STRUCTURE OF THE CENTRAL BOLIVIAN ANDES: IMPLICATIONS FOR OROGENY IN ANDEAN-TYPE MARGINS

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Resume

Un estudio combinado de campo y de fotogeología de los Andes Bolivianos mostró que el estilo de deformación es típico de cinturones de escurrimientos. El acortamiento cortical, más que los procesos magmaticos, fue el mecanismo importante en el desarollo de los Andes centrales. Este acortamiento es debido exclusivamente a la subducción de la litosfera oceánica, sin intervención de colisiones.

Key words: orogeny, crustal shortening, Bolivian Andes, balanced cross sections

Introduction

Exceptionally thick crust (55-70 km) and the high plateau of the Altiplano characterize the central Andes. While this remarkably thick crust has commonly been attributed to mantle-derived magmatic addition (Gill, 1981; Weaver and Tarney, 1982), neither the magnitude of this contribution nor the detailed style of deformation coincident with magmatism have been assessed. This study describes the style and timing of deformation in one part of the central Andes, the central Bolivian Andes, in addition to determining a lower bound on the amount of crustal shortening that has occurred, as revealed by mapping and balanced cross sections.

Methodology and Assumptions

Detailed geologic maps of the Cordillera Oriental and Subandean Zone between approximately 17.5° and 19°S, from 63°15' to 67°W, were constructed from photogeologic and field mapping at 1:50,000. A network of fourteen balanced cross sections was constructed from these maps (Sheffels, 1990). The cross sections are constrained by surface data only. Balance was determined on the basis of the consistency of bed lengths and restorability of cross sections (Dahlstrom, 1969; Woodward et al., 1985).

Three assumptions ensure that the estimate of shortening is a minimum. 1) Subsurface and eroded fold and fault geometries are required to be consistent with observed deformational style. 2) Fault displacement along faults whose hanging wall cutoffs are now eroded is assumed to be minimal; that is, hanging wall cutoffs are inferred just above present topography. 3) Shortening is only calculated along the surfaces of decollement inferred from the surface geology, the shallowest levels of decollement, although there is evidence of deeper deformation.

Style of Deformation

The deformational style of the Bolivian Cordillera Oriental and Subandean Zone is characterized by the thin-skinned deformation typical of foreland fold and thrust belts (Bally et al., 1966). Although the observed style of folding and the steep to moderate dips of most exposed faults in the study area have often been interpreted as indicative of thick-skinned block faulting (Martinez, 1980), the repeated juxtaposition of distinct structural and stratigraphic levels across those faults requires the dip of the faults to become shallower at depth. Narrow, complexly-faulted anticlines typically define the surface expression of the fault ramps. These structures and the presence of numerous backthrusts suggest a weak surface of decollement.

Decollement is observed within three Paleozoic shale levels: undifferentiated lower Ordovician shale, the Silurian Kirusillas Formation, and the middle Devonian Icla Formation. These shale horizons lie within a sequence of Paleozoic, predominantly marine, alternating sandstones and shales, which is overlain by variable, primarily continental, Carboniferous to Recent rocks (Rodrigo and Castaños, 1978; Pareja et al., 1978). The level of decollement ramps up towards the foreland, with variations introduced by tear faults and lateral ramps along strike. Distinct syles of deformation are observed in regions defined by the level of decollement and the fault geometry. Along a particularly large tear fault system, the Cochabamba basins have opened as strike-slip pull-apart basins. The thrust front south of approximately 17.5°S, the latitude of the bend or "elbow" in the mountain belt, is defined by a triangle zone, while north of this latitude, it is emergent. The origin of the bend can be explained, at least in part, by the presence of a wider Siluro-Devonian depositional basin to the south; the thrust front has advanced further east where Siluro-Devonian strata were deposited further east.

The age of the main deformational events appears to be Oligocene or younger throughout the study area (Sheffels, 1988). Although the stratigraphic record is discontinuous from the Carboniferous to the present, no large angular unconformities are present until the Oligocene. Furthermore, Tertiary rocks exposed in the study area are involved in deformation of the same style and strike as the older rocks. Older deformation is indicated in parts of the Altiplano, as well as to the north, in Peru, and to the south, in Argentina. While the possibility of an earlier onset of deformation in the central Bolivian Andes can not be definitively ruled out, the evidence suggests that most shortening occurred since the Eocene.

A Minimum Estimate of Crustal Shortening

A lower bound on the amount of crustal shortening across the width of the mountain belt was determined from five cross sections that form an east-west transect at approximately 18°15'S. Well-constrained because the transect lies close to traverses made in the field, this minimum estimate of shortening is 210 km.

The magnitude of this lower bound indicates that crustal shortening has played an important, if not the dominant role in the formation of the Bolivian Andes. Volumetrically, it can account for from two-thirds to three-quarters of the present-day crustal cross-sectional area, implying that mantle-derived magmatic addition can only have contributed the corresponding one-third to one-quarter. If the restrictive assumptions used to construct the balanced cross sections are relaxed, increasing the estimate of shortening, or if the evidence for additional shortening at depth and in the Altiplano is considered, then crustal shortening could have built virtually the whole mountain range.

Conclusions

Thin-skinned deformation in the central Bolivian Andes has resulted in a substantial, minimum amount of crustal shortening, with the following implications. 1) Orogeny in Andean-type margins is not necessarily primarily due to magmatic processes. 2) The convergence evident in the upper crust implies convergence in and therefore "subduction" of the lower lithosphere. 3) Shortening in the Bolivian Andes occurred contemporaneously with subduction of oceanic lithosphere; therefore substantial crustal shortening is not uniquely the result of continental collision.

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