Typology of Natural Hazards and Assessment of Associated Risks in the Mount Bambouto Caldera (Cameroon Line, West Cameroon)

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Abstract: Mount Bambouto is a polygenic stratovolcano of the Cameroon Volcanic Line, built between 21 Ma and 4.5 Ma. It is situated approximately 200 km NE of Mount Cameroon, between 09° 55′ and 10°15′ longitude east and, 05°25′ and 05°50′ latitude north. The volcano covers an area of 500 km^2 and culminates at 2740 m at Mélétan dome and bears a collapsed caldera at the summit (13 × 8 km). Mount Bambouto is characterized by several natural hazards of different origins: meteorological, such as landslides and rock falls; anthropogenic, such as bushfires, tribal wars and deforestation; and volcanological, such as volcanic eruption. The thematic map shows that 55–60% of the caldera has high probability of occurrence of mass movement. The caldera has a high population density (3000 inhabitants), which increases the level of risk, evaluated at approximately $US3.8 million for patrimony, 3000 civilian deaths and destruction of biodiversity.

Key words: caldera, hazard, risk assessment , Mount Bambouto, Cameroon Line

1 Introduction

The main natural catastrophes in Cameroon occur along the Cameroon Volcanic Line (CVL) (Fig. 1), which is a N30°E volcano-tectonic axis stretching over more than 1800 km from Pagalu Island in the Atlantic Ocean (Guinea Gulf) to Lake Tchad. CVL has a width of approximately 100 km (Tchoua, 1974) and consists of an alignment of plutono-volcanic complexes, including Mount Koupé, Mount Nlonako, Mount Bana and Mount Kapsiki, dated between 67 and 35 Ma; and volcanic complexes, including Mount Cameroon, Mount Manengouba, Mount Bambouto, Mount Bamenda and Mount Oku, dated between 38 Ma and Actual (Déruelle et al., 1991).

Among volcanic complexes, Mount Bambouto, due to its morphological, structural and lithological characteristics, is an example of a volcano that can undergo natural hazards. Studies of its summital caldera allowed us to understand the main mechanisms which rule the natural and anthropogenic hazards, and their impact. Mount Bambouto is a polygenic stratovolcano built between 21 and 4.5 Ma (Nkouathio et al., 2008) and is situated between 09°57′ and 10°15′ longitude east and 05°27’ and 05°48′ latitude north. It is approximately 200 km NE of Mount Cameroon and constitutes the third biggest volcano in the south continental area of CVL (Kagou Dongmo et al., 2001). It culminates at 2740 m at Mélétan dome and presents a large elliptical summital caldera (long axis: 13 km; short axis: 8 km), which opens to the west of the volcano. The caldera ranges between 09° 54′ and 10°07′ longitude east and 05°37′ and 05°44′ latitude north (Zangmo Tefogoum, 2007). The caldera is the area most subject to natural hazards. The objective of the present paper is to perform a qualitative study of natural hazards and assess the associated risks in the Bambouto caldera.

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2 Typological Study of Hazards in the Caldera

The Bambouto caldera is a structure characterized by natural phenomena that have damaging consequences on humans, property and biodiversity. These phenomena are mostly of meteorological, anthropogenic and volcanological origin.

