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JNRAG

E-ISSN : xxxx-xxxx
P-ISSN : xxxx-xxxx

Journal of Applied Geology and Geoscience
Vol xx No xx 20xx

RESEARCH ARTICLE

Petrogenetic Analysis of Ultramafic Peridotite Rocks Case Study: Tinanggea Area, Southeast Sulawesi Province

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Received: Desember 1, 2025; Accepted: Mei 05, 2026.
DOI: 10.24273/Jagg.2025.1.2.001

Abstract
Ultramafic rocks in the ofiolite complex of the Southeast Arm of Sulawesi have a fairly wide distribution in the Tinanggea Region. Administratively, the research area is located in Tinanggea District, Southeast Sulawesi Province. Geographically, it is located at coordinates and 4˚ 22' 15"to 4˚ 24' 14" South latitude (LS) dan 122˚10' 16.88"to 122˚12' 22" East Longitude (East). This study aims to determine the characteristics of ultramafic rocks, the type and origin of magma, and the environment that forms ultramafic rocks in the study area. This research was conducted on ten (10) ultramafic rock surface samples from the results of field mapping activities then carried out petrographic mineralogical analysis and geochemical analysis using XRF (X-Ray Flouresence). From the results of the data analysis, it was found that the types of ultramafic rocks in the study area consist of lherzolite and wehrlite. Based on major rock element data, ultramafic rocks in the Tinanggea area have ultramafic magma types with low SiO_2, with a thoellitic magma series that has high total MgO and FeO values. Ultramafic rocks in the study area were formed in the tectonic environment of the expansion of the ocean floor of the ocean ridge and floor and the ocean islands of the ocean island.

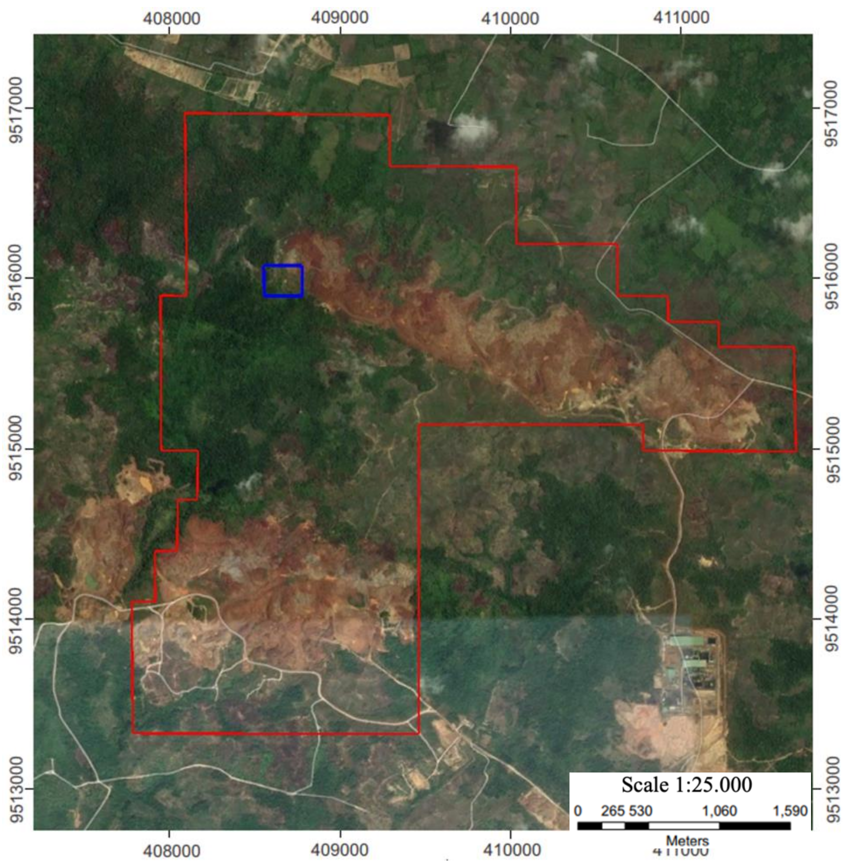
Keywords: Characterization, Ultramafic, Tinanggea, Petrography, Geochemistry

1. Introduction

The island of Sulawesi is an active tectonic region located between three major plates, namely the Eurasian Plate to the northwest, the Indo-Australian Plate to the south, and the Philippine Sea Plate to the east. The convergence and interaction of these three plates have resulted in Sulawesi's complex geological history, marked by various geodynamic phases such as Mesozoic extension,Cretaceous subduction, Paleogene-Neogene collision, and Quaternary double subduction (Silver et al., 1983; Simandjuntak, 1986) in Nugraha and Hall, 2021). One result of these tectonic processes is the formation of a complex ophiolite belt in eastern Sulawesi, including in the Southeast Arm, known as LOST (Lajur Ofiolit Sulawesi Tenggara) and consisting of ultramafic,mafic,and pelagic sedimentary rocks (Hall and Wilson, 2000).

The ultramafic rock complex found in this area generally includes lherzolite, wehrlite, dunite, and harzburgite, which are composed of the main minerals olivine and pyroxene, and have characteristic chemical contents such as low SiO2 and high MgO (Burger, 1996; Mick Elias, 2002). Based on geochemical studies, these rocks are associated with a mid-ocean ridge and ocean island formation environment and exhibit toleitic magma characteristics (Wilson, 1989 in Shallaly et al., 2025). The petrogenesis of ultramafic rocks includes analysis of magma evolution, partial melting processes in the upper mantle, and the influence of tectonic systems on their formation (Wyllie, 1970 in Erzagianetal et al., 2016).

