Long-wavelength subsidence in the Andean broken foreland: Sublithospheric controls on the sedimentation and topography of the Sierras Pampeanas?

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Introduction

Subsidence in retroarc foreland basins has been mostly explained by flexural analysis, in which a thrust belt load elastically bends the lithosphere producing depozones. Particularly in ancient examples, the methodology is based on matching the stratigraphic record, the deformational features that constitute a supracrustal load, and the mechanical properties of the crust. Yet, other controls ("hidden or sublithospheric loads") can act adding extra load. Thus the crustal bending generated only by supracrustal loads may be insufficient to explain the subsidence history, and an attempt to attribute all the subsidence to supracrustal loads results in overestimation of its true influence. Along a subduction margin, oceanic lithosphere subducting under a continent is also a load (Gurnis, 1992). Plausible physical processes in that setting include the effect of the thermal contrast between the slab and the overlying mantle. According to Mitrovica et al. (1989) this may result in up to 1 km of long-wavelength subsidence (dynamic subsidence). Densification of the lower crust (eclogitization, Leech, 2001) may also produce long-wavelength subsidence, particularly when the crustal thicknesses exceed 45 km. Nevertheless, demonstrating from the stratigraphic record that features deeper than the upper crust control subsidence is a challenging issue, still in debate (Liu and Nummedal, 2004).

In the Central Andes, flexural models have been extensively applied to account for the foreland basin subsidence (e.g. Toth et al., 1996; Cardozo and Jordan, 2001; DeCelles and Horton, 2003; among others). Few works have considered subcrustal influences, even though the South American plate has been complexly affected by a long-lasting history of subduction at least since the Early Paleozoic.

We present here surface and subsurface evidence in the Andean broken foreland of Argentina of long-wavelength subsidence, driven by processes occurring in the upper mantle or lower crust, which overlapped with the short-wavelength pattern of deformation, due to local basement thrusting.

Geological setting

The present study focuses on the Sierras Pampeanas (SP) region (27°-34° SL), southern Central Andes, within the broken foreland of western and central Argentina (Fig. 1). The region lies in the distal foreland on the Modern flat-slab segment, although its northern end is located in a transitional zone to normal subduction. The SP is characaterized by a set of ~N-S elongated basement ranges, bounded by doubly-vergent, high-angle faults affecting crystalline basement (Fig. 2). The basement highs are surrounded by Neogene basins, acknowledged as broken foreland or intramontane basins. They are entirely formed by a very thick (occasionally >10 km thick), non-marine, coarse- to fine-grained alluvial megasequence. From outcrop and subsurface, at least three major sequences (early Miocene, mid Miocene and Plio-Pleistocene) can be discriminated (Fig. 2), which suggest major tectonic/climate changes.

Structural and stratigraphic evidences of long-wavelength subsidence

We interpret the shortening in the SP to be inadequate to create supracrustal loads sufficient to drive subsidence of the Neogene basins, given that the shortening is between 2-20% (Jordan and Allmendinger, 1986; Costa et al., 1999; Dávila, 2003); and the vertical displacements, inferred from thermochronology, <<3 km (Jordan et al., 1989; Coughlin et al., 1998; Dávila, 2003). However, the intervening basins possess larger thickness of alluvial strata, deduced from surface (Dávila, 2003) and subsurface data (Alvarez et al., 1990; Fisher et al., 2002; own data; Fig. 3). In contrast, the role of long-wavelength subsidence is not yet evident in the western SP, where basement thrust offsets seem to be larger than in the eastern SP. In this region, subsurface data suggest that long-wavelength subsidence affected the broken foreland region at least since the beginning of the Miocene. Only "old" apatite fission tracks ages have been found thus far, and structural relief is modest (Jordan et al., 1989; Coughlin et al., 1998; Dávila, 2003). Although basement thrusting occurs after deposition of the youngest units in several basins (eg, La Rioja, Mascasin, Los Llanos and Saliniana Basins, Fig 3), the Modern topography is likely a result of superposition of recurrent deformational events (Paleozoic + Mesozoic ?), inferred from facies analysis, reactivated during the Andean deformation. In the subsurface, thicknesses of strata of 1-2 km are widespread between the ranges, not confined to the zones near basement faults. Seismic sequences are bounded by subtle angular or erosional unconformities (Fig. 3). This indicates that regional net subsidence occurred since the Early Miocene (see Fig. 2). The long-wavelength of the subsidence (Fig. 3) and large magnitude of the preserved stratigraphic thicknesses indicate that a regional scale load in addition to fault-related subsidence influenced the distal foreland during the Miocene-Present. Forced aggradation to defeat basement barriers (Astini et al., 2004) would have contributed to both tectonic causes of subsidence.

