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Sedimentological and Micropaleontological Characteristics of the Black Clay Deposit of the Baturetno Formation, Wonogiri, Central Java

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Abstract - A previous research on black clay of the Baturetno Formation identified that this clay was a palaeolake deposit. In this study, the black clay deposit was characterized by using sedimentological and micropaleontological approaches to reveal its origin. The black clay of the Baturetno Formation has a low organic matter (mostly less than 8%) and almost no pollen content. These characteristics are not representative of a lake deposit. This black clay was suggested a mud flow deposit. This conclusion is supported by the occurrence of dispersed rock fragments in the clay deposit. In addition, the previous research has identified that the formation of a palaeolake was related to the Late Pliocene tilting in South Java. The carbon dating indicates that the deposition of this clay has no relationship to the Late Pliocene tilting in South Java as the age of this clay was determined to be much younger (around 7000 BP; early Holocene).

Keywords: Baturetno Formation, sedimentology, micropaleontology, palaeolake, black clay deposits

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Introduction

The Baturetno Formation occupying the Baturetno Basin is situated in the northern part of the Southern Mountain physiographic region of Java, and is part of the Solo Depression Zone (van Bemmelen, 1949; Surono *et al*., 2013, Figure 1). The sedimentary deposits of the Baturetno Formation consist of sand, gravel, and clay (dominated by black clay). The Baturetno Basin is geographically surrounded by Miocene formations that consist of the limestone-dominated Punung and Wonosari Formations to the east, west and south; and volcaniclastic deposits of the Mandalika Formation to the north and northwest.

According to previous studies (Lehman, 1936; van Bemmelen, 1949; Wiyono, 1992; Surono, 2005), the depositional process of the Baturetno Formation was related to the Late Pliocene tectonic uplift in Southern Java. Lehman (1936), van Bemmelen (1949), and Surono (2005) hypothesized that the Bengawan Solo River once flowed from its upper course in the north area and emptied into the Sadeng Beach area (Figure 1) in the Indian Ocean. The course of the river eventually turned northwards as a result of the Late Pliocene tectonic uplift. The old river course, called Bengawan Solo Purba (Lembah Kering Sadeng - Giritontro) is now dry. It has been hypothesized that the northward flow of the

