APPLICATION OF THE INTERFEROMETRY TECHNIQUE IN THE STUDY OF RECENT VOLCANIC ERUPTIONS OF MOUNT CAMEROON (CENTRAL AFRICA)

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Abstract

Interferometry is increasingly being applied in the study of terrestrial phenomena today. Within the framework of this paper, we apply this technique in the assessment of land deformation on Mount Cameroon, an active volcano. With an average eruption interval of fifteen years during the last century, this activity is generally characterized by fissural and effusive eruption, but which is sometimes explosive, accompanied by earthquakes and more or less significant tectonic movements. This is the case of the last two eruptions in 1999 and 2000.

From a set of radar data: ERS 1&2 SAR (1996, 1998 and 2003), ENVISAT ASAR(2006 and 2007) and optical data: Landsat (2000) and Aster (2003 and 2004), we mapped and evaluated volumes of lava flows and projections as well as an outline of some deformations of the volcano. The high coherence of the interferometric radar couple was very significant in the mapping of outcrops.

In February-March and June 2007, 17 geodetic pillars of which eight carried reflectors were built around the volcano. With these pillars having accurate coordinates, simultaneous ALOS PALSAR and ENVISAT ASAR acquisitions with alternate polarimetry AVNIR-2 and PRISM data acquisition scheduled to start in early October 2007 will enable us to fit the model of deformation and to start the study of flood and land movement hazards.

Keywords: Radar interferometry, multi source approach, volcanic eruption, Mount Cameroon.

INTRODUCTION

Located at the bottom of the Gulf of Guinea, Mount Cameroon is the only active volcano of the Cameroon volcanic line. During the 20th century, the population living around this volcano has experienced numerous natural hazards and catastrophes. These include volcanic eruptions, floods, landslides and mudflows which have caused an increasing number of deaths and material damages. Our study aims, among other objectives, to help in the planning and management of coastal development, in order to minimise risks and natural hazards.

Many completed or ongoing research projects, have been carried on this issue, but have essentially relied on data from old and/or less precise sources. The most precise topographical maps are drawn from aerial photographs of 1963-1964 and 1967 1:50 000 scale, with 20 m contour spacing. Field observations are very tedious due to:

- A very uneven topography,
- Forest cover and,
- Harsh climate (strong wind, low temperature and poor visibility due to fog cover).

The new earth observation technologies thus offer better possibilities of acquiring and integrating data: synoptic view, repetitivity and the use of radar images offer many advantages such as:

- overcoming the dense and permanent cloud cover which is a serious limitation for optic images, given the fact that radar wave lengths cross cloud cover,
- The multi-polarisation of these waves which, associated to the multi-frequency (band C and band L), allows good characterisation of objects.

Within the framework of the project entitled “the contribution of the radar and optical multi-scale and multi-date imageries in the assessment of volcanic, flood and land movement hazards around Mount Cameroon”, supported by the ALOS Programme, we have been given the opportunity to apply up-to-date spatial technologies on the assessment and management of natural hazards and disasters on this volcano, one of our most concerns during the last 25 year. On this issue, we apply the interferometry technique in the assessment of volcanic ant tectonic impacts of recent Mount Cameroon eruptions.

The present paper focuses on the presentation of Mount Cameroon: history, volcanic, seismic and tectonic activities and the application of new technologies in the evaluation of the impacts of the different manifestations.

I- PRESENTATION OF MOUNT CAMEROON

With an altitude of 4095 metres, Mount Cameroon is a huge volcanic massif that extends on an area of about 1800 km^2, covered by hundreds of volcanic cones scattered along its elongated shape. Its several million years of history is not well known yet. The earliest reported dates back to 2.500 years BP; this is the eruption that was witnessed by HANNO, the Carthaginian explorer, who named it the « Chariot of the Gods ». Some authors think that HANNO did not reach the Gulf of Guinea and so, doubt the authenticity of this eruption.

It is only from the early 19th century that eruptive manifestations were listed. In the course of that century, seven eruptions were registered: 1815, 1835, 1838, 1839, 1852, 1865-66 and 1868. They are, overall, very few or even undocumented. Moreover, many of these are not even precisely located on the field.

With the May-August 2000 eruption, the 20th century has also registered its seventh volcanic event. The previous ones occurred in 1909, 1922, 1954, 1959, 1982 and 1999. These are much better documented, with eye-witness accounts, aerial and field photographs and nowadays, satellites images.

