Available online http://amq.aiqua.it
ISSN (print): 2279-7327, ISSN (online): 2279-7335

Alpine and Mediterranean Quaternary, 33 (1), 2020, 61-87 https://doi.org/10.26382/AMQ.2020.04

PALAEOGEOGRAPHIC RECONSTRUCTION OF THE MESSARA GULF AND MATALA BAY (CRETE, GREECE): COASTAL RESPONSE TO SEA LEVEL CHANGES DURING PREHISTORIC AND HISTORIC TIMES.

Nikos Mourtzas[1], Eleni Kolaiti[2]

[1] Geologist, PhD NTUA, AKTES NPO, Athens, Greece.
[2] Mining Engineer NTUA, PhD, Researcher of the N.H.R.F, External Coll., AKTES NPO, Athens, Greece.

Corresponding author: E. Kolaiti <*kolaitieleni@gmail.com*>

ABSTRACT: The determination and dating of the former sea level stands and the periods of their relative change, based on geomorphological (i.e. marine tidal notches and beachrocks) and archaeological indicators (i.e. fish tanks and slipway) from the Messara Gulf and Matala Bay, enabled palaeogeographic shoreline reconstruction during the Late Holocene. The total rise in the sea level by 6.60 ±0.30 m, with four intermediate sea level stands at 3.90 ±0.20 m, 2.75 ±0.20 m, 1.25 ±0.20 m and 0.50 ±0.05 m below mean sea level (b.m.s.l.), coincided with the development of a thriving civilization in the western Messara plain and the coastal zone during prehistoric and historic times. Destructive seismic events accompanied by vertical subsiding tectonic displacements between the 17th and 13th c. BC, namely the seismic sequence followed the Thera eruption in the late 17th c. BC (around 1600 BC), the 1425 BC earthquake and the seismic activity between 1225 BC and 1175 BC, brought about major changes in the socio-political and economic life of the plain and changed the sea level from 3.90 ±0.20 m to 1.25 ±0.20 m b.m.s.l. The Kommos coast, at the southern end of the Messara Gulf, was a natural shelter until the end of the 13th c. BC. When the sea level rose from 2.75 ±0.20 m to 1.25 ±0.20 m b.m.s.l., the islet protecting the shore from the strong NW winds and waves was submerged. Therefore, the comparative advantage that allowed ships to approach, temporarily anchor or be hauled onto the sandy beach was eliminated. After the abandonment of Kommos, the harbour site of the Messara plain moved to the neighbouring Matala Bay, which was thenceforth the gateway to the sea of Roman Gortyn. Between the 1st and 4th c. AD with the sea level stable at 1.25 ±0.20 m b.m.s.l., several productive activities flourished there, such as fishing, fish processing and conservation, salt harvesting, shipbuilding and quarrying. In the AD 1604 earthquake, the Matala coast submerged by 0.75 m. The sea level remained at 0.50 ±0.05 m b.m.s.l. for a short time span and at some time before 1924 rose to its current stand.

Keywords: Messara Gulf; Matala Bay; Crete, Greece; relative sea level change; marine notches; beachrocks; archaeological indicators; palaeogeography.

1. INTRODUCTION

The strategic position of Crete during the Late Bronze Age at the crossroads of maritime shipping routes between the Aegean and the Eastern Mediterranean (Watrous, 1992) implied the existence of a series of harbours and ports for shelter. The relationship of the Minoan centres with the sea during the Minoan Thalassocracy has aroused much interest among geoscientists, besides being the subject of archaeological surveys and research (e.g. Leatham & Hood, 1958/59; Gifford, 1995; Fytrolakis et al., 2005; Ghilardi et al., 2018; Mourtzas & Kolaiti, 2017a). The coastal palaeogeography has been significantly changing since the period that Minoan seafarers sought shelter in the natural or manmade harbours of the island. The palaeogeographic evolution of the coast has been directly linked to the sea level changes over time and has had a profound influence on the settlement patterns and the cultural history of the island. Mourtzas & Kolaiti (2017a) attempted to interpret the impacts of the sea level changes on the waterfront of the Minoan centres in the bays of Kato Zakros (E Crete) and Kaloi Limenes (S Crete) and the interaction with historical changes through time. The coast of the plain of Messara and the neighbouring bay of Matala, are probably one of the greatest challenges facing geoarchaelogical research, as they are associated with three of the most important Minoan centres of Crete; namely, Phaistos, Ayia Triada and the harbourside settlement of Kommos (Figs. 1A, 1B, 1C, 1D).

The tectonic graben of Messara, bounded on the north by the Ida (Psiloritis) massif and on the south by the Asterousia mountains, forms an elongated E-W oriented plain. The Neogene-Quaternary Messara basin is limited by normal faults and is filled by Miocene to Quaternary sediments that mainly consist of alluvial clays, silts, sands, gravels, marls and conglomerates (Fig. 1E). Alpine formations comprise Cretaceous and Jurassic limestones and dolomites, Jurassic schists and ophiolites (Fig. 1E). The Geropotamos river (or Ieropotamos) and its tributaries drains the western part of the Messara plain and runs westward into the Libyan Sea. It flows towards a long, nearly straight beach, stretching from the coastal settlement of Kokkinos Pirgos (north) to the coast of Kommos (south) for 9 km. At the strait of the E-W trending steep ridge of Phaistos, the flooding plain of the Geropotamos is bounded by the Neogene hill range located at the margins of the mountains, which geographically and hydrogeologically separate the central section of the plain from the coastal Timpaki basin (Figs.

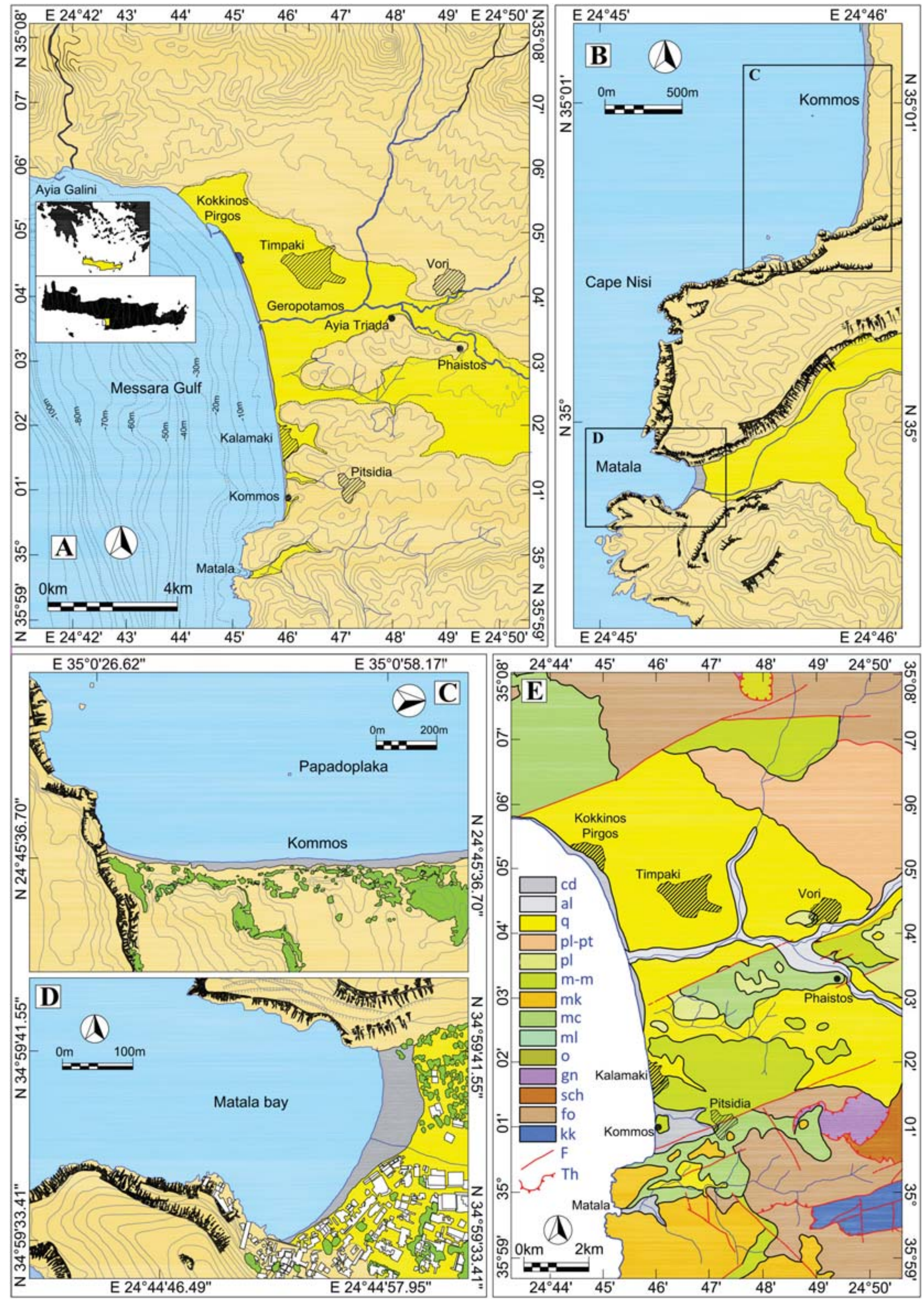


Fig. 1 - (**A**) Location map of the western Messara plain and its coastal zone. The ancient and modern settlements are indicated. (**B**) Location map of the coast of Kommos and Matala Bay. (**C**) Detailed location map of the coast of Kommos and the islet of Papadoplaka. (**D**) Detailed location map of Matala Bay. (**E**) Geological map of the Timpaki basin (modified from Bonneau et al., 1984). cd: coastal deposits, al: alluvial deposits, q: Pleistocene fluvial-lacustrine deposits, pl-pt: Plio-Pleistocene sands and clays, pl: Pliocene marine marls, m-m: Miocene marls, mk: Miocene marly limestones, mc: Miocene marine conglomerates and sands, ml: Miocene lacustrine clays and sands, o: Ophiolitic complex, gn: Gneiss, sch: Vatos schist, fo: Pindos flysch, kk: Pindos platy limestones, F: fault, Th: thrust.

1A, 1E). At a distance of ca. 5 km from the shore, on the ridge of the south hill range along the watercourse of the Geropotamos (Fig. 1A), the palatial sites of Phaistos and Ayia Triada developed a high-level social and economic organization throughout a prosperous cultural period between ca. 1900 BC and 1200 BC (Watrous et al., 1993, 2004; La Rosa, 2010a, b).

Cape Nisi lies at the southern end of the Messara coast. It is a rough headland with intricate coastline and steep cliffs that separates the beach of Kommos from the valley of Matala (Figs. 1A, 1B). The prehistoric Minoan harbour-side settlement of Kommos was a large, walled port complex, probably built by and under the central control of the palace at Phaistos or even ultimately Knossos (Watrous et al., 1993, 2004; Shaw, 2006; Shaw and Shaw, 2010). It is situated on the southernmost of the three bedrock ridges that extend northeast of Cape Nisi (Fig. 1B). At a distance of 285 m offshore there is a rocky reef called Papadoplaka, which is the only nearshore rocky reef along the elongated Messara beach (Fig. 1C). The modern morphology of the Kommos beach, exposed to the prevailing NW winds and gales, as well as the entire Messara coast, does not justify the establishment of a harbour-side settlement 5 km south of the mouth of the Geropotamos river, which is the nearest coastal area to the administrative centres of Phaistos and Ayia Triada (Fig. 1A). Therefore, the comparative advantage of the location would only be a sheltered coast that would allow the ships that were sailing towards Kommos to approach and anchor. Matala Bay (Fig. 1D), extensively settled during Greco-Roman times, was the main harbour town of the Hellenistic-Roman Messara (Sanders, 1982; Chatzi-Vallianou, 1995; Watrous et al., 1993, 2004).

Although the archaeological data is sufficiently strong to substantiate the importance of Kommos as a harbour during the Minoan Thalassocracy (Evans, 1928; Shaw, 2006; Shaw & Shaw, 2010) and of Matala as the gateway to the sea of Roman Gortyn (Lembesi, 1969; Sanders, 1982; Chatzi-Vallianou, 1995; Di Vita, 2010; Mourtzas, 2012a, b), several attempts to reconstruct the shoreline palaeogeography were lacking geoscientific evidence of both the changes in the sea level and the consequent sea transgression, as well as their impacts on the palaeogeographic configuration of the shore (Evans, 1928; Crile & Davaras, 1963; Blackman, 1973; Flemming, 1978; Shaw, 1990; Flemming & Pirazzoli, 1981; Gifford, 1995).

This paper primarily aims at defining the past sea levels in the Messara Gulf and Matala Bay, and the periods of their relative change, based on geomorphological markers, such as marine notches and beachrock generations. The dating of the deduced sea levels results from their correlation with the radiocarbon ages of the uplifted marine notches of western Crete (after Pirazzoli et al., 1982), with precise archaeological indicators, such as the Roman fish tanks and shipsheds, with abrupt historical changes, such as the archaeologically documented seismic disasters and the periods of abandonment of ancient settlements, and with historical sources, such as those concerning Matala Bay given by 14th and 16th century travellers. In a second step, the sea bottom morphology resulting from the underwater geological, geomorphological and bathymetric mapping, in reference to the former, dated, sea levels, has allowed the palaeogeographic reconstruction of the coast of Kommos and Matala during the last 5,000 years.

2. ARCHAEOLOGICAL AND HISTORICAL CONTEXT

Throughout history the western end of the Messara has been the most densely settled part of the plain because of its rich, alluvial bottomland, ample groundwater, and open coastline. The Bronze Age centres of Phaistos, Ayia Triada and Kommos, and the Roman capital of Gortyn, were located there (Watrous et al., 1993, 2004) (Fig. 1A). A significant demographic expansion seems to have been in western Messara from the Final Neolithic to the end of the Early Bronze Age with a number of sites dispersed along the foothills of the south bank of the Geropotamos and the higher south hill range of the Messara plain (Watrous et al., 1993, 2004). Phaistos was the largest settlement in western Messara, while the necropolis of Ayia Triada was connected with ritual practices and processions (La Rosa, 2010a, b). The hill range at Kommos seems to have been largely unsettled in this period with only sand accumulation and a few houses, especially on the sloping side of the southernmost hills (Shaw, 2006).

The Palace of Phaistos was founded at the beginning of the MM IB period (ca. 1900 BC) with the establishment of an autarchic theocratic power with a complex functional articulation and independent economic activity restricted to a limited number of persons controlling and sharing the agricultural and husbandry products (La Rosa, 2010a). During the same period, the ceremonies and processions continued in the necropolis of Ayia Triada, which was still subject to Phaistos (La Rosa, 2010b). In the successive quiet period of prosperity for western Messara, many sites were settled west of Phaistos, either not so far from the shore or close to it. It was during this period, on the hill range of Kommos, behind the protected, wide, sandy beach, that extensive settlement began. Houses with numerous rooms and storerooms were built on the hilltop and part of the hillside. The first large, civic, monumental building with a long covered stoa facing a central court, perhaps for a ritual use, was founded on a huge level platform set on the lower slopes of the Kommos hill. A broad east-west road cut into the hillside, led from inland to the shoreline (Shaw, 2006). At the end of this period, a series of strong earthquakes, the first probably occurring shortly before 1700 BC, the second only a few years later, and the third around 1600 BC, caused the definitive destruction of the Palace of Phaistos, which was then abandoned and left in ruins for more than a century and a half, and of the buildings in Ayia Triada, while abruptly demolishing the Minoan houses in Kommos (Shaw, 2006; La Rosa, 2010a, b).

After this huge natural disaster, the autarkic economic model of the Prepalatial Phaistos fell into crisis. Knossos seems to have absorbed the effects of the disaster and gradually progressed to its political control in central Crete. As a result, by the end of the 17th c. BC the so-called Royal Villa at Ayia Triada was probably founded, Ayia Triada had apparently become the administrative and economic capital of the ex-Phaistian kingdom in the Messara, and Kommos had strengthened its function as a large maritime establishment (La Rosa, 2010a, b). During the Neopalatial period (1625-1425 BC) Kommos had been significantly expanded. A broad paved road separated the houses that were located at the top and on the south slope of the hill from the civic buildings serving commercial purposes that were located next to the shore, on a level platform set on the lower slopes. An earthquake that occurred at some time before the end of the LM I period (ca. 1425 BC) put an end to the Royal Villa at Ayia Triada, while the harbour-side settlement of Kommos was ruined (Shaw, 2006).

The LM III period (1420-1200 BC) is one of maximum splendour for Ayia Triada, which apparently maintained its role as a centre of power over the surrounding territory. The first public building, the Megaron, was then built above the Royal Villa and inherited its function. Several changes in the LM IIIB period (1330-1200 BC) public space suggest that the political-religious structures that controlled it had perhaps become weaker until it ceased to exist as such by the LM III period (1330-1050 BC) (La Rosa, 2010a, b).

At Kommos, the renovation of older public buildings and the construction of new ones testify to a prosperity lasting until the end of LM IIIB, ca. 1200 BC, when the site was deserted (Shaw, 2006).

During the Protogeometric-Geometric period (ca. 1000-725 BC), Phaistos was a large fortified settlement and Ayia Triada and Kommos were sites of shrines. During the Geometric period, the port at Kommos re-established international connections overseas (Watrous et al., 1993, 2004). Around 1025 BC, the first Greek Temple A was founded at Kommos, above the Minoan Building T, whereas around 800 BC temple B was founded over temple A. Imports from other parts of the Aegean and the East, especially from Phoenicia, were found in the temples (Shaw, 1990, 2006; Shaw & Shaw, 2010). Toward the end of the Archaic period, ca. 625 BC, at a time of rich trading, the curious, long building Q was constructed south of the temple B (Shaw, 2006). During the late Classical and Hellenistic periods (ca. 400-30 BC), temple C was built above temple B, larger and better constructed than its predecessor, which was in turn abandoned around 150 AD (Shaw, 2006).

The political independence of western Messara ended in the mid-2nd c. BC, when Gortyn destroyed Phaistos and annexed its territory, while by the 1st c. BC, Gortyn controlled all of Messara. After the Roman conquest of Crete in 69 BC, Gortyn became the capital of the Roman province, which included Crete and Cyrenaica in North Africa. At this time, Gortyn expanded to become the largest city in Crete, with its own acropolis, agora, aqueduct, theatre, odeon, temples, public baths, nymphaeum, basilica, amphitheatre and stadium (Watrous et al., 1993, 2004; Di Vita, 2010). The overseas contacts of western Messara expanded considerably during the Early Roman period. The sanctuary at Kommos was apparently abandoned during the 1st c. AD, but the coastal port of Matala was probably not deserted until the end of the 5th c. AD (Watrous et al., 1993, 2004).

3. ARCHAEOSEISMOLOGY OF THE GRABEN OF MESSARA

Archaeological data enabled us to identify several phases of the construction, destruction and reconstruction of the buildings, which together with dated macroseismic effects, such as collapsed walls, cracks, displaced blocks, piles of fallen stones, and debris, allowed us to define the past earthquakes that affected the western Messara plain.

