Remote Sensing contribution on seismotectonic hazard in a volcanic active area (Nevado Sabancaya, southern Peru)

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Resumen

Utilizando imágenes SPOT de 1990, una red de fracturas recientes NE-SW fueron detectadas entre el cráter activo del Sabancaya y el valle del Colca, a lo largo del valle de Sepina. Dos terremotos con carácter destructor, ocurrieron el 23-07-1991 y el 01-02-1992, con epicentros localizados en el área de Sepina, estarían relacionados a dichas fracturas. Un nuevo escenario de amenaza sismotectónica se delinea en el valle de Sepina, cerca del volcán Sabancaya.

Key words: Remote sensing, Spot images, seismotectonic hazard, Sabancaya volcano,Andes south Peru

Introduction

The Nevado Sabancaya Volcano (NSV) is located near the Colca Valley in the department of Arequipa (Fig. 1). After 200 years of repose, this unknown volcano began an intense fumarolic emission in november 1986. Then, a very abrupt phreatomagmatic eruptive phase started on 28 may 1990 and is still continuing with increasing intensity.We have used two methods to monitor the volcanic eruptive process:

- SPOT imagery allowed us to compare different features before and after the eruption — the modifications of the snow cap, changes in the morphological features of the crater, and the occurence of open fractures —;[1, 2 and,3]
- the measurement of the seismic and tremor activities around the volcano.

The Sepina Valley which is a tributary of the Colca Valley is the most important seismotectonic zone in the area.In this zone the fracture network can be observed clearly and the hyposeismic activity can be recorded. Indeed, two relativety destructive earthquakes occured in this valley on 23 july 1991 and 01 february 1992.

Both methods together constitute a major new tool for identifying hazard zones as demonstrated in the Sepina area example which is described in the following sections.

The aim of this study is to develop a methodology using satellite images, field observation and seismological data.in the study of geological hazards It is a project borne out of the scientific cooperation between the Institut of Geophysics, Peru and the Department of Geotectonics, UPMC-France.

Local geologic setting

Spot images analysis enables detailed geological mapping (1/50 000) which clearly highlight lithological and tectonic features; in particular faults and fractures [4 and 6].

Approximatly 80% of the area studied is covered by Mio-Plio-Quaternary volcanic formations which are in angular unconformity on a deformed Mesozoic sedimentary substratum. This volcanism is

characterised by an enormous volume of ignimbrite, andesitic and dacitic lava streams. During the Quaternary stage the andesitic volcanism predominates; it is accumulated in the valley floor and the high plateau (+ 4500 m.). On this plateau there are several volcanic edifices with various sizes and forms.

The Ampato-Sabancaya-Hualcahualca volcanic complex constitutes a main morpho-structural feature in this area by its height (6000 m.).and by the associated natural hazard. Within this complex, the NSV is a recent edifice built by at least 11 efusive stages of lava rocks. The composition of the lava ranges from andesite to dacite which contain 61-63 % of Si O_2. Morphological analysis of streams on SPOT images and from field observations show that the volcano would belong to the Holocene age. In 1750-1784, spanish chronicles served as witnesses to an eruptive activity possibly similar to the ones observed nowadays (vulcanian explosions).

Recent observations indicate that the eruptive activity of the NSV is evolving dangerously; indeed samples from the december 1992 explosion clearly show a high abondance of juvenile products (fresh magma) as compared to the amount collected in october 1990, (comm. J.C.THOURET).

There are numerous fault alignements detected on the images, some of them are obvious, while others are more discrete. One can distinguish 4 directional groups:

- NW-SE, is poorly represented but belongs to the big regional structures;
- E-W, the most visible, is abondant in the Colca Valley, and shows.downthrows in the south compartment;
- N-S, small and discrete;
- NE-SW, thin and faintly visible. They are mainly localised in the Sepina area where the seismic activity is actually registered. This group defines an important tectonic system : the Sepina Tectonic Faults, STF.