2.1 Hazards of meteorological origin

2.1.1 Landslides are the most frequent and widespread

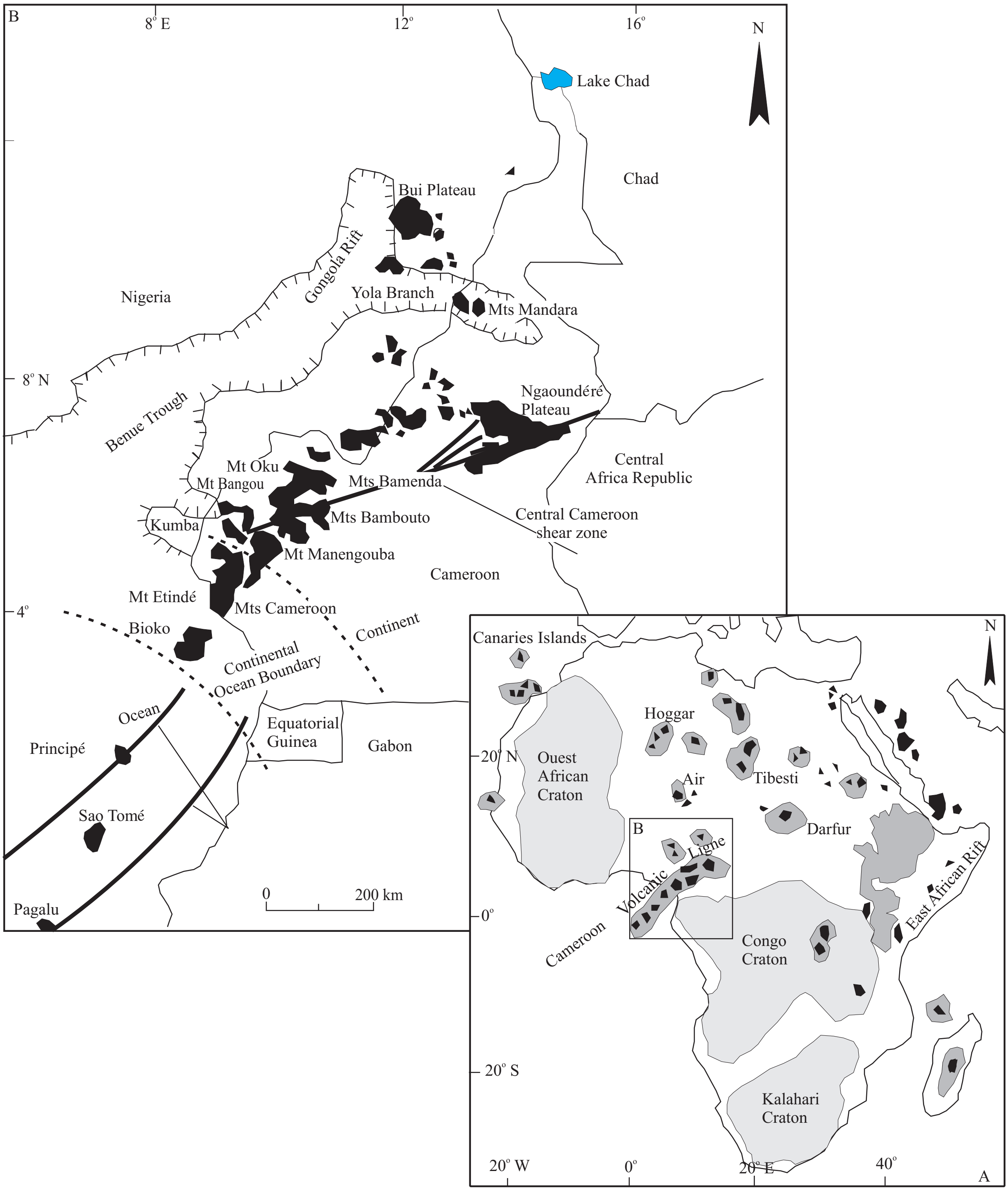

Fig. 1. Location of the Cameroon Volcanic Line (CVL) in central Africa (A) and position of Mount Bambouto in the CVL (B).

hazard in the Bambouto caldera and are triggered by numerous combined factors, such as:

Slopes: This factor is very diversified in the caldera. Fig. 2 shows the distribution of different types of slopes in the region. Approximately 73% of the caldera is made up of slopes ranging between 11 and 90°. These slopes are located mainly in the central part of the caldera and toward the caldera rim. In contrast, approximately 27% of the caldera is made up of slopes ranging between 2 and 10°. These slopes are sporadically distributed in the east and south of the caldera.

