Dynamic and evolution of the Mounts Bamboutos and Bamenda calderas by study of ignimbritic deposits (West-Cameroon, Cameroon Line)

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Abstract

The studies realized in Bambouto and Bamenda volcanoes highlight the volumetric importance of ignimbritic formations that cover about 180 km² of the massifs with thickness between 150 and 200 m. Their massive lapilli tuff (mlT) and massive lithic breccias (mlBr) facies are made up of various natures of lithic fragments (mainly trachytic) and have same mineralogy made up of alkali feldspar (sanidine and anorthoclase), quartz, plagioclase, clinopyroxene, biotite and oxide. The abundance of fragmented minerals (40-85%), accretionary lapilli and co-ignimbritic breccias in the caldera and its surroundings reflects the highly explosive character of eruptions that have presided the setting up of these rocks and therefore favored collapses which are at the origin of the calderas formation. The structural, petrographic and morphological features show that these calderas belong to explosive and collapse types.

Keywords: Cameroon Line, Mounts Bambouto, Mounts Bamenda, ignimbrites, calderas

Résumé

Les études menées dans les Monts Bambouto et Bamenda mettent en exergue l’importance volumétrique des formations ignimbritiques qui couvrent environ 180 km² des massifs avec des puissances atteignant 150 à 200 m. Leurs faciès tuf de lapilli massif (Tlm) et brèches de lithiques massifs (Brlm) possèdent en plus de fragments lithiques de nature variée (essentiellement trachytique), une minéralogie identique faite de feldspaths alcalins (sanidine et anorthose), quartz, plagioclase, clinopyroxène, biotite et oxyde. L’abondance de minéraux fragmentés (40-85%), accretionary lapilli et co-ignimbritic breccias dans la caldera et son environnement reflète le caractère très explosif des éruptions ayant présidé à la mise en place de ces roches et donc favorisé les effondrements à l’origine de la formation des caldeiras. Les éléments structuraux, pétrographiques et morphologiques montrent que ces caldeiras sont de types d’explosion et d’effondrement.

Mots-clés: Ligne du Cameroun, Monts Bambouto, Monts Bamenda, ignimbrites, caldeiras.

Introduction

Cameroon alkaline volcanism is related to a major fracture direction N30°E. These fractures are confined to a band of about 100 km wide and more than 1600 km long known as the Cameroon Line (CL) or Cameroon Hot Line (Déruelle et al., 2007). This line is characterized by alignment of oceanic and continental volcanic massifs, and anorogenic plutonic complexes extending from Pagalu island in the Atlantic Ocean to Lake Chad (Fig. 1). It is segmented by N70°E Central Cameroon Shear Zone (Fig 1) along the volcanism of Adamawa. The volcanism along the CL seems to have started during the Eocene with the emplacement of the Bamoun plateau between 51.8 and 46.7 Ma (Moundi et al., 2007) and Mount Bangou between 44.7 and 43.1 Ma (Fosso et al., 2005), and is still active at Mount Cameroon (1999 and 2000 eruption).
The products of this volcanism are mainly basalt, trachyte, phonolite and rhyolites; ignimbritic deposits are found only in the continental part of the CL, particularly in the Mounts Bambouto and Bamenda. Other small deposits (< 10 km²) are also reported in Nkogam massif (Kamgang, 1986), and in Mount Oku (Dunlop, 1983 and Lissom, 1991). The purpose of this work is to constrain the ignimbritic deposits of the Mounts Bambouto and Bamenda in relation with the caldera genesis.

