# 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 thermochonological 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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# Questions

- **Structural configuration of the study area?**

**Structural analysis: surface mapping, seismic reflection, balanced cross sections**

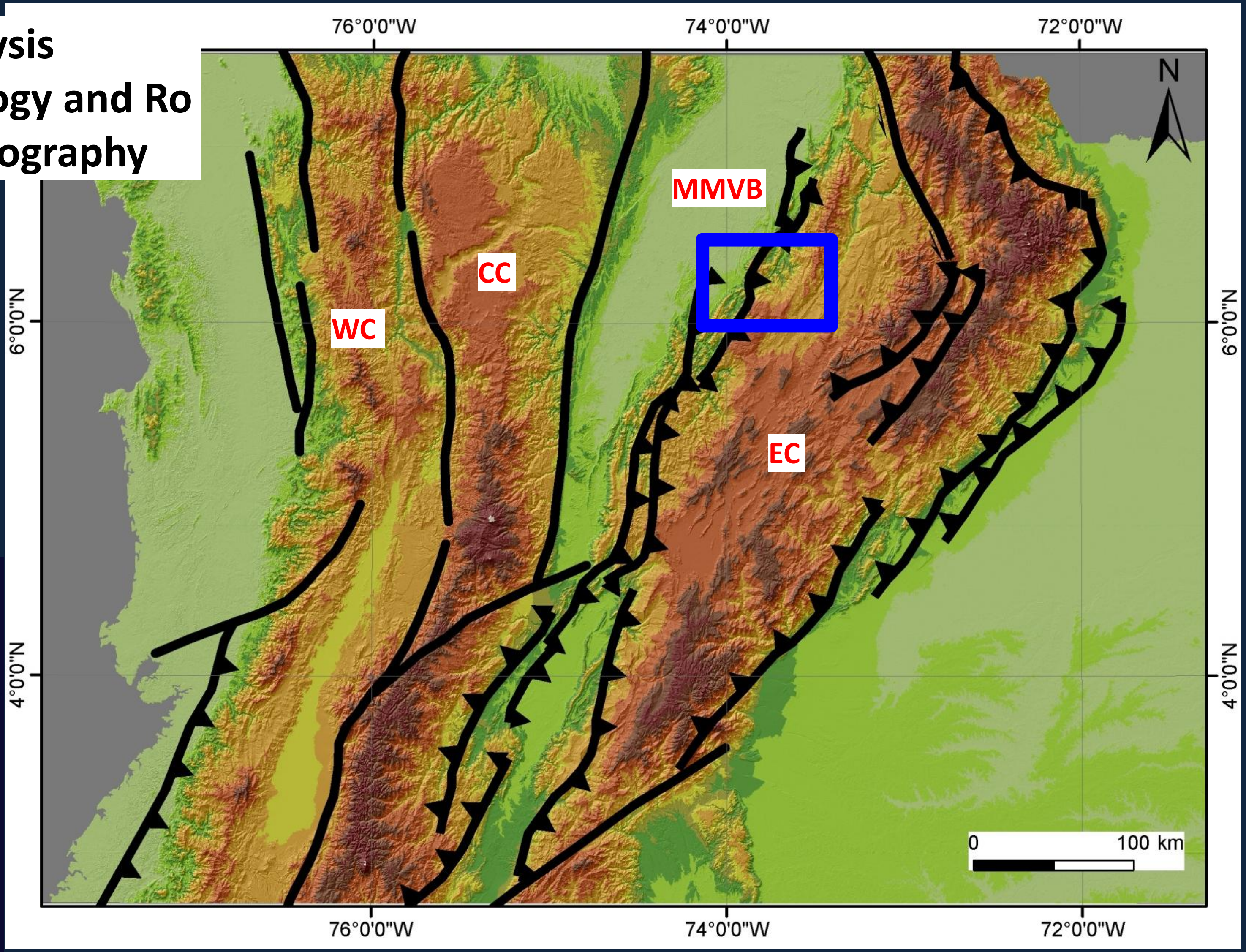
- **Patterns and timing of exhumation (cooling)?**

**Fission-Track and (U-Th)/He Thermochronology**
**Vitrinite reflectance**
**Sandstone petrography**

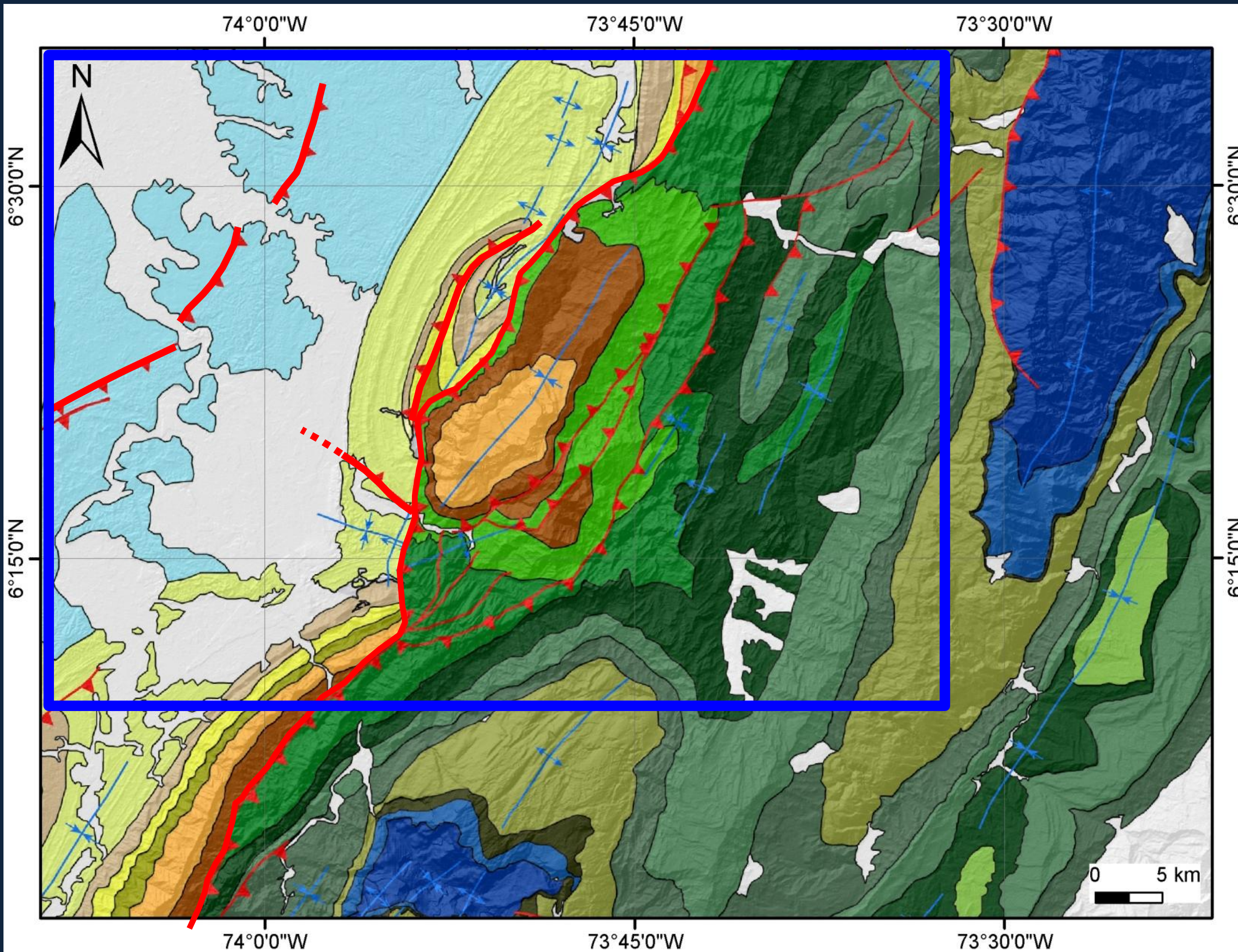
- **Association of exhumation with deformation in a thrustbelt?**

