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Nanggulan Formation and Its Problem As a Basement in Kulonprogo Basin, Yogyakarta

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Abstract - Nanggulan Formation consists of the oldest clastic rock sequence exposed in Kulonprogo area, Yogyakarta. This paper discusses the position of Nanggulan Formation as a basement. The method used in this research is surface and subsurface investigations based on gravity surveys. The rock assemblage is exposed and distributed partly in the east flank of Kulonprogo Mountains with weak undulated morphology. The rock sequence is composed of sand to clay grain sizes such as sandstone, quartz sandstone, calcareous sandstone, claystone, fossiliferous claystone, calcareous claystone, siltstone, and coal seam intercalations. The total thickness of the sequence is less than 200 m. Based on the fossil and palynology investigations, previous investigators concluded the age of the rock was Eocene to Middle Miocene. The geological structures developed in the rocks are the lithological stratification, fractures, folding, and faulting. The subsurface interpretation based on gravity data revealed the rock was located under the andesite breccias with 2.44 g/cc density. The density of the rock sequence was 2.63 g/cc. The gravity interpretation shows a strong indication that Nanggulan Formation underlies the andesitic breccias presumably associated with Old Andesite Formation exposed in Kulonprogo Mountains. The limited distribution, the thickness, and the closed environmental deposition of Nanggulan Formation found in the present investigation raised problems on the position of the formation as the basement of Old Andesite Formation occurring in the Kulonprogo Mountain.

Keywords: Nanggulan Formation, shallow marine environment, Old Andesite Formation, basement

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Introduction

The researched area is located in Nanggulan Sub-regency, Kulonprogo Regency, Yogyakarta Special Province (Figures 1 and 2). Geologically, this area is widely known because it harbours the location type of Nanggulan Formation described among others by van Bemmelen (1949) and Rahardjo *et al*. (1977) as the oldest sediments of Java with the age ranging from Middle Eocene to Early Oligocene. Many investigators carried out intensive researches on Nanggulan Formation.

The present research puts the emphasis on the genesis of the formation, including the rock provenance of the sedimentary materials, the sedimentary mechanism, the age of sedimentation, and its particular environment. It includes the gravity surveys to clarify the interpretation of the surface investigation which was carried out integratedly.

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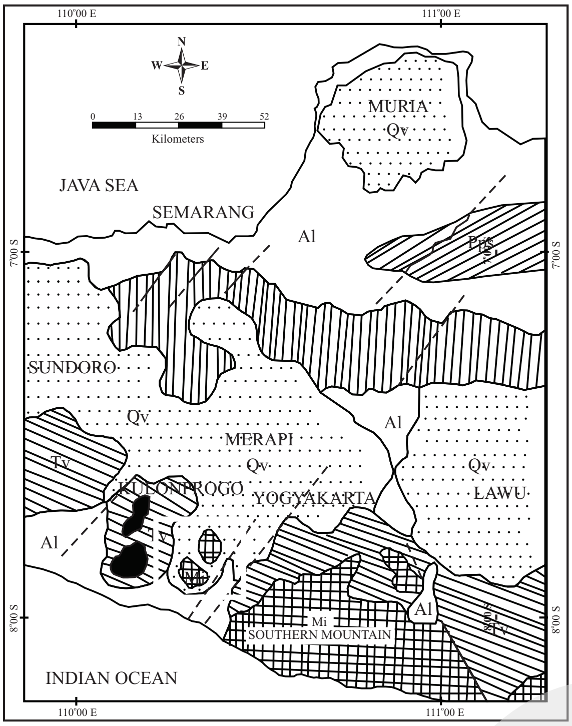

Figure 1. Regional geologic map and the location of the investigated area (red rectangular). Legend: Al stands for alluvial deposit, Qv for Quaternary volcanics, PPs for Plio-Pleistocene sediments, MPs for Mio-Pliocene sediments, Ml for Miocene limestone of Southern Mountains and Kulon Progo, Tv for Undifferentiated Tertiary volcanics, faultings are represented by heavy straight lines. (Modified from various sources).

