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Tin Mineralization in Tanjung Genting Sandstone, Terap Village, Bangka Belitung Islands Province

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ABSTRACT

The research area is located in Terap Village, Tukak Sadai District, South Bangka Regency, Bangka Belitung Islands Province. The research was conducted at PT Timah Tbk. The purpose of this study was to understand the geology of the study area and the mineralization present, as well as the rocks that serve as the source of mineralization in the study area. The methodology used in this study was direct geological mapping and laboratory analysis in the form of petrography, XRF, XRD, and mineragraphy. The stratigraphy obtained included the Tanjung Genting sandstone unit, the Klabat granite intrusion, and alluvial sediment units. The petrographic analysis revealed quartz wacke and lithic wacke. Portable XRF analysis revealed a tin content of 2183 ppm. The XRD analysis revealed clay minerals in the form of goethite, quartz, kaolinite, muscovite, and illite. The mineragraphy analysis revealed cassiterite and hematite mineralization. The research concludes that this mineralization can be grouped into the greisenized deposit type, with the Cassiterite + Hematite mineral group only found in the mineralization zone with the highest Sn element content obtained in the research area of 2183 ppm.

Keywords: Terap Village, geological, mineralization, vein

INTRODUCTION

Indonesia is the world's second-largest producer of tin, trailing only China [1]. As a nation with vast mineral resources, Indonesia's mining sector remains highly significant to the global market [2]. Tin (Sn), with an atomic number of 50, is characterized by its low melting point (232 °C), allowing for ease in processing and recycling. At standard operating temperatures (130–600 °C), the metal is lustrous, malleable, and possesses a specific gravity of 7.3 g/cm³. However, beyond this temperature range, tin becomes increasingly brittle and susceptible to pulverization [3]. Due to its high thermal and electrical conductivity, tin is an essential component in the automotive and electronics industries.

Tin ore contains associated minerals in the form of ilmenite, zircon, quartz, monazite, and others. From the various accompanying minerals, they must be separated to obtain the desired tin content. Mineral separation is achieved by exploiting specific physical properties; primarily, magnetic separation techniques utilize the differences in magnetic susceptibility between various minerals [4]. Tin ore deposits can be found in the form of primary and placer tin [5]. Tin mineralization in Indonesia is of significant geological interest due to its boundary with the western region of the archipelago. Specifically, it forms part of the Southeast Asian Tin Belt, a major metallogenic province extending from Myanmar through Thailand and Malaysia, into the 'Tin Islands' of eastern Sumatra, and terminating in western Kalimantan [6].

The Bangka Belitung Islands Province is renowned for its abundant mineral resources and its diverse agricultural sector. The Bangka Belitung Islands are located near the South Sumatra Province, known as the only tin producer in Indonesia. The name Bangka itself comes from wangka, which means tin [7]. PT Timah Tbk is currently the leading company for tin exploration, exploitation, and processing within the Indonesian Tin Islands, which represent one of the world's most significant tin-producing regions [8]. Exploration is the foundational phase of the mining lifecycle, aimed at quantifying subsurface mineral reserves through various analytical methods. This process is essential for delineating ore bodies and mitigating the financial risks associated with mining investment. This phase represents a systematic follow-up to the initial regional review and prospecting surveys [9].

This research is necessary to further examine the geological characteristics and tin mineralization in an area. This research will be conducted in Terap Village, Tukak Sadai District, South Bangka Regency, Bangka Belitung Islands Province (Figure 1). This study will enable a comprehensive characterization of the local geology and the determination of specific hydrothermal alteration patterns associated with mineralization in the research area. The findings of this study provide a technical basis for identifying future exploration targets, thereby enhancing tin prospecting efforts both across Indonesia and specifically within the Bangka Belitung Province.

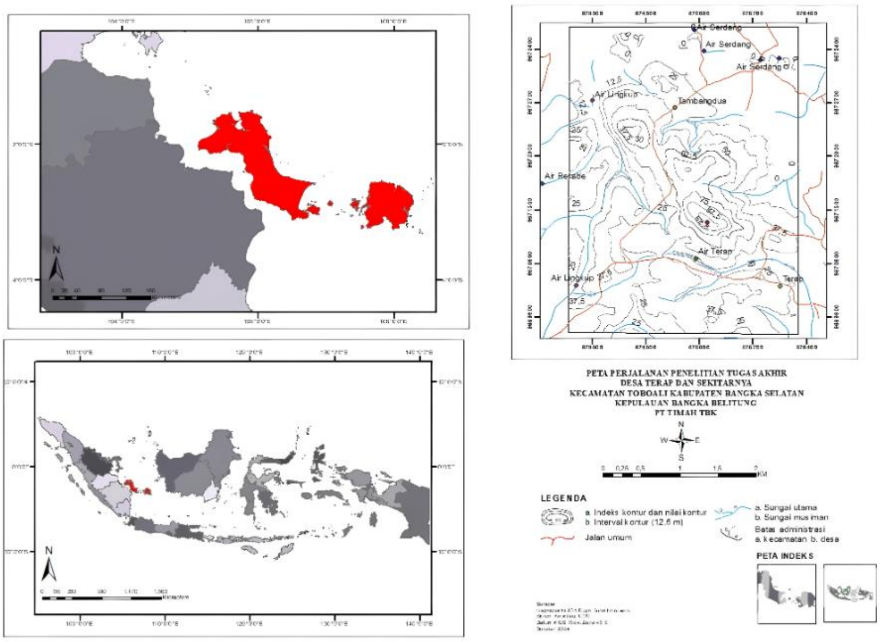

Figure 1. The research area is located in Terap Village, Tukak Sadai District, within the South Bangka Regency of the Bangka Belitung Islands Province

THEORY

Tin mineralization in the Southeast Asian Tin Belt is genetically associated with S-type granites. Through subsequent erosion and weathering processes, these primary sources underwent secondary enrichment, resulting in

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the formation of high-grade alluvial (placer) deposits. [10]. Bangka Island is the largest island on the Sunda Shelf [11]. The land is generally in the form of denudational plains with localized hills left over from erosion. The tectonic process that pushes acidic igneous rocks or granite from the depths of the earth to the surface, where it is then exposed by the work of exogenic weathering forces on rocks [12].

