U N I V E R S I D A D   D E   C O N C E P C I Ó N
DEPARTAMENTO DE CIENCIAS DE LA TIERRA
10° CONGRESO GEOLÓGICO CHILENO 2003

GEOLOGY AND STRATIGRAPHY OF NEVADO DE LONGAVÍ VOLCANO (36.2° S), CHILEAN SOUTHERN VOLCANIC ZONE.

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INTRODUCTION

Nevado de Longaví volcano (NL) is a late-Quaternary stratovolcano located in the Southern Volcanic Zone (SVZ) of the Chilean Andes at 36°12'S-71°10'W (Fig. 1). It is located just south of an offset in the position of the volcanic front, which has been defined as a segment boundary in the SVZ (Dungan *et al.*, 2001). Although visible from the Central Depression, this center has not attracted much interest from geologists. It was mapped by Gardeweg (1981) and Muñoz &

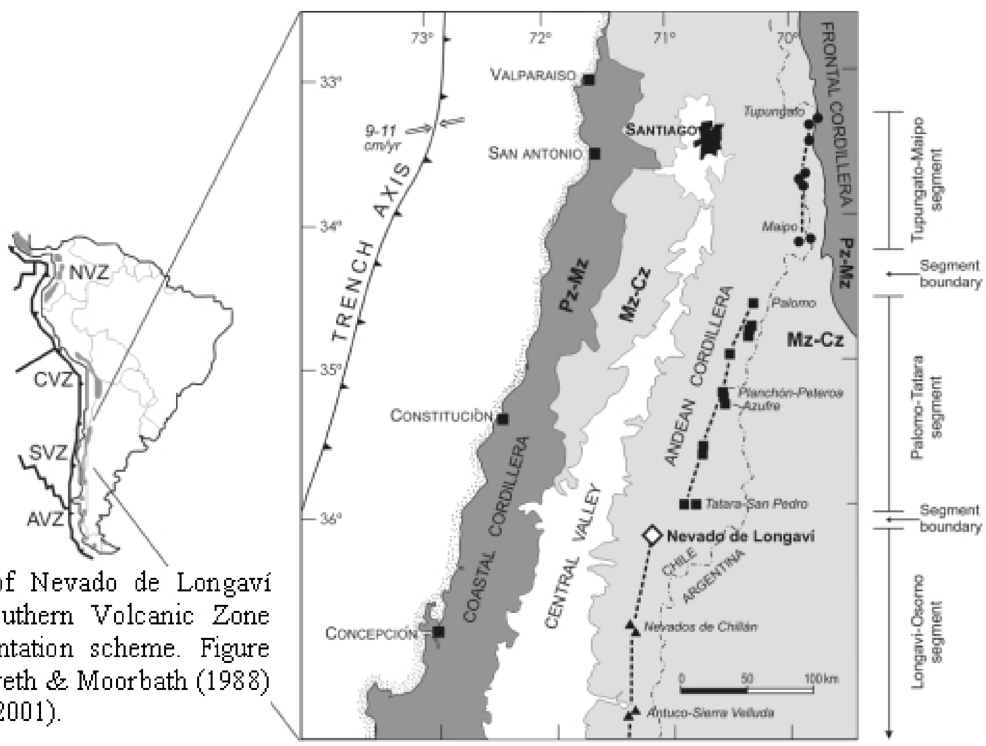

Fig. 1: Location of Nevado de Longaví volcano in the Southern Volcanic Zone (SVZ), and segmentation scheme. Figure modified from Hildreth & Moorbath (1988) and Dungan *et al.* (2001).

Niemeyer (1984) in a regional framework, but little additional work has been done, in part due to the fact that no historical eruptions are recorded, and it shows no signs of activity other than a thermal spring on its southern flank and occasional snow-melt patches in the summit area.

The volcano is composed mainly of thick andesitic flows that radiate from the current summit area. The volcanic edifice is a relatively small single cone (base altitude ~1500 m; summit altitude 3242 m; ~50 km^2 surface; ~22 km^3 estimated volume), without evidence of a caldera or other catastrophic phenomena. The summit area has no craters, and no satellite vents have been found, except for one glaciated andesitic lava flow on the opposite slope of Rio Blanco, south of NL (Rincón de Soto flow in Fig. 2).

