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A Reinterpretation of the Baturetno Formation: Stratigraphic Study of the Baturetno Basin, Wonogiri, Central Java

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Abstract - This paper focuses on the Quaternary Baturetno Formation. An earlier research concluded that the black clay of the Baturetno Formation formed as a 'palaeolake' deposit. The 'palaeolake' was interpreted to form due to the shifting course of the Bengawan Solo Purba River in relation to Pliocene tectonic tilting in the southern Java. The stratigraphy of the Baturetno Formation was observed in the western part of the Baturetno Basin, and based on marker beds, the Baturetno Formation was classified into three units: (1) Gravel unit (GR) in the upper part, (2) clay unit (CU) in the middle part, and (3) sand-gravel unit (SG) in the lower part. There are floating gravel fragments of andesite, claystone, coral, and limestone with diameters of up to 10 cm in the clay unit. The particle size of sediment reflects the environment, but the lake deposition occurs under very quiet conditions. The occurrence of these fragments within the clay cannot be explained if the clay was deposited within a lake environment. The occurrence of floating fragments in the black clay of Baturetno Formation can best be explained through mudflow process. The cohesive strength of the mudflow is responsible for the ability of large fragments to float within the mud matrix. In general, the Baturetno Formation is inferred to be an alluvial fan deposit. The presence of sand, gravel, and mud are characteristics of alluvial fan deposits.

Keywords: Baturetno Formation, black clay deposits, mud flow deposit, alluvial fan

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Introduction

Baturetno Formation is part of the Solo Depression Zone (Figure 1) situated in the northern part of Southern Mountains, Java (van Bemmelen, 1949). The Baturetno Basin is composed of Quaternary deposits, consisting of sand, gravel, and clay (dominated by black clay). Boediarto (1962) named these sand and clay deposits the Baturetno Formation. The basin is surrounded by Miocene age units consisting of limestone-dominated Punung and Wonosari Formations to the east, west, and south, and volcaniclastic deposits of the Mandalika Formation to the north and northwest.

Previous studies of this formation (Lehman, 1936; van Bemmelen, 1949; Wiyono, 1992; and Surono, 2005) have described depositional processes of the Baturetno Formation that are related to the Late Pliocene tectonic uplift in southern Java.

According to Lehman (1936), van Bemmelen (1949), and Surono (2005), the Bengawan Solo River used to flow from the north to the south,

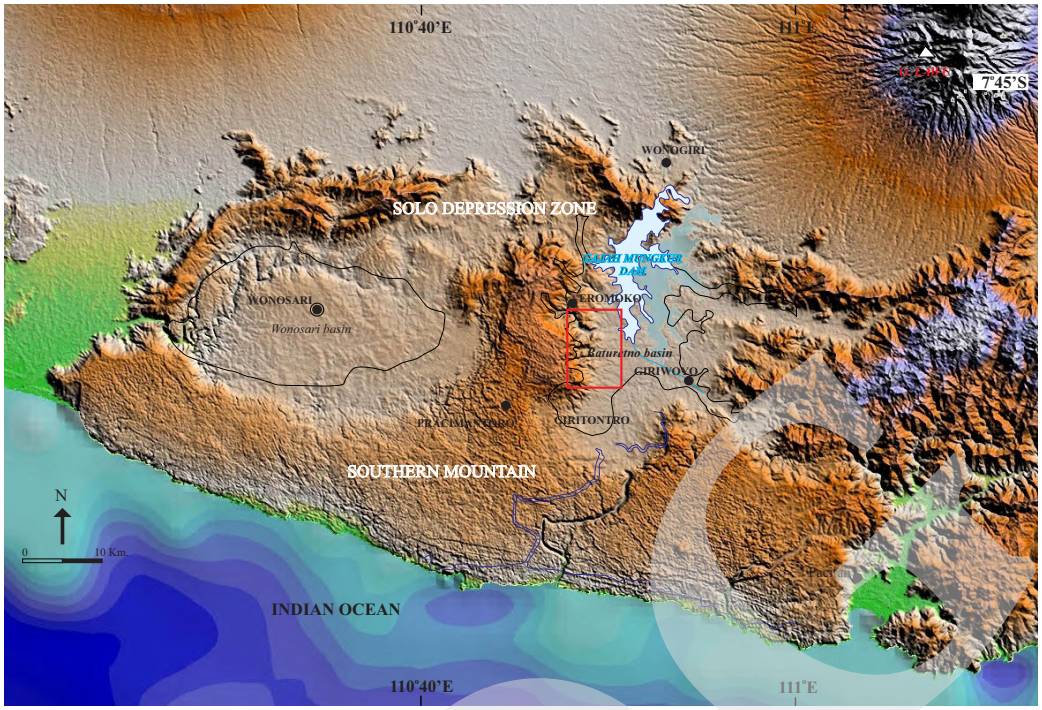


Figure 1. Map of SRTM elevation showing the researched area (red box) located within the Solo Depression Zone in the northern area of Southern Mountains (modified from Surono, 2005).

discharging into the Indian Ocean at Sadeng Beach. Late Pliocene tectonic uplift then caused the course of the river turns northwards. The old river channeled its water into the south called Bengawan Solo Purba (or called Lembah Kering Sadeng - Giritontro), then dried-up as its water source was diverted. It is interpreted that the new northerly course of the Bengawan Solo river then formed the Baturetno palaeolake (Figure 2). Based on a satellite imagery analysis and field observations, Surono (2005) identified that the deposition of the Baturetno Formation occurred after Lembah Kering Sadeng - Giritontro formed. Surono (2005) found that two segments of Lembah Kering Sadeng - Giritontro were separated by the Baturetno Formation deposits.

