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STUDY OF BEACHROCKS IN EAST ATTICA

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Abstract

Sea level indicators, such as tidal notches and beachrocks, may provide valuable information for the relative sea level changes of an area. Beachrocks in particular have received various arguments concerning their use as reliable sea level indicators and their formation environment. This work focuses on the coasts of East Attica in order to trace the palaeoshorelines of the Upper Holocene through the study of beachrocks. The coastal zone was surveyed in detail by snorkelling and diving, in order to locate, map and sample beachrocks. The samples were studied under a SEM, which showed that the beachrocks are mainly composed of quartz grains, a few calcites and feldspars, while the carbonate cement is characterized with the presence of MgO at percentages between 5 and 7.8%. Based on correlations with published drillings in the study area, the studied beachrocks should not be older than 2000 years BP.
Keywords: *beachrocks, Late Holocene, coastal changes, sea level.*

Περίληψη

Οι δείκτες θαλάσσιας στάθμης, όπως οι παλιρροιακές εγκοπές και οι ακτόλιθοι, παρέχουν πολύτιμες πληροφορίες για τις σχετικές μεταβολές της θαλάσσιας στάθμης μιας περιοχής. Συγκεκριμένα οι ακτόλιθοι έχουν συζητηθεί αρκετές φορές, ως προς την χρήση τους ως αξιόπιστοι δείκτες θαλάσσιας στάθμης και ως προς το περιβάλλον σχηματισμού τους. Η συγκεκριμένη εργασία εστιάζει στις ακτές της Ανατολικής Αττικής ώστε να εντοπίσει τις παλαιοακτογραμμές του Ανώτερου Ολόκαινου, με την χρήση των ακτόλιθων. Για τον σκοπό αυτό, η παράκτια ζώνη ερευνήθηκε λεπτομερώς, ώστε να εντοπιστούν και να χαρτογραφηθούν οι εμφανίσεις ακτόλιθων καθώς να ληφθούν δείγματα. Τα δείγματα μελετήθηκαν στο Ηλεκτρονικό Μικροσκόπιο Σάρωσης, το οποίο έδειξε ότι οι ακτόλιθοι της περιοχής αποτελούνται κυρίως από χαλαζία, ασβεστίτες και αστρίους, ενώ το ανθρακικό συγκολλητικό υλικό χαρακτηρίζεται από την παρουσία MgO σε ποσοστά μεταξύ 5 και 7.8%. Η συσχέτιση των ακτόλιθων με διαθέσιμα στρωματογραφικά έδειξε ότι η ηλικία των ακτόλιθων της περιοχής δεν είναι μεγαλύτερη από 2000 χρόνια BP.
Λέξεις κλειδιά: *ακτόλιθοι, Ανώτερο Ολόκαινο, παράκτιες μεταβολές, στάθμη θάλασσας.*

1. Introduction

Remains of past sea levels, such as tidal notches, benches and beachrocks, may provide valuable information for the investigation of relative sea level changes. Beachrocks are formed in the coastal zone, consisting of beach sediments that are lithified through the precipitation of carbonate cements. Beachrocks have been used as indicators of sea level change in various studies (e.g. Kindler and Bain, 1993; Chowdhury *et al.,* 1997; Tatumi *et al.,* 2003; Desruelles *et al.,* 2004, 2009), and have proven particularly useful when no other indicators are available or when they are coupled with other sea level data. Nevertheless, their role as sea level indicators has received some arguments. According to Hopley (1986), beachrocks are more reliable in microtidal environments, while Kelletat (2006) considers a supratidal genesis and has discussed that their relation to other sea-level indicators should be taken into consideration, i.e. the deposition and cementation history of the beachrock material should not contradict other objective indicators, such as notches. According to Desruelles *et al.* (2004), beachrocks that have formed in the intertidal zone by carbonate cementation during periods of stable relative sea-level, are good sea-level indicators. A recent study by Mauz *et al.* (2015) has reported how a beachrock can be transformed into a sea-level index point (cf. Shennan *et al.,* 2015) with well-defined indicative meaning. Furthermore, the cement mineralogy and morphology is indicative of the diagenetic environment (Gischler, 2007), and by examining the cement characteristics and microstratigraphy it is possible to identify the cement type and the spatial relationship between coastline and beachrock formation zone (Mauz *et al.*, 2015).

