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RESEARCH ARTICLE

Heavy Mineral Characteristics and Sediment Maturity of Alluvial Tin Deposits in Kemingking, Central Bangka, Indonesia

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Abstract
Bangka-Belitung is part of the Southeast Asian tin belt, which has significant potential for alluvial tin deposits formed by weathering, transportation, and redeposition from its primary sources. This study aims to identify the characteristics of alluvial tin deposits in the Kemingking area, Sungaiselan District, Central Bangka Regency, using grain counting (GCA), petrography, and zircon-tourmaline-rutile (ZTR) index analyses from four drill wells. GCA results identified eleven types of heavy minerals, namely cassiterite, zircon, monazite, ilmenite, rutile, tourmaline, garnet, topaz, anatase, epidote, and quartz, with subangular to subrounded-rounded grain shapes indicating medium to long-distance transport. Mineral distribution patterns indicate hydrodynamic sorting by density, with cassiterite concentrated in the high-energy downstream zone. The ZTR index values in the four wells ranged from 34.71 to 58.27% (average 52.16%), indicating a generally mature sedimentary maturity. These findings suggest that alluvial tin deposits in the study area were formed through long-distance transport from source rocks, with a depositional environment that can be interpreted as an ancient placer system.
Keywords: Alluvial tin; heavy minerals; grain counting; petrography; ZTR index; sediment maturity; Bangka

1. Introduction

The Bangka-Belitung region is part of the Southeast Asian tin metallogenic belt, which stretches from southern China through Thailand, Myanmar, Malaysia, and Indonesia. Tin in this belt is generally found in primary deposits formed within granite bodies or in contact zones with metamorphic rocks, and is commonly associated with tourmaline and quartz veins. These quartz veins occur in two forms: fissure veins and sheeted veins, both of which are genetically linked to Upper Triassic granite intrusions (Naibaho, 2016).

Bangka Island is known as one of Indonesia's major tin producers, with a long history of tin mining. Tin resources on the island are generally divided into two types: primary tin, which originates directly from granite rocks, and secondary or alluvial tin, which forms through a series of weathering, transportation, and deposition processes in alluvial, colluvial, and littoral environments (Khoirunnisa, 2022). This complex series of geological processes contributes to the diverse characteristics of alluvial tin deposits, including mineral composition, maturity, and evidence of the distance the material has been transported from its source.

The characteristics of alluvial tin deposits—including grain composition, heavy mineral content, and the degree of weathering of accompanying minerals as reflected in the zircon-tourmaline-rutile (ZTR) index—are fundamental aspects that need to be understood to reveal the formation process and transportation history of the material making up the deposit. This information is an important basis for interpreting the genesis and provenance of the deposit, given that the characteristics of alluvial tin deposits can vary across regions due to differences in geological conditions, original material sources, and sedimentation mechanisms in each area.

Based on this description, research on the characteristics of alluvial tin deposits in the Kemingking area, Sungaiselan District, Central Bangka Regency, Bangka Belitung Islands, is deemed important. This study aims to identify the characteristics of alluvial tin deposits in the region using grain-composition and petrographic analyses based on the zircon-tourmaline-rutile (ZTR) index.

2. Literature Review

Regional Geology

Based on the South Bangka Geological Map (Margono et al., 1995), the regional stratigraphy of Bangka Island is composed, from oldest to youngest, of the Pemali Complex (CpP), Tanjung Genting Formation (Trt), Klabat Granite (TrJkg), Ranggam Formation (TQr), and Alluvium (Qa). The study area is located within two units: the Tanjung Genting Formation and the Alluvium.

The Tanjung Genting Formation is composed of alternating sandstone and mudstone, interbedded with limestone lenses containing Triassic fossils (Osberger, in Margono et al., 1995). It is therefore interpreted as Early Triassic and formed in a shallow-marine environment. This formation unconformably overlies the underlying metamorphic rocks and is in contact with a granite body in the northern part of the sheet. The Alluvial Unit (Qa) consists of mud, clay, sand, gravel, and cobbles deposited in river, swamp, and coastal environments. This unit is the main host of alluvial tin deposits in the study area.

Structurally, Bangka Island is characterized by lineaments, joints, folds, and faults in Permian–Triassic rocks, with fold axes trending northeast–southwest and steep dips (Mangga and Djamal, 1994; Margono et al., 1995). The distribution of plutonic rocks and the coastline of Bangka Island generally follow the direction of these structures. The pattern of joints and faults has north–south, northeast–southwest, and southeast–northwest orientations, with the north–south faults representing the youngest phase. (Katili, 1967; Mangga dan Djamal, 1994; Crow, 2005).