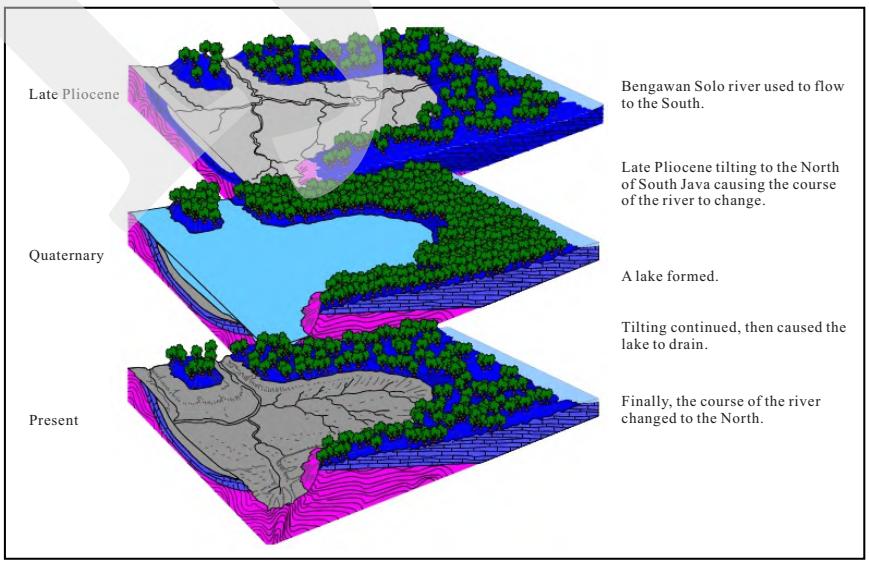


Figure 2. Schematic diagram of palaeolake formation according to Lehman (1936).

Lehman (1936) documented wide distribution of sands, gravels, and black clay deposits in Wonogiri area. Based on a geomorphological evidence only, Lehman (1936) concluded that the black clay represents a palaeolake deposit. Wiyono (1992) also showed that the Baturetno Formation consists of intercalation of yellowish white tuff and sands grading into gravel lenses. The black clay deposit is massive and contains caliche fragments. Speculatively, Wiyono (1992) concluded that this black clay deposit was deposited as a palaeolake and named it the Baturetno Palaeolake. However, it is believed that these studies are not conclusive, and a wider and more in-depth investigation is warranted.

The purpose of this paper is to describe the stratigraphic characteristics of the Baturetno Formation in order to understand its origin. If the Baturetno Formation is a palaeolake deposit, the sedimentology and stratigraphy of this deposit should reflect processes seen within lake environments. The black clay deposit must not contain large clasts as deposition within lakes occurs under low energy conditions. If the shifting course of Bengawan Solo River did occur, its process would be represented in the stratigraphy and sedimentology of the Baturetno Formation. The lower part of the Baturetno Formation, which was deposited when the Bengawan Solo Purba flowed southward, should be characterized by an abundance of andesite fragments sourced from the Miocene volcaniclastic formation in the northern part of the Baturetno Basin. The upper part of the Baturetno Formation, deposited when the Bengawan Solo flowed northward, should be dominated by limestone fragments due to the occurrence of the Miocene dominated limestone units of the Wonosari and Punung Formations in the south of the Baturetno Basin.

Material And Methods

To study the deposition history of the Baturetno Formation, detailed outcrop observations were made in six locations in Eromoko and Sumberwatu, Wonogiri, Central Java (Figure 3). Data collected during outcrop observation include sedimentary unit thickness, textures, sedimentary structures, and lithostratigraphic boundaries. The fragments of the conglomerates were counted. First, the fragments were separated into the fine (< 2 cm) and coarse (> 2 cm) gravels. Each fine and coarse gravel, at least 200 grains, were examined to identify the fragments and counted manually.

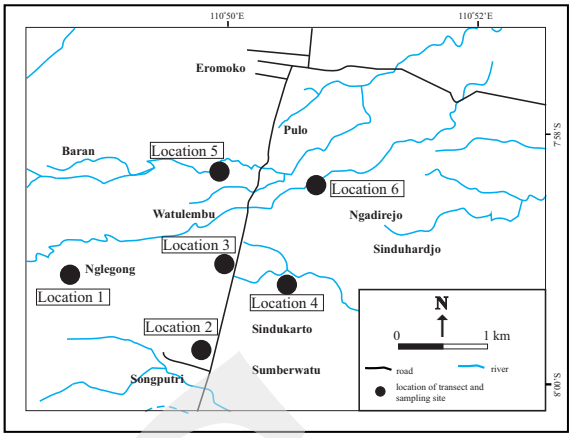


Figure 3. The locality map of the six locations.

Results

Location 1

Location 1 is located at Nglegong Village. Alluvial deposits of the Baturetno Formation in this location have an unconformable contact with the underlying Miocene rocks of the Semilir Formation (Figure 4). Outcrop reconstructions of this location can be seen within Figure 5. Location 1 consists of massive hard layers of black clay, some of which are well indurated, with abundant

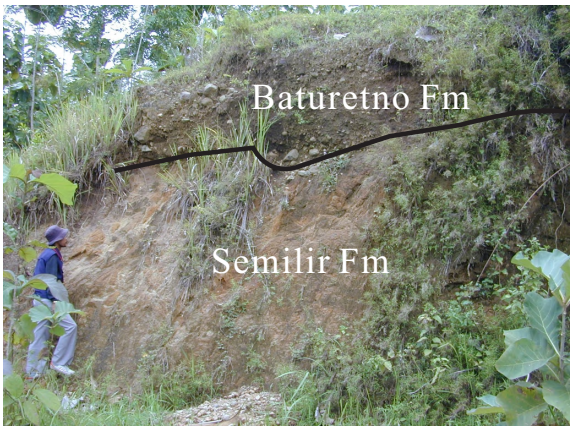


Figure 4. An unconformable contact between the Baturetno and Semilir Formations.

