RGNZ/MGPB

An Update to the Geology of Sebuku Island, South Kalimantan, Indonesia: Constraints From Petrological Studies

Rudarsko-geološko-naftni zbornik
(The Mining-Geology-Petroleum Engineering Bulletin)
UDC: 551.1/.4
DOI: 10.17794/rgn.2024.5.9

Preliminary communication

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Abstract
Sebuku Island is located at the southeastern tip of Kalimantan Island and has geological similarities with the Bobaris-Meratus complex in distribution pattern and stratigraphic sequence. The pattern of straightness of geological structures between the two, both folds and faults, is generally directed from northeast-southwest to northwest-southeast. The previous geological research on Sebuku Island focused on the distribution of ultramafic rocks, which are speculated to contain iron, particularly from laterite soils. This research aims to determine the rock units in the study area to update the geological map of Sebuku Island, especially in the Sei Pinang and Halaban areas.
The research method consists of fieldwork, laboratory analyses, and data analyses. The geological fieldwork collected 34 samples from detailed mapping on outcrops, trenching, and drilling. Geological structure observations were carried out on fresh outcrops and measured 57 structural geological elements from 6 locations. Petrographic analysis of 34 samples was carried out with the aim of determining rock type and mineralogical composition. Stereographic analysis of geological structure measurement data was used to define the general direction and type of geological structures in the investigated outcrops. The geological map is constructed on the basic topographic map in the scale 1:50,000 using MapInfo Pro v17.0.5.
Based on petrographic observations and detailed field observations, especially in North Damar, from surface outcrops and drill core observations from Madang, the following results are revealed. In the geology of North Damar, in particular, and Sebuku Island, in general, the lithology can be described as an ultramafic rock unit (lherzolite, harzburgite, and dunite), pyroclastic rock unit (crystallo-lithoclastic tuff and crystalloclastic tuff), limestone unit, dike rock unit (microgabbro and diorite), sandstone unit, and alluvial deposit.
Almost 60% of Sebuku Island outcrops belong to the ultramafic rock units, which are tectonically covered by crystalline lithic tuff and crystalline tuff and volcaniclastic rock units with interbedded limestone, unconformably covered by sandstone units, alluvial deposits, and swamp deposits. Microgabbro and diorite were observed from the drill core and were not exposed to the surface. Hydrothermal mineralization is indicated by quartz veins cross-cutting the pyroclastic rock group observed in drill cores. This research shows a more detailed geological description of the study area compared to previous research and regional geological map.

Keywords:
Sebuku Island; ultramafic; pyroclastic; microgabbro

1. Introduction

Sebuku Island, with an area of 35 x 12 km^2 extending northwest-southeast, is located at the southeastern tip of Kalimantan Island. The undulating characterizes the island with gently sloping plains morphology and the strait separates it from Laut Island. Sebuku Island has geological similarities with the Bobaris-Meratus geological complex, such as its distribution pattern and stratigraphic sequence. Some rock units or formations not found on Sebuku Island are metamorphic and gabbro rocks (**Sikumbang and Heryanto, 1994**). The pattern of straightness of geological structures between the two, both folds and faults, is generally directed from northeast-southwest to northwest-southeast (**Sikumbang and Heryanto, 1994; Rustandi et al., 1995**). In addition to regional geological mapping (**Rustandi et al., 1995**),

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another geological study was conducted by **Abbas and Maulana (2022)** who conducted a petrological study on several peridotite samples that had undergone strong serpentinization. Several studies have been conducted on Sebuku Island regarding the potential for economic mineral deposits. The study has been focused on obtaining a more detailed distribution of ultramafic rocks, which are estimated to contain iron ore and nickel mineral resources, particularly from oxide and silicate-type laterite soils (**Aribowo et al., 2018**). The research has also identified high-content chromite deposits of types Al and Cr (**Sihombing et al., 2019; Imani et al., 2020; Idrus et al., 2022**). **Rakhmawati et al. (2022)** and **Hartono (2023)** researched the geophysical characteristics of iron deposits associated with the lateritization of ultramafic rocks.

This study aims to find out the geological conditions on Sebuku Island in detail, especially in the Sei Pinang and Halaban areas. This research contributes to updating the lithological types, distribution, lithological boundaries, stratigraphic relationships, and geological structures, compared to the previously published regional geological map sheet Kotabaru, Kalimantan scale 1:250,000 (**Rustandi et al., 1995**). Economically, the distribution of mafic-ultramafic rocks gives potential to deposited economic metals, i.e. iron, nickel, chromite, and PGM.

2. Tectonic and general geology

The Bobaris-Meratus Mountain accretion complex results from an emplacement involving complicated geological processes from the Jurassic, Late Cretaceous to the Paleogene. The tectonic activity of southeast Kalimantan began in the Jurassic, which resulted in tectonic mixing to form a mélange complex composed of ultramafic rocks, metamorphic rocks, and scaly sedimentary rocks. Further tectonic activities occurred in the Late Miocene in the form of uplift and formation of Meratus heights, folding and scattering in older rocks (**Sikumbang et al., 1994; Heryanto & Sanyoto, 1994; Rustandi et al., 1995**).

The accretion complex is composed of metamorphic bedrock and mafic-ultramafic rock, which is tectonically covered by volcanic and magmatic products of Cretaceous age (Pitap Formation) and volcanic deposits of Cretaceous age (Haruyan/Manunggul Formation). It is also covered unconformably with Paleogene and Quaternary sedimentary deposits. The relationship of rock units is generally in the form of tectonic contacts due to tectonic processes that occurred from the Cretaceous to the Neogene.

The formation of the Bobaris-Meratus accretion complex is intricately tied to the northwest-southeast direction structure's straightness. This structure primarily manifests as thrust faults or strike-slip faults formed during the accretion process. Additional faults, oriented in the north-south or northeast-southwest direction, are believed to be normal faults or shear faults. These geological features witness the complex tectonic processes that have shaped the area over time (**Sikumbang and Heryanto, 1994; Rustandi et al., 1995; van Bemmelen, 1949; Hamilton, 1979**).

Priyomarsono (1986) stated that the Bobaris-Meratus complex and its metamorphic rocks are part of the old oceanic lithosphere. **Hamilton (1979)** mentioned the formation of a mélange complex on the island of the Late Cretaceous-Tertiary of Laut Island due to the subduction of old oceanic crust. **Wakita et al. (1998)** distinguish the accretion complex of the Bobaris-Meratus Mountains associated with an arc ophiolite in the mélange complex of Laut Island that is thought to be part of an old oceanic crustal plate. **Parkinson (1998)** considers the complex formed within the scope of fore-arc ophiolites. However, **Monnier et al. (1999)**, based on geochemical studies of peridotite rocks, proved that the ophiolite of the Bobaris-Meratus complex is associated with a sub-continental ophiolite on the southeastern edge of the Eurasian Plate or Sundaland. Chromite from Sebuku Island is classified as podiform chromite (**Idrus et al., 2022**).

The Sebuku and Laut Islands are part of the Bobaris-Meratus accretion complex, forming an en-echelon ridge in a northeast-southwest direction (**Sikumbang and Heryanto, 1994**) detached by the Asam-asam basin (**Nuay, 1985**).

Geological information on Sebuku Island has been published in the geological map sheet Kotabaru, Kalimantan (**Rustandi et al., 1995**), with a scale of 1:250,000. Sebuku Island's geology comprises four rock formations, namely the Jurassic-aged ultramafic rock group (Mub), forming the bedrock of Sebuku Island. The ultramafic rocks tectonically covered by the Pitap Formation (Ksp) which have an interfingering relation with Haruyan Formation (Kvh) of Cretaceous age. The ultramafic rocks also unconformably covered by the Tanjung Formation (Tet) of Eocene age. An unconformity is covered by alluvium of rivers, swamps, and coast deposits (Qa) of Holocene age (see **Figure 2**). The presence of Mesozoic mélange and ophiolite complex rocks and diamonds in Pamali breccia in southeast Kalimantan was reported by **van Bemmelen** (**1949**) and **Hamilton** (**1979**).

Sebuku Island extends north-south along approximately 33 km with a width ranging from 3 – 10 km with an area of about 219 km^2, bounded by the Makassar Strait on the east side and the Sebuku Strait on the west side. Morphometrically and morphographically, Sebuku Island is elevated 0 to 205 m above sea level. The morphology of the study area based on the slope can be divided into four morphological groups, namely plain morphology with a slope of 0 – 2%, undulating morphology of sloped slopes of 3 – 7%, wavy morphology with a slope of 8 – 13% and morphology of undulating hills with slopes of 14 – 20% (**van Zuidam, 1983**), (see **Figure 1**).

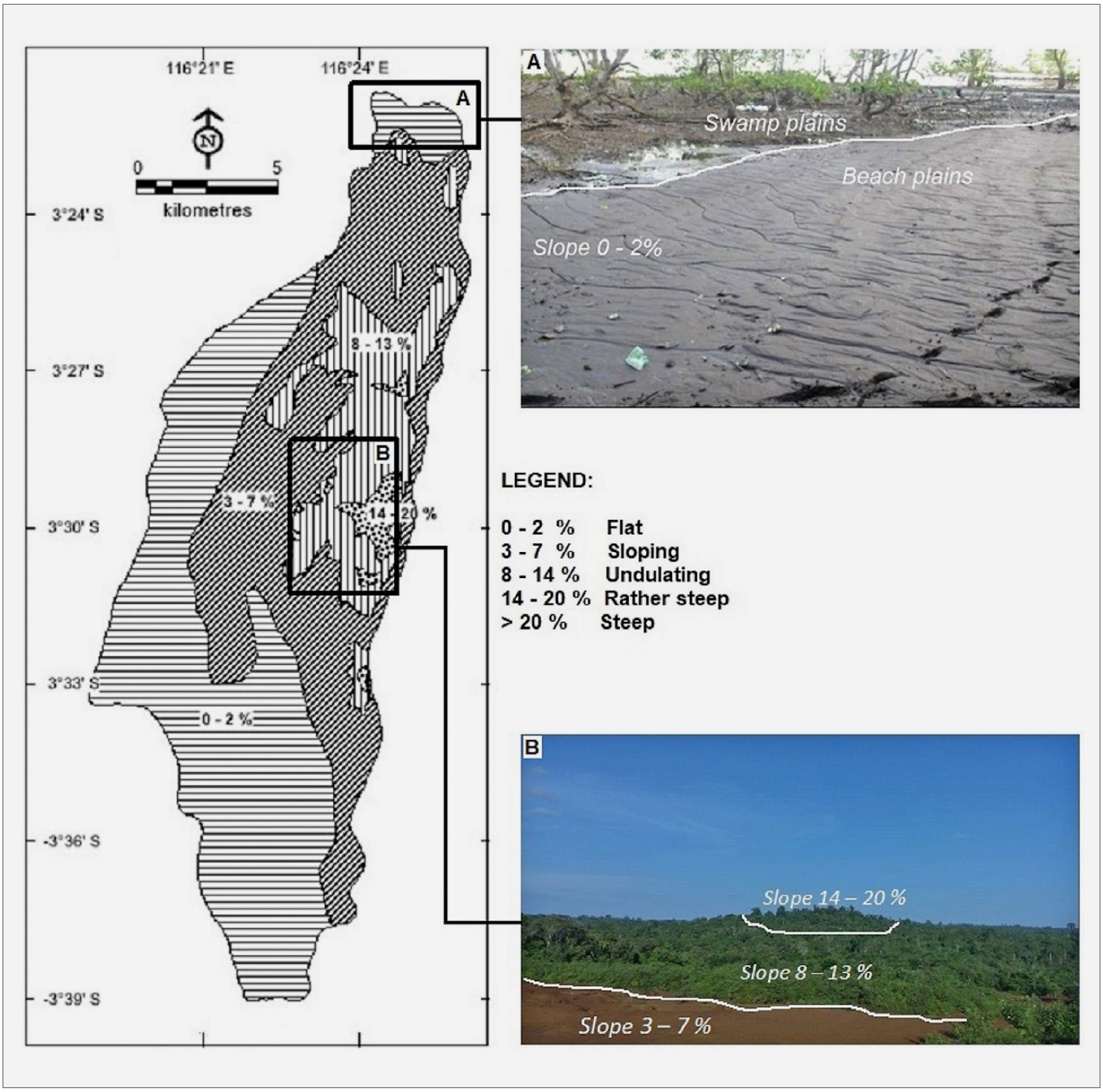

Figure 1: Morphometry map of partial landforms of Sebuku Island and morphological photos (morphometric categories after **van Zuidam, 1983**)

