LATE MIOCENE VOLCANIC ARC THICKENING IN THE CHILEAN CENTRAL ANDES :Seismic and gravity constraints

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INTRODUCTION

Two main unconformities have been advanced for the thick Meso-Cenozoic rocks of the central Chilean Andes : an upper Cretaceous and a Lower Tertiary (Klohn, 1960; Charrier 1981).

The former, however, has either not been recognized east of Santiago (Thiele, 1980) or has been reinterpreted as an out-of-sequence thrust SE of that city (Godoy, 1990). Only recently has the latter, according to Sempere et al (1993) closely related to development of Late Oligocene-Early Miocene foreland basins from Colombia to Central Chile, been subject to a major revision south of 33°45'. Godoy and Lara (1994) report that, south of that latitude and along its eastern margin, the Miocene arc (over 3,000 m thick Middle to Upper Miocene andesites and ignimbrites of the Farellones Formation) lies either conformable or is thrust eastward on top of its lower Cretaceous to lower Miocene (Flynn et al, 1995) pyroclastic basement. Godoy et al (1996), on the other hand, show that most of the miocene arc western margin is underthrusted by that basement.

In this paper we present preliminar seismic and gravimetric data of the arc western margin across 34° S.lat. They support the structural relations of Godoy et al. (1996) and help constrain the Late Miocene to Early Pliocene contribution to upper crustal thickening.

MIOCENE ARC GEOLOGIC SETTING

Contrary to Thomas (1953) and Godoy (1993), who describe interfingering of the Farellones andesites with its underlying pyroclastics, most authors stress an unconformable contact (Aguirre, 1960; Rivano et al, 1990). Thiele et al (1991), on the other hand, while favoring deposition of the Farellones Formation inside "caldera-grabens", state that "no generalizations can be made about the contact relations between the two formations". Lastly, Crystallini et al (1994), recognize -along its easternmost outcrops- that deformation started before, but outlasted deposition of the lavas.

As recently pointed out (Godoy et al, 1996), three segments characterize the present-day western margin of the Miocene arc. North of 33°35' Farellones is slightly detached westward, mainly along its basal ignimbrite. The detachment is interpreted as the upper limit of a triangular zone whose enclosed volcaniclastics (Abanico formation) become tightly folded southwards. South of 33° 10' the older unit (here known as Coya-Machalí Formation) is tuffaceous siltstone-bearing and tightly folded against the triangular zone. Sub-vertical fault-propagation folds, some of them broken, characterize the intermediate segment of the arc western margin .

In addition to the controversial basal contact relation, age of uplift and erosion rates of the miocene arc in the chilean central Andes have also been debated. 2,000 to 2,350 m of post-Miocene uplift has been calculated using paleobotanic and fluid inclusion data (Pons and Vicente, 1985; Skewes and Holmgren, 1993). Erosion rates of 260 to 150 m/Ma are advanced by the latter authors, while 800 m/Ma for the last 8.4 Ma and 700 m/Ma for the Pleistocene are proposed by Kay and Kurtz (1995) and Godoy (1993).

The isotopic signature of the Coya-Machalí rocks points to magma generation under a thinned crust (Nystrom et al., 1993). The crust was slightly thickened during the mid-Miocene to a 10 km thickness, rapidly increasing to reach a maximum (35 km?) near the Miocene-Pliocene boundary (Kurtz et al., 1995). Thickening controls the dramatic increase of La/Yb ratios (20 to 61) recorded in the El Teniente porphyries (Kay and Kurtz, 1995) and cannot be accounted solely by the upper crustal shortening discussed in this paper. According to the last authors, rapid crustal thickening in the Miocene arc should coincide with failure of the ductile lower crust.