Dating of beachrocks is also a challenging task (Hopley, 1986; Goodwin, 2008). As Hopley (1986) has argued, although biogenic material can be easily dated with radiocarbon, the results must be evaluated with caution. The age obtained is the date of death of the organism and there is likelihood that the difference in time from the death of the organism to its incorporation in the beachrock may be hundreds or thousands of years (Hopley, 1986). During the last decade, the OSL method has also been attempted to date beachrocks for the reconstruction of palaeoshorelines along the Brazilian coast (Barreto *et al.,* 2002; Tatumi *et al.,* 2003), India (Thomas, 2009) and Turkey (Erginal *et al.,* 2010) and the results were also compared/constrained by radiocarbon dating.

In this context, this work focuses on the east Attica coasts in an attempt to trace the palaeoshorelines of the Upper Holocene through the study of beachrocks and their correlation with other available sea level indicators from the study area (e.g. stratigraphic data, archaeological data, etc.).

2. Study area

The study area is located in the eastern coasts of Attica (eastern Greece), extending from Porto Rafti to Marathon (Figure 1). The lithology of the coastal area consists of Quaternary sediments, in the northern part, while towards the south the area is composed mainly of schists and marbles.

The dominant features of NE Attica are Parnitha and Pendeli mountains, bounded by Neogene shallow basins of NW-SE and NE-SW direction (Freyberg, 1951; Mettos *et al.,* 2000). According to Papanikolaou and Papanikolaou (2007) NE Attica forms a tilted tectonic block rotating to the S-SW, bounded by the Afidnai fault to the south and the Oropos fault to the north. The wider area shows no indications of major earthquakes during the last 2500 years (Ambraseys and Jackson, 1998). Both historical and instrumental data provide no evidence for large earthquakes for the period 1700-2000, with the exception of two events, in 1705 and 1938 (Ganas *et al.,* 2005; Papanikolaou and Papanikolaou, 2007).

Palaeogeographic research in the study area has also taken place in Vravron by Triantaphyllou *et al.* (2010), and in Marathon by Baeteman (1985) and Pavlopoulos *et al*. (2006). According to Pavlopoulos *et al.* (2006), the relative sea level rise in Marathon, for the period 5250-1252 BP, was estimated between 2 and 2.5 m (0.50-0.62 mm/yr), while for the last 3800 years it reached a rate of about 0. 43 mm/yr. In Vravron, a relative sea level (RSL) rise at a rate of about 0.49mm/y for the

last 3462 years BP was estimated based on peat, while, based on marine gastropod datings, the RSL rise was estimated at a rate of 0.69mm/y for the last 4709 years BP (Triantaphyllou *et al.*, 2010).

