

Remnants blocks of pyroclastic surge deposits in Bambili, Cameroon volcanic Line: New insights into the lithostratigraphy of Mount Bamenda

ABSTRACT

Field studies in Bambili locality (NE of Bamenda city, West-Cameroon), situated in the central part of Cameroon Volcanic Line, have recently permitted us to discover-identify above the welded massive lapilli tuff (mLT), remnant blocks (up to 6.5 x 11 m) of pyroclastic surge deposits. The latter are characterized by well-sorted and distinctly stratified layers with thicknesses ranging between 8 to-and 35 cm and showing graded bedding. The layers are matrix-supported and heterolithic, with the lithic fragments consisting of devitrified fiammes, vitrophyres, trachytic and rhyolitic cognates, granites and ignimbrites. The ignimbrites. The mineralogy of these surge deposits is quasi identical to that of the welded mLT which consists of alkali feldspar (sanidine), quartz, plagioclase, clinopyroxene, biotite and Fe-Ti oxides. The presence of these remnants blocks of pyroclastic surge deposits in the Bambili locality, emitted probably from Mt Oku vent permit to reconsider the chronostratigraphy of the Bamenda Highlands. In fact, after a trachytic lava flow, a pyroclastic flow deposits permitted the formation of the welded ignimbrites represented by dark gray and whitish units; pulsating hydrostatic and magma pressures have subsequently produced alternating phreatomagmatic pyroclastic surges, which have afterward cover the massif followed by basaltic flows.

Keywords: surge deposits, welded ignimbrites, Bamenda volcano, West-Cameroon

1. INTRODUCTION

The intraplate Cameroon Volcanic Line (CVL) forms one of the major lineament of the African continent (Fig. 1) [1]. It can be compared to the East African rift system, which is currently defined by an almost SW-NE geological lineament (mean value: N30°E). It is made up of a continental part and an oceanic part, making it a unique feature in Africa and even in the world [1]. The continental part includes both plutonic complexes (67 to 10.8 Ma) and volcanic massifs (51.8 Ma to present) ([1] and references therein). The oceanic part is entirely volcanic and consists of four well-studied islands (Bioko, Principe, São Tomé, and Annobon) and two large seamounts [2].

Recent work [3] reported the existence of ignimbritic deposits only in the continental part of the CVL; these-These deposits are found mainly in the central area of the CVL, especially within the Mount Bambouto and the Mount Bamenda with estimated volumes of respectively 13.5 and 6.3 km³ respectively [3]. Considering both alteration and poor condition of these outcrops, their actual volumes could be significantly higher than the estimated ones. Outcrops of smaller sizes (<1 km³) were identified in Oku [4, 5], Nkogam [6] and Nganha [7]

volcanoes. Studies in these massifs so far have shown that these ignimbrites are only deposits of pyroclastic flows with no internal stratification [3].

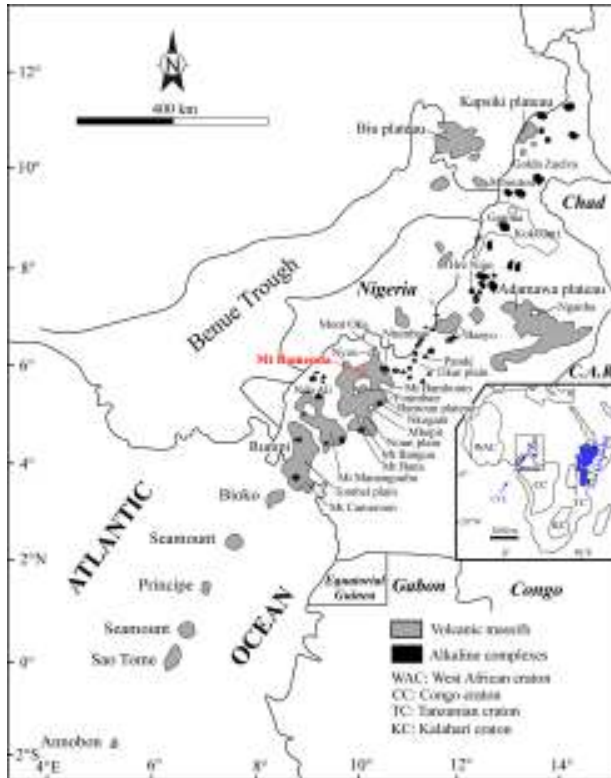


Fig. 1. Map of Cameroon showing: A) Location map of CVL in Africa, and B) the distribution of the Cameroon Volcanic Line (CVL) magmatism. Locations of the seamounts are after Burke [2]. C.A.R.: Central African Republic. Inset: location map of CVL in Africa.