The Tinanggea subdistrict in Southeast Sulawesi is a geologically strategic location because it has extensive and fresh ultramafic rock outcrops. This area is included in the WIUP (Mining Business Permit Area), an area that also has potential for laterite nickel deposits, making it important in the context of mineral resource exploration. Based on the Kolaka regional geological map and previous studies, the ultramafic rocks in this region belong to the ophiolite complex and are closely associated with Miocene rock formations such as the Langkowala Formation (Simandjuntak, 1993; Surono, 2013). Therefore, this study aims to identify the petrographic and geochemical characteristics of peridotite ultramafic rocks in the area and interpret their petrogenesis and relationship with the regional tectonic setting.



Source: Landsat Image Google Earth

Fig. 1. Geological map of Kolaka, the red box indicates the research area

2. Research Method

This study applies a combinative approach between qualitative and quantitative methods with an emphasis on field observations and laboratory analysis to obtain a comprehensive understanding of the petrogenesis of ultramafic rocks in the study area. The data used are classified into two main categories, namely primary data and secondary data. Primary data includes field observation results in the form of geomorphological information, rock outcrops, geological structures, geochemical data using X-ray Fluorescence (XRF), and ultramafic rock samples. Meanwhile, secondary data consists of literature studies (books, scientific journals, and online sources), topographic data from remote sensing imagery, and spatial data of the region research. These two types of data complement each other in the process of analyzing and interpreting the genesis of ultramafic rocks. The research procedure was carried out systematically through several main stages. The first stage was the collection of ultramafic rock sample data. The next stage was data processing, which began with a macroscopic description of the rock samples and continued with the preparation of thin sections 0.03 mm thick for microscopic.

Laboratory analysis was conducted using two main approaches, namely petrography and geochemistry. Petrographic analysis was performed on six ultramafic rock samples using a polarizing microscope, with the aim of identifying mineral composition and classifying rocks based on the ultramafic classification system according to Streckeisen (1974). Meanwhile, geochemical analysis was performed on ten samples using the XRF method to determine the characteristics of major elements such as Fe, Ni, Co, MgO, SiO_2, CaO, Al_2O_3, Cr_2O_3, and MnO. This analysis was also used to interpret the type of magma normatively based on the chemical characteristics of the rock constituents. All data obtained were then analyzed and interpreted integratively. The results of the analysis were used to answer the research objectives, namely to reveal the mineralogical and geochemical characteristics and petrogenetic processes of ultramafic rocks in the study area.

RESULTS AND DISCUSSION

The research was conducted in Tinanggea District, South Konawe Regency, Southeast Sulawesi. The main objectives were to identify the macroscopic and microscopic characteristics of ultramafic rocks, determine the type and origin of magma through geochemical analysis, and compile an interpretation of the petrogenesis of rocks at the site. Based on the results of geological mapping and field observations, the geological conditions of the study area were analyzed through the aspects of petrographic characteristics and geochemical elements of ultramafic rocks (adapted from field research data, 2025).

Petrological Analysis

Macroscopically, peridotite at the study site is blackish green in color, with a hypocrystalline phaneritic texture. Its composition is dominated by olivine, pyroxene, serpentinite, and silica, with allodiomorphic granular crystals (Fig. 2). The presence of serpentinite indicates mild serpentinization, while weathering is evident from the color change to light brown and reddish, which is associated with the precipitation of silica and iron oxide minerals (Fig. 2A–B), indicating chemical alteration processes.

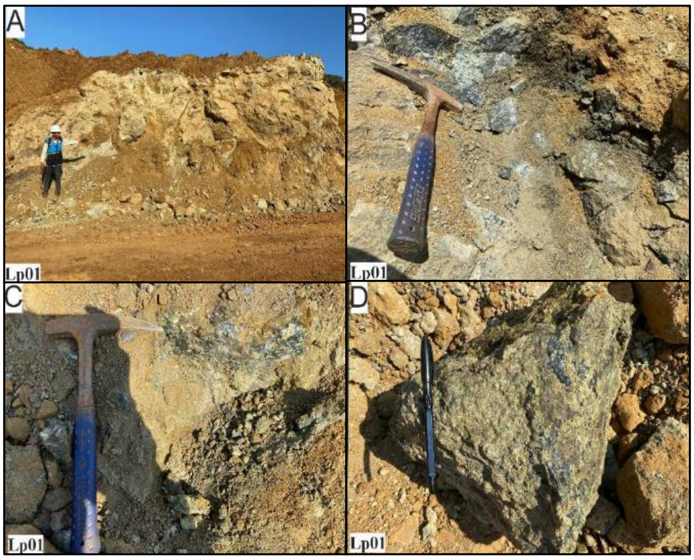
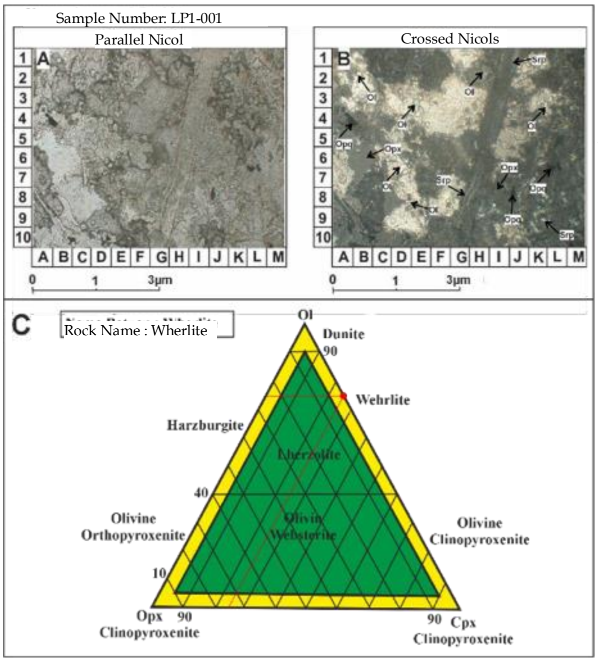