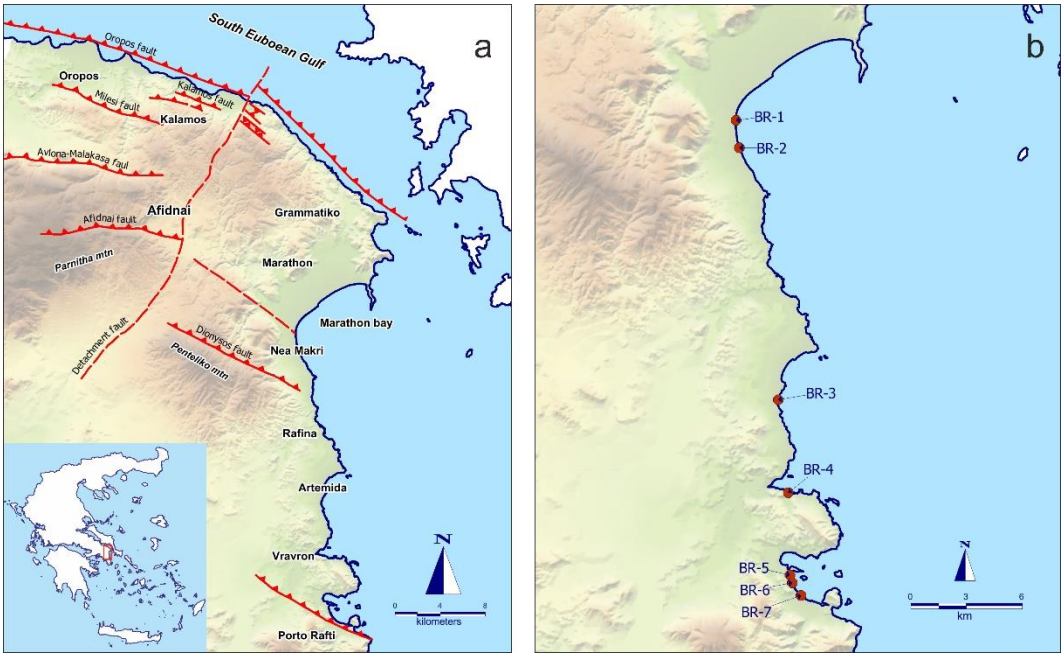

Figure 1 - Location of the study area (a) and sites of investigated beachrocks (b).

3. Materials and Methods

The coastal zone of Eastern Attica was surveyed in detail in order to locate beachrocks. All submarine features were surveyed in detail by snorkelling. In beachrock occurrences, their thickness, width and inclination were measured, while their depths were referred to the sea level at the time of the measurement. At each site, one or more transects were performed, depending on the particular features of beachrocks (Figure 2).

In order to determine the nature and composition of the beachrock cements, samples were collected from all sites by diving. Thin sections were cut from the samples and were studied and analysed under a Scanning Electron Microscope (SEM), in order to determine the carbonate composition of the cements and characterize the nature of the constituents and the geochemistry of the cements.

An attempt was made to date selected samples with OSL, however, because the samples were too coarse grained, it was impossible to proceed with the method. As a consequence, relative dating of beachrocks was made, by correlating them with ^{14}C datings from sedimentological data of drillings in nearby locations.

