PHYSICAL VOLCANOLOGY OF PYROCLASTIC TEPHRA DEPOSIT AT BATOKE MT. CAMEROON, WEST AFRICA: AN OVER VIEW.

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ABSTRACT

In this contribution, we report an overview of the physical attributes of pyroclastic deposit at the foot of Mt. Cameroon, West Africa. In the deposit three facies types; which are the lava flow, the lapilli and ash are common. The ash is the dominant facies and occurs irregularly in alternation with the lapilli. The most common types of depositional features include cm-dm planar beds and impact sags. We infer from field observations of facies types, clasts types and depositional features that this deposit is a phreatomagmatic fall deposit which resulted from an interaction between lava flow and surface water. The occurrence in the deposit of accretionary lapilli, impact sags, fragments of country-rock and juvenile clasts is ambiguous evidence in support of phreatomagmatic activity. The presence of a lava flow flanked by the tephra pile, the lack of accidental clasts, and the scarcity of bombs are evidence in support of a surface water-lava flow interaction.

KEY WORDS: Pyroclastic Deposit, Batoke, Mt. Cameroon,

INTRODUCTION

Pyroclastic deposits are a significant volcanic hazard associated with all types of volcanoes (Sigurdsson et al., 1987, Waters and Fisher, 1971, Moore, 1967). Most of these deposits are produced during collapse of eruption columns and some by phreatomagmatic eruptions (Cioni et al., 2003, Formenti et al., 2003, Belousov et al., 2002, Water and Fisher, 1971, Moore, 1967). The importance of understanding the characteristics and dynamics of such deposits is underscored by their deadly nature to numerous populated areas (Johnston et al., 1997, Crandell, 1975). Thus, knowing the composition of pyroclastic deposits in terms of their origin, clasts and facies types can help for future planning in areas of active volcanoes. In this paper we present a volcanological study of pyroclastic deposits at the foot of Mt. Cameroon. The aim is to document field aspects while inferring an origin for this deposit. We hope that this study will find direct implication in hazard planning and management around Mt. Cameroon while contributing to the general study of physical volcanology.

Geological Setting

The Cameroon Volcanic Line (CVL) is a 1600 km long chain of Cenozoic volcanoes that extends from the island of Annobon in the Gulf of Guinea into mainland Africa (Fig. 1). The CVL can be divided into three sectors: the oceanic sector made of Annobon, Saõ Tomé and Principe, the continent/ocean boundary composed of Bioko, Etinde and Mt. Cameroon as well

as the continental sector made of Mounts Manengouba, Bambouto, Oku, Ngaoundéré Plateau, Mandara Mountains and Biu plateau.

Mt. Cameroon, the only presently active volcano on the CVL is a stratovolcano with an estimated volume and height of about 1200 -1250km^3 and 4095 m, respectively (Suh et al., 2003). This mountain rises between two sedimentary basins: the Douala, to the southeast and the Rio del Rey, to the northwest. Its basement, made of Pan-African granites and gneisses, is covered by 3-7 km of Cretaceous to Recent sedimentary rocks from these two basins (Dumort, 1968, Tsafack et al., 2007 and Mathieu et al., 2011). The eruptive style of this volcano has ranged from dominant effusive (Suh et al., 2003) to moderately explosive resulting in the production of pyroclastic deposits and numerous Strombolian cones. There has also been prehistoric phreatomagmatic activity at the volcano (Wandji et al., 2008, Ngwa et al., 2010). With an annual population growth rate of 2.7% and much infrastructural development at the foot and flanks of this volcano, there is a need for constant monitoring of the edifice to allow for hazard mitigation and management campaigns. This requires the use of many methods amongst which is the physical study of erupted material; the aim of the present work.

Overview of the deposit

The pyrolcastic deposit exposed at Batoke on the southwest flank of Mount Cameroon was studied. The total surface area covered by this deposit could not be ascertained partly because of human settlements

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and their anthropogenic activities and degradation by the sea. The exposed part of the deposit is about 1650 m wide. The ejecta common in the tephra deposit include unoxidized black basaltic juvenile clasts, lithic basaltic clasts and ash sized matrix. The lithic basaltic clasts are referred to here as``cognate clast´´ using the terminalogy of Fisher and Schmincke, (1984). There are no accidental clasts in the deposit. The deposit can be divided into three groups – the lava flow, the lapilli and the ash dominated facies.

