Characteristics of Deposited mine tailing on the Senunu Canyon, Indonesia

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Abstract. The characteristics, distribution, and accumulation of detrital sediment on the surface sediment in the Senunu Sea are used as a preliminary study to identify the detrital and sedimentation processes’ origin. This study aims to present the characters and composition of detrital sediment on Senunu seabed. It illustrates the influence of land sediment sources on sediment compositions settled on the bottom of the surrounding seas. Specific review on the sediment character in this region was done to identify surface sediment layers carrying tailings materials from ore mining on land and differentiate them from natural sediment. 53 sediment core from the Senunu bottom were collected and analyzed for their detrital characteristics using a binocular microscope. In general, sediment composition in Senunu seabed was terrigenous sediment with dominant material quartz, andesite, and tuffaceous breccia. Based on the detrital analysis, sediment lithology of natural seabed sediment and sediment containing tailing material is distinguished by color, layer contact, grain packing, grain shape, biota association, and specific mineral content quartz, mica, and magnetite. Surface sediment containing tailing material had more quartz mineral, had more similar grain size and crystal shape, fresher mineral condition, clearer color, and looser grain relation than seabed sediment that did not contain tailings material. Based on the different characters and distribution patterns, sediment carrying tailings in the Senunu seabed. Based on the other characters and distribution patterns, sediments carrying tailings in the Senunu seabed on average were 2-167 centimeter thick at the surface with accumulated tailing 1-50% of total sediment at the sea bottom. Furthermore, the distribution of these tailing deposits is influenced mainly by morphodynamic, hydrodynamic conditions and the process of redeposition.

1. Introduction
Since being handed over PT Amman Mineral Nusa Tenggara (AMNT) in 2016, a copper/gold mining, located in Batu Hijau, Sumbawa Island, Indonesia, has processed ore rate of 120,000 tons per day. A major by-product of this mining is finely ground rock material from the milling process called tailings, and flows by gravity as a slurry or mixture of water and crushed rock through a pipeline. The pipeline discharges the tailing at 125 m at the head of the Senunu Canyon. The tailing is a dense slurry of ~ 20-30% solids. As it exits from the pipe, the energy is rapidly dissipated. The solids and entrained liquid
flow downslope by gravitational forces as a bottom-attached density current. Seawater is entrained into and mixes with the tailing flow during its descent until it reaches density equilibrium with the ambient seawater and plumes of water, carrying the finest suspended particles shear off from the main flow and spread laterally into the water column. This process continues throughout the material’s descent, such that plumes may be formed at many depths.

Batu Hijau’s tailing is relatively coarse, which is a high proportion (55%) is sand. Therefore, most tailing solids are expected to remain on the seabed, ultimately settling where the gradient of the seabed is too low for other gravitational flow. The tailing slurry flowing with a velocity of 5.7 – 6.4 meter/second at the opening of the pipeline and 0.5 – 1.0 meter/second along the seabed, and finally come to rest at a depth of 3,000 – 4,000 meters. Then, the residues of tailing are discharged to the deep ocean floor of Lombok Basin through a pipeline under the thermocline layer’s depth at Senunu Canyon [1].

The research aims to obtain sedimentological characteristics, the origin of seafloor sediment, and tailings distribution to determine the deposition mechanism of natural sediment mixed with tailing. This study aims to provide an understanding of how morphodynamic and physical features of continental slopes are related to minerals deposition in deep-sea canyon areas.

2. Materials and Method

The survey was carried out from May 16 till June 12, 2018, by using RV Baruna Jaya VIII at the southern waters of Sumbawa Island (Figure 1). Mapping of seabed morphology is generated from a single beam echo-sounder SIMRAD EA 640 that was installed on this research vessel. Recording of the bathymetric data takes place during the cruise as mentioned above, and it has been measured along the survey trajectory around 662 Nm or about 1227 Km.

![Figure 1. Study Area and location of sampling stations of Deep Sea Study](image)

The ocean floor sediments were taken using a 3 m gravity corer of RV Baruna Jaya VIII. The lithology was described throughout the sedimentary section included the physical properties of sediment (type, color, odor, grain shape, grain packing, grain sorted), the composition of sediments
(minerals, rock fragments, organic matters), depositional characteristic and patterns (bedding structure, bedding contact). Grain size, grain shape, and sediment composition were analyzed with a geological loupe, and the color of sediment was examined by [2].

The sediment classification is based on the procedure and method of [3]. In the laboratory, the sediments were sieved through > 16, 8, 4, 2, 1, 0.5, 0.250, 0.125, 0.063 mm mesh sizes. The volumetric glass with the settling velocity method is used to analyze the sediments of 0.043 mm and below 0.043 mm mesh sizes [4].