Pyroclastic density currents are inhomogeneous mixtures of volcanic particles and gas that flow according to their density relative to the surrounding fluid (generally the atmosphere) and due to Earth's gravity [8, 9]. They move at high speeds (100 to 300 m/s [10]) on the earth surface, mainly controlled by gravity [11, 12, 13, 14], and frequently implying a turbulent regime [11, 15, 16, 17]. Deposits of pyroclastic density currents are generally categorized according to lithology and sedimentary structure, as ignimbrites, block-and-ash flow deposits and pyroclastic surge deposits [8]. Pyroclastic surge deposits come from turbulent flows, less concentrated or diluted, in which the ashy and gaseous fraction predominates. They generally consist of successive parallel and stratified beds and occasional cross-stratification [8]. The beds are relatively low thickness, well sorted, with or without fine ashy matrix. Until now, only the Recently, deposits of pyroclastic flows deposits represented characterized by welded and non-welded ignimbrites with their massive lapilli tuff (mlT) facies and massive lithic-rich breccias (mlBr) facies have been were described in the Mount Bamenda [3]. In this work, we highlight the existence of pyroclastic surges deposits in the volcanic sequence of the area. These surges deposits are found in remnants

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pyroclastic blocks at Bambili locality, situated in the NE of Bamenda town. They are investigated here in detail in order to understand their origin, and to bring insight into the eruptive history of the Oku volcano and thus to give their importance in the chronostratigraphy of the Bamenda volcanic field.

2. GEOLOGICAL SETTING

The Mount Bamenda (600 km²) constitute in volumetric importance the fourth largest volcano of the CVL after Mount Cameroon, Mount Manengouba and Mount Bambouto. It constitutes with the Bambouto mountains to the SW and the Oku massif to the NE (Fig. 2), the three central volcanoes belonging to the volcanic centers of the Western Cameroon Highlands. Their basement consists of Pan-African granitoids [18, 19, 20]. The Bamenda volcano, on top of which exists the lake Bambili, lies between longitudes 10°00'E and 10°30'E and latitudes 05°45'N and 06°10'N and culminates at 2621 m asl.

The Mount Bamenda is characterized by the presence of two calderas: calderas of Santa-Mbu (6 x 4 km width) and Lefo (4 x 3 km width) (Fig. 2). They are small sized compare to neighboring Bambouto caldera and open respectively to the west and southeast [21]. Their floors, located at elevation of 550 m and 400 m respectively, are mainly composed of trachytic domes, which are also abundant on the external slopes of the volcano. In addition to Bambili Lake, many other craters, caused created probably by phreatomagmatic explosive explosions volcanism, are and occupied by lakes generated by phreatomagmatism like Bare present in the area. Case examples are ambili Lake, Lake Awing and Lake Oku.



Fig. 2. Digital Elevation Model (DEM) of Mt Bamenda and surroundings.

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Petrographic and geochemical studies showed that the Mt Bamenda lavas consist of basanites, basalts, hawaiites, mugearites, benmoreites, trachytes, rhyolites and ignimbrites [22]. These ignimbrite overlays the granite and gneiss basement rocks and are

covered by laterized basaltic flows. The felsic lavas are most abundant than intermediate types (mugearites and benmoreites). The radiometric dating of this active volcano gives ages ranging from 0 Ma to 17.4 Ma for the basaltic lavas and from 18.98 Ma to 27.40 Ma for the felsic lavas [22]. As in the case of neighboring Mt Bambouto, it can be assumed that the ignimbrites of the Bamenda volcano belong to Miocene formations because the succession of deposits is similar for the two volcanoes with Precambrian basement rocks (granite in the majority) at the base of each stratigraphic section [3].

3. MATERIAL AND METHODS

Field investigations were made on remnants blocks of surge deposits of Bambili situated in Bamenda volcanic area. Stratigraphic section of Bambili ignimbrites and pyroclastic surge deposits were obtained from the field data. Only blocks in place were taken into account to establish the complete succession of pyroclastic surge deposits. In order to characterize the mineral assemblages and textures of welded ignimbrites, optical studies using transmitted and reflected-light microscope were undertaken on thin sections from representative samples.

For geochemical analysis, samples were collected from outcrops, as well as from a few detached blocks of ignimbrites. The samples consist of glassy or vitric clasts and fiamme from within the ignimbrite matrix or, more commonly, material taken from unaltered vitrophyres of the ignimbrites. Seven samples have been analyzed for major elements. These samples were crushed in a steel jaw crusher and reduced to fine powder in agate mortars. Powders were analyzed for major oxides by X-ray fluorescence spectrometry (XRF) with Bruker S4 PIONEER spectrometer at Mission de Promotion des Matériaux Locaux (MIPROMALO, Yaoundé) laboratory in Cameroon with analytical precision of 1%.

4. FACIES CHARACTERISTICS OF THE BAMBILI IGNIMBRITE AND PYROCLASTIC SURGE-REMNANTS DEPOSITS

The ignimbrite and pyroclastic surge deposits of Bambili (Fig. 3 and 4) consists are characterized by of two main volcanic facies: a massive lapilli tuff (mLT) and a massive lithic breccias (mLBr) facies. Based on these facies, the pyroclastic sequence of Bambili was subdivided into three stratigraphic units (Fig. 5b):

- A lower unit (U_1) characterized by the mLT-facies in itsThis basal lower part is represented by a single cooling unit constituted by two flow units (dark gray unit
- A second whitish unit (U_2) also characterized by the mLT facies, and
- whitish unit), covered by An upper unit (U_3) consisting of a series of alternating multiple layers of poorly sorted and matrix-poor clasts-supported -mLBr beds facies and ashy beds (Fig. 5b). The pyroclastic surge deposits of Bambili are characterized by stratified ashy layers insert in mLBr facies.

