Characteristics and Depositional Processes of Coastal and Marine Sediments of The Northern Part of Obi Island, Molucca

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Abstract. This paper presents the characteristics of coastal and marine sediments of the northern part of Obi Island, Molucca. Grain size analyses were conducted on 24 coastal sediment and 32 marine sediment samples. Taphonomy of Homotrema rubrum was studied on three samples from coral reef that grows on the slope off Laiwui to determine current direction. The mean grain size ranges between 0.01 – 2.6 mm, very well sorted to very poorly sorted, and while skewness varies from very finely skewed to very coarsely skewed. While lithic fragments predominate coastal sediments, biogenic fragments form the majority of marine sediment grains. Textural parameters and sediment composition show three distinctive groups that represent: 1) Adeleletango in the west that is characterized by moderately sorted coarse to fine sand; 2) Tabuji – Laiwui that is characterized by poor to moderately sorted fine granules to fine sand that is interpreted as debris flow deposit; and 3) Anggai in the east that is characterized by poorly sorted coarse sand. Linear discriminate function analysis shows the dominance of shallow marine deposits in beach sediments with strong fluvial influence. The taphonomy of H. rubrum indicates that the prevailing current direction off Obi is westward, which is supported by current observation.

1. Introduction
Obi Island is the largest island in Obi islands group that is located to the southwest of Halmahera. The small archipelago is surrounded by Seram Sea to the south, Molucca Sea to the west and Obi Strait to the north and east. The population density of Obi islands archipelago is 15.2 people/km² [1] and the majority of inhabitants live in the narrow and restricted lowland of northern part of the island.

The northern Obi is characterized by slightly sloping to steep morphology that form the highland and gently inclined (1-5°) alluvial plain. The alluvial plain in this area is limited to the area around river mouth. The highland is located further inland and is mostly composed of Jurassic Ultramafic Rocks and Loleobasso Formation, Bacan Formation (Oligo-Miocene), and Obit Formation (Mio-
Pliocene) that is covered by Alluvium [2]. The erosional products of those rock formation are transported to the sea via four large rivers that flow into Obi Strait (Figure 1). The four large rivers are mostly wandering gravel or sand bed rivers (Figure 2) of the extended river typology of [3].

![Figure 1. Slope of northern Obi that shows gently inclined alluvial plain (yellow) cut by four large wandering rivers. Data source: Geospatial Information Agency, Marine Geological Institute, and Alos Palsar.](image1)

![Figure 2. Akeleletango river that wanders through the alluvial plain. Gravel-bed that form at the bottom of the channel (a). Gravel bars that form in the Akeleletango river (b).](image2)

Considering the majority of the island's activity and population is concentrated in the coastal area, it is imperative to understand the characteristics of the coastal zone, including the beach and seafloor sediments. The aim of this study is to characterize coastal and marine sediments of northern Obi Island and identify their depositional processes.
2. Materials and Methods

This study used 56 sediment samples consisting of 24 beach samples and 32 seafloor samples (Figure 3) that were acquired in June 2013 by Marine Geological Institute. Beach sediments were obtained from beach face, and seafloor samples were taken from 1 – 200 m water depth with a maximum distance of 2.6 km from the shoreline. The samples were obtained from Akeleletango to Anggai (Table 1).

![Figure 3. Sample location and seafloor sediment distribution. Dots denote sample location: red for beach samples and blue for seafloor samples. Seafloor sediment types are represented by colored area: green for mS, orange for gS, brown for sM, and yellow for S. Section 3.1 describes sediment types in detail. Red arrow shows current direction that was reconstructed from the taphonomy of Homotrema rubrum.](image)

| Area            | Sample No.                                |
|-----------------|-------------------------------------------|
| Akeleletango    | P-14, P-15, P-16A, P-17A, P-17B, P-18     |
|                 | 4, 11, 12, 13, 17                         |
| Tabuji – Laiwui | P-08, P-10, P-11, P-12, P-13B, P-20A, P-20B, P-21A, P-24, P-25A, P-25B, P-26A, P-26B |
|                 | 14, 16, 18, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 34, 35 |
| Anggai          | P-06, P-22, P-23A, P-28, P-29              |
|                 | 36, 37, 40, 41, 42, 43, 44, 45, 46, 47    |

