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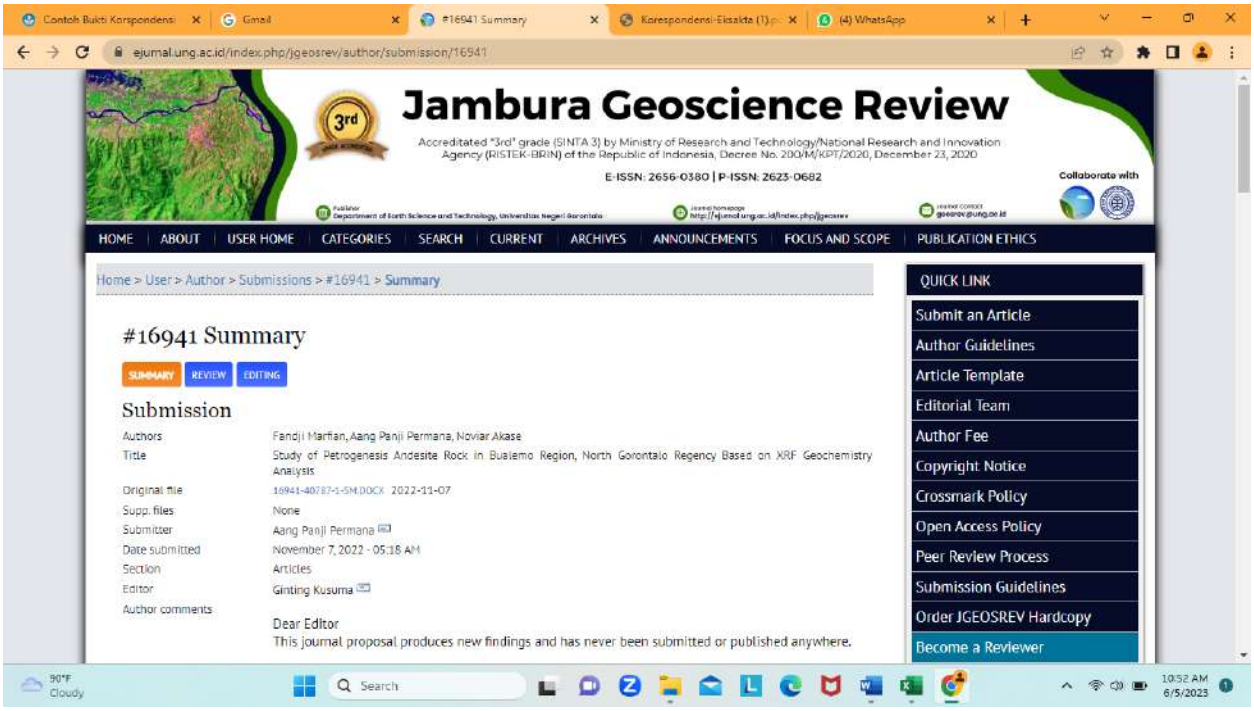
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Department of Earth Science and Technology, Universitas Negeri Gorontalo

STUDY OF PETROGENESIS ANDESITE ROCK IN BUALEMO REGION, NORTH GORONTALO REGENCY BASED ON XRF GEOCHEMISTRY ANALYSIS

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ABSTRACT

The research area is in Bualemo Village, Kwandang District, North Gorontalo Regency. With coordinates 0° 47' 10" - 0° 48' 40" North Latitude and 122° 55' 0" - 122° 57' 5" East Longitude with an area of about 10 km2. This study aims to determine the petrogenesis of andesite rocks and the tectonic setting in the study area. The method used in this study is a mapping method to determine the geological conditions of the research site and geochemical analysis (XRF) to determine the chemical content of rocks. The results showed that the stratigraphy of the study area, sorted from oldest to youngest, was an andesite unit, an altered andesite unit, and an alluvial deposit unit. The geological structure in the study area is in the form of a tension joint with a general direction of relative north-south. Based on geochemistry results, it was found that the type of magma is tholeiitic, with is name basalt and basaltic trachyte andesite. The origin of the magma is island arc tholeiitic and island arc calc-alkaline basalt, with the tectonic setting of the study area being subduction between two oceans, namely between the Sulawesi sea plate and the Sula sea plate.

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1. Introduction

Petrogenesis studies is a field of science that focuses on the abundance of minerals observed in rock incisions under a microscope and analyzes the content of chemical elements in rocks to determine the formation process in rocks and their tectonic environmental conditions (Yuwono, 2015). Geochemistry is a grouping of the relative and absolute abundances of various elements on earth, the study of the distribution and migration of single elements in various places on earth with objects in the form of basic patterns of distribution and migration of elements (Mason, 1958).

Sulawesi is located at the collision of three large plates, namely the Indo-Australian plate, the Eurasian plate, and the Pacific plate and there is also a smaller plate located to the north, namely the Philippine plate (Hamilton, 1979; Hutchison, 1989; Hall and Wilson, 2000; Permana, 2018, 2019; Permana et al, 2021). This island was formed due to the collision of Sunda land, the

easternmost part of the Eurasian plate, with the microcontinent of the Australian plate (Bachri, 2011).

The Kwandang area and its surroundings are an area with a geological setting that is very interesting to study because it is composed of complex rock formations of the Tertiary to Quaternary age. This rock formation was formed since the start of the collision of the Sula oceanic plate with the Sulawesi north arm oceanic plate, which was then followed by a collision towards the eastern arm of Sulawesi in the mid-Pliocene along with the formation of a subduction strip along the northern arm of Sulawesi until now (Hall and Spakman, 2015).

Previous research in the research area has been carried out (Harun, 2020), previous research in the Bualemo area with a map scale of 1:25,000. Bualemo Village is one of the villages located in Kwandang District, In previous research in the Bualemo area there were volcanic rocks that were included in the Bualemo Andesite Unit (Harun, 2020). Bualemo andesite is thought to have formed in the Middle Miocene to Late Miocene period (Bachri et al, 1994).

However, previous studies have not carried out more detailed research related to the petrogenesis of andesite rocks. Therefore, the authors are interested in exploring these rocks in more detail by conducting a petrogenesis study in order to produce new findings. For this reason, the purpose of this research is to study the petrogenesis of andesite rocks in the Bualemo area, North Gorontalo Regency based on XRF geochemistry analysis.

2. METHOD

2.1. Research Location

The research was conducted in Bualemo Village, Kwandang District, North Gorontalo Regency. With coordinates 0˚ 47' 10" - 0˚ 48' 40" North Latitude and 122˚ 55' 0" - 122˚ 57' 5" East Longitude, has an area of 10 km^2.

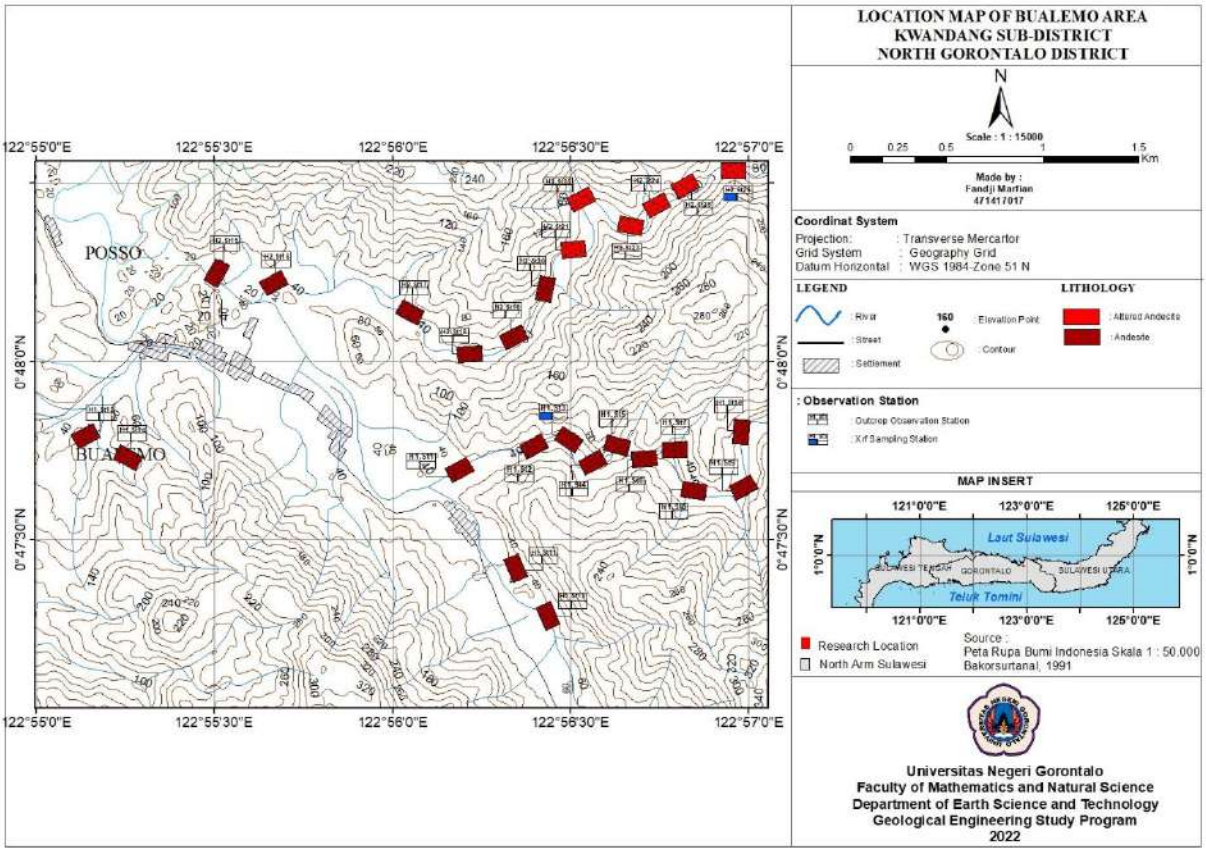

Figure 1. Research location map

2.2. Research Method

In this study, the research method used the method of geological mapping and geochemical analysis. The geological mapping method used at the time of observation and data collection in the field. For geochemistry analysis, X-ray fluorescence (XRF) analysis was carried out on selected rock samples to determine the chemical content of the rocks. For geochemistry analysis, XRF was carried out at the Central Laboratory of Mineral Resources for Coal and Geothermal in Bandung. XRF analysis in geology is very important to determine the main chemical elements and trace elements of a rock, mineral, sediment, and liquid after interacting with radiation (Rollinson., 1993; Boogs., 2009; Shackley., 2011; Wahyudiono et al., 2016). ; Permana, 2018).

Data collection at the field in the form of lithological data, and geological structures as well as sampling for XRF geochemistry analysis will be carried out later. Lithological data collection was carried out to determine the stratigraphy of the research area, then geological structure data collection was carried out to determine the general direction of the geological structure found in the research area. Sampling is taken for geochemistry analysis and will be processed to find out the name of the rock, magma series, magma origin, and tectonics in the research area. Processing of geochemistry data is using *Petrograph* software.

3. RESULTS AND DISCUSSION

3.1 Stratigraphy

The stratigraphy of the study area consists of three lithological units, namely the andesite unit, altered andesite unit, and alluvial deposit unit. The andesite unit occupies 70% of the research location, with a thickness that can be seen on the map as 400 meters. The lithology contained in this unit is andesite rock with gray color, holocrystalline, massive with a mineral composition of plagioclase, pyroxene, and k-feldspar (Figure 2). This unit is included in the Bilungala Volcano Rock Formation (Tmbv) in the Tilamuta map geology sheet (Bachri et al, 1994).

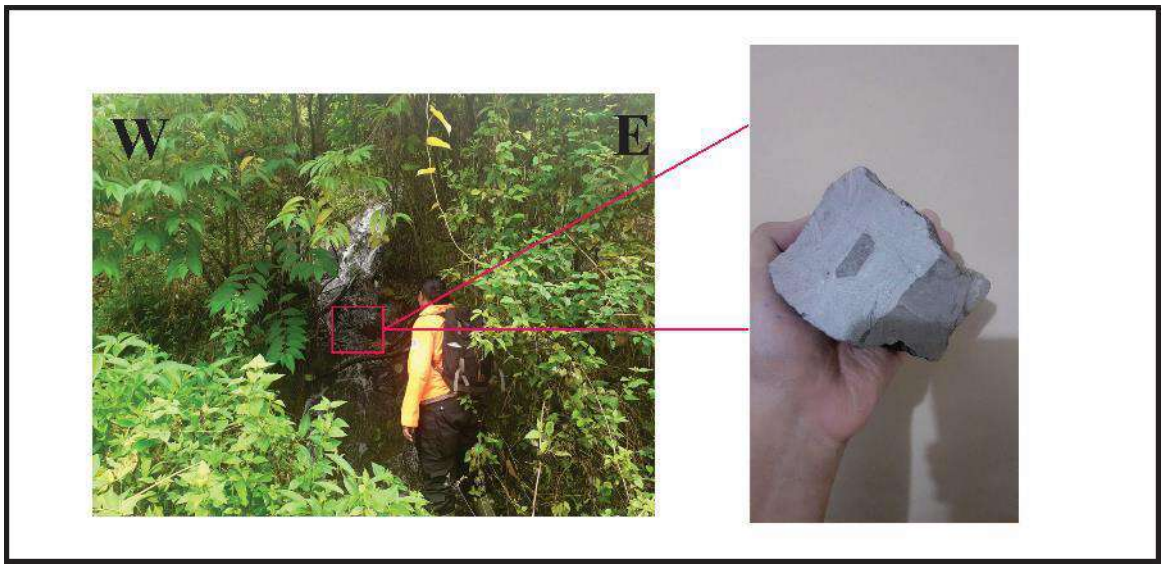

Figure 2. Outcrop of andesite units at the research site and hand specimen of andesite rock samples

The altered andesite unit at the study site occupies 5% of the study site with a thickness of 200 meters. The lithology contained in this unit is andesite rock that has been altered with a brownish-gray color, aphanitic, and holocrystalline with massive properties. Has a mineral composition such as a little quartz, k feldspar minerals, and plagioclase (Figure 3). This unit is included in the Bilungala Volcano Rock Formation unit (Tmbv) on the Tilamuta geological map sheet (Bachri et al, 1994).

Figure 3. Outcrop of altered andesite units at the study site and hand specimen of altered andesite rock samples

The alluvial deposit unit occupies 25% with a thickness of 75 meters. The lithology contained in this unit is the result of weathering of rocks in the form of sand, gravel, gravel, to lumps, and is not compact (Figure 4). This unit belongs to the Alluvium Formation (Qal) on the geological map of the Tilamuta sheet (Bachri et al, 1994).

Figure 4. The appearance of alluvial deposits at the research site

The complete division of the three lithological units can be seen on the geological map of the Bualemo area, North Gorontalo Regency (Figure 5).

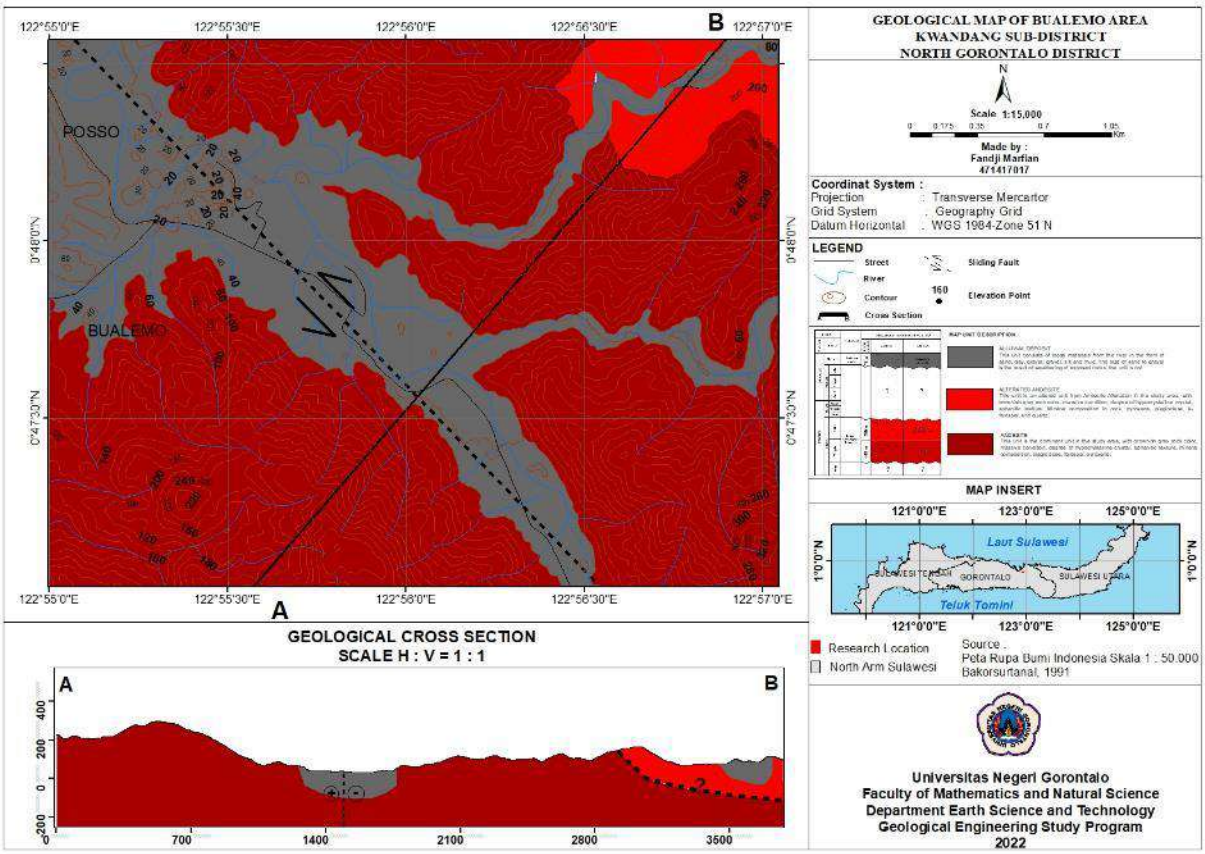

Figure 5. Geological map of the research area

3.2 Geological Structure

At the research site, there is a primary geological structure in the form of a joint (Tension Joint), precisely located at ST 7 (Figure 6). After analyzing the joint structure data, the results of the relative joint direction are north-south with an N value of 171˚ E/79˚ (Figure 7).

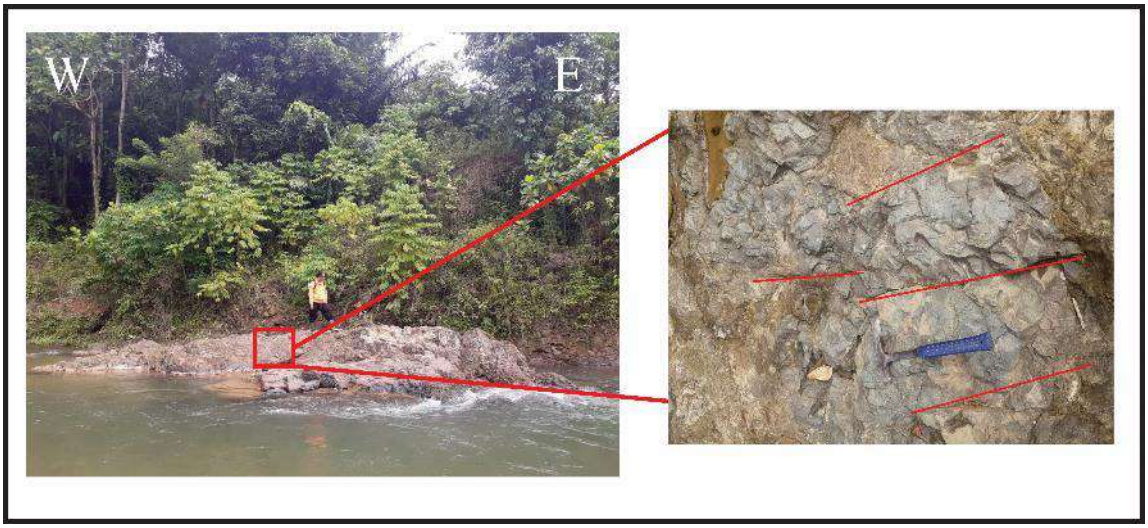

Figure 6. Andesite rock outcrop with tension joint structure at the research site

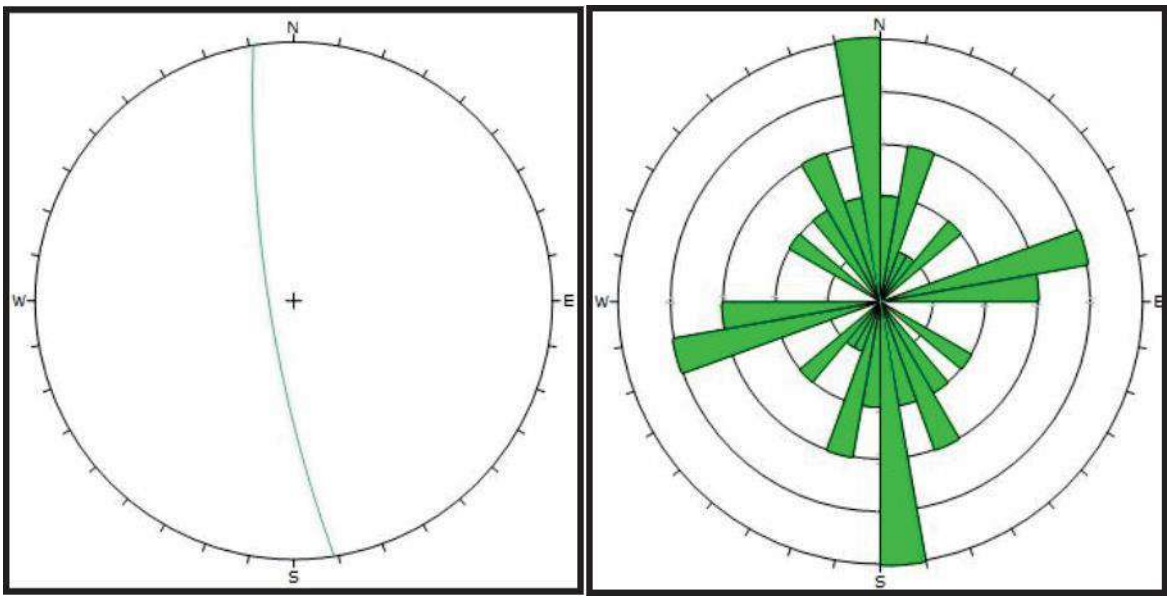

Figure 7. The results of the analysis of the tension joint structure

3.3 Geochemistry

Geochemistry analysis (XRF) to determine the type of rock, magma series, and origin of magma to the tectonic setting in the research area. After geochemistry analysis (XRF) has been carried out, the results will be entered into several diagrams which will later determine the magma series to the tectonic setting of the research area. The following data results from geochemistry analysis (XRF) to produce major element data (Table 1). Two samples will be subject to geochemistry analysis, namely, sample ST 3 and sample ST 26. The diagrams used in this analysis are Na_2O and K_2O diagrams with SiO_2 (Le Bass et al, 1986), FeO*/MgO vs SiO_2 diagrams (Miyashiro and Shido, 1975), and ternary diagrams of Na_2O+K_2O, FeO* and MgO (Irvine and Baragar, 1971), and triangular diagrams of TiO_2, $MnOx_{10}$, $P_2O_5x_{10}$ (Mullen, 1983).

Table 1. Table of *major elements*

Sample Code	ST 3 (% Weight)	ST 26 (% Weight)
SiO_2	50,53	52,77
Al_2O_3	15,68	18,50
Fe_2O_3	13,28	9,86
MgO	11,39	5,82
CaO	2,81	5,39
Na_2O	3,72	3,29
K_2O	1,07	2,71
TiO_2	1,09	1,00
P_2O_5	0,13	0,28
MnO	0,30	0,38
LOI	3,22	4,11

Source: XRF Geochemical Analysis Results (2022)

3.3.1 Rock Type

The diagram used to determine the rock type in the St 3 and St 26 samples is a binary diagram of (Le Bass et al, 1986), this diagram is Total Alkali-Silica (TAS) namely the accumulation of Na_2O

+ K_2O (Total Alkali) and SiO_2 (Silica). show that the two rock samples belong to the basic igneous rock group, Basalt and Basaltic-Trachy Andesite (Figure 8).

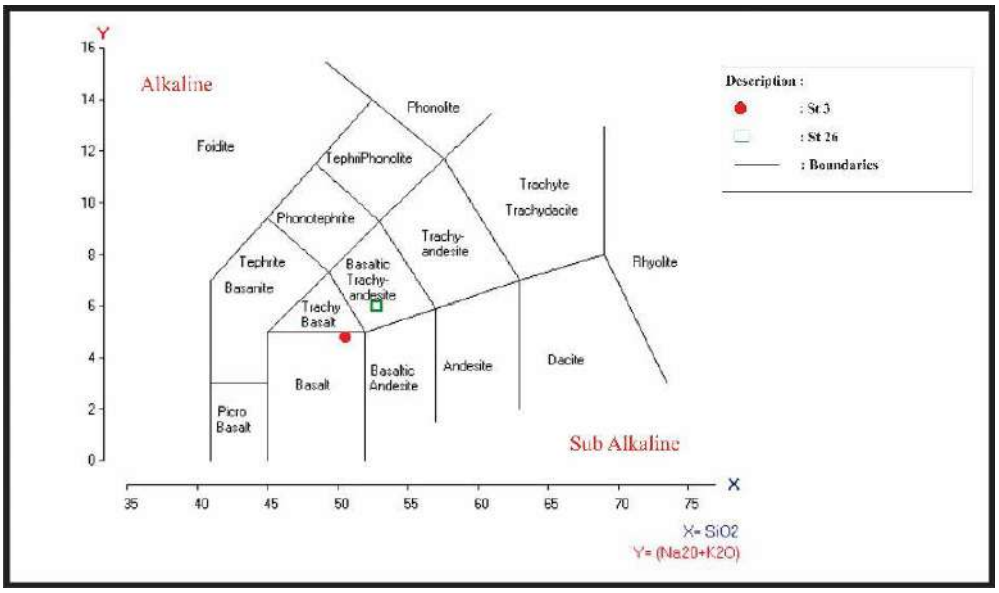

Figure 8. (Na_2O+K_2O) vs SiO_2 diagram (Le Bass et al, 1986)

3.3.2 Magma Series

Furthermore, the plotting is carried out on the AFM diagram of F (Total FeO), A (K_2O+NaO), and M (MgO) (Irvine and Baragar, 1971). In this diagram, two types of magma series divided, namely Calc-Alkaline and Thoeleitic. Based on this diagram, it is know that the samples with codes St 3 and St 26 of the study area belong to the Tholeitic magma series, where in the tholeiitic magma series the Fe content is very rich and higher than that of the Tholeiitic magma series. alkaline element value. Based on the results of geochemistry analysis (XRF) the elemental Fe values at both stations were 6.89%-9.28% (Figure 9).

