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Volcanostratigraphic Sequences of Kebo-Butak Formation at Bayat Geological Field Complex, Central Java Province and Yogyakarta Special Province, Indonesia

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Abstract - Bayat Complex is usually used as a work field for students of geology and other geosciences. The study area is located in the southern part of the Bayat Complex. Administratively, it belongs to Central Java Province and Yogyakarta Special Province. The lithology of Bayat is very complex, composed of various kinds of igneous, sedimentary, metamorphic, and volcanic rocks. Most of previous researchers interpreted Bayat as a melange complex constructed within a subduction zone. Kebo-Butak is one of formations that forms the Bayat field complex. The formation is composed of basalt, layers of pumice, tuff, shale, and carbonaceous tuff. Most of them are known as volcanic rocks. These imply that volcanic activities are more probable to construct the geology of Bayat rather than the subducted melange complex. The geological mapping, supported by geomorphology, petrology, stratigraphy, and geological structures, had been conducted in a comprehensive manner using the deduction-induction method. The research encounters basalt, black pumice, tuff with basaltic glasses fragments, zeolite, argilic clay, as well as feldspathic- and pumice tuff. Petrographically, the basalt is composed of labradorite, olivine, clinopyroxene, and volcanic glass. Black pumice and tuff contain prismatic clinopyroxene, granular olivine, and volcanic glasses. Feldspathic tuff and pumice tuff are crystal vitric tuff due to more abundant feldspar, quartz, and amphibole than volcanic glass. Zeolite comprises chlorite and altered glasses as deep sea altered volcanic rocks. The geologic structure is very complex, the major structures are normal faults with pyrite in it. There were two deep submarine paleovolcanoes namely Tegalrejo and Baturagung. The first paleovolcano erupted effusively producing basaltic sequence, while the second one erupted explosively ejecting feldspathic-rich pyroclastic material. The two paleovolcanoes erupted simultaneously and repeatedly.

Keywords: volcanism, Bayat Complex, Kebo-Butak Formation

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Introduction

Bayat Complex is one of regions in Java which is usually used as a geological field laboratory for geological students and other geoscientists, in addition to Karangsambung (Kebumen) and Bayah (Ciletuh). In fact, up to now, debates about the geology of Bayat are still continuing. The oldest methamorphic rocks exposing in Jiwo Hills, were interpreted as a Cretaceous subduction zone (Asikin, 1974; Katili, 1975; Hamilton, 1979; Suparka, 1988; and Parkinson, 1998). The argumentation is still followed by many students and others, up to now. Later, other experts no longer argue that

Bayat is a Cretaceous subduction zone (Bronto *et al*., 2002 and 2004; Sutanto, 2003; Laksono, 2007; Bronto, 2009 and 2013; and Satyana, 2014 pers. comm). Volcanism played a major role in affecting geology of Jiwo, forming basaltic lavas, gabbro, and diorite intrusions (Bronto *et al*., 2002 and 2004; Bronto, 2009 and 2013;).

In general, geology of Bayat is divided into two major groups, *i.e*., Jiwo in the north and Southern Mountain in the south. The lithology of Jiwo is composed of mica schist, gabbro, diorite, marble, limestone with *Numulithes* sp., and calcarenite. The Southern Mountain is also known as Baturagung Range consisting of shale, black tuff, basalt, and zeolite of Kebo-Butak Formation; pumiceous tuffs and breccias of Semilir Formation; as well as andesitic agglomerates, lavas, and breccias of Nglanggeran Formation. All of those rocks unconformably overlay claystone and marl of Gamping/Wungkal Formation (Sumarso and Ismoyowati, 1975; Samodra dan Sutisna, 1997; Rahardjo, 1983; Surono *et al.*, 2006;).

Many geologists have different opinions on the formation and the origin of Kebo-Butak Formation (Rahardjo *et al*., 1977; Soesilo, 2003; Surono, 2008; and others). According to Hidayat (2006), Trianto (2006), and Surono (2008) sandstones of Kebo-Butak Formation are epiclastic volcanic rocks, which were quickly transported by a turbiditic mechanism along slope areas. So, there is no abundance of fossils. According to Rahardjo (1983) and van Gorsel *et al*. (1987), the Kebo-Butak Formation comprises layers of conglomeratic sandstones, claystones, and siltstones of Late Oligocene (N2-N3; Sumarso and Ismoyowati, 1975) in age, deposited in a lower submarine fan with few interruptions of the mid fan type sedimentation. Bronto *et al*. (2002 and 2004) and Bronto (2009 and 2013) argued that rocks composing the Kebo-Butak, Semilir, and Nglanggeran Formations, are volcanic rocks formed by volcanisms. Thereby, these volcanic rocks are associated with basalts and other intrusive rocks exposed in Jiwo Hills. However, based on stratigraphy and petrology studies of the Kebo-Butak Formation, it is hypothesized that the volcanisms took place in a very long period.

The studied area is located in the southern part of the geological complex of Bayat. Administratively, it belongs to Gedangsari Subregency, Gunungkidul Regency, Yogyakarta Special Province, and Cawas and Bayat Subregencies, Klaten Regency, Central Java Province (Figure 1). This study uses a volcano-stratigraphic ap-

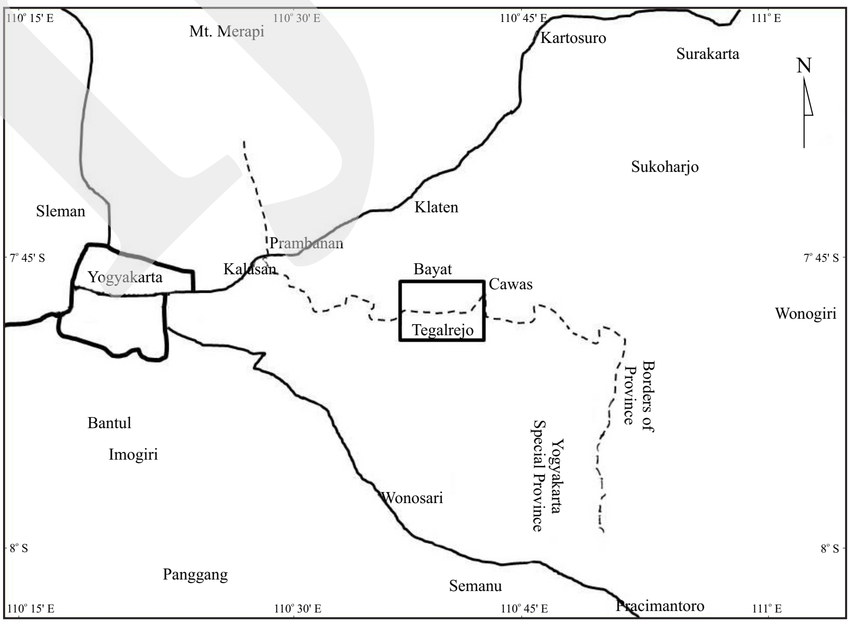


Figure 1. Locality map in surrounding Yogyakarta Special Province and Central Java Province (withoutscale).

proach covering geomorphological observations, stratigraphic and structural geological measurements, as well as other related geological mapping. Geomorphological observations cover the western, southern, eastern, and northern sides of Baturagung Range. Stratigraphic measurements were done in Santren, Nampurejo, Jumbleng, Trembono, Gedangan, and Eyangkuto of the eastern site; and Talun, Tegalrejo, Curug, Cermo, and Watutumpeng Hill of the western site.

Basic Theory and Regional Geology

Geologists have agreed that sedimentary rocks are formed from pre-existing rocks or pieces of once-living organisms, which then deposited on the earth surface. Sedimentary rocks often have distinctive layering or bedding. On the other words, sedimentary rock is the rock that has formed through deposition and solidification of sediments, especially sediments transported by water (rivers, lakes, and oceans), ice (glaciers), and wind. Sedimentary rocks are often deposited in layers, and frequently contain fossils. A turbidite is the geologic deposit of a turbiditic current, which is a type of sediment gravity flow responsible for distributing vast amounts of clastic sediment into a deep ocean. Bouma (1962) determines that turbidites begin with an erosional contact of a coarse lower bed of pebble to granule conglomerate in a sandy matrix. Then they grade up through coarse then medium plane parallel sandstone through cross-bedded sandstone; rippled cross-bedded sand/silty sand, and finally laminar siltstone and shale. This vertical succession of sedimentary structures, bedding, and changing lithology is a representative of strong to waning flow regime currents and their corresponding sedimentation. Volcanic rocks can be coherent or noncoherent. Coherent volcanic rocks are produced by effusive eruptions and/or shallow intrusions beneath a volcano. Noncoherent volcanic rocks are formed by explosive volcanic eruptions and/or glowing avalanches. The materials are called tephra, pyroclastics, or ignimbrites. In principle, turbidite and pyroclastic origins are physically different (Figure 2).

