What controls long-term orogeny at a convergent continental margin ? The Andean case

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To this date, the question of why and how a plateau-type orogen formed with crustal thickening at the leading edge of western South America remains one of the hotly debated issues in geodynamics. During the Cenozoic, the Altiplano and Puna plateaux of the Central Andes (average elevation some 4 km, with an extent of 400 x 2000 km) developed during continuous subduction of the oceanic Nazca plate in a convergent continental margin setting – a situation that is unique along the 60,000 km of convergent margins around the globe. The key challenge is to understand why a first-order mechanical instability of the later plateau extent developed along the central portion of the leading edge of South America only, as well as why and how this feature developed only during the Cenozoic, although the cycle of Andean subduction had been ongoing since at least the Jurassic. Moreover, it would appear that only rarely has this style of orogeny occurred in Earth history, another example probably being the Cretaceous North American Laramides. Since the 1980s, a plethora of models has been published that attempt to find a solution to this 'geodynamic paradox' (Allmendinger et al., 1997). A major integrated research program hosted by Berlin and Potsdam Earth science research units has attempted to unravel the mechanisms underlying plateau formation at a convergent continental margin.

Deep geophysical data across the Central Andes between 20°S and 24°S (ANCORP'96 and associated geophysical studies; ANCORP working group 2003) indicate the widespread presence of partial melts or metamorphic fluids at mid-crustal level under the plateau between the Cordilleras bounding the latter. From structural balancing studies, these fluids or melts are associated with decoupling of upper crustal shortening and lower crustal thickening. Based on similar indications from the distribution of magmatism it has been argued commonly that in fact upper plate weakening from widespread heating and partial melting may have been the key to understanding its widespread shortening behind the volcanic arc (Isacks, 1988; Allmendinger et al., 1997). In addition, changes in plate convergence are usually considered to have been responsible in tuning the changes in the upper plate system. While the available wealth of geophysical data would seem to lend support to the role of melts and fluids in upper plate orogeny, the sensitivity of elastic, thermal, and conductivity parameters as registered by most geophysical imaging techniques, may overemphasize this role.

We therefore analyzed the temporal and spatial evolution of deformation to provide better constraints for the identification of key mechanisms (see Elger et al., 2005, and Oncken et al., 2005 for details). Another feature unique to the Central Andes, is the complete preservation of syntectonic volcanics and sediments throughout the orogen and at its margins allowing high spatial and temporal reconstruction of the deformation history. Isotopic age-dating on these deposits as well as seismic-sequence analysis demonstrate that the Southern Altiplano crust was deformed with a complex partitioning of deformation between various subunits that were partly synchronized. The general acceleration of shortening rate shows only a weak link to plate convergence rates for the early stages. In contrast, our results show that the differential velocity between upper plate velocity and oceanic plate hinge and slab rollback velocity is crucial in determining amount and rate of shortening as well as their lateral variability at the leading edge of the upper plate (see suggestions by Russo and Silver 1996, Heuret and Lallemand, 2005). This first order control is tuned by factors affecting the strength balance between the upper plate lithosphere and the plate interface of the Nazca and South American plates. These factors particularly include a stage of reduced slab dip accelerating shortening (33 and 20 Ma) and an earlier phase of higher trenchward sediment flux reducing plate interface coupling with slowed shortening and enhanced slab rollback (45 and 33 Ma). The latter was not controlled by the Cenozoic climatic evolution (cf. Lamb and Davis, 2003) but rather by construction and erosion of local relief during early stages of shortening. As a consequence of the interaction of these parameters at the site of the southern hemisphere global arid belt, a plateau accumulating significant shortening developed in the backarc of the South American volcanic arc – as opposed to most other circum-Pacific margins that focus deformation in the forearc. The combination of these parameters (in particular differential trench-upper plate velocity evolution, high plate interface coupling from low trench infill, and the lateral distribution of weak zones in the upper plate leading edge) was highly uncommon during the Phanerozoic leading to very few plateau style orogens at convergent margins like the Cenozoic Central Andes in South America or the Laramide North American Cordillera.

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