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## Geomorphosites inventory in the Eboga Volcano (Cameroon): contribution for geotourism promotion

### *Inventaire des géomorphosites du volcan Eboga (Cameroun) : contribution à la promotion du géo-tourisme*

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#### ABSTRACT

The Cameroon Volcanic Line (CVL) is a series of volcanic and plutonic morphologies crossing Cameroon at N30° E orientation. Between volcanoes, there is Mount Manengouba that is composed of two nested volcanoes, Eboga and Elengoum. Eboga volcano (EV) reaches 2,391 m with a well-defined caldera (4x5 km). Several geotouristic assets comprising a set of geomorphosites are located in the caldera floor, rims, and slopes. These landforms are lakes (Female, Male and Child), broken scoria cones, a dome (Mboriko), and a depression. We used an integrated approach for the inventory and management of geomorphological heritage (Reynard et al., 2016). The average scientific value of the geomorphosites is 0.75, since they are well preserved (0.96), rare (0.79) and representative (0.82) of the whole geomorphology of EV. They also play an important role in the geographical history (0.43) as well have significant use and management characteristics. These assets attract local and foreign tourists, and researchers. This study could raise the EV to a potential geotouristic destination with the implementation of sustainable management policy. The promotion of geotourism in the EV is an utmost opportunity for the alleviation of poverty and rural migration in the entire Manengouba region. This study can encourage more geoheritage studies in volcanic landscapes of Cameroon and Africa.

**Keywords:** geomorphosites, Eboga Volcano, Cameroon Volcanic Line, assessment.

#### RÉSUMÉ

*La Ligne Volcanique du Cameroun (LVC) est un ensemble de morphologies volcaniques et plutoniques d'orientation N30°E qui traversent le Cameroun. Le mont Manengouba fait partie des volcans. Il est formé de deux volcans à savoir Eboga et Elengoum. Le Volcan Eboga (VE) culmine à 2 391 m où se trouve une caldeira bien définie (4x5 km). Cette dernière expose plusieurs atouts géotouristiques comprenant des géomorphosites retrouvés sur le plancher de la caldeira, les remparts et les versants. Ces reliefs sont les lacs (Femme, Homme et Enfant), les cônes égueulés de scories, un dôme (Mboriko) et une dépression. Ces morphologies ont été évaluées en utilisant une approche intégrée pour l'inventaire et la gestion de l'héritage géomorphologique (Reynard et al., 2016). La valeur scientifique moyenne des géomorphosites est 0,75 puisqu'ils sont bien préservés (0,96), rares (0,79) et représentatifs (0,82) de la géomorphologie générale du VE. Ces géomorphosites jouent aussi un rôle important dans l'histoire géographique régionale (0,43) et ont des caractéristiques d'usage et de gestion significatifs. Ces atouts attirent des touristes locaux et étrangers, ainsi que des chercheurs. Cette étude pourrait ériger le VE en une potentielle destination géotouristique basée sur le développement d'une politique de gestion durable. La promotion du géotourisme dans le VE est une opportunité exceptionnelle pour la réduction de la pauvreté et le ralentissement de l'exode rural dans toute la région du mont Manengouba. Cette étude peut encourager d'autres travaux sur le patrimoine géo(morpho)logique dans les paysages volcaniques au Cameroun et en Afrique, où les volcans sont nombreux.*

**Mots clés :** géomorphosites, volcan Eboga, ligne volcanique Cameroun, évaluation.

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## 1. Introduction

Geomorphosites are landforms with particular and significant geomorphological attributions, which qualify them as a component of a territory's cultural heritage in a broad sense (Panizza and Piacente, 1993; Panizza, 2001). The attributes that may confer value to a geomorphosite are scenic, scientific, socioeconomic, and

cultural (Coratza and Hobléa, 2018). The geomorphosite is one of the components of the geodiversity, which is defined as the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landform, physical processes) and soil features. It includes their assemblages, relationships, properties, interpretations and systems (Gray, 2004, 2013).

In several countries, where geoconservation has a very poor

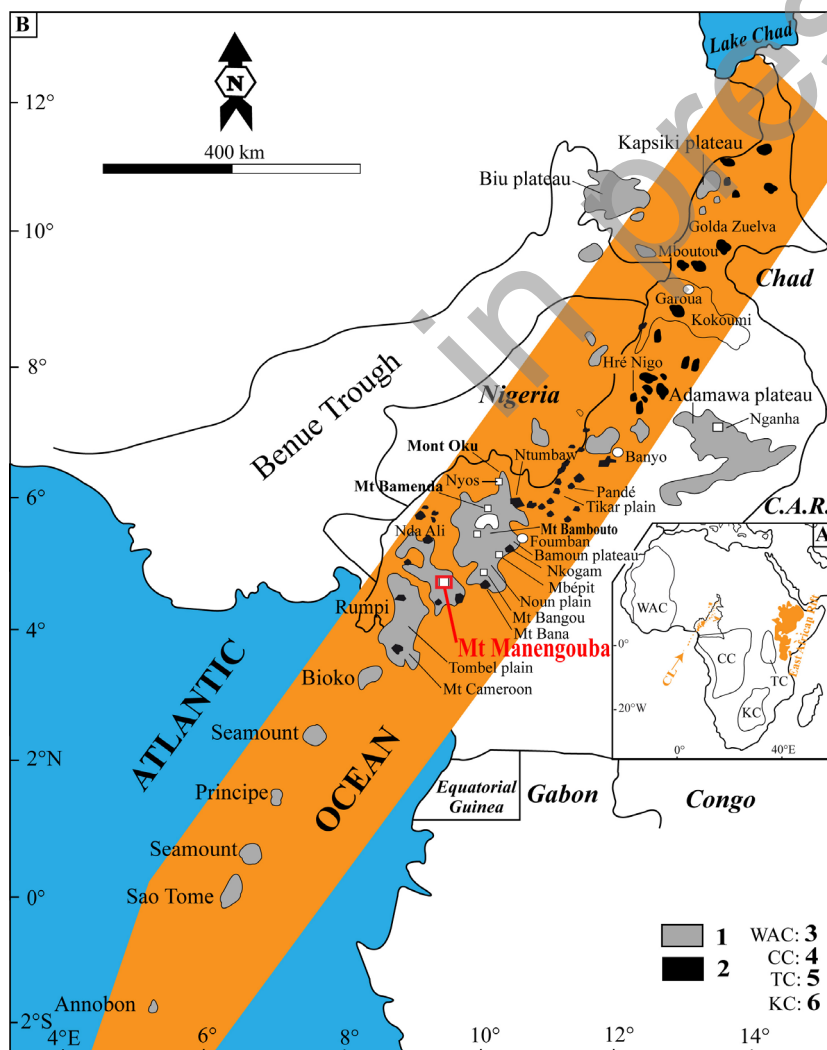
record, the nature conservation policies focus on biodiversity conservation concerns (Reimold, 1999; Brilha 2002; Henriques and Neto, 2015; Randriany et al., 2015; Zangmo Tefogoum et al., 2017). Geoconservation refers to the actions and measures taken to conserve geodiversity and geoheritage for the future (Gray, 2013). The selection and the promotion of geomorphosites for geotouristic purposes are useful tools for the conservation of the geodiversity and the understanding of geological heritage (Henriques et al., 2012; Newsome and Dowling, 2018).

The Earth history is one of the main aspects of geoheritage, commonly reflected in its geodiversity (Németh et al., 2017b). Volcanic geomorphosites are the testimony of the past and recent volcanic activities. Depending on their origin, volcanic landforms are classified as constructional or destructional features (Wood, 2009). The recognition of volcanic geoheritage has gained attention in recent years, where many studies of geoheritage, geoconservation and geotourism have emerged (Németh et al., 2017a). According to some geoheritage studies (Németh and Moufti, 2017; Szepesi et al., 2017; Aquino et al., 2017; Fepuleai et al., 2017; Pérez-Umaña et al., 2019a, 2019b; Rózycka and Migoń, 2018), geological landscape around the world are made up of numerous volcanic geomorphosites that include crater lakes, lava flows, scoria cones, domes, dykes, plugs/necks, calderas, canyons, craters, and volcanic relicts.

Along the CVL (Cameroon Volcanic Line) (fig. 1), volcanic geomorphosites are identified from the Gulf of Guinea (Atlantic Ocean) (Henriques and Neto, 2015) to the Kapsiki Plateau (Cameroon, Africa Continent). Although the fact that Henriques and Neto (2015) highlighted some geomorphosites (falls on volcanic columnar disjunctions, plug, basaltic prismatic disjunctions, domes, and volcanic crater) in São Tomé, they are mainly concentrated on the south continental branch of the CVL. Other geomorphosites studies along the CVL are focused on volcanoes edifices (Zangmo Tefogoum et al., 2012, 2013a, 2013b, 2015a; Henriques and Neto, 2015; Zangmo Tefogoum et al., 2017, 2018, 2019). The Eboga Volcano (EV) is one of the two volcanoes making up the Manengouba Volcano (Kagou Dogmo et al., 2005; Zangmo Tefogoum, 2007, 2016). EV possesses an interesting range of geomorphosites mainly located on the caldera floor. This paper aims at (i) analyze the geological and geomorphological features of EV, (ii) assess the geomorphosites of EV, and (iii) implement a geotourism strategy in EV.

