Characteristics of chromitite mineralization in Sebuku Island based on thin section, polished section, and geochemical data

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Abstract. Sebuku Island is located in Kotabaru Regency, South Kalimantan and is known as one of the main sources of laterite iron in Indonesia. Based on its tectonic setting, Sebuku Island is located within the suture zone that connects Southwest Borneo Block (SWB) and East Java West Sulawesi Block (EJWBS). Due to its tectonic setting, Sebuku Island is composed of various rocks associated with suture zone, such as ophiolite rocks. The ophiolite rocks could host mineralization that occurred in Sebuku Island. The aim of this study is to determine the characteristics of lithology and mineralization as determinants of geological processes that influence the formation of rocks and mineral deposits in Sebuku Island. This study was carried out through petrological, petrographic, ore microscopy analysis, and geochemical analysis (x-ray fluorescence). 22 rock samples from Sebuku Island were collected and the result of this research shows that the chromite host rocks are composed of serpentinitized dunite and serpentinite. Chromite minerals (FeCr₂O₄) were found in massive forms with cataclastic, brecciated texture and disseminated with pull-apart texture. Based on observation of the polished sections, it is known that the associated mineral of chromite is magnetite which is an alteration of chromite minerals. Chromitite chemical data shows the chromite composition is Al-rich (Cr# = 0.6) and classified as podiform chromitite formed by fractional crystallization. There are two magma series of igneous rock in the study area i.e. tholeiitic series consisting of ultramafic-mafic rocks and calc-alkaline consists of micro-diorite. The abundance of Al₂O₃ and TiO₂ in chromitite shows that Al-rich chromitite has formed in Supra Subduction Zone (SSZ) and has occurred near or above the Moho-transition zone.

Keywords: Sebuku island, meratus, suture zone, ultrabasic, chromitite, mineralization

1. Introduction
Sebuku Island is an island located in Kotabaru Regency, South Kalimantan. Sebuku Island is part of the Meratus ridge framework or tectonic setting [1] as a result of tectonic events that lasted from jurassic to early tertiary [2]. Based on regional stratigraphy in the study area, there were Mesozoic ultramafic-mafic rocks consist of basalt lava, harzburgite, dunite, serpentinite, gabbro, basalt and serpentinitized pyroxenite [3]. Mafic-ultramafic rocks in Sebuku Island are part of an ophiolite sequence.

The potential of iron ore minerals in Sebuku Island in the form of laterite deposits [4] shows the presence of chromite mineralization. In addition, some ultramafic rock samples obtained from Sebuku
Island show lateral mineral chromite accumulation which is a product of magmatic crystal settling. This feature is common in chromite deposits which are the result of orthomagmatic mineralization processes. Chromite (Mg, Fe$^{2+}$) (Cr$^{3+}$, Al, Fe$^{3+}$) is a spinel-group mineral and it is the only mineral that is a source of chromium (Cr) [5]. Chromium is most important used in stainless steel, chromium plating and nonferrous alloys [5]. Scientific research in Sebuku Island which focuses on chromite mineralization is still relatively small, so a study was conducted to find out the association of rocks in Sebuku Island with chromite mineralization. The aim of this preliminary study was to determine the characteristics of chromite host rocks, chromite mineralization, type and genesis of chromitite deposits on Sebuku Island. The results of this study are expected to be useful in further exploration activities in the local area of Sebuku Island and in other areas with the same tectonic conditions.

2. Geological background
The research area is located in Sebuku Island, South Kalimantan. Based on the Indonesian physiographic map of scale 1:10,000,000 by the Geological Agency [6], the study sites belong to the physiographic zone of hilly areas with separate hilly morphology. According to Rustandi et al. [7] in the geological map of the Kotabaru on a scale of 1:250,000, a Sebuku Island is part of Ultramafic Rock (Mub), Haruyan Formation (Kvh), Pitap Formation (Ksp), Tanjung Formation (Tet) and Alluvium (Qa).

