Beachrock Identification using Geology and Geophysical Approaches in Indonesia

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Abstract
A unique carbonate rock developed naturally as a natural barrier presumably appropriate for advanced marine ecosystems including microbiotas in shorelines. A great deal of progress has been made in recent years to investigate the chemical characteristics of beachrocks. Beachrocks found in Krakal-Sadranan Beach can be categorized into non-beachrocks, unconsolidated beachrocks (similar to carbonate sands), and well-consolidated beachrocks, which mainly consist of rocks and minerals. A depletion of Sr concentration in the beachrocks indicates that the diagenetic processes have progressed from the land to the seashore, most likely post-deposition of the beachrock and carbonate sand. An increased concentration of Rare-Earth-Element (∑REE), both heavy REE (Tb, Dy, Y, Ho, Er, Tm, Yb and Lu) and light REE (La, Ce, Pr, Nd, Sm, Eu and Gd) signals that the beachrock deposition process happened at oxidative environmental conditions. Unmanned aerial vehicle (UAV) drone mapping, geological analysis, and geophysical surveys were conducted to detect the underground structure of the beachrocks and to emphasize the coastal mapping based on targeted beachrock. The mechanism of beachrock formations obtained in this study would be a novel concept and applicable for the coastal zone improvements and preservations for further studies.

Keywords: Beachrock, Diagenetic process, Rare-Earth-Elements, Geophysical methods, Rock properties, UAV drone

1 Introduction

Beachrock (Figure 1) is an important feature of many tropical coastlines as it appears to have an anchoring effect for dynamic islands and provides protection from erosion. Yet, many things about its origin and properties remain unknown or debated hitherto. Outcrops of beachrock sediment are valuable records of the past climate of low-lying reef islands, despite the application beachrock sediment as an indicator of paleo-environment in the Pacific is still underdeveloped [17].

Figure 1: Location Research Area in Krakal-Sadranan Beaches, Yogyakarta, Indonesia.

Indonesia is an archipelago country whose coastline is the fourth largest in the world after the United States, Canada, and Russia respectively. As one of the countries with the longest coastline, Indonesian beaches have its quirks and issues. As compounding effects and conflicts arise in a complex, emergent and cross-scaled impact manner, a manifold of change drivers (e.g. climate change, urbanization, tourism development, and marine resource exploitation) may be at fault [18, 12, 8, 15, 3]. In addition, through an understanding of the beachrock formation process, artificial rocks may be able to be formed at an accelerated speed of consolidation [6]. Erosion will have damage impact for construction developments near or on the sea, such as highways, bridge concretes, and airport buildings.

There has been a paucity in the beachrocks research studies in Indonesia, hence being one of the main motivations of this research. Similarly, beachrocks in that area has also never been a subject of study in any of the past researches. The beachrocks found on Krakal-Sadranan Beach were spread locally, parallel to the coastline with a coverage of around 10-30 m^2. The southern coast of Java is known for its large waves, causing very intensive abrasions; which subsequently also made the characteristics of the beachrocks in those areas a very interesting subject to study. This study aims to reveal the physical characteristics of the beachrocks and the type of cement that forms them, as well as diagenesis processes at the beaches based on geology-geophysical approaches.

2 Geology of Southern Yogyakarta, Gunungkidul Regency

Beaches of Gunungkidul Regency, Province of Special Region Yogyakarta (Prov. DIY), Indonesia have economic potential as limestone mine deposits and tourism. The research site is at coordinates 07°08'42,55" and 110°26'11,31". The characteristics of the Karst Mountains of South Beach indicate that there is steep topography that rises to the east of Java Island. Continuing eastward hummocky valleys occur (Drini Beach to Krakal to Sadranan). The coast of Sadranan have a slope ~12,33° with the tidal range of 12 m that makes the sedimentary process in this coast were thicker than the deeper slope. The tidal reach of the littoral zone provides an opportunity for strong sea wave energies to erode the beach.