This region belongs to the Southeast Asian Tin Belt, a major metallogenic province extending from southern China through Myanmar, Thailand, and Malaysia, before terminating in the Indonesian archipelago. The confluence of several microcontinents that form Bangka Island is bordered by the West Sumatra Block to the south and west, the Southwest Kalimantan Block to the east, and East Malaya to the north. [13]. The South Bangka Regency is characterized by a complex tectonic framework of faults and fractures, which function as the primary structural controls for hydrothermal fluid migration and subsequent mineral deposition. The regional geology is dominated by the Tanjung Genting Formation and Klabat Granite; the latter serves as the primary source of mineralization, while both formations act as host rocks for mineral deposits.

Alteration is a change in the mineralogy, texture, or chemical composition of rocks resulting from the interaction of hydrothermal fluids with the rocks they pass through under certain physical and chemical conditions [14-15]. Hydrothermal fluids are residual solutions derived from magmatic cooling, typically ranging in temperature from 100 to 500 °C. These fluids facilitate the formation of new mineral assemblages while altering the texture and composition of the surrounding host rocks, particularly in high-porosity lithologies or structural weak zones that serve as conduits for fluid migration. [14]. Hydrothermal alteration is a complex process that includes mineralogical, chemical, and textural changes resulting from the interaction of hydrothermal solutions with the rocks through which they pass under certain chemical-physical conditions [15]. Alteration is closely related to mineralization. Tin mineralization involves the precipitation of cassiterite (SnO_2) from late-stage magmatic fluids during the intrusion of granitic bodies into the upper crust. This process typically results in the formation of primary tin-bearing minerals hosted within vein systems, stringers, or disseminated layers. [16].

Previous studies, such as research conducted in the Paku area of Payung District, South Bangka, indicate that tin mineralization in this region primarily occurs as vein-filling and disseminated deposits. High Sn content is also found in compressed veins and is present in the form of cassiterite minerals in hydrothermal breccias [17]. Furthermore, in the Rengas area (Bencah Village, Air Gegas District), tin deposits originate from S-type syeno-granite and sandstone host rocks [18]. Investigations into the primary mineralization here reveal a greisen-type deposit, where geological structures are the predominant factor driving alteration and mineralization. These processes are controlled by a network of fractures and faults, with the primary mineralization occurring as greisen deposits during the vein deposition phase [19].

METHODOLOGY

The research methodology involves direct geological mapping to collect primary lithological and structural data, complemented by laboratory analyses to characterize the mineralogical and physical properties of the collected samples. Geological observations included rock descriptions, observing the physical properties of rocks in petrology, and collecting rock samples for analysis. A total of 36 samples were observed from the outcrops. The field investigation utilized standard geological instrumentation, including a geological hammer, a geological compass, a tape measure, a magnifying glass, sample bags, books, recording equipment, and a cell phone camera for field documentation. Structural data, specifically focusing on fault planes and joint sets, were measured and recorded alongside photographic documentation to ensure a comprehensive geological record. Laboratory analyses included petrography using thin sections, portable XRF using intact samples from the field, mineragraphy using polished sections, and XRD analysis using field rock samples.

Petrographic analysis was performed using a polarizing microscope to determine the mineralogical composition and textural characteristics of the rock samples. Petrographic analysis serves as a critical complement to X-ray diffraction (XRD); while XRD provides definitive mineral identification, petrography characterizes the textural relationships and spatial distribution of those minerals. This integrated approach allows for the cross-verification of mineralogical data, ensuring a more accurate interpretation of the sample's composition. [20]. Portable X-Ray Fluorescence (pXRF) analysis is a critical tool in geological research for determining the concentration of major and trace elements in rocks, minerals, and sediments, including tin. The technique relies on the emission of characteristic secondary X-rays from a material that has been excited by an external radiation source. [21]. XRD (X-ray Diffraction Analysis) analysis to determine the alteration minerals in rock samples. Mineragraphy analysis is an analysis method that aims to identify the types of metal and non-metal minerals, one of which is cassiterite (SnO_2) [22].

RESULTS AND DISCUSSION

This research was conducted in a location covered by PT Timah Tbk mining business permit, in Terap Village, Tukak Sadai District, South Bangka Regency, Bangka Belitung Islands Province (Figure 2).