3. Methods and materials

The research method consists of fieldwork, laboratory analyses, and data analyses. Geological fieldwork was conducted to observe and collect samples from outcrops, trenches, and drill cores. A total of 34 representative rock samples were collected from the surface and trenches (7 samples), in addition to 27 rock samples collected from drill cores. Geological structure observations on gash fractures, shear fractures, slide slides, and fault planes were carried out on fresh outcrops where the indication of structures can be observed and measured clearly. Due to strong weathering, only 57 structural geologies can be measured from 6 fresh outcrops (see **Figure 3**).

The laboratory analysis carried out is a petrographical observation of 34 samples to identify the mineralogy and rock types. The standard petrographic thin sections were observed under a Nikon Eclipse 20ipol microscope with the magnification of objective lenses 5X and 10X, and an ocular lens of 10X.

The data analysis is a stereographic analysis of geological structure measurement data to define the general direction and type of outcropped structures. The geological map is drawn on the base map with a scale 1:50,000 using MapInfo Pro v17.0.5.

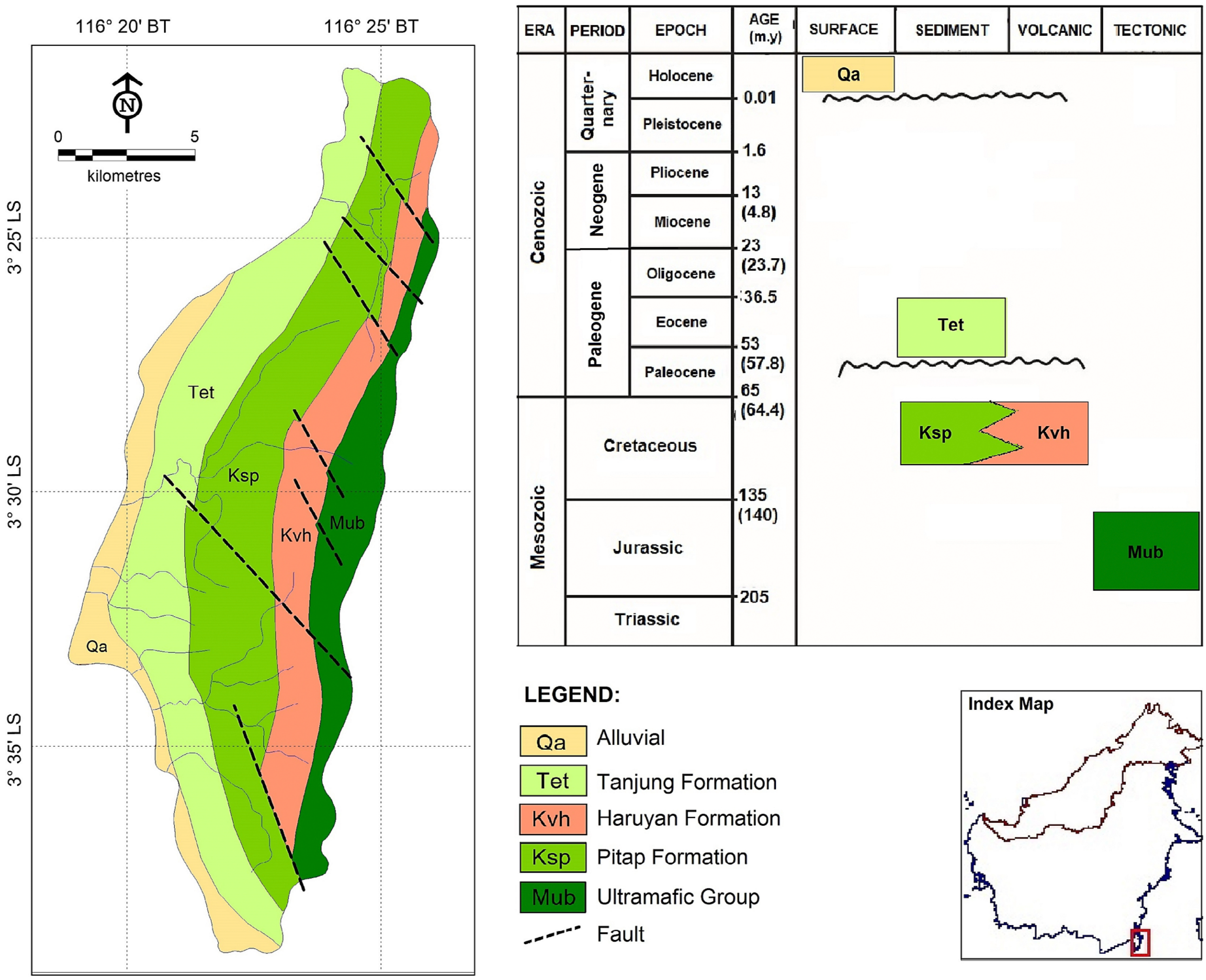

Figure 2: Geological Map of Sebuku Island (redrawn from **Rustandi et al., 1995**)

4. Results

Along the observation track, fresh rock outcrops are very limited and difficult to obtain, especially on the plain – obliquely undulating morphology due to intense weathering and thick overburden. This condition is evidenced by excavating a test trench using an excavator to a depth of 3 m, still showing a layer of overburden (see **Figure 4**). The results of geological test drilling show a soil thickness of at least 7 m to obtain relatively fresh bedrock. Outcrops of surface rock observed in plains generally have undergone intense weathering, while those on hillsides look fresher. The pyroclastic rocks are megascopically identified as silty tuff, sandy tuff intercalations, and volcanic breccia (see **Figure 5** and **Figure 6**).

4.1. Petrography

The results of the petrographic analysis of 34 samples can be grouped as follows. Nine samples were identified as ultramafic rocks (after **Streckeinsen, 1978**), consisting of serpentinite (serpentinization of lherzolite, harzburgite, and dunite); nine samples of mafic to intermediate rocks and 16 samples identified as pyroclastic rock types, consisting of crystalline lithic tuff and crystalline tuff.

4.1.1. Ultramafic rocks

Ultramafic rocks generally comprise relicts of olivine and pyroxene mineral grains sized 2-3 mm of anhedral to subhedral shape, showing a "mesh" structure made by olivine minerals and an indication of "bastite". Almost all of the primary minerals transformed into serpentine. Cubic opaque minerals fill rock fractures with a size of up to 0.1 mm.

Samples A5, A6, and UM-01 (see **Figure 7**) were classified as serpentinized lherzolite. These rocks are composed of serpentine (60-70%) in the form of dark white flakes forming mesh and bastite structures, olivine (5-15%) as relic measuring up to 1.5 mm, hypersthene (up to 10%) in the short prismatic form of with a size of 0.75 mm, augite (5-10%) in the form of light green short prismatic measuring up to 0.25 mm and opaque minerals (up to 5%) in dark color with a size of up to 0.25 mm.

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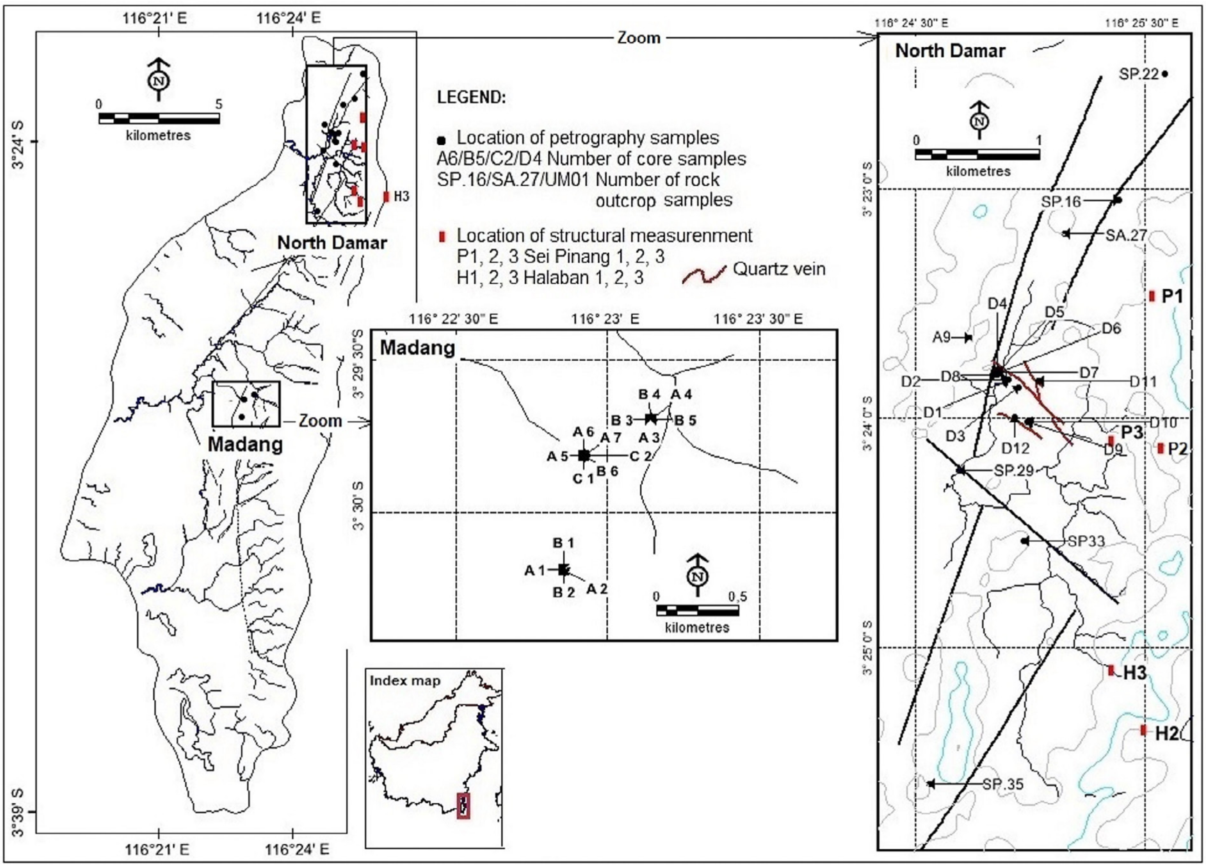