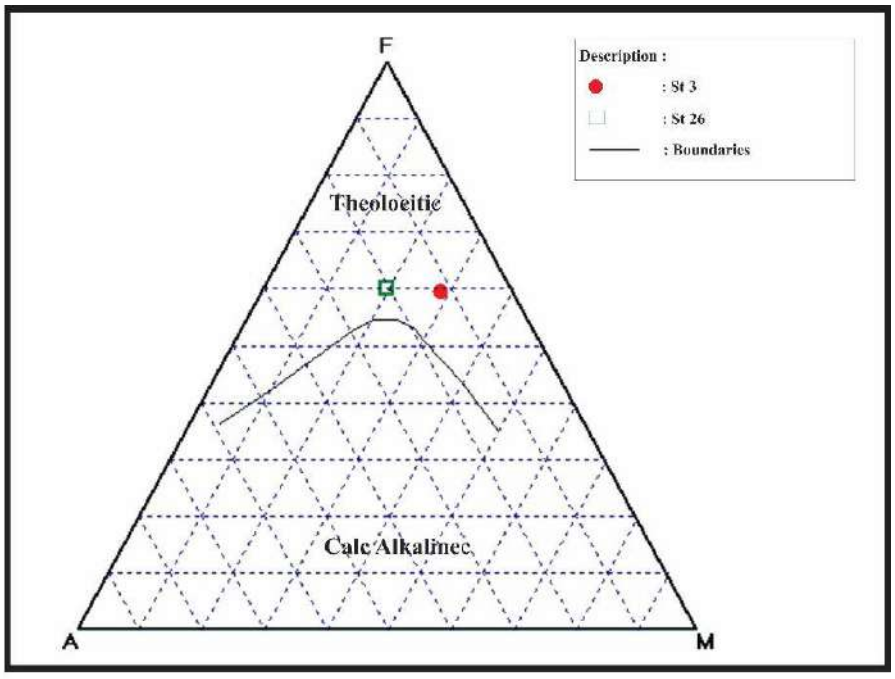

Figure 9. AFM diagram (Irvine and Baragar, 1971)

Then plotting the FeO/MgO vs SiO_2 diagram (Miyashiro and Shido, 1975) both samples belong to the Tholeiitic magma series. Where this diagram is aligned with the Ternary AFM diagram of (Irvine and Baragar, 1971). In the Tholeiitic magma series, it can form in all tectonic settings (Figure 10).

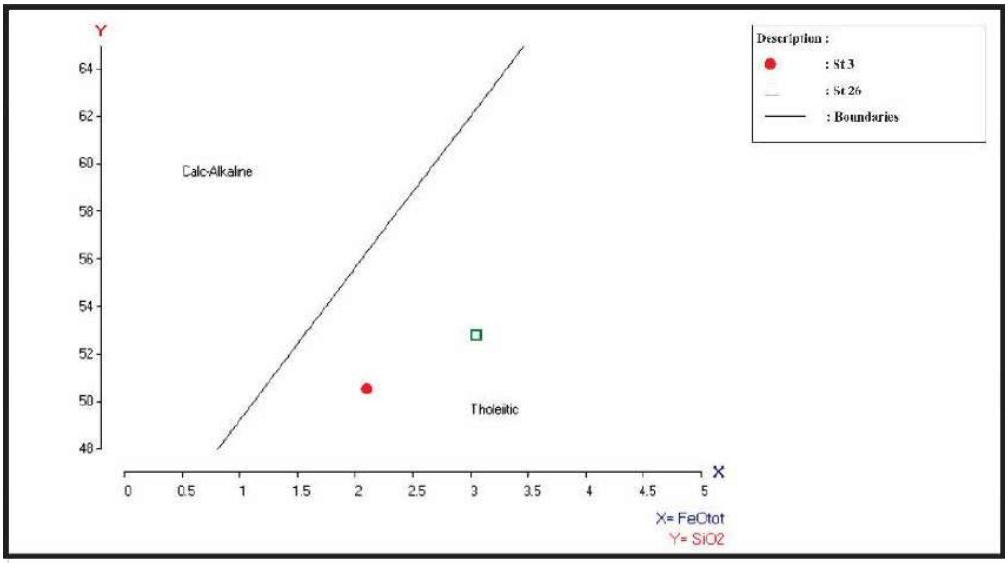

Figure 10. FeO/MgO vs SiO_2 diagram (Miyashiro and Shido, 1975)

3.3.3 Magma Origin

This diagram shows in more detail the origin of magma, based on the plotting results from the ternary diagram (Mullen, 1983), St 3 belongs to the Tholeiitic Island Arc tectonic setting, and ST 26 belongs to the Calc-Alkaline Basalt Island tectonic setting. Based on the diagram above, it is possible that further tectonic events occurred in the ST 26 sample, which resulted in more acidic magma in the St 26 sample (Figure 11).

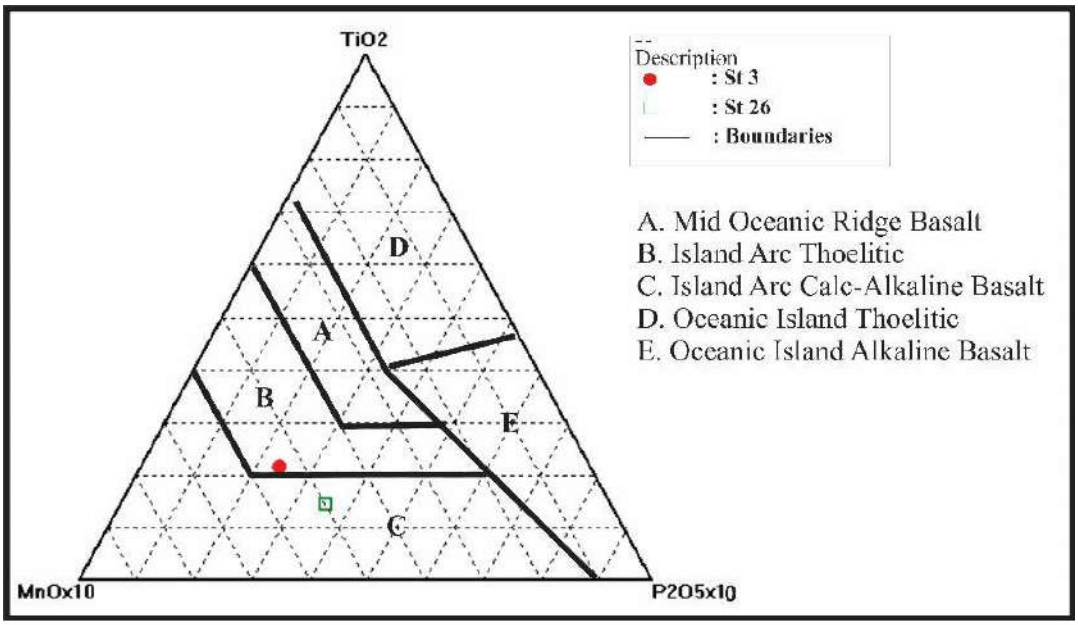

Figure 11. TiO_2, MnOx10, P_2O_5x10 triangle diagram (Mullen, 1983)

3.4 Tectonic Setting

Based on the results of the analysis of several diagrams above, show that there are two magma series contained in the rock of the study area with sample codes St 3 and St 26. The magma series formed at St 3 is Tholeitic based on the magma series diagram from (Irvine and Baragar, 1971) and the diagram binary from (Miyashiro and Shido, 1975). The tholeiitic magma series is a typical magma that forms in the early stages of island arc formation. The tholeiitic magma series is a type of magma that can exist in various tectonic settings, for St 3 basalt rocks belonging to a convergent tectonic setting or being in a subduction zone. This is evidenced by the TiO_2 content of <1.3% (Gill, 1981 in Yuwono, 2015), where the TiO_2 content in St 3 rock is 1.08%. The St. 26 rock according to the binary diagram (Le Bass et al, 1986) belongs to the Basaltic Trachyte Andesite rock. So it can be concluded that these two samples belong to the island arc. It is clarified by the analysis results from diagrams of TiO_2, $MnOx_{10}$, and $P_2O_5x_{10}$ from (Mullen, 1983) where St 3 rock belongs to the origin of Tholeiitic Island Arc magma, and St 26 rock belongs to the origin of Island Arc Calc Alkaline Basalt magma. Both of these magma origins are included in the subduction zone/orogenous zone (island arc and active continental margin).

To find out the depth of magma origin can be calculated using the content of SiO_2 and K_2O (Hutchinson, 1977). Calculations carried out to determine the depth of origin of magma can use the formula:

$$\mathbf{h= [320-(3{,}65 \times \%\ SiO_2)] + (25{,}52 \times \%\ K_2O)}$$

Based on calculations using this formula, it can be seen that the depth of origin of magma from rocks in the study area is at a depth of about 163-196 km below the earth's surface in the Benioff Zone. It is estimated that the rock was formed during the Middle Miocene to Late Miocene, when subduction occurred between two oceanic plates, namely between the Sulawesi sea plate and the Sula ocean plate about 15 to 10 million years ago (Hall and Spakman, 2015).

4. CONCLUSIONS

1) The stratigraphy of the study area divided into three lithological units, namely, the andesite unit, the altered andesite unit, and alluvial sediment unit.
2) The geological structure in the study area is in the form of tension joints and interpretation faults in the form of shear faults.
3) Based on the geochemistry analysis (XRF), it was found that the rock names are basalt and basaltic trachy andesite, the type of magma is theoleiitic, and the origin of the magma is island arc theoliitic and island arc alkaline basalt.
4) Tectonics that occur at the research area is the result of subduction between 2 oceanic plates, namely the Sulawesi sea plate and the Sula sea plate.

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Manuscript Title : **Study of Petrogenesis Andesite Rock in Bualemo Region, North Gorontalo Regency Based on XRF Geochemistry Analysis**

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1. Impact on science and technology:

[ ] Give a new theory base
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[√] Is a confirmation
[ ] Nothing new

2. Priority for publication in Jambura Geoscience Review (JGEOSREV):

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[ ] Low

3. Comments

No.	Object	Comments
1.	***Title***	suitable
2.	***Abstract***	I can't comment on this part because many aspects of the main text need to be corrected.
3.	***Introduction***	The introduction is sufficient. However: • The writers should clarify about the existence of 'Sula ocean plate', 'Sulawesi ocean plate', and other tectonic plates. I've never heard about those plates. • Many paragraphs are only composed of two-three sentences. He/she/they should combine the short paragraphs or add more information. • The English is not clear. He/she/they must improve it
4.	***Method***	The English is not clear. He/she/they must improve it

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No.	Object	Comments
5.	***Results and Discussion***	• The English is not clear. He/she/they must improve it • The English is not clear. He/she/they must improve it • The writers should clarify about the existence of 'Sula ocean plate', 'Sulawesi ocean plate', and other tectonic plates. I've never heard about those plates. • Many paragraphs are only composed of two-three sentences. He/she/they should combine the short paragraphs or add more information.
6.	***Conclusion***	Do not use 'bullets and numbering' in writing the conclusions.
7.	***References***	I did not check it. Writer(s) must improve the text!
8.	***Special Notes***	This paper needs a lot of improvement, especially about the English. The writer(s) should learn more about plate tectonics and plate interactions

SUBMISSION DECISION*

- ☐ ***Accepted***
- ☐ ***Accepted with some revision by editorial board***
- ☐ ***Accepted with some revision by authors >>>> a lot of revisions***
- ☐ ***Rejected***

* *Please fill/mark the form*

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REVIEW NOTES

Manuscript Title : Study of Petrogenesis Andesite Rock in Bualemo Region, North Gorontalo Regency Based on XRF Geochemistry Analysis

Manuscript ID : ID JGEOSREV-16941

1. Impact on science and technology:

[ ] Give a new theory base
[ ] Give new information
[ ] Is a confirmation
[√]] Nothing new

2. Priority for publication in Jambura Geoscience Review (JGEOSREV):

[ ] High
[ ] Moderate
[√] Low

3. Comments

No.	Object	Comments
1.	***Title***	The title is recommended to be changed to Petrogenesis Andesite Rock in Bualemo Region, North Gorontalo Regency, Based on Major Element Analysis… or Petrogenesis Andesite Rock in Bualemo Region, North Gorontalo Regency.
2.	***Abstract***	In the abstract, this study aims to determine the petrogenesis of andesite rocks and tectonic settings using geochemical mapping and analysis methods using XRD instruments. In my opinion, for petrogenesis studies using the mapping method, stratigraphy is not enough to determine the sequence of rock formation. Still, detailed mapping is needed that focuses on the physical properties of andesitic outcrops so that there is a correlation between the analysis results in the field and the geochemical analysis results.
3.	***Introduction***	Based on this background, it is necessary to add references from previous journal studies related to the Middle Miocene Bualemo volcanic to the Late

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No.	Object	Comments
		Pliocene. For example, the book Outline of Indonesian Geology states that the Bualemo volcano intersects with the Lonsio Molasse formation and consists of pillow lava and volcanic rock.
4.	***Method***	It is necessary to add detailed mapping methods to andesitic rock outcrops. So that the samples to be analyzed in the laboratory are representative of andesite rocks in all study areas. It is also essential to carry out petrographic analysis for rock classification based on mineral composition and texture, which form the basis for determining geochemical analysis.
5.	***Results and Discussion***	- Geological mapping that produces stratigraphy of the research area is not enough to support petrogenesis studies. - Need petrographic analysis to analyze the types of minerals composing the rock and its petrogenesis analysis based on special textures in volcanic rocks, especially andesite. - Major element analysis of the two samples cannot represent all of the outcrops observed in the field. In addition, the analysis results show a fairly high level of LOI (3.22% and 4.11%), indicating high alteration of the rock. So it is not sufficiently valid to show the nature and origin of the magma that forms andesite rocks in the research area.
6.	***Conclusion***	Of course, the research methods and results cannot be concluded petrogenesis of Bualemo andesite rocks.

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No.	Object	Comments
7.	***References***	Some references are not related to the research topic, such as Permana, A.P. (2018), Permana, A. P. (2019), Shackley, M. S. (2011), etc.
8.	***Special Notes***	Field data and petrographic analysis will explain the results of the geochemical analysis, which are less valid due to the high LOI.

SUBMISSION DECISION*

☐	***Accepted***
☐	***Accepted with some revision by editorial board***
√	***Accepted with some revision by authors***
☐	***Rejected***

* *Please fill/mark the form*

doi: 10.34312/jgeosrev.vxix.xxxxxxx ejurnal.ung.ac.id/index.php/jgeosrev

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Department of Earth Science and Technology, Universitas Negeri Gorontalo

Study of Petrogenesis Andesite Rock in Bualemo Region, North Gorontalo Regency Based on XRF Geochemistry Analysis

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ABSTRACT

The research area is in Bualemo Village, Kwandang District, North Gorontalo Regency. With coordinates 0° 47' 10" - 0° 48' 40" North Latitude and 122° 55' 0" - 122° 57' 5" East Longitude with an area of about 10 km2. This study aims to determine the petrogenesis of andesite rocks and the tectonic setting in the study area. The method used in this study is a mapping method to determine the geological conditions of the research site and geochemical analysis (XRF) to determine the chemical content of rocks. The results showed that the stratigraphy of the study area, sorted from oldest to youngest, was an andesite unit, an altered andesite unit, and an alluvial deposit unit. The geological structure in the study area is a tension joint with a general direction of relative north-south. Based on geochemistry results, it was found that the type of magma is tholeiitic, with its name basalt and basaltic trachyte andesite. The origin of the magma is island arc tholeiitic and island arc calc-alkaline basalt, with the tectonic setting of the study area being subduction between two oceans, namely between the Sulawesi sea plate and the Sula plate.

How to cite: Last name, Initials. (Year). Article title. *Journal Name, Volume*(issue), page range. https://doi.org/xxxx

1. Introduction

Petrogenesis studies is a field of science that focuses on the abundance of minerals observed in rock incisions under a microscope or analyzes the content of chemical elements in rocks to determine the formation process in rocks and their tectonic environmental conditions (Yuwono, 2015). Geochemistry is a grouping of the relative and absolute abundances of various elements on earth, the study of the distribution and migration of single parts in multiple places on earth with objects in the form of basic patterns of distribution and migration of elements (Mason, 1958). ~~The method used in~~ this study used X-ray fluorescence (XRF) spectroscopy analysis, an analytical technique that detects X-ray radiation from the emitted sample in the sample being analyzed as a basis (John *et al.*, 2001).

Sulawesi is located at the collision of three large tectonic plates: the Indo-Australian, the Eurasian, and the Pacific. There is also a smaller plate located to the north, namely the Philippines (Hamilton, 1979; Hutchison, 1989; Hall and Wilson, 2000; Permana, 2018, 2019; Permana et al., 2021). The island was formed due to the collision of Sunda land, the easternmost part of the Eurasian plate, with the microcontinent of the Australian plate (Bachri, 2011).

The geological setting of Kwandang is exciting to study because it is composed of complex rock formations of the Tertiary to Quaternary age. This rock formation was formed since the start

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Are Indo-Australia and Pacific classified as continental plates?
If they are not please change this word

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of the collision of the Sula plate with the Sulawesi sea plate, which was then followed by a collision towards the eastern arm of Sulawesi in the mid-Pliocene along with the formation of a subduction strip along the northern arm of Sulawesi until now (Hall and Spakman, 2015). ~~Previous research in the area has been carried out (Harun, 2020), and previous research in the Bualemo area with a map scale of 1:25,000.~~ Harun (2020) research used~~s~~ the mapping method to determine the geological conditions of the study area. Bualemo Village is one of the villages located in the Kwandang District. In previous research in the Bualemo area, volcanic rocks were included in the Bualemo Andesite Unit (Harun, 2020). Bualemo andesite was thought to have formed in the Middle to Late Miocene period (Bachri et al., 1994).

However, no previous studies describe the petrogenesis of andesite rocks. This research aims to describe the petrogenesis of andesite rocks in the Bualemo area, North Gorontalo Regency, based on XRF geochemistry analysis.

2. METHOD

2.1. Research Location

The research was conducted in Bualemo Village, Kwandang District, North Gorontalo Regency. With coordinates 0° 47' 10" - 0° 48' 40" N~~orth Latitude~~ and 122° 55' 0" - 122° 57' 5" E~~ast Longitude~~, it has an area of 10 km^2. (Figure. 1)

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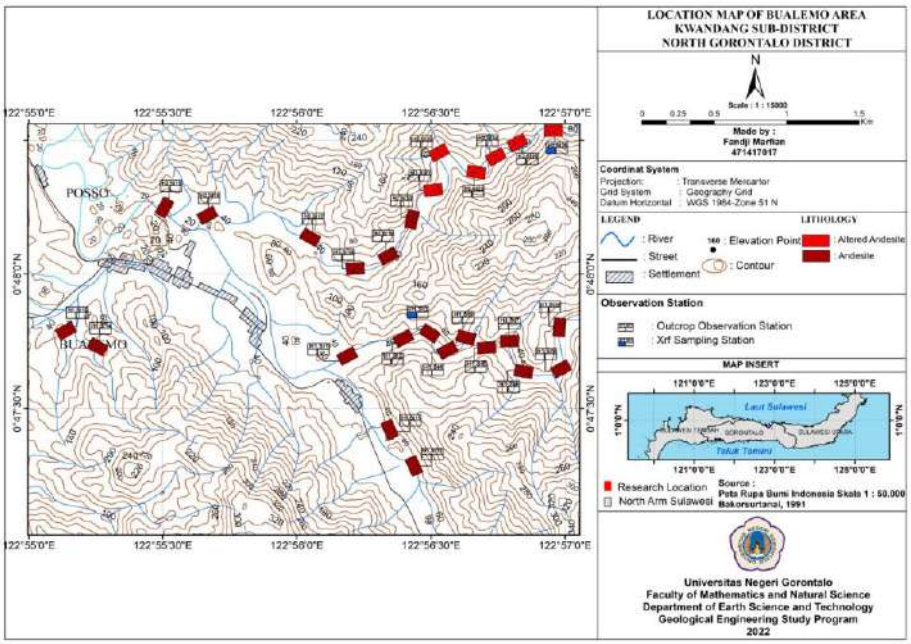

Figure 1. Research location map

2.2. Research Method

In this study, geological mapping and geochemical analysis are applied. The geological mapping method was used during observation and data collection in the field. X-ray fluorescence (XRF) analysis at the Central Laboratory of Mineral Resources for Coal and Geothermal in Bandung was carried out on selected rock samples to determine the chemical content of the rocks. XRF analysis is essential to determine the major oxides and trace element composition of

a rock, mineral, sediment, and liquid (Rollinson., 1993; Boogs., 2009; Shackley., 2011; Wahyudiono et al., 2016., Permana, 2018).

Data collection at the field in the form of lithological data, geological structures, and sampling for XRF geochemistry analysis will be carried out later. Lithological data collection was carried out to determine the stratigraphy of the research area; then, geological structure data collection was carried out to determine the general direction of the geological structure found in the research area. A sample for geochemistry analysis was selected to determine the name of the rock, magma series, magma origin, and tectonics in the research area. Processing of geochemistry data is used *Petrograph* software.

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Commented [A6]: A means one... So you only analysed one sample?

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3. RESULTS AND DISCUSSION

3.1 Stratigraphy

The stratigraphy of the study area consists of three lithological units, namely the andesite, altered andesite, and alluvial deposit. The andesite unit occupies 70% of the research location, with a thickness of 400 meters. The lithology contained in this unit is andesite rock with gray color, holocrystalline, massive, and mineral composition is plagioclase, pyroxene, and k-feldspar (Figure 2). This unit is included in the Bilungala Volcano Rock Formation (Tmbv) in the Tilamuta map geology sheet (Bachri et al., 1994).

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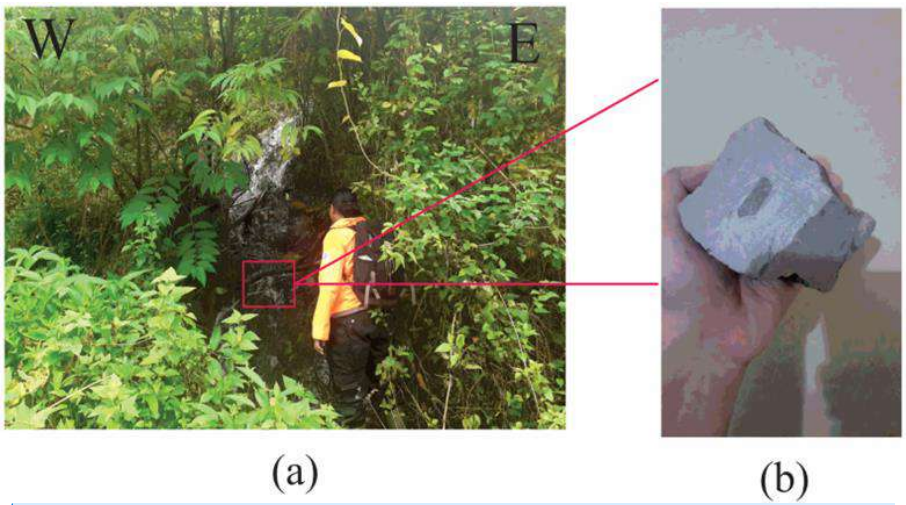

Figure 2. Outcrop of andesite unit~~s~~ at the research site (a) and hand specimen of andesite rock sample~~s~~ (b)

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The altered andesite unit at the study site occupies 5% of the ~~site~~ studied location with a thickness of 200 meters. The lithology contained in this unit is andesite rock that has been altered with a brownish-gray color, aphanitic, and holocrystalline massive properties. The rock has a mineral composition such as a little quartz, k feldspar minerals, and plagioclase (Figure 3). This unit is included in the Bilungala Volcano Rock Formation unit (Tmbv) on the Tilamuta geological map sheet (Bachri et al., 1994).

Figure3. Outcrop of altered andesite units at the study site (a) and hand specimen of altered andesite rock samples (b)

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The alluvial deposit unit occupies 25% of the studied area and has a thickness of 75 meters. The lithology in this unit results from weathering rocks in the form of sand, gravel, and gravel to lumps and is not compact (Figure 4). This unit belongs to the Alluvium Formation (Qal) on the geological map of the Tilamuta sheet (Bachri et al., 1994). The division of the three lithological units can be seen on the geological map of the Bualemo area, North Gorontalo Regency (Figure 5).

Figure4. The appearance of alluvial deposits at the research site

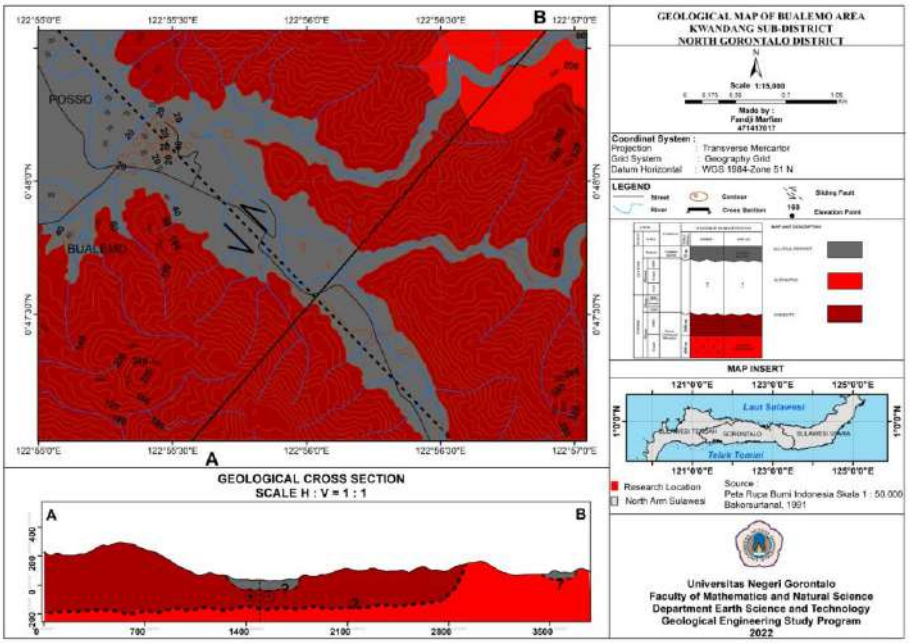

Figure 5. Geological map of the research area

3.2 Geological Structure

At the research site, there is a primary geological structure in the form of a joint (Tension Joint), precisely located at ST 7 (Figure 6). After analyzing the joint structure data, the results of the relative joint direction are north-south with an N value of 171˚ E/79˚ (Figure 7).

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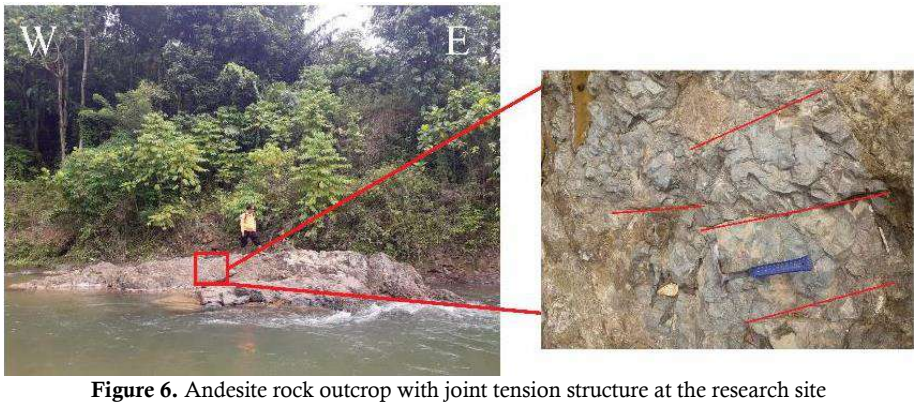

Figure 6. Andesite rock outcrop with joint tension structure at the research site

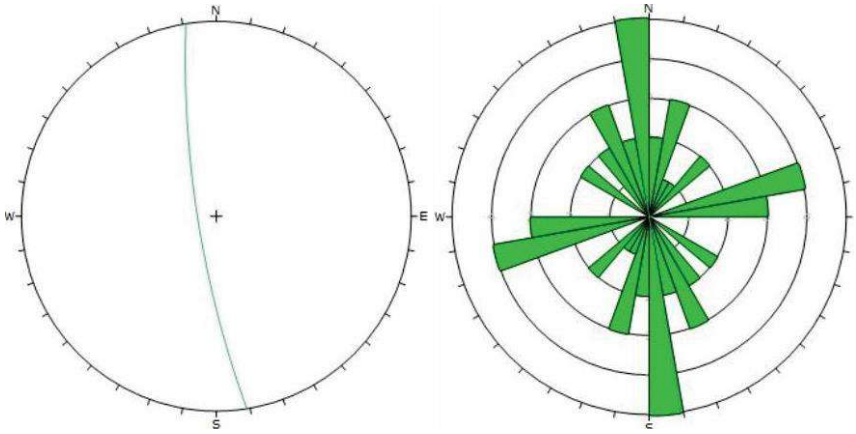

Figure7. The results of the analysis of the joint tension structure

3.3Geochemistry

Geochemistry analysis (XRF) to determine the type of rock, magma series, and origin of magma to the tectonic setting in the research area. The following data results from geochemistry analysis (XRF) produce major element data (Table 1). ~~, and~~ the chemicals composition for samples ST 3 and ST 26 is SiO_2 (50.53-52.77%), Al_2O_3 (15.68-18.50%), Fe_2O_{3T} (13.28-9.86%), MgO (11.39-5.82%), CaO (2.81-5.39%), Na_2O (3.72-3.29%), K_2O (1.07-2.71%), TiO_2 (1.09-1.00%), P_2O_5 (0.13-0.28%), MnO (0.30-0.38%). Two samples will be subject to geochemistry analysis: sample ST 3 and sample ST 26.