GEOPHYSICAL FRAMEWORK: A JOINT SEISMIC AND GRAVIMETRIC MODELING

Gravimetric stations were measured every 500 m along the main roads of El Teniente Copper Mine, using differential GPS for the horizontal and vertical positioning. The strong terrain correction has been thoroughly computed using a digital terrain model from 1:50,000 topographic charts and an analytical near-field correction in very rough topography sections. As a whole, the residual gravity signal has an envelope of error below 3 mgals. Additionally a seismic refraction line was acquired using experiment El Teniente Copper Mine induced events (rockbursts) and mining blasts as seismic source. Arrivals from these sources were recorded during a period of several days by portable seismic stations in a total of 14 points located along an approximately E-W profile to distances of about 40 km westward from the mine. A station located inside the mine was used to measure the origin time of the rockburst or blasting events.

The profile in Figure 1 was constructed from the 2-4 per day events, strong enough (magnitude=0.8-1.5) to be detected unambiguously in the different stations. The seismic interpretation was carried out by travel time forward modeling of first arrivals using laterally homogeneous velocity models. Our final model and the predicted travel time curves are also shown in Figure 1. The seismic data indicate a superficial 4.5 km/sec, 2.3-km-thick low-velocity layer overlying a 6.2 km/sec half space. The boundary between the upper low-velocity layer and the high-velocity half space is interpreted as the decoupling plane between a deformed uplifted core of the Coya-Machalí Formation and its more competent lower section. Further east, this detachment plane crops out as a northward shallowing out-of-sequence thrust (Figure 2).

The more continuous and detailed gravimetric experiment uses the seismic modeling constraint expressed in terms of a density contrast between an upper low-density layer at the deformed Coya-Machalí core and relatively high-density layer underneath the detachment. We adopted a standard two-layer density section of 2.67 gr/cm^3 in the upper 2.5 km, over a pseudo half space of 2.7-2.75 gr/cm^3. Density estimates from seismic velocities are consistent with a pseudo-half space of 2.7 gr/cm^3 and a low density zone of 2.45-2.5 gr/cm^3 in the upper section (a density contrast of -0.12 gr/cm^3 w/r to the standard section). 2-D gravimetric modeling (Figure 3) using the seismic and geological constraints, agrees well with a decoupling plane at ~ 2.5 km, and a deformed core of the Coya-Machalí Formation bounded by two antithetic structures that accommodate deformation and thickening in the western flank of the area.

CONCLUSIONS

Uplift of the Miocene arc at 34^o S.lat. is related to an asymmetric compressional horst with a 2.5 km deep detachment level. Decoupling is interpreted from seismic and gravimetric profiles in its western flank, where a low velocity/density upper layer of 2.3-2.5 km rests on top of a more competent basement. The geometry of the 2-D gravimetric modeling is also consistent with a compressional regime in the western margin of the arc, a triangular zone linked to a narrow belt of tightly folded underlying volcaniclastics.

Both boundary faults of the horst are younger and thus "out-of- sequence" when compared to the main Neuquén Basin fold-and-thrust belt, close to the Argentinian border. They are however "in-sequence" in relation to the Pleistocene to Holocene basement faults uplifting the Frontal Cordillera.

This Late Miocene to Early Pliocene upper crustal shortening matches the progressively southward shallowing of the Nazca plate recorded by geochemical signatures. Its contribution to crustal thickening, however, is minor (15%) compared to the overall increase. A deeper crustal contribution to thickening is therefore expected.

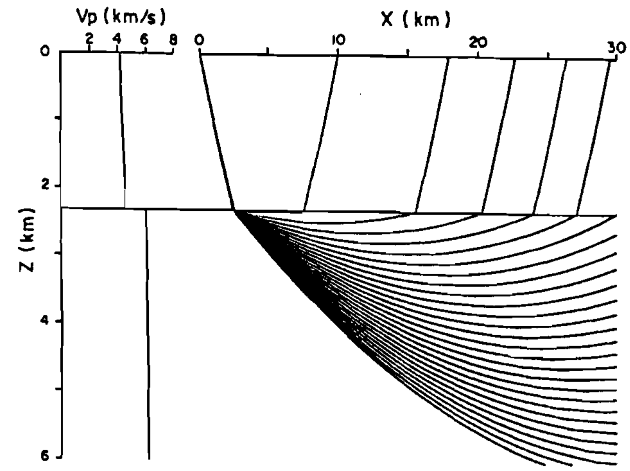

Figure 1: Seismic refraction profile velocity model and predicted travel time curves.