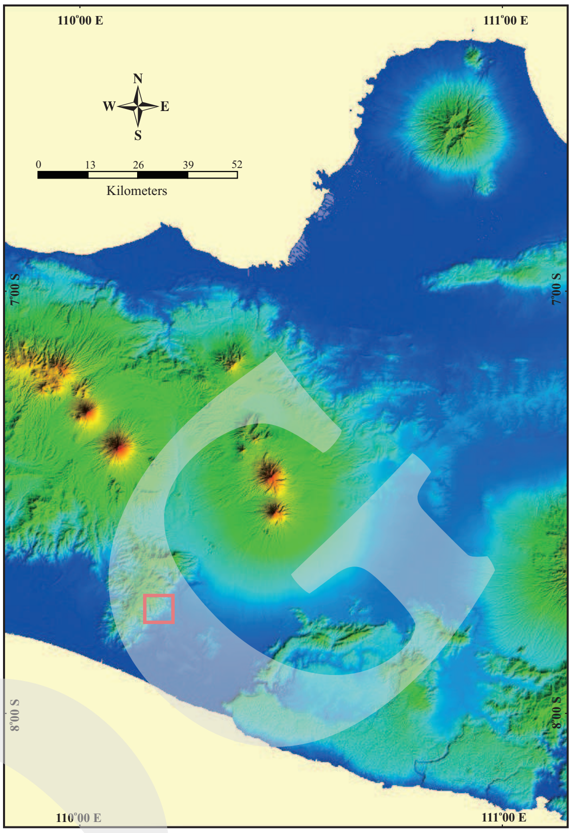

Figure 2. Location of the investigated area (red rectangular) is plotted on the satellite image of Central Java. Not to scale. (Courtesy of the Geological Survey).

The origin of the materials composing Nanggulan Formation remains unknown, whether it was from the continental crust or from highs located in the vicinity. The situation is the same with the configuration of the basin where the formation formed.

The arising question is whether the basin a tectonic origin or it developed as a sag related to intrahighs or intramountains. This paper also puts the attention on the question of fossil determination applying the short living index. The sedimentation environment raises the question on the open or closed basin.

Van Bemmelen (1949) mentioned that Kulonprogo Mountains are composed of old volcanic rocks produced by Mount Gajah, Mount Idjo, and Mount Menoreh distributed in an elongated oblong dome in northeast - southwest direction, 32 km long and 15 - 20 km wide (Figure 3). The volcanic rocks in general dominated the area. Pringgoprawiro and Riyanto (1987) divided the rocks into Kaligesing and Dukuh Formations.

Rahardjo *et al.* (1977, 1995) outlined the stratigraphy of Kulonprogo Mountains, and started the sequence with siliciclastic sedimentary rocks classified as Nanggulan Formation (Figure 4). The sequence consists of marl at the upper part underlying conformably the intercalations of volcanic rocks and coherent lavas. He called it as Seputih Member. The volcanic rocks partly consists of shallow intrusions unconformably underlying Nanggulan Formation. The rocks were assigned as Old Andesite Formation. Intercalated Jonggrangan and Sentolo Formations unconformably lay upon the Old Andesite Formation.

Lelono (2000) determined Eocene age of Nanggulan Formation based on palynomorphs depicting lowlands and wet forest representing the tropical climate. Hartono and Pambudi (2015) concluded that the deposition of rocks sequence of Nanggulan Formation most likely took place in

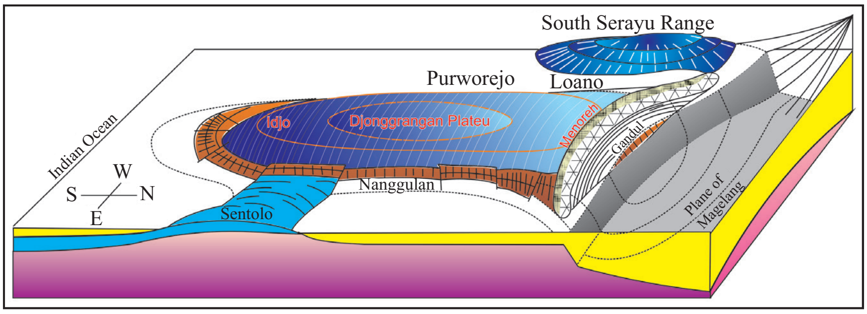

Figure 3. Landscape view showing the oblong dome consisting of remnants of ancient Gadjah, Idjo, and Menoreh Volcanoes (modified from van Bemmelen, 1949).