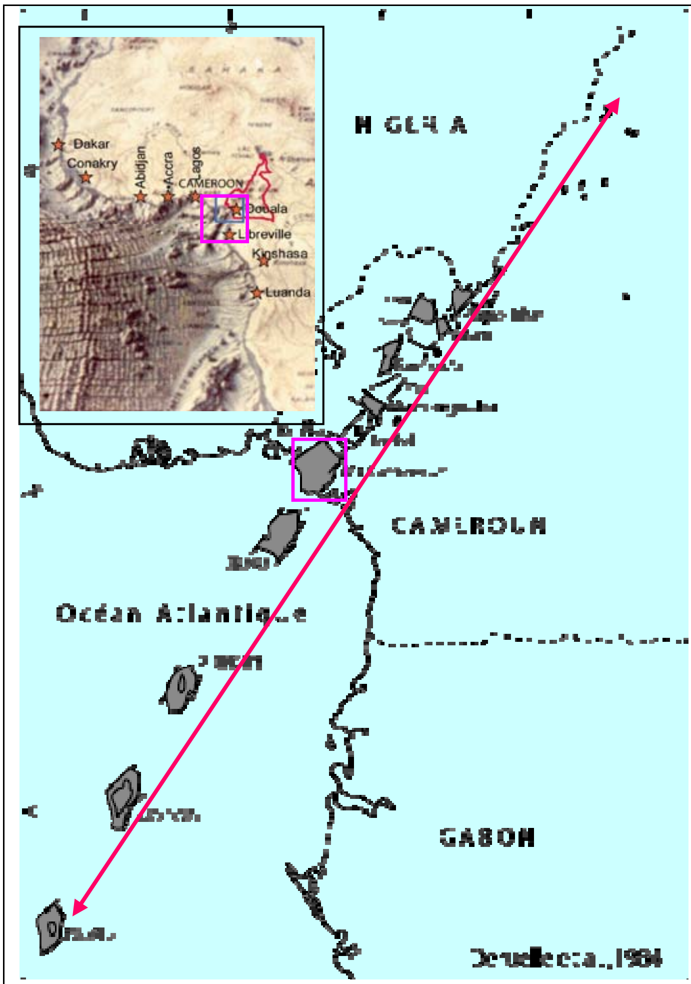


Fig.1 The Cameroon Volcanic Line

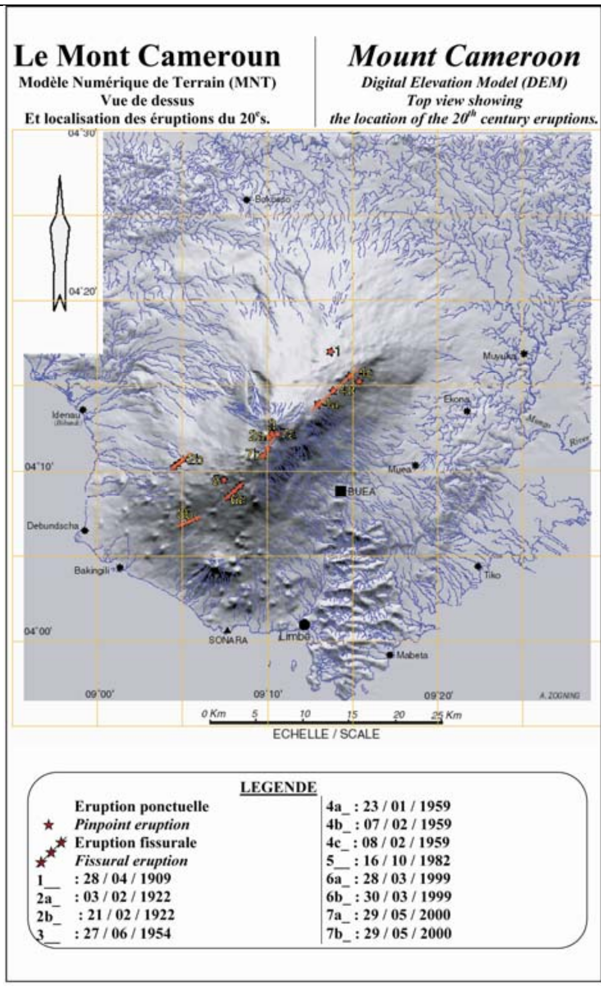


Fig.2 Geographical distribution of the Mountt Cameroon 20th century eruptions.

The activity of Mount Cameroon is mainly characterized by volcanic eruptions, earthquakes, tectonic movements and fumerolle manifestations.

VOLCANIC ERUPTIONS AND IMPACTS

The eruptive dynamism of Mount Cameroon is relatively complex and varies from moderate explosive dynamism, close to vulcanian type to very effusive dynamism, close to Hawaiian type, including strombolian type of eruption. According to the explosivity index, some eruptions are exclusively explosive; but more often, they combine explosive and effusive activity, either along a fissure, or on a single site.

The vulcanian type of dynamism

The June-July 1954 eruption is an example of vulcanian dynamism, mainly characterized by explosive manifestations, with no lava flow. The average frequency consists of one powerful explosion every 30 seconds, followed by smaller ones, which are sometimes not strong enough to project debris out of the crater. The Fig.3below shows a typical powerful discharge, with the formation of the vortex of ash, volcanic bombs, scoria, and lapilli, rising up to 1000m.

This is also the case of the Mai 2000 eruption in the summit site. The Fig.4 below shows a remote view, from Buea, of that eruption. The flattened form (from right to left) of the streaked ash clearly indicates the effects of the strong NE winds which constantly blow over the upper plateau of the volcano.

Similarly, the height of that ash plume (about 1000m), as well as its decreasing and successive wavelike morphology, are evidences of the very explosive nature of the eruptive forces. These are characterised by one violent explosion every 30 seconds, followed by two or three others, of lesser magnitude.

Fig.3: Vulcanian type of dynamism (1954 eruption)

Fig.4: Vulcanian type of dynamism (2000 eruption)

The strombolian type of dynamism

In the case of strombolian type of dynamism, explosive activity alternates with more or less effusive phases, characterised by emission of lava fountains. Picture 6 below shows a phase of generalised emission of lava fountains, during the 1999 eruption, with almost all the vents (9 on 12) active, while picture 5 shows a generalised explosive phase of these very same vents.

Fig.5: 1999 eruption : Explosive phase

Fig.6: 1999 eruption : lava fountain phase.

The October-November 1982 eruption was, like that of 1909, a pinpoint strombolian type of eruption. In less than one month of activity, it produced about 9 million cubic meters of both projections and lava flow. With a low explosivity index, it was characterised by impulsive explosions every 5 to 10 seconds, projecting dense plumes of ash, lapilli and scoria into the sky.

The explosive vent in the Fig.7 is in full activity. The form of the plume indicates the high frequency of the explosions (vertical columns) and the influence of the very strong NE winds, which blow, horizontally, the ash clouds south-westwards.

From time to time, the eruptive activity is interrupted by a few seconds of general calmness, characterised by the emission of more smoke and water vapour than lava. Underground grumblings however remain constant.

Generally after lull, the resumption of activity is marked by powerful explosions, projecting bombs and large packets of fluid lava of more than 500m above the craters (Fig.8).

Fig.7 1982 eruption: The explosive vent.

Fig.8: 1999 eruption: Resumption phase

Effusive dynamism

With a low explosivity index, the strombolian type of activity can be much more effusive than explosive. During the October-November 1982 eruption, the effusive activity was particularly concentrated on a vent located at the base of the old cone. The very fluid lava flowed as fast as a river rapid, with a speed estimated at 20 km/H.