**Kinematic restorations of balanced cross sections**

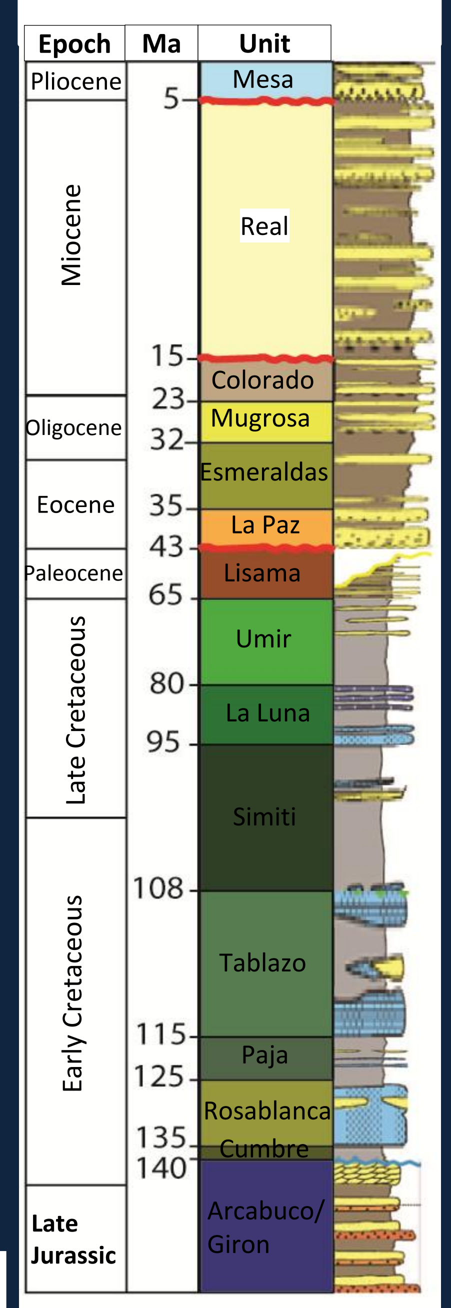
- Structural analysis
- Thermochonology and Ro
- Sandstone petrography




