EXPLORING MARINE GEOLOGY AND OCEANOGRAPHY IN MANGGAR WATERS: A PRELUDE TO THE BURGEONING BELITONG GEOPARK

PENYELIDIKAN GEOLOGI KELAUTAN DAN OSEANOGRAFI DI PERAIRAN MANGGAR: SEBUAH LANGKAH AWAL PADA UPAYA PENGEMBANGAN GEOPARK BELITONG

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(Received 10 November 2023; in revised from 20 November 2023; accepted 27 December 2023)

DOI : http://dx.doi.org/10.32693/bomg.38.2.2023.859

ABSTRACT: A survey on marine geology and oceanography was conducted in Manggar Waters, East Belitung, in order to protect the geological heritage of the newly inaugurated Belitong UNESCO Global Geopark (UGGp) in 2021. This study is aimed at understanding the characteristics of the seabed, marine sediments, currents, and coastal features in the area. A bathymetrical survey was done using an Echotrac echosounder to measure water depths, and current measurements were taken with an Infinity device. Forty sediment samples were collected and analyzed for their characteristics. The coastal features were examined through direct observation, and an unmanned aerial vehicle (UAV) drone was used to investigate the morphology of small islands. The results showed that the seabed was mainly composed of coarse sediments, such as sand and clayey sand, with some areas containing gravel near Buku Limau Island. The microfauna foraminifera analysis indicated a relatively low diversity, with *Operculina* and *Amphistegina* being the dominant species. Two types of beaches were recognized: the northern part, consisting of rocky beaches made of igneous rocks, and the southern part, which has flat beaches made of beach alluvium deposits. Abrasion was found to be dominant in the southern part, particularly at Tambak Beach. The study provides valuable information for the planning and management of marine areas in the Belitong Geopark. It also highlights the importance of preserving and protecting the geological heritage of the region. With this newfound knowledge, stakeholders can make cognizant decisions to ensure the conservation of the Belitong Geopark and its unique geological features.

Keywords: Belitong UGGp, marine geopark, marine sediment characteristic, coastal characteristic

***ABSTRAK**: Dalam rangka melindungi dan menjaga warisan geologi di Belitong UNESCO Global Geopark (UGGp) yang baru diresmikan pada tahun 2021, maka telah dilakukan survei geologi kelautan dan oseanografi di Perairan Manggar, Belitung Timur. Penyelidikan ini bertujuan untuk memahami karakteristik dasar laut, sedimen permukaan dasar laut, sifat arus, dan karakteristik pantai di daerah tersebut. Survei batimetri dilakukan dengan menggunakan echosounder Echotrac untuk mengukur kedalaman air; sedangkan arus diukur dengan menggunakan alat Infinity. Empat puluh sampel sedimen diambil untuk dianalisis sifat dan kandungan di dalam sedimen. Tipe pantai dianalisis berdasarkan hasil observasi langsung; dan drone kamera tanpa awak digunakan untuk mengamati morfologi di pulau-pulau kecil. Hasil penyelidikan menunjukkan bahwa dasar laut Perairan Manggar sebagian besar terdiri dari sedimen kasar, seperti pasir dan pasir lempungan, sedangkan kerikil hanya dijumpai di beberapa lokasi di dekat Pulau Buku Limau. Analisis mikrofauna foraminifera menunjukkan keanekaragaman yang relatif rendah, dengan Operculina dan Amphistegina sebagai spesies yang dominan. Terdapat dua jenis pantai,* *yaitu di bagian utara yang merupakan pantai berbatu tersusun oleh batuan beku, dan di bagian selatan yang berupa pantai datar dengan endapan aluvium pantai. Abrasi dominan terjadi di bagian selatan, khususnya di Pantai Tambak. Diharapkan hasil survei dan penyelidikan ini dapat memberikan informasi berharga bagi perencanaan dan pengelolaan kawasan laut di Geopark Belitong dengan menitikberatkan pada pentingnya melestarikan dan melindungi warisan geologi di wilayah tersebut. Berdasarkan informasi ini, diharapkan pihak-pihak yang berkepentingan dapat mengambil keputusan yang tepat dalam menjamin keberlangsungan upaya konservasi Geopark Belitong dan keunikan fitur-fitur geologinya.*

Kata Kunci: *Geopark Belitong, marine geopark, karakteristik sedimen laut, karakteristik pantai*

INTRODUCTION

Geoparks are geographical areas that are differentiated based on geodiversity, biodiversity, and cultural diversity (Hutabarat, 2023). Geological heritage is managed through the concepts of conservation, education, and sustainable development. Geological heritage containing geological history is the main subject of a geopark area, which can show a unique geological story. Therefore, to build the geological story is not only by observing existing geosites but also by completing and comprehending geological data both on land and at sea.

As one of the ten UNESCO Global Geoparks (UGGp) in Indonesia, the Belitong UGGp, also known as Belitong Geopark, has gained global recognition since 2021. Belitong Geopark is located off the eastern coast of Sumatra in the Bangka Belitung province, Indonesia. The geopark occupies the entire Belitung Island (Belitong UGGp, 2021). It is renowned for its geological heritage, exceptional landscapes and beaches, rich biodiversity, and cultural significance that has noteworthy scientific, educational, and cultural values, undeniably. Zukhri et al. (2021) implied that it is seen as a fresh and compelling magnet for both domestic and foreign visitors. In order to protect the geosites, especially the ones located on the beaches, it is crucial to enhance marine geological and oceanographic information as part of an ongoing effort to conserve and promote the natural and cultural features of the region.

Belitong Geopark is surrounded by the Karimata Strait to the north, the Java Sea to the east and south, and the Gaspar Strait to the west. Being a part of the Karimata Strait, the waters of Bangka Belitung are heavily influenced by tides. According to Wei et al. (2015), tidal