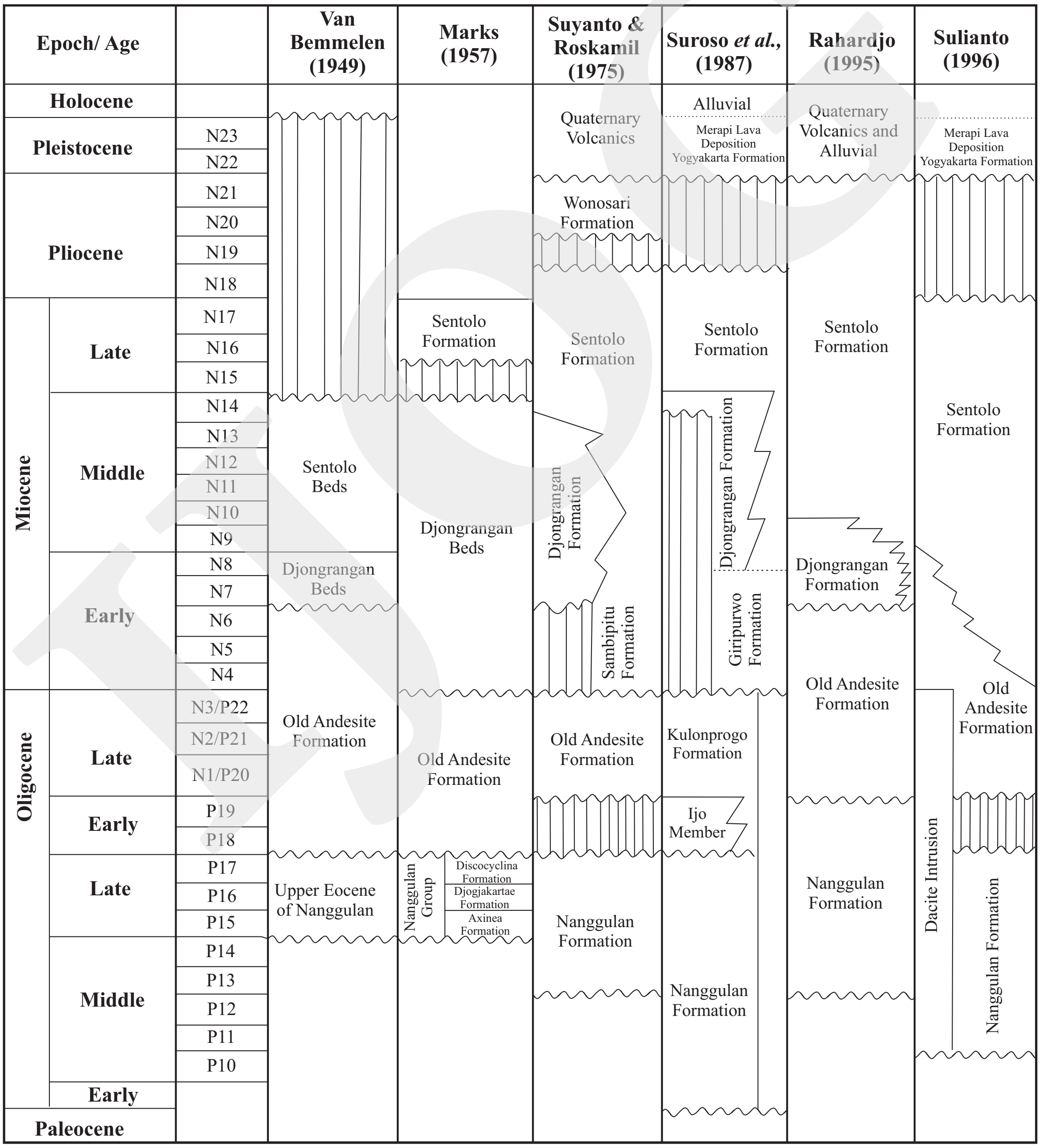

Figure 4. Stratigraphic column of Kulonprogo Area (after the previous authors).

a limited basin located between the highs. Budiadi (2008) mentioned that the tectonic origin involved in the genesis of Kulonprogo Mountains.

The present investigation attempts to reveal that Nanggulan Formation is a basement underlying the Old Andesite Formation of Kulonprogo taking into account the limited distribution and the shallow marine depositional environment. This research also aims to uncover the possibility of hydrocarbon potentials in this area.

Methods

The methodology applied in this research is general surface geologic observations including geological mapping, detailed stratigraphic measurements, and petrography and fossil analyses. Subsurface investigation includes gravity surveys which were also carried out to uncover the configuration of Nanggulan Basin.

The geologic mapping was directed to describe the detailed distribution of Nanggulan Formation based on the existing available information. The detailed stratigraphic works aim to determine the vertical and lateral distributions of the rock units. Hence, the deposition characteristics and the configuration of the basin could hopefully be outlined. The petrographic analysis would contribute to the understanding of the provenance based on the modal of mineral composition. The micro structure of the sediments would reveal the environment of the deposition. Combined with the fossil analysis, the configuration of the basin could be constructed. The gravity surveys also contribute to the interpretation of the basin configuration where the Nanggulan Formation was formed.

Results And Discussion

The findings in the field show that the rocks composing Nanggulan Formation are exposed in the east flank of Kulonprogo Mountains and distributed to the east forming a weakly undulated morphology to almost flat terrain with the slope of less than 7^0 with the total differential altitude of less than 15 m.