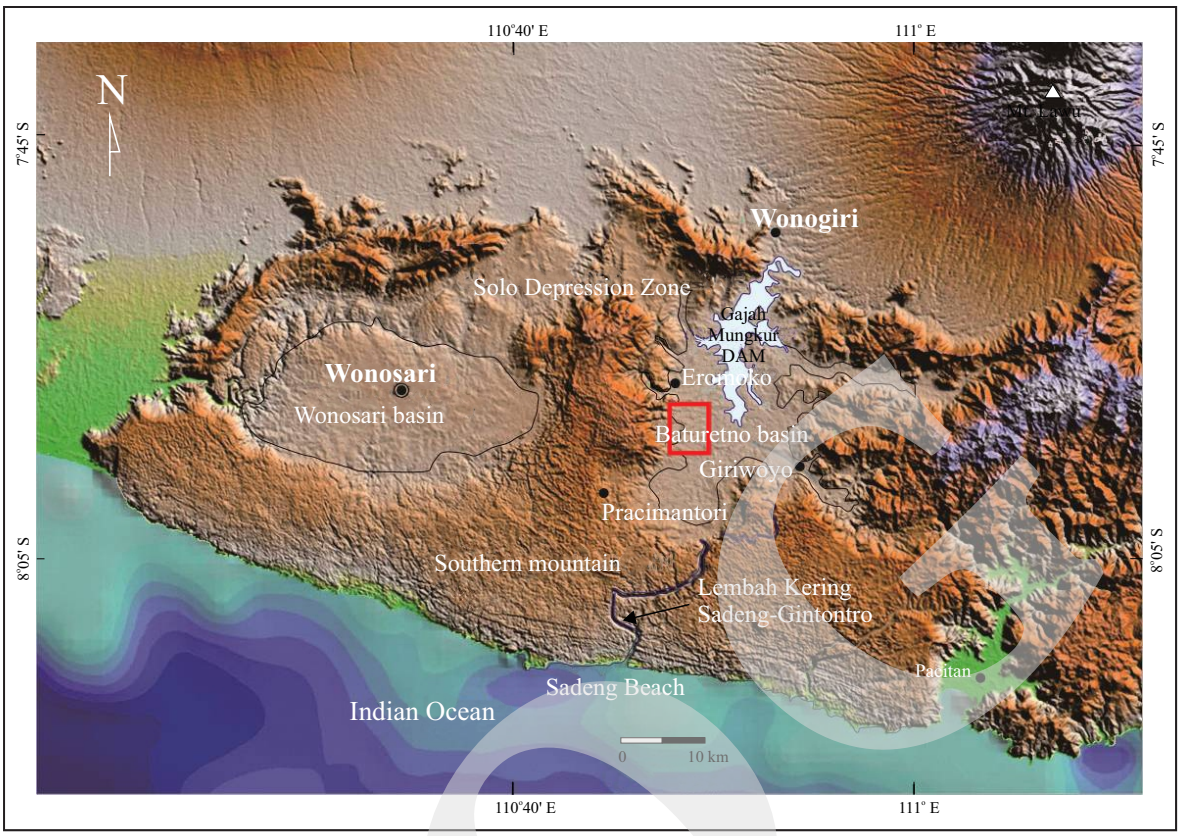

Figure 1. Research area (red box) located within the Solo Depression Zone in the northern area of Southern Mountain (modified from Surono *et al*., 2013).

Bengawan Solo River filled the Baturetno Basin with water and formed the Baturetno palaeolake (Figure 2).

Based on the geomorphological evidence and the wide distribution of the black clay deposits in the Baturetno Basin, Lehman (1936) concluded that the black clay is from the Baturetno palaeolake. Wiyono (1992) observed that the Baturetno Formation consists of intercalation of yellowish white tuff and sands that show gradation, with gravel lenses. The black clay deposit is massive and contains caliche fragments. Speculatively, Wiyono (1992) concluded that the black clay layer was deposited as part of the the Baturetno palaeolake unit.

Surono (2005) observed that Lembah Kering Sadeng - Giritontro valley can be divided into two segments based on an analysis from satellite imagery and field observations. These segments are separated by the deposits of the Baturetno Formation. This means that the deposition of the Baturetno Formation occurred after the Lembah Kering Sadeng Giritontro valley formed. Based on this, Surono (2005) agreed with the previous researchers that the Baturetno Formation was related to the Late Pliocene tectonic uplift in Southern Java. Samodra (2007) and Surono *et al.* (2013) however give a different conclusion. They conclude that there was no relation between the Lembah Kering Sadeng - Giritontro river course and the Bengawan Solo River, and there was no shifting of course in the Bengawan Solo Purba flow, as the relic Lembah Kering Sadeng - Giritontro river was a different system not related to the Bengawan Solo River. Although Surono *et al.* (2013) identified that the black clay of the Baturetno Formation was a lake deposit; there was no clear geological evidence or explanation that supported this conclusion. Putra and Yulianto (2015) studied the Baturetno Formation in the western part of Baturetno Basin and found that the stratigraphy of the Baturetno Forma-

