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SUBMERGED ANTIQUITIES ON PAROS AND NAXOS ISLANDS, AEGEAN SEA, GREECE. NEW EVIDENCE FOR THE MEAN SEA LEVEL DURING THE LATE BRONZE AGE AND THE ROMAN PERIOD

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Abstract

Sea level changes are the combined effect of eustatic, glacio-isostatic and tectonic factors. Oxygen isotope data and geophysical models are often used to assess the first two factors, while the third factor can be assessed by field data. In this context, detailed mapping of palaeo sea-level markers may be used to evaluate coastal tectonic movements and the relative sea level changes in a particular region. Although various sea level markers exist, e.g. geomorphological, biological, archaeological, their reliability varies depending on their relationship to sea level. Amongst geomorphological indicators, tidal notches stand out as they can indicate former sea-level positions, with up to a decimeter confidence, while their shape may also provide qualitative information on the rate of sea-level change and on tectonic movements. Biological markers may also provide useful information provided that their relationship to mean sea level is clearly defined. Last but not least, archaeological remains, emerged or submerged, may also be used to quantify relative sea level changes; however, their reliability varies depending on the functionality of the structure.

*In this framework, the aim of this paper is the study of sea level changes in the Central Aegean Sea (Paros and Naxos islands) through the use of various sea level indicators. Submerged beachrocks and tidal notches bear witness to the extent and depth of ancient shores. The submerged antiquities of Paros include cemeteries of various time periods and harbour installations, while the Baccini antiquities in Naxos include quarries and coastal settlements. Archaeological data in Grotta and Aplomata (Naxos), give evidence of at least two seismic events, coinciding with the profiles of two submerged tidal notches found at a depth of -3 m and -2.5 m respectively. The tsunami that covered the northern part of the Hellenistic Agora of Naxos in the 2nd c. AD is additionally confirmed by a submerged tidal notch at a depth of -1.70 m and dated by shells of *Cerastoderma*.*

Keywords: sea level changes, Cyclades, Aegean Sea, sea level indicators, Late Bronze Age, Roman Period.

Περίληψη

Οι μεταβολές της θαλάσσιας στάθμης είναι αποτέλεσμα ευστατικών, παγετο-ισοστατικών και τεκτονικών παραγόντων. Ισότοπα οξυγόνου και γεωφυσικά μοντέλα χρησιμοποιούνται συχνά για την εκτίμηση των δυο πρώτων παραγόντων, ενώ ο τρίτος παράγοντας μπορεί να αξιολογηθεί μέσω δεδομένων υπαίθρου. Η λεπτομερής χαρτογράφηση δεικτών στάθμης θάλασσας μπορεί να χρησιμοποιηθεί για την εκτίμηση παράκτιων τεκτονικών κινήσεων και των μεταβολών της θαλάσσιας στάθμης σε μια συγκεκριμένη περιοχή. Παρόλο που υπάρχουν πολλοί δείκτες θαλάσσιας στάθμης, όπως γεωμορφολογικοί, βιολογικοί, αρχαιολογικοί, η αξιοπιστία τους ποικίλλει ανάλογα με την σχέση τους με την θαλάσσια στάθμη. Στους γεωμορφολογικούς δείκτες, ξεχωρίζουν οι παλιρροιακές εγκοπές καθώς μπορούν να υποδείξουν παλαιές στάθμες θάλασσας με ακρίβεια εκατοστού, ενώ η μορφολογία τους παρέχει ποιοτικές πληροφορίες σχετικά με τους ρυθμούς μεταβολής της θαλάσσιας στάθμης και τις τεκτονικές κινήσεις. Οι βιολογικοί δείκτες παρέχουν επίσης χρήσιμες πληροφορίες εφόσον είναι καλά καθορισμένη η σχέση τους με την μέση θαλάσσια στάθμη. Τέλος, τα αρχαιολογικά κατάλοιπα, βυθισμένα ή ανυψωμένα, μπορούν να χρησιμοποιηθούν για την ποσοτικοποίηση της μεταβολής της θαλάσσιας στάθμης. Ωστόσο, η αξιοπιστία τους ποικίλλει

ανάλογα με την λειτουργικότητα της εκάστοτε κατασκευής. Σε αυτό το πλαίσιο, στόχος της εργασίας είναι η μελέτη των μεταβολών της θαλάσσιας στάθμης στο κεντρικό Αιγαίο (Πάρος, Νάξος) μέσω της χρήσης δεικτών θαλάσσιας στάθμης. Η παρουσία βυθισμένων ακτόλιθων και παλιρροιακών εγκοπών παρέχουν ενδείξεις για την έκταση και το βάθος παλαιών ακτογραμμών. Οι βυθισμένες αρχαιότητες στην Πάρο περιλαμβάνουν νεκροταφεία και λιμενικές εγκαταστάσεις, ενώ στην Νάξο περιλαμβάνουν λατομεία και παράκτιους οικισμούς. Αρχαιολογικά δεδομένα στη Γρόττα και τα Απλώματα (Νάξος) παρέχουν ενδείξεις για τουλάχιστον δυο σεισμικά γεγονότα, τα οποία συσχετίζονται με δυο βυθισμένες παλιρροιακές εγκοπές σε βάθη -3 και -2,5 μ., αντίστοιχα.

Λέξεις κλειδιά: Κυκλάδες, Αιγαίο, δείκτες στάθμης της θάλασσας, Ύστερη Εποχή του Χαλκού, Ρωμαϊκή περίοδος.

1. Introduction

Sea level indicators play a significant role in the study of sea level changes during the Late Holocene and can be found along most coastlines, either submerged or emerged. Sea level indicators may be of biological (e.g. Laborel and Laborel-Deguen, 1994), geomorphological (e.g. Desruelles *et al.*, 2009; Pirazzoli, 1993, 1994), or archaeological origin (e.g. Blackman, 1973; Flemming, 1979; Pirazzoli, 1979). However, they may depict either rapid or slow sea level changes, mainly depending on whether the fluctuation comes from ice melting and eustasy or tectonic activity. In areas of the world, such as the Mediterranean, sea level indicators may represent a combination of both causes.

This study focuses on the archaeological sea level indicators that have been found in Paros and Naxos islands in correlation with geomorphological and stratigraphical features (e.g. notches, beachrocks and drillings) with the aim to investigate relative sea level changes during the Upper Holocene. The study area, the islands of Paros and Naxos, is situated in the central Aegean Sea, Greece and is part of the Cyclades Islands complex (Fig. 1a). Naxos is the largest island in the Cyclades, with a diverse coastal zone, mainly due to the lithological variety and tectonics that have affected the wider region. The north, east and south coasts of the island consist mainly of marbles and schists, while the west coasts are formed mainly on alluvial deposits and granodiorite (Evelpidou, 2001; Jansen, 1973.). The majority of the coastal zone is characterized by

low land morphology, while steeper slopes are located in the north and south part of the island (Evelpidou, 2001). Paros is the third largest island of the Cyclades with a rocky coastal zone, particularly in the NE and NW part, characterized by the alternation of carbonate rocks, gneisses-schists and alluvial deposits (Papanikolaou, 1980). Beaches form a smaller part of the coastal zone.

