolaiti, 2019), was used. Convincing evidence in the study area is the coincidence of the depth of the base of the marine notch at 1.25 m bmsl with the depth of the seaward base of the younger beachrock generation (IV) at 1.25 ± 0.05 m bmsl, thus clearly indicating that both were formed during the same

former sea level.

15 The ancient harbour installations were mapped using satellite images (Google Earth Pro) and high-resolution orthophotos at a scale of 1:500 (Ktimatologio S.A.). During the underwater snorkelling survey, depths were obtained at 20 selected points of the ancient structures related to the former sea levels (Fig. 5). Based on robust evidence of maritime constructions and harbour installations that were partially built below sea level throughout the microtidal Aegean Sea at some point during an extensive period from the Final Neolithic (4500 BC) to Modern times (19th c. AD), a mean elevation of the top surface of a dock, jetty or breakwater of 0.60 ± 0.30 m above the mean sea level during the period it was in use is suggested (e.g. Auriemma and Solinas, 2009; Mourtzas *et al.*, 2016; Benjamin *et al.*, 2017; Seeliger *et al.*, 2017; Kolaiti, 2019). The submerged remains of buildings and other coastal structures (e.g. tanks, walls etc.) that were constructed on land and their use is not directly connected with a former sea level (i.e. fishtanks), provide only evidence of the rsl rise in a particular coast but they do not determine the precise amount of it. If the archaeological age of the ancient remains is known, then they are a *'terminus post quem'* for the rsl change that certainly occured after their construction (e.g. Benjamin *et al.*, 2017; Kolaiti, 2019).

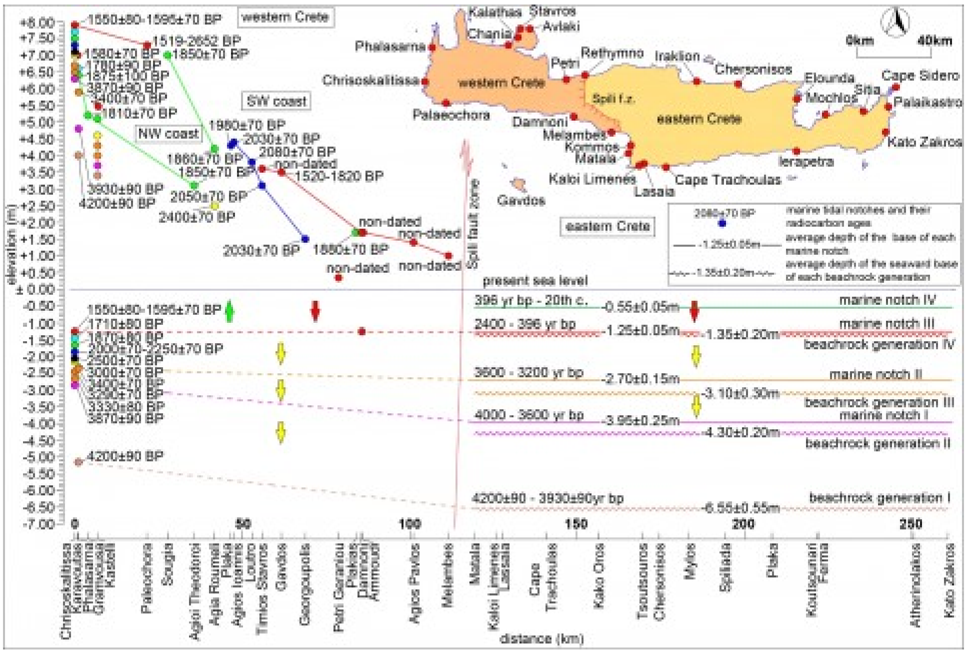
2 - Relative sea level changes along the coast of central and eastern Crete

16 The Late Holocene history of the rsl change along the coast of Crete began 4.200 ± 90 years ago (Lamporel *et al.*, 1979; Pirazzoli *et al.*, 1982; Mourtzas *et al.*, 2016), with the sea level 5.15 m lower than at present (Figs. 6, 7). On the Phalasarna coast (westernmost Crete), a marine notch formed that is today uplifted at +4 m above mean sea level (amsl). On the eastern coast of Crete, this sea level formed the earliest beachrock generation on the coast of Ierapetra (SE Crete) and Palaikastro (easternmost tip of Crete) and in the bay of Sitia (NE Crete), all today submerged at 6.55 ± 0.55 m bmsl (Mourtzas *et al.*, 2016). This indicates that the eastern part of Crete has sunk by 1.40 m more than the western part (Figs. 6, 7).

17 A paroxysmal subsidence event followed that led to the sinking of the entire island by 2.30 to 2.60 m (Figs. 6, 7). On the Chrysoskalitissa coast (westernmost part), a marine notch formed during this sea level at 2.90 m bmsl, presently uplifted at +6.30 m amsl and dated to 3870 ± 90 BP (Lamporel *et al.*, 1979; Pirazzoli *et al.*, 1982). On the eastern coast, a marine notch presently submerged at 3.95 ± 0.25 m bmsl and the respective beachrock generation at 4.30 ± 0.20 m bmsl have been dated to between 3900 and 3600 years before present, on the basis of archaeological sea level indicators (Mourtzas *et al.*, 2016). The 1.10 m-difference in elevation between the geomorphological sea level indicators of the western and eastern part of the island is indicative of a higher subsidence rate of the eastern part during this period (Figs. 6, 7). In the eastern part of the island, this sea level stand remained stable for about 300 years, and its change to the next stand coincides with the wider neotectonic upheavals in the area of the South Aegean that accompanied the strong eruption of the Thera volcano around 1600 BC (for discussion of the date of eruption see e.g. McCoy and Heiken, 2000; Dimopoulou-Rethemiotaki, 2004; Sakellarakis, 2009; Hardman, 2009; Papadopoulos, 2011; Soles *et al.*, 2017; Macdonald, 2017; Mourtzas and Kolaiti, 2017b). At the same time as the collapse of the Minoan Protopalatial period around 1600 BC, there was an abrupt change in sea level, which is dated by archaeological indicators (Fig. 6): In the bay of Kato Zakros, this change is evidenced by the brackish groundwater rise in the remains of the building, destroyed in the mature LM IA, on which the LM IB palace was constructed, and also the partial submersion of the natural harbour morphology of the bay (Mourtzas and Kolaiti, 2017b). On the coast of Minoan Mochlos, the strip of land that connected the islet with the mainland significantly narrowed after 1600 (Mourtzas *et al.*, 2016). Moreover, the islet that offered protection from the NW winds and favoured the mooring and anchoring in the great naval establishment of Minoan Kommos was significantly reduced (Mourtzas

and Kolaiti, 2020).