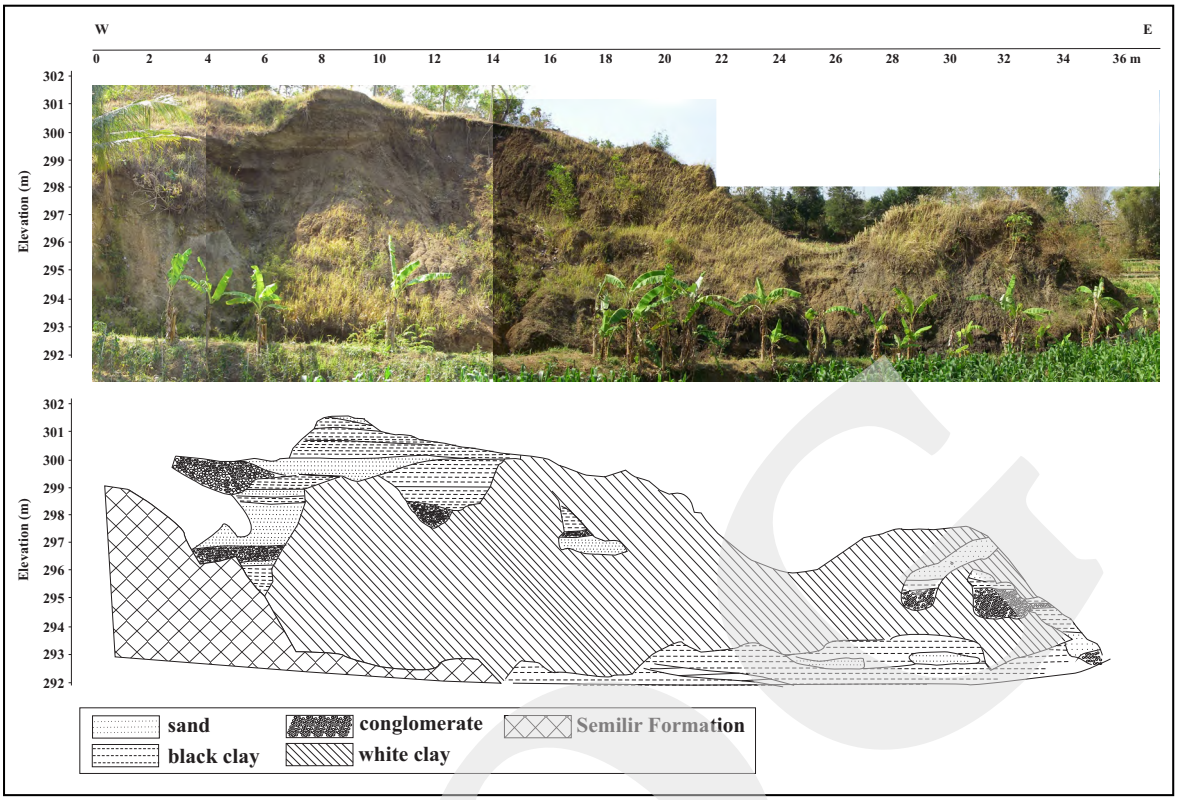


Figure 5. Outcrop reconstruction of Location 1.

caliche and andesite fragments, and intercalation of a white clay layer (Figure 6).

In the eastern part of Location 1, the clay layers are cut by a channel of open fabric (sometimes the clasts are not in contact each other), poorly sorted conglomerate. The dominant clasts of this conglomerate are andesite, which also form the largest clasts with diameters of up to 15 cm. In the upper part of this conglomerate lense, dark to yellowish brown, soft clay layers with abundant

Figure 6. Layer of a white clay intercalation in the black clay.

andesite clasts are noted. In the western part, these clay layers are cut by a massive and poorly sorted conglomerate. The uppermost deposits of Location 1 consist of medium-grained sand and clay layers.

Location 2

Location 2 is located at Sumberwatu Village. In general, the stratigraphy of Location 2 can be divided into lower, middle, and upper parts. The lower part of this location is dominated by clay deposits; the middle part is dominated by sand layers and conglomerate lenses, whilst the upper part of this location is dominated by sand and clay layers. The lowermost layers of this location consist of black to brown soft clay layers with abundant fragments of caliche and andesite. In these clay layers, desiccation cracks were observed and these are filled with fine- to medium-grained sands. A white clay layer was observed overlying those clay layers. On the middle part of this outcrop, the deposit is composed of a medium- to coarse-grained massive sand layer with abundant andesite clasts. In the upper part, the deposits are

thick sand layers (> 3.5 m) consisting of graded-bedded and stratified layers of coarse-grained sands. In these coarse-grained sands, a continuous channel of conglomerate was observed. The conglomerate has close fabric (no matrix in between the clasts) and poorly sorted fragments, with andesite as the dominant fragments. A clay layer was deposited in the uppermost part of the outcrop. Detailed stratigraphic reconstruction of Location 2 can be seen in Figure 7.

Location 3

Location 3 is located in Karangnongko Village. The lowermost part of this location consists of medium- to very coarse-graded sand layers, with abundant andesite fragments. The upper part of these layers have gradational contacts and massive layering of medium- to coarse-grained sand. These sand layers contain andesite and limestone fragments. Conglomerate lenses are clast supported in the lower part of this sand layer. The dominant fragment of this conglomerate is andesite, with minor amount of diorite fragments. The maximum size of the fragments is around 18 cm.

Laterally, in the middle part of this location, a large conglomerate channel developed and can be observed from the bottom to the top of the location. This conglomerate has graded bedded, fragment supported, and poorly sorted characteristics (Figure 8). Analyses of fragment composition of this conglomerate (as seen on Table 1) show that andesite (73.3 %) is the most dominant fragment. Detailed stratigraphic reconstruction of Location 3 can be seen in Figure 9.