Throughout the karst coast of the DIY Prov., Gunungkidul Regency the soil is derived from limestone bedrock, similar to the Mediterranean, i.e., the level of physical weathering is high. Grains of sediment along Krakal and Sadranan beaches are largely bright colored along most of the coastline as a result of the erosion of seabed being deposited on the beach. Composition of this sediment mainly formed by coral, skeletal fragment, Foraminifera and Mollusca.

3 Methodology

3.1 Fieldworks

At this stage, two horizontal - vertical sections (trenches) are made and extended laterally from onshore to the sea, namely α-location (the AB and CD geological stratigraphic measurement), coastal mapping using UAV drone and beachrocks sampling. In this section also the seismic surface acquisition was conducted to identify the subsurface body of beachrock and the beachrock properties. This aerial mapping and geophysical approaches were strong methods to identify beachrock body modelling toward cross-section of formation model. For this purpose, the respective image overlap is provided from the so-called block configuration. By these means, suitable search areas can be defined, which considerably speeds up the matching step. The gap between technologies also promote this method that is applicable to support the acceleration of data procurement because it offers many advantages, including the ease of operation and low operational cost.

3.2 Data Processing and Analysis

At this stage, preparation of stratigraphic columns, rock sample identification and petrographic identification were carried out to get the characteristics of beachrocks.

a. Stratigraphic columns

The Stratigraphic columns describe the location of sample, description of columns and the thickness of beachrocks.

b. Petrological identification

This stage is to identify megascopiscally the fragment and matrix of the beachrock.

c. Petrographic identification

This stage is to identify rock textures and mineral constituent using polarization microscope.

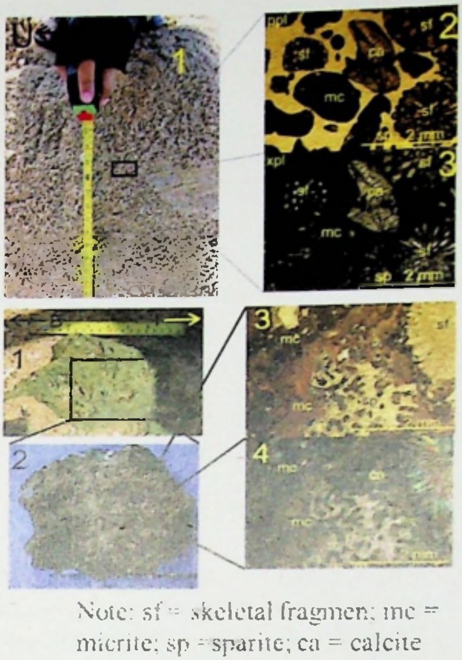
d. Geophysical model

Based on the field acquisition, analyse the data to eliminate the noise and other factors for rock subsurface model.

4 Results and Discussion

4.1 Geology of the Study Area

Throughout the karst coast of the DIY Prov., Gunung Kidul Regency, the soil is derived from limestone bedrock, similar to the Mediterranean, i.e., the level of physical weathering is high. Grains of sediment along Krakal and Sadranan beaches are largely bright-colored along most of the coastline due to the erosion of seabed being deposited on the beach. The composition of this sediment is mainly made up of coral, skeletal fragment, *Foraminifera* and *Mollusca.*



