

The formation of beachrock on the North Cyprus Coast

Kuzey Kıbrıs Kıyılarında Yalıtışı Oluşumu

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Abstract

Beachrocks were determined along the northern coasts of Cyprus Island. Their petrographic composition and nature of cementation were studied based mainly on detailed field descriptions, thin section interpretations and ICP-AES analyses. The present findings show that beachrocks take place preferentially on beaches backed by coastal sand dunes and marine terraces, but exceptionally on tectonically uplifted wave-cut platforms. Beachrocks show an enrichment of sand and gravel derived from Troodos massive and Girne range. Commonly, cementation has been likely occurred in the salt water-fresh water mixing zone.

Key Words: Beachrock; intertidal cementation; coastal geomorphology; Cyprus Island; Mediterranean Sea.

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Introduction

Beachrock is a type of lithified conglomeratic formation or a characteristic layered coastal deposit (Ginsburg, 1953; Neumier, 1998) that most commonly occurs within the intertidal zone of tropical and subtropical beaches. Numerous investigations, however, pointed out that they may occur in a wide range of climatic regions such as humid climates (Moore, 1973; Hanor, 1978; Beier, 1985; Meyers, 1987) and arid-semiarid environments (Taylor and Illing, 1969; Freidman and Gavish, 1971; Webb *et al.*, 1999). The precipitation of beachrock cements has been preferably ascribed to mixing of marine and meteoric water fluxes (Moore, 1973), CO₂ degassing of shallow groundwater in the vadose zone (Hanor, 1978) and accumulation of CaCO₃ by evaporation of sea water (Scoffin, 1970). Although many researches have been reported for Mediterranean beachrock cementation (Goudie, 1966; Alexanderson, 1969; Freidman and Gavish, 1971; Bener, 1974; Erol, 1983; El-Sayed 1988; Avşarcan, 1997, Ertek and Erginal, 2003), beachrocks of the northern Cyprus have not been documented so far except the recent work of Ertek and Erginal (2004). The present paper aims to discuss the development of beachrock cementation on the five beaches of northern Cyprus, namely in Kayalar, Güzelyalı, Esentepe and Dipkarpaz beaches (Fig. 1).

Study area

Beachrock formations occur along the northern beaches of Cyprus Island, which has an area of about 9250 km² and a total coastline of 648 km. The island that lies within latitudes 34°33'57" N to 35°41'44" N and longitudes 32°16'09" E to 34°35'18" E is placed at only 47 miles south of the Cape Anamur in southern Turkey.

The geology and tectonics of Cyprus has been previously discussed by many researchers (Robertson, 1977; Dreghorn, 1978; Ketin 1987; Poole *et al.*, 1990). The prominent geologic units in the island are characterized by well-defined actively emplacing oceanic lithosphere, i.e. Troodos terrane, Troodos serpentinites, Mamonia terrane, Kyrenia (Girne) terrain, Upper Cretaceous-Pliocene sediments and Quaternary alluvium (Poole and Robertson, 1991). The Troodos massif which is made up of ultramafic rocks, gabbro, sheeted dyke complex, and pillow lavas forms the highest terrain in central and southern parts of the island (Ketin, 1987). Along the north margin of the Troodos massif, a wide fluvial fanglomeratic sequence extends, which is explicitly observed on mesa-type hills in the east. Between

the Troodos massif and Girne Range, the Mesaoria Neogene basin which is composed mainly of gypsum, limestone, marl, kalkarenite and sandstone deposits of Oligo-Miocene to Holocene age occupies an extensive area (Ketin, 1987). To the north, Girne Range is predominantly formed by carbonate rocks, such as dolomite, limestone and marble of Permo-Carboniferous to Oligocene age, implying that hinterland area appears to be rich in carbonate rocks that may provide suitable conditions for cementation process.