Deep controls in the Andean broken foreland?

Considering that the SP was located above a flat slab segment at least since the Early Miocene (Dávila et al, 2004), the long-wavelength stratigraphic record and the uncommon thicknesses might be due to shallow subduction. Laramide subsidence has been partially explained by dynamic topography, when flat subduction occurred in western North America. Theoretically, during slab flattening the corner mantle wedge tends to shift toward the continent (eastward in the Andes), hence increasing the mantle flow in that direction, and creating an extra downwarping force that favors regional subsidence, not accounted for in previous flexural analysis in the SP and the Argentine Precordillera (eg., Cardozo and Jordan, 2001).

Besides providing a logical interpretation for the stratigraphic record and deformation, dynamic topography would also explain elevations in the SP. The northern and southern SP differ, based on geological, geophysical and topographic characteristics. The northern SP has thicker Neogene units involved in deformation than the southern regions, and possesses higher altitudes of both peaks and valleys (Fig. 4). Both regions are isostatically unbalanced, but the northern SP presents evidence of isostatic "rebound" (Martínez and Giménez, 2003), with peaks >4-5 km and crustal thicknesses ~45 km. In contrast the southern SP seems to be pulled downward (Fromm et al., 2004), possessing altitudes that barely exceed 2 km, but crustal thickness that locally reaches 55 km (Fig. 3). The mean altitude in the valleys contrasts as well, >650 m in the northern SP and <500 m in the southern SP (Fig. 4). Dynamic topography modeling predicts that when subsidence diminishes the zone will recover progressively, favoring surface uplift. If we presume that flat subduction migrated southward as a propagation wave through the SP (cf. Yañez et al., 2001; Kay and Mpodozis, 2002), then during the early Miocene dynamic subsidence would have affected the northern portion of the SP producing extra subsidence and a great thickness of alluvial sequences. These sequences were exposed later, when the dynamic wave migrated to its present position in the southern SP, provoking the regional subsidence pattern recorded by seismic velocity studies (Fromm et al., 2004). This progression may also explain the differences in altitudes, not easily accounted for basement deformation.

Eclogitization during crustal thickening (by thrusting or/and lower crustal flow) has a similar effect, driving regional subsidence by crustal densification. This densification could be associated with the arrival and interaction of the Juan Fernandez ridge in the SP region, affecting the northern SP in the early Miocene, and then the southern SP in the late Miocene-Pliocene. Both dynamic topography and eclogitization may have occurred, with overlapping consequences on the present topography and stratigraphy.

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Fig. 1

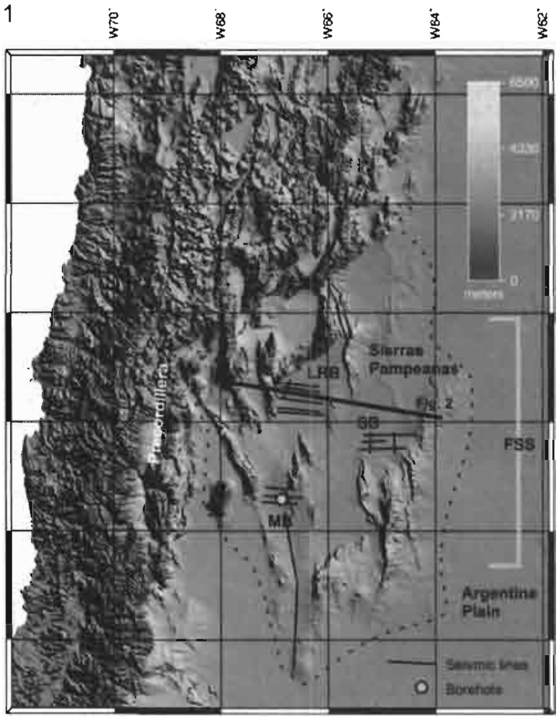


Fig. 1. Shaded topographic relief image, showing: The Sierras Pampeanas (inside the contoured line) and its boundary regions (the Argentina Plain to the E and the Precordillera to the W). The area affected by the flat slab is shown with FSS. Short black lines show locations of available reflection seismic data. Longer black line shows location of section in Fig. 2. MB: Mascasin Basin, Saliniana Basin, LRB: La Rioja Basin.

