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Dynamic topography control on Patagonian relief evolution as inferred from low temperature thermochronology

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ABSTRACT

We combine low-temperature thermochronology apatite (U–Th)/He data and semi-analytical modeling of dynamic topography to investigate the role of slab window and climate on cooling/heating history and relief evolution of the Patagonian Cordillera. In particular, we discuss a new thermochronological dataset consisting in 22 samples divided into four elevation transects. Sampling sites were chosen at the same distance from the trench (250–300 km), on the leeward eastern side of the orogen, for latitudes ranging between 45°S and 48°S to detect a potential northward migration of the thermal signal associated with the northward migration of the slab window. We show that history of heating and cooling for this region of the southern Andes compares well with the northward migration history of slab window. In particular, a phase of heating is recorded at 15–10 Ma to the south and at ≤ 5 Ma to the north, preceding by ~ 5 Ma the opening of the slab window beneath Patagonia, followed by a phase of rapid cooling and denudation to the south, with values as high as 650 m/Myr between 5 and 3 Ma. We also show that present-day latitudinal topographic variations require a support by dynamic topography associated with slab window.

1. Introduction

The formation and evolution of relief in subduction-related orogens result from a variety of processes acting at different scales of time and space. The interplay between tectonics and erosion (river incision, glacial erosion…) is generally the principal contributor to the relief development (e.g., Beaumont et al., 1992; Willett, 1999; Montgomery et al., 2001; Whipple and Meade, 2006). Earth's surface topography is also shaped by mantle convection, the latter producing a long-wavelength uplift or depression of the surface as a response to the distribution of density anomalies in the mantle (e.g., Ricard et al., 1984, 1993; Hager et al., 1985; Hager and Clayton, 1989; Cazenave et al., 1989; Mitrovica et al., 1989; Gurnis, 1993; Le Stunff and Ricard, 1995). But inferring dynamic topography is not straightforward as the signal is often blurred by the isostatic signal, topography being more sensitive to crustal and lithospheric structures.

The Andes are a classic example of subduction-related orogen, in which the effect of dynamic topography produced by the sinking of oceanic lithosphere is potentially important. Indeed, global models of present-day dynamic topography show that central and northern Andes, where subduction has been continuous since at least $\sim$40 Ma, are regions where the subsidence associated with mantle dynamics is one of the strongest in the world (e.g., Hager and Clayton, 1989; Ricard et al., 1993; Lithgow-Bertelloni and Gurnis, 1997; Steinberger, 2007; Conrad and Husson, 2009). Conversely, beneath the southern Andes, subduction during Tertiary has been discontinuous because of the interaction of oceanic ridges separating the Nazca, Antarctic and Phoenix plates with the trench at $\sim$18 Ma, which led to the formation and progressive enlargement of a slab window underneath Patagonia (e.g., Breitsprecher and Thorkelson, 2009).

The formation and the migration of this slab window have caused a hiatus of calc-alkaline arc volcanism, the emplacement of alkaline magmas in the eastern foreland (e.g., Kay et al., 1993; Gorring et al., 1997; Guivel et al., 2006), and produced positive

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dynamic topography, i.e. a broad uplift of the continent, that may have been responsible for the modification of the drainage network in the eastern foreland since at least the late Miocene (Guillaume et al., 2009) and for the differential uplift rates of Quaternary coastal sequence along the Atlantic passive margin (Pedoja et al., 2011). Slab-window-related dynamic topography should have also been active in the Patagonian Cordillera. However, its contribution has never been considered mainly because local flexural and isostatic adjustments due to tectonics and erosion obscure the dynamic topography signal. In particular, glaciations, recorded by the oldest glacial till preserved in South America, played an important role in shaping the Andean landscape as early as ca. 5–7.4 Ma (Mercer and Sutter, 1982; Ton-That et al., 1999).

Recently, Thomson et al. (2010) documented the role of glaciers in the recent erosional history of the Patagonian Andes through low temperature thermochronology (Apatite Fission Track (AFT) and (U–Th)/He on apatite (AHe) dating). These authors report that samples south of 49°S are systematically older, indicating that they have been eroding, on average, more slowly in the last 5 Myr, and with less total erosion. They ascribe the lower erosional rates and increased height of the orogenic divide at these latitudes to glaciers protection (Thomson et al., 2010). However, the influence of vertical motions associated with the opening of the slab window is not discussed, despite the change in erosion rates which coincides with the present-day triple junction latitude.

The role of slab window on cooling/heating history in the Patagonian Cordillera has been partially addressed by Haschke et al. (2006), who provided the first and only AFT age–elevation profile so far, reaching the conclusion that slab window might have participated to a phase of reheating between ca. 10 and 6 Ma. However, their study is restricted to one specific location (Cerro Barrancos, 47.57°S) and does not allow for comparison with other regions that may have known different thermal stories.

