ANNALI DI GEOFISICA, VOL. XXXIX, N. 2, March 1996

Geophysical monitoring of the Purace volcano, Colombia

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Abstract
Located in the extreme northwestern part of the Los Coconucos volcanic chain in the Central Cordillera, the Purace is one of Colombia's most active volcanoes. Recent geological studies indicate an eruptive history of mainly explosive behavior which was marked most recently by a minor ash eruption in 1977. Techniques used to forecast the renewal of activity of volcanoes after a long period of quiescence include the monitoring of seismicity and ground deformation near the volcano. As a first approach toward the monitoring of the Purace volcano, Southwest Seismological Observatory (OSSO), located in the city of Cali, set up one seismic station in 1986. Beginning in June 1991, the seismic signals have also been transmitted to the Colombian Geological Survey (INGEOMINAS) at the Volcanological and Seismological Observatory (OVS-UOP), located in the city of Popayan. Two more seismic stations were installed early in 1994 forming a minimum seismic network and a geodetic monitoring program for ground deformation studies was established and conducted by INGEOMINAS.

Key words *Colombia – Purace volcano – volcanic monitoring*

1. Introduction

The Purace (2.37°N, 76.38°W) is an active stratovolcano which rises 4650 m approximately 30 km southeast of the city of Popayan, Cauca department, in the Central Cordillera of Colombia. It is the northernmost volcano of Los Coconucos volcanic chain (fig. 1). An estimated two hundred thousand people live within 35 km of the crater rim (Dane, 1988). After the 1985 eruption of the Ruiz volcano, the Colombian government funded a national scientific program in order to study and to survey the active volcanoes in the country. The historical activity and geological investigation of the Purace volcano combined with the density of the population within its sphere of influence led to the decision by INGEOMINAS to establish the Volcanological and Seismological Observatory (OVS-UOP) in the city of Popayan. Along with the monitoring of the Purace volcano, this observatory monitors all the active volcanoes in the region including the rest of the Los Coconucos volcanic chain, the Nevado del Huila volcano and the Sotara volcanic complex. Research on the Purace volcano started in 1986 with a complete geological study including petrologic, stratigraphic and structural mapping along with basic surveillance, consisting of visual observations of the crater and temperature checking in fumaroles and hot springs which led to the decision to install the first seismic station on the Purace to be recorded at the OSSO in the city of Cali. This paper will detail the development of the geophysical monitoring network as implemented by INGEOMINAS at its OVS-UOP branch since 1991.