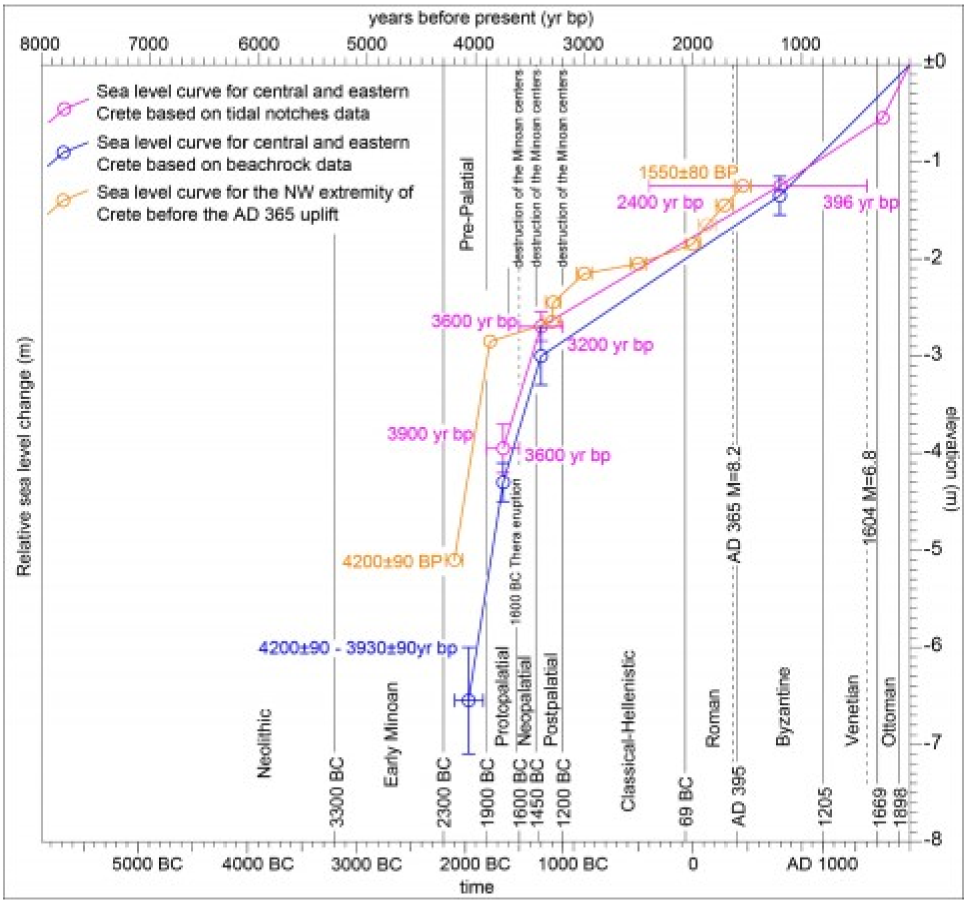
Fig. 6 - Comparison between the 14C dated marine notches of the westernmost part of Crete, which formed during ten subsidence tectonic events and then uplifted during the tectonic event of 1550 ± 80 ÷ 1595 ± 70 BP (AD 365 earthquake), and the submerged marine notches and beachrocks of the eastern part of Crete, dated using archaeological sea level indicators



The mean depths (bmsl) and dating of the four marine notches and the corresponding beachrock generations of central and eastern Crete are shown on the right half plot. The elevations (amsl) and dating of the uplifted marine tidal notches of western Crete are shown on the upper left plot. The lower left plot indicates the depths (bmsl) of the marine notches of western Crete when the sea level on the entire island was at 1.25 ± 0.05 m bmsl. The yellow arrows indicate the subsidence of the entire island between 4200 ± 90 BP and 1595 ± 70 BP. The green arrow indicates the co-seismic uplift of the western part during the AD 365 earthquake. The red arrows indicate the subsidence of the entire island during the AD 1604. During the AD 365 earthquake, the western part of Crete separated from the eastern part along the neotectonic graben of Spili and uplifted by 9 m (after Mourtzas et al., 2016). Shown on the map of Crete (top left) are the locations of the archaeological sea level indicators and the separation of western and eastern part of Crete along the Spili fault zone (modified from Mourtzas and Kolaiti, 2020). BP: for radiocarbon dating, yr bp: years before present (indirect dating).

Credit: Authors

Fig. 7 - Relative sea level curves for western and central and eastern Crete during the Late Holocene



As deduced from beachrock data (blue line) and marine notches data (magenta line). The orange line indicates the subsidence on the NW tip of Crete before the AD 365 uplift, when the marine notch of 1550 ± 80 BP was at 1.25 ± 0.05 m bmsl (after Mourtzas, 2012a, b; Mourtzas *et al.*, 2016). Error bars indicate time and depth uncertainties. Historical periods and major catastrophic events are also reported. BP: for radiocarbon dating, yr bp: years before present (indirect dating).

Credit: Authors

18 On the western coast of Crete, the next observed sea level stand is dated to around 3400 ± 70 BP and is the result of an abrupt rsl rise of 0.50 m (Figs. 6, 7). Clear evidence is a marine notch on the Phalasarna coast, formed during a sea level 2.40 m below present and now uplifted at +5.90 m amsl (Lamporel *et al.*, 1979; Pirazzoli *et al.*, 1982). In the eastern part of Crete, both the marine notch observed all along the coast at 2.70 ± 0.15 m bmsl and the widespread beachrock generation at 3.10 ± 0.30 m bmsl have been dated to between 3600 and 3200 years before present on the basis of archaeological sea level indicators (Mourtzas *et al.*, 2016; Mourtzas and Kolaiti, 2017b, 2020) (Figs. 6, 7). This 400 year-period coincides with the Minoan Neopalatial period. This sea level stand is evidenced by the brackish groundwater rise in the archaeological remains and the water supply installations of the New Palace of Kato Zakros (N. Platon, 1974; L. Platon, 2004, 2010), as well as the entire submersion of the natural harbour morphology on the sea front of the Minoan settlement (Mourtzas and Kolaiti, 2017b). The change to the next sea level stand is connected with the demise of the Minoan centres of Crete and can be attributed to the destructive co-seismic tectonic events between 1225 and 1175 BC (Mourtzas and Kolaiti, 2017b). Around 1200 BC, the flourishing harbour of Kommos was abandoned, when the islet in front of Kommos settlement was entirely submerged, thus no longer protecting the coast from the winds. Similarly, the end of the settlement of Mochlos is placed around 1250 BC (Brogan and Smith, 2011), when the narrow strip of land that linked the islet of Mochlos with the mainland during the Bronze Age was also entirely submerged. On the western coast of Crete, the marine notches that formed during a sea level 2.50 m lower than at present between 3330 ± 80 BP and 3290 ± 70 BP (Lamporel *et al.*, 1979) seem to be consistent with the corresponding sea level of the eastern part dated to between 3600 and 3200 years before present (Mourtzas *et al.*, 2016) (Figs. 6, 7).

After 3290 ± 70 BP, seven successive paroxysmal tectonic events resulted in the westernmost coast of Crete subsiding by totally 1.20 m. The sea level rose to 1.25 m lower than at present between 1880 ± 70 and 1595 ± 70 BP (Lamporel *et al.*, 1979; Mourtza *et al.*, 2016) (Figs. 6, 7). Six marine notches with a difference in elevation of 0.20 m between them were formed during this extended period, from the end of the Minoan period (1200 BC) to the Roman domination of the island (late 1st c. AD). The notch datings (Lamporel *et al.*, 1979) clearly indicate a repetition of the vertical tectonic movements every 400 years approximately for the three earliest events and every 150 years approximately for the three most recent. During the same period, the eastern part of the island subsided to almost the same extent as the western part. Both the marine notches observed all along the eastern coast at 1.20-1.30 m bmsl and the corresponding beachrock generations at 1.35 ± 0.20 m bmsl determine a sea level stand at 1.25 ± 0.05 m bmsl (Figs. 6, 7). Based on archaeological sea level markers and historical sources, this sea level stand is dated to the period between 400 BC and AD 1604 (Mourtzas, 2012a, b; Mourtzas *et al.*, 2016). Robust evidence is provided for the following (Fig. 6): the submerged Classical temple of Samonio Athena at Cape Sidero, the Hellenistic and Roman harbours of Chersonisos, Ierapetra and Lasaia, the Roman fish tanks and other maritime installations along the coast of eastern Crete, and the Byzantine and Venetian coastal installations at Elounda and Rethymno (Blackman and Branigan, 1975; Mourtzas, 1990; Mourtzas and Marinos, 1994; Mourtzas and Kolaiti, 2017b). According to historical sources, the AD 1604 paroxysmal event resulted in a rsl rise of 0.70 m (Mourtzas, 2012a, b).

