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RESEARCH ARTICLE

Petrogenetic Study of Ultramafic Rocks from Waturapa and Surrounding Areas, South Konawe Regency, Southeast Sulawesi Province, Indonesia

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Abstract

The petrogenesis study of ultramafic igneous rocks in the South Konawe Region has been carried out by several previous researchers. However, petrogenesis of ultramafic igneous rocks in the Waturapa Region (located in South Konawe) has never been carried out in detail due to the unexposed ultramafic rock. With the exposure of ultramafic rocks by mining activity, it is important to understand the process and tectonic setting of the formation of the rocks. Therefore, this study aims to determine the characteristics and petrogenesis of ultramafic igneous rocks in the Waturapa area using petrographic and geochemical analysis using the XRF method. Petrographic analysis was carried out to determine the relative abundance percentage of primary minerals in the form of olivine, clinopyroxene, orthopyroxene, and opaque minerals as well as secondary serpentine minerals which were formed later. Meanwhile, XRF geochemical analysis is used to determine the major and minor oxide content in rocks. This geochemical data is used to determine ultramafic rock types, and magma series and to interpret the tectonic setting of the research location. The results showed that the ultramafic rocks in the study area consisted of olivine websterite and lherzolite, both of which have been serpentinized which is characterized by the presence of serpentine minerals such as lizardite and chrysotile. These serpentine minerals are present as replacement minerals and fracture-filling minerals. The geochemical characteristics of the analyzed rocks showed a SiO_2 content of less than 45%, high MgO content, and low K_2O, TiO_2, Na_2O3, and P_2O_5 compounds. The igneous rocks in the study area are classified as ultramafic rocks (peridot gabbro). Ultramafic rocks in the study area belong to the tholeiitic magma series that formed in oceanic islands or oceanic intraplate margins.

Keywords: Petrogenesis, Ultramafic rocks, Waturapa, South Konawe, Serpentine, Oceanic island.

1. Introduction

Sulawesi Island is part of the confluence of three large plates that form the territory of Indonesia, two of which are still actively moving. The western part is the Eurasian continental plate, also known as the relatively stationary Sunda Shelf. The southeastern part is formed by the Australian Continental Plate, which is moving northward, and the eastern part is occupied by the Pacific Ocean Plate, which is moving westward. The collision between these plates causes subduction which results in the lifting of oceanic crust rocks and deep-sea sediments to the surface which is called ophiolite (Surono, 2013). Ultramafic rocks are present as the main component of the upper mantle beneath the continental or oceanic crust (Kadarusman et al., 2004). In simple terms, ultramafic rocks are known as a host for some ore minerals such as chromite, nickel sulfide, magnetite, and nickel laterite (Sufriadin et al., 2017).

Petrogenesis of igneous rocks includes the characteristics of the magma source and the conditions of gradual melting, as well as the extent of changes that occur after the magma is transported (Wilson, 1989). Petrogenesis studies are considered very important because they can be used to interpret the processes and tectonic settings of rock formation (Erzagian et al., 2016).

Previous researchers have previously conducted research on petrogenesis in the East Arm region and the results indicated that the East Arm ophiolite of Sulawesi was formed in the tectonic environment of the Mid Oceanic Ridge, Oceanic Plateau, and Minor Island Arc (Kadarusman et al., 2004). Meanwhile, a petrogenesis study of ultramafic igneous rocks in the southeastern arm of Sulawesi was conducted by Aznah (2019) with the conclusion that ultramafic rocks in the Lalembuu Region, Konawe Selatan, Southeast Sulawesi were formed in a tectonic setting in the form of oceanic ridge and floor or mid-oceanic ridge basalts.

Referring to the regional geological map (Simandjuntak et al., 1993), ultramafic rocks in the study area, specifically in the Waturapa area, South Konawe, Southeast Sulawesi, were unmapped regionally. However, mining activities in this area exposed ultramafic rocks that were previously covered by the Sulawesi Molasse (Langkowala Formation and Eemoiko Formation). With the exposure of ultramafic rocks, it is important to carry out research related to petrogenesis to understand the process and tectonic setting of the formation of these rocks.