Lava flow facies

At the middle of the pyroclastic deposit, is a lava flow which is 40 m high and 31 m wide (Fig. 2). The lava flow is blocky (Fig. 3a) with individual blocks having a maximum length of about 60-70 cm. The surface of these blocks is smooth with little or no mineral grains in hand specimen. The top of the flow is composed of soil, possibly resulting from the weathering of the underlying lava. The tephra deposit flanks this lava flow on both sides. Moving outwards from the flow front, the immediate surrounding pyroclasts are baked and brown in colour (Figs. 2 and 3b). These baked brown areas are composed mostly of particles greater than 2 mm in diameter (Fig. 3b). In this study, we call such baked rocks `contact breccias` according to the terminology of Clement (1982). There are no observable depositional structures on these baked brown areas.

Ash-and lapilli-dominated facies

These are the most common facies at the Batoke pyroclastic deposit. The lapilli-dominated beds mostly occur as clast supported (having about 70% clasts). These clasts are composed of fragments of cognate as well as juvenile lava. In a few cases, some lapilli-dominated beds are made up mostly of juvenile clasts. In the deposit, there is an alternation of ash-and lapilli-dominated beds (Fig. 4a). This alternation however does not occur in a regular manner and does not define any regular pattern. At distal locations from the flow front, occurs ash-dominated (about 70% ash) facies. Another important clast type present at Batoke pyroclastic deposit is the accretionary lapilli. The maximum size of these lapilli is 07 mm in diameter. The accretionary lapilli are commonly found in the lapilli-dominated beds (Fig. 4b). Structurally, the accretionary lapilli belong to the core type according to Waters and Fisher (1971); Fisher and Schmincke (1984), and the Schumacher and Schmincke (1991) classification schemes.

Depositional structures

Although the sections are well exposed, there are generally few depositional structures on them. The most common of these structures are centimeter to decimeter planar beds (Fig. 5a). These beds remain planar even as one moves away from the flow front and can be traced laterally. Most of these beds are composed of fine and coarse ash facies. Impact sags (Fig. 5) are observable below either the juvenile bombs or the cognate blocks found mostly in the ash beds. These sags are symmetrical. There are no dune and channel structures in the deposit. All layers are traceable with no evidence of lateral thinning and thickening of individual beds.

Maximum clast size distribution

According to Palladino and Agosta (1997), maximum clast sizes measured in a given deposit reflect the energetic conditions of the eruption and can also be used to estimate the eruptive parameters (Sottili et al., 2004). Maximum clast sizes from the Batoke pyroclastic deposit were determined based on the method described by Cas and Wright (1987), and Walker (1981), by measuring and averaging the long axes of 3-5 clasts that seemed to be the largest at each bed. Juvenile bombs were scarce while lithic blocks were very scarce to absent in some cases. These juvenile bombs (Fig. 6a) and lithic blocks are non vesicular. There was no evidence of lateral and vertical increase or decrease of these ejecta. The size of an avarage juvenile bomb ranges from 5 to 7 cm while that of cognate block ranges from 3-8 cm. Accretionary lapilli on their part, measure up to 07 mm. In the classification scheme of Schmid (1981), the pyroclastic deposit falls in the lapilli-stone to tuff boundary (Fig. 6 b).

Interpretation

From field observations, the pyroclastic deposit at Batoke is phreatomagamtic in origin. Unlike pheatomagmatic deposits which are formed as a result of rising magma- ground water interaction (e.g., Ngwa et al., 2010, Befus et al., 2008), the Batoke pyroclastic deposit resulted from magma-surface water interaction. The presence of the lava flow flanked by the pyroclastic deposit (Fig. 2), scarcity of lithic and juvenile bombs, as well as the absence of accidental fragments from the deposit enable us to suggest that the phreatomagmatic activity did not involve ascending magma and ground water. Instead, there was an interaction of this lava flow when it was in motion with surface water which then resulted in the fragmentation of the advancing lava. The small sizes of the bombs (5 to 7cm) also support this interpretation.

We interpret the presence of accretionary lapilli, impact sags and the widespread occurrence of planar beds to indicate the presence of moisture during formation, transportation or deposition (Crowe and Fisher, 1973, Lorenz, 1974, 1985, Nemeth et al., 2001).