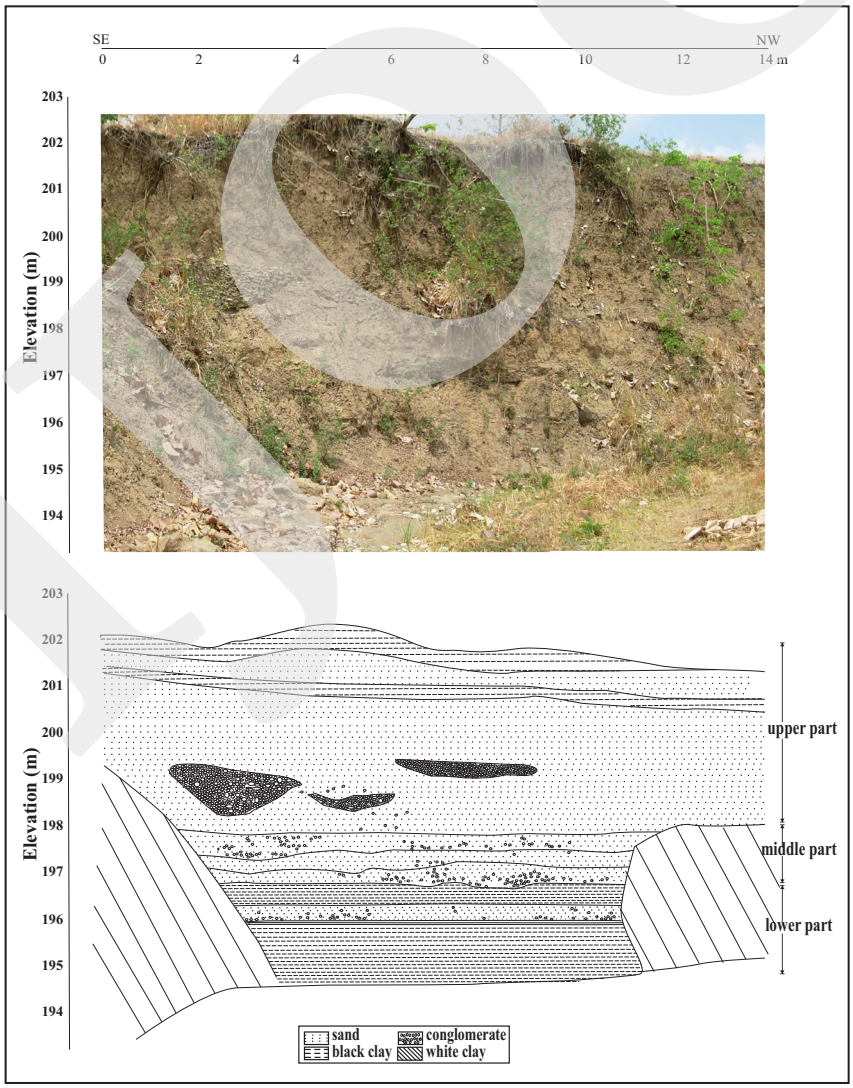


Figure 7. Outcrop reconstruction of the Location 2.

Figue 8. Channel of fragment supported, poorly sorted, and graded bedded conglomerate at Location 3.

Table 1. Fragment Composition of Conglomerate at Location 3

Fine Gravel (<2 cm)		Coarse Gravel (> 2 cm)	
Andesite	73.33%	Andesite	96.33%
Claystone	15%	Claystone	3.64%
Diorite	11.67%		

Location 4

Location 4 is located at Sindukarto Village and shows the longest exposure (180 m length). Lithologically, the location is dominated by fine- to coarse-grained sands with conglomerate lenses (Figure 10). In general, the lower part of this location consists of parallel stratified to cross-bedded sands that are medium to coarse grained (Figure 11). Conglomerate lenses can be observed within these sand layers. In the middle part of this location, the presence of a soft white clay layer can be traced to contain minor amounts of weathered andesite fragments. The upper parts of this outcrop are composed of conglomerate lenses and fine- to medium-grained sand layers, with black clay in association with the white clay layer observed in its lowermost part. The dominant fragment within the conglomerate is andesite (61.67 %, Table 2).

Location 5

Location 5 is located at Watulembu Village. The lower part of this location consists of massive to graded bedded of fine- to coarse-grained sand layers. In the eastern part of the outcrop, conglomerate can be observed in the lower part of these sand layers. These conglomerate lenses have closed fabric, poorly sorted, and the dominant fragment type is andesite. Andesite and diorite are the dominant fragments within these conglomerate lenses.