Geological setting

Mounts Bambouto and Bamenda belong to the most important geomorphologic system in the region called West-Cameroon Highlands (Morin, 1988).
Mounts Bambouto
Mounts Bambouto are the third largest volcano (800 km²) of the CL after Mounts Cameroon and Manengouba. This massif is situated between longitudes 09°57'E and 10°15'E and latitudes 05°27'N and 05°48'N. Mount Mélétan (2740 m) is the highest point of the massif. Volcanic products of the massif are made up of basalts, trachytes, phonolites, rhyolites and ignimbrites. Their ages ranged from 21.12 Ma to 0.50 Ma (Gouhier et al. 1974; Tchoua, 1974; Dunlop, 1983; Fitton and Dunlop, 1985; Marzoli et al. 1999; 2000; Youmen et al., 2005; Nkouathio et al. 2008; Kagou Dongmo et al., 2010)

The lower part of Bambouto massif is composed of basaltic rocks that cover in places thick ignimbritic flow deposits with various facies (Gountié Dedzo, 2002, 2004; Nono et al., 2003, 2004; Gountié Dedzo et al., 2011a). In the upper and middle parts, felsic rocks (trachyte, phonolite, rhyolite and ignimbrite) predominate and represent 60-65% of the massif. The Miocene ignimbrites (12.7 to 18.1 Ma) (Gouhier et al. 1974; Tchoua, 1974; Marzoli et al. 1999; Youmen et al., 2005) that lie on granitic basement have been considered as the first products of volcanic activity of the massif (Tchoua, 1973). The discovery of enclaves of basaltic scoriae in some of these ignimbritic formations lying on basement rock helped highlight an early volcanic stage which is strombolian and pre-ignimbritic in the south of the massif (Nono et al., 2004)

A synthetic revision of the volcanic story of Mount Bambouto is proposed as follows by Kagou et al. (2010) and Zangmo Tefogoum et al. (2011). The first stage (precaldra stage), ca. 21 Ma, corresponds to the building of the initial basaltic shield volcano and characterized by the tumescence of the volcanic shield due to magma injection giving rise to several annular fissures observed in the whole volcano. The second stage (syncaldera stage), from 18.5 to 15.3 Ma, is marked by the collapse of the caldera linked to the pouring out of ignimbritic rhyolites and trachytes. Zangmo Tefogoum (2007) has shown that the model of formation of this caldera is comparable to that of Cole et al. (2005). The third stage (postcaldera stage), from 15 to 4.5 Ma, renews with basaltic effusive activity, together with post-caldera extrusions of trachytes and phonolites. The 0.5 Ma Totap basaltic effusive activity could indicate the beginning of a fourth phase.

Mounts Bamenda
Mounts Bamenda (600 km²), which constitute in volumetric importance the fourth largest volcano of the CL, are the NE extension of the Mounts Bambouto with which they do not have clear limit. This massif lies between longitudes 10°00'E and 10°30'E and latitudes 05°45'N and 06°10'N and culminates at 2621 m at Lake Bambili. Petrographic and geochemical studies (Kamgang et al. 2007; 2008; 2010) show that the Mounts Bamenda consist of basanites, basalts, hawaiites, mugearites, benmoreites, trachytes, rhyolites and ignimbrites. These rhyolitic ignimbrites overlies basement rock (constituted by granite and gneiss) and are covered by laterized basalt. The felsic lavas are most abundant than intermediate types (mugearites and benmoreites). The radiometric dating gives ages ranging from the current to 17.4 Ma for the basaltic lavas and from 18.98 Ma to 27.40 Ma for the felsic lavas (Kamgang et al., 2007, 2008).

Mounts Bambouto and Bamenda calderas
The Mounts Bambouto caldera (Fig. 2 and 3a) is located in the uppermost zone of the massif and is an asymmetrical depression with a roughly elliptical shape of about 13 km from West to East and 8 km from North to South. It has on its southeast side, subvertical walls (Fig. 4a) rising up to 1300 m above its floor bristling with trachytic and phonolitic domes and flow-domes. These walls are lowered from East to West until it disappears at the opening of the caldera.

