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Mt Galeras: activities and lessons to be learned

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Galeras, a volcano in the south of Colombia, has historically been very active. Nevertheless, the memory of the tragic eruption of Nevado del Ruiz in 1985 caused great anxiety in the surrounding region as the first signs of reawakening were perceived in early 1989. Decision makers were unprepared as they tried to organize their communities. The media were obsessed with another potential tragedy, the community scared and disorientated. Banks, businesses and traders—seriously affected by the uncertainties of the situation—forced the regional and local authorities to ignore the volcano activity. The relationship between scientists, the authorities and the community suffered from inappropriate management of the situation. Seismic swarms that could be felt and eruptions that were observed in 1993 helped to focus the minds of all involved. Recently, the relative quietness of the volcano has allowed scientists, the authorities and the community to achieve remarkable results. Awareness of the hazards is now growing among the community. Policies need to be implemented while the volcano is dormant.

Keywords: Galeras; preparedness; prevention; volcanic crisis

1. Introduction

Mt Galeras volcano is located in the southwest part of Colombia. Pasto, a city with a population of *ca.* 350 000 people, is located at the foot of the volcano (figure 1). The active crater rises 1600 m above Pasto only 8 km from its central square. Galeras has long symbolized the city. Because Pasto was the required pass for the Spanish conquerors, there are numerous reports and accounts of the volcano and its eruptions. Pasto's citizens have always been proud of their volcano, and have seen its awe-inspiring eruptions as spectacular events of nature.

Until the catastrophic eruption of Nevado del Ruiz in 1985, the local population was not fully aware of the danger the volcano represented. The consequences of this eruption motivated them to question their future safety, fears for which were naturally heightened during the first signs of unrest at Galeras in 1989.

The Nevado del Ruiz tragedy motivated the Colombian government to establish the National System of Disaster Prevention and Preparedness (SNPAD) in 1988. The National Direction of the SNPAD was based in Bogotá. Regional and local committees were formed throughout the country, established by official and private institutions with responsibility for identifying hazards, evaluating risk and preparing plans for risk mitigation, disaster preparedness and land use. But, in early 1989, when Galeras showed the first clear signs of reactivation, very few of those committees had been established, and the emergency plans in Pasto and the surrounding