The case was relatively different during the 1999 and 2000 eruptions. Being fissural eruptions, the effusive vents developed on different sites, quite away from the explosive ones. Fig. 10 shows a close view of a confluence zone of the lava flow, stemming from numerous eruptive vents upstream. The Hawaiian nature of this flow is stressed, with completely liquid lava, flowing at a speed of more than 20 Km/hour.

Fig.9: 1982 eruption : lava source

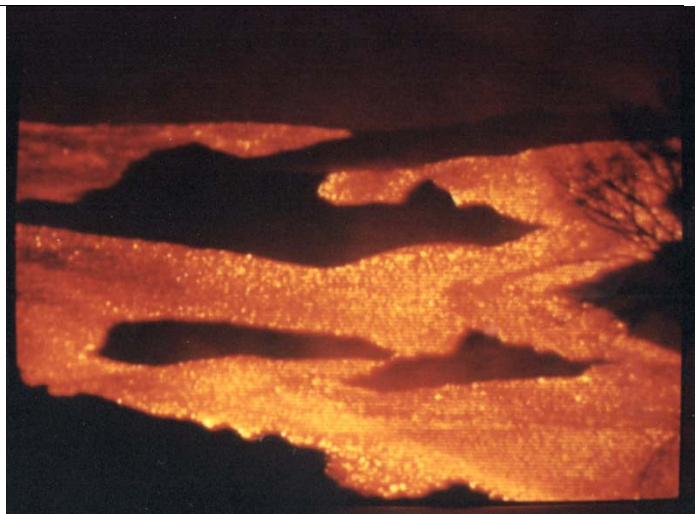


Fig.10: 1999 eruption : lava stream

Nevertheless, because of the slope and its cooling down, this speed rapidly reduced to some few hundreds of metres per day. The Fig.11 presents a view of an active aa lava front, marked by numerous large and glowing avalanche corridors. The zoom in, focuses on an incandescent block of several tons that rolled several metres ahead of the glowing lava front, due to its round shape.

Fig.11: 1999 eruption Active aa lava front

Fig.12: 1999 eruption :Damage on a palm tree plantation

IMPACTS OF VOLCANIC ERUPTIONS ON THE LANDSCAPE

The different types of manifestations described above generate many types of products which, more or less, modify the landscape, especially the topography. The most visible impacts are:

- The building up of volcanic cones and craters, by the explosive activity and,
- The filling up of the valleys and depressions with lava flows.

Fig. 13 below shows a Northeast-Southwest view of the fissure of the first eruptive site the 1999 eruption, approximately more than one month after the end of the eruptive manifestations. One can note the total calmness along this part of the fissure, the alignment of cones and craters, their various sizes and their East-West dissymmetry.

Fig.13: 1999 eruption: New range of volcanic cones

Fig.14: 1999 eruption : Dissymetric distribution of lapilli and ash, due to the E-NE Wind action on the vortex of projections

Fig. 14 presents a view of the western zone of the eruption site, the windward side of the eruptive fissure. At the background, the most important cone of the new range can be seen. In the mid-ground, the tephra zone (field covered with ash and lapilli) is very developed here, due to the strong winds blowing essentially from the opposite side (ENE). In the completely covered zone, the thickness is above 60cm, but it decreases progressively as you move away from the site.

As usual, these ENE-WSW winds were constant throughout the eruption period, thus subjecting a large area of the SW flank of the mountain to abundant and more or less hot rain of ashes and lapilli, and a sustained bath of magmatic gases. This resulted in the destruction of tens of hectares of forest.

