

## LATERAL VARIATIONS IN LATE CENOZOIC DEFORMATION, CENTRAL ANDES, 20 – 28°S

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### RESUMEN:

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### INTRODUCTION

Major changes in the timing and geometry of late Cenozoic Andean structure occur between 23 and 24°S and include: (1) The southward terminus of the Subandean thin-skinned thrust belt occurs at between 23 and 24°S and farther south the foreland is dominated by the thick-skinned, basement-cored blocks of the Sierras Pampeanas. (2) The temporal transition from major thrust faulting to minor normal and strike-slip faulting across the entire plateau region occurs much later in the south (at ~1-4 Ma) than it does in the north (at ~10 Ma). In general, neotectonic activity is much greater in the Puna than it is in the Altiplano. (3) The average topography of the Puna is about 1 km higher, and its internal relief is greater, than that of the Altiplano. (4) Cenozoic sedimentary basins of the Eastern Cordillera-northern Puna are 2-4 km thinner than those of the southern Puna. Major geophysical and petrologic changes between 23 and 24°S — including the southward termination of a high-low paired isostatic residual gravity anomaly, lateral variations in seismic waves attenuation, and primitive mafic magmatism — are described in the accompanying paper by Whitman et al. (this volume). We suggest that these spatial and temporal variations in late Cenozoic structure and volcanism in the Central Andes are probably linked to major, N-S changes in lithospheric structure and thickness. Some of these changes have been associated with changes in angle of subduction (e.g. Jordan et al., 1983) and several are spatially correlated with major paleotectonic features.

### FORELAND: SUBANDEAN BELT TO SIERRAS PAMPEANAS

Throughout Bolivia, the thin-skinned Subandean foreland thrust belt bounds the eastern margin of the Andes. The thrust wedge taper varies from about 7° north of Santa Cruz to 2-3° in southern Bolivia. The basal decollement is at ~12 km beneath the Principal Frontal thrust which marks the boundary between the Subandean belt and Eastern Cordillera. Between 23° and 24°, the structure of the foreland changes dramatically. At 24°, Cahill et al. (1992) showed that seismicity in the foreland extends to depths greater than 30 km. This area, known as the Santa Barbara ranges, constitutes the northernmost extent of the Sierras Pampeanas province of thick-skinned basement deformation. Seismicity data throughout the Sierras Pampeanas shows that virtually the entire crust is involved in young deformation (Chinn & Isacks, 1983; Smalley et al., 1993).



Fig. 1. Regional location map of the Central Andes between 18 and 28° S, showing some of the major lateral changes. (a) region of primitive mafic magmatism in the southern Puna. (b) Approximate boundary between cessation of thrusting at ~10 Ma to the north and 1-2 Ma to the south. (c, d) Positive and negative, respectively, isostatic residual gravity anomalies. (e) Location of longitudinal stratigraphic section shown in Fig. 3.

Miocene strata, locally dated at 12-17 Ma. Deposits near the top of the surface have yielded ages between 2 and 4 Ma. Kinematic analysis of the Miocene deformation near the international border indicates WNW shortening, perpendicular to the strike of the mountain ranges, and vertical extension. The surfaces are deformed by well preserved scarps of younger normal and strike-slip faults which have produced minor, SSE subhorizontal extension and WSW or vertical shortening.

South of 23°S, the southern Puna and Eastern Cordillera display the same relative kinematic

