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BEACHROCK

Formation and Distribution of Beachrock

Beachrock is defined by Scoffin and Stoddart (1987, 401) as "the consolidated deposit that results from lithification by calcium carbonate of sediment in the intertidal and spray zones of mainly tropical coasts." Beachrock units form under a thin cover of sediment and generally overlie unconsolidated sand, although they may rest on any type of foundation. Maximum rates of subsurface beachrock cementation are thought to occur in the area of the beach that experiences the most wetting *and* drying - below the foreshore in the area of water table excursion between the neap low and high tide levels (Amieux et al, 1989; Higgins, 1994). Figure B49 shows a beachrock formation displaying typical attributes.

Figure B49 Multiple unit beachrock exposure at barrio Rio Grande de Aguada, Puerto Rico. The sculpted morphology, development of a nearly vertical landward edge, and dark staining of outer surface by cyanobacteria indicate that this beachrock has experience extended exposure. Landward relief and imbricate morphology of beachrock units define shore-parallel runnels that impound seawater (photo R. Turner).

There are a number of theories regarding the process of beach sand cementation. Different mechanisms of cementation appear to be responsible at different localities. The primary mechanisms proposed for the origin of beachrock cements are as follows:

1) physicochemical precipitation of high-Mg calcite and aragonite from seawater as a result of high temperatures, $CaCO_3$ supersaturation, and/or evaporation (Ginsburg, 1953; Stoddart and Cann, 1965);
2) physicochemical precipitation of low-Mg calcite and aragonite by mixing of meteoric and fresh ground water with seawater (Schmalz, 1971);
3) physicochemical precipitation of high-Mg calcite and aragonite by degassing of CO_2 from beach sediment pore water (Thorstensen et al, 1972; Hanor, 1978); and
4) precipitation of micritic calcium carbonate as a byproduct of microbiological activity (Taylor and Illing, 1969; Krumbein, 1979; Strasser et al, 1989; Molenaar and Venmans, 1993; Bernier et al, 1997).

Although most beachrock cement morphologies suggest an inorganic origin, physicochemical mechanisms operating alone do not adequately account for the discontinuous distribution of beachrock formations. As Kaye (1959, 73) put it, "the problem hinges more on an adequate explanation for the absence of beachrock from many beaches than on its presence in others." The discontinuity of beach cementation, along with the complex assemblage of cement types found in adjacent samples of beachrock led Taylor and Illing (1971) to propose that the micro-environment exerts a greater influence on the cementation process than does the macro-environment.

Several beachrock researchers concur with this assessment and support the theory that *initial* cementation in beach sands is controlled by the distribution and metabolic activity of bacteria because: 1) dark, organic-rich micritic rims have been identified around cemented grains in most petrographic studies of beachrock (Krumbein, 1979; Beier, 1985); 2) microbially-mediated precipitation of carbonates has been repeatedly demonstrated in both marine and terrestrial environments (Buczynski and Chafetz, 1993); and 3) bacterial populations are particularly large and productive in the intertidal zone of water table fluctuation where beach lithification occurs. Once biologically mediated cryptocrystalline cements are established as nucleation sites, larger crystals precipitated via physicochemical processes can grow and bridge the sediment grains.

Rates of beachrock formation are undoubtedly variable but are generally believed to be quite rapid, on the scale of months to years (Frankel, 1968). For example, Hopley (1986) reported that beachrock formed within six months on Magnetic Island near Townsville, Australia, while Moresby (1835) wrote that Indian Ocean natives made an annual harvest of beachrock for building stone and within a year they had a new lithified crop.

Several Pleistocene and older beachrock formations have been identified. However, the dynamic nature of sandy coastlines and a historically fluctuating sea level necessitate that most occurrences of *intertidal* beachrock are less than 2,000 years old. This is commonly supported by the incorporation of modern man-made artifacts in beachrock formations rather than by ^{14}C dates, as beachrock is poorly suited for radiocarbon dating.

The majority of Recent beachrock is formed on beaches in the same regions that favor coral reef formation. This is generally below 25° latitude where there is a well-defined dry season and "the temperature of ground water at a depth of about 76 cm in beaches remains above 21° C for at least 8 months of the year" (Russell, 1971, 2343). However, beachrock can also form at higher latitudes. For example, beachrock exposures are common throughout the Mediterranean and have been reported along portions of the coasts of Norway, Denmark, Poland, Japan, New Zealand, South Africa, the Black Sea, and the northern Gulf of Mexico. Beachrock formations have also been reported on lakeshores in Pennsylvania, Michigan, Africa, New Zealand, southeast Australia, and the Sinai Peninsula.

Subaerially exposed beachrock units constitute only a small proportion of the cemented sediments in the intertidal zone. For example, Emery and Cox (1956) found beachrock *exposures* on only 24% of the predominantly calcareous beaches of Oahu, Kauai, and Maui, whereas jet-probing conducted by Moberly (1968, 32) revealed that "exposed or covered beachrock appears to be present at all calcareous beaches in the state" of Hawaii. In the event of continued sea level rise and human activities that exacerbate coastal erosion, much more beachrock will be exhumed.

Morphology of Beachrock Formations

Beachrock formations typically consist of multiple units, representing multiple episodes of cementation and exposure. Beachrock that forms below the foreshore has an upper surface slope that tends to mimic that of the seaward dipping (4 - 10°) internal beach bedding. However, beach sand cementation has also been found to occur below the berm and foredune of a beach (Russell, 1971; Hopley and MacKay, 1978). Those authors found that the beachrock forming below the backshore had a nearly horizontal upper surface that corresponded to the ground water table and truncated the original beach bedding.