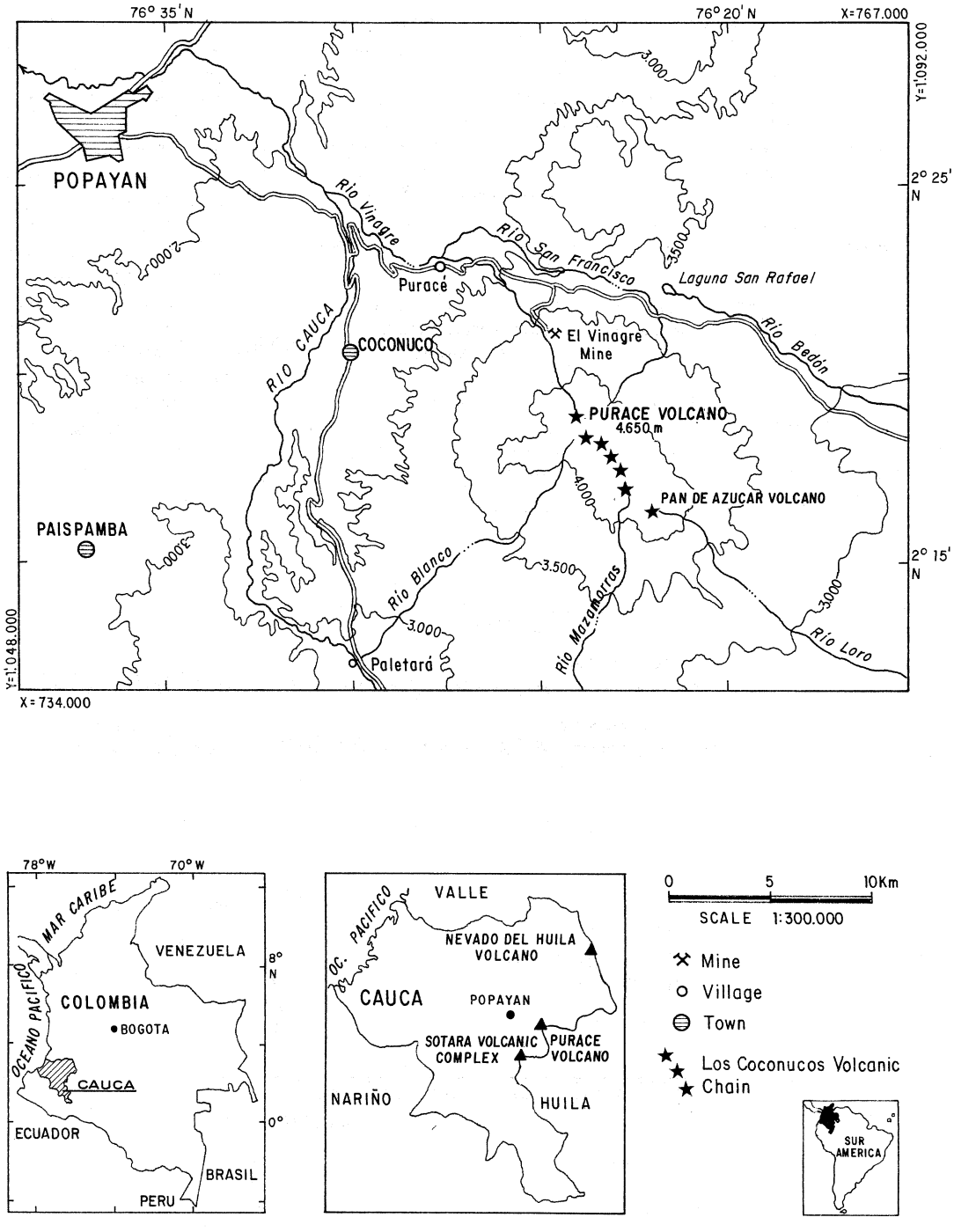


Fig. 1. Location of Purace volcano.

2. Geological setting and historical record of eruptions

The Los Coconucos volcanic chain consists of 15 recently eruptive aligned centers that are oriented N40°W. This differs from the N25°E orientation for the Central Cordillera (Monsalve and Pulgarín, personal communication, 1992). Structural studies of the area detected the existence of two main fault systems. One, name Coconucos, has a NW strike similar to the orientation of the Los Coconucos volcanic chain while the other, Moras, has a NE strike and crosses the base of the Purace edifice. The Nevado del Huila volcano is also located within this NE striking fault system. These faults appear to be active as the June 6, 1994 Paez earthquake (M_s = 6.4) is thought to be associated with them (Monsalve and Arcila, personal communication, 1994). Purace volcano is a truncated cone consisting of Tertiary-Quaternary age, intermediate to acidic volcanic rocks. The recent edifice is composed of intercalated lavas and pyroclastic debris of andesitic composition and the basement rocks are Cretaceous basic volcanic (Kuroda and Paris, 1978). Historical activity has been recorded since the sixteenth century and best documented since 1816. Field observation reveals a history of at least 15 eruptive periods lasting 4 to 8 years, separated by periods of calm lasting 5 to 20 years (table I) prior to 1977. Given the eruptive history of the Purace, it is recognized as one of the most active volcanoes in Colombia having a mostly explosive character with a historical record of pyroclastic flows (1849, 1869 and 1949) and pyroclastic falls in the form of ash rain in areas far from the city of Popayan (Pulgarín *et al.*, 1994).

Table I. Historical eruptions and earthquakes of Purace volcano (modified from Pulgarín *et al.*, 1994).

Date	Observations
1977	Minor ash emissions
1946-1958	Explosions, ash emissions Dome explosion, pyroclastic flows generation, bombs, ash fall, 16 deaths (1949) Earthquakes (1946)
1936-1941	Ash emissions, atmospheric shock waves effects in Popayan Earthquake (1939)
1925-1927	Explosions, ash emissions
1919-1920	Ash emissions, atmospheric shock waves effects in Popayan
1914	Minor ash emission
1902-1907	Explosions, ash emissions Earthquake (1907)
1885	Explosion, earthquake
1878	Ash emissions
1869-1870	Explosions, lahars, pyroclastic flows, ash and earthquake
1849-1852	Dome explosion: the strongest known eruption of Purace (1849)
1827	Lahars produced, probably by pyroclastic flow
1816	Explosions and earthquake
1789	Ash emissions, fumarolic activity
1559-1560-1583	Reports on the frequent activity of the volcano