20 When the sea level was at 1.20 ± 0.10 m bmsl, Crete was shocked by the severe earthquake of July 21, AD 365 (Pirazzoli, 1986a; Guidoboni *et al.*, 1994). This seismic event split the island into two parts along the neotectonic graben of Spili (Figs. 6, 7). The uplifted marine notches at 1.00 ± 0.15 m amsl on the Melambes coast (S Crete, easternmost tip of the western tectonic block) and at 0.35 ± 0.05 m amsl on the Petri Geraniou coast (N Crete, easternmost tip of the western tectonic block) both dated around AD 360, and the submerged Roman fish tanks and the related geomorphological features on the Messara coast (S Crete, westernmost tip of the eastern tectonic block) and the slipway on the Rethymno coast (N Crete, westernmost tip of the eastern tectonic block) precisely define a NW-SE trending tectonic boundary, which separates the western from the eastern part of Crete and corresponds to the neotectonic graben of Spili and its north and south prolongation (Fig. 6). As a result of the AD 365 earthquake, the westernmost coast of the island uplifted by 9.15 ± 0.20 m amsl and tilted north-eastwards (Laborel *et al.,* 1979; Pirazzoli *et al.,* 1982; Pirazzoli 1986a; Mourtzas, 1990; Mourtzas *et al.,* 2016). Geomorphological and precise archaeological sea level indicators east of Spili graben such as the Roman fish tanks (Mourtzas, 2012a, b) clearly demonstrate that the sea level remained stable at 1.25 ± 0.05 m bmsl after the AD 365 earthquake (Mourtzas, 2012a, b). Based on historical reports (Buondelmonti, 1415; Spratt, 1865), (Mourtzas, 2012a, b) concluded that the submersion of the Roman (ca. AD 1-400) fish tanks in Matala Bay and of the entire eastern Crete occurred at some time between 1415 and 1865 and attributed the coastal subsidence to the 1604 earthquake (Mourtzas *et al.*, 2016).

21 The tidal notch at 1.25 ± 0.10 m bmsl on the south coast of western Crete (Damnoni) and the youngest beachrock generation with the ruins of the AD 365 earthquake embedded in it (Phalasarna, ancient harbour entrances) at 1.25 ± 0.15 m bmsl, which is steadily observed throughout the western part of the island, clearly indicate that the 1604 subsidence applies to the entire island. The submerged Venetian slipway on the Rethymno coast at 1.55 m bmsl and the inundated floors of the Venetian quarries of Koumpes, Stavros, Kalathas and Agioi Apostoloi on the north coast of western Crete (Fig. 6) suggest that the sea level formed after the AD 365 co-seismic uplift remained stable until the late Venetian period. The western part of Crete sunk uniformly along with the eastern part during the 1604 earthquake (Mourtzas *et al.,* 2016) (Figs. 6, 7).

22 The 1604 paroxysmal event resulted in an rsl rise of 0.70 m (Mourtzas, 2012a, b). A marine notch recorded all along the eastern coast at 0.45-0.65 m bmsl determines a sea level stand at 0.55 ± 0.05 m bmsl and also provides an estimate of the 1604 co-seismic subsidence of the island. The submerged salt pans of Poros Eloundas, the slipway of Avlaki at Chania peninsula and the millstone quarry near Palaeochora (Fig. 6), all dated

after 1604 (Makrakis 2006; Mourtzas *et al.*, 2016; Antonioli *et al.*, 2017, respectively), allow us to date this sea level stand to the 17th c. (Mourtzas *et al.*, 2016). The last change in sea level to its current position happened at some time before 1924 (Mourtzas *et al.*, 2016) (Figs. 6, 7).

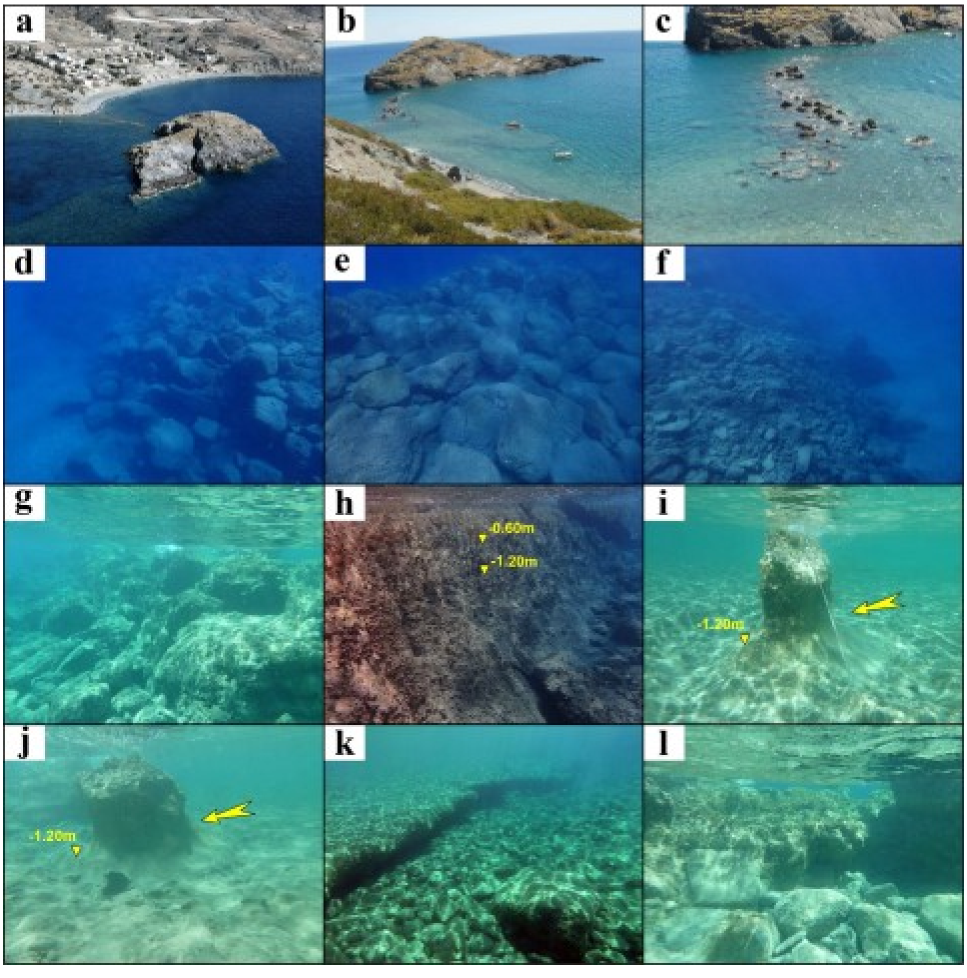
3 - Description of ancient Lasaia and its seafront

3.1 - The ancient harbour-town

23 The Minoan occupation in the wider area is mainly limited to a small farmstead on the height of the headland, west of Kaloi Limenes village, which may have seen some occupation in Middle Minoan times, and to four tholoi of the Early Minoan period east and west of ancient Lasaia (Blackman and Branigan, 1975). Although no trace of a related Minoan settlement was found there, the presence of the tholoi suggests an earlier Minoan occupation of the site located near a well-known source of low-grade copper and with a beach suitable for the landing of the small boats (Blackman and Branigan, 1975).

24 The ridge of the small headland facing the island of Traphos is separated from the coastal zone by a 35 m-high steep cliff, forming a 20 m-wide sandy-pebble shore at its foot and a narrow smooth rising strip at its top (Figs. 1, 2, 3, 5, 8a, 9). The ancient town developed on the ridge, occupying an area of 25,000 m^2, bounded on the east by a deep ravine and on the west by a steep slope dipping towards SW.

Fig. 8



(a) Aerial view of ancient Lasaia and the island of Traphos from the SW. (b, c) Views of the Hellenistic-Roman inner breakwater and Traphos from the North. (d, e, f) Underwater views of the Minoan outer breakwater at the SW edge of Traphos island. (g) Underwater view of the submerged Hellenistic inner breakwater. (h) The two submerged tidal notches on the underwater portion of the fault plane on Traphos. (i, j) The tidal notch at 1 m to 1.20 m bmsl on the boulders of the inner breakwater. (k) The submerged younger beachrock generation (IV). (l) The intermediate coarse beachrock (III) that underlies beachrock (IV), west of the inner breakwater.