Table 1. Table of*majorelements*

Sample Code	ST 3 (% Weight)	ST 26 (% Weight)
SiO_2	50.53	52.77
Al_2O_3	15.68	18.50
Fe_2O_3	13.28	9.86
MgO	11.39	5.82
CaO	2.81	5.39
Na_2O	3.72	3.29
K_2O	1.07	2.71
TiO_2	1.09	1.00
P_2O_5	0.13	0.28
MnO	0.30	0.38
LOI	3.22	4.11

3.3.1 Rock Type

The diagram used to determine the rock type ~~in~~ of ~~the~~ ST~~t~~ 3 and ST 26 samples is the binary diagram of Le Bass et al.(1986). This diagram is Total Alkali-Silica (TAS), namely the accumulation of Na_2O + K_2O (Total Alkali) and SiO_2 (Silica). The two rock samples belong to the basic igneous rock group, Basalt and Basaltic-Trachy Andesite (Figure 8).

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You have analysed them already

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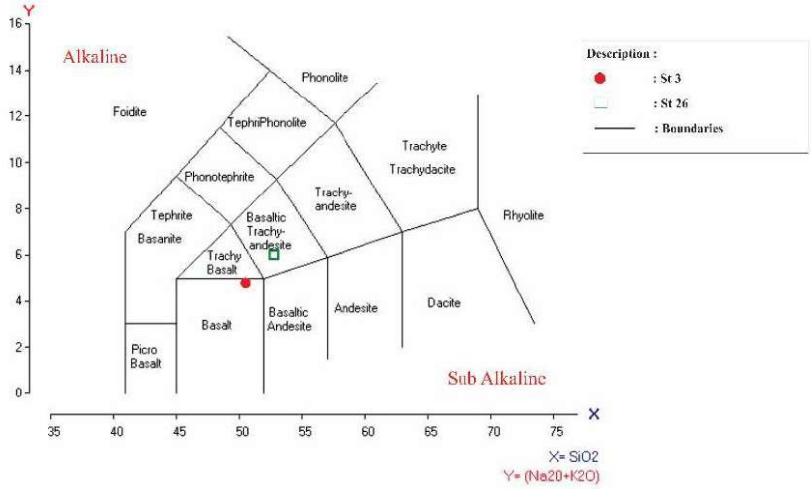

Figure 8. (Na_2O+K_2O) vs. SiO_2diagram(Le Bass et al., 1986) of the studied rocks

3.3.2 Magma Series

Furthermore, the plotting ~~is~~ was carried out on the AFM diagram of F (Total FeO), A (K_2O+NaO), and M (MgO) (Irvine and Baragar, 1971), as shown in Figure 9. In this diagram, two types of magma are divided: Calc-Alkaline and Thoeleitic. Based on this diagram, it belongs to the Tholeitic magma series, where in the tholeiitic magma series, the Fe content is vibrant and higher than that of the Tholeiitic magma series alkaline element value. Based on the geochemistry analysis (XRF) results, the elemental Fe values at both stations were 6.89%-9.28%.

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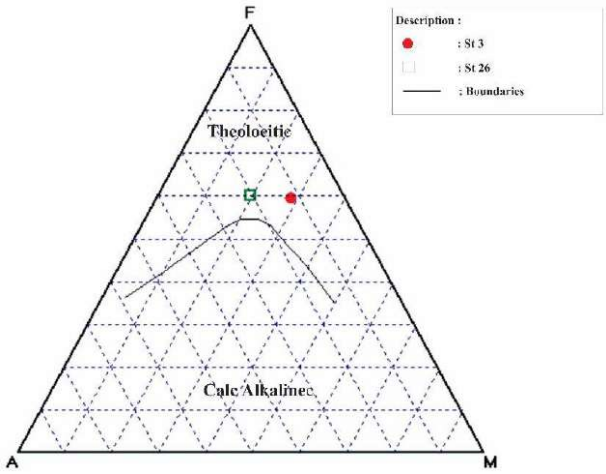

Figure 9. AFM diagram (Irvine & Baragar, 1971) of the studied rocks

Then plotting the FeO/MgO vs. SiO_2 diagram (Miyashiro and Shido, 1975); both samples belong to the Tholeiitic magma series. This diagram is aligned with the Ternary AFM diagram (Irvine and Baragar, 1971). ~~In the~~ Tholeiitic magma series~~, it~~ can form in all tectonic settings (Figure 10).

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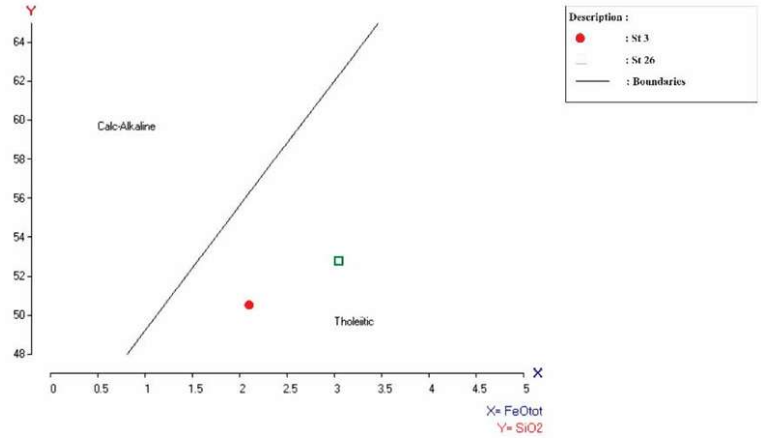

Figure 10. FeO/MgO vs. SiO_2 diagram (Miyashiro & Shido, 1975)

3.3.3 Magma Origin

The diagram of (Figure 11) shows magma's origin in more detail, based on the plotting results from the ternary diagram (Mullen, 1983). St 3 belongs to the Tholeiitic Island Arc ~~tectonic setting~~, ~~and~~ while ST 26 belongs to the Calc-Alkaline Basalt Island tectonic setting. Based on the diagram above, it is possible that other tectonic events occurred in the ST 26 sample, which resulted in more acidic magma in the St 26 sample (Figure 11).

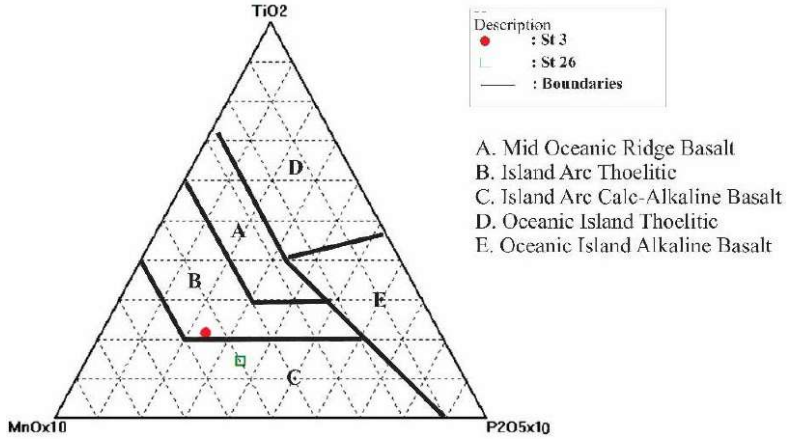

Figure 11. TiO_2, MnOx10, P_2O_5x10 triangle diagram (Mullen, 1983) of the studied rocks

3.4 Tectonic Setting

~~Based on the analysis of several diagrams above, it is shown that two magma series are found in the studied area.~~ The magma series formed at St 3 and St 26 is Tholeitic based on the magma series diagram of Irvine and Baragar(1971) and the diagram binary from (Miyashiro and Shido, 1975). The tholeiitic magma series is a typical magma that forms in the early stages of island arc formation. The tholeiitic magma series is a type of magma that can exist in various tectonic settings. For St 3 basalt rocks belonging to a convergent tectonic setting or subduction zone. This is evidenced by the TiO_2 content of <1.3% (Gill, 1981 in Yuwono, 2015), where the TiO_2 content

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It makes your study confusing.....
Previously you said that all of the samples are Thoeleitic, but here you said that one of them is Calc-Alkaline

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in St 3 rock is 1.08%. The St. 26 rock, according to the binary diagram (Le Bass et al., 1986), belongs to the Basaltic Trachyte Andesite rock. So it can be concluded that these two samples belong to the island arc. It is clarified by the analysis results from diagrams of TiO_2, $MnOx_{10}$, and $P_2O_5x_{10}$ from (Mullen, 1983), where St 3 rock belongs to the origin of Tholeiitic Island Arc magma, and St 26 rock belongs to the origin of Island Arc Calc Alkaline Basalt magma. These magma origins are included in the subduction zone.

The subduction process will produce heat in the bending path so that high heat flow can cause magma activity in the Benioff line. To find out the depth of magma origin can be calculated using the content of SiO_2 and K_2O (Hutchinson, 1977). Calculations carried out to determine the depth of origin of magma can use the formula:

$$\mathbf{h = [320-(3{,}65 \times \%\ SiO_2)] + (25{,}52 \times \%\ K_2O)}$$

Based on calculations using this formula, it can be seen that the depth of origin of magma from rocks in the study area is at a depth of about 163-196 km below the earth's surface in the Benioff Zone. It is estimated that the rock was formed during the Middle Miocene to Late Miocene, when subduction occurred between two oceanic plates, namely between the Sulawesi sea plate and the Sula ocean plate, about 15 to 10 million years ago (HallandSpakman, 2015).

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What is Benioff line?
Are you sure that your sample come from the Benioff line? Give me your reference(S)

4. CONCLUSIONS

Based on the petrological and geochemical analysis, the constituent rocks in the study area are andesite and altered andesite. The rock types obtained based on geochemical analysis are basalt and basaltic trachy andesite, with the type of magma being tholeiitic. The origin of magma in the rock comes from island arc tholeiitic and island arc calc-alkaline basalt. The research location area is the result of subduction between 2 oceans, namely between the Sulawesi sea plate and the Sula sea plate, around 15-10 million years ago, with a depth of origin of magma of 163-196 km, including in the Benioff zone.

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Study of Petrogenesis Andesite Rock in Bualemo Region, North Gorontalo Regency Based on XRF Geochemistry Analysis

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ABSTRACT

The research area is in Bualemo Village, Kwandang District, North Gorontalo Regency. With coordinates 0° 47' 10" - 0° 48' 40" North Latitude and 122° 55' 0" - 122° 57' 5" East Longitude with an area of about 10 km2. This study aims to determine the petrogenesis of andesite rocks and the tectonic setting in the study area. The method used in this study is a mapping method to determine the geological conditions of the research site and geochemical analysis (XRF) to determine the chemical content of rocks. The results showed that the stratigraphy of the study area, sorted from oldest to youngest, was an andesite unit, an altered andesite unit, and an alluvial deposit unit. The geological structure in the study area is in the form of a tension joint with a general direction of relative north-south. Based on geochemistry results, it was found that the type of magma is tholeiitic, with its name basalt and basaltic trachyte andesite. The origin of the magma is island arc tholeiitic and island arc calc-alkaline basalt, with the tectonic setting of the study area being subduction between two oceans, namely between the Sulawesi sea plate and the Sula sea plate.

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1. Introduction

Petrogenesis studies is a field of science that focuses on the abundance of minerals observed in rock incisions under a microscope and analyzes the content of chemical elements in rocks to determine the formation process in rocks and their tectonic environmental conditions (Yuwono, 2015). Geochemistry is a grouping of the relative and absolute abundances of various elements on earth, the study of the distribution and migration of single elements in various places on earth with objects in the form of basic patterns of distribution and migration of elements (Mason, 1958).

Sulawesi is located at the collision of three large tectonic plates, namely the Indo-Australian ~~plate~~, the Eurasian ~~plate~~, and the Pacific plate. There is also a smaller plate located to the north, namely the Philippine ~~plate~~ (Hamilton, 1979; Hutchison, 1989; Hall and Wilson, 2000; Permana, 2018, 2019; Permana et al., 2021). The island was formed due to the collision of Sunda land, the easternmost part of the Eurasian plate, with the microcontinent of the Australian plate (Bachri, 2011).

The Kwandang area and its surroundings are an area with a geological setting that is very interesting to study because it is composed of complex rock formations of the Tertiary to Quaternary age. This rock formation was formed since the start of the collision of the Sula oceanic plate with the Sulawesi north arm oceanic plate, which was then followed by a collision towards

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the eastern arm of Sulawesi in the mid-Pliocene along with the formation of a subduction strip along the northern arm of Sulawesi until now (Hall and Spakman, 2015).

Previous research in the area has been carried out (Harun, 2020), and previous research in the Bualemo area with a map scale of 1:25,000. Bualemo Village is one of the villages located in Kwandang District; in previous research in the Bualemo area, volcanic rocks were included in the Bualemo Andesite Unit (Harun, 2020). Bualemo andesite was thought to have formed in the Middle to Late Miocene period (Bachri et al., 1994).

However, no previous studies ~~have not conducted more detailed research on~~ describe the petrogenesis of andesite rocks. ~~Therefore, the authors are interested in exploring these rocks in more detail by conducting a petrogenesis study to produce new findings. For this reason,~~ the purpose of this research is to describe ~~study~~ the petrogenesis of andesite rocks in the Bualemo area, North Gorontalo Regency, based on XRF geochemistry analysis.

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Commented [A12]: Are you sure that the rocks are andesites?

2. METHOD

2.1. Research Location

The research was conducted in Bualemo Village, Kwandang District, North Gorontalo Regency. With coordinates 0° 47' 10" - 0° 48' 40" North Latitude and 122° 55' 0" - 122° 57' 5" East Longitude, it has an area of 10 km^2.

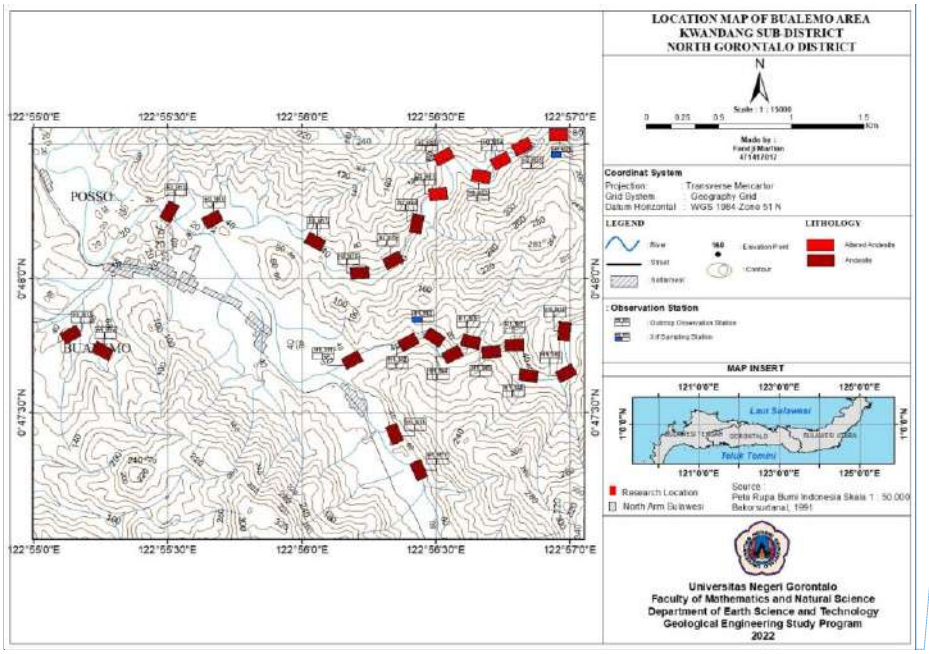

Figure 1. Research location map

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2.2. Research Method

In this study, ~~the research method used the method of~~ geological mapping and geochemical analysis are applied. The geological mapping method was used during observation and data collection in the field. ~~For geochemistry analysis,~~ X-ray fluorescence (XRF) analysis at the Central

Laboratory of Mineral Resources for Coal and Geothermal in Bandung was carried out on selected rock samples to determine the chemical content of the rocks. ~~For geochemistry analysis, XRF was carried out at the Central Laboratory of Mineral Resources for Coal and Geothermal in Bandung.~~ XRF analysis ~~in geology~~ is ~~very~~ important to determine the ~~main chemical elements~~ major oxides and trace elements composition of a rock, mineral, sediment, and liquid ~~after interacting with radiation~~ (Rollinson., 1993; Boogs., 2009; Shackley., 2011; Wahyudiono et al., 2016~~). ;~~ Permana, 2018).

Data collection at the field in the form of lithological data, geological structures, and sampling for XRF geochemistry analysis will be carried out later. Lithological data collection was carried out to determine the stratigraphy of the research area; then, geological structure data collection was carried out to determine the general direction of the geological structure found in the research area. Sample~~ing is taken~~ for geochemistry analysis was selected to determine ~~and will be processed to find~~ the name of the rock, magma series, magma origin, and tectonics in the research area. Processing of geochemistry data is using *Petrograph* software.

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Kok bisa?

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3. RESULTS AND DISCUSSION

3.1 Stratigraphy

The stratigraphy of the study area consists of three lithological units, namely the andesite ~~unit~~, altered andesite ~~unit~~, and alluvial deposit ~~unit~~. The andesite unit occupies 70% of the research location, with a thickness ~~that can be seen on the map as~~ of 400 meters. The lithology contained in this unit is andesite rock with gray color, holocrystalline, massive with a mineral composition of plagioclase, pyroxene, and k-feldspar (Figure 2). This unit is included in the Bilungala Volcano Rock Formation (Tmbv) in the Tilamuta map geology sheet (Bachri et al., 1994).

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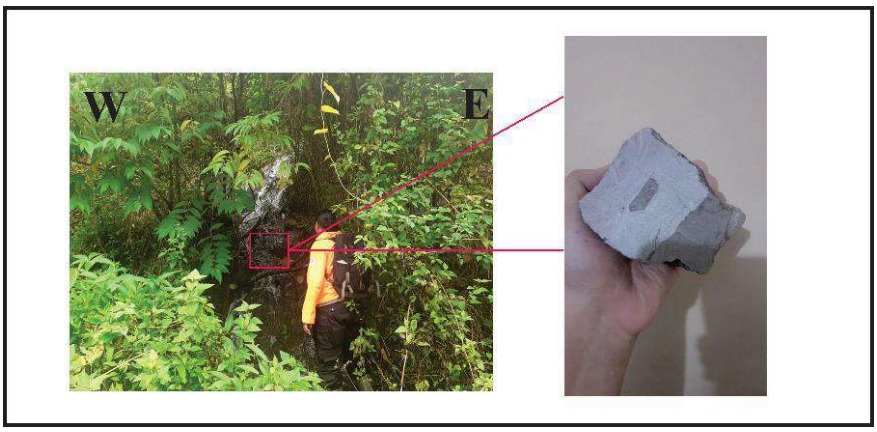

Figure 2. Outcrop of andesite units at the research site and hand specimen of andesite rock samples

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The altered andesite unit at the study site occupies 5% of the site with a thickness of 200 meters. The lithology contained in this unit is andesite rock that has been altered with a brownish-gray color, aphanitic, and holocrystalline with massive properties. Has a mineral composition such as a little quartz, k feldspar minerals, and plagioclase (Figure 3). This unit is included in the Bilungala Volcano Rock Formation unit (Tmbv) on the Tilamuta geological map sheet (Bachri et al., 1994).

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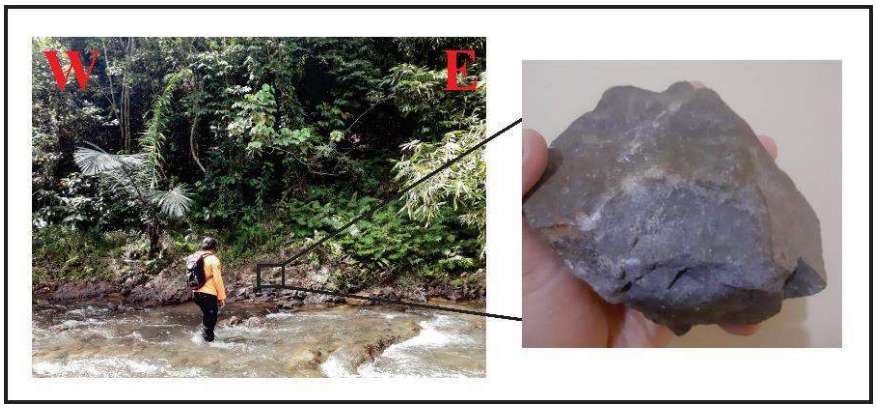

Figure 3. Outcrop of altered andesite units at the study site and hand specimen of altered andesite rock samples

The alluvial deposit unit occupies 25% with a thickness of 75 meters. The lithology in this unit results from weathering rocks in the form of sand, gravel, and gravel to lumps and is not compact (Figure 4). This unit belongs to the Alluvium Formation (Qal) on the geological map of the Tilamuta sheet (Bachri et al., 1994).

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Figure 4. The appearance of alluvial deposits at the research site

The division of the three lithological units can be seen on the geological map of the Bualemo area, North Gorontalo Regency (Figure 5).

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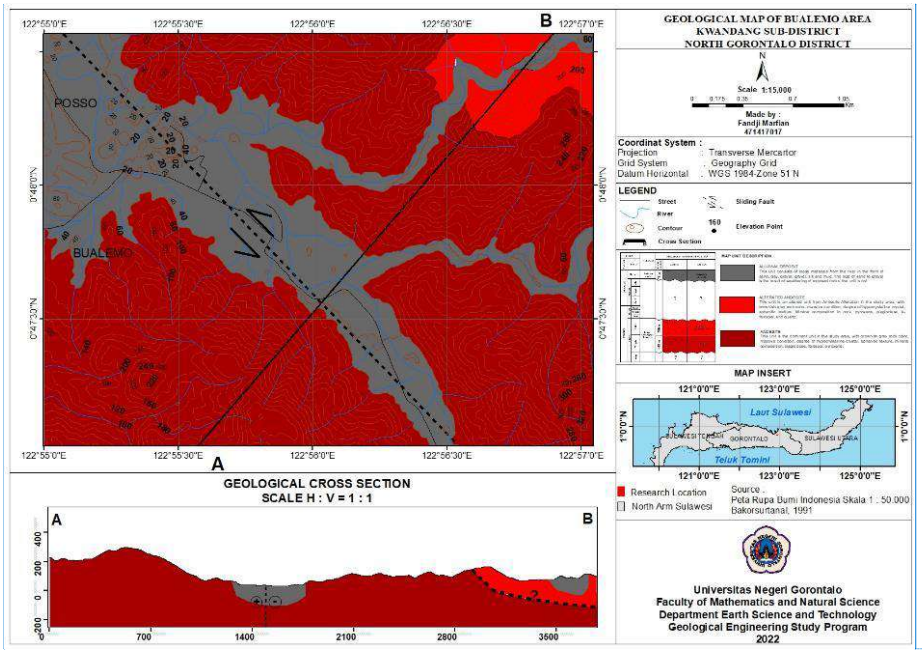

Figure 5. Geological map of the research area

3.2 Geological Structure

At the research site, there is a primary geological structure in the form of a joint (Tension Joint), precisely located at ST 7 (Figure 6). After analyzing the joint structure data, the results of the relative joint direction are north-south with an N value of 171° E/79° (Figure 7).

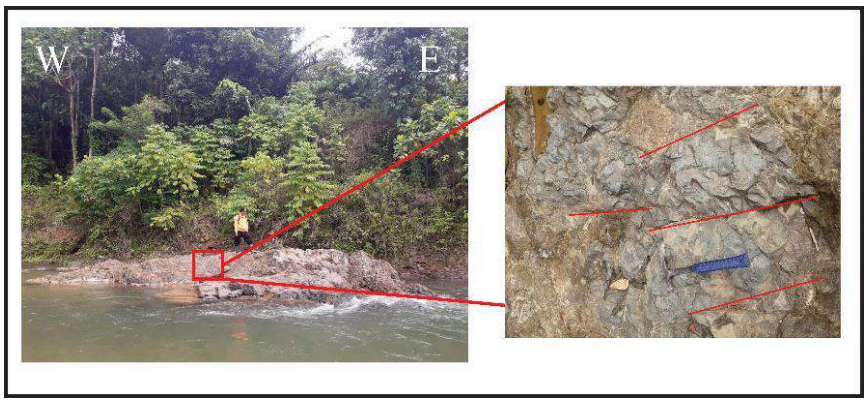

Figure 6. Andesite rock outcrop with tension joint structure at the research site

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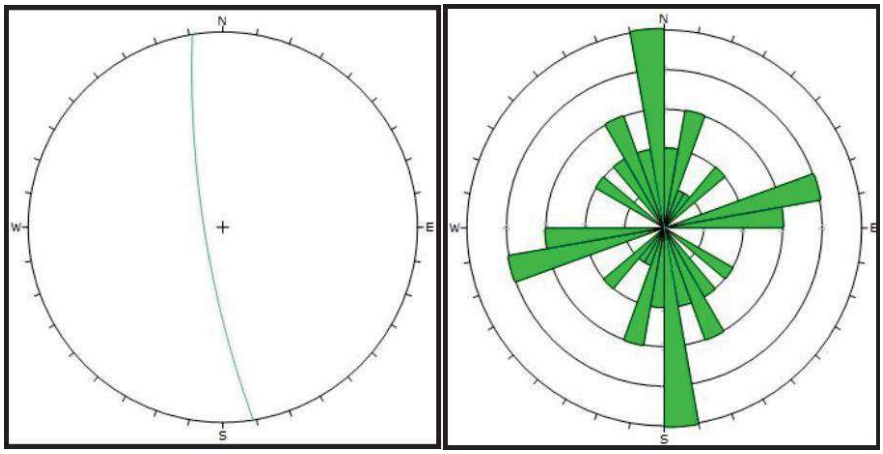

Figure 7. The results of the analysis of the joint tension structure

3.3 Geochemistry

Geochemistry analysis (XRF) to determine the type of rock, magma series, and origin of magma to the tectonic setting in the research area. ~~After geochemistry analysis (XRF) has been carried out, the results will be entered into several diagrams, which will later determine the magma series to the tectonic setting of the research area~~. The ~~following data~~ results ~~from~~ of geochemistry analysis (XRF) are shown in ~~to produce major element data (~~Table 1~~)~~. Two samples will be subject to geochemistry analysis: sample ST 3 and sample ST 26. ~~The diagrams used in this analysis are Na_2O and K_2O diagrams with SiO_2 (Le Bass et al., 1986), FeO*/MgO vs. SiO_2 diagrams (Miyashiro and Shido, 1975), and ternary diagrams of Na_2O+K_2O, FeO* and MgO (Irvine and Baragar, 1971), and triangular diagrams of TiO_2, $MnOx_{10}$, $P_2O_5x_{10}$ (Mullen, 1983)~~.