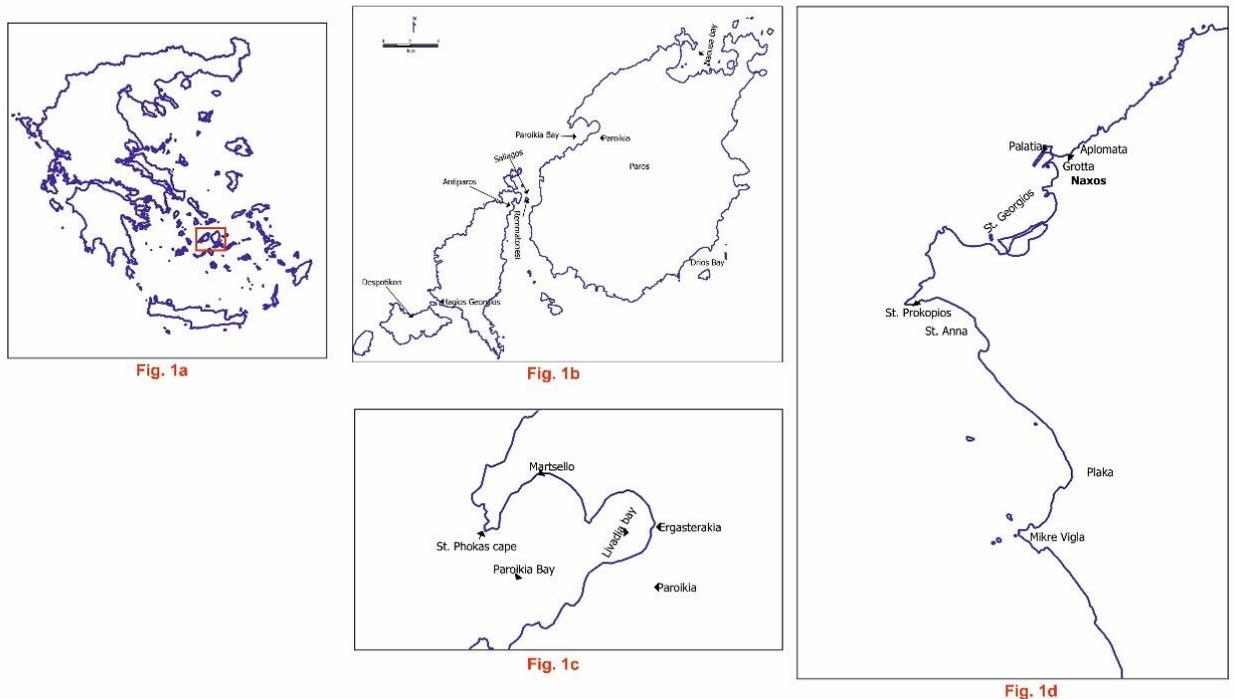


Fig. 1: a. The islands of Paros and Naxos in Greece and Aegean Archipelago. b-c. The sites of Paros and surrounding islands mentioned in the text. d. The sites of Naxos island mentioned in the text.

2. Materials and Methods

For the purposes of this study, an extensive bibliographic research was accomplished for the various coastal and submerged antiquities. Excavation diaries were also used. A submarine geoarchaeological fieldwork took place, which included locating and measuring archaeological and geomorphological sea level indicators. For each site, the time and the GPS coordinates were collected (with an average accuracy of ± 5 cm) and, underwater, the observed features were photographed and measured in relation to sea level at the time of observation. The elevation in relation to sea level was subsequently corrected through the comparison with real tide records at the time of measurements. The different types of markers (archaeological, geomorphological, stratigraphic),

obtained both from fieldwork and bibliographic research, were afterwards cross-compared in order to increase the accuracy of our results.

For the dating of the various sea level positions, ^{14}C dating was used from sedimentological data of drillings in Naxos (Evelpidou *et al.*, 2012). For the dating used in this paper, the conventional radiocarbon age was converted to calendar years by using the MARINE04, an internationally accepted calibration curve for marine data, and has been calibrated using a local marine reservoir correction factor (DR) of 154 ± 52 as average value for the Aegean Sea (Reimer and McCormac, 2002).

3. Upper Holocene sea level indicators

3.1 Paros Island

A submerged Roman building in the bay of Livadia in Paroikia was first indicated by Rubensohn (1901) and afterwards by Rubensohn (1949) (Fig. 1b). Its date is deduced by the use of hard limestone bonded with pozzolanic mortar in its construction (Papathanassopoulos and Schilardi, 1981; Rubensohn, 1901). According to Rubensohn (1901) the local name Ergasterakia or Magazakia (i.e. small workshops or small stores) explained the original use of the building. In 1979, the remains of this construction were found 1 m offshore at a depth of 0.50 m below sea level (Papathanassopoulos and Schilardi, 1981).

In the eastern coast of Livadia bay, at Krotēri, an underwater survey by Papathanassopoulos and Schilardi (1981) revealed the existence of a mole. In 1979 the top of the mole was found -2 m to -3 m below sea level (Papathanassopoulos and Schilardi, 1981). It measures approximately 100 m long, and looks trapezoidal in section (it is 9 m wide at its base and 6 m wide at its top) (Papathanassopoulos and Schilardi, 1981) (Fig. 2). The satellite photographs on the other hand show that the width in the middle of the mole reaches 15 m and almost 9 m at its tongue shaped end. Its height is not mentioned by Papathanassopoulos and Schilardi (1981), but during our research, we measured a height of 2-3 m. The mole is now totally submerged, and visible to its full length only from a higher point of view.



Fig. 2: A trapezoidal mole at Krotēri, eastern coast of Livadia bay, Paros island.

An underwater excavation conducted in 2000 at the site of Haghios Nikolaos in the harbor of Paroikia revealed in a relatively undisturbed stratum the foundations of the byzantine city wall at a depth of -4 m (Kraounaki and Kourkoumelis, 2000). This city wall by the sea is estimated for the time being around the 6th or 7th century AD (Kraounaki and Kourkoumelis, 2000). During our fieldwork in the NW part of Paros, at Martselo beach, submerged constructions were found and described hereby for first time. The submerged remains include wall parts and a structure that appears to be a pavement *in situ* and they are located at a depth between -1.7 and -1.8 m.