Source: Photo a: https://www.tripinview.com/en, photos b, c, d, e, f, g, h, I, j, k, l: Nikos Mourtzas

Fig. 9 - **Satellite image of the seafront of ancient Lasaia**

Source : Map data: Image © 2020 Google Earth Pro, European Space Imaging, date of image: 22.07.2015, accessed 15.5.2018

25 The earliest finds of the settlement date to the end of the 4th c. - mid-3rd c. BC; the town flourished until the Late Roman period (late 5th c. AD). Lasaia was most likely dependent on Gortyna, initially the capital of the Roman senatorial province of Crete and Cyrenaica and later of the province of Crete. Its economy was connected with the stone quarries and deposits of copper and other minerals in the neighbouring area of Chrisostomos. The harbour installations of Lasaia coupled with its location suggest that it served as a harbour-town on the exposed south coast of Crete, home to from 400 to 500 people (Blackman and Branigan 1975, p. 36).

26 Remains of at least five large buildings, probably warehouses, are located on the shore. The walls of the warehouses were made of rubble and irregular stone blocks bound with mortar, parts of which are still standing up to a height of 3 m to 4 m. The back of the walls touches the rocky slope, whereas the seaward side is completely or partially eroded. The interior of the warehouses is filled with fallen materials from the eroded cliff. Remains of buildings were also found in the ravine, at the foot of the eastern slope of the cliff (Figs. 3, 5). On the top of the headland, there are clear traces of buildings, among them a church with a large apse, a nave and two aisles, a group of buildings that were presumably the houses of merchants, a temple, a complex building with a courtyard and other constructions such as a cistern lined with mortar, which was supplied with water by an aqueduct tracing about 600 m to the east to its source (Blackman and Branigan, 1975). The Hellenistic acropolis was behind and above the town to the north, on a flat-topped hill with steep slopes (Figs. 3, 5). The Classical to mid-Hellenistic cemetery was located west of the ancient town (Fig. 2). Further north, an undefined number of tombs were most likely used during the Roman period. A small Hellenistic-Roman farmstead overlooking Lasaia was found on a raised knoll NNW of the ancient town (Blackman and Branigan, 1975).

3.2 - The seafront and the ancient harbour works

27 Traphos is a small elongated island composed of marble, with a 215 m long axis oriented NE-SW, a 130 m short axis and a maximum elevation of 22 m. It is crossed by a fault plane in a NE-SW direction dipping towards the west with a visible throw of 7 m that separates the elevated eastern part of the island from the western part. The distance between the island and the nearby shore is about 100 m at its narrowest point. A submerged reef about 50 m long, with its top at 0.30 m to 2.10 m bmsl is the NE submarine extension of the island. A slightly inclined, up to 10 m-wide, rocky shelf

located at 1 m bmsl surrounds the island and ends at a steep rocky cliff which plunges into the seafloor at the depths of 6 m and 12 bmsl, west and east of the island, respectively (Figs. 5, 9).

28 At the SW edge of the island, a rockfill 142 m long, 77 m wide and 7.50 m high, composed of boulders up to 2 m in diameter, forms an artificial breakwater ('outer breakwater') prolonging the island towards the west. The top of the rockfill is at 2.30 m bmsl and its base reaches 10 m bmsl (Figs. 5, 8d, e, f, 9).

29 A second breakwater ('inner breakwater') 96 m long and up to 11 m wide, composed of boulders up to 2.50 m in diameter, is observed between the island and the nearby coast. It runs for 76 m towards SSE, with its top at 1.10 m to 1.30 m bmsl. In its central section, at least 30 boulders protrude from the sea. It then turns SW for 20 m and is entirely submerged at 1 m bmsl, leaving a channel 12 m wide and 2.90 m deep between its southern end and the northern coast of the island (Figs. 5, 8a, b, g, 9). The eastern part of the breakwater is founded on a nearly flat surface 40 m wide, at a mean depth of 3 m bmsl and ending in a slope that appears to be covered by a protective rockfill. Between the rockfill and the NE undersea extension of the island, there is a 20 m-wide channel with a maximum depth of 8.40 m bmsl (Figs. 5, 9).

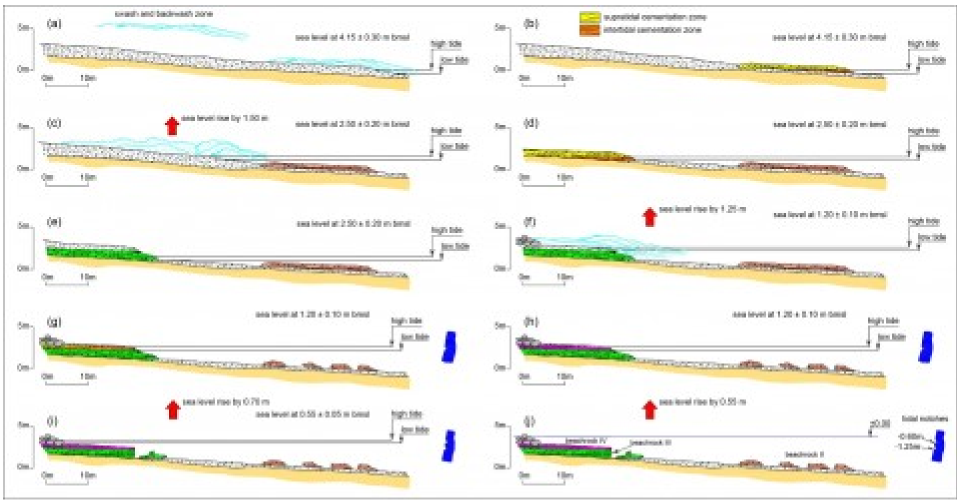
4 - Geomorphological and archaeological indicators of the rsl change

4.1 - Geomorphological indicators

30 On the coast of Kaloi Limenes, 2.3 km west of Lasaia, Mourtzas (1990) identified three submerged marine tidal notches with their base at 0.50 m, 1.10 m and 3.70 m bmsl. At a distance of 12 km further east, around the limestone cape of Trachoulas, three submerged notches were also identified. On the western cliff of the cape, these are observed at 0.50 m, 1.10 m and 3.90 m bmsl and on the eastern cliff at 0.40 m and 1.10 m bmsl, while a broad marine terrace was identified between the depths of 3.10 m and 4.0 m bmsl. The three notches were also observed at Tripiti Cape, 1.5 km further east, with their base at 0.50 m, 1.30 m and 3.70 m bmsl.

31 Two submerged marine tidal notches run along the underwater portion of the fault plane on Traphos Island, with their base at 0.60 m and 1.25 m bmsl. The deeper notch is also incised in the boulders of the inner breakwater with its base at 1.20 m bmsl and an opening of 0.40 m (Figs. 5, 8h, i, j, 10).

Fig. 10



(a) Cross-section of the relatively protected, microtidal, western coast of the strip of land consisting of sand and pebbles. (b) When the sea level was at 4.15 ± 0.30 m bmsl, the beachrock generation (II) was cemented in the intertidal and supratidal zones. (c) A rsl rise of 1.65 m sunk the earliest beachrock generation (II). (d) In the intertidal and supratidal zones of the new sea level at 2.50 ± 0.20 m bmsl, the new beachrock generation (III) was formed. (e) As a result of the constant supply of sediments, a large part of beachrock slab (III) was covered by a layer of sand and pebbles. (f) The sea level rose by 1.30 m and, at the new sea level stand, the Hellenistic inner breakwater was constructed. (g, h) In the intertidal and supratidal zones of the new sea level stand at 1.20 ± 0.10 m bmsl, beachrock (IV) was cemented over beachrock (III), incorporating the boulders of the Hellenistic inner breakwater. The tidal notch at 1.20 m bmsl was incised on the fault plane of Traphos and on the boulders of the inner breakwater. (i) The sea level rose by 0.70 m at 0.55 ± 0.05 m bmsl forming the tidal notch of 0.60 m bmsl on the fault plane of Traphos. (j) After the recent rsl rise by 0.55 m, the sea level shifted to its current stand. The tidal notches and the three beachrock generations submerged below the sea level. The earliest beachrock (II) was eroded and broken into large pieces over time. The depths of the base of the tidal notches and the seaward base of the beachrock generations correspond - with minor deviations - to the mean sea levels of 4.15 ± 0.30 m, 2.50 ± 0.20 m, 1.20 ± 0.10 m and 0.55 ± 0.05 m bmsl, during which they were formed.