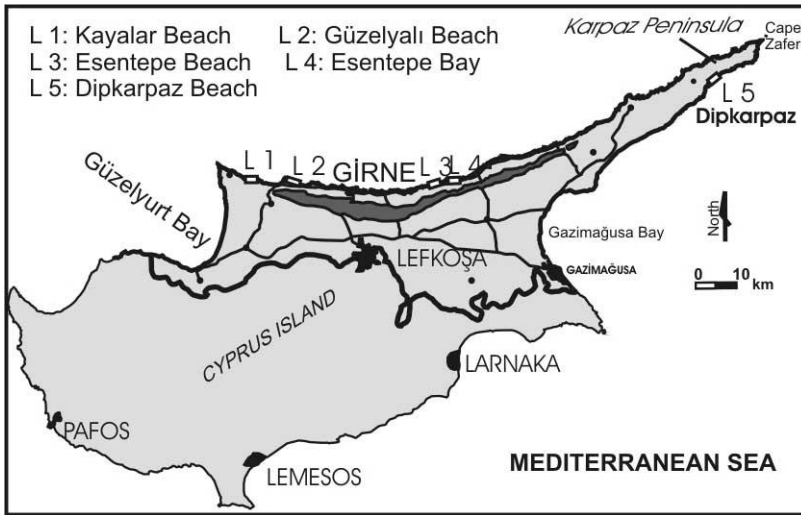


Figure 1. Locations of studied beachrocks.

The prominent geomorphic features of the island are mountainous areas to the north and south, a central plain and several scattered alluvial coastal plains along southern coast. Marine terraces are widely developed from 2 m to 360 m above sea level (a.s.l.) in southern Cyprus (Poole and Robertson, 1991). The narrow Girne (or Five Finger) coastal range with 160 km long and a maximum 1023 m height in Selvili Hill extends in the direction of E-W running parallel to the coastline. The Karpaz Peninsula that constitutes a NE extension of the Girne range is 55 km long from Yedikonuk Village to Cape Zafer. Bounded by Girne range on the north and Troodos range on the south, the Mesaoria plain has an area of about 1000 km².

According to the long-term temperature and precipitation data from Girne and Lefkoşa meteorology stations, Northern Cyprus has the typical Mediterranean climate regime characterized by average air temperatures of

19.9 °C to 19.3°C, and average precipitations ranging between 481 mm and 310 mm, respectively. Based on the distribution of tidal range on the coasts of the world (Guilcher, 1965), the tide amplitude is between 0.1 m and 1 m along the coastline.

Material and Method

Petrographic examination of beachrocks was carried out in petrographic microscope (Olympus BX51) to determine their texture, composition and particle size features. For chemical analyses, beachrocks were crumbled and cement was separated from grains. 1 g. sample (dry weight) was analyzed by ICP-AES (Varian Axial Liberty II Series ICP-AES) to determine the proportion of Ca^{++} , Mg^{++} , Fe^{++} and Si^{++} in chemical composition of beachrock cement.

Results and Discussion

Beachrock of the Kayalar beach

Beachrock developed in front of a Holocene marine terrace which is found at an elevation of +2 m a.s.l. (Fig. 2A). The exposed cemented area with maximum height of 105 cm a.s.l. occupies an area of 157-m long and 37.7-m width, 17 m of which is submerged. The E-W trending beachrock ledges generally dip seaward (to the north) at an average angle of 5°.

On-site observations point out that the cemented ledges are composed mainly of amalgamated siliciclastic and carbonate sands with commonly medium to coarse grain size and, in particular, well-rounded small gravels consisting mainly of marble, radiolaria, quartz, sandstone, abundant serpentine and various lithoclasts. It is noteworthy that many flat fragments of beachrocks are found within the sequence of Holocene marine terrace at the back of the shoreline. Petrographic thin section show that beachrock consists mainly of cromite and magnetite as opaque minerals, small fragments of olivine with parting cleavage, hypersthene, enstatite, amphibole and well-rounded limestone and dolomitic limestone lithoclasts (Fig. 2B). Opaque grains are the predominant constituent. All of them are amalgamated with carbonate cement. Porosity ranges between 20% and 25%.