Preliminary study found that the Kebo-Butak Formation comprises volcaniclastic rocks consisting of basaltic tuff, dacitic to andesitic pumice, and basalt pillow lava locally contains shale, marl, and zeolite. On the basis of volcanism, explosive eruptions constructed volcanostratigraphy sequences composed of very high grade clastic materials; effusive eruptions producing coherent lava. All of those materials constructing the body form stratovolcano. It means that the volcano is composed of vocanic materials consisting of lavas, pyroclastic deposits, and intrusions. Those could be basaltic-, andesitic-, dacitic-, and rhyolitic compositions, or all of them occur within the volcano.

Explosive eruptions are caused by the enormous accumulated energy originated from the magma chamber. Even though the energy is able to throw the entire contents of the magma chamber, the wall rocks and third parts of the body volcano are known as "caldera forming eruption". During the Quaternary period, most of the submarine caldera-forming eruptions were accompanied by tsunamis that were caused by the collapse of volcanic edifice (Maeno and Imamura, 2011; Figure 3). Following the 1883 eruption of the Krakatau, Indonesia, a large pyroclastic flows and tsunamis arrived at numerous coastal villages in Java and Sumatra (Carey *et al.*, 1996; 2000), depositing few qubic kilometers of volcanic materials under sea water.

It can be interpreted that submarine volcanic materials may be interupted with marine sediments, such as marls, carbonates, and sandstones that contain fossils. But within the thick volcanic materials they will not be able to preserve fossils, caused by the acidity of the materials. After that, during the quite period of volcanism, thin sediments may contain fossils. Figure 4 shows that deposition of volcanic materials of submarine explosive eruptions happened within high and huge energy generated by collapsing column eruption mixing with sea water (Figure 4b). That can form mud supported suspension composed of blocks,

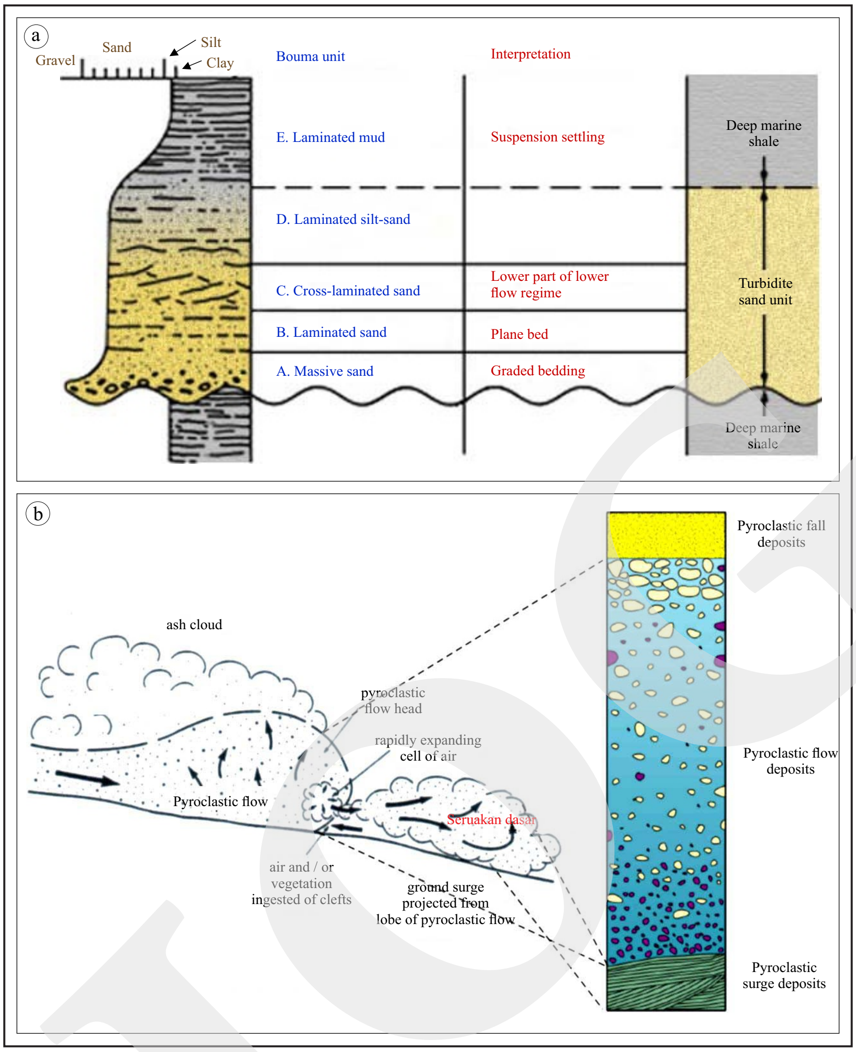


Figure 2. Characteristics of: a. turbidite formation (Selley, 1970) and b. pyroclastic formation (Cas and Wright, 1987).

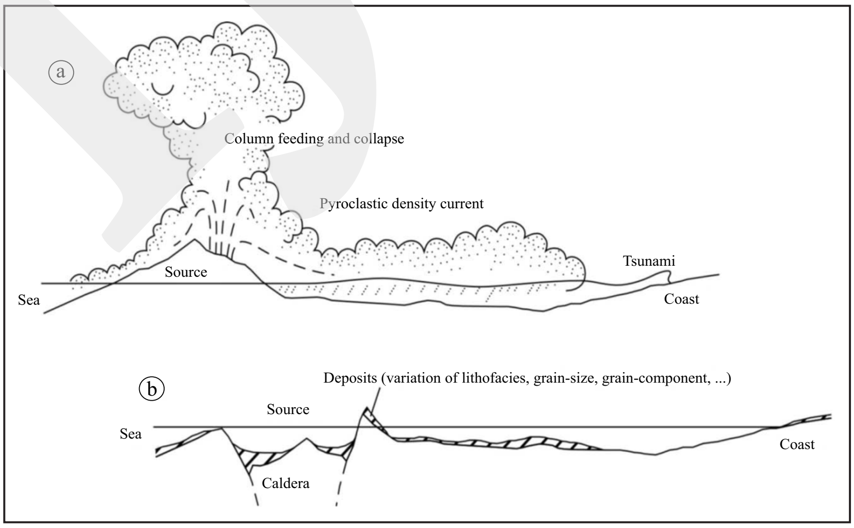


Figure 3. Idealized processes during a marine caldera-forming eruption (Maeno and Imamura, 2011). a. Pyroclastic density currents are generated from column collapsing, and they enter or travel over the sea. Tsunamis may be generated during these processes and reach coastal areas. b. Resultant deposits are distributed on subaerial and submarine fields near the volcano.