Sample analyses consist of granulometry and sediment composition. Preparation for grain size analysis involved wet-sieving to separate coarse fraction (grains coarser than 63 µm) and fine fraction (grains finer than 63 µm). The coarse fraction was analyzed by a series of sieve with 0.5 φ (0.7 mm) interval. The fine fraction was examined using the pipette method. Detail description of preparation and analysis for grain size can be found in [4]. The result is reported in dimensionless φ that is computed by equation (1) [5] with \(d\) represents grain diameter in millimeter:

\[
\phi = -\log_2 d
\]
A total of 13 beach samples and 16 seafloor samples have been observed under binocular microscope to identify sediment composition. Three components were identified in Obi samples: lithic and biogenic fragments and organic matters. Each component is presented as percentage.

The taphonomy of benthic foraminifer *Homotrema rubrum* has been used to identify prevalent current direction in Bangka Island, Minahasa [6], following the method of [7]. Analysis of *H. rubrum* taphonomy was conducted on three seafloor samples (25, 26, and 27) obtained around coral reef off Laiwui (Figure 3) from 48 m, 58 m, and 26 m water depth, respectively. Detail description of sample preparation and taphonomy observation can be found in [6].

Sediment type and statistical parameters were determined by computing the result of granulometry using GRADISTAT [8]. Sediment classification from [8] follows physical description of textural class of [9]. Four statistical parameters: mean grain size ($X$), sorting ($\sigma$), skewness ($Sk$) and kurtosis ($K$) were selected for their geological significance [10]. The four parameters were used for linear discriminate function analysis (LDF) to understand the variations in the energy and fluidity factors [11].

3. Results and Discussion

3.1. Sediment Classification

The beach and seafloor sediments of northern Obi can be classified into four groups: gravelly sand (gS), sand (S), muddy sand (mS), and sandy mud (sM), as is shown in Table 2. Gravelly sand was observed from 36 sampling sites (64% of total samples) and characterized by gravel to fine sand that is moderately sorted with subangular to subrounded grains that are composed of lithic fragments (sedimentary, igneous and metamorphic rocks), biogenic or shell fragments (molluscs, foraminifer, corals), and negligible organic matter. The average statistical parameters of this group are: mean grain size of 0.56 $\phi$, sorting of 1.4 $\phi$, skewness of -0.17 and kurtosis of 0.87.

Sand covers the majority of the northern Obi seafloor, particularly the bays that were located in the west and east of the study area. This sediments type is characterized by dark sands, coarse to fine sand grains, well-sorted, subangular–subrounded, and is composed of lithic fragments, biogenic fragments, and negligible organic matter. The average statistical parameters of this group are: mean grain size of 1.52 $\phi$, sorting of 1.1 $\phi$, skewness of -0.13 and kurtosis of 1.79.

Muddy sand was found further to sea from gS and seaward of Tabuji river mouth. This group is characterized by dark muddy sand that consist of lithic and biogenic fragments with considerable organic matter content. The average statistical parameters of this group are: mean grain size of 1.28 $\phi$, sorting of 1.87 $\phi$, skewness of 0.05 and kurtosis of 1.43.

Table 2. Summary of average, maximum and minimum statistical parameters of each group of beach and seafloor sediments.

| Sed. Class. | Mean ($\phi$) | Sorting ($\sigma$) | Skewness ($Sk$) | Kurtosis ($K$) |
|-------------|---------------|-------------------|-----------------|---------------|
| gS          | 0.56          | 1.40              | -0.17           | 0.87          |
| Max         | 2.00          | 2.33              | 0.27            | 2.00          |
| Min         | -1.38         | 0.60              | -0.77           | 0.52          |
| mS          | 1.28          | 1.87              | 0.05            | 1.43          |
| Max         | 2.00          | 2.33              | 0.27            | 2.00          |
| Min         | 0.56          | 1.40              | -0.17           | 0.87          |
| S           | 1.52          | 1.00              | -0.13           | 0.79          |
| Max         | 1.90          | 1.39              | 0.13            | 0.94          |
| Min         | 1.08          | 0.99              | -0.46           | 0.66          |
| sM          | 5.36          | 1.44              | -0.34           | 0.67          |
| Max         | 6.31          | 2.09              | 0.41            | 0.87          |
| Min         | 4.41          | 0.80              | -1.00           | 0.50          |
Sandy mud was observed off Tabuji river mouth. This group is characterized by dark mud with lithic and biogenic fragments and a considerable amount of organic matter. The average statistical parameters of this group are: mean grain size of 5.36 $\phi$, sorting of 1.44 $\phi$, skewness of -0.34 and kurtosis of 0.67.

