Geomorphological Features of the Galeras Volcanic Complex

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Abstract

The Galeras volcanic complex, near the city of Pasto, was formed in several steps. At ~560 ka, BP a major caldera (the *Coba Negra* Caldera) appeared with its center ~5 km west of the present-day active volcano top. This caldera was 5 km in diameter and elongated in the E–W direction. The wall of the subsequent Jenoy caldera is covered by glacial morphology indicating a pre-glacial (<ca. 20 ka) age. These data suggest that the location of the eruptive main centers changed several times, moving eastward. Another 4-km-diameter caldera was formed during the Jenoy stage. The E–W migration trend of the volcanic centers can be seen in the Coba Negra caldera. Between 12.8 and 5 ka, the summit portion of the cone collapsed toward WSW and formed the youngest avalanche debris deposits. The collapse scar has a horseshoe shape and the sliding surface almost certainly cut across the main magma conduit. The presence of other, older avalanche debris deposits suggests previous lateral collapses, the scars of which can be recognized on the upper southern slope of the volcano. The active cone lies in the uppermost part of the sector collapse depression. Most of the surroundings are covered by pyroclastic deposits from the Galeras and neighboring volcanoes. The Galeras volcano is still active and constitutes a real hazard for the surrounding inhabitants.

Keywords

Active volcanism • Volcanic landforms • Glacial landforms

16.1 Introduction

The Galeras volcano, the most active volcano in Colombia (Stix et al. 1997) is located in the southwestern part of the country, near the city of San Juan de Pasto, the capital of the Department of Nariño (Fig. 16.1). Pasto is a city of 430,000 inhabitants, located 9 km east from the active volcano summit. Pasto lies within the Galeras volcanic complex (GVC) influence area, which covers an area of approximately 220 km^2, including several other localities such as Nariño, Yacuanquer, Consacá, Sandoná, and La Florida, with a total of more than 90,000 inhabitants. All those localities are communicated by the *Circunvalar* road, which surrounds the volcanic complex (Fig. 16.2) and constitutes the best way to see ancient and recent GVC volcanic deposits. The Galeras volcano itself rises to 4276 m a.s.l. and 1600 m above the so-called "Knot of the Pastos" or Huaca Massif, a geographic place where the Andes Cordillera divides itself into two different branches (eastern and central-western).

The GVC has always been an attractive site, visited during the last two centuries by foreign naturalists, such as

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Fig. 16.1 Galeras volcano seen from city of Pasto, (*Photo* Michel Hermelin)