- In the settlement of Ayia Triada, a habitation quarter, attributed to a final stage of the EM IIA period (ca. 2400 BC), was abandoned as the result of an earthquake (La Rosa, 2010b).
- A strong earthquake, probably just before 1700 BC, destroyed the Palace and the houses of the Protopalatial settlement of Phaistos, which were never rebuilt (La Rosa, 2010a).
- A second earthquake at Phaistos at the end of the MM IIB period (ca. 1700 BC), only a few years after the earlier one, caused the definitive destruction of the First Palace and had heavy repercussions on the economic and political structures. In a massive operation, the ruins were levelled off and covered with a thick layer of *calcestruzzo*, in an attempt to construct a new palatial building during the following MM IIIA period (ca. 1700 BC). This seismic destruction, is mainly attested in Ayia Triada by the large dumps and the terracing containing pottery of that period (La Rosa, 2010a).
- A MM III (ca. 1700 BC) earthquake seems to have brought an abrupt end to the Middle Minoan houses at Kommos. There appears to have been such extensive damage that the notion of remodelling and reuse was generally rejected, in favour of building anew after appropriate levelling had taken place (Shaw, 2006; Shaw & Shaw, 2010).
- A new earthquake destroyed Phaistos toward the end of MM IIIA (ca. 1600 BC). The palace was completely abandoned and thereafter left in ruins for more than a century and a half (La Rosa, 2010a).
- A seismic event accompanied by a violent fire ended the life of the so-called Royal Villa at Ayia Triada, founded in the MM IIIA period (ca. 1700 BC), destroying the entire settlement toward the end of the LM IB period (ca. 1425 BC). The lack of bodies at the destruction levels implies a series of earthquakes, only the last of which occurred at a time in which many lamps and braziers were in use (La Rosa, 2010b). Building T, of palatial proportions, located next to the shore of Kommos for commercial purposes, was constructed at the beginning of the Neopalatial period (ca. 1600 BC). By the end of the LM I period (ca. 1425 BC) it lay in ruins, perhaps as a result of an earthquake (Shaw & Shaw, 2010).
- The second palace at Phaistos was reconstructed at the beginning of the LM IB (ca. 1600 BC). The reconstruction project was provided with a large monumental entrance and a fourth court was created on the eastern side of the building. This new palace had a short life, perhaps less than fifty years. It was most probably destroyed by an earthquake followed by fires (La Rosa, 2010a).

- The villa at Pitsidia, 2.5 km NE of Kommos, was built as a residential building in the Neopalatial period on earlier foundations assigned either to the Protopalatial period or even earlier. It was destroyed and completely abandoned in the LM IB period (ca. 1425 BC). The overall destruction patterns most likely indicate tremendous seismic destruction, before which the inhabitants had enough time to remove their most valuable items. The building was not repaired and the area was not reoccupied until much later during historic times (Vallianou, 1996).
- The Minoan settlements of Phaistos and Ayia Triada seem to have been destroyed by two major seismic events of potential magnitude 6.5 on the Richter scale with IX-X intensities that occurred at the end of the Protopalatial (ca. 1600 BC) and the Neopalatial (ca. 1425 BC) period, respectively. According to Monaco & Tortorici (2004), the successive Holocene activations of the adjacent Spili Fault and Ayia Galini Fault (Fig. 2A), under a NW-SE extensional stress regime, were responsible for the destruction of the Minoan sites of western Messara. However, this assumption was rejected by Mouslopoulou et al. (2012), who proved that the Spili Fault experienced a long phase of seismic quiescence during the Minoan period.
- Between the 4th and 7th c. AD, Gortyn was destroyed by three strong seismic events, while a destructive earthquake seems to have preceded during the 1st c. AD (Di Vita, 1995). The AD 62-64 earthquake (Ambraseys, 2009), which dated to 46 AD by Di Vita (1996), caused the partial destruction of Gortyn. During the AD 168 earthquake, some statues at the Praetorium in Gortyn may have been knocked down, while the Praetorium suffered damage and was rebuilt (Ambraseys, 2009). The seismic sequence of 365 AD was very strong and struck the whole eastern Mediterranean. The bath complex of Gortyn, erected upon the ruins of the 1st c. AD Gymnasium, collapsed along with other civic and private buildings of the town, while in its place the Praetorium was built, inaugurated in 383 AD (Stiros, 2010). Extensive destruction of the town corresponds to an earthquake during the Justinian period, between 527 and 565 AD (Di Vita, 1996) when the water supply system of Gortyn, consisting of an extensive network of pipes, was completely destroyed. The earthquake around 618-621 AD caused the extensive destruction of residential areas of Gortyn, which seem to have been subsequently rebuilt. The Basilica at Metropolis collapsed and the Novum Praetorium and the Great Nymphaeum were rebuilt (Di Vita, 1996). Following shortly after, the earthquake of 666 AD disrupted the urban fabric of Gortyn and only the Acropolis of the ancient urban centre survived (Di Vita, 1995).
- The 1604 AD earthquake (M=6.8) with its epicentre located offshore of the south coast of central Crete, caused land subsidence in the eastern and central part of the island (Georgiades, 1904; Papazachos & Papazachou, 1989; Platakis, 1950; Spyropoulos, 1997; Stavrakakis, 1890) and sunk the Roman fish tanks of Matala Bay (Mourtzas, 2012a, b; Mourtzas al., 2016).
- The very strong earthquake of 1856 (M=8.2), mentioned by Spratt (1865), completely destroyed Heraklion and the villages at the foot of Mt Psiloritis (Ida) and put an end to a long period of relative seismic quiescence.

4. RELATIVE SEA LEVEL CHANGES IN CRETE

Geomorphological survey along the coast of Crete revealed evidence of 11 uplifted and 4 submerged marine notches at 25 locations on western Crete and 14 locations on eastern Crete, 4 beachrock generations at 19 locations on western Crete and 25 locations on eastern Crete, and numerous relics of ancient coastal constructions at 47 locations throughout the coast of Crete (Mourtzas et al., 2016). The Late Holocene history of the relative sea level (r.s.l.) change in Crete is characterized by the gradual subsidence of its coast between 4200 BP and 1600 BP. The western part of the island gradually submerged by 3.90 m during ten successive tectonic subsidence episodes (Pirazzoli et al., 1982; Mourtzas et al., 2016). In the same period, four of them have been recorded in the eastern part, submerging it by 1.40 m more than the western part, thus reaching 5.30 m in total (Mourtzas et al., 2016) (Figs. 2C, 2D).

Although the earliest sea level stand at 6.55 ±0.55 m b.m.s.l. was identified throughout the eastern coast of Crete, evidence of dating was not found. Mourtzas et al. (2016) assumed that it might be related to the lowermost marine notch of western Crete dated to 4200 ±90 BP by Pirazzoli et al. (1982) (Fig. 2C). The change in the subsequent sea level probably occurred at some time before the establishment of the older phase of the Minoan centres around 2000 BC (Mourtzas et al., 2016; Mourtzas & Kolaiti, 2017a). The sea level stand at 3.95 ±0.25 m b.m.s.l. is dated to between 3900 and 3600 years before present, based on the Protopalatial period of the Prehistoric settlement of Kato Zakros (Mourtzas & Kolaiti, 2017a), the submerged Minoan quarry at Nirou Chani (Mourtzas, 1990; Mourtzas et al., 2016), the submerged Prehistoric settlement at Spiliada (Simosi, 2003), as well as the submerged isthmus of Minoan Mochlos (Leatham & Hood, 1958/59; Mourtzas, 1990; Soles, 2007) (Figs. 2B, 2C). The change in the next sea level at 2.70 ±0.15 m b.m.s.l. was abrupt and can be associated with the enhanced tectonic activity in the area of the south Aegean that accompanied the strong eruption of the Thera volcano between 1627 BC and 1600 BC (Friedrich et al., 2006; Mourtzas et al., 2016; Mourtzas & Kolaiti, 2017a). Based on the groundwater level rise in the Neopalatial water basins and wells of the Minoan palace of Kato Zakros (Mourtzas & Kolaiti, 2017a), this sea level stand is dated to between 1600 and 1200 BC (Figs. 2B, 2C). The 1.45 m r.s.l. rise to the next sea level stand at 1.25 ±0.05 m b.m.s.l., can be attributed to the destructive co-seismic tectonic events in the middle or at the end of the LM IIIB period, probably between 1225 and 1175 BC (Nur & Cline, 2000; Mourtzas et al., 2016; Mourtzas & Kolaiti, 2017a). Based on archaeological sea level markers and historical sources, the r.s.l. stand at 1.25 ±0.05 m b.m.s.l. is dated to the period between 400 BC and AD 1604 (Mourtzas, 2012a, b; Mourtzas et al., 2016). Robust evidence provides the submerged Classical temple of

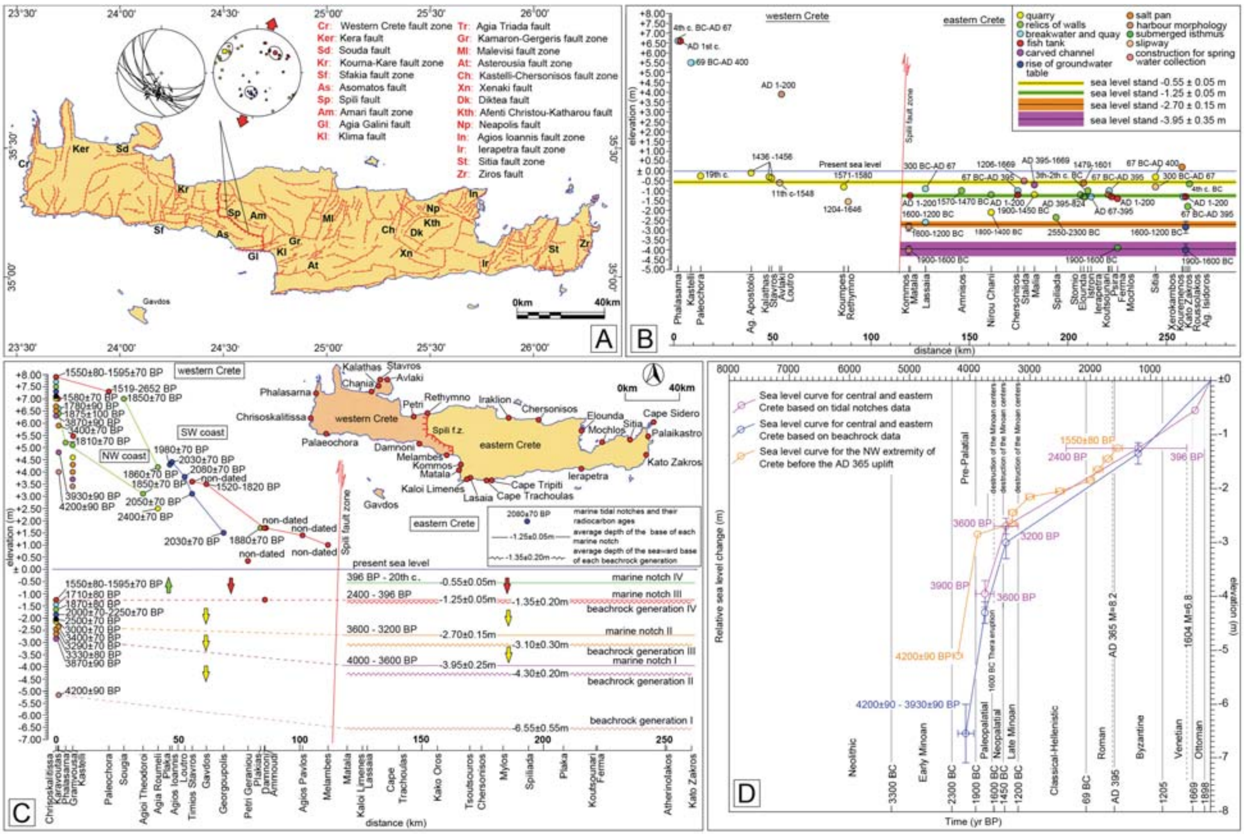


Fig. 2 - (**A**) Tectonic map of Crete. The major fault zones and faults of Crete are indicated by red lines. Thick lines show the neotectonic fault of Spili and its extensions across central Crete, which separate the western from the eastern tectonic block. Structural analysis of the Spili fault is also presented. (**B**) The functional height of the dated archaeological r.s.l. indicators in relation to the five sea level stands determined for Crete. **(C)** Comparison between the 14C dated marine notches of the westernmost part of Crete (after Pirazzoli et al., 1982), 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 (b.m.s.l.) 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 (a.m.s.l.) and dating of the uplifted marine notches of western Crete are shown on the upper left plot. The lower left plot indicates the depths (b.m.s.l.) of the marine notches of western Crete when the sea level on the entire island was at 1.25 ±0.05 m b.m.s.l. 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. (**D**) 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 b.m.s.l. (after Mourtzas, 2012a, b; Mourtzas et al., 2016). Error bars indicate time and depth uncertainties. Historical periods and major catastrophic events are also presented.

Samonio Athena (NE Crete), the Hellenistic and Roman harbours of Hersonisos, Ierapetra and Lasaia, the Roman fish tanks and other coastal installations along the coast of eastern Crete, the Byzantine and Venetian coastal installations at Elounda and Rethymno, as well as the inundated floors of the Venetian quarries of Koumpes, Stavros, Kalathas and Agioi Apostoloi (Blackman and Branigan, 1975; Mourtzas, 1990; Mourtzas & Marinos, 1994; Mourtzas & Kolaiti, 2017b) (Figs. 2B, 2C). According to historical sources, the AD 1604 paroxysmal event resulted in a r.s.l. rise by 0.70 m (Mourtzas, 2012a, b). Based on the submerged salt pans of Poros Eloundas and the slipway of Avlaki at Chania peninsula, the sea level stand at 0.55 ±0.05 m b.m.s.l. is dated to the 17th c. (Mourtzas et al., 2016) (Fig. 2C). The last change in the sea level to its current position had already happened before Evans visited Matala in 1924, as it is proved in this study.

When the sea level was at 1.25 ±0.05 m b.m.s.l., Crete was shocked by the severe earthquake of July 21, 365 AD (Pirazzoli, 1986a; Guidoboni et al., 1994). This seismic event split the island into two parts along the neotectonic graben of Spili (Figs. 2A, 2C). The uplifted marine notches at 1.00 ±0.15 m above mean sea level (a.m.s.l.) on the coast of Melambes (S Crete, easternmost tip of the western tectonic block, Fig. 2C) and at 0.35 ±0.05 m a.m.s.l on the coast of Petri Geraniou (N Crete, easternmost tip of the western tectonic block) both dated to 1550 BP, as well as the submerged Roman fish tanks and the related geomorphological features on the coast of Messara (S Crete, westernmost tip of the eastern tectonic block, Fig. 2C) and the slipway on the coast of Rethymno (N Crete, westernmost tip of the eastern tectonic block, Fig. 2C) precisely define a NW-SE trending tectonic boundary, which separates the western from the eastern tectonic block of Crete and corresponds to the neotectonic graben of Spili and its north and south prolongation (Figs. 2A, 2C). As a result of the AD 365 earthquake, the westernmost coast of the island uplifted by 9.15 ±0.20 m a.m.s.l. 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 b.m.s.l. after the AD 365 earthquake (Figs. 2B, 2C, 2D).

5. METHODS

The determination of the several sea level stands was based on geomorphological indicators such as tidal notches, marine terraces and beachrock generations.

Marine tidal notches are accurate indicators of former sea level stands (e.g. Carobene, 1972, 2015; Higgins, 1980; Pirazzoli, 1986b; Kelletat, 1997, 2005; Furlani et al., 2014; Antonioli et al., 2015; Trenhaile, 2015; Kolaiti, 2019 and references therein). Small-scale changes in the sea level can form a marine terrace inclined towards the sea, through a process of successive formation and collapse of notches, in continuously rising sea levels (Pirazzoli, 2005). Uplifted marine notches can be directly dated applying radiocarbon dating on the marine organisms that form the biological rim covering part of the notch (Laborel & Laborel-Deguen, 1996). Dating of submerged notches is indirectly achieved by correlating their elevation with other datable markers (Antonioli et al., 2015), as it is also attempted in the present study. During the present underwater snorkelling survey, we measured the morphometric features (opening, inward depth, base width) and elevation of the base of the tidal notches, which represents or is slightly below the mean sea level (e.g. Kelletat, 1997, 2005; Antonioli et al., 2015; Kolaiti, 2019). The length, gradient and elevations of the inner shoreline angle (landward end) and outer edge (seaward end) of each marine terrace were also measured.

Beachrocks are formed along the shoreline in the intertidal zone, under complex physicochemical and biological cementation processes. In the microtidal Aegean environment, where the maximum tidal range does not exceed 0.30 m, the cementation exceeds the tidal range and expands into the swash, saturated zone (e.g. Bernier & Dalongenvile, 1996). The geological field observation and the correlation of the current position of beachrocks above or below the sea level with other geomorphological and precise archaeological sea level markers give us the possibility to define the cementation environment and the relation between beachrocks and former sea levels. From the systematic observation and mapping of widespread uplifted or submerged beachrocks throughout the Aegean (Crete, Northern Cyclades, Saronic Gulf, Eastern Peloponnese, Euboean Gulf, Corinth Gulf, Lesvos island) and their correlation with other sea level indicators, we can deduce that the seaward base of a beachrock slab in its well-preserved parts that have not undergone erosion or fragmentation represents the mean low tide of a former sea level (Mourtzas et al., 2016; Kolaiti, 2019). The constant supply of sediments and their cementation in the zone of saturation can produce a beachrock slab thicker than the tidal range. Different sea level stands form distinct beachrock slabs at several elevations that correspond to different generations of a fossilized palaeoshoreline. A strip of sand between two distinct beachrock generations represents a period of r.s.l. change (e.g. Kambouroglou, 1989; Mourtzas, 1990, 2018; Desruelles et al., 2009; Vacchi, 2012; Mourtzas et al., 2016; Karkani et al., 2017; Kolaiti et al., 2017; Kolaiti 2019).

At Kommos, beachrock cements of multiple morphologies reflect diagenesis in environments ranging from marine phreatic (intertidal) to vadose (near-surface soil) zones (Gifford, 1995). On the Kalamaki coast, 1.5 km to the north of Kommos, the beachrock composition shows an intertidal diagenesis (Neumeier, 1998).

A detailed mapping of the distinct beachrock generations throughout the shore of the Messara Gulf and Matala Bay was conducted in the present survey (Figs. 3, 4A, 5). For this purpose, at both sites, aerial photogrammetric surveys were initially carried out by an unmanned autonomous vehicle (UAV) followed by underwater mapping. The length, width and thickness, as well as the depth of the seaward and landward end of the top and bottom of each beachrock generation were measured. Most of the beachrock generations are intact and well-preserved in terms of erosion and fragmentation. On the coast of Messara measurements were conducted per 150 - 200 m for a total length of 4,800 m (Fig. 3B, 4A). On the Matala coast, depths were measured at selected points of each beachrock slab that has not undergone erosion or fragmentation, covering the entire occurrence (Fig. 3A).

