Geochemical Distribution of REE and Grain Size Analysis of Heavy Mineral Associated with Tin Placer-Type Deposit, Bangka

Syafizal 2, AYA Hakim 2, A Sulastri 1

1 Faculty of Mining and Petroleum Engineering, Bandung Institute of Technology, Bandung, Indonesia.
2 Earth-Resources Exploration Research Group, Bandung Institute of Technology, Bandung, Indonesia.

Email: syafizal@mining.itb.ac.id, astisulastri@students.itb.ac.id

Abstract. Indonesia is included in the East Malaya Block of the Southeast Asian Tin Belt. Two types of tin deposits in Indonesia are primary and secondary tin deposits (placer). Factors that can cause the formation of placer tin deposits include S-type granite, weathering, transportation, and sedimentation. Factors that control the formation of placer tin deposits include the presence of source rock (granite type S), weathering processes, erosion, transportation and sedimentation, and the presence of basins or valleys where weathering materials are deposited. The transportation process has a major role in the grain shape of a material. This study aims to determine the geochemical distribution and characteristics of heavy mineral grains at the accumulation of placer tin deposits, e.g., colluvial, alluvial, and tailings, in which there are 62 sample points located Bangka Island, Indonesia. The research method used in this study was grain size analysis, radiation level measurement using a scintillometer, and geochemical analysis using ICP-MS.

1. Introduction
The Southeast Asian Tin Belt exists spreadly in a North-South direction along 2,800 km and 400 km starting from Myanmar, Thailand, Malaysia, and the Tin Island in Indonesia. Tectonically, the tin island in Indonesia has included in the East Malaya Block formed during the geological age of Lower Carbon. The characteristic of Indonesian Tin Island is the presence of metasediments with inserts of limestone, shale, schist, chert, and volcanic rock. There are two types of tin deposits in Indonesia, namely primary and secondary (placer) [1].

The genesis of placer tin deposits in Indonesia is mostly the source rock naturally containing primary cassiterite. The liberation of cassiterite in the primary rock does not need excessive comminution. The current mechanical concentration is the breakdown of cassiterite grains where the cassiterite is not consolidated due to mechanical erosion, while other additional factors are control stratigraphy, geological time scale, paleo-environment changes, and climatic conditions [2] (Yim, 2000).

Heavy minerals are generally defined as dense minerals with a specific gravity greater than 2.85. The REE-bearing minerals in placer-type deposits are monazite [(Ce, La, Nd, Th) PO₄] and sometimes
xenotime (YPO₄), which are high-density minerals accumulated as heavy minerals. Monazite has been extracted from many heavy mineral placers as a by-product of the recovery processes in the industry, e.g., titanium oxide (ilmenite, rutile), zircon, sillimanite, garnet, staurolite, and others. Xenotime is usually obtained from some alluvial deposits as a by-product of tin (cassiterite) placer mining. Trace elements associated with heavy mineral placers are useful as pathfinder elements, including Ti, Hf, REEs, Th, and U. Reported thickness of economic deposits ranges from 3 to 45 m [3]. Individual ore deposits typically comprise at least 10 million metric tons (Mt) of ore (total size of the individual sand-silt body), with an overall heavy mineral content of 2% to >10% [3].

In Australia, most of the heavy mineral and associated monazite resources are found on the old beach and sand dune deposits, some of which are found on Canning, Perth, Murray, and Eucla basins. In Eneabba (Perth), heavy minerals compose about 6% of the paleoshore sands mined in this district, with monazite composing 0.5 to 7.0% of this heavy mineral. WIM150 mineral sands deposit (Murray Basin) reportedly contains substantial resources of monazite and xenotime, associated with titanium minerals and zircon in the heavy mineral suit, with a deposit thickness of 14 m [3]. The length of that deposit is about 400 km, and the heavy minerals in the sand deposits were formed due to natural weather (storm) and weathering by water (wave).

In Brazil, the monazite placers of the Brazilian coast include elevated paleobeaches, modern beaches, sand dunes, banks, channels, and bars of streams that deposit sediments near the shore. Sources of the heavy mineral are sandstone, strandline deposits, and inland source of detrital monazite, which are amphibolite-granulite rock and sedimentary rock. Some sandstone intervals are rich in monazite, ilmenite, and zircon. These sandstones are eroded and disaggregated by high-tide waves and storm surges. These processes re-deposit sand and heavy minerals into the surf zone, where the heavy minerals are again reworked and sorted by waves, longshore drift, and tides. Thus, the Cretaceous-Tertiary strandline deposits, which occur in slightly higher outcrops near the modern beach, are another source (often containing a very high amount) of monazite. Monazite was recovered as a co-product of the more profitable titanium minerals (ilmenite, rutile) and zircon. In the Guarapari coastline, it is reported that monazite content is 0.83% [4]. Analyses of Brazilian monazites suggest that their average REE oxide content is typically around 57 to 60%, with preferential enrichment in the light REEs.