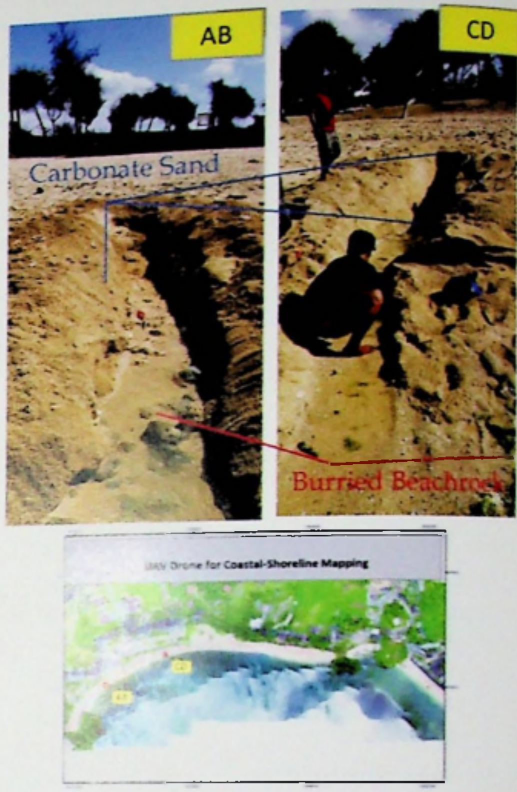


Figure 2: Outcrop Photo of Beachrocks on Trench AB and CD Position (Note: sf = skeletal fragmen; mc = micrite; sp =sparit; ca = calcite).

4.1.1 Carbonated Sand Deposits

Petrological analysis showed whitish yellow-colored, 2 mm fragment size and 1 mm matrix, subangular grain shape, nonconsolidated rocks with a thickness of 70 cm. The precipitate granules are limestone fragments (30%) and fossil shell material (40%), limestone sand material (30%) (Figure 2). Based on microscopic observation, it appears brown (PPL) and brownish

yellow (XPL), grain sizes 1 - 2 mm, not consolidated. The composition of skeletal fragments (40%) and calcite (23.33%), micrite (20%), and spars (16.67%) (Figure 2)

4.1.2 Sparse Biomicrite (Based on Folk, 1962)

In the petrological analysis, it appears whitish yellow, the size of 4 mm fragment grains and a base mass of less than 1 mm, the shape of sub-angular grains, open boxed. Massive structure. The composition of limestone fragments (10%) and fossil shell material (20%), mineral calcite (40%) and limestone sand material (30%). (Figure 2)

Petrographic analysis showed a yellowish-brown color (PPL and XPL), grain size less than 1-4 mm, grain relationships supported with interparticle porosity types. The composition of fragments of skeletal fragments (20%) and calcite (16.67%), micrite (33.33%) and spars (30%). (Figure 2)

It is evident that the megascopic Sadranan beachrock has the same grain characteristics and the same grain composition as the non-solidified material along its beaches, with a dominance of shell fragments, corals, Foraminifera, and relatively anhedral-shaped grains varying from 2 mm to 4 cm. There is also carbonate cement. Figure 2 shows a sample of Krakal-Sadranan beachrock that has fragments of relatively large size (> 3 mm to 3 cm) with a grey to brownish grey color.

In the past decades, there have been a number of studies on beachrocks. Hopley [7] was the first to provide a methodological synthesis on the use of beachrocks as sea level indicators with particular guidelines, and further stated that beachrocks should be used in conjunction with other types of evidence, particularly in macrotidal areas. Furthermore, the potential of beachrocks as useful records of shore position has been suggested by Semeniuk and Searle [14], while Cooper and Kaplan [5] suggested they may preserve former shoreline morphology and alignment. Based on the cement characteristics and sediment bedding information, reliable sea level changes may be achieved, by defining the position of a beachrock and transforming it into an index point [10].

4.2 Drone Coastal Mapping

Counter-mapping tended to delineate and formalize claims to forest territories and resources that certain communities or villages had traditionally managed by using sketch maps. Automatic aerial triangulation (AAT) method which is used to determine the orientation of captured images is usually the first step of a photogrammetric evaluation.

Commercial software systems to solve this task have been available for more than a decade [16, 4]. First step of image marching are extracted the data which is the primitives suitable step, and then for a second step are determined by similarity and consistency measures from the data. In order to efficiently transfer the extracted feature points to the respective neighbor images, usually a priori information is additionally integrated in order to speed up the required search effort. The outcome as Digital Surface Model (DSM) that is produced from UAV data acquisition is also accurate to generate tsunami hazard modelling.

