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Winarti 90 <winarti.itny@gmail.com>

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Ref.: Ms. No. SJST-D-21-00283R2
Nanggulan Formation as a roof pendant at the central part of Kulon Progo Mountains, Yogyakarta-Indonesia
Songklanakarin Journal of Science and Technology

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12/22/2021 23:24:42	Author Submits Revision Confirmation	Winarti Winarti, Ph.D.	SJST-D-21-00283R2	Nanggulan Formation as a roof pendant at the central part of Kulon Progo Mountains, Yogyakarta-Indonesia
12/22/2021 23:22:46	PDF Built and Requires Approval	Winarti Winarti, Ph.D.	SJST-D-21-00283R2	Nanggulan Formation as a roof pendant at the central part of Kulon Progo Mountains, Yogyakarta-Indonesia

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Nanggulan Formation as a roof pendant at the central part of Kulon Progo Mountains, Yogyakarta-Indonesia

--Manuscript Draft--

Manuscript Number:	SJST-D-21-00283R2
Full Title:	Nanggulan Formation as a roof pendant at the central part of Kulon Progo Mountains, Yogyakarta-Indonesia
Article Type:	Original Article
Section/Category:	Natural Resources
Keywords:	roof pendant, metasediment, fragments, dike, alteration
Corresponding Author:	Winarti Winarti, Ph.D. Institut Teknologi Nasional Yogyakarta Sleman, Yogyakarta INDONESIA
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Institut Teknologi Nasional Yogyakarta
Corresponding Author's Secondary Institution:	
First Author:	Winarti Winarti, Ph.D.
First Author Secondary Information:	
Order of Authors:	Winarti Winarti, Ph.D.
Order of Authors Secondary Information:	
Manuscript Region of Origin:	INDONESIA
Abstract:	The Nanggulan Formation sediments form a weakly undulating hill and range in age from the Middle Eocene to the Late Oligocene. In Samigaluh and Sermo areas, a series of sedimentary rocks with small dimensions resembling fragments and forming a steep hilly morphology is exposed. Outcrops are mainly made up of sandstone and claystone interbedded with lignite intercalation. An outcrop in Sermo-2 found andesite intruding claystone. Claystone is found near rock contact, where it is an alteration to metasediment and chlorite is formed. Petrographic data showed the presence of chlorite, pyrite, and kaolinite. Andesite dike is one factor that contributes to the Nanggulan Formation being exposed to the surface. The Nanggulan Formation is a roof pendant above a dike. The implications of the roof pendant are related to propylitic to argillic of hydrothermal alteration, which produce chlorite, pyrite, illite, and kaolinite minerals.
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Type of Article (Original Article)

Nanggulan Formation as a roof pendant at the central part of Kulon Progo Mountains, Yogyakarta-Indonesia

Winarti[1,*], Al Hussein Flowers Rizqi[1], and Emi Sukiyah[2]

[1]Geology Department, Faculty of Mineral Technology, Institut Teknologi Nasional Yogyakarta, Babarsari Street, Caturtunggal, Depok Sub-District, Sleman Regency, Yogyakarta 55281, Indonesia

[2]Geosciences Department, Faculty of Geological Engineering, Universitas Padjadjaran, Dipati Ukur Street No. 46, Bandung 40132, Indonesia

***Corresponding author, Email address:** winarti.itny@gmail.com

Abstract

The Nanggulan Formation sediments form a weakly undulating hill and range in age from the Middle Eocene to the Late Oligocene. In Samigaluh and Sermo areas, a series of sedimentary rocks with small dimensions resembling fragments and forming a steep hilly morphology is exposed. Outcrops are mainly made up of sandstone and claystone interbedded with lignite intercalation. An outcrop in Sermo-2 found andesite intruding claystone. Claystone is found near rock contact, where it is an alteration to metasediment and chlorite is formed. Petrographic data showed the presence of chlorite, pyrite, and kaolinite. Andesite dike is one factor that contributes to the Nanggulan Formation being exposed to the surface. The Nanggulan Formation is a roof pendant above a dike. The implications of the roof pendant are related to the propylitic to argillic of hydrothermal alteration, which produce chlorite, pyrite, illite, and kaolinite minerals.

Keywords: roof pendant, metasediment, fragments, dike, alteration

1. Introduction

The Nanggulan Formation, as the oldest formation in the Kulon Progo Mountains, has a minimal spread. This formation is only exposed on the Kulon Progo Mountains eastern side (Widagdo, Pramumijoyo, & Harijoko, 2018). Surface geological studies show that the Nanggulan Formation, which is exposed in the eastern part of the Kulon Progo Mountains, is caused by a thrust fault, sinistral fault, dextral fault, and anticline (Widagdo, Pramumijoyo, & Harijoko, 2020).