Credit: Authors

32 On the sandy beach of Kaloi Limenes, an 800 m long beachrock generation has developed. It has a width of 30 m to 55 m and a thickness of 1.10 m to 1.20 m at its seaward end. The average of seven depth measurements at the top and base all along the length of the formation is 3.30 ± 0.15 m and 4.40 ± 0.30 m, respectively.

33 Three distinct beachrock generations have developed along the seafront of ancient Lasaia (Figs. 5, 8k, l, 9, 10). Remnants of the earliest and deepest generation (II) appear up to a depth of 3.80 m to 4.30 m bmsl. The intermediate and coarse generation (III) underlies the younger beachrock generation (IV) and can only be seen west of the inner breakwater. It is up to 1 m thick with a seaward base at 2.40 m to 2.60 m bmsl. The younger beachrock generation (IV) is 0.20 m thick and its seaward base is at 1 m to 1.30 m bmsl. A number of Hellenistic and Roman potsherds and the boulders of the base of the inner breakwater have been embedded in it (Figs. 5, 8k, l, 9). The cementation process and evolution of the three beachrock generations in relation to the rsl rise are shown on Fig. 10.

4.2 - Archaeological markers

34 The following archaeological sea level indicators were identified in the study area: (a) the two submerged breakwaters; that is, the outer rockfill on the SW edge of Traphos Island with its upper surface at 2.30 m bmsl, and the inner rockfill between the island and the nearby coast with its upper surface at 1 m bmsl, (b) the submerged walls on the shore at 0.10 m bmsl, and (c) the submerged base of a tank coated with mortar, now located at 0.55 m bmsl between the shore and the inner breakwater (Figs. 5, 8d, e, f, g, 9).

5 - Interpretation and discussion

35 In the narrow and wider coastal area of ancient Lasaia, the three marine notches and beachrock generations clearly determine four distinct sea level stands during which the geomorphological features were formed.

36 The deepest marine notch on the rocky limestone cliff of Kaloi Limenes and the corresponding deepest notch at Trachoulas and Tripiti Cape at 3.85 ± 0.20 m bmsl, as well as the deepest beachrock generation at 4.40 ± 0.30 m bmsl, identify a mean sea level during which they were formed of 4.15 ± 0.30 m.

37 The intermediate beachrock generation at 2.40 m to 2.60 m bmsl, which borders the inner breakwater of the ancient harbour, determines a second sea level at 2.50 ± 0.20 m bmsl.

38 The intermediate submerged marine tidal notch on the Kaloi Limenes coast and Trachoulas and Tripiti Cape, the deepest notch on the rocky cliff of Traphos and on the boulders of the inner breakwater at 1.10 m to 1.30 m bmsl, and the younger beachrock generation with intergrated boulders of the inner ancient breakwater at 1.25 m bmsl, determine a third sea level stand at 1.20 ± 0.10 m bmsl.

39 Finally, the marine tidal notch on the Kaloi Limenes coast, Trachoulas and Tripiti Cape and Traphos Island at 0.50 m to 0.60 m bmsl identifies a younger sea level at 0.55 ± 0.05 m bmsl.

The four sea level stands identified in the – wider and narrow - study area at 4.15 ± 0.30 m, 2.50 ± 0.20 m, 1.20 ± 0.10 m and 0.55 ± 0.05 m bmsl are consistent with the sea level stands that have been determined throughout the entire central and eastern coast of Crete (Figs. 6, 7), as detailed in section 3 above.

41 The dating of the above sea level stands can be indirectly deduced from the comparison of their elevations with the functional elevation of the coastal archaeological markers at 35 locations throughout the coast of Crete (Mourtzas, 2012a, b; Mourtzas *et al.,* 2016; Mourtzas and Kolaiti, 2017b, c). As previously mentioned in section 3 above, the earlier sea level stands at 4.15 ± 0.30 m and 2.50 ± 0.20 m bmsl have been linked to the Minoan Protopalatial (1900-1600 BC) and the Neopalatial (1600-1450 BC) periods, respectively. The relative change to the next sea level at 1.20 ± 0.10 m bmsl occurred between 1200 BC and the 4th c. BC. This sea level stand is definitely associated with characteristic ancient coastal installations throughout the coast of central and eastern Crete that were constructed and used during the Classical, Hellenistic, Roman, Byzantine and Venetian periods. According to historical sources, an rsl rise of 0.70 m can be attributed to the paroxysmal event of AD 1604. The rsl rise by 0.55 m occurred at some time during the next 320 years and definitely before the early 20th c. (Mourtzas, 2012a, b; Mourtzas *et al.*, 2016; Mourtzas and Kolaiti, 2017b, c).

6 - Palaeogeographic reconstruction of the seafront of ancient Lasaia

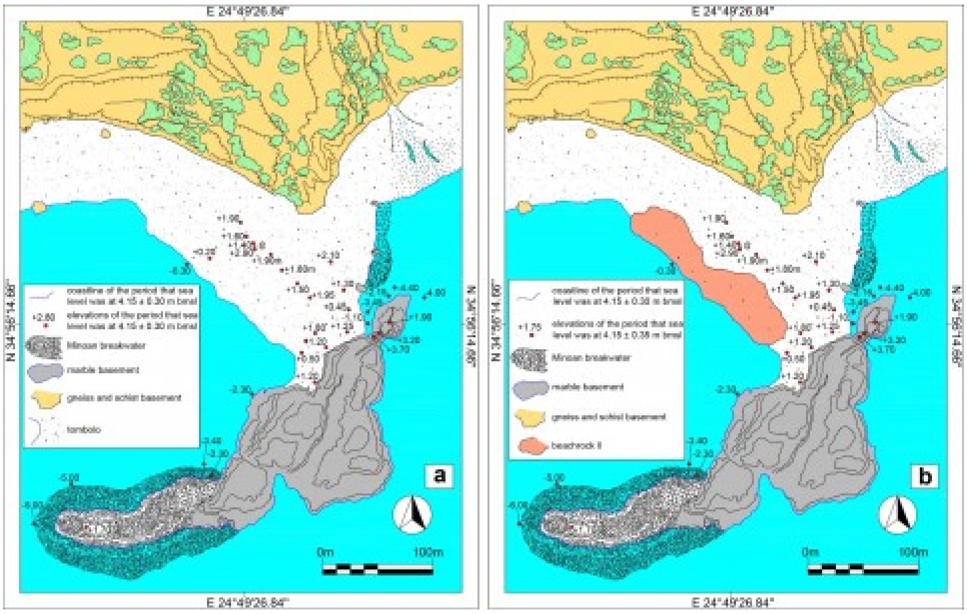
42 The palaeogeographic reconstruction of ancient Lasaia and Traphos Island is deduced from the rsl changes and their impact on the coastal morphology and the sea-land interaction over time, as detailed in section 3 above.