China has considerable monazite resources within their placer deposits, where monazite is produced as a by-product. Some of China's productive monazite-bearing placer districts are Beihei District, Dianbai District, Haikang District, Nanshanhai District, Sai-Lao, Wuzhang Xinglong, and Xinjiang. The content of heavy minerals in all districts is about 1.5% -6%, which contains minerals including rutile, zircon, monazite, ilmenite, xenotime, magnetite, chromite, anatase, and cassiterite.

Xenotime-bearing alluvial placer deposits in Malaysia were the largest sources of yttrium in the world. It is found as alluvial tin placer deposits containing considerable cassiterite with other minerals, including ilmenite, monazite, and xenotime. Recently, tailings produced from past tin placer mining have been reprocessed to recover monazite and xenotime. Around 350 tons of REOs were produced from Malaysia in 2012 [4].

Modern beach deposits on the northeastern coast of Sri Lanka contain some of the highest concentrations of heavy minerals in the world. These include ilmenite, rutile, and zircon. Sillimanite, monazite, and garnet also exist, with monazite reportedly composing 0.3% of the heavy mineral fraction. In some stretches of beach, the heavy minerals can compose as much as 90% of the sand deposits, while ilmenite, rutile, and zircon formed 65%, 10%, and 10% of the sand deposits, respectively. The Bentota river system carries monazite into seasonal beach sand deposits at Kaikawala and Beruwala, and these have been described as "one of the world's most thorium rich sediments" [4]. The deposits are enriched in LREE to HREE.

Similar to the Malaysian rare-earth resources, the monazite and xenotime deposits in Thailand are recovered as by-products from the upstream process in the production of tin metal in the plant. The host tin placers, enriched with monazite and xenotime, are alluvial deposits usually mined by gravel pumps, and these occur mainly in the southern Thailand area.
The Delta Epsilon SC -133 Portable Scintillation Counter represents a handheld gamma radiation detection device [4]. To determine the mineral’s grain size distribution, Udden-Wentworth Grade Scale was used in this study. Krumbein (1934) [5] was introduced as a logarithmic transformation of the scale, which converts the boundaries between grades to whole numbers, and this method was also used later. This scale is known as the Phi Scale: $\phi = -(\log_{10}d)/\log_{10}2$ [5]. In the present study, cumulative frequency curves (smooth curves) were drawn manually from the cumulative weight of sediment and phi (\(\phi\)) units using graph papers. Phi units, \(\phi_5\), \(\phi_{16}\), \(\phi_{25}\), \(\phi_{50}\), \(\phi_{75}\), \(\phi_{84}\), and \(\phi_{95}\), were determined manually from smooth curves. Then the Median (Md), Mean (M), Standard Deviation (s), Skewness (SK), and Kurtosis (K) of each sediment sample were calculated using graphic method [6], as follows:

\[
\text{Median (Md)} = \phi_{50} \quad (1)
\]
\[
\text{Mean (M)} = \frac{\phi_{16} + \phi_{50} + \phi_{84}}{3} \quad (2)
\]
\[
\text{Standard Deviation (s)} = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_{5}}{6.6} \quad (3)
\]
\[
\text{Skewness (SK)} = \frac{\phi_{84} + \phi_{16} - 2\phi_{50}}{2(\phi_{84} - \phi_{16})} + \frac{\phi_{95} + \phi_{5} - 2\phi_{50}}{2(\phi_{95} - \phi_{5})} \quad (4)
\]
\[
\text{Kurtosis (K)} = \frac{\phi_{95} - \phi_{5}}{2.44(\phi_{75} - \phi_{25})} \quad (5)
\]

Figure 1. Conventional phi scale showing grain size increasing to the left and decreasing to the right [7].

Particle morphologies are included for at least four concepts: form, sphericity, roundness, and surface feature [8]. Form refers to the gross, overall morphology or configuration of particles. Most measures of form consider the three-dimensional shape of the grains. Roundness measures the sharpness of the corners of grain and is commonly measured in two dimensions only. Surface texture refers to microrelief features, e.g., scratches and pits, that appear on the surfaces of clastic particles, particularly particles that have undergone transport [9].