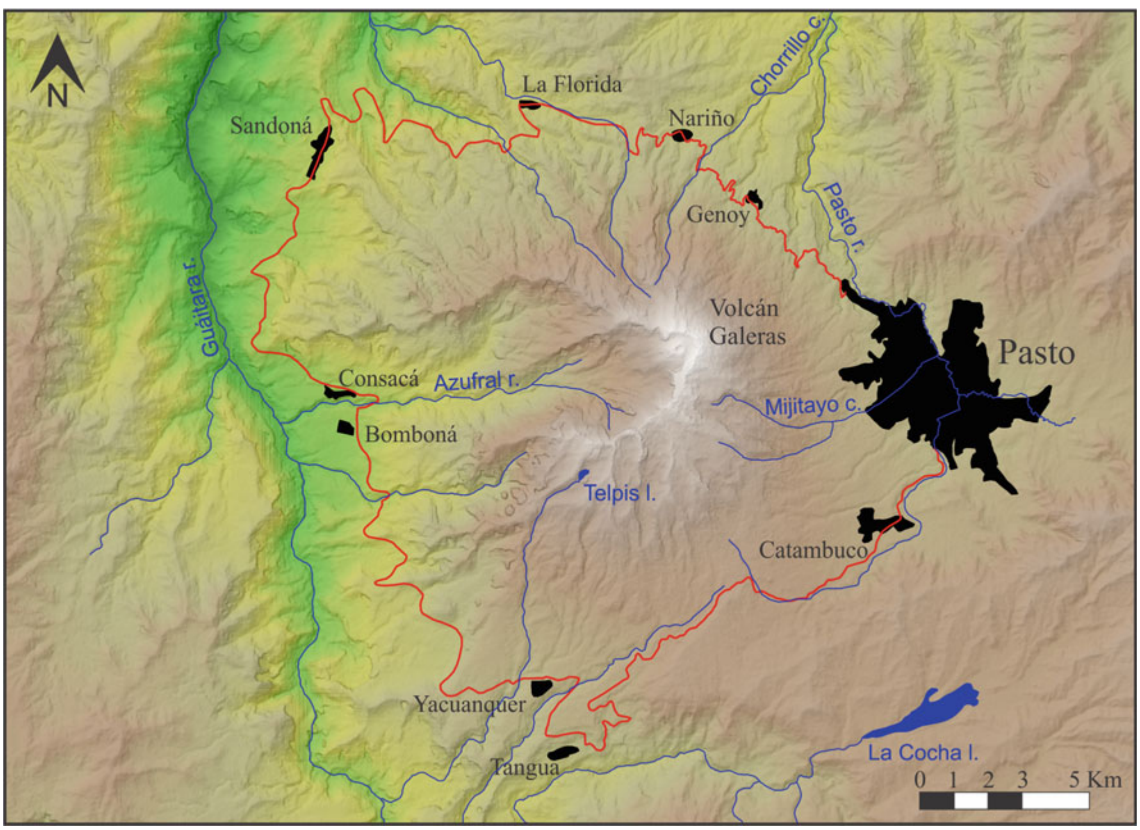

Fig. 16.2 Road itinerary around the Galeras volcano. Notes. *l* lake, *c* creek, *r* river

Pierre Bouguer in 1743, Alexander von Humboldt in 1801, J.B. Boussingault in 1831, Wilheim Reiss and Alphons Stuebel in 1868 (Stuebel 1906), and E. Friedlaender in 1925.

For several years, government agencies have taken on the task of raising awareness among the inhabitants of Pasto and surrounding villages of the risks represented by the volcano, and have carried out much work on the prevention measures that the population should take. But the idea that "the volcano is our best friend, and never would never do us harm" is a deeply rooted idea in the collective imagination and people feel that the volcano is more likely an old family friend than a dangerous neighbor.

The volcano dominates the Atriz Valley, where the city of Pasto is located and its majestic presence, often capped by fumarolic smoke, can be perceived from far away. Its name was given by the first Spaniards who visited the place, due to its remote resemblance to a galley hull (Figs. 16.1 and 16.3).

16.2 Geological Background

The actual tectonic configuration of the Colombian Andes is characterized by an intimate relationship between the orogenic chains and large reverse and strike-slip fault systems with a regional N–S to NE–SW trend, kinematically compatible with a stress field (E–W oriented σ_1, and N–S σ_3), controlled by the convergence between the Nazca and South American plates and the Chocó Block. The convergence between the Nazca and South American plates (Fig. 16.4) is distributed between the subduction under South America and stresses along some of the continental fault systems subparallel to the Cordilleras (Taboada et al. 2000; Trenkamp et al. 2002).

The Romeral fault zone (RFZ) is one of the main structural elements in the Northern Andes. It extends from the Gulf of Guayaquil in Ecuador to Barranquilla in Colombia (Fig. 16.5) (Chicangana 2005; Tibaldi and Romero 2000). In Colombia, this fault is associated with an important change in basement composition, putting together the Precambrian–Paleozoic poly-metamorphic continental basement intruded by the Mezosoic–Cenozoic plutons of the Central Cordillera and Mesozoic to Cenozoic accreted terrains of oceanic affinity of the Western Cordillera from the west, which constitute the GVC basement (Nelson 1962; Botero 1963; Barrero 1979). This basement is covered by a thick volcanic and volcaniclastic sequence of Tertiary age, produced by ancient volcanic activity along the inter-Andean valley between the Central and Western Cordillera (Barrero and Vesga 1976; Alvarez et al. 1983; Restrepo et al. 1981).

The GVC is located over the Romeral fault zone, where its main trace is intersected by a minor scale Buesaco Fault