6.1 - Middle and Late Bronze Age

6.1.1 Protopalatial period (ca. 1900 - ca. 1600 BC)

43 Palaeogeographic evidence of the earlier phase of the seafront of ancient Lasaia is provided by the sea level at 4.15 ± 0.30 m bmsl, which is dated to the period between 1900 BC and 1600 BC. During this sea level, the earliest beachrock generation (II) formed, today observed west of the inner breakwater at 3.80 m to 4.30 m bmsl. The extent of the beachrock combined with the bathymetry of the seafloor suggests that the shore was 80 m wider than at present and the island was attached to the mainland by a strip of land consisting of beach materials, with a maximum elevation of 2 m and an average width of 150 m (Fig. 11a). A protective rockfill was placed at the eastern side of the strip. The beachrock (II) was cemented on the western side of the strip (Figs. 10a, b, 11b). At the same time, the top of the rockfill at the SW edge of Traphos stuck out 1.70 m from the then sea level (Fig. 11a, b).

Fig. 11 - Palaeogeographic reconstruction of the seafront of ancient Lasaia between 1900 BC and 1620 BC



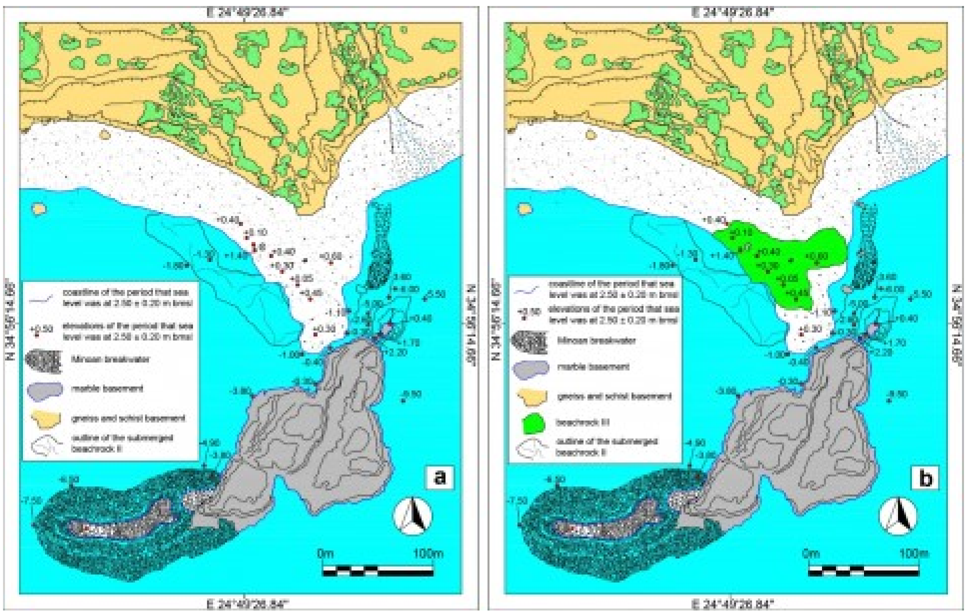
The sea level was at 4.15 ± 0.30 m below mean sea level (bmsl). The coastal morphology before (a) and after (b) the formation of the earliest beachrock generation (II)

Credit: Authors

6.1.2 Neopalatial period (ca. 1600 - ca. 1450 BC) to the end of the Postpalatial period (ca. 1200 BC)

44 The abrupt rsl rise by 1.65 m around 1600 BC shifted the sea level to 2.50 ± 0.20 m bmsl and is associated with the wider neotectonic upheavals in the area of the southern Aegean that accompanied the strong eruption of the Thera volcano. As a result, the coastline receded for 15 m, the earlier beachrock generation (II) submerged, the average width of the strip of land reduced to 100 m and, probably, its southern end slightly submerged, thus separating the island from the mainland (Fig. 12a).

Fig. 12 - Palaeogeographic reconstruction of the seafront of ancient Lasaia between 1620 BC and 1200 BC



The sea level was at 2.50 ± 0.20 m bmsl. The coastal morphology before (a) and after (b) the formation of the intermediate beachrock generation (III)

Credit: Authors

45 The sandy pebble deposits in the central part of the strip were cemented forming the intermediate beachrock generation (III) (Figs. 10c, d, e, 12b). The top of the rockfill at the SW edge of Traphos still protruded 0.40 m above the then sea level, which remained at 2.50 ± 0.20 m bmsl until 1200 BC (Mourtzas *et al.*, 2016; Mourtzas and Kolaiti, 2017b). The subsequent rsl rise of 1.30 m most likely occurred at the end of the Late Bronze Age.

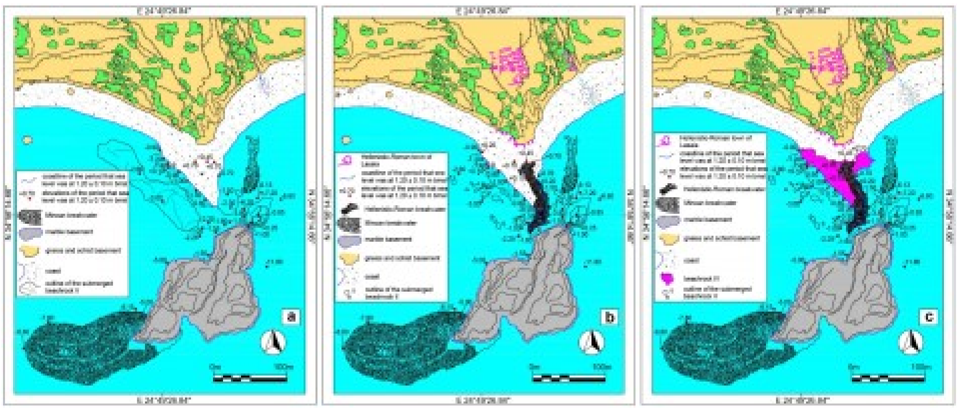
Then, a great number of sites in the Aegean and the Eastern Mediterranean were partly or totally destroyed over a 50-year period as a result of seismic events (e.g. Nur and Cline, 2000; Nur and Burgess, 2008; Jusseret *et al.*, 2013; Mourtzas and Kolaiti, 2020) or a combination of human and natural events, such as internal rebelions, climate change, drought and mainly earthquake storm, which caused systems collapse and brought the Late Bronze Age to an end (Cline, 2014).

46 Although the archaeological survey does not so far provide sufficient evidence to support the existence of a Minoan settlement during the Middle and Late Bronze Age in Lasaia, the manmade rockfill at the SW edge of Traphos, which stuck out from the then sea for a length of 130 m, thus shaping a safe anchorage, combined with the exploitation of the copper minerals and the Minoan burial remains on the headland, allow us to hypothesise another prehistoric harbour on the southern coast of Crete.

6.2 - Hellenistic and Roman periods

47 At the end of 4th c. BC to mid-3rd c. BC, the harbour-town of Lasaia was established on the coast opposite Traphos, while the sea level was at 1.20 ± 0.10 m bmsl. At that time, the shore was 35 m wide, the sandy spit extended 85 m into the sea and its southern end was 35 m away from the rocky coast of Traphos Island. The intermediate beachrock generation (III) was overlaid by coastal deposits and the top of the outer breakwater had submerged at 1 m bmsl, no longer providing protection from the south winds (Fig. 13a).

Fig. 13 - Palaeogeographic reconstruction of the seafront of ancient Lasaia between 1200 BC and 1604 AD



The sea level was at 1.20 ± 0.10 m bmsl. The coastal morphology before (a, b) and after (c) the formation of the intermediate beachrock generation (IV)

Credit: Authors

48 The rockfill of the inner breakwater was then constructed, leaving a wide channel between the end of it and the island to allow the safe passage of vessels, depending on the wind (Fig. 13b). However, the harbour, being exposed to SW winds, was not safe. Since the eastern basin was perilous for boats due to the rocky reefs, vessels would mostly approach the western harbour basin. It provided protection against the NE winds. When the wind was blowing from the SW, vessels would cross the channel towards the eastern harbour basin taking great care to avoid the shallow rocks. Despite the inherent dangers, the harbour of Lasaia was the safest anchorage on the extremely exposed southeastern coast of Crete.