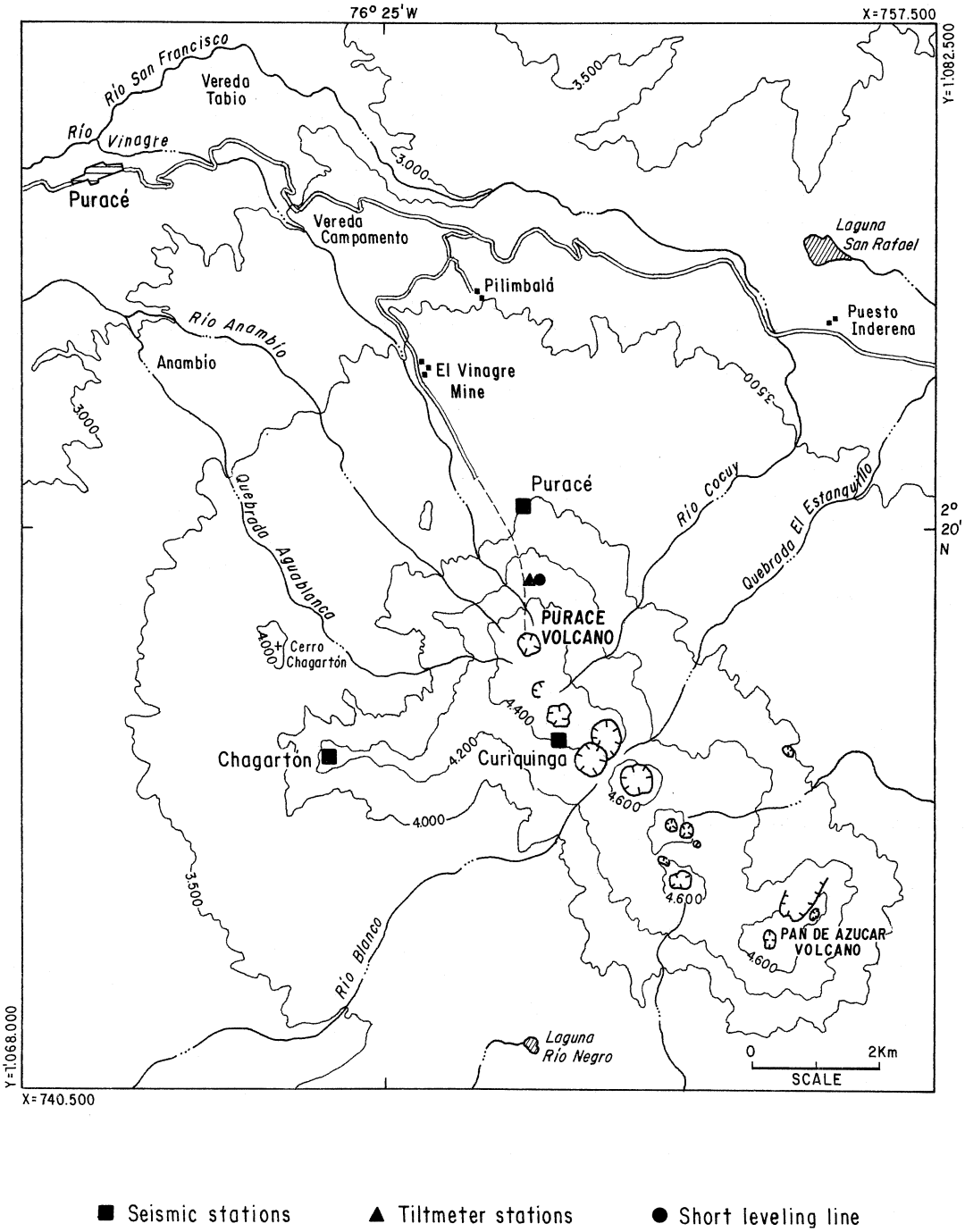


Fig. 2. Monitoring network at Purace volcano.

3. Volcanic monitoring

Worldwide, volcanic monitoring is done using some combination of geological, geophysical and geochemical techniques. A description of some of the techniques employed in Colombia by INGEOMINAS for monitoring the Purace volcano follows. It must be emphasized that some of these studies are at their initial stages.