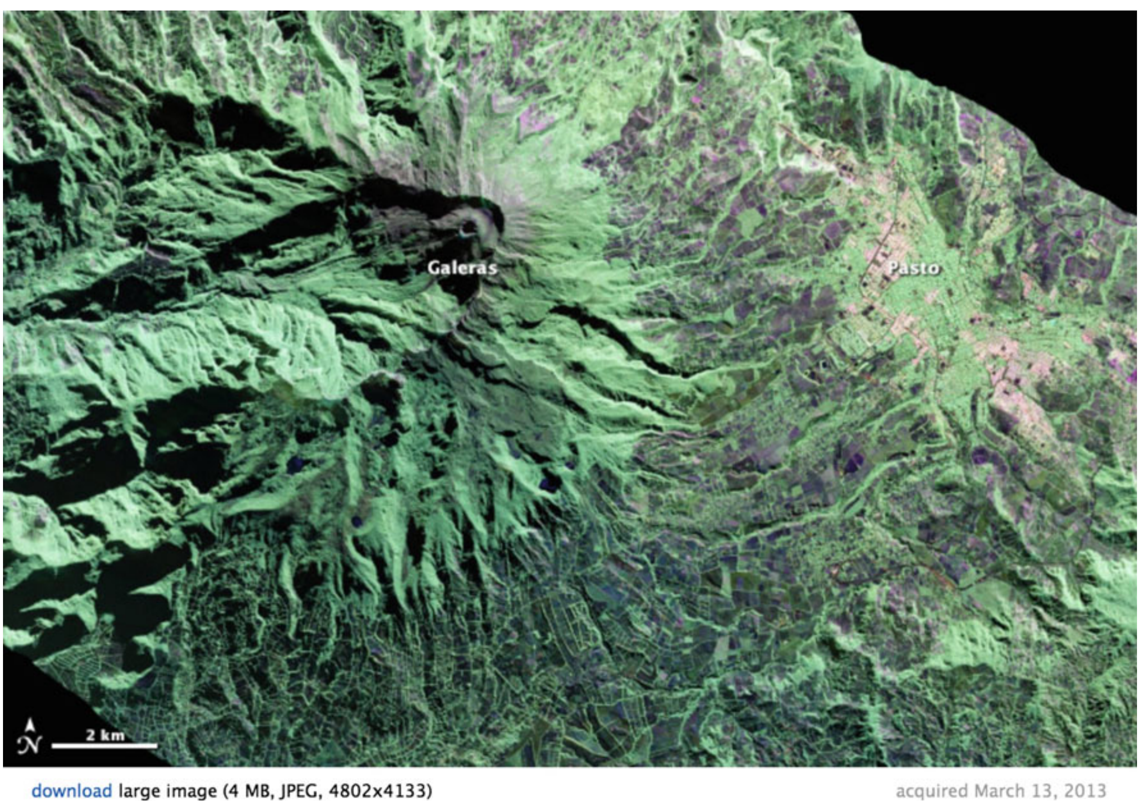

Fig. 16.3 Satellite image of the Galeras volcano. INGEOMINAS

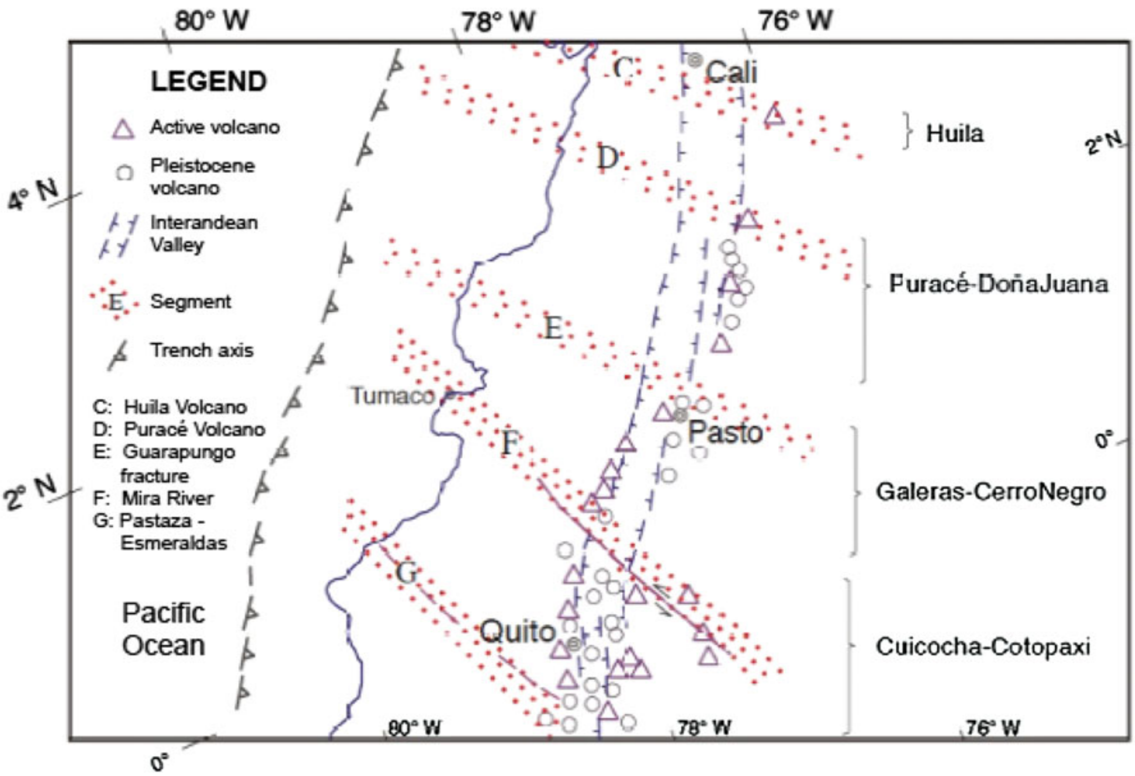

Fig. 16.4 Tectonic setting of the Galeras volcanic complex (after Hall and Wood 1985)

