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Holocene volcanism and vertical displacements along a major intra-arc transpressional system in the Southern Andes

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Introduction

As for other convergent margins, Quaternary volcanism in the Southern Andes is strongly related to the kinematics of margin-parallel intra-arc fault systems. Microtectonic analysis shows evidence of post-Pliocene NE dextral transpression over the entire arc, at least from 38° to 46°S where the Liquiñe-Ofqui Fault system (LOF) develops. Nevertheless, the Holocene activity along this fault remains poorly known and no clear evidence for strike-slip displacement has been found. Holocene flank cones on stratovolcanoes are mainly oriented NE, compatible with the ongoing dextral transpression if they are interpreted as maximum horizontal stress (σhmax) indicators (*e.g.*, Nakamura, 1977). In addition, some isolated oblique (NE) chains of Holocene monogenetic centres can be assumed as tension cracks (*e.g.*, Dhont *et al.*, 1995) and therefore support the dextral transpression. Nevertheless, master faults from the LOF system does not show clear strike-slip displacement markers on surface nor when it runs underneath the Holocene volcanic centres or cut long-live river valleys. In contrast, morphological features along these faults suggest recent vertical displacement with westward downgoing blocks. Because several monogenetic cones lie on top of traces of north-south master faults of the LOF system, the nature of the relationship between vertical movements and volcanism is a key topic for understanding the Holocene tectomagmatic evolution in Southern Andes. In this contribution we examine an area of the volcanic arc around 39°S, where outstanding morphological features suggest vertical displacement controlled by master faults of the LOF system and several stratovolcanoes and monogenetic cones were built on top of the fault traces or over different structural blocks bound by them.

Numerical geomorphology: evidences of vertical movements along the LOF system

A numerical approach for the study of river networks shows systematic kink points on the river profiles when crossing the structural blocks and master faults of the LOF system (Fig.1). Because in orogenic settings with high rates of denudation these morphologic markers can be considered very young, a causal relationship between vertical displacement on the master faults and monogenetic volcanism sitting on top of them should be direct. For a quantitative analysis, the Trancura river (39°S) watershed basin was automatically extracted from the SRTM Digital Elevation Model. By means of the D8 algorithm of RiverTools™ software we have analysed sub basins and their morphometric parameters. For example, hypsometric curves (Strahler, 1952) are sensitive to the incision-erosion equilibrium and describe the juvenile or mature stage of valley development. Thus, convex curves with high hypsometric integrals (>0.4) are typical of deep incised and non-recovered channel profiles. Near concave curves with low hypsometric values suggest a mature geomorphic stage. Across the central block,

Trancura river shows a mature stage of braided river with low slope and high sinuosity but its tributaries Liucura and Maichin rivers show juvenile profiles. Sharp changes of sinuosity that coincide with the branches of the LOF system can be observed on the along-channel profile of Trancura river. On the contrary, the Malleo river shows a flat profile on the eastern stable block.

In addition two topographic profiles across the transpressional orogen at 39°S show outstanding changes in the mean altitudes next to the main traces of the LOF or Reigolil-Pirihueico Fault (RPF).

Microtectonic data: evidence of Quaternary compression and transpression

Mainly from Lavenu and Cembrano (1999) and unpublished data of the authors, a Quaternary transpressional regime is recognised along the entire volcanic arc in Southern Andes. Scarce focal mechanisms for earthquakes that accompanied eruptions (Barrientos and Acevedo, 1992; Cifuentes, 1989) are compatible with this framework. Nevertheless, in several places, microtectonic data indicate compressive regime or strike-slip with high stress ellipsoid shape ratio ($R=[\sigma_2- \sigma_1]/ [\sigma_3- \sigma_1]$). This is the case of 39°S area, similar than the Puyehue-Cordón Caulle sector (40°S) where a singular magmatic and tectonic evolution has been (Lara *et al.*, submitted).

Volcanic geomorphology: local evidence of a strike-slip component or 'passive' role of regional faults

Volcanic features as alignment of flank cones on Villarrica or Quetrupillán stratovolcanoes show a systematic NE-trending direction compatible with a strike-slip dominated regime. Flank vents on Lanín volcano are radially distributed, which is reasonable if this volcano was built on the eastern non-deformed block. However, Holocene monogenetic cones built on top or near the traces of LOF system (Huelemolles and Caburgua groups) have circular basal shapes without other tectonic markers on surface. In addition, while Holocene flank vents erupt evolved basalts, monogenetic cones erupt primitive ones from deeper sources (López *et al.*, 1995; Hickey-Vargas *et al.*, 2002) suggesting a connection between tectonics and magma ascent throughout the crust.

Discussion

Despite the poor geochronological resolution, the Quaternary tectonic evolution of the area shows evidence of transpressional strike-slip deformation and vertical displacement along the master faults of LOF system. At least a part of the total amount of vertical dip-slip should be Holocene. Thus, Holocene monogenetic cones that lies on top of these master faults should be related to the vertical displacement along them instead of lateral movements. Possible mechanisms to account for local extension orthogonal to master faults include the following: (1) 'postorogenic' collapse allowing short periods of arc-normal extension in an ongoing transpressional regime, aided by postglacial isostatic rebound and (2) coseismic extension of the upper plate during very large earthquakes triggering widespread extension along trench-parallel fault zones within the arc (*e.g.*, Lara *et al.*, 2004). Thus, local strain related to vertical displacements along the master faults would allow magma extraction from the MASH zone by non-Andersonian dykes which would feed monogenetic volcanoes on surface.