2. Study Area

2.1. Location
The location of this study is in Bangka Island, Indonesia. The area has a tropical climate with medium rainfall. The area is accessible via asphalt paved road, followed by garden path or small street to reach the location.

2.2. Geomorphological setting
Bangka Island is at an altitude between 0 to > 400 meters above sea level, with slopes ranging from 0 - > 25%. Some parts of the areas with an altitude of > 400 meters above sea level are around the upper reaches of the Mabat River, namely Mount Maras, mostly dominated by flat to hilly areas. Areas with a
slope between 0-5% are generally located at the foot of the hill and have a relatively short and small inter-river valley with alluvial plains to the South-East, South, West and North of Bangka Island. [10].

Figure 2. a. The hierarchal relationship of form, roundness, and surface texture [9]. Component aspect to describe particle morphology: b. Roundness [11]; c. Form [9] d. 2D Visually of the sphericity [12].

3. Geological Setting
Samples were collected in the Quaternary-Alluvium (QA), which contained mud, clay, coarse sand, and sediment from swamps, rivers, and beaches; the second was in the Triassic-Sandstone and Claystone of the Tanjung Genting Formation (Trt); the third was the intrusive Late Triassic-Granite Kelabat (TrJkg) which contained biotite-granite, granodiorite, gneissic granite [13] [14]. Regionally, Bangka Island has a strike-slip geological structure, both sinistral and dextral.
4. Material and Method

4.1. Sample and Preparation
In this study, 62 samples were collected, in which 36 were categorized as secondary data while the remaining 26 samples were taken directly from the field. Sample code names were based on sample type, peak location, and serial number. Generally, two types of samples are used: alluvial samples (A) and tailing samples (T). Peak location domain codes were M for Menumbing, P for Pemali, A for Mangkol, B for Bebulu, and T for Toboali.

Alluvial samples were collected from a stream while tailing samples were taken from ex-alluvial-mining locations. Location coordinates were recorded using a handheld GPS device. Samples taken from the location weighed around 2-3 kg were then dried, split using a quartering coning, and sieved into several mesh fractions (#5, #35, #60, #100, and #120) using a standard American mesh sieve. Some ICP-MS samples were crushed using hand mortar then sieved until they passed through the #200 sieve.
Figure 4. Grain size distribution of the alluvial and tailing sample used in this study. In general, medium sand and fine sand grains dominate the alluvial and tailing samples. However, 2 sand samples have a very fine size, possibly because these samples are the farthest from the peak morphology.

**Figure 5.** Heavy mineral index in percent. A. Tailing, B. Aluvial and Coluvial, C. Mean

4.2. Extraction Procedure and Chemical Analysis

Samples passing through the #5, #35, #60, #100, and #120 sieve sizes were measured for their radiation exposure using an SC-133 portable scintillo counter. The grain minerals and grain morphology of the samples were analyzed using a binocular microscope. Some samples were also subjected to a detailed grain morphological description of a polished incision sample.

The samples were analyzed for their metal concentration (a total of 60 major and trace elements) using ICP-MS. Samples for ICP-MS analysis were taken based on the high radiation values and dominated by the finest fraction (-120 mesh). The ICP-MS analysis was carried out at PT Intertek Laboratory, Indonesia, using 4 solvents, namely HNO₃, HClO₄, HF, and HCl.
5. Result

5.1. Mineral Composition of Alluvial and Tailing in Bangka

In general, the light minerals present in the alluvial and tailings samples on Bangka Island are quartz (Qz). Meanwhile, the heavy minerals present include cassiterite (Cass), zircon (Zr), ilmenite (Ilm), rutile (Rtl), xenotime (Xtm), tourmaline (Tour), muscovite (Ms), limonite (Lim), and small amounts of siderite, spinel, magnetite (Mg), and pyrite (Px). Zircon is very abundant in the downstream areas in Bebulu (AB17 and AB19), Jebus (AJ1), and Toboali (AT3 and AT5), presumably since these locations are the farthest locations from each peak of morphology so that heavy minerals are well deposited.