Table 1. Table of *major elements*

Sample Code	ST 3 (% Weight)	ST 26 (% Weight)
SiO_2	50,53	52,77
Al_2O_3	15,68	18,50
Fe_2O_3	13,28	9,86
MgO	11,39	5,82
CaO	2,81	5,39
Na_2O	3,72	3,29
K_2O	1,07	2,71
TiO_2	1,09	1,00
P_2O_5	0,13	0,28
MnO	0,30	0,38
LOI	3,22	4,11

~~Source: XRF Geochemical Analysis Results (2022)~~

3.3.1 Rock Type

The diagram used to determine the rock type in the St 3 and 26 samples is ~~a~~ the binary diagram of Le Bass et al. (1986). This diagram is Total Alkali-Silica (TAS), namely the accumulation of

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$Na_2O + K_2O$ (Total Alkali) and SiO_2 (Silica). show that the two rock samples belong to the basic igneous rock group, Basalt and Basaltic-Trachy Andesite (Figure 8).

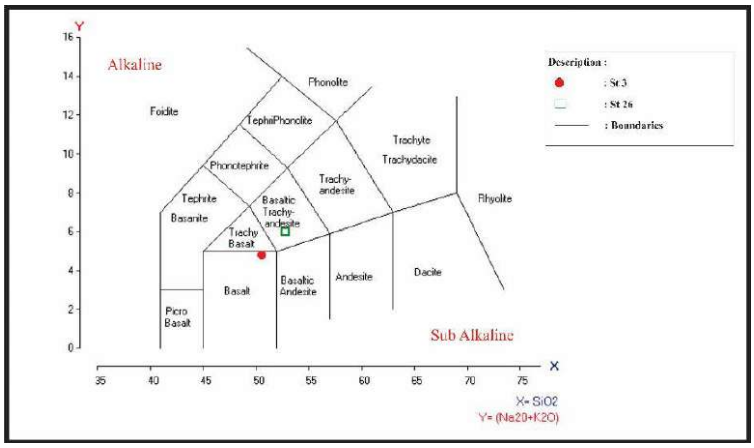

Figure 8. (Na_2O+K_2O) vs. SiO_2 diagram (Le Bass et al., 1986) of the studied rocks

3.3.2 Magma Series

Furthermore, the plotting is carried out on the AFM diagram of F (Total FeO), A (K_2O+NaO), and M (MgO) (Irvine and Baragar, 1971) as shown in Figure 9. In this diagram, two types of magma are divided: Calc-Alkaline and Thoeleitic. Based on this diagram, ~~it is known that the~~ both samples ~~with codes St 3 and St 26 of the study area~~ belong to the Tholeitic magma series, where in the tholeiitic magma series, the Fe content is very rich and higher than that of the Tholeiitic magma series. Alkaline element value. Based on the geochemistry analysis (XRF) results, the elemental Fe values at both stations were 6.89%-9.28% ~~(Figure 9)~~.

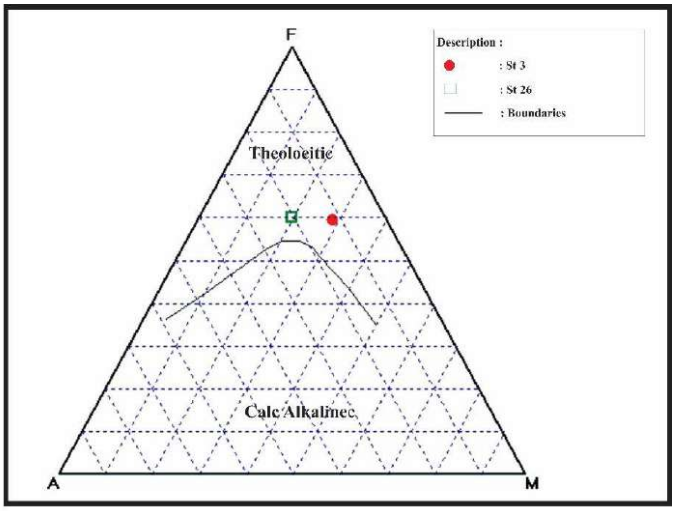

Figure 9. AFM diagram (Irvine and Baragar, 1971) of the studied rocks

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Then plotting the FeO/MgO vs. SiO_2 diagram (Miyashiro and Shido, 1975); both samples belong to the Tholeiitic magma series. This diagram is aligned with the Ternary AFM diagram (Irvine and Baragar, 1971). In the Tholeiitic magma series, it can form in all tectonic settings (Figure 10).

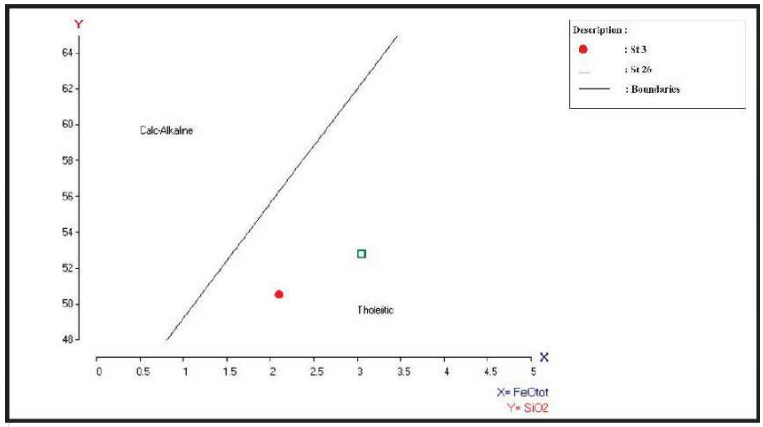

Figure 10. FeO/MgO vs. SiO_2 diagram (Miyashiro and Shido, 1975)

3.3.3 Magma Origin

This diagram shows magma's origin in more detail, based on the plotting results from the ternary diagram (Mullen, 1983), St 3 belongs to the Tholeiitic Island Arc tectonic setting, and ST 26 belongs to the Calc-Alkaline Basalt Island tectonic setting. Based on the diagram above, it is possible that other tectonic events occurred in the ST 26 sample, which resulted in more acidic magma in the St 26 sample (Figure 11).

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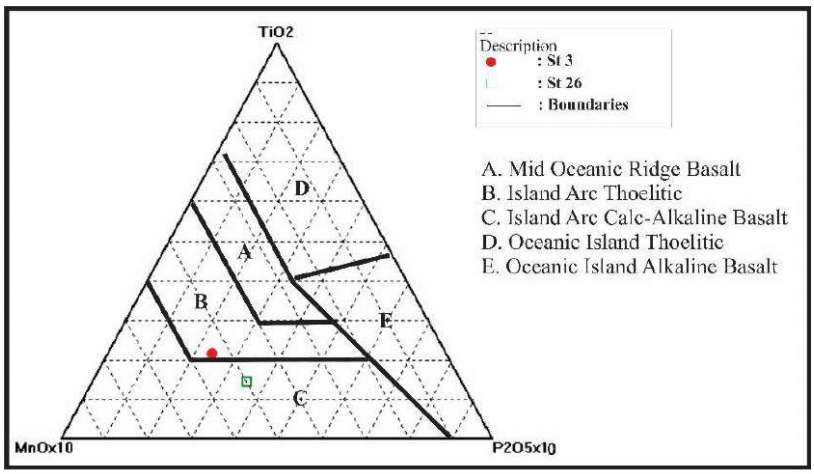

Figure 11. TiO_2, MnOx10, P_2O_5x10 triangle diagram (Mullen, 1983) of the studied rocks

3.4 Tectonic Setting

Based on the analysis of several diagrams above, it is shown that two magma series are found ~~contained~~ in the studied area~~'s rock with sample codes St 3 and St 26~~. The magma series formed at St 3 is Tholeitic based on the magma series diagram ~~from~~ of Irvine and Baragar (1971) and the diagram binary from (Miyashiro and Shido, 1975). The tholeiitic magma series is a typical magma that forms in the early stages of island arc formation. The tholeiitic magma series is a type of magma that can exist in various tectonic settings, for St 3 basalt rocks belonging to a convergent tectonic setting or subduction zone. This is evidenced by the TiO_2 content of <1.3% (Gill, 1981 in Yuwono, 2015), where the TiO_2 content in St 3 rock is 1.08%. The St. 26 rock, according to the binary diagram (Le Bass et al., 1986), belongs to the Basaltic Trachyte Andesite rock. So it can be concluded that these two samples belong to the island arc. It is clarified by the analysis results from diagrams of TiO_2, $MnOx_{10}$, and $P_2O_5x_{10}$ from (Mullen, 1983), where St 3 rock belongs to the origin of Tholeiitic Island Arc magma, and St 26 rock belongs to the origin of Island Arc Calc Alkaline Basalt magma. These magma origins are included in the subduction zone/orogenous zone (island arc and active continental margin).

To find out the depth of magma origin can be calculated using the content of SiO_2 and K_2O (Hutchinson, 1977). Calculations carried out to determine the depth of origin of magma can use the formula:

$$\mathbf{h= [320-(3{,}65 \times \% SiO_2)] + (25{,}52 \times \% K_2O)}$$

Based on calculations using this formula, it can be seen that the depth of origin of magma from rocks in the study area is at a depth of about 163-196 km below the earth's surface in the Benioff Zone. It is estimated that the rock was formed during the Middle Miocene to Late Miocene, when subduction occurred between two oceanic plates, namely between the Sulawesi sea plate and the Sula ocean plate, about 15 to 10 million years ago (Hall and Spakman, 2015).

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4. CONCLUSIONS

1) The stratigraphy of the study area is divided into three lithological units: the andesite unit, the altered andesite unit, and the alluvial sediment unit.
2) The geological structure in the study area is tension joints and interpretation faults in the form of shear faults.
3) Based on the geochemistry analysis (XRF), it was found that the rock names are basalt and basaltic trachy andesite, the type of magma is theoleiitic, and the origin of the magma is island arc theoliitic and island arc alkaline basalt.
4) Tectonics in the research area result from subduction between 2 oceanic plates, namely the Sulawesi sea plate and the Sula sea plate.

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Hindari 'bullets and numbering' dalam penulisan kesimpulan

5. REFERENCES

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Perbaiki dulu papernya

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Revised Results/Authors Response

A

Aang Panji Permana <aang@ung.ac.id> 26 Des 2022, 05.42

kepada Jambura

Dear editors

We submit column comments from authors and revised journals. Thank you for your attention.

Regards,
Aang Panji Permana

A

Aang Panji Permana <aang@ung.ac.id> 5 Jan 2023, 06.12

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Dear Editors,

We sent again the comments column and the second revision of the journal. Thank you for your attention.

Regards
Aang Panji Permana

Jambura Geoscience Review

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COMMENT REVIEWER

Manuscript Title: **Study of Petrogenesis Andesite Rock in Bualemo Region, North Gorontalo Regency Based on XRF Geochemistry Analysis**

COMMENT	RESPONSE	PAGE
Coliision is a convergence of two continental plates. Are Indo-Australia and Pacific classified as continental plates? If they are not please change this word	Collision here means a collision between the three large plates, not leading to a particular plate. According to the references source used.	**1**
You explain Sulawesi in the prev paragraph. What is the relation of Kwandang and Sulawesi? Is it located in Sulawesi?	Kwandang is the name of a sub-district in North Gorontalo district. Meanwhile, North Gorontalo district is in the central part of Sulawesi Island, precisely in Gorontalo Province	**1**
Separate it into another sentence please	Done	**2**
'will be'? … It is not correct sentence. If you use will be so you haven't done it yet	Done	**3**

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Separate this into two sentences	Done	**3**
A means one… So you only analysed one sample?	There are 2 samples analyzed, they have been replaced	**3**
Not s good sentence… Rearrange this sentence.	Done	**3**
Plese give reference	Readings are made based on field results and applied to the map (division of geological units)	**3**
Please be careful with single or plural noun	Done	**3**
Again…. Is this singular or plural?	Done	**4**
Do you need to use capital letter for this	Done	**5**
Not a complete sentence	I think the sentence is clear enough to explain the purpose of geochemical analysis	**6**
What do you mean???? You have analysed them already	This sentence describes the stages, for samples that have been analyzed in the laboratory and then processed to be included in a diagram to	**6**

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	determine the type of rock, the type of rock and the origin of magma to the tectonics of the research area	
Not a clear sentence. Do you mean both of the sample beliong to Basalt or Basalt Trachy Andesite? Or one of them belongs to Basalt and the other one belong to another type?	It has been clarified, for St 3 Basalt, and St 26 Basaltic Trachy Andesite	**6**
Again…. Please be careful if singular and plural noun..	It's a plural noun, because it refers to 2 samples that belong to the toleiitic magma series	**7**
Give your reference(s)	Based on the table of the relationship between the tectonic position and the magmatic series formed (Best, 1982). Already answered in the previous revision	**7**
Give reference(s)	The research location area is included in the tertiary formation of the volcanic mesion bilungala (Tmbv), where the Tertiary was about 15-10 million years ago. the rocks are at different magma origins	**8**
You have to erase this part. It makes your study confusing….. Previously you said that all of the samples are Thoeleitic, but here you said that one of them is Calc-Alkaline	I don't think it's necessary to delete this section, because it's already explained	**8**

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Give me your reference(s)	Already answered	**9**
Come on who said that? You have to explain this	The answer is the same, based on the tectonics of the study area is the result of a collision between 2 oceanic plates	**9**
Look at comment 18	Already answered	**9**
What is Benioff line? Are you sure that your sample come from the Benioff line? Give me your reference(S)	Yes im sure, the depth of the benioff zone from the surface reaches up to 670 km (Lowrie, William.2007.Fundamentals of Geophysics.2nd ed. Cambridge: Cambridge University Press)	**9**

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COMMENT REVIEWER

Manuscript Title: **Study of Petrogenesis Andesite Rock in Bualemo Region, North Gorontalo Regency Based on XRF Geochemistry Analysis**

COMMENT	RESPONSE	PAGE
Apakah referensi anda menyebut seperti ini bahwa harus ada data data mikroskop dan geokimia? Setahu saya tidak harus ada keduanya. Kemudian, tujuan dari petrogenesis saya setuju Jadi mohon baca lagi referensi anda	Sudah diperbaiki. Diganti atau (or)	**1**
Sebaiknya satu paragraph tidak hanya tersusun atas dua kalimat. Coba tambahkan kalimat lain yang sesuai dengan tema paragraf ini	Sudah diperbaiki. Satu paragraph menjadi tiga kalimat.	**1**

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Hanya kolisi atau ada subduksi? Atau konvergensi?	Sudah diperbaiki. Sesuai referensinya dinyatakan collision.	**1**
Sama seperti komen pada paragraph sebelumnya. Coba tambahkan kalimat lagi yang sesuai	Sudah diperbaiki dengan ditambahkan kalimta	**1**
Kalimat tidak rapi. Coba mulai dengan 'The geological setting of Kwandang……'	Sudah diperbaiki sesuai saran, kalimat diperbaiki	**1**
Lebih baik paragraph ini disatukan karena setiap paragraph terlalu singkat	Sudah diperbaiki, kalimat disatukan.	**1**
Apakah ada yang Namanya Sula Oceanic Plate?	Namanya Lempeng Sula namun komposisinya magma mafic/oceanic yang bergerak menunjam ke utara di bawah Lengan Utara Sulawesi. Hal ini sesuai pustaka dalam Hall dan Spakman, 2015. Berikut gambarnya.	**1**

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	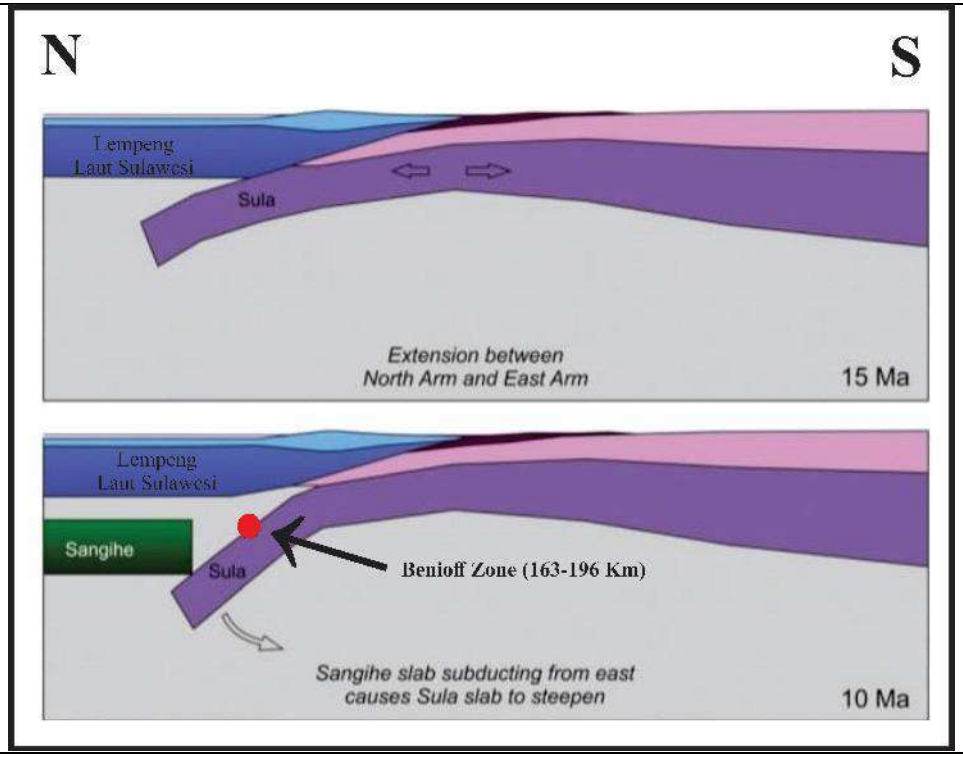	
Ini maksudnya batuan di Kwandang atau di seluruh Sulawesi? Anda memulai paragraph ini dengan Kwandang		**1**
Apakah ada istilah ini. Apakah lengan	Istilah yang dimaksud adalah lempeng laut Sulawesi atau lempeng laut Celebes. Lempeng laut Sulawesi ini bergerak menunjam ke selatan di bawah Lengan Utara Sulawesi. Hal ini	**1**

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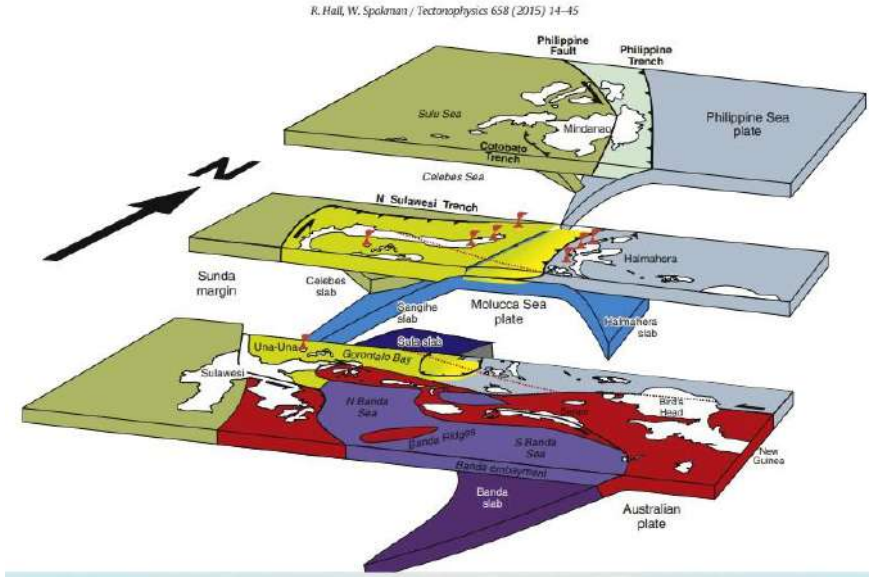
selatan Sulawesi adalah pelat oceanic?	sesuai pustaka dari Hall dan Spakman, 2015. “Seismicity and tomography show that at depths below 400 km this slab is straight and strikes NNE. There is a second slab below the North Arm of Sulawesi, which we term the Celebes slab, that subducts Celebes Sea lithosphere southwards from the North Sulawesi trench (Hall and Spakman, 2015)”. Gambar selengkap sebagai berikut :  	

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	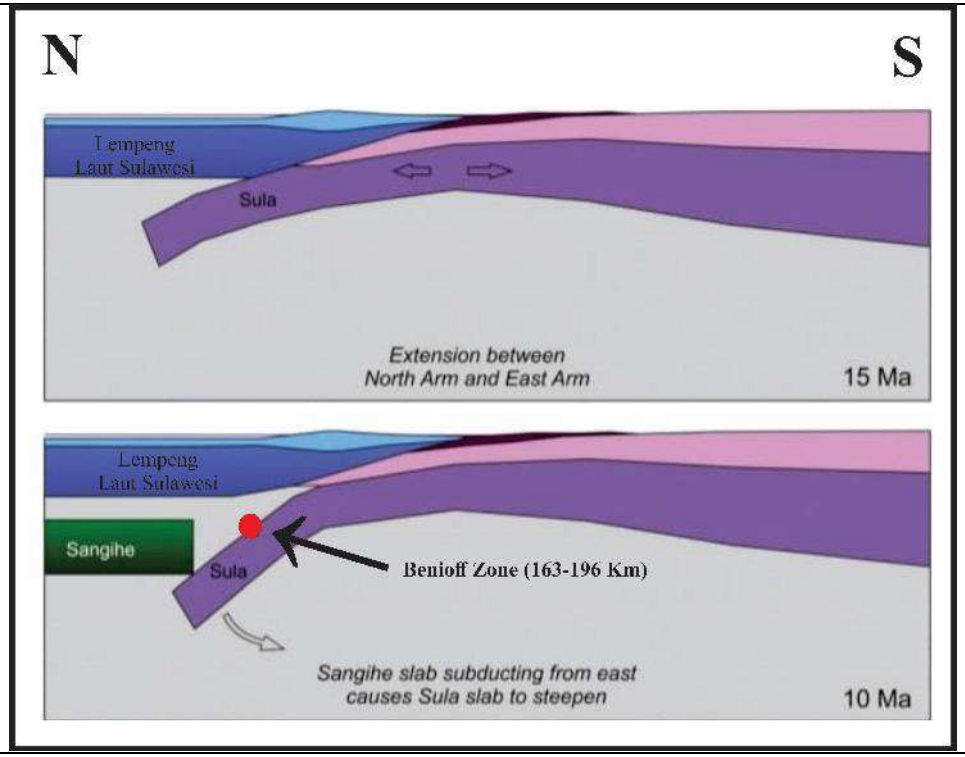	
Jelaskan singkat saja apa yang dilakukan Harun (2020). Jangan hanya 'telah ada penelitian di sana….'	Sudah dijelaskan singkat penelitian sebelumnya hanya berupa pemetaan geologi skala 1 : 25.000 membagi satuan litologi	**2**
Kalimat jadi rancu karena terlalu	Sudah diperbaiki menjadi dua kalimat	**2**

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panjang, sebaiknya pecah jadi dua kalimat		
Are you sure that the rocks are andesites?	Iya. Di paragraph ini menjelaskan hasil penelitian sebelumnya, dan setelah dilakukan penelitian batuannya memang andesit	**2**
I can't read clearly., Please enlarge the text	Sudah diperbaiki gambar semakin jelas keterangan dibuat mudah dibaca dan singkat padat	**2**
You have not mentioned 'Figure 1.' In your text	Sudah diperbaiki. Figure 1 sudah dimasukan dalam kalimat	**2**
Maksudnya bagaimana? Analisis XRF dulu baru studi lapangan? Kok bisa?	Maksudnya hasil data lapngan khususnya data sampling yang nantinya akan digunakan untuk analisis geokimia xrf	**3**
Kurang jelas kalimatnya,… coba buat menjadi kalimat pasif	Sudah diperbaiki dibuat kalimat pasif	**3**
Any reference(s)?	Ini hasil survei geologi lapangan	**3**
Ada dua 'with' sehngga bikin bingung, coba tata lagi. Gampangnya	Sudah diperbaiki menghilangkan satu kata with	**3**

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tiru aja kata-kata pada peta acuan		
Yang mana gambar yang dimaksud. Gambar dapat dibagi dua menjadi (a) dan (b)	Sudah diperbaiki ditambahkan notasi gambar A dan B dalam foto	**3**
Lagi, dua with dalam satu kalimat. Mohon perbaiki	Sudah diperbaiki menghilangkan satu kata with	**3**
Mana subjeknya?	Sudah diperbaiki menambahkan subyek kalimat	**3**
Of studied area? Or what…?	Iya di studied area	**4**
Satu paragraph satu kalimat? Sangat janggal… Coba gabungkan dengan paragraph lain	Sudah diperbaiki dengan digabung dalam satu paragragf	**4**
Banyak tulisan tak terbaca. Sebaiknya gambar ulang atau buang tulisan-tulisan yang tidak penting	Sudah diperbaiki keterangan gambar yang kecil dihilangkan diganti dengan yang lebih jelas	**5**
Tidak bermakna apa-apa jika hanya dituliskan begini.	Ini hasil data lapngan untuk struktur geologi di lokasi penelitian, dijelaskan dsini jenis struktur dan arah umum strukturnya	**5**

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Coba kembangkan apa maksudnya atau dihapus sekalian		
Kalimat ini tidak ada kata kerjanya	Sudah diperbaiki ditambahkan kata kerja	**6**
Kenapa pake kata 'will"?	Karena sampel st 3 dan st 26 merupakan sampel terpilih dari beberapa sampel yang diambil di lapangan	**6**
Deskripsikanlah angka-angka yang ada dalam Tabel. Misal: 'Komposisi SiO2 berada pada rentang…. dst'	Sudah diperbaiki sesuai saran setiap rentang komposisi senyawa	**6**
Kalo Bahasa Inggris, koma itu ditulis (.)	Sudah diperbaiki diganti titik	**6**
Kalimat rancu. Coba tiru dari paper berbahasa Inggris bagaimana menuliskannya	Sudah diperbaiki kalimatnya	**6**
Bagian ini dipotong dan buat kalimat baru saja agar tidak rancu	Sudah diperbaiki kalimatnya	**7**
Mana predikatnya?	Sudah diperbaiki ditambahkan predikat	**7**
'This' yang mana?	Sudah diperbaiki	**8**

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Ini kamu membahas dua sampel dan kondisi yang berbeda..., pisahkan kalimatnya ya	Sudah diperbaiki dipisahkan kalimatnya	**9**
Kok bisa? Apa Basaltic Trachy Andesit pasti Island arc?	Yaa dia masuk ke island arc calk alkaline ssuai dengan diagram mullen	**9**
Ada referensi???	Brdasarkan tabel hubungan antara posisi tektonik dengan seri magmatik yang terbentuk (Best, 1982)	**9**
Apa rumus ini berlaku umum untuk semua batuan, atau ada kondisi khusus? Coba baca lagi dan beri sedikit keterangan apa yang dijelaskan oleh Hutchinson (1977)	Sudah ditambahkan keterangan rumus dan hanya batuan beku	**9**
Apa benar ada Sulawesi Sea Plate?	Benar ada. Istilah yang dimaksud adalah lempeng laut Sulawesi atau lempeng laut Celebes. Lempeng laut Sulawesi ini bergerak menunjam ke selatan di bawah Lengan Utara Sulawesi. Hal ini sesuai pustaka dari Hall dan Spakman, 2015. "Seismicity and tomography show that at depths below 400 km this slab is straight and strikes NNE. There is a second slab below the North Arm of Sulawesi, which we term the Celebes	**9**