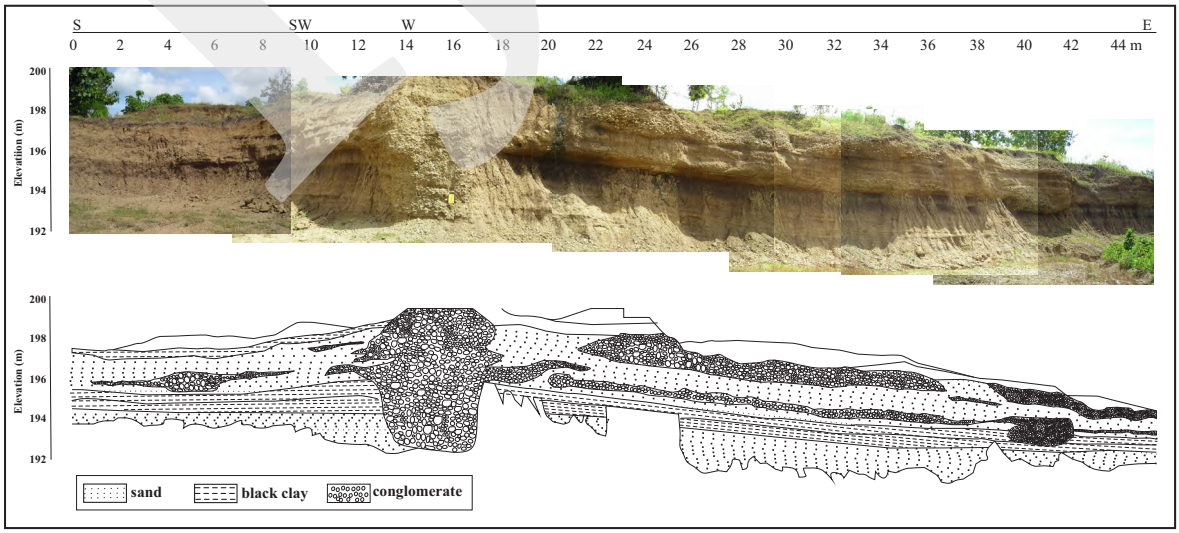
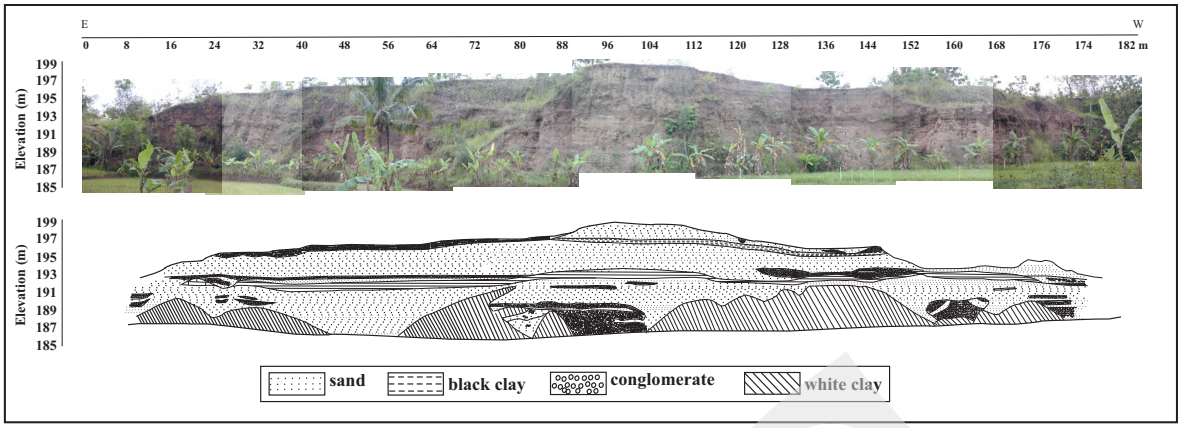


Figure 9. Outcrop reconstruction of Location 3.



Figue 10. Outcrop reconstruction of Location 4.

Figure 11. Parallel stratified and cross-bedded sands in the lower part of Location 4. The scale is 20 cm long.

Table 2. Fragment Composition of Conglomerate at Location 4

Fine Gravel (<2 cm)		Coarse Gravel (>2 cm)	
Andesite	61.67%	Andesite	68.33%
Claystone	18.33%	Diorite	21.67%
Limestone	11.67%	Claystone	8.33%
Diorite	6.67%	Limestone	1.67%

The upper part of this outcrop is composed of clay and sand layers. Clay layers comprise soft black clay with abundant caliche fragments and white clay layers. Sand layers consist of coarse- to very coarse-grained, graded-bedded to massive sands and cross-bedding of medium-grained sands. Conglomerate lenses can be observed within these sand layers. Detailed stratigraphy of Location 5 can be seen in Figure 12.

Location 6

In general, in the western part, Location 6 is dominated by coarse-grained deposits, meanwhile the eastern part is dominated by fine-grained deposits of clay. The lowermost part of Location 6 consists of a soft greenish-white clay layer with limestone fragments. Overlying this greenish-white clay layer, very fine to fine grained sand layers with conglomerate lenses can be observed in the middle to the western part of Location 6. Andesite is the dominant fragment in the graded-bedded conglomerate lenses, with minor fragments of limestone and tuffaceous clay.

The upper part of this location is composed of conglomerate lenses exhibiting a graded bedding structure. Dominant fragments of the conglomerate lenses are andesite and diorite, with minor amount of tuffaceous claystone. Maximum diameters of these lenses are up to 14 cm. Lenses of sands with graded-bedding occur within these conglomerate lenses. Detailed stratigraphy of Location 5 can be seen in Figure 13.

Discussion

Sedimentology and Stratigraphy of the Baturetno Formation

As described from all locations, the Baturetno Formation is composed of sand, gravel, and clay deposits. Sands and gravels of the Baturetno Formation are best and most simply explained by invoking a fluvial origin. The bedrock of this formation is a Miocene volcanic rock unit of the