2. Geological setting

Sulawesi Island is located in the central part of Indonesia and is the location where three plates meet, namely the Eurasian plate, the Pacific-Philippine plate and the Indian-Australian plate (Hall and Wilson, 2000). This situation makes Sulawesi a geologically complex island. Rocks that were once at the bottom of the ocean are now found exposed on the surface. This is reflected in the widespread distribution of ultramafic rocks in the eastern and southeastern arms of Sulawesi (Atmadja et al., 1974; Panggabean and Surono, 2011; Surono, 2013). In the study area, located in the southern part of the southeastern arm of Sulawesi, to be precise in the Waturapa area, Palangga Selatan District, South Konawe Regency, ultramafic rock is exposed locally and belongs to the East Sulawesi Ophiolite (ESO) Belt (Fig. 1) which is covered by Neogene and Quaternary sediments (Kadarusman et al., 2004).

Regionally, the Waturapa area is included in the regional geology of the Kolaka sheet (Simandjuntak et al., 1993). Based on this geological map, the Waturapa Area (study area) is composed of two rock formations, from old to young, namely, the Langkowala Formation (composed of conglomerates, sandstones, shales, and local calcarenite) and the Eemoiko Formation (consisting of calcarenite, coral limestone, sandstone, and marl) (Fig. 2a). Simandjuntak et al. (1993) considered the Langkowala Formation and Eemoiko Formation to be Miocene and Pliocene in age, respectively (Fig. 2b). On the other hand, Surono (2013) stated that the Langkowala Formation and Eemoiko Formation are part of the Sulawesi Molasa, both of which are Miocene in age and have a stratigraphic relationship fingering each other. Recent research on Sulawesi molasses shows that the Langkowala Formation and Eemoiko Formation also have a finger-finger stratigraphic relationship with a relatively longer depositional age range, from Miocene to Pleistocene (Fig. 2c) (Nugraha et al., 2022).

In Fig. 2a, regionally, the study area (red rectangle) does not appear to be composed of Ultramafic Complexes (Ku). However, ultramafic rocks are found locally exposed in this area due to mining activities.