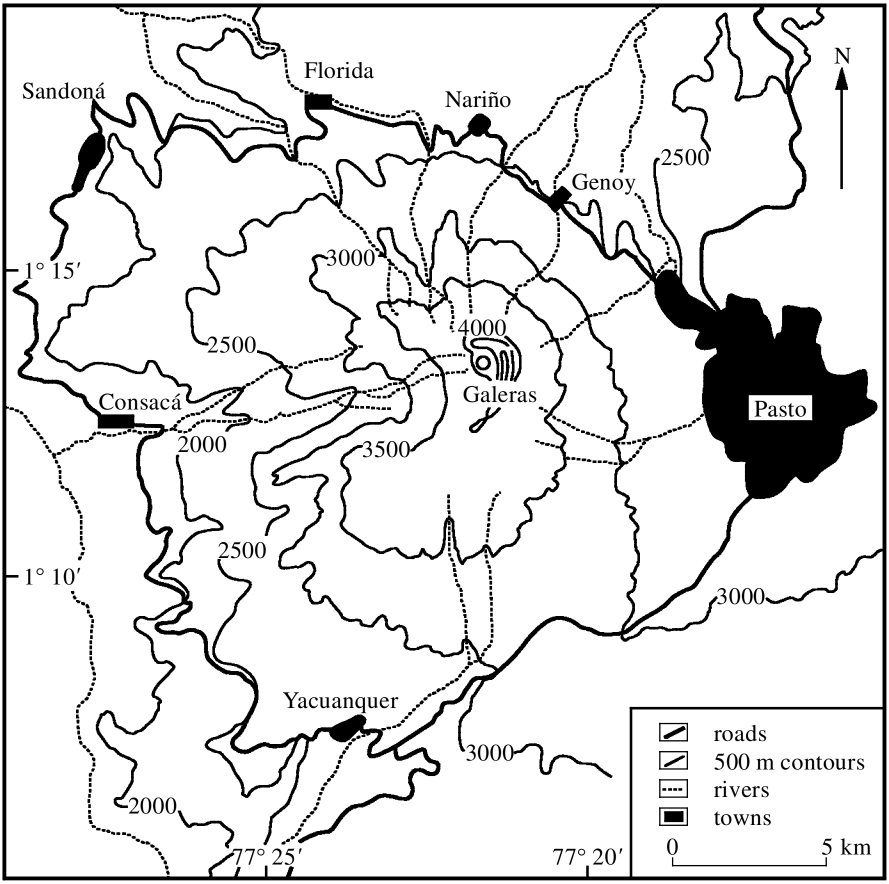

Figure 1. Map of the surrounding area of the Galeras volcano. There are several small towns and the city of Pasto within a 10 km radius.

region were incomplete. In 1989, there was no volcanic surveillance or hazard assessment of Galeras, and there was neither a mitigation nor an emergency preparedness plan. This situation had not only economic and political implications, but also social consequences, in the attitude that the population and the authorities adopted during the first months of the reactivation and in subsequent years. Anxiety and panic in early 1989 were replaced by disbelief and apathy as, in time, no large eruptions were observed.

I present the situation in Pasto before the eruption, which led to economic losses and social setbacks in disaster-prevention activities. I summarize a brief description of the events during the Galeras reactivation, including some volcanological aspects, as well as the reaction of the community, decision makers, government officials and scientists during the reactivation.

2. Galeras's past activity

We learn about Galeras's past activity by studying the deposits (geological method) and the written accounts of past eruptions (historical method). These methods give different kinds of information: broadly speaking, information provided by the geological method covers periods of time not covered by the historical records. In our country, the written history goes back *ca.* 500 years. Studying the deposits, we find first-hand information about periodicity, dynamic characteristics and the magnitude of the volcanic activity. The historical method provides reliable information of how eruptions affected the population of the surrounding region, although details of the eruption—for example, how strong were the noise of the eruption and the related seismic activity—depend very much on the individual writer, or, as happens in many cases, on the interpretation of 'second-hand' experience. Many small eruptions do not leave a distinguishable deposit and therefore can never be detected using geological methods. In this case, it is only through historical descriptions that we can estimate the behaviour of the volcano.

Galeras is the youngest of a sequence of several volcanoes (perhaps four or five) that have collapsed during caldera-forming explosions. According to Calvache Velasco (1990), the last caldera formation happened between 4500 and 10 000 years ago. The most recent activity at Galeras (less than 4500 years ago) included six major eruptions. Galeras is a strato-volcano, its activity characterized by andesitic lava flows, pyroclastic flows and fallout deposits. Most of the lava flows are located on the western flank of the volcano. The pyroclastic flow deposits could be found on the eastern, northern and western flanks. The most hazardous events by far are the occurrence of pyroclastic flows. Gravitational column and dome collapse are the most common origin of the pyroclastic flow deposits detected around the volcano. Although Galeras eruptions are small in size, compared with volcanoes like Pinatubo, pyroclastic flow deposits, carried by rivers of erupted material flowing from the summit, have been found at a distance of 9 km from the crater.