The existence of a thrust fault on the surface lends support to gravity research on Sentul and Mujil lines (Winarti, Sukiyah, Syafri, & Nur, 2020). The Nanggulan Formation, exposed on the eastern side of the Kulon Progo Mountains, is relatively widespread.

The Nanggulan Formation, which is exposed around Mount Mujil, is caused by a pressure factor from an Old Andesite Formation with brittle and rigid properties, known as a tumor-like bulge (Winarti, Sukiyah, Syafri, & Nur, 2021b). In the eastern Kulon Progo Mountains, Mount Gede found tuff that was exposed after becoming broken through by igneous rock, resulting in the tuff forming a roof pendant above the broken through rock. It is characterized by tuff in igneous rock as xenolith (Bronto, Ratdomopurbo, Asmoro, & Rani, 2014).

The Nanggulan Formation is found on weakly undulated hills, while the Old Andesite Formation is found on steep hills (Winarti, Sukiyah, Syafri, & Nur, 2020). The Nanggulan Formation will generally be at the bottom, while the Old Andesite

Formation will be at the top. If the Nanggulan Formation is found above the Old Andesite Formation and has the morphology of steep hills, then it is influenced by factors.

Sedimentary rocks exposed between andesite breccias in the central part of the Kulon Progo Mountains raise two questions: are these fragments of the Nanggulan Formation? and how can these sedimentary rocks be exposed above the Old Andesite Formation? This research aims to reveal the factors that cause sedimentary rock to be constructed in the central Kulon Progo Mountains (Samigaluh and Sermo), the implications for hydrothermal alteration zoning and mineralization processes.

2. Materials and Methods

2.1. Geological Setting

The Kulon Progo Mountains, which are part of the micro-continent Gondwana, is assumed to be a structural boundary that extends northeast–southwest to Mount Muria (Smyth, Hamilton, Hall, & Kinny, 2007). These boundaries have an irregular shape and are associated with complex tectonics. In contrast, the Kulon Progo Mountains have many structural lineaments which trend northwest–southeast, west–east, north–south, and northeast–southwest (Smyth, Hamilton, Hall, & Kinny, 2007). Some of the lineament of structure develops into faults, and so do some of the triggering intrusions (Widagdo, Paramumijono, Harijoko, & Setiawan, 2016).

The Kulon Progo Mountains comprise of the Nanggulan Formation, the Old Andesite Formation, the Jonggrangan Formation, the Sentolo Formation, and volcanic deposits (Widagdo, Paramumijono, & Harijoko, 2018). The Nanggulan Formation comprises clastic sedimentary rocks such as sandstone, claystone, quartz sandstone with lignite, and calcareous claystone intercalation. The rocks have plastic properties (Winarti, Sukiyah, Syafri, & Nur, 2020). The Nanggulan Formation ages from the Middle Eocene to Early Upper Eocene (Saputra & Akmaluddin, 2015), and the Middle Eocene to Late Oligocene (Coxall et al., 2021).

Overlaying the Nanggulan Formation is the Old Andesite Formation, which is comprised of volcanic rocks (andesitic intrusion and andesitic lava, with andesite breccia dominant) (Winarti, Sukiyah, Syafri, & Nur, 2021a). The age of the Old Andesite Formation is Late Oligocene to Middle Miocene (Soeria-Atmadja et al., 1994), and early Oligocene (Coxall et al., 2021).

Sedimentary rock outcrops in Samigaluh and Sermo are found above andesite dike and occupy a steep hill. If plotted on a regional geological map (Rahardjo, Sukandarrumidi, & Rosidi, 2012), it is relatively located in the middle of the Kulon Progo Mountains (Figure 1).

The sedimentary rock outcrop is surrounded by volcanic rocks known as the Kebobutak Formation (Tomk) and the Andesite (a) (Rahardjo, Sukandarrumidi, & Rosidi, 2012) or the Old Andesite Formation (Bemmelen, 1949).

2.2. Intrusion and Alteration Zone

When magma freezes before reaching the surface, it causes intrusion (Martí, Groppelli, & Silveira, 2018). Plutonic rocks that break through the rock series above have a non-conformity relationship (Martí, Groppelli, & Silveira, 2018).

The intrusion that breaks through rock walls can impact hydrothermal alteration of the porphyry system (Sukisman, Yoyok, Mulyaningsih, & Hidayah, 2021). Complex geological structures can also trigger hydrothermal alteration of porphyry types (Adriansyah, Zakaria, Muslim, & Hirnawan, 2018).