BASEMENT

The volcanic edifice was emplaced on top of folded volcaniclastic strata of the Cura-Mallín Formation, of Eocene to Early Miocene age (Muñoz & Niemeyer, 1984; Fig. 2). This formation is intruded by Miocene granitoid plutons, and the ensemble is uncomformably covered by a sequence of basaltic to basaltic andesitic lavas and breccias of the Late Pliocene-Pleistocene Cola

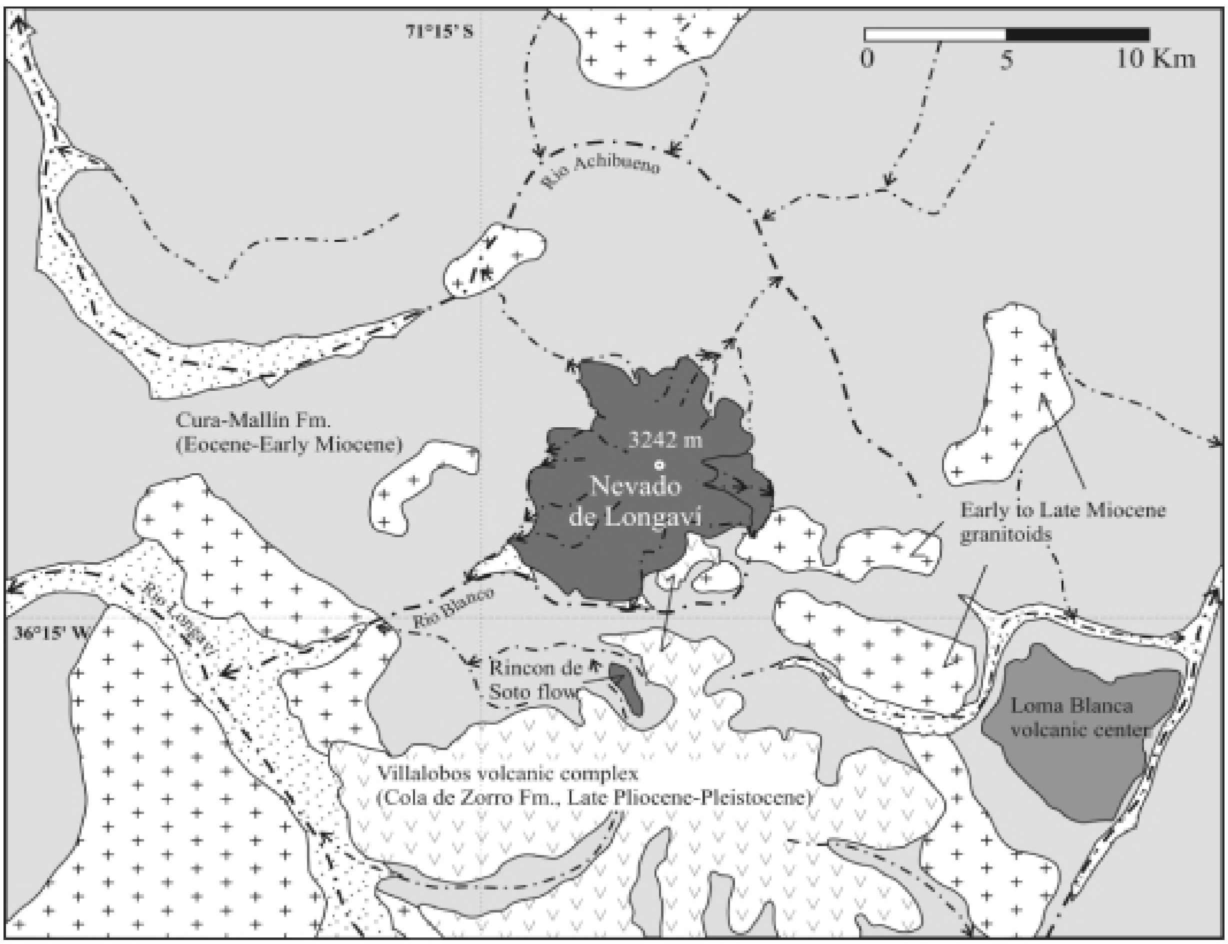

Fig. 2: Geological sketch of the Nevado de Longaví area. Main drainage is shown.

de Zorro Formation. South of NL, in the Cordón de Villalobos, outcrops of this formation define a large, low-profile deeply eroded volcanic edifice. Basaltic outcrops of this center are found on both sides of the Rio Blanco valley, 600 m above the current river base level.