Grain-size distribution of tephra-fall deposits is a crucial eruptive parameter necessary for hazard mitigation plans as it is used in tephra-dispersal modeling to assess the risk and vulnerability of populations (e.g Barberi et al., 1990; Connor et al., 2001; Bonadonna et al., 2002). It is also an important indication of the level of particulate pollution dangerous for human health (e.g. Moore et al., 2002). The dominance of ash and lapilli facies over bombs in this Batoke tephra deposit, calls for more awareness of the population at the foot and flanks of Mt. Cameroon as a whole as ash particles during eruptions are dangerous to humans, plants and animals. Ash produced by volcanic eruptions can lead to the closure of airports, state highway as well a caused damage to hydroelectric power facilities, (Johnston et al., 2000, Guffanti et al., 2003).

DISCUSSION

The data presented in this paper throw light on the physical volcanology of the pyroclastic deposit at Batoke, Mt. Cameroon. Observed charateristics of this deposit such as: juvenile and lithic particles, lack of vesicularity of the juvenile clasts are typical of phreatomagamtic tephra (White and Houghton, 2000, Lorenx, 1985, Zimanowski, 1998). Although there are indications of moisture (impact sags, accretionary lapilli) during formation of the tephra deposit, we infer from the absence of dunes, channel structures, the symmetrical nature of impact sags, lack of lateral thinning and thickening of individual beds, as well as no inter-fingering of beds that although water was involved during fragmentation, the water was not enough to be involved in the transportation. Pyroclastic deposits transported by surface water will have channel structures, dunes and in most cases asymmetrical impact sags, usable in tracing the direction of flow. Thus, we conclude that due to the lack of the above mentioned depositional features, the presence of impact sags under bombs is rather an indication of deformation during fall. Studies elsewhere (e.g., Befus et al., 2008) have shown that the presence of impact sags in phreatomagmatic deposit is typical evidence of direct fallout from eruption columns during pulsatory phreatomagmatic eruptions. Impact sags are also indicative of the plastic deformation of beds underneath the blocks (Lorenz, 1985) as well as the energy of ejection.

A phreatomamagtic deposit resulting from magma - ground water interaction would have an inter-mixture of cognate, juvenile and accidental ejecta types. Such a deposit is an indication of significant quarrying of the vent zone (Nemeth, 2003) as a result of high-energy phreatomagmatic explosion (Zimanowski, 1998). These deposits will indicate a complex fragmentation regime (White and Schmincke, 1999) and the population of the different ejecta types will also decrease laterally away from the crater and vertically up the deposit (e.g Ngwa et al., 2010). However, these variations are not observed at the Batoke pyrolcastic deposit. Phreatomagmatic activity at Batoke was possibly initiated by a simple lava flow-surface water interaction during which there was no `throat clearing` activity which would lead to a mixture of different eject types. More so, one will expect to have particles of sedimentary rocks typically shale and sandstone in the deposit (Ngwa et al., 2010) because the basement of Mt. Cameroon is covered by 3-7km of Cretaceous to Recent sedimentary rocks from Douala and Rio del Rey basins between which the mountain rises (Dumort, 1968, Tsafack et al., 2007 and Mathieu et al., 2011).