## 2. Study area

The CVL is the main plutonic-volcanic complex crossing Cameroon in the N30°E direction (fig. 1). It has been formed between 51.8 and 46.7 Ma (Bamoun Plateau) (Moundi et al., 2007) to present



**Fig. 1 - Location of the study area.**

A: Cameroon Volcanic Line (CVL) in Africa; the main geologic features of Africa are indicated. B: Map of Cameroon showing the distribution of the CVL magmatism including Mount Manengouba. Locations of seamounts are after Burke (2001). 1. Volcanic massifs; 2. Alkaline complexes; 3. WAC: West African Craton; 4. CC: Congo Craton; 5. TC: Tanzanian Craton; 6. KC: Kalahari Craton.

**Fig. 1 - Localisation de la zone d'étude.**

A : Ligne Volcanique du Cameroun (LVC) en Afrique ; les principaux traits géologiques en Afrique indiqués ; B : Carte du Cameroun montrant la répartition du magmatisme de la LVC incluant le Mont Manengouba. Localisation des nouvelles îles d'après Burke (2001). 1. Massifs volcaniques ; 2. Complexes Alcalins ; 3. COA: Craton Ouest Africain ; 4. CC: Craton du Congo ; 5. CT: Craton de la Tanzanie ; 6. CK: Craton du Kalahari.

(Mount Cameroon); but his origin has been subject of controversy since several decades. However, the only hypothesis retained to date is that CVL originates from the alternation between hotspots and Precambrian Faults Reactivation during the African Plate Drift (Ngako et al., 2006; Njonfang et al., 2011). It has 1,600 km long and 100 km wide and stretches from the Gulf of Guinea (Atlantic Ocean) to Lake Chad (African Continent) (Tchoua, 1974). The oceanic branch is 700 km long dominated by several volcanic islands namely Annobon, Sao Tomé, Principe, Bioko, and two recently discovered ones (Burke, 2001). The continental branch is 900 km long and is the succession of horsts and grabens (Gèze, 1943). The grabens are a set of collapse plains including Kumba, Tombel, Mbo, Ndop, Noun, Tikar, and Benoue. The horsts are made up of a series of volcanic complexes, *i.e.*, Mount Cameroon (4,100 m), Mount Manengouba (2,391 m), Mount Bambouto (2,744 m), Mount Bamenda (2,621 m), Mount Oku (3,011 m), moreover composed of lavas flows and plugs/ necks of the Benoue Trough and Kapsiki plateau and, plutonic-volcanic complexes (Koupé, Bana, Nlonako, Koukoumi, Nkogam, Ntumbaw, Nda Ali, and others) (Tempier and Lasserre, 1980; Ghogomu et al., 1989; Ngounouno et al., 2000; Ngako et al., 2006). Among the volcanic complexes, Mt Manengouba that is located at about 116 km NE of Mt Cameroon, occupies a surface of 500 km<sup>2</sup> between the Tombel and Mbo grabens. It is a polygenic volcanic

complex characterized by adventive fissural volcanic activity, giving rise to around 70 strombolian cones, of which some were initiated by phreato-magmatic explosive events (Kagou Dongmo et al., 1998). It lies on an uplifted granite-gneiss basement of 800 m relief and is made up of two fitted volcanoes (Elengoum and Eboga) built up from 1.55 to 0 Myr. Several volcanic rocks outcropping in numerous landforms. The Eboga Volcano (EV) (fig. 2) was chosen for the present study because it is a well-defined volcano and it summarizes very well Mount Manengouba in geomorphological terms. The particularity of the EV relies on several levels: it is the only volcano of the CVL nested in another volcano (Elengoum); both defining a structure similar to that of the Fogo volcano in Cape Verde. The EV is the unique volcano in Africa with a subcircular caldera, a well-defined floor with aligned crater lakes and cones. The geological history of the EV has been dominated by a plate collapse type of its crater that gave rise to the formation of a significant sub-circular caldera (4 to 5 km in diameter) (Kagou Dongmo, 2006; Zangmo Tefogoum et al., 2014; Pouclet et al., 2014) at the summit (around 2,391 m). Numerous volcanic rocks crop out in the volcano and they usually include basalts, mugearites, ejectas, trachytes, benmoreites and hawaiites (fig. 3). These petrographic units are in the caldera floor and rims. The caldera's floor topography is flat and is composed of two main craters and several volcanic lakes with volcanic cones

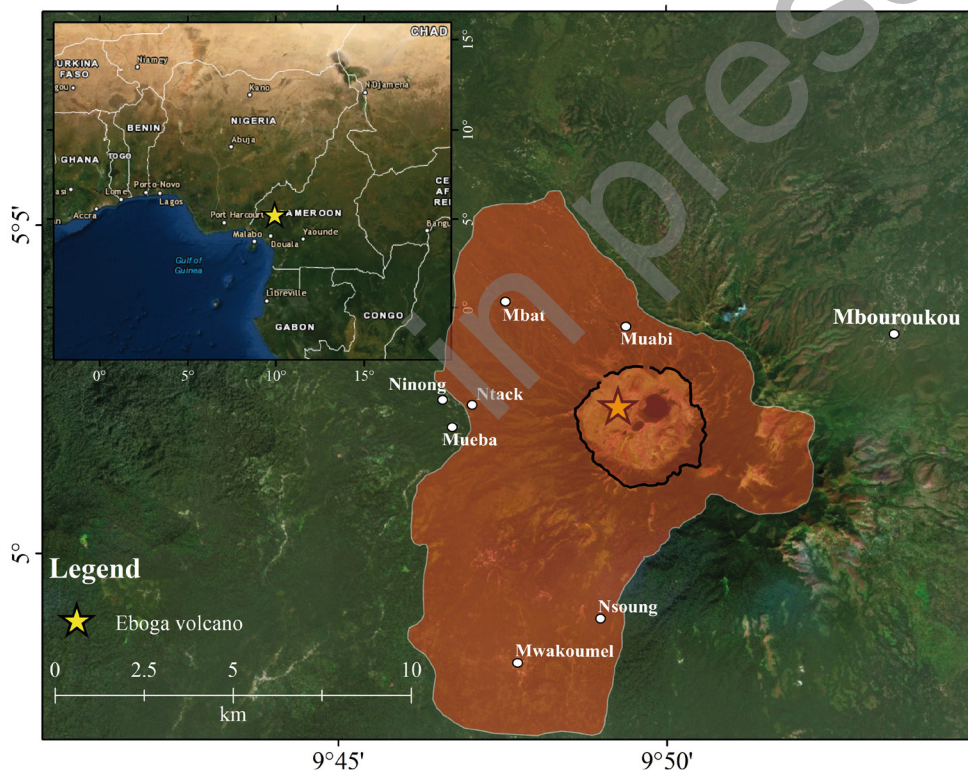


Fig. 2 - Location map of the Eboga Volcano.  
Fig. 2 - Location map of the Eboga Volcano.

remnants (fig. 4). Around and outside the caldera, the volcanic slopes draw gentle hills that coincide with some volcanic cones and domes remnants. The caldera rims are subvertical to vertical and present stair-like morphology (fig. 5) mainly in the southern inward-facing cliffs of its wall (Zangmo Tefogoum, 2016).

Muslim people called Mbororo who's the usual religion is Islam occupy the EV's crater. They migrated there after the major drought

that threatened the Northern part of Cameroon towards the 1970s. In the EV they created some villages and are leading agropastoral activities. The presence of the crater lake favoured the practice of human ritual since several decades until nowadays. Neighbouring populations (mainly Bakossi and Mbo people) use the waters of the Female Lake to solve health issues. Usually, young people of Mbouroukou and Banguem localities organize every year