Several fossil shorelines have been identified in Paros Island, through tidal notches (Evelpidou *et al.*, 2014); it is worth mentioning a tidal notch (PA3) with a vertex near -180±10 cm, indicating a former sea level at -170±20 cm (Fig. 3). It exhibits a type e' profile that suggests some gradual relative sea-level rise followed by relative sea-level stability. The inward depth of about 43 cm corresponds to a period of relative sea level stability that ranges from 4 to 20 centuries (Evelpidou *et al.*, 2014).

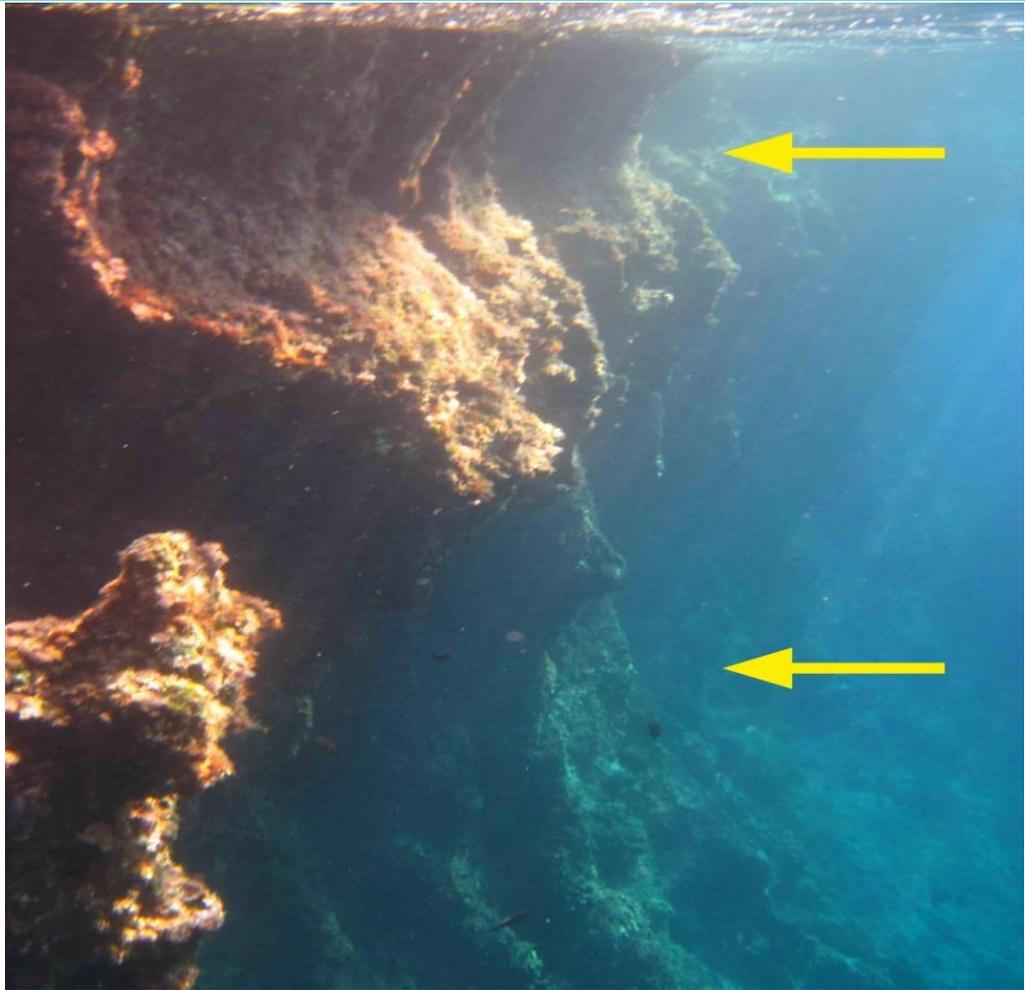


Fig. 3: Two submerged tidal notch at Paros Island, with the lower one at about -180 cm.

3.2 Naxos Island

In Grotta the floors of House B and Room A of House A were found at -0.55 m (Cosmopoulos, 1998; Kontoleon, 1967) (Fig. 1). They both date to the LH IIIA1-III A2 period (ca. 1400-1300 BC; Cosmopoulos, 1998). After an earthquake demolished House B in an early phase of LH IIIA2 (ca. 1375-1350 BC), life in the settlement continued (Cosmopoulos, 1998; Kontoleon, 1967). In fact, Room A' was built in its place, thus becoming the third room of House A (Cosmopoulos, 1998; Kontoleon, 1967). The floor of Room A' was constructed slightly higher than that of Room A; a layer of pebbles was placed under the floor of Room A' that stood at -0.45 m, i.e. 0.10 m higher than the rest of the floors of House A (Cosmopoulos, 1998, Fig. 5). Room B was added later to House A, in the LH IIIC period (ca. 1190-1075 BC); its floor stood at -0.20 m to -0.10 m (Cosmopoulos, 1998, Fig. 5).

In Plateia Metropoleos the ruins of the Mycenaean settlement were revealed in a height approximately as that of the sea level (Zapheirou and Lambrinoudakis, 1982). In Grotta, in a distance of 30 m from the coast, it seems that the ruins of the Mycenaean settlement were preserved in a height from +0.40 m to at least -1.20 m related to the modern sea level (Lambrinoudakis, 1985). The pure Mycenaean strata were preserved up to the height of +0.20 m to +0.40 m above modern sea level (Lambrinoudakis, 1985). Below the level of -1.20 m the excavation could not proceed due to technical difficulties (Lambrinoudakis, 1985). During the excavation of the Cathedral Square (Plateia Metropoleōs) it was made quite clear that between the older and the younger phase of the settlement a time period of abandonment intervened (Lambrinoudakis and Zapheirou, 1985). The ruins of the older phase (the Mycenaean one) were revealed already in the water, as happened in other areas of the capital of Naxos; water springs in this area approximately 0.60 m above the modern sea level and almost in the base of the walls of the younger (Geometric) phase (Lambrinoudakis and Zapheirou, 1985). Could this period of abandonment be explained or even attributed to certain tectonic phenomena?