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Fig. 3. a) Google map of Bambili town showing the ignimbrite outcrops; **b)** Landscape with ignimbritic remnants of whitish unit of welded mIT lithofacies.



Fig. 4. a) and **b)** Remnant blocks of pyroclastic surge deposits of Bambili; **c)** Fine-poor matrix of mIBr; **d)** Remnant block of whitish unit of welded mIT. mIBr: massive lithic breccia; mIT: massive lithic tuff; ST: stratified tuff/ash

4. 1 The Lower unit (U_1) of the mIT facies

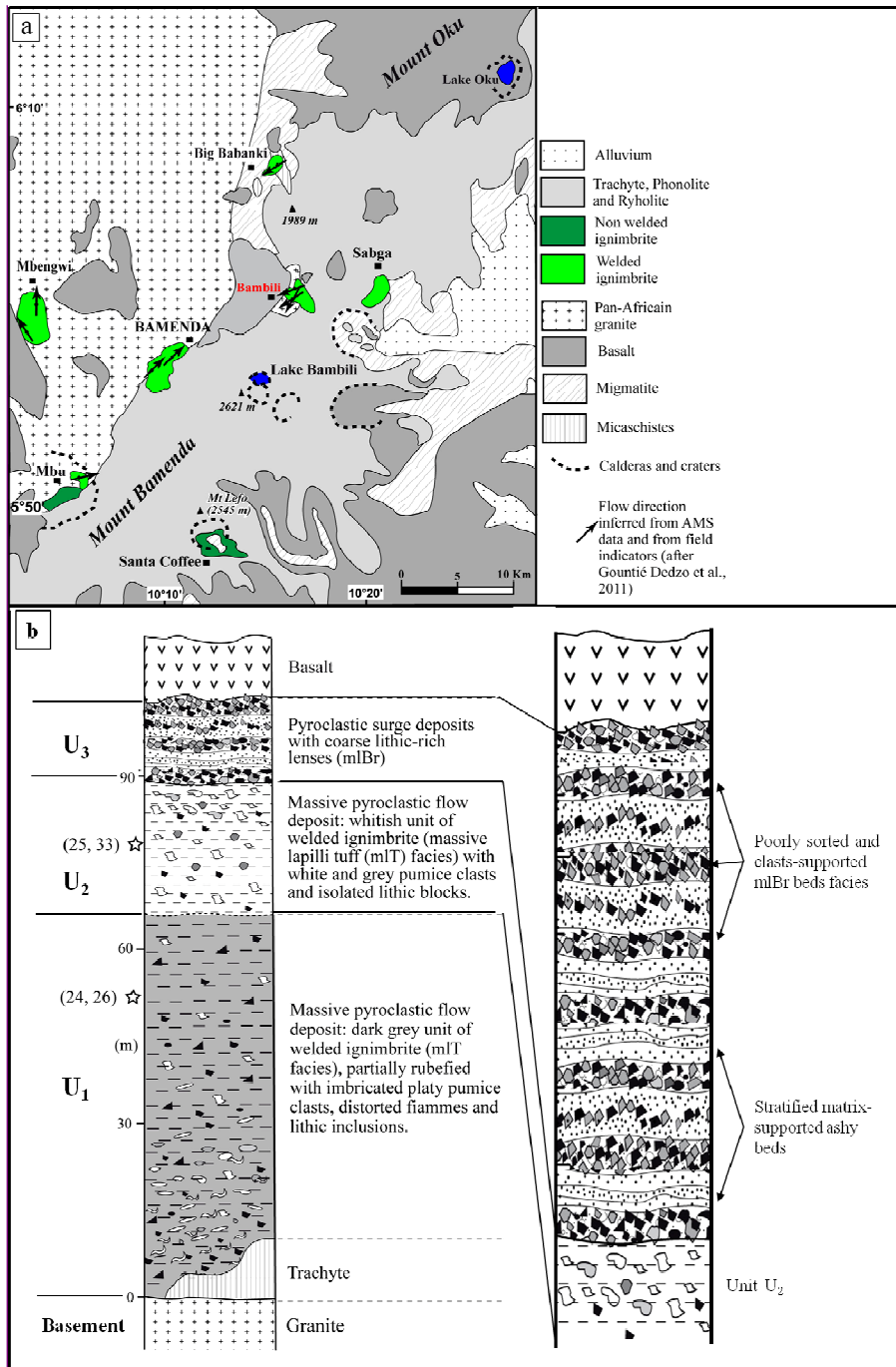
The Lower unit of the mIT facies is a dark gray pyroclastic flow, which locally is being unit whose color is dark gray and rubeficated in places (Fig. 5, 4 and 6a). This rubefaction is reflected by the presence of reddish areas in the deposit. The rock is dense and massive.

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Fig. 5. a) Geological map of mounts Bamenda and surroundings. **b)** Stratigraphic section of Bambili ignimbrites and pyroclastic surge deposits; the numbers 24, 25, 26, 33 represents sampled sites for anisotropy of magnetic susceptibility (AMS) studies (modified after [3]).