Alluvial Deposits and Tin Placer Deposits

Alluvial deposits are accumulations of unconsolidated sediment formed by fluvial processes in non-marine environments, typically siliciclastic and characterized by sedimentary structures such as cross-bedding, lamination, and cut-and-fill structures resulting from river channel migration (Nichols, 2020; Boggs, 2006). These deposits form in three main fluvial facies: channel facies (sand–gravel), levee-splay facies (fine sand–silt), and floodplain facies (silt–clay) (Miall, 2014).

Alluvial tin is classified as a placer deposit, namely a concentration of chemically and physically stable heavy minerals resulting from weathering, transportation, and redeposition processes from primary sources (Schwartz, 1995). These deposits are enriched through a sorting process during erosion and transportation, so that heavy minerals such as cassiterite are separated and concentrated relative to light minerals. Based on the depositional environment, tin placer deposits can be divided into eluvial, colluvial, alluvial, coastal and marine placers (Atkinson, 1986).

Eluvial placers form directly from the weathering of primary deposits on steep slopes around mineralized bodies. In contrast, colluvial placers form in the transition zone between eluvial and alluvial deposits, where gravitational sorting increases the concentration of cassiterite (Best and Brayshaw, 1985). Alluvial placers themselves are divided into kaksa placers and mincan placers (Schwartz, 1995). Kaksa placers are characterized by angular grains measuring 200–1000 μm, indicating a short transport distance from the source, while mincan placers are allochthonous, not directly related to the source rock, and have undergone long transport (Batchelor, 1988).

In the alluvial tin deposits of Bangka Island, cassiterite is concentrated locally in the valley floor with a maximum transport distance of no more than 500 m from the source. It shows a correlation between grain size and tin content, with coarse sediments tending to have higher cassiterite content than fine sediments (Aleva, 1973).

Bangka Island Tin Deposits

According to Aleva (1973), alluvial tin deposits on Bangka Island were formed by sediment accumulation in valley environments, with cassiterite concentrated locally on the valley floor under morphological controls such as low zones, basins, or areas behind natural barriers that inhibit mineral transport. The distance of cassiterite transport by river flow generally does not exceed 500 meters from its source. Grain size also correlates with tin content, where coarse sediments such as gravel tend to have higher cassiterite concentrations than fine sediments—a condition reinforced by the uneven topography of the valley floor, as found in the Kinta Valley due to the undulating karst limestone surface. In addition, the composition of heavy minerals in residual deposits (kaksa) is directly correlated with the surrounding bedrock and primary mineralization. In contrast, mincan placers, as allochthonous deposits, have no genetic relationship with these residual deposits.