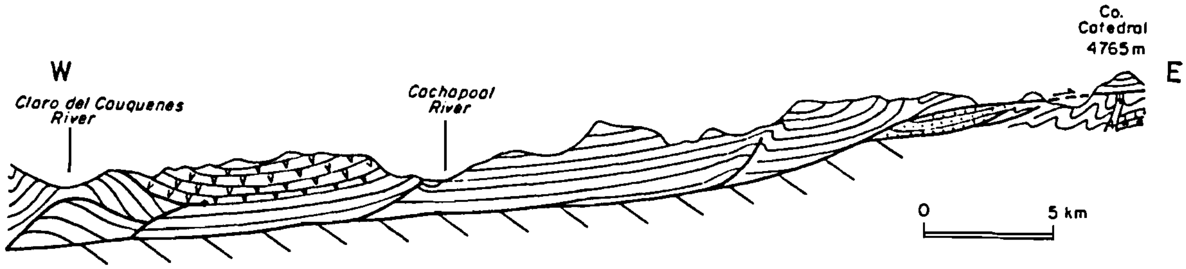

Figure 2: Geological section south of Cachapoal River. Detachment level assumed at the same depth as further north, where geophysical control is available. vv = Farellones Formation overlying Coya-Machalí volcani-clastics. Folded Mesozoic rocks under the C° Catedral klippe.

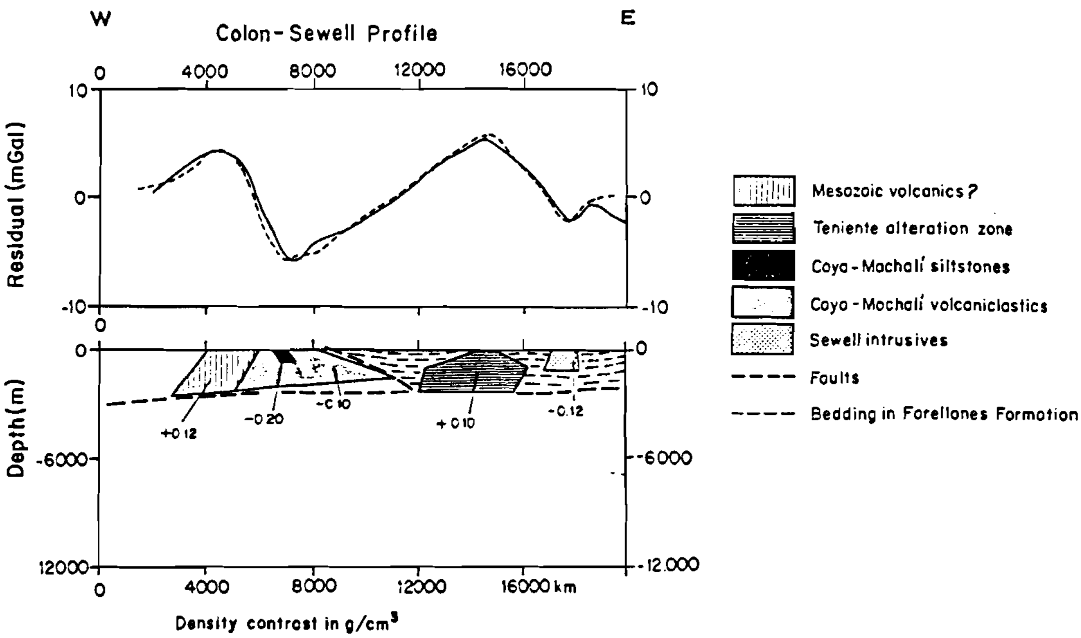

Figure 3: 2-D gravimetric model. Solid line: gravimetric data; dashed lines: predicted model.

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