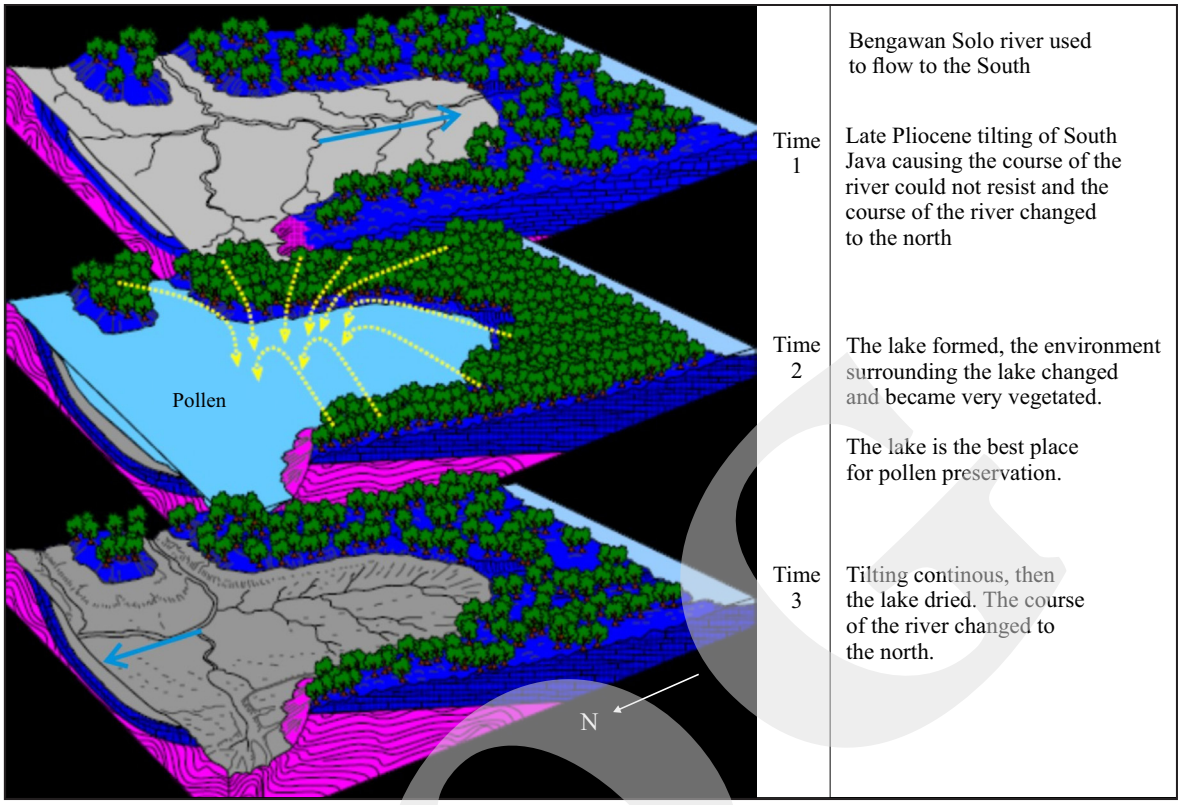

Figure 2. Schematic diagram of palaeolake formation, according to Lehman (1936).

tion shows no evidence of paleolake formation and concluded that the Baturetno Formation is an alluvial fan deposit and the black clay layer deposited from a mud flow process, as there are dispersed gravel fragments in the black clay layer.

In this paper, a combined approach of sedimentology and micropaleontology has been used to describe the characteristics of the black clay of the Baturetno Formation in order to understand its origin. Furthermore, there has been no scientific explanation on the mechanism of formation for the Baturetno Palaeolake. If the black clay of Baturetno Formation is a palaeolake deposit, the sedimentology and micropaleontogy of this deposit should be characteristics of a lake environment. The black clay deposit should not contain rock fragments as lake deposition occurs under very calm or quiet conditions. The percentage of organic content within the lake deposit should also be high, more than 25 % (see Shuman, 2003; and Gasiorowski, 2008). On the other hand, lake environments are good places for pollen and diatom preservation. Thus, it is hypothesized that the black clay of the Baturetno Formation should contain significant quantities of pollen and diatoms. If so, the pollen data could be used to reconstruct the paleoecological development and vegetational changes around the lake.

Material and Methods

In this study, an outcrop at Nglegong Village was observed in detail (Figure 3). Data collected include stratal thickness, textures, sedimentary structures, and lithostratigraphic boundaries. Samples of the black clay from this outcrop were collected for laboratory analyses (Figure 4) that consisted of sedmentological, micropaleontological, and dating analyses. The analysis to understand the sedimentological characteristics consists of loss on ignition (LoI) and x-ray diffraction (XRD). A total of twenty-three samples were analyzed for LoI. LoI is a common method to estimate the organic material and carbonate content of sediments (*e.g.* Bengtsson and Enell,