In this study we used a different approach consisting in collecting 22 samples divided into four elevation transects. Sampling sites were chosen at the same distance from the trench (d=250–300 km), for latitudes ranging between 45°S and 48°S to detect a potential northward migration of the thermal signal associated with the northward migration of the slab window (Fig. 1). After a presentation of the obtained results and their interpretation in terms of exhumation/burial/heating history, we will discuss how the subduction of an active ridge and the successive formation of a slab window can impact the relief history of the Patagonian Andes.

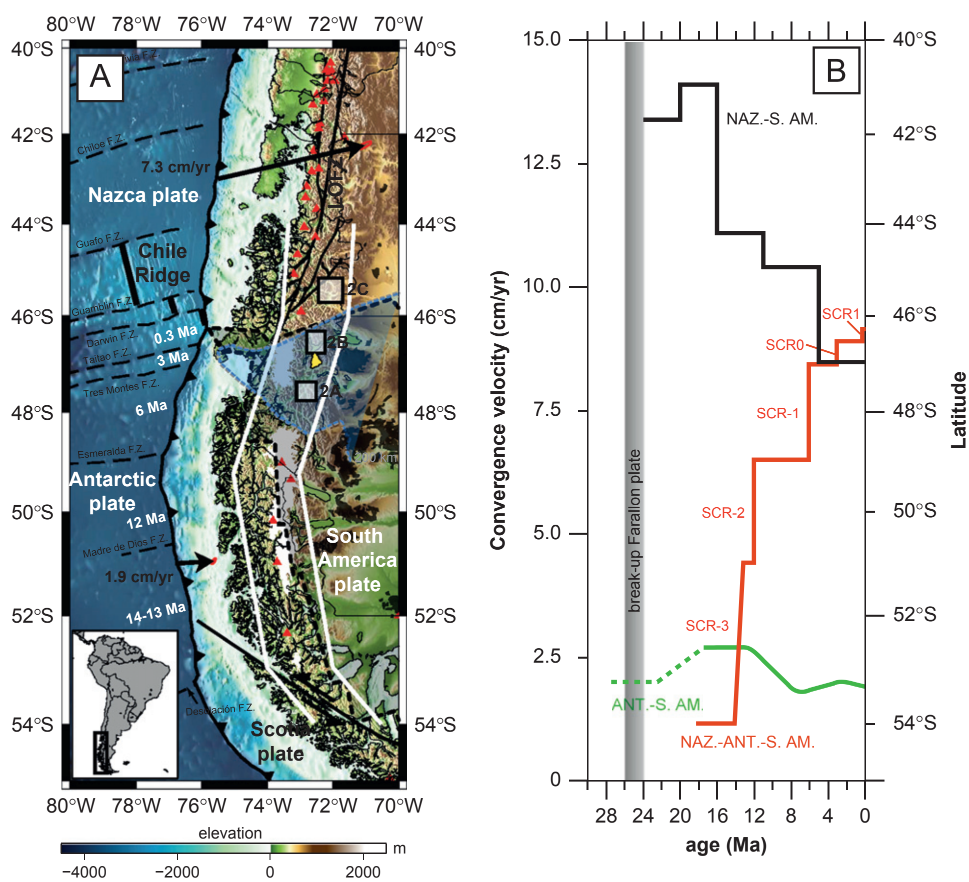

Fig. 1. (A) Tectonic setting of the western Patagonia. White squares indicate sampling sites for Apatite (U–Th)/He dating. Topography has been extracted from the SRTM30_PLUS V6.0 data set (Becker et al., 2009). Convergence velocities have been calculated using the MORVEL2010 plate model (DeMets et al., 2010) (http://www.geology.wisc.edu/~chuck/MORVEL/motionframe_mrvl.html). The black dashed lines correspond to the present-day kinematically-reconstructed Nazca and Antarctic slab edges (Breitsprecher and Thorkelson, 2009), which define the extension of the Patagonian slab window. The blue dashed line underlines the −0.5% velocity perturbation at a depth of 200 km of the P-wave tomography model of Russo et al. (2010a). The location of the Liquiñe-Ofqui fault zone (LOFZ) is taken from Cembrano et al. (2002) and Thomson (2002). Red triangles correspond to the Holocene arc volcanoes taken from the Smithonian Institute database (http://www.volcano.si.edu/index.cfm). White lines define the lateral extension of the area used to build the swath profiles of Fig. 5. Location of the Cosmelli Basin is displayed in yellow. Numbers indicate the age of arrival at trench of the ridge segments between the corresponding fracture zones. Neogene plateau basalts are displayed in black (from Panza et al., 2003). (B) Trench-perpendicular convergence rate between the Nazca (NAZ.) and South American (S. AM.) plates at ~42°S (black line) (Somoza and Ghidella, 2012) and between the Antarctic (ANT.) and South American plates at ~52°S (green line) (after Sdrolias and Müller, 2006) during the last 28 Myr, the subduction of the Antarctic plate starting only ~18–17 Ma ago. The red line indicates the triple junction (Nazca–Antarctic–South American plates) position during the last 18 Myr (after Cande and Leslie, 1986 and Breitsprecher and Thorkelson, 2009). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)