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The volcanic clasts population includes about 5% of both aphyric and porphyritic hyolite hyolitic fragments (whose with dimensions do not exceeding 0.5 x 0.3 cm, and represent 5% of the facies) and many aphyric black and white aphyric fiammes, (30 to 35% of the facies; up to 1.2 x 0.2 cm;) which are wispy, lenticular to much stretched and generally distorted. These aphyric fiammes are up to 1.2 x 0.2 cm in sizes and represent about 30 to 35% of the facies, giving to the deposit displaying an eutaxitic texture:-. We interpret them these fiammes are interpreted to be flattened, juvenile pumice lapilli.

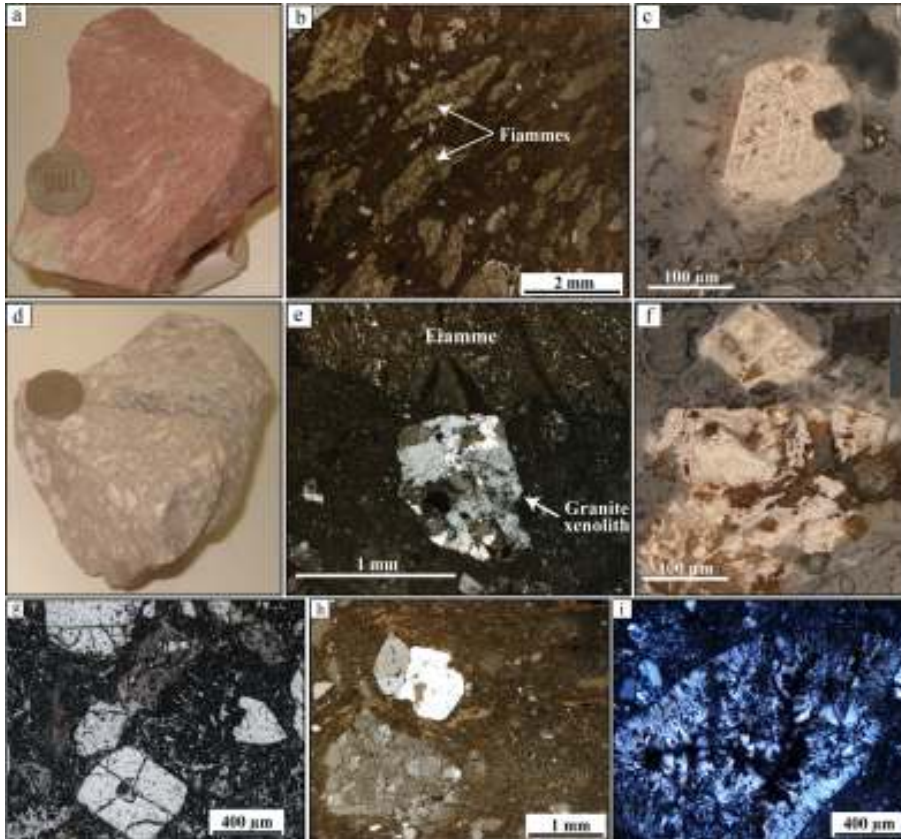


Fig. 6. a) Sample of the rubefacated dark grey unit (DGU) of mIT and b) the corresponding microphotograph showing the eutaxitic texture with imbricated fiammes; c) Crystal of titanohematite with thin exsolution lamellae of ilmenorutile in the DGU; d) Sample of mIT whitish unit (WU) and e) the corresponding microphotograph showing xenolith of granite; f) Crystals of titanohematite with thin exsolution lamellae of ilmenorutile in the WU; g) Devitrified matrix of WU showing relict shards, lithic fragments and multiple alkali feldspar fragments; h) Basal DGU showing subhorizontal compaction foliation defined by the fiammes and deformation of fiammes around the margins of lithic clasts; i) Devitrification of large fiamme in DGU showing micropoikilitic texture characterized by crystallization of microlites (mainly cristobalite and alkali feldspar) along the boundaries of the glass shards or within glassy masses.

In thin sections, this eutaxitic texture is well characterized by preferentially oriented or imbricated devitrified fiammes ~~showing~~ suggesting that transport direction of pyroclastic current was roughly directed toward azimuth 235 (Fig. 6b). The chemistry of these fiammes ~~shows~~ showed that there are rhyolitic in composition, with (SiO_2 : 73.65 – 76.44% and $\text{Na}_2\text{O} + \text{K}_2\text{O}$: 8.5 – 9.75%) (Fig. 7). The matrix is devitrified and comprises various proportions of relict shards (Fig. 6g) and lithic fragments (mainly trachytic) with a diameter inferior to the millimeter. The ignimbrite underwent hot welding compaction, as indicated by the subhorizontal compaction foliation defined by the fiamme, deformation of fiamme around the margins of lithic clasts (Fig. 6h), plastic deformation of cusped matrix shards and the presence of spherulitic and micropoikilitic textures (Fig. 6i) within the fiamme (resulting from high-temperature crystallization of a glassy precursor [23, 24, 25]). The minerals such as quartz and alkali feldspar (sanidine), are abundant; plagioclase, clinopyroxene, biotite and Fe-Ti oxides (ilmenorutile; Fig. 6c) are less represented.