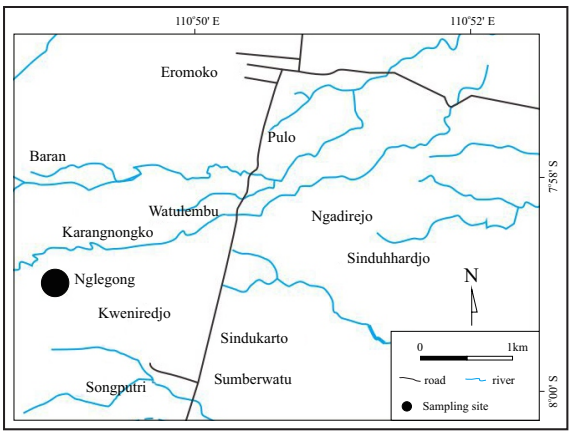

Figure 3. Map showing locations of the outcrop at Nglegong village (black circle) where samples for the laboratory analysis were taken. Other name are local villages. This map is the detail of the red box seen on Figure 1 (Modified form Putra and Yulianto, 2015).

Figure 4. Outcrop of sampled black clay layer. Inset picture is the layer which was sampled (layer shown here is 2 m thick).

1986; Heiri *et al*., 2001). In a first reaction, the organic matter is oxidized at 550°C and in a second reaction, the carbon dioxide is evolved from carbonate at 950°C (Heiri *et al*., 2001). The sample weight difference before and after burning at 550°C is used to calculate the percentage of the organic matter. The weight difference before and after burning at 950°C is used to calculate the carbonate content.

An X-ray diffraction (XRD) analysis was used to determine the mineralogy of the clay deposits. Two samples of black clay taken from the upper (X1) and lower part (X2) of the layer were analyzed for the XRD analysis. The XRD analysis was conducted using X-ray Diffraction PANalytical X'Pert PRO PW3040/x0 at the XRD Laboratory, Centre for Geological Survey, Geological Agency in Bandung. The micropaleontology analysis consists of palynology and diatom analysis using twenty-eight and twenty-three samples, respectively. Palynological analyses were conducted at the Palynology Laboratory, Centre for Geological Survey, Geological Agency. Diatom analyses were conducted at the Biological Department of Diponegoro University in Semarang. Samples for carbon dating (two bulk samples) which were also taken from the black clay layer, were analyzed using Koken 292 and Perkin Elmer Quantulus Spectrometer 1220 at Geochronology Laboratory Centre for Geological Survey, Geological Agency in Bandung.

Result

Stratigraphy of the Baturetno Formation at Nglegong Village

Alluvial deposits of the Baturetno Formation in this location have an unconformable contact with the underlying Miocene-age Semilir Formation (Figure 5). Outcrop reconstructions can be seen on Figure 6. Stratigraphically, the outcrop at this location consists of a massive and hard layer of black clay with abundant caliche and andesite fragments (up to 15 cm in diameter), intercalated with a white clay layer (Figure 7).

Figure 5. Unconformable contact between the Baturetno and Semilir Formations. From Putra and Yulianto (2015).