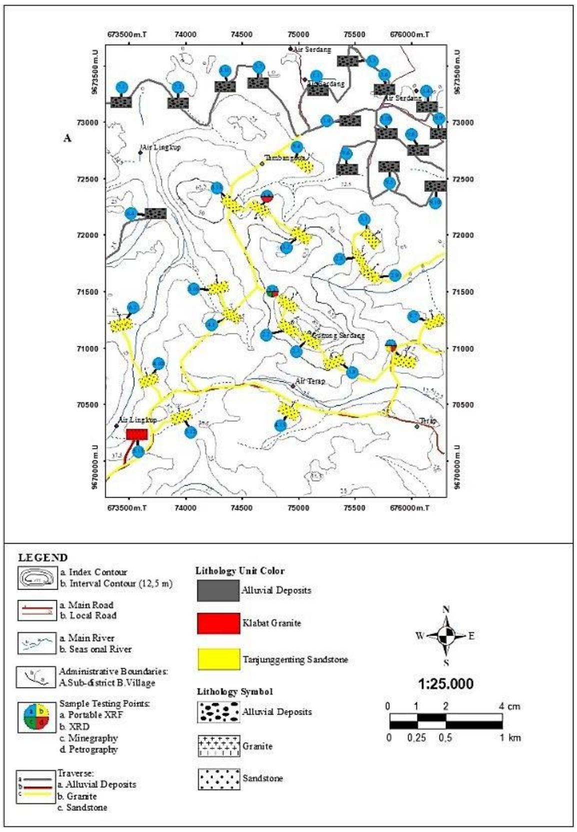

Figure 2. Observation map and sampling locations

The stratigraphy of the study area was determined from field data related to the rock units encountered. Based on field conditions, these rock units are divided into several units: the Tanjung Genting Sandstone Unit, the Klabat Granite Intrusion Unit, and the Alluvial Sediment Unit (Figures 3 and 4). Mineral-bearing vein samples were found in the study area. These vein samples were analyzed to confirm the presence of cassiterite, the tin-bearing mineral. Other minerals, such as clay minerals, are also found to support the study.

Based on the field results obtained in the form of rock samples, petrographic analysis was conducted, providing petrological descriptions. he elemental tin concentrations identified via pXRF provided the geochemical basis for selecting samples for subsequent X-ray diffraction (XRD) and mineragraphic analysis. This sequential approach ensured that the mineralogical investigations were targeted toward zones of known mineralization.

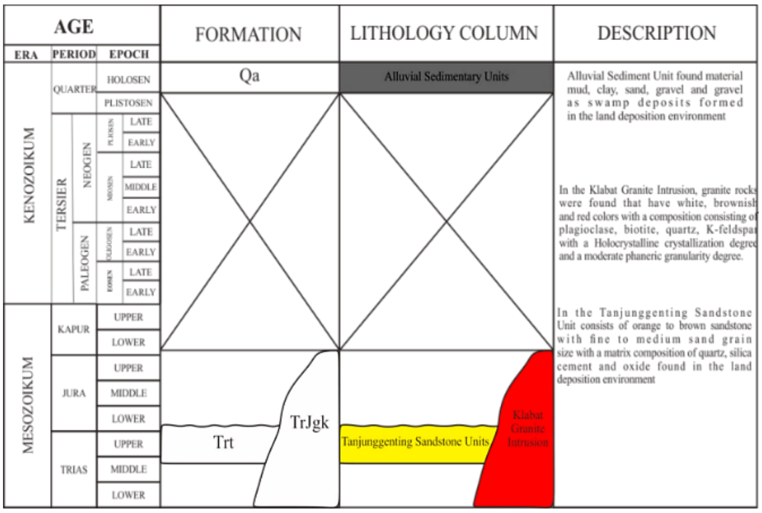

Figure 3. Stratigraphic column of the research area

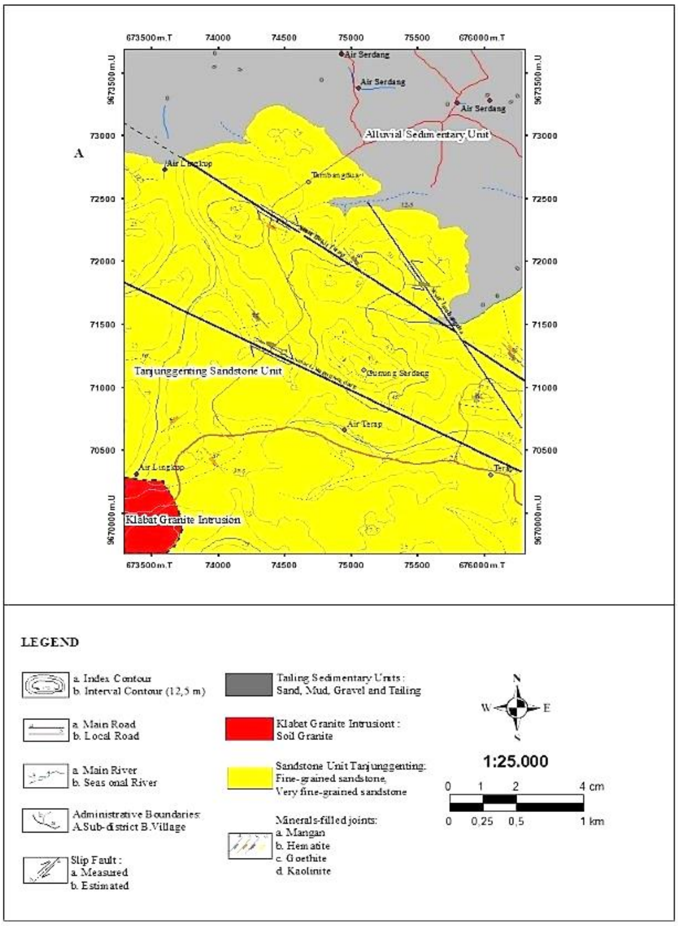

Figure 4. Geological map of the research area

Petrography

Petrographic analysis was conducted on thin sections using a polarizing microscope. At observation point TR 2.1, the Tanjung Genting Formation is characterized by a white, fine-grained sedimentary rock (grain size 0.0625–0.125 mm). The sample exhibits a well-sorted texture with interparticle fabric-selective porosity. Mineralogical composition includes quartz, limonite, and hornblende. According to the Pettijohn (1987) classification, the rock is identified as a Quartz Wacke [23].