belonging to the same system, which has the same sense of movement as the Romeral Fault and shows a similar degree of recent tectonic (Tibaldi et al. 2005; Tibaldi and Romero 2000).

16.3 The Galeras Volcanic Complex

The Galeras volcanic complex (GVC) consists of ancient and recent volcanic deposits from previous volcanic stages and from the contemporary active cone of Galeras (Calvache 1995). Several stages of its evolution have been identified on the basis of geological and geochronological studies performed by Calvache (1995), Calvache and Cortés (1996) and Calvache et al. (1997).

Detailed studies allowed Calvache et al. (1997) to define six different stages in the evolution of the GVC. Each of these eruption stages is the result of numerous eruption episodes, which occurred during long periods of time. Some of the older eruptive stages are difficult to trace, due to subsequent weathering, erosion, and burial by later deposits, especially by thick ash falls erupted from various volcanic centers located around the GVC (Figs. 16.5 and 16.6).

16.3.1 Pre-Galeras History

The pre-Galeras history is divided into five stages. The oldest of them is the Cariaco stage, whose only remnant is a pinnacle in three directions re-shaped by glacial activity at three sides, suggesting that it was a topographic high during the Pleistocene glaciation (Calvache et al. 1997). This was followed by the Pamba Stage, which left deposits around the town of Sandoná, where the best exposure of the edifice can be seen (Fig. 16.2). Lava flow deposits are by far the major volcanic products of the next Coba Negra eruptive stage. These are mainly composed by two pyroxene-high silica andesites, with few dacites and basaltic andesites, whose eruptions began around 793 ka (Calvache et al. 1997). Around the end of this stage and before the activity of the Jenoy stage, a small monogenetic cinder cone (0.2 km^3) named La Guaca was formed on the southwestern side of the GVC. La Guaca is dated at 166 ± 34 ka and it is characterized by eruption of lapilli to block-sized scoria clasts, and