Lithology: Several petrographical units outcrop in the

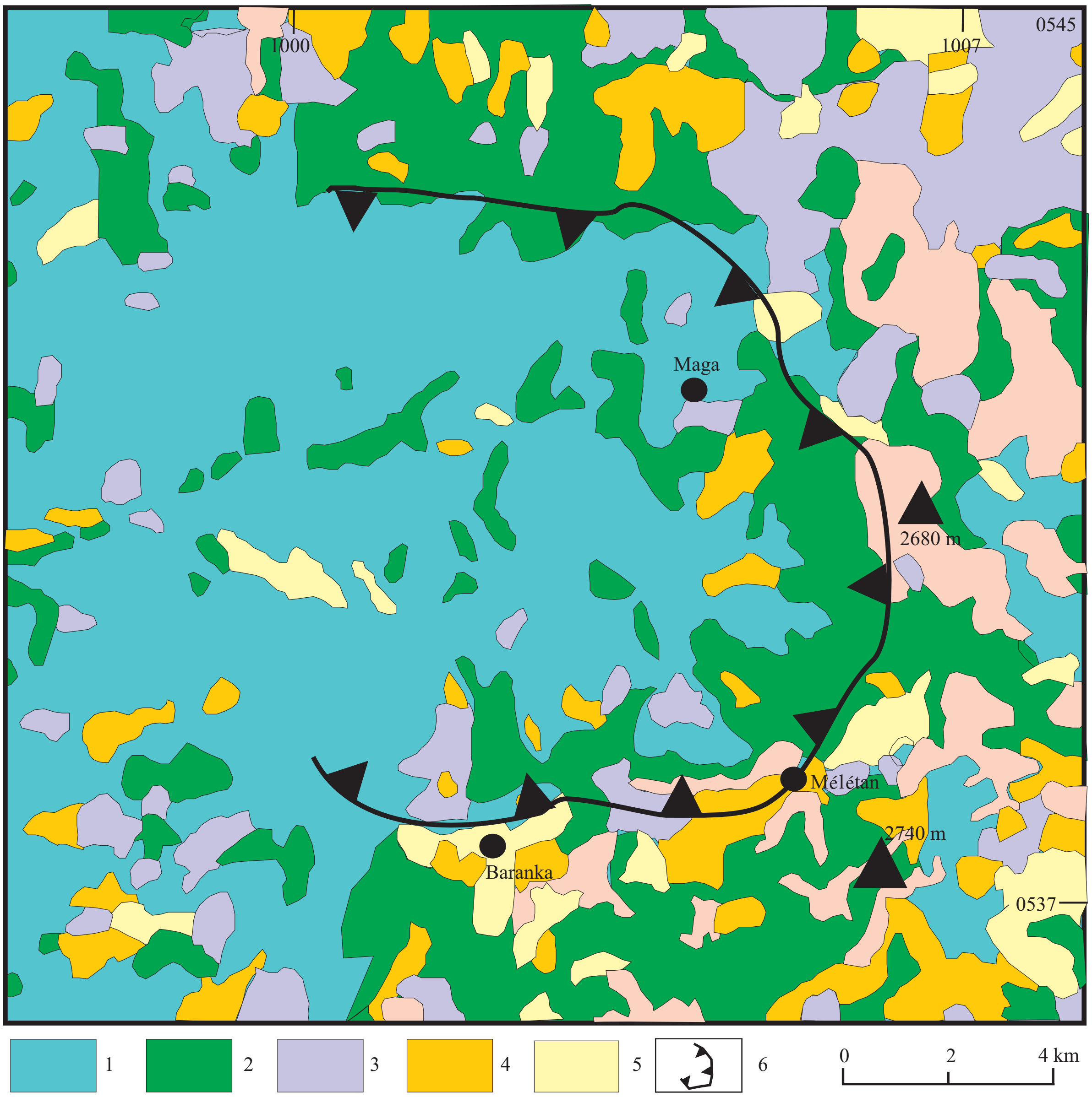

Fig. 2. Slopes map. 1, steep; 2, uneven; 3, undulating; 4, wavy; 5, plate; 6, caldera boundary.

Bambouto caldera. Seventy five percent of this area is covered by pyroclastite rocks (tuffs, breccias and ignimbrites), 20% lava flows (basalt, trachyte and phonolyte) and 5% crystalline basement (Fig. 3). These petrographical units are overlain by lateritized soil with a thickness ranging between 30 and 2.5 m. The sequence on the geological cross-section of the caldera (Fig. 4), shows a succession of pyroclastite-lava flows and crystalline basement. Pyroclastic materials are placed by several successive eruptive explosions. Between the different consecutive explosions, there is a period of rest during which pedogenetic processes take place.

Earthquakes play a role in creating desequilibrium of pyroclastic materials. In this region, earthquakes globally have a magnitude less than four on the Richter scale (Zogning et al., 2007) and result from underground volcanic manifestations.

Vegetal cover consists of grassland, mainly close to the caldera rim and the forest in the center of the caldera.

Rainfall: The region has a Cameroonian submountainous type equatorial climate (Valet, 1985), characterized by pouring rains in June, July, August and September (Fig. 5). These rainfalls have a significant action on the chemical and physical destabilization of the surface and subsurface materials. The Bambouto caldera has an important dendritic hydrographical network (Fig. 6). Streams have a remarkable influence on the weathering of their beds and, therefore, create structural desequilibrium. By this phenomenon, streams continue to increase zones of weakness, which can provoke the