3.1. *Seismic monitoring*

The permanent seismic monitoring network of the Purace volcano (fig. 2 and table II), consists of 3 short period seismic stations (1 component, 1 s). The analog seismic data are telemetered (real-time) to the OVS-UOP and recorded on smoked paper recorders. Additionally, since 1994, the data have been digitally recorded on computer using a data acquisition system developed by the International Association of Seismology and Physics of the Earth's Interior (IASPEI) for the PC's.

INGEOMINAS has adopted the volcanic seismic events classification used by most seismo-volcanic observatories, following the directions of the USGS in different training courses through the Cascades Volcanological Observatory (CVO). Although the seismic activity has been monitored almost continuously since 1991, the data from Purace are considered sparse and the released seismic energy calculation are made using the Mt. St. Helen's magnitude formula.

Seismicity at Purace is characterized by events related to magmatic fluid dynamics (Long-Period (LP) events) and to faulting processes (Volcano-Tectonic (VT) earthquakes, fig. 3). Mejia *et al.* (1993), report this activity as concentrated around the volcanic cone at depths between 10 and 20 km and interpreted it as the early phase of magma rise.

Processed information establishes a basic level of volcanic behavior as 5 events per day on average (fig. 4a) with 19 events as the maximum number recorded for any one day (May 26th, 1993). The maximum peaks of released energy (fig. 4b) correspond to VT-type events recorded in 1991 on July 7th (M_l 2,5) and October 31st (M_l 2,4), and the cumulative curve of the energy release shows a regular increasing trend without abrupt changes in slope (fig. 4c).

After the June 6th, 1994 Paez earthquake, Monsalve *et al.* (personal communication, 1994) observed minor changes in the seismic behavior of the Purace volcano compared to the seismic pattern previously detailed. The changes observed are as follows:

1) slow increase in the number of LP-type events;

2) record of modulated tremor;

3) appearance of «tornillo» (screw) type signals similar to those recorded at the Galeras volcano. (These signals were also seen in 1991)

Although seismicity at the Purace remains at low levels, there is some speculation that its pattern level could be altered by the reactivation of the faults which crosses at the base of the Purace edifice by the 1994 Paez earthquake. Historically, this volcano has exhibited destabilization after tectonic movements.

3.2. *Deformation*

In order to obtain information on the ground motion in the vicinity of the volcano, a dry-tilt-meter station and short spirit leveling line were built in June 1994 to complement the surveil-

Table II. Telemetric seismic stations of Purace volcano.

Station	Distance from crater (km)	Lat./Lon.	Altitude (m)
Purace	2.5	2°18.17'N/76°23.84'W	3975
Curiquinga	1.5	2°18.17'N/76°23.76'W	4400
Chagarton	4.0	2°18.03'N/76°25.59'W	4320

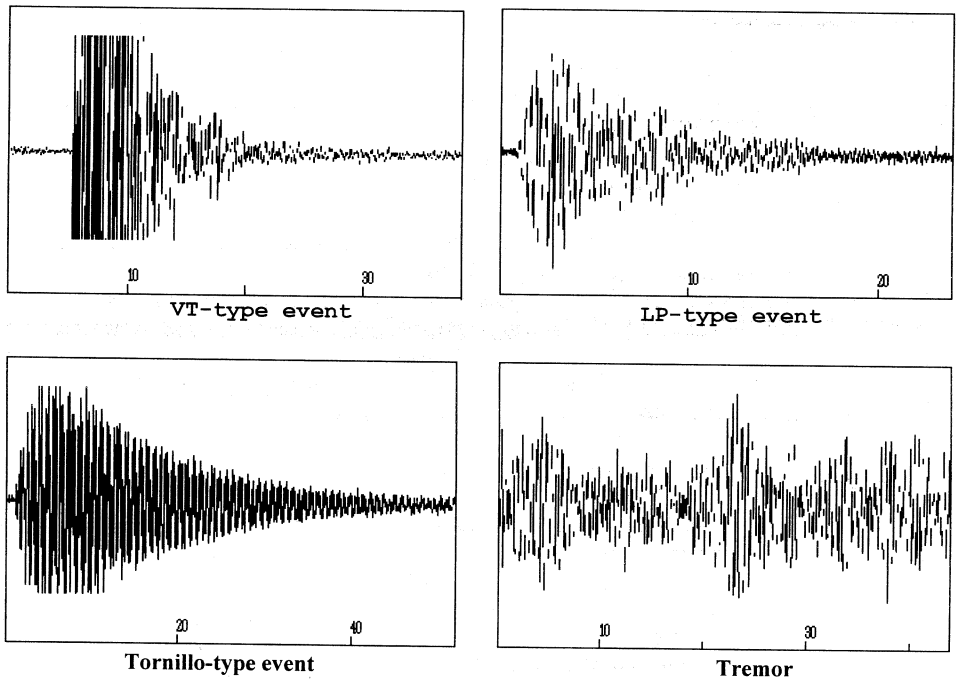


Fig. 3. Examples of digital seismograms of different type events recorded at Purace volcano. The time scale is in seconds, and the amplitude is not indicated.