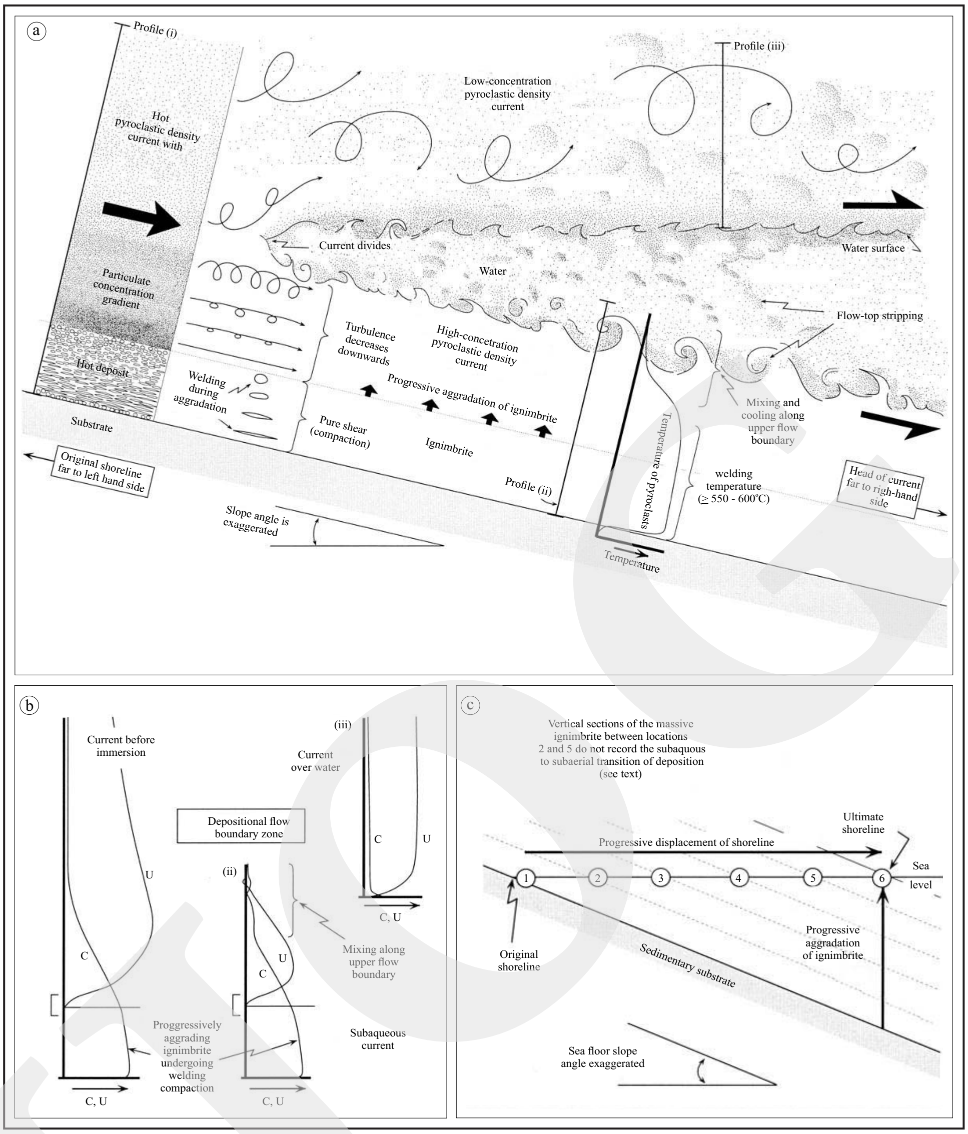


Figure 4. Profile of hot submarine pyroclastic density currents sequences (Peccerillo and Frezzotti, 2015): a. The dynamic of submarine pyroclastic density currents; b. Graphic showing the immersion during depositional until welding compaction that causes mixing of the ignimbrites and the submarine sediments; c. Vertical section of the massive ignimbrite since the original shoreline and deep sea.

bombs, lapillis, ashes, and dust. The suspension then goes down the slope very quickly, pushing sea water up to the beach forming tsunamis, and depositing the pyroclastic materials. The profile of the volcanic materials from the bottom to the top is started by very hot ignimbrite (could be welded), very high concentration of pyroclastic density currents (could be co-ignimbrite breccia with coarse-grained fragments and dense pumice), ashy to dusty lapilli materials with very high energy of surging/turbulent currents (Peccerillo and Frezzotti, 2015).

The regional stratigraphy of study area according to some researchers (Surono *et al*., 1992; Soeria-Atmadja *et al*., 1994; Smith, 2005; Akmaluddin *et al*., 2005; and Prasetiadi, 2007; Surono, 2008), from the bottom to the top, is Cretaceous methamorphics as a basement rock, Eocene Gamping/Wungkal Formation, Oligocene Kebo-Butak Formation, Miocene Semilir and Nglanggeran Formations, Sambipitu Formation, Oyo Formation, Wonosari Formation and Kepek Formation (Figure 5). According to Rahardjo (1983) and van Gorsel *et al*. (1987), the sequence

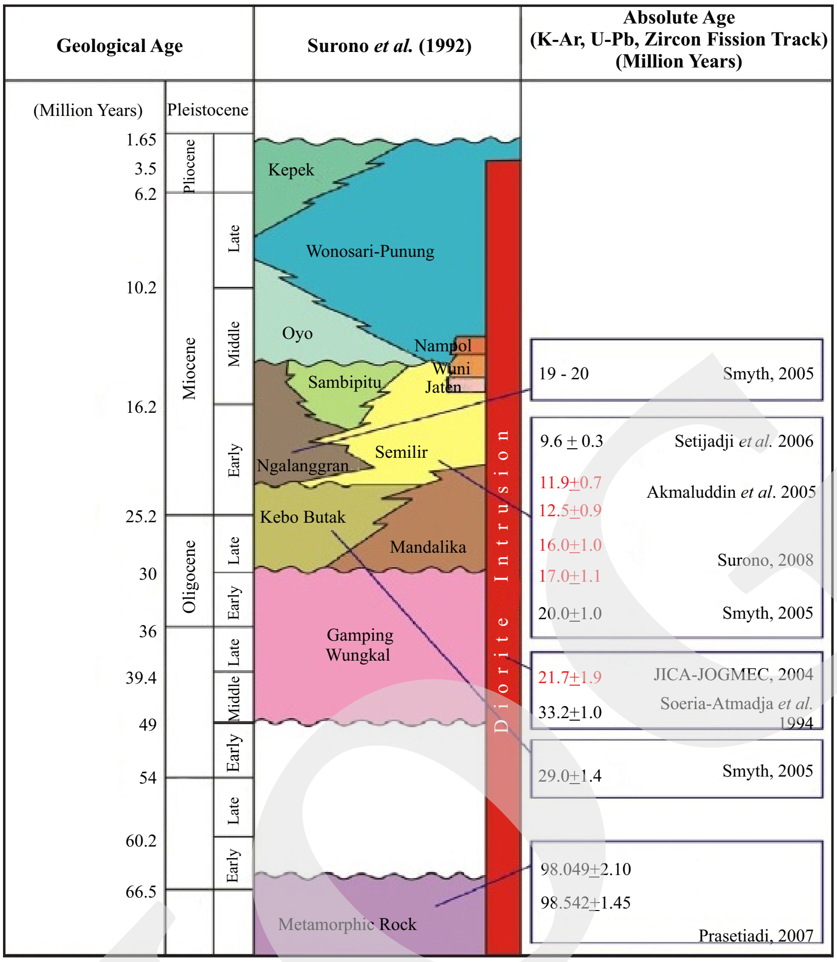


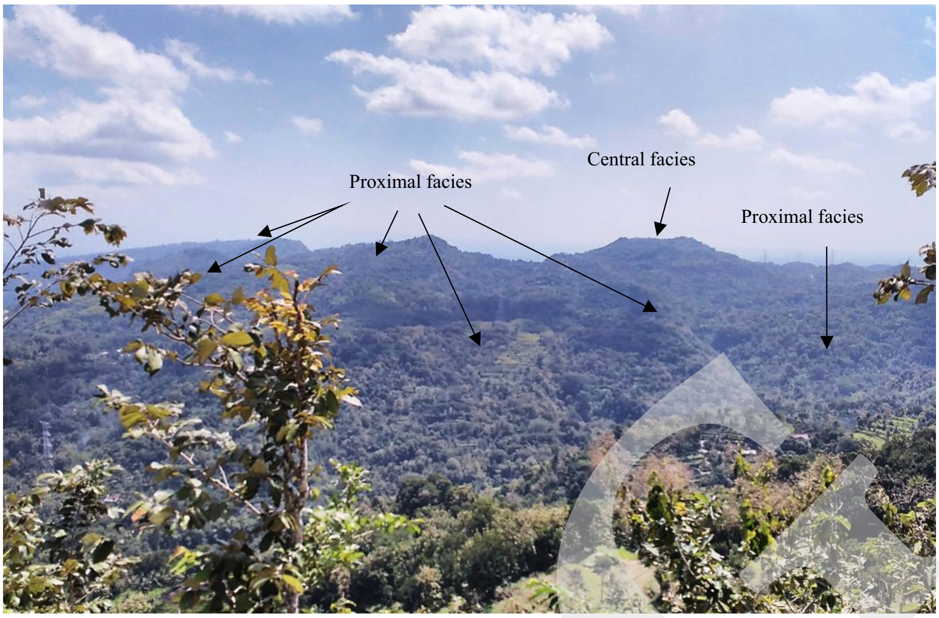
Figure 5. Southern Mountain stratigraphic column (summarized from some previous authors) (image source: Triana, 2013).

of Kebo-Butak Formation is interpreted to form within a lower submarine fan environment with few interruptions of mid-fan type deposition which was formed in the Late Oligocene, N2-N3 (Sumarso and Ismoyowati, 1975).