# Study area

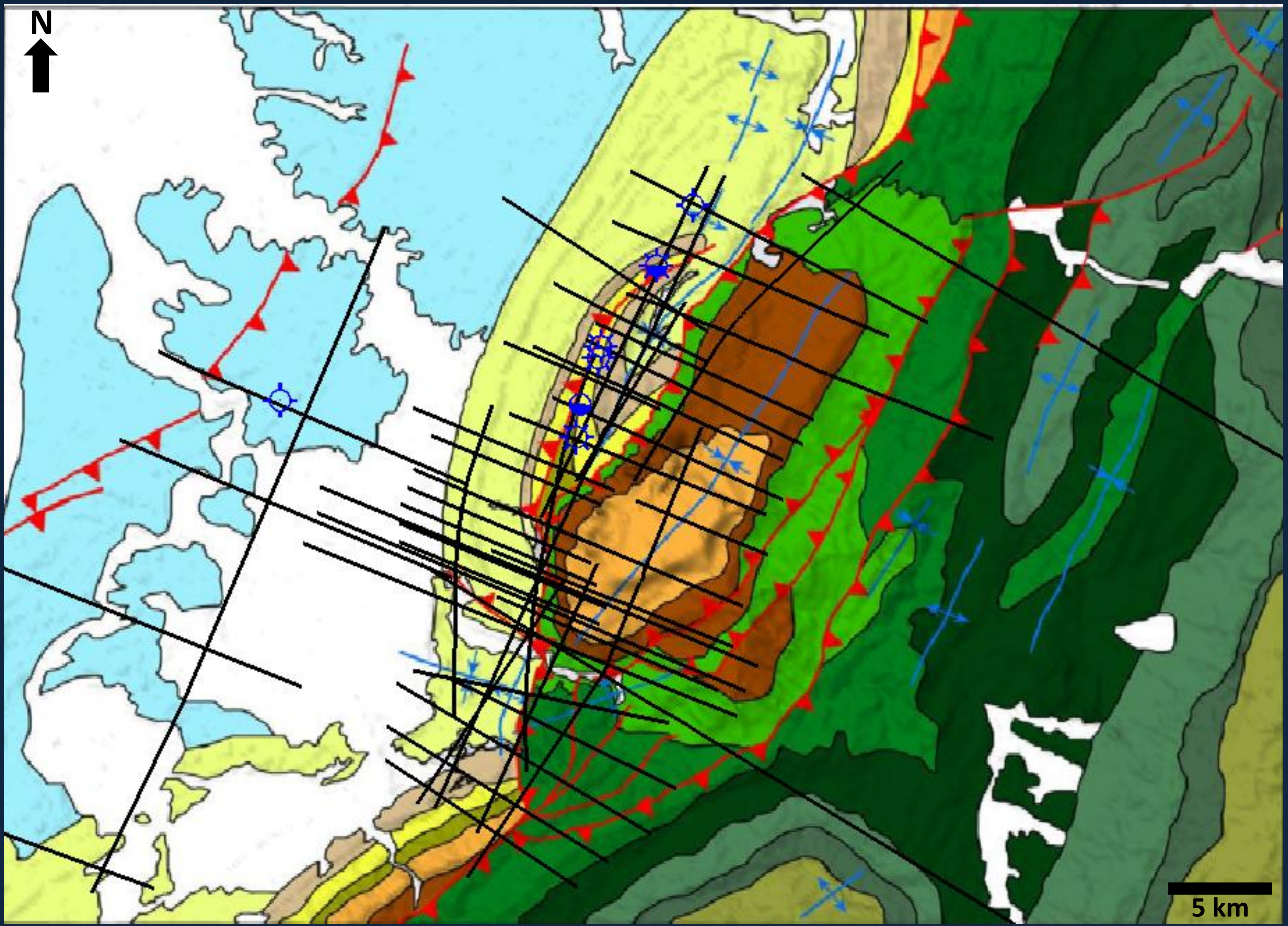



Modified from Teson and Castellanos (ICP), 2010

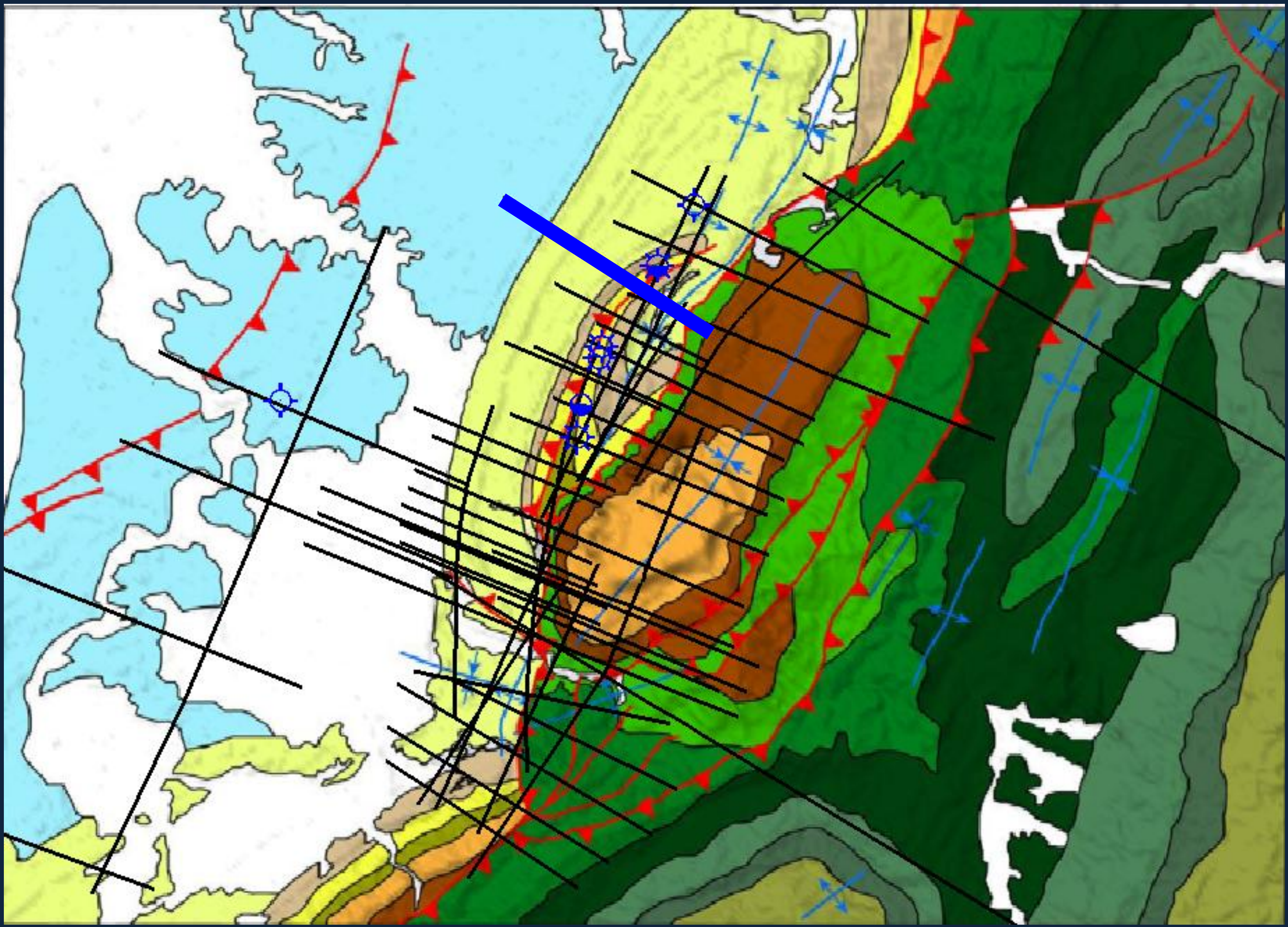



Modified from Rolon, 2004