Fig. 2. Ultramafic peridotite rock outcrops in the Tinanggea area, with an azimuth direction of N 284° E (B, C, and D) close-up view of rock outcrop.

Wherlite Rock in LP1-001

Petrographic analysis of peridotite rock in LP1-001 shows that olivine in the LP1-001 section sample is characterized by regular fractures and an interlocking texture. Orthopyroxene is present in subhedral crystal form, as well as opaque minerals that are thought to be altered minerals from primary minerals formed as a result of oxidation reactions during the weathering process (Fig. 3).



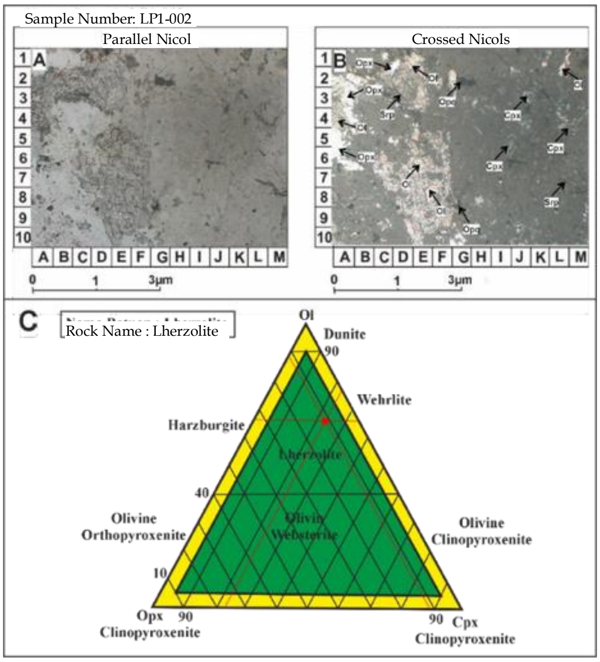


Fig. 4. Thin Section of Lherzolite LP1-002, (A) Parallel Nicol view, (B) Crossed Nicol view, Ol: Olivine, Opx: Orthopyroxene, Cpx: Clinopyroxene, Srp: Serpentine, and Opq: Opaque, and (C) Ultramafic rock naming diagram according to classification (Streickeisen, 1976).

Fig. 3. Thin section of Wehrlite LP1-001, (A) parallel nicols view, (B) crossed nicols view, Ol: olivine, Opx: orthopyroxene, Srp: serpentinite, and Opq: opaque, and (C) ultramafic rock naming diagram according to classification (Streickeisen, 1976).

Lherzolite Rock at LP1-002

Petrographic analysis of peridotite rock in LP1-002 shows that olivine minerals are characterized by irregular fractures and interlocking texture. Orthopyroxene is present in anhedral crystal form, clinopyroxene is present alongside serpentine minerals and is characterized by anhedral crystal form, and opaque minerals are suspected to be altered minerals from primary minerals formed as a result of oxidation reactions during the weathering process (Fig. 4B).

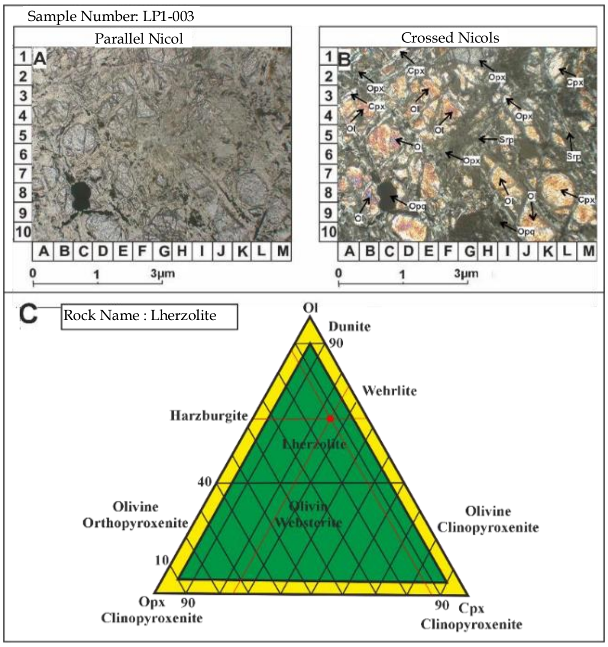


Fig. 5. Thin Section of Lherzolite LP1-003, (A) Parallel Nicol view, (B) Crossed Nicol view, Ol: Olivine, Opx: Orthopyroxene, Cpx: Clinopyroxene, Srp: Serpentine, and Opq: Opaque, and (C) Ultramafic rock naming diagram according to classification (Streickeisen, 1976).

