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Architectural characteristics and deposition of the 3635 ± 50 yr BP Pucón Ignimbrite of the Villarrica volcano, Southern Andes, Chile

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INTRODUCTION

Villarrica (39°25'S, Chile) is an Upper Pleistocene to Recent composite stratovolcano belonging to the volcanic front of the Southern Volcanic Zone (SVZ) of the Andes, and is one of the most historically active volcanoes in South America. It has shown recurrent explosive activity in postglacial times, in addition to its more typical effusive behaviour.

This paper deals with the explosive eruption that took place 3635±50 yr BP ago (^{14}C uncalibrated), called the Pucón Eruption. This event generated a complicated sequence of basaltic andesite pyroclastic-current deposits ('Pucón Ignimbrite'; Moreno, 1993; Clavero 1996), that extends up to 16 km from the volcano and has an estimated bulk (non-compacted) volume of 3±1 km^3. Today, approximately 15,000 people live within the area impacted by the Pucón pyroclastic currents, and even more in the zones covered by associated lahars and ash fallout. Tourism swells this figure to more than 40,000 in summer, particularly in the nearby towns of Pucón and Villarrica. This, combined with the past tendency of Villarrica for large-scale explosive activity, makes it important to reconstruct and understand the eruptive processes involved in ignimbrite-forming eruptions at Villarrica.

We have carried out a detailed field study of the Pucón Ignimbrite, including detailed logging of outcrops, along with lithological counting of fragments in key sections, allowing us to reconstruct the internal architecture of the deposit. This preliminary report is the first phase of a longer-term study of this important eruption.

ARCHITECTURE OF THE IGNIMBRITE

The Pucón Ignimbrite is a complicated sequence of pyroclastic current deposits, including massive and stratified facies. A strong topographic control is responsible for thick (up to 70 m) sequences in valleys and thinner (a few m) deposits on ridges. The main juvenile component of the deposits is basaltic andesite scoria and ash. The percentages of scoria and accidental clasts vary greatly in the deposits, scoria ranging from 40 to 90% in 4 mm fraction, and from 10 to ~100% in 16 mm fraction.

The base of the Pucón Ignimbrite is marked by a scoria fall deposit that crops out on the eastern, southern and northern flanks. It is up to 10 cm thick ~14 km northeast of the present-day summit. The conformable contact between the fall deposit and overlying current deposits indicates a short intervening time interval.

This study is the first to recognise two distinct units (P1 and P2) in the Pucón Ignimbrite, each with a different distribution around the volcano and with a distinct assemblage of accidental components. In particular, the upper unit, P2, is characterised by the presence of basement granitoids, both as free fragments and as inclusions in scoria, whereas these are absent in the lower unit, P1. The boundary between P1 and P2 is very sharp and whereas P1 occurs only on the western and northern flanks, P2 was deposited all around the volcano (Figure 1).

Lower unit (P1)

The P1 unit occurs only to the western and northern flanks of the volcano, covering an area of ~180 km^2 and extending radially up to 15 km from the present-day summit. It has an estimated volume of 0.6 km^3, about 20% of the total volume of the ignimbrite. The maximum thickness (up to 13 m) is attained where confined to valleys, and the unit is drastically thinned on ridges, even proximally (Figure 1). The absence of granitoid clasts within P1 enables this unit to be to readily distinguished from P2.

P1 is composed of up to ten stacked, well defined beds. The majority of the beds in valleys consist of massive lapilli tuffs deposited from high-concentration pyroclastic currents, since they show strong valley confinement, and, in some cases, steep flow fronts. Thin, subordinate beds of planar to cross stratified tuffs laid down by currents of lower concentration, also occur in the sequence. Degassing pipes rooted on charcoal traverse contacts between some beds, suggesting rapid emplacement of successive flows. On the other hand, lenses and beds of debris flow deposits within P1 indicate syn-eruptive remobilisation of pyroclastic debris by water.

Abundances of juvenile and accidental components vary vertically within P1. Beds in the lower half of the unit are relatively juvenile-poor, whereas a prominent black bed rich in juvenile ash, lapilli and bombs is widespread in the upper half.

Upper unit (P2)

In contrast to the restricted distribution of P1, the P2 unit occurs all around the volcano up to 15 km from the present-day summit, covering an area of ~530 km^2. It has an estimated volume of 2.5 km^3, about 80% of the ignimbrite. P2 occurs up to 70 m thick in valleys and up to 6 m thick on topographic highs. It consists of multiple pyroclastic current beds and only minor syn-eruptive reworked horizons. P1 deposits have not been found below P2 on the southern and eastern flanks.

Unit P2 is mostly composed of pale-brown, massive to stratified lapilli tuff (scoria flow deposits) that reach up to 30 m thick in valleys. The stratification can occur on a dm or even meter scale, producing a stacked succession of several layers that are laterally impersistent over a few metres or tens of metres, with possible bed forms tens of metres in scale. Ridge facies of this unit display spectacular dunes and cross bedding up to several meters in wavelength. P2 is locally highly erosive on the underlying P1 deposits, forming angular unconformities and meter-scale channels. The pale brown colour of these deposits reflects the generally high abundance of accidental lithic material.

Intercalated within P2 on the eastern, southern and (scarcely) western flanks of the volcano, there occurs a level rich in black juvenile ash, lapilli and bombs that can locally reach 30 m in thickness.

Post-Pucón sequence

Overlying the Pucón Ignimbrite is a sequence up to 2.5 m thick of scoria-fall deposits with thin, intercalated ashes that extends across the northern and eastern flanks of the volcano. This is interpreted as recording construction of a new cone following the Pucón eruption (Moreno, 1993). Some reworking of the ignimbrite took place prior to the onset of airfall activity, as witnessed by local preservation of intervening deposits from debris flows, hyper-concentrated flows and streams.