At observation point TR 10.1, petrographic analysis of the Tanjung Genting Formation reveals a brownish-white sedimentary rock. As shown in Figure 6, the sample exhibits a grain size distribution ranging from medium sand (0.25–0.5 mm) to very fine sand (0.0625–0.125 mm). The rock is well-sorted with interparticle fabric-selective porosity. It is mineralogically composed of quartz, plagioclase, K-feldspar, and clay minerals (predominantly kaolinite). Following the Pettijohn (1987) classification, this rock is identified as a Lithic Wacke [23].

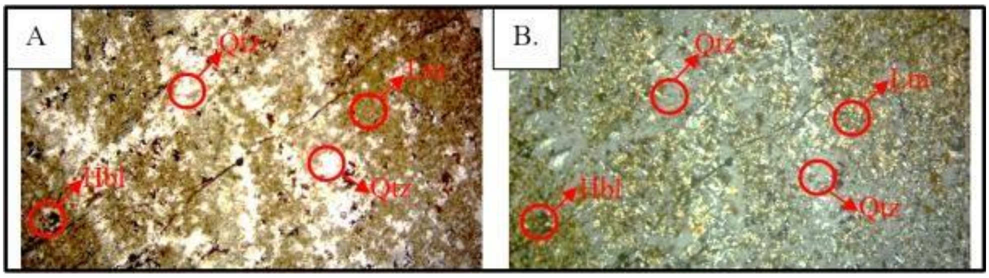

Figure 5. Petrographic analysis results of Tanjung Genting sandstone TR 2.1 (a. PPL, b. XPL).

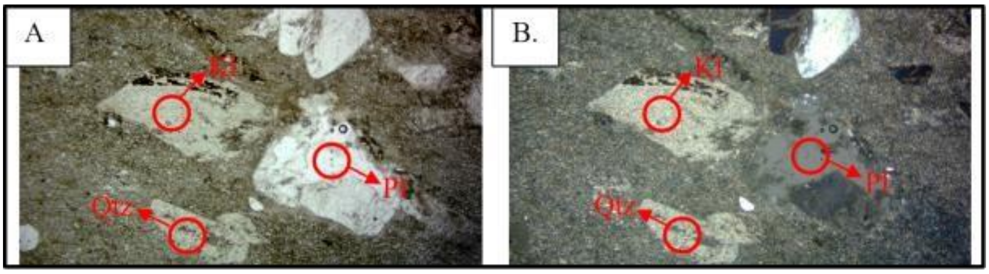

Figure 6. Petrographic analysis results of Tanjung Genting sandstone TR 10.1 (a. PPL, b. XPL).

Alteration

The argillic zone alteration group is characterized by the presence of muscovite + kaolin minerals. The type of rock that experiences this alteration is sandstone with strong alteration intensity, with a distribution pattern in one place. The intensity of this alteration can be seen from the rock body, which experiences total changes in the main minerals into alteration minerals. A clear color change in minerals indicates a high degree of alteration. Field observations reveal that the primary pink K-feldspar crystals have undergone partial alteration to grayish-white kaolinite. This pseudomorphic replacement is indicative of argillic alteration, likely driven by the circulation of acidic hydrothermal fluids within the granitic source rock. This color change can be very striking and even throughout the rock body or vein. Rocks that were initially hard or solid become more fragile or easily destroyed due to alteration, and this indicates the presence of strong alteration intensity (Figure 7).

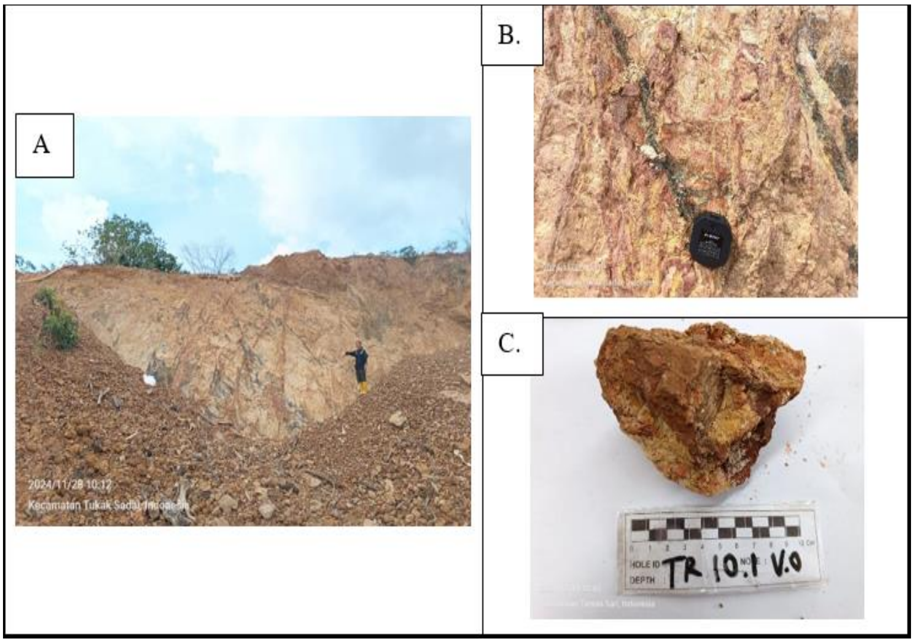

Figure 7. Appearance of hydrothermal alteration in the TR 10.1 research area (a. Distant photo of the outcrop, b. Close photo of the outcrop, c. Photo of samples taken to clarify the description of the alteration minerals).