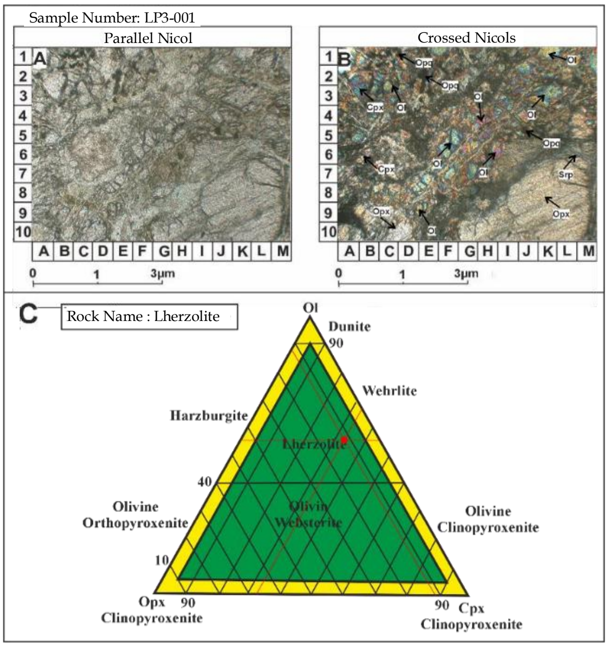


Fig. 6. Thin Section of Lherzolite LP3-001, (A) Parallel Nicol appearance, (B) Crossed Nicol appearance, Ol: Olivine, Opx: Orthopyroxene, Cpx: Clinopyroxene, Srp: Serpentine, and Opq: Opaque, and (C) Ultramafic rock naming diagram according to classification (Streickeisen, 1976).

Petrography of *Lherzolite* Rocks at LP1-003

Petrographic analysis of peridotite rocks in LP1-003 shows that molivine in LP1-003 section samples is characterized by regular fractures and interlocking texture. Orthopyroxene is present in anhedral crystal form, clinopyroxene is present in subhedral monoclinic form, and opaque minerals are suspected to be alteration minerals from primary minerals formed as a result of oxidation reactions during the weathering process (Fig. 5B).

Petrography of *Lherzolite* Rocks at LP3-001

Petrographic analysis of peridotite rocks in LP3-001 shows that olivine minerals are characterized by irregular fractures and interlocking textures and are almost aligned (foliation). Orthopyroxene is present in subhedral crystal form, clinopyroxene is present in subhedral monoclinic form, and opaque minerals are suspected to be altered minerals from primary minerals formed as a result of oxidation reactions during the weathering process (Fig. 6B).

Petrography of *Lherzolite* Rocks at LP3-002

Petrographic analysis of peridotite rock in LP3-002 shows that olivine minerals are characterized by irregular fractures and interlocking texture. Orthopyroxene is present in anhedral crystal form, clinopyroxene is present in anhedral form, and opaque minerals are suspected to be altered minerals from primary minerals formed as a result of oxidation reactions during the weathering process (Fig. 7B).

Petrography of *Lherzolite* Rocks at LP3-003

Petrographic analysis of peridotite rock in LP3-003 shows that olivine minerals are characterized by irregular fractures and interlocking texture, as well as a brownish color on the cross-section, suggesting that the olivine minerals have undergone further alteration or weathering. Orthopyroxene is present in subhedral crystal form with moderate relief, as well as opaque minerals that are suspected to be altered minerals from primary minerals formed as a result of oxidation reactions during the weathering process (Fig. 8B).

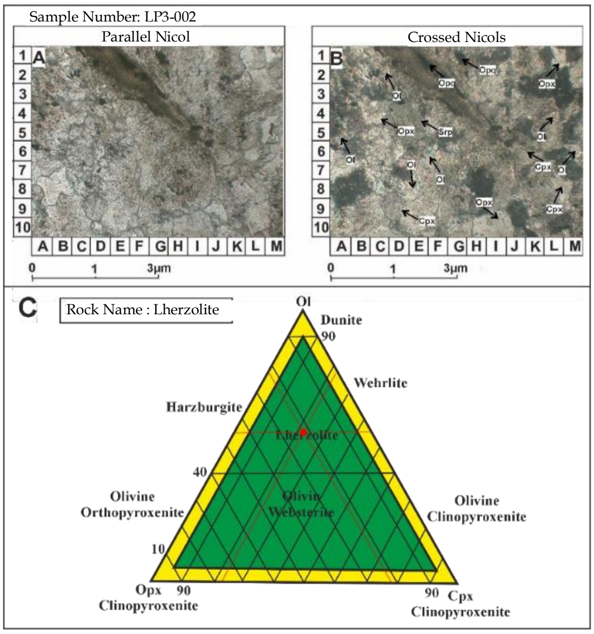


Fig. 7. Thin Section of Lherzolite LP3-002, (A) Parallel Nicol view, (B) Crossed Nicol view, Ol: Olivine, Opx: Orthopyroxene, Cpx: Clinopyroxene, Srp: Serpentine, and Opq: Opaque, and (C) Ultramafic rock naming diagram according to classification (Streickeisen, 1976).