The case of three LH IIIC (1190-1075 BC) chamber tombs in Aplomata provides intriguing evidence. Part of these tombs has been detached from the slopes of the coastal hills and fallen into the sea; that is why the excavation took place in the crest of a cliff overlooking the sea (Kontoleon, 1958; Vlachopoulos, 2006). The western part of the chamber as well as the equivalent part of the *dromos* in tombs A and C had collapsed into the sea (Kontoleon, 1958; Vlachopoulos, 2006). A closer examination of the finds in the interior of these tombs showed that the smashing of the bones and the clay vases is owed to a sudden collapse of the ceiling a little while after the use of the tomb, and definitely before the penetration of rain water and mud or before the gradual detachment of parts of the ceiling (Vlachopoulos, 2006). Vlachopoulos (2006) interprets the detachment of the tombs in Aplomata and the immersion of the settlement in Grotta as a result of both an earthquake and a sea level rise.

Indeed, at Plateia Metropoleōs, the trench D3 (Walls 9 and 59) reached the depth of 3.00 m (i.e. +0.30 m above modern sea level) because of the springing water that prevented the archaeologists from digging much lower (Chalepa-Bikake, 1983a; Chalepa-Bikake, 1983b, p. 76). On the 22nd of August 1983 Chalepa-Bikake (1983b, p. 55) noticed a layer of pure sand at the western part of Trench D3 at a depth of 2.40 m, i.e. at +0.90 m above modern sea level. She is not sure about its interpretation and wonders whether it is a flood. On the 23rd of August 1983 a floor is revealed at 2.78 m (i.e. +0.52 m above sea level) (Chalepa-Bikake, 1983b, p.67). On top of the floor a part

of the roof lies. Between the pieces from the collapsed roof and the floor Chalepa-Bikake (1983b, p. 67) observed a very thin layer of sand. The floor is made of clay and lies on top of a thick stratum of sea sand with many stones and relics of the pre-existing Wall 60 (Chalepa-Bikake, 1983b, p. 70, 24-08-1983).

The lowest 0.70 m of this deposit consisted of pure sand with very few sherds that date to the LH IIIB2 or LH IIIC period (Chalepa-Bikake, 1983a; Chalepa-Bikake, 1983b, p.70, 24-08-1983). The few sherds found on the floor (and therefore correspond to a second building phase) date the destruction to the LH IIIC period (1190-1075 BC) (Chalepa-Bikake, 1983a). This layer of destruction is followed by a deposit (0.20 m to 0.90 m thick) that shows no architectural relics (Chalepa-Bikake, 1983a). This means that after the destruction of the LH IIIC period this area was abandoned (Chalepa-Bikake, 1983a). It appears that this was not the only case that the sea transgressed to the north coast of ancient Naxos.

In the Hellenistic *Agora* of Naxos both Welter (Karo, 1930) and Kontoleon (1970) noticed a thick layer of sand without sherds exactly above the ruins of the *Stoas*. According to Kontoleon (1970) this proves that the beach extended remarkably towards the South, right after the destruction of the building. Part of the North *Stoa* was revealed close to the East one. It is located in the free space between the road to Eggares and the beach, in the west side of the stream that runs close to the city of Naxos (Kontoleon, 1967). It was revealed in a depth of 5.40 m below modern ground surface (Kontoleon, 1967). The foundation of the building was revealed 1 m below the modern sea level (Kontoleon, 1967). The ruins of the North *Stoa* were also covered by a modern deposit 1 m thick and a layer of sand that obviously demonstrated the older surface of the beach (Kontoleon, 1967).

The 1988 excavation season continued the research in the interior of the *Agora* (Lambrinoudakis, 1988). The trench reached the depth of +0.85 m. The layer of sand mentioned by G. Welter (Karo, 1930) and Kontoleon (1967) was revealed at a depth of +0.60 m (Lambrinoudakis, 1988). The layer of destruction lies between +1.10 m and +0.60 m; it consists of a few sherds mixed with stones, mortar, pieces of lime and mosaic, as well as traces of fire (Machaira, 1988). At approximately +1.00 m the archaeologists found smoothed sherds and a large amount of pebbles (Machaira, 1988). The ruins of the *Stoa* along with the Roman structures that were built close to it seem to have been abandoned in the 2nd c. AD (Lambrinoudakis, 1988; Machaira, 1988). At Mikre Vigla the survey of 1981 traced a coastal settlement that probably dates to the Early Bronze Age, according to the presence of obsidians and numerous sherds that are

scattered in a quite vast area covered by a thin layer of sand (Treuil, 1983). A submerging water spring exists a little further to the east (Treuil, 1983). These field observations are consistent with the core of borehole NB2, which reached 3.21 m and drilled in the east margin of the lagoon in Mikre Vigla (Evelpidou *et al.*, 2012). The first 0.80 m revealed gray clayey sand with small charcoal fragments and pottery at 0.54-0.57 m (Evelpidou *et al.*, 2012).

In Mikre Vigla, two beachrock benches appear; the lower beachrock bench is situated 100 m off the modern coastline at a depth ranging from -2.70 to -3.40 m (Evelpidou *et al.*, 2012). The upper beachrock bench in Mikre Vigla extends along the coastline for almost 15 m (Evelpidou *et al.*, 2012). It is 0.70 m wide and its depth ranges between 0 m and -1.70 m (Evelpidou *et al.*, 2012). The fact that it is developed in the supra-littoral area tends to prove certain instability in this zone (Dalongeville and Renault-Miskovsky, 1993). It is exactly this beachrock formation that has been quarried for the extraction of large thin rectangular or square slabs (Fig. 4). Dalongeville and Renault-Miskovsky (1993) attribute them to the Hellenistic period, not without reservations. These beachrock quarries are lying partly below sea level today (Dalongeville and Renault-Miskovsky, 1993). The bottom of the quarry lies at about -0.23 m.

Beachrock formations are also observed in Plaka. According to Dalongeville and Renault-Miskovsky (1993), they are totally submerged at a depth of -0.50 m to -1.20 m; three different alignments of the beachrock, parallel to each other are reported.

Tidal notches also exist in Naxos Island. It is worth mentioning a tidal notch found at about -280 cm (Fig. 5) indicating a former sea level at about -280 ± 20 cm (Evelpidou *et al.*, 2014).



Fig. 4: Naxos, Mikre Vigla: Beachrock formation with traces of quarrying.

