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Rapid Late Cenozoic surface uplift of the central Chile Andes (33°-35°S)

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INTRODUCTION

The Andes of Central Chile, located S of the flat-slab subduction zone, is segmented into 4 morphostructural units: Coastal Range, Central Depression, Main Cordillera and Frontal Cordillera. E of the Central Depression, between 33° and 35°S, the range rises of >2000 m in a few tenths of km (west-orogenic front, WOF, Fig. 1), reaching over 4000 m a.s.l. At the water divide (Andean crest) the highest summits correspond to Pliocene-Recent volcanoes. The Main Cordillera consists of late Eocene-early Miocene deposits of the Abanico Fm.

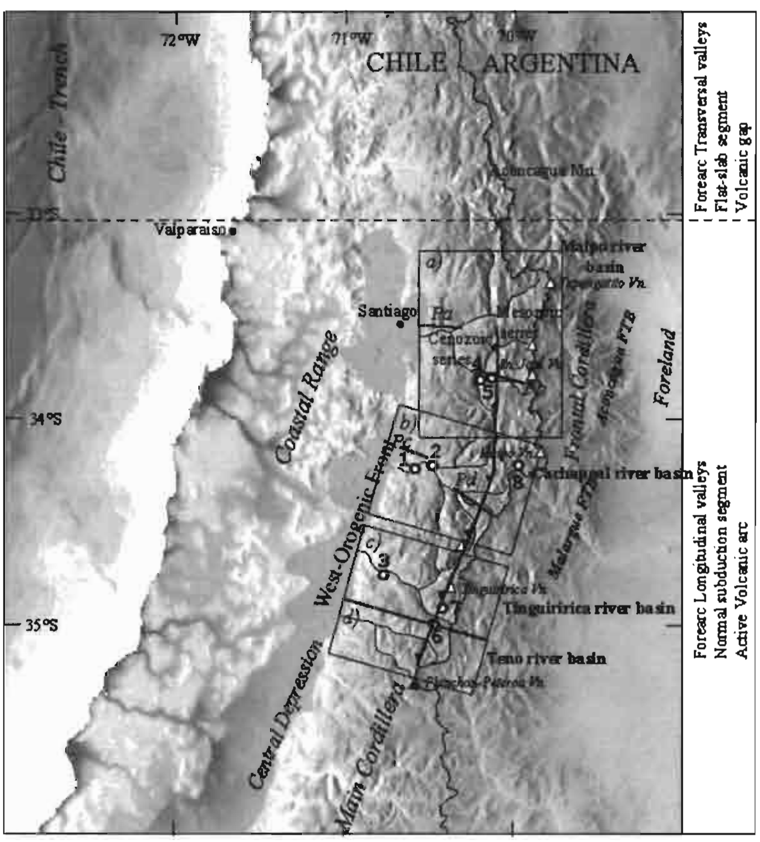

Figure 1. Shaded relief map of the study region showing the main morphostructural units of the southern Central Andes south of the flat-slab segment. a, b, c and d boxes show the segments used in Fig. 3. White hexagons (1-8) show samples location (Table 2). Pa, Pb, Pc and Pd lines correspond to the sections shown in Fig. 2.