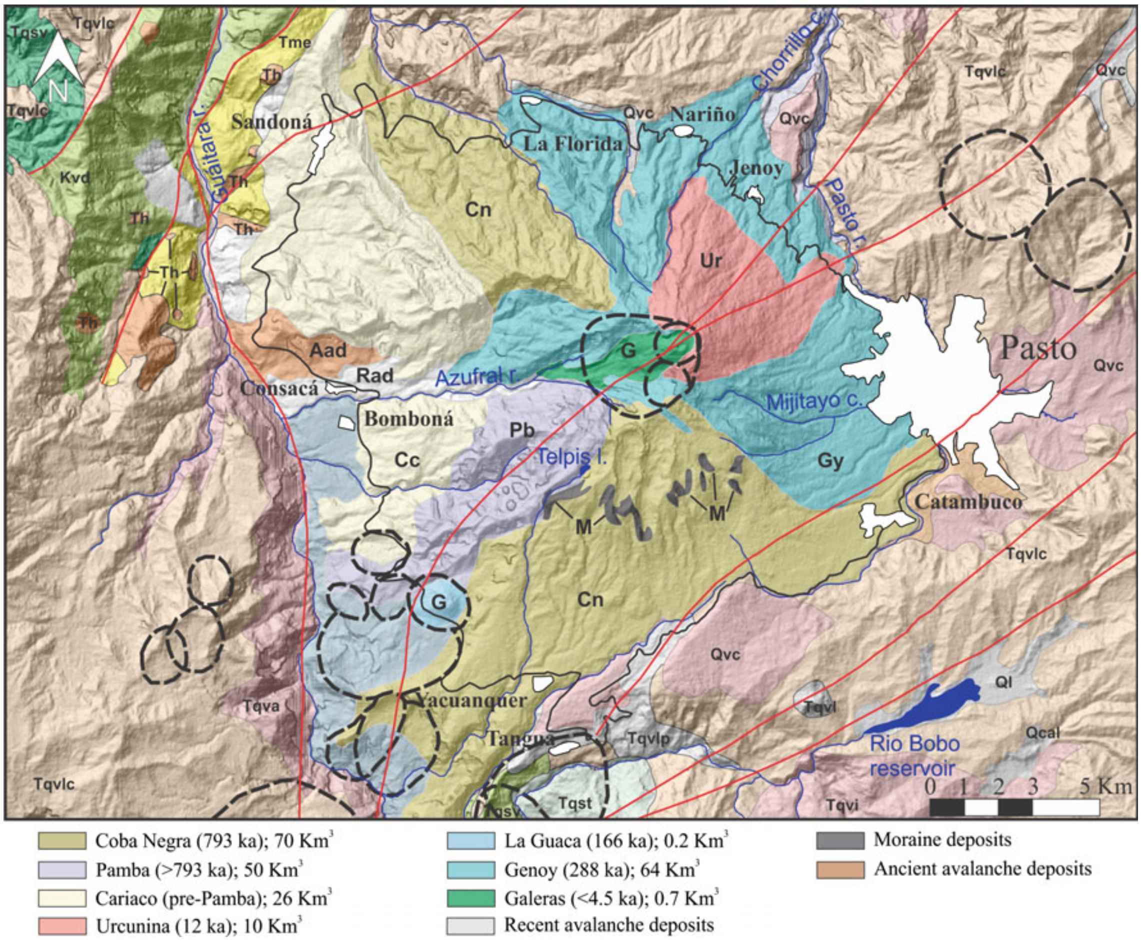

Fig. 16.5 Geological map of the Galeras volcanic complex, modified from Calvache et al. (1997). Abreviations: *Cn* Coba Negra stage; *Pb* Pamba stage; *Cc* Cariaco stage; *Ur* Urcunina stage; *G* La Guaca stage; *Gy* Genoy stage; *Rad* Recent avalanche deposits; *M* Moraine deposits; *G* Galeras stage; *Kvd* Diabase group; *Tqsv* La Macarena sediments; *Tqvlc* Tertiary ashes and lavas; *Th* Hypabyssal rocks; *Tme* Esmita formation; *Tqva* Pyroclastic and debrie flow deposits; *Tqst* Tapialquer sediments; *Tqvlp* Lahar and pyroclasts; *Qvc* Ash fall deposits; *Tqvi* Eutaxitic ignimbrites; *Tqvl* Tertiary Lavas; *Ql* Lacustrine deposits. Regional geology from Murcia A, Cepeda H (1991); detailed geology from GVC from Calvache et al. (1997)

some small lava flows at the end of its activity. The volcanic materials erupted by La Guaca are composed exclusively of olivine-bearing basaltic andesites (Calvache et al. 1997) (Fig. 16.7).

The source of the ensuing Jenoy-stage activity has been located east of the Coba Negra caldera, or along the eastern border of this caldera. The caldera-forming event at the Jenoy stage has been dated to be as old as 40 ka (Calvache et al. 1997). Explosive activity continued during the Jenoy stage with minor eruptions that formed valley-controlled pyroclastic deposits and dated for 41–31 ka (Calvache et al. 1997). The evidence of the next Urcunina Stage is one among the best preserved old GVC stages (Fig. 16.2). Actually, it is the tallest edifice, which can be seen directly from the city of Pasto (it is commonly called “The Galeras Volcano”). The major part of Urcunina is formed by a two pyroxene-andesite lava flows with some associated lava flow collapse pyroclastic flows (Calvache et al. 1997).

16.3.2 The Galeras volcano

The Galeras volcano (Cepéda 1985) is the present focus of volcanic activity in the GVC. It is localized at the center of the complex, inside the scar left by the summit collapse of the Urcunina edifice (Fig. 16.8). The Galeras active cone is 800 m wide and 150 m high and contains the main crater which is ~350 m wide, representing only a volume of 0.7 km^3 (Ordóñez and Cepeda 1997).

The Galeras activity apparently began at 4500 years BP and was characterized by vulcanian-type eruptions (Banks et al. 1997) that basically consisted of a dense cloud of ash and gas exploding from the volcano crater in repetitive, but