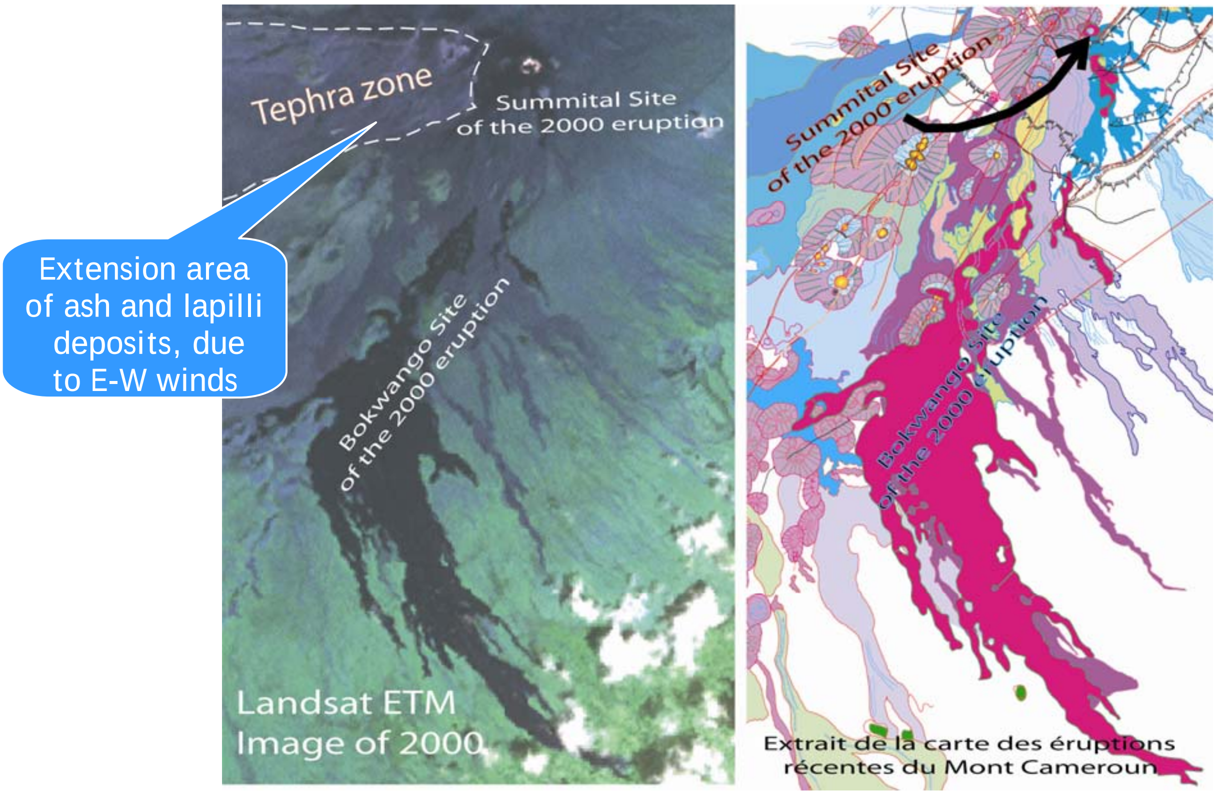


Fig.15: Map of the 2000 eruption from Landsat imagery

SEISMIC AND TECTONIC ACTIVITIES AND IMPACTS

Volcanic eruptions are generally preceded by more or less significant seismic and eventually tectonic manifestations.

The seismic activity

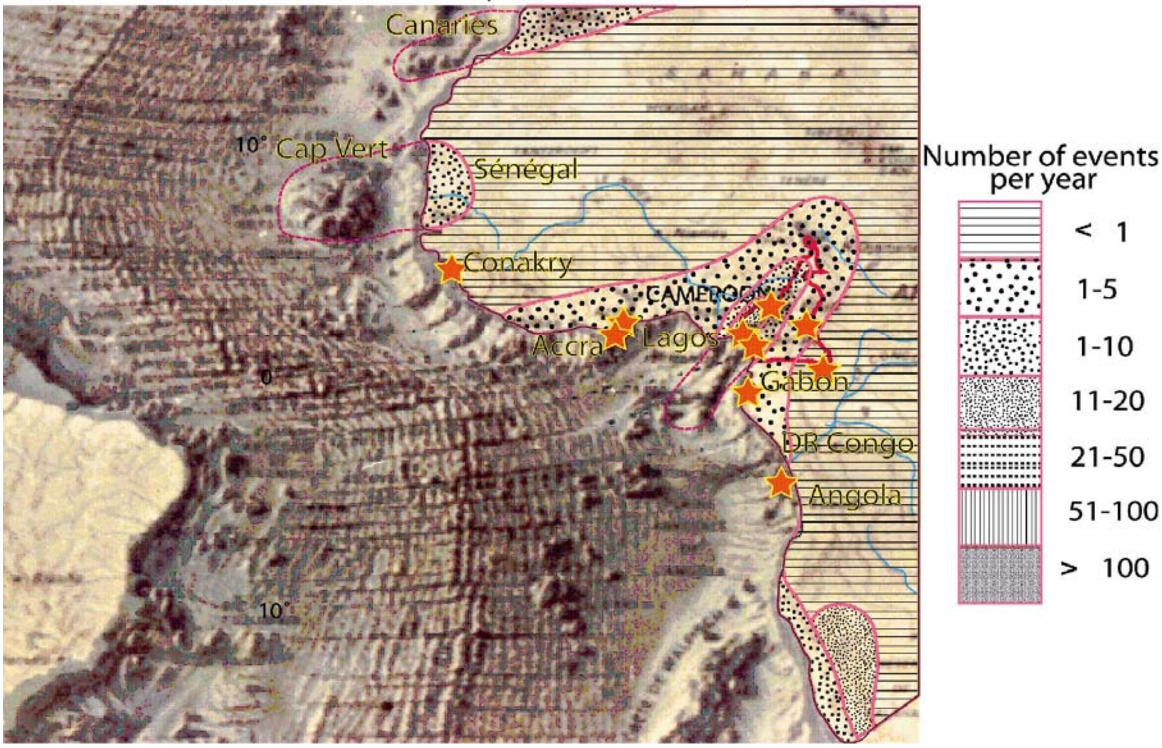
*In an earth-qua*ke distribution map of Africa, KRENKEL, in 1921, indicates a large zone along the continental margin of the Gulf of Guinea as being seismically active, with 1 to 5 manifestations per year. The Cameroon Line, with an elbow which extends deeply up to Lake Chad, is underlined as having the highest frequency: 5 to 10 events per year.

Extensive studies on the sites are more revealing and show that, every week, Cameroon experiences an average of 2 to 3 seismic events. The chocks are, in fact, generally weak, sometimes very weak to be perceptible by even the most informed and keenest observers. However, catastrophic seismic events are not uncommon.

In fact, a retrospective study of this phenomenon shows that, since the middle of the 19th century, many potentially catastrophic earthquakes have been registered, related or not to volcanic activity. As far as Mount Cameroon is concerned, the main seismic events are those of 1868, April 1909, February and November 1922, December 1946, January 1947, July 1990 and March 1999. These can be divided in two main categories:

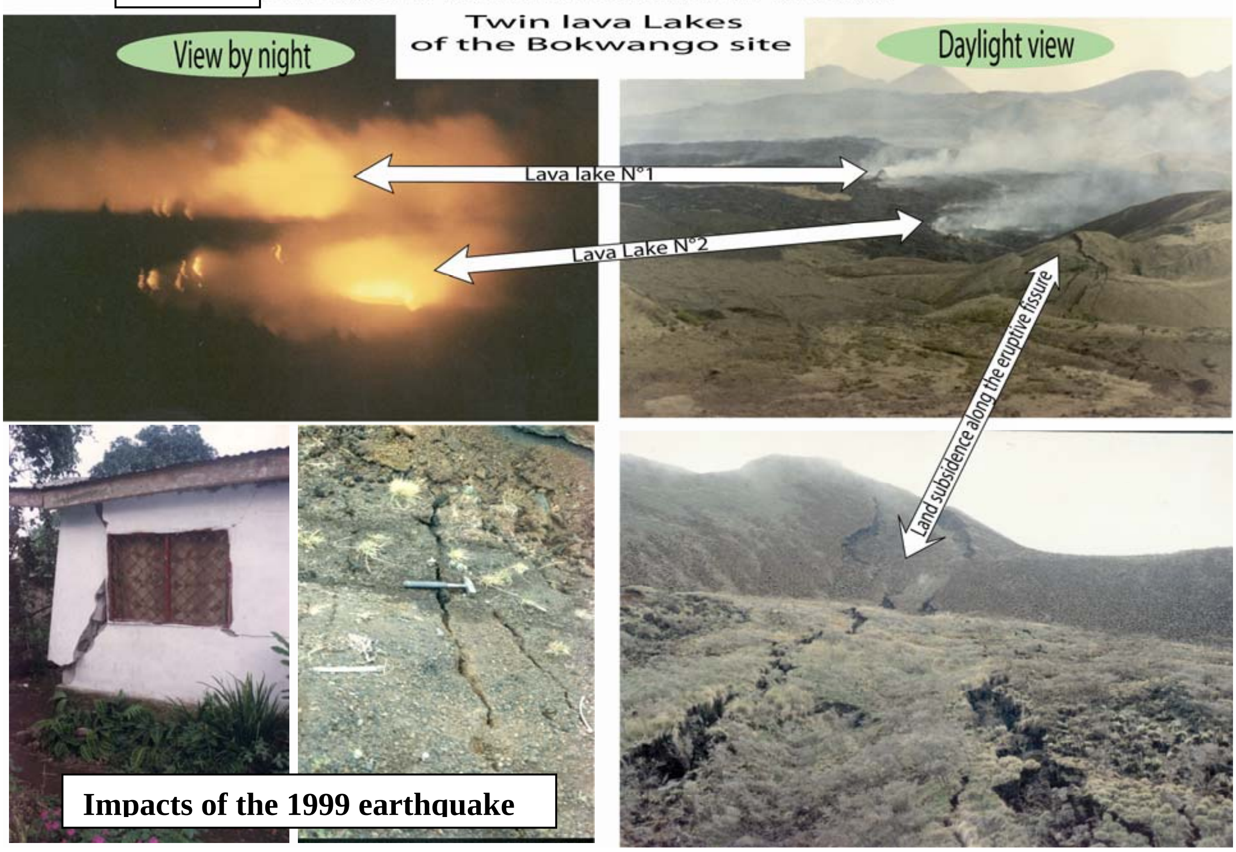
- Those related to the volcanic activity such as in 1815, 1835, 1838-39, 1865-66, 1868, 1909, 1922, 1954, 1959, 1982, 1999 and 2000.
- Those which occur independently from any volcanic eruption and which are mostly related to tectonic movements such as those of 1885, 1905, 1906, 1907 and 1908, of November 1922, 1946, 1947, 1948, that of 1975, 1977, 1986, 1989 and1990 etc.

Fig. 16 MEAN ANNUAL FREQUENCY OF SEISMIC ACTIVITY IN THE GULF OF GUINEA
(Adapted from KRENKEL 1921)



Although it was not the most powerful earthquake registered in Cameroon, the March 1999 event appeared to be the one that has, up to now, caused the most significant damage to material property, notably to houses. Numerous edifices laterally split up along the angles and, in some other cases, entire walls collapsed. It is a miracle that no casualties occurred.

Fig. 17 SOME PHASES OF THE 2000 ERUPTION OF MOUNT CAMEROON



Seismic activity is a good indicator of the ground instability. It thus accompanies tectonic movements. Fig. 17 shows a SW-NE partial view of the fissure which linked the 2000 two eruptive sites. This represents a surface view of the vertical projection of the underground channel of the magma and covers a distance of 3 to 4 km. The horizontal and vertical movements caused openings of 1 to more than 2 metres wide and of up to 10 metres deep in some areas, especially on the volcanic cones.