CHEMISTRY AND MINERALOGY

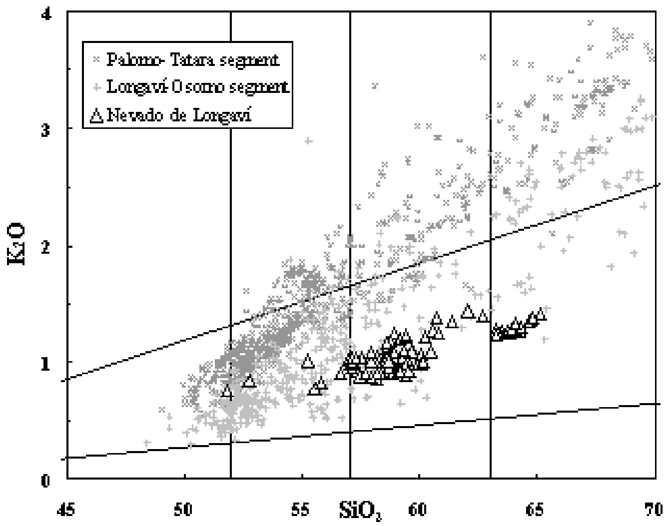

Fig. 3: Silica versus potassium plot for Nevado de Longaví lavas (magmatic enclaves excluded). Data from Palomo-Tatara and Longaví-Osorno segments is shown for comparison.

Andesites with 57-61 wt% SiO_2 are the most abundant magma type at NL. In addition, small amounts of basaltic (51.7% SiO_2) and dacitic (64-65% SiO_2) magmas were also erupted. Truly dacitic compositions were only produced during Holocene activity, while basalts dominate within a pre-Holocene sequence of nearly 300 m thickness, and a few basaltic flows are present in the Holocene units. Apart from this, basaltic to basaltic andesitic compositions have only been found in magmatic enclaves and cognate (?) xenoliths that are abundant in the andesitic lavas.

The suite of magmatic products from Nevado de Longaví shows a very singular and strong chemical signature when compared to other frontal arc centers of the SVZ, especially with respect to nearby centers. NL magmas are characterized by low abundances of nearly all the incompatible elements, both major (K_2O, P_2O_5, TiO_2; Fig. 3) and trace elements (Rb, Zr, Nb, REE, Y, etc), in addition to high Sr and Al_2O_3 values. The compositional spectrum at NL defines trends that are best explained as the consequence of magma mixing between a silicic component similar to the Holocene dacites and a basaltic end-member not too different from other basalts of the SVZ. The silicic component in these hybrid magmas is thought to have been derived from a high-pressure, metabasaltic source rather than having evolved from a mafic parent via fractional crystallization (see Rodríguez *et al.*, this volume).

In NL lavas, the most common phenocryst assemblage is ortho- and clinopyroxene plus olivine and/or amphibole; plagioclase is ubiquitous. Amphibole is a common phenocrystic phase in magmas with >57% SiO_2 (as a comparison, amphibole appears at ~68% SiO_2 in the Cerro Azul-Quizapu and Tatara-San Pedro complexes), and is dominant in dacites (>63% SiO_2), whereas olivine is common in rocks with <60% silica. Where olivine and amphibole coexist, one or both of them display disequilibrium textures such as reaction coronas. These textures may reflect the fact that olivine and amphibole are phases largely inherited from the components participating in the magma mixing.

VOLCANIC GEOLOGY

We present a subdivision of the NL volcanic edifice into four informal stratigraphic units. Three pre-Holocene units of unknown age are defined in terms of their dominant magmatic composition and mineralogy, whereas Holocene (i.e. post-glacial) products, with a wide range of compositions, have been grouped together.