Galeras has been very active throughout its history. The last dormant period, from 1948 to 1988, was one of the four longest known in the last four centuries. Most of the descriptions of eruptions are very similar. Earthquakes and/or explosions were felt in Pasto and in towns in the surrounding region shortly before a dark column was seen to rise into the sky; occasionally, shock waves opened doors and windows, breaking glass. The height of the column varied from eruption to eruption, but, according to the eye-witness accounts, never reached tens of kilometres. However, ash fall from Galeras has been detected in Quito, Ecuador, more then 200 km south of the volcano. The eruption column usually carries large blocks that fall back into the crater and its surroundings. Sometimes, blocks of 50 cm in diameter were projected as far as 3 km from the vent. Incandescence and fires on top of the volcano are often reported during eruptions. They are related to the fall of glowing blocks or the occurrence of pyroclastic flows. On the morning of 27 August 1936 an eruption took place. Several photographs reveal partial column collapse on the northeastern side and a pyroclastic flow *ca.* 3–4 km long. This fact was not mentioned in the eruption reports. Many of the historic small eruptions may have been accompanied by pyroclastic flows, which may have been hidden by clouds at the moment of eruption. Nevertheless, in the historical records, fatalities were never reported.

3. Activity of Galeras volcano

Since April 1988, signs of increasing fumarolic activity were noticeable in the crater, but it was only in early 1989 that the activity within the crater could be detected by

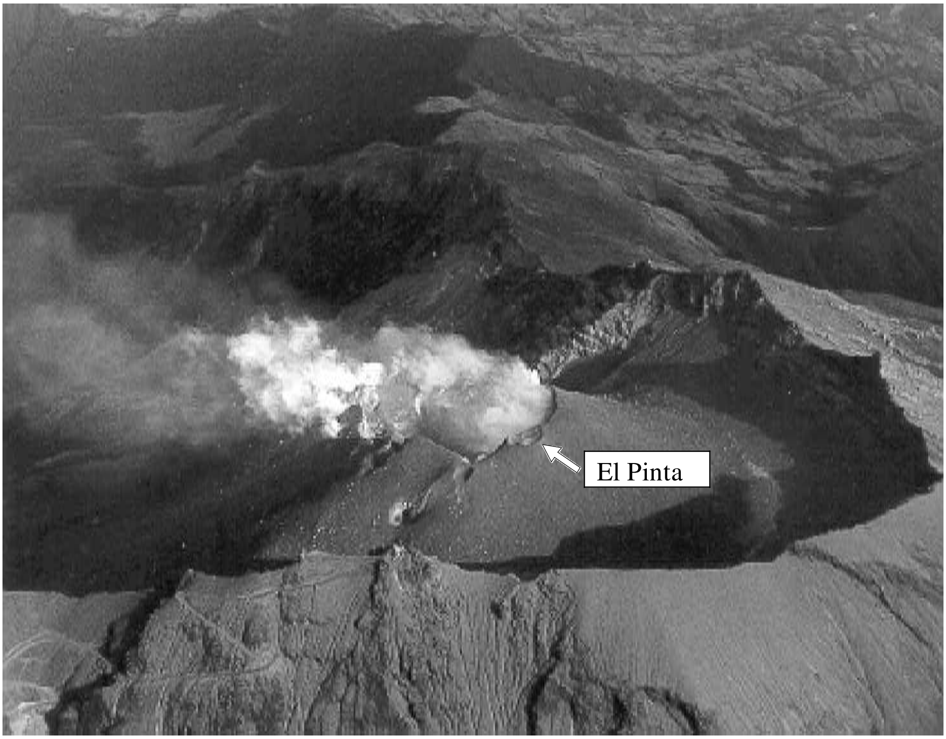

Figure 2. View of Galeras's summit. The active cone is located inside a 2.2 km-wide amphitheatre open to the west. The main and the secondary craters can be seen in the picture. The diameter of 'El Pinta' is 50 m.

the people and the authorities of Pasto. Between February and April 1989, fumarolic activity in the El Pinta crater (figure 2) was very strong; there were probably many small eruptions during this time, such as the one on 19 February, when there was an explosion that deposited lithic blocks and fine ash in the crater area, and the one on 27 March 1989 when ash fell in Pasto.

The geological survey of Colombia (INGEOMINAS) began to monitor volcanic activity by means of four seismic stations in February 1989. Periodic SO_2 measurements of the volcanic plume, performed with a correlation spectrometer (COSPEC), started one month later. Three tiltmeters were installed in June.