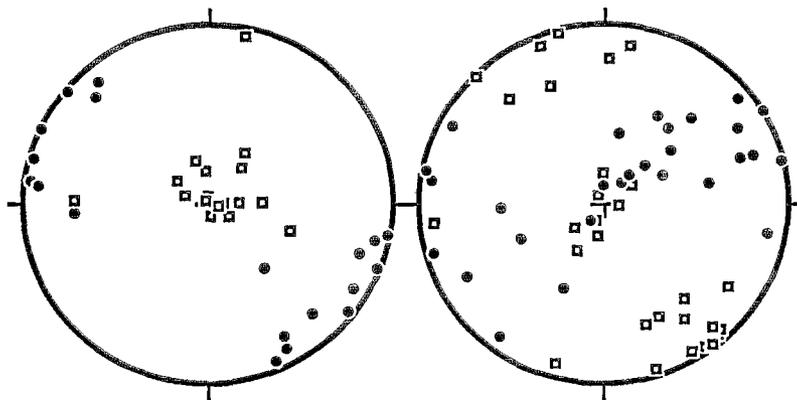


Fig. 2. Lower hemisphere equal area projections summarizing kinematic data from the Puna and southernmost Bolivian Eastern Cordillera. Left: Older deformation (pre-9 Ma in north and pre-1 Ma in the south). Right: Younger deformation. In both, solid dots are shortening and open boxes are extension.

Shortening in the Subandean belt is probably less than 10 Ma in age (Gubbels et al., in press). Several different areas in the northern Sierras Pampeanas contain evidence for uplift younger than 6 Ma and locally younger than 2-3 Ma ago (Allmendinger et al., 1989; Strecker et al., 1989).

#### ALTIPLANO-PUNA-EASTERN CORDILLERA

The morphology of the Altiplano is dominated by a broad flat basin at an average elevation of about 3.7 km (Isacks, 1988). In contrast, the Argentine Puna has many interior mountain ranges and has an average elevation of just under 4.5 km. The high flat, shallow basins in the vicinity of La Quiaca and Abra Pampa are continuous in northern Argentina but in Bolivia they occur as isolated erosional remnants in the Eastern Cordillera. These basins overlie a regionally extensive unconformity, the San Juan del Oro surface, that truncates compressional structures and is deformed only by small normal and strike-slip faults. Tufts overlying the unconformity have been dated at 8-9 Ma; they unconformably overlie folded and thrust faulted mid-

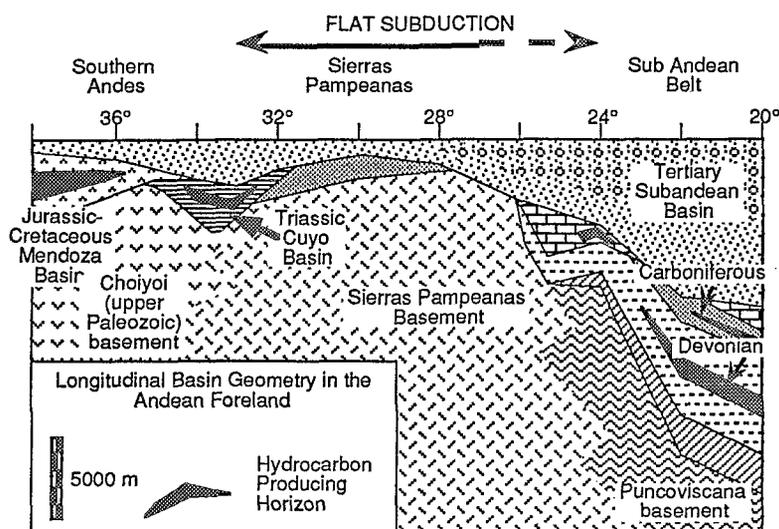


Fig. 3. Longitudinal stratigraphic section which shows the orogen-parallel variation in basin geometry in the Andean foreland. Note that most of the variation is in the pre-Tertiary subcrop and thus pre-dates the Cenozoic Andes.

## PALEOTECTONICS

Comparison of Cretaceous subcrop and pre-Cretaceous isopach maps with modern geologic maps of the Central Andes clearly shows that the many of the modern tectonic provinces have inherited their location, extent, and even structural geometry from pre-Andean tectonic events (Allmendinger et al., 1983; Gubbels et al., in press). The style of late Cenozoic foreland deformation in Bolivia and Argentina correlates almost exactly with the extent of pre-Andean basins (Fig. 3). The Subandean thin-skinned belt is restricted to the thick previously undeformed Paleozoic basins which mostly pinch out between 23 and 24°S; the basement rocks of the Sierras Pampeanas have been at or near the surface for the last 150 Ma (Jordan et al., 1989). The Bolivian Eastern Cordillera was deformed prior to the Mesozoic and was a relative positive element during the Cretaceous.