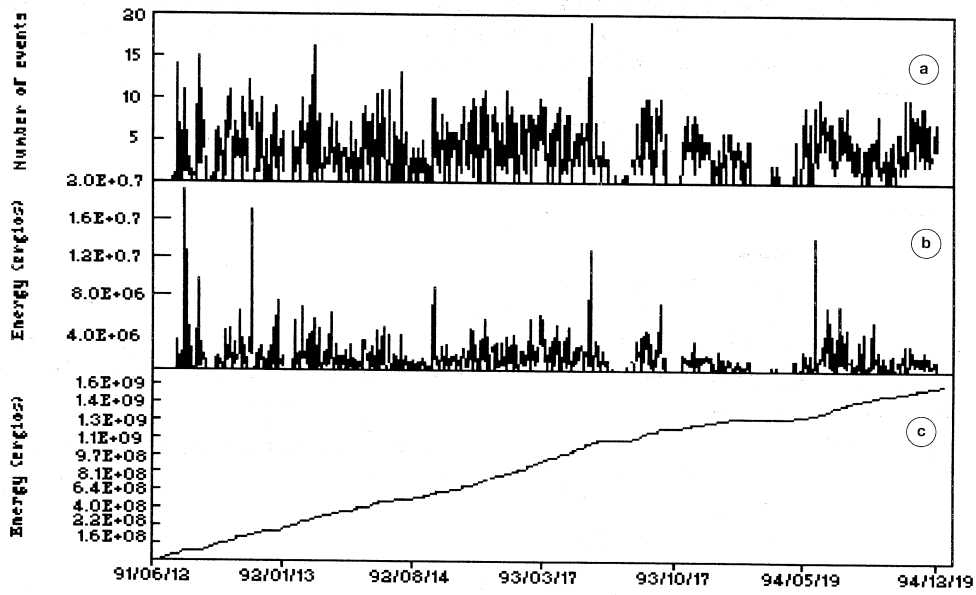
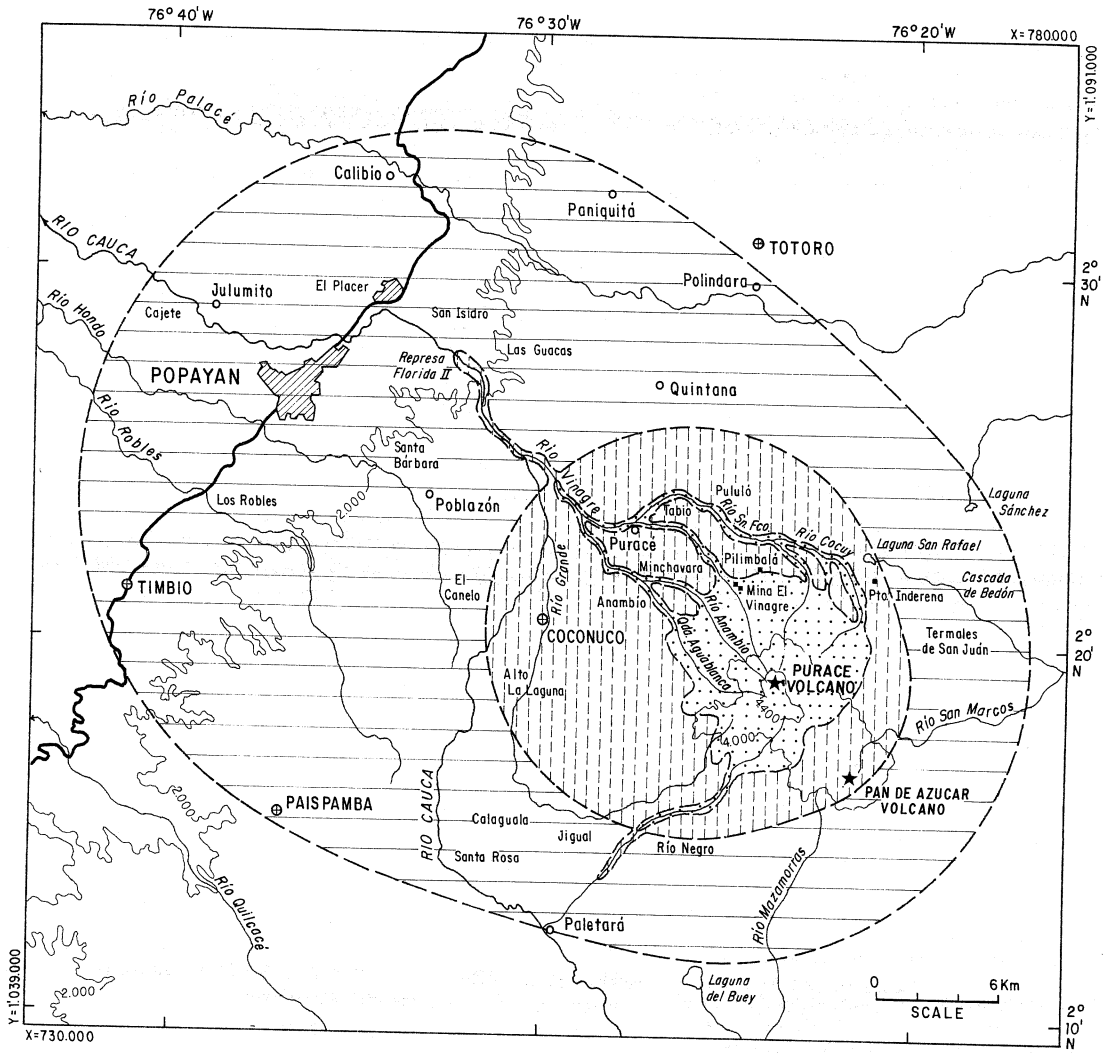