The Mounts Bamenda are characterized by the presence of two calderas (Fig. 2 and 3b) of smaller dimensions: the calderas of Santa-Mbu (6 x 4 km) and Lefo (4 x 3 km). Their floor located respectively at elevation of 550 m and 400 m is mainly composed of trachytic domes, which are also abundant on the external slopes of the massif (Fig. 4b).

The calderas of these volcanic massifs are covered by felsic rocks; such as trachyte, ignimbrite, phonolite and rhyolite. These rocks uneven the calderas morphology; they are found in prismatic lavas on the caldera rims and in the protrusions on the caldera floor (Fig. 5). Therefore, the slopes are very diverse in several directions; the “V” shaped valleys are found in the different directions of the calderas.
The methodology of this work is essentially based on field observations, thin sections studies and bibliographic review. Nature of feldspars, the most dominant mineral phase, was investigated in GET (Géosciences Environnement Toulouse) laboratory by electron microprobe analyses on CAMECA SX50 apparatus operating at the usual conditions. The ages are from Youmen et al. (2005) (Ar/Ar method), Kamgang et al. (2007) (K/Ar method) and Fitton and Dunlop (1985) (K/Ar method).

**Methodology and analytical methods**

The ignimbrites outcrop discontinuously on about 17% of the massif (Fig. 3a) representing approximately 135 km² for a total volume estimated at 13.5 km³. This volume is really much important (> 20 km³) because these formations are covered in the South of the massive by generally lateritized basalts. In the lower zone of the massif, they lie on the metamorphic basement, whereas in the upper zone, they cover the trachytes. The different facies which are essentially massive lapilli tuff (mlT, Branney and Kokelaar, 2002), were identified in many localities (Dschang, Baranka, Mbeng, Lepo, Nzema I and Nzema II); the massive lithic breccia facies (mlBr, Kokelaar and Branney, 2002) outcrop at Mbou. The largest outcrop covers an area of about 17 km long and 3 to 3.5 km wide with thickness ranging from 10 to 120 m. These ignimbrites have high aspect ratio of about 1.5 x 10⁻² to 3.2 x 10⁻². Indeed, the general shape of an ignimbrite sheet may, apart from its volume,
be simply and quantitatively described by the aspect ratio which is defined as the ratio of average sheet thickness to the diameter of a circle that covers the same area as the sheet (Walker, 1983, Wilson et al. 1995; Freundt et al., 2000). The ratios of the ignimbrites range from $<10^{-5}$ (low ratio) to $>10^{-2}$ (high aspect ratio). In the field, according to the degree of welding we distinguish the welded and non-welded ignimbrites.

The welded ignimbrites

The welded ignimbrites are abundantly represented in the southern slopes of the Bambouto massif. They are classified according to the density, the degree of welding and the color of the rock. The nature and ratio of lithic fragments vary from one facies to another (Table 1).

The ignimbrites of Dschang and Mbeng

The ignimbrites of Dschang (18.1 Ma; Youmen et al., 2005) outcrop in sheets in the Menoua valley on about 9 km² with a maximum thickness ranging between 80 and 120 m. Its mIT facies consists of a simple cooling unit made of two flow units overlay by basalt flow (Fig. 3a and 5c). The fiammes with ovoid to lenticular shapes represent 5-20% of the rock. The welded ignimbrites of Mbeng, identified along the roadcut (Fig. 6a) are covered successively by a first paleosol, non welded ignimbrites, rhyolitic flow, a second paleosol and finally the second deposit of non welded ignimbrites. The thickness and the area covered by this facies cannot be directly known. Its mIT facies also consists of two flow units representing one simple cooling unit. The fiammes represent 5-10% of the rock. The enclaves of rocks, mostly trachytic are more abundant in the upper units (10-15%). Enclaves of granite, vitrophyre and fragments of fossilized wood entirely or partially charred are less represented (Table 1). The matrix is made of alkali feldspar (15-25%) sanidine and anorthoclase: Ab$_{68.50}$Or$_{37.31}$; Fig. 4b, Table 2), plagioclase (1-2%), quartz (3-5%), biotite (2%), oxides (2%), clinopyroxene (1%).