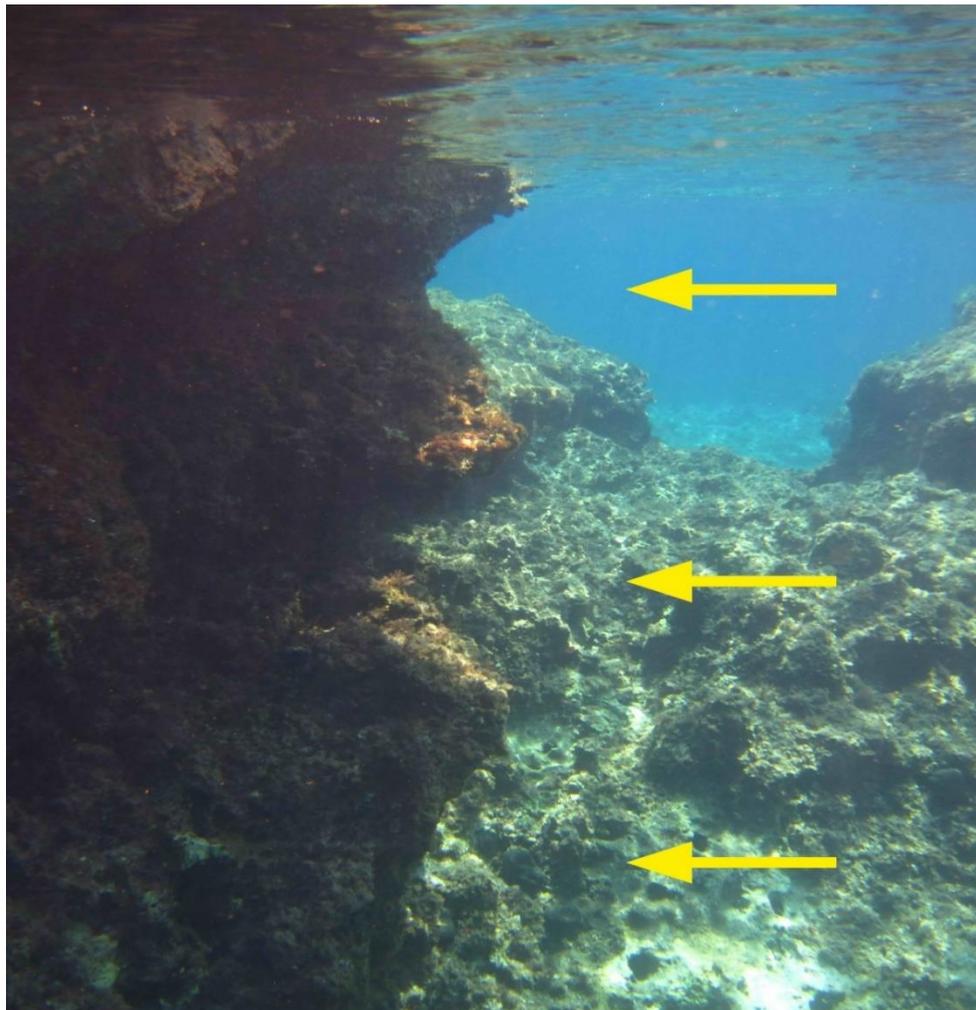


Fig. 5: Multiple submerged tidal notches at Naxos Island, with the lower one at about - 280 cm.

4. Results and Discussion

In the bay of Livadia, Paroikia, the upper course of the walls in the Roman building was measured at a depth of -0.80 m (Fig. 6). In the eastern coast of Livadia bay, at Krotēri, our measurements on the mole, taken in August 2011, differentiate from those of Papathanassopoulos and Schilardi (1981); close to the shore the submerged mole is preserved in a low height, but approximately at the middle of its length its upper part lies at -0.80 m. The surface of the mole close to its tongue-shaped projection is located at -1.23 m.

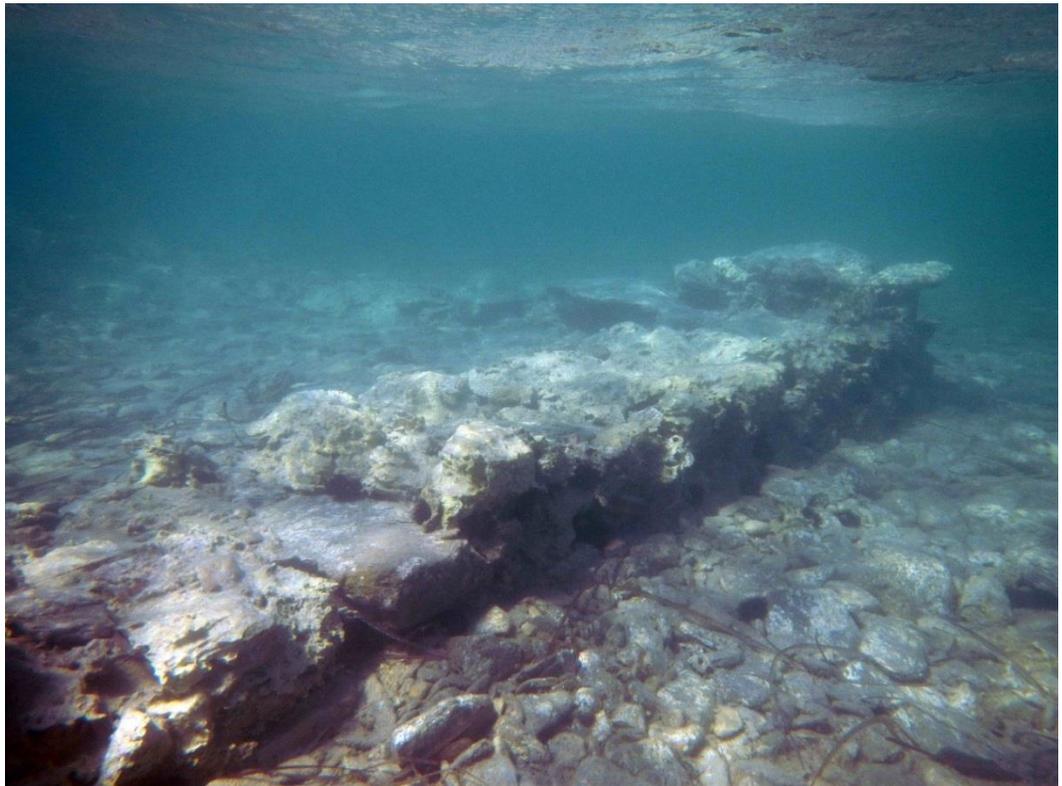


Fig. 6: Submerged Roman building in Paroikia Bay (Paros). Detail of the lower part of a wall, whose width measures almost 1 m.