Visual assessment and microscopic analysis of sediment properties provided a preliminary indication of tailing distribution. The visual identification was conducted through several identifications of the sediment at the field (onboard) immediately after sediment core samples were obtained. These include the identification of color of sediment (the tailing usually has a pale color when it is drying); the sediment of tailing usually forms soft and fluid mud; the sediment texture of tailing usually is fine sand; the grain size distribution of tailing usually well sorted; and the grain packing of the tailing usually is poor and unconsolidated.

The binocular microscope analysis was conducted in the Geology laboratory of RCO-LIPI. This analysis focused on three parameters. The first is the grain size and shape of the sediment. Usually, the tailing sediment has angular to sub-angular shapes. The second is the mineral content analysis. Usually, the mineral content of tailing sediment is rock fragments that can shape in angular to sub-angular. The rock fragment can form andesite, diorite, and quartz.

3. Results and Discussion

3.1. Bathymetry and morphology

Bathymetry of the Senunu sea has recognized the depositional channel-related erosive channels and furrows, canyon terraces, and ridge scarp features. There were three terraces in the different water depth: 1) Terrace is a continental shelf which is present in the northern part with the depth of about 100 m; 2) Terrace is in the center of the survey area with located at a depth of about 2700 m; 3) The terrace occurs below the second terrace and is located in 3300 m depth.

Figure 2 shows the valleys and ridges’ positions in three dimensions (3D), where the blue dotted line shows the valleys’ position while the red dotted line shows the ridge positions. Based on that picture, it can be seen clearly that the valleys and ridges are elongated from north to south and relatively perpendicular to the coastline of Sumbawa Island. The tailing pipe’s position can be predicted the direction of the tailing sediment flows from the end of the pipe to the Lombok Basin as illustrated with solid light bluish color arrow lines. The Positions of each sediment sampling station are located on both of the valleys and ridges.

Detailed bathymetry of the head of Senunu Canyon and continental slopes in South West Sumbawa is shown in Figure 3. This area’s main morphology is dominated by a series of canyons and ridges that are perpendicular to the coast.

The morphology of the western part of the survey area is mainly canyons and ridges. The canyon and ridge are parallel and perpendicular to the coastline, with the main orientation in N-S direction. Even though there is one ridge at the southern part of the survey area with a water depth of about 3400 m which has orientation direction W-E. Figure 2 also shown canyons start from water depth 100 m and end at the Lombok basin with water depth >4200 m with a distance of about 80 Km. A small Lombok Basin area was found in the south corner of the survey area’s western part. Figure 3 shows that the eastern part of the survey area has three terraces in the different water depths. The first terrace is a continental shelf present in the northern part with a depth of about 100 m. The second terrace is in the center of the survey area, located at about 2700 m. The third terrace occurs below the second terrace and is located at 3300 m depth. This terrace exists in the middle part of the survey area.
Besides the terraces, another morphology that dominated the survey area, which appears as a Gullied wall. The Gullied wall is the wall or cliff that consists of a series of the canyon and ridges with the same orientation (Figure 3).

Figure 2. Morphodynamical of the deep sea Senunu is the result of the interaction between current flow, sediment transport, and bottom changes.
3.2. Morphodynamics that controlled tailing distributions

Two main driving forces exist for currents in the southern waters of Sumbawa. These include southward Alas Strait and northwestward monsoonal. The southward Alas Strait driven current in combination with northwestward monsoonal driven current generates southwestward the primary current within the waters. This gives rise to a predominantly southwesterly and offshore movement of water to open the Indian Ocean. This will ultimately transport any suspended quartz sediments southwestward.

Tailing distribution at sea is basically distributed via two mechanisms: flow as bottom attached density current and settlement of suspended sheared plumes from the main flow. The majority and the coarse part of the tailing will flow as a bottom density current following the bathymetry, as shown in figure 4.

The deposition mechanism in the deep sea is not always in low energy. Slowly mass water flow and precipitation are only affected by the downward slope gravitational process. However, the process of deposition in the deep sea demonstrated that the mass of water can relatively high velocity and play a dominant depositional role in certain areas. This condition mainly occurs when water masses interact with local seafloor irregularities (i.e., seamounts, ridges, hills, mounds, banks, scarps). Flow-through straits and deep ocean basins can also generate high-velocity and turbidite flows, resulting in regional-scale erosion and deposition in the deep sea [6]. A similar deposition mechanism is applied to the tailings-carrying sediment flow process on the Senunu seabed.
Figure 4. Detailed morphology of Senunu Canyon that controlled tailing deposits in bed

The analysis of sediment characteristics revealed that tailing distribution spread to the south and southwest due to bathymetric contour and current pattern. This resulted in the differences in tailing thickness among the stations, even for sampling stations that were close together. This is due to these stations’ location, which is located in deeper parts of the canyon (with a depth of 1106 m, 2057 m, and 2287 m, respectively), where the gradient is less, resulting in more deposition and accumulation. The tailing distributions increased to the southwest area due to the lower gradient topography (tailing tends to fill the basin and depression). Tailing distribution decreased at the high-gradient topography in the northern area (Figure 5).
Figure 5. Distribution of Tailing Through the channel at Senuu Canyon [1])