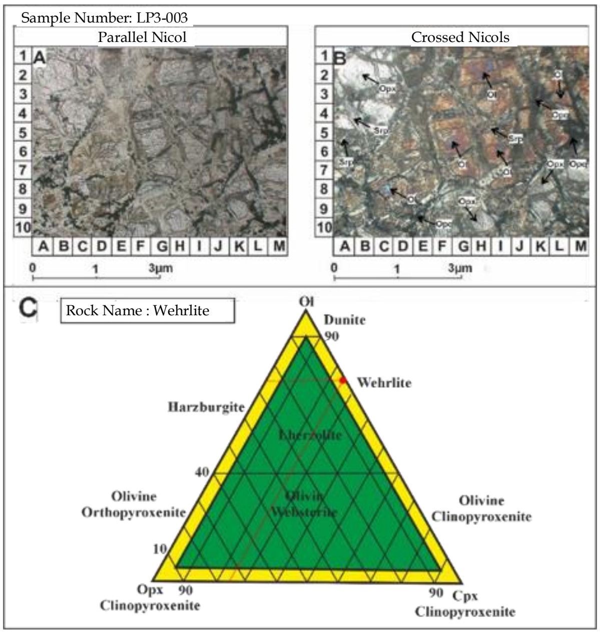


Fig. 8. Thin section of Lherzolite LP3-002, (A) parallel nicols, (B) crossed nicols, Ol: olivine, Opx: orthopyroxene, Srp: serpentinite, and Opq: opaque, and (C) ultramafic rock naming diagram according to classification (Streickeisen, 1976).

The results of petrographic analysis, ultramafic rocks are suspected to have undergone a low degree of serpentinization, causing changes in their primary minerals. Serpentine texture can be divided into two types: pseudomorphic and non-pseudomorphic. Microscopically, all section sample show a pseudomorphic texture, in which the section samples show the growth of serpentinite minerals but still reveal the texture of the altered primary mineral relics (Fig. 3, 4, 5, 6, 7, and 8B). Serpentine veins are also present and penetrate the primary mineral body, forming a non-pseudomorphic texture, which means that in the section samples, the primary minerals have begun to transform into serpentine minerals. Petrographic analysis shows that ultramafic rocks at the study site underwent serpentinization, marked by there placement of olivine by chrysotile serpentine minerals with a kink band texture. The dominant content of olivine and pyroxene, as well as the presence of serpentine, indicates that the rock originated from a magmatoleitic series. This process likely occurred in a mid-ocean ridge environment due to the interaction of rocks with seawater (Razak et al., 2024).

The results of ultramafic rock classification based on rock mineralogical composition in Table 1 present the mineralogical composition of six ultramafic rock samples coded as LP1-001 to LP3-003. The main mineral compositions analyzed include olivine, orthopyroxene, clinopyroxene, serpentinite, and opaque minerals, which are expressed as percentages (%).

a. Olivine is the dominant mineral in all samples, ranging from 50–60%, indicating the ultramafic nature of the rock.
b. Orthopyroxene is present in the range of 20–30%, playing a role in distinguishing the types of ultramafic rocks formed.
c. Clinopyroxene is only found in some samples, with a maximum content of 20%, which also influences rock classification.
d. Serpentine and opaque minerals appear as alteration and accessory minerals, with relatively small contents, each <15%

Table 1. Mineralogy of Ultramafic Rocks in the Study Area

Mineral %	LP1-001	LP1-002	LP1-003	LP3-001	LP3-002	LP3-003
Olivine	60	60	50	50	50	60

Orthopyroxene	20	20	20	30	20	20
Clinopyroxene	-	10	10	10	20	-
Serpentine	15	5	15	5	5	10
Opaque	5	5	5	5	5	10
Nama Batuan	***Wehrlite***			***Lherzolite***		***Wehrlite***

Geochemical Characteristics of Ultramafic Rocks in the Study Area

Geochemical analysis of ten samples (LP1-001, LP1-002, and LP3-003) categorized as wehrlite, ultramafic rocks in the study area, was conducted using the X -Ray Fluorescence (XRF) method with a focus on major elements, such as Ni, Fe, Co, SiO_2, Al_2O_3, MnO, MgO, CaO, Cr_2O_3, SiO_2/MgO ratio, and forms of iron oxide (FeO, Fe_2O_3, and Fe_3O_4). This data was used to determine petrogenetic parameters, including rock type, magma series, and magma origin, with the complete analysis results presented in the relevant in Table 2.

Table 2. Major elements of ultramafic rock geochemical analysis in the study area

Major Element	LP1-001	LP1-002	LP1-003	LP3-001	LP3-002	LP3-003	LP3-004	LP3-005	LP3-006	LP3-007
Fe	6.52	7.29	5.57	5.54	6.10	6.10	5.57	6.02	7.21	8.04
Ni	0.30	1.05	0.19	0.17	0.44	0.47	0.16	0.20	0.21	0.23
Co	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02
SiO2	39.22	36.92	35.50	37.90	41.10	41.23	38.79	40.02	39.50	36.06
Al2O3	1.30	2.24	0.72	0.77	1.23	1.24	0.78	0.93	1.61	1.81
MnO	0.16	0.09	0.09	0.04	0.01	0.01	0.05	0.13	0.09	0.29
MgO	28.81	28.61	39.84	37.27	27.68	25.34	36.09	31.54	24.71	25.59
CaO	2.88	0.40	1.39	1.68	0.67	0.57	1.77	2.77	2.80	2.66
Cr2O3	0.36	0.55	0.44	0.30	0.36	0.37	0.30	0.34	0.33	0.38
SiO/MgO	2.83	3.15	1.18	1.36	5.95	8.19	1.44	1.80	4.06	3.21
FeO	8.35	9.33	7.13	7.09	7.80	7.81	7.13	7.70	9.23	10.29
Fe2O3	9.26	10.35	7.92	7.87	8.66	8.67	7.91	8.55	10.24	11.42
Total	100	100	100	100	100	100	100	100	100	100

The data from the geochemical analysis of major elements from ten ultramafic rock samples (coded LP1-001 to LP3-007) taken from the research site. This analysis aims to identify the main elements that play a role in the petrogenetic characteristics of ultramafic rocks and to interpret the type of magma from which they originated.

