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Remote sensing of beachrock and other geomorphological indicators of sea-level rise on Lesvos, Greece

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What is Beachrock?

Beachrock is a friable to well-cemented sedimentary rock composed of calcium carbonate ($CaCO_3$) and particulate matter. It forms beneath intertidal sands during beach progradation[6, 12]. Lithification is catalyzed by wave processes in seas where warm waters are supersaturated with calcium carbonate[3]. $CaCO_3$ precipitation creates cements which bind sand grains, gravel, and organic or anthropogenic materials [3]. This process can take months to years, depending on factors such as sediment availability, wave action, and beach erosion[6, 15]. Beachrock slabs form parallel to the shore and can exceed 100m in length, though are typically less than 4m[6]. Marine transgression or regression encourages erosion and fracturing of beachrock[12]. Submerged beachrock continues to cement and may accrue algae, causing rocks to darken[3]. It may also act as a substrate for coral reef growth, making it difficult to distinguish between the two [15].

Figure 1: Beachrock formation parallel to the shore
Source: wikipedia.org/wiki/Beachrock.

As oceans rise, features become submerged and can act as indicators of sea-level change. Beachrock, which correlates with more reliable proxies such as benches, tidal notches, and wave cut platforms, has organic inclusions which can be radiocarbon dated. Beachrock can be used as a chronological constraint on sea-level rise [9, 10].

Study Site

Regional sea-level curves don't reflect the complexities of local sea levels, which are impacted by eustatic and regional isostatic changes and local tectonics[9]. Lesvos, Greece is located at a crux of tectonic activity; even parts of the island have experienced differential sea-level rise due to tectonic and seismic uplift[10]. Lesvos is home to many beachrock outcrops, and was selected because there is information available about the formations as well as on the faulting and geomorphology of its coasts[7].

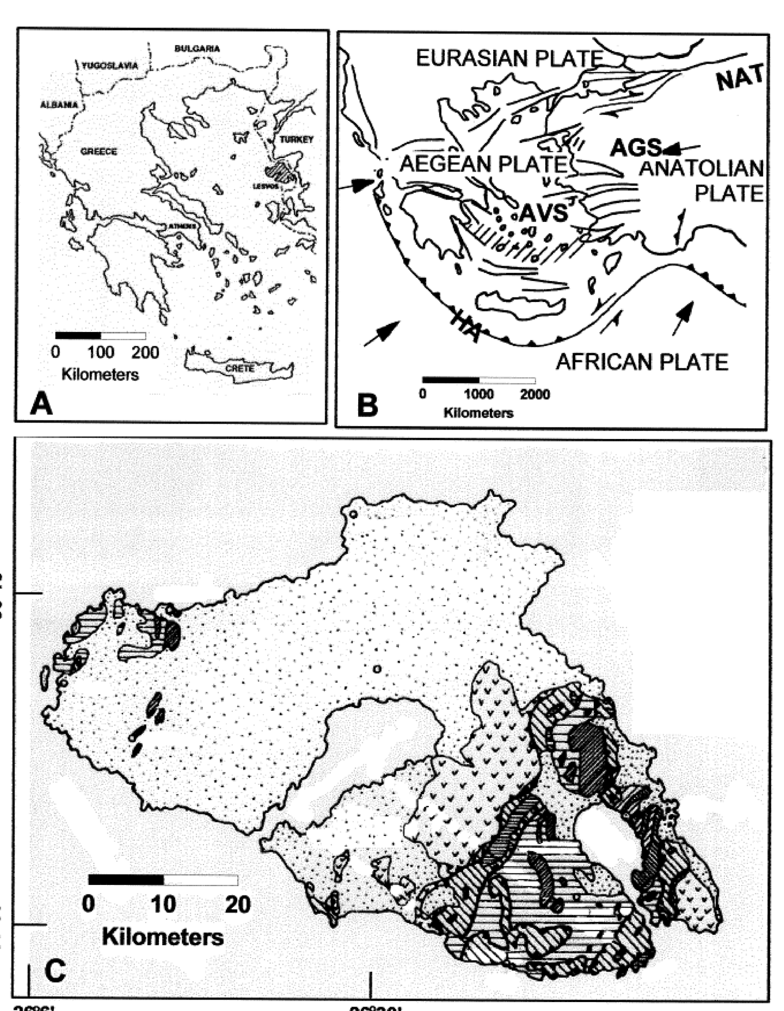


Figure 2: Aegean Sea (A); Aegean tectonics (B); Lesvos, Greece (C)
Source: Novak, 2003.