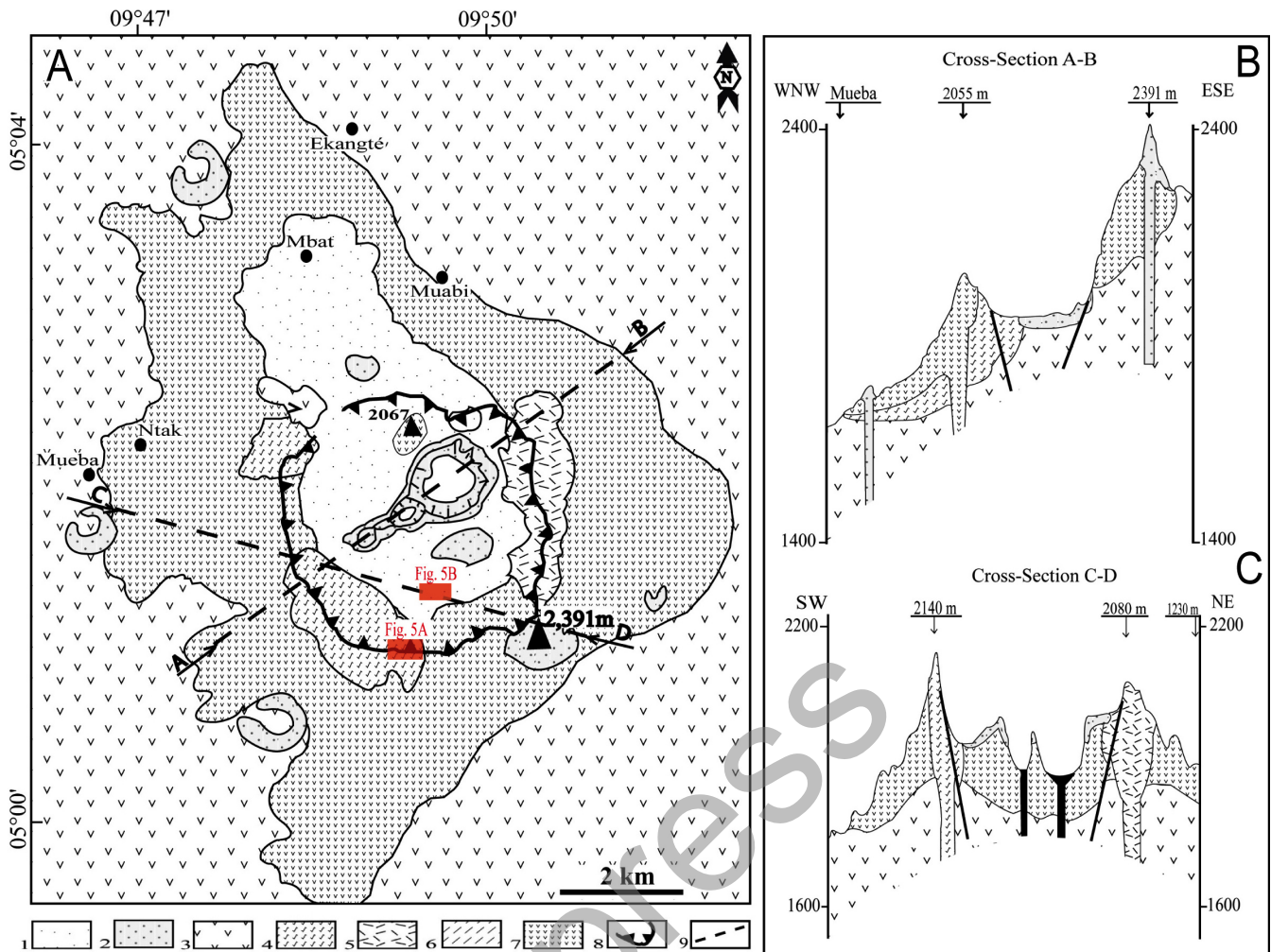


Fig. 3 - A: Geological map of the Eboga Volcano. B: Cross-sections A-B; C: Cross-sections C-D.

1. Pyroclastic Ejectas from the main Volcanic vent; 2. Pyroclastic Ejectas from cones 3- Basalts; 4. Trachytes; 5. Benmoreites; 6. Hawaiites; 7. Mugearites; 8. Caldera Boundaries; 9- Supposed faults.

Fig. 3 - A: Carte géologique du Volcan Eboga; B: Coupe A-B; C: Coupe C-D.

1. Projections pyroclastiques issues du cratère principal; 2. Projections pyroclastiques issues des cônes; 3. Basaltes; 4. Trachytes; 5. Benmoréites; 6. Hawaiites; 7. Mugéarites; 8. Limites de la Caldera; 9. Failles supposées.

excursions firstly on February 14<sup>th</sup> because of the Valentine day and secondly on December 24<sup>th</sup> because it is the Christmas holiday during which many native people go back to the village to celebrate with their respective family. Foreign tourists yearly visit the volcano to enjoy the volcanic landscape and to learn more about the local communities' traditions.

### 3. Materials and methods. Inventory and management of geological heritage

Several studies worldwide highlighted the geological heritage assessments. These assessments found geodiversity as the main geological heritage (Najwer et al., 2016; Zwolinski et al., 2018). Moreover, numerous quantitative and qualitative methodologies have been proposed to assess geomorphosites (Reynard et al., 2016, Mucivuna et al., 2019). The method used in this study is consistent with Reynard et al. (2016). This method consists of two main steps: (i) the inventory of geomorphological heritage of the study area, and (ii) the assessment of the selected geomorphosites.

For the selection of the geomorphosites, we used a geomorphological

map to describe the different landforms of Eboga caldera formation (fig. 5). Secondly, based on literature survey, consultation of cartographic material, field survey, and the author's knowledge, a first list of landforms is established and stored in a database. The assessment is divided in four main steps (Reynard et al., 2016). First, the description of the site, in two parts (general data and descriptive data) (tab. 1). Second, the assessment of the intrinsic value, in two parts: the central or scientific value (tab. 2) and additional values (tab. 3), which are divided into three kinds of characteristic: ecological, aesthetic and cultural. Third, the documentation of the present use and management of the site also divided in two parts: the protection issues (protection status, property, damages and threats), and a series of factors influencing the (tourist) use of the site (visit conditions and educational interest). Finally, the fourth a synthesis. The management phase is composed of two parts, the elaboration of a management strategy done directly by the scientists or by site management bodies and the management, which should have enough financial, personal and jurisdictional means to be accomplished.

The intrinsic value that is inherent to each site, relatively to its

**Tab. 1 - General and descriptive data of the geomorphosite (Reynard et al. 2016).**

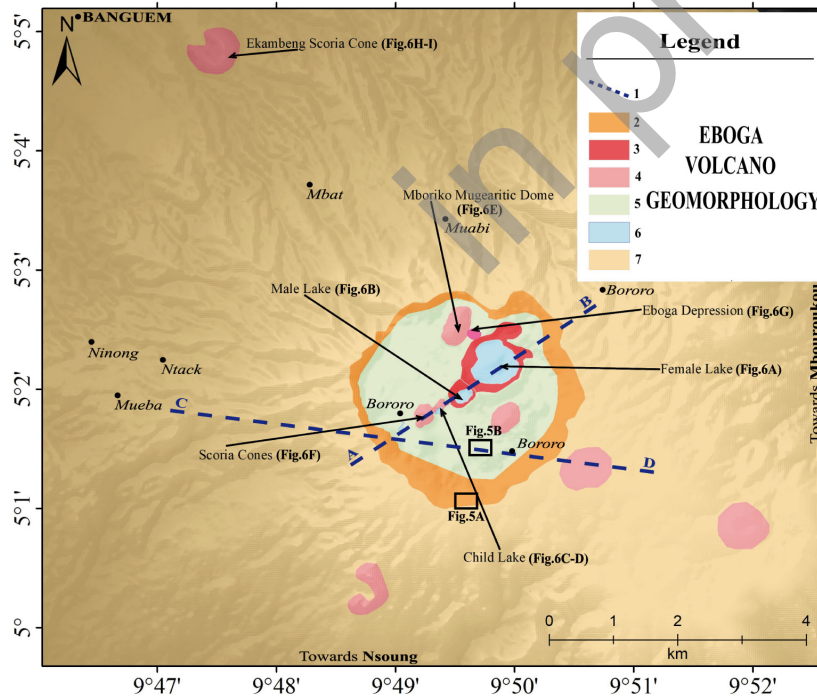
**Tab. 1 - Données générales et descriptives d'un géomorphosite (Reynard et al. 2016).**

Data	Description
Identification Code	This number is important in the localization of the site in the synthesis map. The code has three parts: capital letters for the region, letters for the process, and numerical code for the site. Each code has three characters
Name	Name of the landform or very simplified description of the geomorphosite
Toponymy	Area where the geomorphosite is situated
Coordinates, Minimum altitude, Maximum altitude	
Type	PCT: Punctiform (e.g. erratic boulder) Lin: Linear (e.g. valley, dike) AER: Areal (Crater, caldera, dome, cone, plug...)
Size	Punctiform: no indication or width [m] (e.g. sinkhole) or volume [m3] (e.g. erratic boulder) Linear: length [m] Areal: surface [m2]
Property	PR: Private ASS: Association PUB: Public COM: Common
Protection status	Mention the protection status of the geomorphosite (inventories, natural reserves, zone of protection of the nature, etc). If existing, precise the name and the number of elements of an inventory or the protection regulation must be cited
Location map	Location of the site relatively to the study area
Photographs	Good quality, 300 dpi
<b>Descriptive data of the geomorphosite</b>	
Description	Geomorphological features, archaeological findings, human infrastructures, and biotopes related to the site
Morphogenesis	Processes responsible for the landform genesis and development and can include temporal information (dating) and landform activity. Moreover, human transformations if existing are also analyzed

**Tab. 2 - Criteria used for the assessment of the scientific value of the géomorphosite (Reynard, 2006 and Reynard et al., 2016).**

**Tab. 2 - Critères utilisés pour l'évaluation de la valeur scientifique d'un géomorphosite (Reynard, 2006 et Reynard et al., 2016).**

Criteria	Qualitative assessment	Value
Integrity	State of conservation of the site. Bad conservation may be due to natural factors (e.g. erosion) or human factors	0 = Destroyed 0.25 = Practically destroyed 0.5 = Partially destroyed 0.5 = slightly damaged 1 = Intact
Representativeness	Concerns the site's exemplarity. Used with respect to a reference space (e.g. region, commune, country). All selected sites should cover the main processes, active or relict, in the study area	0 = Null 0.25 = Weak 0.5 = Moderate 0.75 = High 1 = Very high
Rareness	Concerns the rarity of the site with respect to a reference space (e.g. region, commune, country). The criterion serves to identify exceptional landforms in an area	0 = More than 7 0.25 = Between 5 and 7 0.5 = Between 3 and 4 0.75 = Between 1 and 4 1 = Unique
Paleogeographical interest	Importance of the site for Earth or climate history (e.g. evolution of volcanic landscape)	0 = Null 0.25 = Weak 0.5 = Moderate 0.75 = High 1 = Very high
Synthesis of scientific value	A sentence to summarize the scientific importance of the site	Average