Rudnik Mts. is a volcano-intrusive complex with shallow intrusions associated with mineralization (Cvetković, Šarić, Pécskay, & Gerdes, 2016). The intrusion contains many xenoliths of schists, gneiss and amphibole fragments as a side effect of contact metamorphism.

Metamorphic rocks of the Pinoh Formation in the Schwaner Mountains become large-scale roof pendants due to tonalite intrusions, characterized by the presence of metamorphic xenoliths in tonalite (Nurdini, Febyani, & Budiman, 2012). Roof pendants are commonly found as small fragments and crushed rock due to intrusion (Stevens & Greene, 1999).

The roof pendant at La Medrelena mine is 300 meters long and 50 meters wide (Nokleberg, 1981). According to theory, a roof pendant is a rock exposed on the surface due to a relatively shallow intrusion (volcanic plutonic), and rocks that have undergone metamorphism such as metasediment quartzite and schists (Dunning, Walstrom, & Lechner, 2018).

The Andesite intrusion in the Kulon Progo Mountains has weathered and parts have experienced hydrothermal alteration in propylitic and argillic phases (Phyu, Hendrayana, Indrawan, & Kamai, 2021). The intrusion at Mt. Gede that forms a roof pendant is characterized by silica and argillic tuff as a mineral altered from pumice lapilli, coarse tuff, and fine tuff (Bronto, Ratdomopurbo, Asmoro, & Rani, 2014).

Based on the mineral assemblage produced, the alteration is classified as propylitic type (chlorite, epidote, carbonate), argillic type (smectite, montmorillonite, illite-smectite, kaolinite), low temperature advanced argillic type (kaolinite, alunite), advanced temperature argillic type high (pyrophyllite, diasporic, andalusite), potassic type (adularia, biotite, quartz), philic type (quartz, sericite, pyrite), sericytic type (sericite, quartz, muscovite), and silicified type (quartz) (Guilbert, & Park, 1986).

According to Seager et al. (1982 vide Evans, 1987), the propylitic zone develops in the outer and peripheral alteration zones and is characterized by mineral assemblages of epidote, calcite, and chlorite. When H^+ and CO_2 are added, the primary mafic minerals (biotite and hornblende) are altered to chlorite and carbonate. This zone is also dominated by metal sulfides such as pyrite. The argillic zone is distinguished by mineral assemblages of clay, quartz, and carbonate. Pyrite can be found in trace amounts. Argillic is found in the hydrothermal system's outer layer.

2.3. Methods

Methods used in this research involved field observations, micropaleontology analysis, petrography, and X-Ray Diffraction (XRD) analysis. Micropaleontology analysis was carried out using a binocular microscope, the Olympus CX-31 P, with a 10x magnification. This micropaleontology analysis aimed was to identify planktonic and benthic foraminifera fossils, which are used to determine the relative age of rocks and their depositional environment.

Petrographic analysis was carried out using a polarized microscope Olympus with a magnification of 40x. Petrography analysis aimed to identify the presence of mineralization that could be used as an indicator of a metamorphic process. Samigaluh (WSG) rock samples are sandstone and claystone, whereas Sermo (SRM) rock samples are sandstone, claystone, and andesite.

The goal of XRD analysis is to determine the types of minerals that are not identified by petrography analysis. An XRD analysis was performed on altered rocks to identify the type of mineral that resulted from the alteration. The alteration zone is determined by minerals formed as a result of the alteration.

3. Results and Discussion

3.1. Observation in the Field

Based on field observation, the sedimentary rock outcrop in Samigaluh has a height of 6–7 meters and a width of 20 meters. Overall, outcrops are composed of interbedded sandstone and claystone, with lignite intercalation and brittle rock properties (Figure 2). Sandstone layer thickness ranges from 8 to 50 cm, claystone layers range from 7 to 30 cm, and lignite layer thickness is 8 cm, with strike and dip of rock bedding N26°E/5°. The slope of the small rock layers (relatively horizontal) indicates whether the rock is still in normal condition or disturbed by tectonics. At the bottom, the sedimentary rock is surrounded by andesite breccia, a volcanic product rock.

The sedimentary rock outcrop at Sermo-2 is also composed of interbedded sandstone and claystone with coal intercalation, with strike and dip of rock bedding N210°E/30°. The rock can be found above the andesite dike (Figure 3A). A chloritization zone forms between the two rocks' contacts (Figure 3B).

The sandstone is brownish-gray, layered, and composed primarily of quartz. Claystone is characterized by its incredibly dark color, complex properties, shale structure, extensive fracture, and the rock has been altered into metasediment. A normal fault cuts through sedimentary rocks at Sermo (SRM-2), and sedimentary rocks overlap above andesite dike in a stratigraphic position.