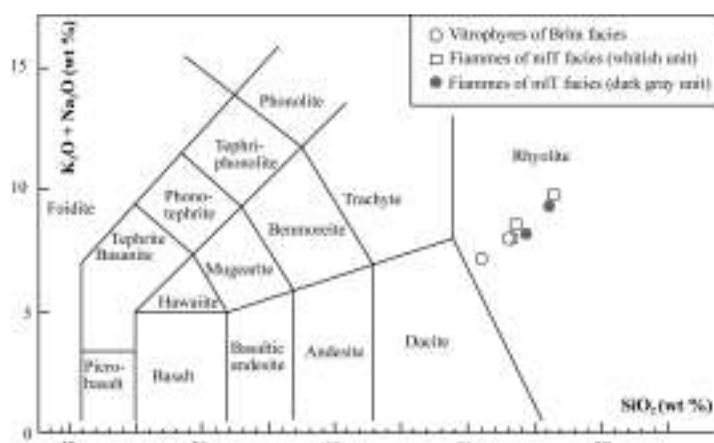


Fig. 7. TAS classification graph [26] for whole rock pumice and vitrophyres samples collected from the Bambili ignimbrites during this study.

4. 2 The intermediate second unit (U_2) of the mIT facies

The second unit U_2 of the mIT facies (Fig. 5) is whitish ~~and has low density~~ (Fig. 5-4 and 6d). ~~The Juvenile rock fragments from the unit is consist of characterized by the presence of numerous highly vesicular vesiculated pumice. They, with chalkare chalk-white in color and also and~~ rhyolitic (SiO_2 : 74.36 – 76.11% and $\text{Na}_2\text{O} + \text{K}_2\text{O}$: 8.1 – 9.23%) in composition (Fig. 7); SiO_2 : 74.36 – 76.11% and $\text{Na}_2\text{O} + \text{K}_2\text{O}$: 8.1 – 9.23%. ~~Those Ppumices shapes are subrounded to ovoid and they constitute about 35 to 40 vol. % of the volume of the clasts population rock; their They dimensions vary in size from 2.2 x 1.9 cm to 0.3 x 0.2 cm. The other fraction of the clasts population comprises Trachytic enclaves lithics are rare (less than 5%); trachytic lithics, about 2 vol. % enclaves lithics of black vitrophyres, represent less than 2% of the rock; 2 vol. % of xenoliths of ignimbrite (2%) are that are~~ difficult to identify because of their advanced status of alteration. Xenoliths of granite (1%) (Fig. 6e) are also observed and are generally well preserved in this unit. The dimensions of these ~~enclaves lithics granitic xenoliths~~ do not exceed 0.4 x 0.2 cm. The deposits' matrix is made up of submillimetric devitrify fiammes, small (< 1mm) rock fragments ~~smaller than one millimeter and individual minerals mineral fragments~~ such as:

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sanidine, plagioclase, biotite and Fe-Ti oxides (ilmenorutile; Fig. 6f). Subvertical elutriation pipes (0.5 to 0.7 cm in diameter) are present in the surface regions of the outcrop.

4. 3 The upper unit (U₃): the mlBr facies

The surface upper unit of the Bambili pyroclastic sequence consists of the mlBr facies (Fig. 5 and 8a), is represented by an ignimbrite whose The unit has an overall color is white with a low consistency (Fig. 4a-d) compared to the previous facies. This white color and is lithic-rich, with a low consistency in volume fraction of lithics compared to the previous mlT facies on ignimbrite generated by the second eruption episode has which it lies with a sharp contact with precedent mlT unit. Consistency depends on the abundance of enclaves lithics, so areas of high rocky enclaves lithics are more resistant to erosion and that's why the remnant blocks are predominantly made up. The unit U₃ is characterized by a distinct Sstratification (Fig. 5b) is that appears observable in some of these remnant blocks. The stratification and is characterized by alternating coarse-grained clast-supported deposit of beds of more than up to 35 cm thick, and fine-particle size deposit-grained matrix-supported beds, with thicknesses not exceeding 8 cm of thickness (Fig. 4a). Pyroclastic surge divisions are ash-to lapilli-sized The fine-grained and matrix-supported beds, are grey to whitish in colour color with low proportion of accretionary lapilli (Fig. 4b). In contrast, the coarse-grained clast-supported beds are lithic-rich, breccia is generally poorly sorted and diffusely stratified in some outcrop.

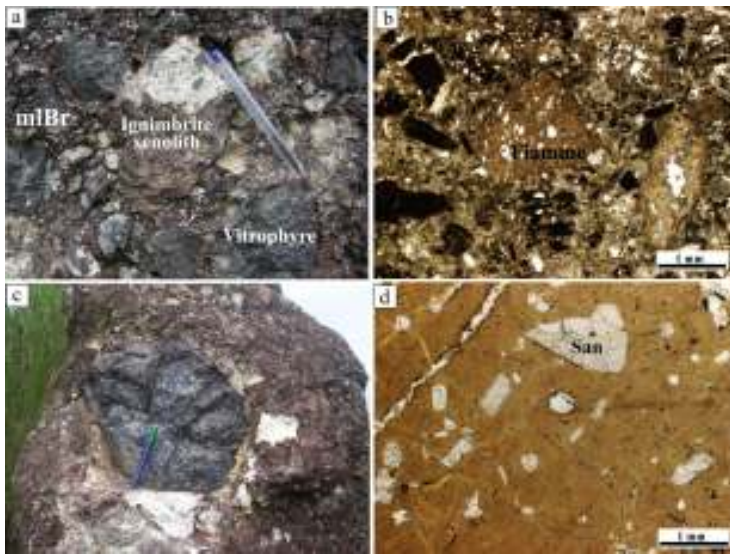


Fig. 8. a) Detail of mlBr facies and **b)** microphotograph of ignimbrite enclave **c)** Enclave of vitrophyre and **d)** the corresponding microphotograph.