Tectonic activity in Sebuku Island is thought to have been going on since jurassic [7]. Started from the subduction of the meso-tethys oceanic plate beneath the southeastern continental plate of Eurasia (SE Sundaland) during pre-tertiary [8]. Subduction continued until the occurrence of Paternoster microcontinent plate collisions with the southeast Sundaland boundary [9]. This collision event causes the oceanic plate (ophiolite) obducted to the SE Sundaland boundary and at the present time, it can be found in Meratus Range. In Late Cretaceous magmatism activity occurred in the Meratus zone due to the subduction of oceanic plates located at the southeast of the Paternoster microcontinent plunged down the Paternoster microcontinent [8]. This process caused diorite intrusion (Kdi) which intrudes the bottom of the pitap formation (Ksp) [7]. In Late Miocene, a tectonic event led to the uplift of the almost whole Mesozoic rocks, then forming Meratus ridge [7].

3. Methodology
The rock samples used in this study were obtained from Sebuku Island. As many as 20 rock samples were prepared into thin sections, 3 rock samples were prepared into polished sections and 11 rock samples were milled and mashed for geochemical analysis.

The method of this research was carried out through laboratory analysis which consists of petrology, petrography, ore microscopy, and geochemical analysis. Petrology analysis is the macroscopic observation of rock samples and is intended to know the characteristics and types of rock samples. Petrography analysis were carried out by observing thin sections under a polarizing microscope and intended to determine the compositions and characteristics of minerals in rocks that are useful in naming rocks. Microscopic observation of thin sections was carried out at the Petrographic Laboratory in the Geoscience Department Universitas Indonesia.

Ore microscopy analysis was performed on polished sections under reflection microscope and was intended to determine the type and characteristics of ore minerals in rock samples. This microscopic observation of ore minerals was carried out at the Laboratory of Petrology and Mineralogy at Geology Engineering Trisakti University. The geochemical analysis was carried out using the X-Ray Fluorescence (XRF) method and testing was carried out on rock samples in the form of compacted or pressed powder. The elements used for this geochemical analysis are Cr$_2$O$_3$, SiO$_2$, TiO$_2$, Al$_2$O$_3$, Fe$_2$O$_3$, FeO, MnO, MgO, CaO, Na$_2$O, K$_2$O, P$_2$O$_5$, Cr, Al, Fe$^{3+}$ dan Fe$^{2+}$. These elements are plotted on the related diagram using "Petrograph" software. Fe$^{3+}$ dan Fe$^{2+}$ values are obtained based on spinel calculations using "Gabbro software 2011" [10]. XRF analysis was carried out at the UPP IPD Research Laboratory at Universitas Indonesia.
4. Results and discussion

4.1. Petrology and petrography

Most of the igneous samples obtained from Sebuku Island have undergone serpentinization, among them are serpentinized dunite, serpentinized harzburgite, and serpentinite. In addition, other igneous rocks are chromitite (high-grade chromite ore), basalt, and micro-diorite (figure 1).

Generally, serpentinized dunites have green fresh colors and weathered brown colors, consists of serpentine (±70%), olivine (±20%), chromite ore (±20%) and opaque (±3%) minerals. The general texture of serpentinized dunite is mesh texture, which shows that serpentine has replaced olivine minerals (figure 1a). Unlike serpentinite, it has a honey-comb texture which indicates that the olivine minerals have been completely replaced (figure 1b). It consists of serpentine (±85%) and opaque (±15%) minerals. In serpentinized harzburgite, it contains relict olivine (±35%), orthopyroxene (±23%), clinopyroxene (±7%), serpentine (±30%), and opaque (±5%) minerals (figure 1c). Serpentine minerals in this rock have a mesh and bastite texture. The bastite texture shows that the serpentine minerals in this rock have replaced the pyroxene minerals. Each of rock samples obtained from Sebuku Island represents the geological rock formation in Sebuku Island, ultramafic rocks samples including basalt represents Ultramafic Rock (Mub) formation and micro-diorites represents Intrusion Diorite (Kdi) [7].