Muscovite has a hardness of 2.5 on the Mohs scale. Muscovite is white to colorless. Kaolin has a hardness of 2–2.5 and is a milky white with a waxy luster formed from aluminum silicate of feldspar. Goethite has a hardness of 5–5.5 on the Mohs scale. Goethite is black to grayish in color and is the result of the weathering of various minerals. The alteration process that occurs causes the sandstone unit to change its nature to become more compact or hard. This alteration process causes changes in the color of the minerals that are visible in their distribution.

The following are the results of the XRD analysis of two samples, TR 10.1.1 and TR 10.1.3. The analysis results in Figure 8 show the presence of goethite, quartz, kaolinite, muscovite, and illite. These minerals serve as reference alteration minerals in the study area.

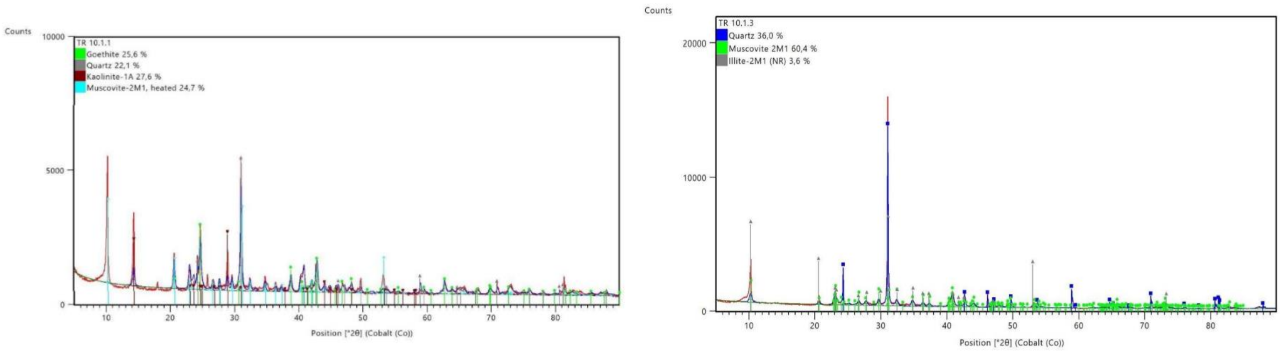

Figure 8. X-ray diffraction (XRD) patterns for samples TR 10.1.1 and TR 10.1.3, identifying the characteristic alteration mineral assemblages within the study area.

Mineralization

Mineralization in the research area is generally associated with the presence of veins. Identifiable mineralization is cassiterite mineralization in goethite veins in field rock samples. The portable XRF analysis results in

Table 1 show the tin content of several samples analyzed. This indicates the presence of mineralization in the form of veins in several samples with high tin content. The size of these mineral-filled veins varies widely, ranging from less than a millimeter to several meters. Cassiterite minerals are present in various colors, ranging from brown, gray, and black to pink. It can be seen from its luster, which shows the luster of diamonds, making the surface of the cassiterite mineral look shiny like a jewelry stone. A tin mineral can be said to be economical for further exploration if its content is 0.1% which is equivalent to 1000 ppm.

At the research location at TR 2.1, rocks were found with a tin (Sn) content of 2183 ppm, as known from the results of portable XRF analysis. Rocks with high content are the benchmark for analysis. In addition to portable XRF analysis and supporting mineragraphy data, cassiterite mineralization was found at observation point TR 2.1. The mineragraphy analysis results indicate the presence of Cassiterite as a tin-bearing mineral (Figure 9).

Table 1. Portable XRF analysis results at several sampling location

Observation Point	Tin Level (Sn)
TR 1.4	201 ppm
TR 2.1	2183 ppm
TR 2.3	1810 ppm
TR 2.6	1373 ppm
TR 3.1	239 ppm
TR 3.4	198 ppm
TR 4.10	35 ppm
TR 5.8	0 ppm
TR 7.2	0 ppm
TR 9.6	597 ppm

Cassiterite with a light gray color is replaced by arsenopyrite. Cassiterite is present in euhedral form. The oxidation stage produces hematite in rock samples. Pyrite is cubic in shape, which is still left and partially replaced by arsenopyrite. Pyrite is golden yellow in color. Pyrite is present in subhedral form because some of its mineral body has been replaced by another mineral, arsenopyrite. Arsenopyrite is present in subhedral form because it is covering or replacing the pyrite mineral in the rock sample.