The ignimbrite of Mbou

The ignimbrite of Mbou (Fig. 6c) is a mBr facies represented by one flow unit and covers an area of 5 km² with a thickness not exceeding 25 m. Black scoriae (20-25%) (Fig. 6b) constitute the majority of the enclaves with accessorially those of trachytes, vitrophyre and granitic basement rocks (Table 1). The ashy matrix with non-devitrified glass shards is made of alkali feldspar (15%), quartz (5%), plagioclase (2%), oxides (2%) and biotite (1%).

The ignimbrites of Lepo, Nzema I and II Nzema

The ignimbrite sheet, which extends from southwest of Bangang to Fongo-Tongo (Fig. 3a) covers an area of about 50 km² with a thickness ranging between 45 to 90 m; it is constituted by three main outcrops: Lepo, Nzema I and II Nzema.

The ignimbrite of Lepo is a mIT facies lying on a granitic basement and covered in places by lateritized basalts (Fig. 3a). It consists of a simple cooling unit represented by two flow units. The lowermost light gray unit has a vitroclastic and eutaxitique texture characterized by stretched and distorted devitrified fiammes (10-15%), which are preferentially oriented. The upper dark grey unit is less rich in fiammes (<10%).

The ignimbrite of Nzema I is represented by a dark gray mIT facies constituted only by one flow unit covered by a mBr facies with limited extension. The texture is marked by eutaxitique fiammes (5%) with unidirectional orientation.

The ignimbrite of Nzema II is characterized by a whitish mIT facies which consists of one flow unit covered by a non-welded mIT overlay by basalt flow (Fig. 3a). The fiammes (15-20%) are often black and generally has lenticular shapes. The lithic fragments of different ignimbrites are essentially trachytic (10-20%). Enclaves of granite, scoriae, ignimbrite and vitrophyre are less represented (Table 1). Devitrified matrix (50-90%) are made up of alkali feldspar (10-35%); sanidine and anorthoclase: Ab$_{68.44}$Or$_{35.53}$; Table 2), plagioclase (1%); oligoclase: Ab$_{81}$Or$_{16}$An$_{3.16}$), quartz (2-5%), biotite (2%), oxides (1-2%) and clinopyroxene (1%).

The ignimbrites of Baranka

The welded mIT ignimbrites of Baranka (15.28-15.5 Ma; Youmen et al., 2005) occupy the uppermost zone of the massif (Fig. 3a); it covers intermittently the south-western rim of the caldera and the bottom of the depression, representing a total surface of about 10 km². The true thickness of the deposits (> 30 m) is difficult to estimate because of the hilly relief and dense vegetation cover. Several ignimbritic
deposits phases are present with intercalation of trachytic and basaltic flows (Fig. 7a). Enclaves of these ignimbrites are mainly trachytes (10-20%) with accessory those of ignimbrites, charred wood and vitrophyre (Table 1). The microscopic observations show identical mineralogy in different flow unit and consists of alkali feldspar (15% sanidine and anorthoclase: Ab_{69}Or_{31}) Table 2), quartz (<5%), plagioclase (2%), oxides (2%), biotite (1%), and clinopyroxene (1%).

The non-welded ignimbrites

The non-welded ignimbrites are volcanic tuff and also belong to mlT facies. These deposits cover about 60 km² of the massif (Fig. 3a). The rocks outcrop in the lowermost zone of the massif, Southwest of Dschang, North of Mbeng and surrounding localities. In the uppermost zone, it occupies the major part of the caldera where they are inserted in places in the trachytic flows and the welded ignimbrites. Petrography of tuffs is similar to those of welded ignimbrites. Trachytic lithic fragments (average diameter: 7 x 5 cm) are more abundant (50-60%); however, they reach several meters in some cases (sharp fragments of trachyte and ignimbrites measuring 4.5 x 6 m at Fotang in the Mts Bambouto caldera). These lithics are similar to co-ignimbritic breccias generally associated with subsidence related to the formation of calderas. Accretionary lapilli (up to 10%), consisting of agglomerated ash are also present in all non-welded mlT with variable size (0.6 to 2.5 cm in diameter). Ashy fine particles of the matrix represent 25-30% of these formations.