Rock fragments constituting this ignimbrite unit are varied vary in nature. The most represented (25 to 35 vol. %) are enclaves accidental lithics of vitrophyres (25 to 35%) with black color (Fig. 8a,c); some pockets-filled channels can contain up to 70 vol. % of these rock inclusion accidental lithic fragments. Their dimensions range in size from 22 x 19 cm to 5 x 2.5 cm. These enclaves lithics are essentially prismatic elements with chilled margins. Under the microscope, the matrix of vitrophyre is shows a glassy matrix essentially

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vitreous with some rare crystals of quartz and feldspar (Fig. 8d). The geochemistry of these vitrophyres (Fig. 7) show that they have are rhyolitic in composition (SiO₂: 71.03 – 73.23% and Na₂O + K₂O: 7.12 – 7.88%) in composition (Fig. 7). Enclaves Lithic fragments of rhyolite are with light gray colored are also observed. They and represent about 5 vol. % of the rock clast population volume with and their sizes ranging range from 14 x 12 cm to 0.8 x 0.6 cm; some Some elements fragments can reach up to 45 x 35 cm. Lithic fragments of the the granitic basement rock enclaves are rare and usually represented by large (11 x 9 cm) quartz crystals (11 x 9 cm) constituting about 5 vol. % of the rock. Enclaves Lithics of the lower first ignimbritic phase unit (Fig. 8a, b) included identified in the second phase unit were are also found in this facies upper unit; they They measure up to 18 x 16.5 cm. These enclaves of ignimbrites and contain the same rock fragments than of the country rock. The deposit Mmatrix is whitish in color, and consists essentially of consolidated volcanic ashes in which are embedded small rocks and minerals fragments.

5. DISCUSSION AND CONCLUSION

The ignimbrites sheets of Bamenda volcano constitute about 7.5% of the rocky outcrops of the volcano representing approximately 45 km² with a volume estimated at 6.3 km³; these These deposits lie ly on the trachytic flows and the granito-gneissic basement and are covered in places by columnar jointed basaltic flows. The studied deposit succession shows evidence of multiple changes of eruptive regime and emplacement modes which likely occurred during a single eruptive event. The stratified character of the deposits observed at Bambili can be attributed to a spatial and temporal variation of the nature of pyroclastic current, which would have been transformed into pyroclastic surge with a current, becoming weakly concentrated and rich in ashy and gaseous fraction.

In particular, phreatomagmatic deposits may form during late eruptive stages following disruption of the top of the magma chamber (e.g., [27]). The presence of vesicular tuff layers in surge pyroclastic deposits, along with a dominance of blocky, poorly vesicular ash particles with hydration cracks, indicates generally suggest an origin as a wet pyroclastic surges origin [28]. of This also indicates a phreatomagmatic origin activity [28]. Anisotropy of magnetic susceptibility study of Mount Bamenda showed that these deposits were emitted from Oku vent (1.8 x 2.2 km) in which is located the lake Oku, situated in mount Oku, the neighboring NE volcano [3]. The location of this lake will justify the presence of these wet surges in the late surge deposits of Bamenda volcanic field.

The mIBr unit is composed of an alternation of stratified clast-supported layers and laminated ash layers, which can be interpreted as a medial-to-distal deposits produced by phreatomagmatic surges and contemporaneous fallout [29]. On other volcanoes, similar deposits were interpreted as fallout deposits or as pyroclastic surge and co-surge fallout deposits, due to the contemporaneous presence of characteristics normally pertaining to both fallout and surge deposits (e.g. [30, 31, 32, 33]). However, it is difficult to confirm this depositional mechanism especially in the absence of an extending outcrop. Nevertheless, given that a single surge layer is composed by a well-graded coarse lapilli-rich bed covered by a more fine ash bed [33, 34], it is likely that our remnant blocks that present the same characteristic were deposited by a phreatomagmatic surge. In addition, these deposits are partly covered by more recent basaltic lava flow. According to [33] and [34], a single surge layer is composed by a well-graded coarse lapilli-rich bed covered by a more fine ash bed.

In the last phase of the eruption, magma has would have encountered a groundwater body and thus generated to generated a large phreatomagmatic explosion, which was likely suspended produced the a huge amount of ash and lithic fragments. Pulsating hydrostatic This explosion resulted and magma pressure produced in the formation of the