Fig. 2

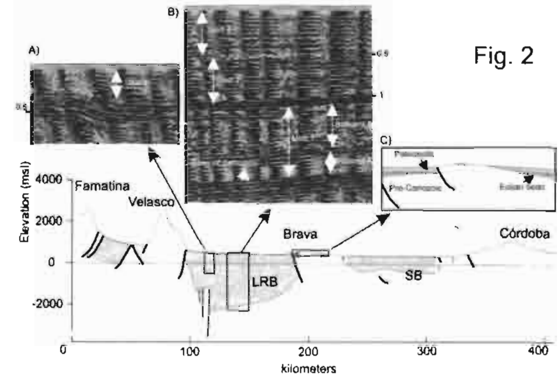
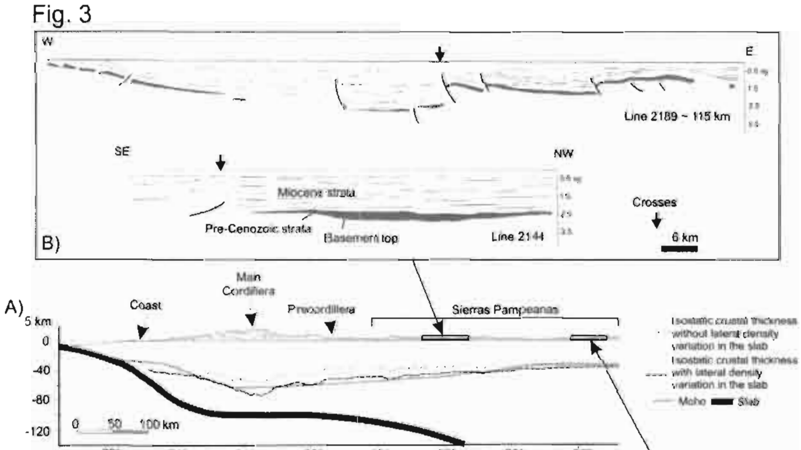


Fig. 2. Composite regional cross-section across the Sierras Pampeanas (SP) region at ~30° S (based on Alvarez et al., 1990; Fisher et al., 2002; Dávila, 2003). Note the thickness and basin geometry in the La Rioja basin (LRB) and Saliniana basin (SB), and their relationship with basement thrusting loads, where the topography/depocenter ratio is <1. A) and B) are seismic interpretations in the LRB. Reflectors allow recognizing several intervals within the Cenozoic, reflecting sequence boundaries within the 'broken foreland megasequence' (BFM), as also supported by outcrops relationships (see C). At least three major sequences can be discriminated from the seismic sections, which may be correlated with the early Miocene, middle Miocene and Mio-Pliocene sequences described in outcrops in the SP. Sharp contacts between major basement thrusts and the Neogene sequences, without evidence of growth strata, suggest that faulting would have occurred during at least two stages within the broken foreland basin deposition: 1) Uplifting related with the formation of the regional basal unconformity and, supply from the basement highs, and 2) thrusting that postdates deposition of sequence 2. This evolution correlates with the stratigraphic record interpreted from surface data in the western SP.

Fig. 3



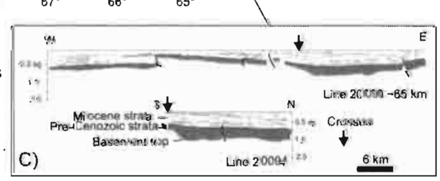


Fig. 3. A) Regional cross section at ~31degrees S, showing the mean topography, the slab geometry and crustal thickness calculated by seismic velocity studies and gravity (Modified from Fromm et al., 2004) across the Central Andes. B) and C) show insets with the interpreted seismic cross sections of Mascasin Basin (B) and Saliniana Basin (C). See also location in Fig. 1. Sections modified from Alvarez et al. (1990).

Fig. 4

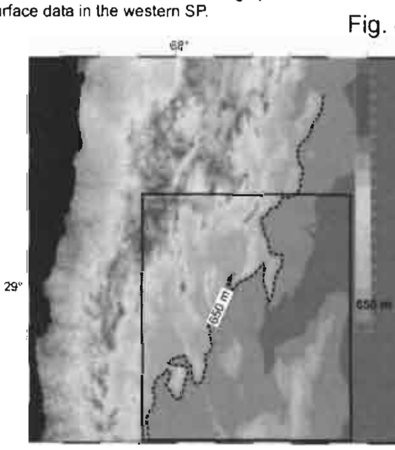


Fig. 4. Topography of the southern Central Andes, depicting the Sierras Pampeanas (SP) area, and the 650-m contour (dash line) separating the high-altitude intermontane valleys in northern SP from the low-altitude intermontane valleys in southern SP. Note that the peaks show a similar topographic relation. The higher altitude ~NE-SW trend in the northern SP largely matches the southward drifting of the Juan Fernandez Ridge (JFR) during the Neogene.