Figure 3: Map of Sebuku Island with insets showing detailed locations of petrographically analyzed rock samples and structural measurements

Figure 4: Photos of the trench wall in Sei Pinang to a depth of 4 m show weathering soil layers of bedrock

Figure 5: Cut drill core sample photo of silty tuff with sandy tuff intercalations

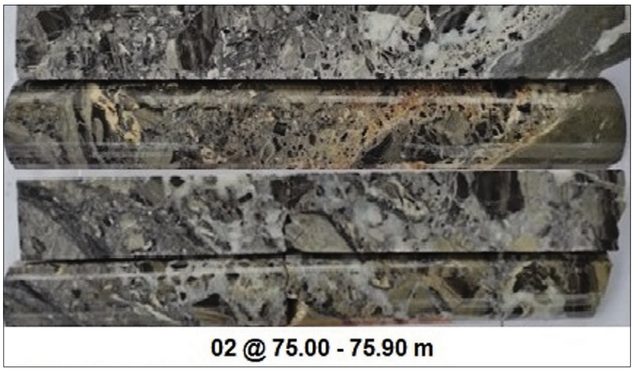

Figure 6: Cut drill core sample photo of volcanic breccia

Samples A1 and A2 (see **Figure 8**) were determined as serpentinized harzburgite. They are composed of serpentine (75-90%) consisting of fine-sized grains antigorite and chrysolite forming veins, fine-grained olivine relict (1-5%), hypersthene (up to 10%), diopside (up to 10%) and opaque minerals (1%). Serpentinized dunite was identified in samples A3, A4, A7 and A8 (see **Figure 9**). These rocks were composed of serpentine (95%) and opaque minerals (5%). The petrography observation of ultramafic rocks is summarised in **Table 1**.

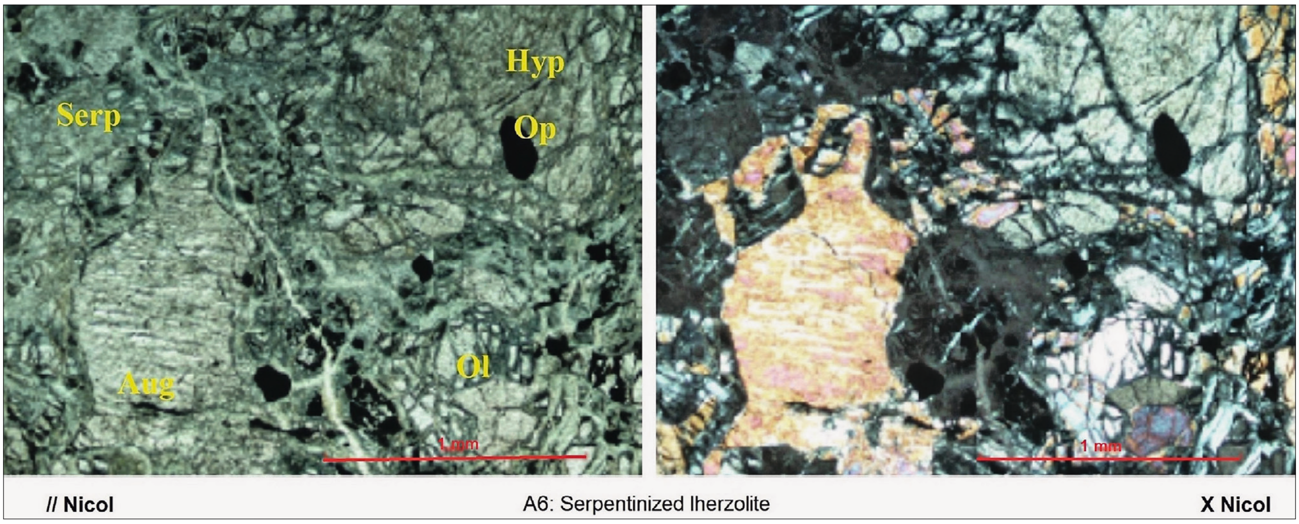

Figure 7: Photomicrograph of thin section No. A6: serpentinized lherzolite (Serp: Serpentine; Hyp: Hyperstene; Ol: Olivine; Op: Opaque; Aug: Augite)

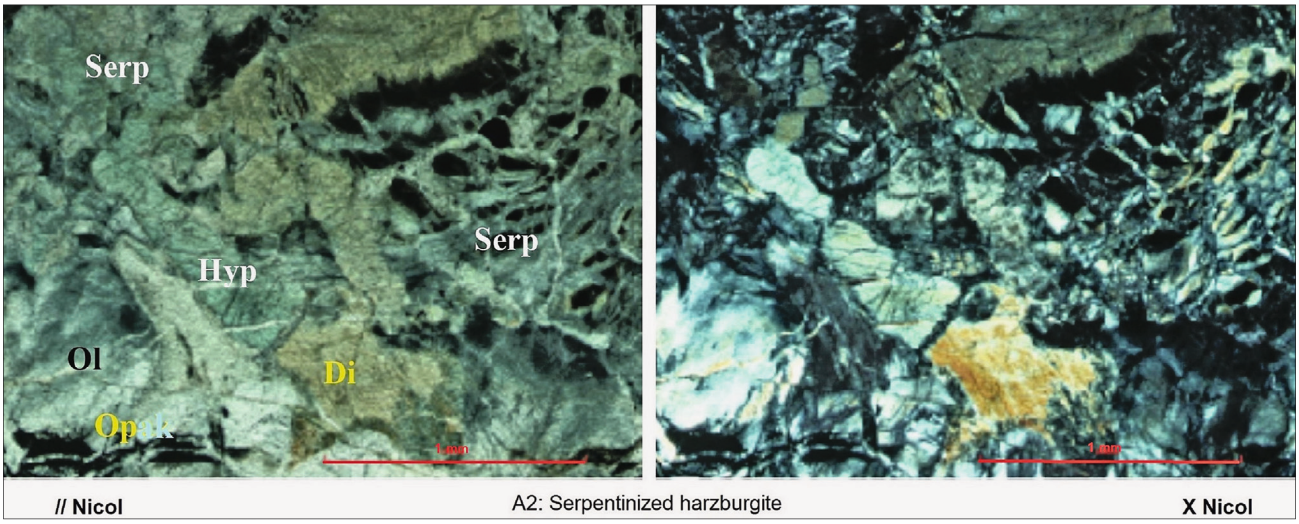

Figure 8: Photomicrograph thin section No. A2 serpentinized harzburgite rocks (Serp: Serpentine; Ol: Olivine; Di: Diopsite; Hyp: Hyperstene)

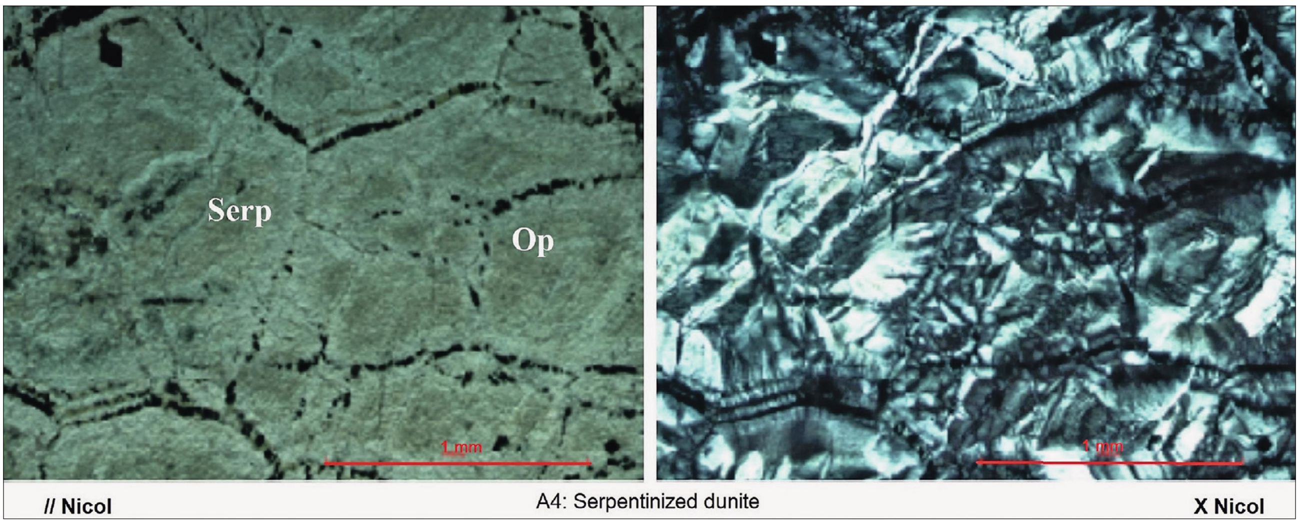

Figure 9: Photomicrograph thin section A4 Serpentinized dunite (Serp: Serpentine; Op: Opaque)

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Table 1: Results of petrographic analysis of ultramafic rock samples from Sebuku Island, Indonesia

No.	Location	Hole ID	Samples No.	Identified of rock	Depth (m) of samples	% Minerals Composition								Remark
						Ser	Ol	Px	Hyp	Di	Op	Aug	Fe ox.	
1	Madang	XPC-01	**A1**	Serpentinized	93.25-	90	1	-	2 to 3	1	1	-	-	
				Harzburgite	93.35									
2		XPC-01	**A2**	Serpentinized Harzburgite	102.01-102.35	74	5	-	10	10	1	-	-	
3		XPC-02	**A3**	Serpentinized Dunite	320.97-321.12	90	-	-	-	-	10	-	-	
4		XPC-02	**A4**	Serpentinized	327.75-	90	-	1 to 2	-	-	8	-	-	Granular, a tracer of olivine, pyroxene minerals, 2-3 mm size, an-subhedral, altered mesh structure of olivine and bastite, almost all of the constituent minerals converted to serpentine
				Dunite	327.95									
5		XPC-03	**A5**	Serpentinized	27.55-	65	15	-	10	-	5	5	-	
				Lherzolite	27.75									
6		XPC-03	**A6**	Serpentinized	62.55-	60	15	-	10	-	5	10	-	
				Lherzolite	62.70									
7		XPC-03	**A7**	Serpentinized	141.85-	95	-	-	2	-	3	-	-	
				Dunite	142.05									
8		XPC-03	**A8**	Serpentinized	210.30-	95	-	-	-	-	5	-	-	
				Dunite	142.05									
9	North Damar	-	**UM01**	Serpentinized	0	70	5	-	-	-	5	5	5	
				Lherzolite										

Note: Ser: Serpentine; Ol: Olivine; Px: Pyroxene; Hyp: Hyperstene; Di: Diopsite; Op: Opaque; Aug: Augite; Fe ox: Iron oxide

4.1.2. Mafic - intermediate rocks

Nine drill core samples, three of which came from Sei Pinang in North Damar and the other six samples from Madang, were generally composed of short subhedral to anhedral prismatic minerals with a fine-grained size of up to 1.5 mm, characterized by the dominant distribution of plagioclase and pyroxene. Some plagioclase is altered to sericite and carbonate minerals, while pyroxene becomes chlorite; other constituent minerals are opaque minerals scattered in rocks, identified as microgabbro rocks.