CONCLUSION

The Batoke pyroclastic deposit is a phreatomagmatic fall deposit which resulted from the interaction between an advancing lava flow and surface water. The deposit consists of alternations of ash-dominated and lapilli-dominated facies. The conspicuous depositional feature present is the cm-dm planar ash bedding. These beds alternate with lapilli dominated beds although not in a regular manner. Impact sags indicate deformation during fall while accretionary lapilli indicate wetness during formation of pyroclastic material. The lack of flow depositional structures within the deposit is indicative of the absence of water during transportation.
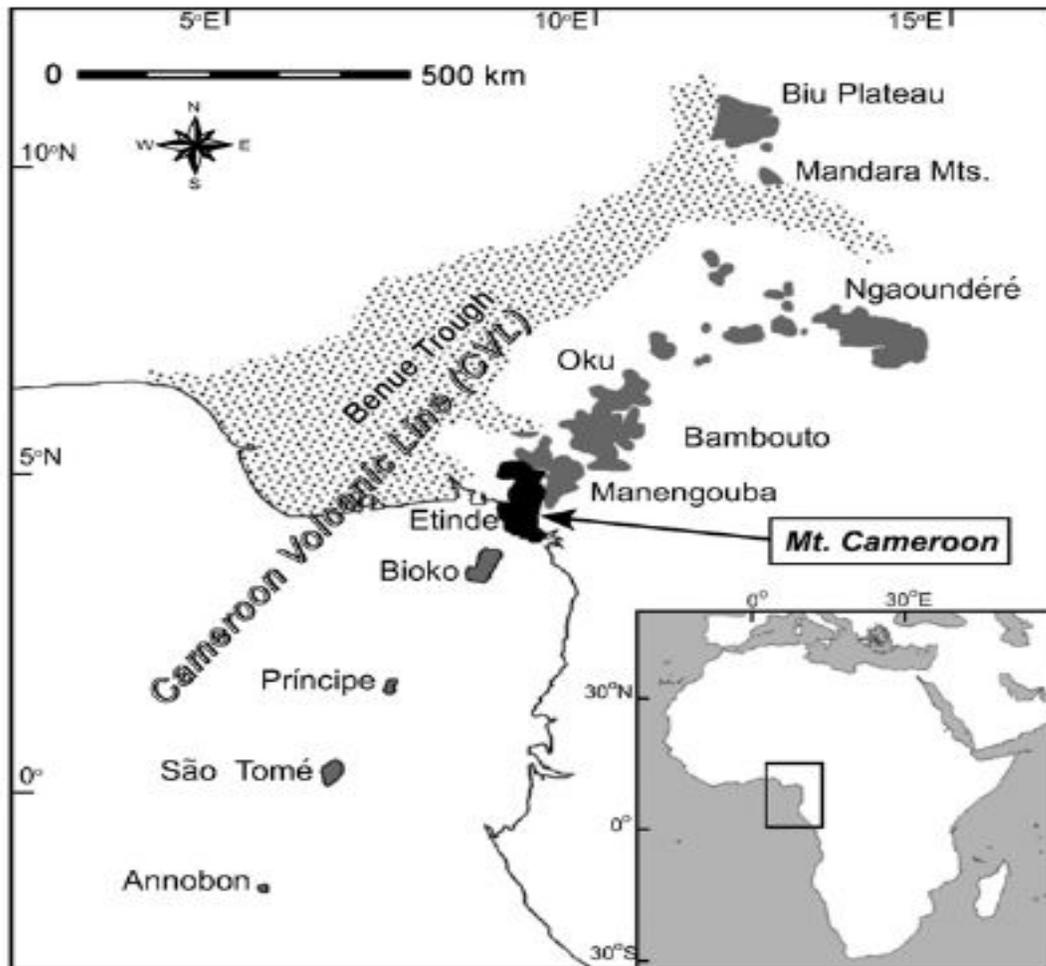
Figure 1: Map of the Cameroon volcanic line showing the main volcanic centers indicated in black: Map taken from Yokoyama et al., 2007
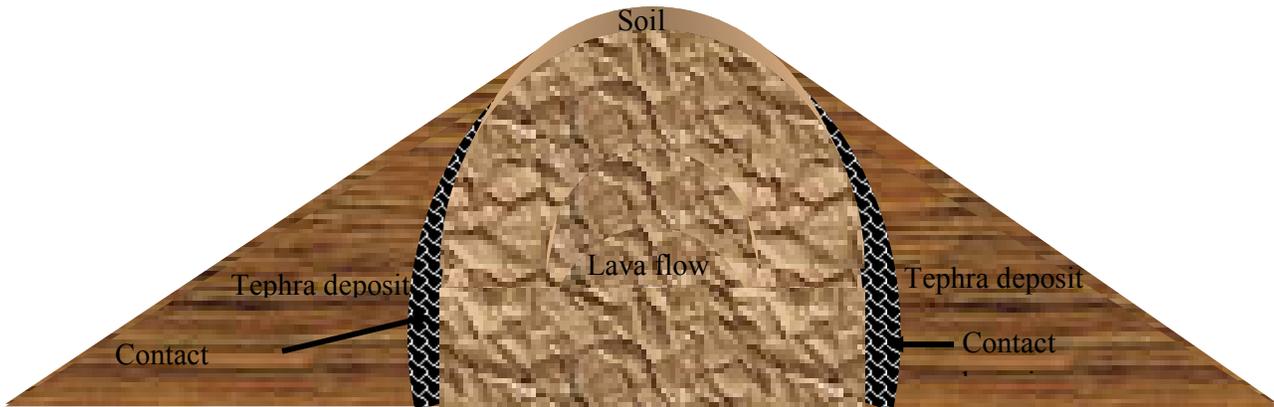
Figure 2: Cross-section representation of the general view of the pyroclastic deposit (Diagram is not drawn to scale)
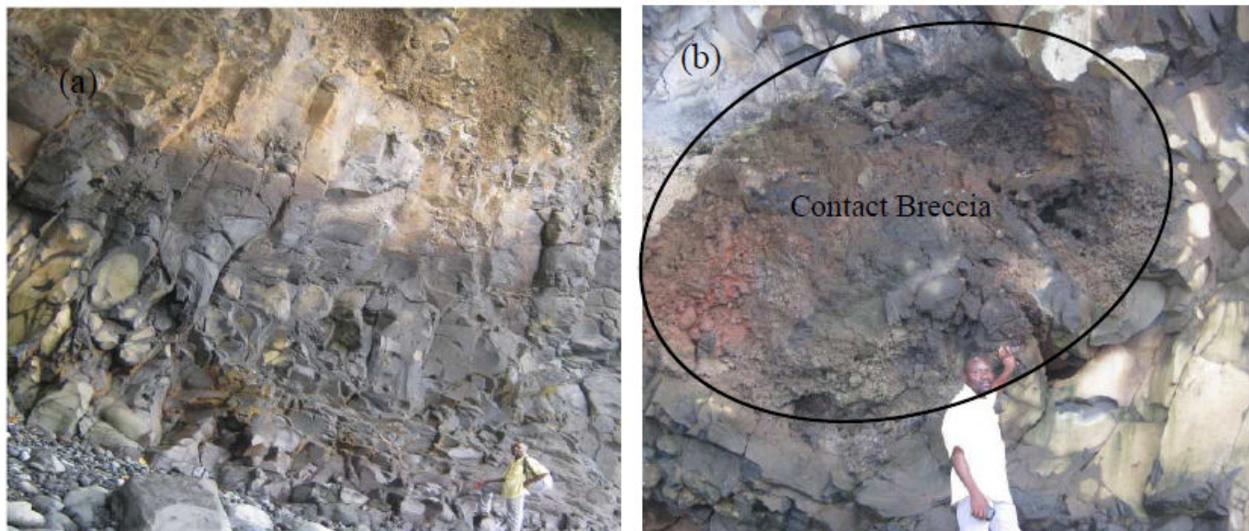