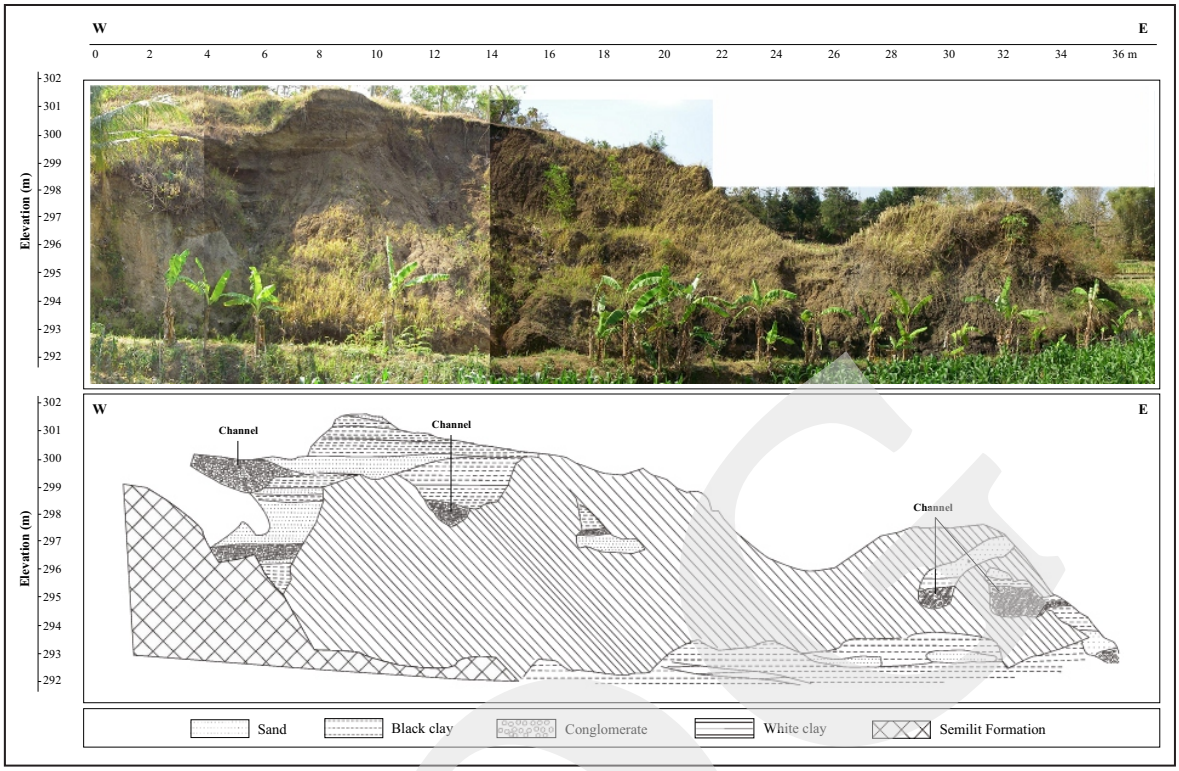

Figure 6. Outcrop photograph (A) and sketch of the Nglegong Village outcrop (B). From Putra and Yulianto (2015).

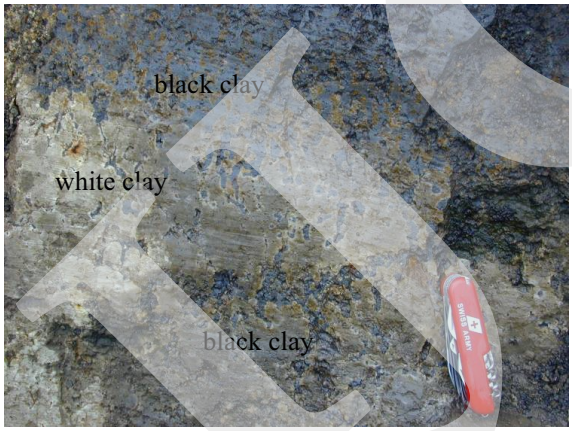

Figure 7. Layer of white clay intercalated in the black clay. From Putra and Yulianto (2015).

In the eastern part of this outcrop at Nglegong Village, the clay layers are cut by a channel of open fabric (no contact between the fragments), poorly sorted conglomerate. The dominant fragment type of this conglomerate is andesite, with the largest fragment diameter measured up to 15 cm. On the upper part of this conglomerate channel, dark – yellowish brown, soft clay layers with abundant andesite fragments were deposited. In the western part, these clay layers are cut by a one-meter-thick massive and poorly sorted conglomeratic channel. The uppermost deposits at this location consist of medium grained sand and clay layers. Each of these sand and clay layers has a thickness of less than 50 cm.

Sedimentological Characteristics

Organic material and carbonate content

The results of LoI analysis are shown in Table 1. The organic content of the clay ranges from 4 to 14.5 %. Most of the samples have LoI values less than 8 %, only 3 samples have LoI value higher than 8 %. On the other hand, the carbonate content in the clay samples was relatively higher than the organic matter content. The carbonate value ranges from 12 to 25 %.

XRD analysis

The XRD analysis of the clay samples shows that the mineralogy consists of montmorilonite and illite. Other observed minerals are chloritoid, quartz, iron, cristobalite, and coalingite (Table 2 and 3).