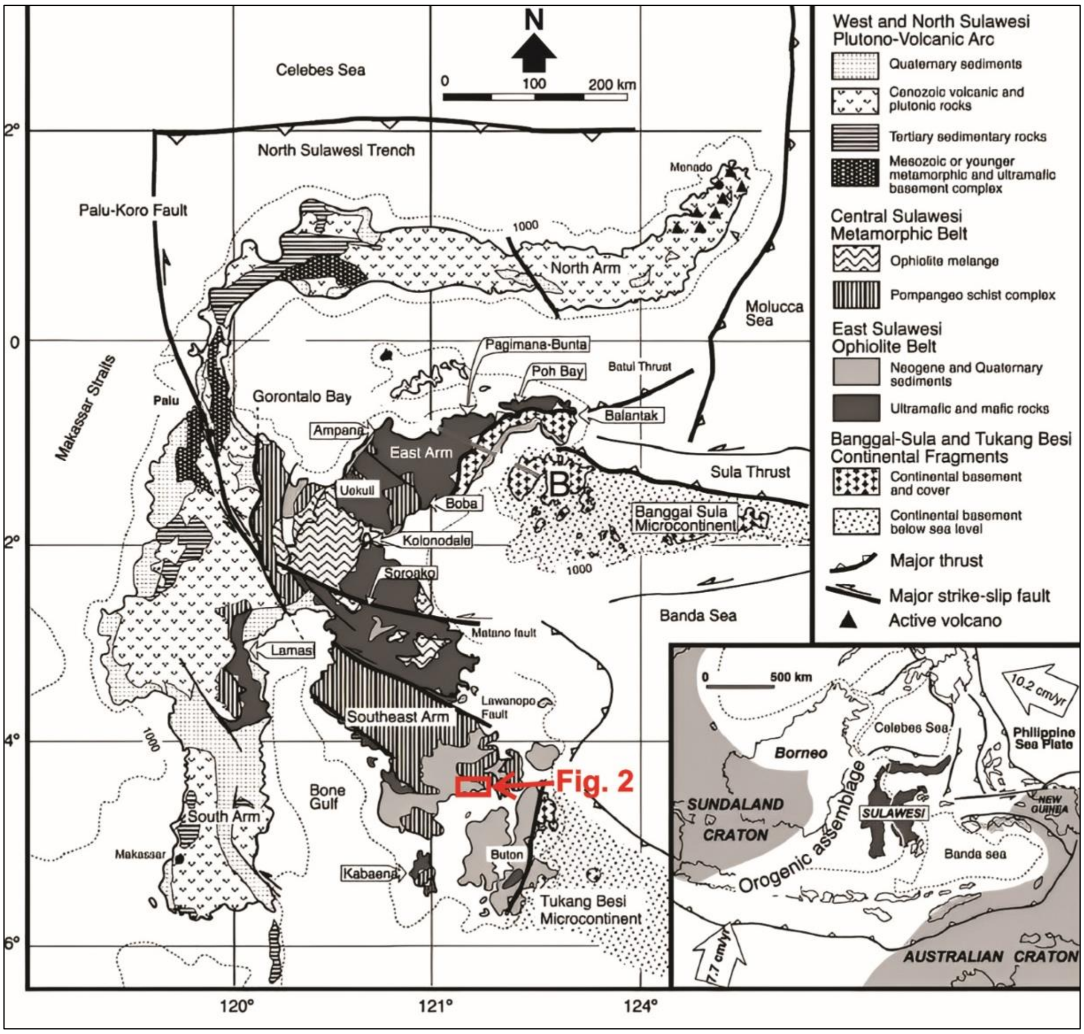

Fig. 1. Simplified geological map of Sulawesi (Kadarusman et al., 2004) and the location of Fig. 2

3. Materials and Methods

The samples used in this study are ultramafic rocks exposed in the study area (Fig. 3). As can be seen in Fig. 2a, samples were taken from five locations and labelled as HST.008, HST.028, HST.030, HST.033 and HST.042. Hand specimen-sized samples from each location were described macroscopically. To determine the texture, structure, and mineral composition microscopically, petrographic analysis was applied. In this analysis, the rock sample is thinly sliced to a thickness of about 0.03 mm and observed under a polarizing microscope. Thin section preparation and petrographic analysis were carried out at the Petrography and Mineral Optics Laboratory, Department of Geological Engineering, Hasanuddin University, Makassar.

The content of major and minor oxides was analyzed using the X-Ray Fluorescence (XRF) method. This analysis involved five ultramafic rock samples and was carried out at the Central Laboratory of Hasanuddin University, Makassar. The data from the XRF analysis were utilized to interpret the type of magma, magma affinity, and the tectonic environment for magma formation using The GeoChemical Data ToolKIT (GCDkit) software.