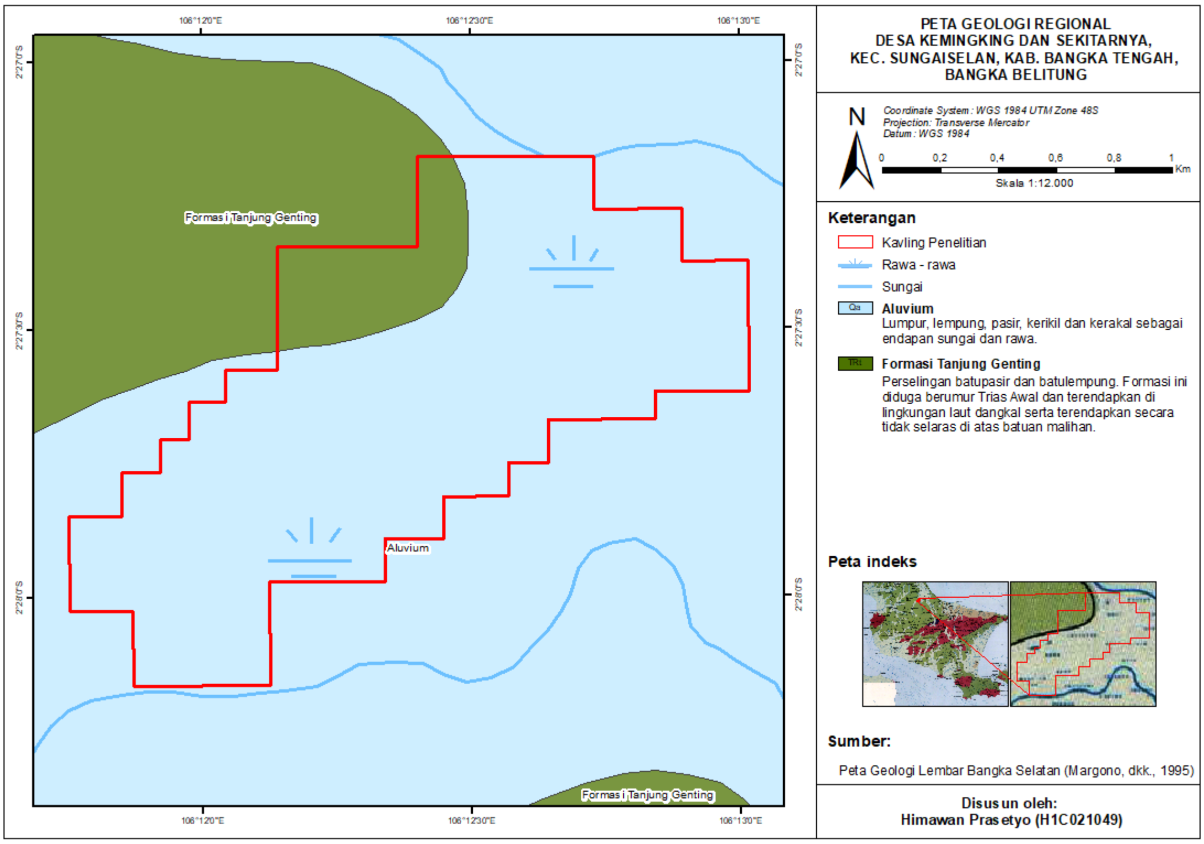

Figure 1. Regional Geological Map of Research Area

3. Research Methods

The characterization of alluvial tin deposits in this study was carried out in three stages: grain counting, petrographic analysis, and calculation of the zircon-tourmaline-rutile (ZTR) index.

Grain counting analysis is used to determine the mineral content based on the ratio of the number of grains to the total mineral in the sample. Analysis is performed using a binocular microscope at 100x magnification, with the sample placed on a 2.5 × 2.5 mm grid-patterned slide as a reference point for observation. The cassiterite (SnO_2) content is calculated using the following equation:

$$K_{SnO_2} = \frac{n_{SnO_2} \times \rho_{SnO_2}}{(n_{SnO_2} \times \rho_{SnO_2}) + (n_X \times \rho_X) + \ldots} \times 100$$

where K_{SnO_2} is the cassiterite content (%), n_{SnO_2} and ρ_{SnO_2} are the number of grains and density of cassiterite per grid box, respectively, while n_X dan ρ_X are the number of grains and density of other minerals per grid box. In addition to content, this analysis produces data on the amounts of each mineral type in the sample, which can be used for further interpretation of mineral composition patterns.

Petrographic analysis was performed to identify mineral types based on their optical properties and to confirm the mineral identification results from grain counting analysis. Samples of heavy mineral grains from drilling were first hardened with resin to allow thin-sectioning, then observed under a polarizing microscope under parallel and crossed-Nicol conditions. Mineral types were determined in detail and accurately based on the optical properties of each mineral.

The level of mineral maturity in clastic deposits, especially transparent heavy mineral grains, is determined by calculating the ZTR index (Hubert, 1962). This index is based on the mineral resistance to chemical weathering and mechanical abrasion during sediment transport and recycling processes. It is calculated by calculating the cumulative percentage of the three most resistant minerals—zircon, tourmaline, and rutile—of the total transparent heavy minerals, using the equation:

$$ZTR\ index = \frac{Zircon + Tourmaline + Rutile}{Total\ transparent\ heavy\ minerals} \times 100$$

The ZTR index value is then classified into four levels of sediment maturity, namely immature (0–25%), sub-mature (25–50%), mature (50–75%), and supermature (75–100%). (Hubert, 1962; Morton and Hallsworth, 1999).

4. Results and Discussion

The four samples were taken at relative depths corresponding to a uniform volume of 2.8 liters in sandy lithology. The weight of the extracted heavy minerals (HM) varied among wells, with the highest in HP-07 (2.05 g) and the lowest in HP-02 (0.12 g). To standardize the analytical weights across wells, all samples were calibrated to the lowest weight (Table 1).