The fish tanks and the accompanying fish traps constitute the predominantly accurate archaeological indicators of the sea level when they were in use (e.g. Lambeck et al., 2004; Auriemma & Solinas, 2009; Mourtzas, 2012a, b; Benjamin et al., 2017). The ancient shipsheds/slipways are also precise indicators of the r.s.l. change. The contemporary submerged or uplifted position of the seaward end of the sloping floor of the slipways reflects the direction and magnitude of the r.s.l. change since the period they were in use (Mourtzas et al., 2016; Benjamin et al., 2017; Kolaiti, 2019). The archaeological indicators presented herein are the result of long-lasting geoarchaeological studies either already published or presented briefly for the first time in this study. The fish tanks and fish traps of the south rocky coast of Matala Bay (Fig. 3A) have been previously surveyed and the relation of their functional features to the sea level at the period that they were used has been interpreted (Mourtzas, 2012a, b). Identifying and recording the northern, now submerged, seaward end of the sloping floor of the Roman slipway on the south coast of Matala Bay (Fig. 3A) enabled us to revise the complicated views on the tectonics (Flemming, 1978; Flemming & Pirazzoli, 1981) and the corresponding fluctuations in sea level (Blackman, 1973; Gifford, 1995).

The underwater morphology was mapped using

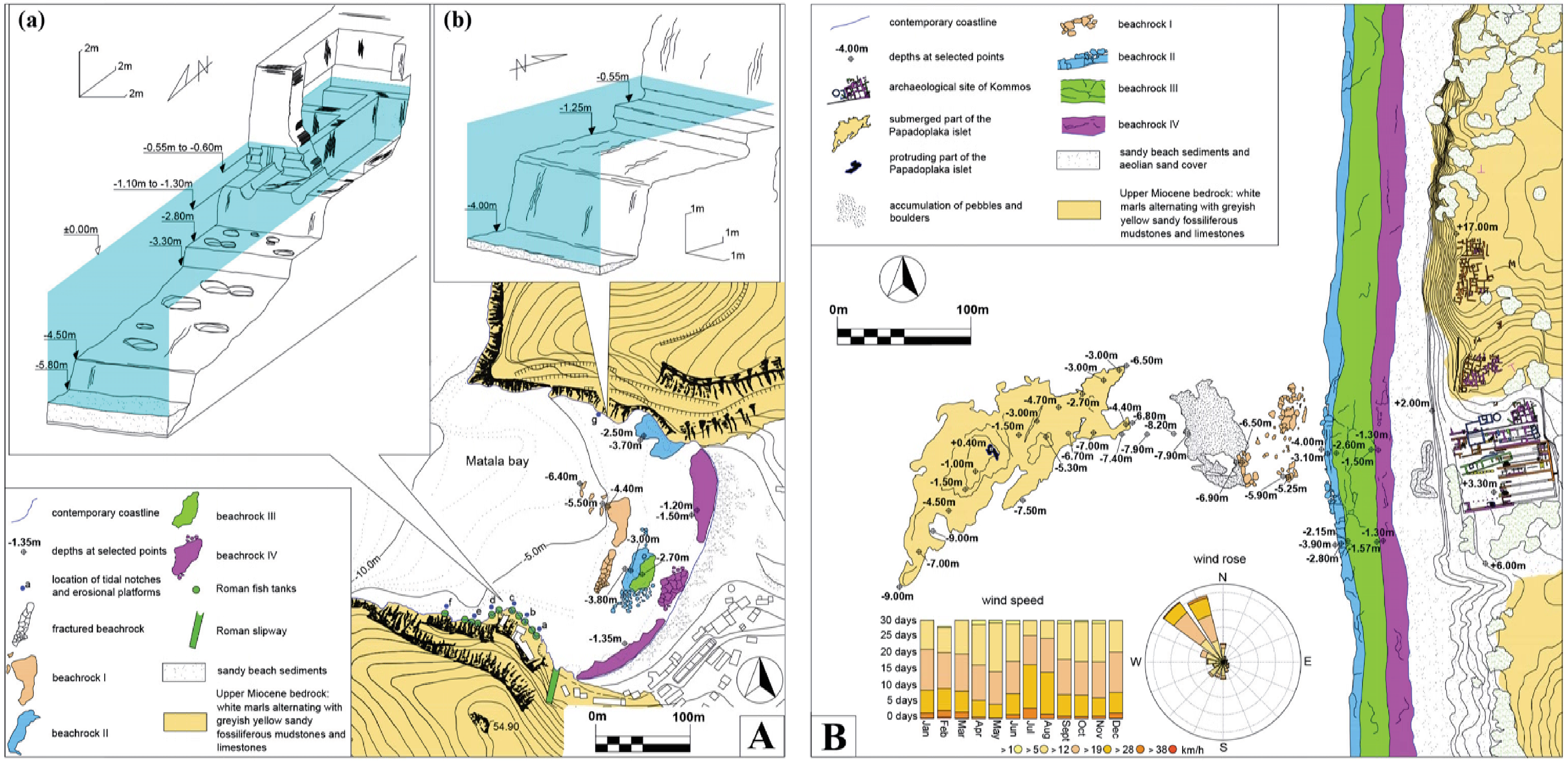


Fig. 3 - (**A**) Matala Bay. The geomorphological features (marine terraces, tidal notches, beachrock generations) and the archaeological remains (Roman fish tanks and slipway) are depicted. (**a**): 3D plan of a fish tank located on the south rocky coast of the bay. The constructional details (channels, entrance, compartments, sidewalks), the marine terraces and tidal notches that have formed in the seaward part of it are shown. (**b**): The marine terraces and tidal notches formed on the north cliff of the bay. (**B**) Coast of Kommos. The geomorphological features (beachrock generations, submerged part of the islet and contemporary rocky reef, aeolian sand cover) and the ancient remains of Kommos site are depicted. A wind rose diagram showing the average monthly wind speed and direction frequencies is presented .
(data from: http://www.hnms.gr/emy/el/forecast/meteogramma_emy?perifereia=Crete&poli=Tympaki)

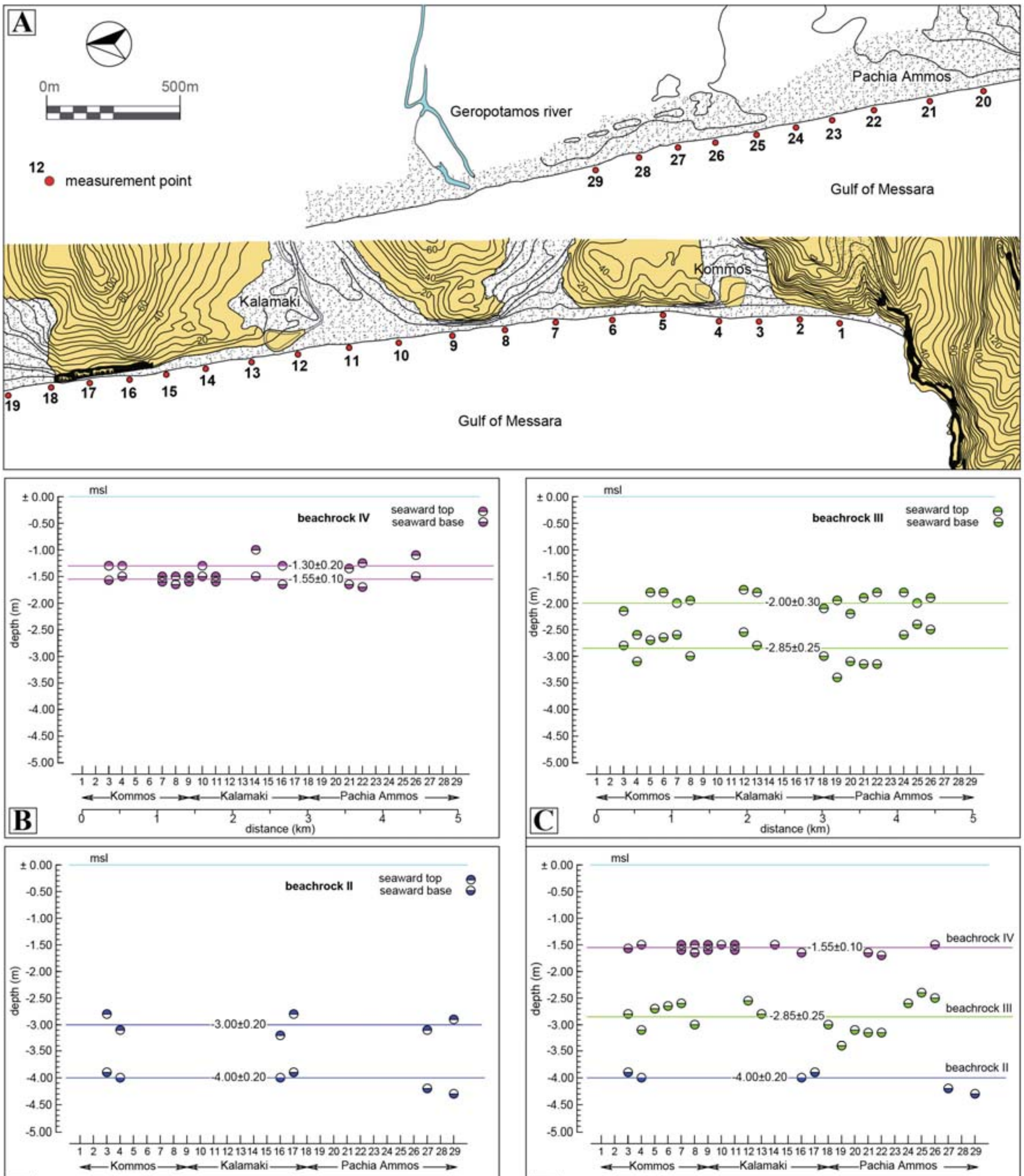


Fig. 4 - (**A**) Topographic map of the coastal zone of Messara that indicates the measurement points of the several beachrock generations. (**B**) Depth diagram of the beachrock generation (IV). (**C**) Depth diagram of the beachrock generation (III). (**D**) Depth diagram of the beachrock generation (II). (**E**) Combined depth diagram of all beachrock generations along the coast of Messara. All depth measurements of the several beachrock generation are presented in Table II. (m.s.l.: mean sea level)

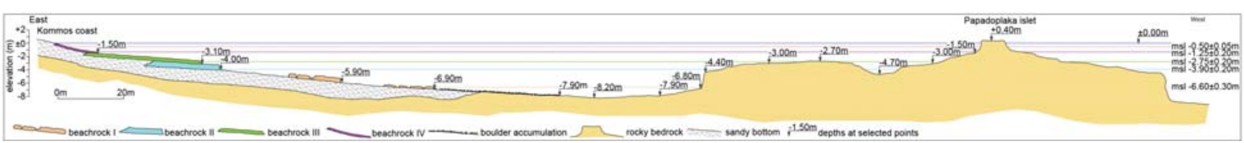


Fig. 5 - E-W cross-section showing the geomorphological features and depths/elevations between the Kommos coast and Papadoplaka islet as well as the former sea levels.

satellite images (Google Earth Pro, v. 7.3.2) and high-resolution orthophotos on a scale of 1:500 (Ktimatologio S.A.), after having conducted aerial photogrammetric surveys by UAV. The map produced was updated during snorkelling surveys.

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. An accuracy of ±1 cm along the vertical is routinely estimated (e.g. Antonioli et al., 2007). The measurements were repeated in two or three different survey periods. To account for tides, observational data have been corrected for tide values at the time of surveys with respect to mean sea level, using tidal data from the Hellenic Navy Hydrographic Service from the closest tide-gauge station at Ierapetra. For each depth measurement, the difference in the tidal sea level at the time of surveys from the mean sea level of the tide-gauge station is added or deducted accordingly. Crete belongs to the microtidal Aegean environment, and therefore sea level corrections during surveys were in the range of 0.04 to 0.15 m. The depth measurements at locations remote from the tide-gauge reference station are further corrected for the effect of atmospheric pressure on the sea level. As the standard pressure is 1013 hPa, a lower pressure will allow the tide to rise more, while the reverse is true for higher pressure. For each unit of the measured pressure less than the standard, the sea level is increased by 1 cm while for each unit higher than the standard pressure, the sea level is reduced by 1 cm; therefore, the correction is varied accordingly by ±1 cm/hPa (Pugh, 1982). Data for atmospheric pressure at the time of surveys are retrieved from the web site meteo.gr of the National Observatory of Athens or from a portable station measuring the atmospheric pressure in the field and then measurements are corrected. Therefore, all depths reported herein correspond to depths below the mean sea level (b.m.s.l.).

6. RESULTS: SEA LEVEL INDICATORS IN THE MESSARA GULF AND MATALA BAY

6.1. Geomorphological indicators

6.1.1. Tidal notches and marine terraces

On the south rocky coast of Matala Bay (Fig. 6a), consisting of hard marly limestones, two marine tidal notches and two marine terraces were found (Tab. I; Figs. 3A, 6c, h, i). The deepest marine terrace (IV), is located at the westernmost side of the coast, where the bottom depths are higher (up to 6 m) than those of the shallower eastern side (up to 4 m). It is up to 6 m wide, has a gradient of 8° seawards and its inner shoreline angle (landward end) is at 3.80 ±0.10 m b.m.s.l. The marine terrace (III), on the eastern part of the south coast is up to 4 m wide, has a gradient of 10° seawards and its average inner shoreline angle is at 2.70 ±0.20 m b.m.s.l. On the surface of both terraces sizeable potholes with diameters up to 1.50 m and inward depths of up to 1 m have been created, indicating an active wave-surge zone around the sea level. Marine tidal notch (II), with its base at 1.20 to 1.30 m b.m.s.l., is observed all along the south coast as a horizontal groove of an opening of 0.30 m and inward depth 0.35 m. Its base is better developed compared to its roof, reaching a width of 1 m. The uppermost tidal notch (I) is also observed throughout the south coast, with an opening of 0.30 m and inward depth 0.25 m. Its base is at 0.50 m to 0.60 m b.m.s.l. (Tab. I).

Along the north rocky protected coast of Matala Bay (Fig. 6a), only the two tidal notches were observed, with their base at 1.25 ±0.05 m (II) and 0.55 ±0.05 m (I) b.m.s.l. The base width of the deepest of these notches (II) reaches 1.50 m (Tab. I; Figs. 3A, 6b).

On the carbonate rocky coast of Kaloi Limenes, 8 km southeast of Matala on the south coast of Crete (Fig. 2C), Mourtzas (1990) identified three submerged marine tidal notches with their base at 3.70 m, 1.10 m and 0.50 m b.m.s.l. At a distance of 12 km further east, around the limestone cape of Trachoulas, three submerged notches were also identified, at 3.90 m, 1.10 m and 0.50 m b.m.s.l. The three notches were also observed at Tripiti Cape, 1.5 km further east on the south coast of Crete, with their base at 3.70 m, 1.30 m and 0.50 m b.m.s.l. (Tab. I).

Two submerged marine tidal notches run along the carbonate cliff of Traphos Island in Lasaia Bay (Fig. 2C), with their base at 1.25 m and 0.60 m b.m.s.l. The deeper notch is also incised in the submerged breakwater of the ancient harbour of Lasaia, with its base at 1.20 m b.m.s.l. and an opening of 0.40 m. (Tab. I).

6.1.2. Beachrock generations

The deepest beachrock generation (I) has been mapped in the Matala Bay (Figs. 3A, 6a) and at Kommos (Figs. 3B, 4A, 7f). At Kommos, the beachrock (I) extends to a width of ca. 45 m, with its seaward and landward end appearing intact to slightly fragmented, without blocks having been moved from their original position. In its intermediate portion, it is very fragmented with sporadic occurrences of 1.50 m to 3 m-long slabs. The base of its seaward and landward end is at 6.90 m and 5.90 m, respectively, and its top at 6.50 m and 5.25 m b.m.s.l., respectively (Tab. II; Figs. 3B, 4A, 7h). At Matala, the seaward end of the beachrock (I) is very fragmented in slabs lying to a depth of 6.40 m b.m.s.l. The landward end is intact, with its base at 5.50 m and the top at 4.40 m b.m.s.l. (Tab. II; Figs. 3A, 6a, d).

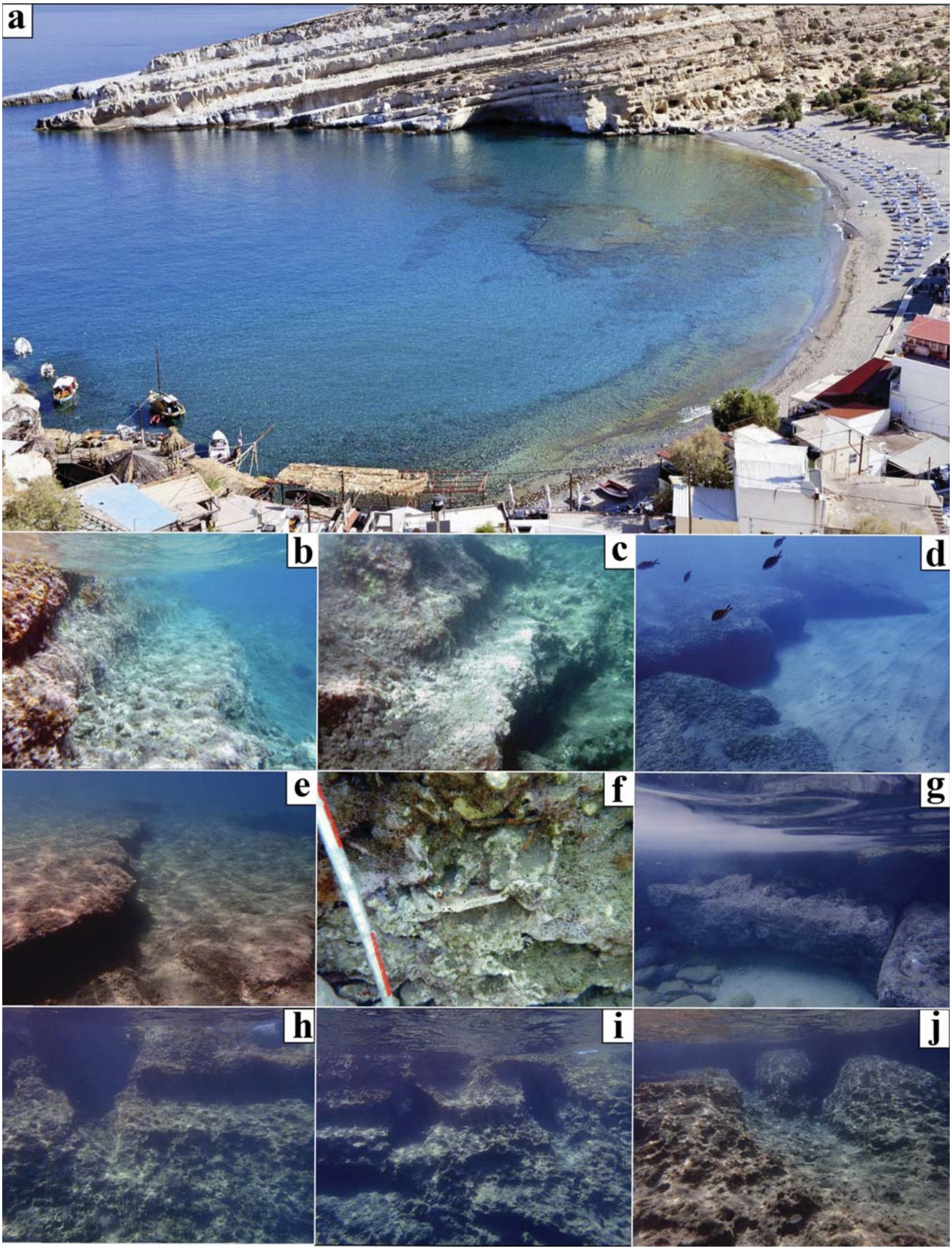
At the beach of Messara, the beachrock (II) appears mostly intact, with only partial fragmentation and dislocation towards its seaward end, the base of which is between 3.80 m and 4.30 m and its top between 2.80 m and 3.20 m b.m.s.l. (Tab. II; Figs. 3B, 4A, 4D, 5, 7i, j, k, l). At Matala, the beachrock (II) was found in the central part of the bay 45 m offshore. It is presented as a limited-size slab, measuring 35 m x 10 m, with its northern and southern end highly fragmented. The seaward base is at 3.80 m and the top at 3 m b.m.s.l. It is also observed inside a cavity on the north rocky coast of Matala, with the base and top of its seaward end at 3.70 m and 2.50 m b.m.s.l., respectively (Tab. II; Figs. 3A,