Sediment grain size of the study area exhibits a clear distinction of beach and seafloor sediment (Figure 4). Beach sediments are dominated by poorly sorted coarse sand, while seafloor sediments show two noticeable groups: poorly sorted coarse sand and poorly sorted silt. Those differences reflect size distribution of source material [10], and different transport processes [12] that include the type of deposition and current characteristics, and duration of deposition [13].

![Figure 4](image-url)

**Figure 4.** Bivariate plot of mean grain size to sorting (a) and mean to skewness (b). Diamond denotes beach samples and cross represents seafloor samples. Abbreviations = w-ms: well- to moderately sorted; ps: poorly sorted; vps: very poorly sorted; cs: coarse skewed; ns: near symmetrical; fs: finely skewed.

Sediment texture comparison from different parts of study area: west, central and east (Figure 5) show distinct characteristics for each part:

- Akeleletango in the west is characterized by moderately sorted coarse to fine sand;
- Tabuji – Laiwui is characterized by poor to moderately sorted fine gravel to fine sand; and
- Anggai in the east is characterized by poorly sorted coarse sand.

![Figure 5](image-url)

**Figure 5.** Statistical parameter values (mean grains size, sorting, skewness, and kurtosis) for Akeleletango (west), Tabuji – Laiwui (central), and Anggai (east) for beach sediments (a) and seafloor (marine) sediments (b). Dashed lines separate each group.
3.2. Sediment Composition

Examination of sediment composition shows that organic matter is negligible in beach sediments, except in sample P-26B from west of Laiwui. Figure 6a exhibits that Akeleletango beach sediments is dominated by shell fragments, Tabuji – Laiwui sediments is predominantly lithic fragments, and Anggai sediments reveal comparable amount of lithic and shell fragments. All seafloor sediments are dominated by shell fragments except for samples 14 and 46 (Figure 6b).

![Figure 6. Composition of beach sediments (a) and seafloor sediments (b). LF is lithic fragments, SF is shell or biogenic fragments, and OM is organic matter. Dashed red lines delineate the area where the samples were obtained.](image)

Four examples of sediment composition are presented as representative of beach and seafloor sediment of study area. The four samples comprise of samples 46 and P-06 from Anggai and Laiwu is represented by samples number 24 and P-25 (Figure 7). Seafloor sediment from Laiwui (24) is dominated by lithic fragments, while Anggai sample (46) consists predominantly of organic matter. The presence of organic matter in seafloor sediment from Anggai indicates lower energy condition compared to Laiwui.

![Figure 7. Seafloor sediments 24 (a) and 46 (b) and beach sediments P-25 (c) and P-26 (d) that represent Laiwui and Anggai, respectively.](image)
Beach sediments of Laiwui (P-25) are relatively finer and well-sorted than Anggai sediment (P-06). Laiwui sample shows that lithic fragments compose the majority of the sediment (80%) with 20% shell fragments, while Anggai samples exhibit equal amount of shell fragments (45%) and lithic fragments (55%). The composition suggests relatively larger sediment load from Anggai river than the rest. The larger sediment load might be related to illegal mining upstream.