Microgabbro from the drill core of Sei Pinang, North Damar, samples D5 and D10, is composed of plagioclase minerals (40 - 50%), augit (15%), enstatite (5%), sericite (30%), opaque (5%), and sometimes calcite minerals (see **Figure 10**).

Microgabbro from Madang (sample number B6) is characterized by the interstitial texture of short prismatic minerals in subhedral-euhedral shape. The sample is composed of primary minerals augite (40%) and hypersthene (15%). The secondary minerals are sericite (15%) and carbonates (5%) as an alteration product of plagioclase and chlorite (15%), which are formed secondary from pyroxene and opaque minerals (10%) and strongly altered microgabbro observed in sample B4 and B5. The strongly altered sample is composed of short prismatic fine-grain accessory minerals in a subhedral-euhedral shape. Plagioclase was changed to form sericite and fine-grained carbonate, and pyroxene was altered to become chlorite.

Sample numbers B1 and B2 from Madang identified as microgabbro norite were observed to be composed of the minerals plagioclase (5 – 25%), augite (10 – 20%), enstatite (10%), opaque (5%), and sericite—chlorite (40 – 60%), while B3, observed as orthopyroxene microgabbro, was prepared with a composition of the minerals plagioclase (5%), augite (5%), enstatite (10%), seric-

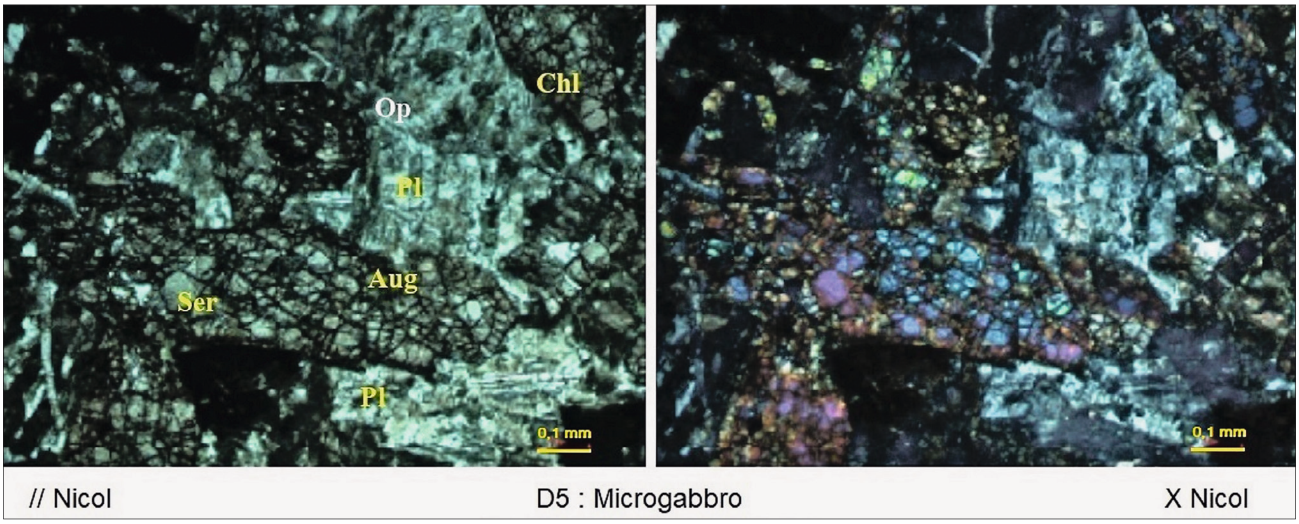

Figure 10: Photomicrograph thin section sample D5 of microgabbro
(Pl: Plagioclase; Ser: Sericite; Aug: Augite; Chl: Chlorite: Op: Opaque)

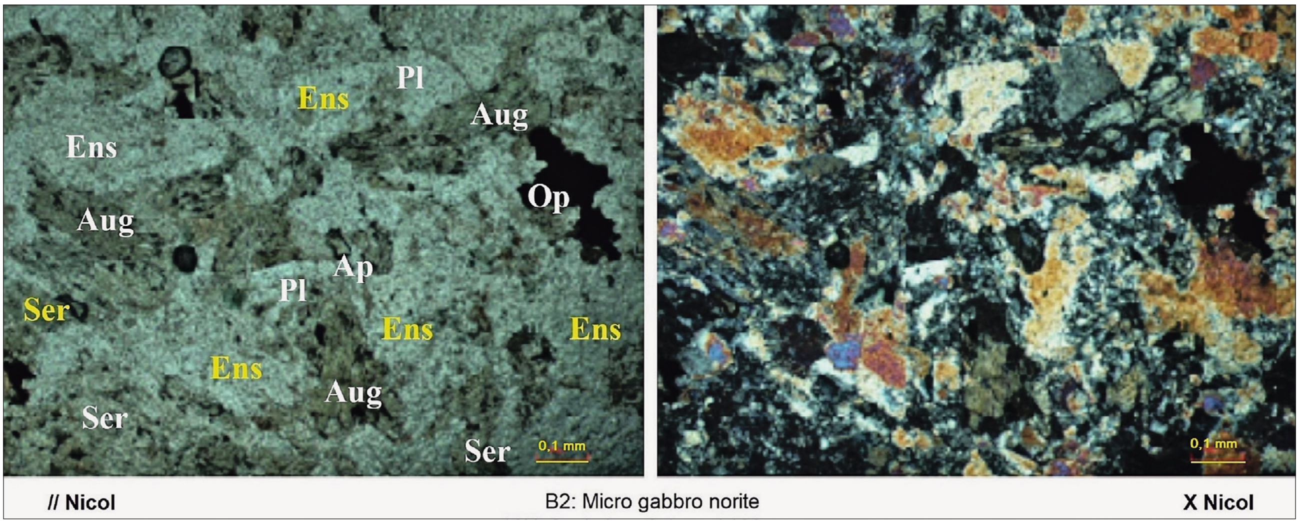

Figure 11: Photomicrograph thin section sample No. B2 of microgabbro norite
(Ens: Enstatite; Aug: Augite; Pl: Plagioclase; Op: Opaque; Ap: Apatite; Ser: Sericite; Chl: Chlorite)

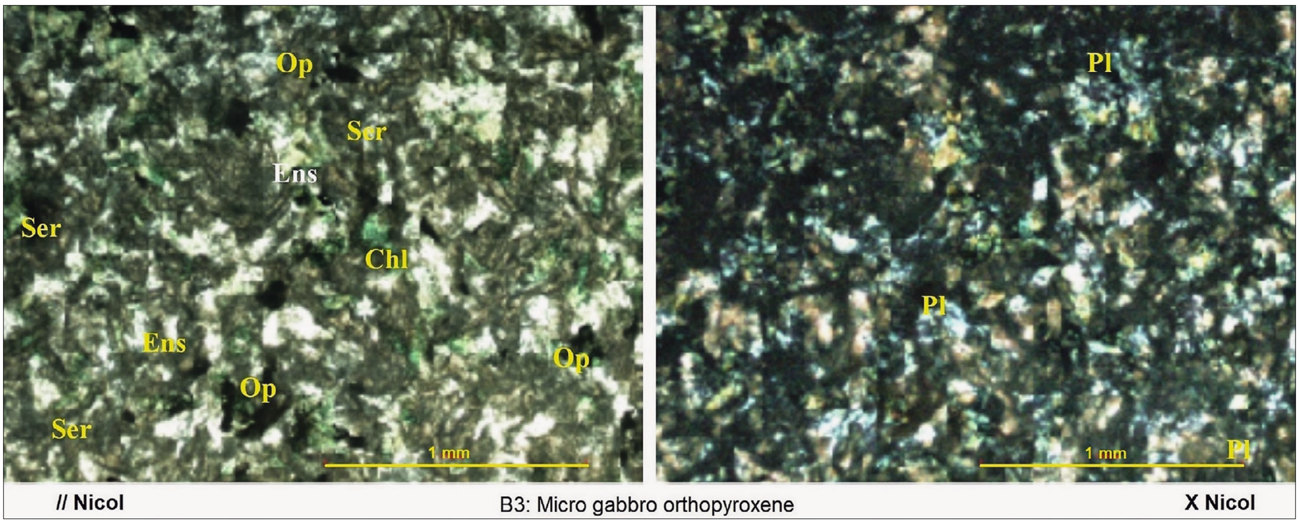

Figure 12: Photomicrograph of thin section sample No. B3 Orthopyroxene microgabbro
(Ens: Enstatite; Aug: Augite; Pl: Plagioclase; Op: Opaque; Ap: Apatite; Ser: Sericite; Carb: Carbonate; Chl: Chlorite)

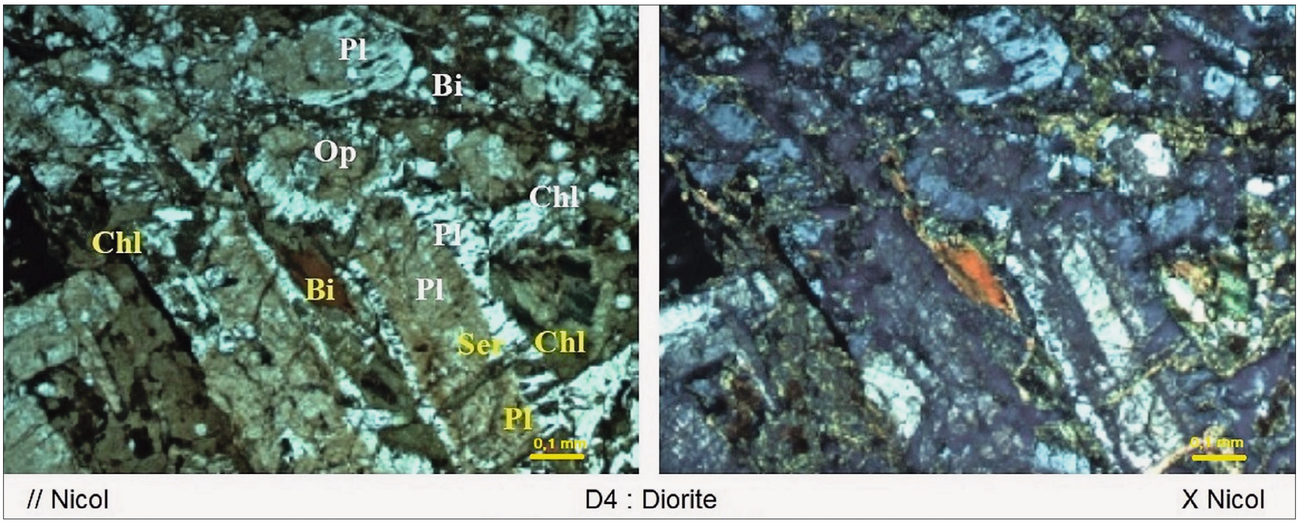

Figure 13: Photomicrograph of thin section sample D4 of diorite, Sei Pinang – North Damar
(Ser: Sericite; Chl: Chlorite; Pl: Plagioclase; Op: Opaque; Bi: Biotite)

ite—chlorite (60%), and calcite (10%) (see **Figure 11** and **Figure 12**).