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phreatomagmatic pyroclastic surges characterizing U₃. The vitrophyres abundantly found in ~~these~~ this surge deposits unit would have derived be from the juvenile lava that cooled rapidly ~~by in the contact of~~ water, and then sprayed out by the explosion. The complex dynamics of water-magma interaction defines the nature of explosive activity, characterized by variable energy outputs and different degrees of magmatic or phreatomagmatic fragmentation [35, 36, 37, 38, 39]. Depending on the extent of water-magma interaction, ~~surge deposits can be formed by fallout layers made of couplets of ash and lapilli~~ fallout layers made of couplets of ash and lapilli can form surge deposits. They can be formed, ~~through~~ the alternation of fallout layers and surge deposits, or by the simultaneous concurrent deposition from both processes, leading to the formation of highly complex deposits made of numerous (from few tens to over thousands) of thin tephra beds (e.g. [16, 33, 40, 41]. ~~As a consequence~~ Therefore, hydromagmatic-phreatomagmatic deposits show remarkable variability in grain-size from layer-to-layer and within layers. Definitively, we inferred that the eruptions of Bamenda volcano were affected by interaction with lake water, generating phreatomagmatic pyroclastic flows and surges. The new chronological succession of geological formations of Bambili can be considered as follows: trachytic flow at the base, followed by welded ignimbrites represented by dark gray and whitish units and pyroclastic surge deposits covered by basaltic flow.

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COMPETING INTERESTS

Authors declare that there are no competing interests.

AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

REFERENCES

1. Déruelle B, Ngounouno I, Demaiffe D. The "Cameroon Hot line" (CHL): a unique example of active alkaline intraplate structure in both oceanic and continental lithospheres. *Compte Rendus Géoscience*. 2007; 339: 589-600.
2. Burke K. Origin of the Cameroon Line of volcano-capped swells. *Journal of Geology*. 2001; 109: 349-362.
3. Gountié Dedzo M, Nédélec A, Nono A, Njanko T, Font E, Kamgang P, Njonfang E, Launeau P. Magnetic fabrics of the Miocene ignimbrites from West-Cameroon: implications for pyroclastic flow source and sedimentation. *Journal of Volcanology and Geothermal Research*. 2011; 203: 113-132.
4. Dunlop HM. Strontium isotope geochemistry and potassium-argon studies on volcanic rocks from the Cameroon Line, West Africa. PhD Thesis, University of Edinburgh, Edinburgh; 1983.
5. Lissom J. Etude pétrologique des laves alcalines du massif d'Oku: un ensemble volcanique de la "Ligne du Cameroun". Thèse Université Pierre et Marie Curie, (Paris VI) ; 1991. French.

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6. Kamgang P. Contribution à l'étude géochimique et pétrologique du massif de Nkogam (pays Bamoun, Ouest-Cameroun). Thèse Doctorat 3^e cycle, Université de Yaoundé; 1986. French.
7. Nono A, Déruelle B, Demaiffe D, Kambou R. Tchabal Nganha volcano in Adamawa (Cameroon): petrology of a continental alkaline lava series. *Journal of Volcanology and Geothermal Research*. 1994;60:147-178.
8. Branney MJ, Kokelaar P. Pyroclastic density currents and the sedimentation of ignimbrites. *Geological Society of London Memoirs*. 2002;27.
9. Valentine GA, Fisher RV. Pyroclastic surges and blasts. In: Sigurdsson H (Ed.) *Encyclopedia of Volcanoes*, Academic Press. 2000;571-580.
10. Wilson CJN, Houghton BF. Pyroclast transport and deposition. In: Sigurdsson H (Ed.) *Encyclopedia of Volcanoes*, Academic Press, 2000;545-554.
11. Carey S. Transport and deposition of tephra by pyroclastic flows and surges. *Sedimentation in volcanic Settings*. Society of Economic Paleontology and Mineralogy Special Publication. 1991;45:39-57.
12. Druitt TH. Pyroclastic density currents. In: Gilbert JS, Sparks RSJ (Ed) *The physics of explosive volcanic eruptions*. Geological Society of London Special Publication. 1998;145:145-182.
13. Belousov A, Voight B, Belousova M, Petukhin A. Pyroclastic surges and flows from the 8-10 May 1997 explosive eruption of Bezymianny volcano, Kamchatka, Russia. *Bulletin of Volcanology*. 2002;64, 455-471.
14. Burgisser A, Bergantz GW. Reconciling pyroclastic flow and surge: the multiphase physics of pyroclastic density currents. *Earth Planetary Science Letters*. 2002;202:405-418.
15. Fisher RV. Transport and deposition of a pyroclastic surge across an area of high relief: the 18 May 1980 eruption of Mount St. Helens, Washington. *Geological Society of America Bulletin*. 1990;92:938-954.
16. Dellino P, La Volpe L. Structures and grain size distribution in surge deposits as a tool for modelling the dynamics of dilute pyroclastic density currents at La Fossa di Vulcano. *Journal of Volcanology and Geothermal Research*. 2000;96:57-78.
17. Valentine GA, Fisher RV. Pyroclastic surges and blasts. In: Sigurdsson H (Ed.) *Encyclopedia of Volcanoes*, Academic Press. 2000;571-580.
18. Toteu SF, Van Schmus WR, Penaye J, Michard A. New U-Pb and Sm-Nd data from north Cameroon and its bearing on the pre-Pan African history of central Africa. *Precambrian Research*. 2001;108:45-73.
19. Nzolang C, Kagami H, Nzenti P, Hotz F. Geochemistry and preliminary Sr-Nd isotopic data on the Neoproterozoic granitoids from the Bantoum Area, West Cameroon: evidence for a derivation from a Paleoproterozoic to Archean crust. *Polar Geoscience*. 2003;16:196-226.
20. Nzolang C. Crustal evolution of the Precambrian basement in west Cameroon: inference from geochemistry, Sr-Nd and experimental investigation of some granitoids and metamorphic rocks. Ph.D. thesis, Graduate School of Science and Technology, Niigata University, Japan; 2005.
21. Gountié Dedzo M, Njonfang E, Kamgang P, Nono A, Zangmo Tefogoum G, Kagou Dongmo A, Nkouathio DG. Dynamic and evolution of the Mounts Bambouto and Bamenda calderas by study of ignimbritic deposits (West-Cameroon, Cameroon Line). *Syllabus Review, Science Series*. 2012;3:11-23.
22. Kamgang P, Njonfang E, Nono A, Gountié Dedzo M, Tchoua FM. Petrogenesis of a silicic magma system: Geochemical evidence from Bamenda Mountains, NW Cameroon, Cameroon Volcanic Line. *Journal of African Earth Sciences*. 2010;58:285-304.
23. Lofgren G. Experimentally produced devitrification textures in natural rhyolite glass. *Geological Society of America Bulletin*, 1971a;82:553-560.