Data

- Landsat 8 satellite images, captured on January 1 2015, were obtained for Lesvos, Greece (path 181; row 33). Data ID: "LC81810332015016LGN00"[5].
- Shuttle Radar Topography Mission digital elevation model (DEM) with 30m resolution, was obtained from NASA. The DEM was created March 27 2003 and has a vertical accuracy of $\underline{+}16$m.
- A basemap satellite image of Lesvos, Greece with 1m resolution was utilized in ArcGIS 10.2 to compare results of Landsat 8 beachrock mapping.
- High resolution aerial images were provided by TripInView. These were obtained by helicopter.[14]
- Prior geologic mapping and MXD was provided by Dr. Irwin Novak (2003)[8].

Methods

Landsat images were clipped to reduce noise and range of pixel values in order to enhance spectral differences. A subset of Vatera Beach – an area with well-known beachrock – was created. Multiple false and true color composites were created and examined for their ability to penetrate shallow water. Panchromatic sharpening techniques, which improve spatial resolution, were reviewed and explored[4]. The Gram-Schmidt method was chosen for its ability to preserve spectral information, an important factor in differentiating between beachrock and beach sediments. Semi-automated methods of classifying beachrock were examined. Pixel training was not found to be successful for land cover analysis, and unsupervised classification algorithms such as the Iso Cluster were unable to accurately discriminate between coastal features. Pixel values were also compared using a two sample t-Test. The mean values of red, green, and blue band pixels of beachrock and non-beachrock were compared. There was no significant difference found between any of the categories, indicating that land cover algorithms for identifying beachrock would not be possible because no spectral signature defines beachrock as a class.

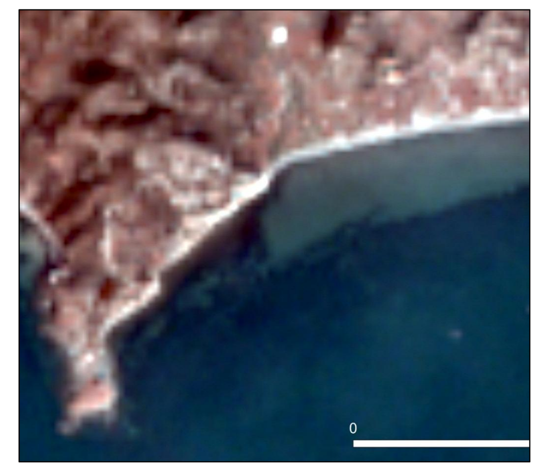
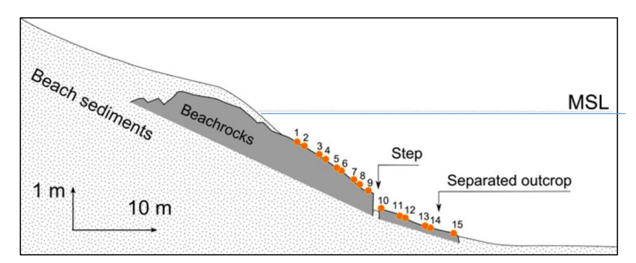
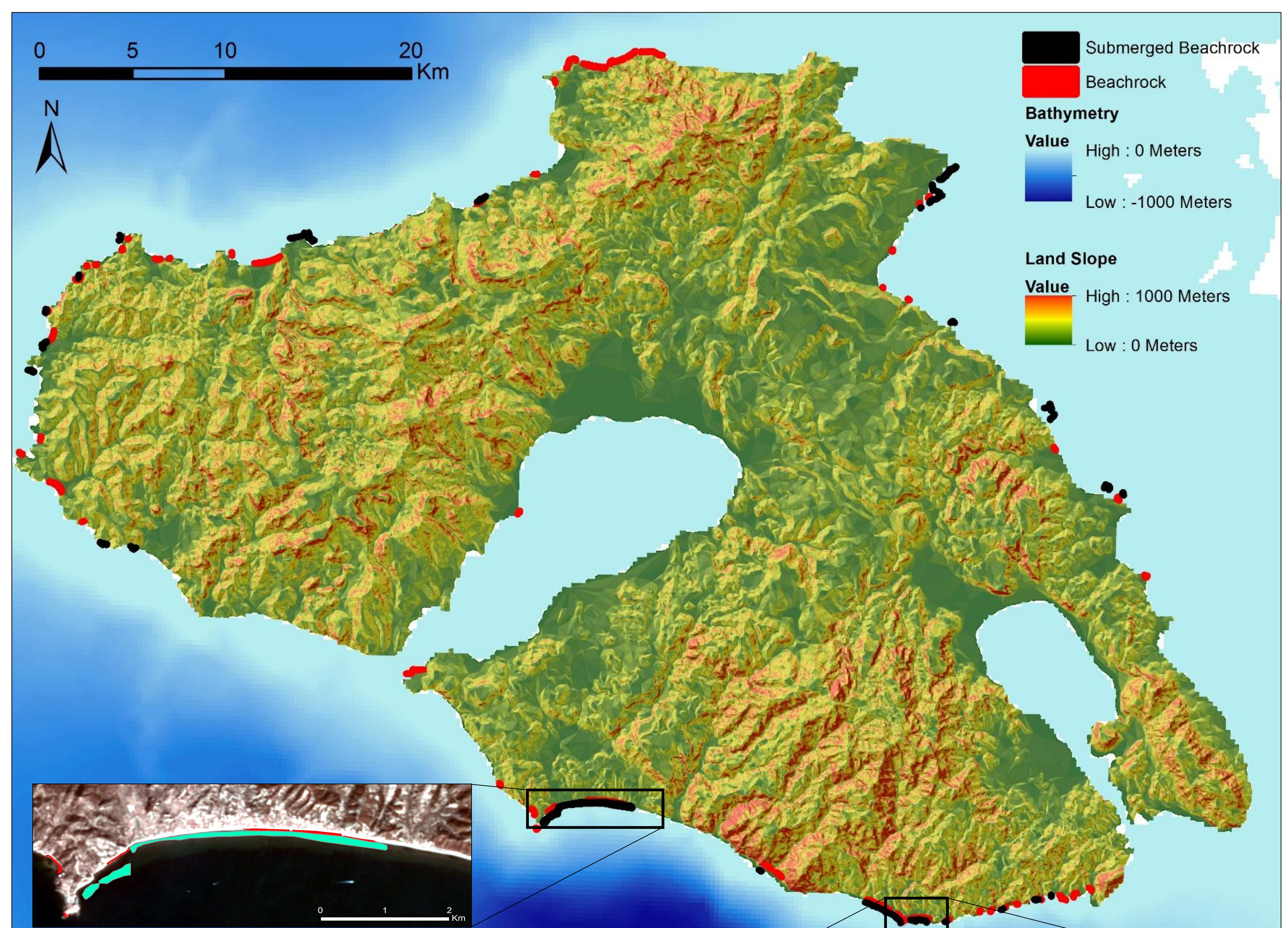