The location is cut by a moderately wide Clumprit River in the north, Songo River in the south, and Puru River in the middle. Those rivers drain to the east as tributaries to Progo River. It cuts the strike, and in places follows the rock stratification as consequence, obsequence as well as subsequent rivers following the strike. The structure of Nanggulan Formation highly controlled the drainage pattern.

The geological structure readily observable and measurable in the field consists of fracture, folding, lateral faulting, and igneous rock intrusions. The evidence demonstrates that the tectonic activities have taken place, and magma intruded the rocks.

These activities raise a question concerning the stratigraphic position of Nanggulan Formation based on the analysis of drainage pattern which is relatively parallel in the southwest-southeast direction. The detailed measurement on the rock sequence in Clumprit, Puru, and Songo Rivers give the pictures on the sedimentation development of the Nanggulan Formation. The measurement and description of stratigraphy in Clumprit River show that the rocks consist of sandstone at the lower most and claystone at the uppermost parts with the thickness exceeded 40.71 m (Figure 5a). In Puru River, the lithology consists of more various rocks such as the intercalations of sandstone and claystone at the upper part, the relatively thick sandstone layer at the middle, and the coal seams at the lowermost part with the thickness of about 0.2 m. The seams are embedded between clays and sandstones and underlain by thin intercalations between sandstone and black shales with the thickness of about 4.2 m. The total thickness exceeds 189.98 m (Figure 5b).

In Songo River at the bifurcation north of the exposed intrusive rock, the stratified sandstone and intercalated claystones underlain the rock sequence consists of claystone with the total thickness of about 12.23 m. At the uppermost part, it is composed of limestone identifying the Sentolo Formation. The intrusive rocks most probably are

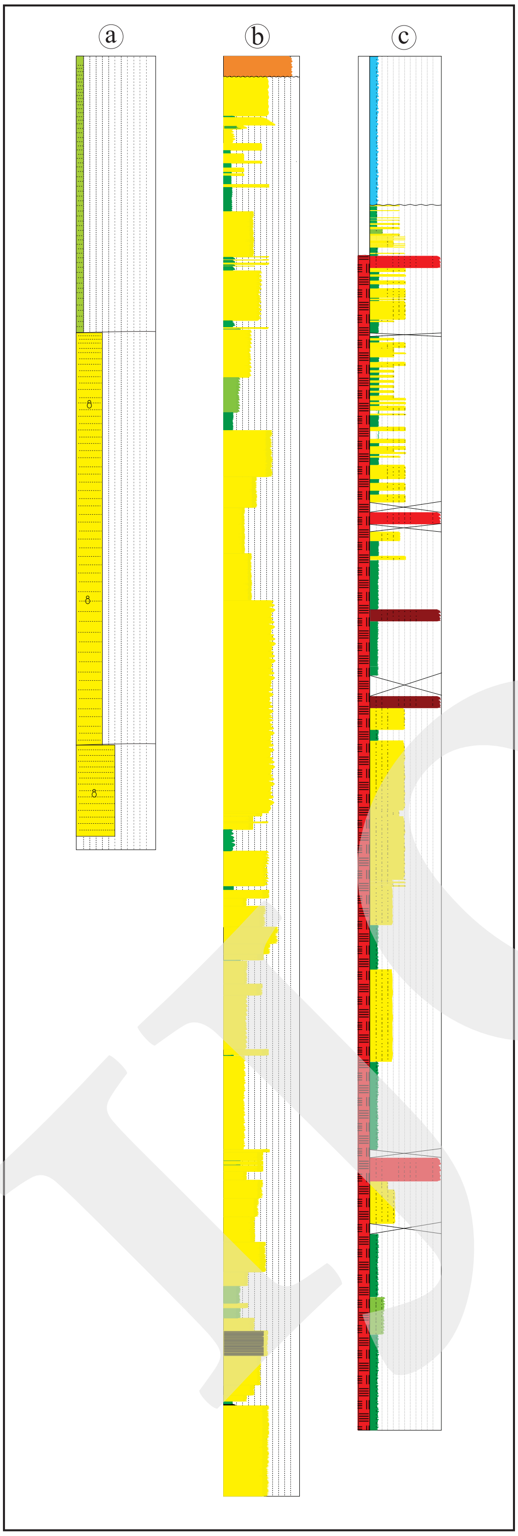

Figure 5. Detailed stratigraphic measurements in Clumprit River (a) and Puru River (b) according to Pambudi and Sujono (2016), and Songo River (c) according to the present authors. Yellow colour denotes sandstones (silisiclastic sandstones), green for claystones, blue for limestones, black for coals (including black shales), red represents intrusive rocks, and purple for soil covers. Thickness of (a) column is 40.71 m; (b) is 189.98 m; (c) is 136 m.

associated with Mujil Volcano (Hartono and Pambudi, 2015) or parts of Old Andesite Formation (Smyth *et al.*, 2003) intruded this silisiclastic rock sequence. The thickness of the sequence exceeds 136 m (Figure 5c). The sequence in Songo River shows the predominated sandstone generally containing quartz.