Result

The study was started by observing geomorphology of the Bayat Complex after Semilir and Nglanggeran areas (Figure 6). It shows a higher range of an overturned morphology in the middle part, interpreted as central facies and supported by andesite dikes as well as lavas exposed at Gedangsari. The feature like geomorphology is surrounded by hills with slopes to the west, south, and east, interpreted as proximal facies. In a view from the east (observed in Pututmati, Bayat Regency), it shows that a hill of the proximal facies located in the eastern side of the Baturagung Range is steeping to the west and sloping slightly to the east. The geomorphological observations in the north, west, and south show that the central facies is located in the centre of each opposing slope.

The stratigraphic measurements have been done in the areas of Talun (stop site 1), Santren (stop site 2), Nampurejo (stop site 3), Jumbleng (stop site 4), Eyangkuto (stop site 5), Trembono (stop site 6), Curug (stop site 7), Tegalrejo (stop site 8), and Watutumpeng Hill (stop site 9) (Figure 7). Those stratigraphic measurements are divided into two groups, *i.e.* western and eastern sides. In the eastern side, the data show two to three sequences of volcanic rocks, from the lower to the top are (1) basaltic pillow lava and basaltic tuffs and pumice, (2) feldspathic tuff and pum-



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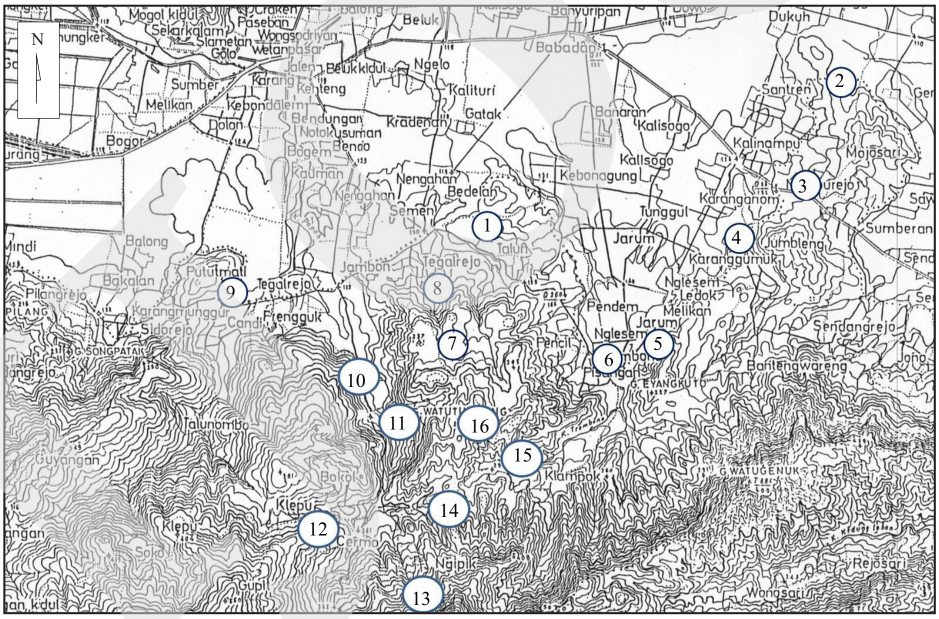

Figure 7. Map of the location and observation research areas (not to scale).

ice, and (3) quartz rich tuff and pumice (Figure 8 - 10). In the western side, the stratigraphic data show two sequences of volcanic materials, namely basaltic sequence and feldspathic-pumice tuff. The first unit is composed of basaltic sill, basaltic pillow lava, and very coarse-grained basaltic pumice. The second one contains brownish andesitic tuff and light grey quartz-rich dacitic pumice (Figure 11 - 12).

Basaltic Sequence

Petrologically, samples taken from Jumbleng (stop site 4), the basaltic pumice, have lighter colour, poorly sorted, diameter 0.5 - 4 cm of basaltic lithic fragments, dark green basaltic lapilli glasses (pumices), clinopyroxene crystals, and some very angular cherty fragments. Basaltic pillow lava is spotedly exposed, some outcrops

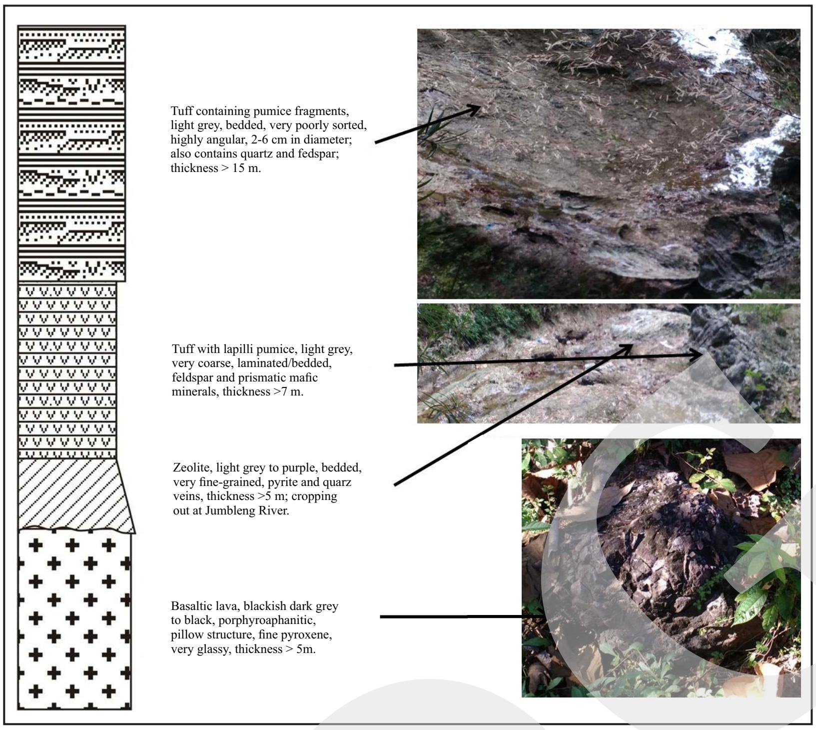

Figure 8. Measured stratigraphic section of Nampurejo-Santren areas showing basalt at the base of the sequence; overlain by bedded zeolite and white tuff.

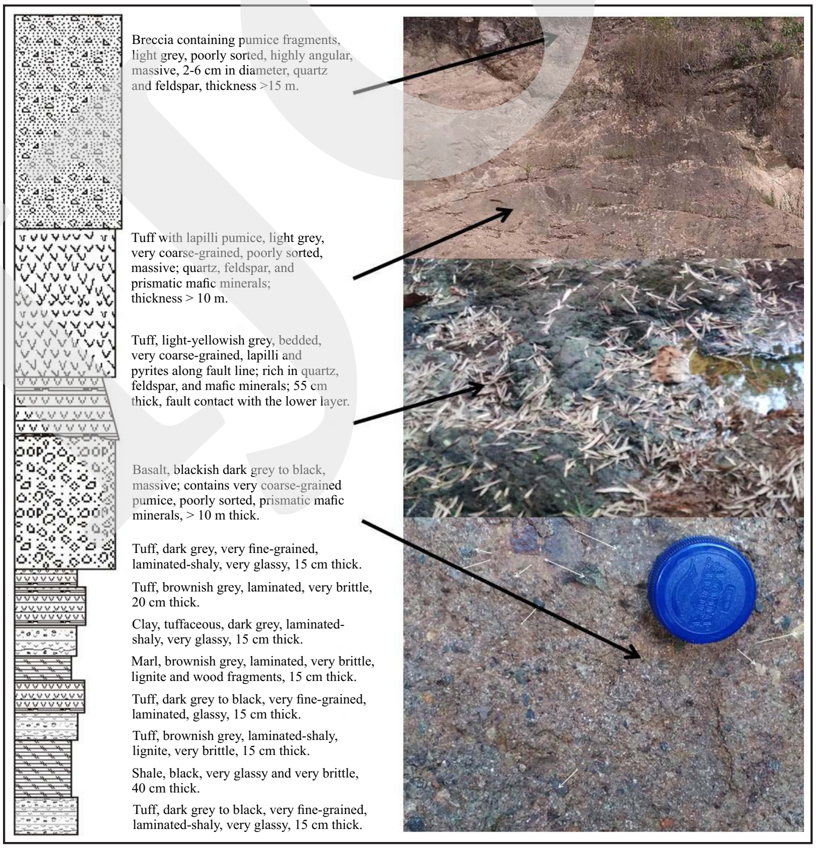

Figure 9. Measured stratigraphic section of Jumbleng River in the lower stream of Trembono that shows dark grey to black tuff and pumice with glassy shale at the base of the sequence; underlying bedded zeolite, white tuff, and feldspathic pumice.