LOWER ANDESITIC UNIT

The oldest recognized unit of NL is exposed primarily on the south and southeast flanks of the edifice (Fig. 4). Scarce remnants of this unit are exposed in valleys draining the northern face. It

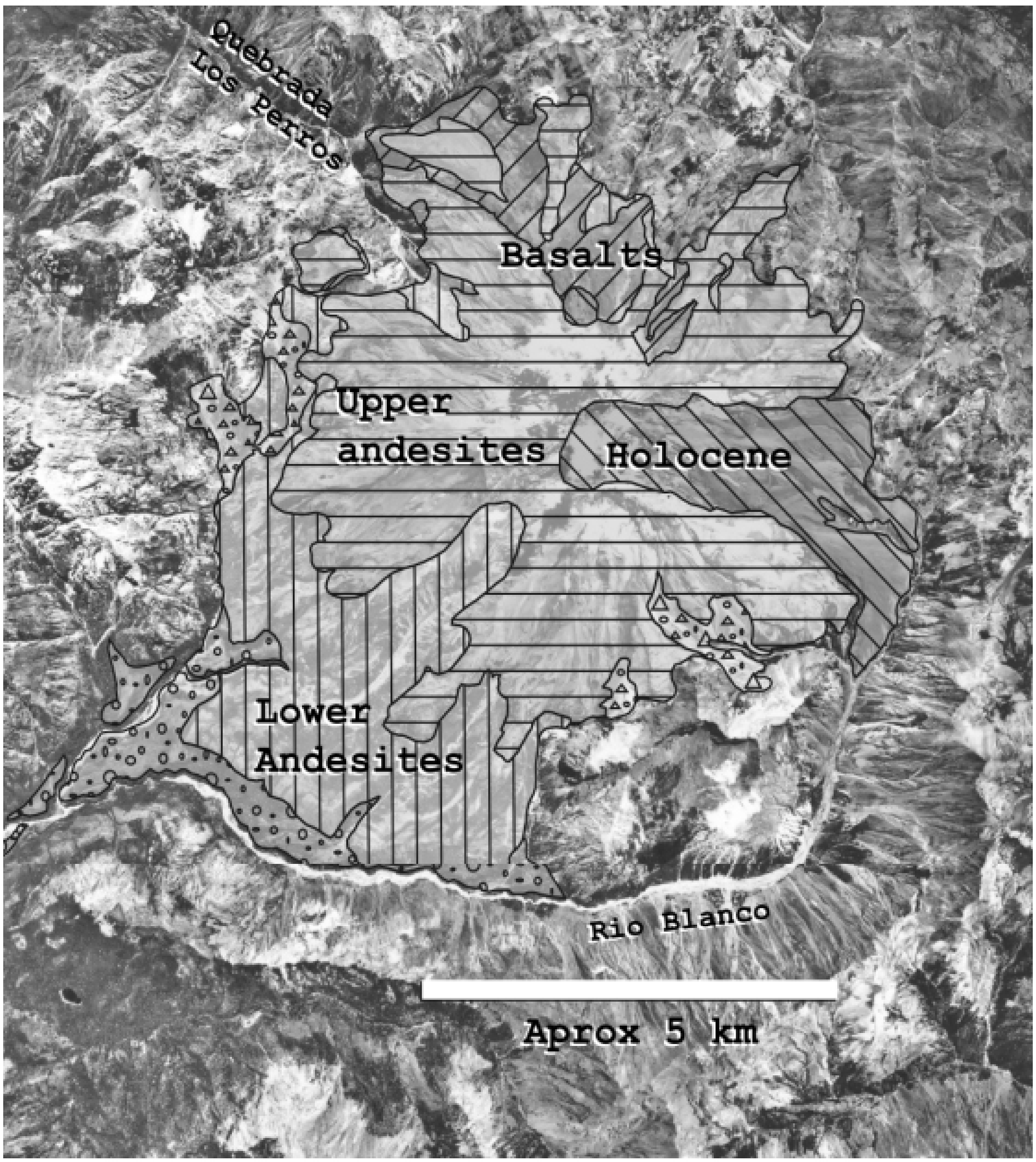

Fig. 4: Simplified sketch of distribution of the units discussed in the text. Circle patterns are for hanging terraces, and triangles for moraines.

is mainly composed of andesitic flows (57-60% SiO_2), and rare basaltic andesitic flows. The most common phenocryst assemblage is plag+cpx+opx±oliv. Scarce amphibole phenocrysts or xenocrysts that show strong disequilibrium textures are also found. Xenoliths and enclaves are uncommon. The flows from this unit have spread mainly towards the southwest, filling what was the drainage of the area before the excavation of the Rio Blanco (Fig. 4). This steep-walled valley has incised the basement ~600 m since deposition of Villalobos volcanics (~1 Ma K-Ar; Muñoz & Niemeyer, 1984).