overlain by the Miocene volcanic Farellones Fm. (Thiele, 1980; Charrier et al., 2002), and the Frontal Cordillera consists of Mesozoic back-arc sedimentary and volcanic rocks (Giambiagi et al., 2003). The contact between Cenozoic and Mesozoic rocks is located in the eastern Main Cordillera. Its nature is tectonic and corresponds to a major E-vergent thrust (Fig.1) that probably induced the development of the fold-thrust-belt (FTB) to the E, and a major back-thrust to the W (Chacayes-Yesillo fault, Fig. 1, 2a). Deformation of the Abanico Fm. during basin inversion since early Miocene times generated folds of variable amplitude and tightness (Godoy et al., 1999; Charrier et al., 2002), whereas the overlying Farellones Fm. is almost undeformed (Fig. 2). The Mesozoic series exhibits higher deformation, and participates in the hybrid thin and thick-skinned Aconcagua FTB (N of 34°S) and thick-skinned Malargüe FTB (S of 34°S) (Fig. 1). The main stage of deformation occurred between Early and Middle Miocene, followed by uplift of the Frontal Cordillera after 9 Ma (Giambiagi et al., 2003). Between 6 and 4 Ma, out-of-sequence faults were reactivated in the eastern Main and western Frontal Cordillera representing the final deformation on this side of the belt. In the Pliocene, deformation migrated to the Cuyo foreland (Giambiagi et al., 2003). Giambiagi and Ramos (2002) calculated about 50 km shortening in the southern Aconcagua FTB. Origin of the Andes is attributed to crustal thickening due to tectonic shortening associated with rapid and almost normal plate convergence since Oligocene times. However, shortening at that latitude is mainly concentrated in the backarc region (e.g. Giambiagi and Ramos, 2002), and is smaller in the Chilean side (e.g. Charrier, 1981). We present a model for the Andean surrection in Central Chile based on drainage basin analysis and morphological analysis, complemented with apatite fission-track (AFT) ages to constrain the time span and rate of exhumation between 33° and 35°S.

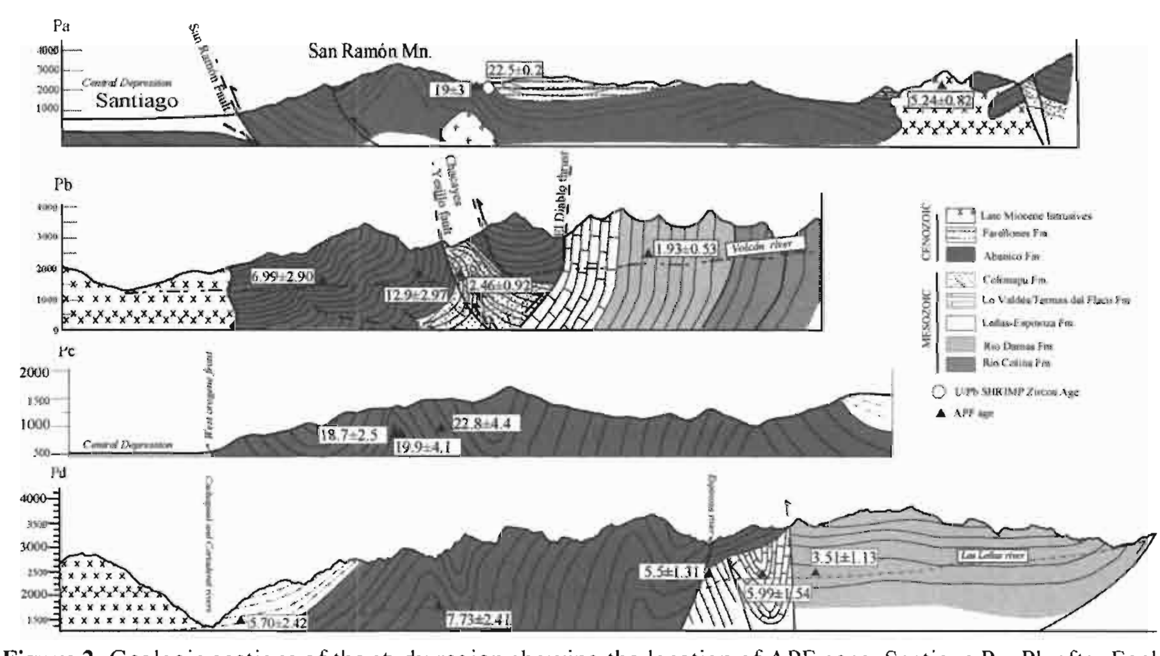

Figure 2. Geologic sections of the study region showing the location of APF ages. Sections Pa, Pb after Fock et al. (this symposium), Pc, Pb modified from Charrier (1981)