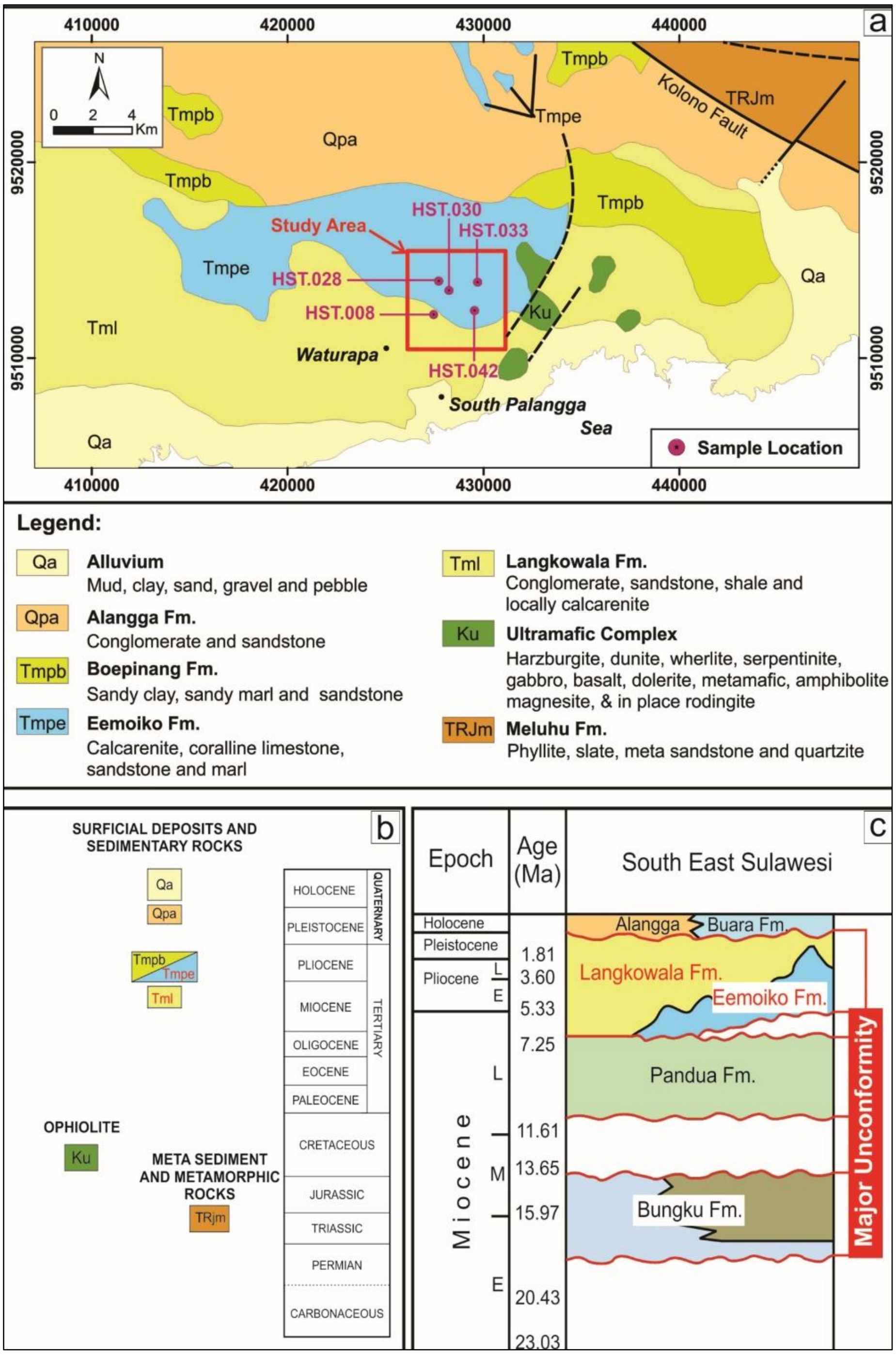

Fig. 2. (a) Regional geological map of the southern Kolaka sheet (Simandjuntak et al., 1993) and the location of the study area; (b) and (c) Regional stratigraphy according to (Simandjuntak et al., 1993) and (Nugraha et al., 2022), respectively. Red texts indicate the rock formations that make up the study area

4. Results and Discussion

4.1 Field Observation and Petrography

Based on the results of field observation, megascopic description, and petrographic analysis, ultramafic rock samples in the study area fall into two rock types. Samples such as HST.008 and HST.042 are classified as olivine websterite, while samples with codes HST.028, HST.030, and HST.033 are plotted as lherzolite (Streckeisen, 1976).

Megascopically, olivine websterite has a white-gray weathered color, blackish green fresh color, shows a texture of crystallinity: holocrystalline, granularity: phaneritic, inter-crystal relationships: equigranular, crystal form: euhedral-anhedral, composed of pyroxene, serpentine, and opaque minerals. The results of the petrographic analysis show a more detailed rock composition with varying abundances. The mineral olivine occurs at 10% abundance and still exhibits a relic texture. The minerals of orthopyroxene (enstatite) and clinopyroxene (augite) are present at 11% abundance each. Another primary mineral identified is an angular-shaped opaque mineral with an abundant of 3% and slightly oxidized at the edges. Generally, the rocks are strongly deformed and serpentinized, indicated by the abundant lizardite and chrysotile-type serpentine minerals showing a mesh texture together with olivine mineral (Fig. 3). Serpentine minerals are very dominant and reach an abundance of 65%.