Figure 10. Photograph of basaltic lava outcrop overlain by feldspatic tuff and pumice at Harjosari (stopsite 14).

have 50 - 100 m^2 wide and 5 - 10 m thick. The lava of each pillow is characterized by 1 - 2 m in diameter and 6 - 8 m in length, having radier fractures within the pillow, scoriaceous, very dark-black colour, aphanitic- to glassy textures.

The basaltic pillow lava is exposed at Talun (stop site 1), Kalinampu (stop site 3), and Harjosari (stop site 14). Microscopically, the samples are characterized by scoria to vesicular structures, fine porphyritic- to hipocrystalline textures, with labradorite and hypersthene phenocrysts floating in volcanic glasses and very fine-grained groundmass crystals of plagioclase, olivine, and pyroxene. Very rarely, there are small grains of golden olivine. Basaltic tuff is characterized by very poorly sorted, medium- to -coarse grained. Some of them contain dark green, black and brown lapilli glasses, open fabrics, very glassy, rich in clinopyroxene, green and brown glasses, bitownites-labradorites, and ore minerals. Some samples taken from Tegalrejo (stopsite 8) contain abundant coarse dark volcanic glasses of black and brown pumices. Basaltic lava at Ngipik (stop site 13) and Harjosari (stop site 14) is characterized by structures of plating (less

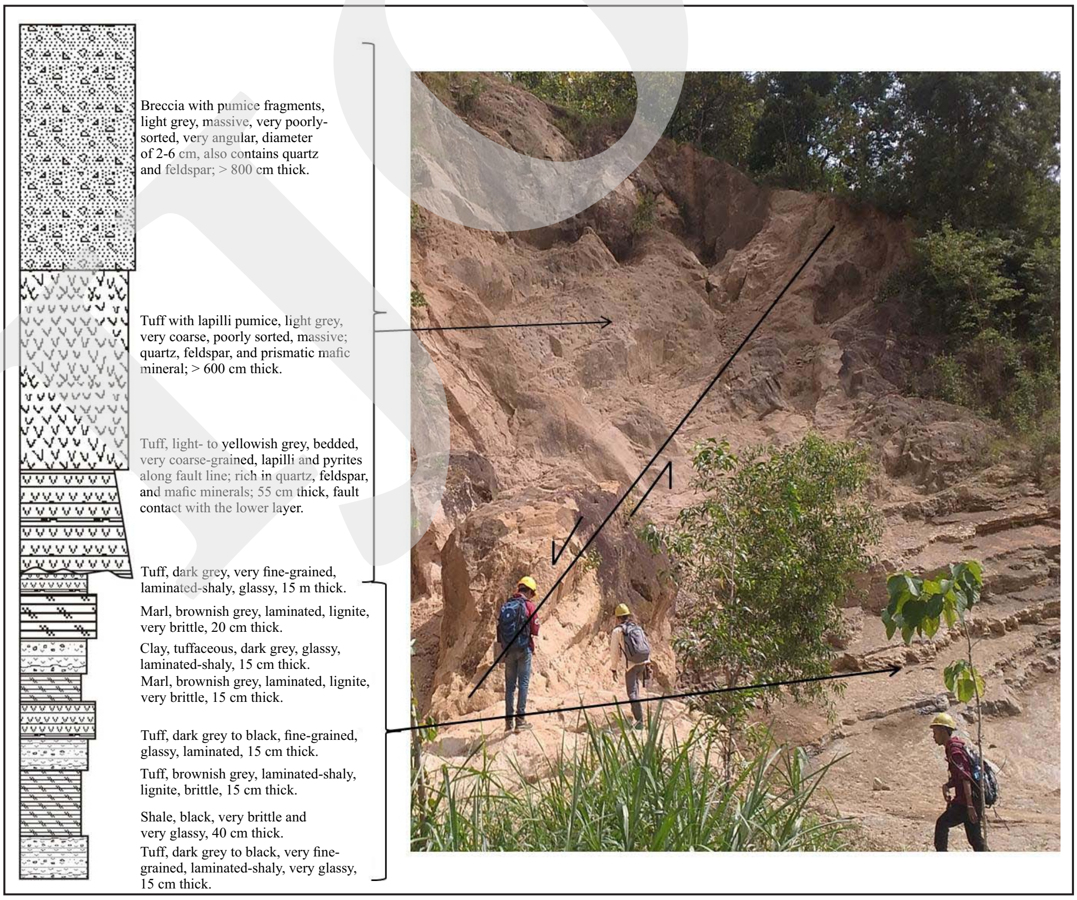

Figure 11. Measured stratigraphic section of Trembono area showing dark grey to black tuff with glassy shale at the base of the sequence; overlain by massive feldspathic tuff and pumice, both are separated by an oblique normal fault plane.

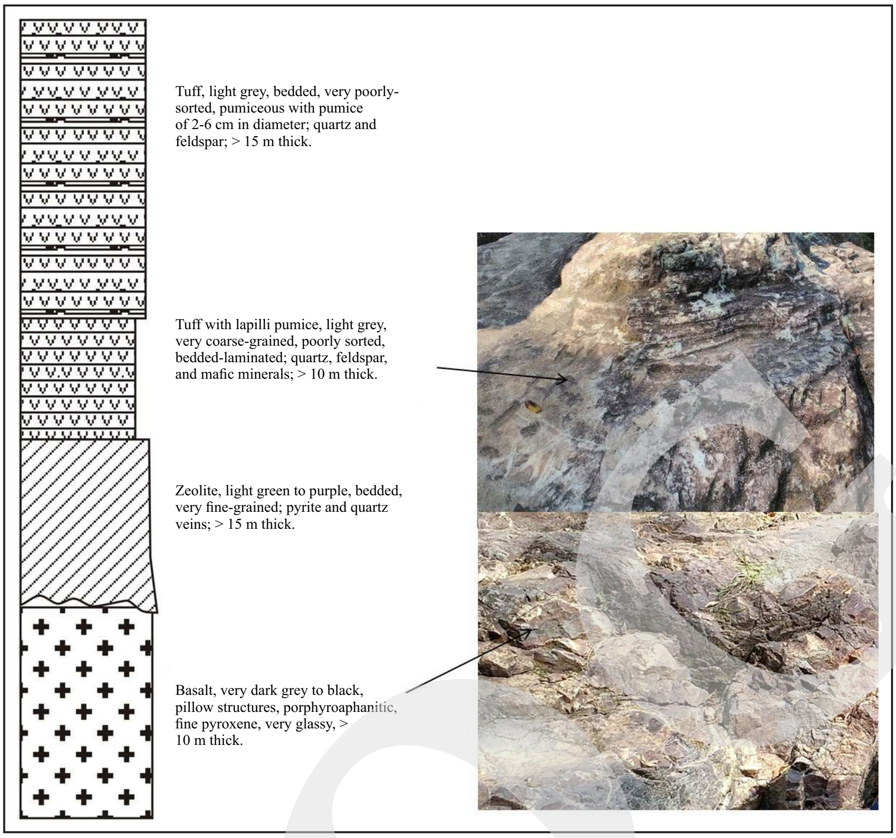

Figure 12. Measured stratigraphic section of Talun area showing basaltic pillow lavas at the base of the sequence; underlying bedded zeolite and white tuff.

than 10 cm per plate) to sheeting (about 10 - 15 cm per sheet) joint, dark grey to dark greenish grey, very fine porphiritic textures with small phenocrysts of feldspars and pyroxene floating within very fine microlith and volcanic glass. This basaltic lava is overlain by light grey tuff and pumice (Figure 10).