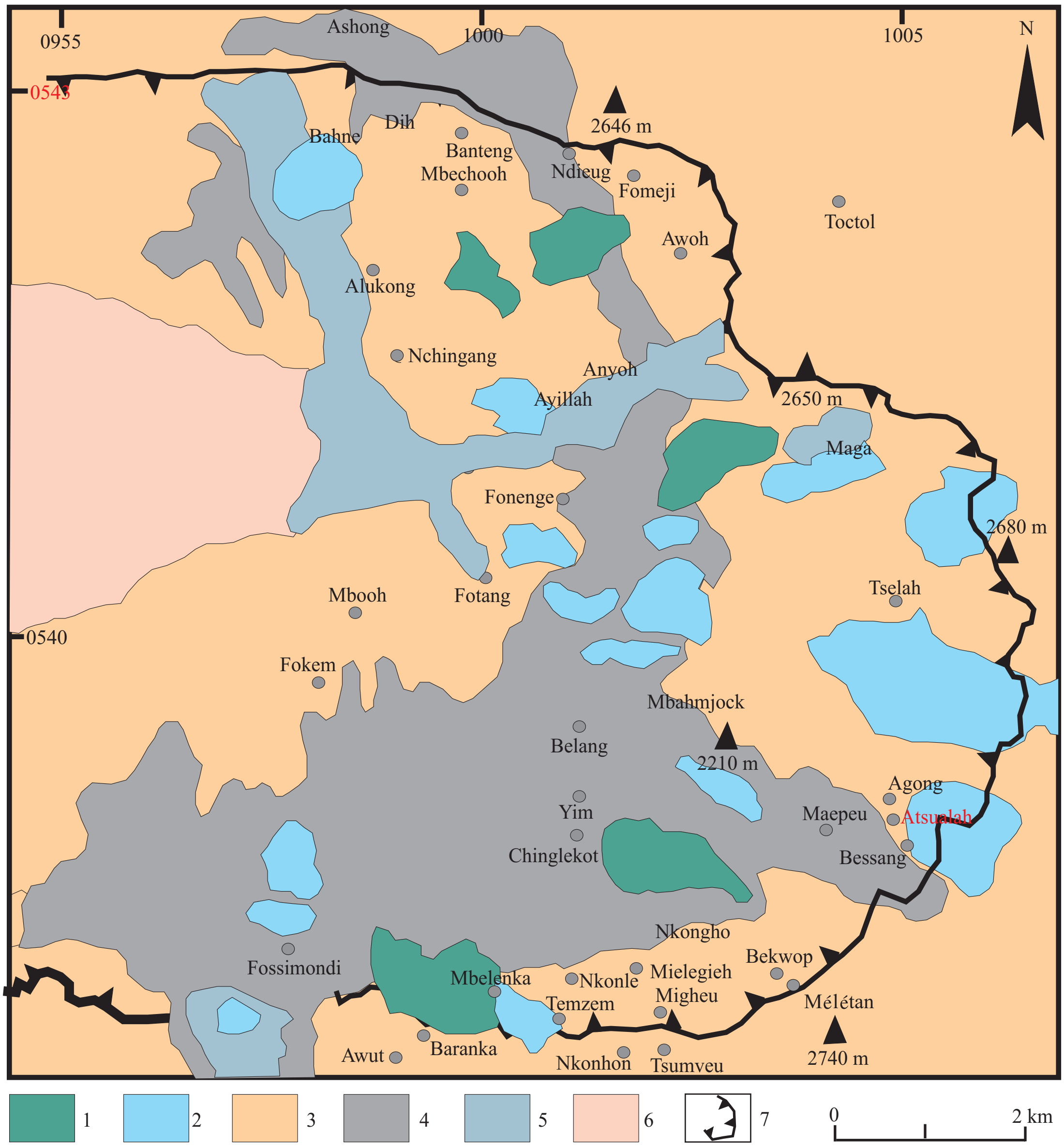

Fig. 3. Geological map of the caldera. 1, phonolites; 2, basalts; 3, trachytes; 4, ignimbrites; 5, tuffs; 6, crystalline basement; 7, caldera boundary.

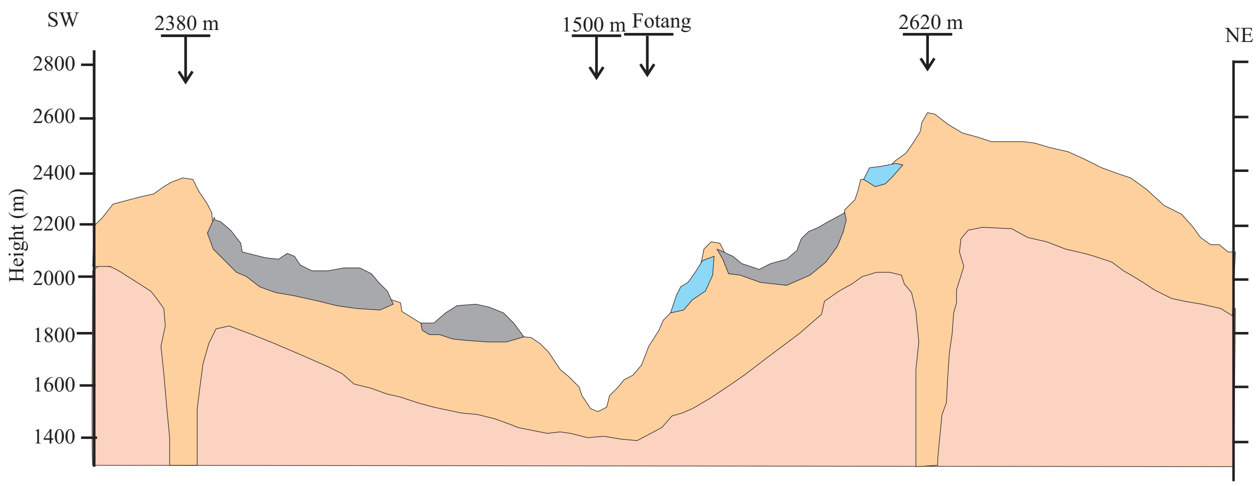

Fig. 4. Geological cross-section of the Bambouto caldera (SW-NE direction). Symbols are the same as in Fig. 3.

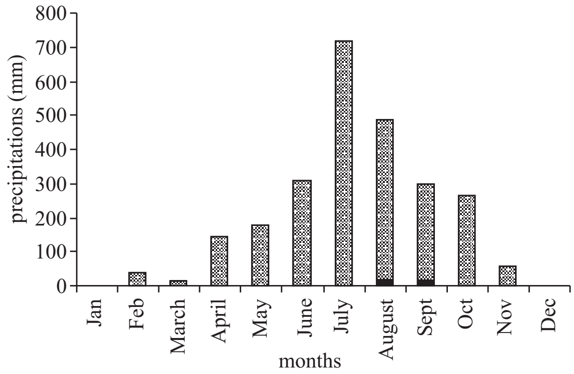

Fig. 5. Histogram of precipitations of the caldera.

collapse of enormous materials saturated with water. Rainfalls often trigger flooding in certain parts of the caldera, where V-shaped valleys dominate geomorphology.