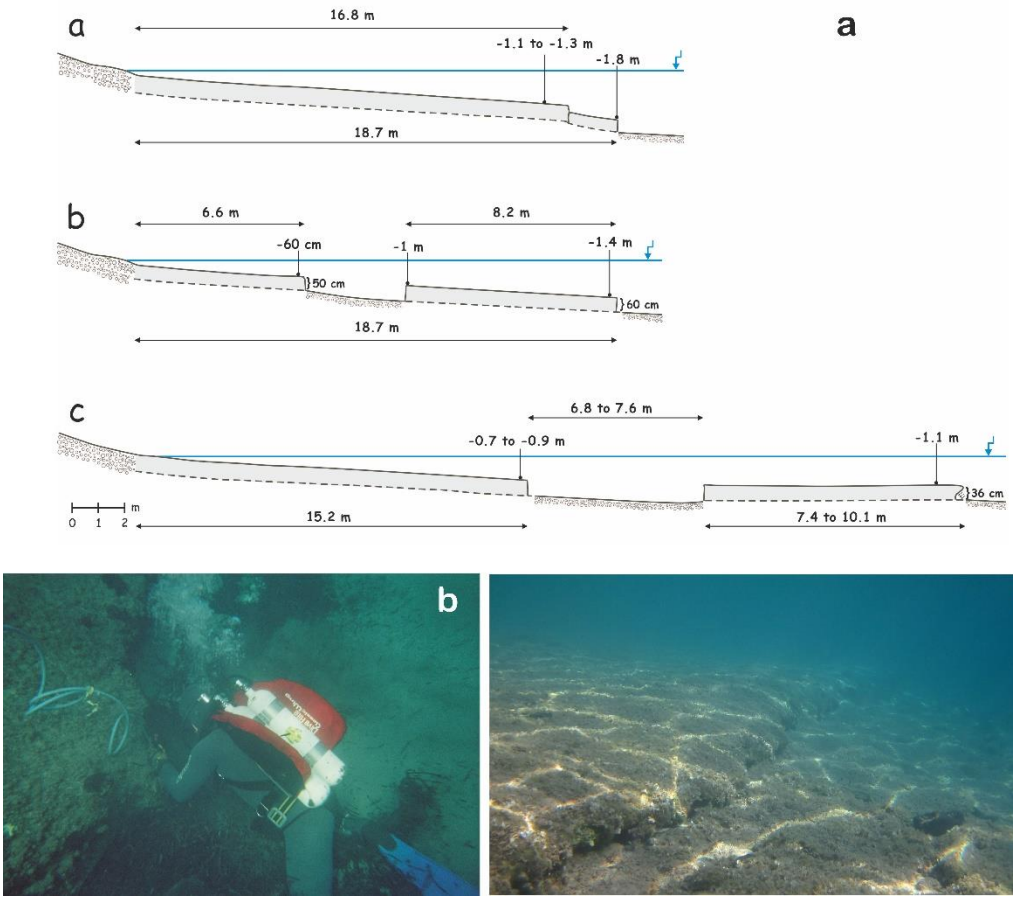

Figure 2 - (A) Submarine transects from Agia Marina (BR-7), (B) sampling of beachrocks, (C) submarine beachrocks in Porto Rafti at about -1.3 m.

4. Results

Beachrocks have been identified in seven locations, from the bay of Porto Rafti to Marathon Bay (Table 6) (Karkani, 2012). In St. Panteleimonas (BR-1), Marathon Bay, the beachrocks have a thickness of 15-20 cm and extend from +21 cm above sea level to a depth of -70 cm. In Nea Makri (BR-2), the beachrocks are found from +36 cm to a depth of -110 cm. In Artemida (BR-3), beachrock benches extend from -32 cm to -180 cm. In Vravron (BR-4) area, beachrock benches are found at sea level down to a depth of 60 cm. In Porto Rafti area, three locations with beachrocks were identified, extending from +16 cm to -130 cm (BR-5), 0-150 cm (BR-5) and 0-180 cm (BR-7) respectively. In each location, various transects were carried out according to the characteristics of the beachrocks (see Figure 1).

At sites BR1, BR2 and BR3 extensive parts of the beachrocks are removed or destroyed by human activities, in order to make the coast more accessible to the general public. In St. Panteleimonas and Nea Makri, in particular, broken and transported slabs were found in the submarine part of the coast.

Table 1 - Location and characteristics of beachrocks				
Location	**Site**	**Longitude**	**Latitude**	**Depth in relation to SL (cm) minimum; maximum**
St. Panteleimonas	BR-1	23° 58' 47.39"	38° 6' 3.34"	+21; -70
Nea Makri	BR-2	23° 58' 52.27"	38° 5' 14.17"	+36; -110
Artemida	BR-3	24° 0' 19.28"	37° 57' 55.75"	-32; -180
Chamolia	BR-4	24° 0' 42.40"	37° 55' 10.01"	0; -60
Porto Rafti	BR-5	24° 0' 45.29"	37° 52' 49.35"	+16; -130
Porto Rafti	BR-6	24° 0' 48.82"	37° 52' 37.08"	0; -150
Porto Rafti	BR-7	24° 1' 6.30"	37° 52' 14.25"	0; -180

Examination of the samples under a Scanning Electron Microscope (SEM) showed that the studied beachrocks are mainly composed of quartz grains, with the presence of a few calcites and feldspars, while no bioclasts were observed (Figure 3). The carbonate cement is characterized with the presence of MgO with percentages between 5 and 7.8%. In terms of cement morphology, micritic and fringe forms have been observed in most samples, as well as meniscus cement.