Diorite from Sei Pinang, North Damar sample D4, thin section arranged euhedral-subhedral prismatic minerals, fine to fine size up to 1.5 mm, intersertal texture, with a composition of plagioclase (60%), biotite (10%), sericite 10%), chlorite (15%), and opaque (5%) (see **Figure 13**). The petrography observation of mafic to intermediate rocks is summarised in **Table 2**.

4.1.3. Pyroclastic rocks

Sixteen pyroclastic rock samples from outcrops and Sei Pinang drill cores – North Damar and Madang, were divided into the following types: crystalline lithic tuff, and crystalline tuff.

Crystalline lithic tuff from 11 thin section samples of rock samples C1, D1, D3, D8, D9, D11, SP16, SP22, SP33, SP35, and SA27 (see **Figure 14** and **Figure 15**) shows hyalophilitic texture, composed of fragments of basalt, tuff, K-feldspar generally fragments have changed. Tuff characterized by sub-rounded with open fabric mineral composition of pyroxene (0 – 15%), opaque oxide (0 – 5%), plagioclase – K, felspar (0 – 50%), biotite (0 – 20%), quartz (0 – 2%), carbonate (0 – 10%) with lithic fragment arrangement (0 – 80%), glass cement (0 – 80%).

Crystalline tuff from five thin sections of rock samples D6, D7, D12, C2, and SP29 (see **Figure 16**), show hyalophilitic texture. Samples were composed of plagioclase with pyroxene fragments and opaque minerals, cemented by volcanic glass, angular fragment shape, and a fine grain size up to 0.1 mm. Their composition consists of volcanic glass (0 - 50%), plagioclase (5 - 35%), pyroxene (0 - 30%), opaque (2 - 15%), and quartz (5 - 35%). The petrographic observations on mafic to intermediate rocks are summarised in **Table 3**.

4.2. Geological structure data analysis

The geological structures around Sei Pinang and Halaban were observed as gash fractures, shear fractures, and slickensides is summarized in **Table 4**.

The structural components observed in Sei Pinang-1, in the form of a fracturing plane positioned N35°E/68°, which shows the presence of slickenside (see **Figure 17**), from the stereographic analysis shows the fault plane N 35° E / 68° and net slip 03°, N 324° E with Rake 15°, it is a northeast-southwest fault, formed along the contact between ultramafic rocks and pyroclastic rocks.

The results of stereographic analysis of structural components around Halaban-1 are known to be the general direction of shear fracture N 106° E / 69°, fault plane N 119° E / 64° and net slip 33°, bearing N248°E and rake 18°, (see **Figure 18**).

Overall, apart from the two locations mentioned above, the results of the respective stereographic analysis can be seen in **Table 5**.

5. Discussion

Based on the results of petrographic observations and detailed field observations, especially in North Damar, the lithology of Sebuku Island can be described as an ultramafic rock unit, pyroclastic rock group, limestone unit, dike rock unit, sandstone unit, and alluvial deposit (see **Figure 19**). The ultramafic rocks unit consists of harzburgite, dunite, and lherzolite, which experienced strong serpentinization. The pyroclastic rocks can be divided into crystalline lithic tuff and crystalline tuff. Microgabbro and diorite dikes both intruding the pyroclastic rock group.

Ultramafic rock units

The ultramafic rock units extend north-south along the east of the study area. On the western side, these

Table 2: Results of petrographic analysis of mafic-intermediate rock samples from Sebuku Island, Indonesia

No.	Location	Hole ID	Samples No.	Identified of rock	(m) depth of samples	% Composition										Remark
						Hyp	Pl	Qz	Bi	Chl	Aug	Ens	Op	Ser - Chl	Carb.	
1	Madang	**XPC-01**	**B1**	Microgabbro Norite	95.95-96.15	-	25	-	-	-	10	10	5	40	-	Short prismatic mineral, sub-anhedral, fine size - 0.75 mm, plagioclase - pyroxene intersertal texture, plagioclase is altered to sericite and carbonate, pyroxene to chlorite.
2		**XPC-01**	**B2**	Microgabbro Norite	99.50-99.70	-	5	-	-	-	20	10	5	60	-	
3		**XPC-02**	**B3**	Orthopyroxene microgabbro	315.95-316.08	-	5	-	-	-	5	10	-	60	10	
4		**XPC-02**	**B4**	Altered microgabbro	317.45-317.5	-	-	-	-	-	10	-	-	30	60	
5		**XPC-02**	**B5**	Altered microgabbro	325.75-325.9	-	-	-	-	-	-	-	10	40	50	
6		**XPC-03**	**B6**	Microgabbro	151.23-151.4	15	-	-	-	-	40	-	10	30	5	
7	North Damar	**CS-05**	**D5**	Microgabbro	49,83-49,89	-	50	-	-	5	15	-	5	25	-	
8		**CS-08**	**D10**	Microgabbro	112,80-112,8	-	45	2			15	5	-	30	3	
9		**CS-05**	**D4**	Diorite	35.60-35.65	-	50	-	10	15	-	-	5	20	-	Eu -sub hedral prismatic minerals, fine - 1.5 mm, interstitial texture of the mineral plagioclase with biotite. Some plagioclase is converted to sericite. The hydrous mineral biotite or hornblende has been chiefly converted into chlorite.

Note: Hyp: Hyperstene; Pl: Plagioclase; Aug: Augite; Ens: Enstatite; Op: Opaque; Bi: Biotite; Ser: Sericite; Chl: Chlorite; Carb: Carbonate; Qz: Quartz

rocks are exposed around the island's northern end or covered by alluvium deposits or swamp deposits. Ultramafic rocks, considered bedrock, have undergone serpentinization and intensive weathering to form laterite soil layers with a high potential for iron ore and nickel enrichment; in some locations, lateritic iron mining has been carried out. Petrographic analysis of several ultramafic rock samples identified different rocks, namely serpentinized lherzolite, dunite, and harzburgite, as described above in samples A1 to A8 and UM-01. Ultramafic rocks are intruded by microgabbro and diorite that are only observed in the drill core but not as surface exposures. This group of rocks is equivalent to ultramafic rocks of the Jurassic age (Mub) defined by **Rustandi et al. (1995)**.

Pyroclastic rock units

Petrographic analysis of several surface outcrops and drill cores from North Damar and Madang identified that

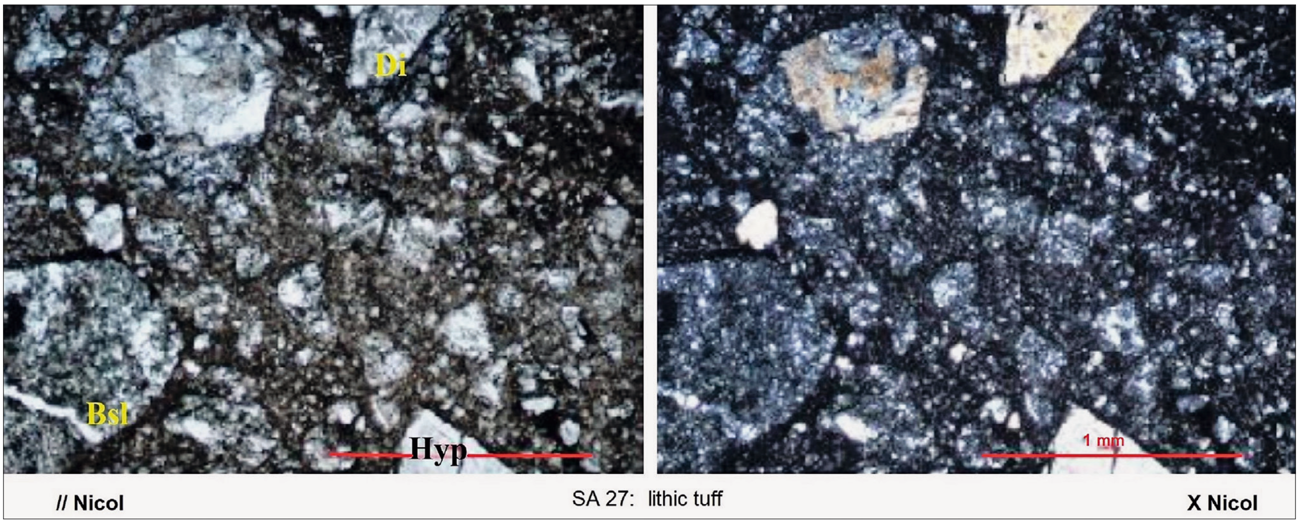

Figure 14: Photomicrograph thin section samples number SA-27 lithic tuff (Bsl: Basalt; Di: Diopsite; Hyp: Hyperstene)

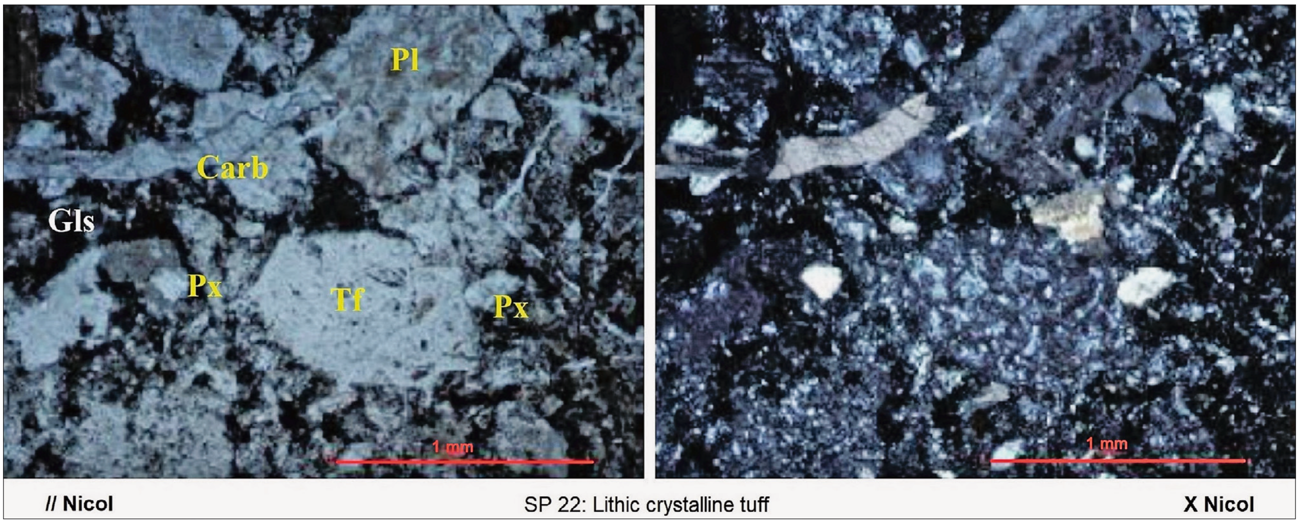

Figure 15: Photomicrograph thin section samples number SP-22 crystalline lithic tuff (Pl: Plagioclase; Px: Pyroxene; Tf: Tuff; Carb: Carbonate; Gls: Glass)