SPOT image after eruption

Seven SPOT images of the NSV have been acquired, — two before the start of the eruption (28 may 1990) and five successive scenes later —, in order to monitor the volcanic process and its consequences on the environment. Volcanic hazards maps were established using SPOT data, Digital Terrain Model and field observations [4 and 5].

- Images acquired in july 1990 (1 scene every week for 3 weeks) showed ash falls covering a 60 x 35 km^2. area. Also the icecap was partially melted by the tephras and new fractures appeared. Two small groups of fractures E-W and NE-SW have been clearly located close to the crater.
- Images acquired in september and december 1990 indicate a continuing evolution of the NE-SW fractures which are aligned along the Sepina Valley (on the STF). That of december shows that the summit of the NSV is bordered by semicircular structures on the outer rim of the crater, an observation that would indicate a possible widening of the latter. After the Sepina earthquake of the 01 february 1992 an observation from an aircraft confirmed that the crater had become wider (an increase of 100 m approximately) after a couldron subsidence.

Seismicity activity

Seismic monitoring started in july 1990, one month after the beginning of the eruption of the NSV. Four portable stations were installed at distances of between 10 and 20 km. around the volcano. There were difficulties during data collection because of geographical contraints and technical problems. However, nearly 9000 microseisms were recorded in the Cajamarcana station (from the end july 1990 to march 1992) and, 131 seismic hypocenters were calculated. The seismic activity is superficial (1 to 9 km. deep) and is concentrated between in a zone 5 and 20 km. NE the volcano in the Sepina area.

The eruptive process of the NSV was accompagnied by numerous seismic crisis which are still going on with increasing intensity.

- On 23 july 1991, at 2:45 p.m. local time, a superficial seism (Mb=5.1; depth= 4 km) was felt 7 km south of Maca. Shaking, landslides and numerous fractures NS and NNE-SSW were observed in the Colca Valley. 80 % of Maca and Lari villages were destroyed and 14 people were killed. The worst surface damages are probably the consequence of the rock formation (sandy clays, laminated shales and, alluvial fans interstratified containing saturation levels that could have amplify the seismic waves) and the unstable nature of the houses too.

- The first february 1992, at noon, another seism with the same characteristics (M=4.5) occured in the rural Sepina area. This earthquake was accompagned with 300 aftershocks recorded the same day by the Cajamarcana station. On day 3rd and 5th of february, other strong aftershocks led to strong damages in the Sepina area. In poorly poblated areas, open fractures NE-SW and NNW-SSE several meters long were observed and boulders were displaced. The landslide failures were formed at the downstream part of the Sepina Valley.

New scenery of the volcanic hazard (Fig. 1)

Is the Sepina Valley a highly geologic hazard area?

Beside the hazards directly associated with the eruptive process of the NSV in the Colca region, the Sepina area appears as a highly unstable geodynamic zone as shown by recent tectonic features and seismics events.

Indeed, the location of the epicenters of the two destructive earthquakes (23 july 1991 and 01 february 1992) on each side of the STF is an evidence of a probable tectonic stress accumulation throughout this structure.

Therefore we can consider that the STF is a high seismotectonic hazard zone centered in Sepina area.

Conclusion

This study clearly demonstrates that the combination of SPOT images and seismical data constitute a valuable tool to monitor the seismotectonic hazards.

In the study area, the Sepina Valley, we have identified a high hazard zone connected to the STF. In case of a high magnitude earthquake inside this structure, we predict severe consequences on the STF itself and also whit in the active volcano area or in the lanslides zone located in the Colca and Sepina valleys.

Therefore the 30,000 inhabitants of the Colca Valley are particulary exposed to a these natural phenomena.