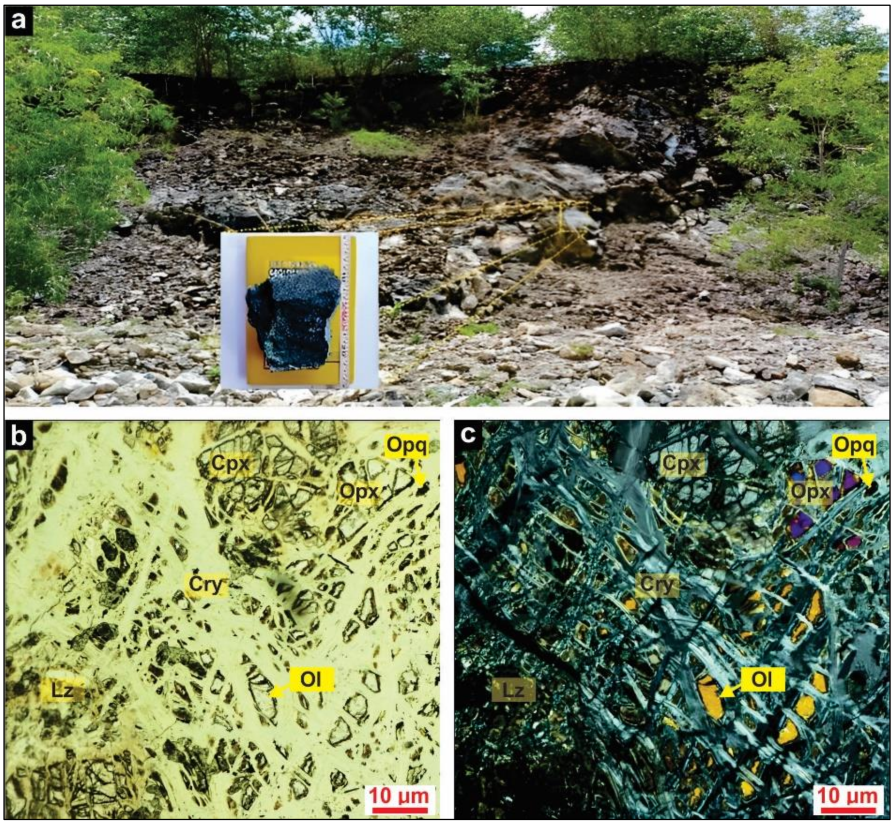

Fig. 3. (a) Typical olivine websterite outcrop and hand specimen. (b) Photomicrograph of olivine websterite on plane-polarized light (PPL) and (c) crossed-polarized light (XPL) of HST.008. Notes: Cpx = clinopyroxene (augite), Cry = chrysotile (serpentine), Lz = lizardite (serpentine), Ol = olivine, Opq = opaque mineral, Opx = orthopyroxene (enstatite).

Lherzolite found at locations of HST.028, HST.030, and HST.033 crop out at the mining site (Fig. 4a) and generally show a litlle different characteristics compared to previous ultramafic rock samples. Megascopically, lherzolite is gray (weathered sample) and dark green in colour (fresh sample). Under the polarized microscope observation, the rock composed of euhedral to anhedral crystals shows a holocrystalline and equigranular-phaneritic texture. Compared to olivine websterite, this rock contains more olivine minerals, with an abundance of up to 14%. Other minerals that are also present are orthopyroxene (enstatite, 7%), clinopyroxene (augite, 9%), and opaque minerals (2%). This rock also experiences serpentinization alteration, characterized by the abundant lizardite (54%) and chrysotile (14%) serpentine minerals. Both minerals are present as fracture-filling and replacement minerals and form mesh texture showing olivine minerals surrounded by serpentine (Fig. 4b–Fig. 4e).