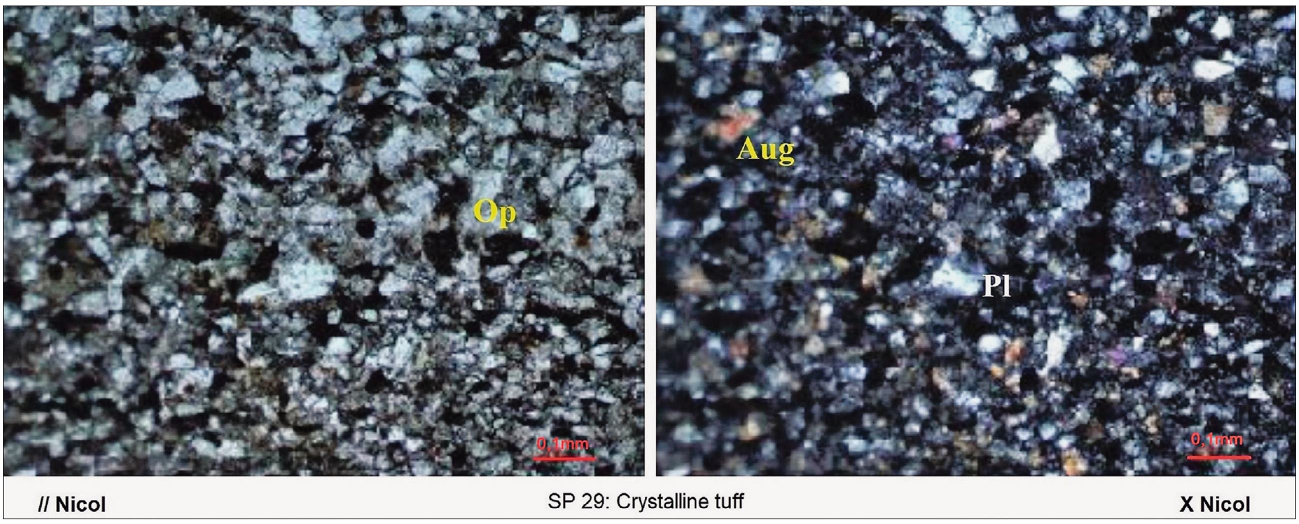

Figure 16: Photomicrograph of SP-29 crystalline tuff (Pl: Plagioclase; Aug: Augite; Op: Opaque)

Table 3: Results of petrographic analysis of pyroclastic rock samples from Sebuku Island, Indonesia

No.	Location	Hole ID	Samples No.	Identified of rock	Depth (m) of samples	(%) Composition													Remark
															Fragment			Cement	
						Px	Op - Ox	Pl - Kf	Nat	Ens	Bi	Qz	Ser - Chl	Carb.	Lithic	x-taline	Fossil	Glass	
1	Madang	XPC -03	C1	Crystalline lithic tuff	87.25 - 87.45	-	-	-	-	-	-	-	-	-	80	-		20	Hyalopiyitic texture. Open pack. Rock fragment angular anhedral 0.1 - 2 mm. Basalt and crystalline tuff. Plagioclase, pyroxene, carbonate, glass groundmass.
2	North Damar	-	SP33	Crystalline lithic tuff	0	5	-	40	-	-	-	-	-	10	-	15		30	
3		CS-08	D9	Crystalline lithic tuff	178.30-178.35	-	-	15	2	-	20	-	-	5	5	-	3	50	
4		CS-13	D11	Crystalline lithic tuff	73.70-73.76	-	-	10	-	-	3			5	27	13	2	40	
5		CS-06	D8	Crystalline lithic tuff	199.75-199.80	-	3	10	-	-	5	-	-	-	2	-	-	80	
6		CS-01	D1	Crystalline lithic tuff	42.10-42.25	-	-	-	-	-	5	-	50	-	30	15	-	-	
7		CS-043	D3	Crystalline lithic tuff	95.01-95.06	-	-	3	-	-	-	2	20	5	60	10	-	-	
8		-	SP.35	Crystalline lithic tuff	0	15	-	50	-	-			-	-	10	-		25	
9		-	SA.27	Crystalline lithic tuff	0	10	-	10		-			-	-	15	65		-	
10		-	SP.22	Crystalline lithic tuff	0	5	5	10	-	-			-	5	-	45		30	
11		-	SP.16	Crystalline lithic tuff	0	5	5	5	-	-			15	-	-	40		25	
12		CS-06	D6	Crystalline tuff	60.25-60.30	-	2	15	-	-	25	5	-	3	-	-	-	50	Hyalopylitic texture. Open pack. Plagioclase. consist of K- feldspar and Plagioclase fragments. Sericite. Opaque minerals and volcanic glass cement. Minerals fragments angular - sub
13		CS-06	D7	Crystalline tuff	135.20-135.3	-	5	15	-	-	15	5	60	-	-	-		-	
14		-	SP.29	Crystalline tuff	0	10	5	35	-	-			-	-	-	-		50	
15		CS-12	D12	Crystalline tuff	87.35-87.40	-	5	30	-	-	-	-	55	10	-	-	-	-	
16	Madang	XPC-03	C2	Crystalline tuff	128.75-128.95	-	15	5	-	30			-	-	-	-		50	

Note: Px: Pyroxene; Pl: Plagioclase; Kf: K-feldspar; Nat: Natrolite; Ens: Enstatite; Op: Opaque; Ser: Sericite Chl: Chlorite; Carb: Carbonate; Bi: Biotite; Qz: Quartz; Ox : Oxide

Table 4: List of structural measurements Halaban and Sei Pinang

Halaban – 1: Coordinate loc. 116° 26' 4,22"E - 3° 25' 14,78"S **Shear Fracture**			
N 115° E /59°	N 109° E /74°	N 112° E /67°	N 118° E /60°
N 118° E /65°	N 106° E /72°	N 121° E /61°	N 102° E /74°
N 104° E /71°	N 109° E /72°	N 119° E /62°	N 110° E /71°
Fault line Azimuth: N 119 E			
Halaban – 2: Coordinate loc. 116° 25' 28,96"E - 3° 25' 21,53"E **Shear Fracture**			
N 218° E /28°	N 222° E /31°	N 220° E /30°	N 217° E /27°
N 227° E /19°	N 221° E /29°	N 219° E /28°	N 220° E /32°
Fault line Azimuth: N223E			
Halaban – 3: 116° 25' 20,61"E - 3° 25' 5,89"S **Shear Fracture**			
N 330° E /70°	N 350° E /59°	N 333° E /65°	N 315° E /62°
Gash Fracture			
N 040° E /65°	N 055° E /54°	N 022° E /68°	N 015° E /50°
N 024° E /70°			
Fault line Azimuth: N 315 E			
Sei Pinang 1: Coordinate loc. 116° 25' 31,23"E - 3° 23' 27,94"S			
Fault Plane	N 035° E /68°		
Net Slip	7°, N 324° E		
Rake	19°		
Sei Pinang 2: Coordinate loc. 116° 25' 33,63"E - 3° 24' 7,86"S **Shear Fracture**			
N 118° E /44°	N 197° E /63°	N 112° E /64°	N 103° E /44°
N 109° E /45°	N 128° E /74°	N 119° E /57°	N 134° E /55°
N 033° E /87°			
Gash Fracture			
N 025° E /68°	N 015° E /69	N 035° E /74°	N 031° E /82°
N 034° E /72°	N 046° E /82	N 034° E /86°	N 033° E /87°
Fault Plan: N 102° E /45°			
Sei Pinang 3: Coordinate loc. 116° 25' 20,61"E - 3° 25' 5,89"S **Shear Fracture**			
N 330° E /70°	N 350° E /59°	N 333° E /65°	N 315° E /62°
Gash Fracture			
N 040° E /65°	N 055° E /54°	N 022° E /68°	N 015° E /50°
N 024° E /70°			
Fault line Azimuth: N 315° E			

the pyroclastic rocks consist of crystalline lithic tuff and crystalline tuff.

Pyroclastic rocks, observed from drill core samples that alternate between tuffaceous sandstone and silty tuff, appear to show a sand-silt-sized layer structure inside which there are volcanic breccia (hydrothermal breccia?).

The results of the petrographic observations show rocks with a hyalopilitic texture and corrosion, an open fabric composed of pyroxene and plagioclase fragments, and opaque minerals measuring up to 1 mm. Its constituent minerals exhibit alignment and anhedral shape, angular with volcanic glass cement or clay minerals classified as crystalline tuff. Petrographic observations of volcanic breccia show fragments of diorite and basalt. This rock unit is equivalent to the Pitap (Ksp) or Haruyan Formation (Kvh) (**Rustandi et al., 1995**).

Limestone units

This rock unit (Ls) was observed from drill core samples at two drilling sites in swampy areas. The limestone unit was not observed at the surface. It is a fossiliferous limestone, dense, visible wollastonite mineral, metamorphized and has a marble-like appearance. Regionally, it can be equated with the Kintap Olistolith (Kok) by **Rustandi et al. (1995)**.