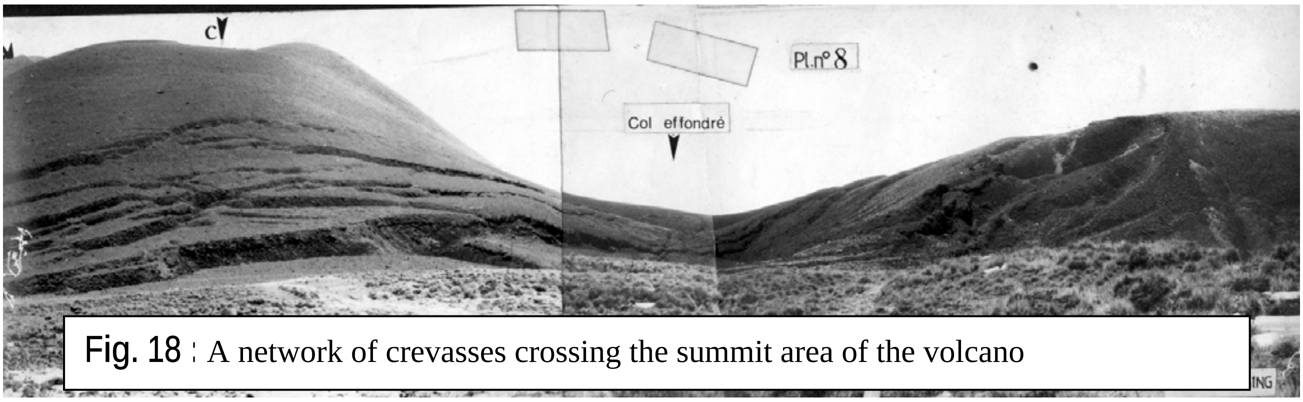


Fig. 18 : A network of crevasses crossing the summit area of the volcano

Fig. 20 : Hut 3 steps faults system

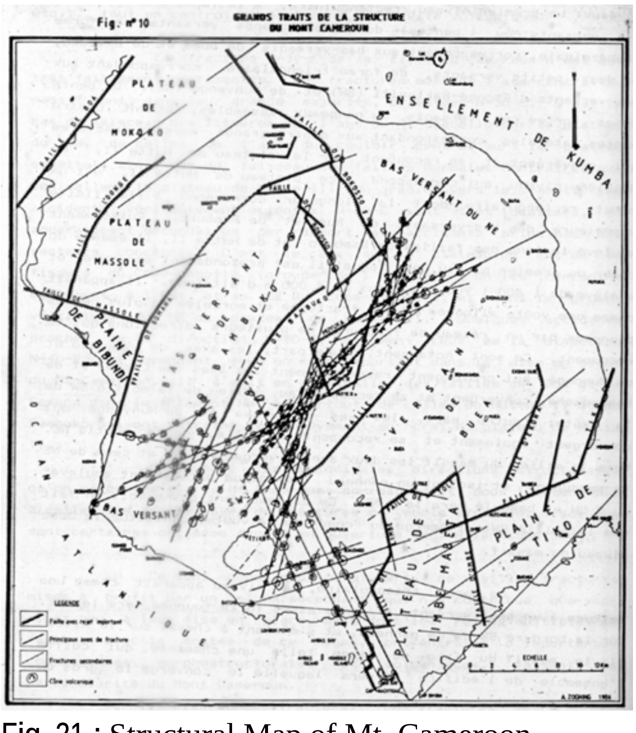


Fig. 21 : Structural Map of Mt. Cameroon

Regional tectonic activity

Unless most of the tectonic movements registered here are local, due to volcanic activity, there are evidences of regional tectonic activity. This is the case of the Bokosso steps faults system which appears clearly as the extension the Gulf of Guinea coastal fault system.

II- APPLICATION OF INTERFEROMETRY TECHNIQUES

The objective of this paper is to contribute to the assessment and characterization of eruptive dynamism of the last two eruptions (1999 and 2000). This will be done through the estimation of the volume and extension of the different types of products emitted (projections of volcanic ashes, surface covered by lavas, forest grilled by ashes) as well as evaluating the impact of seismic and tectonic activities on the landscape.

Synthetic aperture radar interferometry appears today as a very powerful tool for the measurement of land modification (motion, subsidence, lava flow …). To evaluate the impact of the last two Mount Cameroon eruptions, two complementary approaches were adopted:

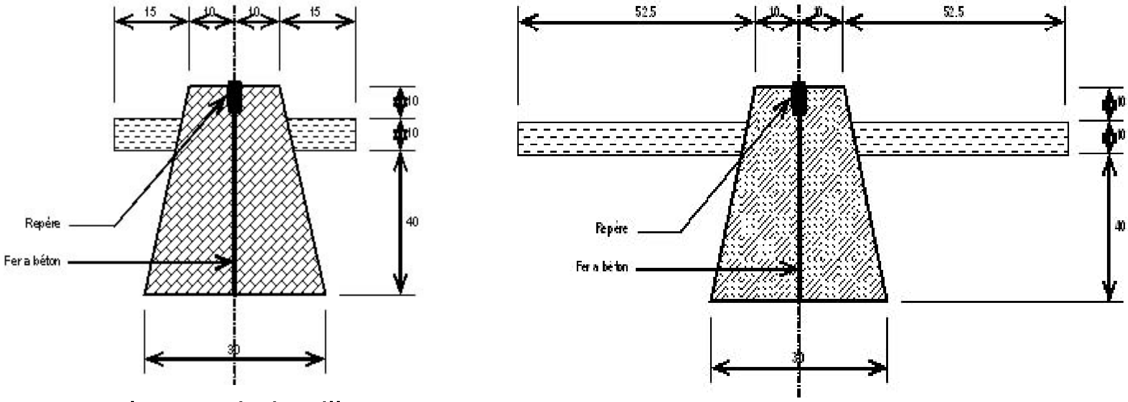
- The field observations and measurements and,
- The SAR interferometry processing.

THE FIELD OBSERVATION AND MEASUREMENTS,

A network of geodetic pillars was implanted around the massif, in order to carry out field measurement in case of any land movement. Two main types of pillars were built:

– The geodetic pillars with reflectors which can be captured by high precision sensors like that of PRISM and therefore, help for precise geo-referencing of images and,
– The regular geodetic pillars which will be used for field measurements.

Fig. 22 : Geodetic pillars



Regular geodetic pillar

Geodetic pillar with reflector

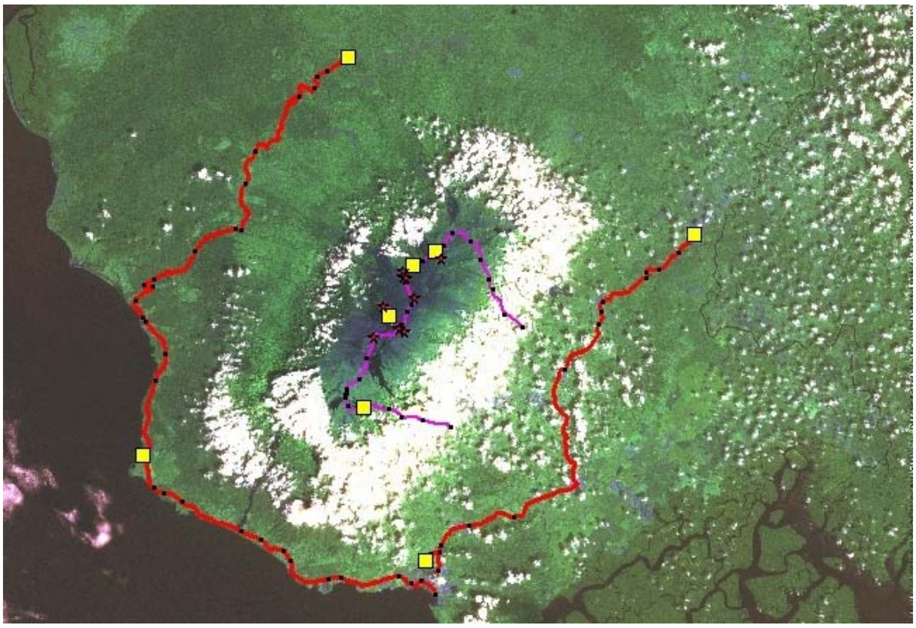


Fig. 23 : **Network of geodetic pillars**

IMAGE PROCESSING: INTERFEROMETRY TECHNIQUE

Two sets of radar single look complex images were selected, one in 1996 (before the 1999 and 2000 eruptions) and the other in 2003 (after the eruptions)

- Couple of ERS1&2 acquired during the Tandem mission with 24 hours separation (April 1996)
- One ERS2 scene (March 2003)

The baseline between the two satellites is 122 m, first indicator of good interferometry predisposition. Due to the environmental changes between the two acquisitions, coherence is very low in vegetation areas. This affects seriously the quality of the interferogram and consequently the DEM quality in that area.