Table 1. Considering factors for identifying tailing

| NATURAL SEDIMENT                                                                 | TAILING                                                                 |
|---------------------------------------------------------------------------------|-------------------------------------------------------------------------|
| ● Normal transport mechanism. It is usually through the rivers that carry materials from the land, consisting of andesite and diorite rock fractions and volcaniclastic sediment rocks comprised of quartz, mica, feldspar, and magnetite. | ● Artificial transport mechanism. Through the pipeline, remnant quartz minerals as the main composer directly from the processing area to the sea. |
| ● Grain shape tended to rounded due to long transportation process                | ● Angular-sub angular grain shape due to destruction process and shows as freshly fractured material |
| ● Normal sedimentation: characterized by layer bedding, color and size gradations of the grains, according to sediment characteristics on the continental slope | ● Fast sedimentation: characterized by erosional contact with the previous sediment. Large quantity and high frequency of sediment supply, similar to thick alluvial deposit on the river mouth |
| ● Sediment textures are appropriate with sediment characters that are deposited on the bottom of the sea. The colorations are generally olive, brown, or dark grey | ● Sediment textures are loose; the color is lighter than the older sediment due to the domination of quartz minerals. In the dry condition, it looks white like powder. |
| ● Usually, the sediment consisted of clayed, and the materials are loose         | ● Materials are brittle and powdered                                     |
- If nearshore: formed as terrigenous sediments, rock fragments from the continent, dominantly sand-gravelly size in poor sortation of grains, neritic organisms with carbonated shell debris are present.

- If close to the land: formed as loose sediment, fine size and composed most by quartz mineral, lack of organism remnant.

- If far from the land, i.e deep-sea: sediments in thick, massive, and tight clay-silt with thin sand lamination, the sedimentation mechanism is generally made by suspended fine-particle.

- If far from the land: fine loose sediments are found with characteristics similar to those from nearshore.

- Accumulation of foraminifera oozes (sphere shape) increases by depth in the sediment composition—minerals from land accumulated in finer size and rounded shape in deeper areas. The native deep-sea minerals like chert and red lime are present.

- Rare foraminifera ooze but dominated by quartz and volcanic rock detrital. The loose finer sediments are accumulated thicker on the crest/ higher area rather than the deeper in some places.

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**Figure 6.** Example of natural sediment and tailing mixed with natural sediment
The tailing sediments’ distributions increased to the southwest area due to the lower gradient topography (quartz tends to fill the basin and depression). Tailing distribution decreased at the high-gradient topography in the northern area (Figure 5). Location with settled suspended quartz will have thin fine-grain tailing sediment at the surface.

3.3. Distribution of Tailing

Before analyzing the grain size and lithology of sediments collected in Senunu Canyon, it is important to discuss tailing and natural sediment characteristics. Information on the geological condition of the mine site or the island is important information that should be analyzed before conducting the identification of tailing and natural sediment.

Volcanic rock formations generally cover Nusa Tenggara from Meiocene and Oligocene periods, consisting of alternated breccia and tuff. The breccia is composed by andesitic – dioritic clasts [5]. In general, the copper-gold mining activity in Nusa Tenggara is the exploitation of volcanic rocks, such as andesite and diorite, which have quartz vein intrusions (1 cm – 10 m diameter) as the products of epithermal and hydrothermal processes carrying mineral ores. Quartz veins carrying the mineral ores are the main target in gold mining. According to this fact, the composition of tailings commonly consists of quartz (85%) as the main component.

Crushing and grinding processes in ore mineral assortment generate quartz with sharp angular grain shape and conchoids fracture in the character of quartz minerals is still evident. The mineral fractures are clearly seen when the mineral is broken due to either the grinding or the crushing processes. According to [7] the mineral fracture is the main characteristic of the tailing that can be used in differentiating the tailing and the natural sediment. Some factors can usually be used as a basis for tailing identification. The considering factors for identifying tailing and the differentiation of natural sediment and tailing, respectively described in Table 1 and Figure 6.

The tailings characteristic analysis revealed that the distribution of fine-sized quartz minerals spread to the south and southwest due to bathymetric contour and current pattern. Quartz distribution at sea is basically distributed via two mechanisms: flow as bottom attached density current and settlement of suspended solids from the main flow. The majority and the coarse part of the quartz will flow as a bottom density current following the bathymetry (Figure 4). The tailings would eventually settle at some low gradient location, and due to the anoxic water column and seabed.

4. Conclusion

The tailing distributions increased to the southwest area due to the lower gradient topography (tailing tends to fill the basin and depression). Tailing distribution decreased at the high-gradient topography in the northern region. The structure of the tailing deposits has a similarity with stream river deposits. The distribution of tailings sediment to the south’s deep areas is progressively thinner with calmer bottom currents. However, in some areas, there are thicker deposits. This is influenced by turbidity current, gravity flow, and bedform. Bedforms were formed predominantly by natural bedload transport.

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