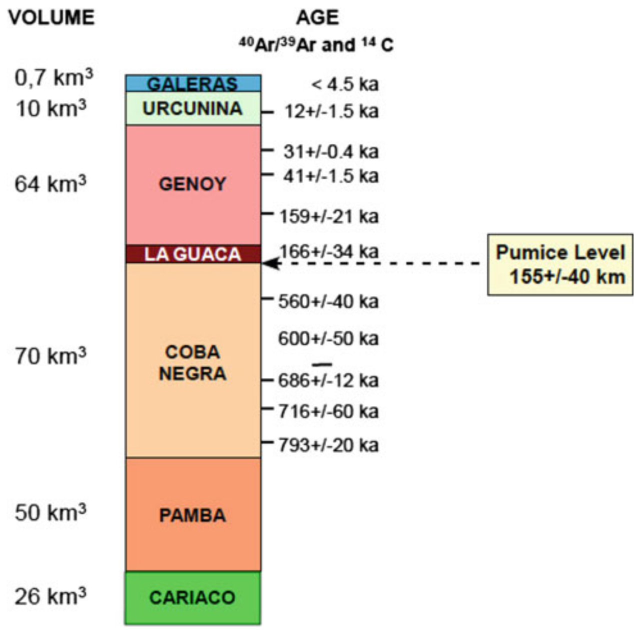

Fig. 16.6 Generalized stratigraphic column of the Galeras volcanic complex. Modified from Calvache et al. (1997)

irregular intervals. Several periods of activity have been identified and associated with pyroclastic flows, pyroclastic falls, mud, and/or debris flow deposits (Cortes and Calvache 2002). Nevertheless, the most characteristic product of Galeras explosive activity is the gravitational column collapse, which usually produces lithic-rich pyroclastic flows due to vent-cleaning processes; later, the column is enriched with juvenile material. This material does not represent an important volume on the GVC and is restricted to the active cone. Debris and/or mudflows can be seen in the north and northwestern areas of the GVC and also along the Azufral River, together with some small Andesitic lava flows (Calvache et al. 1997).

16.4 Main Geomorphologic Features

The diverse volcanic products generated during the volcanic activity on the GVC, the wandering of the emission centers, and the intrinsic instability associated with volcanic

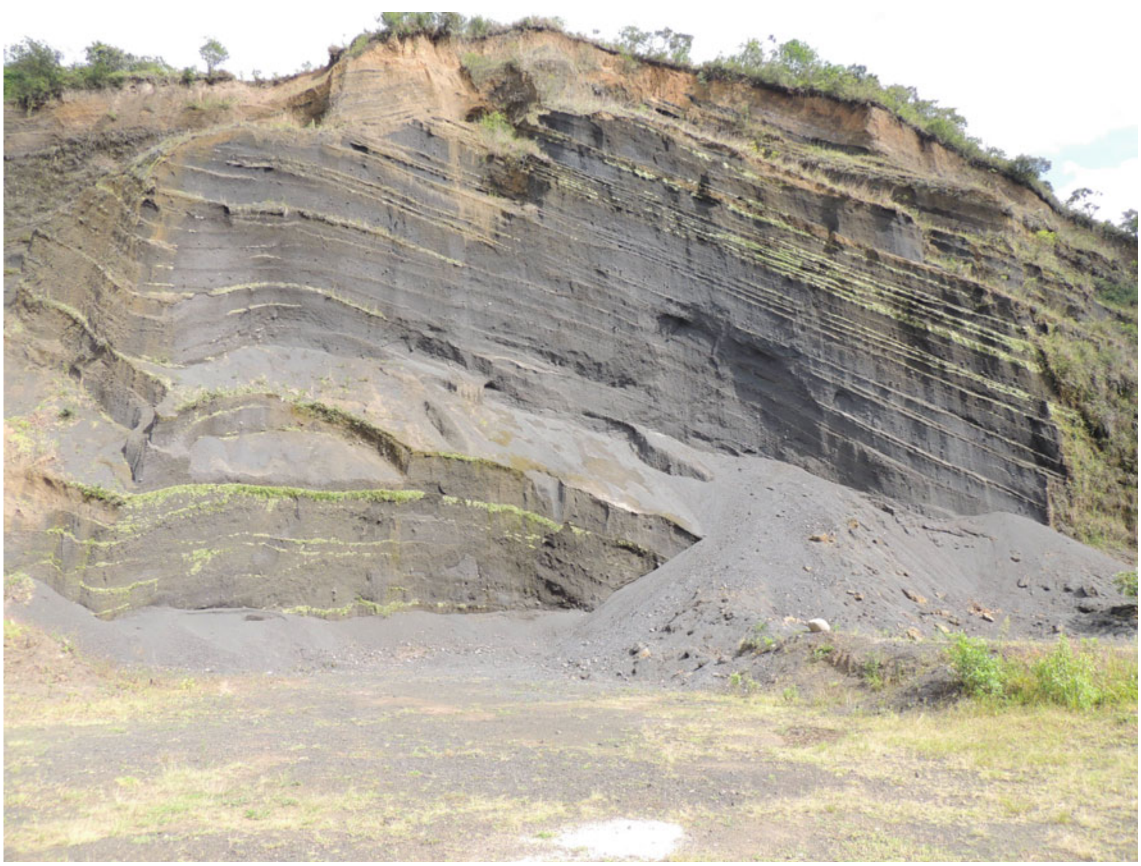

Fig. 16.7 La Guaca pyroclastic deposit (outcrop is about 30 m high), (*Photo* Michel Hermelin)

Fig. 16.8 Aerial view of the Galeras calderas and crater, Ingeominas

complexes have been the main contributors to the GVC landscape.