It can be seen in Fig. 6 that the alluvial sample (KT1) tends to have less amount of heavy minerals compared to the alluvial and tailing samples, while the alluvial sample has the largest heavy minerals composition compared to the tailing and colluvial samples (See Fig. 5c). This occurs since the material deposition process is not mature at the alluvial location, and the heavy minerals in the tailings will present at very little concentration. During the early recovery processes, the material is passed into a sluice box to separate the heavy and light minerals, where the light minerals are reported as tailings.

![Figure 6. Grain size analysis in alluvial and tailings of Bangka Island sample](image)

The alluvial samples Ilm, Cass, Xtm, and Zr, were enriched in the fine size fraction (#65), while Mnz was enriched in medium sand (#48) and fine sand (See Fig. 7). Meanwhile, Mnz tailings are rich in medium sand fraction and abundant in very fine sand fraction (#150). Based on Fig. 6 and Fig. 7, although the difference in the distribution of Zr in the fraction is not so significant (about 30% in Fig. 7), Zr is more enriched in alluvial than tailings samples. This occurs since Zr minerals are recovered to the concentrate stream during the mining process. In contrast Xtm, the highest average Xtm content was in the tailings sample (0.35%), and the tailing Xtm samples were more enriched in medium sand and very fine sand fractions.

![Figure 7. Composition of mineral in each size fraction](image)
5.2. **Heavy Mineral Grain Granulometry**

5.2.1. **Mean of Heavy Minerals**

In order to simplify the mesh number, the fraction value in each mesh is converted into phi units [7]. Based on the mathematical calculations [5], the average grain size of heavy minerals in alluvial samples is 1.58 phi, a classification of medium sand grain fraction in the Wentworth grain size classification [9]. The tailing sample has an average grain size of 1.61 phi, similar to alluvial. These results signify that the sample as a whole has the sand grain dominated as medium size (See Fig. 4). Based on similar findings [6], the mean range of 0-4 phi has good sorting characteristics, and the contribution from source rock is quite large.

5.2.2. **Sorting of Heavy Minerals**

![Figure 8. Sorting of heavy mineral grain in aluvial and tailing, Bangka.](image)

In alluvial samples (See Fig. 8), 2 samples are well sorted, 5 samples moderately well sorted, 9 samples moderately sorted, and 10 samples poorly sorted. In alluvial samples as a whole, the sorting value shows a stable trend in the moderately sorted. This can be seen in alluvial samples in the Toboali area (in order AT1, AT2, AT3, AT4, AT5, and AT6) starting from the closest to the furthest from peak morphology, sorting heavy mineral grain sizes from poorly sorted until well sorted. It is evident that the further away from the source, the better the grain size sorting is. This also occurred on the colluvial samples (KT1), which had poorer sorting than the alluvials.

In the tailings sample (See Fig. 8), a similar pattern was found in the samples in Bebulu (TB11-TB23), Jebus (TJ1-TJ2), Menumbing (TM1-TM2), and Namak (TN1-TN2). It is also noticeable that the farther from the source, the better heavy mineral grain size sorting the morphology is.

5.2.3. **Kurtosis of Heavy Minerals**

Based on the mathematical calculations [15] (See Fig. 9), a good pattern can be found in alluvial samples in the Bebulu (AB11-AB22) and Toboali (AT1-AT6) areas. Meanwhile, the downstream area has a small variation in the size of heavy mineral grains than the upstream area. This indicates that the downstream area is better sorted than the upstream area. On the other hand, heavy mineral tailings predominantly have a very platykurtic value, indicating that the variation in heavy mineral grain size in the tailings sample is quite diverse.
5.2.4. Skewness of Heavy Minerals
Skewness shows the symmetric value of the frequency curve [15]. Fig. 10 shows a good pattern in the samples in Bebulu and Toboali, where the grain size of heavy minerals is becoming coarser in the upstream area. This is quite different from the tailings sample with a random skewness pattern.

5.3. Mineral Grain Morphology

5.3.1. Form of Heavy Mineral Grain
The heavy mineral forms of Cass, Mnz, Ilm, Xtm are predominantly equant, while Zr is predominantly prolate and oblate. The distribution of heavy minerals from upstream to downstream is as follows: Cass oblate to downstream equant, Mnz, Xtm and Ilm in Bebulu from upstream to downstream, changing from equant to oblate, while in the Toboali area, it is consistently oblate. In contrast, it is prolate / oblate to equant from upstream to downstream for Zr.

The predominance of equant and oblate heavy mineral forms is an indication that the transport process tends to occur in a rolling and suspension manner. However, some minerals in prolate and equant forms tend to have bedload transport mechanisms.