Figure 3: Photographs of (a) Blocky Lava flow at Batoke and (b) contact breccia found at the pyroclastic deposit
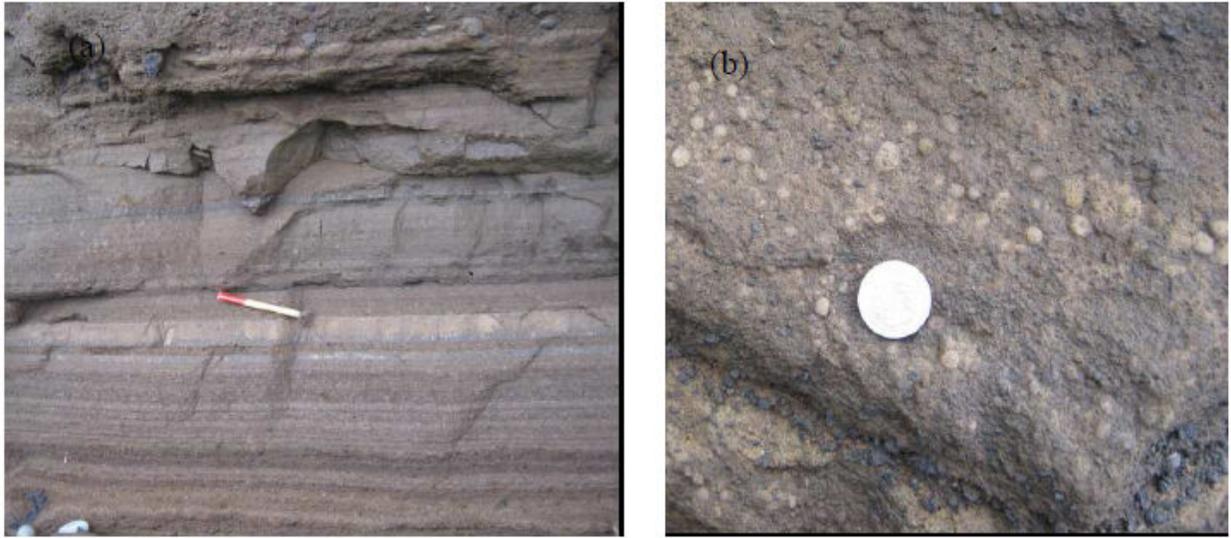
Figure 4: View of ash and lapilli dominated beds. Note the coarse lapilli beds at the top of the section. (b) Accretionary lapilli within Batoke tephra deposit. Coin is 2.1cm in diameter.
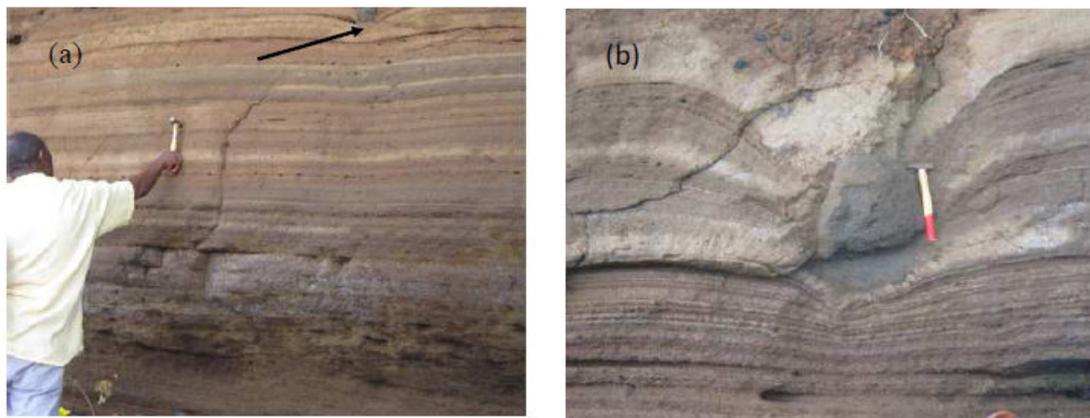