BASALTIC UNIT

The northern flank of the volcano exposes a thick sequence, up to 300 m, of basaltic flows that overlie lower andesites and are covered by amphibole-rich upper andesite flows. The ensemble forms a radial apron on the north and northwest flanks, suggesting eruption from a vent located in this part of the edifice. Directly to the north of the presumed vent there seems to have been a topographic barrier that precluded further advance of the flows in this direction, leading to a diversion to the northwest and filling of a wide paleovalley near present-day upper Quebrada Los Perros (Fig. 4). Individual flows from this unit are 1-2 m thick, although in proximal areas the massive flows can be as thin as 20 cm and pyroclastic ejecta form up to 80% of the sequence thickness, suggesting a dominantly strombolian eruption style.

UPPER ANDESITIC UNIT

The youngest of the pre-Holocene units that built the cone corresponds to most of the upper portion of the edifice. This unit is composed of thick andesitic flows, which in the northern half cover the basaltic unit, while to the south they directly overlie the lower andesitic unit. Most of the unit forms ridges and other topographic highs that denote deposition in a topographic context different from the current landform, whereas some of the youngest flows follow current topography. In the northern slopes, ridges formed by old flows of this unit lay against Tertiary basement outcrops, and younger flows follow valleys excavated directly into the basement. We infer that a period of enhanced erosion is recorded within this unit, possibly a glacial advance that was able to eliminate the topographic barrier that controlled the distribution of the basaltic unit and part of the upper andesitic unit.

Magmas from this unit commonly contain abundant amphibole phenocrysts (besides ortho and clinopyroxene) and commonly carry amphibole-bearing plutonic xenoliths. Remnants of a flow from this unit, directly overlying pyroxene-phyric basalts, host an unusually high proportion (~5%) of gabbroic xenoliths displaying a wide range of textures and grain sizes.

HOLOCENE PRODUCTS

Holocene activity of the volcano has been concentrated in the summit area and on the eastern flank of the edifice, which has undergone pre-Holocene flank failure and collapse that resulted in the accumulation of up to 70m thick terraces along the narrow valley of the eastern and southern drainage, Rio Blanco (Fig. 4). The collapse affected the upper andesitic unit, and the small collapse basin (~2 km^2; Lomas Limpias basin) is currently partially filled with effusive and pyroclastic materials of Holocene age. The post-collapse sequence ranges in composition from basaltic to dacitic; i.e., Holocene activity covers the whole compositional range shown by the main edifice.

The oldest deposit found in the collapse basin is a thick reddish andesitic lava flow, partially polished by a late ice advance. It is an olivine and clinopyroxene (±oxidized amphibole) andesite that contains abundant fine grained enclaves and gabbroic xenoliths. This andesite is covered by a sequence of coarse, nearly monolithological black sediments formed by basaltic and basaltic andesite scoria and massive glassy fragments in a black ashy matrix. These sediments grade laterally to autobreccias and even to massive olivine basalt flows. Total thickness of the black sediments + lavas is <20m. Until the recognition of the basaltic unit in March of this year, this was the only known occurrence of basaltic compositions in the volcano, other than quenched enclaves in andesitic flows.

Covering the black sediments there is a thick pumice fall deposit (5 m) of dacitic composition (65% SiO_2), usually containing andesitic accidental fragments and granitic lithic accessories. Pumice fragments in the proximal areas can reach sizes up to 50 cm in diameter. The pumice blanket extends for more than 18 km to the southeast of NL. A sample of charcoal collected at the base of the pumice deposit some 5 km east of the Lomas Limpias basin was dated at 6,835±65 ybp.