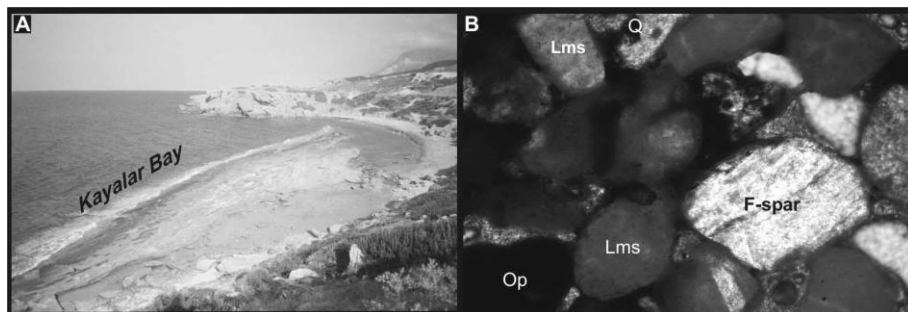


Figure 2. A view of beachrock at the Kayalar Bay (A), and photomicrograph of thin section (B). Lms: limestone; F-spar: feldspar; Q: quartz; Op: opaque.

Beachrock of the Güzelyalı beach

Beachrock ledges extend up to 484 m parallel (east-west) to the Güzelyalı beach (Fig. 3A). It is backed by coastal dunes and Holocene marine terrace with +2 m elevation a.s.l. Although most of the beachrock with average width of 4m-10 m is found close to the current sea-level, they can be also followed up to 16 m offshore (at about -1 m-depth relative to present sea-level). It is an approximately 130 cm thick beachrock, nearly 50% - 80 % of which appears to be submerged. Several beachrock fragments, quartz sands and flat gravels are found within the marine terrace sequence that backs the shoreline to the south.

Petrographic composition of the beachrock demonstrates that it is lithic sandstone with composition consisting primarily of round lithoclasts amalgamated with carbonate cement (Fig. 3B). The 50 % of the bulk rock volume is mainly composed of recrystallized limestone and dolomitic limestone clasts of various size and spherical sand grains ranging in size from 05 mm to 1 mm. The rest of lithoclasts consist of radiolarite, various metamorphics, gabbro, ophiolite and basalt. Porosity is about 30%. The amount of pyroxene and olivine grains is between 1% and 3%.

Beachrock of the Esentepe beach

The well stratified beachrock, conglomeratic sandstone in composition, is exposed at Esentepe beach, east of Girne, which extends for about 940 km along the shoreline (Fig. 4A). Its width is maximum 10 m in the backbeach and 5 m at its most seaward extent. Beds extending SW-NE have dip angles varying between 5° and 10° northward. In the backbeach, it is + 2.5 m in height, however, it can be followed up to - 2 m at its most seaward extend.

Beachrock ledges are mainly composed of fine grains and pebbles of various sizes amalgamated with carbonate cement. The gravels consist of crystallized limestone, dolomite, and limestone with pelloid, serpentine, radiolarite and sandstone lithoclasts and, to a lesser extent, basalt, quartz, opaque minerals and brick fragments (Fig. 4B).