Fig. 4a-c. Recorded activity in the Purace volcano. a) Daily number of events; b) daily energy released and (c) released energy cumulative.



HAZARDS

HIGH: Lava flows, pyroclastic flows, mud flows, ash fall, volcanic gas accumulation, shock waves, volcanic seisms.

INTERMEDIATE: Pyroclastic flows, mud flows, ash fall, shock waves.

LOW: Floods on the Cauca River, ash fall, shock waves.

Fig. 5. Volcanic hazard map of Purace volcano (after Monsalve and Pulgarin, 1993).

lance work (fig. 2). Taking into account the historical eruptive behavior, both stations were located on the north flank of the volcano at a distance of 1.5 km from the crater rim.

3.3. *Other activities*

In addition to the activities recounted above, geochemical studies, including regular sampling of the gases and vapors escaping from fumaroles and the fluids in the hot springs associated with the Purace volcano, were begun in April 1994. Previous chemical analysis done by Martini (personal communication, 1992) of the University of Florence detected a magmatic component in the sampled volcanic fluids. Also, using all available data, Monsalve and Pulgarin (1993) prepared a preliminary volcanic hazard map outlining three main hazard zones (fig. 5).

4. Conclusions

Scientific monitoring of the Purace volcano was initiated due to the historical and geological record of its activity and the devastating effects that it could have a growing population of 200000 persons in the surrounding areas. Initial results of observations indicate a pattern of seismicity at an average level of 5 events per day with a recorded maximum of 19 events during one 24 h period. This seismicity is characterized by LP-type events and could be considered the basic seismic level for the Purace volcano. Recent tectonic events associated with faults that are intimately connected with the Purace and most of the Los Coconucos volcanic chain have evoked a changed response in the seismic pattern of the Purace which has exhibited a past pattern of destabilization after local tectonic activity.

Initial studies indicate that the Purace is still an active volcano responding to tectonic forces with a history of violent eruptive episodes. These results dictate a necessity not only to continue the present studies but also to complement them with different more sophisticated techniques such as GPS motion monitoring and gravity and magnetic surveys. Also, considering the fact that the Purace is only one of 15 eruptive centers in the Los Coconucos volcanic chain, it would be prudent to extend geologic and geophysical monitoring to the rest of this historically eruptive chain.

Acknowledgements

I would like to express my thanks to Maria Luisa Monsalve and Hector Mora (both at INGEOMINAS), for their reviews and comments, and also, to Robert Trenkamp (University of South Carolina) for his help in reviewing this paper.

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