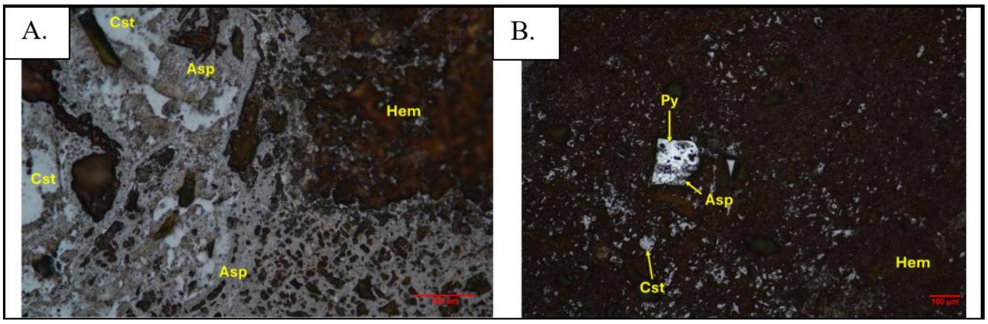

Figure 9. Mineragraphy of sample TR 2.1, representing the zone of highest tin (Sn) concentration. The image illustrates the occurrence of Cassiterite and its textural relationship with associated sulfide or gangue minerals.

Goethite Veins

Veins are fractures or cracks in rock that are then filled with minerals precipitated from water solutions. The size of these mineral-filled veins varies widely, from less than a millimeter to several meters. In the research area, goethite veins were observed, forming continuous black lines. Goethite veins are often yellowish-brown to black in color, and this color is clearly visible in the field. Goethite veins appear as layers that fill cracks in the rock.

In the TR 2.1 Research Area on the observation and sampling location map, the veins found in the research area are goethite veins with position data of N 230º E/70º. These veins are associated with sandstone that has undergone alteration and mineralization processes. Geochemical characterization via portable XRF reveals that goethite veins represent the highest grade of mineralization in the study area, with tin (Sn) concentrations reaching 2183 ppm (Figure 10). The presence of such significant Sn levels within iron oxyhydroxides suggests that these veins may be the oxidized products of primary iron-tin mineral assemblages.

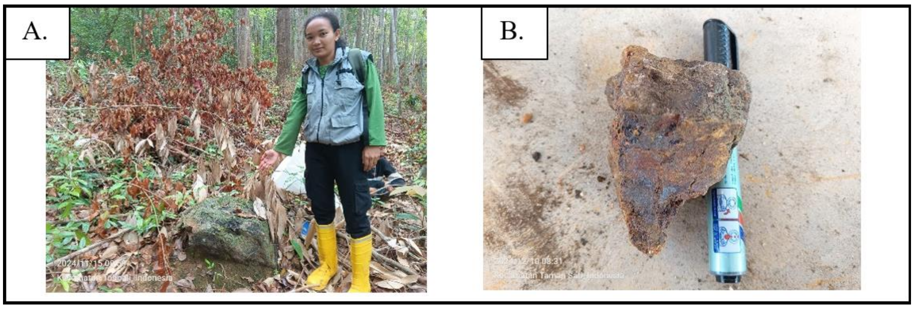

Figure 10. Appearance of goethite veins in TR 2.1 location.

Banded Goethite

Banded goethite is a continuous, elongated opening filled with hydrothermal solution; the opening is in the form of a layered vein texture. Banded goethite is yellowish brown or even black, alternating between light and dark colors. Banded goethite has layers that are neatly grouped. Banded goethite in the TR 4.1 research area on the observation and sampling location map with position data N 290º E/45º. Banded goethite is associated with sandstone that has undergone alteration and mineralization processes. Tin concentration in banded goethite reaches 57 ppm (Figure 11).

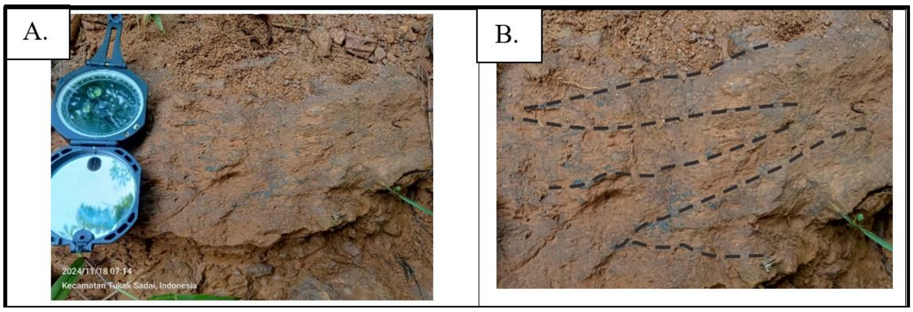

Figure 11. Appearance of banded goethite in TR 4.1 location

Referring to Corbet & Leach (1998) [24], the results of field data and analysis carried out, mineralization in the research area is generally associated with the presence of veins filled with hydrothermal solutions that enter through cracks in the rock body, and this is comparable to mineralization.

Primary Tin Deposits Types

Synthesizing the field data, mineralization in the study area is structurally hosted within vein systems. These are classified as a greisenization system developed within aluminosilicate-rich wall rocks (Figure 12). Aluminosilicates consist of rocks that have acidic properties or high levels of aluminum and silica. The lithological framework of the Terap Village area comprises the Tanjung Genting sandstone as the primary host (wall rock) and granite as the source rock. The mineralizing system is characterized by an ore assemblage of cassiterite, hematite, and goethite, which is genetically associated with a hydrothermal alteration suite of muscovite and kaolinite. Furthermore, both the granitic and sedimentary units exhibit significant overprinting by tropical weathering processes, influencing the current surface distribution of the tin-bearing minerals. To determine the type of side rock, the minerals found in the samples in the research area were examined. The samples from the research area were identified as quartz and muscovite, which indicates the type of wall rock, aluminosilicate rocks.