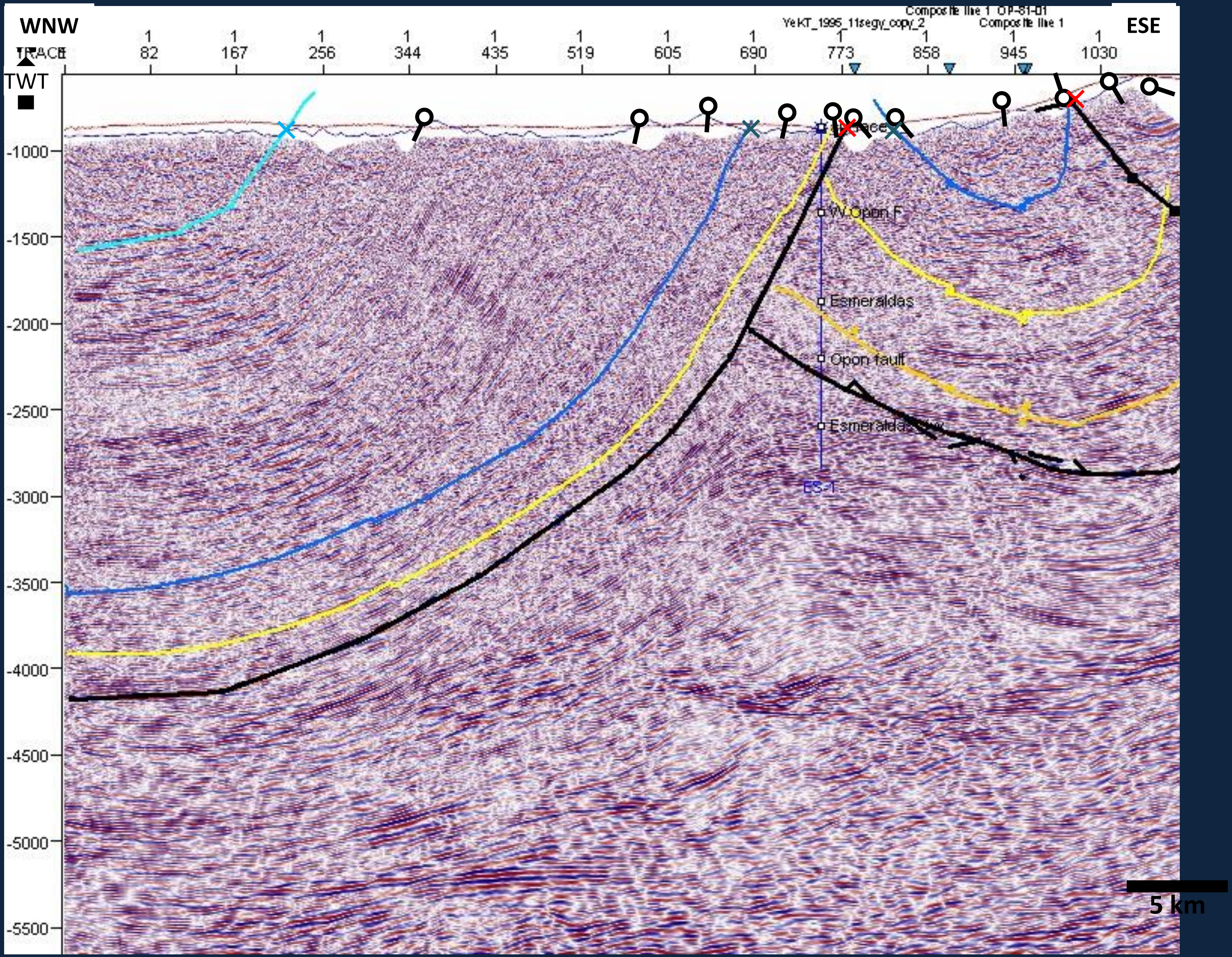
# Study area



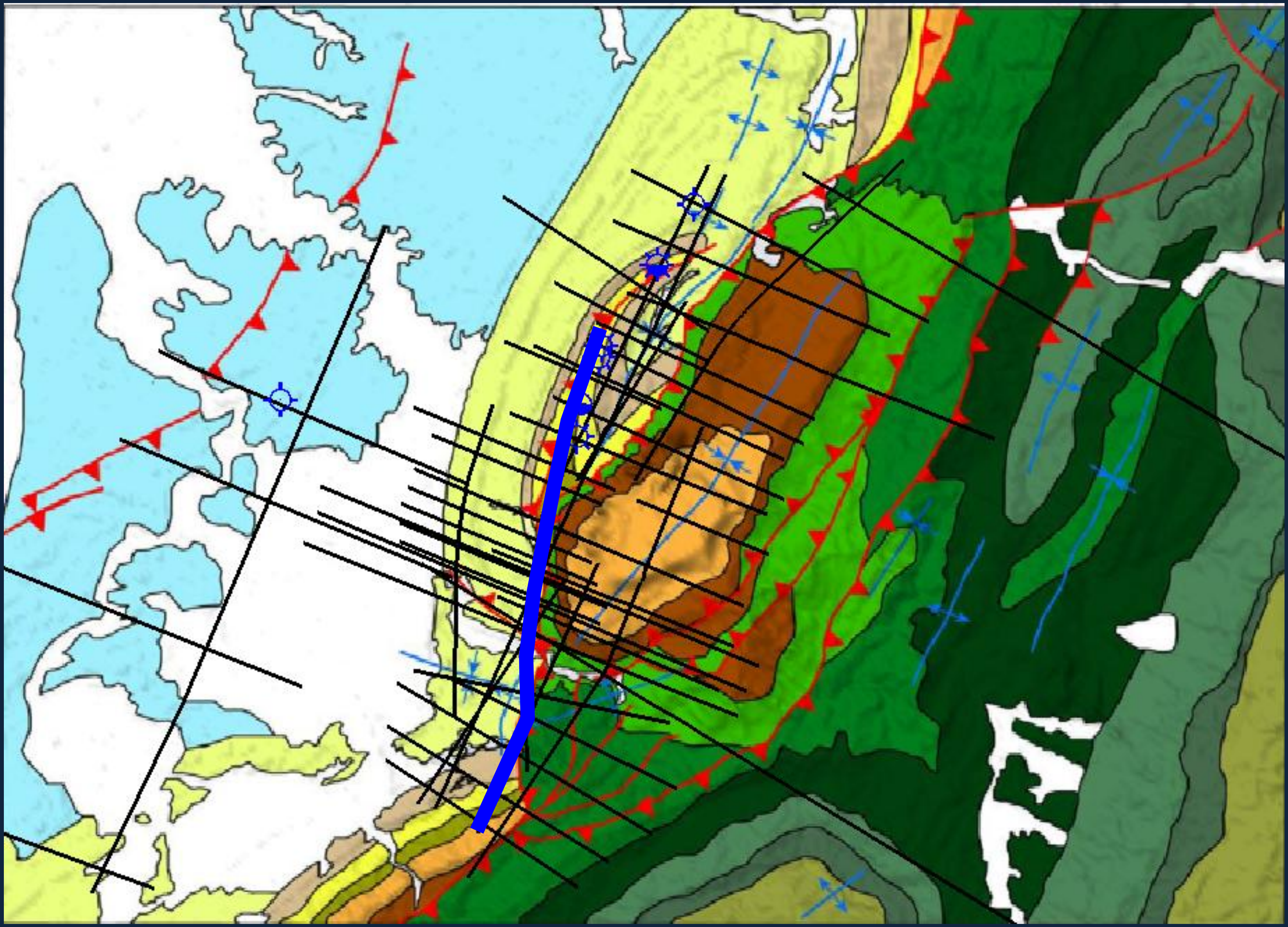
# Seismic Section Location Map



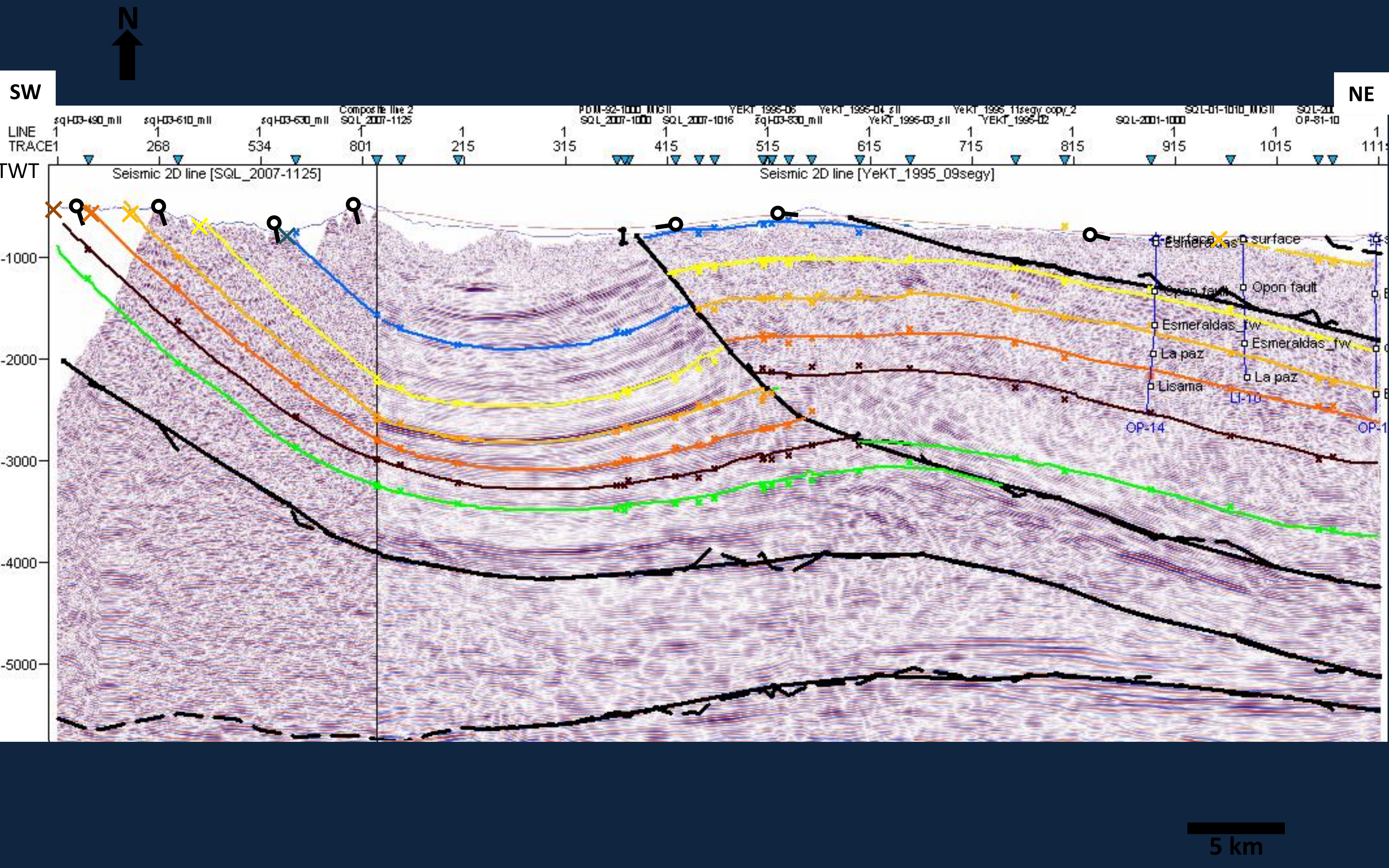
# Structure


WNW
ESE
TRACE
TWT
82
167
256
344
435
519
605
690
773
858
945
1030
-1000
-1500
-2000
-2500
-3000
-3500
-4000
-4500
-5000
-5500
W.Opon F.
Esmeraldas
Opon fault
ES-1
5 km