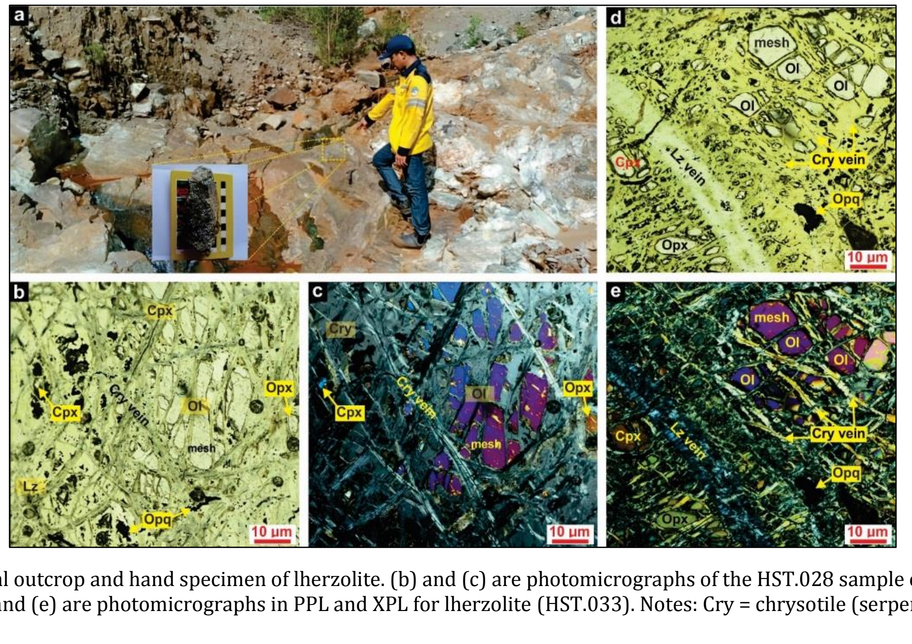

Fig. 4. (a) Typical outcrop and hand specimen of lherzolite. (b) and (c) are photomicrographs of the HST.028 sample on PPL and XPL, respectively. (d) and (e) are photomicrographs in PPL and XPL for lherzolite (HST.033). Notes: Cry = chrysotile (serpentine), Cry vein =

chrysotile vein, Cpx = clinopyroxene (augite), Lz = lizardite (serpentine), Lz vein = lizardite vein, Ol = olivine, Opq = opaque mineral, Opx = orthopyroxene (enstatite) , mesh = mesh texture

4.2 Whole-rock geochemistry

Table 1 shows the results of rock geochemical analysis using the XRF method. As we can see, the geochemical characteristics of the rock analyzed show a SiO_2 content of less than 45%, a high MgO content, and relatively lower K_2O, TiO_2, Na_2O, and P_2O_5 compounds. We utilize this geochemical data to determine several parameters of rock petrogenesis, such as rock type, magma series, and magma origin.

Table 1. Major and minor oxides of ultramafic rocks in the study area

Oxides (in wt.%)	Sample ID				
	HST.008	HST.028	HST.030	HST.033	HST.042
SiO_2	40,31	43,2	39,8	41,21	39,41
MgO	13,2	14,3	10,13	10,51	9,12
Fe_2O_3	24,97	25,09	24,7	21,91	23,65
FeO	15,92	24,41	21,78	17,96	21,32
Na_2O	0,0367	< 0,01	0,0347	< 0,01	< 0,01
Al_2O_3	2,36	2,12	2,35	0,09	1,07
CaO	1,19	1,78	1,18	1,5	1,59
Sb_2O_3	0,0073	0,0123	0,0097	0,0097	0,0132
NiO	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01
MnO	0,473	0,429	0,522	0,453	0,372
P_2O_5	< 0,01	0,0038	0,0144	0,0243	0,0463
TiO_2	< 0,01	0,0531	0,0356	0,0241	0,0224
V_2O_5	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01
K_2O	< 0,01	0,0011	0,3	0,0096	0,0013
CuO	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01
Rh_2O_3	0,0063	0,0106	0,0092	0,0075	0.0108
In_2O_3	0,0116	0,0182	0,0170	0,0158	0,0184
Total	82,5397	86,977	79,0667	75,8174	75,282

The type of ultramafic igneous rock is determined by referring to the classification of igneous rock according to (Middlemost, 1994). This classification is divided based on the weight percent content of total alkali (Na_2O + K_2O) and weight percent of silica (SiO_2). We use the geochemical data of five samples and plot them into the diagram. The results show that all rock samples include in ultrabasic rocks group or ultramafic rocks. The graphic also exhibits that two of the five rock samples analyzed geochemically (HST.028 and HST.033) fall into peridot gabbro (Middlemost, 1994) (Fig. 5).

