GEOLOGICAL ANALYSIS AND MINERAL COMPOSITION OF BARON BEACH SAND: FACTORS CAUSING DARKER COLOUR COMPARED TO SURROUNDING BEACHES

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Abstract

This study aims to analyse the condition of the sand at Baron Beach, Gunung Kidul, which has a darker colour than the sand at surrounding beaches such as Kukup Beach, which is less than 1 km away. Through a geological approach, this study reviewed various literatures to identify the factors that influence the difference in sand colour. The literature analysis involved mineralogical, sedimentological and petrographic studies to determine the mineral composition and origin of the sand constituent materials. Based on the literature study, it was found that the content of heavy minerals, such as magnetite and ilmenite, contributes significantly to the dark colour of the sand at Baron Beach. In addition, geomorphological dynamics and erosion processes in the volcanic rocks that dominate the area are also important factors in the characteristics of sand sediments. The conclusion of this literature study provides insight into the geotourism potential of the Baron Beach area as well as the importance of understanding geological factors in sustainable beach tourism management.

Keywords:
Baron Beach sand, heavy minerals, geological analysis, sedimentology, geomorphology, geotourism, Gunung Kidul, volcanic erosion.

A. INTRODUCTION

Baron Beach, located at UTM 49 S coordinates 450089 mT and 9101090 mU, is a prominent coastal tourism destination in Kemadang Village, Tanjungsari District, Gunungkidul Regency, Yogyakarta. The beach offers a distinctive blend of natural and cultural attractions, featuring sandy shores, karst hills, and a traditional fishing harbor (DIY, 2018). One of its most unique aspects is the presence of an underground river that flows directly into the sea, creating an intriguing hydrological feature. The picturesque karst hills on both sides of the beach enhance its natural beauty, making it a favorite spot for visitors seeking stunning views and geological wonders (Pariwisata Indonesia, 2020).

Beyond its scenic charm, Baron Beach is an active hub of traditional fishing activities, which add a vibrant cultural dimension to the area. Visitors can observe fishermen setting out to sea or selling their fresh catch at local markets, offering an authentic glimpse into the coastal livelihoods of Gunungkidul residents. The combination of breathtaking landscapes and cultural richness makes Baron Beach a versatile destination. Whether for relaxation, exploration, or learning about local traditions, Baron Beach provides a unique experience that showcases the harmonious coexistence of nature and culture along Yogyakarta's southern coast.

The Gunung Sewu karst area, located in the southern mountainous zone of Java, holds a prominent position in the island's physiographic landscape. Based on van Bemmelen's division

(Van Bemmelen, 1949), this zone stretches in a west-east direction, showcasing a distinctive arrangement of karst hills with elevations ranging from 25 to 150 meters (Kusumayudha, 2005). These karst formations are the product of millions of years of geological processes, including uplift, erosion, and dissolution. The combination of tectonic forces and climatic conditions has resulted in a breathtaking karst topography that is both scientifically valuable and aesthetically captivating. The Gunung Sewu region is an archetype of tropical karst systems, where limestone's susceptibility to dissolution has shaped a landscape defined by hills, valleys, and caves.

Tropical karst areas like Gunung Sewu are renowned for their unique cone-shaped formations, which have been extensively studied by geologists and geomorphologists (Haryono, E., & Day, 2004; Hatheway, 2007; Uhlig, 1980). These karst cones, formed through a combination of chemical weathering and erosion, exemplify the intricate relationship between lithology, hydrology, and climate. The warm, humid conditions typical of tropical zones accelerate the dissolution of limestone, creating features that are rarely observed in other regions. Beyond their geological significance, the karst formations also hold ecological and economic importance. They serve as natural reservoirs, trapping and storing rainwater in underground aquifers, which are vital for the region's water supply. Additionally, these landscapes are biodiversity hotspots, providing habitats for endemic flora and fauna. The interplay of natural processes and environmental factors in Gunung Sewu makes it a valuable subject for studies on karst evolution and tropical geomorphology.

The coastal regions of Gunungkidul, where karst hills extend to the shoreline, further demonstrate the dynamic processes shaping the Gunung Sewu area. These coastal karst landscapes are marked by irregular and diverse landforms, including steep cliffs, sea caves, and pocket beaches (Marfai, M. A., 2013). The coastline's complexity reflects the combined effects of uplift, wave erosion, and solutional processes, which have carved out unique features over time. This region's geomorphology not only contributes to its natural beauty but also provides insights into the geological history of Java's southern coast. The ongoing interaction between tectonic activity and the forces of erosion continues to sculpt the landscape, offering a living laboratory for understanding coastal karst dynamics. As a result, Gunung Sewu stands out as a remarkable example of how tropical karst systems evolve, integrating geological, ecological, and cultural dimensions.