The ignimbrites of Mounts Bamenda

The ignimbrites of Mounts Bamenda (Fig. 3b) constitute about 7.5% of the rocky outcrops of the massif representing approximately 45 km² with a volume estimated at 6.3 km³. As in the case of Mounts Bambouto, ignimbrites lie on a granito-gneissic basement and are covered by lateritized basalt. The different facies have been identified at Bamenda, Bambili, Big Babanki, Babanki Tungo, Mbengwi and on inner edges and bottoms of the Santa and Mbu calderas. It are also high aspect ratio ignimbrites (2.77 x 10^{-2} to 7.23 x 10^{-2}).

The welded ignimbrites

The welded ignimbrites outcrop as sheets, metric and decimetric blocks balls. The rock is massive and compact with variable color depending of the type of the facies. The proportions of lithic fragments and minerals are much less important (Table 1) in the ignimbrites of Mt Bamenda compare with those of Mt Bambouto.

The ignimbrites of Bamenda, Mbu, Mbengwi

The ignimbrites of Bamenda (11 km²), Mbu (3 km²) and Mbengwi (12 km²) have thickness ranging between 50 and 200 m and lie on a basement rock made of granite and syenite (Fig. 3b). The welded mlT facies of Bamenda has two light gray cooling units covered by mlBr facies while that of Mbu is represented by a single dark gray cooling unit covered by a non-welded mlT above, which lie a mlBr facies with very limited expansion (Fig. 7b). The entire unit of Mbengwi are made of BrIm facies overlay in the SW by basalt flow (Fig. 3b). The fiamme (5-10%) are predominantly black in Bamenda and generally flattened, giving to the rock a eutaxitique texture. Lithic fragments (10-15%) of mlT facies are mostly trachytes, rhyolites and granites (Table 1); in brecciated part of the deposit, their proportions reach 30 to 40%. The matrix is made of alkali feldspar (5-10%; sanidine: Ab_{52.56}Or_{42.36}) Table 2), quartz (1-3%), oxides (1-3%), plagioclase (1-2%), biotite (1-2%) and clinopyroxene (1%).

The ignimbrites of Bambili, Sabga and Big Babanki

The ignimbrites Bambili (6 km²), Big Babanki (3 km²) and Sabga (5 km²) form small outcrops (Fig. 3b) with maximum thickness between 70 and 120 m. The remnant blocks (up to 6.5 x 11 m) of ignimbrites are also observed at Bambili (Fig. 6d). They lie on a basement rocks made of granite, schist and migmatite. The ignimbrite of Bambili is a welded mlT with trace of rubefaction in places, characterized by two cooling units (dark-grey and whitish) whereas the ignimbrite of Big Babanki is represented only by a whitish unit; the two outcrops are covered in places by a mlBr facies. The ignimbrite of Sabga is also a welded mlT constituted by one dark-gray unit covered by one light grey unit. The fiammes (30-40%) are generally distorted in the basal parts of the outcrops. Enclaves of rocks (10-15%) are represented by trachytes, rhyolites, vitrophyre,
ignimbrites and granites (Table 1); they represent 65 to 70% in mlBr facies of Bambili where there are mainly enclaves of black vitrophyre. The matrix is much devitrified and is made up of alkali feldspar (5-10%; sanidine: Ab88.5Or18.41; Table 2), quartz (2-3%), plagioclase (1-3%), oxides (1-3%), biotite (1%) and clinopyroxene (1%) (Fig. 6e).