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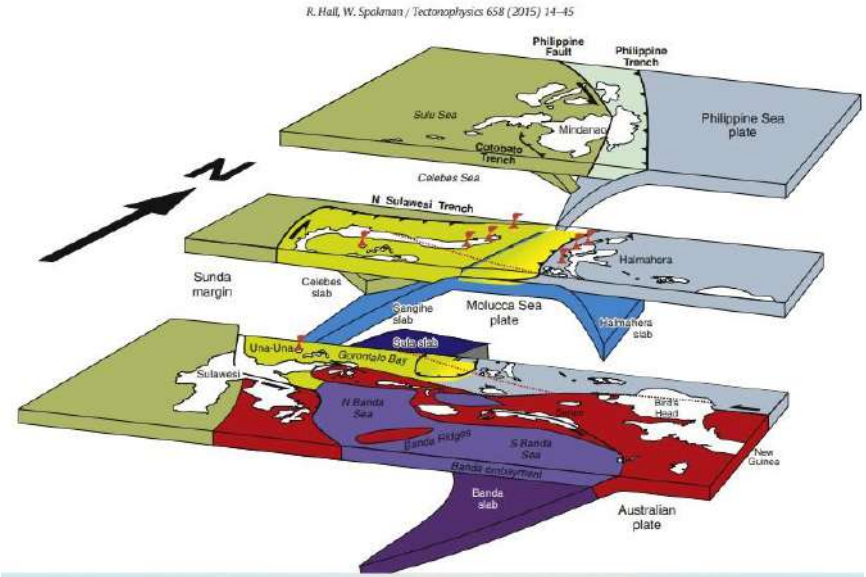
	slab, that subducts Celebes Sea lithosphere southwards from the North Sulawesi trench (Hall and Spakman, 2015)". Gambar selengkap sebagai berikut :  	

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		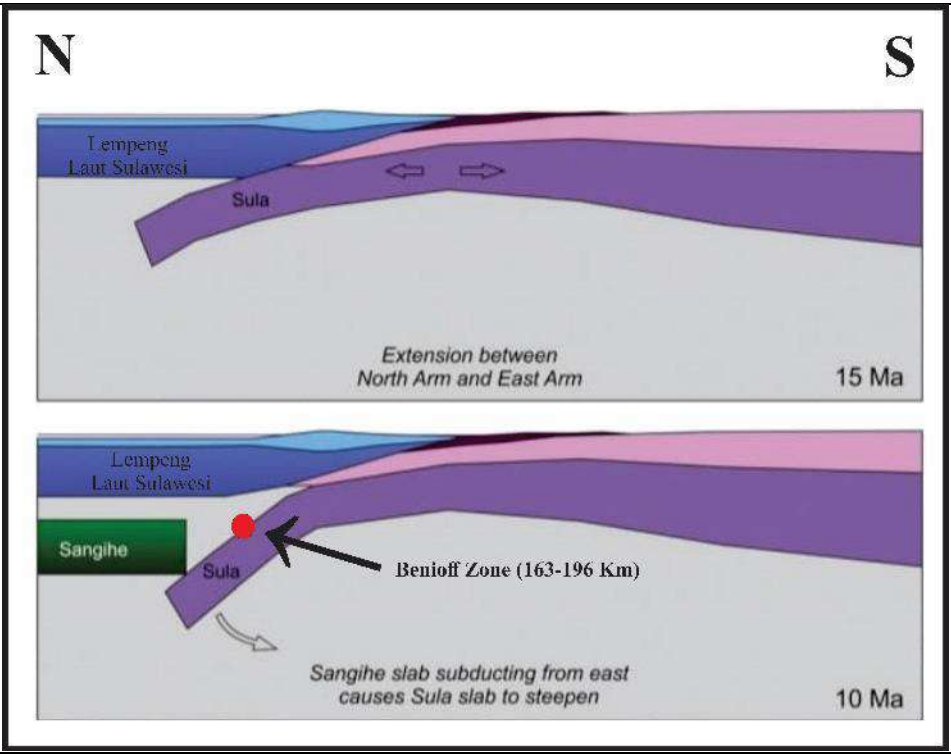	
Apa benar ada 'Sula Ocean plate"		Benar ada. Namanya Lempeng Sula namun komposisinya magma mafic/oceanic yang bergerak menunjam ke utara di bawah Lengan Utara Sulawesi. Hal ini sesuai pustaka dalam Hall dan Spakman, 2015. Berikut gambarnya.	**9**

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		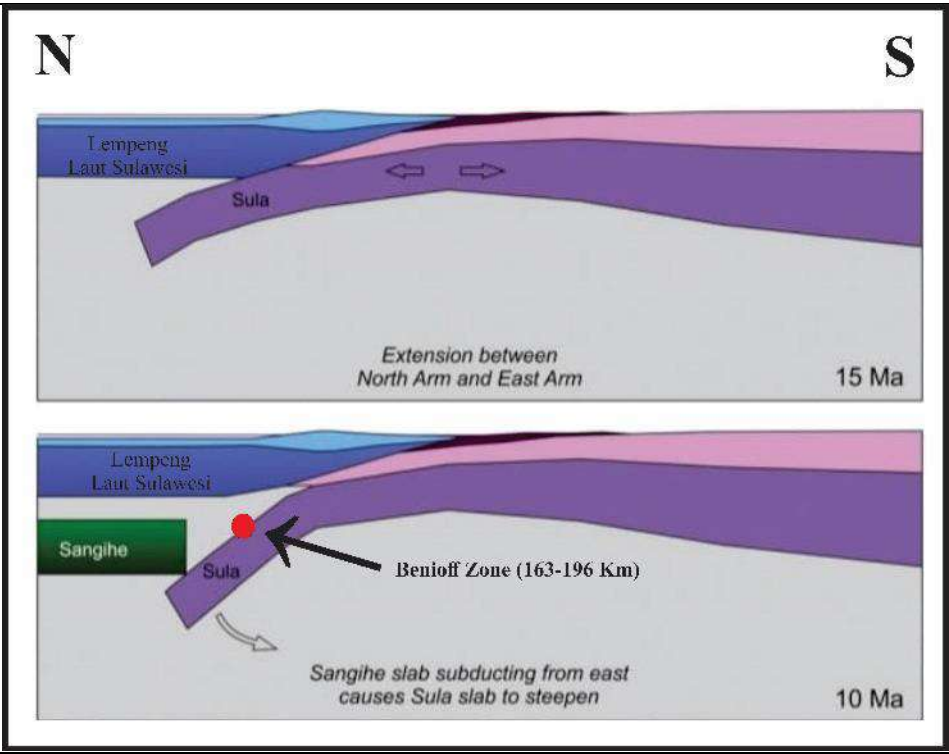	
Mohon tulis kesimpulan dalam kalimat-kalimat sesuai tujuan studi. Hindari 'bullets and numbering' dalam penulisan kesimpulan		Sudah diperbaiki kesimpulan dibuat dalam narasi kalimat lengkap tanpa angka atau huruf pemisah.	**9**

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Bagian ini belum saya periksa. Perbaiki dulu papernya	Sudah dibuat sesuai template.	**10**

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Study of Petrogenesis Andesite Rock in Bualemo Region, North Gorontalo Regency Based on XRF Geochemistry Analysis

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ABSTRACT

The research area is in Bualemo Village, Kwandang District, North Gorontalo Regency. With coordinates 0° 47' 10" - 0° 48' 40" North Latitude and 122° 55' 0" - 122° 57' 5" East Longitude with an area of about 10 km2. This study aims to determine the petrogenesis of andesite rocks and the tectonic setting in the study area. The method used in this study is a mapping method to determine the geological conditions of the research site and geochemical analysis (XRF) to determine the chemical content of rocks. The results showed that the stratigraphy of the study area, sorted from oldest to youngest, was an andesite unit, an altered andesite unit, and an alluvial deposit unit. The geological structure in the study area is a tension joint with a general direction of relative north-south. Based on geochemistry results, it was found that the type of magma is tholeiitic, with its name basalt and basaltic trachyte andesite. The origin of the magma is island arc tholeiitic and island arc calc-alkaline basalt, with the tectonic setting of the study area being subduction between two oceans, namely between the Sulawesi sea plate and the Sula plate.

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1. Introduction

Petrogenesis studies is a field of science that focuses on the abundance of minerals observed in rock incisions under a microscope or analyzes the content of chemical elements in rocks to determine the formation process in rocks and their tectonic environmental conditions (Yuwono, 2015). Geochemistry is a grouping of the relative and absolute abundances of various elements on earth, the study of the distribution and migration of single parts in multiple places on earth with objects in the form of basic patterns of distribution and migration of elements (Mason, 1958). This study used X-ray fluorescence (XRF) spectroscopy analysis, an analytical technique that detects X-ray radiation from the emitted sample in the sample being analyzed as a basis (John *et al.*, 2001).

Sulawesi is located at the subduction of three large tectonic plates: the Indo-Australian, the Eurasian, and the Pacific. There is also a smaller plate located to the north, namely the Philippines (Hamilton, 1979; Hutchison, 1989; Hall and Wilson, 2000; Permana, 2018, 2019; Permana et al., 2021). The island was formed due to the collision of Sunda land, the easternmost part of the Eurasian plate, with the microcontinent of the Australian plate (Bachri, 2011).

The geological setting of Kwandang is exciting to study because it is composed of complex rock formations of the Tertiary to Quaternary age. This rock formation was formed since the start

of the collision of the Sula plate with the Sulawesi sea plate, which was then followed by a collision towards the eastern arm of Sulawesi in the mid-Pliocene along with the formation of a subduction strip along the northern arm of Sulawesi until now (Hall and Spakman, 2015). Harun (2020) research useds the mapping method to determine the geological conditions of the study area. Bualemo Village is one of the villages located in the Kwandang District. In previous research in the Bualemo area, volcanic rocks were included in the Bualemo Andesite Unit (Harun, 2020). Bualemo andesite was thought to have formed in the Middle to Late Miocene period (Bachri et al., 1994).

However, no previous studies describe the petrogenesis of andesite rocks. This research aims to describe the petrogenesis of andesite rocks in the Bualemo area, North Gorontalo Regency, based on XRF geochemistry analysis.

2. METHOD

2.1. Research Location

The research was conducted in Bualemo Village, Kwandang District, North Gorontalo Regency. With coordinates 0° 47' 10" - 0° 48' 40" and 122° 55' 0" - 122° 57' 5". The area of the research location is 10 km^2. (Figure. 1)

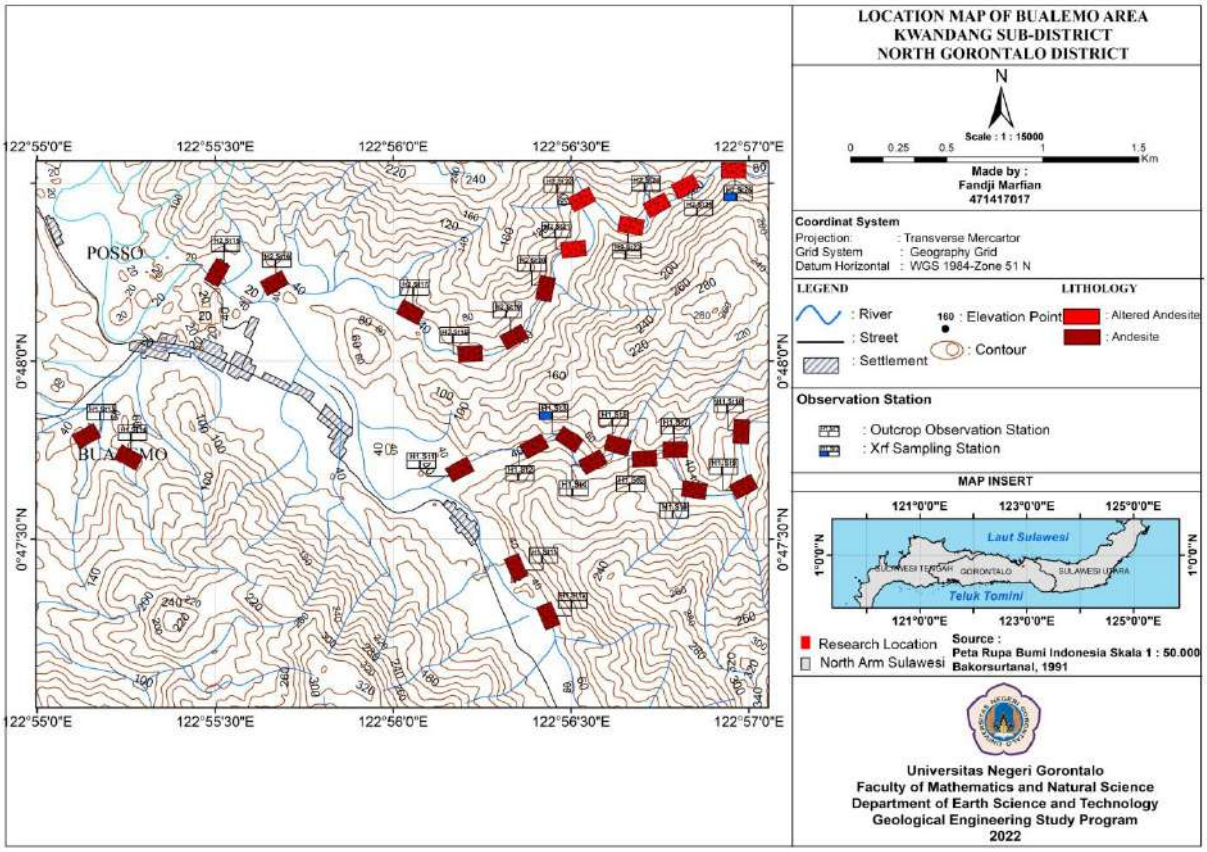

Figure 1. Research location map

2.2. Research Method

In this study, geological mapping and geochemical analysis are applied. The geological mapping method was used during observation and data collection in the field. X-ray fluorescence (XRF) analysis at the Central Laboratory of Mineral Resources for Coal and Geothermal in Bandung was carried out on selected rock samples to determine the chemical content of the rocks. XRF analysis is essential to determine the major oxides and trace element composition of a rock, mineral, sediment, and liquid (Rollinson., 1993; Boogs., 2009; Shackley., 2011; Wahyudiono et al., 2016., Permana, 2018).

Data collection at the field in the form of lithological data, geological structures, and sampling for XRF geochemistry analysis . Lithological data collection was carried out to determine the stratigraphy of the research area. Geological structure data collection was carried out to determine the general direction of the geological structure found in the research area. Samples for geochemistry analysis was selected to determine the name of the rock, magma series, magma origin, and tectonics in the research area. The software used to process geochemical data is *Petrograph*

3. RESULTS AND DISCUSSION

3.1 Stratigraphy

The stratigraphy of the study area consists of three lithological units, namely the andesite, altered andesite, and alluvial deposit. The andesite unit occupies 70% of the research location, with a thickness of 400 meters. The lithology contained in this unit is andesite rock with gray color, holocrystalline, massive, and mineral composition is plagioclase, pyroxene, and k-feldspar (Figure 2). This unit is included in the Bilungala Volcano Rock Formation (Tmbv) in the Tilamuta map geology sheet (Bachri et al., 1994).

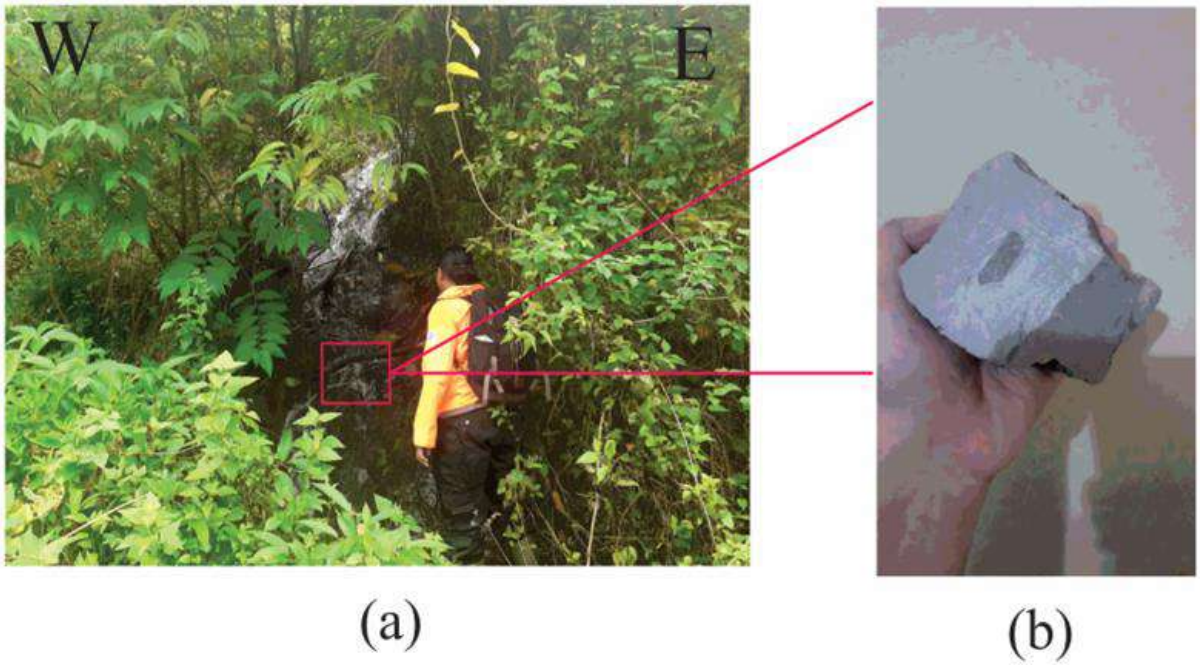

Figure 2. Outcrop of andesite unit at the research site (a) and hand specimen of andesite rock sample (b)

The altered andesite unit at the study site occupies 5% of the ~~site~~ studied location with a thickness of 200 meters. The lithology contained in this unit is andesite rock that has been altered with a brownish-gray color, aphanitic, and holocrystalline massive properties. The rock has a mineral composition such as a little quartz, k feldspar minerals, and plagioclase (Figure 3). This unit is included in the Bilungala Volcano Rock Formation unit (Tmbv) on the Tilamuta geological map sheet (Bachri et al., 1994).

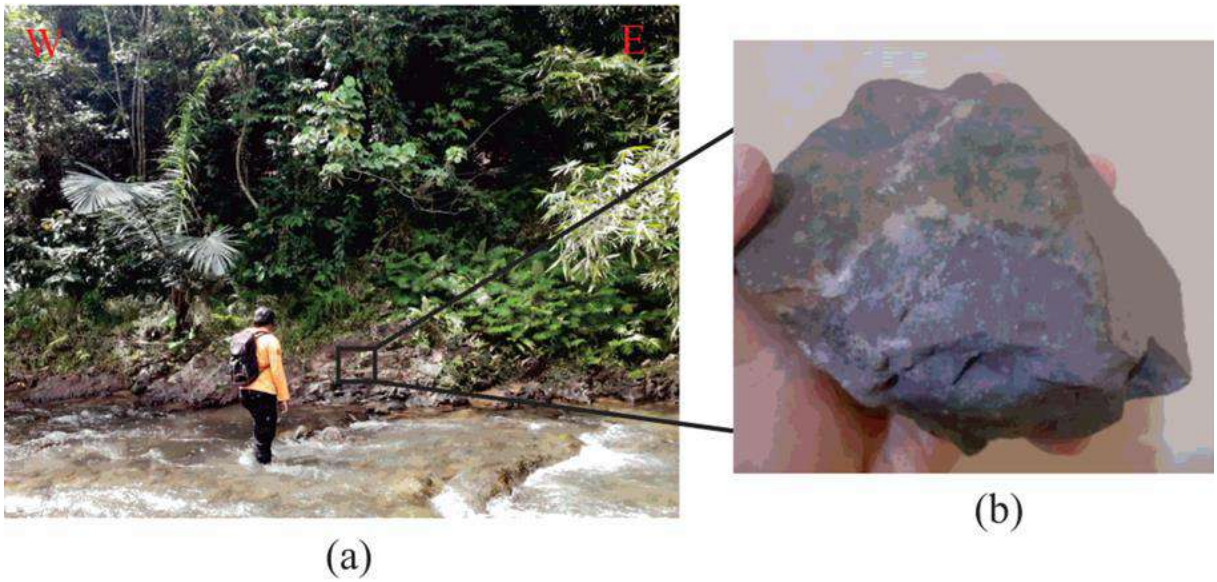

Figure3. Outcrop of altered andesite unit at the study site (a) and hand specimen of altered andesite rock sample (b)

The alluvial deposit unit occupies 25% of the studied area and has a thickness of 75 meters. The lithology in this unit results from weathering rocks in the form of sand, gravel, and gravel to lumps and is not compact (Figure 4). This unit belongs to the Alluvium Formation (Qal) on the geological map of the Tilamuta sheet (Bachri et al., 1994). The division of the three lithological units can be seen on the geological map of the Bualemo area, North Gorontalo Regency (Figure 5).

Figure4. The appearance of alluvial deposits at the research site

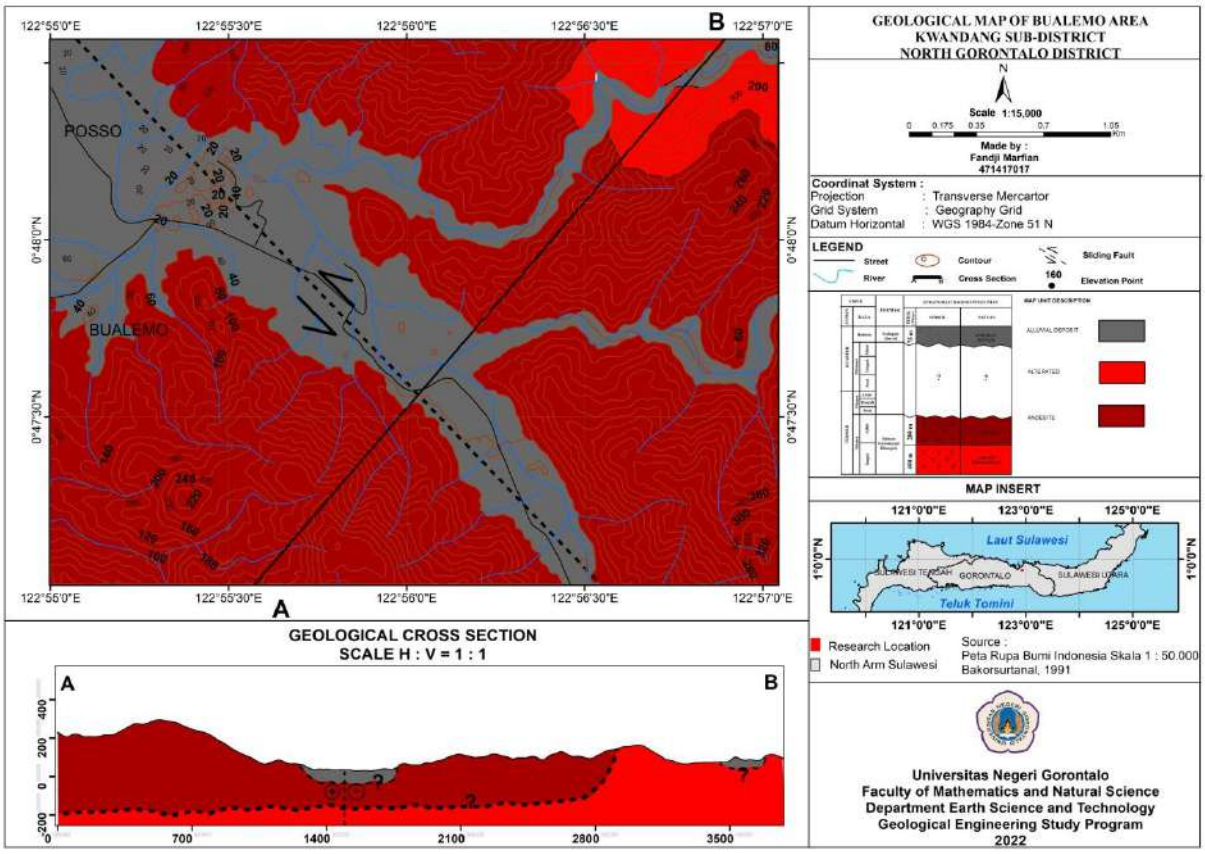

Figure 5. Geological map of the research area

3.2 Geological Structure

At the research site, there is a primary geological structure in the form of a joint (*tension joint*), precisely located at ST 7 (Figure 6). After analyzing the joint structure data, the results of the relative joint direction are north-south with an N value of 171˚ E/79˚ (Figure 7).

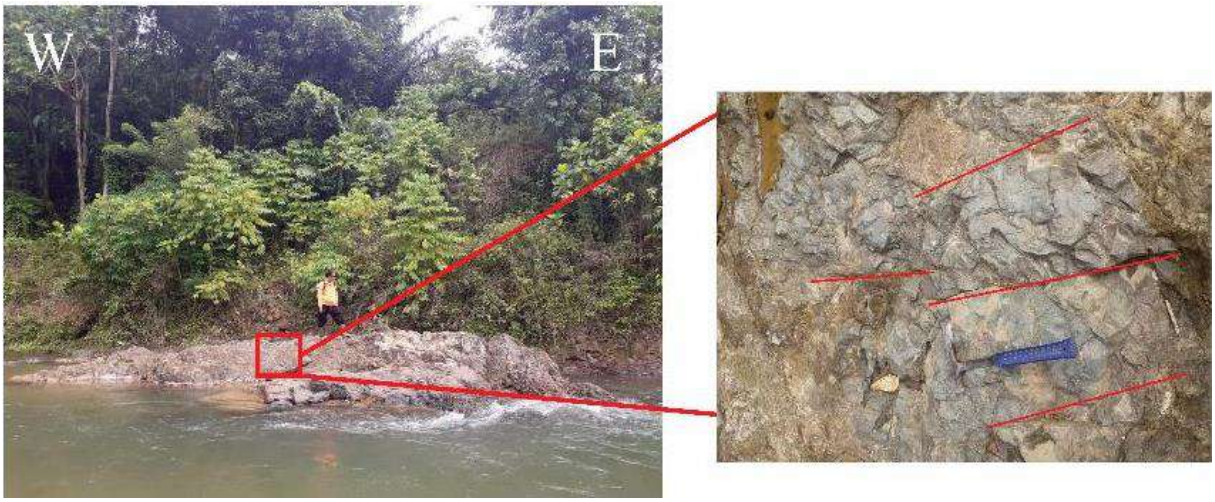

Figure 6. Andesite rock outcrop with joint tension structure at the research site

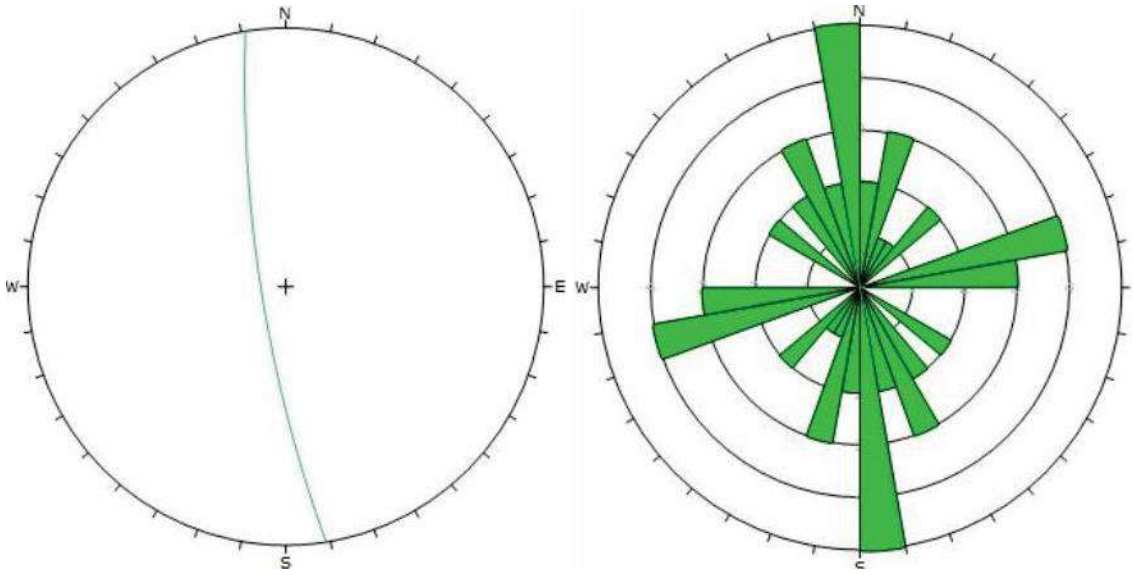

Figure7. The results of the analysis of the joint tension structure

3.3Geochemistry

Geochemistry analysis (XRF) to determine the type of rock, magma series, and origin of magma to the tectonic setting in the research area. The following data results from geochemistry analysis (XRF) produce major element data (Table 1). The chemicals composition for samples ST 3 and ST 26 is SiO_2 (50.53-52.77%), Al_2O_3 (15.68-18.50%), Fe_2O_{3T} (13.28-9.86%), MgO (11.39-5.82%), CaO (2.81-5.39%), Na_2O (3.72-3.29%), K_2O (1.07-2.71%), TiO_2 (1.09-1.00%), P_2O_5 (0.13-0.28%), MnO (0.30-0.38%). The two samples after being analyzed produce 10 main elements which will be processed in several diagrams.