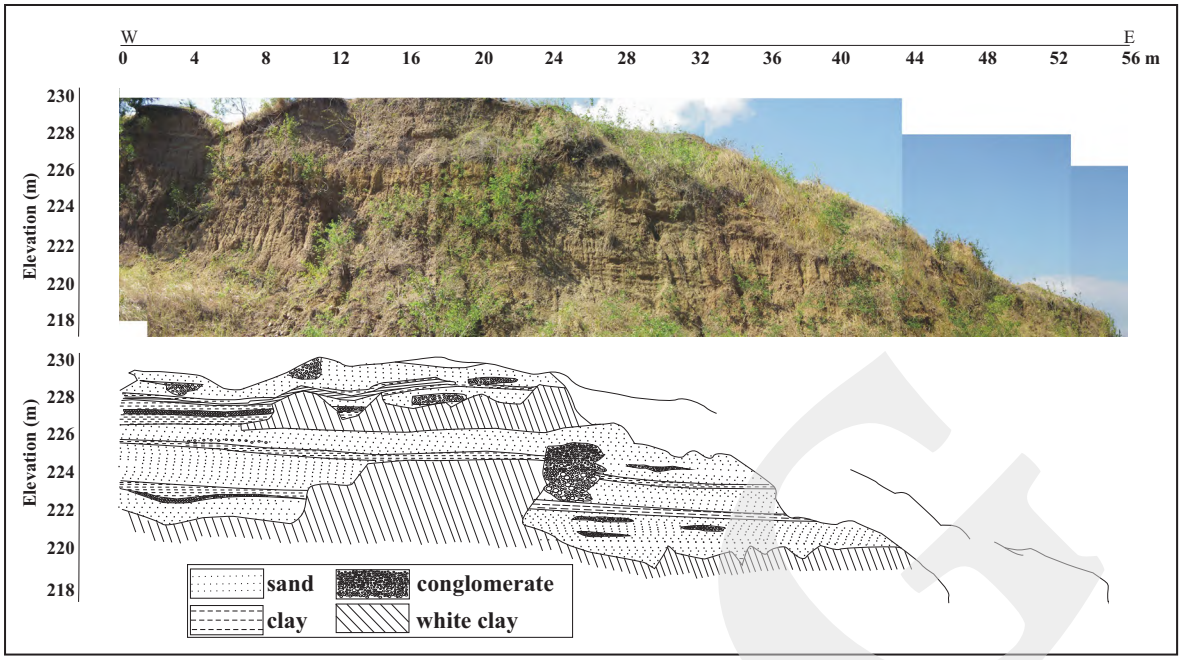
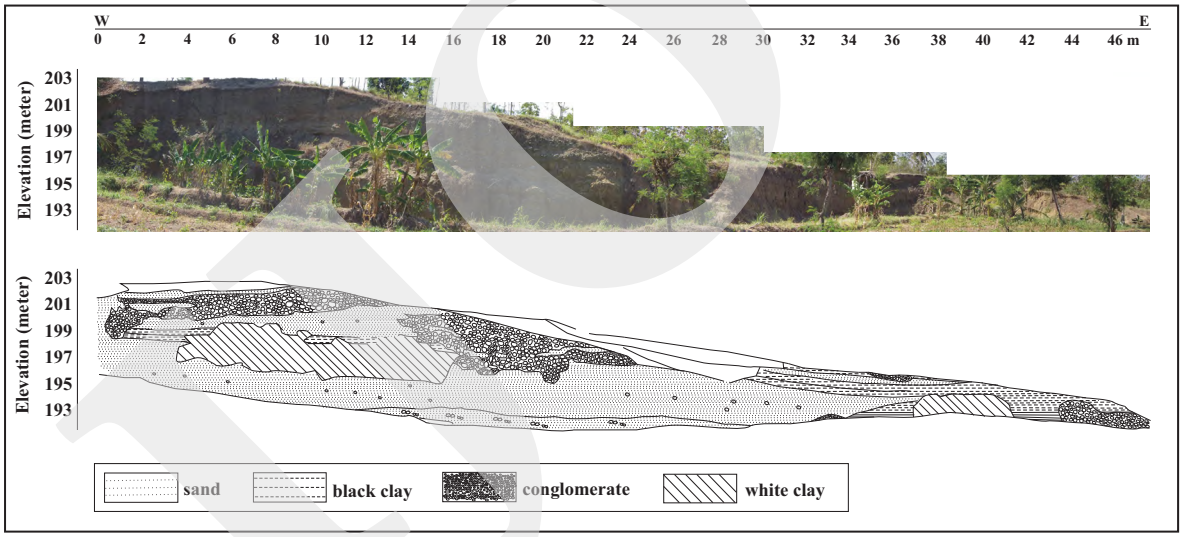


Figure 12. Outcrop reconstruction of Location 5.



Figue 13. Outcrop reconstruction of Location 5.

Semilir Formation, which outcrops in Location 1. To obtain the composite stratigraphy of the Baturetno Formation, the stratigraphic profiles need to be considered from all locations. Due to the lack of materials for absolute age dating, any correlations must be done by identifying marker beds that can be observed in all locations. White clay layer was used which can be found in all locations. Wiyono (1992) identified this white clay layer as a tuff layer, however, under microscopic observation, any pyroclastic materials could not be found in this clay layer. Probably, the pyroclastic material has already been altered into white clay due to weathering processes. If this interpretation is correct, then this layer may have had a wide distribution in the Baturetno Basin. Paleosoil was not used as a marker bed, because the occurrence of paleosoil at every outcrop was not the same, and therefore it is problematical to correlate. Based on the white clay marker bed,

the Baturetno Formation can be divided into three units (Figure 14): a sand-gravel unit (SG) in the lower part, a clay unit (CU) in the middle part, and a gravel unit in the upper part (GR).