The fieldwork took place in the NW part of Paros, in Martselo beach, near the cape of St. Phōkas in the bay of Paroikia, and revealed several submarine constructions as well as submerged beachrock formations (Fig. 7). All the submarine constructions are aligned parallel to the modern coast, in an East-West axis. The beachrocks run parallel to the modern coast in a distance ranging from 5 to 15 m. The beachrocks may be distinguished in two bands. The first band (shallower) is located between -1.5 and -1.7 m, while the second band is found between -2.2 and -2.5 m. Part of a wall was observed in a depth of -1.7 m, 1.5 m wide (Fig. 8), built in the *emplecton* technique (i.e. two parallel lines of large rubble stones whose space in between is filled with smaller

stones), a way of construction applied by the Romans (Plin. *NH* 36, 171. *Vitr.* 2.8,7). About the applied technique, see Orlandos and Travlos (1986). In another location of the same site, 6 large rubble stones are set in line, orientated in an East-West axis, possibly consisting part of a wall. They are located approximately 15 m from the coastline, at a depth of -1.6 m. Close to this location a construction that seems like a pavement *in situ* is identified, consisting of small quadrate stones. Its orientation is East – West, somewhat obliquely to the modern coast; its western end points to the cape of St. Phōkas. It is located approximately 1.8 m below sea level. It cannot be observed in a great length, due to the slabs of beachrock that have covered part of it. A small part of this pavement extends a little farther to the West.



Fig. 7: Submerged beachrock formations in Martsele beach, Paroikia (Paros).

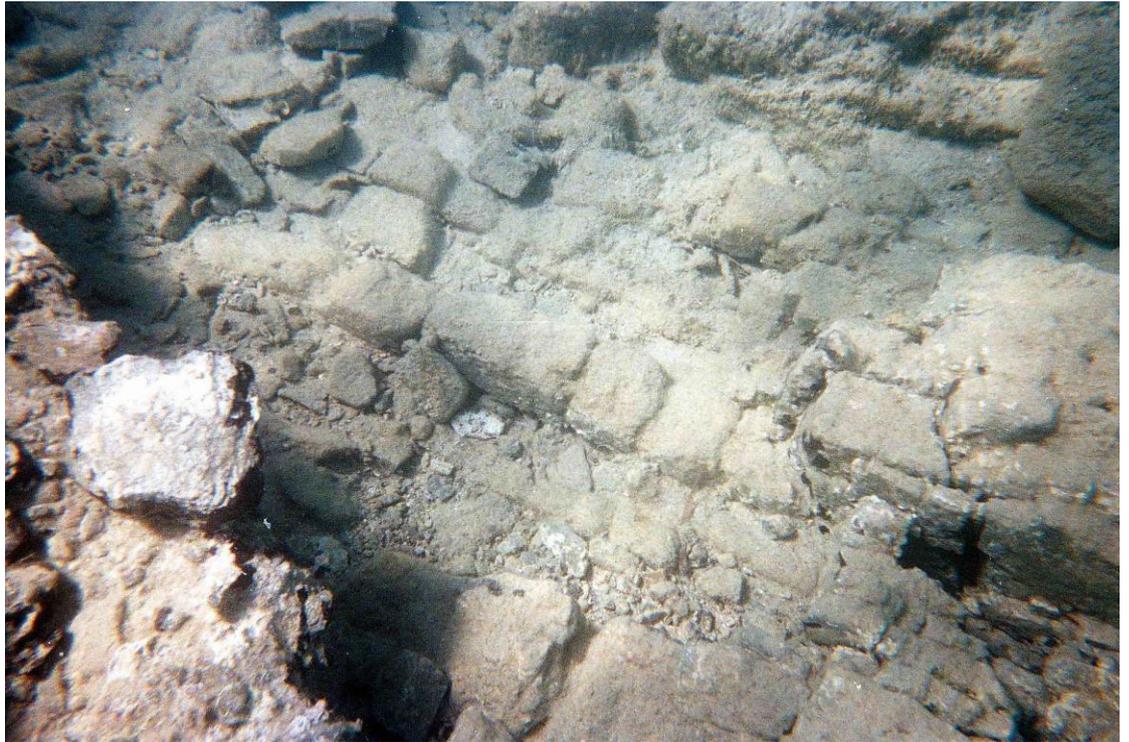


Fig. 8: Part of a wall submerged in a depth of -1.7 m at Martselo beach (each stone has a width of about 10 cm).

The mole of Paroikia resembles a tongue-shaped breakwater in Rheneia, in the area of “Lazaretto”, first published by Négris (1904). The Rheneia breakwater had posts fixed onto the surface of the quay; one of them was found *in situ*; it was roughly dressed and at least its visible part was similar to a cylindrical post (Négris, 1904; Dalongeville *et al.*, 2007). This post recalls the circular depression found in the centre of both moles in Paroikia (their dimensions are 2 m wide by 1 m deep, see Papathanassopoulos and Schilardi, 1981). Could they be the holes, the offprints of a circular pole on which the ships were tied up? The upper surface of the Roman quay at Rheneia lies at a minimum depth of -0.60 m. The breakwater that protects the quay lies a few decimeters under the modern sea level. The upper surface of the mole in Krotēri at Paroikia lies at -0.80 m (Fig. 9). We consider that in structures such as moles and breakwaters, marine abrasion must have lowered their surface; in that case the best preserved part of the structures is more reliable, since it is closer to their original height (e.g. Auriemma and Solinas, 2009; Antonioli *et al.*, 2007). On the contrary, the measurement of the maximum depth can prove very illusive, when it is used as a sea level indicator. It seems that the protruding, perhaps well-built, part of the mole in Krotēri is now missing. The missing parts of the upper surface could have been looted, as in the case of the South Mole in Leukas (see Murray, 1988). There, a curious scatter of numerous worked blocks in the

south side of the Western Arm led to the assumption that this side of the mole originally exhibited a perpendicular face that was systematically quarried for its rectangular blocks at some point after the rise of the sea level that put the mole out of use (Murray, 1988).



Fig. 9: Underwater view of the inclining sides of the submerged mole in Krotēri, Paroikia (Paros).

If on the other hand the submerged construction is a breakwater, then we should examine what urged the Parians to protect the coastline from the waves at a certain period of time. We would then be obliged to estimate three parameters; a) how much of its top has been carried away by the action of the waves; b) the breakwater must have protruded at least 1 m above the surface of the sea; c) in which depth of the harbor could the breakwater be functional for the ships? d) When was this breakwater constructed? e) At which chronological point was this construction abandoned? When did it begin to act more as a reef and less as a breakwater? (cf. Knoblauch, 1972 and Murray, 1988 for analogous discussion).

Evidence of such structures that postdate the classical period is to be found in Southern Italy and the Istrian coast; At Torre Saturo near Taranto a breakwater built with the technique of stone heaps without mortar is dated to the 2nd c. BC (Auriemma and Solinas, 2009). The published figure by Auriemma and Solinas (2009, Fig. 9) depicts very clearly its trapezoidal section. Moreover, Istrian fishponds that date to the 1st c. AD comprise the same building technique of the aforementioned breakwaters, i.e. heaps of pebbles and cobbles without mortar and with a trapezoidal cross-section (Florido *et al.*, 2011).