16.4.1 Glacial Erosion

Although there is no clear evidence of the existence of moraine deposits older than those formed during pre-Late Pleistocene glaciation, some descriptions of subdued moraines and weathered till are given by Schubert and Clapperton (1990). On the other hand, the maximum of the last Pleistocene glaciation in the Northern Andes occurred around 20–18 ka BP, when the glaciers reached 3000–3900 m a.s.l. (Schubert and Clapperton 1990). This glacial timing implies that most of the GVC stages occurred before the last glaciation, and thus, respective landscapes should have been influenced by glacial processes.

Calvache et al. (1997) described evidence of glacial action on remnants of the early stages of the GVC, Cariaco, Coba Negra, and Jenoy. The primary evidence of glacial action on the GVC is found on the volcanic products of the Coba Negra stage. In the southern part, landforms related to glacial erosion, such as amphitheaters, U-shaped valleys, and lakes can be found. Landforms related to glacial deposition in the form of lateral and frontal moraines are found up to 3400 m a.s.l. along the Cubijan, La Magdalena, La Aguada, and Telpis Rivers (Calvache et al. 1997), indicating that the glacial front reached at least 3400 m a.s.l., probably during the glacial maximum, between 20 and 18 ka.

The effects of glacial erosion are evident, especially due to the reduction of the slope angle and the notorious contrast between the U-shaped valleys with gentle slopes and the steep slopes (30°–40°) of the unaffected flanks, characterized by craggy stacking of lavas. The same effect of slope angle reduction can also be observed in the eastern and southeastern part of the Cariaco edifice, which, according to Calvache et al. (1997), also presents evidence of glacial erosion. In fact, the present highest point of this edifice is a glacial horn, flanked by three glacial cirques directed toward the north, the southeast, and the southwest, suggesting that this was also a topographic high during Pleistocene glaciation.

Jenoy-stage remnants, similar to Cariaco and Coba Negra, also include deep valleys and glacial deposition morphology; however, these are not as notable as glacial morphology observed within the extent of the older stages. This may confirm the Pleistocene age of the Jenoy stage (Calvache et al. 1997).

16.4.2 The Caldera Walls

Some of the most distinctive features in the GVC are its caldera walls, located in the upper part of the complex. These caldera-forming eruptions are notorious due to its explosiveness, large volume of material involved, and the spectacular walls which remain until nowadays (Figs. 16.5 and 16.8).

At present, only the northern and southern caldera walls remain. Both walls are nearly 4 km long. The southern wall is ~600 m high, while the northern wall is ~400 m high. The eastern caldera rim was buried and destroyed by Urcunina constructional and collapse processes, and the western rim was completely destroyed by flank collapse and eroded by the Azufral River due to its strong gradient.

16.4.3 The Active Crater

The currently active crater of the Galeras volcano belongs to the last eruptive stage of the GVC, named as the Galeras volcano, which has been active for at least the last 4500 years (Banks et al. 1997). It measures ~350 m in diameter and ~80 m in depth, and contains a cone inside which is 100 m tall and 500 m across (Fig. 16.8). The first direct description of the main crater was made by Boussingaultin in 1903, based on his visit on May 15, 1831. He observed a lava dome, several tens of meters in diameter, in the crater with a major NE–SW fracture, and many fractures, fissures, and fumarolic activities. Boussingault also described recent explosive activity with ash emission. Later, in 1832, an important eruption occurred, which ejected a significant volume of ash, possibly blowing out a part of the dome, cleaning the conduit, and forming a new crater (Espinosa 1989).

The first sketched description of the crater was made by Stübel (1906), who visited the volcano between July 1869 and January 1870, observing the growth of a small scoria cone inside the crater. Many other historical descriptions were compiled by Espinosa (1989) and Ordóñez and Cepeda (1997). These descriptions basically point out the main crater with many fissures and parasite craters located within it, from which gases were released.