Most intertidal beachrock formations are detached from subaerial and subtidal cemented sediments. Beachrock is laterally discontinuous as well, usually exposed for only short distances before disappearing under loose sand or ending entirely. It is likely that the formation and preservation of beachrock on a given section of beach is negatively correlated to alongshore increase in wave energy and frequency of beach erosion.

The reported thickness of beachrock formations ranges from a few centimeters up to 5 meters, with approximately 2 meters being most common. Variations in degree of cementation within a beachrock unit can be controlled by variability in porosity, permeability, and composition of different sand layers (Molenaar and Venmans, 1993). Generally, precipitation of cements is most rapid near the top of a beachrock unit. Accordingly, young beachrock units are better cemented at the top and noticeably less so near the base. This attribute makes them more susceptible to scour at their base upon exposure, commonly resulting in undercutting and slumping. It is this undercutting that fosters the development of nearly vertical landward edges on beachrock units. In areas where a chronic deficit in sand supply or erosive conditions have exhumed the seaward edge of a beachrock formation, it is frequently observed to be steep as well.

Long-term exposure of beachrock will radically change the ecology of a sandy shoreline by providing a hard substrate that can support an increased diversity of animal and plant life. The reader is referred to the papers of McLean (1974), Jones and Goodbody (1984), and Miller and Mason (1994) to learn more about the ecology and biophysical modification of intertidal beachrock exposures.

Beachrock and Coastal Evolution

Although beachrock, as defined, forms in the intertidal zone, it does not always remain there. On prograding coasts, a series of beachrock units may form at depth, leaving older units stranded well behind the active beach. On retreating coasts, outcrops of beachrock may be evident offshore where they may serve as a hard substrate for coralgal reef growth. If the strike of the beach changes over time, then the strike of the beachrock units will reflect that change.

Armed with the knowledge that beachrock is formed in the intertidal zone, many geologists have related beachrock outcrops to changes in sea level for particular coasts. Semeniuk and Searle (1987) demonstrated that beachrock formation can keep pace with slow shore recession, resulting in a wide, continuous band of beachrock, but that rapid shore recessions (or periods of high wave energy and foreshore instability) are represented by gaps (unconsolidated sediment) in a sequence of beachrock units. Assuming a nearly constant rate of sea level rise, these gaps may indicate that beachrock can temporarily stabilize the position of the shore under erosive conditions until sea level has risen enough to cause the shore to jump back (Cooper, 1991). Many other researchers have asserted that beachrock outcrops will protect a beach from erosion, as well as control the plan configuration of a coastline.

Research by Turner (1999) has demonstrated that the influence beachrock has on beach processes will largely depend on the extent and morphology of the exposure, both of which evolve over time. Cumulative exposure and erosion of a beachrock formation over a period of years to decades can foster a gradual increase in the landward and seaward relief of the beachrock units and the development of shore-parallel runnels and shore-perpendicular breaches in the beachrock. The high seaward relief of such a beachrock unit effectively attenuates incident wave energy and retards onshore sediment transport. The high landward relief of the beachrock unit can act as the seaward wall of a runnel that blocks offshore return of backwash and forces impounded seawater and entrained sand to flow laterally on the foreshore to low spots and shore-normal breaches in the beachrock formation. Beachrock breaches and runnels are erosionally enlarged over time, locally increasing onshore inputs of wave energy and longshore sediment transport rates on the foreshore.

On a beach on Puerto Rico’s west coast, beach width and volume were found to be least stable where the seaward beachrock unit was breached and most stable away from the breaches behind high relief beachrock. Sections of foreshore most protected by a high relief beachrock ridge exhibited the lowest volumes of subaerial sand storage, unusually narrow beach widths, and the slowest beach erosion recovery rates. In short, a beach with a high relief intertidal beachrock exposure is more likely to be sediment deficient and out of synch with the wave regime. This puts the backshore of a beachrock beach at risk of catastrophic retreat following the development of a breach in the beachrock or in the event of a high energy wave event coupled with a storm surge or spring high tide.

Conclusions

The transformation of sandy beaches to rocky beachrock beaches is increasingly common in the tropics and subtropics. Where beachrock is exposed by erosion, it acts like a natural breakwater or revetment, decelerating further shoreline and backshore retreat. However, it also tends to retard beach buildup and is poorly suited to recreational use, both major issues in the tropics where tourism is often the primary source of income. The potential for beachrock to significantly alter the evolution of a coast justifies additional research on its influence on beach processes. In particular, the characteristics and affects of beachrock on dissipative beaches have received little attention and are likely to be significantly different than those observed on more reflective beaches.

Despite many petrographic investigations of beachrock cements, the processes responsible for beachrock formation are still poorly understood. Given the likelihood of cement diagenesis in the beach environment, there is a need to pursue other research methods. For example, the subsurface formation of beachrock should be tracked on a variety of beaches over an extended period. The processes affecting beach sand cementation should also be examined under controlled conditions in a laboratory setting. Preliminary experiments conducted by Turner (1995) indicate that the addition of dissolved nitrate or organic carbon to beach sand microcosms stimulates bacterial growth and the precipitation of intergranular calcium carbonate. This leads to the question as to whether coastal discharges of ground water contaminated with fertilizers or human wastes are increasing the rate and geographic range of beachrock formation.

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Cross-references

Beach Features
Coral Reef Coasts
Eolianite
Rock Coast Processes
Sea Level Indicators, Geomorphic