Metasediment occurs when an andesite dike comes into contact with claystone, causing claystone to change into metasediment and chlorite present (Figure 3B). An andesite dike produced the head.

The dike in the field is characterized by igneous rock breaking through claystone, with the majority of the igneous rock weathered. Dike has a massive, interlocking texture, is holocrystalline, and is composed of mafic minerals (mainly pyroxene and biotite), with feldspar partially altered into clay minerals.

3.2. Petrographic Analysis

Petrographic analysis of Sermo-2 (SRM–2) sandstone reveals that the grain shape is anhedral-subhedral, grain supported, and well sorted. The rocks are composed of minerals such as feldspar, quartz, carbon, pyrite, chert, and rock fragments such as metaquartz and granitic fragments. Kaolinite exists to serve as a block of cement and is usually formed through intermediate alteration processes (Figure 4A). The presence of chlorite, pyrite, and kaolinite minerals in sandstones can indicate hydrothermal alteration.

Petrographic analysis of igneous rocks at Sermo-2 (SRM-2) revealed that the rocks have a porphyritic texture with moderate aphanitic to faneric granularity, a degree of crystallization including holocrystalline, relatively subhedral-euhedral mineral form, and phenocryst embedded in the base mass of a finer mineral. The rocks have a unique pilotacitic texture, which is indicative of shallow intrusions.

The rocks contain minerals such as pyroxene, plagioclase, sanidine, chlorite, and opaque minerals with a plagioclase microlite base mass (Figure 4B). The presence of biotite, sanidine, and chlorite minerals as evidence of hydrothermal alteration occurred in that location.

The results of claystone petrographic analysis at the Sermo-1 (SRM-1) location show that grain forms are anhedral-subhedral, matrix-supported, and composed of feldspar, carbon, quartz, and pyrite (Figure 5). In this section, microfractures can be seen. The presence of pyrite indicates that the claystone has been hydrothermally altered too.

The sedimentary rocks in Samigaluh and Sermo, composed of sandstone and claystone interbedded with lignite intercalation, are well layered, and their brittle rock properties are similar to those of the Nanggulan Formation, based on physical characteristics of the rock and petrographic analysis.

3.3. X-Ray Diffraction (XRD) Analysis

Rock samples for XRD analysis were collected from an altered andesite dike at Sermo (SRM-3). The XRD analysis results (Figure 6), show that the constituent minerals are mostly illite (90.4%) and kaolinite (9.6%).

3.4. Micropaleontology Analysis

The analysis of the relative age of sandstone and claystone from outcrop at Samigaluh (WSG) discovered fossils of planktonic foraminifera *Globigerapsis kugleri*, *Globigerinatheka barri*, *Globorotalia sentralis*, and *Globigerina mexicana* (Table 1). Based on the fossil planktonic foraminifera content, the rock age range is Middle Eocene (P14).

The analysis of the relative age of the claystone from outcrop at Sermo (SRM-1 and SRM-2) discovered fossils of planktonic foraminifera *Globigerapsis index*, *Globirerina primitive*, *Globigerina triclocullinioides*, and *Globigerina tripartita* (Table 2). The rock age range is the Middle Eocene (P14) based on the fossil planktonic foraminifera data.

The analysis of the deposition environment in Samigaluh (WSG) discovered benthic fossils such as *Cibicides parki, Textularia zeagguta,* and *Rotaliatina sulcigerina* (Table 3). Characterize the bathymetry of sediment rocks depositional in the outer Neritic at a depth of 100–200 meters based on the fossilized benthic foraminifera content.

The analysis of the deposition environment in Sermo (SRM-1 and SRM-2) discovered benthic fossils such as *Virgulina pontomi,* and *Cibicides sp* (Table 4). Determine the bathymetry of sediment rocks deposited in the inner Neritic at depths ranging from 0 to 200 meters based on the content of benthic foraminifera fossils.

Based on relative ages of rocks, sedimentary rocks in Samigaluh and Sermo that are similar to the Nanggulan Formation are Eocene in age. So, based on outcrop data and the age of the rock, it can be determined whether sedimentary rock outcrops in Samigaluh and Sermo are part of the Nanggulan Formation. However, the rocks exposed in two locations are smaller than the Nanggulan Formation in general, and are in the form of fragments. Furthermore, based on field data and petrographic analysis, it is believed that the Nanggulan Formation in Samigaluh and Sermo has undergone local metamorphism caused by andesite dike**.** These metamorphisms produce metasediments and minerals such as chlorite, biotite, sanidine, pyrite, and kaolinite.