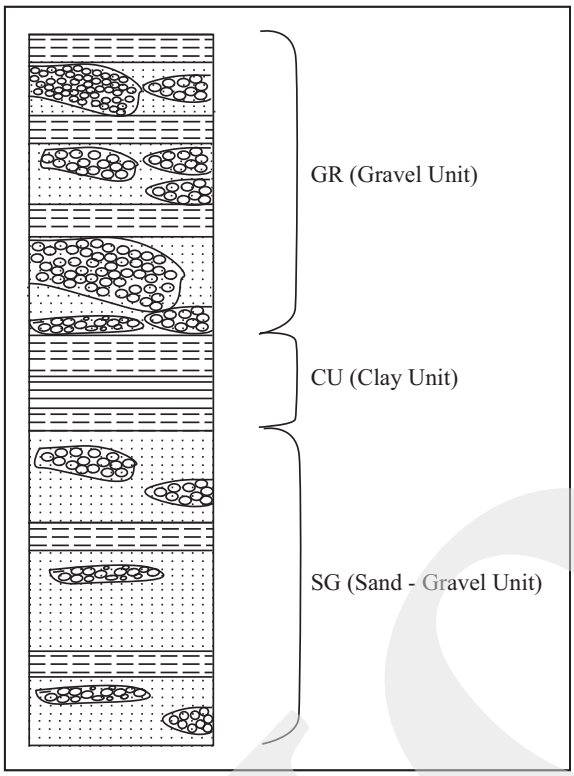


Figure 14. Composite stratigraphy of the Baturetno Formation (not to scale). The white clay layer as the marker bed is intercalated with the black clay, and these two clays make up the Clay Unit (CU).

The SG unit outcrops at Locations 4 and 5 consisting of fine- to coarse-grained sands with horizontally stratified and graded bedding. Clast supported and poorly sorted conglomerate lenses can be traced within these sands. Dominant fragments within these lenses are andesite with minor amount of diorite, tuffaceous clay, and limestone. The CU consists of black and white clay layers. These clay deposits contain andesite, tuffaceous clay, and limestone fragments. The diameters of these fragments are up to 10 cm. The thickness of the black clay layer is up to 2 m. The white clay layers are up to 60 cm thick, as observed at Location 1. The GR can be observed in all locations. The GR is more clay dominated compared with the SG, and also more abundant conglomerate lenses are found in the GR. Moreover, conglomerate lenses in the GR unit are composed of not only andesite and diorite, but also tuffaceous claystone and limestone as minor fragments.

Both in the upper and lower parts of the Baturetno Formation, andesite is the dominant fragment within sand and conglomerate lenses (48 – 96%). Limestone fragments can be found both in the upper and lower parts, but only as minor fragments (maximum 12%).

If deposition of the Baturetno Formation was related to the shifting course of Bengawan Solo Purba River, it can be hypothesized that limestone fragments would dominate the upper part of the Baturetno Formations. This hypothesis is not supported by field observations of this study. Domination of andesite fragments in all units indicates that the provenance of the Baturetno Formation was from the northern area of the Baturetno Basin. Miocene volcaniclastic sediments of the Mandalika Formation which outcrop in the north of the Baturetno Basin are most likely the source of these fragments (Figure 15). This indicates that the shifting course of the Bengawan Solo Purba may never have occurred. This conclusion is in agreement with Samodra (2007) and Surono *et al*. (2013).

Baturetno Formation: Lake Deposit?

Conclusions of previous researches show that the Baturetno Formation was formed as palaeolake deposits. This is based primary on the wide distribution of black clay deposits. This study was observed from the more widespread data within this basin (Figure 16) that black clay deposits contain floating fragments (andesite, tuffaceous clay, limestone, and coral). The presence of those floating fragments in the black clay deposit strongly suggests that this clay was not a lake deposit. The particle size of sediment reflects the energy of the environment, for example, braided streams are mostly found in high slope areas with fast moving water and are mostly characterized by large particles. Unlike braided streams, water contained within a lake has almost no movement. In such condition, deposition occurs under very quiet conditions and the sediments is dominated by fine particles. The occurrence of floating fragments in the black clay can best be explained through mudflow processes. Gani (2004) identified that

Figure 15. Mandalika Formation in the north of the studied area is the main source of the conglomerate fragments in the Baturetno Formation (modified from Surono *et al*., 1995).

mudflows exhibit non-newtonian behaviour and is responsible for the ability of large fragments of rock material to float within the mud matrix due to the cohesive strength. The lithological composition in Baturetno Formation is in agreement with Sharp and Nobles (1953) and Curry (1966) who recognized the lithological composition of mudflow at Wrightwood, Southern California and in Tenmile Range, Colorado, respectively.

Baturetno Formation: Alluvial Fan Deposits?

What kind of processes operated in the Baturetno Basin to deposit the Baturetno Formation? Characteristics of the Baturetno Formation obtained from the western part of the Baturetno Basin indicate that the sediments in this western part of the basin may be of alluvial fan origin. According to Blissenbach (1954) and Bull (1977), alluvial fan deposits are characterized by gravels (deposited as channels) associated with mud-flow deposits. The gravel (conglomerate) may be indicative of braided stream and/or mass flow sequences (Nemec and Steel, 1984). The Baturetno Formation is concluded to closely resemble these kinds of deposits. This conclusion is also supported by the presence of alluvial fan (bajada) morphology and north-south lineaments observed from topographic maps (Figure 17). Bajada is a terminology