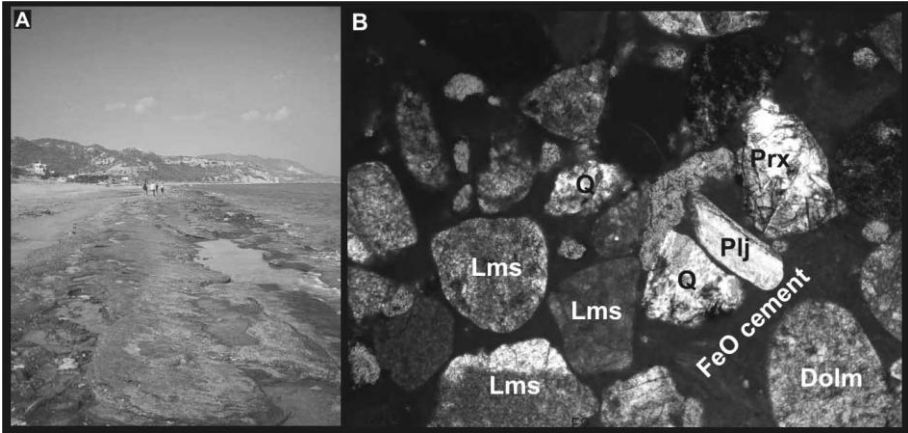


Figure 3. Field views of beachrock of the Güzelyalı Beach (A) and its thin section image (B). Lms: limestone; Dolm: dolomite; Q: quartz; Op: opaque; Prx: pyroxene.

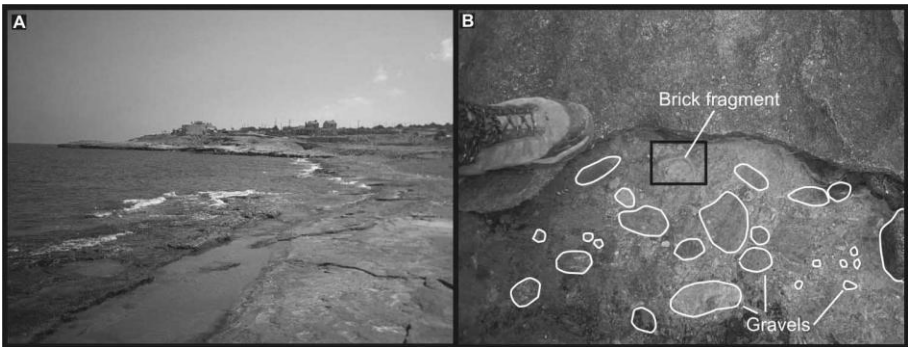


Figure 4. Beachrock of the Esentepe Beach (A), gravels and a small brick fragment within the sequence (B).

Beachrock of the Esentepe Bay

Beachrock in Esentepe Bay, east of Girne, lies across most of the beach area (Fig. 5A). The cemented zone is backed by a 50-m-width beach rich in iron and coastal sand dunes with height up to 2 m a.s.l. Beachrock ledges which

developed along a 258-m-long beach dip about 5° towards the north (seaward). Well-rounded gravels of radiolarite, quartz and limestone are the main constituent. The maximum thickness of beachrock is 2 m. It extends about 11 m offshore and terminates at a depth of -125 cm under present-sea level. At the western edge of the beach, beachrock ledges with 75 cm thickness are observed on wave-cut platforms that developed on sandstone ledges with maximum 25 cm high a.s.l. (Fig. 5B).

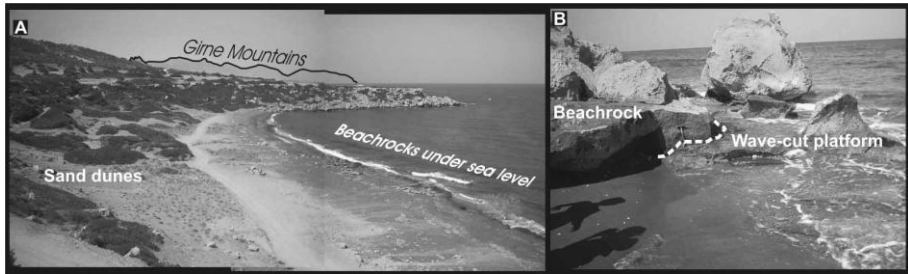


Figure 5. A view of beachrock at the Esentepe Bay (A) and its occurrence on wave-cut platform.

Petrographic examinations show that this beachrock is coarse-grained lithic sandstone in composition. Very well-rounded basalt and limestone gravels are amalgamated with carbonate cement. Its composition is characterized by several lithoclasts composed mainly of dolomite, basalt, chert and various mineral fragments, such as quartz, olivine, pyroxene and opaque minerals.