The Nanggulan Formation, which rode above the Old Andesite Formation and was exposed as a result of a dike, has become a roof pendant in the central part of the Kulon Progo Mountains (Figure 7). So, if the Nanggulan Formation, which is exposed in the central part of the Kulon Progo Mountains, is controlled by volcanism in the form of dike, this becomes evidence.

4. Conclusions

The Nanggulan Formation is the oldest formation in the Kulon Progo Mountains. This formation is mostly exposed on the eastern side of the Kulon Progo Mountains, and tectonics is the main controlling factor. Sedimentary rocks exposed at Samigaluh and Sermo (in the central Kulon Progo Mountains) and forming fragments between volcanic rocks are confirmed to be part of the Nanggulan Formation.

A shallow andesite dike intrudes the sedimentary rocks, forming a chloritization zone at the contact between the two rocks. Furthermore, the heat generated by the andesite dike, claystone, and sandstone changes into metasediment and the form of alteration minerals (chlorite, pyrite, illite, and kaolinite).

The presence of chlorite mineral, as determined by outcrop and petrographic data, characterizes the type of propylitic alteration that occurs in the system's outer zone. The presence of metal sulfides such as pyrite also helps support this zone. Illite and kaolinite identified from XRD analysis are most commonly formed in the low-temperature advanced argillic type alteration, the same as the hydrothermal alteration system's outer zone.

The Nanggulan Formation, which was uplifted to the surface due to andesite dike intrusion, is also characterized by undisturbed rock layers (relatively horizontal). The sediment rocks (Nanggulan Formation) function as a roof pendant to the above dike (Old Andesite Formation). To determine the depth and shape of the dike beneath the surface, a geophysical survey (gravity or magnetic) is required.

Acknowledgements

The author would like to thank the team that assisted with data collection in the field.