Ultramafic Rocks Based on Geochemical Analysis

The highest major element composition in the ten ultramafic rock samples from the study area was SiO2, MgO, Fe2O3, FeO, Fe, and SiO/MgO (Table 7). SiO2 and FeO in rock samples showed compositions of (35.50–41.23%) and (7.09–10.29%). MgO in ultramafic rock samples showed a composition of (24.71–39.84%). From the results of geochemical analysis, the composition of SiO2 in ultramafic rocks tended to be high, which means that the rocks had undergone intense weathering processes.

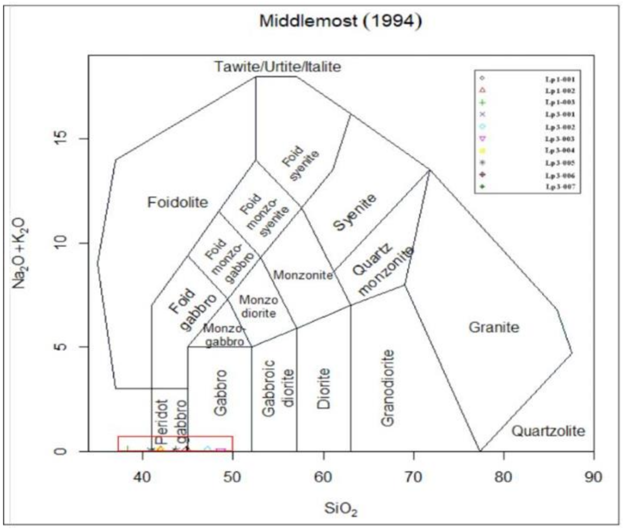


Fig. 9. Classification of ultramafic igneous rocks in the study area (Middlemost, 1994).

The classification of ultramafic igneous rocks in the study area refers to the Middlemost diagram (1994) in (Kurapov et al., 2021), which is based on the total alkali ($Na_2O + K_2O$) and silica (SiO_2) weight percentages. The plotting results (Fig. 9) show that most samples (Lp1-001, Lp1-002, Lp1-003, Lp3-001, Lp3-004, Lp3-005, Lp3-006, and Lp3-007) are classified as peridotite-gabbro, while two samples (Lp3-002 and Lp3-003) are classified as gabbro rocks.

Magma Series Based on Geochemical Analysis

Ultramafic rocks from (Fig. 10) in the study area show that the ten ultramafic igneous rock samples with sample codes Lp1-001, Lp1-002, Lp1-003, Lp3-001, Lp3-002, Lp3-003, Lp3-004, Lp3-004, Lp3-005, Lp3-006, and Lp3-007, belong to the tholeiitic magma series. This type is commonly found in tectonic settings such as oceanic spreading zones, where SiO_2 values are low, while ferromagnesian compositions such as MgO and FeO are abundant.

Magma Origin Based on Geochemical Analysis

Plotting the data shows that samples Lp1-001, Lp1-002, Lp3-002, Lp3-003, Lp3-006, and Lp3-007 originate from oceanic island environments, reflecting a mantle source different from MORB. In contrast, samples Lp1-003, Lp3-001, Lp3-004, and Lp3-005 formed in oceanic spreading zones (Wilson, 1989 in Shallaly et al., 2025). Classification based on (Middlemost, 1994) supports these findings, with rocks classified as mafic to ultramafic, such as gabbro and peridotite, reflecting varied tectonic origins.

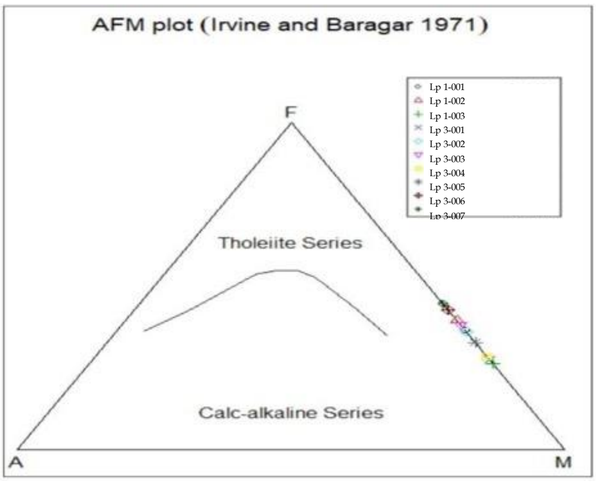


Fig. 10. Determination of magma series using the AFM diagram (Irvine and Baragar, 1971).