Figure 1. Baron Beach
Source: Google Earth, 2024

Beaches in karst environments generally have a distinctive white coloured sand that comes from the erosion of limestone rocks. The eroded limestone particles, such as calcium carbonate, are deposited on the beach and give the sand its white colour. In addition, some karst beaches also have sand from coral remains and shells of marine organisms that are rich in calcium, which adds to the whiteness of the sand. The white sand on these karst beaches is usually finer and softer than the dark-coloured volcanic sand. Volcanic sand has a dark colour because it comes from volcanic eruption material that is rich in certain minerals, such as basalt, pyroxene and olivine. This material then undergoes erosion, breaking into fine grains to form volcanic sand. Based on this information, the question arises why Baron Beach, which is located in the Karst environment, has black beach sand when the surrounding beaches have white sand.

B. RESEARCH METHOD

This research employs a descriptive qualitative approach with a literature review to investigate the geological factors responsible for the darker sand color at Baron Beach compared to the surrounding beaches. The primary focus is on understanding the geological conditions influencing the beach's unique sand color. The analysis was conducted by reviewing literature on various geological aspects, including lithology, geomorphology, regional geology, and genetic factors. Academic sources, research journals, and geological reports that discuss the lithology and geomorphology of the region were examined. Additionally, satellite imagery of the Baron Beach area and its surroundings was used to support the analysis and offer a broader view of the region's geological landscape. This combination of sources helps to create a comprehensive understanding of the factors at play.

The collected data from the literature review were then subjected to detailed analysis and interpretation. The aim was to compare the characteristics of the sand at Baron Beach with the findings from the literature to identify potential geological causes for its darker hue. Various factors, such as the mineral content, sedimentary processes, and the influence of local geological features like the nearby karst hills, were considered in this analysis. After interpreting the data, the results were presented in a descriptive manner, explaining how these geological factors contribute to the distinct coloration of the sand at Baron Beach. This approach provides a thorough exploration of the environmental and geological influences that make Baron Beach's sand darker than those of surrounding coastal areas.

C. FINDINGS AND DISCUSSION

Baron Beach is located in the Karst area of Gunung Sewu, a region known for its distinctive landforms created through the dissolution of rocks, particularly limestone (calcite) and dolomite, by acidic water. This karst process begins when acidic rainwater infiltrates the soil, dissolving the calcium carbonate minerals present in the limestone. As the rainwater seeps deeper, it continues to erode the rock, forming characteristic karst structures such as caves, sinkholes, dolines, and underground rivers. Over time, this dissolution creates large cavities and fissures within the rock, which may evolve into complex cave systems or closed valleys, such as the ones found in the vicinity of Baron Beach. The unique topography of this karst landscape contributes to the geological diversity of the area, offering a glimpse into the dynamic processes that have shaped the region over millions of years. This ongoing process of erosion and dissolution not only alters the landscape but also influences the composition and characteristics of the sand found at the beach.

Limestone, the primary rock in this karst region, forms through sedimentation in warm, shallow marine environments, rich in marine organisms such as algae, coral, and microscopic creatures with calcium carbonate shells. As these organisms die, their shells and skeletal remains settle on the seafloor and accumulate over time, forming layers of sediment. Over millions of years, the pressure from the overlying layers of sediment causes compaction and cementation, eventually transforming the accumulated material into solid limestone. In addition to biological contributions, limestone can also form through the chemical precipitation of calcium carbonate dissolved in water, which then settles as layers of limestone. The continuous erosion of limestone over time, driven by natural forces such as wind, water, and temperature changes, eventually breaks it down into smaller particles, including sand. In karst or limestone regions, beach sand typically has a whitish color due to the high calcium content from the mineral composition of the eroded limestone. This process of limestone erosion contributes not only to the unique geological formations seen at Baron Beach but also to the distinct color and texture of the sand, which serves as a natural indicator of the region's rich geological history.

However, it is different at Baron Beach where the dark-coloured sand comes from the weathering of volcanic rocks dating from the Cretaceous to Tertiary period, which is the result of tectonic activity and volcanism along the subduction zone of the Indo-Australian Plate and Eurasian Plate. Rock types such as basalt, andesite, and volcanic breccia with heavy mineral content, especially iron-rich magnetite and ilmenite, are the main contributors to the dark colour. Widodo (Widodo, S., 2020) explained that physically, Baron Beach sand has a fine to medium grain size (0.125-0.5 mm) with a blackish grey colour, sub-angular to sub-rounded grain shape, and a moderate to well sorted level. Kusumayudha (Kusumayudha, 2021) explained that the materials that make up this sand come from various sources, including massive stage volcanic material, underground river deposits, coastal cliff abrasion results, and volcanic material from the Southern Mountains. The main mineral composition of Baron Beach sand can be seen in the table below.