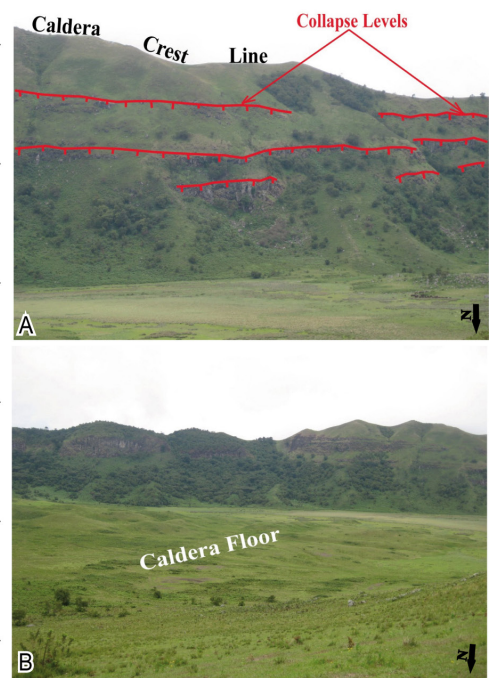


**Fig. 4 - Geomorphology of Eboga volcano.**

1. Geological Cross-sections; 2. Caldera rampart; 3. Crater lakes rampart; 4. Volcanic cones/domes remnant; 5. Caldera floor; 6. Volcanic lakes; Volcanic slopes.

**Fig. 4 - Géomorphologie du Volcan Eboga.**

1. Coupes géologiques; 2. Rempart de la caldeira; 3. Rempart des lacs de cratère; 4. Cônes/dômes volcaniques restants; 5. Plancher de la caldeira; 6. Lacs volcaniques; Versants volcaniques.



**Fig. 5 - Structural features of the Eboga Volcano.**

A: Stair-like morphology of southern inward-facing cliffs of the caldera wall; B- Caldera floor.

**Fig. 5 - Traits structuraux du Volcan Eboga.**

A: Morphologie en escaliers des escarpements internes Sud du rempart de la caldeira; B: Plancher.

**Tab. 3 - Criteria used for the assessment of the additional values of the geomorphosite (Reynard et al., 2016).**

**Tab. 3 - Critères utilisés pour l'évaluation des valeurs additionnelles d'un géomorphosite (Reynard et al., 2016).**

Ecological value	
Criteria	Qualitative assessment
Ecological influence	Importance of the geomorphosite for the development of a particular ecosystem or the presence of a particular fauna and vegetation
Protected site	Consideration is taken of sites that are already protected in a national inventory, or at regional or local level for ecological reasons
Ecological value	A sentence to summarize the ecological value
Aesthetic value	
Criteria	Qualitative assessment
View points	Possibilities of the site to be observed. A site covered by a forest or very difficult to access would, in this case, have a lower score than a site visible from several viewpoints
Contrasts, vertical development and space structuration	Contrasting landscapes (distinction of colors); landscapes with a vertical development (mountain) or landscapes with individual elements (isolated hill) that give that space structure are generally considered the nicest. In the contrary less contrasting landscape, flat and monotone reliefs (e.g. alluvial plain, large plateau) are considered as not nice
Aesthetic value	A sentence to summarize the aesthetic value
Cultural value	
Criteria	Qualitative assessment
Religious and symbolic importance	Spiritual and religious influence of the site
Historical importance	Role of the site in the past. Presence of vestiges
Artistic and literature importance	Presence of the site in artistic realizations (e.g. paintings, sculptures) and in books or poems
Geohistorical importance	Role of the site in the development of geosciences
Cultural value	A sentence to summarize the cultural value

specificity as (i) the witness of the Earth's history (scientific value), (ii) geomorphological object, observation science (aesthetic value), (iii) biodiversity condition (ecological value), and (iv) element integrated by the society (cultural value). The intrinsic value is made up of scientific and the additional values that are specific to geomorphosites unlike the use and management characteristics that regard the potential utilization of the site by human (Bruschi and Cendrero 2005; Serrano and González-Trueba, 2005; Pereira et al., 2007; Martin, 2013).

The assessment of the scientific value (tab. 2) uses four criteria namely integrity, representativeness, rareness and palaeogeographical interest. The assessment is done quantitatively through a brief description and the attribution of a score from 0 (null) to 1 (very high). The assessment of additional values (tab. 3) uses three main values: ecological, aesthetic and cultural values. This assessment is done qualitatively through a series of symbolic pictures or sketches, where the use of signalization (pictograms) are proposed to that end.

The use and management of characteristics highlight the present state of protection of sites against attacks, the presence of interpretation equipment, characteristics related to the visit conditions and to the educational interest of the site (Martin, 2013). Since geomorphosites are considered as a resource, information allowing the characterization of the site is collected in sight of the management that includes protection and valorization. Natural or human attacks that can influence the quality of the site are documented in the Table 4.

The valorization of the site brings out characteristics of current enhancement of sites as well as conditions that could allow an

**Tab. 4 - Criteria used for the documentation of the protection of the geomorphosite (Reynard et al., 2016).**

**Tab. 4- Critères utilisés pour la documentation de la protection d'un géomorphosite (Reynard et al., 2016).**

Subcriteria	Contains
Protection status	Summarize in a sentence the level of protection of the site relatively to its link with different inventories, classifications or natural reserves
Damages and threats	Specify the level of damage of the site by human activities or natural processes. For the active sites (alluvial area), the change of processes allowing their formation or regeneration can be considered as attack even if is not located in the site perimeter. As for threats, one must report if they are based on a real and feasible project in short/medium term

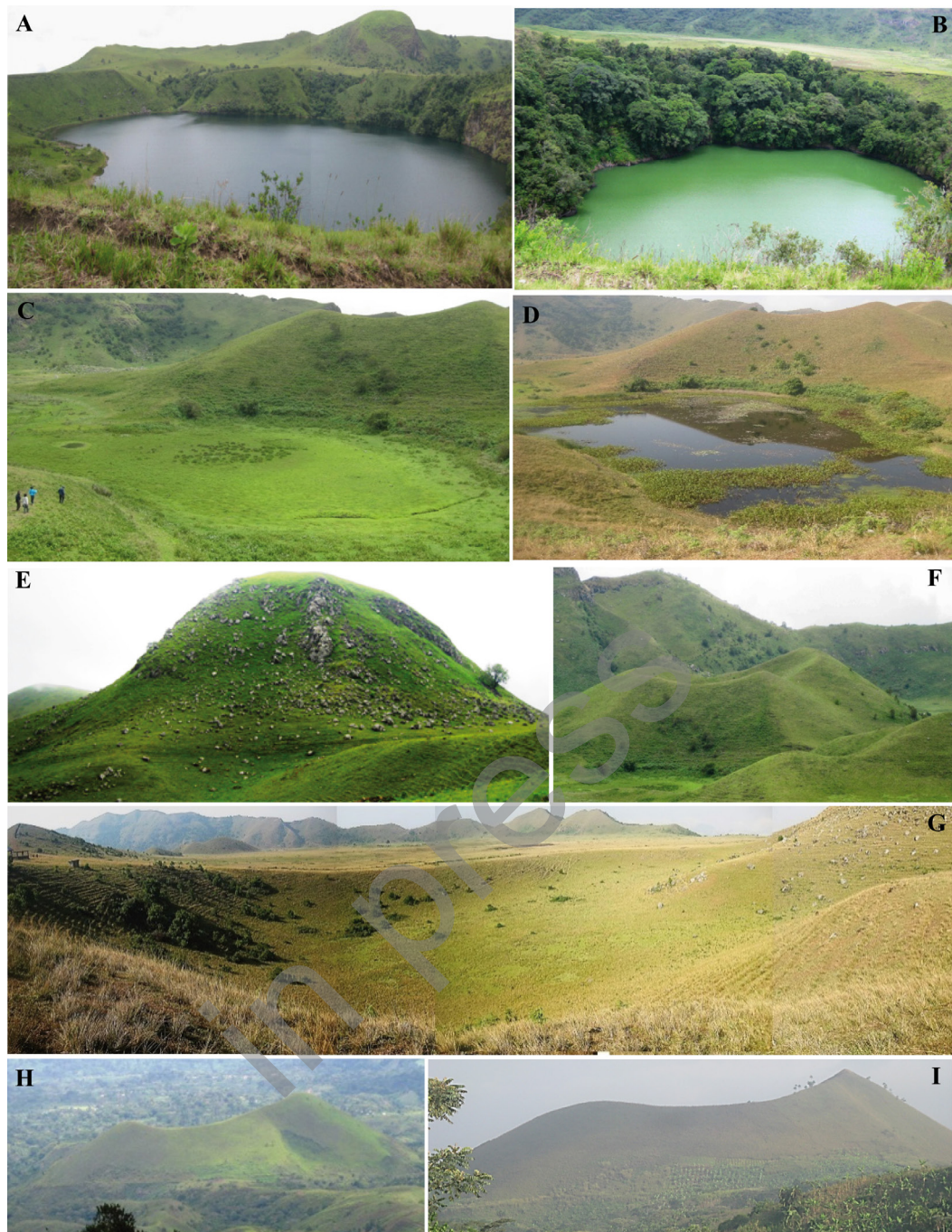
eventual valorization in the future. It is divided into two sub-criteria, visit conditions and educational interest. The former one informs on inescapable elements of a visit to the site such as accessibility, security, environment of the site and touristic infrastructures. The latter assesses the importance of the site for education and training. Sites particularly legible in the landscape, as well as sites that allow the observation of active processes have high educational interest. The presence of interpretative equipment, for example educational panels, is not an element of educational interest assessment, but is reported in order to give an account on the current valorization of the site.