Table 1. Organic Matter and Carbonate Content (in %) in the Clay Samples

Sample Number	LOI		Sample Number	LOI	
	Organic Material (%)	Carbonate (%)		Organic Material (%)	Carbonate (%)
A. 0-2	8.78	12.69	B. 15-17	6.64	15.33
A. 16-18	7.76	14.06	B. 25-27	6.46	15.04
A. 46-48	9.12	14.55	B. 45-47	5.43	13.90
A. 61-63	8.01	14.95	B. 60-62	4.95	13.11
A. 76-78	6.19	13.80	B. 75-77	4.72	13.63
A. 91-99	14.58	24.89	C. 5-7	6.07	16.42
A.100-106	4.71	14.51	C. 15-17	6.77	16.19
A.121-123	6.71	15.30	C. 35-37	6.40	15.33
A.136-138	6.38	15.94	C. 50-52	6.79	13.92
A.151-158	7.17	16.55	C. 55-57	6.77	14.98
A.166-168	6.63	15.08	C. 60-62	7.41	14.99
B. 0-2	7.43	16.33			

Table 2. Result of XRD Analysis of Sample X1, taken from the Upper Part of Clay Layer

Ref. Code	Score	Compound Name	Displacement (° 2Th)	Scale Factor	Chemical Formula
00-003-0010	8	Montmorillonite	0.000	0.470	(Na, Ca)0.3 (Al, Mg)$_2$ Si$_4$O$_{10}$ (OH)$_2$!x H$_2$O
00-006-0158	11	Chloritoid	0.000	0.558	(Fe, Mg)$_2$ Al$_4$ Si$_2$ O$_{10}$ (OH)$_4$
01-071-0785	33	Silicon oxiden (cristobalite)	0.000	0.361	SiO$_2$
01-082-0511	20	Quartz	0.000	0.023	SiO$_2$

Table 3. The Result of XRD Analysis of Sample X2. Sample X2 taken from the Lower Part of Clay layer

Ref. Code	Score	Compound Name	Displacement (° 2Th)	Scale Factor	Chemical Formula
01-089-7194	54	Iron	0.000	0.997	Fe
00-029-1496	2	Illite-1\ITM\RG [NR]	0.000	0.075	K 0.7 Al$_2$ (Si, Al)$_4$ O$_{10}$ (OH)$_2$
00-026-1217	6	Coalignite	0.000	0.455	Mg$_{10}$ Fe$_2^{+3}$ CO$_3$ (OH)$_{24}$!2 H$_2$O
01-086-1560	28	Quartz	0.000	0.153	SiO$_2$
00-004-0379	13	Cristobalite	0.000	0.174	SiO$_2$

Micropaleontological Characteristics

Pollen content

Palynological analysis of twenty-eight black clay samples show that the pollen content is very low to barren. Only one sample contains five individual pollen species.

Diatom analysis

From the twenty-eight samples that have been analysed, the diatom content is dominated by the occurrence of *Achananthes minutissima, Cyclotella stelligera, Tabellaria, Synedra ulna, Eurotia exigua, E. incise, Frustullia rhomboids, Neidrum affine, T. flocculosa, Fragillaria construens, F. cappucina, F. virescens,* and *Nitzschia palea*. These species are fresh water species (du Buf and Bayer, 2002). *A. minutissima* has a habitat in upstream rivers (heading towards the source of the river) (Medley ad Clements, 1998). *C. stelligera, Tabellaria, S. ulna*

characterize mesotrophic water. *Achananthes, E. exigua, E. incise, F. rhomboids, N. affine,* and *T. flocculosa* are species found in acidic environments with pH less than 5. Meanwhile, the habitat of *F. construens, F. cappucina, F. virescens,* and *Nitzschia palea* are found in water with normal pH.

Age of the Black Clay of Baturetno Formation

The result of carbon dating of two bulk samples taken from the upper and lower part of the clay layer at Nglegong Village outcrop indicates that the age of the clay is approximately 7.000 years BP (Early Holocene, Table 4).