![Figure 1](image-url)

**Figure 1.** Photomicrograph of ultramafic and mafic rocks obtained from Sebuku Island, (a) serpentinized dunite, (b) serpentinite, (c) serpentinized harzburgite, (d) chromitite, (e) basalt and (f) micro-diorite. Abbreviations: Cr: Chromite, Srp: Serpentine, Opk: opaque, Opx: orthopyroxene, Cpx: clinopyroxene, Olv: olivine, Plg: plagioclase, Cal: calcite, Qtz: quartz.
4.2. Chromite mineralization

4.2.1. Chromite texture. There are two rock samples that show chromite mineralization, that is serpentinized dunite and chromitite. The term chromitite is used when the chromite content in rocks exceeds 30% (monomineralic chromite) [11]. The chromite mineral has a grain size range from 0.1 mm to more than 5 mm and present. In chromitite, chromite minerals are present in massive forms and have cataclastic and brecciated texture (figure 2a). While in serpentinized dunite, chromite minerals were found to be disseminated and have a pull-apart texture (figure 2b to figure 2d).

4.2.2. Composition of chromite. Based on the geochemical analysis that has been done, it is known that chromitite samples contain oxides consisting of Cr2O3 (40.24 wt %), Al2O3 (18.21 wt %), MgO (21.88 wt %), Fe2O3 (11.94 wt %), SiO2 (6.39 wt %), MnO (0.45 wt %). The results of plotting chromitite chemical data on the spinel classification diagram [12] show that the elemental content in chromitite approached the chromite mineral point with chemical formulas FeCr2O4 (figure 3) [3]. Based on the results of plotting on the binary diagram of Cr# versus Fe2+# [13], the chromitite of Sebuku Island is a podiform deposit type and classified as Al-rich with Cr# = 0.6 and Fe2+# = 0.29. This result is compared with the chemical data of Cuba complex podiform chromite deposits which also has Al-rich chromitite (minimum Cr # = 0.45) (figure 4a). Based on the results of plotting on the ternary diagram the ratio of Cr-Al-Fe3+ [13], the chromitite at Sebuku Island classified as podiform chromite type as well as podiform chromite deposits in Cuba Complex (figure 4b). The results of plotting on the binary diagram of Cr2O3 vs Al2O3 [13] showed that the chromitite of Sebuku Island was included in the stratiform deposit type, that is because the Sebuku Island chromitite is Al-rich with a Cr2O3 content is less than 50 wt % and Al2O3 more than 15 wt % (figure 4c). The chromitite composition of Sebuku Island is almost the same as some chemical compositions in Sulawesi's podiform chromitites although most of them belong to the type of podiform deposits. (figure 4c). The content of Sebuku Island chromitite TiO2 is low (0.17 wt %), which is a characteristic of podiform chromitite deposits (figure 4d).

4.2.3. Fractional crystallization and magma affinity. In the AFM diagram (figure 5a), serpentinized dunite and harzburgite are included as metamorphic peridotite and ultramafic cumulate ophiolite, whereas basalt is almost included in ultramafic cumulate ophiolite [14]. The evolution of magma is represented by a trend formed from the three rocks (serpentinized dunite, serpentinized harzburgite, and basalt). This trend is the expected result of fractional crystallization which involves removing the initial crystallization of olivine and pyroxene from the tholeiitic basaltic liquid [1]. The results of plotting rock samples in the AFM [15] and Harker diagram [16] show the affinity of magma rocks, serpentinized dunite, serpentinized harzburgite, chromitite, and basalt classified as tholeiitic and micro-diorite classified as calc-alkaline (figure 5a and figure 5b). There is an anomaly in one of the micro-diorite samples, this is because it has a higher Mg content (figure 5a).