3.3. Linear Discriminate Function Analysis

LDF analysis is used to interpret energy and fluidity variations [9]. The analysis uses mean grain size (X), sorting (σ), skewness (Sk), and kurtosis (K) to identify four depositional processes and environments: aeolian or beach (Y₁), beach or shallow agitated water (Y₂), shallow marine or fluvial environment (Y₃), fluvial or turbidity (Y₄). The equations are as follow:

\[ Y_1 = -3.5688(X) + 3.7016(σ)^2 - 2.0766(Sk) + 3.1135(K) \] (2)
\[ Y_2 = 15.6534(X) + 65.709(σ)^2 + 18.1071(Sk) + 18.5043(K) \] (3)
\[ Y_3 = 0.2852(X) - 8.7604(σ)^2 - 4.8932(Sk) + 0.0482(K) \] (4)
\[ Y_4 = 0.7215(X) + 0.403(σ)^2 + 6.7322(Sk) + 5.2927(K) \] (5)

The results can be used to determine depositional environment and mechanisms by applying the values in Table 3.

| Environment | Y₁ values | Environment |
|-------------|-----------|-------------|
| Beach       | <-2.7411< | Aeolian     |
| Y₂          | <63.3650< | Shallow marine |
| Y₃          | <-7.4190< | Shallow marine |
| Fluvial     | <10.000<  | Turbidite   |

Bivariate plot of Y₁ to Y₂ and Y₂ to Y₃ show that the majority of beach and seafloor sediments in the study area is strongly influenced by fluvial processes (Figure 8). The strong fluvial influence indicates greater energy fluctuation and resulted in less sorted sediments [10], which explained the poor sorting of both beach and seafloor sediments (Figure 4).
3.4. Taphonomy of *Homotrema rubrum*

The living habitat of benthic foraminifer *H. rubrum* (Lamarck) that encrusts corals and reef detritus can be applied to determine the source, accumulation, and direction of sediment transports [7] in a carbonate setting. Previous studies in Minahasa [6] and Polynesia [7] show the potential of employing the taphonomy of *H. rubrum* as sediment transport indicator.

Taphonomy observation was conducted on seafloor samples 25, 26 and 27, that were taken from the reef off Laiwui. The samples were obtained from 48 m, 58 m, and 26 m water depth, respectively. This study examined the angularity and color of *H. rubrum* fragments. Although there is no existing data on chamber structure, we still endeavor to determine the degree of preservation by modifying the degree of preservation of [7] into only three degrees: well-preserved, moderately preserved, and highly altered (Table 4). Figure 9a shows that although white is the dominant color in all samples, site 27 exhibits higher percentage of red *H. rubrum* fragments. Living *H. rubrum* is usually bright red that changes into whitish pink when detached from the reef [7]. The angular percentage of *H. rubrum* shows slight decrease from sample 27 to 25 (Figure 9b). Angularity is also a function of distance from reef source [7]. The slight discrepancy between color and angularity might be related to sampling sites that are all located in fore reef area (Figure 3). Nevertheless, color and angularity of *H. rubrum* indicate that the prevailing current direction is westward (Figure 3). This finding needs to be verified by *in situ* current measurement.

| Degree of Preservation | Color               | Angularity          |
|------------------------|---------------------|---------------------|
| Well Preserved (WP)    | Pink                | Angular             |
| Moderately Preserved (MP) | Pink             | Rounded             |
| High Altered (HA)      | Light Pink to White | Highly Rounded      |

Table 4. Degree of Taphonomy Preservation to determine sediment transport direction. Modified from [7].
4. Conclusion

A total of 24 beach samples and 32 seafloor samples from northern Obi were studied to determine their depositional processes. The analyses include granulometry, sediment composition and taphonomy of *H. rubrum*. Grain size analysis shows that beach and seafloor sediments of northern Obi can be classified into four textural groups: gravelly sand (gS), sand (S), muddy sand (mS), and sandy mud (sM). Alongshore comparison of the sediments show different characteristics of sediments that were acquired from Akeleletango (west), Laiwui (central), and Anggai (east). Determination of depositional processes was conducted by applying Linear Discriminate Function (LDF). The result reveals that most beach and seafloor sediments in the study area are strongly influenced by fluvial processes indicating greater energy fluctuation that resulted in less sorted sediments. This finding is consistent with poor sorting of both beach and seafloor sediments. The color and angularity of *H. rubrum* fragments from samples 25, 26 and 27, point to westward current direction. However, this finding needs verification from in situ current measurement.

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Grain size analysis was conducted by technician from MGI Core Laboratory, and computation was carried out by IA. Sediment composition was observed by IH. Taphonomy of *H. rubrum* was examined by MA. Maps were prepared by GL. RZ, UH and LG are responsible for writing the manuscript. FBP coordinate the fieldwork and laboratory analyses.

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