DRAINAGE BASINS ANALYSIS

The study area includes 4 major drainage basins (Maipo, Cachapoal, Tinguiririca and Teno river basins, Fig. 1). The drainage areas diminish from N to S, as well as their relief (Table 1 and Fig. 3a). However, the minimum elevations for each section normal to the WOF are similar (Fig. 3b). Minimum profiles in the WOF present a convexity that can be correlated with a major W-vergent thrust (San Ramón-Pocuro fault, Rauld, 2002), although these knickpoints can be alternatively explained by the passage to an almost unchannellized morphology. Upstream a convexity can also be observed spatially related to the structural system that bounds the former Abanico basin with the FTB (Fig. 3b). This system is still active, but accommodates strike slip deformations (Barrientos et al., 2004; Charrier et al., 2004). Hypsometric analyses of the basins described above show integral values close to 0.4 (Table 1), within the equilibrium range (Strahler, 1952). This situation is interpreted as resulting from a long-term equilibrium between uplift rates and erosion rates.

Basin	Maipo	Cachapoal	Tinguiririca	Teno
Drainage area [km^2]	5006.5	2753.1	1840.3	1411.6
Basin relief [km]	5.680	4.297	4.006	3.171
Hypsometric integral	0.4138	0.4219	0.4166	0.4240

Table 1. Main drainage basins morphologic data

	Altitude from valley bottom [m]	Age [Ma]	Incision rate [mm/yr]
1	150	2.3 ± 0.2[1]	0,08 ± 0.01
2	75	1.3 ± 0.7[2]	0.06 ± 0.03
3	0	0.93±0.05[3]	0
4	150	0,45±0.6[4]	0.3±0.4
5	1750	0.91±0.02[5]	1.86±0.04
6	1250	1.10±0.07[6]	1.68±0.10
7	1125	0.95±0.24[6]	1.71±0.43
8	710	0.352±0.048	2.443±0.3

Table 2. Incision rates calculated from the position of lava units with respect to present-day bottom valleys. Ages from (1) Charrier and Munizaga (1979), (2) Gómez (2001), (3) Malbran (1986), (4) Stern et al. (1985) and Baeza (1999), (5) Baeza (1999), (6) Arcos (1987). See Fig. 2 for the position of samples.

APATITE FISSION TRACK AGES

15 AFT ages were obtained for the study region (Fig. 2). AFT ages obtained in samples collected close to the WOF correspond to depositional ages because they coincide with U-Pb ages from neighbor levels (earliest Miocene; Fock et al., this symposium) (Fig. 2, Pa). To the E, AFT ages are younger than the radiometric or fossil ages, and are, thus, considered to be exhumation ages. These ages range between ~12 and ~2 Ma. Considering the dynamic equilibrium deduced above, exhumation would actually equal surface uplift. Therefore, considering a normal thermal gradient of 25° to 30°C (Maksaev et al., 2003) the surface uplift rate is about 0.6-2.6 mm/yr, being higher for the eastern samples. This situation, in conjunction with the absence of contractional deformations along the structural system that delimits the Cenozoic from the Mesozoic series since Pliocene times and morphological evidence (next section), can be interpreted as the development of a westward tilting of this part of the Andes (see below). Alternatively, the younger ages to the east could be explained by an increase in the thermal gradient close to the volcanic arc, as has been calculated by Springer and Forster (1998) in northern Chile.