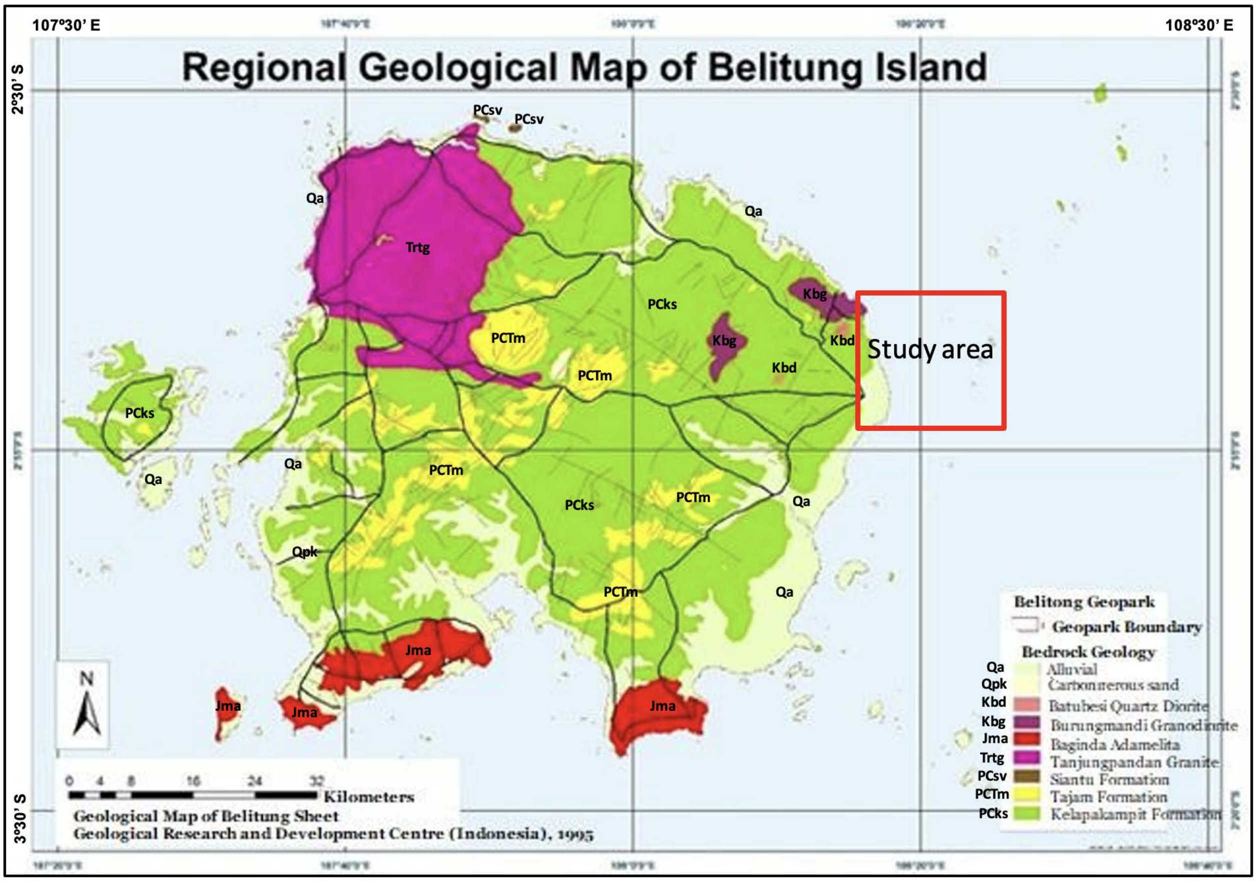

Figure 1. Geological map of Belitung Island surrounding Belitong Geopark (modified from Baharuddin & Sidarto, 1995; Bhinekawati et al., 2020); and the study area of Manggar Waters, off east Belitung Island (red square).

patterns in the Karimata Strait are predominantly diurnal type. These diurnal tides coincide the location of the anti-nodal band of the diurnal tidal waves, where diurnal (daily) tidal waves exhibit looping patterns, as opposed to the nodal band of the semi-diurnal tidal waves, where semi-diurnal (twice-daily) tidal waves exhibit nodal, or stationary, behavior. This distinction is supported by the greater amplitudes and smaller spatial phase-lag changes observed in the diurnal tides compared to the semi-diurnal tides. Wicaksana et al. (2015) argued that the Karimata Strait is greatly impacted by the South China Sea, especially in terms of wind movements and their effects on wave characteristics. The authors reported that significant wave characteristics are observed during the peak of the west monsoon (January) and the east monsoon (August) each year. In January, significant waves in the Karimata Strait reach heights of 1.5–3 m and may continue into February, albeit with a slight decline. In the Java Sea, significant waves can reach heights of 0.5–2.5 m.

Belitong Geopark has a total area of about 4,800 km^2 of land and 13,000 km^2 of sea, with 241 small islands within its boundaries, exposing various geological features (UNESCO, 2021). Among them, there are 27 small islands in the west of Belitung Island (Gaspar Strait) (Hartoko, 2019). Different rock formations can be found in different areas of the geopark, including sedimentary rocks and plutonic rocks (Figure 1). Tin mining has also been a significant contributor to the local economy.

As described by Baharuddin & Sidarto (1995), there are nine lithologies occupy Belitung Island (Figure 1), from youngest to oldest in age formation, namely: alluvial (Qa), carbonaceous sand (Qpk), both are agded Quaternary; Batubesi Quartz Diorite (Kbd) and Burungmandi Granodiorite (Kbg), as stated by Priem et al. (1975) that both having similar age range between 115 – 160 million years ago (Mya), or Cretaceous period; Baginda Adamellite (Jma), aged ranging from 160 – 208 Mya (Priem et al., 1975), or Jurassic period; and Tanjungpandan Granite (Trtg) as Priem et al. (1975) stated as of 208 – 245 Mya, or Triassic period; as the oldest formations in the area, the three interfingering rock formations of Siantu Formation (PCsv), Tajam Formation (PCTm), and Kelapakampit Formation (PCks), dated as of Permo-Carboniferous age, about 250 million years ago.

Quaternary alluvial and beach deposits (Qa) is composed of gravel, pebble-cobble, sand, silt, clay, and coral fragments. Quaternary carbonaceous sand (Qpk) consists of black carbonaceous sand intercalated with clay, with fine to medium grain size, containing heavy minerals, lignite fragments, and occasional cassiterite (tin oxide) layers. Batubesi Quartz Diorite (Kbd) is composed of quartz diorite with a green to light grey color, enclosing minerals such as quartz, K-feldspar, plagioclase, biotite, hornblende, chlorite, and iron oxide. Burungmandi Granodiorite (Kbg) of I-type granite (Pitfield, 1987) consists of granodiorite with a light grey-greenish color and is composed of minerals such as quartz, feldspar, plagioclase, biotite, and hornblende with secondary minerals like chlorite, carbonate, and iron oxide but devoid of cassiterite minerals. Baginda Adamellite (Jma) of I-type granite (Pitfield, 1987) is grey to greyish coarse-grained adamellite, composed of quartz, feldspar, plagioclase, biotite, and hornblende with secondary minerals like chlorite, carbonate, limonite, and iron oxide but lacking cassiterite minerals. Tanjungpandan Granite (Trtg) of S-type granite (Pitfield, 1987) is composed of foliated granite with a light grey color, containing minerals such as quartz, plagioclase, feldspar, biotite, and hornblende. Siantu Formation (PCsv) is only exposed on small islands to the north, deposited in a marine environment, and consists of dark green, massive, and aphanitic lava basalt and volcanic breccia containing subangular-subrounded basalts. Tajam Formation (PCTm) comprises white to green quartz sandstone intercalated with green to brownish siltstone, with both sandstone and siltstone being slightly metamorphosed. Quartz-associated primary tin is found in stockwork veins and fissures found in this rock formation. Kelapakampit Formation (PCks), which is the dominant lithology on Belitung Island, comprises flysch-type sediments indicating marine environment. This formation consists of metasandstone, slate, mudstone, shale, tuffaceous siltstone, and chert. Metasandstone and other sedimentary rocks appear in alternating layers, up to 500 m thick.