Based on depositional structures, Kebo-Butak Formation cropping out within the south-southwestern side of the study areas (Sambeng; Figure 13), is mostly thin layered to laminated structures even splintery (shale-like), intersected with brown marl and lignite. That is why, some of the previous researchers (Bothe, 1929; Surono *et al*., 1992; and Surono, 2008) mentioned that the Kebo Beds are composed of shales, marls, and sandstones with andesitic-basalt/diabas sill. Moving from the northeast to the east of the study area (Ngawen), the bottom of the Kebo-Butak Formation is made up of black tuff and intersection of very fine black tuff and black shale (basaltic glasses), and thin layers of basaltic lavas. These sediments are thin layered until laminated, even splintered, no lignite layers, and spotedly inserted marls. In the areas of Curug-Cermo (stop site 7) the lithology of Kebo-Butak Formation comprises very thick layers of basaltic lapillistones (some more than 2.5 m thick), poorly sorted, often inserted by thin basaltic lavas. Previous researchers (Samudra and Sutisna, 1997; Hidayat, 2006; Laksono, 2007; Surono, 2008) described the basalt layers as black sandstones, some others describe them as *asuit formation* (Rahardjo, pers. comm). The basaltic layers are characterized by dark grey to black colour, very glassy, less crystals initiated by the glassy contains, thin (< 10 cm thick). The top and bottom of the layer often show fractured perlitic borders. No marl and shale over the areas, the sequence thickness is more than 100 m, exposed along the River of Cermo to Tegalrejo.

Depositional structures of the Kebo-Butak Formation exposed at Jumbleng (stop site 5) and

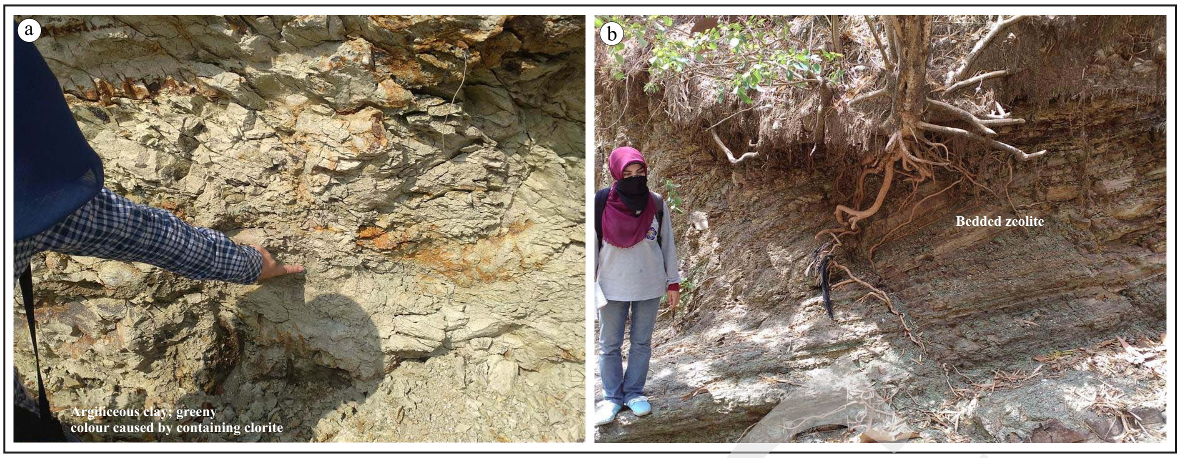

Figure 13. Photographs of outcrops of: a. Argiliceous rocks within Kebo-Butak Formation as part of the feldspathic grey tuff and pumice exposed at Bantengwareng (stopsite 2); b. Yellowish green layered zeolitic tuff as upper clay of Gamping/ Wungkal Formation by previous researchers.

Trembono (stop site 6) are characterized by massive and very thick deposits of dark/black lapilli pumices. The thickness is even more than 75 m, and above them are zeolite beds, dark grey tuffs, and light yellowish grey to brown tuffs (Figure 9). Dark/black lapilli pumices and rocks above them are separated by very deformed rocks of Trembono fault zone. Cherty fragments (interpreted as hydrothermally altered silica) within the black lapilli sequence indicate that the deposits were originated from deep marine conditions. Shale beds crop out at Trembono, in the base of light grey lapilli tuff.

Based on stratigraphic correlation, from the bottom to the top, the basaltic sequence is composed of basaltic pillow lavas overlain by basaltic lapillistones, dark grey to black tuffs, and layers of black shale and marls. Some of them had been deeply deformed, so the older rocks often occupy the higher geomorphology. (stopsite 1, 4 and 5).

Feldspathic-pumice Tuff

These volcanic rocks generally lie on top of the basaltic sequence. Stratigraphic measurements have been done in Eyangkuto (stop site 5), Trembono (stop site 6), Ngipik (stop site 13), Cermo (stop site 12), and Tegalrejo River (stop site 7 - 8). From the bottom to the top, generally the sequence is composed of altered rocks, tuff and pumice layers that is often intersected with basaltic tuff and lapillistone beds (Figure 10 and 11). The altered rocks are zeolite beds and clays. The clays especially occur along fault zones, exposed at Bantengwareng (stopsite 2 and its surroundings), zeolite crops out at Talun, Jumbleng, Trembono, and others (Figure 13 and 14). The clays are characterized by very brittle features in dry condition and very plastic in wet condition, also green colour caused by chlorite content. These clays are concentrated along the fault zones. Zeolites are characterized by green to brownish green colour, bedded, composed of lithified tuff (very hard). The total thickness is more than 10 m, but locally less than 2 - 5 m.

Above the altered zone, there are feldspar-rich volcaniclastic rocks. Some outcrops show tight bedded feldspathic tuffs, feldspathic pumices, and thin basaltic lavas (for example at Mojosari (northern stop site 2), Klepu (stop site 12), and Tegalrejo River (stop site 7 - 8). Those rocks are light brown to yellowish grey coloured, pseudo-laminated to bedded, very hard by glass content, containing crystals of K-feldspar, plagioclase, quartz, and biotite/ hornblende. The total thickness is more than 15 m; interpreted as pyroclastic fall and surge deposits. Above the bedded tuff there are massive pumices, tuffs, and pumiceous tuffs; exposed in most study areas. These rocks are characterized by massive beds