A preliminary hazard map of Galeras, taking into account morphology and volcanic deposits, was published by INGEOMINAS in May 1989.

During March 1989, activity steadily increased (Cortés & Raigosa 1997). The seismic network recorded 204 volcano-tectonic (VT) earthquakes and 1748 long-period (LP) events. VTs are related to fracturing of competent rocks, as discussed by Latter (1979). According to Aki *et al.* (1977) and Chouet (1985), LPs are seismic signals caused by variation in the fluid-conduit pressure field. The examination of VT and LP characteristics (number per unit time, localization, etc.) leads to the identification of premonitory activity, and is therefore relevant to the process of monitoring and forecasting. In April and May, the number of VTs (134 and 162, respectively) and LPs (3534 and 2739, respectively) remained significantly high. Using COSPEC, the estimation of SO_2 content in the plume before May reached peak values of *ca.* 1000 t d^{-1}.

Figure 3. Snapshot of the eruption on 4 May 1989. The maximum column height was estimated to be *ca.* 3.3 km. The ash was dispersed mainly to the southwest.

Between 4 and 9 May 1989, eruptions took place at the El Pinta crater. Blocks, surges and fall deposits were later found in the area surrounding the crater. On 4 May, the eruption column was observed to reach 3.3 km in height (figure 3) above the summit, and it deposited 3 mm of fine ash in towns 15 km south and southwest of the volcano.

After the May 1989 eruption, seismicity continued at a moderate level, with monthly averages of 137 VTs and 1362 LPs. From the second half of 1990, the CO_2 content of fumarole gas increased with respect to SO_2 (Zapata 1993). Symonds *et al.* (1994) assume that magma arriving from deeper levels should have high CO_2/SO_2 ratios, while magmas after storage will have low gas content and low CO_2/SO_2 ratios. This assumption and the CO_2 and SO_2 fumarole gas behaviour suggested, therefore, that magma was rising from deeper levels in a short period of time.

In August 1990, the occurrence of vulcanian explosions in the crater became more frequent. Electronic tiltmeters also started to measure significant deformation (INGEOMINAS 1990*a*; GVN Bulletin 1990*a*). In September, a new fracture (called Besolima) with fumarolic activity was reported on the northwest slope of the cone. In Besolima, the temperature increased drastically from 400 to 1000 K, and the fracture grew in length from 12 to 36 m (INGEOMINAS 1990*b*; GVN Bulletin 1990*b*). In the period up to early 1991, steady and significant increases in the deformation, number of vulcanian explosions, and CO_2/SO_2 ratio of fumarole gas were noted. In April, new fractures on the inner west wall of the main crater appeared. In the crater, incandescence was widespread, particularly in the new fracture. Several small vulcanian explosions occurred each day.

September 1991 had the highest LP number (4984) since the start of seismic monitoring in February 1989 (GVN Bulletin 1991). By contrast, the VT remained at low levels (less than 50 per month). During the first two weeks in August, the 'crater' tiltmeter—installed 0.9 km east of the crater—became saturated after 231 μrad of

Figure 4. Eruption of 16 July 1992. Most of the dome, built in 1991, was destroyed by this eruption. The ash deposit had a northwestern distribution. Due to clouds, this eruption was not seen in the city of Pasto (left of the picture), only 8 km from the vent.

accumulated inflation. During this time, the number of explosions was in the range of hundreds per day. The explosions produced continuous emissions of ash and occasional block ejection, which affected the areas close to the crater.

During an aerial inspection on 9 October, the presence of a dome at the base of the crater was detected for the first time. This dome grew until the middle of November. A great part of it was destroyed on 16 July 1992 by a powerful explosion (figure 4) that generated shock waves that were felt in some of the surrounding villages. Erupted material included blocks up to 3.5 m in diameter deposited within a 500 m radius of the crater and ash that was dispersed mainly to the northwestern side. The total volume of the eruption was estimated to be 2.8×10^5 m^3 (Cortés & Calvache 1993). In Pasto, little of this eruption was seen because of clouds in the eastern flank and because of the fact that most of the column was turned towards the W–NW side of the volcano.