Coastal area spatial planning involves the study and analysis of the physical, geological, and oceanographic processes, i.e., wave action, tides, and currents, that shape coastal areas. It helps in understanding the dynamics of coastlines, the interaction between land and sea, and the potential risks and vulnerabilities associated with coastal zones. According to Clark (1996), coastal and marine spatial planning intends to manage and coordinate different uses and activities more efficiently and sustainably. Meanwhile, Suparno et al. (2022) proposed the Marine Spatial Allocations of the Coastal and Small Islands Zoning Plan, emphasizing the significance of marine spatial planning in balancing economic development and environmental conservation, thereby promoting the sustainability of marine resources. All the knowledge will be used to determine suitable locations for various coastal development activities, such as ports and areas for coastal tourism or aquaculture. This study aimed to gather scientific information on the marine geology and oceanography surrounding Manggar Waters to the east of Belitung. Hence, a wide-ranging marine geological survey was conducted to collect data and enrich insights into not only the overall geological knowledge that form the geopark's landscape but also the potential risk of marine hazards related to the region. Potentially, the preliminary findings can be used as a scientific basis for the sustainable management and development of Belitong Geopark.

METHODS

The Marine Geological Institute (MGI, or BBSPGL in Bahasa) entirely ran and provided all the equipment deployed in the survey. Datasets were acquired by employing various methods. This study sought to identify and map the geological features, surface sediment distribution, and sedimentary deposits of the Manggar Waters through a combination of sediment sampling, tidal and current data collecting, bathymetric surveys and coastal observation.

The marine survey was carried out on a fishing boat. The bathymetrical survey involved using an echosounder called Echotrac E20 Teledyne to measure the depth of the water and the morphology of the seabed. This was done along a distance of 390.6 nautical km. On the other hand, LWS, also known as Lowest Water Spring, which represents the lowest tidal level that occurs during the year, is an essential parameter in bathymetric mapping. LWS serves as a consistent reference point for measuring and representing water depths accurately, disregarding varied water levels due to tides, seasonal changes, or other factors. The water depth consistency and accuracy help providing information for the safety of vessel navigation and underwater infrastructure development. Tidal measurements were taken in 15 days on the north coast of Buku Limau Island to validate the results of the bathymetrical survey and comprehend the water conditions.

Current velocity was measured by Infinity AEM Current Meter and is used to serve as data sources for modeling the current in the area to better understand its patterns and intensity. In order to create the current model, Flow Model Flexible Mesh from DHI Mike21 software was used (Danish Hydraulic Institute, 2007). This software includes modules for hydrodynamics (HD) and mud transport (MT). The input data included for generating the model were bathymetry that was collected during the survey, tidal predictions from Globaltide, measurements of total suspended solids (TSS), and discharge measurement rate of the Manggar River from research by Sabri et al. (2017).

Forty marine sediment samples, as shown in Figure 2, were collected along the seabed surface by using grab samplers to study sediment characteristics and composition, including microfauna composition. Mapping work was done on the eastern side of Belitung Island, covering the coast of Manggar and the coasts of small islands (Buku Limau and Siadung Islands), to identify coastal characteristics by using an unmanned aerial vehicle (UAV) drone. It is important to understand sediment properties and composition, as well as coastal characteristics, as is crucial for coastal development and spatial planning.

The environmental condition of the seawater could be recognized by studying various parameters. About twenty seawater samples were collected and analyzed using a multiparameter Milwaukee instrument. This instrument measured temperature, salinity, and turbidity, which are key parameters in assessing the current condition of seawater. Furthermore, to gain a more

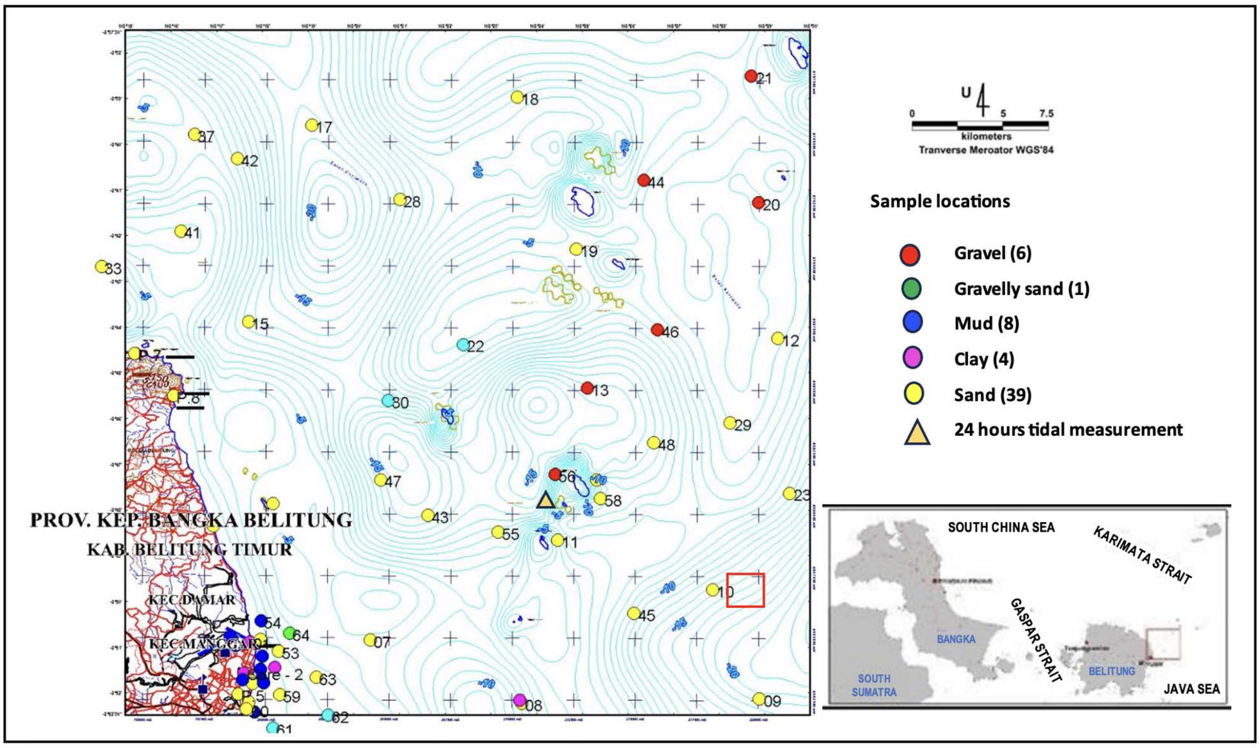

Figure 2. Survey area and sampling locations, shown by sampling number (see map with number attached to each site) and type of sediment samples represented by color, comprises: gravel (red) in 6 locations, gravelly sand (green) in 1 location, mud (blue) in 8 locations, clay (magenta) in 4 locations, and sand (yellow) in 39 locations (see map legend for color and total numbers of each sediment type).

comprehensive understanding of the seawater quality, the collected samples were sent to the Sucofindo Laboratory for additional analysis. In this laboratory, various environmental parameters were analyzed, including biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), and heavy metal levels. These parameters are essential in evaluating the level of organic pollution, nutrient availability, and the presence of toxic substances in the seawater.

Along with the study of water column, sediment samples were also subjected to analysis. The sediment samples were analyzed for grain size distribution in the Marine Sedimentology Laboratory at MGI. Measuring the particle grain size helps determine the sediment composition and transport processes during deposition. For further analysis of sediment sample composition and micropaleontological studies, the Petrology and Micropaleontology Laboratory at MGI was utilized. The laboratory is specialized in studying mineral composition and microfossils. The identification and examination of sediment composition and microfossils support comprehending the geological processes and paleoenvironmental conditions of the area being studied.