## INTERPRETATION

We suggest the following scenario to explain the family of changes that occur near 23°S: The entire region shares a similar mid-Miocene structural history. Crustal shortening, oriented WNW-ESE (~120°), was concentrated in the regions of the Altiplano, Eastern Cordillera, and Puna. A major change occurred at about 10 Ma: horizontal shortening in the Altiplano and Eastern Cordillera ceased and shifted eastward into the thick, undeformed, eastward-tapering Paleozoic through Tertiary cover of the Brazilian Shield. Subsequent shortening in the Subandean belt was predisposed to be thin-skinned because of the pre-existing basin geometry; thin-skinned shortening requires underthrusting of cold Brazilian shield lithosphere beneath the orogen north of ~23°. In contrast, shortening in the Puna and Argentine Eastern Cordillera continued to <4 Ma and locally is as young as 1 Ma. Shortening probably remained concentrated in the thermally weakened Puna rather than propagating eastward as a thin-skinned belt because pre-existing basins in the foreland are thin and irregular. Thus, north of 23°S, the Andes have experienced a two phase deformation sequence during the Late Cenozoic with a transition at about 10 Ma (Gubbels et al., in press). The Puna remained in phase 1 until much more recently and only entered phase 2 with the uplifting of the northern Sierras Pampeanas.

Geochemical data, the difference in altitude, seismic wave attenuation, and an inferred change in stress regime all suggest that the lithosphere south of 24°S is substantially thinner than it is to the north; delamination, sub-lithospheric erosion or stoping are the most logical explanations (Whitman et al., 1992;

sequence (Fig. 2) but the transition from older thrust faulting to younger strike-slip and normal faulting occurred as recently as 1 Ma in the Quebrada del Toro and < 4 Ma in the Puna. Younger deformation is probably no older than about 1 Ma and continues today. Tertiary strata in the northern Puna and Eastern Cordillera are generally less than 1 km in thickness. Tertiary strata in the Puna from ~23° southward are much thicker than farther north. Several Neogene basins have more than 2000 m of strata, including the Hombre Muerto region with 5000 m of Miocene rocks (Alonso et al., 1991).

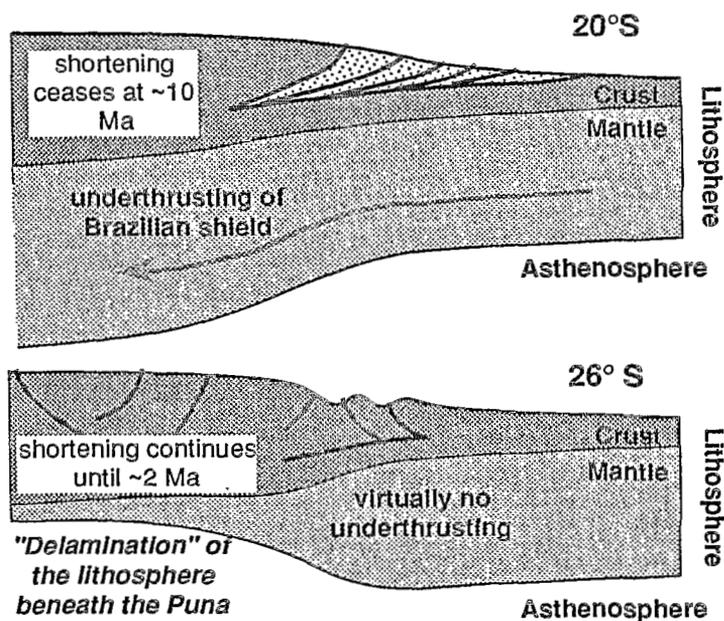


Fig. 4. Schematic, lithospheric-scale cross-sections across the Andes at the latitudes of the Altiplano and the southern Puna. See accompanying abstract by Whitman et al. (this volume) for the discussion of geophysical and geochemical data relating to the same model. Not to scale.

Kay & Kay, 1993). Lithospheric thinning may be due to continued shortening concentrated in the high plateau or more likely to thinning in front of a northward migrating zone of flat subduction.

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