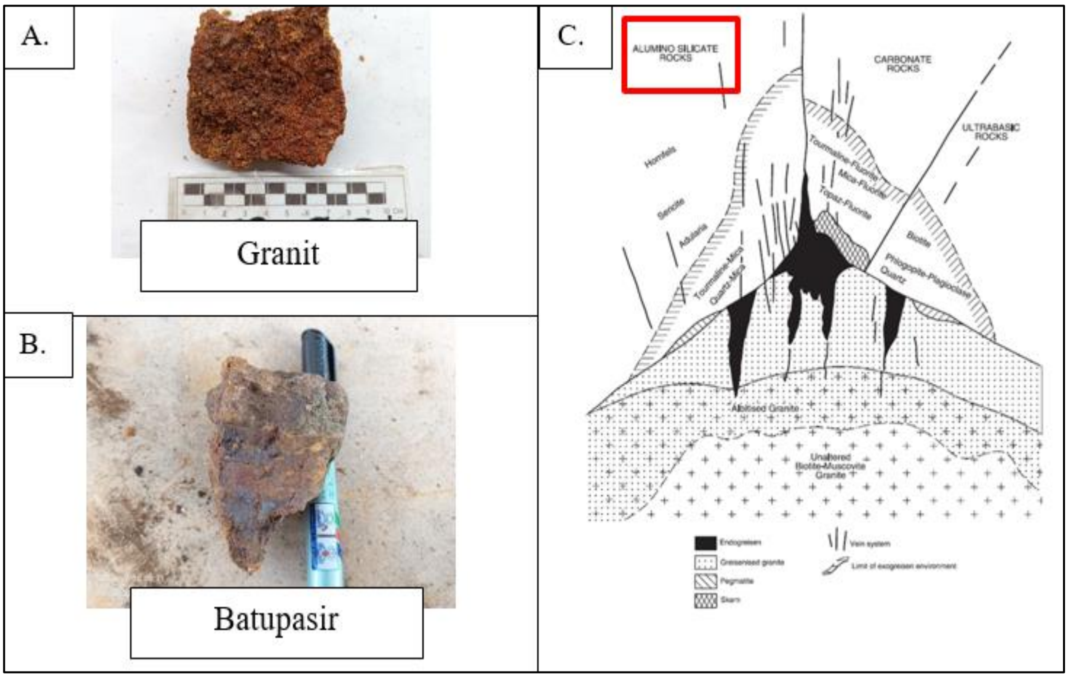

Figure 12. Schematic representation of primary tin mineralization styles within a greisenization system, illustrating the variation in deposit morphology across different host rock lithologies [25].

Lithology controls mineralization through the interplay of source and host rocks. Within the study area, granitic intrusions acted as the thermal engine and fluid source, driving the hydrothermal alteration system. In contrast, the sandstones served as the primary host rocks, offering the necessary chemical and physical conditions for mineral deposition.

Distribution of Sn Anomaly

The distribution of tin anomalies in the research area is almost even. The levels of tin (Sn) metal elements were obtained using the Portable XRF analysis method at all outcrops in the research area. The identified tin anomalies are genetically linked to hydrothermal vein systems and their associated lithological carriers. Both the granitic source rock and the Tanjung Genting sandstone function as the primary tin-bearing units, hosting the mineralization within a framework of structurally controlled veins. From the results of the Portable XRF analysis made on the Sn anomaly map, the highest levels were found in Bukit Terap (Figure 13). On the Sn anomaly map, the lowest Sn content in ppm is symbolized by a round shape measuring <100 ppm, while the highest

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content is symbolized by a hexagonal shape measuring >700 ppm. The highest Sn anomaly level was obtained at the TR 2.1 observation point with a level of 2183 ppm. This tin anomaly level is included in the economic value of tin minerals, because 2183 ppm is equivalent to 0.2%. The highest Sn anomaly levels are associated with veins that are filled with cassiterite minerals.

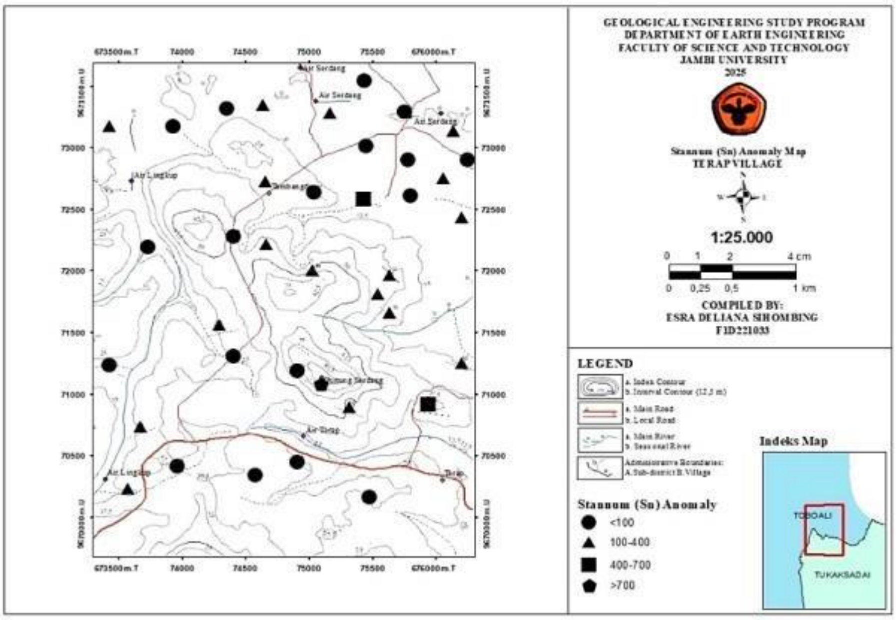

Figure 13. Distribution of tin (Sn) anomalies in the research area

Geological Control of Mineralization

In the research area, geological structure control affects mineralization. Geological structure affects the formation of fractures as gaps for hydrothermal fluids that form veins. Veins in the research area have a Northwest - Southeast direction. Veins with a Northwest-Southeast straightness pattern are the veins that were formed first, with a composition of cassiterite, hematite, and kaolin minerals (Figure 14).