## 4. Results and discussion

### 4.1. Description of the geomorphosites selected

The geomorphosites selected (fig. 6-7) for this study include caldera, crater lakes, lake, scoria cones, domes, and basin. The caldera is not a closed system. Its floor is located over 1,900 m and it is a relative relief and constitutes the bottom of geomorphosites selected for this study (tab 5).

The lakes are made up of crater lakes (Female Lake and Male Lake) and a Child Lake. These lakes are similar to other lakes encountered along CVL and in the East African Rift. The Female Lake (fig. 6A) is the biggest lake in the volcano with an area of 408,391 m<sup>2</sup> and 168 m depth (Kling, 1988; Zangmo Tefogoum, 2016). It has a sub-circular shape which is similar to the African continent seen the other way around (fig. 8). The crater rim slopes are significant, and they reach 90° in the southern side. The northeastern rim is truncated by two V-shaped valleys. These valleys are active and are flowing inside the crater lake. The meadow dominates the major part of the crater while the gallery forest is poorly found on the southern, eastern and northeastern rim of the crater. The water temperature ranges between 19.2°C to 20.6°C (Tanyileke, 1994), also the chemical and physical characteristics of water need a treatment to be potable (Chakam Tagheu et al., 2005). Although the local population is drinking that water, it is restricted to tourists. The Male Lake (fig. 6B) is also a sub-circular volcanic cone with 5 m to 30 m height. The depth and the surface of the lake are respectively 92 m and 41,252 m<sup>2</sup> (Kling, 1988; Zangmo Tefogoum, 2016). The internal slopes of the crater are steep (approximately 80°). The temperature of water ranges between 16.8°C to 21°C (Tanyileke, 1994). The presence of phytoplanktons gives to the waters a greenish color. According to Chakam Tagheu et al., (2005) these waters can be treated for



**Fig. 6 - Pictures of Geomorphosites in the Eboga Volcano.**

A: Female Lake; B: Male Lake; C&D: Child Lake; E: Mboriko Mugearitic Dome; F: Scoria Cones; G: Eboga Depression; H&I: Ekambeng Scoria Cone.

**Fig. 6 - Photos des géomorphosites dans le Volcan Eboga.**

A- Lac de la Femme; B- Lac de l'Homme; C&D- Lac de l'Enfant; E- Dôme Mugéaritique Mboriko; F- Cônes de Scories; G- Dépression d'Eboga; H&I- Cône de Scories Ekambeng.

drinking issues. Contrary to the Female Lake, this water is not drunk by the local population. The vegetation cover is characterized by the meadow that dominates the Male lake slopes. However, the gallery forest is found on the eastern slopes of the crater. The Child Lake (fig. 6C-D) is located precisely at about 60 m to the Male Lake. It is not a crater lake like the previous ones. It is defined by two cones (one partly and another totally broken) that partially encompassed an elliptical area (4,464 m<sup>2</sup>) in which the water can accumulate (fig. 6F). It is shallow and seasonal, recharging during the rainy season

(June to October). During the dry season, the lake floor is overgrown with endemic grasses.

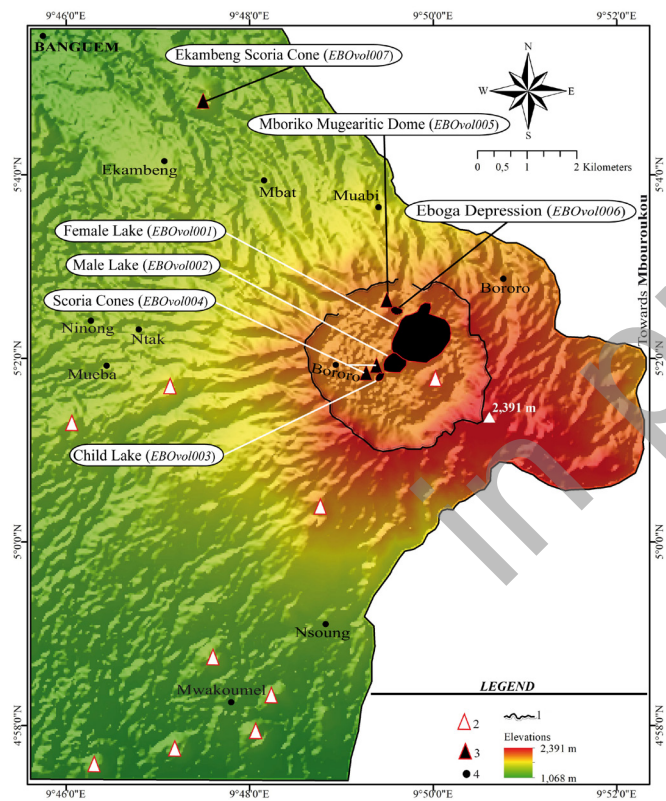
The main dome in the EV is Mboriko Mugearitic Dome (fig. 6E). It is the elongated (SW-NE direction) mugearitic dome culminating at 2,067 m. Numerous columnar joints and diaclases are found on the top of the dome. These gave rise to the collapse of numerous blocks. Two scoria cones in the caldera were selected for this study (fig. 6F). They are very close each other. The first one is entirely broken in the NW-SE direction. The second one is partially broken. Four

**Tab. 5 – General data of geomorphosites in the Eboga Volcano.**

**Tab. 5 – Données générales des géomorphosites dans le Volcan Eboga.**

Code	Name	Altitude (m)	Surface (m <sup>2</sup> )	Coordinates	Main geomorphological process	Characteristics	Type of geometry
MBAvol001	Female Lake	1911	408 391	05°02'18" N 09°49'54" E	Volcanic	Natural	SUR
MBAvol002	Male Lake	1900	41 252	05°02'10" N 09°49'39" E	Volcanic	Natural	SUR
MBAvol003	Child Lake	1949	4 464	05°01'44" N 09°49'22" E	Fluvial	Natural	SUR
MBAvol004	Scoria Cones	1970	215 795	05°01'47" N 09°49'16" E	Volcanic	Natural	SUR
MBAvol005	Mboricko Mugearitic Dome	2067	275 107	05°20'30" N 09°49'30" E	Volcanic	Natural	SUR
MBAvol006	Eboga Depression	1960	71 000	05°02'20" N 09°49'30" E	Volcanic	Natural	SUR
MBAvol007	Ekambeng Scoria Cone	1461	625 277	05°04'49" N 09°47'30" E	Volcanic	Natural	SUR

\*EBO= Eboga SUR=Surface



**Fig. 7 - Location map of geomorphosites in the Eboga Volcano.**

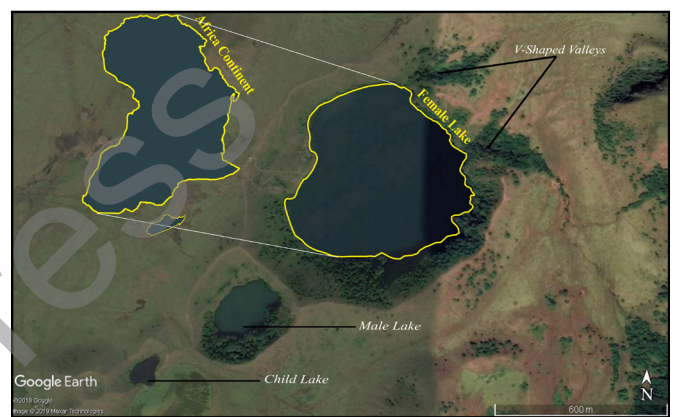
1. Caldera boundaries; 2. Selected geomorphosites for assessment; 3. Potential geomorphosites; 4. Localities.

**Fig. 7 - Carte de localisation des géomorphosites dans le Volcan Eboga.**

1. Limites de la Caldeira; 2. Géomorphosites sélectionnés pour l'évaluation; 3. Géomorphosites Potentiels; 4. Localités.

broken directions have been identified, the major one in SW-NE. Both cones are about 30 m high and are covered by the meadow and some sporadic trees.

The basin (fig. 6G) is observed between the Mboriko and the Female Lake, and it is an elongated structure (SE-NW direction).



**Fig. 8 - Satellite image highlighting the likeness of shape between Female Lake and Africa Continent.**

**Fig. 8 - Image satellite mettant en évidence la ressemblance de forme entre le Lac de la Femme et le Continent Africain.**

The basin covers an area of 71,000 m<sup>2</sup> and the slopes of its walls reach 60° in some areas. The depth of that depression decreases along its direction of elongation, its floor is sub-homogeneous, and slightly inclined SE-NW. Heterogeneous vegetation covers the entire structure. A lawn made of natural grass covers the depression floor and ramparts. Some shrubs dominate the structure including the southern and eastern ramparts.