Figure 3: A 321 FCC penetrates shallow waters of western Vatera Beach on Lesvos Island.



	Beachrock			Non-beachrock		
	Red	Green	Blue	Red	Green	Blue
Mean pixel value	7776	8460	8961	7904	8504	8974
Standard deviation (Error)	623	434	337	597	389	299
T-Test: t-stat	-0.833	-0.42617	-0.161	--	--	--
T-Test: t Critical two-tail	2.00	2.00	2.00	--	--	--

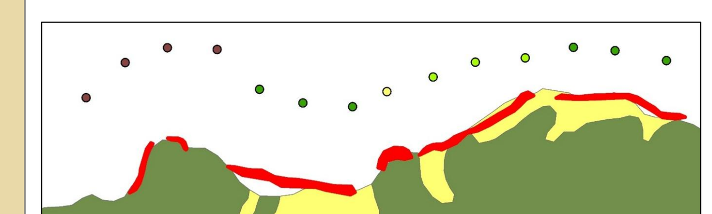
Figures 4 & 5, above: To the left is a diagram showing the difficulties in remotely sensing and identifying submerged beachrock outcrops, source Vacchi et al, 2011:; to the right is a summary of pixel comparisons and the results of a t-test to determine if there are significant differences between beachrock and non-beachrock that can be used to differentiate between the two. **Figure 6**, below: A georeferenced map of Lesvos created in ArcGIS 10.2, showing beachrock and submerged beachrock locations on the entire coast. **Figures 7 & 8**, bottom: left inset: a Gram-Schmidt pan-sharpened 321 FCC of Vatera Beach; right inset: a high resolution aerial image from TripInView of Plomari Beach, another popular tourist destination (TripInView, 2015).