The veins with a northwest-southeast alignment were formed due to the filling of hydrothermal fluids that filled the weak zone, which was formed together with the initial phase of the formation of Klabat granite. This process forms a structural opening that is classified as a syn-mineralization phase. The syn-mineralization phase is the process which mineral formation occurs. In the research area, the control of the geological structure that occurs affects the formation of the alteration zone as a place for the exit of hydrothermal fluids through fractures in the form of veins.

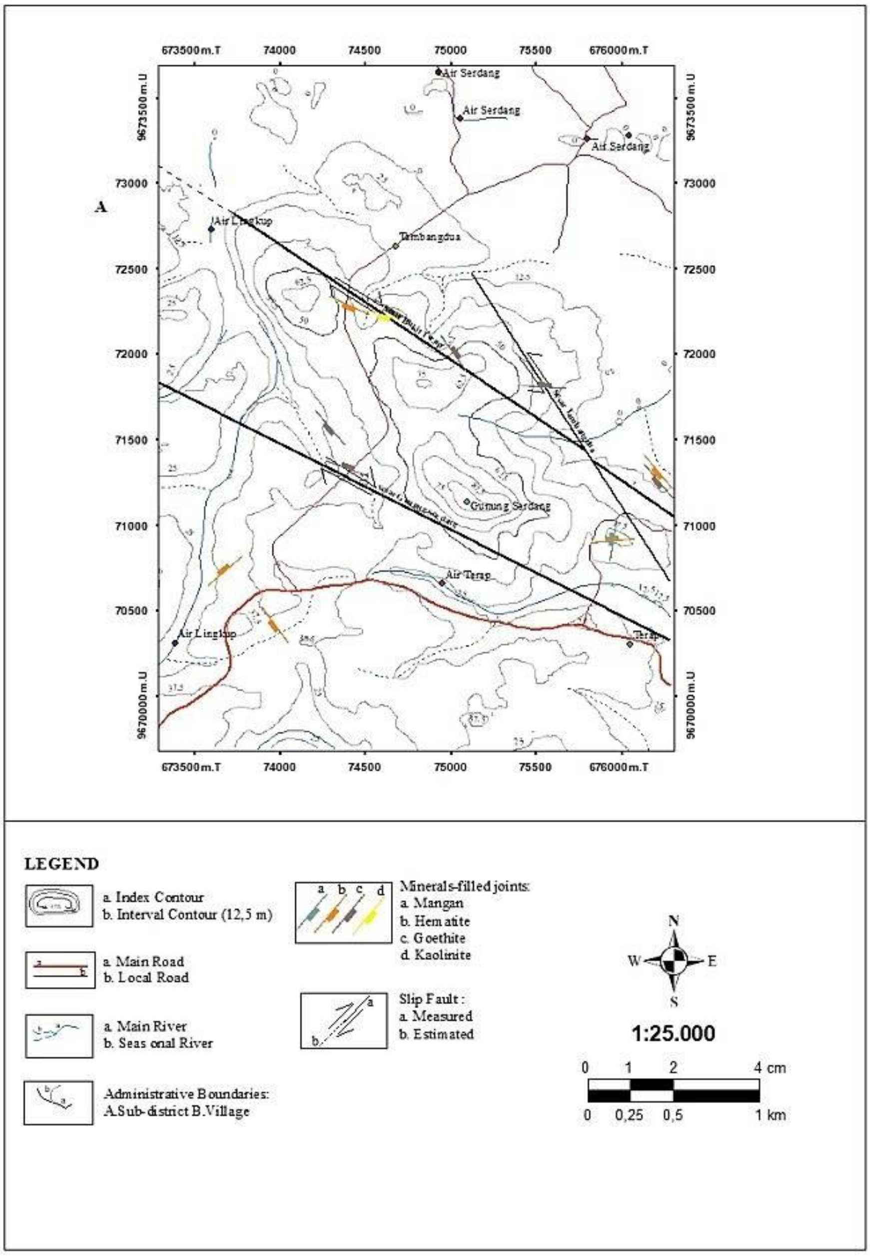

Figure 14. Map of the structure of the research area

CONCLUSION

The research results concluded that the geology of the study area identified three rock units: the Tanjung Genting Sandstone Unit, the Klabat Granite Intrusion Unit, and the Alluvial Sedimentary Unit. Mineral-filled veins were also found. Mineralization in the Tanjung Genting Sandstone is in the form of goethite veins and banded goethite. The type of alteration of mineralization in the research area was found to be an argillic deposit type with the Muscovite + Kaolin mineral group, where this argillic deposit type was found to be spread across the research area. Meanwhile, the greisenized deposit type with the Cassiterite + Hematite mineral group was found only in the mineralization zone with the highest Sn element content obtained in the research area. In the research area, Tanjung Genting Sandstone is the host rock of mineralization, and Klabat Granite Intrusion is the source rock of mineralization.

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