Fig. 24 : Image processing approach

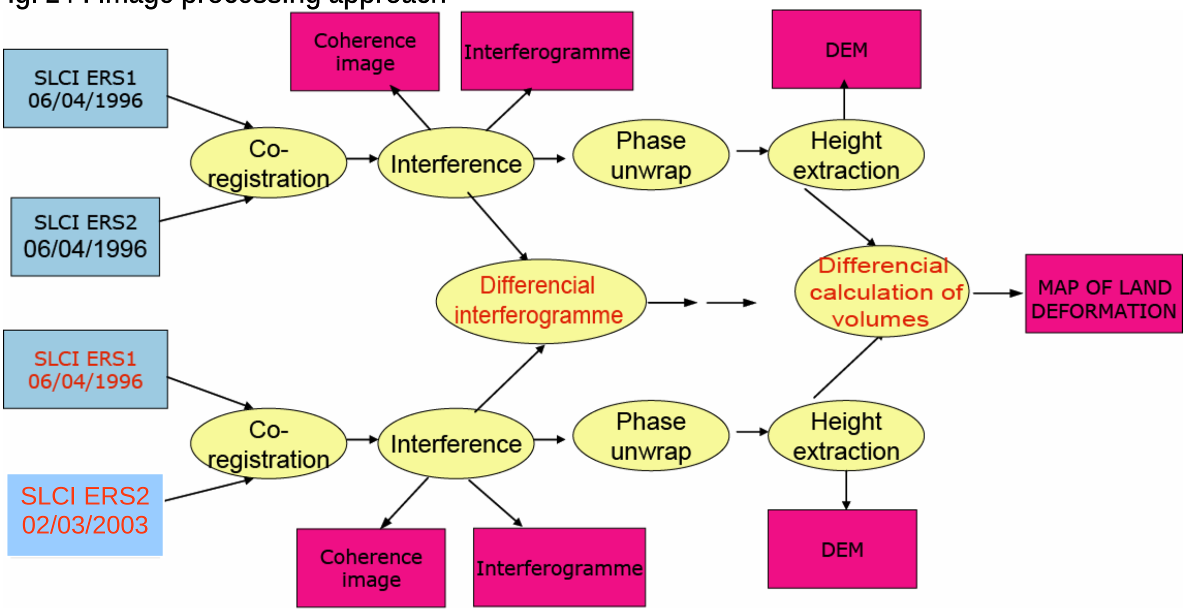
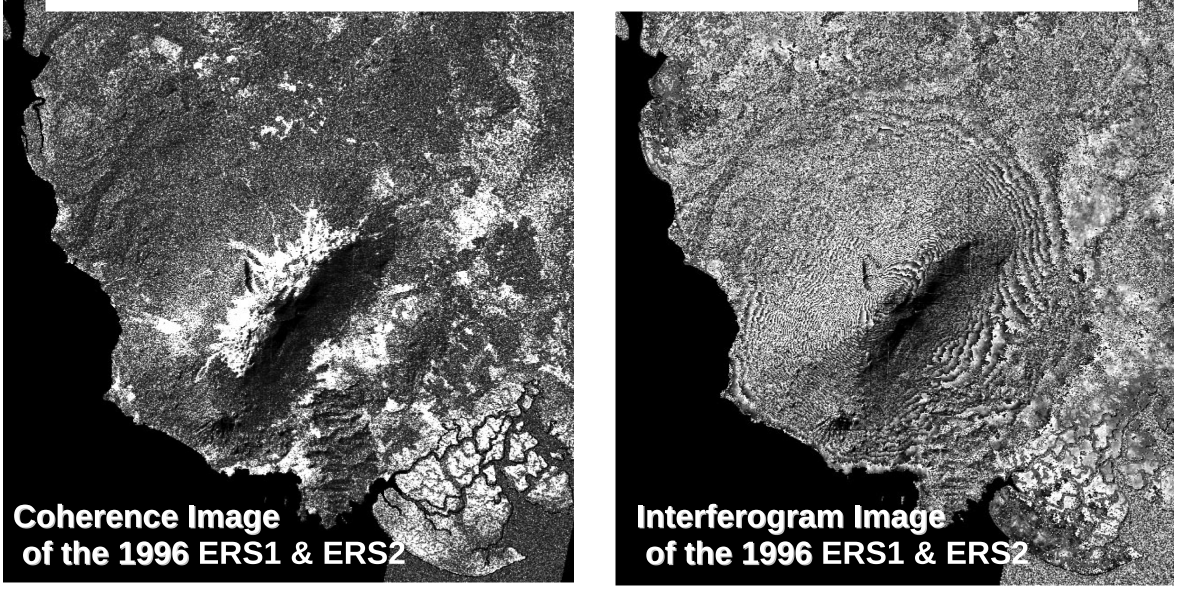
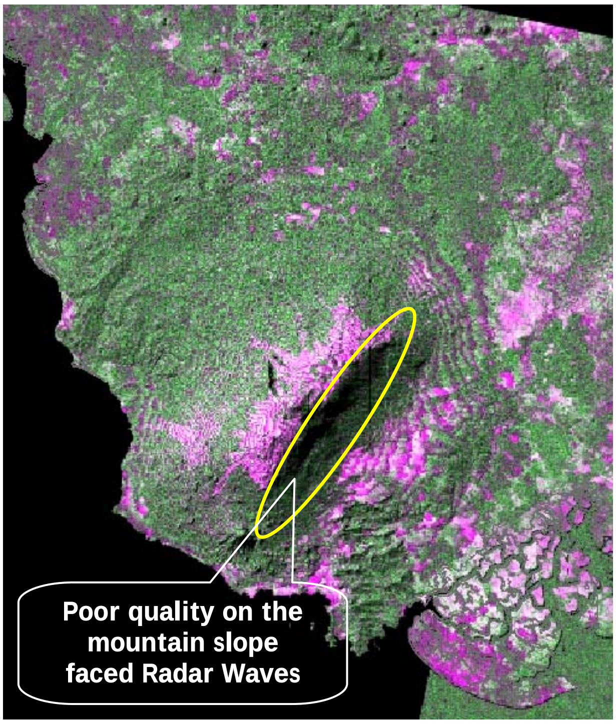