In 1993, the region was affected by five eruptions and two seismic crises. The eruptions occurred on 14 January, 23 March, 4 and 13 April and 7 June. All were similar in terms of style, emitted material and activity levels (e.g. seismicity) preceding and following each eruption. The quantity of material varied between 1.8×10^5 m^3 on 4 April and 12.5×10^5 m^3 on 7 June. Very low seismic activity preceding each eruption and low SO_2 contents in fumaroles were characteristic of all eruptions.

Most of the material emitted was andesitic blocks and ash. The blocks affected the area closer to the crater and the ash was dispersed mainly towards the northwest and southwest. The biggest of those eruptions took place on 7 June, with an estimated deposit of 12.5×10^5 m^3. The most tragic of those eruptions was the first one, which occurred on 14 January, during the development of an international workshop on

Galeras in Pasto. The eruption happened when scientists were taking gas samples and doing gravity measurements at the crater rim. Nine people were killed, six of them scientists participating in the workshop.

The first of the 1993 seismic crises occurred between 26 and 30 April. In this period, a swarm of 350 quakes was recorded by the seismic network. The hypocentral region was estimated to be 3 km north of the active crater and at depths ranging between 2 and 6 km. The earthquake with the highest magnitude (4.1) was recorded on 27 April (Gómez *et al.* 1993). With 107 events, the second seismic crisis took place between 24 November and 4 December. The quakes were located 3 km northeast of the crater at depths between 3.5 and 8 km, with the highest magnitude recorded being 3.9 (GVN Bulletin 1993).

A third seismic crisis affected the region in 1995. On 4 March, a magnitude 4.7 event happened, with an intensity of VIII on the MSK–European macroseismic scale in the epicentral region. It was to be the strongest earthquake felt in the region recently. Six people were killed by the collapse of a building. After this main event, 2500 aftershocks were recorded up until 15 July, 70 of which were clearly felt in the region. The swarm was located at 1.5–9 km N–NE of the active crater at depths of 2.5–13 km (Gómez *et al.* 1995). Seismicity, generated at the same source region, although smaller in magnitude and not very frequent, continues to be recorded by the permanent seismic network.

4. Management of the crisis

The recent tragedy of Nevado del Ruiz, the perception of the danger of Galeras, but mainly floods and landslides that affected the country, were the main concerns and the reason why the Nariño Governor decided to form the Regional Committee for Disaster Prevention and Preparedness (CRPAD) in early 1989.

In late February 1989, local—as well as the regional and national—government officials reacted promptly when faced with a possible eruption of Galeras. The central office of SNPAD gave economic support for the INGEOMINAS investigation of hazard assessment and for surveillance equipment. This national office also advised and sustained local groups acting in areas like education or rescue with experienced people from other regions. They also contacted international organizations such as the United Nations Disaster Relief Organization (UNDRO), the World Organization of Volcano Observatories (WOVO) and the USGS asking for experts to advise on the volcanological work.

Logistic support of the surveillance activities was available at regional and local level, but was hindered by economic problems. Committees were organized in preparation for a possible Galeras eruption. From the beginning, there was evidently a difference in style between the governor of the department and the mayor of the city in how to deal with the problem. In time, the situation degenerated into an open confrontation between both government officials.

In relation to preparedness activities, INGEOMINAS proposed to adopt the alert levels proposed by UNDRO (1985). With minor modifications, the city of Pasto accepted this proposition. A further proposition of the observatory was related to the need to educate the community over the meaning of the different alert levels. This was, of course, before alert levels were introduced. Explanations by radio, newspapers and booklets were the chosen tools for performing this exercise. The booklets also included a description of historical eruptions and of the main hazards posed by Galeras.