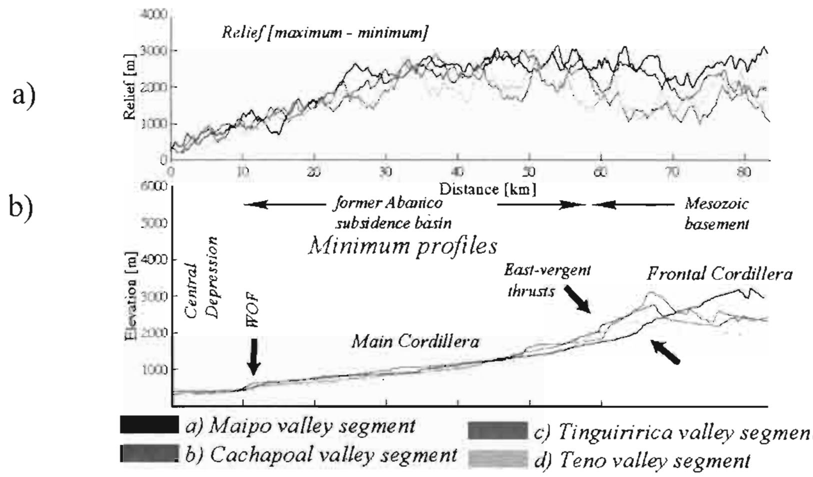

Figure 3. Topographic profiles constructed on the basis of normal segment to the orogene shown in Fig. 1. For each segment, minimum and maximum was obtained, calculating the relief as the diference between these 2 values (a). (b) shows the minimum profiles, where it can be observed.

MORPHOSTRATIGRAPHIC MARKERS OF INCISION, UPLIFT AND TILTING

Several Pliocene to Recent volcanic lavas are exposed either over flat unconformities or hanging on valley slopes, depending of their location relative to the Central Depression (Table 2). In general, older lavas overlie unconformably flat surfaces near the headwater of drainage basins, whereas younger lavas filling river valleys are exposed slightly above the present-day valley bottoms or directly on them near the WOF (Table 2). The emplacement of lava flows in the valleys is indicative of base level lowering. In the Tinguiririca valley, lava deposits do not exhibit displacements caused by faults. S of the Teno river, the Pliocene volcanic Cola de Zorro Fm. (González and Vergara, 1962) forms continuous slightly west-dipping deposits that can be followed from the high Cordillera to the Central Depression. Their basal contact, to the E, is located high above the present-day valley bottom, but almost reaches the thalweg next to the WOF (Table 2). The continuity of the lava deposits in conjunction with the higher incision upstream suggests that the decrease of base level is possibly triggered by westward tilting of the forearc, as proposed above on the base of the AFT ages analysis.

ORIGIN OF SURFACE UPLIFT.

Obtained AFT ages register a surface uplift that began in Late Miocene times, coeval with the beginning of uplift of the Frontal Cordillera (Giambiagi et al., 2003). The main stage of exhumation beginning at ~5 Ma shown by the AFT (see above; Maksaev et al., 2003) can be correlated with the E-vergent out-of-sequence faults development on the western side of the FTB. Considering the temporal relationship between the proposed tilting of the Chilean Andes and the FTB deformation, it appears reasonable to postulate the development of a wedge of FTB that pushed to the west the rigid block formed by the Abanico and Farellones fms. (Fig. 4), facilitated by the rheologic contrast between these two blocks. On the other hand, this contraction would be increased by the rigid slab-coupled forearc composed by Mesozoic rocks in the Coastal Range, which form an east-dipping homocline. Convergence between the slab-coupled forearc and the Cenozoic block (Fig. 4) compelled the reactivation in the WOF of faults bounding the Abanico basin, which, indeed, show contractional focal mechanisms (Pardo et al., 2004). This situation is similar to that observed in the Argentina foreland, where contractional events have been registered by the Harvard CMT, contrasting with the strike-slip solutions obtained in the Eastern boundary of the Cenozoic block (Barrientos et al., 2004; Charrier et al., 2004). Strain partitioning accommodating the oblique subduction of the oceanic plate (Fig. 1) would result from the high elevation that opposes horizontal shortening in the main Cordillera, shortening concentrating in lowlands (Central Depression and foreland).

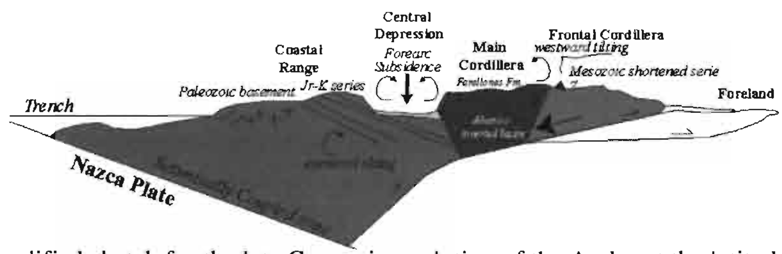

Figure 4. Simplified sketch for the late Cenozoic evolution of the Andes at the latitude of Santiago.

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