2.1.2 Rock falls are also common in the caldera. They are usually influenced by the following factors:

Fissures are found along the lava flows encountered on the caldera rim and along domes, dykes, and plugs scattered in the caldera.

Water also plays a significant role in this phenomenon. When it percolates domes, dykes, lava flows and plugs through their fissures, it facilitates the detachment of blocks with the weathering process.

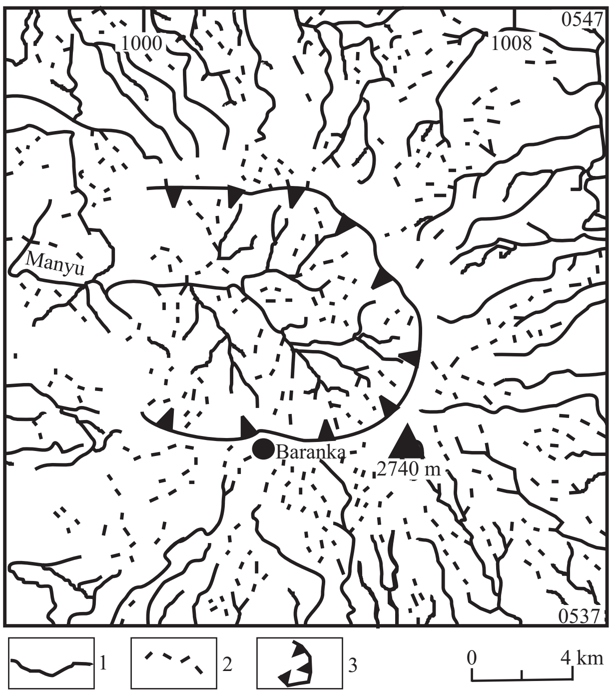

Fig. 6. Hydrographical network.
1, permanent streams; 2, seasonal or temporary streams; 3, caldera boundary.

Winds are violent in the caldera. Wind velocity ranges between 4.2 and 4.4 m/s (Wouendeu, 2002). Winds that change direction during the day are aggressive.

2.2 Hazards of anthropogenic origin

The Bambouto caldera, as a whole volcano, has natural trumps for touristic, agricultural and breeding activities. Fig. 7 shows an activities zonation map of the caldera. A strong agglomeration of agricultural populations is observed in the south, southeast, north and east of the caldera. Breeding activities are widespread in the northeast and east of the caldera. The system of land use in the region is poor, resulting in bushfires, tribal wars and deforestation.

Bushfires are used by the population during the first stages of agricultural activities. This hazard is often difficult to control by farmers and, thus, produces enormous damages, such as the destruction of several hectares of plantation and pasture land.

Tribal wars are interethnic confrontations between the population of the North (Bororo), who lead pastoral activities and populations of the South (Bamileke and Bamenda), who lead agricultural activities. These wars originate from the following causes: (1) conquest of green space by these two large ethnic groups for their different activities and (2) poor system of land use between farmers and stockbreeders.

Deforestation activity is important in farm enlargement, building activity and firewood.

Anthropogenic activities have a double impact. First, the soil is uncovered, remobilized and mellowed. Second, deforestation and bushfires contribute to increased greenhouse gases.

2.3 Hazards of volcanological origin

Hazards of volcanological origin are regulated by volcanic eruptions, involving lava flow, gases, lahars, and pyroclastic materials. The Mount Bambouto volcano can be considered extinct because its last activity is dated at 4.5 Ma (Youmen et al., 2005; Nkouathio et al., 2008). The probability of renewed activity is important because of the following pertinent indicators:

(1) the recent discovery of a strombolian cone on the north-east external flanks of Mount Bambouto (Kagou Dongmo et al., online) dated at 0.5 Ma.

(2) the position of Mount Bambouto between Mount Cameroon, Lake Nyos and Lake Monoun, where recent activity has taken place.

(3) registered regional earthquakes that could be precursors of magma uplift.