Dike rock units

The dike rock units were observed from drill core samples in the Madang area. This rock unit is not ex-

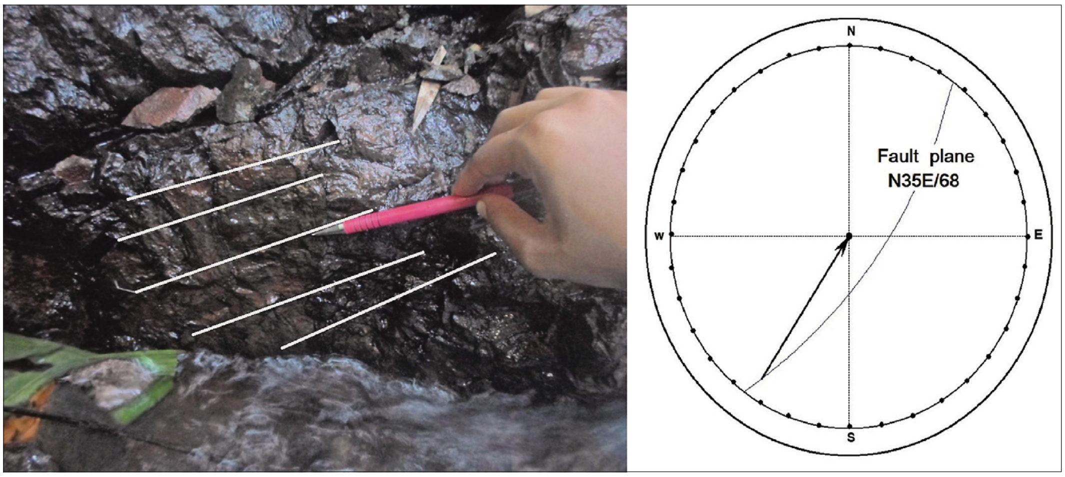

Figure 17: Observation photo of fault plane showing slickenside in the fracturing plane and stereographic analysis in Sei Pinang-1

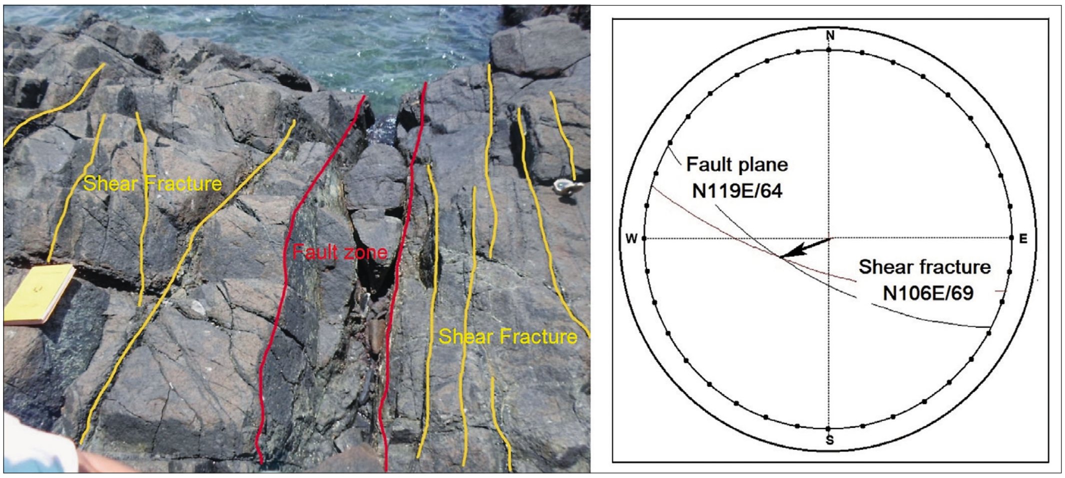

Figure 18: Observation photo of fault plan showing shear fracture and fault zone and stereographic analysis in Halaban 1

Table 5: List of stereographic result analysis

Location	General direction of Fracture		Net slip	Rake	Fault plane	Name of fault by Rickard, 1972
	Shear	Gash				
Halaban-1	N 106 E /69	-	43, N 243 E	18	N 119 E /64	Normal Right Slip Fault
Halaban-2	N 220 E /30	-	19, N 179 E	40	N 149 E /39	Thrust Right Slip Fault
Halaban-3	N 331 E /67	N 023 E /67	11, N 329 E	9	N 315 E /45	Left Slip Fault
Sei Pinang-1	-	-	03, N 324 E	15	N 035 E /68	Left Slip Fault
Sei Pinang-2	N 110 E /44	N 034 E /79	07, N 107 E	7	N 102 E /44	Left Slip Fault
Sei Pinang-3	N 331 E /67	N 315 E /45	11, N 329 E	9	N 315 E /45	Left Slip Fault

posed on the surface. Megascopic observation shows medium-grained, greenish-gray alkaline igneous rock. The results of the petrographic analysis of thin sections of samples B1 - B6 generally show short prismatic minerals, sub-anhedral shape, and fine grain size of up to 1.5 mm. Microgabbro rocks are characterized by the intermediate texture of plagioclase with pyroxene, and part of the plagioclase is altered to sericite. In contrast, pyroxene becomes chlorite and opaque and apatite minerals. Inside the drill core, microgabbro rocks are seen crosscutting through ultramafic rocks. Besides gabbro, it is suspected that there may be dike diorite rocks in the research area, based on petrographic analysis of drill core samples in the Sei Pinang part of the North Damar area. This possibility is shown by the presence of breccia inserts in the alternating of tuffaceous sandstone and

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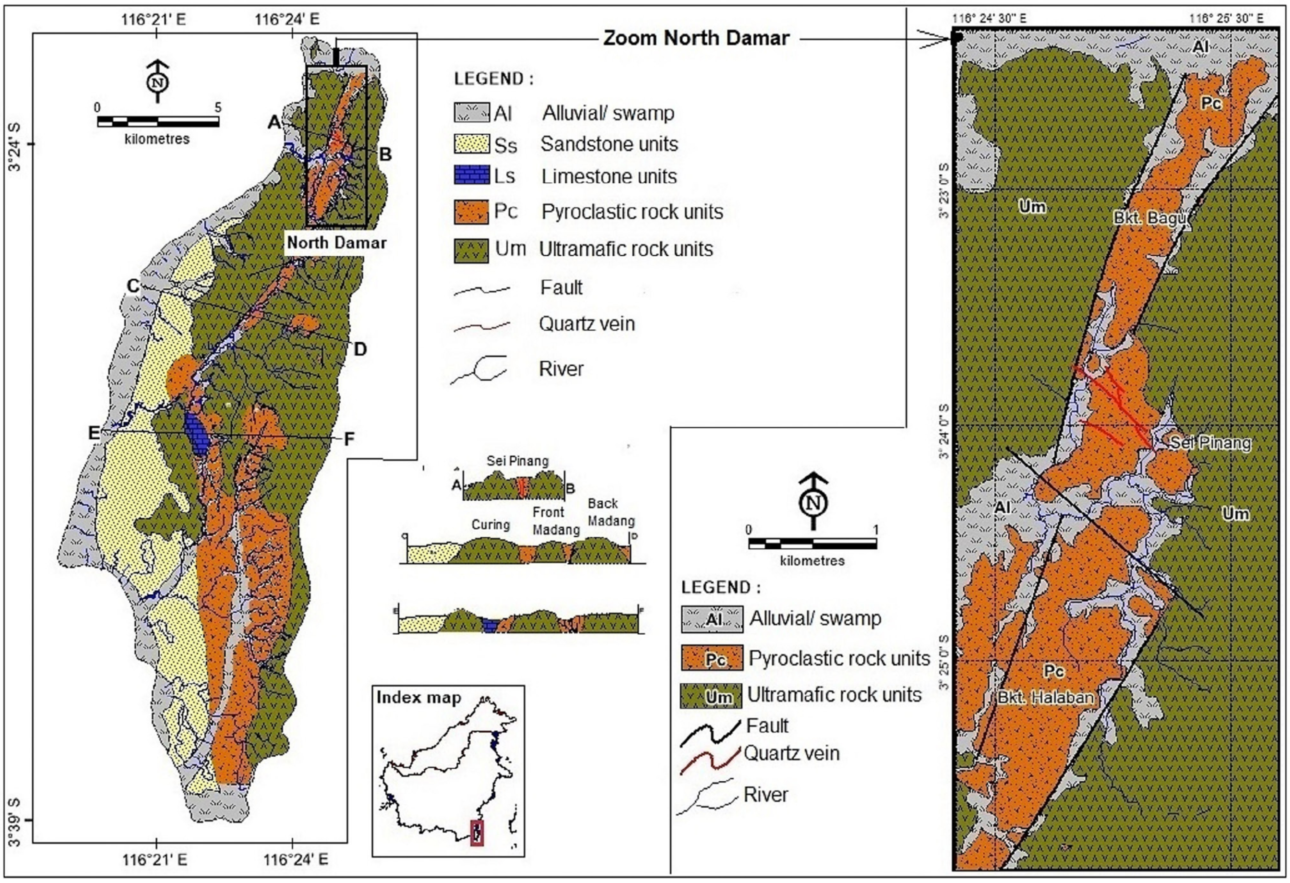

Figure 19: Detailed new geological map of Sebuku Island, South Kalimantan, Indonesia

silty tuff, where the breccia fragments are of the diorite rock type, as described above. Therefore, drilling efforts are still being carried out to find the presence of diorite rock bodies.

Sandstone units

Sandstone units are (Ss) intercalated between sandstones, conglomerated sandstones, claystone, and siltstones with shale and coal intercalations, and they are distributed in the central–southern part of the western part of the study area. This formation is equivalent to the Tanjung Formation (**Rustandi et al., 1995**).

Alluvial deposits

These alluvial deposits consist of river alluvials, swamp deposits, and coastal deposits, which are surface deposits of sand and silt that occupy the coastal plain on the west side of the island and along the river. The alluvial deposits are composed of gravel, sand, mud and clay materials.

Stratigraphic relations

The lithological boundaries are based on the distribution of fresh rock outcrops data that are more commonly found in hilly areas. In lower morphology or plains, it is difficult to obtain fresh and unaltered or unweathered rock outcrop because the degree of weathering is high, resulting in thick soil layers or outcrops covered with swamp deposits. Therefore, the determination of lithological boundaries based on differences in soil color resulting from the weathering of rocks is the approach taken. The contrast between soils derived from ultramafic rocks and other rocks is reinforced by observations of drill core samples from below the surface, assuming that the overburden is the result of weathering of the bedrock below.

Determination of the stratigraphic sequence of rock formation, carried out relatively from observational data of surface rock outcrops and drill core rock samples equivalent to the geological stratigraphy of Kotabaru sheets (**Rustandi et al., 1995**) as shown in **Table 3**. Determination of rock age is carried out relatively and correlated with the age of rock formations from previous geological information sources (**Sibkumbang and Heryanto, 1994; Rustandi et al., 1995**). Not all types of rocks from the Kotabaru sheet are exposed on Sebuku Island or have experienced erosion due to weathering or tectonic erosion during the accretion process.