By 1982, the main crater had markedly enlarged, and two new secondary craters named El Pinta and El Paisita appeared, which showed considerable activity until 1991 (Ordóñez and Cepeda 1997).

By the end of October 1991, a dome of 400,000 m^3 was detected inside the crater. The dome was partially destroyed by an explosive eruption on July 16, 1992; the rest of the dome was blown by the January 14, 1993 eruption, which resulted in the deaths of 6 scientists and 3 tourists who were attending a workshop on Galeras, declared as the "Decade Volcano" (Ordóñez and Cepeda 1997; Cortés and Raigosa 1997; Stix et al. 1997). After destruction of the dome, the crater suffered minor changes, with the activity concentrated on the western side and the same centers of eruption as

Fig. 16.9 Pyroclastic materials quarried south of Pasto, (*Photo* Michel Hermelin)

Fig. 16.10 Collapsed tunnels signify the site of underground exploitation of pyroclastic materials south of Pasto, (*Photo* Michel Hermelin)

during earlier episodes of activity (Ordóñez and Cepeda 1997).

16.4.4 Ash Fall Deposits

Ash cover tends to smooth the landscape around southern Pasto, Catambuco, and Yacuanquer; this zone has very gentle slopes due to the thick pyroclastic fall out coverage (Banks et al. 1997), consisting of a series of ash fall layers alternating with paleosoils, which indicate periods of volcanic quiescence. The ash fall cover is usually more than 25–30 m thick. Murcia and Cepeda (1991), Calvache (1995), and Cortés and Calvache (2002) mapped these deposits as non-differentiated ash falls. Banks et al. (1997) and Cortés and Calvache (2002) described and dated the ash fall sequence around the city of Pasto, identifying many ash fall events and defining the Los Pastos Formation, which includes the sequence of fall off deposits (Fig. 16.9).

Several layers of these ash fall deposits are targets of artisanal exploitation for building materials. The main quarries are located near Pasto and along the *Circunvalar* road, near Catambuco and Yacuanquer. These exploitations are done by means of long tunnels inside the deposits, where laborers and trucks extract the material. This has generated major subsidence problems at the surface immediately above locations where this material has been extracted (Fig. 16.10).

16.4.5 Structural Landforms

The GVC and its surroundings present an important influence from the Romeral fault system. In fact, the location of the actual Galeras active cone and its wandering along the GVC evolution may respond to sustained tectonic control, which allowed the magmatic ascent along cortical weakness zones. Like the GVC activity centers, other volcanic features are or have been controlled by the tectonic regime present in the area. The La Guaca cinder cone is aligned in NE–SW, within the Telpis Lake fault swarm. This swarm is also affecting the active cone and the southern scarp of the Urcunina sector collapse (Tibaldi et al. 2005). The tectonic regime since the Late Pliocene has been dominated by a right-lateral strike-slip motions along the NE striking vertical to subvertical faults. These faults also control minor uplift of the northwestern block (Tibaldi and Romero 2000). This tectonic setting could respond to a regional compressional stress regime characterized by a horizontal E–W trending major vector, and a minor stress vector located in N–S (Tibaldi and Romero 2000).

16.4.6 The La Guaca Cinder Cone

La Guaca is known as a small cinder cone located on the southwestern flank of the GVC near the town of Yacuanquer. The La Guaca cone is slightly elongated along E–W, 200 m tall and has a diameter of 1800 m in E–W direction and 1500 m in N–S direction (Figs. 16.5 and 16.7). It is totally composed of layers of black scoria clasts, which vary from lapilli to block size. Layer thickness ranges between 1.2 and 40 m. Only one lava unit has been described; it crops out on the western flank and exhibits the same composition as the scoria clasts. Composition of this cinder cone is totally different from the rest of the GVC volcanic products because it is exclusively composed by olivine-bearing basaltic andesites.

16.5 Visiting Galeras

Although the volcanic behavior of the Galeras volcano is well known, and the Colombian Geological Service is continuously monitoring its activity level through its telemetric surveillance station (Seidl 2003; http://www.sgc.gov.co/Pasto/Volcanes/Volcan–Galeras/Generalidades.aspx), the area near the Galeras summit is a high-risk area and access is generally forbidden. The best way to observe the volcanic deposits that compose the different volcanic stages of the GVC (except for most of the current Galeras deposits) is the *Circunvalar* road, which runs through different towns around the volcano, including Pasto, La Florida, Sandoná, Consacá, and Yacuanquer, allowing visitors to observe different landscapes, climate zones, and touristic attractions, such as coffee-producing farms, artisanal products, and sugarcane plantations. The complete circuit by car takes approximately 5 h.

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