

Influences of tectonic inheritance and exhumation patterns in the timing and structural styles of the Eastern Cordillera of Colombia

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INTRODUCTION

The Eastern Cordillera of Colombia is interpreted as an asymmetric inversion orogen, which coincides with the location of a Lower Cretaceous rift province. The degree of asymmetry of its central segment is depicted by the basement lying at a higher elevation on the eastern side than on the western side (Cortès et al., 2005), and the apparent higher amount of shortening in the eastern flank (Colleta et al., 1990; Dengo & Covey, 1993). Although the role of inherited basement structures can be demonstrated at various scales, the exact role of inversion tectonics in the overall structural styles has remained highly speculative and the causes and consequences of such asymmetry are often ambiguous. Here, we analyze the structural evolution of the Eastern Cordillera in light of structural inheritance, resulting structural styles, and exhumation patterns using field observations and apatite fission track thermochronology. Our new data sheds light on the mechanisms responsible for orogenic development in pre-strained regions of the crust.

METHODS

We identified and reconstructed Lower Cretaceous extensional structures by mapping lateral facies changes above the basal Cretaceous unconformity. We also constructed geologic cross sections using field observations and seismic reflection profiles. In addition, strain analysis was used to quantify the amount of shortening that occurred through penetrative strain. This permitted us to locate the most important Cretaceous normal faults and former transfer structures and determine the style and amount of Cenozoic folding and shortening. Finally, apatite fission track thermochronology was performed on samples collected along vertical profiles in order to assess the role of erosional exhumation in the Eastern Cordillera.

RESULTS

Our mapping identified several individual halfgrabens and small grabens inside the larger early Cretaceous basin of the Eastern Cordillera. This area experienced a complex episode of pervasive straining of basement rocks that were subsequently subject to compression. Along strike of these older structures we find polarity changes of normal fault systems and pronounced thickness changes in synrift fills. Thus, this extensional basin was not simply a large extensional basin limited by master faults as previously envisioned. Rather, it comprises a wide, internally faulted extensional province.

During initial contraction, the ancestral normal faults acted as strain risers, with contractional folding concentrated in the footwall blocks of the old normal faults. This produced vergence toward the structural highs; contractional penetrative fabrics are associated with the main folds, typically produced by burial to depths >4

km. This and the absence of elements showing associated major surface uplift, such as palynological changes associated with increasing paleoelevation or an intense influx of coarse gravels towards the foreland basins, implies that an initial stage with shortening experienced minor surface and rock uplift. E-W dominant contraction is expressed by folding and penetrative deformation, as well as calcite and SiO₂ filled tension veins oriented parallel to maximum compressional stresses. Extensional structural highs and extensional folds were amplified, but as the resulting rock uplift associated with folding was minor, reactivation of extensional faults was likely not substantial during this initial deformation phase. Quantifying the amount of shortening by internal strain supports this notion of folding by buttressing and minor reactivation. Shortening by folding is close to 20% and penetrative deformation resulted locally in an additional 20%, localized in the inclined limbs of anticlines and the hinge zones of some synclines.

Syntectonic facies changes in the foreland basin to the east since the late Eocene (Parra et al. this volume) and the presence of what we interpret to be synfolding mineralizations dated as old as Maastrichtian-Paleocene in the eastern flank of the Cordillera (Cheilletz & Giuliani, 1996; Romero-Ordoñez et al., 2000) constrains the timing of early deformation. This initial contractional phase predates the main Pliocene and Quaternary episode of exhumation and shortening episode.

The main results of our apatite fission-track (AFT) analysis show a significant cooling event younger than 4 my, documented from 3 vertical profiles from the eastern flank of the Eastern Cordillera. Palynological data obtained from the present highlands of the Sabana de Bogotá within the Eastern Cordillera suggest that important surface uplift occurred at the end of the Miocene (van der Hammen et al., 1973). Our data show that this uplift was accomplished by reactivation of normal faults and continues to the present day only on the eastern side of the Cordillera, as documented by uplifted Quaternary terrace systems in addition to our AFT analysis. In contrast, in the Sabana de Bogotá palynology suggests that it has remained at a similar elevation and has not experienced significant exhumation since the Pleistocene (Hooghiemstra & Cleef, 1995). A comparison of our cross sections and AFT data with that from Gomez et al. (2003) shows that, since the Pleistocene, exhumation and shortening on the eastern flank have been much higher than on western flank and almost absent in the axial Sabana de Bogotá. Therefore, the most important uplift and shortening of the central segment of the Eastern Cordillera occurred after the initial low amplitude folding and was not an ubiquitous phenomenon beginning in the Late Miocene, as previously interpreted (van der Hammen et al 1973; Dengo & Covey, 1993; Cooper et al., 1995). This uplift has resulted in a 4000-m-high orographic barrier that must have been fully established in (early?) Pliocene time (Hooghiemstra & Cleef, 1995). Since then, this barrier has effectively focused orographic precipitation and accounts for important climatic and erosional gradients in eastern Colombia. The big contrast between a continued and intense uplift on the eastern side of the orogen, which is also the region undergoing the highest erosion, and the stability of the internal Sabana de Bogotá since the Pliocene, demonstrates that inherited structure and erosion interact in a diachronous pattern during the Neogene and Quaternary to produce the present-day structural configuration.

The compilation of available data on palinology and AFT together with our own data also suggests that for the past 2 Ma, rock uplift and denudation appear to have been in equilibrium in the central segment of the Eastern Cordillera. This implies that the orogen is close to a steady-state condition. We propose that this balance is mainly conditioned by the presence since the Pliocene of an orographic barrier on the eastern side of the orogen.

Therefore, the long-term structural asymmetry (eastward vergence) appears to be conditioned by a feed-back loop between tectonics and climate that had not been previously identified in the Northern Andes.

CONCLUSIONS

Tectonic inheritance and exhumation patterns are both important in the configuration of the Eastern Cordillera at the latitude of Bogotá. Pre-existing extensional structures exert the primary control on the location and style of contractional structures. After the establishment of an orographic barrier, efficient denudation triggers more intense and continued shortening in the eastern flank. The precise location of this shortening is conditioned by inherited structures.

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