Higher resolution images were necessary to complete the study. TripInView, a geotourism company providing geotagged photos and video of coastlines, has aerial images with coverage of most of coastal Lesvos. Using TripInView's images, I was able to successfully identify exposed and submerged beachrock. In ArcGIS 10.2, I mapped these features as separate shapefiles. Exposed and submerged beachrock were analyzed against slope, elevation, coastal geology, and beach type. These analyses were made possible by prior geologic mapping conducted by Dr. Novak (2003).

Results and Conclusions

While research has shown the possibility of seafloor mapping at depths of up to 30m, a number of factors restrict exploration of bathymetry such as pixel size, sun azimuth, season, water turbidity and suspended sediments, as well as seafloor topography[13]. Though the 30m composite images of Lesvos were able to penetrate shallow water to expose submerged features, pixel size prevented mapping of beachrock outcrops because they couldn't be differentiated from other sediments or underwater features. Higher resolution aerial images enabled accurate beachrock mapping. These images were obtained by a helicopter but increasingly, remote drones are a cost-effective way of collecting spectral and spatial data for further analysis. Spatial analysis of the mapped beachrock shows correlations between beach type and sediment availability (figure 9), as well as slope, and proximity to freshwater sources such as rivers mouths and tidal flats.



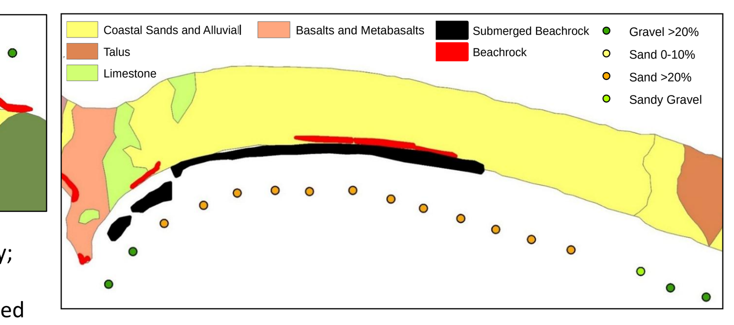
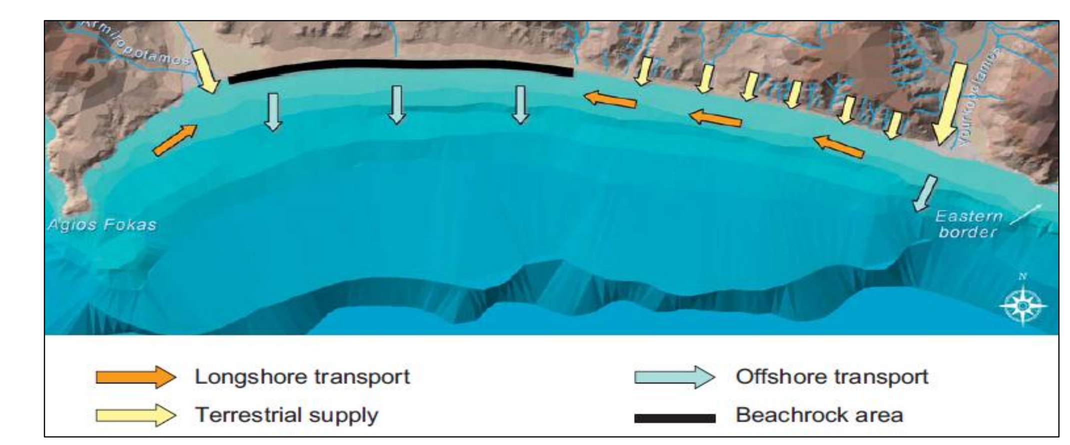


Figure 9, above: beachrock correlates to sediment availability; **Figure 10**, below: beachrock lithifies fluvial and offshore transported sediments, as well as marine sediments transported by longshore and offshore transport. Source: Vousdoukas, 2009.



Next Steps

Spatial analysis of the mapped beachrock shows correlations between beach type and sediment availability (figure 9), as well as slope, and proximity to freshwater sources such as river mouths and tidal flats. Future studies should use higher resolution satellite images or aerial imagery to further investigate areas with mapped coastal and alluvial sediments for beachrock formations. As global temperatures continue to rise, $CaCO^3$ solubility and precipitation from seawater may increase.[11] As a result, beachrock lithification processes may accelerate in coming decades, which will impact sediment transport, coastal wave action and erosion of beaches, as well as beach and coastal environments and use.[11]

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