location of measurements			depth b.m.s.l. (m)							
location	shown on Figure	coordinates	tidal notch (I)	tidal notch (II)	marine terrace (III)		marine terrace (IV)		tidal notch (IV)	sea bottom
			base	base	inner shoreline angle, landward	outer edge, seaward	inner shoreline angle, landward	outer edge, seaward	base	
Matala bay southern rocky coast	Fig. 3A, a	34°59'35.44"N 24°44'50.37"E	0.55 ±0.05	1.20 ±0.05	2.40 ±0.10					3.50 ±0.10
	Fig. 3A, b	34°59'35.63"N 24°44'50.29"E	0.60 ±0.05	1.25 ±0.05	2.10 ±0.10	2.80 ±0.10				3.90 ±0.10
	Fig. 3A, c	34°59'36.02"N 24°44'49.74"E	0.60 ±0.05	1.20 ±0.05	2.85 ±0.10					3.90 ±0.10
	Fig. 3A, d	34°59'36.16"N 24°44'49.53"E	0.60 ±0.05	1.30 ±0.05	2.80 ±0.10					3.90 ±0.10
	Fig. 3A, e	34°59'35.97"N 24°44'47.29"E	0.55 ±0.05	1.25 ±0.05			3.80 ±0.10	4.50 ±0.10		5.80 ±0.10
	Fig. 3A, f	34°59'36.10"N 24°44'46.59"E	0.60 ±0.05	1.20 ±0.05	2.70 ±0.10	3.80 ±0.10				6.10 ±0.10
Matala bay northern rocky coast	Fig. 3A, g	34°59'42.80"N 24°44'53.76"E	0.55 ±0.05	1.25 ±0.05						4.00 ±0.10
Kaloi Limenes	Fig. 2C	34°55'25.27"N 24°47'23.30"E	0.50 ±0.05	1.10 ±0.05					3.70 ±0.10	4.00 ±0.10
Lasaia		34°56'12.80"N 24°49'28.34"E	0.60 ±0.05	1.25±0.05						2.80 ±0.10
Cape Trachoulas		34°55'43.93"N 24°57'16.83"E	0.50 ±0.05	1.10 ±0.05					3.90 ±0.10	11.0 ±0.10
Cape Tripiti		34°55'53.36"N 24°58'49.06"E	0.50 ±0.05	1.30 ±0.05					3.70 ±0.10	13.0 ±0.10
Average depth b.m.s.l. (m)			*0.50 ±0.05*	*1.25 ±0.05*	*2.70 ±0.20*		*3.80 ±0.10*		*3.80 ±0.10*	

Tab. I - Depths of tidal notches and marine terraces measured in the bay of Matala. Values correspond to depths below the mean sea level (b.m.s.l.), according to the methodology presented in section 5.

location of measurements (shown on Fig. 3B, 4A)		beachrock (IV)				beachrock (III)				beachrock (II)				beachrock (I)			
		depth b.m.s.l. (m)		length	width	depth b.m.s.l. (m)		length	width	depth b.m.s.l. (m)		length	width	depth b.m.s.l. (m)		length	width
		top	base	(m)	(m)	top	base	(m)	(m)	top	base	(m)	(m)	top	base	(m)	(m)
Messara Gulf	1																
	2																
	3	1.30	1.57	29	0.27	2.15	2.80	30	0.75	2.80	3.90	5.50	1.10				
	4	1.30	1.50	12	0.20	2.60	3.10	32	0.50	3.10	4.00	8.00	0.90	6.50	6.90	42	0.40
	5					1.80	2.70	24	0.90								
	6					1.80	2.65	23	0.85								
	7	1.50	1.60	16	0.10	2.00	2.60	25	0.60								
	8	1.50	1.65	20	0.15	1.95	3.00	26	1.05								
	9	1.50	1.60	19	0.10												
	10	1.30	1.50	18	0.20												
	11	1.50	1.60	25	0.10												
	12					1.75	2.56	23	0.80								
	13					1.80	2.80	20	1.00								
	14	1.00	1.50	10	0.50												
	15																
	16	1.30	1.65	17	0.55					3.20	4.00	68	0.80				
	17									2.80	3.90	74	1.10				
	18					2.10	3.00	56	0.90								
	19					1.95	3.40	60	1.45								
	20					2.20	3.10	60	0.90								
	21	1.35	1.65	17	0.30	1.90	3.15	60	1.25								
	22	1.25	1.70	16	0.45	1.80	3.15	56	1.35								
	23																
	24					1.80	2.60	63	0.80								
	25					2.00	2.40	60	0.40								
	26	1.10	1.50	14	0.40	1.90	2.50	65	0.60								
	27									3.10	4.20	79	1.40				
	28																
	29									2.90	4.30	73	1.40				
Matala Bay (Fig. 3A)		1.20	1.35 - 1.50	35	0.30	2.70	3.00	25	0.30	3.00	3.80	30	0.80	6.00	6.40	40	0.30
Average depth b.m.s.l. (m)		*1.30 ±0.20*	*1.55 ±0.10*			*2.00 ±0.30*	*2.85 ±0.25*			*3.00 ±0.20*	*4.00 ±0.20*			*6.25 ±0.25*	*6.60 ±0.30*		

Tab. II - Depths of the several beachrock generations recorded and measured in the Messara Gulf and Matala Bay. Depth values correspond to depths below the mean sea level (b.m.s.l.). The top and base correspond to the seaward part of each beachrock generation, according to the methodology presented in section 5.


a
b
c
d
e
f
g
h
i
j

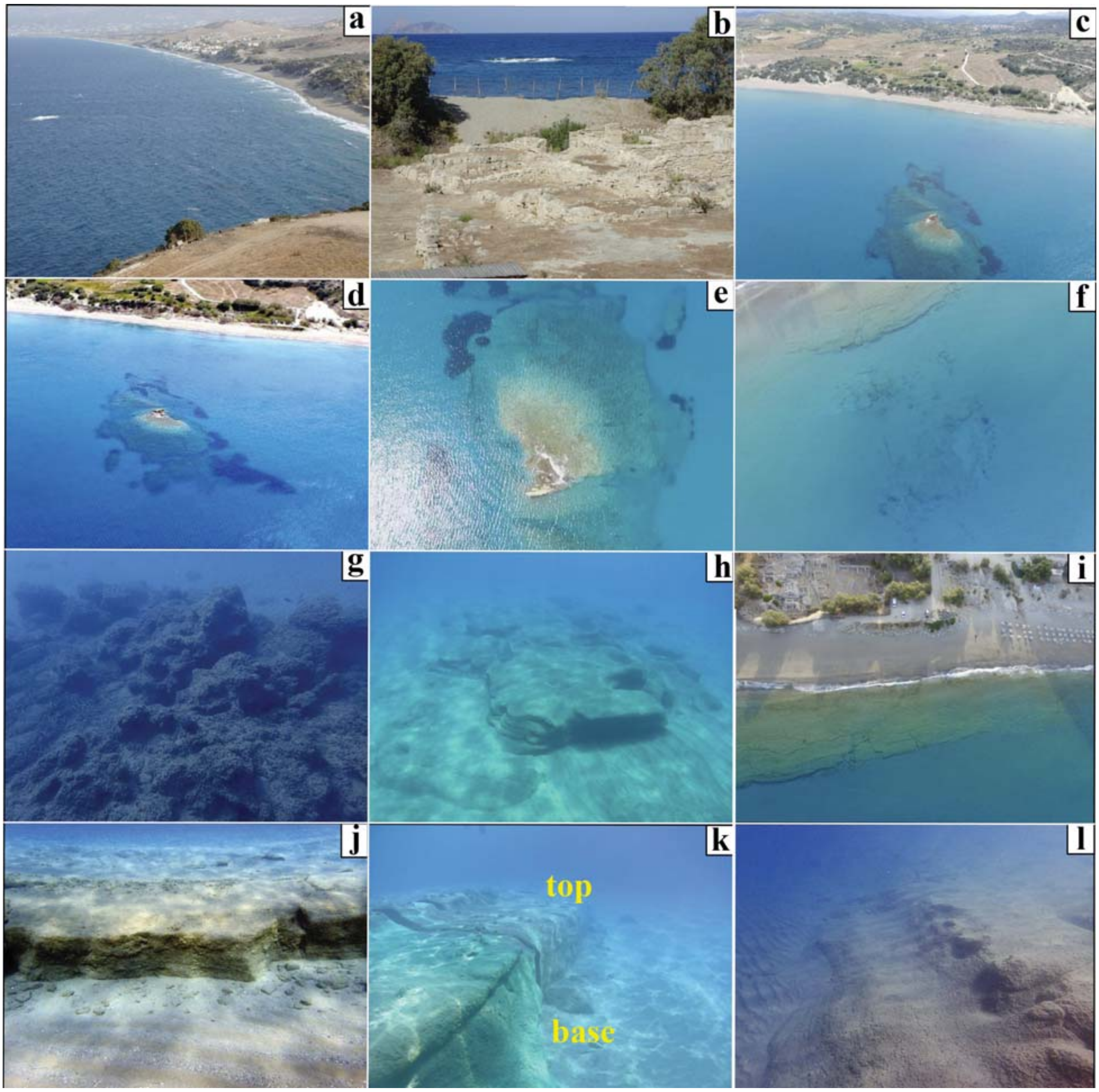


Fig. 7 - Gulf of Kommos. (**a**) View from the south. The sandy beach and the rocky reef of the Papadoplaka islet are shown. (**b**) View of the contemporary rocky reef of Papadoplaka islet from the archaeological site of Kommos. (**c**, **d**, **e**) Aerial views of the submerged part of the Papadoplaka islet and the contemporary rocky reef (source: https://vimeo.com/groups/313728/videos/129287824). (**f**) Aerial view of the sea bottom between the shoreline and the islet offshore. The submerged beachrock generations and the accumulation of boulders are shown. (**g**) Underwater view of the accumulation of boulders at the sea bottom between the oldest beachrock generation (I) and the islet. (**h**) Underwater view of the oldest beachrock generation (I) at 6.90 m b.m.s.l. (**i**) Aerial view of the three younger beachrock generations (II, III and IV), the beach and the archaeological site of Kommos. (**j**) Underwater view of the three younger beachrock generations (II, III and IV) that overlap each other producing a staired morphology. (**k**, **l**) Underwater views of the beachrock generation (III) that overlaps the older beachrock generation (II), creating a staired morphology.

<<<<<<<< --

Fig. 6 - Bay of Matala. (**a**) View from the south (source: https://www.google.com/search?q=matala+photo+by+sky&ved=isch&ved). The four submerged beachrock generations are distinguished. Underwater views of: (**b**) The marine tidal notches and marine terraces of the north rocky coast, (**c**) The tidal notches of the south rocky coast, (**d**) The oldest beachrock generation (I), (**e**) The beachrock generation III partly overlaps the older beachrock generation (II), (**f**) Potsherds incorporated into the youngest beachrock generation (IV), (**g**) The seaward end of the sloping floor of the slipway, beneath the modern embankment, (**h**) The marine notch of 1.25 m b.m.s.l., at the base of which the channel of the fish tank was cut, (**i**) The two tidal notches at 1.25 m and 0.60 m b.m.s.l.; on the base of the deepest notch, the channel of the fish tank was cut, (**j**) The rock-cut channels and the entrances of the fish tank.

6e).

The beachrock generation (III), which overlaps the earlier beachrock generation (II), is observed both along the sandy coast of Messara and at Matala. It forms an overlying slab 0.30 m to 0.50 m thick. The base and top of its seaward end at Kommos is at 2.85 ±0.25 m and 1.95 ±0.25 m, respectively (Tab. II; Figs. 3B, 4A, 4C, 5, 7j, k, l) and at Matala at 3 m and 2.70 m b.m.s.l., respectively (Tab. II; Figs. 3A, 6e).

Finally, the beachrock generation (IV) develops along the entire length of the Messara beach and the Matala coast. At Kommos, it overlaps the earlier beachrock generation (III) and forms an overlying slab 0.20 m to 0.30 m thick. The base and top of its seaward end is at 1.50 m and 1.30 m, respectively (Tab. II; Figs. 3B, 4A, 4B, 5, 7i). On the northern and southern side of the sandy coast of Matala, it appears intact with lots of potsherds incorporated into it (Fig. 6f), whereas only its central portion is extensively fragmented. The base of its seaward end is at 1.35 m to 1.50 m and the top at 1.20 m b.m.s.l. (Tab. II; Figs. 3A, 6a).

To summarize, four distinct beachrock generations have been recorded along the coast of Messara and Matala. The depths of the seaward end of each generation are: 6.60 ±0.30 m (I), 4.00 ±0.20 m (II), 2.85 ±0.25 m (III) and 1.55 ±0.10 m (IV) (Tab. II; Fig. 4E). These depths are consistent with the depths of the respective beachrock generations that were found along the entire length of the Cretan coast at 6.55 ±0.55 m, 4.30 ±0.20 m, 3.10 ±0.30 m and 1.35 ±0.20 m b.m.s.l. (Mourtzas et al., 2016).

6.2. Archaeological markers

6.2.1. Roman fish tanks

The submerged fish tanks on the southern cliff of Matala Bay are impressive monuments from Roman times, not only in terms of their use and functionality but also concerning their construction technique. A detailed survey of the seven - out of a total of eleven – well-preserved, submerged fish tanks along a ca. 140 m stretch of coast was carried out by Mourtzas (1990, 2012a, b). They are tanks entirely cut into the rock, usually in the form of parallelograms with sides 3.50 m to 6 m long, each one covering an area of 11 m^2 to 20 m^2. They were designed carefully and constructed diligently, so as to recreate the natural habitat of the fish. The renewal and ventilation of the water was achieved through channels, one per each seaward entrance. They were carved exactly at the same elevation as the then sea level so as to communicate with the sea. Continuous waves striking the exposed rocky coast would refresh the sea water in the interior of the tank, so as to retain a high oxygen percentage. A partition of intact rock, 0.30 m to 0.50 m wide and 1.35 m to 1.50 m high, divided the fish tanks into two compartments, each one 1.50 m to 2.30 m wide, so as to separate fish according to size and species. The inward depth of the cutting of the tanks from the upper surface of the surrounding rock varies from 1 m to 5 m. All around the tanks there are sidewalks, 0.45 m to 0.70 m in width and 1.35 m to 1.50 m in height above the tank floor, which permit access at any point for both the feeding and the catching of fish. At some entrances, pairs of carved grooves are preserved, which served the purpose of sliding sluice gates in and out to prevent fish from escaping (Fig. 3A). The fish traps that usually accompany the fish tanks, and in some cases communicate with them, are ellipsoidal or parallelograms, featuring carved channels on their seaward side that permitted communication with the sea. Fish entered the tank through the channel, possibly with bait placed inside them, and subsequently entrapped (Mourtzas, 2012a, b).

The channels that ensured communication of the tanks with the sea have been carved at the base of a well-preserved marine notch at the depth of 1.25 ±0.05 m, with their upper part to be at the same elevation as the then mean sea level (Figs. 3A, 6h, i, j). With the inner depth of the channels at 0.30 m, even at low tide (that is 0.20 m b.m.s.l.), the sea water in the tank could be renewed through the channel (Mourtzas, 2012a, b; Kolaiti 2019).

6.2.2. The slipway

The slipway at the SE corner of the rocky coast of Matala, just to the east of the fish tank (I) (Fig. 3A), is a deep cutting in the bedrock, 36 m long, 5.50 m wide, with a maximum depth of 12 m. The rock-cut sloping floor of the cutting starts at an altitude of 8 m, has a gradient of 14° seawards, and ends underwater with its deepest trace at a depth of 1.14 m. According to Blackman (1973), who first described it, the slipway would have been covered with a gable roof with a sloping ridge -beam or a horizontal-ridged gable roof with two or three steps. However, no trace is now preserved. The seaward end of the sloping floor today is covered with concrete to form the floor of a modern tavern. The side walls of the slipway protrude from the modern embankment and extend northward to the sea. The underwater survey revealed the sloping floor of the slipway underneath the concrete, projecting about 0.40 m from it towards the sea, with its edge at a depth of 0.42 m. There, it is abruptly disrupted, apparently due to its destruction, but clear carved lateral traces are preserved up to a depth of 1.14 m before it ends in the sandy bottom (Fig. 6g).

7. INTERPRETATION AND DISCUSSION

7.1. Correlation between geomorphological and archaeological markers, determination and dating of former sea level stands

The formation and evolution of the geomorphological r.s.l. indicators in relation to the archaeological r.s.l. markers, their correlation, the respective sea level stands, their dating and the curve of the r.s.l. change are shown on Figs. 8, 9 and 10.

Comparing the depths of the distinct beachrock generations (seaward base) with those of the marine terraces (inner shoreline angle) and tidal notches (base), a good correlation between them can be deduced that suggests the same sea level stands during their formation (Fig. 10A; Tabs I, II). The beachrock generation (II), at 4.00 ±0.20 m b.m.s.l., matches the marine terrace (IV) and the tidal notch (IV), both at 3.80 ±0.10 m b.m.s.l. The beachrock generation (III), at 2.85 ±0.25 m b.m.s.l., agrees with the marine terrace (III), at 2.70 ±0.20 m b.m.s.l. The depth of the top and base of the youngest beachrock (IV), between 1.30 ±0.20 m και 1.55 ±0.10 m b.m.s.l., respectively, is consistent with the marine notch (II), at 1.25 ±0.05 m b.m.s.l. This is the sea level stand when the Roman rock-cut constructions in the south coast of Matala Bay were in use, thus dating it to from the 1st to the 4th c. AD. As far as the youngest marine notch (I) at 0.50 ±0.05 m b.m.s.l. and the earliest beachrock generation (I) at 6.60 ±0.30 m b.m.s.l. are concerned, comparable beachrocks and marine notches, respectively, were not found. Based on the geomorphological indicators of the r.s.l. change and by correlating them, five distinct sea levels at 6.60 ±0.30 m, 3.90 m ±0.20 m, 2.75 ±0.20 m, 1.25 ±0.20 m and 0.50 ±0.05 m can be determined (Fig. 10B).