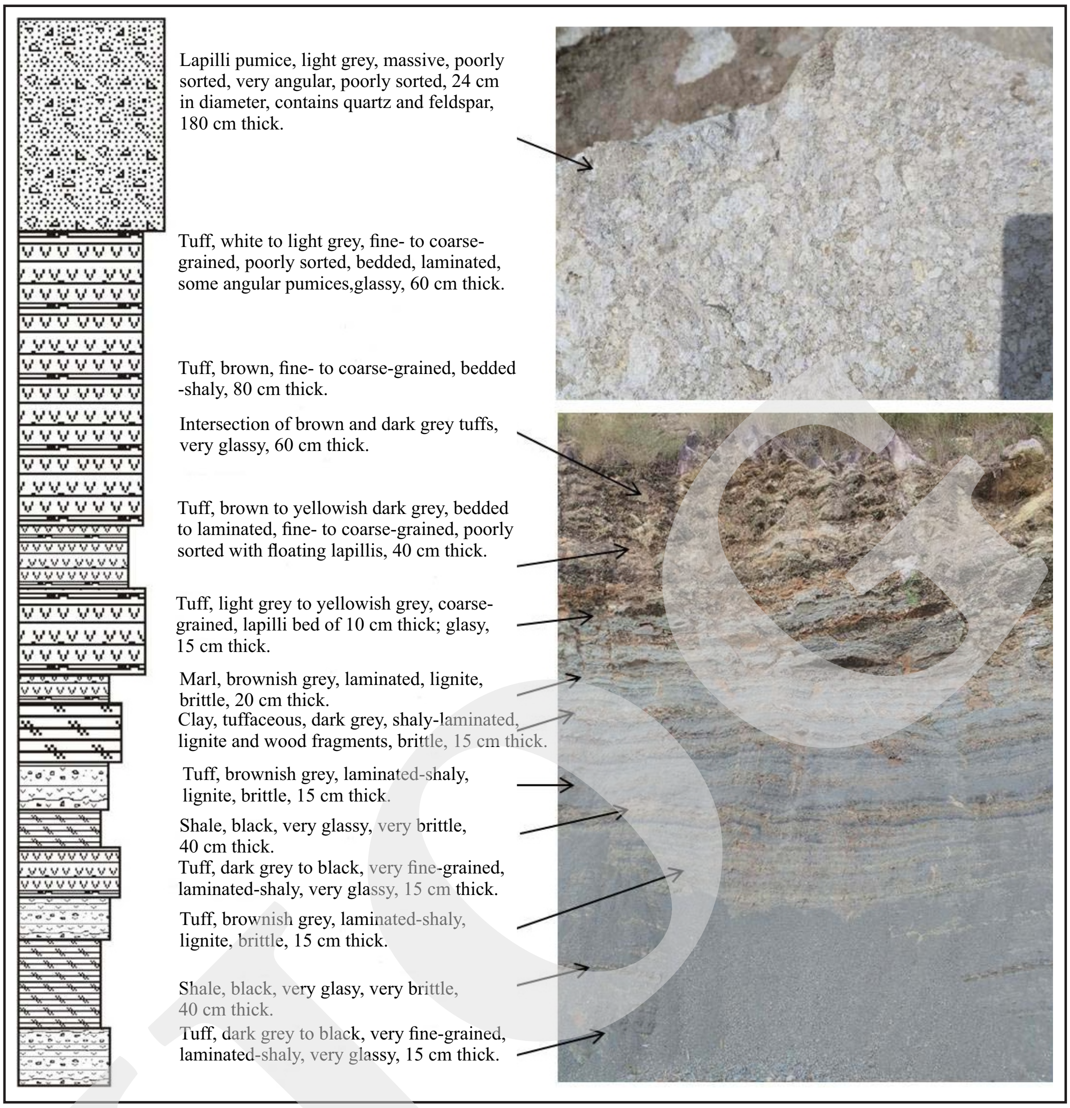

Figure 14. Measured stratigraphic section of Sambeng area showing bedded basaltic tuff and glassy shales with lignite at the base of the sequence; overlain by bedded pale yellowish grey tuff and light coloured pumice rich in feldspar.

(thick more than 10 m per layer), well sorted; composed of crystals of K-feldspar, plagioclase, hornblende, and quartz; interpreted as pyroclastic flow deposits. Some outcrops also contain lithic lapilli, *i.e.*, angular basalt and rounded to elliptical tuff fragments, such as exposed at stop site 7 (Tegalrejo River). The tuff fragments seem to be unlithified glasses eroded during the pyroclastic transportation and deposition. The massive beds of feldspathic pyroclastic flow deposits are more than 50 m thick. Intersected with them are bedded to pseudo-laminated feldspathic tuffs and pumices (Figure 15a). All of the feldspathic tuff and pumice overly basaltic lavas. The lava is characterized by dark grey colour, columnar joints (Figure 15b), porphyritic, with phenocryst olivine, clinopyroxene, and plagioclase (labradorite) in microlite of small crystals and volcanic glass. The top of the columnar joints show pillow structures, indicating it was deposited in a submarine environment. The basalt is overlain by bedded feldspathic tuff and feldspathic pumice (Figure 15b), but some outcrops also indicate altered clays. The total thickness of the basaltic material is more than 130 m, including lava flows overlain by feldspathic tuff and pumice, basalts with pillow structures, and columnar jointed basalts.

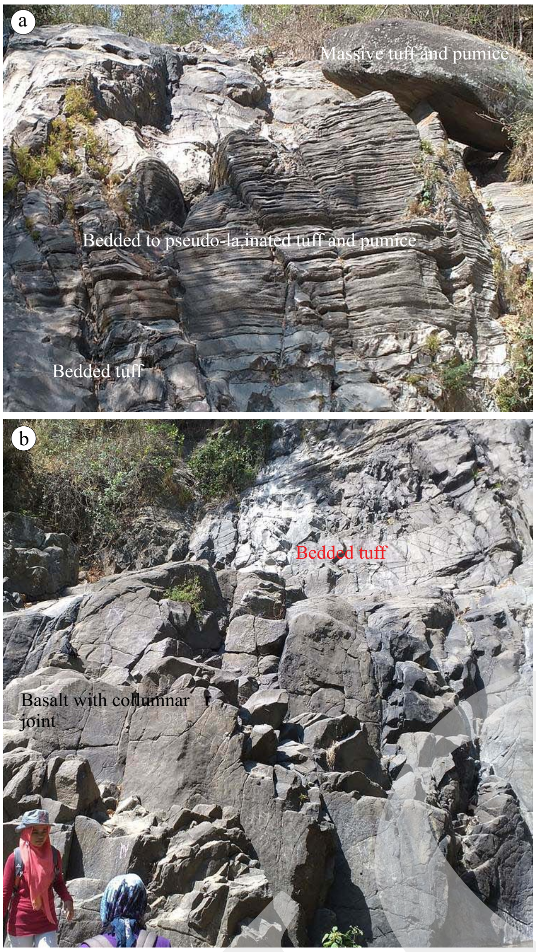

Figure 15. Photograph of: a. Bedded feldspatic tuff and pumice; b. Basaltic lava underlies bedded tuff; exposed at Tegalrejo River (stopsite 7 and 8).

Discussion

On the basis of stratigraphic data corelation, two sequences of volcanic rocks, *i.e.* basaltic volcanic and feldspathic volcanic sequences (Figures 16 and 17) occur. The basaltic volcanic sequence is situated at the bottom, while the feldsphatic volcanic sequence is present at the top. Both volcanic sequences are mainly the constituents of Kebo-Butak Formation mainly composed of volcanic material produced by repeatedly effusive and explosive submarine volcanic eruptions. Big questions arise related to the conditions; whether they were produced by the same volcano or by a couple of different volcanoes depositing their materials simultaneously as recent volcanoes conducting their activities in rows.

The volcanic depositions took place in a bathyal to abyssal submarine environment, evidenced by the presence of basaltic pillow lava. In the depositional environment, low temperature and high pressure occured, which means the basalts should be flowed down not too far from the source. The wide distribution (ca. 5 km^2) and the thick bed (ca. 30 m in Tegalrejo) of the basaltic lava flows indicate that there were many eruption points in the area. The bottom of basalt body is columnar jointed and the top is pillow structured. The flow structures of the columns and pillows may indicate a thick lava flow erupted in a deep marine. There are two explanations in this case, the first as volcanic fields only, and the second one could be Tegalrejo area was a volcanic central facies producing the basaltic volcanic sequence. The second explanation requires further verification with a more detailed study.

According to Trønnes (1990), a basaltic pillow lava occurs wherever mafic to intermediate lavas are extruded under water, such as along the marine hotspot of Iceland volcanoes and the Mid-Atlantic oceanic ridges. Pillow lavas are also found in an early stage of submarine and subglacial stratovolcanic eruption (Jakobsson *et al*., 2000; Thordarson and Höskuldsson, 2006). In both subglacial and submarine, the eruption is likely to start with an effusive phase due to high overburden pressure, then pillow lavas formed. They evolve into pillow breccias and later into hyaloclastites when the pressure decreases, allowing explosive fragmentation (Schopka *et al*, 2006). Possibly, in the following subaerial stage, the volcanic vent emerged above the water level and effusive eruptions created a lava cap. This similarity in evolutional stages of a submarine and a subglacial eruption is due to the constant presence of external water provided by the ocean or by melting of the glacier (Schopka *et al*., 2006; Thordarson and Höskuldsson, 2006). Basalt pillow lavas are also exposed in wide areas of the Southern Mountain, such as Watuadeg, Imogiri, Wonogiri, and Pacitan. Most of them are not associated with other basaltic volcanic materials (Soeriaatmadja *et al*., 1994;