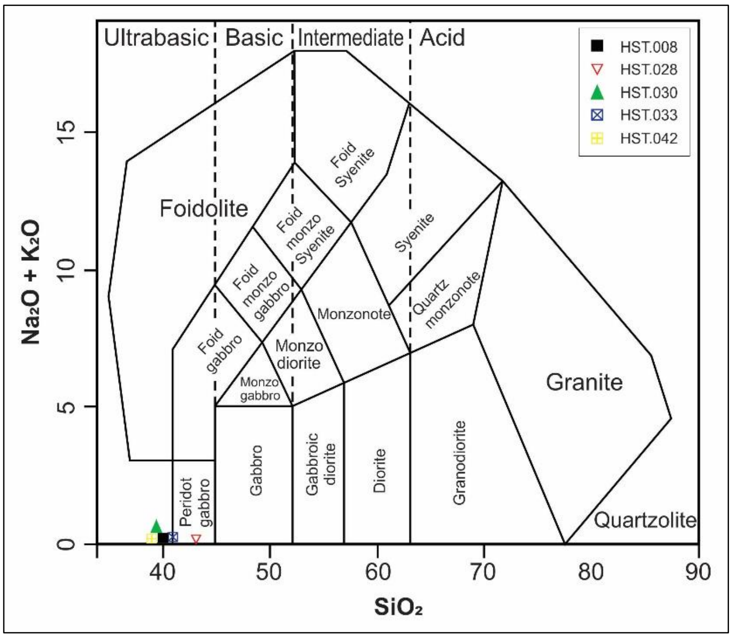

Fig. 5. The classification of plutonic rocks (Middlemost, 1994) and the result of the plotted geochemical data of five rock samples.

After knowing the types of ultramafic rocks that make up the research area, then the magma series is determined. A magma series is a compositional group that can describe the evolution of magma. Initially, magma from the mantle has an ultramafic composition rich in Mg and Fe. As a result of magma differentiation (fractional crystallization), the composition of magma will evolve into more acidic magma, characterized by relatively lower Mg and Fe contents (Wilson, 1989 and Winter, 2014).

Determination of the magma series that forms ultramafic rocks can be carried out by utilizing the AFM triangle diagram (A = $Na_2O + K_2O$; F = $FeO + Fe_2O_3$; and M = MgO). Genetically, Vermeesch and Pease (2021) have proposed a new classification of the magma series into tholeiitic or calc-alkaline by replacing the F component ($FeO + Fe_2O_3$) with TiO_2. However, because the TiO_2 content in this study sample was very little, the determination of the magma series still used the AFM diagram by Irvine and Baragar (1971). The plot results in the AFM diagram show that the five ultramafic igneous samples from the study area with sample codes HST.008, HST.028, HST.030, HST.033, and HST.042 belong to the tholeiitic magma series (Fig. 6a). Tholeiitic magma series is formed when magma is reduced (Osborn, 1959). In reduced magma, the content of iron (Fe) and magnesium (Mg) will relatively decrease because these two components are crystallized as ferromagnesian minerals such as olivine and pyroxene (Fig. 3b and 3c; and Fig. 4b – Fig. 4e).

The tholeiitic magma series may form in several tectonic settings, either in island arcs, mid-oceanic ridges, oceanic islands, or continental rift zone environments (Wilson, 1989). To interpret the tectonic environment of the origin of the ultramafic rock-forming magma in the study area, we used the triangular diagram by Pearce et al. (1977), in which this diagram compares the main elements of rock in the form of FeO^T (total), MgO and Al_2O_3 (Fig. 6b). The plotting results in the diagram show that the ultramafic rocks in the Waturapa area formed in an oceanic island environment (Pearce et al., 1977) or widely known as oceanic intraplate margin (Wilson, 1989; Winter, 2014). An illustration of the oceanic island tectonic environment is provided in Fig. 7. It is well-known that Hawaiian Islands are an example of a product of oceanic intraplate volcanism (Winter, 2014).