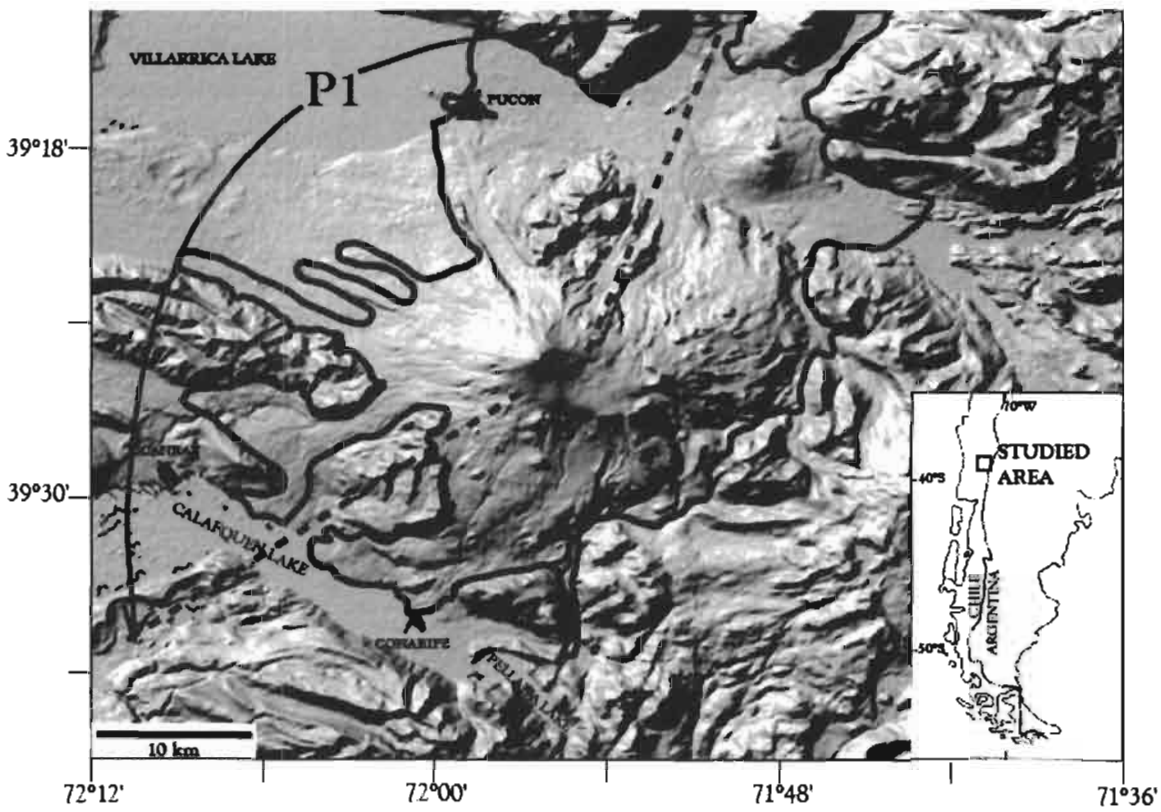

Figure 1: Shaded relief map of Villarrica Volcano and surroundings, including the lakes and the main towns. Field delimited by solid line shows the distribution of the Pucón Ignimbrite (modified from Clavero, 1996) that coincides with the distribution of P2 unit. Field delimited by dashed line shows the distribution of the lower P1 unit, restricted to the western and northern flanks

DISCUSSION

Emplacement of the Pucón Ignimbrite was preceded by scoria fallout extending to the north, east and south of the volcano. During the P1 eruptive phase, multiple pyroclastic currents swept down the western and northern flanks of the volcano. These were probably not very energetic, most being highly concentrated and valley-confined. Thin deposition on ridges was limited to the upper, more dilute parts of the currents. Syn-eruptive remobilization of these deposits by water generated lahars. Overall, field evidence suggests that the P1 phase may have been quite long in comparison with the subsequent P2 phase.

Emplacement of P1 may have been followed by a pause in eruption, because degassing pipes rooted on wood at the top of the P1 are locally cut by the P2 deposits. The length of this pause is unknown, but it must have been long enough for wood in P1 to stop burning.

The eruption then flared up again with the outpouring of highly energetic and unsteady pyroclastic currents, which spread all around the volcano. It was during this climactic phase that ~80% of the magma was discharged. The evidence indicating the high-energy nature of the P2 pyroclastic currents is: (1) the great extent of their deposits (2) the presence of large-scale cross-stratification and bedforms, (3) the presence of erosive structures such as channels and angular unconformities carved by the P2 flows into the already deposited P1 unit. The absence of laterally persistent, well defined beds (and syn-eruptive reworking) implies probable rapid emplacement of P2.

Strong vent erosion, possibly with caldera collapse, must have accompanied the Pucón eruption, because most of the deposits are rich in accidental lithic components. However the eruption was punctuated, during both the P1 and P2 phases, by discharges of hot, magma-rich pyroclastic flows, forming prominent black-juvenile-rich horizons. The presence of abundant granite in P2 shows that violent and deep fragmentation of the basement of the volcano must have accompanied this phase.

The conformable contact between the precursor air fall and the ignimbrite indicates that a relatively low-hazard fallout eruption was rapidly followed by the generation of voluminous and destructive pyroclastic currents. This has implications for hazards mitigation at Villarrica Volcano.

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