The non-welded ignimbrites

The non-welded ignimbrites outcrop in the Santa-Mbu caldera on about 2 km², at Santa Coffee and Ndzhah in the Lefo caldera on about 3 km². In the Lefo caldera, they lie on a basement rock consisting of micaschist covered successively by trachytic and basaltic flow (Fig. 7c). Their exact thickness (> 20 m) is difficult to assess because of the abundant vegetation and uneven terrain. As in the Bambouto massif, the rock is very powdery and consists of enclaves (20-25%) mainly trachytic in nature with minor proportion of ignimbrite, rhyolite, granite and obsidian. The average size of these enclaves is 3 x 2.4 cm; few enclaves reached 1.5 x 2.5 m. As in Mount Bambouto, they have characteristics close to co-ignimbritic breccias. The accretionary lapilli are poorly represented (<5%) probably due to the very advanced state of alteration in the deposits. In the ashy matrix, there is presence of quartz, feldspar and relic of pumices.

The ignimbritic volcanism of the CL began in Mounts Bamenda by non-welded deposits in the Lefo caldera (> 22 Ma; Fig. 7c) followed by those of the Santa-Mbu caldera (> 20.6 Ma; Fig. 7b). The ignimbrites are younger in Mounts Bambouto; the first deposits are observed in Southern lower slope of the volcano, in Dschang locality (18.1 Ma). Three episodes of ignimbritic deposits are identified in the Bambouto caldera; each deposit lie on a trachytic flow: the first episode (approximately 15.5 Ma) is the most important in terms of volume of deposit; the second episode is dated at 15.28 Ma; the latter younger than 12.93 Ma, is essentially represented by non-welded deposit.

The fiammes

The fiammes are flat pumices present in almost all welded ignimbrites. Their abundance in different sites is very variable (5-60%). Their shapes display a wide range of geometry and depend of the degree of compaction and their position in the deposit sequences. Some of them are very flattened, distorted (Bambili and Lepo) and preferentially oriented, giving to the rock a eutaxitic texture. Devitrification is very advanced in most fiammes (Fig. 6f,i) and is characterized by the formation of quartzofeldspathic fibres with radial disposition in relation to the axial channel (axiolitic structure). When the channel is absent, the fibres have a spherulitic arrangement; they constitute in this case the spherulites (Fig. 6f,ii). Splinters of glass, products the bursting of bubble coming from pumice are numerous and generally have a devitrification on their borders.

Enclaves of rock formations in ignimbrites

In both massifs, enclaves of trachyte are the most abundant comprising mostly fragments of juvenile lava, having a typical trachytic structure marked by the preferential orientation of the laths of alkali feldspar (about 75%).

Enclaves of rhyolite are abundant in the brecciated zones and their porphyritic texture is made of quartz (5%), alkali feldspar (10-15%) and a dark grey glass.

The enclaves of vitrophyre or obsidian are shiny black and are also juvenile lava fragments; they are most represented in mlBr facies of Bambili and Mbu. In welded mlT, their proportions are generally low. The vitreous mass is formed in some cases of alkali feldspar (< 2%).

Enclaves of granites are observed in ignimbrites of Dschang, Nzemla II Baranka and Bambili. Those of Dschang are very flat (Fig. 6g) and show signs of melting at their edges. Their texture is granular or microgranular and the mineralogy is made up of quartz, alkali feldspar, microcline, biotite and plagioclase (Fig. 6h).

The enclaves of ignimbrites are present in Bambili, Mbu, Mbengwi, Lepo and Baranka. Despite their advanced state of alteration, trachytic enclaves and fiammes are still identifiable. Eutaxitic texture is still observable in most cases.