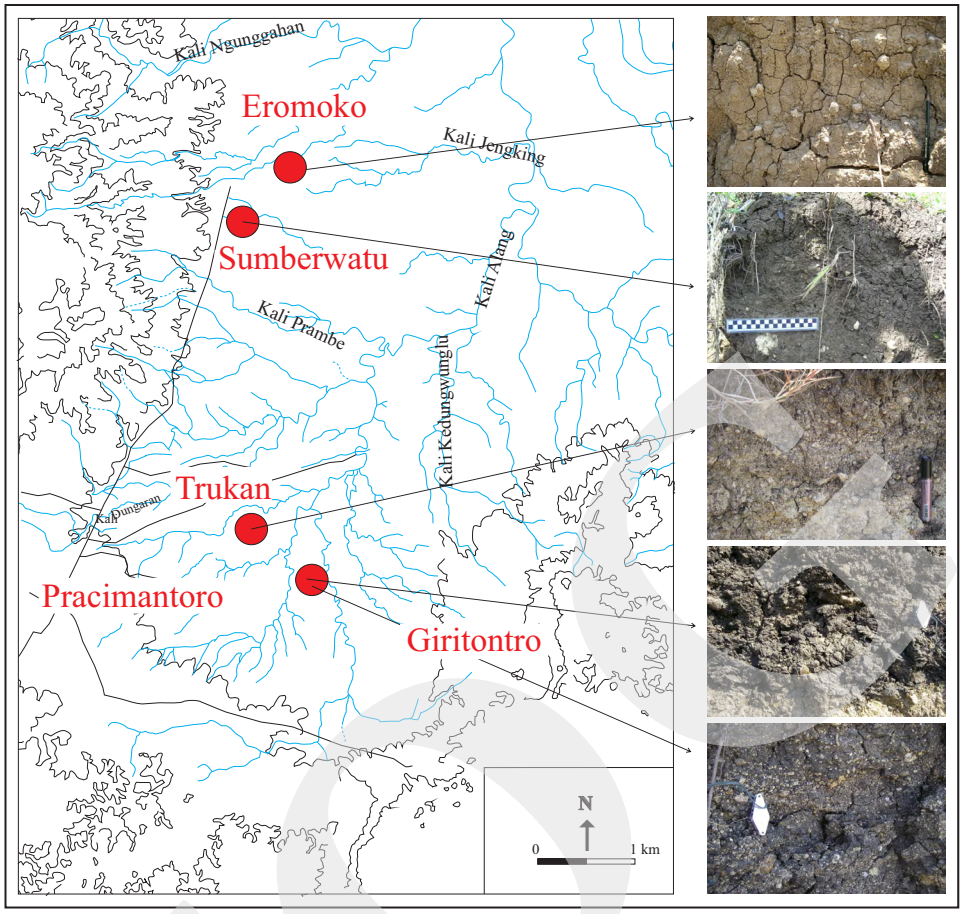


Figure 16. Floating fragments in the clay deposits from several sites. The scale bar in the second upper photo is 20 cm long, the loupe in the bottom and second bottom photos is 4 cm long, and the pen in the middle photo is 10 cm long.

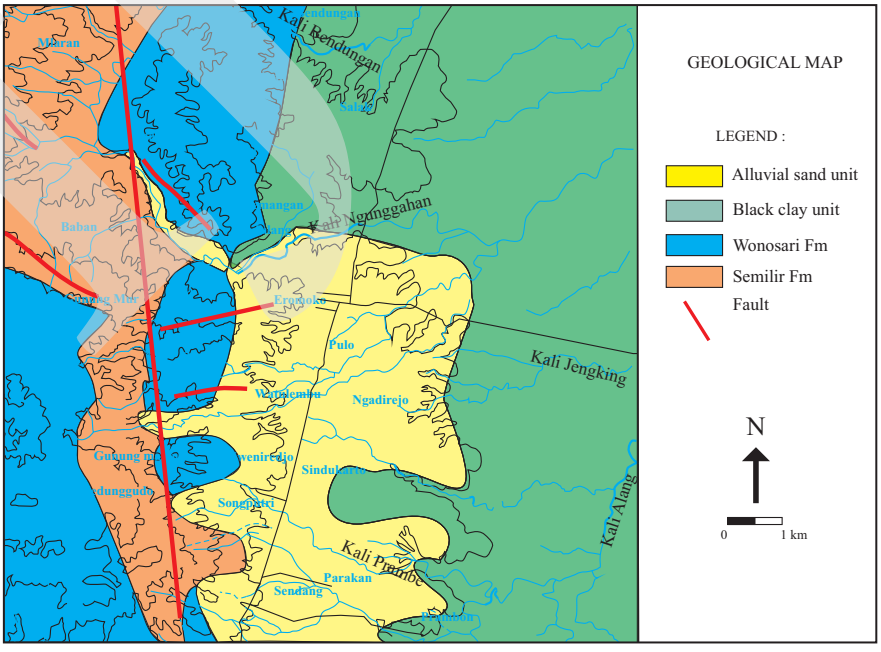


Figure 17. Geological map of the researched area showing structural lineaments (fault, red line) and bajada morphology (alluvial sand unit) (modified from Pamungkas, 2000).

for a series of coalescing alluvial fans; sometimes the fan-shaped morphology of a bajada is not recognized. Alluvial fans form primarily because the feeder channel experiences a loss in confinement, as it emerges from the mountains onto the plains (Chamyal *et al*., 1997). The lineament is one of the important factors for alluvial development (Blair and McPherson, 1994). This lineament is the agent for topographic change that is important for such an abrupt loss in confinement (Bull, 1997; Blair and McPherson, 1994). Pamungkas (2000) observed a slicken slide in the clay layer of the Baturetno Formation indicating that there was an active tectonic process currently working in the Baturetno Basin.

Conclusion

The stratigraphic observation of the Baturetno Formation at six locations in the western part of the Baturetno Basin, shows that the Baturetno Formation is composed of sand, conglomerate lenses, and clay layers. Using the white clay layer as a marker bed, the Baturetno Formation can be classified into three units: (1) a gravel unit (GR) in the upper part, (2) a clay unit (CU) in the middle part, and (3) a sand-gravel unit (SG) in the lower part. As the dominant fragment of the conglomerate lenses both in the GR and the SG units is andesite, it can be concluded that there was no shifting course of the Bengawan Solo Purba River due to Pliocene tectonic tilting that controlled the deposition of the Baturetno Formation. Its mean that there was no palaeolake formed in relation to tectonic tilting and the black clay layer is not a palaeolake deposit. As also further evidenced by the occurrence of floating fragments in the clay layers, the Baturetno Formation was deposited by mudflow/alluvial fan processes. The result of this research adds significantly to the understanding of recent sediments in Java.

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