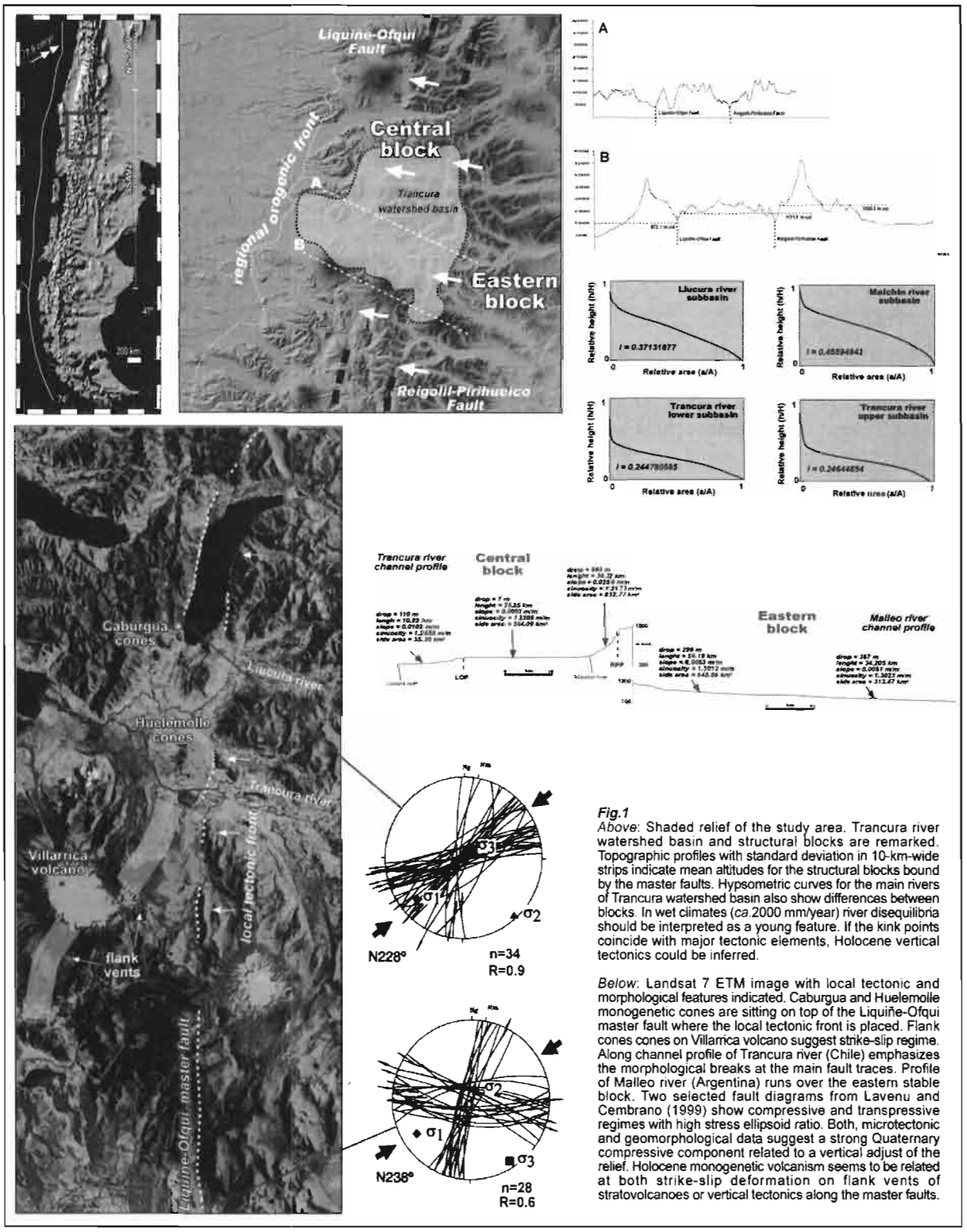

Fig.1
Above: Shaded relief of the study area. Trancura river watershed basin and structural blocks are remarked. Topographic profiles with standard deviation in 10-km-wide strips indicate mean altitudes for the structural blocks bound by the master faults. Hypsometric curves for the main rivers of Trancura watershed basin also show differences between blocks. In wet climates (*ca.*2000 mm/year) river disequilibria should be interpreted as a young feature. If the kink points coincide with major tectonic elements, Holocene vertical tectonics could be inferred.

Below: Landsat 7 ETM image with local tectonic and morphological features indicated. Caburgua and Huelemolle monogenetic cones are sitting on top of the Liquiñe-Ofqui master fault where the local tectonic front is placed. Flank cones cones on Villarrica volcano suggest strike-slip regime. Along channel profile of Trancura river (Chile) emphasizes the morphological breaks at the main fault traces. Profile of Malleo river (Argentina) runs over the eastern stable block. Two selected fault diagrams from Lavenu and Cembrano (1999) show compressive and transpressive regimes with high stress ellipsoid ratio. Both, microtectonic and geomorphological data suggest a strong Quaternary compressive component related to a vertical adjust of the relief. Holocene monogenetic volcanism seems to be related at both strike-slip deformation on flank vents of stratovolcanoes or vertical tectonics along the master faults.

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