The Ekambeng scoria cone has the same SE-NW broken direction (fig. 6H-I). This cone reaches about 46 m high and its external slopes are steeper than 40°. A scar is observed on its southern slope. The internal and external slopes of the cone are covered by vegetation dominated by the meadow.

#### 4.2. Scientific value assessment

The results of the assessment of the scientific value of geomorphosites have been compiled in the Table 6. The histogram (fig. 9) is a graphical expression of the score attributed to criteria of

**Tab. 6 – Scientific value of geomorphosites in the Eboga Volcano.**

*Tab. 6 – Valeur scientifique des géomorphosites dans le Volcan Eboga.*

Geomorphosites		Criteria				
Code	Name	Integrity	Representativeness	Rareness	Paleogeographic Interest	Scientific value
MBAvol001	Female Lake	1	0.75	0.75	0.5	0.75
MBAvol002	Male Lake	1	0.75	0.75	0.5	0.75
MBAvol003	Child Lake	1	0.5	1	0	0.63
MBAvol004	Scoria Cones	1	1	0.75	0.5	0.81
MBAvol005	Mboricko Mugaritic Dome	0.75	0.75	1	0.5	0.75
MBAvol006	Eboga Depression	1	1	1	0.5	0.88
MBAvol007	Ekambeng Scoria Cone	1	1	0.25	0.5	0.69
<b>Average</b>		<b>0.96</b>	<b>0.82</b>	<b>0.79</b>	<b>0.43</b>	<b>0.75</b>

\*EBO= Eboga SUR=Surface

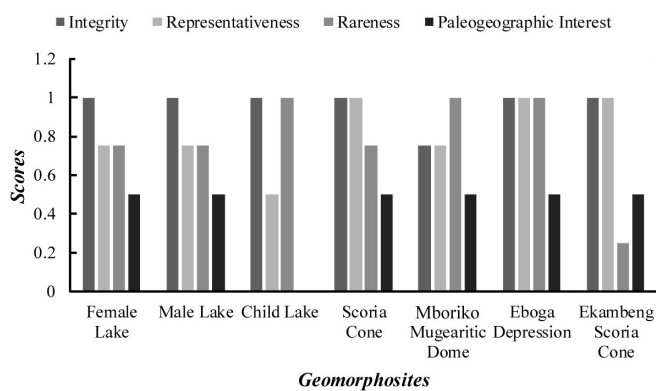
each geomorphosites in the EV.

According to these results, only the Child Lake has zero paleogeographic interest, unlike other geomorphosites that have an average paleogeographic interest (0.5). This score has been obtained by some volcanic geomorphosites (Dome East, Dome Mbu 1, Dome Mbu 2, Mount Manah and Awing Lake) and in the Santa Mbu and Lefo calderas (Mount Bamenda, CVL) (Zangmo Tefogoum et al., 2017). The scoria cones, the Mboriko Mugaritic Dome and the Eboga Depression have a relatively high scientific value due to their integrity (they are well preserved), representativeness (witness of EV geomorphological features) and rarity (they are unique in the EV). The highest score is 0.88 obtained on Eboga Depression. Dome Mbu 2 in the Santa-Mbu caldera obtained the same score although it constitutes a positive relief. Despite the characteristics of integrity, representativity and rarity, geomorphosites such as the Female Lake, the Male Lake, the Child Lake and the Ekambeng Scoria Cone have a high scientific value. The lowest score is 0.63 obtained on the Child

Lake. In the Mount Bamenda caldera that score (the lowest one of the assessed geomorphosites), has been obtained by Dome East and Mbu Valley (Zangmo Tefogoum et al., 2017). For the both cases, this score relies on the fact that geomorphosites are not representative of the regional geomorphology and they do not teach about past climate and geography. Overall site integrity has a very high average value (1); it shows that the geomorphological heritage of the EV is overall well preserved. In addition, these landforms have very high average (0.82) of their representativity, with EV's geomorphological features notably domes, cones, basin, flows, and crater lake. The geomorphosites of the EV are very concentrated because of the average obtained from their score on rareness criterion is 0.79.

### 4.3. Additional values assessment

In the EV, the ecological value is overall rather variable. The Female and the Male Lakes have a high ecological value unlike the other geomorphosites, which have a generally low value (fig. 10). In fact, their ecological influence remains quite high because they are undisturbed sites that represent varied natural environments, important for biological diversity and that sometimes shelter typical (even endemic) fauna and flora. For example, the Female and the Male Lakes present a forest and a forest gallery, which abounds a well-developed flora and some faunal species. The waters of the Female Lake harbor many aquatic lives that favor fishing as observed in the Awing Lake (located on the northern slopes of Lefo caldera) and in the Beme Lake (located on the Northwestern slopes of Mount Manengouba). The inaccessibility of the waters of the Male Lake gives rise to the development of phytoplankton during the rainy season. In addition, the Child Lake is marked by the presence of phytoplankton in the rainy season and a floor covered by a lawn in the dry season (Zangmo Tefogoum et al., 2015b, 2017). Conversely, the level of protection of these geomorphosites is globally nil to very



**Fig. 9 - Histogram of the scientific value of Eboga Volcano geomorphosites.**

*Fig. 9 - Histogramme de la valeur scientifique des géomorphosites du Volcan Eboga.*



low which has a significant impact on their local average ecological value.

In the EV, the color contrasts are due to the changing vegetation, lithology and water. The mugearitic rock outcrops (Mboriko) presented as banks or columns, contrast strongly with the vegetation on the domes, and the walls of the lakes and caldera ramparts, play here a great role. These features have been found in several geomorphosites along the CVL notably the trachytic and phonolitic domes in the Mount Bambouto and Bamenda calderas (Zangmo Tefogoum et al., 2017, 2019). Differences due to slope variations also participate in the structuring of space, mainly in the case of dome constructions, cones, and crater lakes. Moreover, the morphology of Cones is unique and is attributed to the breaking off stage during their formation. According to the reference zone, which is the floor or slopes of the calderas, there is a positive vertical development at the dome and cones and negative at the crater lakes and depression. The presence of individualized elements is undeniable because geomorphosites in the EV are well defined and clearly distinguishable each other. All these criteria give all geomorphosites in the EV a high average aesthetic value (fig. 10). Along the EV, only the Female Lake are of considerable cultural value. As matter of fact, according to some authors (Tchindjang, et Fodouop, 2003; Tchawa, 2012; Coliat, 2019), Cameroon is considered an *Africa in miniature* through several aspects. This highlighted by the shape of the Female Lake that is close to that of Africa, giving it the symbolic value. Moreover, as woman take care of humankind (Merchant, 1989), the Female Lake waters are used for therapeutic issues by the neighboring population and the purification of haunted houses in nearby localities. In addition, many traditional rites are practiced by surrounding populations. It also offers activities like swimming on the western side, and fishing on the northern side. In addition, Female Lake along Male Lake, Broken Cones and Mboriko Mugearitic Dome have been the subject of some scientific publications (Kagou Dongmo et al., 1999, 2005; Zangmo Tefogoum et al., 2014, 2015a).

#### 4.4. Use and management characteristics

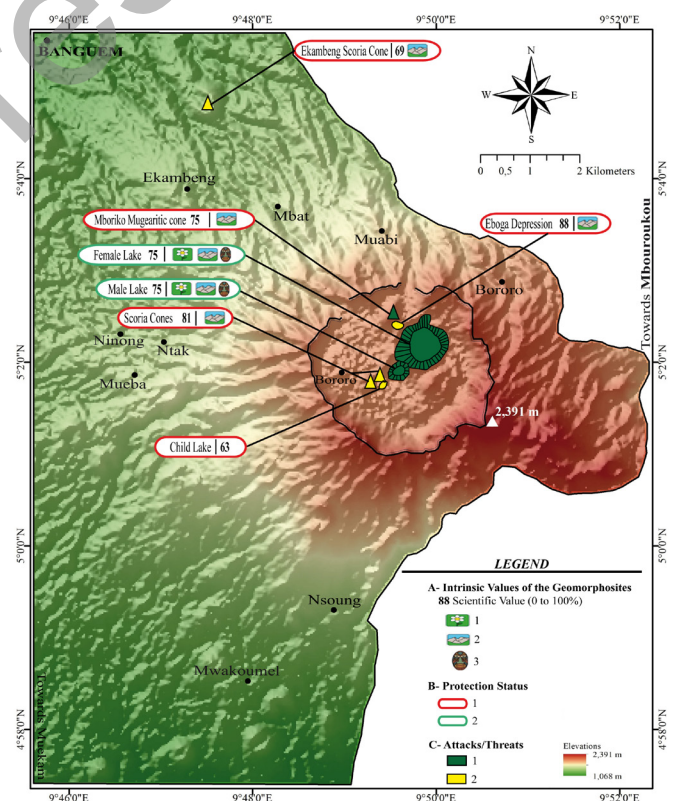
Most of the sites (#5) have no protection, two have a very low protection status (fig. 10). The protection of the two crater lakes is materialized at the village level Mbat and it is limited to a barrier called "rain" next to a sentry box (fig. 11A). This kind of barrier is used throughout the country to reduce the road traffic in order to prevent de rapid degradation of non-asphalted roads. Moreover, the inventoried geomorphosites are subject to anthropogenic attack through grazing that modifies the topography and the natural lawn of the outer lower slopes of craters and cones. However, this threat is insignificant because it does not affect the general topography of the geomorphosites observed from afar. Moreover, the population growth in the caldera could lead to the destruction of geomorphosites through the conquest of green space in the future. Since sites are quickly accessible, tourists could damage them. In fact, geomorphosites (fig. 11B-C) that are inaccessible and more distant from human activities (fig. 11D) are generally preserved and very little threatened (Bussard, 2014). Mboriko Mugearitic Dome is the only site naturally threatened. Indeed, rocks and debris falls are occurring on its southern slopes and they give rise to numerous

erratic boulders cropping out on the piedmont (Zangmo Tefogoum et al., 2011).