To summarize, the detailed measurements in those three places reveals the rocks predominated by sandstone. The evidence totally differs from the so far known description on the Nanggulan Formation prepared by the earlier authors stating that the formation consisted mainly of clay containing fossil index identifying Eocene age. Based on the observation by the present authors, it reveals that the formation consists predominantly of sandstone. The thickness according to the previous authors was 300 m, whilst our investigation shows the maximum thickness of less than 200 m. The evidence would affect the clarification of the basin configuration where the sequence was formed. The provenance of the rocks composing Nanggulan Formation needed further investigation interpreting the origin of the rocks.

The Nanggulan Formation containing fossil index consists of large and small size quartz, coal seams, black shales, and calcareous rocks. The evidence drew the attention that the known descriptions by previous authors stating that the formation consisted of fine texture sediments needed a further evaluation, in particular the environmental deposition of the Nanggulan Formation.

It might be noted that the fine texture represents the far distant location of the source rocks. The present investigations however, found out the coarse textural deposits of calcareous sandstone indicating the shallow environment. The occurrence of the fragmented shells of mollusc in claystone supported the interpretation of the shallow transitional environment of the sea margin (Figure 6a).

In Nanggulan Formation, the brown clay concretions measuring about 20 cm with perfect circular shape occur. It smelled corrosive containing pyrite with the maximum size of 2 mm. The origin of such a concretion is supposed to come from the rocks containing ferromagnesian

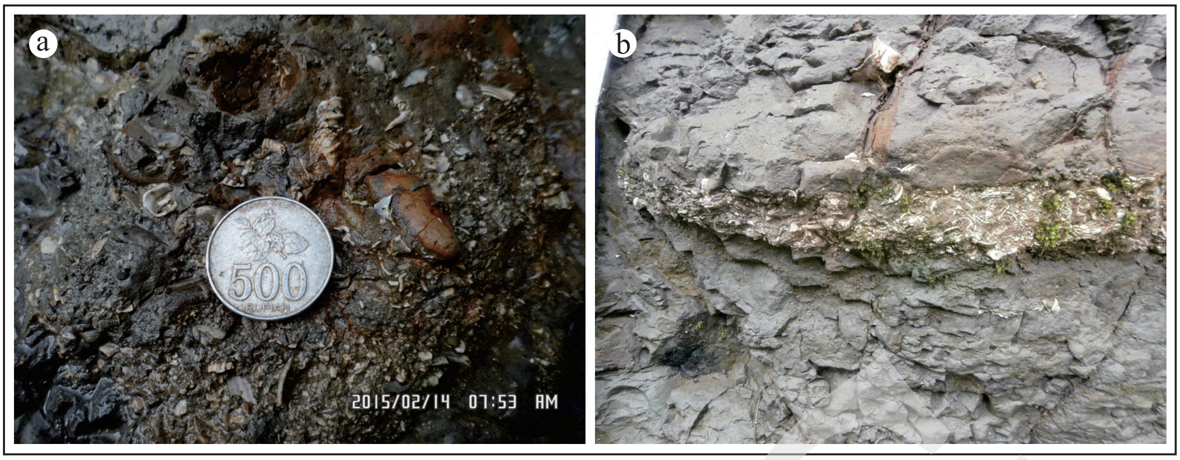

Figure 6. Photographs show the fragmented mollusc shells scattered within the Nanggulan Fornation (a) and in the stratified layer (b), both were found in the Nanggulan Formation.

minerals. The origin of the rocks contained in the Nanggulan Formation most unlikely came from the Sundaland which was the continental crust rich in high silica minerals. The fragmented mollusc shells in a random position lead to the interpretation of the transportation process and the burden as demonstrated by the stratified fragmented layer (Figure 6b).

The phenomena of the fragmented mollusc shells might change the interpretation of the genesis of the Nanggulan Formation. The questions are raised on the sedimentation process and the depositional environment. The occurrence of 80 cm thick of coal seams (Figure 7a) and the black shales of 20 cm thick (Figure 7b) in the stratigraphic column in Puru River, shows the evidence of the shallow transitional marine environment. Pyrite found in the sediments might have been formed in the closed environment lack of oxygen. The locations where the photographs were taken are presented in Figure 8.