RESULTS AND DISCUSSIONS

LWS was used as a reference point for bathymetric analysis, resulting in varied bathymetry from 0 to over 45 m. Within 5 km of the coast, the water depths ranged from 0 to 10 m. Beyond that distance, the water depths become deeper, ranging between 25 and 45 m (Figure 3). Near the coast, the southern part of the Manggar Waters area is shallower compared to the northern part. However, the deepest water depths are observed further to the eastern part of the area toward the open sea. Several high areas composed of coral reefs were also observed, particularly nearby small islands such as Buku Limau, Siadung, Memperak, and others.

There are two dominant currents in the northern part of Manggar Waters, which are flowing westward and eastward. In the deeper section of the water, specifically at 16 m water depth, the mean (average) of the strongest current speeds is measured to be 0.671 m/s. This indicates that the deep currents in the north part, either in westward or eastward direction, have a speed close to 0.671 m/s on average. On the other hand, at a slightly shallower location with a water depth of 12 m, the maximum (highest) speed of the strongest currents is measured to be 0.764 m/s. This implies that the middle currents reach higher speeds compared to the deeper part, with a maximum speed of 0.764 m/s.

Figure 5 shows the concentrate pattern of current distribution, revealing a correlation between the movement of the concentrates and the direction of the seawater current in different tide phases. During low tide, the concentrate pattern shows a movement towards the north, suggesting that the seawater current moves northward along the coast. On the other hand, during high tide, the distribution of the concentrates is less prominent, signifying that the seawater current is likely being blocked by the high tide, which restricts their movement. Nonetheless, the pattern of concentrate during high tide still shows a relatively southward movement, which implies that the seawater current is moving southward during this time.

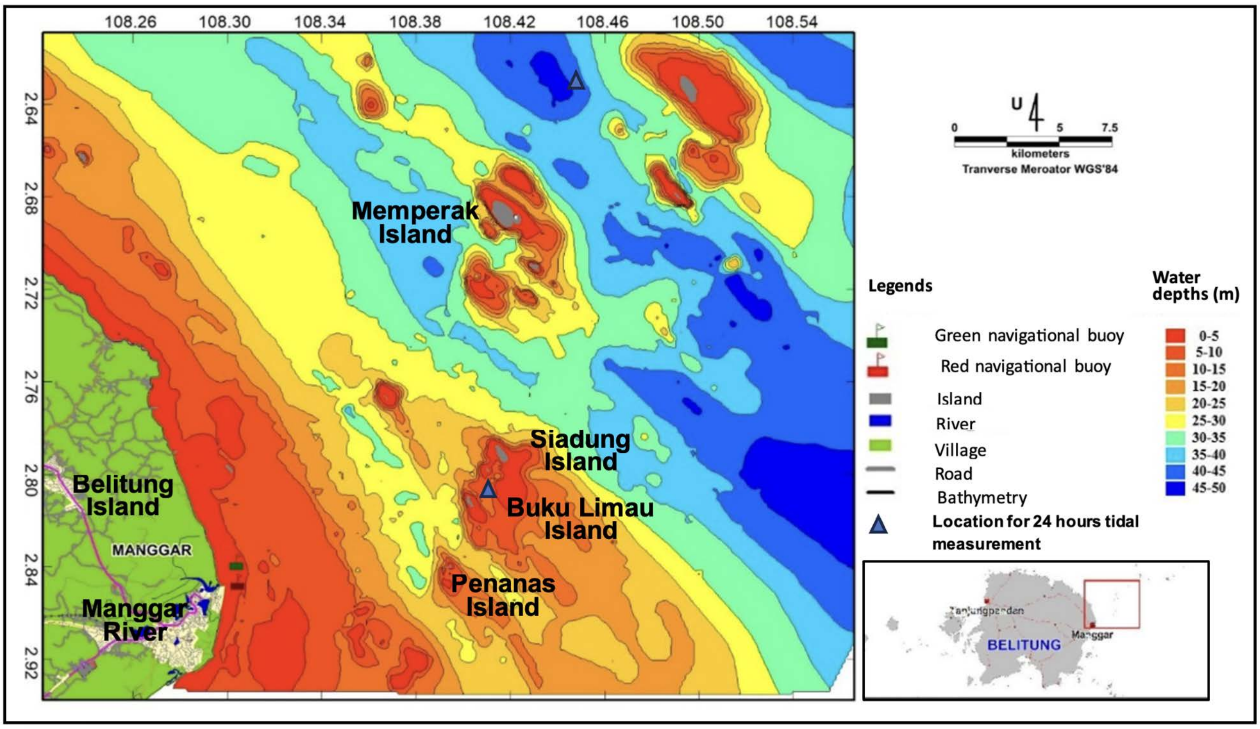

Figure 3. Bathymetry of Manggar Waters, using LWS as the reference point

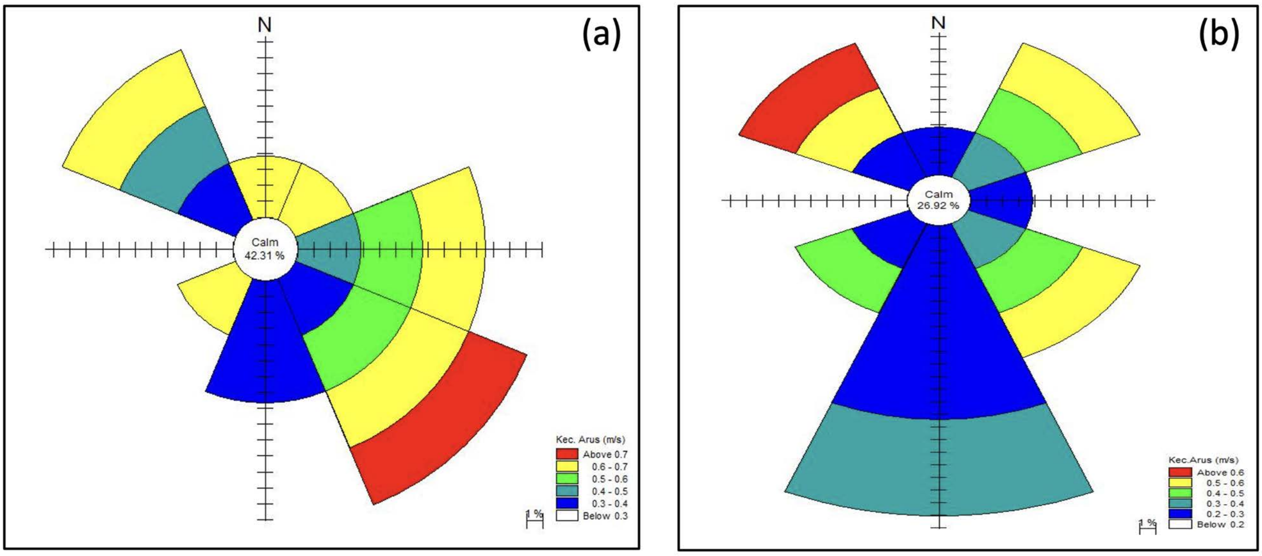

Figure 4. Rose diagrams showing current speed and direction in the north part of Manggar Waters, i.e., (a) the maximum current at 12 m depth (measured at 0.6d, meaning 0.6 X water depth at the location), and (b) the mean current at 16 m depth (measured at 0.8d, meaning 0.8 X water depth at the location).

