Influence of the Eastern Cordillera Exhumation on the Structural Evolution of the Eastern Part of Middle Magdalena Valley Basin, Colombia*

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Abstract

The timing of deformation and uplift of the Eastern Cordillera in the northern Andes of Colombia has been being constrained by recent themochronological and geochronological results. These approaches allow linking of the process of thrusting-inducing denudation along the western front of the Eastern Cordillera fold-thrust belt to deformation in the eastern part of the Middle Magdalena Valley Basin.

Structural analysis, based on subsurface and surface information, permits the construction of a kinematic model for the evolution of the deformation. Age control for the kinematic restorations is provided by thermochronological and petrographic provenance analyses. In the study area, the La Salina Fault marks the boundary between the Paleogene foreland basin and thrust belt provinces. New apatite fission track and U-Th/He thermochronological results allow us to identify an early Miocene (~25-20 Ma) timing for initial exhumation of the La Salina hanging wall.

We propose a deep master fault system which accommodated the deformation in both provinces in response to shortening of the Cretaceous section as part of a duplex system. Although kinematically linked, shortening in the Cenozoic section is characterized by backthrust structures constituting the passive roof of the main duplex structure. The most recent deformation, an out-of-sequence event, is suggested by irregular crosscutting relationships of the La Salina Fault with some footwall structures.
Increased exhumation rates over the last 10 Myr in the hangingwall of the La Salina Fault coincide with (a) the greatest thickness of the Upper Miocene Real Formation in the footwall, and (b) increased sedimentary lithic fragments, evidence of sedimentary recycling of the lower part of Cenozoic succession. Additionally, the concealment (burial) of some faults, and the presence of growth strata in the Real Formation related to the northward structural plunge would indicate lateral variation in the development of the duplex system, the advance of a thrust front, and late-stage out-of-sequence faulting. Structures in the foreland display modestly different orientations relative to the La Salina Fault and its associated structures, possibly suggesting a shift in the direction of maximum shortening. This proposed kinematic scenario may imply a coalescence of two generations of structures which could provide trapping configurations in the proximal foreland basin province along the eastern Magdalena Valley.

**Selected References**


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Nestor Moreno
Questions

• Structural configuration of the study area?
  Structural analysis: surface mapping, seismic reflection, balanced cross sections

• Patterns and timing of exhumation (cooling)?
  Fission-Track and (U-Th)/He Thermochronology
  Vitrinite reflectance
  Sandstone petrography

• Association of exhumation with deformation in a thrustbelt?
  Kinematic restorations of balanced cross sections
• Structural analysis
• Thermochronology and Ro
• Sandstone petrography
Study area

Modified from Teson and Castellanos (ICP), 2010

Epoch | Ma | Unit
----- | --- | ----
Pliocene | 5 | Mesa
Miocene | 15 | Real
| 16 | Colorado
| 23 | Mugrosa
Oligocene | 32 | Esmeraldas
| 35 | La Paz
Eocene | 43 | Lisama
| 80 | Umir
| 95 | La Luna
| 108 | Simiti
Paleocene | 115 | Tablazo
| 125 | Paja
| 135 | Rosablanca
| 140 | Cumbre
| 140 | Arcabuco/Giron
Late Jurassic

Modified from Rolon, 2004
Seismic Section Location Map
Structure

N 5 km  TWT  ESE  WNW

TRACB  TWT

Seismic 2D line 1 [OP-81-02]
Seismic 2D line [SL-35-630_MGII]

5 km
Cross Section Location Map
- Main displacement along the La Salina fault (LSF)
- Minor deformation propagated along the frontal thrust
- Passive roof duplex (backthrust) in the footwall of LSF
- Basement-involved deformation, possible inverted structure to east
Shortening:  \( \sim 27 \text{ Km} \)
\( \sim 25 \% \)
Sampling

Vitrinite Reflectance (Ro)

Thermochronology

Petrography
Thermochronology and Vitrinite Reflectance

Thermochronometers: Information about time and thermal history
- **U-Th/He**: Apatite: ~ 70 - 90 °C
  Zircon: ~ 180 °C
- **Fission tracks**: Apatite: ~ 100-120 °C
  Zircon: ~ 220- 250 °C

Geothermometers: Information about temperature
- **Vitrinite reflectance (Ro)**: Maximum paleo-temperature
Thermochronology

Age (Ma)

La Salina fault
Hangingwall

La Salina fault
Footwall

PAZ (La Salina FW)

Depositional age

Mesa
Real
Colorado
Mugrosa
Esmeraldas
La Paz
Lisama
Umir

U-Th/He in apatite
AFT

1000 m.
Vitrinite reflectance

- Kinetic model: Burnham and Sweeney, 1990 (normal heating rate of 1°C/Ma)
- Geothermal gradient: 25°C/km

Different structural blocks

1000 m.
Sandstone Petrography

Central Cordillera provenance:
- Volcanic rock fragments
- Feldspar (Gomez, 2005)
- Metamorphic rock fragments: schist facies (McCourt et al 1984)

Eastern Cordillera provenance:
- Sedimentary rock fragments
- Recycling from Paleocene and Cretaceous rocks
- Metamorphic rock fragments: schist and gneiss facies; after ~20 Ma (Shagam et al 1984)
**Sandstone Petrography**