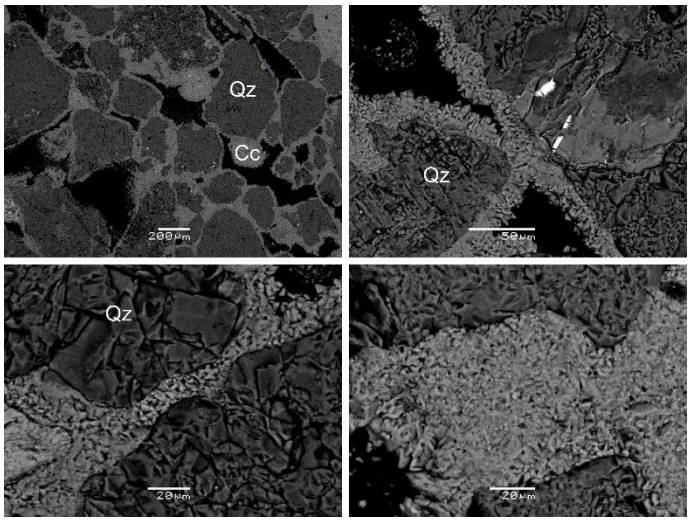

Figure 3 - Cements observed in the studied beachrocks.

5. Discussion

Beachrocks were identified at various depths, and in particular, in St. Panteleimonas at - 70 cm, in Nea Makri at -110 cm, in Artemida at -180 cm, in Chamolia at -60 cm, in Kalos Yialos at -130 cm, in Porto Rafti at -140 cm and in St. Marina at -180 cm. The presence of beachrocks at depths ranging between -60 and -180 cm testify to a regime of subsidence for the study area. At first view, this subsidence appears greater towards the south. On the other hand, in Marathon bay, beachrock slabs were also found between +21 cm (BR-1) and at +36 cm (BR-2).

Based on some available stratigraphic data from Triantaphyllou *et al.* (2010), who performed drillings on the coastal plain of Vravron bay, an attempt is made to estimate the age of the beachrocks. Based on radiocarbon ages from drillings by Triantaphyllou *et al.* (2010), the beachrocks, located at a depth between 60-70 cm (BR-1, BR-4) may be tentatively dated at about 950±50 BP (1434-1645 AD), based on marine gastropod shells (*Murex sp.*) that were found at a depth of 65 cm below sea level (Triantaphyllou *et al.*, 2010).

In a similar manner, the beachrocks found at a depth of about -180 cm (BR-3, BR7) may be tentatively dated at about 1730 ± 50 BP (692–934 AD), based on marine gastropods (Murex sp.) found at -1.7 m (Triantaphyllou *et al.*, 2010).

The aforementioned correlation indicates that the studied beachrocks overall may not be older than 2000 years BP. Although the presence of beachrocks at various depths, reaching -1.8 m, suggests a general subsidence for the study area, in the north part beachrock outcrops above sea level (Figure 4) imply uplift. This observation is consistent with the presence of uplifted tidal notches found on the coastal zone north of Marathon at +24 and +40 cm (Evelpidou *et al.*, submitted).

Figure 4 - Beachrocks outcrops above sea level at sites BR1 (left photo) and BR2 (right photo)

6. Conclusions

This work focused on the coasts of East Attica in order to trace and study beachrocks. Beachrocks were identified in various depths, reaching -1.8 m, in the south part, while on the north part beachrock slabs were also found between +21 cm and +36 cm. Examination of the samples under SEM showed that the studied beachrocks are mainly composed of quartz grains, with the presence of a few calcites and feldspars, while the carbonate cement is characterized with the presence of MgO at percentages between 5 and 7.8%. Based on correlations with published drillings in the study area, the studied beachrocks should not be older than 2000 years BP.

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