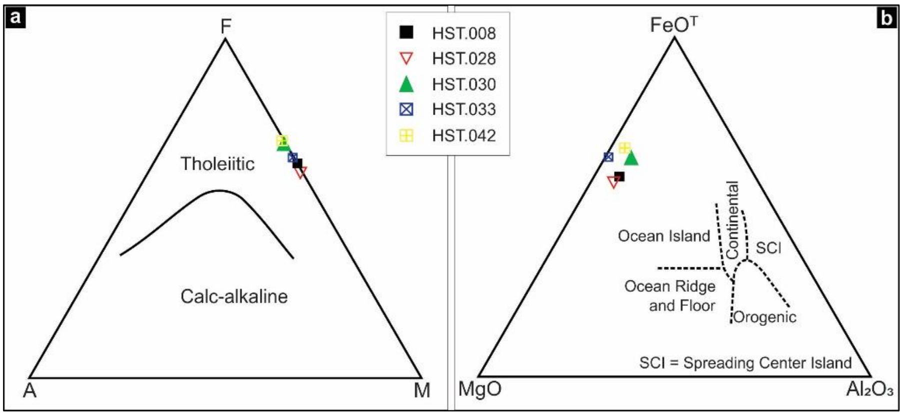

Fig. 6. (a) Determination of magma series using AFM diagrams (Irvine and Baragar, 1971) and (b) Interpretation of tectonic settings (Pearce et al., 1977). Notes: A = $Na_2O + K_2O$; F = $FeO^T = FeO + Fe_2O_3$; and M = MgO

Interpretation of the tectonic setting of the magma that formed ultramafic rocks in the eastern and southeastern arms of Sulawesi has also been carried out by previous researchers and the results show that these ultramafic rocks originate from mid-oceanic ridges (Atmadja et al., 1974; Asfar and Eric, 2019; Hasria et al., 2020) and suprasubduction zone (Bergman et al., 1996; Parkinson, 1998). Nonetheless, Kadarusman et al. (2004) interpret that the ultramafic rocks in the eastern and southeastern arms of Sulawesi are grouped as East Sulawesi Ophiolite (ESO) belt, originating from mid-oceanic ridges, oceanic plateaus or seamounts, and minor supersubduction zones (SSZ) where the oceanic plateau or seamount is the product of the oceanic intraplate volcanism (Winter, 2014).

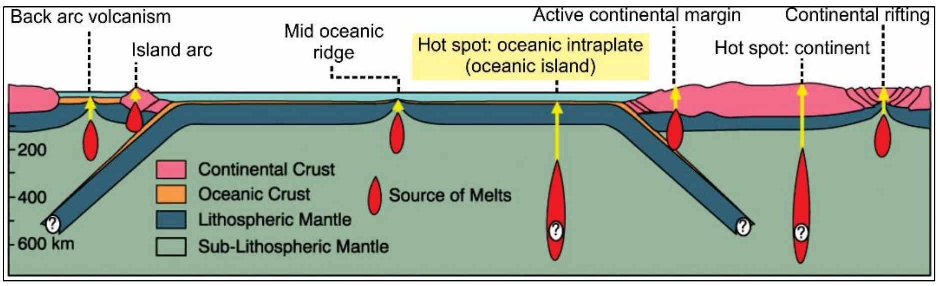

Fig. 7. Illustration of the location of magma formation and their tectonic setting association (after Winter, 2014). The yellow block is the result of the tectonic setting interpretation of the study area

5. Conclusions

The conclusions of this study are as follows:

- Based on the petrographic analysis, the ultramafic rocks in the study area consist of olivine websterite and lherzolite, characterized by the presence of chrysotile and lizardite minerals which appear as fracture-filling minerals and replacement minerals
- The results of geochemical data interpretation indicate that the igneous rocks in the study area are classified as ultramafic/ultramafic rocks (peridot gabbro) exhibiting a tholeiitic magma series and formed in an oceanic island or oceanic intraplate margin.

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