The sandstone occurrences at first were thought to be associated with acidic rocks as the detritus originated from Sundaland (Smyth *et al*., 2008). On the other hand, the Godean High located east of the investigated area composed of intrusive porphyritic gabbro to dioritic rocks rich in silica (van Bemmelen, 1949; Rahardjo *et al*., 1977). The intrusive rocks of Godean High most likely produced the quarzitic sandstone. Further,

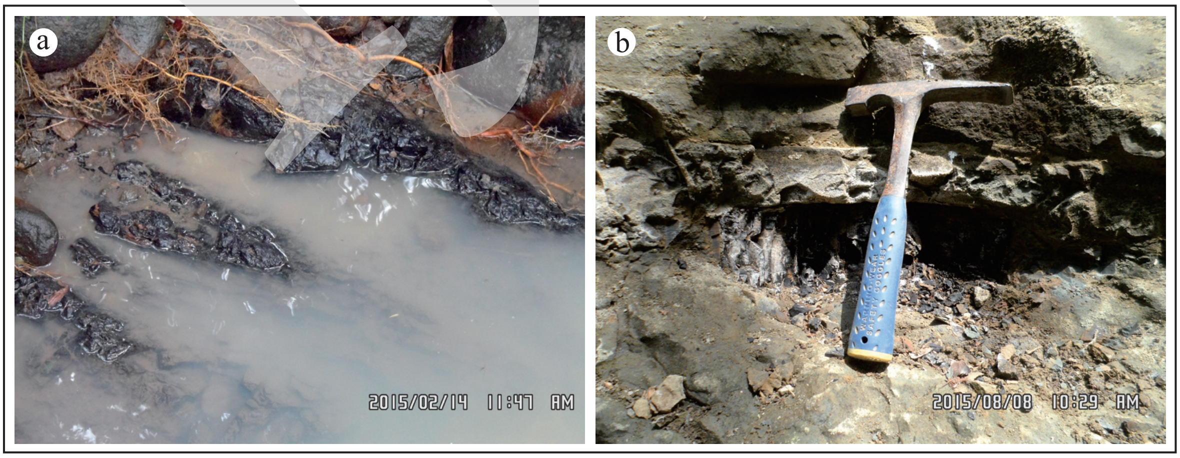

Figure 7. Photographs show the coal seam (a) and the black shale stratifications (b) contained as intercalations in the lower part of Nanggulan Formation.