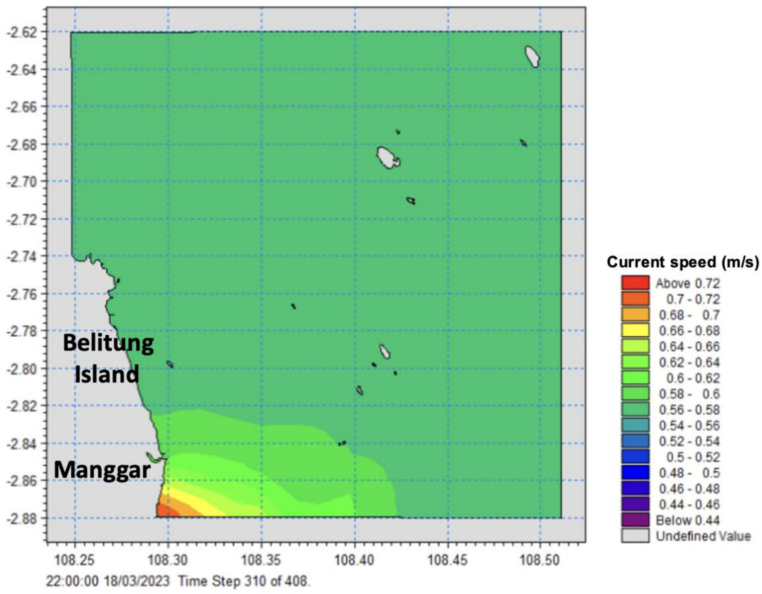

Figure 5. Current model of Manggar Waters, derived from MIKE21 modeling

Based on megascopic identification, the surface sediments of Manggar Waters seabed are predominantly composed of sand, which is distributed around Belitung Island (Figure 6). Sand-sized coral fragments are particularly found around the coral reefs of small islands such as Buku Limau, Siadung, Memperak, and Penanas. Towards the eastern part of the survey area, muddy sand and sandy mud occupy most of this part, i.e., along the Manggar coast and nearby Penanas Island. As identified by Baharuddin & Sidarto (1995), Quaternary alluvium (Qa) predominates beaches in the study area, with revealed rock formations being mostly Kelapakampit (PCks) and occurrences of Burungmandi Granodiorite (Kbg) and Batubesi Quartz Diorite (Kbd) in scarce locations.

Microfauna observation in five samples has shown that the foraminifera diversity in Manggar Waters appears to be relatively low, comprising only twelve genera. This is in contrast to a previous study by Irlani et al. (2013) conducted in the nearby location in Karimata Strait, which revealed 50 genera consisting of 85 species of benthic foraminifera. However, similar to that study, broken benthic foraminiferal tests were found abundantly in the surveyed area. The dominant foraminiferal genera within the sediments are *Amphistegina* and *Operculina* (Figure 7). Other abundant genera include *Quinqueloculina*, particularly *Q. philippinensis*, *Textularia*, and *Calcarina* in some of the samples. These genera are typically associated with coral reef habitats within middle to coarse

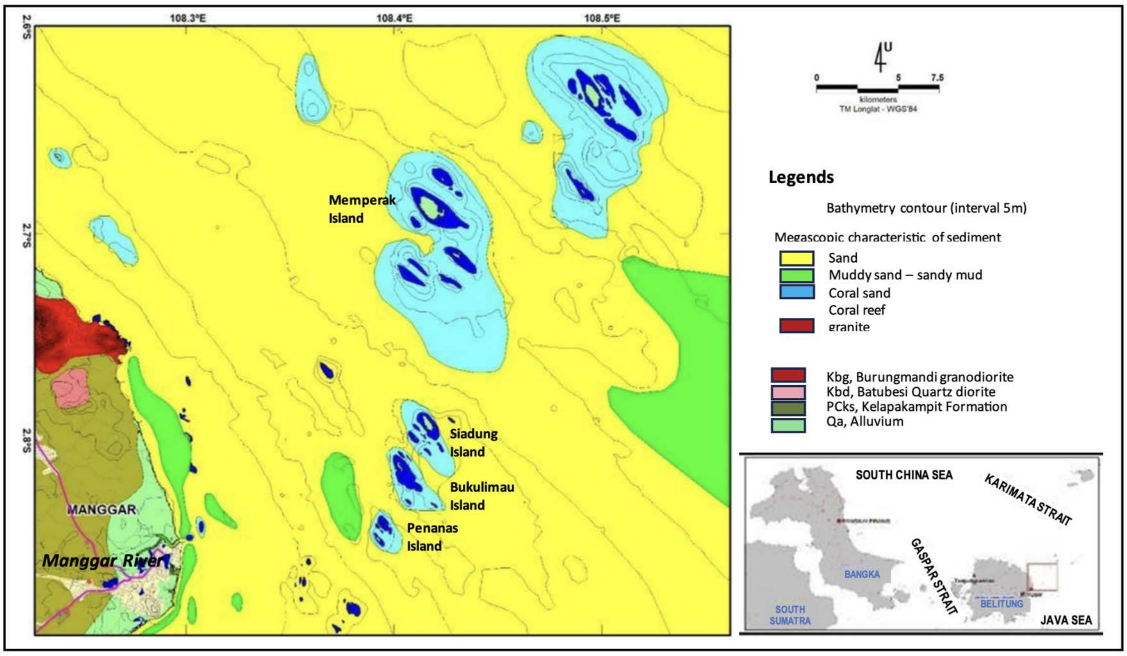

Figure 6. Map of seabed surface sediment distribution around Manggar Waters based on megascopic identification

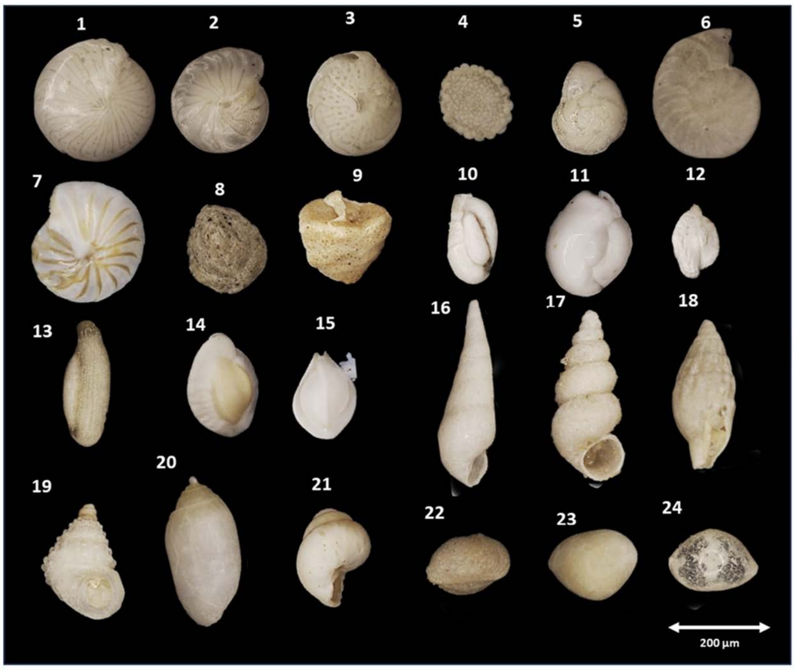

Figure 7. Dominant genera of foraminifera, and other microfauna found in sediment samples of Manggar Waters (1-15. Foraminifera: 1-3. *Amphistegina,* 4. *Planorbulinella,* 5. *Eponides,* 6. *Operculina,* 7. *Peneroplis,* 8-9. *Textularia,* 10-14. *Quinqueloculina,* 15. *Triloloculina;* 16-21: Micro-molluscs; 22-24: Ostracod