The ultramafic rock unit extends north-south along the east of the study area. On the western side, these rocks are exposed around the island's northern end or covered in alluvium deposits or swamp deposits. Ultra-

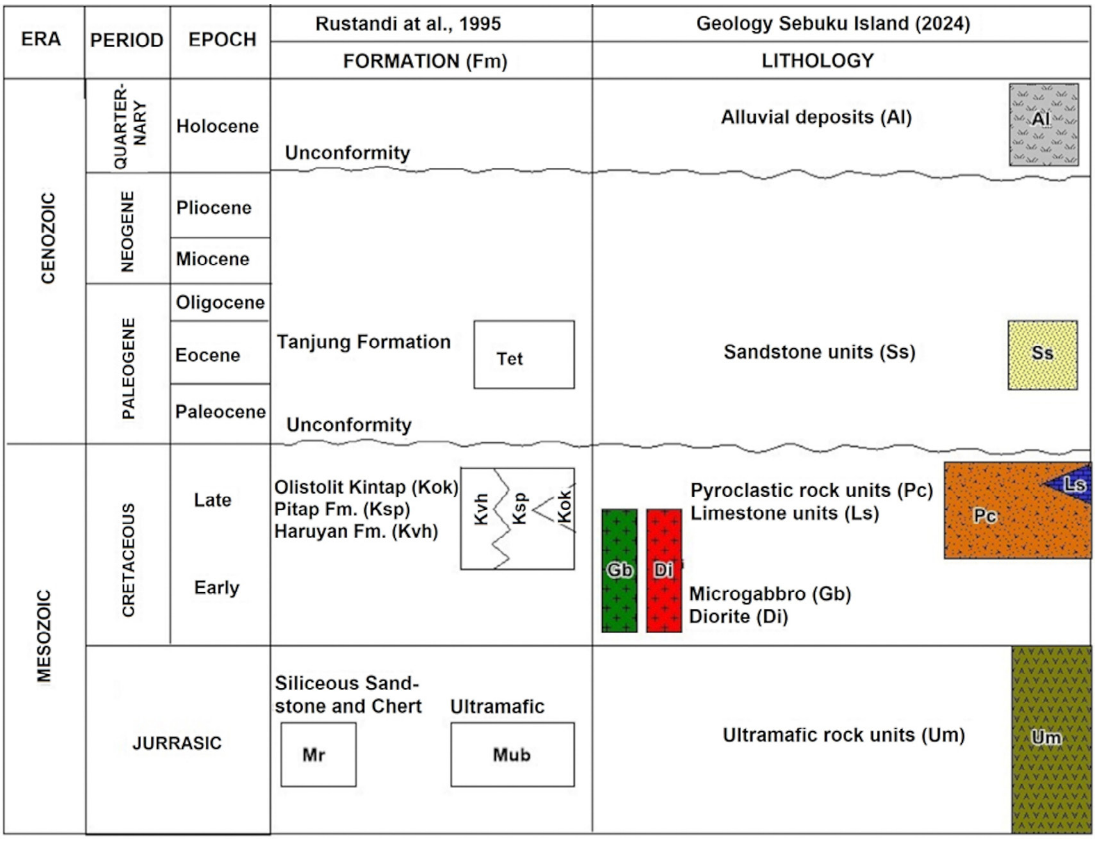

Figure 20: The correlation of the geological stratigraphy of Sebuku Island is compared with regional data of the geological map of the Kotabaru sheet (**Rustandi et al., 1995**)

mafic rocks, considered bedrock, have undergone serpentinization and intensive weathering to form laterite soil layers with a high potential for iron ore and nickel enrichment; in some locations, lateritic iron mining has been carried out.

Ultramafic rocks are intruded by microgabbro and diorite that are only observed in the drill core but not exposed on the surface. This group of rocks is equivalent to ultramafic rocks of the Jurassic age (Mub) (**Rustandi et al., 1995**).

The stratigraphic relationship of lithological units on Sebuku Island is equivalent to lithological units published in 1995 (**Rustandi et al., 1995**). Lithological units on Sebuku Island are shown **Figure 20**. The geological relations of the study area can be divided into five rock units and alluvial deposits. Relatively from old rocks to the youngest rocks as follows: ultramafic rock units, pyroclastic rock units consisting of volcanic rock units and volcaniclastic rocks, limestone units, quartz sandstone units, and alluvial deposits.

The geological structure of the measurement results in Sei Pinang shows a strike-slip fault structure with a general direction of SE-NW and NE-SW that occurs in ultramafic and pyroclastic rocks. These minor structures result from developing the main structure in Sei Pinang, which is trending NE-SW. In Halaban, the measured minor structures identified as normal right slip faults, thrust right slip faults, and left slip faults with a general direction of NW-SE, are a continuation order of the main structure that cross-cut Sei Pinang.

Ore mineralization that has been and is being mined in this area is iron ore deposits and laterite nickel due to weathering ultramafic rocks, as has been done in several locations. With further exploration research/development activities, deposits of other metal minerals besides iron ore and nickel laterite are expected to be found in this area. Indications of mineralization found as quartz veins cross cutting pyroclastic rocks. The occurrence of microgabbro and diorite dikes intruding ultramafics and pyroclastics indicates the source of hydrothermal mineralization processes. The general direction of quartz veins is northwest-southeast as found in Sei Pinang with a thickness up to 1 m. The quartz veins are characterized by a milky white colour, as well as a sugary-crystalline, bladed, comb, and vuggy structure.

The results of the reconstruction of the distribution and position of quartz veins show at least three directions of quartz veins, which generally show a northwest-southeast direction, a minimum distribution length of 250 m to 750 m, and a thickness of 60 – 135 cm.

In general, the distribution of rocks still has a similar pattern in the northeast-southwest direction, parallel to the pattern of the main structure of Bobaris-Meratus accretion. The distribution of ultramafic rocks (Um) was only about 20% of the island's area (**Rustandi et al., 1995**). However, the detailed mapping results show that the spread of ultramafics along the eastern side of Sebuku Island occupied almost 60% of the land. Pyroclastic rocks with limestone intercalation in the middle, equivalent to the Pitap or Haruyan Formations, occupy about 30%. Alluvium deposits or swamps occupy the rest, 10%, on the western side. The research results show that the ultrabasic rocks consist of harzburgite, dunite, and lherzolite which have experienced strong serpentinization and are distributed more widely than the regional geological map by **Rustandi et al.** (**1995**). Pyroclastic rocks in the previous regional map can also be distinguished into crystalline lithic tuff and crystalline tuff. Previously unidentified intrusive rocks were observed as microgabbro and diorite.

6. Conclusions

Sebuku Island, which extends north-south, is morphologically grouped into plain, gentle wavy, wavy, and undulating hill morphology. Through field observations and petrographic analysis, this research gives an update to previous research on the geological relations in the research area.

The lithology of North Damar consists of ultramafic rock units, pyroclastic rock units, limestone units, dike rock units, sandstone units, and alluvial deposits. The identified stratigraphic sequence generally corresponds to previous research, whilst the results of this research provide more detail on the lithology in the mentioned units.

The ultramafic rock group consists of serpentinized lherzolite, dunite, and harzburgite. The Haruyan Formation at the research location was identified as pyroclastic rock consisting of crystalline lithic tuff and lithic tuff. Microgabbro and diorite dikes intruded the ultramafics and pyroclastic units. The limestone, which is a member of the Kintap Olistolith, has an interfingering relationship with the pyroclastic unit.

The Tanjung Formation is identified as sandstone observed from outcrops. The alluvial deposits, which are the final product of the erosion process, are composed of gravel, sand, mud, and clay materials.

The geological structure that develops in the northeast-southwest fault research area is a structural contact between ultramafic unit rocks and pyroclastic rock units observed in Sei Pinang and cut by a northwest-southeast fault around Halaban.

The economic aspect of this area comes from weathered ultramafics which form laterite deposits with iron and nickel enrichment. Hydrothermal mineralization is indicated by quartz veins cross-cut the pyroclastic rocks with the general direction of west-southeast.

Acknowledgement

The authors thank the management of PT. Sebuku Iron Lateritic Ore (SILO) for research funding and permission to publish the data and information. Many thanks go to the Exploration Team of PT. SILO for support in the fieldwork.

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SAŽETAK

Ažuriranje geologije otoka Sebuku, Južni Kalimantan, Indonezija: ograničenja iz petrološke studije

Otok Sebuku nalazi se na jugoistočnome vrhu otoka Kalimantan i geološki ima sličnosti s kompleksom Bobaris-Meratus u obrascu distribucije i stratigrafskome razvoju. Obrazac pružanja geoloških struktura, bora i rasjeda, uglavnom pokazuje orijentaciju od sjeveroistok-jugozapad do sjeverozapad-jugoistok. Prethodna geološka istraživanja na otoku Sebuku usredotočila su se na distribuciju ultramafitnih stijena, za koje se temeljem istraživanja lateritnih tala pretpostavlja da sadržavaju željezo. Cilj je ovoga istraživanja odrediti geološke jedinice istraživanoga područja kako bi se unaprijedila geološka karta otoka Sebuku, posebno u područjima Sei Pinang i Halaban.
Metoda istraživanja sastoji se od terenskoga rada, laboratorijskih analiza i analiza podataka. Geološkim terenskim radom prikupljena su 34 uzorka za vrijeme detaljnoga kartiranja izdanaka, kopanja rovova i bušenja. Na šest lokacija provedeno je mjerenje 57 strukturnih geoloških elemenata. Petrografska analiza 34 uzorka provedena je s ciljem utvrđivanja tipa stijena i njihova mineralnog sastava. Stereografska analiza strukturno-geoloških podataka korištena je kako bi se odredili generalni smjer i tip geoloških struktura istraživanih izdanaka. Geološka karta nacrtana je na osnovnoj topografskoj karti mjerila 1: 50.000 pomoću MapInfo Pro v17.0.5.
Na temelju petrografskih i detaljnih terenskih opažanja izdanaka stijena i jezgara bušotina Sjevernoga Damara i područja Madanga mogu se iščitati sljedeći rezultati: litološki sastav Sjevernoga Damara posebno i otoka Sebuku općenito može se opisati kao geološka jedinica ultramafitnih stijena (lerzolit, harzburgit i dunit), jedinica piroklastičnih stijena (kristalolitoklastični tuf i kristaloklastični tuf), jedinica vapnenca, jedinica žilnih stijena (mikrogabro i diorit), jedinica pješčenjaka i jedinica aluvijalnih naslaga.
Gotovo 60 % izdanaka stijene površine otoka Sebuku pripada jedinici ultramafitnih stijena, koja je u tektonskome kontaktu s gornjom jedinicom kristalolitoklastičnim tufom i kristaloklastičnimn tufom te jedinicom vulkanoklastičnih stijena sa slojevima vapnenca. Povrh svega diskordantno se nalazi jedinica pješčenjaka, jedinica aluvijalnih naslaga i jedinica močvarnih naslaga. Jedinica mikrogabra i diorita uočena je u jezgri bušotine, a izdanci ove jedinice nisu uočeni na površini. Hidrotermalna mineralizacija karakterizirana je kvarcnim žilama koje presijecaju jedinicu piroklastičnih stijena, a uočena je u jezgrama bušotine. Ovo istraživanje daje detaljniji geološki opis istraživanoga područja u odnosu na prethodna istraživanja i regionalnu geološku kartu.

Ključne riječi:
otok Sebuku, ultramafitne stijene, piroklastične stijene, serpentinizacija, mikrogabro

Author's contribution

Wahyu Widodo (1) (B.Sc, Researcher) conceptualization, field work, petrography analyses, data analyses, and writing. **Haryadi Permana (2)** (Prof. Dr. Researcher) petrography analyses, data analyses, and discussion. **Ernowo (3)** (Dr, Researcher) conceptualization, field work, data management, discussion, writing. **Yoseph C.A. Swamidharma (4)** (MSc, researcher), conceptualization, discussion. **Inu Pinahalan (5)** (B.Sc, Researcher) discussion. **Andhi Cahyadi (6)** (B.Sc, Researcher) field work, visualization and preparation. **Yudhi Krisnanto (6)** (B.Sc, Researcher) field work, visualization, and discussion.