Still, there are some discrepancies between the aforementioned breakwaters. The one in Krotēri is not depicted in Rubensohn's maps nor are any visible sherds or vases between the schist stones. A large rectangular block of stone lying in its north flank could be either of marble or cement. Macroscopically the view is illusive, because the surface is coated with slimy green algae. Moreover, locals insist that the breakwater is a work of Nazis during the German occupation of the island in World War II. The submerged breakwater is depicted in aerial photographs taken in 1946 (Source: Hellenic Military Geographical Service). Under these circumstances, the mole in Krotēri should be approached with scepticism concerning its ancient date.

Naxos on the other hand provides clear data that can be securely correlated with various geomorphological indicators. For instance, a co-seismic event is depicted by a tidal notch at -2.3 m on the submarine rocky carbonate areas of central Cyclades (Evelpidou *et al.*, 2014). The inward depth of 23 cm suggests a relative sea level stability of 2.5 to 11 centuries before its rapid subsidence (see Evelpidou *et al.*, 2014; Table 1, Tidal Notch B). This event could possibly be dated around 3100 BP based on the corresponding depth of the submerged settlement in Grotta. This tremor is probably the reason why the roofs of the LH IIIC chamber tombs in Aplomata collapsed and part of the settlement in Grotta submerged and subsequently flooded by a tsunami. The Mycenaean settlement was abandoned for a long period of time, until the new settlers of the Geometric period used the same space for the burial of their ancestors.

Below notch B, a deeper tidal notch exists at approximately -2.8 m (Evelpidou *et al.*, 2014). This notch must have been developed at least before 3350 to 4200 BP. Its shape indicates a gradual subsidence followed by a co-seismic event (Evelpidou *et al.*, 2014). The lower beachrock bench of Mikre Vigla, which is found in a depth of -2.70 m and -3.40 m, should also be attributed to the same period. In that context, it is possible that the inhabitants of the coastal settlements were obliged to live with a gradual flooding and slow sea level rise. Around 3300 BP (LH IIIA2 period) an earthquake destroyed

House B in Grotta. Excessive moisture could be the result of the rise of the sea level caused by the earthquake at an early phase of LH IIIA2 (1350 BC). This could explain the construction of the floor of Room A' at 0.10 m higher than the earlier floors of House B and Room A of House A. The pebbles under the floor of Room A' were probably used as a means of drainage, a way of preventing the moisture to penetrate into the room. Cosmopoulos (1998) additionally points out that deposits of the LH IIIA2 period in general were found in depths ranging from -0.35 m to 0.00 m.

According to Sample NA2/1.87 from the coastal area of St. Georgios on Naxos, the sea level around 1752±40 BP was above -1.78±0.5 m; the sample is dated according to an articulated *Cerastoderma glaucum*, for more see Evelpidou *et al.* (2012). This result may be coherent with the presence of the upper beachrock bench between 0 m and -1.70 m at Mikre Vigla (Evelpidou *et al.*, 2012). This upper beachrock bench was partially protecting the area up to 1000 AD (Evelpidou *et al.*, 2012). The formation of this beachrock started around 198 AD. The date of 198 AD excludes the quarrying of the coastal beachrocks in Mikre Vigla in the Hellenistic period. The technique of wading while quarrying, as Barber and Hadjianastasiou (1989) suggest, is not elsewhere recorded. On the contrary, coastal quarries normally have a strip of rock that is not quarried, so that it forms a barrier to sea waves. That is the case in Stavros Akroteriou and Phalasarna, both in West Crete (Kelletat, 1979; Pirazzoli, 1988; Tziliggaki, 2014). In any case, the view of the quarries in Mikre Vigla depicts the last phase of its use. We assume a beachrock bench that was originally thicker before its exploitation started.

Furthermore, beachrocks at Plaka on Naxos may be found at deeper depths than previously reported by Dalongeville and Renault-Miskovsky (1993); based on our fieldwork observations, beachrocks may be distinguished in three or four generations, with the shallower one reaching nowadays a depth of 1.6 m. The deeper beachrocks lie at -1.5 to -2 m, -1.8 to -4.3 m and -4.5 to -6.3 m. It is therefore plausible to conclude that the younger generation of Plaka beachrocks could also be contemporary with the upper beachrock bench of Mikre Vigla and could be dated around 1752±40 BP (i.e. 198±40 AD). The approximate depth of -1.70 m corresponds therefore to the submerged tidal notch that is mainly confirmed on the island of Paros at a depth of 1.70±10 m (Evelpidou *et al.*, 2014). The inward depth of this tidal notch measures approximately 0.37 m and indicates relative sea level stability that ranges from 2 to 10 centuries or from 3.5 to 17 centuries or even from 4.5 to 23 centuries (Evelpidou *et al.*, 2014).

The sea transgression in the Hellenistic Agora of Naxos should be interpreted as another tsunami that crushed onto the north beach of ancient Naxos. The fact that all archaeologists (Karo, 1930; Kontoleon, 1967; Machaira, 1988) refer to a single layer of sand is indicative of a tsunami incident. Tsunami events often leave a single layer of sand and coarser deposits, whereas floods or storms leave several interfingering sand layers, because of their frequency (Pirazzoli, 1996). This observation is further attested in Late Bronze Age Naxos. Although Chalepa-Bikake (1983b, p.55, 22-08-1983) wonders whether she is excavating a flood, she is in fact describing a tsunami (the excavation notebook and report though simply refer to a layer of sand). A thin layer of sand was sealed between the floor and the collapsed roof in Trench D3 (Chalepa-Bikake, 1983b, p. 67, 23-08-1983).

The tidal notch at -1.70 m seems to correspond to the stratum of tsunami found in the Agora in Naxos. This sudden tectonic phenomenon in the 2nd c. AD recalls the Greek historian Herodian (I, 1, 4), who wrote contemporary history. His work covers a time period from the death of Marcus Aurelius (180 AD) till the rise of Gordianus III (238 AD) (Herodian I, 1, 4). In the introduction of his history he states that during his era the alternation of the emperors, the civil wars, the wars with the enemies, the riots in the prefectures, the fall of cities and finally *earthquakes* and epidemics happened with increasing frequency in comparison with the previous 200 years (for more see Alföldy, 1971; 1976; Pirazzoli, 1986). Indeed, the sudden co-seismic event that submerged Shoreline C covers the time span of Herodian's history; 1752±40 BP corresponds to a time period between 158 AD and 238 AD. The frequency of earthquakes during the first half of the 2nd century AD is depicted in the initiative of the Roman emperors to repair and reconstruct buildings in several cities of Asia Minor (Winter, 1996). Emperor Hadrian (117-138 AD) helped Nikaia of Bithynia, whereas Emperor Antoninus Pius (138-161 AD) helped Rhodes and Kos, Stratonikeia, Iasos, Mytilene and the coast of Ionia, Smyrna, Magnesia on the Maeander, Ephesos and Termessos in Lycia (Winter, 1996). According to Magie (1950, p. 1492 notes 6 and 7) the earthquake in Asia Minor may have occurred as early as 139 AD, whereas the one that shook Mytilene is dated to 147/8 AD. The tsunami that hit Naxos in the middle of the 2nd c. AD seems to be contemporary with the seismic events along the coasts of Asia Minor.