4.2.4. Implication of tectonic setting. Based on the ternary diagram of TiO2-K2O-P2O5 [2] to distinguish oceanic and continent rocks, it shows that basalt and chromitite classified as oceanic rocks, whereas micro-diorite classified as a continental rock (figure 6a). In the ternary diagram of TiO2-MnOx10-P2O5x10 [17] which distinguish between mid-oceanic ridge basalt (MORB), oceanic-island tholeiite, oceanic island alkalic, island arc tholeiite, island arc calc-alkaline basalt, and boninite show that basalt is included in the island arc tholeiite field and micro-diorites included in the island arc calc-alkaline field. Ultramafic rocks have very low content of TiO2 and P2O5 so that the sample shifts towards MnO and included in boninite zone (figure 6b).

Tectonic setting information can also be known from the results of the chromitite geochemistry based on the abundance of Al2O3 and TiO2 in the binary diagram by [18] (figure 7). Based on the results of the plotting of chromitite composition (figure 7a), it is known that the sample is included in the Chromite Supra Subduction Zone (SSZ). The diagram in figure 7b shows that chromitite belongs to the supra-Moho. Chromitite obtained from Sebuku Island is classified as Al-rich, which generally identical to the
tectonic setting of mid-oceanic ridge basalt (MORB), but chromitite has been found in many parts of the world with different compositions in the same environment of ophiolite complex. This could occur, partly because of the mechanism of magma differentiation which allows for the composition of different chromite formed in short periods of time with close distances.

Based on research conducted by Wijaya [19], chromitite with Al-rich and Cr-rich composition was found in Sebuku Island. It is well known that the ophiolite complex in Sebuku Island is not too grand and the length of the island itself is less than 34 km, so it is known that Cr and Al-rich chromite are formed at close distances. Therefore, from both of these diagrams show that chromitite formed in the SSZ and suspected was derived from boninitic magma which has differentiated through crystallization fractional and magma mixing process to produced Al-rich chromitite and formed near or above the supra-moho zone.

Figure 2. Photomicrograph of chromite ores under reflected light, A. massive chromite with brecciated texture and B. disseminated chromite with pull-apart texture; C and D are photomicrograph of chromite ores with pull-apart texture under a polarization microscope.

Figure 3. Plotting of elements in chromite ore obtained from Sebuku Island on the classification of spinel minerals diagram.
Figure 4. (a) Binary diagram of Cr\# = Cr/(Cr + Al) vs Fe\(^{2+}\)# = Fe\(^{2+}\)/ (Fe\(^{2+}\) + Mg) [13], (b) Ternary diagram of atomic ratios Cr-Al-Fe\(^{3+}\) [13], (c) Negative correlation of Al\(_2\)O\(_3\) vs Cr\(_2\)O\(_3\) [13] and (d) Binary diagram of TiO\(_2\) vs Cr\(_2\)O\(_3\) [13], with P: podiform chromite, S: stratiform chromite, Sulawesi chemical data [13], Cuba chemical data [20].

Figure 5. (a) AFM ternary diagram (A = Na\(_2\)O + K\(_2\)O, F = FeO\(_{\text{total}}\), M = MgO), the trend of the differentiation of tholeiitic and calc-alkaline magmas [15], the field of cumulate ophiolite and metamorphic peridotite [14] and (b) Harker diagram FeO\(_{\text{total}}\)/MgO versus SiO\(_2\) [16].
5. Conclusion
The igneous rocks obtained from Sebuku Island consists of chromitite, serpentinized dunite, serpentinized harzburgite, and basalt which are part of an ophiolite sequence and derived from tholeiitic magma series, whereas micro-diorite represents a calc-alkaline intrusion that happened in Late Cretaceous. Chromite mineralization has occurred in serpentinized dunite and serpentinite. The chromitite obtained from Sebuku Island is a podiform deposit type and classified as Al-rich. Chromitite deposit in the supra-subduction zone and derived from boninitic magma which has differentiated to produced Al-rich chromitite and formed near or above the supra-moho zone.

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