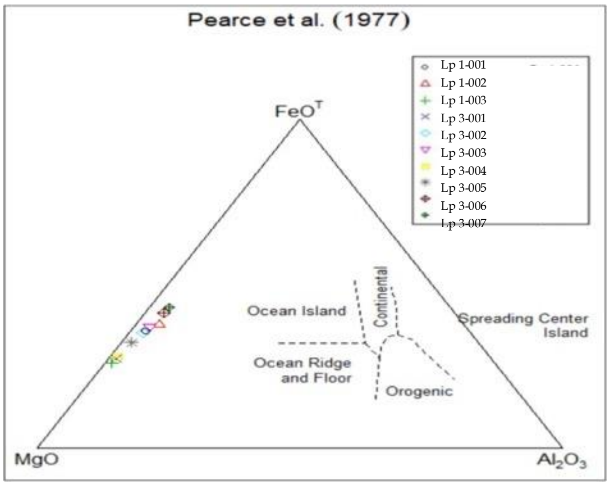


Fig. 11. Interpretation of tectonic settings according to the diagram (Pearce et al., 1977).

Petrogenesis of Ultramafic Peridotite Rocks

The ultramafic rocks in the study area, located in Tinanggea District, are part of the southeastern Sulawesi ophiolite complex, which tectonically resulted from the obduction of oceanic crust onto continental crust during plate collision in the late Oligocene to early Miocene. This complex is composed of ultramafic rocks such as harzburgite, lherzolite, and dunite, and shows formation processes closely related to geodynamic activity in subduction zones and mid-ocean ridges. Geochemical analysis using the XRF method shows that peridotite samples have SiO_2 content between 35.50–41.23%, MgO 24.71–39.84%, and FeO 7.09–10.29%. The results plotted on the AFM diagram (Irvine and Baragar, 1971 in Kurapov et al., 2021) show that all samples belong to the toleitic magma series, which are generally formed in the mid-ocean ridge basalt (MORB) zone through high-grade partial melting.

Based on the tectonic diagram (Pearce et al., 1977 in Kurapov et al., 2021), the rocks show two formation environments, namely mid-ocean ridge basalt (MORB) and ocean island basalt (OIB).

An illustration of the tectonic environment from the results of petrological analysis, petrographic analysis, and geochemical analysis is presented in (Fig. 12). The cross-section shows the tectonic history of ESO and the Tinanggea area from the Early-Late Cretaceous to the present, where (A) ESO was formed near a large composite mass of oceanic highlands and volcanoes by the Pacific mantle approximately 80-120 million years ago, and ESO then moved westward towards the Sundaland continental margin. (B) The ESO began accreting onto the Sundaland margin 30-40 million years ago. (C) The Banggai-Sula microcontinent moved westward and a new subduction zone was formed, creating a volcanic arc zone that currently covers the ESO. (D) The ESO was subsequently blocked by the subduction of the Banggai-Sula microcontinent approximately 0-5 million years ago.

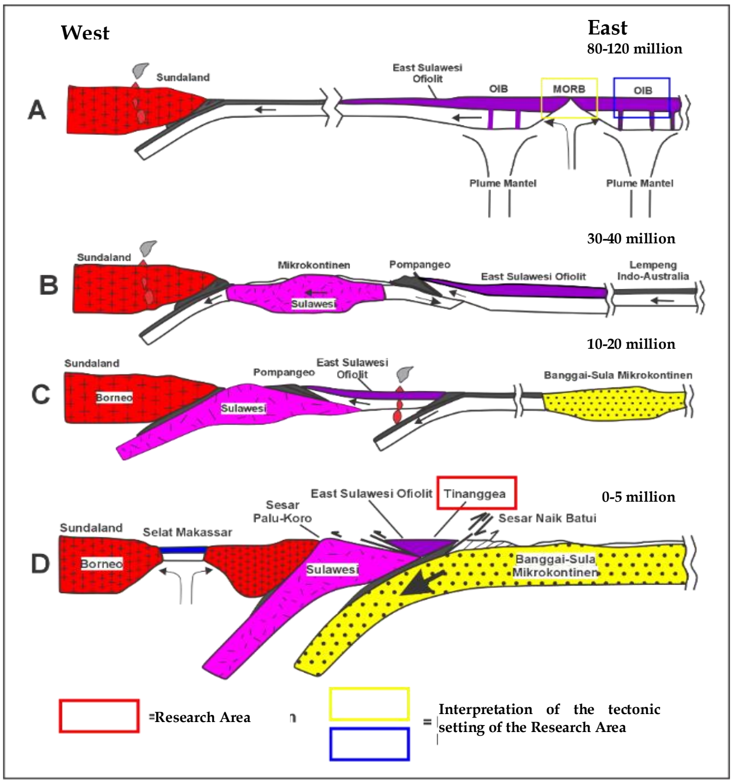


Fig. 12. Illustration of the tectonic arrangement of ultramafic rocks in the inanggea area (Modified from Kadarusman et al., 2004.