Table 1. Table of*majorelements*

Sample Code	ST 3 (% Weight)	ST 26 (% Weight)
SiO_2	50.53	52.77
Al_2O_3	15.68	18.50
Fe_2O_3	13.28	9.86
MgO	11.39	5.82
CaO	2.81	5.39
Na_2O	3.72	3.29
K_2O	1.07	2.71
TiO_2	1.09	1.00
P_2O_5	0.13	0.28
MnO	0.30	0.38
LOI	3.22	4.11

3.3.1 Rock Type

The diagram used to determine the rock type ~~in~~ of ~~the~~ ST~~t~~ 3 and ST 26 samples is the binary diagram of Le Bass et al.(1986). This diagram is Total Alkali-Silica (TAS), namely the accumulation of Na_2O + K_2O (Total Alkali) and SiO_2 (Silica). The two rock samples belong to the basic igneous rock group, Basalt (St 3) and Basaltic-Trachy Andesite (St 26) (Figure 8).

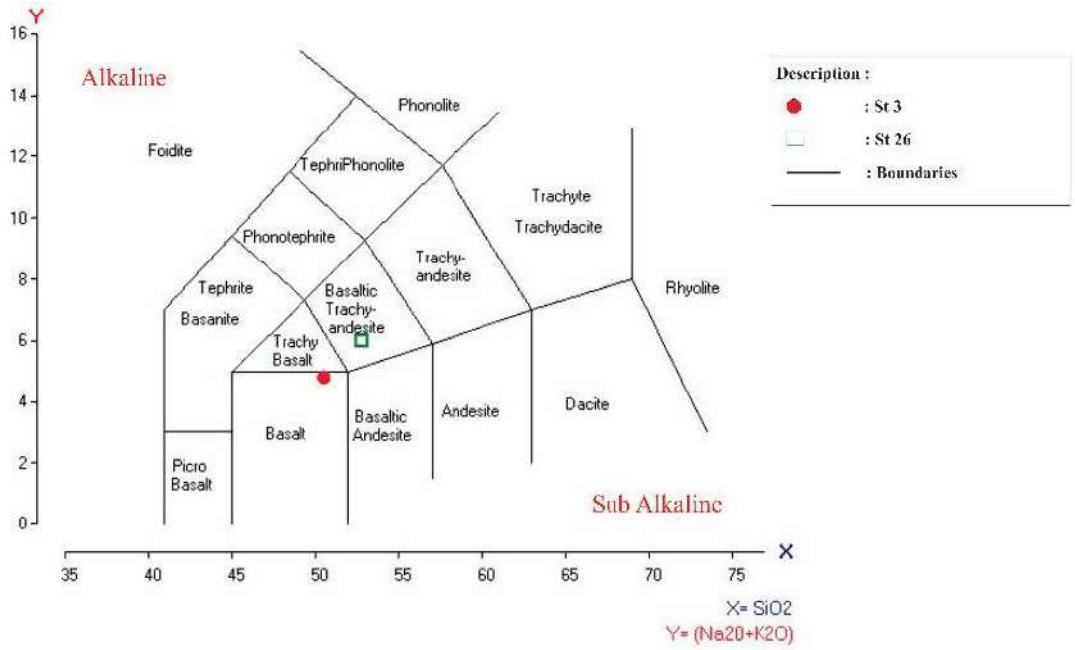

Figure 8. (Na_2O+K_2O) vs. SiO_2diagram(Le Bass et al., 1986) of the studied rocks

3.3.2 Magma Series

Furthermore, the plotting ~~is~~ was carried out on the AFM diagram of F (Total FeO), A (K_2O+NaO), and M (MgO) (Irvine and Baragar, 1971), as shown in Figure 9. In this diagram, two types of magma are divided: Calc-Alkaline and Thoeleitic. Based on this diagram, it belongs to the Tholeitic magma series, where in the tholeiitic magma series, the Fe content is vibrant and higher than that of the Tholeiitic magma series alkaline element value. Based on the geochemistry analysis (XRF) results, the elemental Fe values at both stations were 6.89%-9.28%.

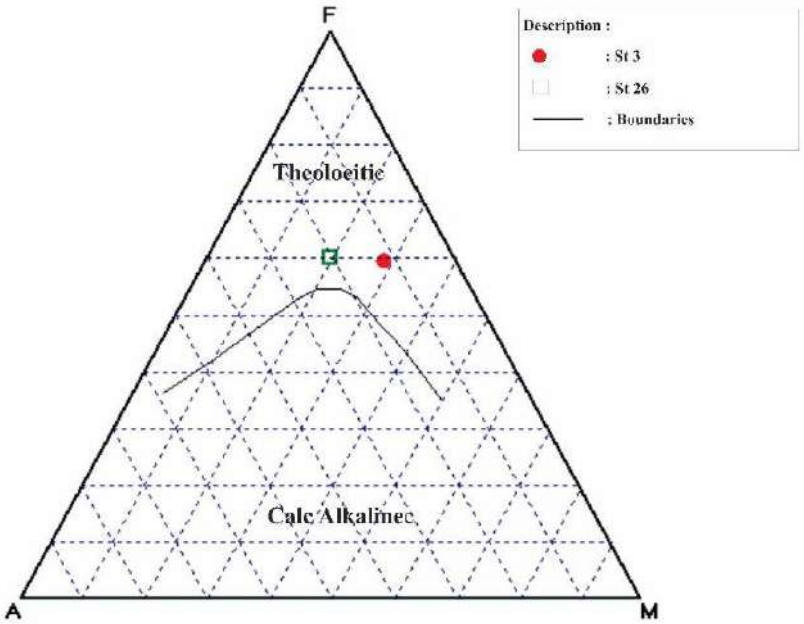

Figure 9. AFM diagram (Irvine & Baragar, 1971) of the studied rocks

Then plotting the FeO/MgO vs. SiO_2 diagram (Miyashiro and Shido, 1975); both samples belong to the Tholeiitic magma series. This diagram is aligned with the Ternary AFM diagram (Irvine and Baragar, 1971). Tholeiitic magma can form in all tectonic settings (Figure 10).

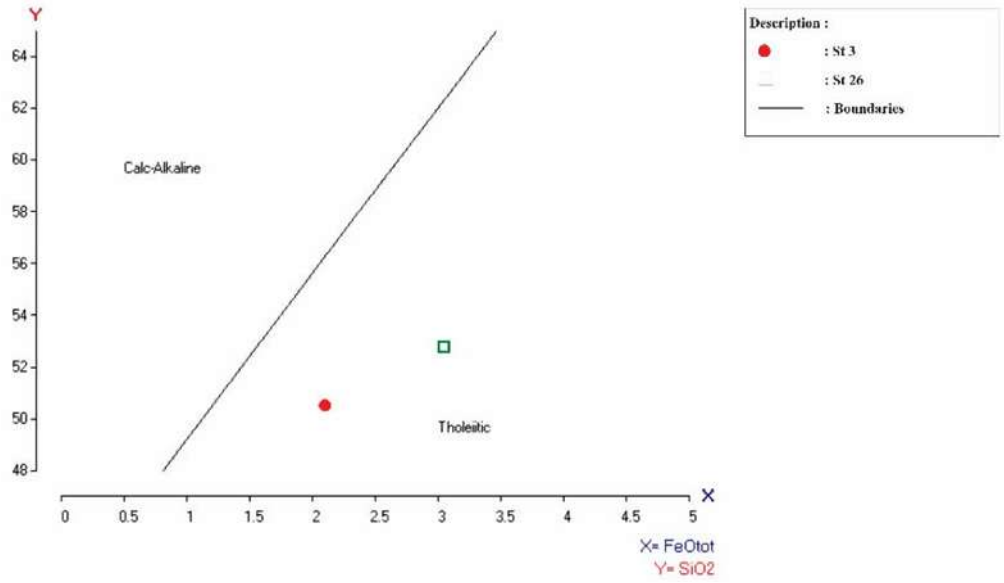

Figure 10. FeO/MgO vs. SiO_2 diagram (Miyashiro & Shido, 1975)

3.3.3 Magma Origin

The diagram of (Figure 11) shows magma's origin in more detail, based on the plotting results from the ternary diagram (Mullen, 1983). St 3 belongs to the Tholeiitic Island Arc, while ST 26 belongs to the Calc-Alkaline Basalt Island tectonic setting. Based on the diagram above, it is possible that other tectonic events occurred in the ST 26 sample, which resulted in more acidic magma in the St 26 sample (Figure 11).

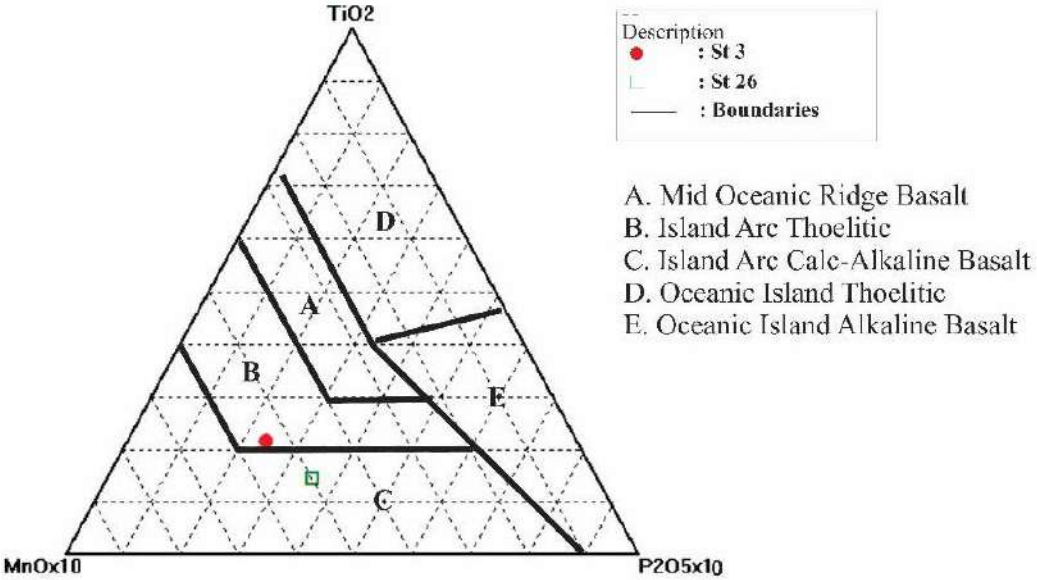

Figure 11. TiO_2, MnOx10, P_2O_5x10 triangle diagram (Mullen, 1983) of the studied rocks

3.4 Tectonic Setting

The magma series formed at St 3 and St 26 is Tholeitic based on the magma series diagram of Irvine and Baragar(1971) and the diagram binary from (Miyashiro and Shido, 1975). The tholeiitic magma series is a typical magma that forms in the early stages of island arc formation. The tholeiitic magma series is a type of magma that can exist in various tectonic settings. For St 3 basalt rocks belonging to a convergent tectonic setting or subduction zone. This is evidenced by the TiO_2 content of <1.3% (Gill, 1981 in Yuwono, 2015), where the TiO_2 content in St 3 rock is 1.08%. The St. 26 rock, according to the binary diagram (Le Bass et al., 1986), belongs to the Basaltic Trachyte Andesite rock. So it can be concluded that these two samples belong to the

island arc. It is clarified by the analysis results from diagrams of TiO_2, $MnOx_{10}$, and $P_2O_5x_{10}$ from (Mullen, 1983), where St 3 rock belongs to the origin of Tholeiitic Island Arc magma, and St 26 rock belongs to the origin of Island Arc Calc Alkaline Basalt magma. These magma origins are included in the subduction zone.

The subduction process will produce heat in the bending path so that high heat flow can cause magma activity in the Benioff line. To find out the depth of magma origin can be calculated using the content of SiO_2 and K_2O (Hutchinson, 1977). Calculations carried out to determine the depth of origin of magma can use the formula:

$$\mathbf{h= [320-(3{,}65 \times \%\ SiO_2)] + (25{,}52 \times \%\ K_2O)}$$

Based on calculations using this formula, it can be seen that the depth of origin of magma from rocks in the study area is at a depth of about 163-196 km below the earth's surface in the Benioff Zone. It is estimated that the rock was formed during the Middle Miocene to Late Miocene, when subduction occurred between two oceanic plates, namely between the Sulawesi sea plate and the Sula ocean plate, about 15 to 10 million years ago (Hall and Spakman, 2015).

4. CONCLUSIONS

Based on the petrological and geochemical analysis, the constituent rocks in the study area are andesite and altered andesite. The rock types obtained based on geochemical analysis are basalt and basaltic trachy andesite, with the type of magma being tholeiitic. The origin of magma in the rock comes from island arc tholeiitic and island arc calc-alkaline basalt. The research location area is the result of subduction between 2 oceans, namely between the Sulawesi sea plate and the Sula sea plate, around 15-10 million years ago, with a depth of origin of magma of 163-196 km, including in the Benioff zone.

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Study of Petrogenesis Andesite Rock in Bualemo Region, North Gorontalo Regency Based on XRF Geochemistry Analysis

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ABSTRACT

The research area is in Bualemo Village, Kwandang District, North Gorontalo Regency. With coordinates 0° 47' 10" - 0° 48' 40" North Latitude and 122° 55' 0" - 122° 57' 5" East Longitude with an area of about 10 km2. This study aims to determine the petrogenesis of andesite rocks and the tectonic setting in the study area. The method used in this study is a mapping method to determine the geological conditions of the research site and geochemical analysis (XRF) to determine the chemical content of rocks. The results showed that the stratigraphy of the study area, sorted from oldest to youngest, was an andesite unit, an altered andesite unit, and an alluvial deposit unit. The geological structure in the study area is in the form of a tension joint with a general direction of relative north-south. Based on geochemistry results, it was found that the type of magma is tholeiitic, with its name basalt and basaltic trachyte andesite. The origin of the magma is island arc tholeiitic and island arc calc-alkaline basalt, with the tectonic setting of the study area being subduction between two oceans, namely between the Sulawesi sea plate and the Sula plate.

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1. Introduction

Petrogenesis studies is a field of science that focuses on the abundance of minerals observed in rock incisions under a microscope or analyzes the content of chemical elements in rocks to determine the formation process in rocks and their tectonic environmental conditions (Yuwono, 2015). Geochemistry is a grouping of the relative and absolute abundances of various elements on earth, the study of the distribution and migration of single elements in various places on earth with objects in the form of basic patterns of distribution and migration of elements (Mason, 1958). The method used in this study uses X-ray fluorescence (XRF) spectroscopy analysis, which is an analytical method which uses the detection of X-ray radiation from the emitted sample in the sample being analyzed as a basis (John *et al.*, 2001).

Sulawesi is located at the collision of three large tectonic plates, namely the Indo-Australian , the Eurasian , and the Pacific .There is also a smaller plate located to the north, namely the Philippine (Hamilton, 1979; Hutchison, 1989; Hall and Wilson, 2000; Permana, 2018, 2019; Permana et al., 2021). The island was formed due to the collision of Sunda land, the easternmost part of the Eurasian plate, with the microcontinent of the Australian plate (Bachri, 2011).

The geological setting of Kwandang that is very interesting to study because it is composed of complex rock formations of the Tertiary to Quaternary age. This rock formation was formed since

the start of the collision of the Sula plate with the Sulawesi sea plate, which was then followed by a collision towards the eastern arm of Sulawesi in the mid-Pliocene along with the formation of a subduction strip along the northern arm of Sulawesi until now (Hall and Spakman, 2015). Previous research in the area has been carried out (Harun, 2020), and previous research in the Bualemo area with a map scale of 1:25,000. Harun's research uses the mapping method to determine the geological conditions of the study area. Bualemo Village is one of the villages located in Kwandang District. In previous research in the Bualemo area, volcanic rocks were included in the Bualemo Andesite Unit (Harun, 2020). Bualemo andesite was thought to have formed in the Middle to Late Miocene period (Bachri etal., 1994).

However, no previous studies describe the petrogenesis of andesite rocks. The purpose of this research is to describe the petrogenesis of andesite rocks in the Bualemo area, North Gorontalo Regency, based on XRF geochemistry analysis.

2. METHOD

2.1. Research Location

The research was conducted in Bualemo Village, Kwandang District, North Gorontalo Regency. With coordinates 0° 47' 10" - 0° 48' 40" North Latitude and 122° 55' 0" - 122° 57' 5" East Longitude, it has an area of 10 km^2. (Figure. 1)

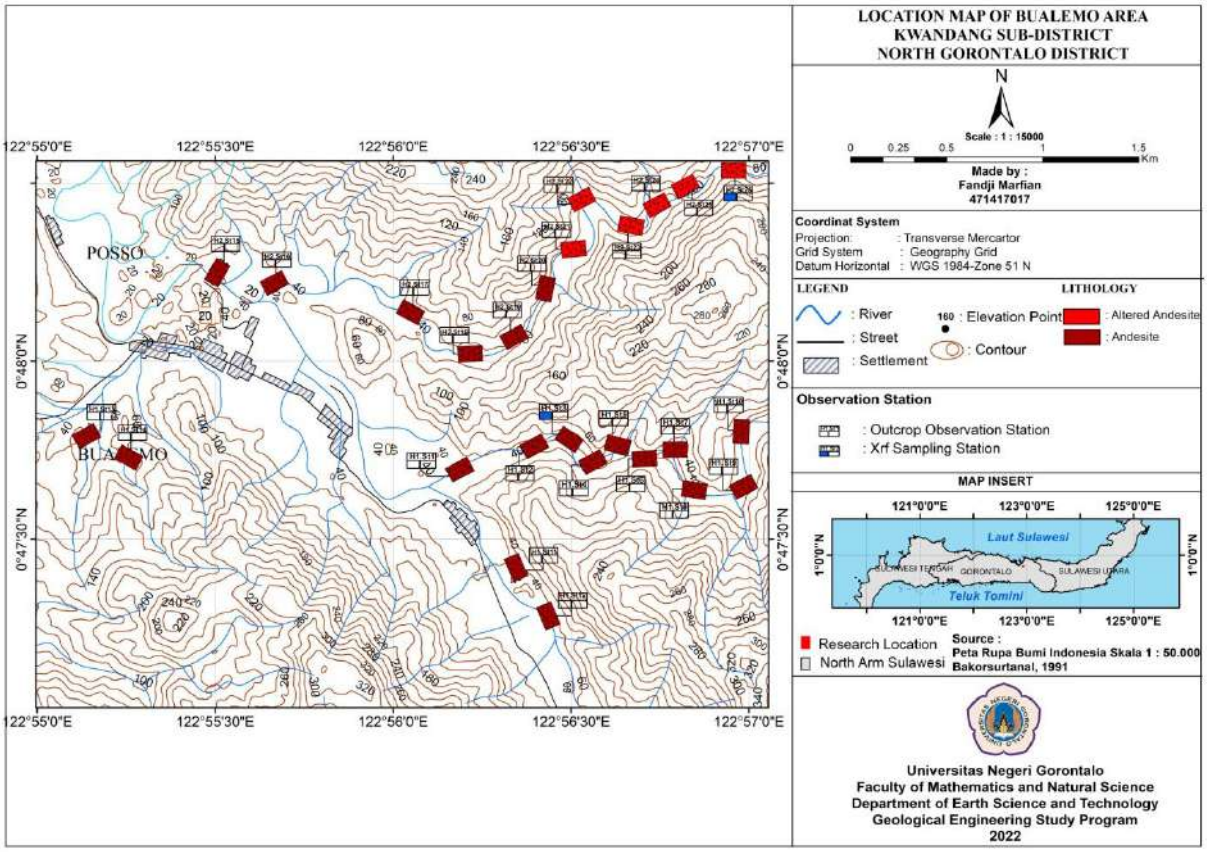

Figure 1. Research location map

2.2. Research Method

In this study, geological mapping and geochemical analysis are applied. The geological mapping methodwas used during observation and data collection in the field. X-ray fluorescence (XRF) analysis at the Central Laboratory of Mineral Resources for Coal and Geothermal in Bandung was carried out on selected rock samples to determine the chemical content of the rocks. XRF analysis is important to determine the major oxides and trace elements compositionof a rock, mineral, sediment, and liquid (Rollinson., 1993; Boogs., 2009; Shackley., 2011; Wahyudiono et al., 2016., Permana, 2018).

Data collection at the field in the form of lithological data, geological structures, and sampling for XRF geochemistry analysis will be carried out later. Lithological data collection was carried out to determine the stratigraphy of the research area; then, geological structure data collection was carried out to determine the general direction of the geological structure found in the research area. Sample~~ing is taken~~ for geochemistry analysis was selected to determine~~and will be processed to find~~ the name of the rock, magma series, magma origin, and tectonics in the research area. Processing of geochemistry data is used *Petrograph* software.

3. RESULTS AND DISCUSSION

3.1 Stratigraphy

The stratigraphy of the study area consists of three lithological units, namely the andesite, altered andesite, and alluvial deposit. The andesite unit occupies 70% of the research location, with a thickness of 400 meters. The lithology contained in this unit is andesite rock with gray color, holocrystalline, massive, and a mineral composition is plagioclase, pyroxene, and k-feldspar (Figure 2). This unit is included in the Bilungala Volcano Rock Formation (Tmbv) in the Tilamuta map geology sheet (Bachri et al., 1994).

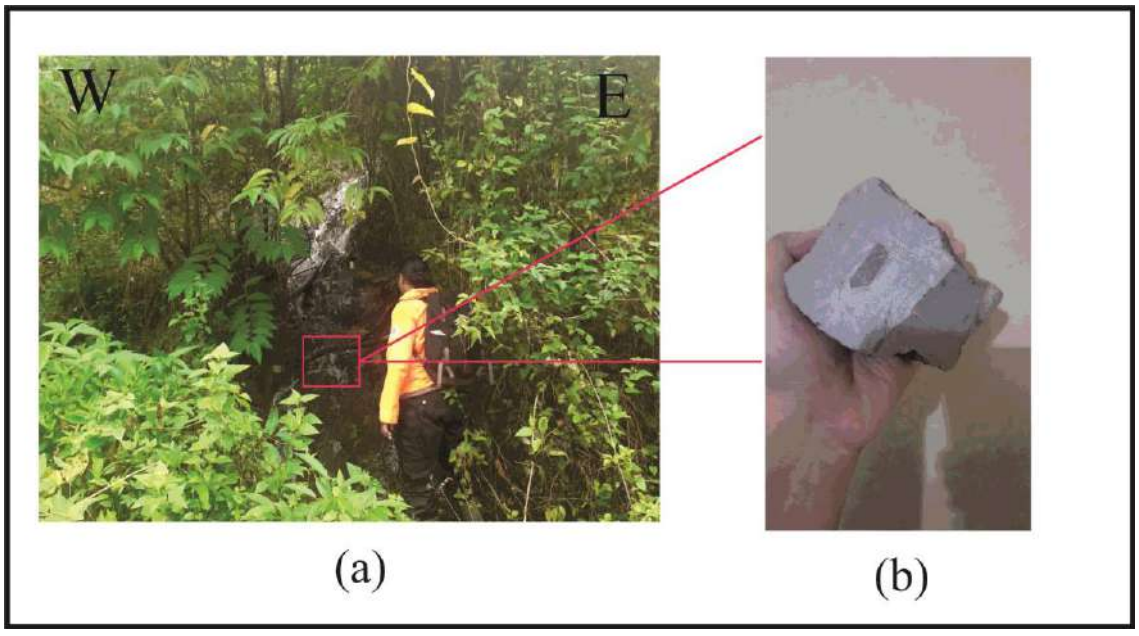

Figure 2. Outcrop of andesite units at the research site (a) and hand specimen of andesite rock samples (b)

The altered andesite unit at the study site occupies 5% of the site with a thickness of 200 meters. The lithology contained in this unit is andesite rock that has been altered with a brownish-gray color, aphanitic, and holocrystalline massive properties. The rock has a mineral composition such as a little quartz, k feldspar minerals, and plagioclase (Figure 3). This unit is included in the Bilungala Volcano Rock Formation unit (Tmbv) on the Tilamuta geological map sheet (Bachri et al., 1994).

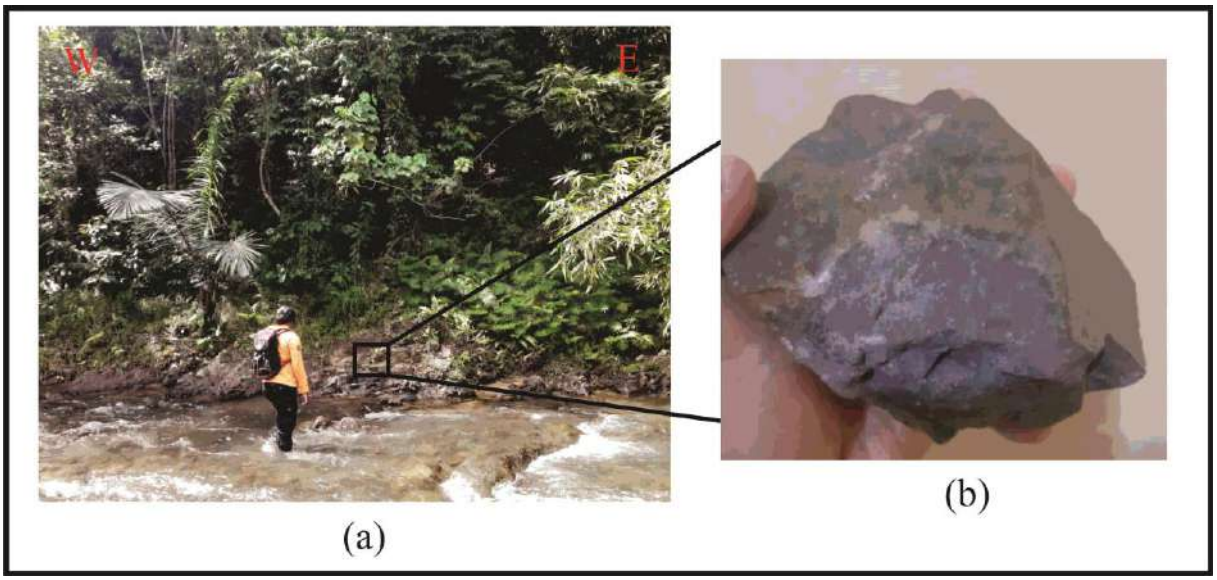

Figure3. Outcrop of altered andesite units at the study site (a) and hand specimen of altered andesite rock samples (b)

The alluvial deposit unit occupies 25% of studied area and a thickness of 75 meters. The lithology in this unit results from weathering rocks in the form of sand, gravel, and gravel to lumps and is not compact (Figure 4). This unit belongs to the Alluvium Formation (Qal) on the geological map of the Tilamuta sheet (Bachri et al., 1994). The division of the three lithological units can be seen on the geological map of the Bualemo area, North Gorontalo Regency (Figure 5).