#### 4.5. Visit conditions

In the Eboga caldera, only two shelters are built and are located a few meters from the western ridge of the Female Lake (fig. 11B). Most tourist attractions are concentrated without surprise in some localities near the volcano including Banguem and Mbouroukou. However, three accesses (fig. 12), have been proposed by Kagou Dongmo et al. (1999) and Zangmo Tefogoum et al. (2015a), to facilitate tourism activity in the whole Manengouba Mountain. In the first one (off-road vehicle access #1), tourists with off-road vehicle can pass through Banguem town and Mbat Village (NW of Mt Manengouba) to access the Eboga caldera directly. In the second one (a trail #4), which is, three hours of walking through Mbouroukou, tourists arrive on the NE flank of the Eboga caldera where is a panoramic view of the whole caldera. In the third one (a trail #7), which is 2.5 hours walking on the uneven track through Nsong, tourists arrive on the southern flank of the Eboga caldera.

The accessibility of geomorphosites in the Eboga caldera is very good, because the caldera floor is relatively flat and therefore, limits the difficulties of walking in the region. In addition, stairs have been constructed to facilitate access to the shores of the Female Lake and to allow a panoramic view of the lakes. The lakes and eastern caldera crest line gives rise to some viewpoints that enhance



**Fig. 10 - Geomorphosite value and status protection**

A: Intrinsic value. 1. High ecological value; 2. High aesthetic value; 3. High cultural value. B: Protection Status. 1. Null; 2. High. C: Attacks/Threats. 1. None; 2. Low.

#### Fig. 10 - Valeur du géomorphosite et statut de protection

A: Valeur intrinsèque. 1. Grande valeur écologique; 2. Grande valeur esthétique; 3. Grande valeur culturelle. B: Statut de Protection. 1. Nul; 2. Elevé. C: Attaques/Menaces. 1. Aucune; 2. Faible.

the aesthetic value of geomorphosites. However, the crest line (fig. 11C) separating the two crater lakes is not recommended for people who are not experienced in a mountain environment. In fact, the crest line is between 2 to 3 meters width. In addition, it is made up of loose materials and can be altered by natural/anthropic erosion accordingly. Actually, most of the geomorphosites in the EV have a particularly quiet environment. However, the local population sporadically practices grazing around the EV geomorphosites. Since it is sporadic at the site level it is rather negligible. Nevertheless, its perpetuity could be a real threat for the tranquility of the sites in the region in the future. EV is a preserved natural setting with a beautiful and very open landscape (fig. 11D) without high human disturbances. Thus, the aesthetic value of geomorphosites is enhanced because tourists can enjoy them through easy access and relatively quiet environment.

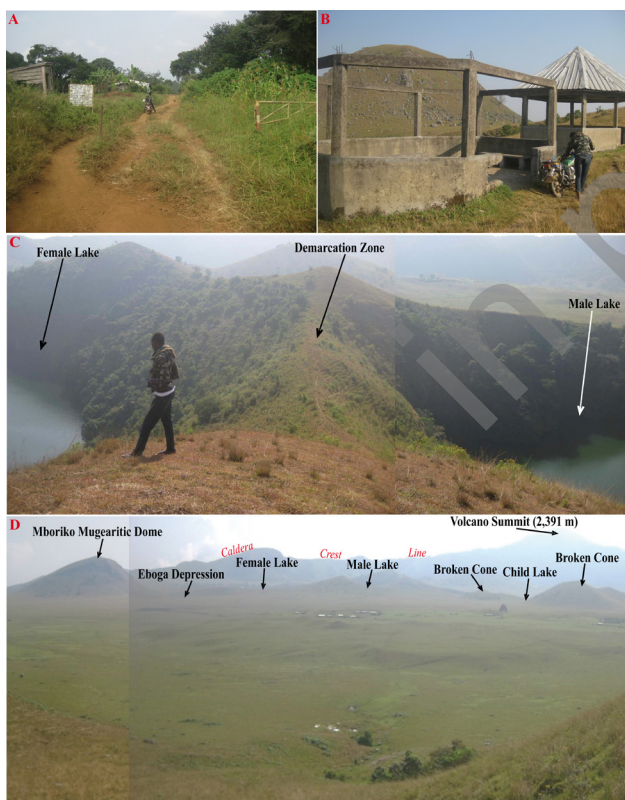
#### 4.6. Educational interest

The activity of the geomorphological processes is an important element that influences the legibility of the sites. However, the geomorphological processes at the origin of geomorphosites in the Eboga volcano are passive; this does not necessarily affect their readability, which remains high. Rainfall erosion is active in the

region especially on the geomorphosites slopes that are not overlay by grasses. We can list the western inward slopes of Female Lake and the southern slopes of Mboriko Mugearitic Dome. Yet, in the EV five landforms (Female Lake, Male Lake, Scoria Cones, Mboriko Mugearitic Dome, Ekambeng Scoria Cone) have high educational value (fig. 12):

Female and Male Lake result from the phreatomagmatic volcanic dynamism that occurred in the central part of the EV. Moreover, they are crater lakes that give tourists the impression that they may experience an event similar to Lake Nyos in 1986. Erratic boulders found on the Female Lake shore and western ramparts are evidences of explosive events that ruled the formation of the Female Lake. The southern inward cliffs of the Female Lake exhibit some columnar joints that inform about the cooling process in magmatic system.

The Mboriko Mugearitic Dome formed through an extrusive volcanic dynamism type. Numerous columnar joints traversed by cracks and diaclasses are found on the southern slopes of the dome.

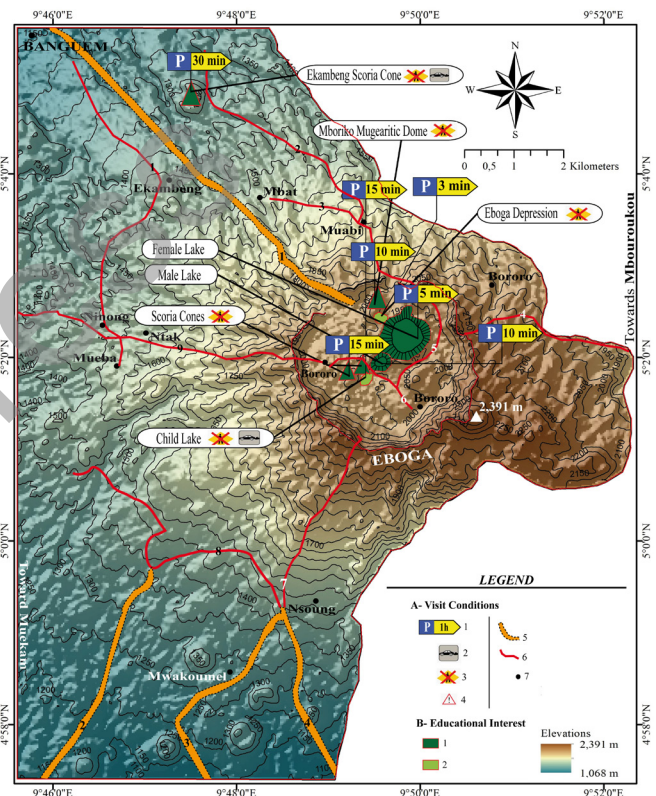


**Fig. 11 - Pictures displaying the tourism infrastructures and geological features in the Eboga Volcano.**

A: Barrier called "rain"; B: Boucarous near the Female Lake; C: Demarcation zone between Female and Male Lakes; D: Panoramic view of geomorphosites.

**Fig. 11 - Photos mettant en évidence les infrastructures touristiques et les traits géologiques dans le Volcan Eboga.**

A: Barrière de pluie; B: Boucarous proche du Lac de la Femme; C: Zone de démarcation entre les Lacs de la Femme et de l'Homme; D: Vue panoramique des géomorphosites.



**Fig. 12 - A: Visit conditions.**

1. Walking Time from a parking; 2. Disturbed environment; 3. Untagged way/No Path; 4. Difficult or dangerous path; 5. Roads for off-road cars; 6. Walking trails; 7. Localities. B: Educational interest. 1. High; 2. Medium.

**Fig. 12 - A: Conditions de visite.**

1. Temps de marche à partir d'un parking; 2. Environnement perturbé; 3. Chemin non balisé/Pas de chemin; 4. Chemin difficile ou dangereux; 5. Routes pour voitures tout-terrain; 6. Piste pour la marche; 7. Localités. B: Intérêt éducatif. 1. Élevé; 2. Moyen.

The rockfalls hazards occurring at that side constitutes an active geological mechanism.