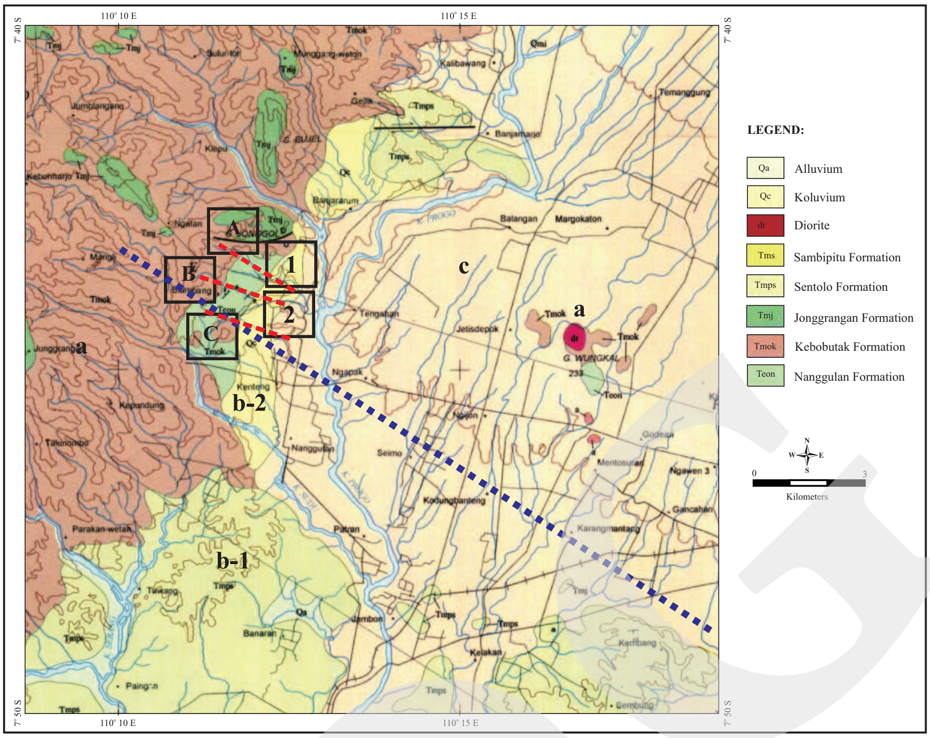

Figure 8. Geologic map of the investigated area shows the locations where the photographs of Figure 6 (location 1) and Figure 7 (location 2) were taken and also the sections where the detailed stratigraphic measurements presented in Figure 5 were carried out. (Rahardjo *et al*., 1977 and 1995). a. Undifferentiated Tertiary volcanics of Kulon Progo; b-1. Miocene marly sandstone and marl; b-2. Miocene sandstones (b-1 and b-2 are members of Sentolo Formation); c. Merapi volcanic products, lahars dominate. A. Section (heavy red dash line) representing a measurement in Clumprit River; B. Section for Puru River, and C for Songgo River. Those three lines also represent the cross-sections appearing on Figure 9. The heavy blue dotted line indicates the locations where gravity data were collected.

the location of the Godean intrusive rocks is only 10 km east of the investigated area.

The dacite and trachy andesite (van Bemmelen, 1949) in Kulonprogo Mountain might also be the origin of the quartz found in sandstones of the Nanggulan Formation. The stratigraphic measurements in the three places show that these intervals are predominantly sandstones.

A slight different is found in Clumprit and Puru Rivers with the absence of intrusive rocks. Coal seams and thin black claystone occur in the lower part of the rock sequence in Puru River. No contact observed between silicic sediments and Old Andesite Formation in Songo River, instead it shows a clear relationship with calcareous rocks, most probably part of Sentolo Formation. In Clumprit and Puru Rivers, the sandstone unit underlain directly the andesitic breccias characterizes the Old Andesite Formation. The phenomenon indicates that the basin was shallow.

The structure identified in both Clumprit and Puru Rivers shows that the rock sequence had undergone folding and faulting. The folding resulted in the formation of synclines and anticlines, horizontal dextral faulting and unthrusting. In Songo River, the anticline and the faulting occur. The intrusive rock fills the weak zone of the faulting.

Those evidences lead to the conclusion that the Nanggulan Formation had undergone a strong deformation, particularly affected fine-grained sediments (Figure 8). The deformation displaced the stratigraphic position is contrary to the law of superposition. Hence, the oldest stratigraphic position of Nanggulan Formation in Kulonprogo became debatable.

The subsurface geophysical information acquired from various methods might reveal the problem. In this regard, the gravity data from the limited number of traverses had already contributed to the interpretation of Nanggulan Formation. The rock deposited in a shallow marine environment of Paleogene age shows the density of 2.63 g/cc with the thickness of 1,100 m (Table 1 and Figure 9). An investigation by Pertamina (2008, in Winardi *et al*., 2013) outlined the rock distribution in Yogyakarta

Table 1. Subsurface Rock Thickness Based on Gravity Data

Age	Rock Unit	Thickness (m)	Density (g/cc)
Recent	Alluvium	200	1.59
Neogene	Carbonate	1,000	2.49
	Volcanoclastics	2,500	2.49
Paleogene	Shallow marine sediments	3,600	2.63

(Modified from Pertamina, 2008 in Winardi *et al.*, 2013). For location see Figure 7.

subbasin. The rocks exposed in the investigated area, on the other hand, are limited to less than 200 m thick.

Based on the characteristic of the rocks showing the shallow marine and transitional environmental, the subsurface interpretation indicating the thickness of 1,100 m might be suspicious and perhaps debatable. Further, the very limited exposure of Nanggulan Formation and the closed basin environment put more doubt on the thick deposits of Nanggulan Formation obtained from geophysical surveys.

The present study reveals that the Nanggulan Formation might only distribute in a very limited location and unlikely to spread over in a large area as suggested by the subsurface geophysical survey. The characteristics of the rock sequence very clearly demonstrate the closed basin depo-