The lack of knowledge about the baseline in the volcanic activity and of a hazard map, the memory of what occurred in Nevado del Ruiz, and the proximity of the volcano to the city made the volcanologists very cautious. After the installation of the monitoring system, the number of earthquakes, the SO_2 flux and crater changes were increasing. These facts motivated the volcanologists to suggest a change from 'not alert' to 'white alert' on 28 March. The change of the alert level was officially announced by the CRPAD. A small eruption that deposited ash on Pasto produced great concern among the inhabitants of the city, especially as a 300–400 m high plume was clearly observable on top of the volcano.

At 11:45 on 5 April, INGEOMINAS suggested to the central office of the SNPAD a change in alert level to 'yellow alert'. Unfortunately, this suggestion was not properly transmitted to the CRPAD. At 12:30 the SNPAD announced the alert change nationally, only a few minutes after the CRPAD had announced that the situation of Galeras was stable. This contradiction was used by the media to emphasize the lack of coordination and understanding among the institutions in charge of risk minimization and preparedness. This fact was also used by the mayor of the city to state that the situation was even worse. He said that the 'orange alert' should have been declared, but because of the lack of funds to evacuate the city, the governor would not declare it. On 11 April, the mayor announced a voluntary evacuation. He also prohibited new licences for construction on the western part of the city. These decisions generated a chaotic situation. There were traffic accidents, people suffered heart attacks, and worried parents did not send their children to school.

The media played an important role in the development of the Galeras crisis. Most of the main newspapers, television news and radio stations were focused on Pasto, Galeras and the expected 'great tragedy'. Although they tried their best to help, they alarmed and misinformed the community. Sensational press stories contributed to the acceleration of a chain of events in which the wholesalers refused to send goods to Pasto that were not paid for in advance, all credit facilities were suspended, and transportation companies did not want to send their trucks through Pasto. Unemployment increased drastically. The supply of goods and food was scarce. Production fell to unexpectedly low levels and the living cost rose abnormally. Tourism, a significant factor in the local economy, disappeared totally.

On 4 May an eruption took place at the El Pinta crater. The column rose *ca.* 3.3 km above the summit (figure 3). The situation was frightening initially, but, as the eruption continued for several days, people become accustomed to it. On 5 May the 'orange alert' level was declared. At this time, a volcanological workshop was taking place at Pasto—cosponsored by UNESCO, the Volcano Early Warning and Disaster Assistance Program of the USGS, and several Colombian Agencies—with participants from eight countries. One of the goals of the workshop was to define the most likely hazardous scenarios posed by the volcano. This workshop came just in time. The presence of prestigious scientists during this crisis situation was a great support for the Colombian volcanologists.

The activity of the volcano continued at a moderate level, but the 'orange alert' was kept until 26 May. This fact became a target of criticism; the media and people frequently asked why such a high volcanic alert level was in place despite insignificant volcanic activity. Although the educational campaigns continued in 1989, the community remained very sceptical. People lost confidence in the volcanologists and the government. They felt deceived.

In late 1989, elections for governor and mayor took place. The Galeras situation was used as a political platform. The main discussion points centred on the way the whole volcanic crisis was managed and on the persistent critical economic and social situation in the region. The new mayor of the city 'decided' that Galeras was responsible for the majority of the very heavy regional problems. He organized a seminar in which the main objective was a 'de-galerization' (desgalerización) of the economy. The main speaker was a well-known geophysicist from the Instituto Geofísico de los Andes and a member of the Jesuit congregation. The prestige of the Jesuit community in Pasto was very high due to the fact that this community heads a prestigious school and controls a radio station. His intervention sought to diminish the importance of the Galeras danger. The Instituto Geofísico has had a seismic station at a distance of *ca.* 5 km from Galeras's crater for several decades. Some of the main points that this geophysicist emphasized in his talk were related to the fact that this station did not record the number or magnitude of signals that the observatory reported. Additionally, he said that the long record of more than 30 years of seismic activity at Galeras suggested that this kind of small unrest reflected normal behaviour of the volcano. More than that, spokesmen from the Jesuit community stated that no pyroclastic flows had occurred at the Galeras volcano in the past. The result of this seminar was that the credibility of the Colombian volcanologists fell to a very low level.