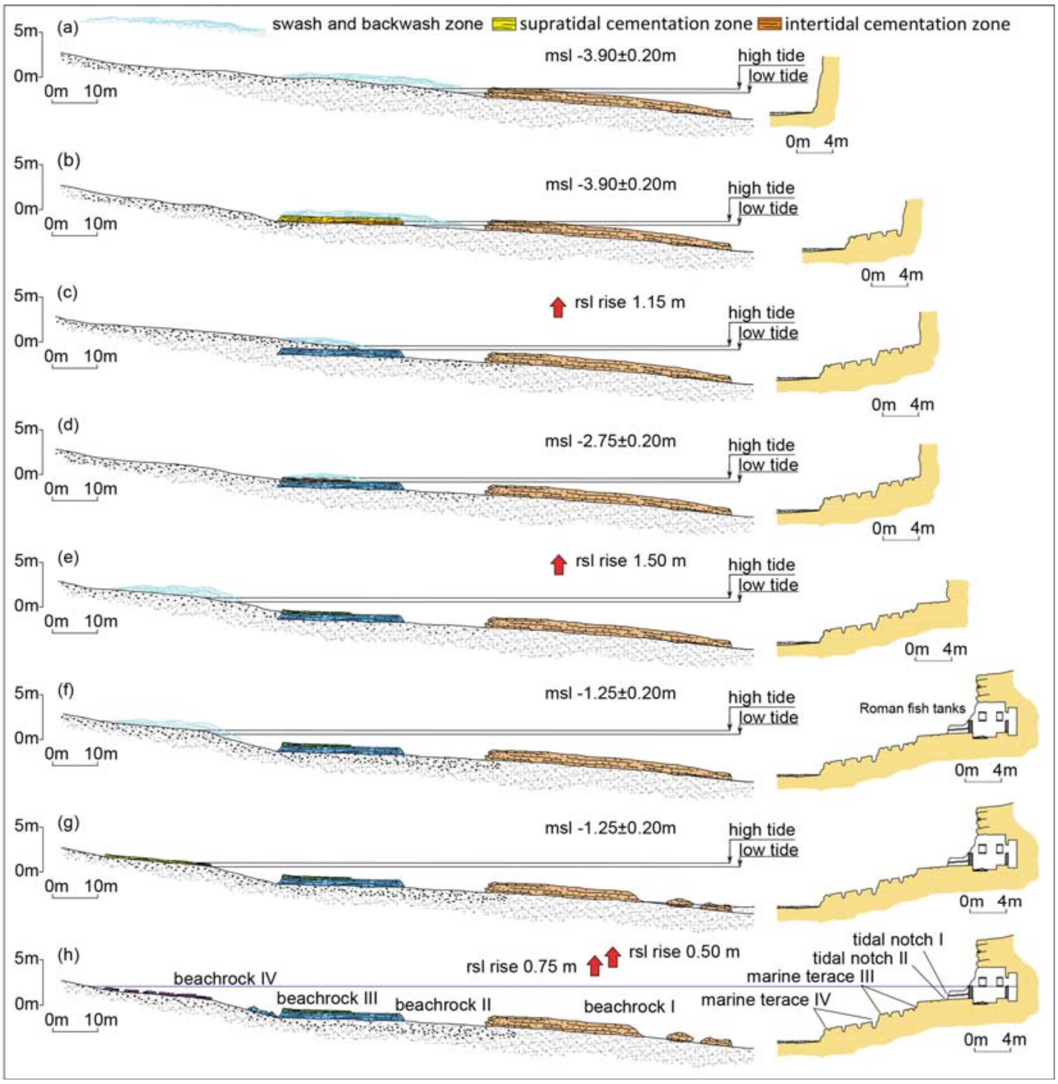
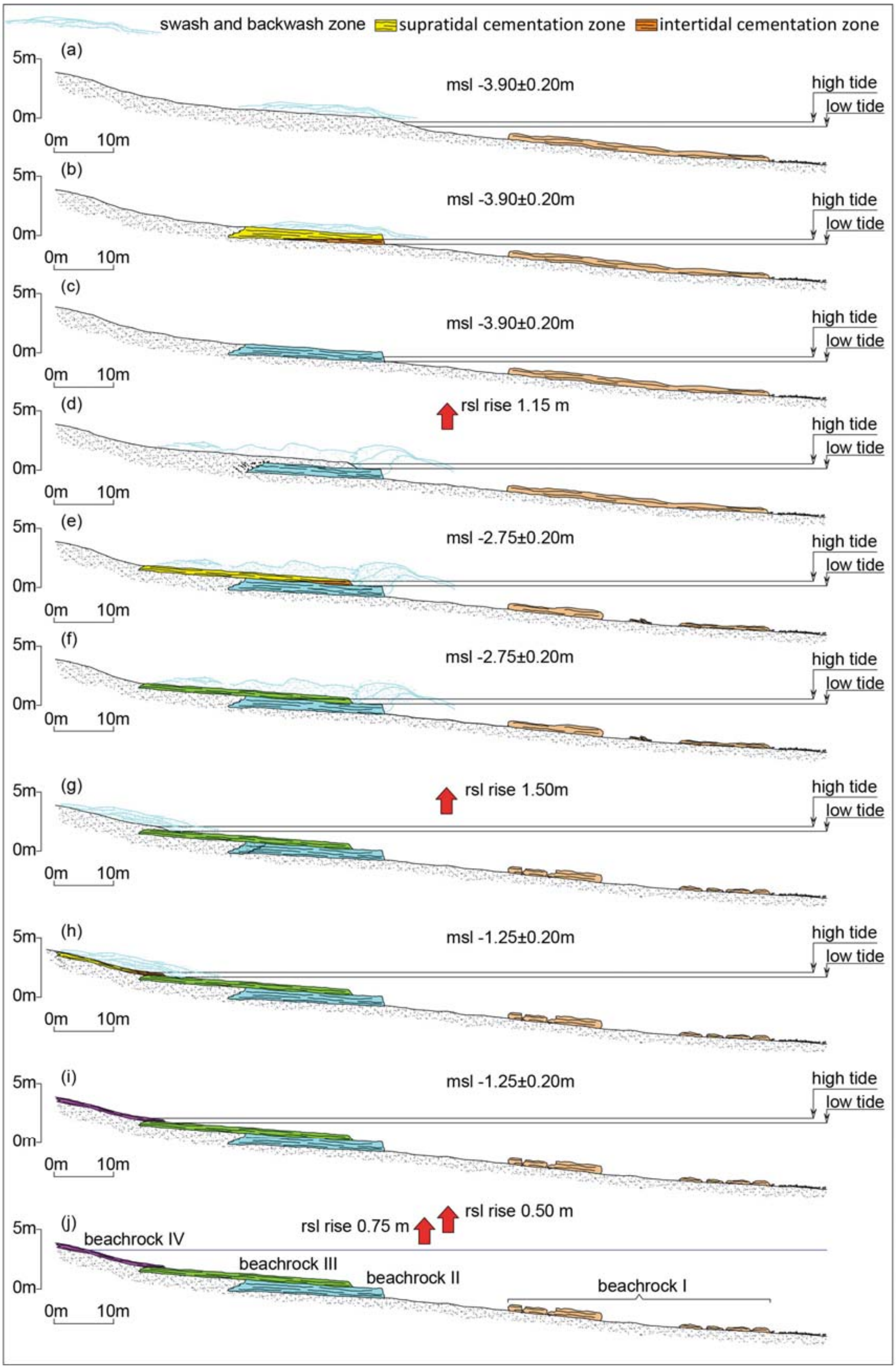


Fig. 8 - Beachrock evolution in the Matala Bay. (**a**) The sea level is at 3.90 ±0.20 m b.m.s.l. The beachrock generation (I), which had already formed when the sea level was at 6.60 ±0.30 m b.m.s.l., is now submerged due to the r.s.l. rise by 2.60 m. Alluvial deposits are accumulated on the palaeoshore. (**b**) During that period of the r.s.l. stability at 3.90 ±0.20 m b.m.s.l., the alluvial deposits are cemented between the low tide and the upper limit of the swash and backwash zone creating the beachrock generation (II). On the rocky coast, a marine terrace is formed by the retreat of the cliff face. (**c**) During a paroxysmal tectonic event, the coast subsided and the sea level rose by 1.15 m at 2.75 ±0.20 m b.m.s.l. New alluvial deposits partly cover the older beachrock (II). (**d**) The overlying alluvial deposits are cemented in the intertidal and supratidal zone of the new sea level. The continuing retreat of the cliff face widens the marine terrace. Two different beachrock slabs have been formed, the younger generation (III) overlying the older generation (II). (**e**) During a new paroxysmal tectonic event, the coast subsided and the sea level rose by 1.50 m at 1.25 ±0.05 m b.m.s.l. (**f**) On the marly limestone coast, a marine notch is formed. During the 1st and 2nd c. AD eleven fish tank complexes were carved into the south rocky coast. The channels that provided communication with the sea were cut at the base of the marine notch at exactly the same elevation as the then sea level. (**g**) In the same period, the accumulated alluvial deposits at the stream mouth are cemented between the low tide and the upper limit of the swash and backwash zone producing the new beachrock generation (IV). (**h**) R.s.l. rise by 1.25 m in two stages: the first by 0.70 m shifts the sea level at 0.55 m ±0.05 m b.m.s.l., in which a marine notch is cut into the rocky cliff and the second by 0.50 m shifts the sea level at its current position. (m.s.l.: mean sea level, r.s.l.: relative sea level).


swash and backwash zone
supratidal cementation zone
intertidal cementation zone
(a)
msl -3.90±0.20m
high tide
low tide
(b)
msl -3.90±0.20m
(c)
msl -3.90±0.20m
(d)
rsl rise 1.15 m
(e)
msl -2.75±0.20m
(f)
msl -2.75±0.20m
(g)
rsl rise 1.50m
(h)
msl -1.25±0.20m
(i)
msl -1.25±0.20m
(j)
rsl rise 0.75 m
rsl rise 0.50 m
beachrock IV
beachrock III
beachrock II
beachrock I
5m
0m
0m 10m

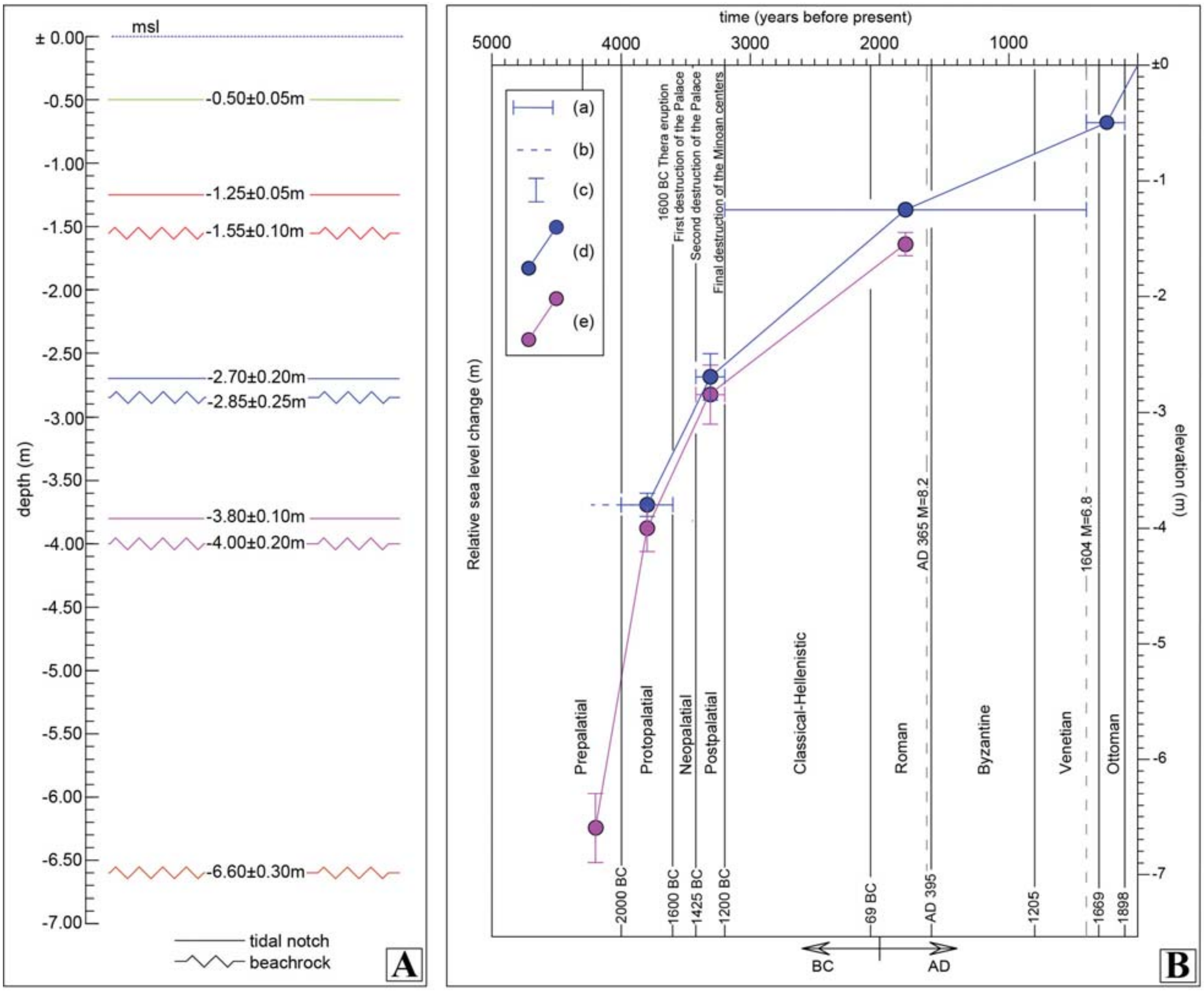


Fig. 10 - (**A**) Correlation of depths between the base of marine notches and the seaward base of the several beachrock generations recorded in Matala Bay and the Messara Gulf. (**B**) Curve of the r.s.l. change for the Messara Gulf and Matala Bay for the last 5,000 years. (**a**) maximum estimated period of the r.s.l. stability, (**b**) possible extension of the r.s.l. stability period, (**c**) depth error bar, (**d**) data from tidal notches, (**e**) data from beachrock generations.

The above sea levels are consistent with the sea level stands determined for the entire eastern part of Crete (as detailed in section 4) and are dated back to: 4200 ±90 BP the deepest sea level at 6.60 ±0.30 m b.m.s.l., from 1900 BC to around 1600 BC the sea level stand at 3.90 ±0.20 m b.m.s.l., between 1600 BC to 1200 BC the sea level stand at 2.75 ±0.20 m b.m.s.l, between 400 BC and 1604 AD the sea level stand at 1.25 ±0.20 m b.m.s.l. and, finally the most recent sea level stand at 0.50 ±0.05 m b.m.s.l. after the 1604 AD earthquake and definitely before 1924.

Previous studies on the sea level changes in the Messara Gulf and Matala Bay have suggested up-down vertical tectonic model, which resulted in fluctuations in the sea level. Blackman (1973), ignoring the depth of the seaward end of the sloping floor of the slipway, as re-

<<<<<<<< --

Fig. 9 - Beachrock evolution in the Gulf of Kommos. (**a**) The sea level is at 3.90 ±0.20 m b.m.s.l. The beachrock generation (I), which had already formed when the sea level was at 6.60 ±0.30 m b.m.s.l., is now submerged due to the r.s.l. rise by 2.70 m. (**b**) During this period of r.s.l. stability at 3.90 ±0.20 m b.m.s.l., the coastal sediments are cemented between the low tide and the upper limit of the swash and backwash zone, creating the beachrock generation (II) (**c**). (**d**) During a paroxysmal tectonic event, the coast subsided and the sea level rose by 1.15 m at 2.75 ±0.20 m b.m.s.l. New coastal sediments partly cover the older beachrock (II). (**e**) The overlying coastal deposits are cemented in the intertidal and supratidal zone of the new sea level, producing the beachrock generation (III) (**f**). (**g**) During a new paroxysmal tectonic event, the coast subsided and the sea level rose by 1.50 m at 1.25 ±0.05 m b.m.s.l. (**h**) In the same period, the new coastal sediments are cemented between the low tide and the upper limit of the swash and backwash zone, producing the new beachrock generation (IV) (**i**). (**j**) The r.s.l. rise by 1.25 m in two stages, initially by 0.70 m at 0.55 m ±0.05 m b.m.s.l. and then by 0.50 m, shifts the sea level to its current position. (m.s.l.: mean sea level, r.s.l.: relative sea level).

vealed in the present study, assumed that this covered slipway, or shipshed, would *"have been built when the sea level was very similar to what it is now"*. Furthermore, considering that fish tanks at Matala were tombs with their floors up to 1.80 m *"under water"*, which probably date back from the 1st to 2nd c. AD, he assumed a relative sea level rise of more than 2 m since that period and, on this assumption, he suggested that the shipshed would post-date the tombs and their submergence. On the assumption that considerable ground movements occurred up and down, he suggested *"that the shipshed dates from the Classical or Hellenistic period; that the land then rose; that the tombs were then built and then later submerged"* (Blackman, 1973). On balance, he concluded that the Matala shipshed is most likely to date from the Roman Imperial period at the earliest, without excluding an earlier date. However, the present underwater survey provided fresh evidence proving that the edge of the slipway, when it was in use, was 0.10 m at most, higher than the mean sea level of 1.25 ±0.05 m b.m.s.l., which represents the mean sea level of the Roman fish tanks at Matala when they were in use (Mourtzas 2012a, b; Mourtzas et al., 2016). Consequently, the slipway dates back to the period of prosperity enjoyed by Roman Gortyn (1st - 4th c. AD).

The up-down land movements in Matala Bay assumed by Blackman (1973) have led subsequent researchers (Flemming, 1978; Flemming & Pirazzoli, 1981; Shaw, 1990; Sanders, 1982; Gifford, 1995) to adopt a tectonic model that does not correspond with the field data. According to this incorrect model, the probably Early Roman rock-cut tombs have been submerged by ca. 2 m (instead of 1.25 ±0.05 m according to Mourtzas, 2012a, b), but the nearby *"slipway is at the correct functional height above present sea level"* (instead of -1.14 m as shown in this study). *"If the latter feature dates from the Classical or Hellenistic age, then two tectonic events are recorded; the shoreline around Matala fell to -2 m between ca. 300 BC and AD 100, the tombs were cut, and then the sea level rose again to almost the same position it had held in the Classical/Hellenistic age. Alternatively, the land might have subsided by about the same amount it had risen, to produce the same relationships observed today"* (Sanders, 1982).

7.2. Palaeogeographic reconstruction of the seafront of Kommos settlement and the coast of Matala Bay

The palaeogeographic reconstruction of the seafront of Kommos settlement and the coast of Matala Bay was based on the assessment of all the available geomorphological, archaeological and historical r.s.l. markers in the study area, and their integration with the established and dated Late Holocene sea level stands throughout the entirety of Crete (Mourtzas et al., 2016).