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List of figures

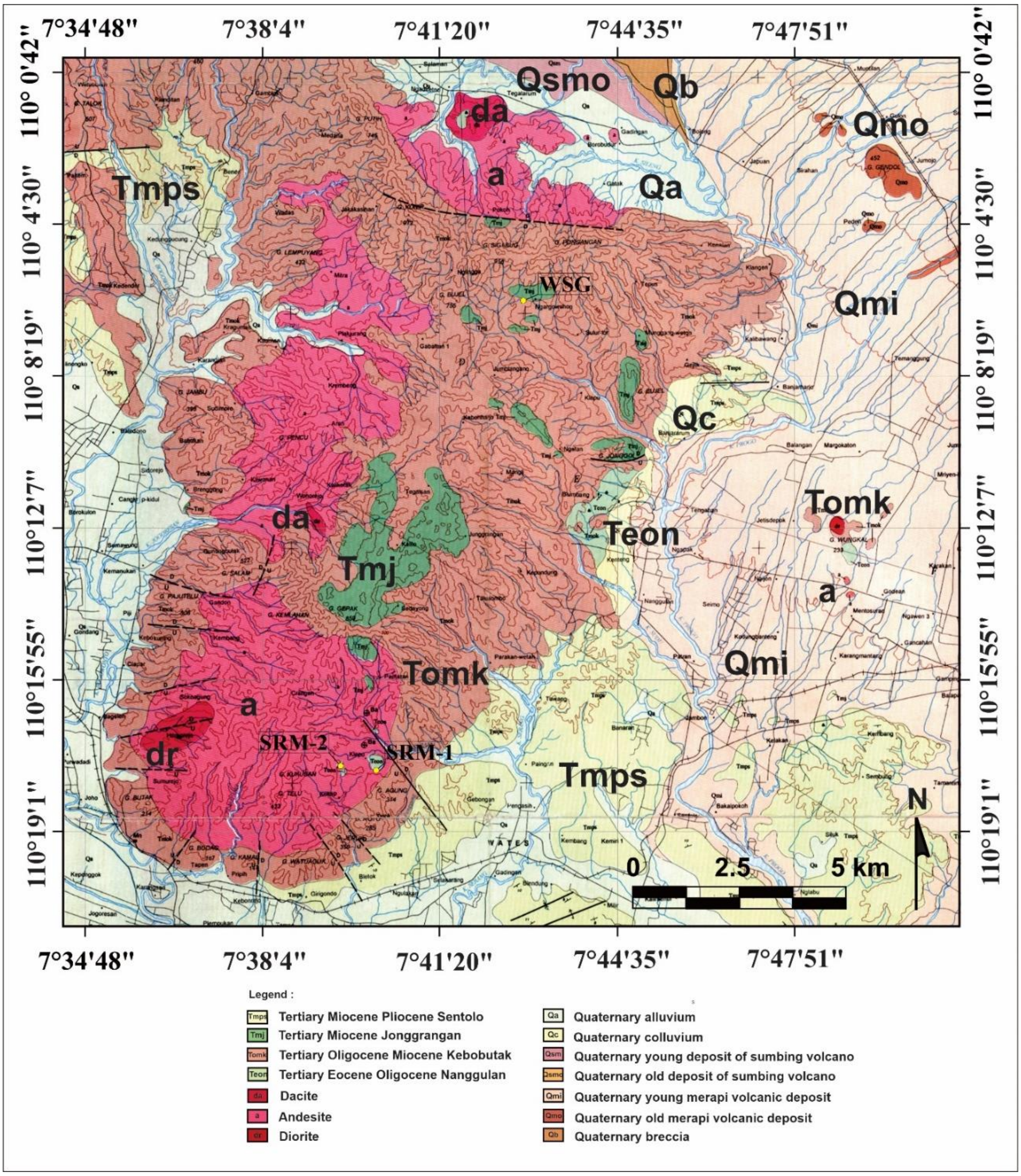

Figure 1 Samigaluh (WSG) and Sermo (SRM-2) are located in the central Kulon Progo Mountains, which are part of the Kebobutak Formation (Tomk) and Andesite (a).

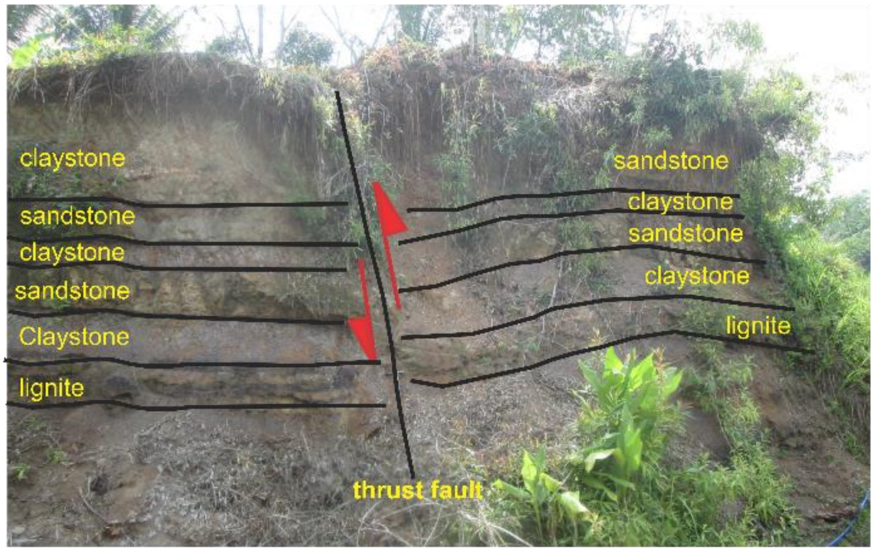

Figure 2 Sandstone and claystone interbedded with lignite intercalation.

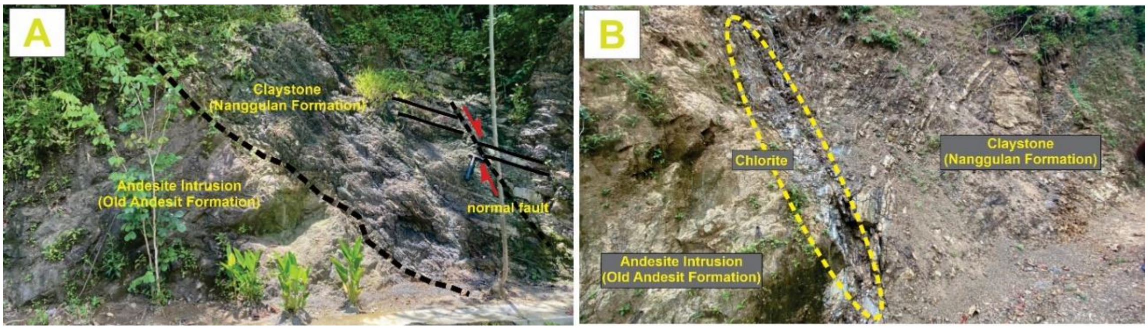

Figure 3 A. An Andesite dike Old Andesite Formation) intrudes sedimentary rock (Nanggulan Formation) at Sermo (SRM-2). B. Chlorite as a characteristic of the metamorphism process caused by the andesite dike at Sermo (SRM-2).

