The evolution of beachrock morphology and its influence on beach morphodynamics

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Coastal erosion of low latitude beaches frequently results in exposure of beachrock, layers of beach sand cemented in the subsurface by the intergranular precipitation of calcium carbonate. Exposed beachrock can have a profound impact on the event, seasonal, and long-term morphodynamics of a beach. The influence of beachrock on beach processes will largely depend on the extent and morphology of the exposure, both of which evolve over time.

Five distinct stages in the life cycle and morphological evolution of beachrock are identified in a conceptual model based on research conducted on the coast of Puerto Rico (**Fig. 1**). Stage I is the pre-exposure cementation phase (**Fig. 2**), which primarily takes place in the foreshore subsurface between the high tide and low tide water table excursion. The duration of beach stability necessary for formation of erosion-resistant beachrock ranges from a few months to decades and is negatively correlated to seawater temperature. Upon initial exposure (**Fig. 3**), the more weakly cemented landward portion of the beachrock is preferentially eroded and the landward edge of a beachrock unit is defined (Stage II). After several weeks of exposure, the outer surface of the beachrock is case hardened and colonized by epilithic biota (Stage III). Cumulative exposure and erosion of a beachrock platform over a period of months to decades (**Fig. 4**) fosters a gradual increase in the landward and seaward relief of the beachrock units and the development of shore-parallel channels and shore-perpendicular breaches in the beachrock (Stage IV). Exposure over several decades without significant new cementation results in the disintegration of the beachrock units into blocks and slabs that become displaced and buried in unconsolidated sediment (Stage V).

As a beachrock platform evolves from Stage I to Stage IV in its erosional development, its influence on beach processes increases. The characteristically high seaward relief of a Stage IV beachrock unit reflects the most wave energy and effectively retards onshore sediment transport. The high landward relief of a Stage IV beachrock unit acts as the seaward wall of a channel 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 (**Fig. 5**). Beachrock breaches and channels are erosionally enlarged over time, locally increasing onshore inputs of wave energy and longshore sediment transport rates.

Currents in the shore-parallel beachrock channels on the west coast of Puerto Rico are strongly unidirectional, can flow in the direction opposite incident wave approach, and exhibit a pulsing behavior associated with low frequency fluctuations of the sea surface at discharge points. Longshore current power and frequency composition are better correlated to tide height than to wave height, despite the microtidal range. Median current velocities exceed 30 cm/sec even when wave heights are less than 0.5 m.

Enhanced reduction of incident wave energy by Stage II, III, and IV beachrock exposures provides protection for the backshore and results in unusually narrow, sediment deficient beaches. Morphodynamic variability of the study beach with beachrock is more a function of proximity to breaches in the seaward beachrock unit and degree of shore-parallel beachrock channel development than of alongshore variation in incident wave energy. Sections of beach with Stage IV beachrock exhibit the highest frequencies and durations of beachrock exposure, the lowest volumes of subaerial sand storage, and the slowest beach erosion recovery rates.

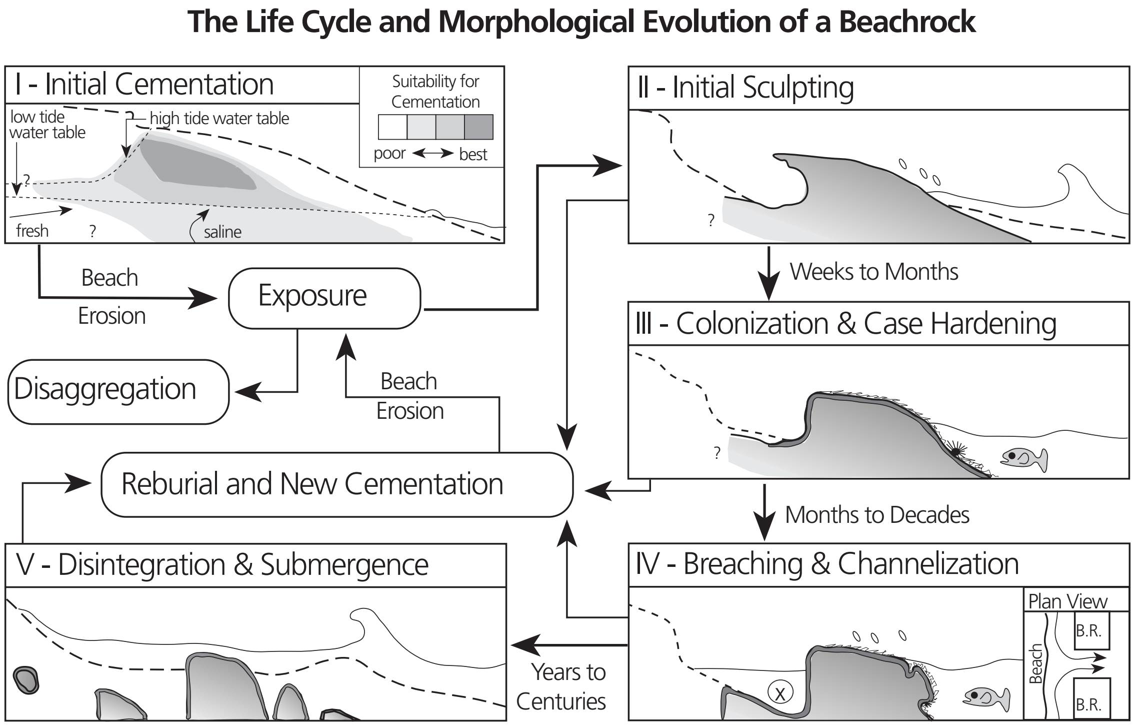

Fig. 1 Conceptual model of the stages of beachrock development. Although this model only illustrates the evolution of a single beachrock unit, it does allow for multiple episodes of beachrock formation.

Fig. 2 Weakly cemented sand layers at the water table at Barrio Rio Grande de Aguada, Puerto Rico. This incipient beachrock was exposed by an erosion event and was subsequently reburied.

Fig. 3 Beachrock in Stage II of its development. This beachrock is weakly cemented and the outer surface has the same color as the unconsolidated sand. Longshore flow of seawater impounded on the foreshore during high tide is eroding the landward margin of the unit, increasing its relief and fostering the development of an overhang. This overhang subsequently failed, resulting in a nearly vertical landward edge. Barrio Rio Grande de Aquada, Puerto Rico.

Fig. 4 This photograph displays multiple stages of beachrock development. The beachrock platform as a whole is in Stage IV of its development, as indicated by the shore-parallel channel and the breach in the seaward beachrock unit in the background. The beachrock under the notebook is Stage IV as well. Extended exposure is indicated by the dark staining of the outer surface by cyanobacteria, the colonization of the outer surface by algae, the sculpted morphology, the vertical landward edge, and the shore-perpendicular fracture. Following the formation of the shore-perpendicular fracture and displacement of the block in the foreground, this unit was buried for an extended period of time and another cementation episode occurred. The light colored beachrock in the foreground and landward of the sculpted beachrock is a Stage II eroded remnant of that more recent cementation. Barrio Rio Grande de Aguada, Puerto Rico.

Fig. 5 Multiple unit beachrock exposure at Barrio Rio Grande de Aguada, Puerto Rico. Seawater impounded by the beachrock flows from right to left and discharges to the sea in a rip current where there is an eroded gap in the seaward beachrock unit. Maximum variability of beach volume and width occurs opposite this gap.