4.3 Geophysical Analysis

Geoelectrical data was processed based on resistivity value, true resistivity, and contrasts resistivity interpreted lithology of sub-surface and structural sub-surface geology, based on field acquisition in the α-location. Furthermore, the interpretation is carried out quantitatively by determining the rock resistivity according to the depth indicated by the results of refraction seismic processing. The resistivity section were derived from the measured data using 2D inversion technique. This method involves numerical calculation of the electric field and constrained smoothing by a nonlinear least-squares method [9, 13]. From the acquisition data, the seismic wave travel time data is obtained. The data is determined when the first wave arrives and is plotted into the travel time curve and analyzed the value of the travel time. Seismic wave velocity in the first layer and seismic

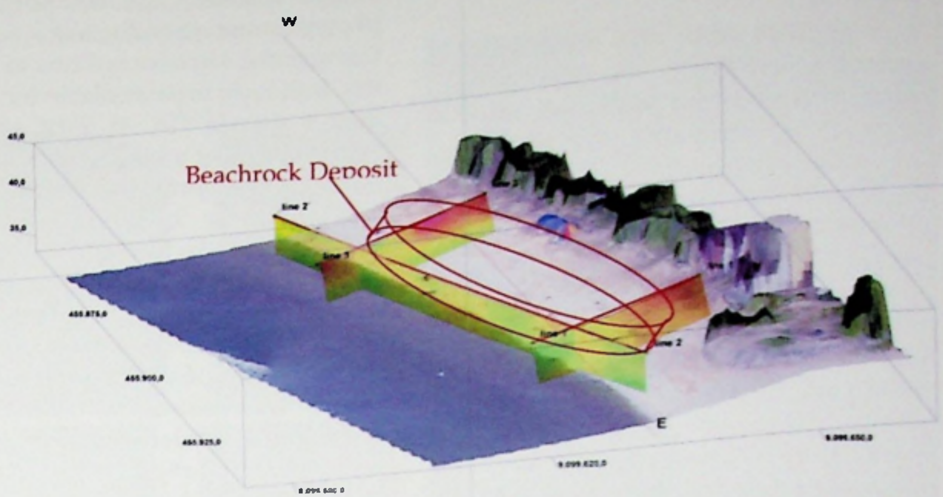


Figure 3: 3D Model of Geophysic Measurement and UAV Drone for Beachrock Deposit Mapping.

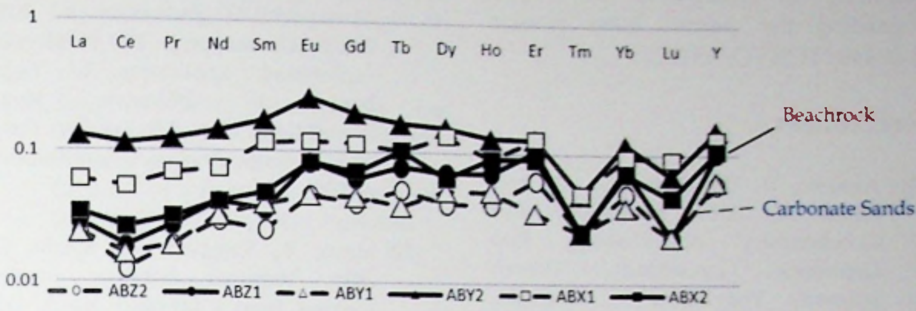
wave velocity in the second layer are obtained from the travel time curve. Modeling of the subsurface cross-section is different in wave velocity in the first layer (v1), wave velocity in the second layer (v2) and depth in each path.

This location was constructed by three measurement lines, which were line-1, line-2, and line 3. The analysis data of this research were explained by each line to make it detailed and more comprehensible. The α-location (Figure 3) is a depth profile obtained from data processing. If the elastic waves that propagate in the Earth's medium meet the plane boundary with different elasticity and density, then reflection and refraction of the wave will occur. From the dispersion curve of S-wave propagation that represented frequencies, phase velocity and amplitude were used. The graphic of S-velocity versus depth described that penetrating of source wave were propagated around ~4.5 m beneath the surface of beachrock within S-wave velocity around 250~600 m/s. In other word, toward reinforcing the thickness of beachrock, based on the results of data processing that has been done, v1 is obtained for the first layer of 209.67 m/s with a depth of 1.5-2.5 m. Meanwhile, v2 in the second layer obtained a value of 647.77 m/s. From the results of data processing, it is interpreted that natural beachrock has a thickness of 1.5-2.5 m which is in the first layer.