Figure4. The appearance of alluvial deposits at the researchsite

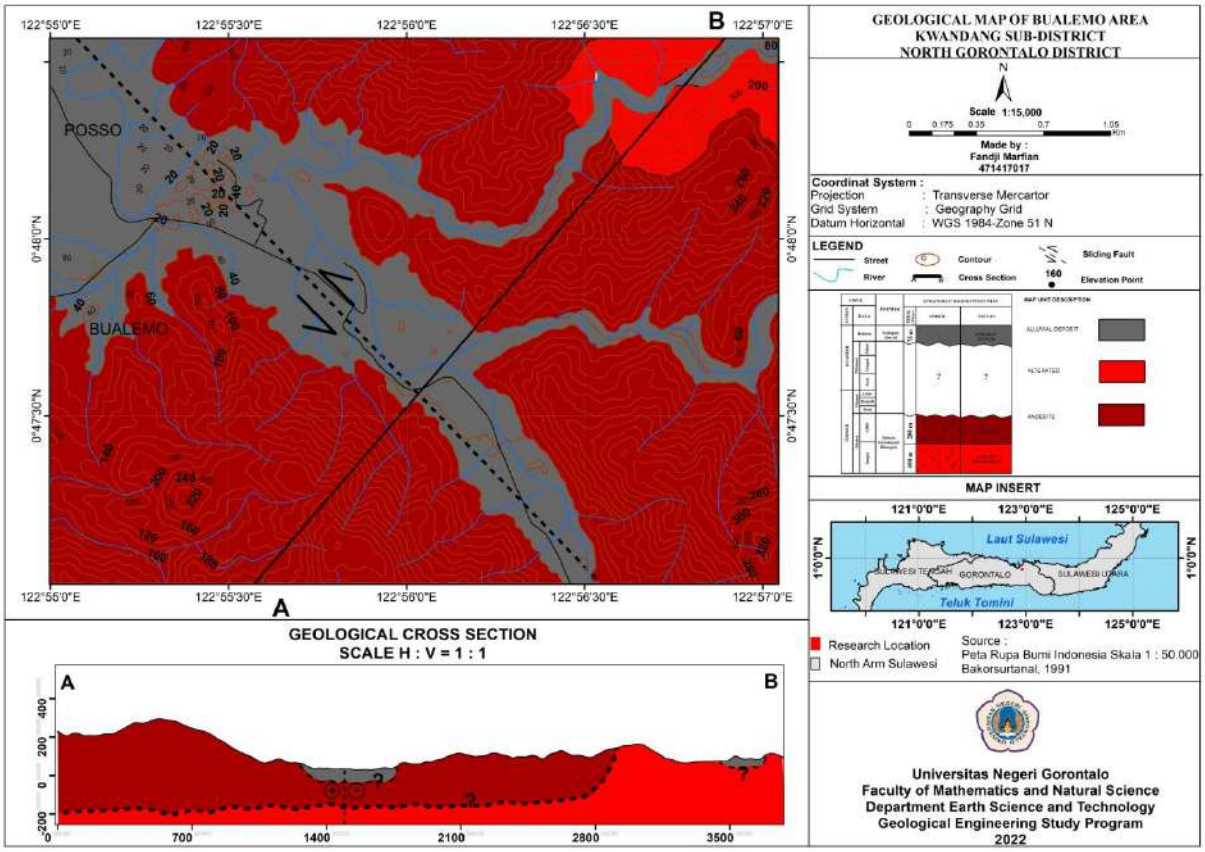

Figure 5. Geological map of the research area

3.2 Geological Structure

At the research site, there is a primary geological structure in the form of a joint (Tension Joint), precisely located at ST 7 (Figure 6). After analyzing the joint structure data, the results of the relative joint direction are north-south with an N value of 171° E/79° (Figure 7).

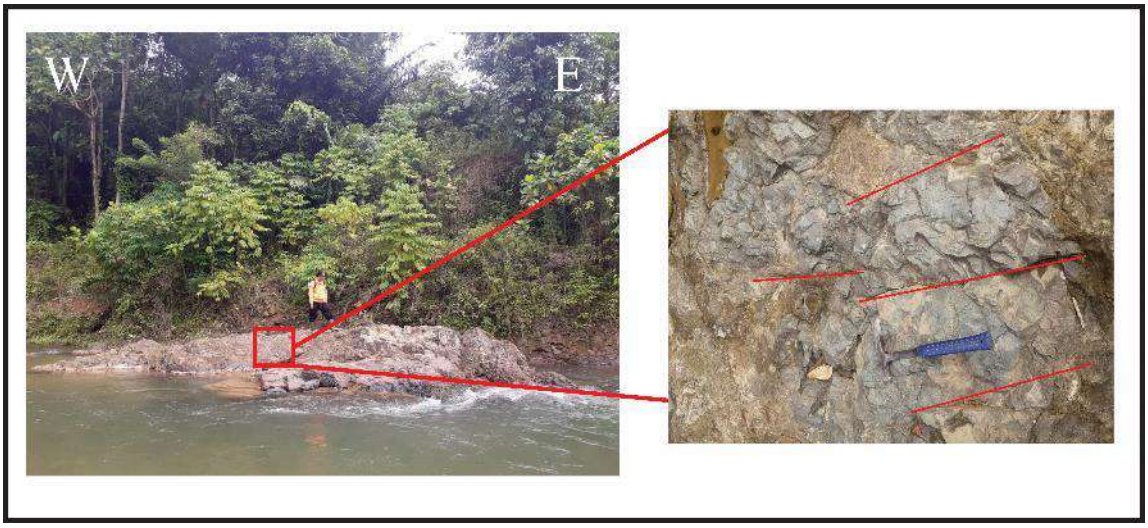

Figure6. Andesite rock outcrop with tension joint structure at the research site

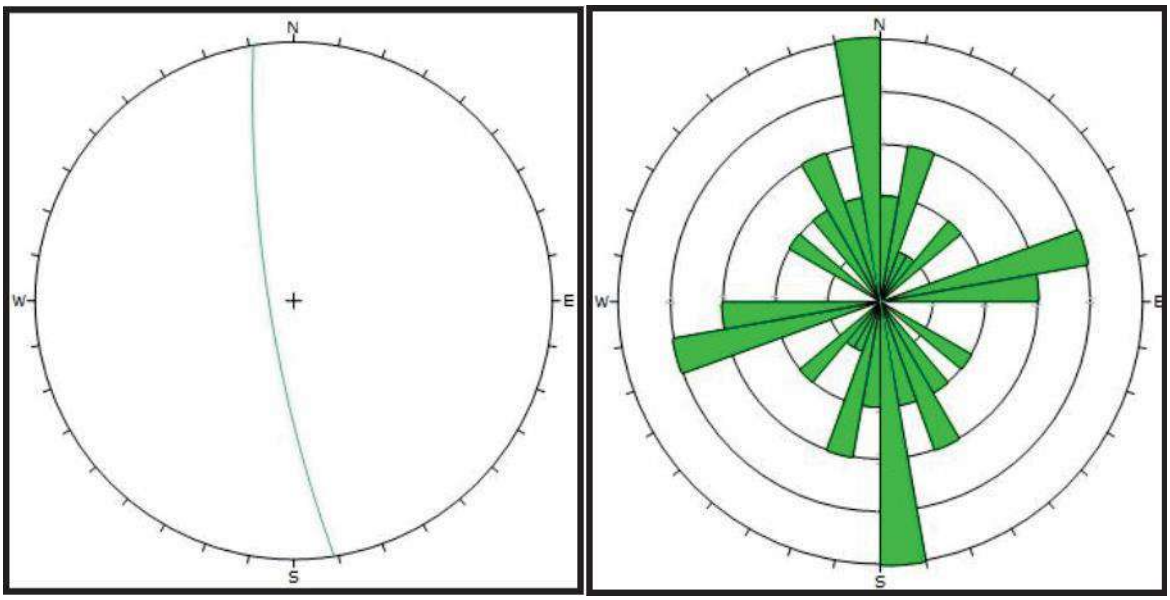

Figure7. The results of the analysis of the joint tension structure

3.3Geochemistry

Geochemistry analysis (XRF) to determine the type of rock, magma series, and origin of magma to the tectonic setting in the research area.. The following data results from of geochemistry analysis (XRF) are shown in to produce major element data (Table 1), and the chemicals composition for sample ST 3 and ST 26 is SiO_2 (50.53-52.77%), Al_2O_3 (15.68-18.50%), Fe_2O_3 (13.28-9.86%), MgO (11.39-5.82%), CaO (2.81-5.39%), Na_2O (3.72-3.29%), K_2O (1.07-2.71%), TiO_2 (1.09-1.00%), P_2O_5 (0.13-0.28%), MnO (0.30-0.38%). Two samples will be subject to geochemistry analysis: sample ST 3 and sample ST 26.

Table 1. Table of*majorelements*

Sample Code	ST 3 (% Weight)	ST 26 (% Weight)
SiO_2	50.53	52.77
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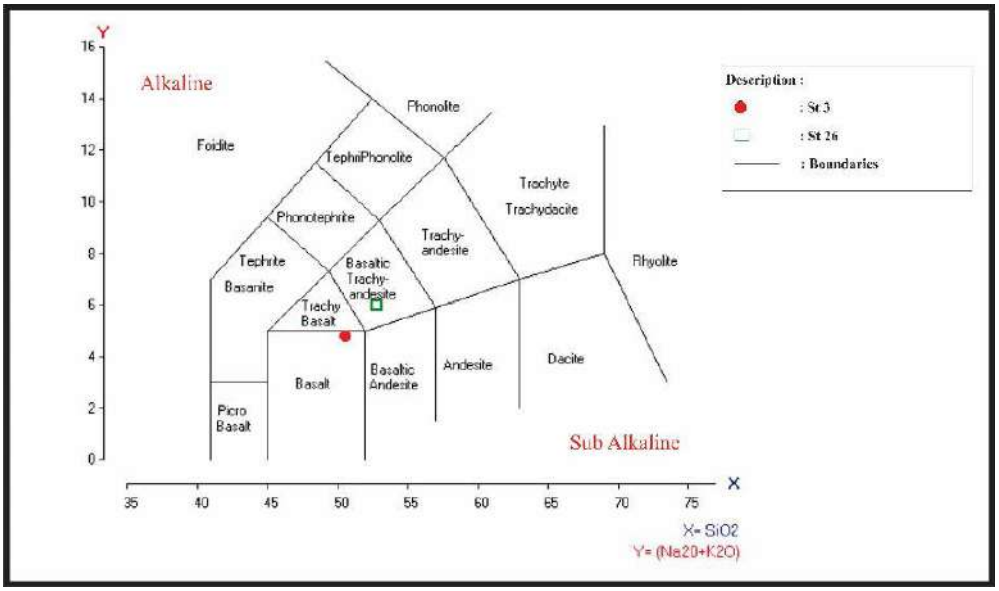
P_2O_5	0.13	0.28
MnO	0.30	0.38
LOI	3.22	4.11

~~Source: XRF Geochemical Analysis Results (2022)~~

3.3.1 Rock Type

The diagram used to determine the rock type in the St 3 and 26 samples is ~~a~~ the binary diagramof Le Bass et al.(1986). This diagram is Total Alkali-Silica (TAS), namely the accumulation of Na_2O + K_2O (Total Alkali) and SiO_2 (Silica). show that the two rock samples belong to the basic igneous rock group, Basalt and Basaltic-Trachy Andesite (Figure 8).



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3.3.2 Magma Series

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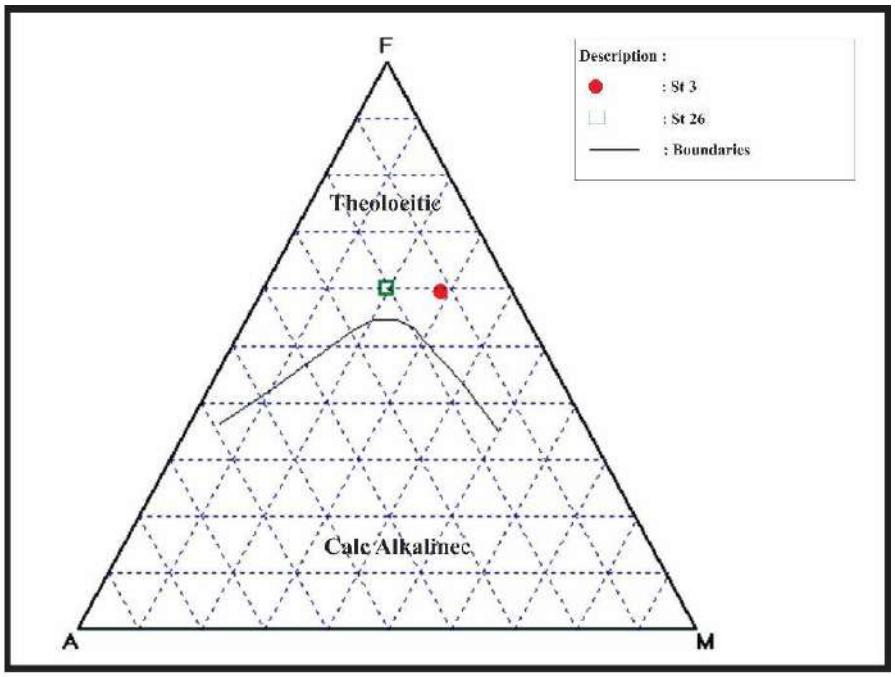

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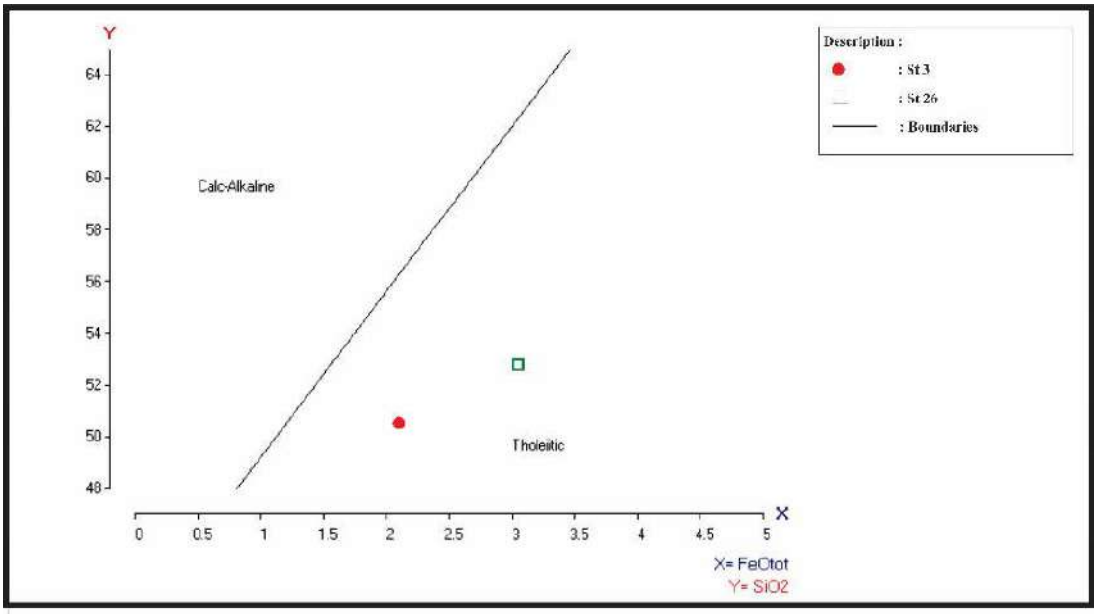

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3.3.3 Magma Origin

The diagram of (Figure 11) shows magma's origin in more detail, based on the plotting results from the ternary diagram (Mullen, 1983), St 3 belongs to the Tholeiitic Island Arc tectonic setting, and ST 26 belongs to the Calc-Alkaline Basalt Island tectonic setting. Based on the diagram above, it is possible that other tectonic events occurred in the ST 26 sample, which resulted in more acidic magma in the St 26 sample (Figure 11).

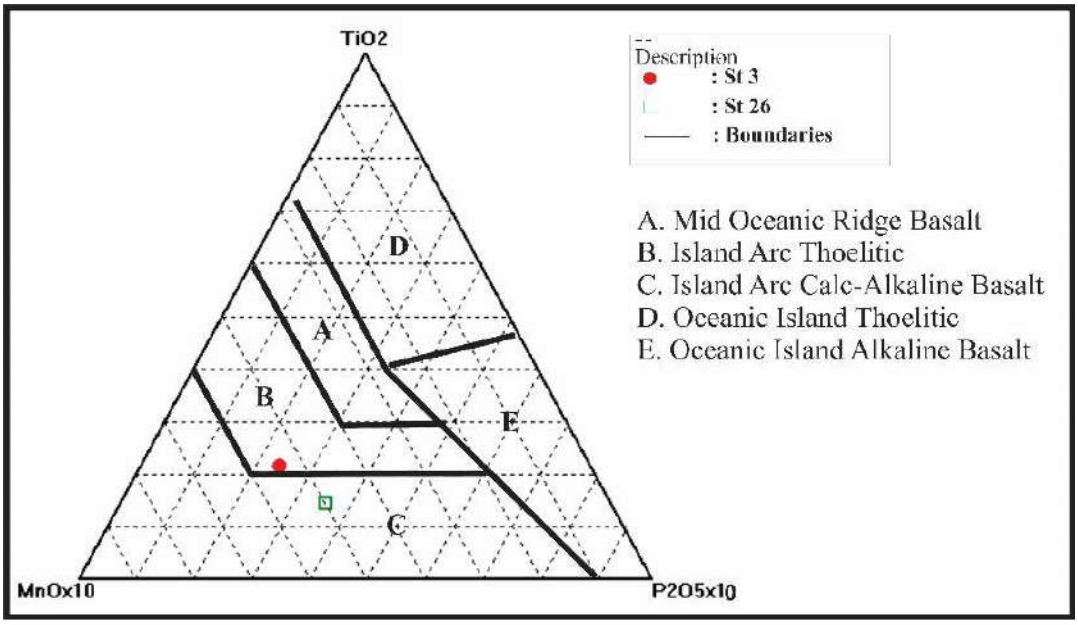

Figure 11.TiO_2, MnOx10, P_2O_5x10 triangle diagram (Mullen, 1983) of the studied rocks

3.4 Tectonic Setting

Based on the analysis of several diagrams above, it is shown that two magma series are found in the studied area. The magma series formed at St 3 and St 26 is Tholeitic based on the magma series diagram of Irvine and Baragar(1971) and the diagram binary from (Miyashiro and Shido, 1975). The tholeiitic magma series is a typical magma that forms in the early stages of island arc formation. The tholeiitic magma series is a type of magma that can exist in various tectonic settings. For St 3 basalt rocks belonging to a convergent tectonic setting or subduction zone. This is evidenced by the TiO_2 content of <1.3% (Gill, 1981 in Yuwono, 2015), where the TiO_2 content in St 3 rock is 1.08%. The St. 26 rock, according to the binary diagram (Le Bass et al., 1986), belongs to the Basaltic Trachyte Andesite rock. So it can be concluded that these two samples belong to the island arc. It is clarified by the analysis results from diagrams of TiO_2, $MnOx_{10}$, and $P_2O_5x_{10}$ from (Mullen, 1983), where St 3 rock belongs to the origin of Tholeiitic Island Arc magma, and St 26 rock belongs to the origin of Island Arc Calc Alkaline Basalt magma. These magma origins are included in the subduction zone.

The subduction process will produce heat in the bending path so that high heat flow can cause magma activity in the Benioff line. To find out the depth of magma origin can be calculated using the content of SiO_2 and K_2O (Hutchinson, 1977). Calculations carried out to determine the depth of origin of magma can use the formula:

$$\mathbf{h = [320-(3{,}65 \times \% SiO_2)] + (25{,}52 \times \% K_2O)}$$

Based on calculations using this formula, it can be seen that the depth of origin of magma from rocks in the study area is at a depth of about 163-196 km below the earth's surface in the Benioff Zone. It is estimated that the rock was formed during the Middle Miocene to Late Miocene, when

subduction occurred between two oceanic plates, namely between the Sulawesi sea plate and the Sula ocean plate, about 15 to 10 million years ago (HallandSpakman, 2015).

4. CONCLUSIONS

Based on petrological analysis and geochemical analysis, the constituent rocks in the study area are andesite and altered andesite. The rock types obtained based on geochemical analysis are basalt and basaltic trachy andesite, with the type of magma being thholeiitic. The origin of the magma in the rock comes from island arc tholeitic and island arc calc alkaline basalt. The research location area is the result of subduction between 2 oceans, namely between the Sulawesi sea plate and the Sula sea plate around 15-10 million years ago, with a depth of origin of magma of 163-196 km including in the benioff zone.

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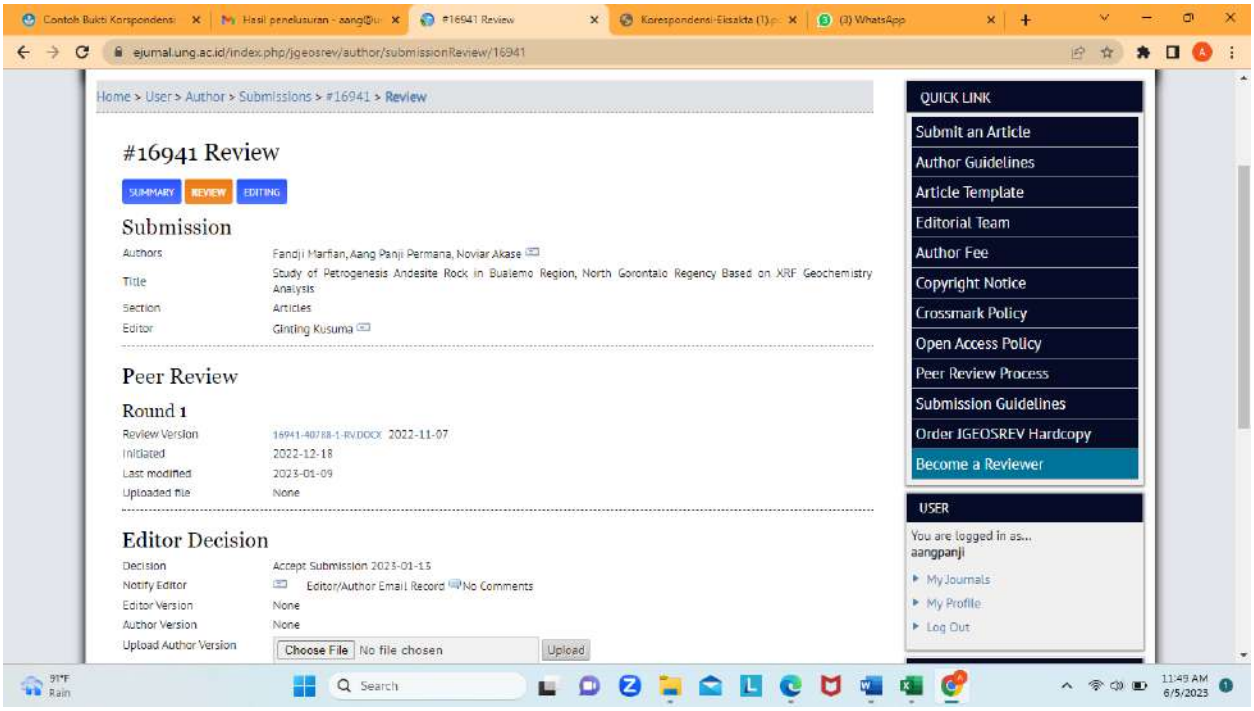
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Study of Petrogenesis Andesite Rock in Bualemo Region, North Gorontalo Regency Based on XRF Geochemistry Analysis

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ABSTRACT

The research area is Bualemo Village, Kwandang District, North Gorontalo Regency. With coordinates 0° 47' 10" - 0° 48' 40" North Latitude and 122° 55' 0" - 122° 57' 5" East Longitude with an area of about 10 km^2. This study aims to determine the petrogenesis of andesite rocks and the tectonic setting in the study area. The method used in this study is a mapping method to determine the geological conditions of the research site and X-ray fluorescence (XRF) geochemical analysis to determine the chemical content of rocks. The results showed that the stratigraphy of the study area, sorted from oldest to youngest, was an andesite unit, an altered andesite unit, and an alluvial deposit unit. The geological structure in the study area is a tension joint with a general direction of relative north-south. The tension joint structure data analysis results have a value of N 171ºE/79º. Based on geochemistry results, it was found that the type of magma is tholeiitic, with its name basalt and basaltic trachyte andesite. The origin of the magma is island arc tholeiitic and island arc calc-alkaline basalt, with the tectonic setting of the study area being subduction between two oceans, namely between the Sulawesi sea plate and the Sula plate.

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1. INTRODUCTION

Petrogenesis studies is a field of science that focuses on the abundance of minerals observed in rock incisions under a microscope or analyzes the content of chemical elements in rocks to determine the formation process in rocks and their tectonic environmental conditions (Yuwono, 2015). Geochemistry is a grouping of the relative and absolute abundances of various elements on earth, the study of the distribution and migration of single parts in multiple places on earth with objects in the form of basic patterns of distribution and migration of elements (Alekseenko & Alekseenko, 2013; Adi, 2021). This study used X-ray fluorescence (XRF) spectroscopy analysis, an analytical technique that detects X-ray radiation from the emitted sample in the analyzed sample as a basis (Simon, 2012; Nasrazadani & Shokrollah, 2016).

Sulawesi is located at the subduction of three large tectonic plates: the Indo-Australian, the Eurasian, and the Pacific. A smaller plate is also located to the north, namely the Philippines (Hamilton, 1979; Hutchison, 1989; Hall & Wilson, 2000; Payuyu et al., 2022; Permana et al., 2022). The island was formed due to the collision of Sunda land, the easternmost part of the Eurasian plate, with the microcontinent of the Australian plate (Bachri, 2011).

The geological setting of Kwandang is exciting to study because it is composed of complex rock formations of the Tertiary to Quaternary age. This rock formation was formed since the start of the collision of the Sula plate with the Sulawesi sea plate, which was then followed by a collision towards the eastern arm of Sulawesi in the mid-Pliocene along with the formation of a subduction strip along the northern arm of Sulawesi until now (Hall & Spakman, 2015). Harun (2020) research used the mapping method to determine the geological conditions of the study area. Bualemo Village is one of the villages located in the Kwandang District. In previous research in the Bualemo area, volcanic rocks were included in the Bualemo Andesite Unit (Harun, 2020). Bualemo andesite was thought to have formed in the Middle to Late Miocene period (Bachri et al., 1994). However, no previous studies describe the petrogenesis of andesite rocks. This research aims to describe the petrogenesis of andesite rocks in the Bualemo area, North Gorontalo Regency, based on XRF geochemistry analysis.