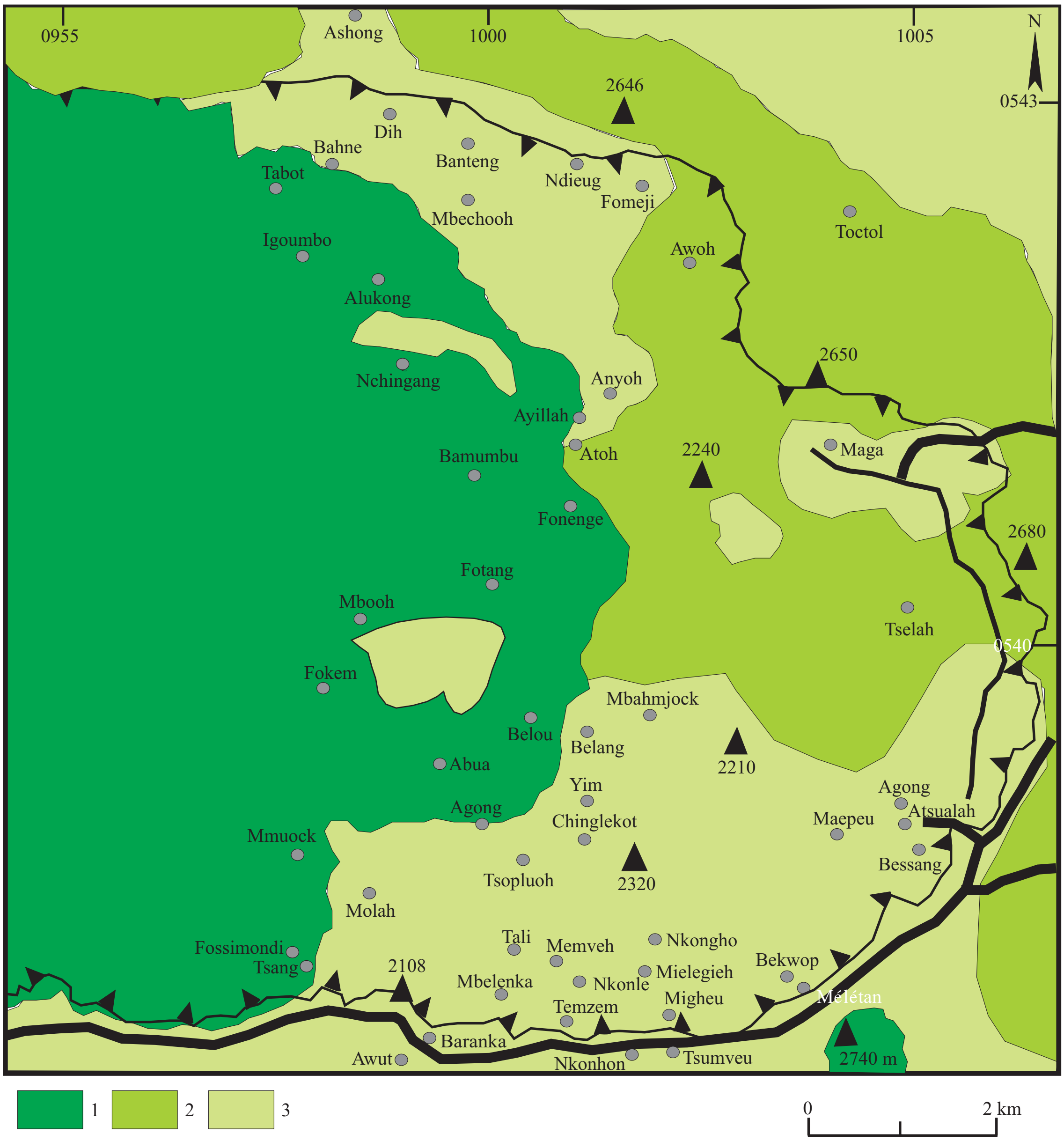

Fig. 7. Activities zonation map of the caldera. 1, forest areas; 2, grassland areas for breeding; 3, cultivation areas.

3 Activities Assessment in the Caldera

3.1 Different activities

Numerous activities are practiced by approximately 500 families in the caldera (Fig. 7), involving culture (cultivation), breeding and investment:

(1) cultivation of potatoes, cabbage, leek, carrots, onions, vegetables, beans, coffee, maize and fruit. This activity covers approximately 30% of the whole surface of the caldera.

(2) breeding of pigs, beef and sheep, which is essentially domestic and less developed than farming. Beef and sheep farming are the most representative kind of breeding in the caldera and cover approximately 25% of the whole surface of the caldera.

(3) investment, which includes building, equipment, roads and school fees.

3.2 Assessment

Agropastoral products are marketed in situ and in the Communauté Economique et Monétaire d'Afrique Centrale (CEMAC) market zone.

Close investigations were performed of the families' financial annual income from most marketed culture (cultivation), animals and investments in the caldera region. The following results were obtained (Table 1). Investment in houses (Table 2). Investment in house equipment (Table 3). Investment in children's school fees (Table 4).

Table 1 The families' financial annual income from most marketed culture (cultivation), animals and investments in the caldera region

Stocks		The average annual income of each family (AAIP)	The total annual income (TAI)
Potato	Every family practices this type of cultivation.	300000 FCFA (Francs de la Communauté Financière d'Afrique). The family number (FN) is 500.	The TAI from potatoes is (TAIP) = AAIP×FN = 300 000 × 500. **TAIP = 150 000 000 FCFA**
Cabbage	Cultivation of cabbage is practiced by 66% of all families (i.e.500 × 66% = 333 families).	The average annual income of each family (AAIC) = 175 000 FCFA.	The total annual income from cabbage is TAIC = 175 000 × 333. **TAIC = 58 275 000 FCFA**
Leek	Cultivation of leek is practiced by 66% of families (333)	The average annual income of each family (AAIL) = 100 000 FCFA.	The total annual income from leeks is TAIL = 100 000 × 333. **TAIL = 33 300 000 FCFA**
Carrot	Only 33% of families cultivate carrots (i.e. 500 × 33% = 167 families).	The average annual income of each family (AAICa) = 75 000 FCFA.	The total annual income from carrots is TAICa = 75 000 × 167. **TAICa = 29 225 000 FCFA**
Beef	Approximately 800 beef (cows) are encountered in the caldera.	The average cost of each cow is evaluated at 120 000 FCFA.	The annual income from beef is AIB = 120 000 × 800. **AIB = 96 000 000 FCFA**
Sheep	Approximately 100 sheep exist in the caldera.	The average cost of each sheep is evaluated at 20 000 FCFA.	The annual income from sheep (AIS) is AIS = 20 000 × 100. **RaM = 2 000 000 FCFA**