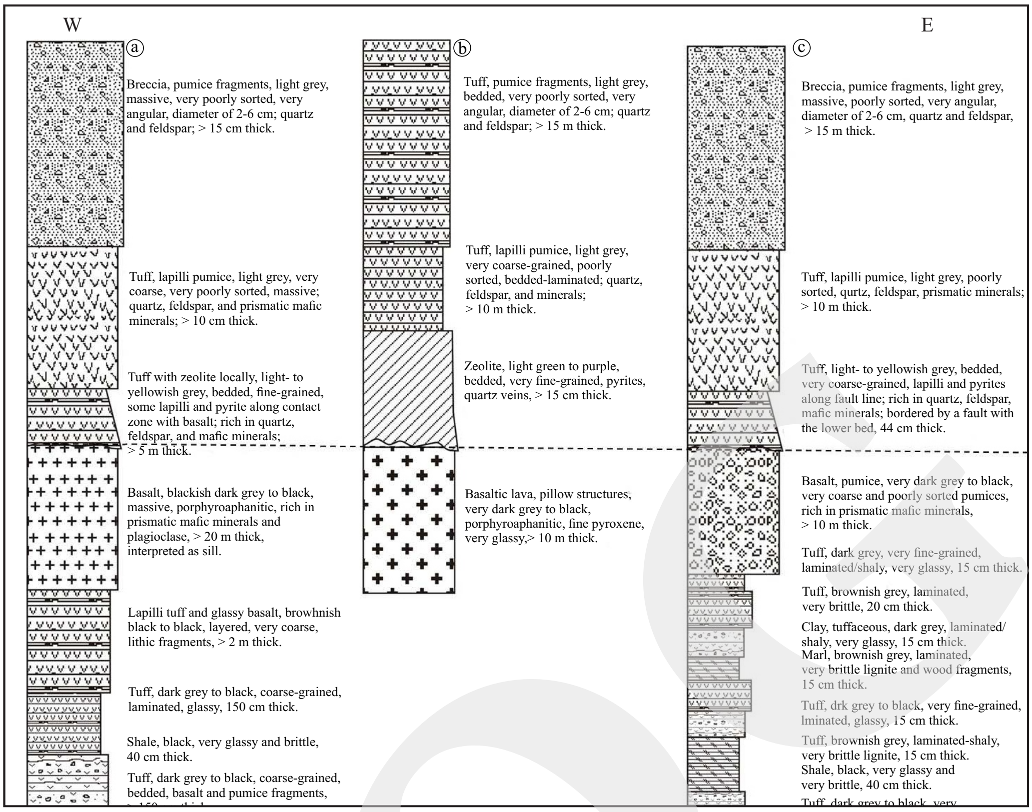

Figure 16. Stratigraphic correlation of Tegalrejo: (a) in the west, Nampurejo-Talun (b) in the middle, and Jumbleng-Eyang-kuto (c) in the east, showing basaltic volcanic sequences deposited within deep water and overlain by light coloured volcanic sequence rich in feldspar; both rocks are separated by green zeolite interpreted as hydrothermal volcanic deposits.

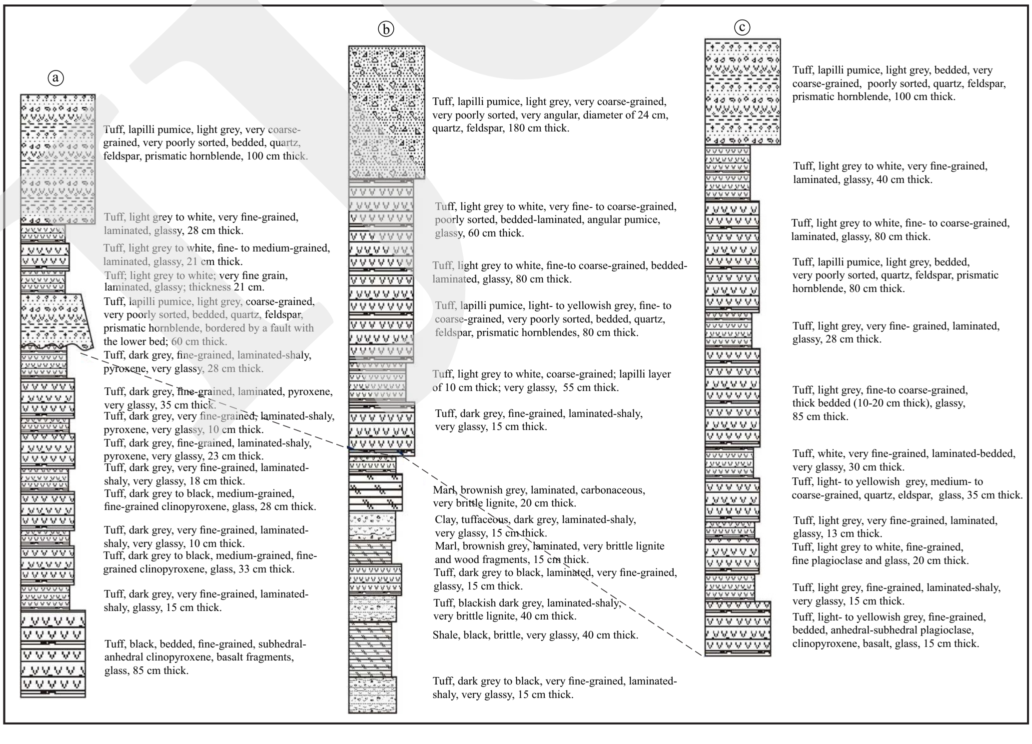

Figure 17. Measured stratigraphic section of: a. Sambeng, b. Gedangan, and c. Gesikan, indicating two different sequences of volcanic rocks. The bottom part comprises basaltic volcanic rocks, while the upper part is andesitic-dacitic volcanic rocks.

Bronto *et al*., 2008; Surono, 2008; and Hartono *et al*., 2008). They tend to form by monogenetic volcanic activities.

Basaltic pillow lavas generally occur at the lower part of sequences, suggesting the initial phase of early volcanism started by effusive eruption of lava flows. The activities were then followed by weak explosive eruptions producing black tuffs and pumices in a long period. In a more distall facies (Sambeng and Ngawen areas, northern side of the study area), the volcanic rock is dominated by a very fine tuff with dark grey colour and beds are finely flake structures (shale-like). This tuff layers are found interspersing with marls. The presence of marl beds within the sequence indicates that the volcanic eruptions took place periodically. When the volcanic activity increased, the deposition was dominated by volcanic materials, and when the volcanic activity decreased, the deposition was dominated by normal marine sediments that contain a lot of fossils. On the other hand, according to Bronto *et al*. (2002), calcareous material between basaltic lava flows in Kalinampu may be resulted by a deep marine hydrothermal alteration. The calcareous materials could also be resulted by leize, *i.e.* gas produced by hot lava touched by sea water. Both deep marine hydrothermal alteration and leize generating the calcareous rocks between the lava layers should not contain fossils.

Feldspathic volcanic sequence overlies the basaltic volcanic sequence. It seems the paleomorphology of the basaltic volcanic sequence was undulating in some outcrops (Tegalrejo-Curug Cermo: stopsites 7, 8, 10,11, 15 and 16). Therefore, in this area the stratigraphic correlation between the group of basaltic rocks and the group of feldspathic rocks is locally not conformable, although both were deposited in the same deep marine environment.

The lower part of the feldspathic volcanic rocks is composed of thin layers of dark grey vitric tuffs; interpreted as base surge deposits. Pseudo-layers of crystal rich tuffs overly vitric tuffs. Vitric tuffs and crystal rich tuffs are gradually interpreted as base surge deposits associated with fall deposits. Moreover, both vitric and crystal tuffs are interpreted as the end of glowing avalanche that were possibly formed by collapsing column eruptions. The environmental deposition was a deep-sea with a high salinity level, so it contains salts by leize. The high energy of the avalanche was sorting heavy vitric tuff in a lower formation, pseudo-layers to massive crystal tuffs in the middle, and light grey in the top. Some outcrops of the middle layers and the upper layer of feldspathic sequence interfingers with basaltic sequence, shown by intersection of thin basalt and thick feldspathic tuffs.

Most outcrops are deeply deformed, some normal faults contain pyrite, chlorite, even sericite. Some others are also associated with argilic clays. Bronto *et al.* (2002) also found altered mineral at Gunung Sepikul, near the study area. It can be interpreted that the sulfidation occurred soon after the tectonic activity, while the magmatic heat source (from local volcano) was still present.

Mineralogically, both basaltic and feldspathic volcanic sequences are very different in composition, textures, and structures. The basaltic rocks are rich in mafic minerals, while the feldspathic group contains abundant feldspars, quartz, hornblende, and biotite. It can be concluded that both volcanic sequences were formed by different volcanic sources. Further researches, discussing the magmatology of both basaltic and feldspathic volcanic sequences of Kebo-Butak Formation are neccessarry.

Chronostratigraphy is urgently required to interpret the geological history reciting basaltic volcanic event and feldspathic volcanic event. Further researches, which are going to discuss the absolute age of basaltic tuffs, feldspathic tuffs, and the origin of sulphidation, will be very useful.

Conclusion

It could be concluded that there were two stratopaleovolcanoes developing Kebo-Butak Formation. Both volcanoes were in a deep marine. One of them generating basaltic volcanic sequence in early activity was effusively forming basalt pillow lavas, then followed by alternating small explosive and effusive activities. The central facies was Tegalrejo. The second stratovolcano had a central facies probably located at Baturagung, also submarine, erupted explosively ejecting feldsphathic volcanic sequence. At first, Tegalrejo paleovolcano erupted, but then the two paleovolcanoes erupted simultaneously and repeatedly along the geologic time to form alternating volcanic rocks.

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