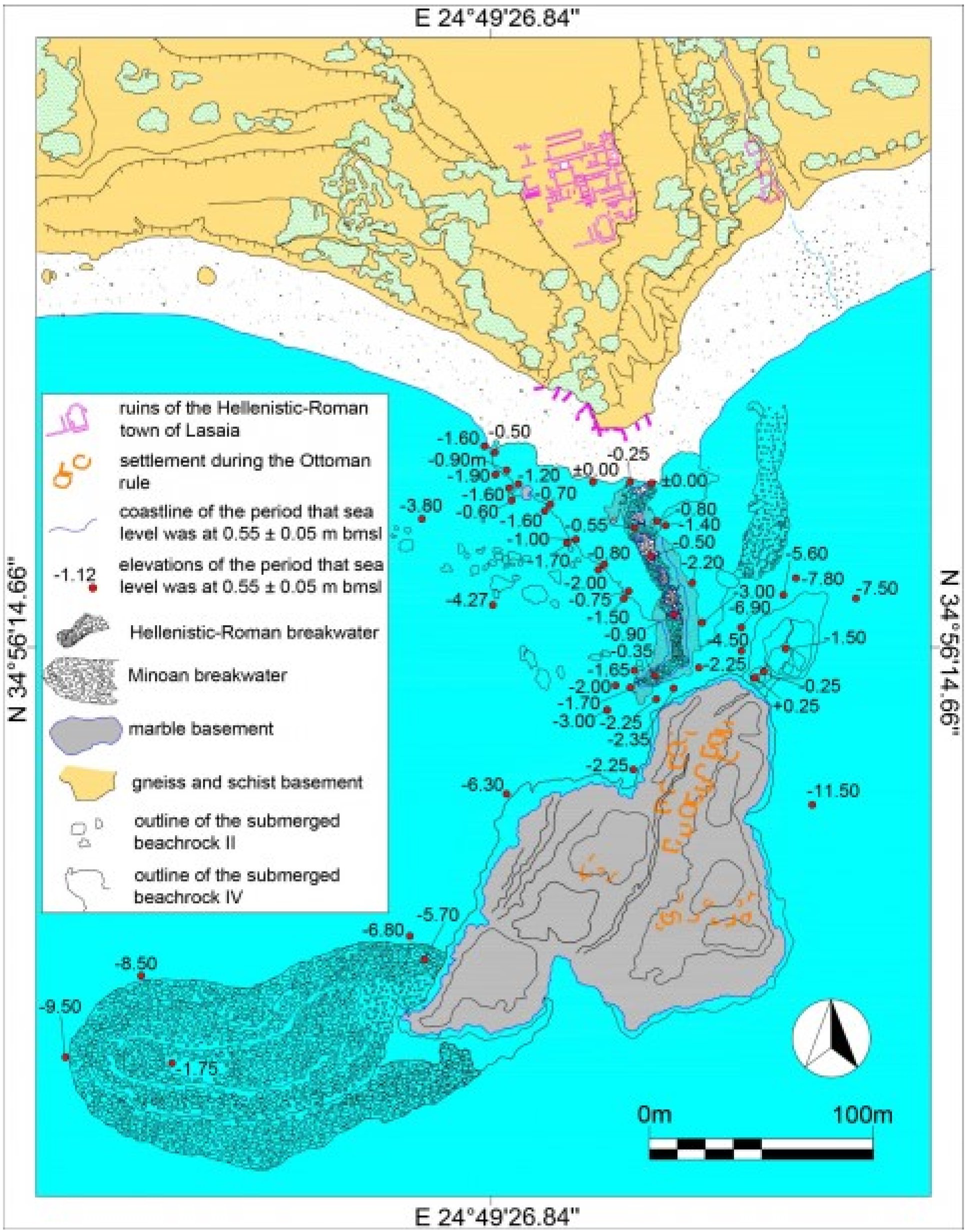
49 During this sea level, the coastal deposits on both sides of the inner breakwater were cemented and formed the younger beachrock generation (IV), which also intergrated the boulders of the rockfill (Figs. 10f, g, h, 13c).

6.3 - Venetian and Ottoman periods

According to historical evidence, the next change in sea level occurred between 1440 and 1865, most likely during the strong earthquake of 1604. The sea level rose to

0.55 ± 0.05 m bmsl, the shoreline further receded, the beachrock generation (IV) and the inner breakwater submerged at 0.50 m to 0.80 m bmsl (Fig. 10i), with the island becoming completely isolated from the mainland (Fig. 14). The settlement on Traphos, which provided shelter to natives from the persecution of the Ottoman conquerors, is attributed to this period (Blackman and Branigan, 1975, p. 34, 35).

Fig. 14 - Palaeogeographic reconstruction of the seafront of ancient Lasaia after 1604 AD



The sea level was at 0.55 ± 0.05 m bmsl

Credit: Authors

Conclusions

51 The relatively protected coastal morphology of ancient Lasaia on the inhospitable – to shipping – southeastern coast of Crete, seems to have provided shelter for ships since the end of the Early Bronze Age, prior to their sailing around Cape Lithino and heading towards the harbour-town of Kommos (Messara Gulf).

52 The coastal morphology of the headland facing the rocky island of Traphos has systematically changed following the significant changes in sea level over the last 4000 years: from a tied island connected to the mainland by a strip of land when the sea level was at 4.15 ± 0.30 m and 2.50 ± 0.20 m bmsl, to a low promontory protruding into the sea at a short distance from the coast of Traphos when the sea level was at 1.20 ± 0.10 m bmsl, and finally to a narrow shore opposite the island when the sea level was at 0.55 ± 0.05 m bmsl.

53 Since the Bronze Age, the diversity of the infrastructures reflects both the technological progress and the human needs over time. Technical measures to ensure access, mooring and anchoring of vessels seem to have been adapted to sea level changes. A rockfill that was dumped at the SW edge of Traphos Island was the outer breakwater during the Minoan palatial period. It protected the harbour basin from the SW winds, while the strip of land was a shield against the NE winds. It is the first Minoan harbour to be reported on the southeastern coast of Crete, thus providing new evidence on the Minoan maritime constructions as well as the ancient seafaring and sea routes in the Aegean.

54 The inner breakwater was constructed during the Hellenistic-Roman periods, when the outer breakwater had been submerged and the western harbour basin was no longer safe due to its exposure to the SW winds. The channel between the end of the inner breakwater and the island allowed mariners to pass from the western to the eastern basin, depending on the weather.

55 As a result of the rsl rise at the beginning of the 17th c., the ancient harbour installations and the coastal morphology were submerged, isolating the island from the mainland. Traphos provided shelter for the Cretan refugees from the Ottoman conquerors.

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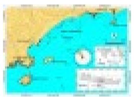
List of illustrations

Title	Fig. 1 - Map of the southern coast of central Crete
Caption	Place and location names as mentioned in the text
Credits	Source: Evans, 1928
URL	http://journals.openedition.org/mediterranee/docannexe/image/12549/img-1.jpg
File	image/jpeg, 199k



Title	Fig. 2 - Location map of the bay of Kaloi Limenes and site wind rose diagram
Caption	Isobaths in metres
Credits	Credit: Authors
URL	http://journals.openedition.org/mediterranee/docannexe/image/12549/img-2.jpg
File	image/jpeg, 807k

Title	**Fig. 3** - Ancient Lasaia
Caption	Plan of the seafront as it now stands
Credits	Credit: Authors
URL	http://journals.openedition.org/mediterranee/docannexe/image/12549/img-3.jpg
File	image/jpeg, 1003k

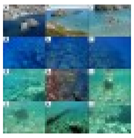
Title	**Fig. 4** - Ancient Lasaia and the island of Traphos
Caption	Lithographic print depicting the bay of Kaloi Limenes
Credits	Source : Spratt, 1865
URL	http://journals.openedition.org/mediterranee/docannexe/image/12549/img-4.jpg
File	image/jpeg, 248k