sediments (Hallock et al., 2003; Javaux & Scott, 2003). *Operculina* is a larger symbiont-bearing foraminifer that thrives in shallow oligotrophic waters and plays a significant role in calcium carbonate ($CaCO_3$) production (Oron et al., 2018). *Amphistegina*, on the other hand, prefers high-quality reef environments, so a decrease in its abundance suggests environmental quality degradation (Hallock et al., 2003). Notably, in the southern part of the survey area, MGR-10 exhibits a decline in *Amphistegina* abundance.

The levels of heavy metals are relatively low and below the detection limit of the equipment used, based on the analysis of twenty seawater samples. This indicates that the seawater environment is in good condition. However, in certain locations, Zn levels were found to be above the detection limit (Table 1, see numbers in red color), although still below the threshold value for marine

Table 1. Seawater parameter analysis

Samples	Hg (mg/L)	Cr (mg/L)	As (mg/L)	Cd (mg/L)	Cu (mg/L)	Pb (mg/L)	Zn (mg/L)	Ni (mg/L)
MGR-0	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	0.03	<0.02
MGR-1	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	<0.01	<0.02
MGR-2	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	0.02	<0.02
MGR-3	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	<0.01	<0.02
MGR-4	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	<0.01	<0.02
MGR-5	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	0.06	<0.02
MGR-6	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	<0.01	<0.02
MGR-9 D1	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	0.01	<0.02
MGR-9 D2	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	<0.01	<0.02
MGR-9 D3	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	<0.01	<0.02
MGR-11 D1	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	<0.01	<0.02
MGR-11 D2	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	0.07	<0.02
MGR-11 D3	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	<0.01	<0.02
MGR -12 D1	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	0.01	<0.02
MGR-12 D2	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	<0.01	<0.02
MGR-12 D3	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	0.01	<0.02
MGR-15 D1	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	<0.01	<0.02
MGR-15 D2	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	<0.01	<0.02
MGR-15 D3	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	<0.01	<0.02
MGR-17 D1	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	<0.01	<0.02
MGR-17 D2	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	<0.01	<0.02
MGR-17 D3	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	<0.01	<0.02
MGR-18 D1	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	<0.01	<0.02
MGR-18 D2	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	<0.01	<0.02
MGR-18 D3	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	<0.01	<0.02
MGR-19 D1	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	<0.01	<0.02
MGR-19 D2	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	<0.01	<0.02
MGR-19 D3	< 0.0008	<0.001	<0.001	<0.0008	<0.006	<0.003	<0.01	<0.02
Threshold value for marine tourism	0.002	0.002	0.025	0.002	0.05	0.008	0.095	0.075
Threshold value for marine biota	0.001	0.005	0.012	0.001	0.008	0.008	0.05	0.05

Notes: D1: surface water, D2: 0.6 x water depth, D3: 0.8 x water depth
Threshold value: according to KEP-51/MENLH/2004

tourism (0.095 mg/L according to KEP-51/MENLH/2004). Specifically, MGR-5 near the river mouth of Manggar River and MGR-11 near Penanas Island in the southern part of the survey area contained Zn levels of 0.06 and 0.07 mg/L, respectively, which are close to the threshold value for marine tourism but still above the threshold value for marine biota, i.e., 0.05 mg/L.

Similar to the seawater, the heavy metal content in the surface sediments is relatively low and does not exceed the marine sediment quality standard, according to WAC 173-204-320 (Washington State Department of Ecology, 2013). Table 2 demonstrates that while most sediment samples did not contain detectable levels of mercury (Hg), certain areas displayed inconsistent concentrations of mercury that exceeded the threshold value of 0.41 parts per million (ppm). These marine surface sediment samples from those areas showed mercury high concentrations above 4 ppm, with an average concentration of 14.58 ppm. The particularly high levels of mercury are found in locations in close proximity to the estuary of Manggar River, as well as in the northern area of Manggar.

Valuable elements, such as Ti, Th, Fe, Cu, and Au, were analyzed by portable XRF scanning. These elements were found to be mostly high, particularly in samples near the Manggar River estuary (Samples MGR-4, 33, 34, 54, and MGR-64), as well as in the southern part of the survey area (Table 3). However, the concentration of Au should be cautiously evaluated due to our XRF equipment having Au composition as a part of its elements. Therefore, further analysis using more quantitative methods (AAS or ICP-MS equipment) is necessary.

Three parameters were considered in coastal characteristic mapping, including: beach morphology, lithological type, and coastline characteristics, in order to categorize and describe different aspects of a coastal area in Manggar (Figure 8). In terms of beach morphology and lithological type, the coastal area of Manggar can be divided into two types. The first type is the rocky beach, which is located in the northern part, from Burungmandi to Malanglepau Beaches. Along these beaches, the dominant