7.2.1. Before the Protopalatial period (before ca. 2000 BC)

In a period during which the Kommos hill was substantially uninhabited, the sea level was 6.60 ±0.30 m lower than at present and the beach was up to 150 m wide. At a short distance from the shoreline, an elongated islet (Papadoplaka) with its major axis oriented NE-SW, 200 m in length, 85 m in width and a maximum altitude of +7 m, protected the shore against the strong NW winds and waves. To the south, the cliff of cape Nisi provided further protection. The distance between the islet and the shore, not exceeding 100 m, had been reduced by half due to the accumulation of pebbles and boulders on the coastline (Figs. 5, 11A). As the sea level remained stable, the deepest beachrock generation (I) formed behind the accumulation of boulders, along the section of the beach protected by the islet (Figs. 5, 11B).

The Matala bay, also uninhabited in that period, had a limited length and an exposed coast ca. 130 m wider than at present. The stream that drains the extended drainage basin of Matala ended in the central part of the beach, accumulating coarse alluvial deposits at its mouth (Fig. 12A). The deepest beachrock generation (I) was cemented at the north part of the estuary of the stream and behind the marsh that had probably formed at the front of the stream mouth (Fig. 12B).

7.2.2. Protopalatial period (MM IA to LM IA, ca. 2000 - 1600 BC)

During this period, the sea level rose by 2.70 m and shifted at 3.90 ±0.20 m b.m.s.l. The coastline of Kommos retreated by at least 60 m, submerging both the accumulation of boulders and the deepest beachrock generation (I) (Fig. 7f, g). The islet was shrunk by 40 m in length and now it was ca. 170 m offshore. However, it is still sizeable, with a length of ca. 160 m, a width of 60 m and an average altitude of +4.40 m (Figs. 5, 9, 13A). In this period, Kommos was first settled on the hilltop and on parts of the hillside. Houses, storerooms with storage jars and the first large civic monumental building (AA), perhaps for a ritual use, were founded on a huge level platform set on the lower slopes of the Kommos hill. The building AA was later interpreted as a shipyard of the MM II period (Shaw, 2017, 2018). In the MM IIB period (1850-1700 BC), a broad E-W road cut into the hillside began at the shoreline and extended to the east (Shaw, 2006; Shaw & Shaw, 2010). In a new interpretation of the paved E-W road leading from the sea that was first thought to be associated with the court, Shaw (2017, 2018) assumes the use of wooden beams between the stone slabs to haul ships, but without providing evidence of such.

The Kommos coast, protected from the NNW wind and the surges, unique to the entire SE coast of Crete stretching from Kokkinos Pirgos to Cape Lithino, and including the Messara Gulf, provided favourable conditions for ships to approach, temporarily anchor or be hauled onto the sandy beach. The sheltered location of the harbour site rendered Kommos a significant centre for local and international trade. Goods destined for the Minoan centres inland were landed at Kommos, while agricultural and locally processed products were probably exported (Shaw, 2006). Evidence of fishing at Kommos in the Minoan period is plentiful. Local fishermen used small boats that could moor between the coastline and the islet even in bad weather, whereas the shoreline served them timelessly: they simply pulled their boats far enough up the beach to be secure, the distance probably depending on the weather (Shaw, 2006). The

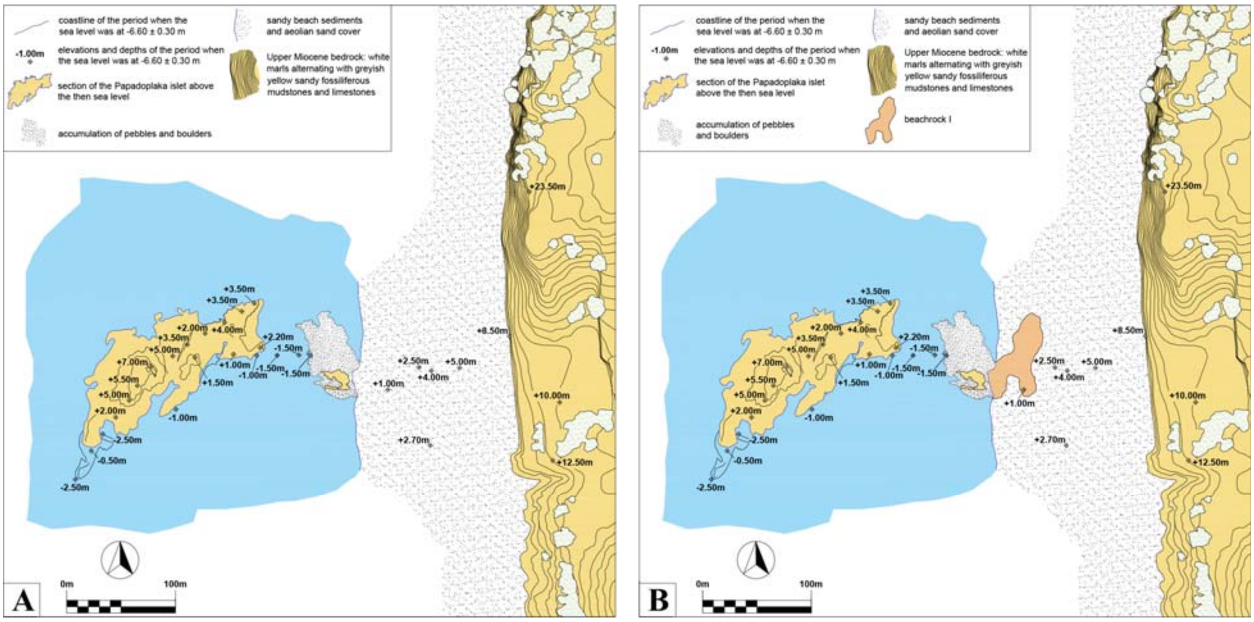


Fig. 11 - Palaeogeographic reconstruction of the coast of Kommos before the Protopalatial period (before 2000 BC), when the sea level was at 6.60 ±0.30 m b.m.s.l. before (**A**) and after (**B**) the formation of the deepest beachrock generation (I).

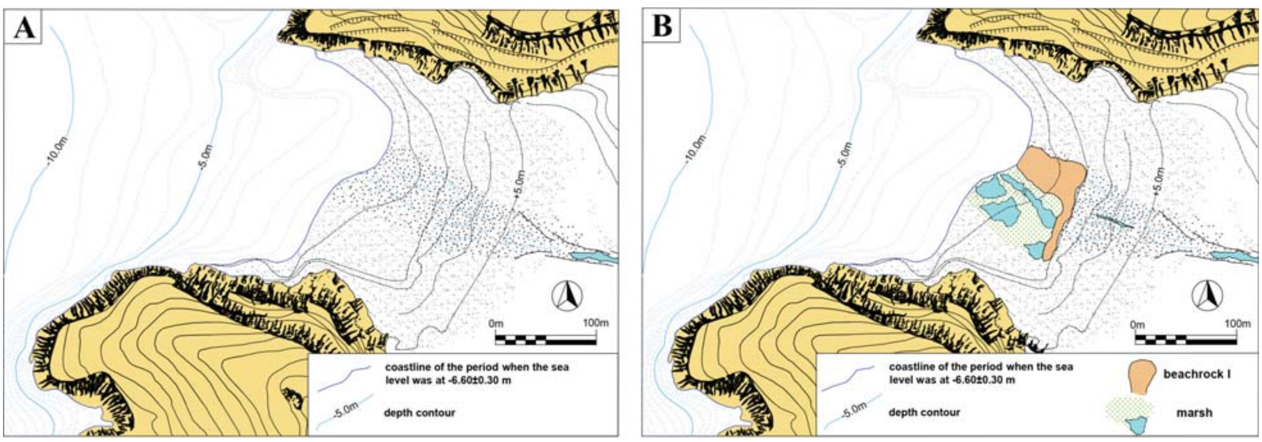


Fig. 12 - Palaeogeographic reconstruction of the Matala Bay before the Protopalatial period (before ca. 2000 BC), when the sea level was at 6.60 ±0.30 m b.m.s.l. before (**A**) and after (**B**) the formation of the deepest beachrock generation (I).

beachrock generation (II) formed all along the entire Messara coast during this period of r.s.l. stability (Figs. 5, 9, 13B).

In neighbouring Matala Bay, still uninhabited, the change in the sea level caused the coastline to recede by ca. 70 m, the deepest beachrock generation (I) to sink and the length of the bay to increase (Figs. 8, 14A). The stream was still accumulating coarse alluvial deposits, the cementation of which during this period formed the beachrock slab (II) in the central section of the beach. In the south cliff of the bay, the deepest marine terrace (IV) was gradually formed (Figs. 8, 14B).

At the end of this period, a series of strong seismic events, the first probably before 1700 BC, the second only a few years later and the third around 1600 BC, completely destroyed the Minoan sites of western Messara (La Rosa, 2010a, b; Shaw, 2006). The earthquakes seem to have brought an abrupt end to the MM houses at Kommos.

The strong seismic sequence around 1600 BC and the vertical subsiding tectonic movements accompanying it, were related to the eruption of the Thera volcano and the enhanced tectonic activity caused in the area of the south Aegean. The pre-earthquakes and aftershocks of the Thera eruption caused the total destruction of the Prepalatial centres of Crete and the r.s.l. change by 1.15 m that shifted the sea level at 2.75 ±0.20 m b.m.s.l. (Mourtzas et al., 2016; Mourtzas & Kolaiti, 2017a).

7.2.3. Neopalatial period (LM IB, ca. 1600 - 1425 BC) to the end of the Postpalatial period (ca. 1200 BC)

Towards the end of the 17th or 16th c. BC, after the huge natural disaster that preceded, Kommos was strengthened as a great naval establishment under the

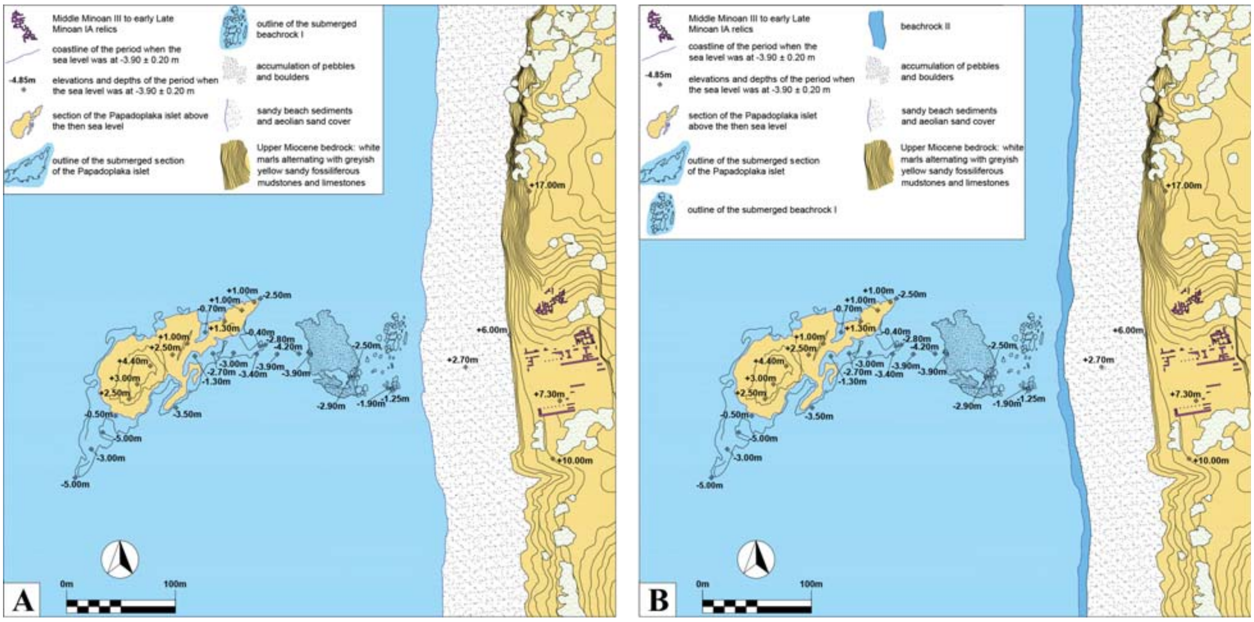


Fig. 13 - Palaeogeographic reconstruction of the coast of Kommos during the Protopalatial period (MM IA to LM IA, ca. 2000 - 1600 BC), when the sea level was at 3.90 ±0.20 m b.m.s.l. before (**A**) and after (**B**) the formation of the beachrock generation (II).

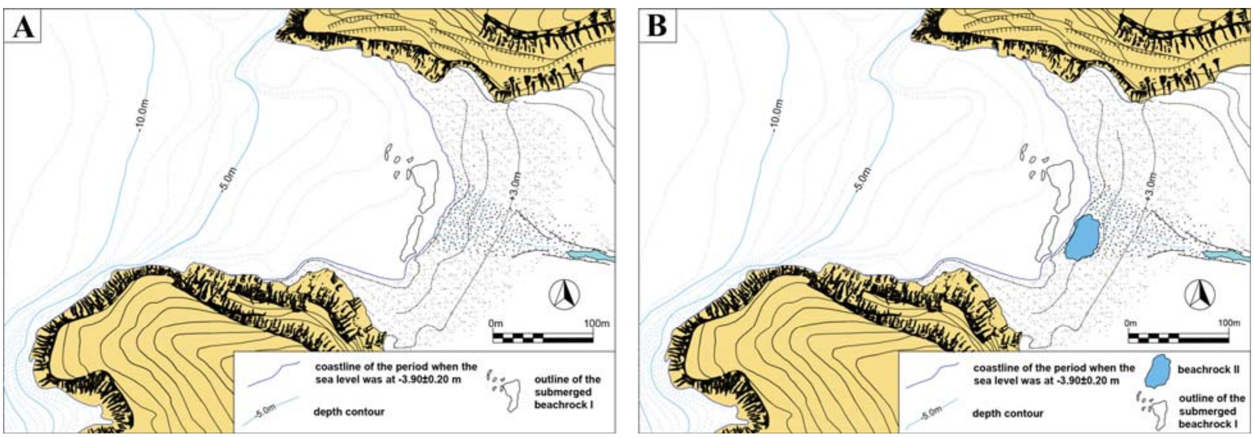


Fig. 14 - Palaeogeographic reconstruction of the Matala Bay during the Protopalatial period (MM IA to LM IA, ca. 2000 - 1600 BC), when the sea level was at 3.90 ±0.20 m b.m.s.l. before (**A**) and after (**B**) the formation of the beachrock generation (II).

control of the Knossian power established in Ayia Triada. In the Neopalatial period (ca. 1600-1425 BC), Kommos town expanded. A broad Minoan paved road separated houses from civic buildings. The major hillside "House with the Snake Tube", the important "House X" and Building T - located next to the shore for commercial purposes- that were constructed at the beginning of the period, were in ruins by the end of LM I period (1425 BC), perhaps as a result of an earthquake (Shaw, 2006).

Throughout the Neopalatial period, with the sea level at 2.75 ±0.20 m b.m.s.l., the coastline receded by 10 m and the beachrock generation (II) sank. Although the protective islet further shrank, now being 100 m long and 40 m wide with a 40 m-long rocky reef 20 m to the north of it, it was still protruding from the sea by almost 4 m (Figs. 5, 9, 15A). It was at a distance of ca. 200 m from the coast, but it continued to protect the coast, although probably to a lesser extent compared to previous periods. In the same period, a new beachrock generation (III) formed along the then coastline (Figs. 9, 15B). The 1425 BC earthquake that put an end to the Royal Villa at Ayia Triada and left the harbour-town of Kommos in ruins (Shaw, 2006; La Rosa, 2010a, b) does not seem to have brought about any change in the sea level along the entire coast of Crete (Mourtzas et al., 2016; Mourtzas & Kolaiti, 2017a). Further evidence to support this view is the coast of Kommos, since Kommos served uninterruptedly as an important trade harbour for more than 200 years after the 1425 BC earthquake until its abandonment around 1200 BC (Shaw, 2006). The comparative advantage the islet provided the location, relative to the rest of the Messara coast, indicates that the sea level remained at this stand through-

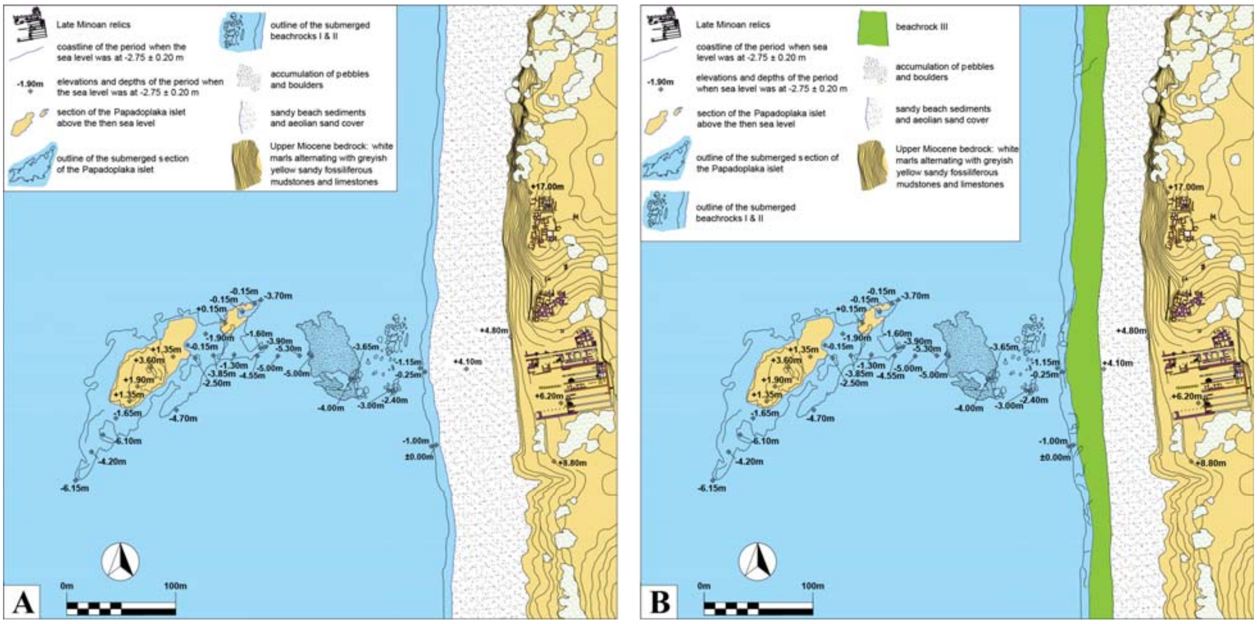


Fig. 15 - Palaeogeographic reconstruction of the coast of Kommos from the Neopalatial period (LM IB, ca. 1600 - 1425 BC) to the end of the Postpalatial period (ca. 1200 BC), when the sea level was at 2.75 ±0.20 m b.m.s.l. before (**A**) and after (**B**) the formation of the beachrock generation (III).