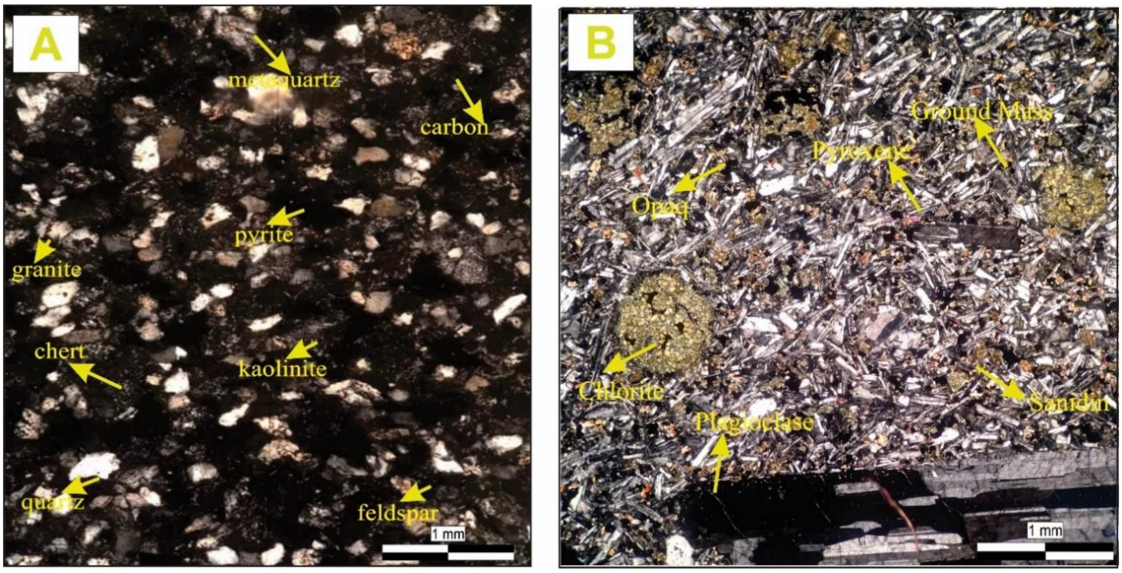

Figure 4 Petrographic analysis results at Sermo-2 (cross-polarized light position). A. Sandstone indicated the existence of pyrite and kaolinite, which indicate hydrothermal alteration. B. Chlorite minerals indicate andesite dike as evidence of hydrothermal alteration.

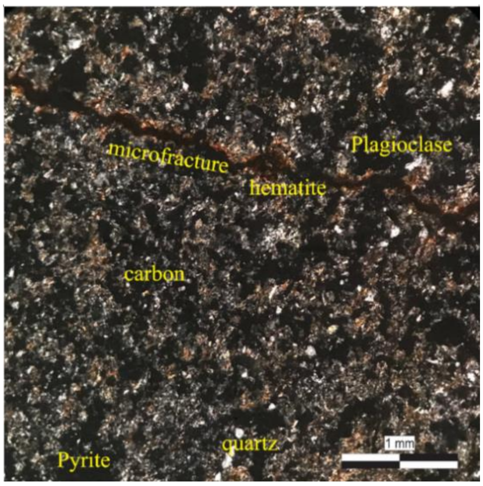

Figure 5 Petrographic analysis of Sermo-1 claystone indicated the existence of pyrite, which indicates hydrothermal alteration (cross-polarized light position).

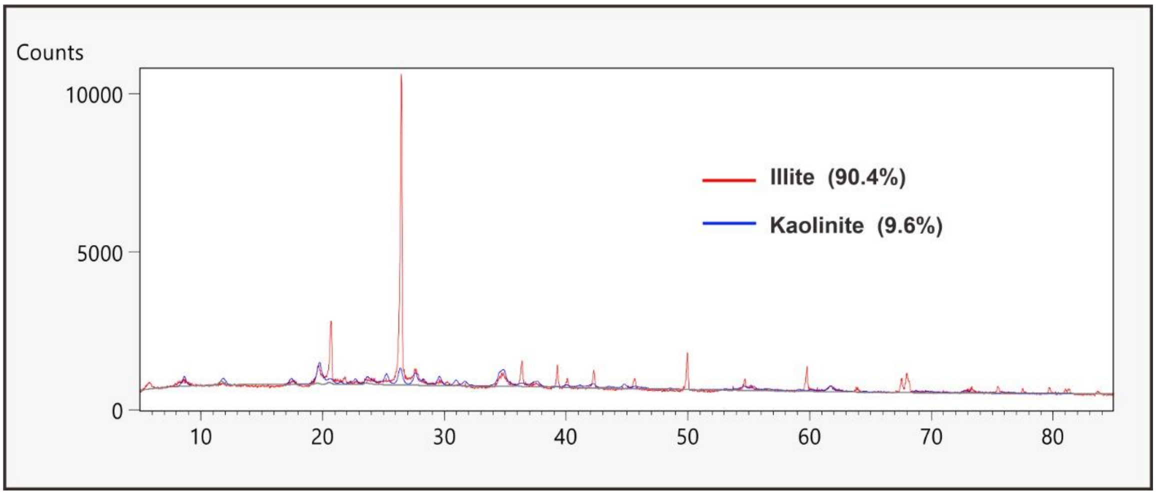

Figure 6 XRD analysis of an andesite dike (SRM-3 location) that has mostly been altered to illite and kaolinite.