Beachrock of the Dipkarpaz beach (Karpaz Peninsula)

Beachrock which is located in eastern coast of the Karpaz peninsula is exposed along the Dipkarpaz beach (Fig.6 A). It is backed by a coastal sand dune area. It is about 200 m long, 10-17 m wide and up to 1m thick. A part of 1 to 2 m of the beachrock beds can be followed at its most seaward extent. It is characterized by two different horizons that dipped in average 2° - 5° seaward; (1) a 10-15 cm-thick horizon with pebble and boulder sized gravels close to the present shoreline, and (2) another horizon consisting basically of firmly cemented fine grains with 8 m wide towards the backshore. The composition of beachrock is predominantly characterized by quartz, limestone, radiolarite, claystone and sandstone. Numerous brick fragments are found within the pebbly horizon. Thin section analysis shows that the rock is lithic sandstone with high cavity rate (about 40%). Less rounded carbonate grains, pyroxene, olivine and opaque minerals amalgamated with iron oxide cement are predominant.

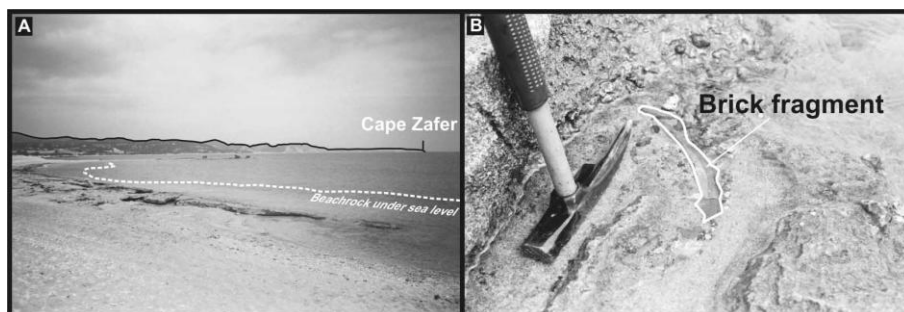


Figure 6. Beachrock at the Dipkarpaz Beach (A), a brick fragment within the beachrock material (B).

Overall assessment of beachrock composition

The Northern Cyprus beachrocks are generally coarse-grained lithic sandstones consisting predominantly of cemented gravels of limestone, dolomite, serpentine, radiolarite and sandstone that are similar in composition and texture to petrographic features of the modern adjacent beaches. The cavity rate within beachrocks ranges between 20 % and 40 %. Composition and texture of beachrocks indicate that they have lithoclasts of various size likely derived from Troodos terrain and Girne range.

Thin sections showed that the cemented material consists of a mixture of grains, such as siliciclasts, carbonate and abundant heavy minerals. Quartz, opaque and olivine form the main constituent in bulk rock volume. Petrological examinations display that carbonates cement is most common.

The origin of beachrock cementation: elemental geochemistry

The elemental geochemistry of the beachrock cements are shown in Table 1. It is clearly seen that Ca^{++} and Fe^{++} are main constituents of elemental composition in the beachrock cements with average amounts ranging from 6262.2 ppm to 6697.6 ppm and 216.82 ppm to 3114.3 ppm, respectively. The presence of abundant Ca^{++} in all samples may indicate that carbonate used for cementation was derived from carbonate-rich deposits of the Girne Range lying closely parallel to the beaches. Fe^{++} that was possibly derived from Troodos ophiolite could also be thought to be, at least in part, responsible for cementation process. The abundant presence of well-rounded gravels of limestone and dolomite as well as carbonate grains and opaque minerals in thin section images also supports the view that both petrographic

composition and types of cements in beachrock samples might be consistent with a terrestrial origin.