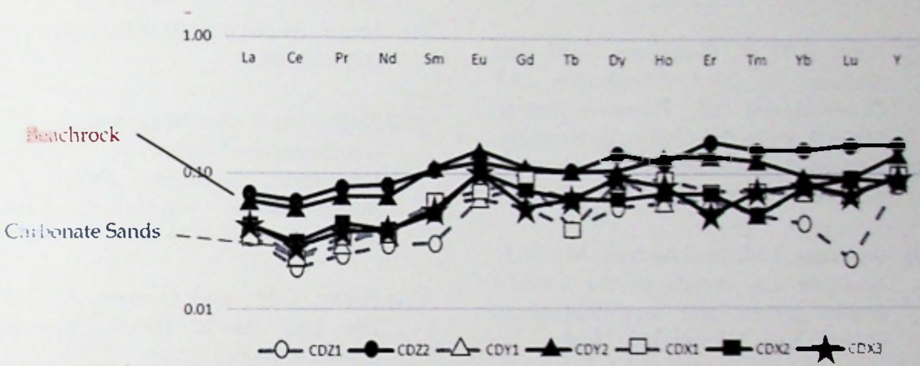
4.4 Geochemical Analysis

The plotting results of trace element (Cr, Mn, Fe, Rb, Y, Ba, La, Ce, and Eu) concentration of the beachrock samples from this study exhibit enrichment trending from the land to seashore that assuming of marine nutrient for cementation process. In contrast, the Sr element shows the highest concentration in the beachrock and also carbonate sands (also assuming as unconsolidated beachrock) (Figure 4).

Based on the Sr concentration in the Wonosari-Punung limestone samples and by referring to studies of Atmoko, et al. [1], Azizi et al. [2], Nagendra and Nagarajan [11], it could be interpreted that beachrock samples of this study with lower Sr content experienced more removal by freshwater during the diagenesis in comparison with carbonate sands (or close to unconsolidated beachrock) which is characterized by higher Sr content of ~3500 ppm. Involving freshwater on accelerating Sr depletion could suggest that the process of diagenesis might have occurred after the deposition of the beachrocks. Therefore, the Sr depletion of the beachrocks suggests that the diagenetic process has not yet occurred in the phase after deposition.



(a)



(b)

Figure 4: Spider Diagrams of Beachrock Elements Analysis (a) Trench AB (b) Trecnh CD.

5 Conclusions

The data anomaly in this study has the characteristics of high velocity anomalies ranging from 250-600 m/s on all trajectories. This anomaly is interpreted as the existence of a beachrock body. In general, the distribution of beachrock is on the surface with a very thin thickness of 1.5-2m. However, there is also beachrocks buried in the sand, so it is ~2 m below the surface. Beachrock from Krakal-Sadranan, Yogyakarta, Indonesia has a fairly consolidated feature, consists of a mixture of gravel-sized deposits of sand in the form of limestone fragments, calcite and fossil minerals, and almost 50% CaO content (Carbonaceous).

Acknowledgement

The authors deeply appreciate Mr. M. Hidayat, Mr. M. Zharfan, Ms. Reny R., Mr. Dobrak Tirani, Mr. Jum Satriani, as field geology and geophysics exploration of UGM

Indonesia for their constant assistance with the experiments; Dr. rer. nat. Doni Eka Prakasa who permitted access to the Get-In CICERO Laboratory that was supported by BMBF, Dept. of Geological Engineering, UGM; Embassy of the Republic of Indonesia in Tokyo regarding the permit letter nomor B-00446/TOKYO/181227.

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