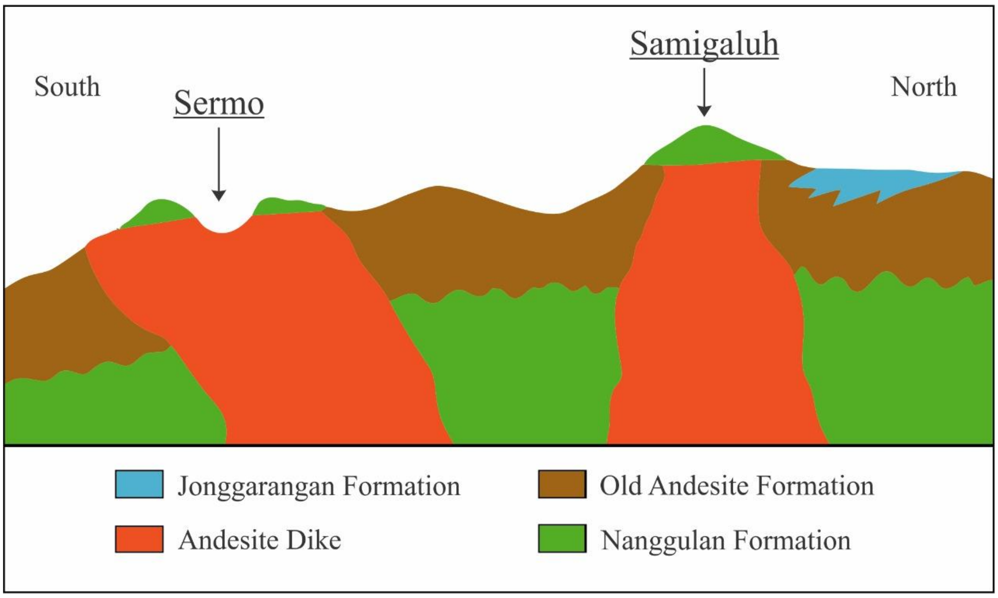

Figure 7 Model of the Nanggulan Formation roff pendant on the central side of Kulon Progo.

List of tables

		Eocene					Oligocene				
		Middle		Upper							
No	**Species**	**P13**	**P14**	**P15**	**P16**	**P17**	**P18**	**P19**	**P20**	**P21**	**P22**
1	*Globigerapsis kugleri*										
2	*Globigerinatheka barri*										
3	*Globorotalia sentralis*										
4	*Globigerina mexicana*										

Table 1 Planktonic foraminifera fossils found in Samigaluh belong to the Middle Eocene.

		Eocene					Oligocene				
		Middle		Upper							
No	**Species**	**P13**	**P14**	**P15**	**P16**	**P17**	**P18**	**P19**	**P20**	**P21**	**P22**
1	*Globigerapsis index*										
2	*Globirerina primitive*										
3	*Globigerina triclocullinoides*										
4	*Globigerina tripartita*										

Table 2 Planktonic foraminifera fossils found in Sermo belong to the Middle Eocene.

		Neritic			Bathyal			Abysal
No	**Species**	**Inner (0-20) m**	**Middle (20-100) m**	**Outer (100-200) m**	**Upper (200-500) m**	**Middle (500-1000) m**	**Outer (900-2000) m**	**(2000-5000) m**
1	*Cibicides parki*							
2	*Textularia zeagguta*							
3	*Rotaliatina sulcigerina*							

Table 3 Benthic foraminifera fossils found in Samigaluh show that the rock was deposited in an outer Neritic.

		Neritic			Bathyal			Abysal
No	**Species**	**Inner (0-20) m**	**Middle (20-100) m**	**Outer (100-200) m**	**Upper (200-500) m**	**Middle (500-1000) m**	**Outer (900-2000) m**	**(2000-5000) m**
1	*Virgulina pontomi*							
2	*Cibicides sp*							

Table 4 Benthic foraminifera fossils found in Sermo show that the rock was deposited in an inner Neritic.