Cenozoic Orogenic Growth of the North Andes: Shortening and Exhumation Histories of the Eastern Cordillera of Colombia*

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Search and Discovery Article #30071 (2008)
Posted November 26, 2008

*Adapted from oral presentation at AAPG Annual Convention, San Antonio, Texas, April 20-23, 2008

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Abstract

Cenozoic to Recent oblique subduction and tectonic accretion of oceanic terranes in the NW corner of South America have resulted in orogenesis and foreland basin formation in the Colombian Andes. Basin analysis and apatite and zircon fission-track data from west of the modern volcanic arc of the Central Cordillera reveal a Cenozoic history of tectonic inversion and orogenic propagation. Late Cretaceous to Paleocene uplift of the Central Cordillera resulted in initial foreland basin development. Subsequent bivergent tectonic inversion of the Eastern Cordillera subdivided a formerly continuous basin into the present-day Magdalena Valley basin to the west and the Llanos basin to the east. Growth strata and episodes of rapid accumulation documented by the Cenozoic foreland record of these basins, as well as the present structural configuration of the mountain range, suggest eastward transferal of the tectonic load through an initial pop-up uplift of the Eastern Cordillera during the late Eocene-early Oligocene. Limited eastward migration of the leading edge of deformation since then seems to have resulted from contractional and transpressional deformation being accommodated along pre-existing anisotropies. Furthermore, variable thickness of the pre-orogenic stratigraphy may have prevented eastward orogenic migration by modifying critical taper angles. Denudation inferred from bedrock thermochronology and gravel petrography in palynologically dated foreland deposits at the eastern margin suggest moderate exhumation rates (~0.3 mm/yr) during the late Oligocene-Miocene, followed by rapid exhumation (1-2 mm/yr) in the Pliocene. We attribute this Pliocene acceleration in exhumation to focused denudation on the windward side of the orogen, where moisture-laden winds caused an effective erosional regime, resulting in a positive feedback with tectonic processes.
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Dating rock deformation vs Dating rock exhumation

- Assessment of oil prospectivity
- Processes and rates of orogenesis

Are deformation and exhumation synchronous across an orogen?

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Dating rock deformation

Direct indicators
- Fault mineralization
- Cross-cutting relations
- Growth strata

Indirect indicators
- Subsidence analysis
- Provenance signal of newly uplifted sources
- Cooling related to erosional or tectonic exhumation

Can we use thermochronology to date deformation?

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The Eastern Cordillera

- Seismic reflection lines
- Borehole information
- Stratigraphy of Cenozoic basins
- Subsidence history

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The Eastern Cordillera

- Deformation history
- Exhumation history
- Conceptual model that reconciles temporal discrepancies between both processes

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The Eastern Cordillera

- Double-verging orogen
- Inversion tectonics
- Mesozoic rift basin
- Cenozoic foreland basin system

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Deformation history

1. Provenance-basin analysis
2, 6. Cross-cutting relations
3, 4. Growth strata
5. Subsidence analysis

- Cratonward migration of orogenic front

Locus of Cenozoic deformation largely controlled by inherited anisotropies

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Fission-track dating

- Thermal stratigraphy for various thermochronometers

Apatite FT: ~110 °C (3-4 km)  
Zircon FT: ~250 °C (8-10 km)

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Fission-track dating

- Thermal stratigraphy for various thermochronometers
- Sub-vertical age-elevation profiles provide information on time, rate and amount of exhumation.
- Track-lengths reveal possible time-temperature paths of the rocks

Fitzgerald et al (1993)

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Fission-track dating

- Thermal stratigraphy for various thermochronometers
- Sub-vertical age-elevation profiles provide information on time, rate and amount of exhumation.
- Track-lengths reveal possible time-temperature paths of the rocks
- Results from multiple thermo-chronometers from a single site are better analyzed by means of stacked pseudo-vertical profiles.

Reiners and Brandon (2006)

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Exhumation history

Eastern flank:

- 38 AFT
- 19 ZFT

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Exhumation history

1. Western foothills

- Thermal modeling of Upper Cretaceous samples orogenic front suggests initiation of cooling sometime between 55 and 35 Ma

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Exhumation history

2. Axial Eastern Cordillera

- Thermal modeling of Paleocene samples orogenic front suggests initiation of cooling sometime between 45 and 25 Ma

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Exhumation history

3. Quetame Massif

Two transects comprising Paleozoic basement to Paleocene sedimentary rocks

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Exhumation history

3. Quetame Massif (FT ages vs Stratigraphic Position)

- Integration of Ro data with the distribution of FT ages with respect to their stratigraphic position reveals the limits of the AFT and ZFT partial annealing zones (PAZ)

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Exhumation Patterns (Stacked pseudo-vertical profiles)

- Stacked pseudo-vertical profiles reveal initiation of erosional exhumation at \(~26\,\text{Ma}\) for the northern transect and at \(~21\,\text{Ma}\) for the southern transect.

- Exhumation accelerates from \(~0.3\) to \(~1.5\,\text{mm/yr}\) at \(~4\,\text{Ma}\).

M. Parra et al, AAPG 2008

Parra et al, in review
• Long-term eastward progradation of actively exhuming areas

Data Sources: Gómez, 2001; Gómez et al, 2003; Parra et al, submitted
Exhumation vs. deformation histories

• Temporal decoupling of exhumation and deformation along the more deeply exhumed areas along the margins of the former rift

M. Parra et al, AAPG 2008
Conceptual model of shortening and exhumation along a compressionally reactivated listric fault

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Conceptual model of shortening and exhumation along a compressionally reactivated listric fault

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Conclusions (1)

- Thrust-induced cooling postdates initial shortening due to fault geometry
Conclusions (2)

- Deeper thermo-chronometers show a longer lag time between shortening and exhumation

M. Parra et al, AAPG 2008
Acknowledgements

M. Parra et al, AAPG 2008
THE ANDES AS AN OROGRAPHIC BARRIER

Satellite rainfall data; Bookhagen and Strecker, GRL, in review
Selected References