The last volcanic event recorded at the volcano is the extrusion of a dacitic (64% SiO_2) dome in the upper part of the collapse basin and part of the summit area. The dome partly collapsed towards the east, forming block and ash deposits (estimated volume ~0.12 km^3) that cover the pumice-fall bed in the collapse basin. The dacitic magma is hornblende and orthopyroxene bearing, and it contains a high proportion (~3%) of quenched mafic enclaves. The major and trace element composition of this dacite is virtually identical to that of the underlying pumices, suggesting that both are products of a same eruption that evolved from open vent to dome extrusion. This dacitic magma is a close approximation to the evolved end member thought to be generally present as a mixing component in intermediate NL lavas (see Rodríguez *et al.*, this volume).

XENOLITHS AND ENCLAVES

The products from Nevado de Longaví volcano commonly contain abundant fine-grained quenched magmatic enclaves and coarse-grained plutonic xenoliths. They could represent as much as 0.5-1 % volume of the bulk upper andesite and Holocene units, whereas they are less abundant in the lower andesites and almost absent from the basaltic unit.

Mafic enclaves are rounded, decimetric-sized, fine-grained fragments included in massive lavas, and their compositions range from 52 to 58 % SiO_2. In thin section, enclaves are finely vesiculated, and highly crystallized (<15% interstitial glass), composed of acicular laths of plagioclase and amphibole and clinopyroxene granules. Some enclaves contain variably reacted or overgrown phenocrysts of plagioclase, pyroxenes and olivine.

Plutonic textured xenoliths are of two main types: 1) biotite and quartz-bearing granitoids and 2) hornblende-rich gabbroids. Type 1 granitoid xenoliths have only been found associated with the Holocene pumice-fall deposit as accidental ballistic fragments up to 40 cm diameter. They are petrologically and chemically similar to Miocene plutons cropping out in this area, and lack evidence of partial melting or other reactions with the juvenile magma despite their fertile mineralogy. Thus, they probably have been ripped from the basement at very shallow levels during the explosive eruption and have not participated as contaminants of the magmatic system.

Fig. 5: Appearance of a hornblende gabbro included in a flow from the upper andesitic unit. This fragment is highly reacted, with large amphibole crystals floating in a light, foamy glass matrix. Relict plagioclase appear as lighter dots. Note band of finer crystals towards bottom of the xenolith.

Gabbroic xenoliths (47-55% SiO_2) are common in the upper andesitic and Holocene units, and are very abundant in certain flows (~5% volume). They are angular or rounded fragments from a few centimeters to >30 cm diameter (Fig. 5). They are medium- to coarse-grained hornblende gabbros and pyroxene-hornblende norites and gabbronorites (nomenclature after Le Maitre, 1989), composed of calcic plagioclase (An ~90), calcic amphiboles (pargasite, magnesio-hastingsite), and less abundant orthopyroxene; olivine has not been observed. Amphibole is normally surrounded by dehydration coronas, being transformed to fine-grained aggregates of clino- and orthopyroxene plus less calcic plagioclase (An ~40-65) and iron oxides. This dehydration reaction often seems to trigger grain-boundary partial melting, which is seen as glass pockets (or channels if pockets are interconnected) that can represent up to 30% volume. Glass pockets are normally partially crystallized to plagioclase and pyroxene microlites. Rounded plagioclase and pyroxene crystals in and around melt pockets suggest that glass is an in-situ partial melt rather than a percolated liquid (Fig. 6). Grain boundary melting can also cause disaggregation of the crystalline network, releasing crystals into the host magma (i.e. xenocrysts formation).

