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Unsteady evolution of the Bolivian Subandean thrust belt: The role of enhanced erosion and clastic wedge progradation

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ABSTRACT

The Subandean fold and thrust belt of Bolivia constitutes the easternmost part of the Andean orogen that reflects thin-skinned shortening and eastward propagation of the Andean deformation front. The exact interplay of tectonics, climate, and erosion in the deposition of up to 7.5 km of late Cenozoic strata exposed in the Subandes remains unclear. To better constrain these relationships, we use four W–E industry seismic reflection profiles, eight new zircon U–Pb ages from Mio-Pliocene sedimentary strata, and cross-section balancing to evaluate the rates of thrust propagation, shortening, and deposition pinch-out migration. Eastward thrusting arrived in the Subandean belt at ~12.4±0.5 Ma and propagated rapidly toward the foreland unit approximately 6 Ma. This was followed by out-of-sequence deformation from ca. 4 to 2.1 Ma and by renewed eastward propagation thereafter. Our results show that the thrust-front propagation- and deposition pinch-out migration rates mimic the sediment accumulation rate. The rates of deposition pinch-out migration and thrust propagation increased three- and two fold, respectively (8 mm/a; 3.3 mm/a) at 8–6 Ma. The three-fold increase in deposition pinch-out migration rate at this time is an indication of enhanced erosional efficiency in the hinterland, probably coupled with flexural rebound of the basin. Following the pulse of pinch-out migration, the Subandean belt witnessed rapid ~80 km eastward propagation of thrusting to the La Vertiente structure at 6 Ma. As there is no evidence for this event of thrust front migration being linked to an increase in shortening rate, the enhanced frontal accretion suggests a shift to supercritical wedge taper conditions. We propose that the supercritical state was due to a drop in basal strength, caused by sediment loading and pore fluid overpressure. This scenario implies that climate-controlled variation in erosional efficiency was the driver of late Miocene mass redistribution, which induced flexural rebound of the Subandean thrust belt, spreading of a large clastic wedge across the basin, and subsequent thrust-front propagation.

1. Introduction

The Subandean fold-and-thrust belt of the Central Andes is the type-example of an active thin-skinned fold-and-thrust belt in a retroarc, non-collisional tectonic setting (e.g., Gubbels et al., 1993; Dunn et al., 1995; Kley et al., 1996; Moretti et al., 1996; Echavarria et al., 2003). With a maximum elevation of 1.7 km, this tectonic province is located to the east of the Cordillera Oriental and the Altiplano in the orogen interior. The Subandes are characterized by NNE–SSW oriented thrusting and deeply incised valleys that are connected with the foreland. Many investigations have ascribed shallow crustal shortening in this region directly to the crustal thickening processes that produced the Altiplano (e.g., Isacks, 1988; Gubbels et al., 1993).

The chronology of the clastic sediments preserved within and adjacent to the Subandes furnishes a unique archive about the geodynamic, topographic, and climatic evolution of the Andean tectonic provinces. Furthermore, volcanic ash horizons in the thick synorogenic Subandean strata of Bolivia provide the opportunity to develop a chronology of deformation and depositional processes and to study the interaction between tectonics, climate, and erosion.

To date the study by Echavarria et al. (2003) provides the only well-constrained study concerning the geometry and timing of the Subandean fold-and-thrust-belt in adjacent northwestern Argentina, documenting lowered shortening rate of 0–5 mm/yr between 7 and 2 Ma. In the central Andes, Garzione et al. (2006) and Ghosh et al. (2006) used oxygen isotope data obtained from paleosol carbonates to propose that the northern Altiplano rose to an elevation of ~3900 m between 10.3 and 6.8 as a result of mantle delamination. However, the lack of quantitative data for most of the Subandean region, especially in the north and east of these investigations, has hampered the validation of these models. Surprisingly, despite the fundamental role

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attributed to the Subandean belt in conjunction with the evolution of the orogen interior, relatively little is known about the timing and magnitude of deformation in the Subandes. Indeed, a rigorous assessment of timing of deformation, propagation rate of the thrust belt, and the relationship between tectonics and climate-driven processes in shaping the Subandes has been prevented by the lack of a reliable chronostratigraphy and rigorous analyses of the Neogene synorogenic stratigraphic records.

With this study, we aim to unravel and better constrain the onset of thrusting, propagation of deformation, and erosional processes in the Bolivian Subandes. To achieve this, we used 8 new zircon U–Pb age determinations augmented by recently published ages across the belt (Echavarria et al., 2003; Hulka, 2005; Uba et al., 2007), industry seismic reflection profiles, well-log data, and outcrop studies. Our new chronology combined with deposition pinch-out migration and sedimentologic data provides a detailed record of the tectonic evolution of the Subandes in Bolivia. In addition, this study furnishes proxies for past erosional and transport efficiency, and information on the mechanisms governing deformation patterns in this thrust belt.