Table 4. The Carbon Dating Result of Two Bulk Samples of the Clay Layer

Sampling part	Age
Upper part	6400 ± 760 B.P (1950)
Lower part	7010 ± 210 B.P (1950)

Discussion

Based solely on the wide geographic distribution of the clay deposit, a previous research concluded that the black clay of the Baturetno Formation was formed as a palaeolake deposit (*e.g.* Lehman, 1936; van Bemmelen, 1949; Wiyono, 1992; Surono, 2005). The palynological analysis of this clay, however, indicates that it is mostly barren of palynomorphs. This result is very surprising because if the black clay was deposited within a lake environment, then it should contain significant amounts of pollen (Morley, 1982). Typically, lake edges are well vegetated which normally results in abundant terrestrial plant material (including spores and pollen) being deposited within those lakes (Morley, 1982). A likely explanation for the barren pollen content is that the black clay was not formed within a lake deposit but was a result of a depositional system with a high rate of sedimentation. On the other hand, the diatom content indicates that the black clay was deposited in fresh water under mesotrophic, acidic to pH normal conditions.

The results of LoI analysis indicate that the black clay has a very low organic matter content (maximum 14.5%). If this black clay deposit was a lake sediment, the organic matter content would be expected to be higher. Gasiorowski (2008) analyzed the LoI of lake sediments in the Polesie Lubelskie region, eastern Poland, and identified that the organic matter content is up to 70% (mostly ≥ 25%). The results of Gasiorowski (2008) are consistent with Shuman (2003) who studied the LoI of sediments from two lakes in the northeastern part of United States. Shuman (2003) identified that the organic matter content varies little across the deep portion of the lake, and the maximum value of organic matter is up to 65%. On the other hand, Meyers and Eadie (1993) identified that the organic carbon in the sediment of Lake Michigan in North America ranges from ~5 to 46 %. Because Meyers and Eadie (1993) only measured the organic carbon content, the organic matter content is most likely higher.

The palynological and LoI analysis results indicate that the black clay layer was not formed as a lake deposit. The XRD analysis results show that montmorilonite and illite are dominant within the black clay layer. Montmorilonite and illite mostly resulted from the weathering of volcanic rocks. The Miocene-age volcaniclastic sediments, which outcrop to the north of the Baturetno Basin, may be a source for the clay layer. In addition, it is also found that there were floating fragments of volcanic rocks in the black clay layer (Figure 8). These floating fragments cannot be explained if

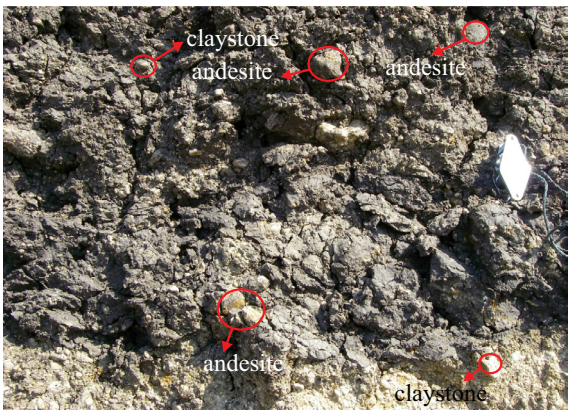

Figure 8. The floating rock fragments in the black clay deposit.

the clay was deposited within a lake environment (Putra and Yulianto, 2015).

Previous studies of this black clay always correlated the Pliocene tilting in the South Java region with the formation of a palaeolake in the Baturetno Basin. The dating indicates that the formation of the black clay has no relation with the Pliocene tilting in South Java as the age of the black clay is much younger. The dating results support the hypothesis that the black clay was not a lake deposit. This black clay was interpreted a mud-flow deposit. This is consistent with the stratigraphic study of the Baturetno Formation by Putra and Yulianto (2015) who identified the Baturetno Formation as alluvial fan deposits with the black clay layer as mud flow deposits.

Conclusion

The black clay deposit of Baturetno Formation has characteristics of very low organic matter content, rare palynomorphs, mostly montmorilonite and illite clay minerals, diatoms which indicate fresh water, and age dates indicating deposition around 7,000 BP. Very low organic matter content and lack of pollen are not the characteristics of a lake deposit. Thus, this black clay deposit was inferred not to be formed within a palaeolake and is more likely to have originated as a mud-flow deposit.

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