Scoria Cones result from the explosive and fissural volcanic dynamisms type. In fact, these cones are composed of scoria arranged in layers of different thickness and grain size. This structure tells tourists about the rhythmicity of explosions during the formation

of Scoria cones. Moreover, Scoria Cones are partially/totally broken. The breaking direction clearly explains the downslopes fissural eruption that occurred after the formation of the Scoria Cones.

Despite the legibility of geomorphosites in the EV, there are no interpretation facilities (educational panels, brochures, books) or simple explanations of the geomorphosites to provide to the public. However, this paper is of great importance and will be made available to the competent authorities for any project initiated in the promotion of geotourism.

## 5. Conclusion

EV geological heritage inventory identified seven volcanic origin geomorphosites. Different geomorphosites such as lakes (Female Lake, Male Lake, and Child Lake), Ekambeng scoria cones, Mboriko Dome, and Eboga Depression compose this geological heritage. The assessment revealed that the scientific value of these geomorphosites varies from 0.63 to 0.88 with an average of 0.75. The geomorphosite with the highest value in the evaluation was the Eboga Depression (0.88). The EV as a group of geomorphosites have high integrity, a very high representativity and rareness values. These conditions turn this volcano as an important place for the people and the country.

The EV geomorphosites through their scientific value constitute significant geotouristic assets. They should benefit from legal protection and tourist infrastructures that will ease the practice of geotouristic and recreational activities. It is important to have more and better signage for visitors to learn about the natural attractions to increase the visitor's knowledge about EV and enhance its scientific value. As Cameroon is traversed by the CVL, numerous geomorphosites can be found in other volcanic regions. A wide inventory of such geomorphosites must be performed throughout the CVL in order to protect, promote and preserve them for future generations. The promotion of geotourism in the EV is an utmost opportunity for the alleviation of poverty and rural migration in the entire Manengouba region. This work can be extended to other African and developing countries that present alluring volcanic landforms that could be promoted as touristic destinations favoring local economies.

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### Version Française Abrégée

*Le Cameroun est traversé par un système océano-continentale de fractures circonscrites dans une bande d'orientation majeure N30°E, appelée Ligne Volcanique du Cameroun (LVC). La LVC présente des édifices volcaniques et plutoniques s'étendant du Golfe de Guinée jusqu'au lac Tchad. Parmi les édifices volcaniques, le mont Manengouba, est constitué de deux volcans : Elengoum et Eboga. Le Volcan Eboga qui a fait l'objet de quelques travaux antérieurs, a été choisi pour la présente étude car c'est le volcan le mieux défini et qui résume le mieux le mont Manengouba au plan géomorphologique. Il présente à son sommet (2 391 m) une caldeira sub-circulaire (4 à 5 km de diamètre). Ce massif expose un patrimoine géologique extrêmement diversifié. Ce patrimoine naturel mérite une étude scientifique détaillée car à travers la diversité des géomorphosites, il est un atout pour le géotourisme. Un inventaire et une sélection des sites en vue d'une valorisation à des fins géotouristiques est nécessaire pour permettre leur rentabilisation et assurer leur protection. Plusieurs études en laboratoire (littérature existante et analyse de cartes topographiques et géologiques, des photographies aériennes, des images satellites et des MNT) ont été effectuées sur le Volcan Eboga, ainsi que des missions de terrain. Elles ont permis d'acquies une bonne connaissance de la géomorphologie de la région et de mener une sélection et une évaluation des géomorphosites selon la méthode développée à l'Université de Lausanne (Reynard et al., 2016), qui comprend la documentation du site, l'évaluation de la valeur scientifique et l'étude des caractéristiques d'usage et de gestion. Pour l'évaluation de la valeur scientifique, on attribue des*

scores ; par contre, pour l'évaluation des valeurs additionnelles, on n'attribue pas de scores chiffrés mais plus tôt des pictogrammes.

Sept géomorphosites tous d'origine volcanique ont été sélectionnés et évalués dans ce travail. Ce sont des lacs de cratère, des cônes égueulés, une dépression et un dôme. Les lacs de cratère comprennent le Lac de la Femme et le Lac de l'Homme. Le Lac de la Femme couvre une superficie de 408 391 m<sup>2</sup> pour une profondeur de 168 m. Par contre, le Lac de l'Homme ne couvre qu'une superficie de 41 252 m<sup>2</sup> pour une profondeur de 92 m (Kling, 1988 ; Zangmo Tefogoum, 2016). Les eaux de ces deux lacs doivent être traitées avant toute consommation (Chakam Tagheu et al., 2005). Par ailleurs, il n'est pas exclu que ces eaux connaissent dans leurs profondeurs une accumulation de gaz toxique tel que le CO<sub>2</sub>, comme aux lacs Nyos et Monoun (Kagou Dongmo et al., 2005). À côté de ces lacs de cratère, le Lac de l'Enfant est saisonnier, peu profond et couvre une superficie 4 464 m<sup>2</sup>. Ce lac expose sur son plancher une pelouse naturelle en saison sèche. Les cônes égueulés sont ceux d'Eboga et d'Ekambeng. Ces cônes sont caractérisés par une ou plusieurs directions d'égueulement, et des altitudes variables allant de 1 460 à 1 970 m. La dépression d'Eboga couvre une superficie de 71 000 m<sup>2</sup>. C'est une structure allongée dans la direction SE-NW avec un plancher d'altitude variable suivant la même direction. Le dôme, celui de Mboriko, est allongé suivant la direction SW-NE. Il est mugéaritique et est dominé par de nombreux prismes fissurés qui favorisent le détachement de nombreux blocs polygonaux retrouvés à sa base.

La valeur scientifique varie d'un géomorphosite à l'autre dans la zone d'étude. Les cônes de scories égueulés d'Eboga et la dépression d'Eboga ont une valeur scientifique relativement élevée respectivement 0,81 et 0,88. Les autres sites ont une valeur scientifique comprise entre 0,63 et 0,75. Cela tient au fait que le Lac de l'Enfant présente un intérêt paléogéographique nul, contrairement aux autres géomorphosites qui présentent un intérêt paléogéographique moyen. Par ailleurs, ces sites sont dans l'ensemble bien préservés (0,96), rares (0,79) et représentatifs (0,82) de la géomorphologie générale du VE. Tout ceci confère aux géomorphosites du VE une valeur scientifique moyenne relativement élevée, de 0,75.

Les valeurs additionnelles sont propres à chaque géomorphosite. La somme de ces valeurs varie selon la valeur écologique, la valeur esthétique et la valeur culturelle. La valeur écologique qui est régulée par l'influence écologique et l'état de protection d'un géomorphosite donné, est dans l'ensemble variable dans la zone d'étude. En effet, l'influence écologique apparaît assez élevée pour la plupart des géomorphosites dans le VE ; car ce sont des sites peu perturbés qui représentent des milieux naturels variés, importants pour la diversité biologique et qui abritent parfois des espèces typiques de faune et de flore. Par contre, le niveau de protection de ces géomorphosites est en général nul à très faible, ce qui se répercute nettement sur leur valeur écologique moyenne. Toutefois, seuls les Lacs de la Femme et de l'Homme sont protégés ; ce qui leur confère une valeur écologique très élevée. La valeur esthétique est généralement intéressante car la couleur grise à sombre des roches tranche fortement avec la couleur verte du couvert végétal sur les dômes et les parois des lacs et remparts. En outre, des contrastes dus aux variations de pente, participent aussi à la structuration de l'espace, principalement dans le cas des constructions des cônes, des dômes et des lacs de cratère. Cette valeur esthétique est aussi caractérisée par le développement vertical des géomorphosites en fonction d'un repère défini qui peut être le plancher

de la caldeira ou les versants du VE. Ce développement vertical est positif pour les cônes, les dômes et remparts des caldeiras, négatif pour les lacs de cratère. La valeur culturelle des géomorphosites est majoritairement plutôt faible à l'exception de celle des lacs de la Femme et de l'Homme qui sont des lieux de pratiques des rites traditionnels et ont fait l'objet de quelques publications et citations (Kagou Dongmo et al., 1999, 2005 ; Zangmo Tefogoum et al., 2014, 2015a). Enfin, malgré le manque d'infrastructures géotouristiques et quelques menaces liées à l'activité pastorale, les géomorphosites du VE présentent un intérêt éducatif élevé et un environnement calme, et ils sont pour la plupart accessibles. La valorisation de ces géomorphosites à travers le géotourisme viendrait augmenter l'offre touristique, et par conséquent, le nombre de visiteurs du VE.

L'originalité du VE est multiforme : il s'agit de l'unique volcan de la LVC emboîté dans un autre volcan (Elengoum) ; les deux appareils définissent une structure semblable à celle du volcan Fogo au Cap Vert. Le VE est aussi le seul volcan d'Afrique qui présente une caldeira subcirculaire avec un plancher bien défini où subsistent des lacs de cratère et des cônes parfois alignés. Toutefois, la forme des lacs de la Femme et de l'Homme est comparable à celle des autres lacs le long de la Ligne du Cameroun et de volcans du Rift Est Africain. Avec la mise en place d'un plan de gestion, l'essor du géotourisme permettrait la réduction de la pauvreté, du chômage et de l'exode rural dans les villages du VE, notamment les groupements Bororo de la caldeira et les villages d'Ekambeng, de Mbat et de Muabi.