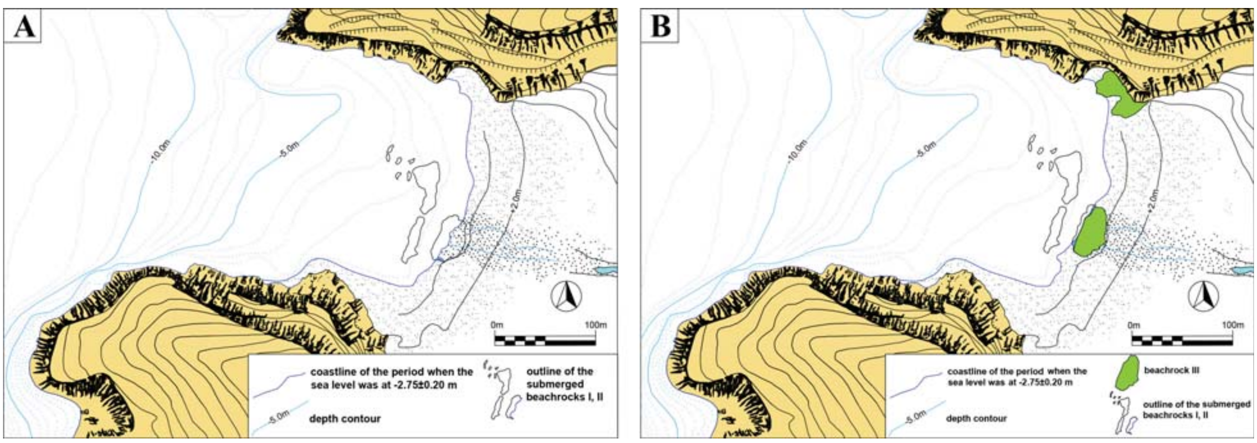


Fig. 16 - Palaeogeographic reconstruction of the Matala Bay from the Neopalatial period (LM IB, ca. 1600 - 1425 BC) to the end of the Postpalatial period (ca. 1200 BC), when the sea level was at 2.75 ±0.20 m b.m.s.l. before (**A**) and after (**B**) the formation of the beachrock generation (III).

out the LM III period (1425-1200 BC) until the conclusive abandonment of the site around 1200 BC.

In the LM IIIA period renovation and construction of older and younger public buildings as well as wares from Cyprus, Egypt, Syria-Palestine and Sardinia found there, testify to the prosperity and internationalism of the era. It was then that the most curious of all buildings at Kommos, Building P, was constructed. According to pottery, it dates back to the LM IIIA period (ca. 1400-1300 BC), was still in use in the LM IIIB period (1300-1200 BC), and went out of use at the end of LM IIIB (ca. 1200 BC) (Shaw, 2006). It is the largest LM III building known so far from Crete, consisting of a series of broad, parallel, galleries without parallel in Minoan architecture, all of them roofed, and clay floors that were meant for storage (Shaw, 2006). Shaw (2006) interpreted the galleries as 'shipsheds', where ships from Messara were stored during the non-sailing, winter months, simply being dragged up from the shore. However, the hearths, cooking vessels, ovens and many fragments of local short-necked LM IIIB storage amphorae found inside Building P (Rutter, 2011) cast doubt on the interpretation of them as storage shipsheds. Cooking vessels and hearths indicate food preparation there and storage amphorae could refer to storage rooms. At the same time, the galleries could have served as shipyards, where craftsmen worked intensively and prepared food (Loizou, 2015).

Building P was located inland at a distance of 120 m from the then shoreline and in the LM III period the

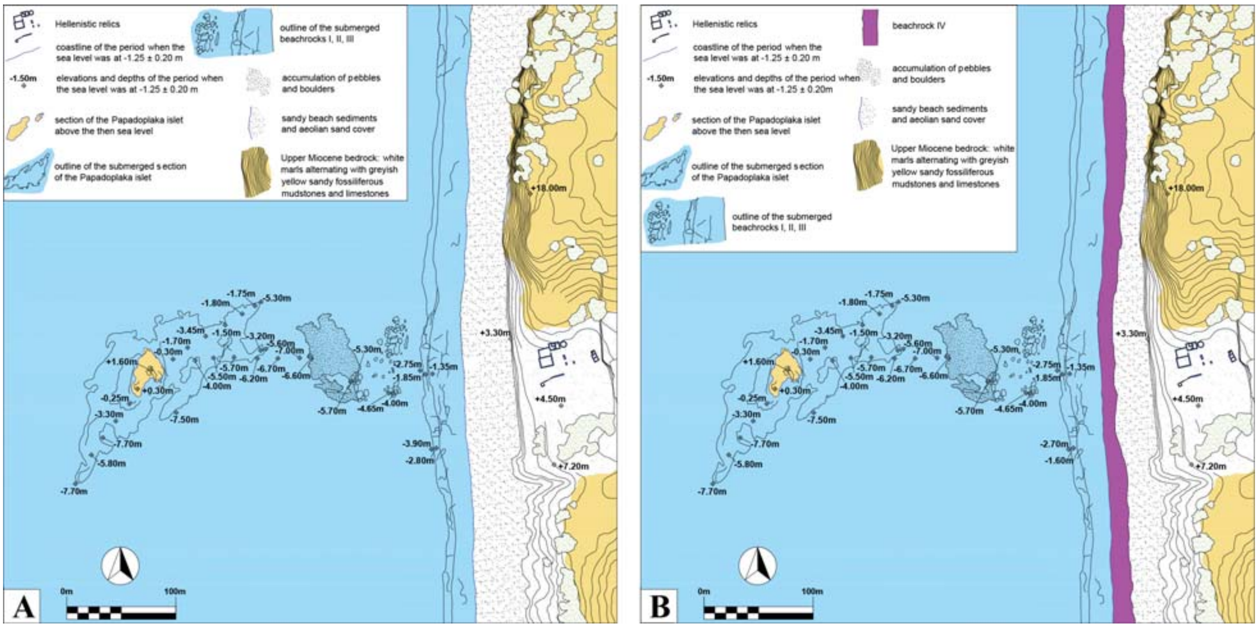


Fig. 17 - Palaeogeographic reconstruction of the coast of Kommos from the end of the Postpalatial period (ca. 1200 BC) to 1604 AD, when the sea level was at 1.25 ±0.05 m b.m.s.l. before (**A**) and after (**B**) the formation of the beachrock generation (IV).

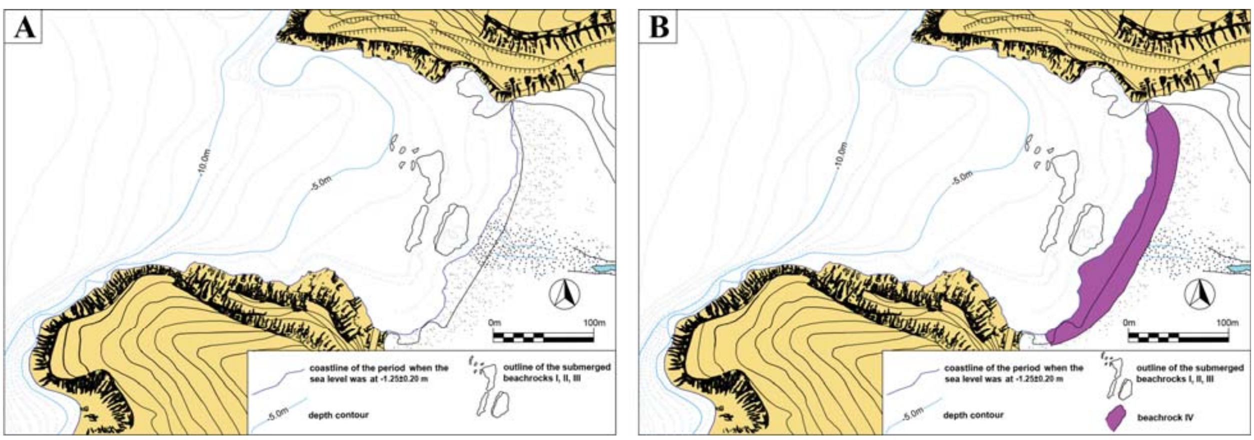


Fig. 18 - Palaeogeographic reconstruction of the Matala Bay from the end of the Postpalatial period (ca. 1200 BC) to 1604 AD, when the sea level was at 1.25 ±0.05 m b.m.s.l. before (**A**) and after (**B**) the formation of the beachrock generation (IV).

galleries would have lain about 6 m above the then sea level (Shaw, 2006). Due to the great distance of the galleries from the then coastline and the substantial difference in height between their floor and the then sea level, make it necessary to reconsider the interpretation of their function as 'shipsheds'. Field observations on the contemporary exposed coast of Kommos show that, with a wind speed of 40 km/h, the run-up of a 3 m wave does not exceed 40 m, reaching a maximum altitude of +2 m (www.meteo.gr). In a sheltered location, such as the Kommos coast during the Minoan period, when the depth between the Papadoplaka islet and the shore was some 3 m lower than at present, the motion of the water volume that generates waves on coast, the wave velocity and the wave run-up would definitely have been smaller, thus not justifying a shipshed too distant from the coastline and at such a high altitude.

Houses and public buildings at Kommos were abandoned at the end of the LM IIIB period (ca. 1200 BC) when the abrupt r.s.l. change by 1.50 m caused the Papadoplaka islet to be almost entirely submerged (Fig. 7a, b, c, d, e) and the Kommos coast to be completely exposed to the strong winds and waves. This period parallels the 50-year period at the end of the Late Bronze Age (1225-1175 BC), in which a great number of sites in Crete (Malia and Sisi, Jusseret et al., 2013), the mainland of Greece (Mycenae, Tiryns, Midea, Thebes, Menelaion and Kynos, and possibly Pylos, Lefkandi, Kastanas, Korakou, Krisa, Nichoria, Profitis Elias and Gla) and the Eastern Mediterranean (Troy, Karaoglun, Ugarit, Alalakh, Megiddo, Ashdod, Akko and possibly Hattusas) were partly or totally destroyed as a result of seismic events (Nur & Cline, 2000).

Throughout the Neopalatial period, Matala Bay was still uninhabited. With the sea level at 2.75 ±0.20 m b.m.s.l., the coastline receded by 10 m and the seaward part of the beachrock generation (II) submerged. At the mouth of the stream, coarse alluvial deposits continued to accumulate, covering the landward part of the beachrock generation (II) (Figs. 8, 16A). As a result, a new beachrock generation (III) formed, partially overlapping the older generation (II) and also on the northern edge of the beach at Matala due to cementation of sediments accumulated in a cavity of the bedrock (Figs. 8, 16B). In this period of r.s.l. stability, the marine terrace (III) on the south cliff of the bay was formed (Fig. 8).

7.2.4. From the end of the Postpalatial period (ca. 1200 BC) to 1604 AD

Since ca. 1200 BC, the sea level has stabilized at 1.25 ±0.20 m b.m.s.l., the coastline has receded by 30 m landward and the beach of Kommos has further shrunk to a width of 40 m at most. The elongated islet does not exist anymore and what has remained is a 35 m-long rocky reef protruding from the sea by a maximum of 1.60 m and a coast directly exposed to the weather (Figs. 5, 9, 17A). During this period, the beachrock (IV) was formed all along the coast (Figs. 9, 17B). As the beach width significantly decreased, large amounts of sand began to cover the southern lower part of the Kommos hill range.

After the Romans conquered Crete in 69 BC, while Messara was experiencing a period of great prosperity, Kommos was deserted and its ruins were gradually buried under a thick cover of aeolian sand. The biggest town in Roman Messara was Gortyn, and in 27 BC it was proclaimed the capital of a new Roman province, including Crete, Cyrenaica and North Africa (Di Vita, 2010).

The beach of Matala receded by 30 m and the older beachrock generation (III) sunk (Figs. 8, 18A). A new beachrock generation (IV) was formed all along the coast, whereas on the rocky north and south coasts of the bay a well-formed marine notch was cut (Figs. 8, 18B). In this period, the coastal activity of the plain of Messara moved to the bay of Matala. An extensive settlement developed in the coastal area of the valley of Matala. Pottery and coinage date the upper buildings to the Early Christian times, whereas in deeper layers Roman ruins and pottery as well as a few remains of Hellenistic occupation have been found (Chatzi-Vallianou, 1995).

On the steep cliff of the northern rocky coast of the bay, in the 1st and 2nd c. AD, the Roman necropolis was established, in cavities and rooms properly formed in the rock. At the same time, on the southern rocky coast of the bay, a thriving productive activity developed. Eleven rock-cut fish tanks and fish traps were built, to entrap and keep the fish alive for short time periods before they are consumed fresh or salted and/or sent to market. The channels, which were cut into the rock exactly at the same level as the then sea level, enabling their communication with the sea, provide the precise dating of the sea level stand during their function at 1.25 ±0.05 m b.m.s.l. A large salt pan complex at cape Nisi, just north of Matala Bay, produced salt for fish curing. On the easternmost side of the south rocky coast of the bay, a Roman slipway was cut, with the seaward edge of its sloping floor at the same sea level as the channels of the fish tanks. On the westernmost side of the south rocky coast, extensive quarrying activity is also observed. The carved bollards found there indicate the mooring and loading position of vessels for the sea transport of the extracted stone. Expanded quarries of the same period for the extraction of building materials destined for the local settlements were found on the westernmost side of the north rocky coast.

The Florentine traveller Christoforo Buondelmonti visited the bay of Matala in 1415. In his book *Descriptio insule Crete*, he depicted vividly the ancient town of Matala, the ruins of a temple with a mosaic floor, the rock-cut tombs and the statues. He also described in detail the fish tanks found on the south coast, stating: *“Look at the edge of the sea at those fish tanks, cut from rock, where sea water could go up and down by a system of narrow channels”* (Buondelmonti, 1415). It is evidently deduced from the description that the fish tanks had not been submerged when Buondelmonti visited Matala and the channels were still located at the same level as the then sea level, thus providing communication with the sea.

One hundred and ninety years after Buondelmonti’s visit to Matala Bay, the r.s.l. rise of 0.75 m, which accompanied the 1604 earthquake, inundated the coastal features and the Roman constructions of the bay and shifted the sea level stand to 0.50 ±0.05 m b.m.s.l. (Mourtzas, 2012a, b; Mourtzas et al., 2016).

7.2.5. The last 400 years

During this period, with the sea level stable at 0.50 ±0.05 m b.m.s.l., the coastline of the Kommos Gulf and Matala Bay receded by 10 m to 15 m and the shallower marine notch was formed in the north and south cliffs of Matala bay (Fig. 8). The fish tanks had sunk so much that the English vice-admiral, hydrographer and geologist Thomas A.B. Spratt, who arrived at Matala in 1851 or 1853, could not distinguish their constructional details because they were under the water. Therefore, in his book *Travels and Researches in Crete* (1865), he erroneously described *“some few rock tombs on the shores of the cove that are in part submerged below the present sea-level”*, the same as *“the groups of rock tombs which line the (north) cliffs of the cove”*.

Evans visited Matala and Kommos in 1924 in search of a roadway that had crossed central Crete and linked Knossos with the Minoan harbours on the Libyan Sea (Evans, 1928). Based on all the evidence, he concluded that Kommos was a commercial port bringing Crete into direct contact with the Nile Valley from the earliest days of the Minoan civilization. In regard to the constructions on the south coast of Matala Bay, he repeated the erroneous interpretation of Spratt (1865) and described them as *“late Greek and Roman tombs”*. However, he pointed out that *“The rock floors of the lower tier of the tombs lay under water and proved by soundings made to be as much as 1.80 metres -or nearly 6 feet- below the sea-level”* estimating *“a submergence since our era of some 5 meters”*. The depth of the floor measured by Evans in 1924 (Evans, 1928) coincides with that measured by Mourtzas in 2012 (Mourtzas, 2012a) who found that *"the floor of the fish tanks today is located at a depth varying from 1.55 m to 1.90 m"*. If we consider that Evans 's depth of 1.80 m refers to the floor of fish tank (I), the only fish tank easily accessible from land, the measurements of Evans and Mourtzas at the same position but with a difference of 88 years are identical, as Mourtzas gave the floor depth of fish tank (I) at 1.75 m after correction for tide. This observation allows us to reach the conclusion that the sea level rise from 0.50 ±0.05 m b.m.s.l. to its current stand had already happened before Evans visited Matala in 1924.

When the University of Toronto began the excavations at Kommos in 1976, the sea level had stabilized at its present stand and the coastline of Kommos and Matala had further receded by 7 m. Thirty years of systematic excavations followed, under the direction of Professor Joseph Shaw, bringing to light the ruins of the Minoan harbour-town of Kommos which played an important role in local and international trade during the Middle-Late Bronze Age in the Eastern Mediterranean.

8. CONCLUSIONS

The present geoarchaeological study, following a particular methodological approach, has enabled the quantitative and qualitative approach and interpretation of the dynamic change of the coastal environment of Messara over the last 5,000 years, recording a complex interaction between natural and socio-economic changes. The coastal area of Messara has undergone dramatic changes through time with significant impacts on local populations.

The r.s.l. change by a total of 6.60 ±0.30 m during the last 5,300 years, with four intermediate distinct sea level stands each lasting from 1200 to 50 years, coincided with the development of a thriving prehistoric civilization in the western Messara plain. Catastrophic seismic events, such as those between the 17th and 13th c. BC, brought about crucial changes in the political and socioeconomic life of the plain and caused the sea level to change by 2.65 m in two stages.

The seismic sequence that followed the eruption of the Thera volcano at the end of the LM IA period (around 1600 BC) put an end to the Protopalatial period and caused a 1.15 m rise in the sea level. The strong seismic sequence of 1425 BC that destroyed the Minoan sites in Messara and throughout Crete ended the Neopalatial period but had no impact on the sea level. Life in the flourishing maritime centre of Kommos, which had served as the trade harbour of inland Minoan centres of power since the Protopalatial period, continued after the disaster. The elongated islet offshore was still protecting the exposed coast of Messara, thus favouring the approach and mooring of vessels even in bad weather, as in the previous periods. The Minoan sites of the Messara were certainly abandoned at the end of the Postpalatial period, ca. 1200 BC, during a period of intense seismic activity that resulted in their catastrophe. Due to the vertical tectonic movements accompanying the earthquakes, the Messara coast subsided by 1.50 m and the islet almost sunk under the sea. The coast of the Minoan maritime centre of Kommos was then directly exposed to the weather.

In the subsequent historical periods, the coastal activities move to the neighbouring bay of Matala which, mainly in Roman times, seems to have been the trade harbour of Gortyn, capital of the Roman province of Crete and Cyrenaica. Between the 1st and 4th c. AD several productive activities, such as fishing, fish processing and conservation, salt harvesting, shipbuilding and quarrying, flourished on the coast of the bay. The severe earthquake that struck the island in 365 AD uplifted the western part of Crete by 9 m at its westernmost tip and by 1 m at its eastern edge located along the Spili Fault and its northern and southern prolongation. Although just a few kilometres to the east of the western uplifted tectonic block of Crete, the Messara coast seems not to have been affected since the sea level remained at 1.25 ±0.05 b.m.s.l. until the 1604 AD earthquake. The most recent history of the r.s.l. changes on the coast of Messara and Matala includes a sea level stand at 0.50 ±0.05 m that shifted to its current position at some time before 1924.

ACKNOWLEDGMENTS

We would like to thank Dr. Andrea Sposato (CNR IGAG, Roma), Editor-in-Chief of Alpine and Mediterranean Quaternary, Prof. Luigi Ferranti (Università Federico II, Napoli) and one anonymous reviewer who provided valuable and insightful comments that greatly improved the final version of this article. Thanks are also due to Mr. Stephen Taylor, Consultant at Cambridge Assessment English for editing the English text.