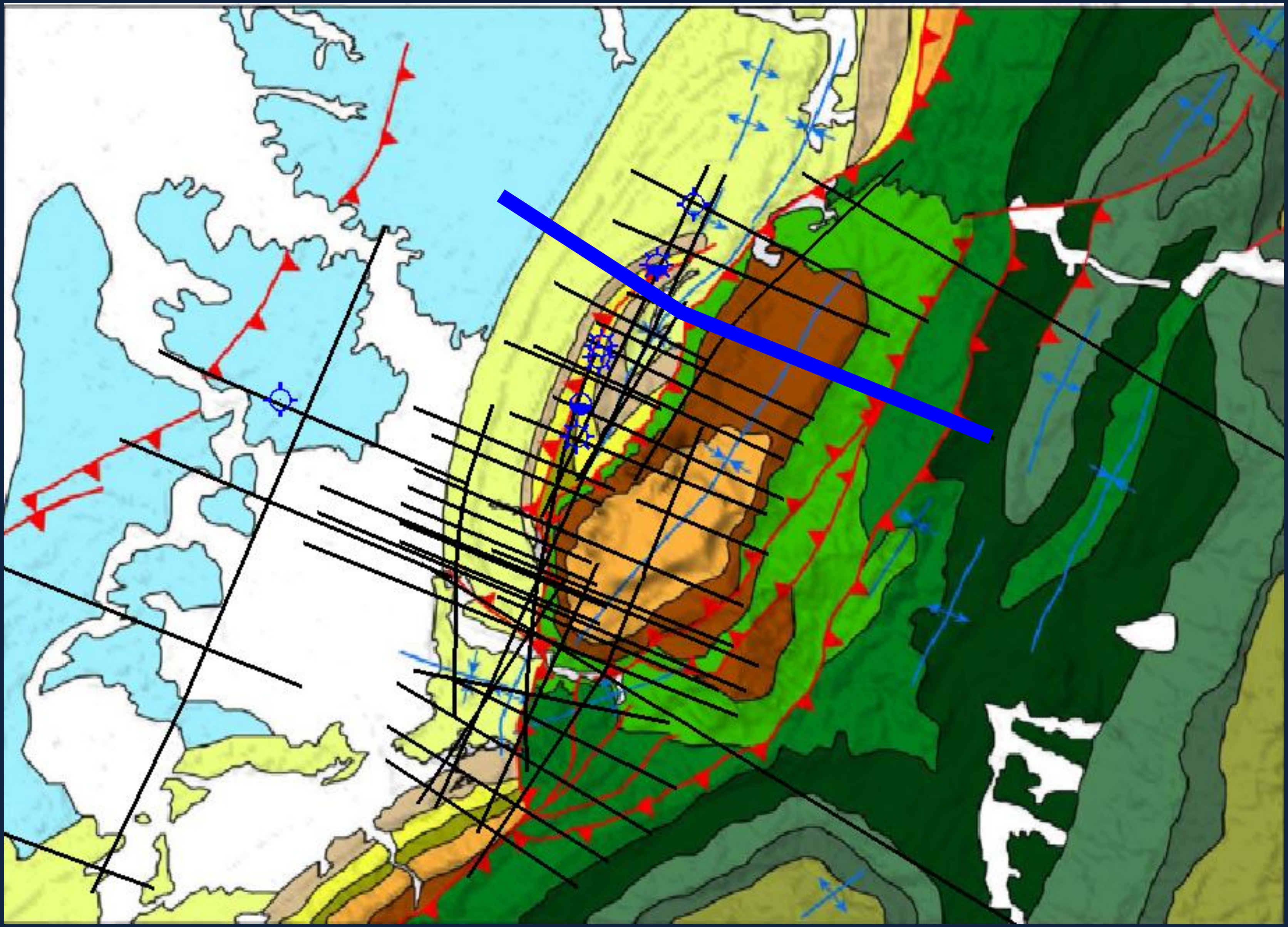
# Seismic Section Location Map



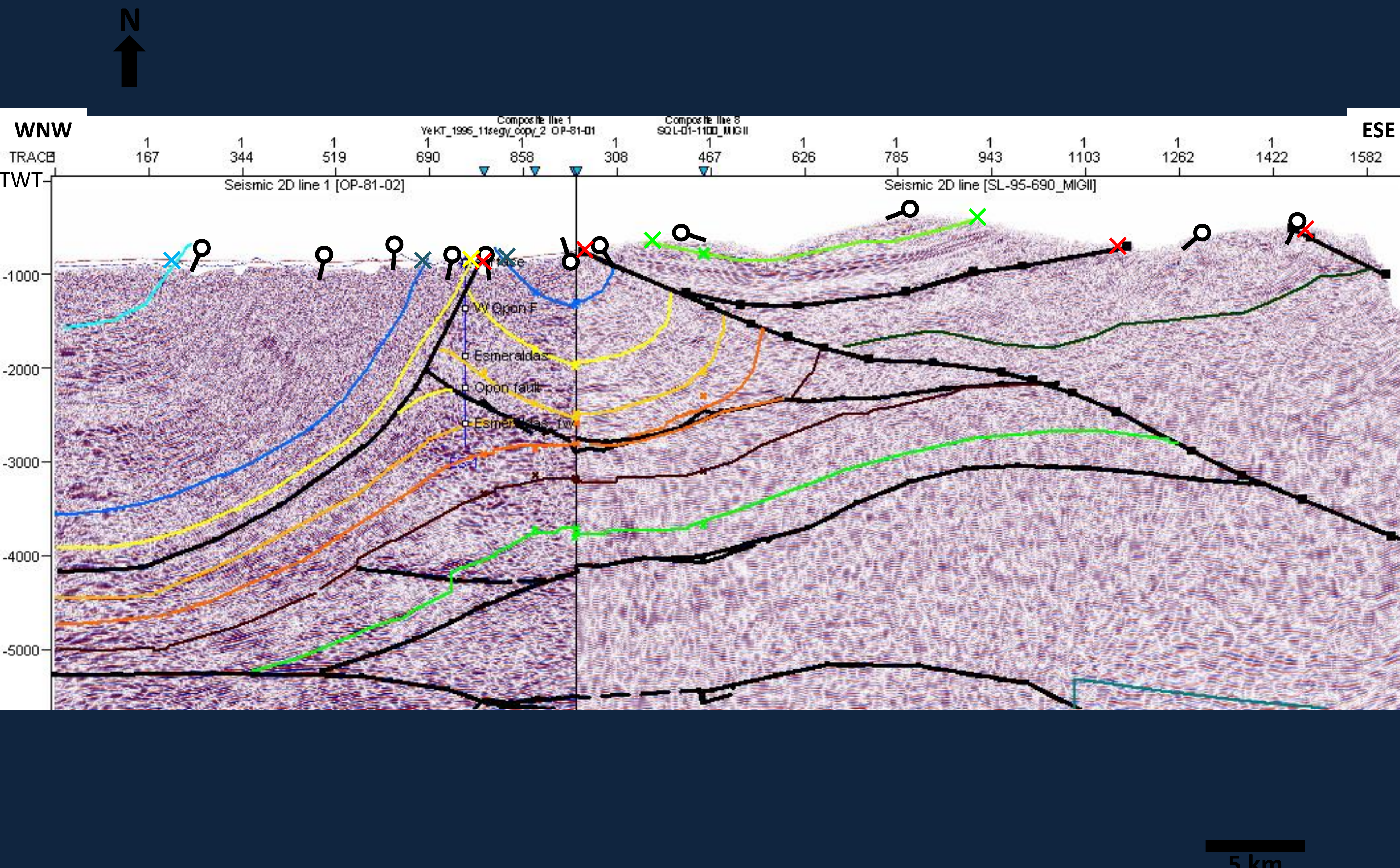
# Structure


N
SW
NE
LINE
TRACE
TWT
Seismic 2D line [SQL_2007-1125]
Seismic 2D line [YeKT_1995_09segy]
-1000
-2000
-3000
-4000
-5000
surface
Esmeraldas
Opon fault
Esmeraldas_fw
La paz
Lisama
OP-14
LI-10
5 km