Table 2. Heavy metal concentration in the sediments

No	SAMPLE ID	Hg	As	Cu	Zn	Pb	Unit
							%
1	MGRS-1	4.13	10.2	10.1	21.3	18.5	PPM
2	MGRS-2	4.6	8.4	11.9	20	14.3	PPM
3	MGRS-10	ND	ND	11	ND	ND	PPM
4	MGRS-11	ND	5.2	ND	ND	ND	PPM
5	MGRS-12	14	3.8	9	ND	ND	PPM
6	MGRS-13	31	6.3	31	ND	ND	PPM
7	MGRS-14	ND	5.5	12	10	6.8	PPM
8	MGRS-15	ND	ND	15	ND	12.3	PPM
9	MGRS-16	ND	ND	ND	ND	6.7	PPM
10	MGRS-17	ND	2.5	14	ND	ND	PPM
11	MGRS-18	16	ND	11	ND	ND	PPM
12	MGRS-22	ND	2.2	16	ND	ND	PPM
13	MGRS-23	ND	7.3	12	ND	5.1	PPM
14	MGRS-28	ND	8	11	ND	ND	PPM
15	MGRS-29	ND	6.7	ND	ND	4.4	PPM
16	MGRS-3	ND	2.9	18	ND	9.9	PPM
17	MGRS-30	ND	4.4	14	ND	4.2	PPM
18	MGRS-32	12	21.1	21	41	31.7	PPM
19	MGRS-33	12	7.9	10	15	13.4	PPM
20	MGRS-34	6	16.1	11	26.1	23.7	PPM
21	MGRS-36	ND	2.6	13	ND	ND	PPM
22	MGRS-4	6	17.4	15	36.9	28.3	PPM
23	MGRS-42	ND	ND	13	ND	5.5	PPM
24	MGRS-43	ND	2.6	9	ND	ND	PPM
25	MGRS-45	14	3.1	12	ND	ND	PPM
26	MGRS-45	ND	3	9	ND	ND	PPM
27	MGRS-47	13	ND	9	ND	3	PPM
28	MGRS-48	19	7.4	16	ND	4.4	PPM
29	MGRS-50U	ND	11	11.1	28.2	16.6	PPM
30	MGRS-53	17	ND	13	ND	ND	PPM
31	MGRS-54	5	19.8	19	43.2	32.8	PPM
32	MGRS-55	ND	ND	10	ND	ND	PPM
33	MGRS-56	15	ND	13	ND	ND	PPM
34	MGRS-58	15	3.9	14	ND	ND	PPM
35	MGRS-59	23	ND	22	ND	ND	PPM
36	MGRS-60	26	ND	17	ND	ND	PPM
37	MGRS-61	19	ND	16	ND	ND	PPM
38	MGRS-62	17.5	ND	16	ND	ND	PPM
39	MGRS-63	17	ND	16	ND	ND	PPM
40	MGRS-9U	ND	2.5	11	ND	ND	PPM
Average		14.58	7.377	13.84	26.86	13.42	PPM
Threshold value (WAC 173-204-320)		0.41	57	390	410	450	PPM

Threshold value according to marine sediment quality standard for chemical criteria WAC 173-204-320

Table 3. Concentration of valuable elements in sediments

No	SAMPLE ID	Ti	V	Fe	Cu	Y	Zr	Au	Th	Unit
										%
1	MGRS-1	1576	14.9	5700	10.1	9.1	368	6.4	8	PPM
2	MGRS-2	2181	20	5975	11.9	15	866	ND	11	PPM
3	MGRS-3	613	4.6	1370	18	3	126	17	ND	PPM
4	MGRS-4	2417	28	11288	15	15.1	449	13	17	PPM
5	MGRS-10	81	ND	1054	11	ND	33	14	ND	PPM
6	MGRS-11	195	ND	760	ND	ND	227	49	33	PPM
7	MGRS-12	167	ND	1602	9	3.8	69	15	21	PPM
8	MGRS-13	419	6.3	2760	31	6.3	354	18	9	PPM
9	MGRS-14	470	6	2534	12	4.2	65	14	16	PPM
10	MGRS-15	525	5.6	2082	15	3.2	77	20	8	PPM
11	MGRS-16	141	ND	1064	ND	3.3	49	20	13	PPM
12	MGRS-17	105	ND	1559	14	2.3	41	25	ND	PPM
13	MGRS-18	100	ND	1188	11	2.4	23	17	ND	PPM
14	MGRS-22	353	ND	1359	16	3.3	80	21	ND	PPM
15	MGRS-23	150	3.6	2907	12	5.3	185	18	20	PPM
16	MGRS-28	472	ND	3666	11	3	145	24	ND	PPM
17	MGRS-29	166	ND	2702	ND	5.7	59	21	22	PPM
18	MGRS-30	131	3.8	1901	14	3.8	41	19	10	PPM
19	MGRS-32	2711	33	12546	21	17.5	334	15	20	PPM
20	MGRS-33	754	10.5	5082	10	6.4	114	ND	19	PPM
21	MGRS-34	2322	23	8003	11	14.7	497	21	18	PPM
22	MGRS-36	101	ND	1338	13	2.6	44	7	ND	PPM
23	MGRS-42	195	ND	1082	13	2.2	36	20	ND	PPM
24	MGRS-43	672	5.8	2095	9	3.4	147	17	9	PPM
25	MGRS-45	92	ND	905	12	2.9	45	21	22	PPM
26	MGRS-45	88	ND	842	9	3.3	41	18	18	PPM
27	MGRS-47	230	4	1815	9	3.2	32	17	8	PPM
28	MGRS-48	411	4.7	4552	16	5.8	303	28	ND	PPM
29	MGRS-50U	2115	20	7703	11.1	10.6	293	ND	11	PPM
30	MGRS-53	473	3.8	760	13	1.9	78	27	ND	PPM
31	MGRS-54	3334	34	11859	19	18.2	587	7.7	28	PPM
32	MGRS-55	171	ND	1308	10	3.1	43	11	ND	PPM
33	MGRS-56	279	4.1	1260	13	3	119	22	6	PPM
34	MGRS-58	57	ND	781	14	ND	52	19	37	PPM
35	MGRS-59	293	3.7	394	22	ND	60	35	ND	PPM
36	MGRS-60	555	3.9	552	17	1.9	202	31	ND	PPM
37	MGRS-61	649	5.5	456	16	2.1	204	33	ND	PPM
38	MGRS-62	552	3.7	436	16	ND	102	29	ND	PPM
39	MGRS-63	151	2.4	448	16	ND	28.4	23	ND	PPM
40	MGRS-9U	87	ND	1095	11	2.5	34	19	ND	PPM
Average		663.9	10.62	2920	13.84	5.709	166.3	20.33	16.7	