Title	**Fig. 5** - Detailed mapping of the submerged geomorphological and archaeological sea level indicators with depths below mean sea level (bmsl) in metres
Credits	Credit: Authors
URL	http://journals.openedition.org/mediterranee/docannexe/image/12549/img-5.jpg
File	image/jpeg, 1.2M

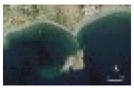
Title	**Fig. 6** - Comparison between the ^{14}C dated marine notches of the westernmost part of Crete, which formed during ten subsidence tectonic events and then uplifted during the tectonic event of 1550 ± 80 ÷ 1595 ± 70 BP (AD 365 earthquake), and the submerged marine notches and beachrocks of the eastern part of Crete, dated using archaeological sea level indicators
Caption	The mean depths (bmsl) and dating of the four marine notches and the corresponding beachrock generations of central and eastern Crete are shown on the right half plot. The elevations (amsl) and dating of the uplifted marine tidal notches of western Crete are shown on the upper left plot. The lower left plot indicates the depths (bmsl) of the marine notches of western Crete when the sea level on the entire island was at 1.25 ± 0.05 m bmsl. The yellow arrows indicate the subsidence of the entire island between 4200 ± 90 BP and 1595 ± 70 BP. The green arrow indicates the co-seismic uplift of the western part during the AD 365 earthquake. The red arrows indicate the subsidence of the entire island during the AD 1604. During the AD 365 earthquake, the western part of Crete separated from the eastern part along the neotectonic graben of Spili and uplifted by 9 m (after Mourtzas et al., 2016). Shown on the map of Crete (top left) are the locations of the archaeological sea level indicators and the separation of western and eastern part of Crete along the Spili fault zone (modified from Mourtzas and Kolaiti, 2020). BP: for radiocarbon dating, yr bp: years before present (indirect dating).
Credits	Credit: Authors
URL	http://journals.openedition.org/mediterranee/docannexe/image/12549/img-6.jpg
File	image/jpeg, 950k

Title	**Fig. 7** - Relative sea level curves for western and central and eastern Crete during the Late Holocene

Caption	As deduced from beachrock data (blue line) and marine notches data (magenta line). The orange line indicates the subsidence on the NW tip of Crete before the AD 365 uplift, when the marine notch of 1550 ± 80 BP was at 1.25 ± 0.05 m bmsl (after Mourtzas, 2012a, b; Mourtzas *et al.*, 2016). Error bars indicate time and depth uncertainties. Historical periods and major catastrophic events are also reported. BP: for radiocarbon dating, yr bp: years before present (indirect dating).
URL	http://journals.openedition.org/mediterranee/docannexe/image/12549/img-7.jpg
File	image/jpeg, 455k



Title	**Fig. 8**
Caption	(a) Aerial view of ancient Lasaia and the island of Traphos from the SW. (b, c) Views of the Hellenistic-Roman inner breakwater and Traphos from the North. (d, e, f) Underwater views of the Minoan outer breakwater at the SW edge of Traphos island. (g) Underwater view of the submerged Hellenistic inner breakwater. (h) The two submerged tidal notches on the underwater portion of the fault plane on Traphos. (i, j) The tidal notch at 1 m to 1.20 m bmsl on the boulders of the inner breakwater. (k) The submerged younger beachrock generation (IV). (l) The intermediate coarse beachrock (III) that underlies beachrock (IV), west of the inner breakwater.
Credits	Source: Photo a: https://www.tripinview.com/en, photos b, c, d, e, f, g, h, I, j, k, l: Nikos Mourtzas
URL	http://journals.openedition.org/mediterranee/docannexe/image/12549/img-8.jpg
File	image/jpeg, 1.1M



Title	**Fig. 9** - Satellite image of the seafront of ancient Lasaia
Credits	Source : Map data: Image © 2020 Google Earth Pro, European Space Imaging, date of image: 22.07.2015, accessed 15.5.2018
URL	http://journals.openedition.org/mediterranee/docannexe/image/12549/img-9.jpg
File	image/jpeg, 177k

Title	**Fig. 10**
Caption	(a) Cross-section of the relatively protected, microtidal, western coast of the strip of land consisting of sand and pebbles. (b) When the sea level was at 4.15 ± 0.30 m bmsl, the beachrock generation (II) was cemented in the intertidal and supratidal zones. (c) A rsl rise of 1.65 m sunk the earliest beachrock generation (II). (d) In the intertidal and supratidal zones of the new sea level at 2.50 ± 0.20 m bmsl, the new beachrock generation (III) was formed. (e) As a result of the constant supply of sediments, a large part of beachrock slab (III) was covered by a layer of sand and pebbles. (f) The sea level rose by 1.30 m and, at the new sea level stand, the Hellenistic inner breakwater was constructed. (g, h) In the intertidal and supratidal zones of the new sea level stand at 1.20 ± 0.10 m bmsl, beachrock (IV) was cemented over beachrock (III), incorporating the boulders of the Hellenistic inner breakwater. The tidal notch at 1.20 m bmsl was incised on the fault plane of Traphos and on the boulders of the inner breakwater. (i) The sea level rose by 0.70 m at 0.55 ± 0.05 m bmsl forming the tidal notch of 0.60 m bmsl on the fault plane of Traphos. (j) After the recent rsl rise by 0.55 m, the sea level shifted to its current stand. The tidal notches and the three beachrock generations submerged below the sea level. The earliest beachrock (II) was eroded and broken into large pieces over time. The depths of the base of the tidal notches and the seaward base of the beachrock generations correspond - with minor deviations - to the mean sea levels of 4.15 ± 0.30 m, 2.50 ± 0.20 m, 1.20 ± 0.10 m and 0.55 ± 0.05 m bmsl, during which they were formed.
Credits	Credit: Authors
URL	http://journals.openedition.org/mediterranee/docannexe/image/12549/img-10.jpg
File	image/jpeg, 528k

Title	**Fig. 11** - Palaeogeographic reconstruction of the seafront of ancient Lasaia between 1900 BC and 1620 BC

	Caption	The sea level was at 4.15 ± 0.30 m below mean sea level (bmsl). The coastal morphology before (a) and after (b) the formation of the earliest beachrock generation (II)
	Credits	Credit: Authors
	URL	http://journals.openedition.org/mediterranee/docannexe/image/12549/img-11.jpg
	File	image/jpeg, 1.3M
	Title	**Fig. 12** - Palaeogeographic reconstruction of the seafront of ancient Lasaia between 1620 BC and 1200 BC
	**Caption**	The sea level was at 2.50 ± 0.20 m bmsl. The coastal morphology before (a) and after (b) the formation of the intermediate beachrock generation (III)
	Credits	Credit: Authors
	URL	http://journals.openedition.org/mediterranee/docannexe/image/12549/img-12.jpg
	File	image/jpeg, 921k
	Title	**Fig. 13** - Palaeogeographic reconstruction of the seafront of ancient Lasaia between 1200 BC and 1604 AD
	**Caption**	The sea level was at 1.20 ± 0.10 m bmsl. The coastal morphology before (a, b) and after (c) the formation of the intermediate beachrock generation (IV)
	Credits	Credit: Authors
	URL	http://journals.openedition.org/mediterranee/docannexe/image/12549/img-13.jpg
	File	image/jpeg, 1.1M
	Title	**Fig. 14** - Palaeogeographic reconstruction of the seafront of ancient Lasaia after 1604 AD
	**Caption**	The sea level was at 0.55 ± 0.05 m bmsl
	Credits	Credit: Authors
	URL	http://journals.openedition.org/mediterranee/docannexe/image/12549/img-14.jpg
	File	image/jpeg, 1.3M

References

Electronic reference
Nikos Mourtzas and Eleni Kolaiti, « Palaeogeography of Ancient Lasaia (SE Crete, Greece) », *Méditerranée* [Online], Paleoenvironment, Geoarchaeology, Historical Geography, Online since 25 May 2021, connection on 17 December 2021. URL : http://journals.openedition.org/mediterranee/12549

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