2. Geological setting and late Cenozoic stratigraphy of the Subandean zone

The central Andean evolution is linked to subduction of the Farallon/Nazca plate under the South American plate. In the course of the non-collisional mountain building in the Andes, under-thrusting

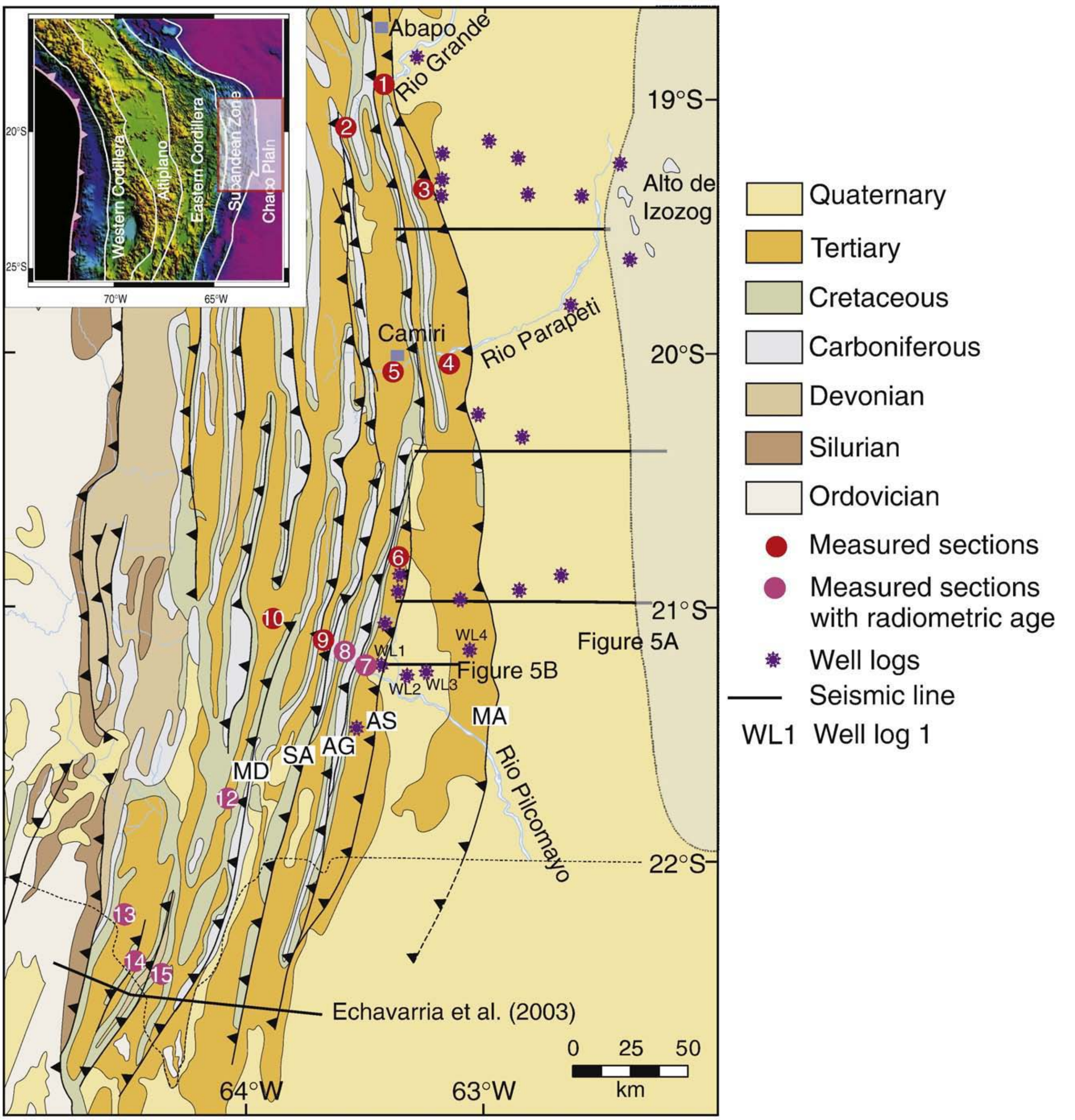

Fig. 1. Digital elevation map of the central Andes with the principal morpho-structural provinces and the location of the study area (inset) and the geological and structural map of the study area showing the location of measured sections, measured sections with radiometric ages, well-log data, and seismic profiles used in this study: 1, Abapo; 2, Tatarende; 3, Saipuru; 4, San Antonio; 5, Itapu; 6, Machareti; 7, Angosto del Pilcomayo; 8, Puesto Salvación; 9, Zapaterimbia; 10, Rancho Nuevo; 11, Sanadita; 12, Chiquiaca; 13, Emborozú; 14, Nogalitos; 15, San Telmo; MA, Mandeyepecua Fault; AS, Agua Salada; AG, Aguarague range; SA, San Antonio; MD, Mandiyuti Fault.