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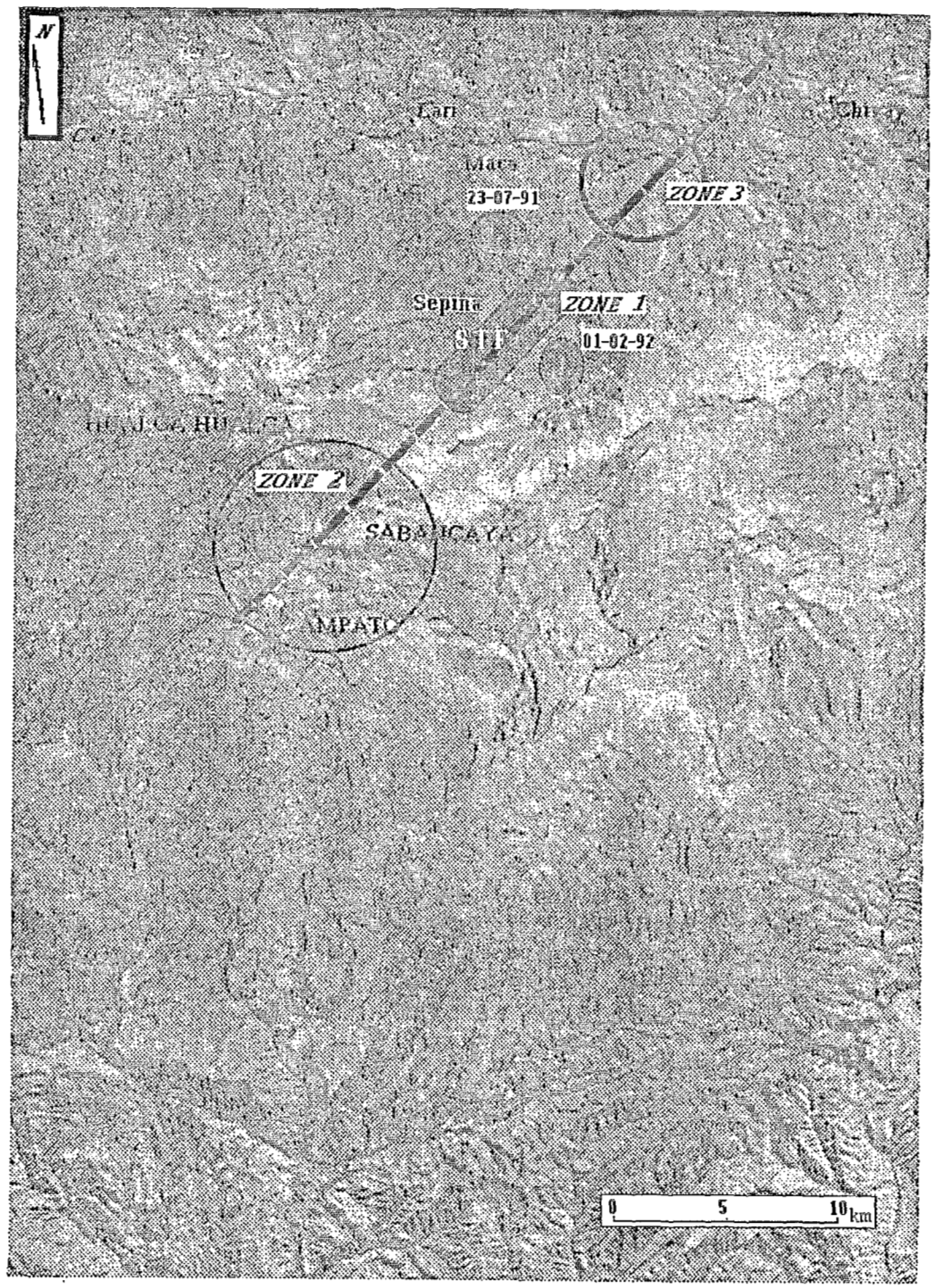

Fig. 1 Sketch of the seismotectonic hazard based on SPOT image.

The STF (zone 1) is a highly unstable geodynamical structure. Both severe earthquakes of 23 july 1991 and 01 february 1992 clearly suggest that a strong seismic event may occur soon along the STF. The 2 and 3 zones could be affected.