The enclaves of scoriae identified at Nzemla I, Baleveng Mbengwi are dark and very porous; their presence in ignimbrites which lie on basement rock, strongly suggests that volcanic activity in the Mount Bambouto began with an
explosive strombolian phase (Nono et al., 2004).
Microphotograph showing the presence of spherulite in the matrix of Bambili ignimbrites.
g) Presence of flat enclave of granite in Dschang ignimbrite. h) Microphotograph of Dschang ignimbrite showing an enclave of granite with their mineral association. Qtz: quartz; San: sanidine; Anor: anorthoclase; Bt: biotite; Mi: microcline

Discussion and conclusion
Mounts Bambouto and Bamenda have the characteristics of shield volcanoes where the felsic lavas are most abundant compare to the basaltic lavas. The presence of ignimbritic deposits in their summit area associated to the calderas is consistent with their important contribution to the genesis of these calderas (Wood, 1984; Lipman, 1997, Roche and Druitt, 2001).
As it is widely reported in the volcanological literature, major explosive eruptions often occur as causes and/or effects of caldera collapses (e.g., Smith and Bailey 1968; Druitt and Sparks 1984; Heiken and McCoy 1984; Scandone 1990; Palladino and Simei, 2005). So it is the presence of large volumes of pyroclastic rocks, in particular ignimbrites widely widespread on the slopes, edges and inside the Bambouto and Bamenda calderas, that provides the main argument for the interpretation in favour of the collapse after highly explosive eruptions, as in the case of the Las Canadas caldera in the Canary Islands (Marti et al. 1994; Aubert and Keiffer, 1998) and Vulcans caldera in Italy (Palladino and Simei, 2005). The current estimated volume of the ignimbritic deposits of Mounts Bambouto (13.5 km$^3$) and Bamenda (6.3 km$^3$), is in fact below the actual volume (Gountié Dedzo et al., 2011b). Indeed, in addition to the erosion that has greatly reduced the volume of the less consolidated deposits since about 13 Ma (age of the youngest ignimbritic deposit), large areas of ignimbrites were covered by recent basaltic and trachytic lavas inside and outside the calderas (Fig. 3 and 5).

<table>
<thead>
<tr>
<th>Locality</th>
<th>Total glass</th>
<th>Devitrification</th>
<th>Mineralogy</th>
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<tr>
<td>Dschang</td>
<td>60-65%</td>
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<td>5-10% trachyte, 2% granite, 2.5% vitrophyre, 1% rhyolite</td>
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<td>Mbeng</td>
<td>40-45%</td>
<td>15-20%</td>
<td>25-33%</td>
<td>15-25% trachyte, &lt;5% rhyolite, 2% carbonized wood, 2% granite, 1% vitrophyre</td>
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<td>Mbou</td>
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<td>5%</td>
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<td>15% KFs, 5% Qtz, 2% Pl, 1% Bt, 1% Cps.</td>
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<td>40-45%</td>
<td>15-25% KFs, &lt;3% Qtz, 1% Pl, 2% Bt, 2% Cps.</td>
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<td>5% KFs, 2% Pl, 1% Ox, 1% Qtz, 1% Cps.</td>
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<td>10-20%</td>
<td>5-10% KFs, 2% Qtz, &lt;3% Pl, 3% Ox, 1% Pl, &lt;1% Cps.</td>
</tr>
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<td>Big Babanski</td>
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<td>15%</td>
<td>10% KFs, 3% Qtz, 1% Pl, 1% Ox.</td>
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<tr>
<td>Sabga</td>
<td>70-85%</td>
<td>5-10%</td>
<td>5-15%</td>
<td>5-10% KFs, 2% Qtz, 2% Pl, 1% Ox.</td>
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Table 2. Representative microprobe analyses of feldspars from selected ignimbrite samples from Mounts Bambouto and Bamenda.