2. METHOD

2.1. Research Location

The research was conducted in Bualemo Village, Kwandang District, North Gorontalo Regency. With coordinates 0° 47' 10" - 0° 48' 40" and 122° 55' 0" - 122° 57' 5". The area of the research location is 10 km^2 (Figure 1).

2.2. Research Method

In this study, geological mapping and geochemical analysis are applied. The geological mapping method was used during observation and data collection in the field. X-ray fluorescence (XRF) analysis at the Central Laboratory of Mineral Resources for Coal and Geothermal in Bandung was carried out on selected rock samples to determine the chemical content of the rocks. XRF analysis is essential to determine the major oxides and trace element composition of a rock, mineral, sediment, and liquid (Rollinson, 1993; Boogs, 2009; Shackley, 2011; Wahyudiono et al., 2016; Permana, 2018; Permana, 2019).

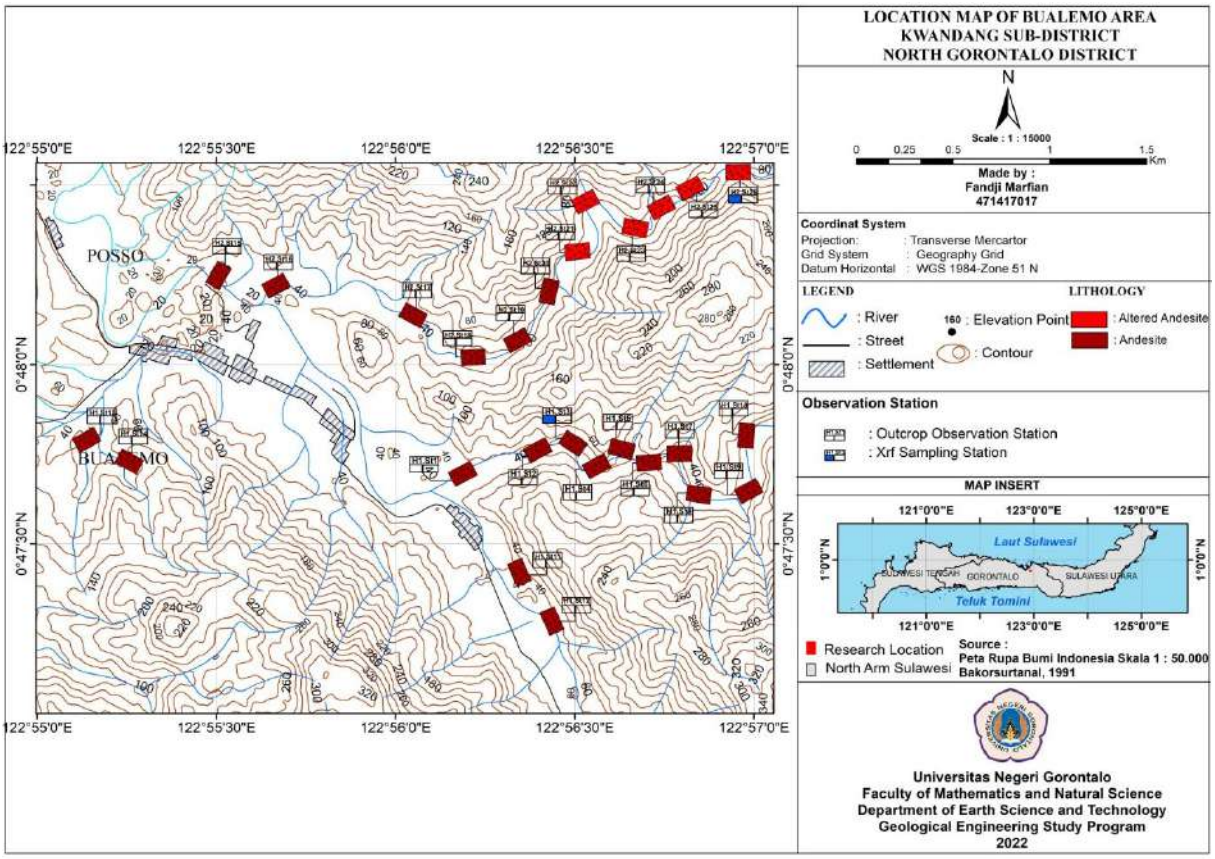

Figure 1. Research location map

Data collection in the field includes lithological data, geological structures, and sampling for XRF geochemistry analysis. Lithological data collection was carried out to determine the stratigraphy of the research area. Geological structure data collection was carried out to determine the general direction of the geological structure found in the research area. Samples for geochemistry analysis were selected to determine the name of the rock, magma series, magma origin, and tectonics in the research area. The software used to process geochemical data is *Petrograph*

3. RESULTS AND DISCUSSION

3.1. Stratigraphy

The stratigraphy of the study area consists of three lithological units, namely the andesite, altered andesite, and alluvial deposit. The andesite unit occupies 70% of the research location, with a thickness of 400 meters. The lithology contained in this unit is andesite rock with gray color, holocrystalline, massive, and mineral composition is plagioclase, pyroxene, and k-feldspar (Figure 2). This unit is included in the Bilungala Volcano Rock Formation (Tmbv) in the Tilamuta map geology sheet (Bachri et al., 1994).

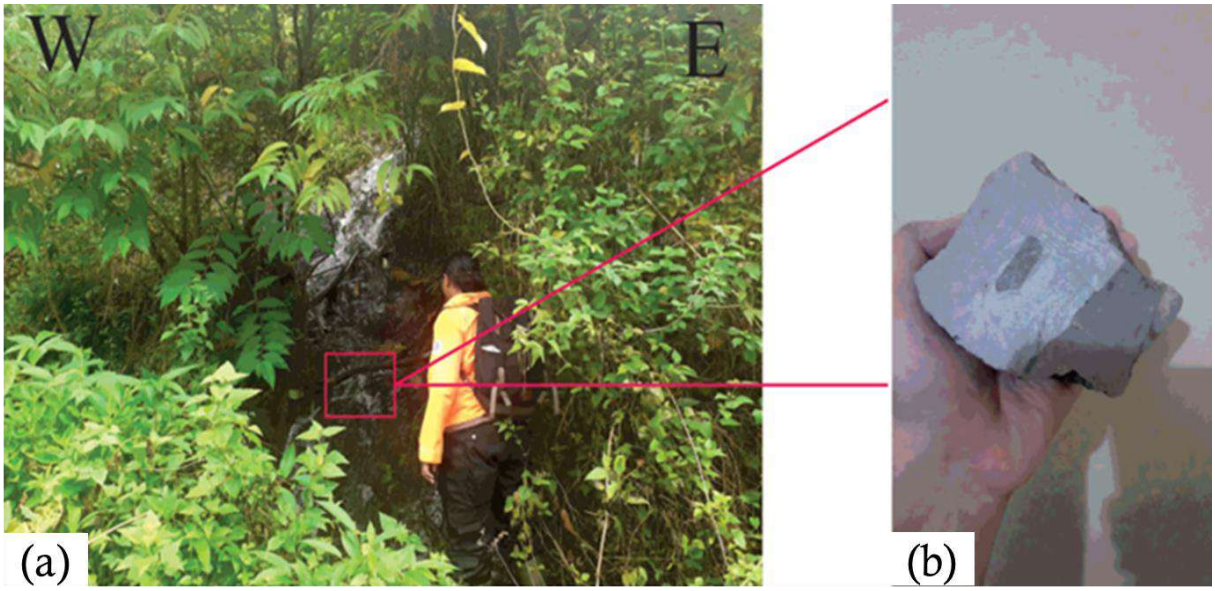

Figure 2. a) Outcrop of andesite unit at the research site; b) hand specimen of the andesite rock sample.

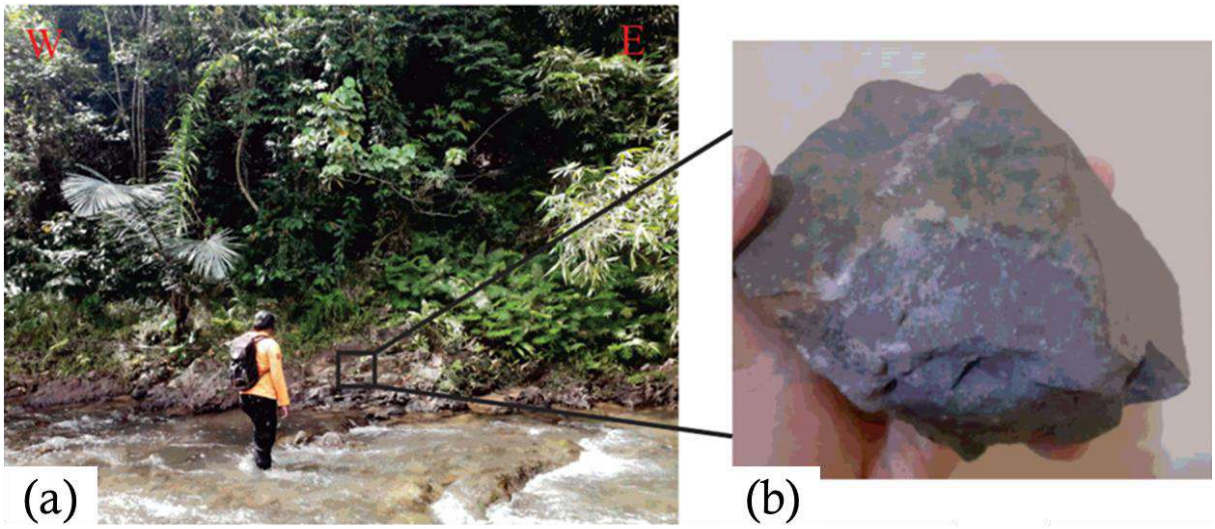

Figure 3. a) Outcrop of altered andesite unit at the study site; b) Hand specimen of the altered andesite rock sample.

Figure 4. The appearance of alluvial deposits at the research site

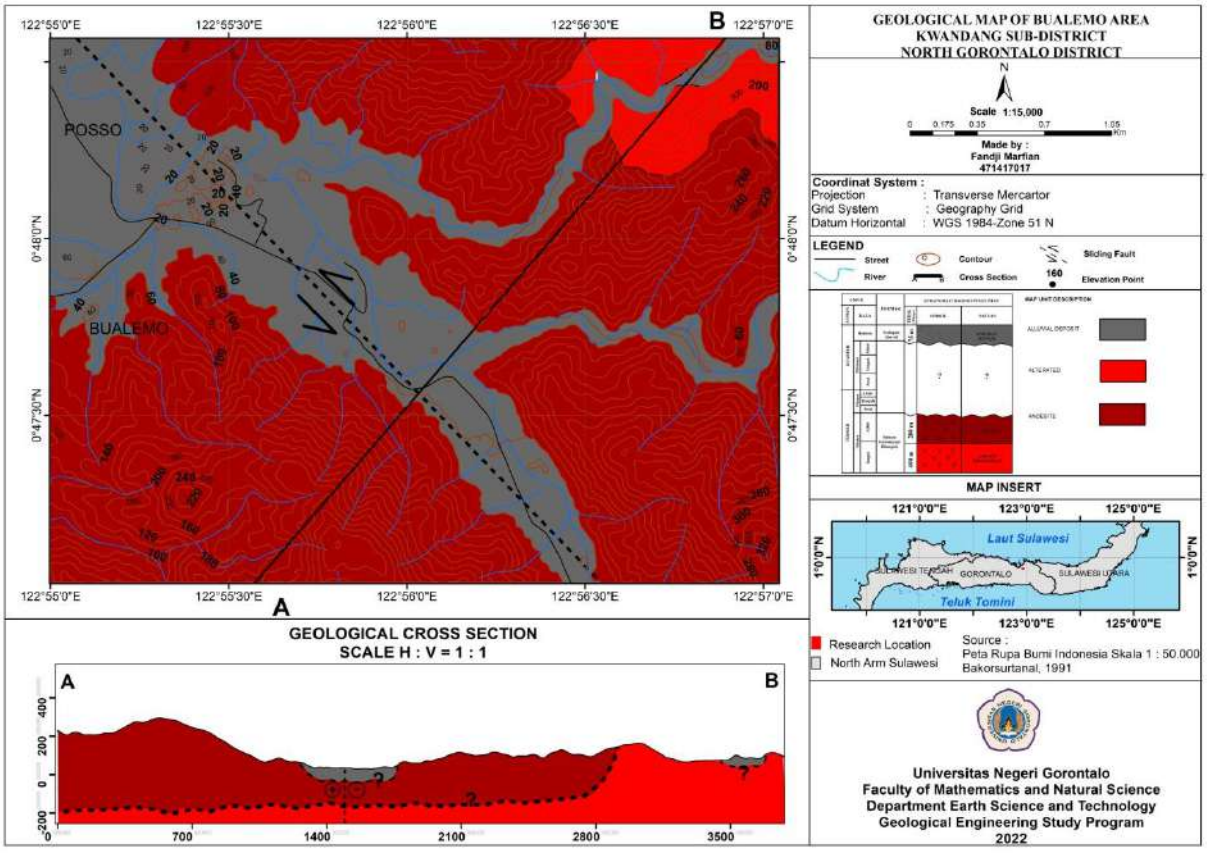

Figure 5. Geological map of the research area

The altered andesite unit at the study site occupies 5% of the studied location with a thickness of 200 meters. The lithology contained in this unit is andesite rock that has been altered with a brownish-gray color, aphanitic, and holocrystalline massive properties. The rock has a mineral composition such as a little quartz, k feldspar minerals, and plagioclase (Figure 3). This unit is included in the Bilungala Volcano Rock Formation unit (Tmbv) on the Tilamuta geological map sheet (Bachri et al., 1994).

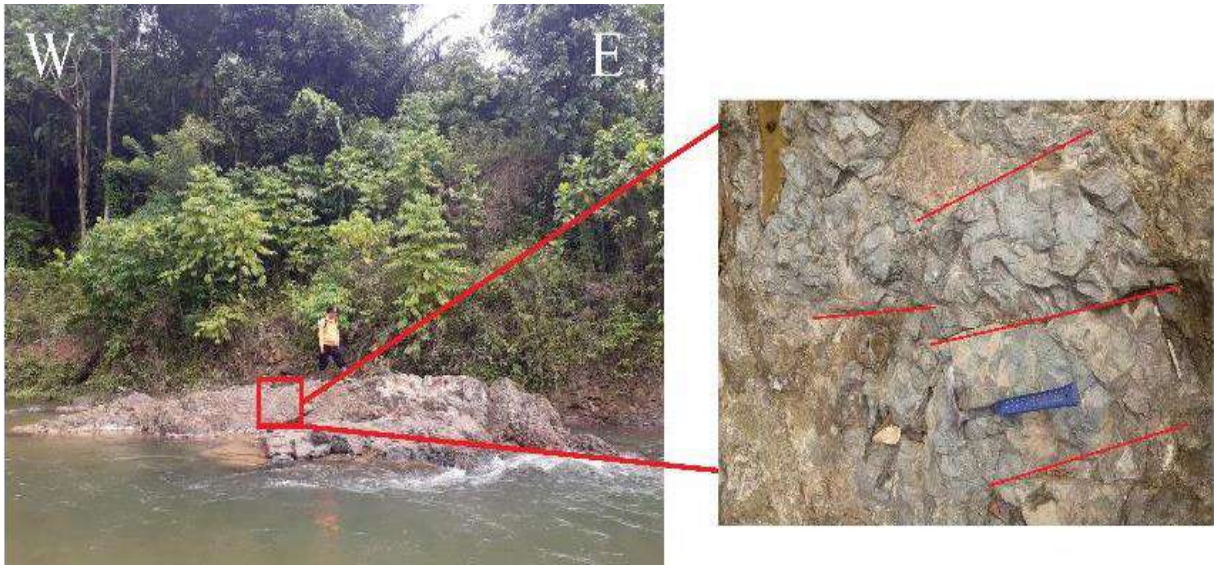

Figure 6. Andesite rock outcrop with joint tension structure at the research site.

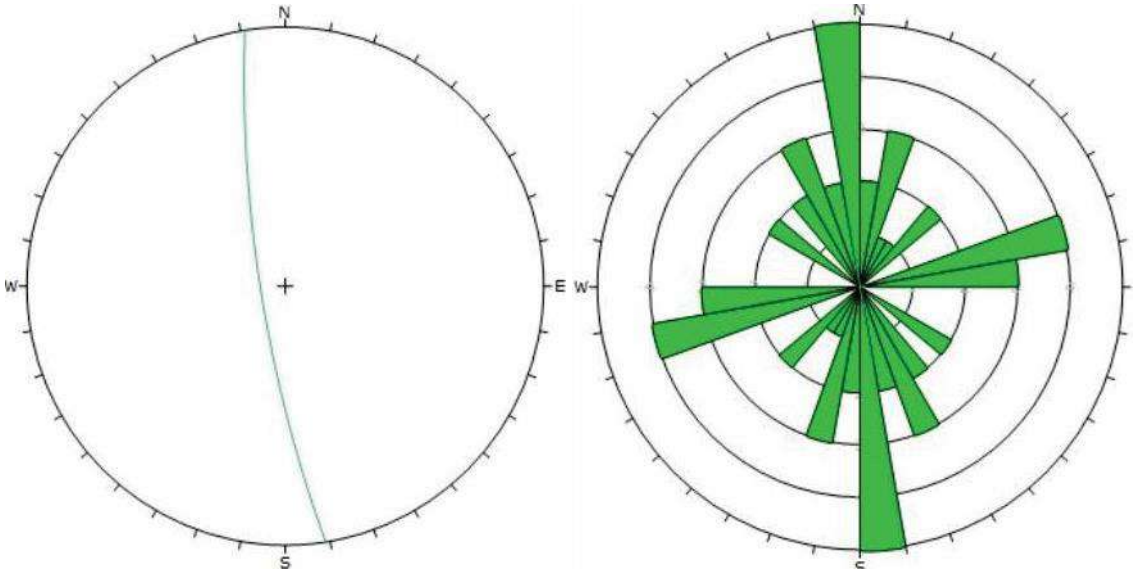

Figure 7. The results of the analysis of the joint tension structure.

The alluvial deposit unit occupies 25% of the studied area and has a thickness of 75 meters. The lithology in this unit results from weathering rocks in the form of sand, gravel, and gravel to lumps and is not compact (Figure 4). This unit belongs to the Alluvium Formation (Qal) on the geological map of the Tilamuta sheet (Bachri et al., 1994). The division of the three lithological units can be seen on the geological map of the Bualemo area, North Gorontalo Regency (Figure 5).

3.2. Geological Structure

At the research site, there is a primary geological structure in the form of a joint (*tension joint*) precisely located at ST 7 (Figure 6). After analyzing the joint structure data, the results of the relative joint direction are north-south with an value of N 171˚ E/79˚ (Figure 7).

3.3. Geochemistry

Geochemistry analysis (XRF) to determine the type of rock, magma series, and origin of magma to the tectonic setting in the research area. The following data results from geochemistry analysis (XRF) produce major element data (Table 1). The chemicals composition for samples ST 3 and ST 26 is SiO_2 (50.53-52.77%), Al_2O_3 (15.68-18.50%), Fe_2O_{3T} (13.28-9.86%), MgO (11.39-5.82%), CaO (2.81-5.39%), Na_2O (3.72-3.29%), K_2O (1.07-2.71%), TiO_2 (1.09-1.00%), P_2O_5 (0.13-0.28%), MnO (0.30-0.38%). The two samples, after being analyzed, produce ten main elements, which will be processed in several diagrams.

Table 1. Geochemistry analysis (XRF) produce major element data

Sample Code	ST 3 (% Weight)	ST 26 (% Weight)
SiO_2	50.53	52.77
Al_2O_3	15.68	18.50
Fe_2O_3	13.28	9.86
MgO	11.39	5.82
CaO	2.81	5.39
Na_2O	3.72	3.29
K_2O	1.07	2.71
TiO_2	1.09	1.00
P_2O_5	0.13	0.28
MnO	0.30	0.38
LOI	3.22	4.11

3.3.1. Rock type

The diagram used to determine the rock type ST 3 and ST 26 samples is the binary diagram of Le Bass et al. (1986). This diagram is Total Alkali-Silica (TAS), namely the accumulation of Na_2O + K_2O (Total Alkali) and SiO_2 (Silica). The two rock samples belong to the basic igneous rock group, Basalt (St 3) and Basaltic-Trachy Andesite (St 26) (Figure 8a).

3.3.2. Magma series

Furthermore, the plotting was carried out on the AFM diagram of F (Total FeO), A (K_2O+NaO), and M (MgO) (Irvine & Baragar, 1971), as shown in Figure 8b. In this diagram, two types of magma are divided: Calc-Alkaline and Thoeleitic. Based on this diagram, it belongs to the Tholeitic magma series, where in the tholeiitic magma series, the Fe content is vibrant and higher than that of the Tholeiitic magma series alkaline element value. Based on the geochemistry analysis (XRF) results, the elemental Fe values at both stations were 6.89%-9.28%.

Then plotting the FeO/MgO vs. SiO_2 diagram (Miyashiro & Shido, 1975); both samples belong to the Tholeiitic magma series. This diagram is aligned with the Ternary AFM diagram (Irvine & Baragar, 1971). Tholeiitic magma can form in all tectonic settings (Figure 9a).

3.3.3. Magma origin

The diagram of Figure 9b shows magma's origin in more detail, based on the plotting results from the ternary diagram (Mullen, 1983). St 3 belongs to the Tholeiitic Island Arc, while ST 26 belongs to the Calc-Alkaline Basalt Island tectonic setting. Based on the diagram above, it is possible that other tectonic events occurred in the ST 26 sample, which resulted in more acidic magma in the St 26 sample (Figure 9b).

3.4. Tectonic Setting

The magma series formed at St 3 and St 26 is Tholeitic based on the magma series diagram of Irvine & Baragar (1971) and the diagram binary from (Miyashiro & Shido, 1975). The tholeiitic magma series is a typical magma that forms in the early stages of island arc formation. The tholeiitic magma series is a type of magma that can exist in various tectonic settings. For St 3 basalt rocks belonging to a convergent tectonic setting or subduction zone. This is evidenced by the TiO_2 content of <1.3% (Gill, 1981 in Yuwono, 2015), where the TiO_2 content in St 3 rock is 1.08%. The St. 26 rock, according to the binary diagram (Le Bass et al., 1986), belongs to the Basaltic Trachyte Andesite rock. So it can be concluded that these two samples belong to the island arc. It is clarified by the analysis results from diagrams of TiO_2, $MnOx_{10}$, and $P_2O_5x_{10}$ from (Mullen, 1983), where St 3 rock belongs to the origin of Tholeiitic Island Arc magma, and St 26 rock belongs to the origin of Island Arc Calc Alkaline Basalt magma. These magma origins are included in the subduction zone.

The subduction process will produce heat in the bending path so that high heat flow can cause magma activity in the Benioff line. To find out the depth of magma origin can be calculated using the content of SiO_2 and K_2O (Hutchinson, 1977). Calculations carried out to determine the depth of origin of magma can use the formula:

$$h = [320-(3{,}65 \times \% SiO_2)] + (25{,}52 \times \% K_2O) \quad (1)$$

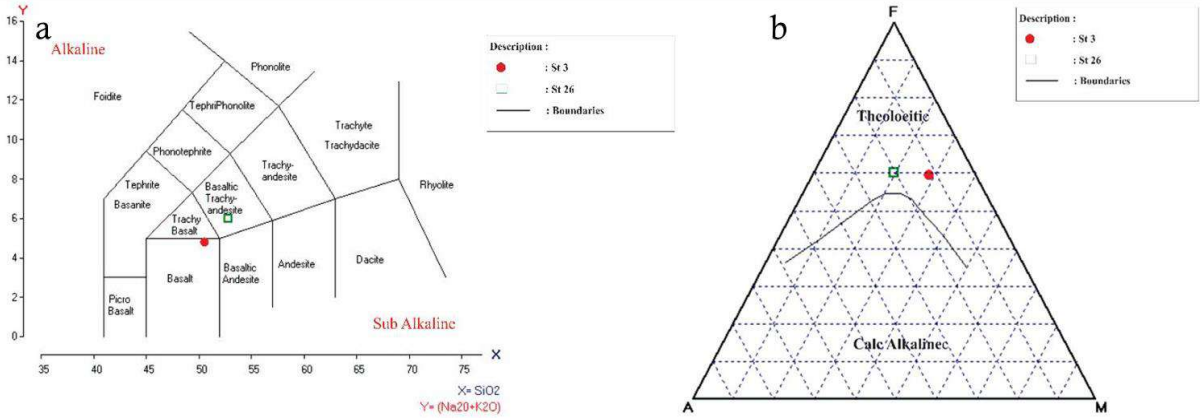

Figure 8. a) Na_2O+K_2O vs. SiO_2 diagram (Le Bass et al., 1986) of the studied rocks; b) AFM diagram (Irvine & Baragar, 1971) of the studied rocks.

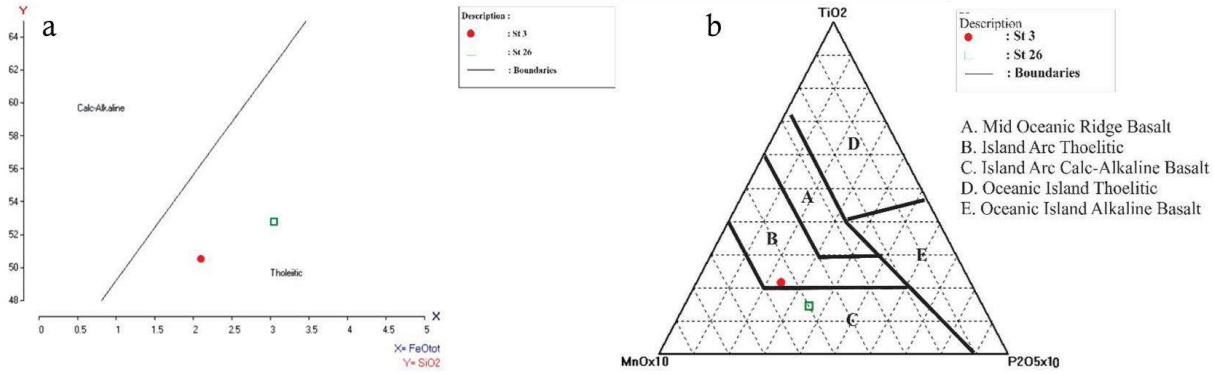

Figure 9. a) FeO/MgO vs. SiO_2 diagram (Miyashiro & Shido, 1975); b) TiO_2, MnOx10, P_2O_5x10 triangle diagram (Mullen, 1983) of the studied rocks.

Based on calculations using this formula, it can be seen that the depth of origin of magma from rocks in the study area is at a depth of about 163-196 km below the earth's surface in the Benioff Zone. It is estimated that the rock was formed during the Middle Miocene to Late Miocene, when subduction occurred between two oceanic plates, namely between the Sulawesi sea plate and the Sula ocean plate, about 15 to 10 million years ago (Hall & Spakman, 2015).

4. CONCLUSIONS

Based on the petrological and geochemical analysis, the constituent rocks in the study area are andesite and altered andesite. The rock types obtained based on geochemical analysis are basalt and basaltic trachy andesite, with the type of magma being tholeiitic. The origin of magma in the rock comes from island arc tholeiitic and island arc calc-alkaline basalt. The research location area is the result of subduction between 2 oceans, namely between the Sulawesi sea plate and the Sula sea plate, around 15-10 million years ago, with a depth of origin of magma of 163-196 km, including in the Benioff zone.

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