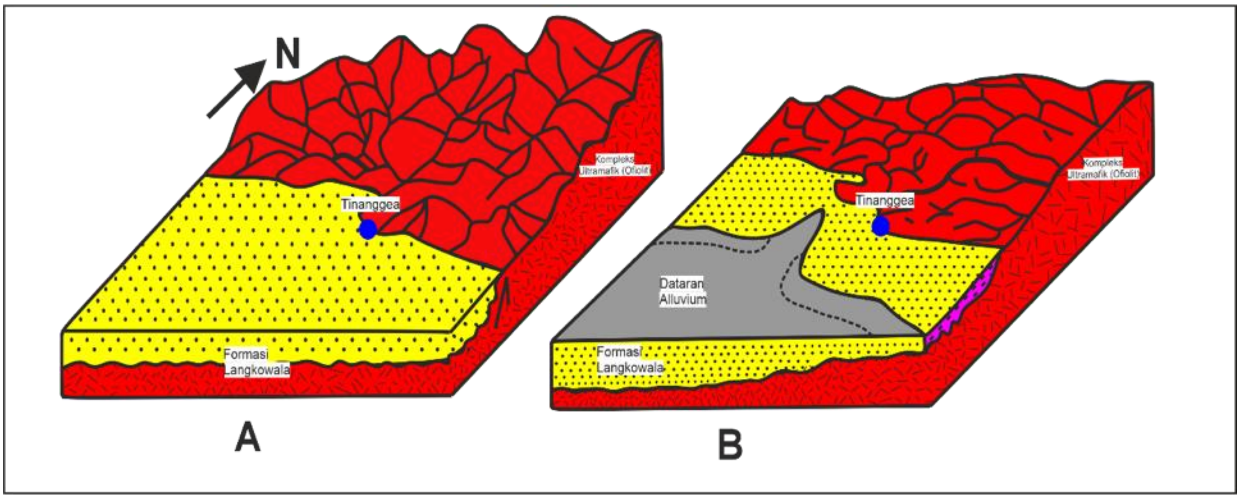


Fig. 13. Interpretation of geological history based on the regional geology of Kolaka (Simandjuntak et al., 1993) depicting (A) the time of rock deposition, with the study area marked by blue dots, and (B) the processes following deposition and exposure of rocks in the study area.

Based on the identification and interpretation of geochemical data, researchers interpreted that the ultramafic rocks found in the study area were classified as part of the southeastern Sulawesi ophiolite complex, originating from mid-ocean ridge basalt (MORB) and ocean island basalt (OIB). Overall, the petrogenesis interpretation of peridotite rocks in the study area reflects a complex magmatic process, beginning with partial melting of the upper mantle that produced ultramafic tholeiitic magma, followed by fractional crystallization and serpentinization in a divergent tectonic setting and oceanic intraplate.

Discussion

Based on macroscopic observations or petrological descriptions in the field, ultramafic rocks in the study area are interpreted as ultramafic peridotite rocks based on diagram classification (Middlemost, 1994 in Kurapov et al., 2021), but some have been transformed into serpentinite. Based on petrological observations, peridotite rocks are generally blackish green in color, hypocrystalline in structure, fine-grained (Aphanitic), and composed of olivine, pyroxene, and some silica and serpentinite minerals resulting from further weathering of the peridotite rocks.

Geochemical analysis using the XRF method shows that peridotite samples have SiO_2 content between 35.50 and 41.23%, MgO between 24.71 and 39.84%, and FeO between 7.09 and 10.29%. The results plotted on the AFM diagram (Irvine and Baragar, 1971 in Kurapov et al., 2021) show that all samples belong to the toleitic magma series, which is generally formed in the mid-ocean ridge zone (MORB) through high-grade partial melting. Furthermore, based on the tectonic diagram (Pearce et al., 1977 in Kurapov et al., 2021), the rocks show two formation environments, namely mid-ocean ridge basalt (MORB) and ocean island basalt (OIB). Analysis using geochemical software also reinforces that Lp3-002 and Lp3-003 tend towards gabbroic rocks. This is thought to be related to serpentinization, especially in olivine minerals, which causes an increase in SiO_2 content due to leaching of Mg and Si elements and the addition of water (Suryawan Asfar and Syarifuddin Erick, 2019).

CONCLUSION

The results of field observations, petrographic and geochemical analyses, and literature studies indicate that the ultramafic rocks in the Tinanggea area are classified as peridotites (lherzolite and wehrlite), with megascopic characteristics ranging from dark green to black in color and a granular-massive texture. Microscopic analysis identified the main minerals as olivine, orthopyroxene, and clinopyroxene, as well as the presence of serpentine, which indicates alteration and serpentinization processes. Geochemically, the rocks show ultramafic magma characteristics with tholeiitic affinity, formed in mid-ocean ridge (MORB) and ocean island basalt (OIB) tectonic environments. The petrogenesis of these rocks originated from partial melting of the upper mantle and crystallization at a certain depth before being uplifted through subduction and obduction.

Acknowledgements

With utmost respect and appreciation, the author would like to express his deepest gratitude to the company for the valuable opportunity given to him to conduct an internship and research entitled "Petrogenesis Analysis of Ultramafic Rocks in the Tinanggea Area, Southeast Sulawesi."

This opportunity provided by the company not only opened up learning opportunities in the real world of work, but also greatly assisted the author in obtaining primary data that supported the direct implementation of research in the field. The various facilities, location access, and technical support provided have contributed significantly to the smooth running of the geological observation process, sample collection, and laboratory analysis stages.

The author also expresses sincere appreciation to all leaders, supervisors, and technical staff who have guided, provided direction, and accompanied the author during the activities. In particular, the author would like to thank the supervising lecturer and geological expert staff of the company, Mr. Ir. Parlindungan Hasibuan, S.T., M.T., CP-ASM and Mr. Ir. Erick Syarifudin, S.T., M.T., IPP., CP-ASM, for their time, knowledge, and assistance, which they provided with sincerity. All forms of support and cooperation provided have been an integral part of the success of this research. May all the kindness and contributions be rewarded accordingly and provide benefits for the development of science and the mining world in the future.

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