- 399 24. Lofgren G. Spherulitic textures in glassy and crystalline rocks. *Journal of Geophysical*
400 *Research*. 1971b;76:5635-5648.
- 401 25. Lofgren G. An experimental study of plagioclase crystal morphology: isothermal
402 crystallization. *American Journal of Science*. 1974;274:243-273.
- 403 26. Le Bas M, Le Maitre R, Streckeisen A, Zanettin B. A chemical classification of volcanic
404 rocks based on the total alkali-silica diagram. *Journal of Petrology*. 1986;27:745-750.
- 405 27. Sigurdsson H, Carey S, Cornell W, Pescatore T. The eruption of Vesuvius in A.D. 79,
406 *National Geographic Research*. 1985;1:332-387.
- 407 28. Palladino DM, Simeì S. Eruptive dynamics and caldera collapse during the Onano
408 eruption, Vulcini, Italy. *Bulletin of Volcanology*. 2005;167:423-440.
- 409 29. Zanon V, Pacheco J, Pimentel A. Growth and evolution of an emergent tuff cone:
410 Considerations from structural geology, geomorphology and facies analysis of São
411 Roque volcano, São Miguel (Azores). *Journal of Volcanology and Geothermal*
412 *Research* 2009;180:277-291.
- 413 30. Wohletz KH, Sheridan MF. A model of pyroclastic surge. *Geological Society of*
414 *American Special Paper*. 1979;180:177-194.
- 415 31. Fisher RV, Schmincke HU. *Pyroclastic rocks*. Springer-Verlag, New York. 1984.
- 416 32. Cole PD, Guest JE, Duncan AM, Pacheco JM. Capelinhos 1957–1958, Faial, Azores:
417 deposits formed by an emergent surtseyan eruption. *Bulletin of Volcanology*.
418 2001;63:204-220.
- 419 33. Dellino P, Isaia R, La Volpe L, Orsi G. Interaction between particles transported by
420 fallout and surge in the deposits of the Agnano–Monte Spina eruption (Campi Flegrei,
421 Southern Italy). *Journal of Volcanology and Geothermal Research*. 2004;133:193-210.
- 422 34. Sohn YK, Chough SK. Depositional processes of the Suwolbong tuff ring, Cheju Island
423 (Korea). *Sedimentology*. 1989;36:837-855.
- 424 35. Wohletz KH, Sheridan MF. Hydrovolcanic eruptions: II. Evolution of basaltic tuff rings
425 and tuff cones. *American Journal of Science*. 1983;283:385-413.
- 426 36. Houghton BF, Hackett WR. Strombolian and phreatomagmatic deposits of Ohakune
427 craters, Ruapehu, New Zealand: a complex interaction between external water and
428 rising basaltic magma. *Journal of Volcanology and Geothermal Research*. 1984;21:207-
429 231.
- 430 37. Kokelaar P. Magma–water interactions in subaqueous and emergent basaltic
431 volcanism. *Bulletin of Volcanology*. 1986;48:275-289.
- 432 38. White JDL, Houghton B. Surtseyan and related phreatomagmatic eruptions. In:
433 Sigurdsson, H., Houghton, B.F., McNutt, S.R., Rymer, H., Stix, J. (Eds.), *Encyclopedia*
434 *of Volcanoes*, Academic Press, San Diego. 2000;495-511.
- 435 39. Mastin LG, Christiansen RL, Thornber C, Lowenstern J, Beeson M. What makes
436 hydromagmatic eruptions violent? Some insights from the Keanakākoī Ash, Kīlauea
437 Volcano, Hawaii. *Journal of Volcanology and Geothermal Research*. 2004;137:15-31.
- 438 40. Chough SK, Sohn YK. Depositional mechanics and sequences 705 of base surges,
439 Songaksan tuff ring, Cheju Island, Korea. *Sedimentology*. 1990;37:1115-1135.
- 440 41. Dellino P, Isaia R, La Volpe L, Orsi G. Statistical analysis of textural data from complex
441 pyroclastic sequences: implications for fragmentation processes of the Agnano–Monte
442 Spina tephra (4.1 ka), Campi Flegrei, southern Italy. *Bulletin of Volcanology*.
443 2001;63:443-461.
- 444