5.3.2. Sphericity of Heavy Mineral Grain
The sphericity value of heavy mineral grains was collected in the very equant category. Sphericity is dominated by very elongated to very equant, starting from upstream to downstream. This indicates an erosion factor in mineral grains during the transportation process and indicates the transportation process that occurs, which is the bedload.

5.3.3. Roundness of Heavy Mineral Grain
The value of the roundness of the colluvial sample shows that all minerals are in the sub-angular, angular, and very angular categories. For the alluvial samples, it shows that heavy mineral grains have a roundness ranging from sub-angular to sub-rounded in the upstream area. In contrast, in the downstream area, heavy minerals range from sub-rounded, rounded, to well rounded. This roundness
rate is in line with the transport distance of each heavy mineral grain. The more downstream area of the sample, the better roundness is.

5.4. Degree of Radiation Exposure
During the measurement of the radiation exposure, the background value used was 194 CPS. Fig. 11 shows that in alluvial samples, all samples tend to have radiation values above the background. In contrast, in the tailings sample, the radiation exposure values are quite high, including some areas such as Jebus, Menumbing, and Pemali. A significant radiation exposure value is found in the very fine grain fraction sample (-120 mesh). However, the radiation value of the tailings sample tends to be higher than the alluvial sample, namely in the Menumbing area (TM1 at 216.33 CPS), while the highest radiation exposure value in the alluvial sample is in the Toboali area (AT6 at 211 CPS).

5.5. Major and Trace Element Content

5.5.1. Relationship into Peak of Morphology
Based on the total REE value, for alluvial, some samples are enriched in REE (REE + Sc + Y > 170ppm) with values ranging from 191.5 ppm - 1860 ppm. These areas are alluvial Mangkol, Bebulu, Menumbing, and Toboali. In the Pemali alluvial, there was no indication of REE enrichment, while in the Jebus area, there was no alluvial location. Meanwhile, there were 2 locations where REE concentrations were high for the tailings sample, namely in Pemali (969.1 ppm) and Menumbing (12,646.5 ppm).

In general, REE is the richest alluvial, especially for the REE. LREE enriches alluvial Bebulu, Menumbing, and Toboali along with Zr, U, Th, Nb, and Sn. The same also applies to Menumbing and Pemali tailings samples. Meanwhile, Mangkol’s alluvial is on the LREE.

The high Th content (> 50 ppm) is in Bebulu (AB15 at 60.4 ppm), but it decreases towards the downstream area. The high Th content in the alluvial sample with a value (90-1370 ppm) is the highest in the Toboali alluvial and Menumbing alluvial. At this alluvial location, the value increases downstream.

Regarding the composition of total REE compared to the distance between the alluvial sample and the morphological peak, the pattern cannot be determined with certainty, as not all samples contain REE. However, in general, it can be seen that the greater the distance between the sample and the

Figure 11. Scintillometer result of alluvial and tailing sample, Bangka.
morphological peak, the total REE concentration increases, as shown in the alluvial of Bebulu, Menumbing, and Toboati.

From the whole sample, the TM2 tailings sample is the sample that has the most significant element composition value, as the content of Total REE, Th, Zr, Nb, and Sn is the highest of all samples.