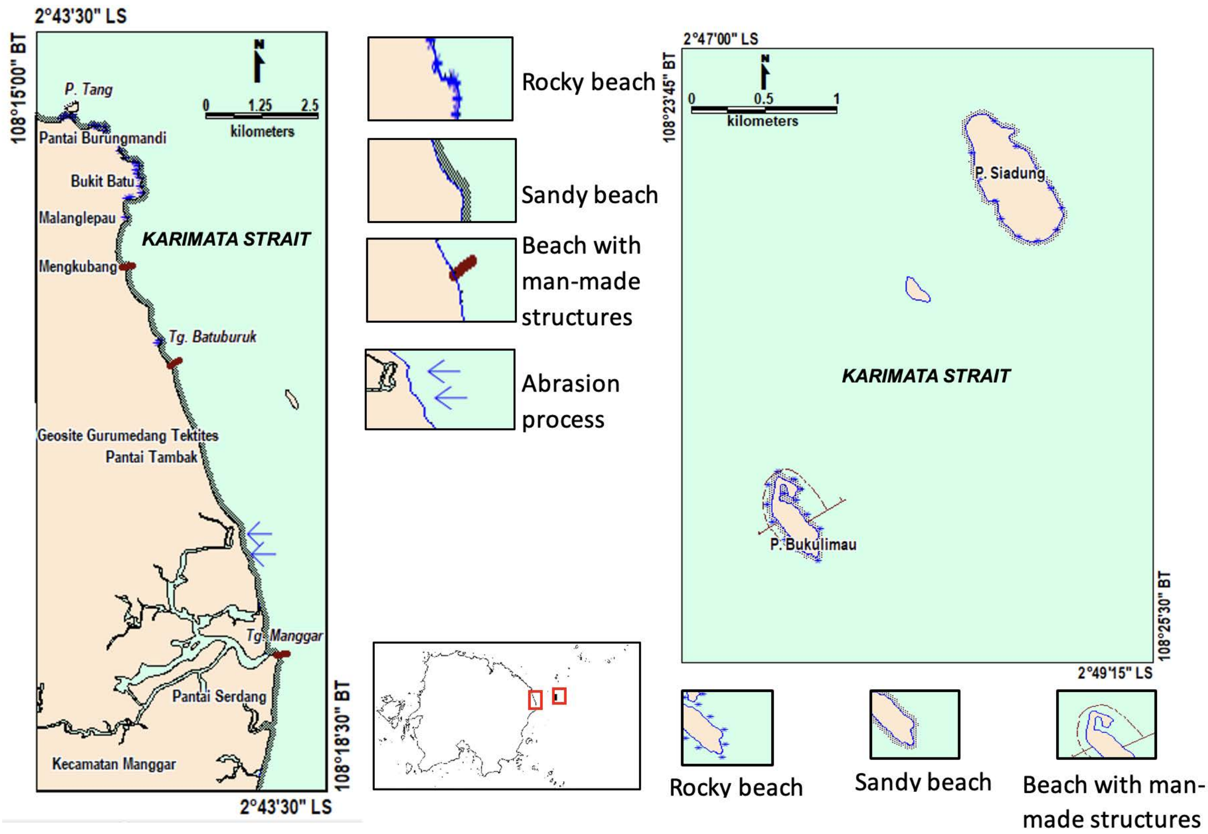

Figure 8. Coastal characteristics of Manggar, Siadung and Buku Limau Island

lithology is igneous rock, specifically Burungmandi Granodiorite of Cretaceous period (Baharuddin & Sidarto, 1995). This means that the beach in this area is characterized by the presence of rocks and a rugged shoreline. The second type is the flat beach, which occupies the southern area from Malanglepau to Serdang Beaches. The lithology composition of this area is different from the rocky beach. It is dominated by the Kelapakampit Formation and Quaternary alluvium. This means that the beach is relatively flat and composed of loose materials of gravel to cobble grains, sand, silt, clay, and Quaternary coral shells.

The characteristics of coastlines concerning lithology, which are influenced by the dominance of beach and sedimentation processes, can be classified into different types. The first type is a sandy beach, consisting of loose material in various sand sizes and coral shells. This type is prevalent in the surveyed area. The second type is a rocky beach made up of igneous rock granodiorite, found on the beaches from Burungmandi to Malanglepau and also in Batuburuk Cape. The third type is a beach with man-made structures, such as an unused pier and breakwater made of igneous rock boulders arranged in gabions. The unused pier is located in Mengkubang Beach and in the southern part of Batuburuk Cape, while the breakwater is situated at the estuary of Manggar River. The fourth type is characterized by the abrasion process, where rocks and other hard materials are continuously transported and fragmented by the action of waves and currents, leading to the erosion and smoothing of the coastline. This beach type occurs in the southern section of Tambak Beach.

Siadung and Buku Limau beaches have similar characteristics to Manggar Beach. Both have rocky beaches composed of coral reefs. They also have sandy beaches made up of coarse to fine-grained sand and contain rocks and coral fragments. Additionally, Buku Limau Beach has man-made structures such as piers and gabions as breakwaters made from igneous and coral boulders.

The rocky beaches of these small islands, made up of igneous rock and coral sand, provide valuable evidence about Belitong Geopark's geological history. Several geosites revealing outcrops of igneous rock, such as Batubesi, Burungmandi, and Baginda rock formations, can be observed. These islands also have coral reefs, which attract tourists. The symbiotic relationship between microfauna benthic foraminifera and coral results in the preservation of various genera, making it an appealing aspect of tourism. However, we have discovered a significant amount of broken foraminifera tests and lower diversity in this area, suggesting a decline in environmental quality compared to normal conditions. This degradation could be due to the high levels of mercury found near the estuary of Manggar River and in the northern part of Manggar. Correspondingly, the decrease of Amphistegina in the northern region of Manggar Waters may be attributed to the elevated mercury level.

The presence of flat beaches and coral reefs in the southern part offers opportunities for studying geological processes more, such as beach formation. In addition, there is likely a relationship between sediment composition and marine biota, given the diversity of the marine ecosystem. It is also possible that the diversity of microorganisms is related to the mercury content in the sediments, as mercury can have an impact on the variety of foraminifera. Therefore, it is necessary to conduct further analysis of the elements in the marine sediments in order to obtain more dependable results.

Going through a comprehensive analysis of seawater, environmental factors, and sediments, these findings can be examined for developing strategies in order to protect and conserve the marine ecosystem. Similarly, the factors that influence the currents and their impacts on sediment transport, erosion, and deposition processes can be determined by understanding the variation in current speeds and directions. It is necessary for managing the risks of coastal erosion and sedimentation. The small islands surrounding the area, which have flat beaches, coral reefs, and interesting geological features such as rock outcrops, can also be developed as marine tourist destinations and activities. Thus, providing information on geological features and coastal erosion risks can contribute to sustainable marine tourism, ensuring that tourism activities do not harm the marine environment.

CONCLUSSIONS

The presence of flat beaches and coral reefs in the southern part, as well as a cluster of volcanic/plutonic rocks, can be a draw for visitors who are interested in the geological processes of the area. Even though it is not significant, the existence of microorganisms in the sediments indicates a diverse marine ecosystem. However, in contrast, the presence of mercury in the sediments in the northern part of Manggar and near the Manggar River estuary, as shown by the concentration analysis of elements, may have an adverse effect on the diversity of foraminifera in that particular area. Additionally, the small islands surrounding the area, with their flat beaches and interesting geological features, have the potential to be developed as attractive marine tourist destinations, particularly for activities related to marine tourism, like fishing, snorkeling, etc.

The northern part of Belitong Geopark experiences varying current speeds and directions. In the deeper part, the average speed is 0.671 m/s, while in the shallower section, the maximum speed reaches 0.764 m/s. In Manggar Waters, the currents move towards the north during low tide, while during high tide, they move towards the south. In terms of natural hazards, except for the southern part which is affected by abrasion processes, the current energy does not pose any risk to the geosites.

The thorough examination of various aspects of seawater, environmental factors, and sediment samples from this survey has provided a better understanding of the geological and environmental conditions and processes in the marine and coastal environment in Manggar Waters. It is expected to use the findings as the contribution to making cognizant decisions and implementing appropriate strategies for the protection and conservation of the marine ecosystem in the marine nature reserve. Moreover, the data acquired will support future research efforts and foster collaborations in order to gain a deeper comprehension of the geological aspects of Belitong Geopark.

ACKNOWLEDGEMENTS

We would like to extend our deep appreciation to the Indonesian government for their profound support in funding this survey by the financial year 2023. Additionally, we extend our heartfelt gratitude to the local government of East Belitung regency and Manggar district for kindly granting us permission to conduct the survey in their region. We would also like to acknowledge and commend the Manggar people for their warm hospitality and acceptance of our survey team. Moreover, we extend our sincere thanks to the Department of Geological Engineering at Padjadjaran University for affording their students the opportunity to carry out their practical work in the MGI's marine sedimentology laboratory.

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