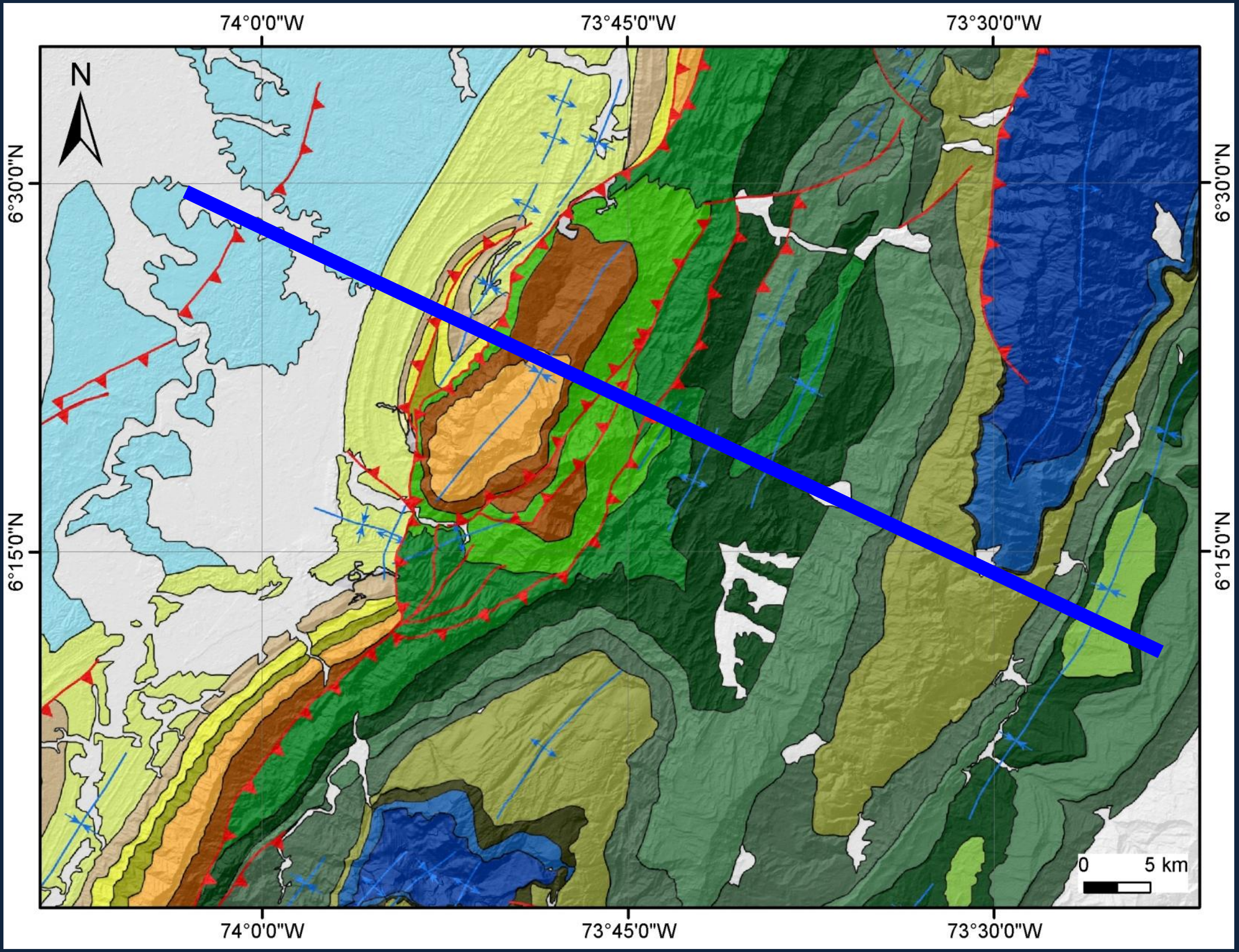
# Seismic Section Location Map



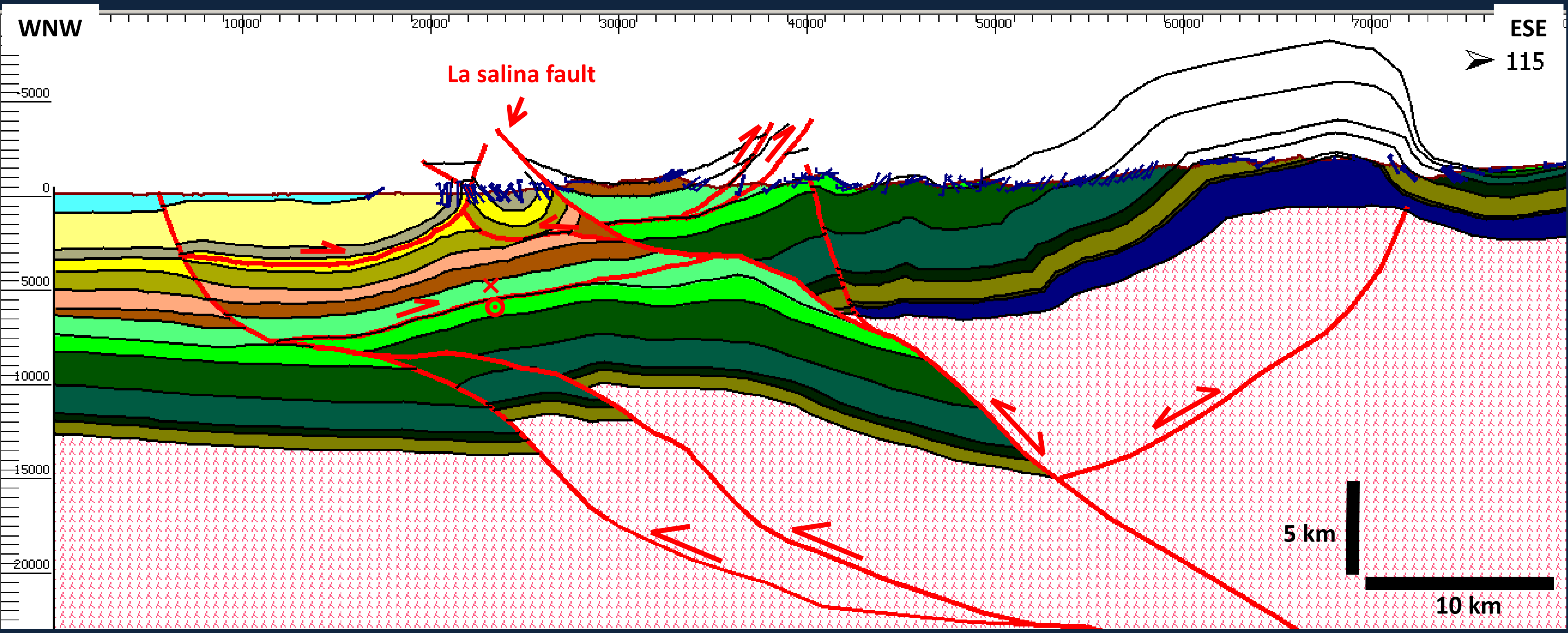
# Structure


N
WNW
ESE
Composite line 1
Composite line 8
TRACE
167
344
519
690
858
308
467
626
785
943
1103
1262
1422
1582
TWT
-1000
-2000
-3000
-4000
-5000