Table 1. Descriptive statistic of ICP-MS and ICP-OES data (Aluvial : 12 sample and tailing: 5 sample)
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| Element | CODE | DET.LIM | Min Alluvial | Max Alluvial | Mean Alluvial | STD Alluvial | Min Tailing | Max Tailing | Mean Tailing | STD Tailing |
|---------|------|---------|--------------|--------------|---------------|--------------|-------------|-------------|--------------|-------------|
| Zr      | %    | 0.01    | 0.5          | 0.5          | 0.5           | 0.0          | 1.6         | 3.2         | 2.4          | 0.8         |
| Hf      | PPM  | 0.1     | 0.2          | 80.2         | 20.4          | 25.9         | 0.7         | 340.0       | 90.0         | 127.9       |
| Re      | PPM  | 0.05    | 0.1          | 0.1          | 0.1           | -            | 0.1         | 0.1         | 0.1          | -           |
| Bi      | PPM  | 0.05    | 0.1          | 15.3         | 3.9           | 4.5          | 0.4         | 47.6        | 11.1         | 18.3        |
| La      | PPM  | 0.1     | 0.5          | 388.0        | 97.6          | 127.5        | 0.8         | 2,720.0     | 595.5        | 1,065.5     |
| Ce      | PPM  | 0.1     | 1.0          | 829.0        | 216.6         | 268.9        | 1.9         | 5,540.0     | 1,154.8      | 2,193.6     |
| Pr      | PPM  | 0.05    | 0.1          | 88.8         | 22.8          | 28.5         | 0.2         | 642.0       | 140.3        | 251.6       |
| Nd      | PPM  | 0.1     | 0.4          | 282.0        | 74.3          | 90.8         | 0.8         | 1,960.0     | 432.4        | 766.8       |
| Sm      | PPM  | 0.1     | 0.1          | 55.2         | 14.4          | 17.2         | 0.3         | 346.0       | 77.1         | 135.1       |
| Eu      | PPM  | 0.1     | 0.1          | 0.7          | 0.3           | 0.2          | 0.1         | 1.8         | 0.8          | 0.8         |
| Gd      | PPM  | 0.1     | 0.1          | 36.5         | 10.3          | 11.4         | 0.4         | 250.0       | 57.5         | 97.1        |
| Tb      | PPM  | 0.05    | 0.1          | 4.5          | 1.3           | 1.4          | 0.1         | 28.3        | 6.8          | 10.9        |
| Dy      | PPM  | 0.1     | 0.2          | 22.8         | 6.7           | 6.9          | 0.6         | 138.0       | 34.5         | 52.8        |
| Y       | PPM  | 0.1     | 0.8          | 100.0        | 31.3          | 29.2         | 2.9         | 571.0       | 155.8        | 216.5       |
| Ho      | PPM  | 0.1     | 0.1          | 4.0          | 1.2           | 1.2          | 0.1         | 24.6        | 6.3          | 9.4         |
| Er      | PPM  | 0.1     | 0.1          | 14.3         | 3.9           | 4.0          | 0.4         | 83.0        | 21.2         | 31.5        |
| Tm      | PPM  | 0.1     | 0.1          | 2.2          | 0.6           | 0.6          | 0.1         | 12.7        | 3.3          | 4.7         |
| Yb      | PPM  | 0.1     | 0.1          | 19.0         | 4.9           | 5.3          | 0.5         | 93.7        | 24.3         | 35.4        |
| Lu      | PPM  | 0.05    | 0.1          | 2.7          | 0.7           | 0.8          | 0.1         | 13.5        | 3.5          | 5.1         |
| Total of REE | |        | 4.8          | 1,860.4      | 491.5         | 594.2        | 10.3        | 12,464.5    | 2,726.0      | 4,882.1     |
| LREE    |     | 2.1     | 1,643.0      | 425.8        | 531.5         | 4.0          | 11,208.0    | 2,400.1     | 4,410.9     |
| HREE    |     | 1.6     | 206.0        | 60.8         | 60.2          | 5.1          | 1,214.8     | 313.1       | 462.4       |
| LREE/HREE |     | 1.3     | 9.3          | 5.2          | 2.5           | 0.8          | 9.2         | 3.1         | 3.1         |
| Ce/Ce*  |     | 3.8     | 6.9          | 4.4          | 0.8           | 1.6          | 4.3         | 3.5         | 1.0         |
| Eu/Eu*  |     | 0.0     | 1.0          | 0.1          | 0.3           | 0.0          | 0.3         | 0.1         | 0.1         |
The Spider diagram (See Fig. 12) shows that REE in Bangka alluvial is enriched by around 1 - 20 times the Upper Continental Crust level, while REE in Bangka tailing is enriched by about 50 times. There are several anomalies, such as the positive Eu anomaly in the alluvial downstream and Pemali tailings. This occurs since the alluvial Bebulu (AB19) is downstream, and the possibility of sea water contamination affects the high concentration of Eu.

6. Conclusion
1. Based on grain size analysis or granulometry of heavy minerals associated with Bangka Island placer tin deposits, the alluvial sample of the soil is dominated in fine sand grain size, while the tailing sample is mostly in the medium-fine sand grain size.
2. Mathematical analysis of grain morphology of heavy alluvial minerals shows that the grain shape is dominated by equant and oblate (except for Zr prolate, which shows the crystal structure of Zr, namely tetragonal and hardness 7, which is the highest than other heavy minerals). Grain distribution from upstream to downstream is in increasing roundness and stability rate. The transport mechanisms that occur are suspended and bedload.
3. The highest REE enrichment occurred in the Bangka tailing sample, which was 50 times the enrichment of the UCC.

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