REFERENCES

Ambraseys N. (2009) - Earthquakes in the Mediterranean and Middle East: A Multidisciplinary Study of Seismicity up to 1900. Cambridge University Press, pp 947
Doi: 10.1017/CBO9781139195430

Antonioli F., Lo Presti V., Rovere A., Ferranti L., Anzidei M., Furlani S., Mastronuzzi G., Orru P.E., Scicchitano G., Sannino G., Spampinato C.R., Paglirulo R., Deiana G., de Sabata E., Sansò P., Vacchi M., Vecchio A. (2015) - Tidal notches in the Mediterranean Sea: a comprehensive analysis. Quaternary Science Reviews, 119, 66-84.

Auriemma R., Solinas E. (2009) - Archaeological remains as sea level change markers: A review. Quaternary International, 26, 134-146.

Bathurst R.G.C. (1974) - Marine diagenesis of shallow water calcium carbonate sediments. Annual Review of Earth and Planetary Sciences, 2, 257-274

Benjamin J., Rovere A., Fontana A., Furlani S., Vacchi M., Inglis R., Galili E., Antonioli F., Sivan D., Miko S., Mourtzas N., Felja I., Meredith-Williams M., Goodman-Tchernov B., Kolaiti E., Anzidei M., Gehrels R. (2017) - Late Quaternary sea-level change and early human societies in the central and eastern Mediterranean Basin: an interdisciplinary review. Quaternary International, 449, 29-57.

Bernier P., Dalongeville R. (1996) - Mediterranean coastal changes recorded in beachrock cementation. Z. Geomorphol. N.F., Suppl.-Bd., 102, 185-198.

Blackman D. (1973) - The neosoikos at Matala. Proceedings of the 3rd International Cretological Congress, Rethymnon, 18-23 Sept. 1971, Athens, vol. I, 14-21.
Blackman D.J., Branigan K. (1975) - An Archaeological Survey on the South Coast of Crete, between the Ayiofarango and Chrisostomos. Annual of the British School at Athens (BSA), 70, 17-36.
Bonneau M., Jonkers H.A., Meulenkamp J.E. (1984) - Geological map of Greece (1:50.000). Timbakion sheet, I.G.M.E., Athens.
Buondelmonti C. (1415) - Descriptio insule Crete. Transl.: M. Aposkitis. Edit. Assoc. Cult. Dev. of Heraclion, 1983, pp 85.
Carobene L. (1972) - Osservazioni sui solchi di battente attuali e antichi nel Golfo di Orosei in Sardegna. Mem. Della Soc. Geol. Ital., 19, 641-649.
Carobene L. (2015) - Marine notches and sea-cave bioerosional grooves in microtidal areas: examples from the Tyrrhenian and Ligurian coasts-Italy. Journal of Coastal Research, 31(3), 536-556.
Chatzi-Vallianou D. (1995) - Matala. Archaeologikon Deltion, vol. 45 (1990), Part B’ 2: Chronika, 420-427.
Crile G., Davaras C. (1963) - The possible site of Menelaus’ shipwrecks. Cretica Chronika, 17(4), 47-49.
Desruelles S., Fouache É., Ciner A., Dalongeville R., Pavlopoulos K., Kosun E., Coquinot Y., Potdevin J.L. (2009) - Beachrocks and sea level changes since Middle Holocene: comparison between the insular group of Mykonos-Delos-Rhenia (Cyclades, Greece) and the southern coast of Turkey. Global and Planetary Change, 66(1-2), 19-33.
Di Vita A. (1995) - Archaeologists and earthquakes: the case of 365 A.D. Annali di Geofisica, 38(5-6), 971-976.
Di Vita A. (1996) - Earthquakes and civil life at Gortyn (Crete) in the period between Justinian and Constant II (6–7th century AD). In: Stiros S., Jones R. (Eds.), Archaeoseismology. British School at Athens, Fitch Laboratory Occasional Paper 7, 45-50.
Di Vita A. (2010) - Gortina di Creta: Quindici Secoli di Vita Urbana. L'Erma di Bretschneider, Rome, pp 405.
Evans A.J. (1928) - The Palace of Minos: a comparative account of the successive stages of the early Cretan civilization as illustrated by the discoveries at Knossos, Volume II, Part I: Fresh lights on origins and external relations. Macmillan and Co Ltd, pp 390.
Flemming N.C. (1978) - Holocene eustatic changes and coastal tec-tonics in the northeast Mediterranean: implications for models of crustal consumption. Phil. Trans. R. Soc. London, A, 289, 405-458.
Flemming N.C., Pirazzoli P.A. (1981) - Archéologie des côtes de la Crète. Hist. Archaeol. Dossiers, 50, 66-81.
Friedrich W.L., Kromer B., Friedrich M., Heinemeier J., Pfeiffer T., Talamo S. (2006) - Santorini eruption radiocarbon dated to 1627–1600 BC. Science, 312, 548.
Doi: 0.1126/science.1125087
Furlani S., Ninfo A., Zavagno E., Paganini P., Zinia L., Biolchi S., Antonioli F., Coren F., Cucchi F. (2014). Submerged notches in Istria and the Gulf of Trieste: Results from the Geoswim project. Quaternary International, 332, 37-47.
Fytrolakis N., Peterek A., Schröder B. (2005) - Initial Geoarchaeologic Investigations on the Holocene Coastal Configuration Near Phaistos/Agia Triada (Messara Plain Central Crete, Greece). Zeitschrift Fur Geomorphologie, Supplementband, 137, 111-123.
Georgiades A.S. (1904) - About Earthquakes and Construction of Antiseismic Buildings, Athens, pp 306.
Ghilardi M., Psomiadis D., Andrieu-Ponel V., Colleu M., Longo F., Rossi A., Amato V., Gasse F., Sinibaldi L., Renard M., Demory F., Delanghe D., Fleury J. (2018) - First evidence of a lake at Ancient Phaistos (Messara Plain, South-Central Crete, Greece): Reconstructing paleoenvironments and differentiating the roles of human land-use and paleoclimate from Minoan to Roman times. The Holocene, 28 (8), 1225-1244.
Gifford J.A. (1995) - The physical geology of the western Mesara and Kommos. In: Shaw J.W. & Shaw M.C. (Eds.), Kommos I: the Kommos Region and Houses of the Minoan Town, 30-90. Princeton University Press, NJ.
Guidoboni E., Comastri A., Traina G. (1994) - Catalogue of Ancient Earthquakes in the Mediterranean area up to the 10th century, vol. 1. ING-SGA, Bologna, pp 504.
Heckel P.H. (1983) - Diagenetic model for carbonate rocks in Midcontinent Pennsylvanian eustatic cyclothems. J. Sedim. Petrol., Tulsa, 53(3), 733-759.
Higgins C.G. (1980) - Nips, notches, and solution of coastal limestone. An overview of the problem with examples from Greece. Estuarine and Coastal Marine Science, 10, 15-30.
James N.P., Choquette P.W. (1984) - Diagenesis 9 - Limestones - The meteoric diagenetic environment. Geoscience Canada, 11(4), 161-194.
Jusseret S., Langohr C., Sintubin M. (2013) - Tracking earthquake archaeological evidence in Late Minoan IIIB (similar to 1300-1200 BC) Crete (Greece): a proof of concept. Bulletin of the Seismological Society of America, 103(6), 3026-3043.
Kambouroglou E. (1989) - Eretria: Palaeogeographic and geomorphological evolution during the Holocene. Relation between natural environment and ancient settlements. PhD Thesis. National and Kapodistrian University of Athens, Athens, Greece, pp 237.
Karkani A., Evelpidou N., Vacchi M., Morhange C., Tsukamoto S., Frechen M., Maroukian H. (2017) - Naxos-Paros Tracking shoreline evolution in central Cyclades (Greece) using beachrocks. Marine Geology, 388, 25-37.
Kelletat H. (1997) - Mediterranean coastal biogeomorphology: processes, forms and sea-level indicators. In: Briand F., Maldonado A. (Eds.), Transformations and evolution of the Mediterranean coastline. Bulletin de l’Institut océanographique Monaco, CIESM Science Series n°3, n° special 18, 209-226.
Kelletat H. (2005) - Notches. In: Schwartz M.L. (Ed.),

Encyclopedia of Coastal Science: Encyclopedia of Earth Sciences Series, Springer, Dordrecht, 728-729.

Kolaiti E. (2019) - Changes in the anthropogenic environment along the eastern coast of the Peloponnese on the basis of archaeological and morphological indicators of the Late Holocene relative sea level changes. Proposing a geoarchaeological method of approach. PhD Thesis. University of the Peloponnese, Kalamata, Greece, pp 674. www.didaktorika.gr/eadd/handle/10442/44943

Kolaiti E., Mourtzas N. (2016) - Upper Holocene sea level changes in the West Saronic Gulf, Greece. Quaternary International, 401, 71-90.

Kolaiti E., Papadopoulos G., Morhange C., Vacchi M., Triantafyllou I., Mourtzas N. (2017) - Palaeoenvironmental evolution of the ancient harbour of Lechaion (Corinth Gulf, Greece): were changes driven by human impacts and gradual coastal processes or catastrophic tsunamis? Marine Geology, 392, 105-121.

La Rosa V. (2010a) - Phaistos. In: Cline E. (ed.), The Oxford Handbook of the Bronze Age Aegean (ca. 3000-1000 BC), 582-595. Oxford University Press, Oxford.

La Rosa V. (2010b) - Ayia Triada. In: Cline E. (ed.), The Oxford Handbook of the Bronze Age Aegean (ca. 3000-1000 BC), 495-508. Oxford University Press, Oxford.

Laborel J., Laborel-Deguen F. (1996) - Biological indicators of Holocene sea-level and climatic variations on rocky coasts of tropical and subtropical regions. Quaternary International, 31, 53-60.

Laborel J., Pirazzoli P.A., Thommeret J., Thommeret Y. (1979) - Holocene raised shorelines in western Crete (Greece). In: Suguio K., Fairchild T.R., Martin L., Flexor J.M. (Eds.), Proceedings 1978 International Symposium on Coastal Evolution in the Quaternary (Sao Paulo, 1979), 475-501.

Lambeck K., Anzidei M., Antonioli F., Benini A., Esposito A. (2004) - Sea level in Roman time in the Central Mediterranean and implications for recent change. Earth Planet. Sci. Lett., 224, 563-575.

Leatham J., Hood S. (1958/59) - Sub-Marine Exploration in Crete, 1955. Annual of the British School at Athens, LIII-LIV, 263-273.

Lembesi A. (1969) - Collecting Antiquities in Crete: Matala. PAE, 241-249.

Loizou E. (2015) - Maritime routes, harbours and navigation in the Aegean of the Late Bronge Age. MSc Thesis. Aristotle University of Thessaloniki, Thessaloniki, pp 133.

Longman M.W. (1980) - Carbonate diagenetic textures from near-surface diagenetic environments. AAPG Bull., 64, 461-487.

Milliman J.D. (1971) - The role of calcium carbonate in continental shelf sedimentation: in the new concepts of continental margin sedimentation. American Geological Institute, Washington, D.C., Application to the geological record (suppl.), lecture no. 14, pp 20.

Monaco C., Tortorici L. (2004) - Faulting and effects of earthquakes on Minoan archaeological sites in Crete (Greece). Tectonophysics, 382, 103-116.

Mourtzas N.D. (1990) - Vertical tectonic movements of the coast of Eastern Crete during the Quaternary. PhD Thesis. NTUA, Athens, Greece, pp 480.

Mourtzas N. (2012a) - Archaeological indicators for sea level change and coastal neotectonic deformation: the submerged roman fish tanks of the gulf of Matala, Crete, Greece. J. Archaeol. Sci., 39, 884-895.

Mourtzas N. (2012b) - Fish tanks of eastern Crete (Greece) as indicators of the Roman sea level. J. Archaeol. Sci., 39, 2392-2408.

Mourtzas N. (2018) - Palaeogeographic reconstruction of the coast of Ancient Andros. In: Palaiokrassa-Kopitsa L. (Ed.), Palaiopolis, Andros: Thirty years of archaeological research, 56-66, Andros.

Mourtzas N., Kolaiti E. (2017a) - Shoreline reconstruction of the submerged Minoan harbour morphology in the bay of Kato Zakros (Eastern Crete, Greece). Journal of Archaeological Science: Reports, 12, 684-698.

Mourtzas N., Kolaiti E. (2017b) - Geoarchaeology of the Roman harbour of Ierapetra (SE Crete, Greece). Méditerranée, 1-14. mediterranee.revues.org/7965

Mourtzas N.D., Marinos P.G. (1994) - Upper Holocene sea-level changes: Palaeogeographic evolution and its impact on coastal archaeological sites and monuments. Environmental Geology, 23, 1-13.

Mourtzas N.D., Kolaiti E., Anzidei M. (2016) - Vertical land movements and sea level changes along the coast of Crete (Greece) since Late Holocene. Quaternary International, 401, 43-70.

Mouslopoulou V., Moraetis D., Benedetti L., Guillou V., Hristopoulos D. (2012) - Is the Spili Fault Responsible for the Double Destruction of the Minoan Palace at Phaistos? Johon S. Latsis Public Foundation, Research Projects 2012, pp 23.

Neumeier U. (1998) - The Role of Microbial Activity in Early Cementation of Beachrocks (Intertidal Sediments). PhD thesis. University of Geneva (Terre et Environment), Geneva, pp 167.

Nur A., Cline E. (2000) - Poseidon's horses: plate tectonics and earthquake storms in the Late Bronze Age Aegean and Eastern Mediterranean. Journal of Archaeological Science, 27, 43-63.

Papazachos V., Papazachou K. (1989) - The Earthquakes of Greece. Editions Ziti, Thessaloniki, Greece, pp 365.

Pirazzoli P. (1986a) - The early Byzantine Tectonic Paroxysm. Z. Geomorphol. N.F., Suppl.-Bd. 62, 31-49.

Pirazzoli P.A. (1986b) - Marine notches. In: Van de Plassche O. (Ed.), Seal-level Research: A Manual for the Collection and Interpretation of Data, 361-400. Geo Books, Norwich.

Pirazzoli P.A. (2005) - Marine terraces. In: Schwartz M.L. (Ed.), Encyclopedia of Coastal Science, 632. Encyclopedia of Earth Sciences Series, 632-633, Springer, Dordrecht.

Pirazzoli P.A., Thommeret J., Thommeret Y., Laborel J., Montaggioni L.F. (1982) - Crustal block movements from Holocene shorelines: Crete and Antikythira (Greece). Tectonophysics, 86, 27-43.

Platakis E. (1950) - The earthquakes of Crete. Cretica Chronika, 4, 463-526.
Psomiadis D. (2011) - Palaeoenvironmental and sedimentalogical conditions for the formation of beachrocks in the Northern Aegean area. PhD Thesis, Aristotle University of Thessaloniki, Thessaloniki, pp 275.
Pugh D.T. (1982) - Tides, Surges and Mean Sea Level. John Wiley, Chichester, pp 472.
Rutter J.B. (2011) - Late Minoan IB at Kommos: a sequence of at least three distinct stages. In: Brogan T.M., Hallager E. (Eds), LM IB Pottery: relative chronology and regional differences. Monographs of the Danish Institute at Athens, 11(1), 307-343.
Sanders I.F. (1982) - Roman Crete: An Archaeological Survey and Gazetteer of Late Hellenistic, Roman, and Early Byzantine Crete. Aris and Phillips, Warminster, Wilts., England, pp 185.
Shaw J.W. (1990) - Bronze Age Aegean Harboursides. In: Hardy D.A. (ed.), Thera and the Aegean World III, Vol. I: Archaeology, 420-436.
Shaw J.W. (2006) - Kommos: A Minoan harbor town and Greek sanctuary in southern Crete. The American School of Classical Studies at Athens, Athens, pp. 163.
Shaw J.W. (2017) - The Middle Minoan Slipway for Ships at the Kommos Harbour, and Harbour Development in Prehistoric Crete. In: Letesson Q., Knappett C. (Eds), Minoan Architecture and Urbanism: New Perspectives on an Ancient Built Environment, 225-244. Oxford University Press, Oxford.
Shaw J.W. (2018) - The Earliest Harbour Installations on Aegean Foreshores. Journal of Nautical Archaeology, 48(1), 85-102.
Shaw J., Shaw M. (2010) - Kommos. In: Cline E. (ed.), The Oxford Handbook of the Bronze Age Aegean (ca. 3000-1000 BC), 543-555. Oxford University Press, Oxford.
Simosi A. (2003) - A Coastal Minoan Settlement in Speliada, Seision, Crete. Enalia, VII, 57-65.
Soles J. (2007) - The impact of the Minoan eruption of Santorini on Mochlos, a small Minoan town on the north coast of Crete. In: Warburton D. (Ed.), Time's up: Dating the Minoan eruption of Santorini, Acts of the Minoan Eruption Chronology Workshop, Sanbdjerg, Monographs of the Danish Institute at Athens, 10, 107-116.
Spratt T.A.B. (1865). Travels and Researches in Crete. John Van Voorst, London, pp 387.
Spyropoulos P. (1997) - Chronicle of the earthquakes of Greece from antiquity until today. Editions Dodoni, Athens, pp. 453.
Stavrakakis N. (1890) - Statistics on population of Crete with several geographical, historical, archaeological, ecclesiastic etc. news about the island. Athens, 107-117.
Stiros S. (2010) - The 8.5+ magnitude, AD365 earthquake in Crete: coastal uplift, topography changes, archaeological and historical signature. Quaternary International, 216, 54-63.
Taylor M.C.J., Illing V.L. (1969) - Holocene intertidal calcium carbonate cementation, Qatar, Persian Gulf. Sedimentology, 12, 69-107.
Trenhaile A.S (2015) - Coastal notches. Their morphology, formation, and function. Earth Science Reviews, 150, 285-304.
Vacchi M. (2012) - Coastal geomorphology of lesvos island: Processes, Late Quaternary evolution and the neotectonic implications. PhD Thesis. Universita degli Studi di Genova, Genova, pp 181.
Vallianou D. (1996) - New evidence of earthquake destructions in Late Minoan Crete. In: Stiros S., Jones R. (Eds), Archaeoseismology, British School at Athens, Fitch Laboratory Occasional Paper 7, 153-167.
Watrous L.V. (1992) - Kommos III: The Late Bronze Age pottery. In: Shaw J.W. & Shaw M.C. (Eds.), Kommos III. Princeton University Press, NJ, pp 258.
Watrous L.V., Hadzi-Vallianou D., Blitzer H. (2004) - The Plain of Phaistos: Cycles of Social Complexity in the Mesara Region of Crete. Monumenta archaeologica, 23, Los Angeles, pp 673.
Watrous L.V., Hatzi-Vallianou D., Pope K., Mourtzas N., Shay J., Shay T.C., Bennet J., Tsoungarakis D., Angelomati-Tsoungarakis E., Vallianos Ch., Blitzer H. (1993) - A survey of the Western Mesara plain in Crete: Preliminary report of the 1984, 1986, and 1987 field seasons. Hesperia, 62(2), 191-248.

Ms. received: January 18, 2019
Accepted: May 28, 2020
Revised: May 26, 2020,
Available online: June 9, 2020