Table 1 Elemental composition of beachrock cements (values ppm)

<i>Elements</i>	<i>Kayalar Beach</i>	<i>Güzelyalı Beach</i>	<i>Esentepe Beach</i>	<i>Esentepe Bay</i>	<i>Dipkarpaz Beach</i>
Al	1616,9	782,117	157,824	619,651	1149,97
B	3,3518	4,95083	16,4858	8,85563	34,3304
Ba	31,7096	12,4364	5,33788	6,18645	11,6781
Ca	6267,17	6538,16	6547,79	6697,58	6490,47
Cr	5,30171	3,02856	1,17075	6,73171	6,16453
Cu	3,8713	4,86825	1,22627	1,6502	2,45123
Fe	2127,66	3114,31	216,822	1800,13	1616,2
K	12,9425	305,89	0	0	0
Mg	367,156	329,85	266,735	332,182	388,355
Na	1292,07	915,442	886,756	353,29	1287,74
Pb	1,04437	1,70139	0,632181	0,852364	1,35277
Zn	5,05215	4,55444	2,67053	2,85927	4,37658

The other significant elements are Na⁺ and Al. The relatively less Na⁺ content varying between 353.29 ppm and 1292.1 ppm in the beachrocks is particularly of prime significance for better interpretation the origin and position of cementation. Because Na⁺ is normally expected to exist at more amounts in sea water composition and thus in intertidal beachrocks, its poor quantity in all samples may explain weak possibility of precipitation from evaporation of sea water. The very little Mg⁺⁺ content in the beachrocks ranging from 266.74 ppm to 388.36 ppm also supports this idea. Thus, elemental geochemistry of beachrock cements indicating precipitation from meteoric waters partly altered by marine waters is consistent with a terrestrial origin. These results reveal that the cementation might have occurred in the salt water-fresh water mixing zone, which constitutes one of the mechanisms proposed for abiotic precipitation (Moore, 1973).

Conclusions

The present paper highlights the development of beachrock along the northern coasts of Cyprus Island preferentially on low beaches backed by coastal sand dunes and marine terraces. The exceptional occurrence of uplifted beachrock on wave-cut platforms on the western end of the Esentepe

Bay prompt us to consider that the younger beachrock may provide sound evidence for uplift rate along the northern Cyprus coast. Beachrocks are mainly coarse-grained lithic sandstone in composition. They are predominantly rich in quartz, opaque and olivine. The moderately to well-rounded gravels are composed of limestone, dolomite, serpentine, radiolarite and sandstone. Petrographic composition indicates that beachrock materials might have been mostly derived from Troodos massive and Girne range.

ICP-AES analyses reveal that low-magnesian calcite is the main cements amalgamating beachrock materials. The results demonstrate more amounts of Ca^{++} and Fe^{++} in beachrock cements. Less content of Na^+ and Mg^{++} , however, indicates that precipitation from meteoric waters partly modified by marine waters is of terrestrial origin as the main cause of precipitation. Namely, beachrock cementation in the area likely occurred in the salt water-fresh water mixing zone except for beachrock of Esentepe Beach where meniscus cementation occurred as the characteristic cementation process under vadose zone conditions. The findings of the present work show that North Cyprus beachrocks are very different from tropical and temperate zone beachrocks. However, beachrocks in the area deserve more detailed studies focusing on the age of beachrocks (from brick fragments) and their relationships with uplifted wave-cut platforms (averaging +1 m to +2 m) located in the east of Girne to explain morpho-dynamic and morpho-tectonic features throughout the northern coast of the island.

Özet

Kıbrıs adasının kuzey kıyılarında yalıtışı oluşumları tespit edildi. Yalıtışların petrografik bileşimi ve çimentolanma özellikleri detaylı arazi çalışmaları, ince kesit yorumlamaları ve ICP-AES analizlerine dayalı olarak gerçekleştirildi. Mevcut bulgular yalıtışlarının genellikle geride kıyı kumulları ve denizel taraçalarla sınırlandırılan plajlarda, istisna olarak da tektonikle yükselmiş dalga aşım düzlükleri üzerinde geliştiğini göstermektedir. Yalıtışları özellikle Troodos masifi ve Girne dağlarından gelen kum ve çakıllarla zengindir. Çimentolaşma tuzlu su-tatlı su karışım zonunda gelişmiştir.

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