It is possible that this co-seismic event had an impact on Paros as well. An inscribed *stele* as well as pieces of an inscribed architrave that were walled in the Venetian fortification of the Kastro in Paroikia and in the Early Christian church of Katapoliani acknowledge that a *Tetragonos* (i.e. Square) *Stoa* in the *Agora* of Paros was reconstructed during the Roman imperial period (Inscriptiones Graecae XII 5, 258. 457.

464. 257. 1019A). This reconstruction must have been very important, because an honorary *stèle* (Inscriptiones Graecae XII 5, 1019A, line 6-8) named the list of the donators; one of them was certainly the priest of an emperor, presumably Hadrian's (for more about the magistrates, see also Berranger-Auserve, 2000, p.157). Unfortunately, the last surviving line is too damaged and the name of the emperor is hard to read (see Inscriptiones Graecae XII 5, 1019A, line 8). Could this initiative reflect the destruction of *Tetragonos Stoa* in Paros by an earthquake? Koenigs (1978) supposes that the location of this *Stoa* should be traced close to the sea, as in the case of Naxos, in the area between Katapoliani and the Venetian Kastro (the former ancient acropolis) (Fig. 1). This area is nowadays densely occupied by modern buildings.

It is also worth mentioning that both *Stoas* on Paros and Naxos point to certain analogies between their plan and the motive of the lion spouts in the *sima* (Koenigs, 1978), since they were contemporary; both were initially constructed in the 3rd c. BC (Kontoleon, 1967; Koenigs, 1978) and were destroyed in the middle of the 2nd century AD. We could therefore assume that both islands enjoyed a certain period of tectonic stability for approximately 5 centuries. This result is additionally confirmed by the submerged tidal notches on Paros and Keros that are found in a depth of $-1.70 \pm 20\text{m}$ (Evelpidou *et al.*, 2014). How important was a small island such as Paros to the Romans? Paros was very famous throughout antiquity for the good quality of its marble. Fine works of art executed in Parian marble have been exported since the 6th c. BC. During the Roman Empire Parian marble was diffused to the most remote places (for more, see Schilardi and Katsonopoulou, 2010). In fact, during this time period Paros was never used as a place of exile like the rest of the islands; instead, Paros enjoyed a certain acme (Rubensohn, 1949).

The co-seismic event of the 2nd c. AD could have affected the trade of the Parian marble, if the harbor of Paroikia suffered from submersion and flooding, while the moles and breakwaters fell into disuse. The small size, the poor quality and the Latin inscribed letters on marble blocks that were abandoned in the rear part of the famous underground "Quarry of the Nymphs" on Paros, lead to the conclusion that the last phase of its use is dated around the middle of the 2nd c. AD (Korres, 2010). Those abandoned marble blocks in the northern chamber of the quarry were inscribed with numbers and the word HERMOS in Latin (Korres, 2010). Ancient deposits of Parian marble blocks found in the bed of Canale di Fiumicino in Ostia were also inscribed in Latin as HERMO/LOC CDLXXV and LOC/XXI/HERMO/LOCD I (Baccini Leotardi, 1989; Pensabene, 1994; Korres, 2010). Other later inscriptions on the same blocks are dated in 163 AD and 164 AD and provide therefore the highest terminus for the date of the word HERMO or

HERMOS (Korres, 2010). In any case, it is the lowest chronological estimation for the submersion of Shoreline C (i.e. 1752±40 BP or 158 AD) that concurs with the tsunami on Naxos, with the reconstruction of the Tetragonos Stoa on Paros and the abandonment of the “Quarry of the Nymphs” on Paros. The only discrepancy is between the inscription IG XII 5 1019A that is presumably attributed to Hadrian’s reign and the date 158 AD that corresponds to the reign of Antoninus Pius.

It seems, however, that the inhabitants of Paros tried to confront the sudden and rapid sea-level rise in their city by reinforcing the old fortification harbor line with accumulated marble items from all over the island and the ancient quarries. This is deduced by the excavations during the dredging work undertaken in Paroikia in 2000 for the enlargement of the modern harbor and the construction of a new larger wharf in front of the chapel of St. Nikolaos (Kraounaki and Kourkouvelis, 2000; Schilardi, 2010). Doric column drums, a large amount of marble architectural members and architraves, almost 300 marble funerary urns, pieces of sarcophagi, half-finished statues, and pottery mainly dating to the Late Roman or Early Byzantine period, were retrieved from the seabed close to the coastal wall (Kraounaki and Kourkouvelis, 2000; Schilardi, 2010).

5. Conclusions

This paper shows that the correlation of geomorphological and archaeological evidence can be very useful not only in the study of sea level changes but also in tracing events, such as earthquakes and tsunamis, that have impacted ancient civilization of central Cyclades. Such evidence can be used in geoarchaeological studies as guides to understand, for instance, the abandonment or destruction of specific archaeological sites.

We correlated the quarried upper beach rock bench of Mikre Vigla with the younger beach rock formation of Plaka, both on Naxos. Their depth, consequently, is related to the submerged tidal notch found at Paros at a depth of -1.70 m. All these data point to a date around 1752±40 BP (i.e. 198±40 AD). The co-seismic event of the 2nd c. AD seems to correspond to the abandonment of the underground “Quarry of the Nymphs”, while it could also have affected the trade of the Parian marble. During the same event, it appears that a tsunami hit the north coast of ancient Naxos. The submerged shoreline at about -1.7 m seems to correspond to the stratum of tsunami found in the Hellenistic Stoa in the Agora in Naxos that dates to the middle of the 2nd c. AD.

The submerged tidal notch A (found at depth of -2.8 m in Naxos) is correlated with the lower beachrock bench at Mikre Vigla, which lies at a depth from -2.70 m to -3.40 m. A gradual flooding and sea level rise explains the measures taken by the inhabitants of LHIII A2 Grotta to secure their houses from moisture.

This study offers geoarchaeological evidence that central Cyclades are characterized by subsidence events at least from around 3300 BP, while the presence of beachrocks at greater depths reveal that the subsidence history of the study area has still more to offer to the research of relative sea level changes during the late Holocene.

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