Table 2 Investment in houses

House	The number of houses in the caldera is estimated at approximately 1000.	The average cost of a house is evaluated at 1 500 000 FCFA.	The total cost of houses in the caldera is (TCH) = 1 000 × 1 500 000 FCFA. **CaM = 1 500 000 000 FCFA**

Table 3 Investment in house equipment

Beds:	The number of beds (NB) in each house is approximately four.	The average cost of a bed plus mattress is (ACB) 8000 FCFA.	The total number of beds in the caldera is (TNB) = NB × FN 4 × 500 = 2000 beds.	The total cost of beds in the caldera is (TCB) = TNB × ACB = 2000 × 8000. **TCB = 16 000 000 FCFA**
Seats:	The number of seats (NS) per house is approximately six.	The average cost of a seat (ACS) is estimated at 1500 FCFA.	The total number of seats in the caldera is (TNS) = 6 × 500 = 3000 seats.	The total cost of seats in the caldera is TCS = TNS× ACS = 3000×1500. **TCS = 4 500 000 FCFA**
Tables:	The number of tables per family is one (NT).	The total number of tables in the caldera is (TNT) =1 × 500 =500 tables.	The average cost of table (ACT) is 3500 FCFA. **TCT = 1 750 000 FCFA**	The total cost of tables in the caldera is TCT =ACT × TNT =500 × 3500. **TCT = 1 750 000 FCFA**
The total cost of investments in equipment = 22 250 000 FCFA				

Table 4 Investment in children's school fees

Number of children provided with schooling	200 in Primary School	100 in Secondary School.
School fees per child	6200 FCFA for Primary School (FSp)	30000 FCFA for Secondary School
Total school fees (TSF) in the caldera	Primary School: 6200 × 200 = 1 240 000 FCFA	Secondary School: 30000 × 100 = 3 000 000 FCFA
TSF = FSp + FSs	= 1240 000 + 3 000 000 **TSF = 4 240 000FCFA**	
The total economy of the Bambouto caldera is 1 895 290 000 FCFA, corresponding to US$3 790 580		

4 Discussion

The Mount Bambouto caldera is densely populated (Fig. 7), containing approximately 3000 inhabitants from different ethnic groups. The economic trumps of the caldera make it a sector of intensive agropastoral, building and tourist activities.

Landslides are the most frequent hazards and are regulated by many factors. Indeed, the hydrographical network is very dense in relation to the basement fracturation. Climatic conditions are very aggressive and favour disequilibrium of the oldest geological formations in the caldera. The level of rainfall is very high, with an average of 718 mm in July, and wind currents are violent (4.4 m/s). High precipitations cause flooding in certain parts of the caldera, where topography is dominated by V-shaped valleys. The actions of these meteorological elements lead to the deposition of boundless mellow and crumbly cover with low stability at the basement. Moreover, rains increase the specific weight of surface materials, which can slide under the effect of steeper slopes (between 11 and 90°), which cover almost 73% of