Table 1. Main Mineral Composition in Baron Beach.

Mineral	**Persentase**
Magnetit (Fe_3O_4)	15-20%
Ilmenit (Fe Ti O_3)	10-15%
Kuarsa (SiO_2)	30-35%
Plagioklas	20-25%
Piroksen	10-12%
Hornblende	5-8%

Source: Harjanto & Saputra, 2019

The volcanic material on Baron Beach is carried by an underground river that empties into Baron Beach, which locals call Bribin River. Bribin River is the outlet of the largest underground river system in the Gunung Sewu karst that empties into Baron Beach. This underground river is formed in hollow limestone rock due to the dissolution of calcium carbonate by water over thousands of years. According to Kusumayudha (Kusumayudha, 2021), the system has a total length of 15-20 km with an estuary width of 12-15 metres and an average discharge of 8-12 m^3/second which varies seasonally between 2-20 m^3/second. Marfai (Marfai, M. A., 2019) identified the hydrogeochemical characteristics of Baron underground river water with pH ranging from 7.2-7.8, temperature 25-27°C, and dominant ion content of Ca^{2+} (60-80 mg/L) and HCO_3- (200-250 mg/L). Rahardjo & Suyoto (S. Rahardjo & Suyoto, 2022) added that this system carries suspended sediment material of 50-200 mg/L with a dominant grain size of 0.125-2 mm derived from volcanic rock fragments, dissolved karst material, and surface sediments. These volcanic rock fragments come from the nglanggeran ancient volcano formation.

The Gunung Kidul area is characterized by three primary rock formations, each with distinct geological histories and contributions to the region's landscape. These formations, which date back to the Miocene to Pliocene epochs, include the Wonosari, Sambipitu, and Nglanggeran Formations. The Nglanggeran Formation consists of lava lithology and volcanic breccia, both of which originated from the Nglanggeran Ancient Volcano. This volcanic rock layer plays a significant role in the area's geology, providing the source of volcanic materials found in the region, including heavy minerals like magnetite and ilmenite. The Sambipitu Formation, on the other hand, consists of sedimentary rocks such as tuff, shale, silt, sandstone, and conglomerates, which resulted from the weathering of the Nglanggeran volcanic rocks. These sedimentary layers were laid down in various depositional environments, further contributing to the geological complexity of the region. The Wonosari Formation, a thick layer of limestone, dominates the karst landscape of Gunung Sewu. It was formed from shallow marine deposits during the Middle Miocene and plays a critical role in the formation of the region's karst topography, which includes features like caves, sinkholes, and underground rivers.

In karst areas like Gunung Sewu, surface water is quickly absorbed into the ground through the fissures and pores in the limestone. This water then flows through a complex network of underground rivers, which is a characteristic feature of karst landscapes. The volcanic material from the Nglanggeran and Sambipitu Formations is transported by surface rivers until it reaches the Karst environment of the Wonosari Formation. Once the water enters the ground through pores, faults, and caves in the limestone, it forms an underground river system. This system remains situated above the Sambipitu and Nglanggeran formations because these igneous rocks are more resistant to dissolution by acidic water than the limestone in the Karst. The interaction between the surface water, volcanic material, and the karst landscape contributes to the unique geological features observed in the Gunung Kidul area, including the dark-colored sand at locations like Baron Beach. This complex interplay between rock formations, water systems, and geological processes makes Gunung Kidul a fascinating region for studying both karst and volcanic geology.