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<th>Sanidine</th>
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<th>Oligoclase</th>
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<td>Mounts Bamenda</td>
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<tr>
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<td>Dscangh</td>
<td>GM2</td>
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<tr>
<td>TiO₂</td>
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<td>MnO</td>
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</tr>
<tr>
<td>CaO</td>
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<td>0.14</td>
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</tr>
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<tr>
<td>K</td>
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Fig. 6. a) Roadcut with ignimbrite outcrop in Mbeng locality. b) Microphotograph of Mbeng ignimbrite showing devitrified matrix and multiple fragments of minerals. c) Presence of multiple enclaves of scoriae in Mbou ignimbrite. d) Remnant blocks of Bambili ignimbrites with enclave of trachyte (i) and vitrophyre (ii). e) Microphotograph of Sabga ignimbrite with crystals and rock inclusions. f) (i) Microphotograph showing eutaxitic texture of the devitrified fiammes in Bambili ignimbrites; (ii) Microphotograph showing the presence of spherulite in the matrix of Bambili ignimbrites. g) Presence of flat enclave of granite in Dschang ignimbrite. h) Microphotograph of Dschang ignimbrite showing an enclave of granite with their mineral association. Qtz: quartz; San: sanidine; Anor: anorthoclase; Bt: biotite; Mi: microcline
The high aspect ratio (1.5 x 10^{-2} to 7.23 x 10^{-2}) reflects the concentrated character of pyroclastic flows at the origin of the formation of ignimbrites of Mounts Bambouto and Bamenda. The important proportion of rocky lithic fragments (10-35%) in most ignimbritic facies and those of fragmented minerals (40-85%) reflects the violence of eruptions (Branney and Kokelaar, 1991) that governed the emplacement of ignimbritic formations. The accretionary lapilli found in the calderas and surroundings of these massifs, are deposits of pyroclastic falls in hydrated conditions and are setting up during the late phases of eruption after the collapse of the top of the magma reservoir (Sigurdsson et al. 1995; Palladino and Simei, 2005). These lapilli are coming from hydromagmatic eruptions characterized by strong explosions pulverizing the overlying bedrock during the transformation liquid-water vapor (Bardintzeff, 2006).

Three main processes can usually cause pyroclastic flows (Sparks et al. 1978; Druitt, 1992, Calder et al., 1999): the collapse of a Plinian column on itself (Saint Vincent Type in Guadeloupe) resulting from an explosive disintegration of magma and rock in a volcanic chimey; the destruction of a lava dome associated with a laterally directed explosion (Pelee type in Martinique); or the collapse of a summital dome of viscous lava by simple gravity (Merapi type in Indonesia), causing avalanches at high temperatures. The ignimbrites of Mounts Bambouto and Bamenda are probably considered to result from the first process, because in addition to evidence of violent explosions, there is a presence of juvenile lava fragments resulting from the explosion of magma. The presence of specific facies in pyroclastic deposits can be assumed as indicators of the formation of a caldera. Large volumes of ash associated to deposits of pumice and lithic fragments compared to co-ignimbritic breccias observed in calderas here studied are generally interpreted to mark the onset of caldera by collapse (Druitt and Sparks, 1982 Walker, 1985; Druitt and Bacon, 1986, Mellors and Sparks, 1991; Perrotta and Scarpati, 1994, Rossi et al., 1996). These co-ignimbritic breccias rich in coarse lithic fragments are proximal facies confined around and inside the vents and are setting up during the collapse of the roof of the magma reservoir (Branney and Kokelaar, 2002; Palladino and Simei, 2005).

Elements of dynamics characterized by subvertical ramparts and subcircular to elliptical shapes reflecting the geometry of magma chambers (Zangmo Tefogouv et al., 2011), show that calderas may have formed by collapse. In both massive collapses were preceded by violent explosions that firstly accelerated emptying of magma reservoirs and also facilitated the faulting causing subsidence. Recent studies were more over shown that
ignimbritic deposits were emitted from Oku vent (Mount Oku: NE extension of Mount Bamenda) and principally from the calderas of these massifs (Gountié Dedzo et al., 2011a). The structural, petrographic and morphological features show that these calderas belong to explosive and collapse types.

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References