Figure 5: (a) View of dc-cm planar beds at the Batoke pyrolcastic deposit. Note the small impact sag at the top of section (b) Symmetical sag beneath a bomb.
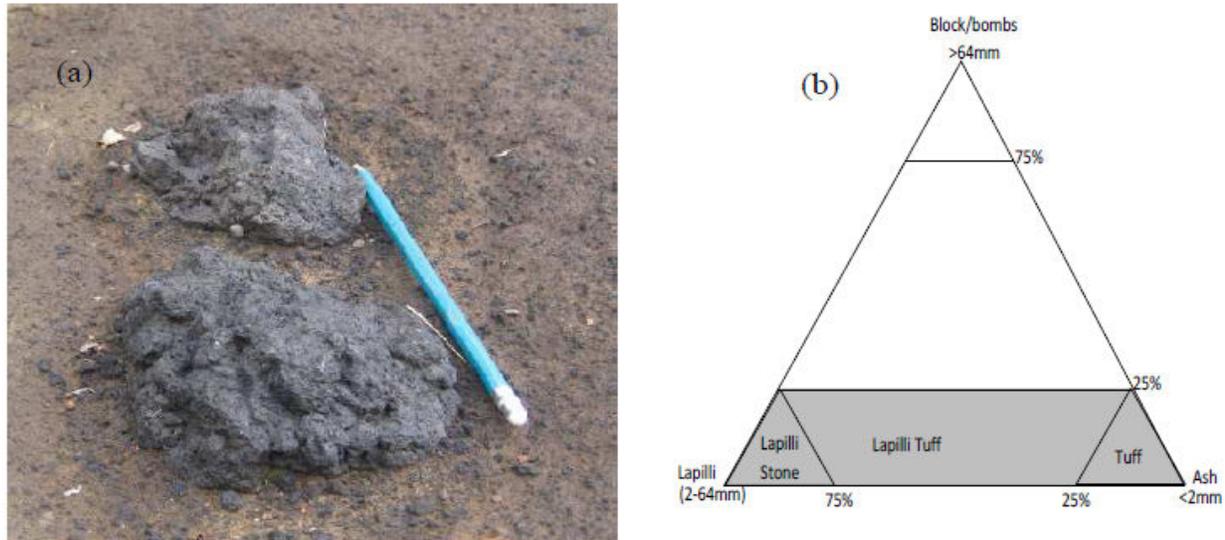
Figure 6: (a) Two juvenile bombs at the deposit. Pencil is 18.8cm long, (b) Schematic classification of the Batoke tephra deposit. Deposit generally falls in the lapillistone to Tuff section of Schmid (1981) classification scheme

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