Table 1. Sample data and heavy mineral weight calibration for each drill hole

Hole	**From (m)**	**To (m)**	**Litho**	**Volume (L)**	**Weight HM (g)**	**Weight Calibrated (g)**
HP-07	35	36	Pasir	2,8	2,05	0,12
HP-02	33	34	Pasir	2,8	0,12	0,12
HP-03	34	35	Pasir	2,8	0,47	0,12
HP-04	35	36	Pasir	2,8	0,34	0,12

Heavy Mineral Characteristics

Grain counting (GCA) analysis results from the four wells identified eleven heavy mineral types: cassiterite, zircon, monazite, ilmenite, rutile, tourmaline, garnet, topaz, anatase, epidote, and quartz. Because GCA can only observe the physical properties of grains without definitively confirming their optical properties, petrographic analysis was performed for further confirmation using samples from well HP-03 in the #70 and #-140 mesh fractions, which were selected to represent the widest grain size range in the study area (210 μm and 88 μm).

In general, these minerals exhibit subangular to subrounded roundness, with cassiterite, monazite, rutile, tourmaline, garnet, topaz, anatase, and epidote indicating moderate transport distances, while zircon, ilmenite, and quartz exhibit subrounded to rounded roundness, indicating longer transport distances (Table 2). The main optical characteristics of each mineral are summarized in Table 2.

Table 2. Summary of physical and optical characteristics of heavy minerals in the study area

Mineral	Color (GCA)	Shape	Roundness	Relief (Petrography)	Transport Interpretation
Cassiterrite	Dark brown-light, translucent	Prismatic/ fragments	Subangular – subrounded	High	Medium
Zircon	Transparent-light purple	Elliptical/ prismatic tabular	Rounded	Very High	Far
Monazite	Greenish yellow	Prismatic	Subangular – subrounded	Medium	Medium
Ilmenite	Black opaque	Tabular–spherical	Subrounded–rounded	Very high	Far
Rutile	Brown-dark red	Prismatic/ fragments	Subangular – subrounded	High	Medium
Turmaline	Black opaque	Prismatic–tabular	Subangular – subrounded	Very high	Medium
Garnet	Orange	Prismatic	Subangular – subrounded	Very high	Medium
Topaz	White	Rounded Fragments	Subangular – subrounded	Low	Medium
Anatase	Light-Dark blue	Tabular–prismatic	Subangular – subrounded	Medium	Medium

Epidote	Dark-light green	Sheeted Fragments	Subangular – subrounded	High	Medium
Quartz	Transparent	Rounded	Subrounde d–rounded	Low	Far

Sediment Maturity (ZTR Index)

GCA results indicate that the sample is dominated by non-opaque heavy minerals (cassiterite, zircon, monazite, tourmaline, rutile, garnet, topaz, anatase, and epidote), with ilmenite as the only opaque heavy mineral and quartz as the non-heavy mineral. The dominance and ultrastable nature of zircon, tourmaline, and rutile in the sample make these three minerals suitable as the basis for calculating the ZTR index to determine the sediment maturity level and to indicate its transport distance.

ZTR index values in the four wells ranged from 34.71–58.27%, with well HP-02 showing the lowest value (34.71%; sub-mature category), while HP-07, HP-03, and HP-04 showed relatively uniform values ranging from 57.59–58.27% (mature category) (Table 3). The average ZTR index of the four wells was 52.16%, indicating that the sediments in the research area were generally classified as mature.

Table 3. ZTR index values for the four drill holes

Well	Zircon	Turmaline	Rutile	Total Non-opaque	ZTR Index (%)	Category
HP-07	385	18	8	708	58,05	Mature
HP-02	551	26	11	1021	57,59	Mature
HP-03	348	34	12	1135	34,71	Sub-mature
HP-04	548	34	3	1004	58,27	Mature
Avg					52,16	Mature

This mature-dominated maturity level is consistent with the dominance of subrounded grain shapes and fine grain sizes across all samples, indicating that the sedimentation process occurred at a relatively distant distance from the source rocks. This finding strengthens the interpretation that the study area's depositional environment is an ancient placer system formed by weathering of source rocks far from the final deposition site.

5. Conclusion

The alluvial tin deposits in the study area are composed of eleven types of heavy minerals with subangular to subrounded to rounded grain shapes, indicating moderate to long transportation distances from their source. The mineral distribution pattern indicates hydrodynamic sorting by density, with cassiterite—the heaviest mineral—tending to accumulate in the high-energy downstream zone. The ZTR index values range from 34.71–58.27% (average 52.16%), indicating that the sediments are generally mature, except in well HP-03, which is classified as submature. The grain characteristics and maturity level of the sediments indicate that the alluvial tin deposits in the study area were formed by long-distance transport from source rocks, suggesting that the depositional environment can be interpreted as an ancient placer system.

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