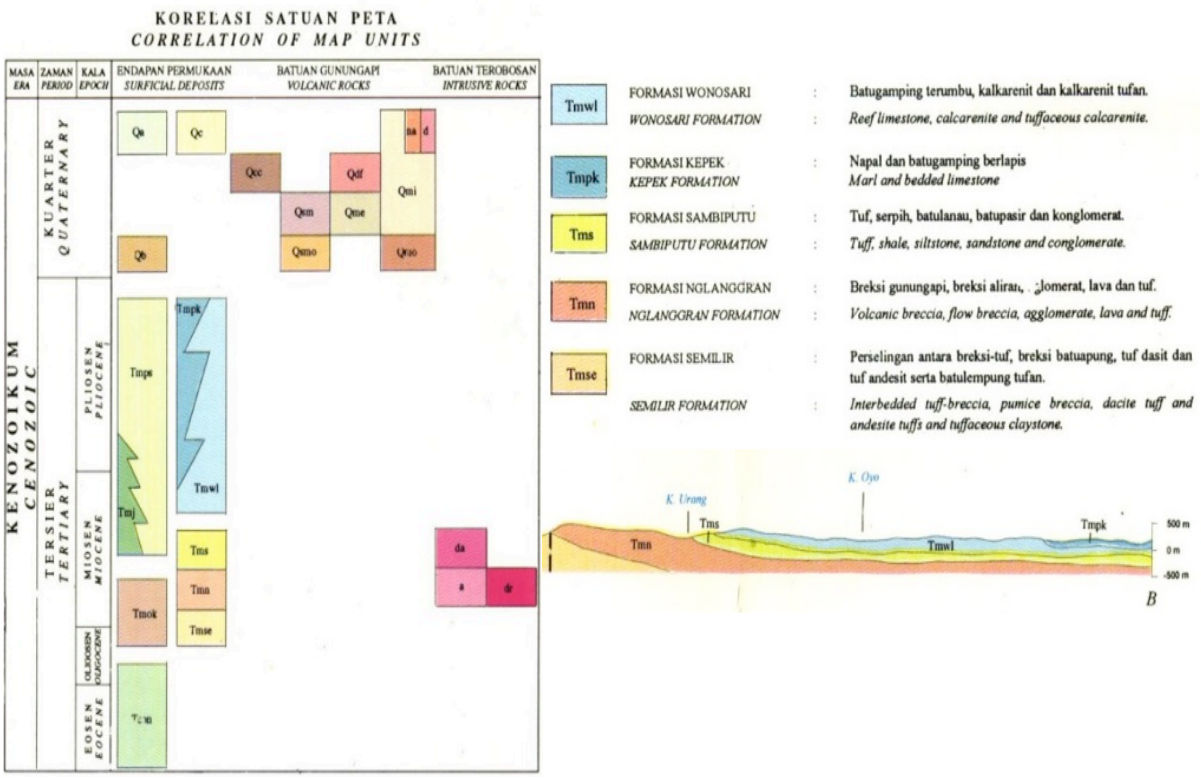

Figure 2. Peta Geologi Lembar Yogyakarta
Source: W. Rahardjo et al., 1995.

An in-depth understanding of the geological conditions and mineral composition of the sand at Baron Beach has significant implications for geotourism management and sustainable tourism development. The underground river that flows directly to the beach creates a freshwater stream that merges with the sea, enhancing the unique landscape and making it an intriguing feature for visitors. The dark-coloured sand, distinct from the surrounding beaches, adds to the beach's allure, providing an additional layer of attraction for tourists. At certain times, when the freshwater from the underground river flows swiftly and overflows, it creates a visually striking effect, resembling a waterfall, further enhancing the natural beauty of the area. This phenomenon highlights the potential of Baron Beach as a geotourism destination. However, the sustainable development of this potential must consider ecological sustainability and the preservation of coastal biodiversity (Martini & Chesworth, 2011). Proper management and conservation efforts are crucial to ensure that the natural and cultural integrity of the area is maintained. Baron Beach offers a combination of natural beauty, cultural heritage, and geological significance, making it an ideal destination for tourists seeking a diverse experience. Its geographical uniqueness, coupled with the educational value provided by its geological formations and traditional fishing practices, makes it a valuable site for learning about the environment and local culture. With the addition of well-developed facilities and its attractive surroundings, Baron Beach stands as one of the most popular destinations in Yogyakarta, appealing to a wide range of tourists interested in both nature and cultural exploration.

D. CONCLUSION

Based on the literature review on lithology, geomorphology, regional geology, and other related fields, it is understood that the dark color of the sand at Baron Beach is primarily due to the presence of volcanic material, including heavy minerals such as magnetite and ilmenite, as well as significant iron content resulting from the weathering of volcanic rocks. These volcanic materials originate from the Nglanggeran ancient volcano, located within the Nglanggeran and Sambipitu Formations. The volcanic materials are transported by underground river flows that traverse the Karst environment and ultimately empty into Baron Beach. In addition to the volcanic materials, geomorphological processes, including the erosion of volcanic rocks, also play a role in shaping the sand characteristics of the beach. This results in a unique sand composition that contrasts with the surrounding beaches, which typically have white sand due to the dominance of limestone. The combination of dark-colored sand and the underground river flowing into the sea adds a distinctive element to the area, creating an intriguing geotourism potential. However, the development of this potential must be approached with careful consideration for environmental sustainability, ensuring that the natural and ecological balance of the region is maintained for future generations

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