New elections in 1992 meant that the governor and mayor changed again. The new governor 'denied' the activity of the volcano and the observatory staff was withdrawn from the CRPAD. A member of this committee was chosen to mediate between the observatory and the CRPAD. In July 1992 a powerful eruption destroyed the dome (figure 4). The governor's office minimized the event; it refused INGEOMINAS permission to inform the community about the eruption. Later on the governor held a press conference on top of Galeras in order to show that the volcano was not dangerous.

Under the conditions described, an international seminar began in January 1993 in Pasto. The unexpected eruption—which killed nine people, six of them participants of the seminar—additionally affected the credibility of the observatory. This eruption had a twofold effect. For some this was proof that the volcano was dangerous and a threat to the community. Others, however, believed the volcano was venting its anger on foreigners that went to disturb it, and that Galeras would never represent a real danger to the people of the region with whom relations were good.

It was not until four eruptions and two seismic crises (clearly felt by the population) occurred in 1993 that it was finally accepted by government officials and the community that Galeras may represent a real threat. The seismic crises deeply affected the population. Even the governor 'decided to believe' that the volcano was active.

The observatory, in collaboration with a local newspaper, began to communicate directly with the community through a weekly column. It published articles that popularized geological topics and natural-hazard subjects such as volcanoes, earthquakes, tsunami and landslides. In 1994, to improve relations with the population and permit people to follow the monitoring activities and observe working seismographs, reports were posted on the windows of the observatory.

In 1997, during a phase of low volcanic activity and using the benefit of experience, a third hazard map was published. INGEOMINAS now works with its emphasis on risk evaluation. This is done in joint collaboration with local institutions and regional universities. At the same time it encourages institutions and interested persons to share the results of their activities, promoting visits by schools and local institutions with the aim of communicating how the monitoring of Galeras is performed and how the current situation of the volcano is estimated by its scientists. Relevant information to be given to the population is periodically updated and communicated through newspapers and posted on the windows of the observatory, near the working seismographs. INGEOMINAS actively participates with the local authorities in the formulation of didactic material related to prevention and preparedness activities.

The experience of the city of Pasto and its surroundings will be useful in helping to mitigate volcanic hazards in places where populations lie on the slopes of an apparently safe volcano. It has taken approximately 10 years for INGEOMINAS to be accepted by the community. Success and setbacks were dictated by the volcano itself every time. The experience gained is laid out in the following section.

5. Lessons to be learned

(1) The presence of a potentially active volcano can lead to serious economic and social problems for the surrounding population without the volcano entering into erupting activity. Everything depends on how emergency situations are managed: how government, community, media and volcanologists are ready to manage critical situations.

(2) When a volcano shows clear signs of unrest, it is easier for the community to perceive and to accept the threat. Nevertheless, at this time it will not be effective or, depending on the particular situation, possible to inform the community of the problems emerging from the volcanic threat.

(3) Hazard evaluation, monitoring of activity, the establishment of prevention, preparedness and mitigation policies, and the introduction of educational plans, must all be started and, as far as possible, performed during a period when the volcano is dormant. It will be too late and in many aspects counterproductive to try to organize basic actions during a threatening activity.

(4) The community must be involved and its active participation must be encouraged in designing prevention and preparedness plans. In addition, plans have to fully consider how the local population's perception of the threat is related to its culture.

(5) Scientists and local and regional committees must gain the confidence of their community, and understand its daily necessities. If the affected population does not have confidence in the crisis team, efficient communication of the estimated situation will be very difficult, and will strongly hinder the introduction of effective emergency measures.

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