Fig. 25 : Coherence and Interferogram **of the 1996 ERS1 & ERS2**



Another factor which had negative effects on the coherence is the incidence angle of the radar waves. The upper mountain slopes, faced to the radar (western part of the mountain) have a very bright response. Pixels in that area are characterized by high backscattering value and low variation.

Fig. 26 : Analysis of the Coherence and interferogram images



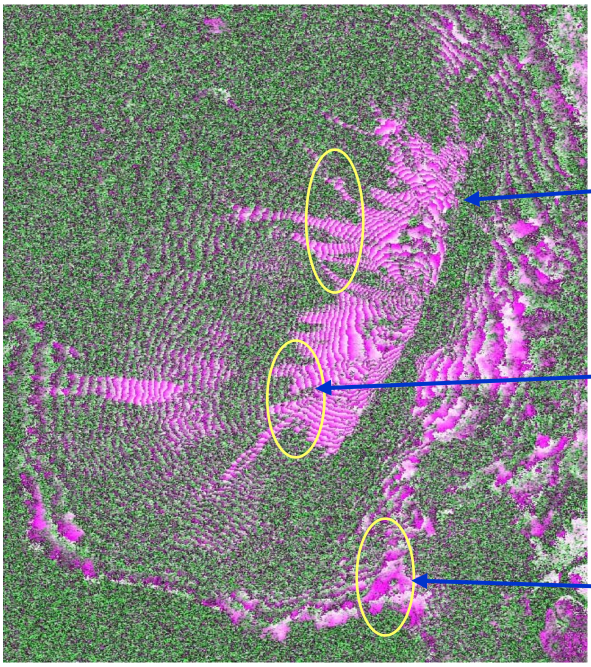
The first couple has good quality at:

- The summit of the Mountain (on lava),
- In main cities (built-up areas)
- and Surroundings (bare soils

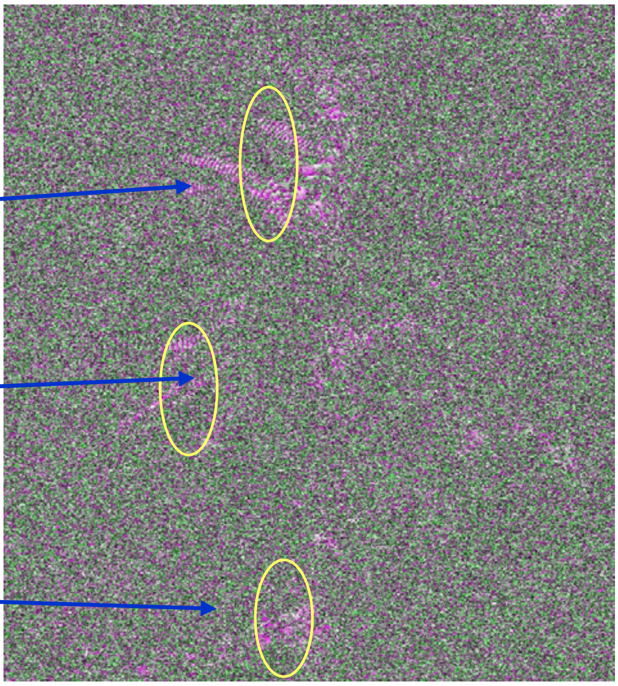
The exercise became more difficult when we try to build on interferogram with images acquired seven years one after the other (1996 and 2003). During this period, many changes occurred on the landscape, including the effects of the 1999 and 2000 eruptions. This may explain why the differential interferometry is just possible in some selected sites (built-up areas, bare soils and volcanic outcrops etc.).

Fig. 27 : Interferogram and coherence for Differential interferometry

Couple - ERS1 06 April 1996
- ERS2 07 April 1996



Couple - ERS1 06 April 1996
- ERS2 02 March 2003



To come out with a solution to this problem it's important to built two separated interferograms one with a pair of images acquired before the 1999 and 2000 eruptions and the other one with images acquired after.

CONCLUSION AND PERSPECTIVE

During the implementation phase, we were faced with many difficulties:

- Low coherence between the ERS1&2 acquisitions of 1996 in forest areas
- Low coherence in steep slope areas, faced to radar waves
- General low coherence between ERS1_1996 and ERS2_2003

That is why it is quite impossible to evaluate the volume of lavas and deformation caused by the 1999 and 2000 eruptions

In perspective, we intend to:

- Order interferometric other ERS1&2 couple with West-East looking direction in order to complete the 1996 DEM;
- Order Envisat couple of 35 days repeat or a joint Alos Palsar and Envisat Asar acquisition to evaluate the volume of lavas accumulated and land deformation resulting from the 1999 and 2000 eruptions;
- Identify and locate precisely some ground control points on the 1996 and newly acquired radar images;
- Order ALOS PRISM and AVNIR-2 data for precise view and positioning.

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