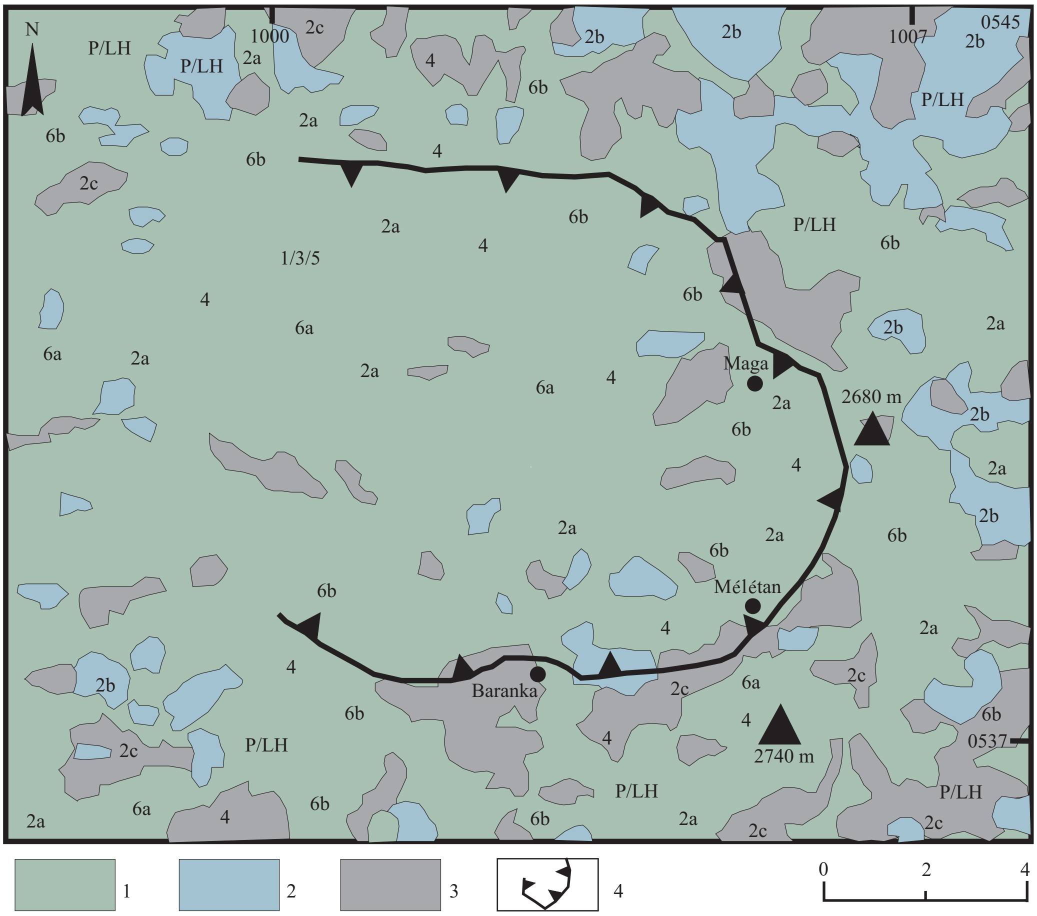

Fig. 8. Mass movements zonation map.
1, high probability of occurrence; 2, average probability of occurrence; 3, low probability of occurrence. Factors: P/L/H, precipitations/lithology/hydrography network; 2, slopes; 2a, high; 2b, average; 2c, low; 4, anthropogenic activity; 6, vegetal cover; 6a, forest; 6b, grassland.

the entire surface of the caldera. These movements are facilitated by boundaries between pyroclastic materials and hard rocks, which are sliding zones of movements.

Soils are affected by intense deforestation, bushfire and significant building activity. These soils are mellowed because they are constantly disturbed and rehandled and can undergo slide movement. This explains the presence of several scars (approximately 300) in the caldera. The vegetation is little developed in the grassland where the most important density of the population exists; therefore, surface and subsurface materials are not well stabilized.

On 21 July 2003, a catastrophic landslide occurred in Maga, resulting in the deaths of 20 people, loss of patrimony (houses, culture [cultivation] and livestock) and destruction of biodiversity.

The rock falls occurred in the caldera in highly cracked domes, plugs and lava flows. Water percolated through the cracks and blocks were formed and can collapse if there is a tremor or high wind. Their path and distance covered depend on the nature of the slopes in the milieu.

Mass movements are thus the most representative hazard in the Bambouto caldera. The thematic map (Fig. 8) shows that 55–60% of the area has a high probability of occurrence of mass movement. The populations of Maga, Fomeji, Fossimondi, Fotang, Fokem, Agong, Alukong, Atsualah, Banteng, Bamumbu, Tabot, Anyo, de Baranka, Tsumveu, Awut, Nkon'hon, and Mélétan are most exposed to mass movement hazards.

The poverty of the population in the region leads the population to dominate nature for survival. This is why although the Bambouto caldera is threatened by multiple hazards, it has been animated by population settlements during the last century. The poor system of land use has given rise to interethnic wars with occasional loss of human life.

Volcanic eruptions are not encountered in the caldera. However, recent activity at Lake Monoun, Lake Nyos and Mount Cameroon, which enclose Bambouto volcano and the young age of strombolian cone (0,5 Ma) on the north-east flank of the volcano are indexes for reactivation of the Bambouto volcano.

The Bambouto caldera is an area where many hazards can occur. The destruction of this structure will cause the loss of patrimony evaluated at approximately US$3.8

million, deaths of approximately 3000 people and destruction of biodiversity.

5 Conclusion and Recommendations

The Mount Bambouto caldera is tormented by hazards of meteorological origin (landslides, rock falls and flooding), anthropogenic origin (bushfires, tribal wars and deforestation) and volcanological origin (lava flow and pyroclastic falls).

Hazards of meteorological origin, such as landslides and rock falls are the most frequent and widespread hazards in the Bambouto caldera. They are controlled by many natural and anthropogenic factors, such as steep slopes, lithology with pyroclastic materials, heavy rainfalls and anthropogenic activities. Hazards of anthropogenic origin are mainly due to the poor system of land use. Hazards of volcanological origin are not yet identified in the caldera, but some pertinent indexes testify the renewal of volcanic activities at any moment.

The high density of population in the caldera increases the level of risk evaluated at approximately US$3.8 million for patrimony, the deaths of 3000 people and destruction of biodiversity.

To reduce the level of risks in this environment, the following recommendations have been provided:

(1) conduct tephrostratigraphical and chronological studies of the entire volcano;

(2) develop preventive methods of fast evacuation of populations;

(3) educate populations in a better system of land use;

(4) avoid building close to cliffs;

(5) take into account the hazards map in the land use plan;

(7) develop aforestation;

(8) avoid deforestation and bushfires;

(9) improve agropastoral techniques and lead a better management of natural resources.

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