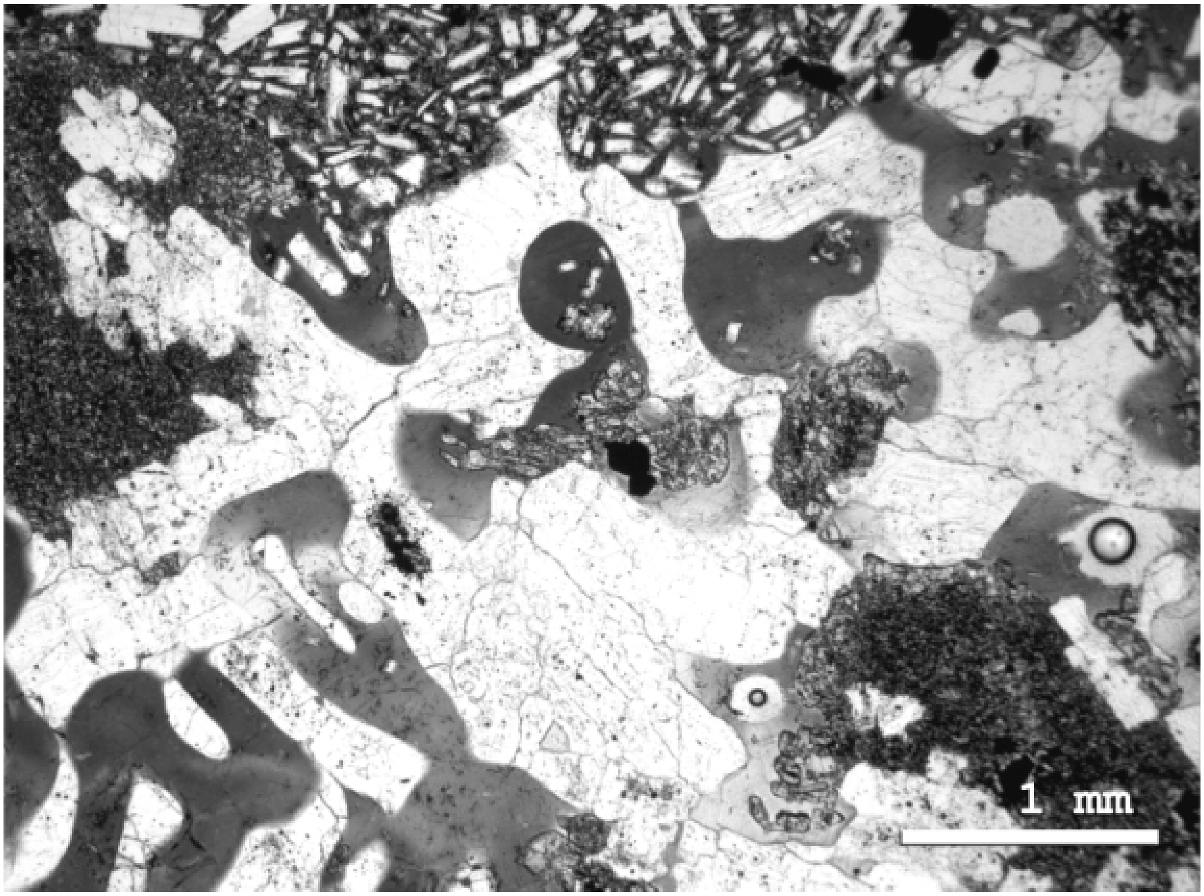

Fig. 6: Gabbroic xenolith with large melt pockets and channels (irregular forms, note rounded edges). Crystalline framework is mostly plagioclase (light) and fine-grained aggregates from amphibole dehydration (dark clusters). To the top, intersertal texture of the host andesitic lava.

SUMMARY AND CONCLUSIONS

Nevado de Longaví volcano has followed a relatively simple history of construction. Most of the edifice is built of andesitic lava flows that radiate from a common source, and no major explosive eruptions are recorded; only the recent history of the volcano comprises a small sector collapse and pyroclastic eruptions. However, a number of geochemical and mineralogical features make this center unique in the context of the SVZ, among which are outstanding the abundance of hydrous minerals and the common occurrence of gabbroic xenoliths, especially in the youngest units. In contrast with other magmatic systems of the SVZ, evolved compositions at Nevado de Longaví are probably not derived from mafic parental magmas via fractional crystallization but reflect participation of a different source. Intermediate compositions are mostly the result of magma mixing. Knowledge of the volcanic geology and internal stratigraphy are required in order to provide a framework to our ongoing petrologic studies.

Characterization of the gabbroic xenoliths contained in NL lavas is important to the understanding of the magmatic system in that: 1) they may represent deep-seated hydrous cumulates derived from NL parental magmas and, therefore, may pose important constrains on the parameters acting during the early stages of magmatic evolution, in particular the water contents implied in the extensive amphibole crystallization in a basaltic system, and 2) they could be modifying whole-rock composition of the host magmas via addition of a xenocrystic population and/or partial melts. We suspect that the high relative abundance of hydrated minerals in lavas and xenoliths and the particular chemical signature observed at Nevado de Longaví are not independent phenomena, but could be two direct consequences of a same particular geodynamical setting.

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