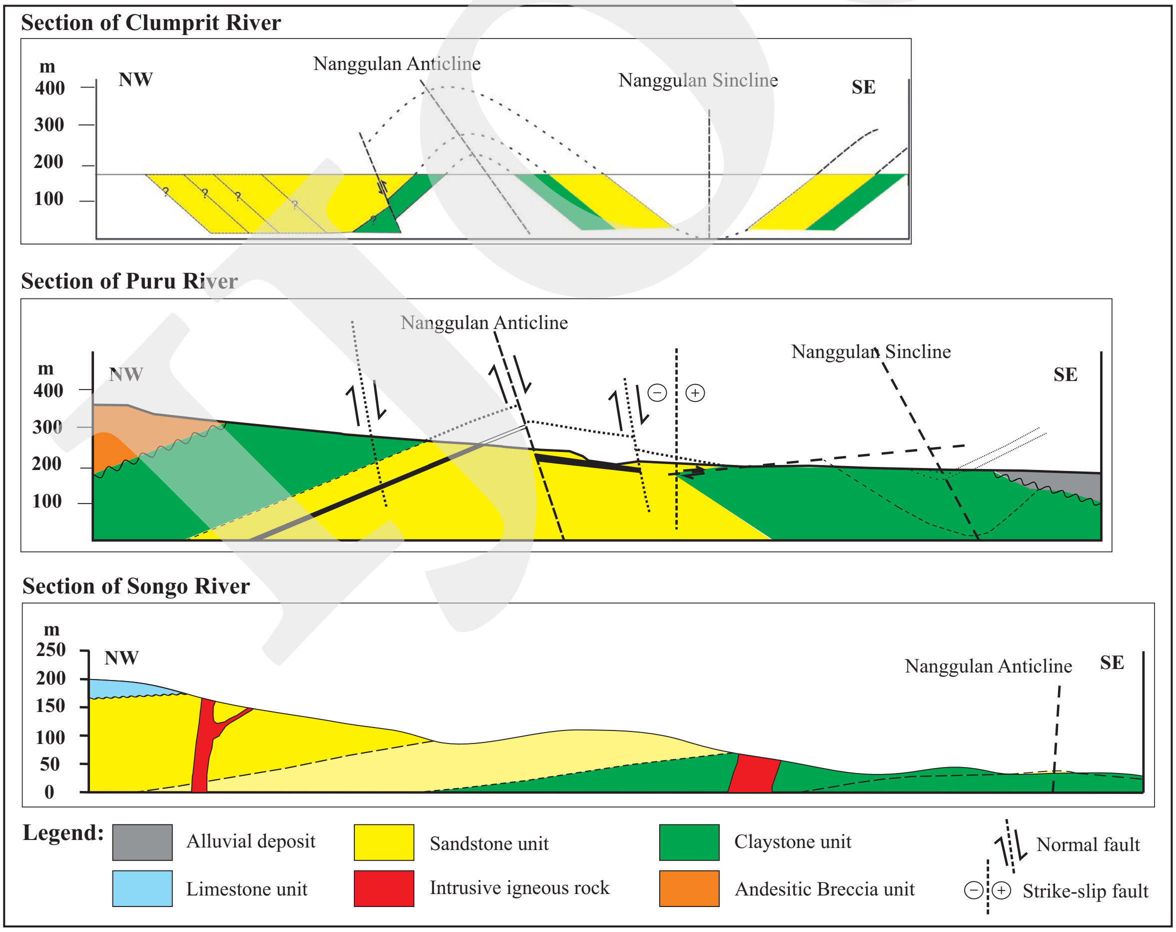

Figure 9. Schematic geologic section analyzed from the stratigraphic measurements in Clumprit River (a), Puru River (b), and Songo River (c). Yellow and green denote Nanggulan Formation; brown and blue represent Old Andesite and Sentolo Formations respectively.

sition, leading to the conclusion that the rocks, both vertically and laterally, would be limited. The expectation to find out a large hydrocarbon potentials from the source rocks of Nanggulan Formation seems to be geologically baseless.

Conclusions and Reccomendations

The distribution of Nanggulan Formation in the investigated area is very limited compared to that of Old Andesite Formation. The position being the basement is therefore questionable. Based on the detailed stratigraphic measurements, the present investigation reveals that the sedimentation of Nanggulan Formation most likely took place in a shallow marine and most probably in a closed environment which confined the distribution. The occurrence of coal seams, black shales, and ferruginous concretions consisting pyrites supports the evidence of such interpretation. The dynamic regime of the shallow sea dominated the sedimentation process exhibited by the occurrence of the fragmented mollusc shells.

Taking into account, the genesis of Nanggulan Formation which was very limited in a closed shallow basin, the position of Nanggulan Formation as the basement in Kulonprogo area is questionable. In contrary, based on the fossil investigation, previous authors concluded that Nanggulan Formation was formed in Late Eocene to Early Oligocene and as the oldest rocks leading to the position as the basement underlying the Old Andesite Formation which was formed in Late Oligocene.

Our investigation however, tends to conclude that it is most likely that the Nanggulan Formation underlies the Old Andesite Formation of Kulonprogo. The intercalations between materials derived from Old Andesite and the lithology similar to the characteristics of Nanggulan Formation might play an important clue to reveal the controversies.

This issue needs further investigations. It is therefore recommended to carry out more fossil analyses to determine the age of Nanggulan Formation, the gravity surveys with sufficient spacing, and finally a well to be drilled up to 1,300 m deep to test the subsurface.

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