<table>
<thead>
<tr>
<th>EPOCH</th>
<th>Ma</th>
<th>Unit</th>
<th>Sandstone grain compositions</th>
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<tr>
<td>Pliocene</td>
<td>5</td>
<td>Mesa</td>
<td>10</td>
</tr>
<tr>
<td>Miocene</td>
<td>15</td>
<td>Real</td>
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<td>23</td>
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<td>10</td>
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<td>Mugrosa</td>
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<tr>
<td>Eocene</td>
<td>35</td>
<td>La Paz</td>
<td>10</td>
</tr>
</tbody>
</table>

- **Increase in feldspar and VRF and feldspar is associated to CC supply**
- **Decrease in compositional maturity could indicate a foreland uplift provenance**
- **Marked increase in Sedimentary rock fragments, suggests exhumation onset of the EC**

Increase in compositional maturity could imply recycling from EC (Caballero, 2010)
Thermal modeling

Thermochronometers:

- **U-Th/He**: Apatite, Zircon
- **Fission tracks**: Apatite

Software: HeFTy 1.6.7 (Ketcham, 2009)
Kinematic restoration

Structural analysis

Themochronology and vitrinite reflectance

Provenance petrography

1.87 %

6.7±1.6 Ma?

246±18.6 Ma

U-Th/He apatite

AFT

U-Th/He zircon

ZFT

Ro

9.3 Ma±0.6 Ma

13.8±1.9 Ma

8 Ma±0.5 Ma

22.5±1.6 Ma

35.4±3.3 Ma

78.4±6.3 Ma

0.63 %

6.1±2.2 Ma

1.17 %

6.6 Ma±0.4 Ma

8.8±1.2 Ma

94.9±7.6 Ma

3.3 Ma±0.2 Ma

29.6±3.9 Ma

4.9 Ma±0.3 Ma

25.1±4.3 Ma

25.4±2.9 Ma

6.6 Ma±0.4 Ma

8.8±1.2 Ma

94.9±7.6 Ma

6.7±1.6 Ma?

246±18.6 Ma

1.87 %

U-Th/He apatite

AFT

U-Th/He zircon

ZFT

Ro
Exhumation pattern
“La Salina” fault hangingwall

- Partially reset sample?
  Cooling onset: ~ 30 - 40 Ma

- Reset sample
  Cooling onset: ~ 8 - 15 Ma

- Reset sample
  Cooling onset: ~ 4 - 8 Ma
  Exhumation rate: ~ 0.7 – 0.9 mm/yr
Exhumation pattern
“La Salina” fault footwall

Partially reset sample
Cooling onset: ~ 10 - 15 Ma

Partially reset sample
Cooling onset: ~ 3 - 6 Ma

Partially reset sample
Cooling onset: ~ 5 - 10 Ma
Pliocene: ~ 0 - 5 Ma

Shortening:  ~ 27 Km
            ~ 25 %
Pliocene-Late Miocene: \(\sim 5 - 6 \text{ Ma}\)

**Shortening:** \(\sim 20 \text{ Km} \quad \sim 18 \%\)

- **Reset sample**
  - Cooling onset: \(\sim 4 - 8 \text{ Ma}\)
  - Accelerated exhumation: \(0.7 - 0.9 \text{ mm/yr}\)

- **Partially reset sample**
  - Cooling onset: \(\sim 3 - 6 \text{ Ma}\)

**AFT = 6.7 ± 1.6 \text{ Ma}?**
Decrease in compositional maturity could indicate a foreland uplift provenance (Real group).

Shortening: ~ 16 Km
~ 15 %

Partially reset sample
Cooling onset: ~ 5 - 10 Ma

Late Miocene: ~ 6 - 8 Ma
Late Miocene: ~ 10 Ma

Shortening: ~ 15 Km
~ 14%

Difference in burial

Partially reset sample
Cooling onset: ~ 10 - 15 Ma

Reset sample
Cooling onset: ~ 8 - 15 Ma
Possible backthrusting
Middle Miocene: ~ 15 Ma

- Shortening: ~ 12 km
  ~ 11%

- Less burial
- Partially reset sample
  Cooling onset: ~ 10 - 15 Ma
Early Oligocene: ~ 30 Ma

Shortening: ~ 10 Km
~ 9%

Marked increase in Sedimentary rock fragments

Partially reset sample
Cooling onset: ~ 30 - 40 Ma

ZFT = ~246 Ma, no reset sample
Middle Eocene: ~40 Ma

Shortening: ~ 2 Km  
~ 2 %

Max burial depth:
~2-3 Km  ~5-6 Km  ~6-7 Km

Partially reset sample  
Cooling onset: ~ 30 - 40 Ma
Late Cretaceous: ~65 Ma

Thinning of Cretaceous section to the East

Ro data suggest different structural blocks
Conclusions

Structural Analysis
• Limited westward thrust front advance into the MMV basin
• Passive-roof duplex system and possible detachment folding
• Oblique shortening, possible basement involvement (reactivation?)

Thermochronology
• Onset of significant exhumation / cooling by \ (~6 \text{ Ma})
• Other exhumation events at \ (~30-40 \text{ Ma}) and \ (~15 \text{ Ma})

Petrography/Provenance
• Eastern Cordillera = potential source since late Eocene-early Oligocene
• Larger magnitude shortening during Miocene - Pliocene

Kinematic History
• West of EC: La Salina fault system is main element, inducing exhumation by \ (~30 \text{ Ma})
• Eastern MMV basin: Tectonic wedging and backthrusting induced exhumation by \ (~15 \text{ Ma})
- Transient growth of structures and a possible difference in shortening orientation:
  - Interference patterns in the folding
  - Domical structures

Curvature calculation shows complex folding patterns with more than one trend.
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