Seismic 2D line 1 [OP-81-02]
Seismic 2D line [SL-95-690_MIGII]
W Opon F
Esmeraldas
Opon fault
5 km

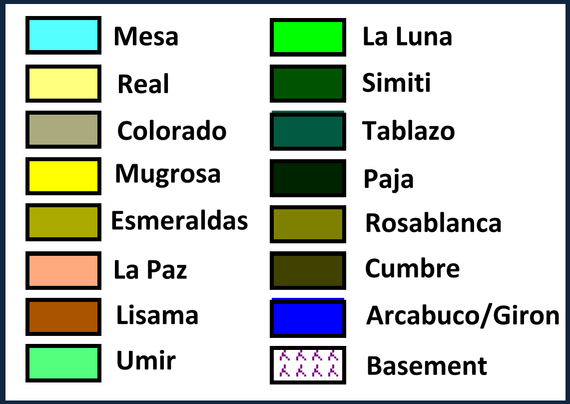
# Cross Section Location Map

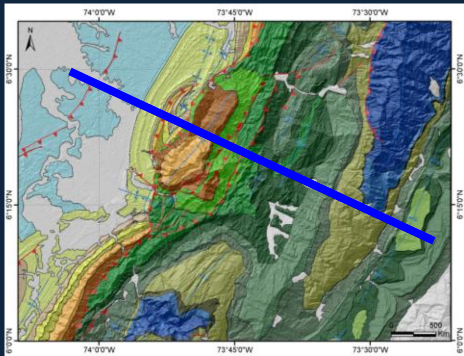


# Structural configuration

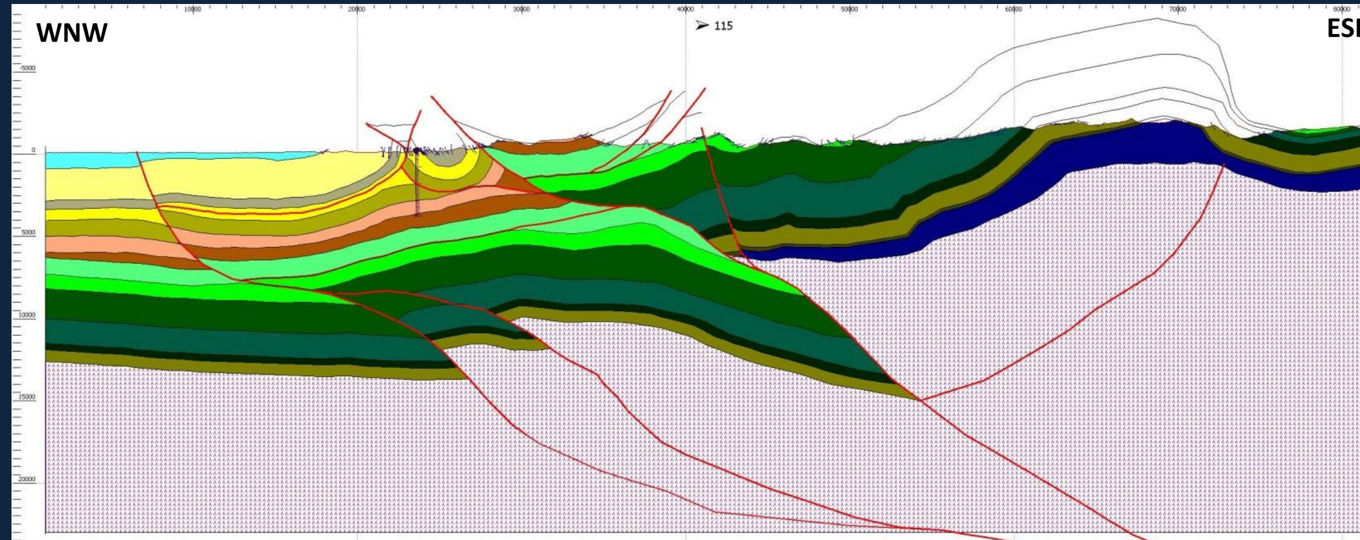


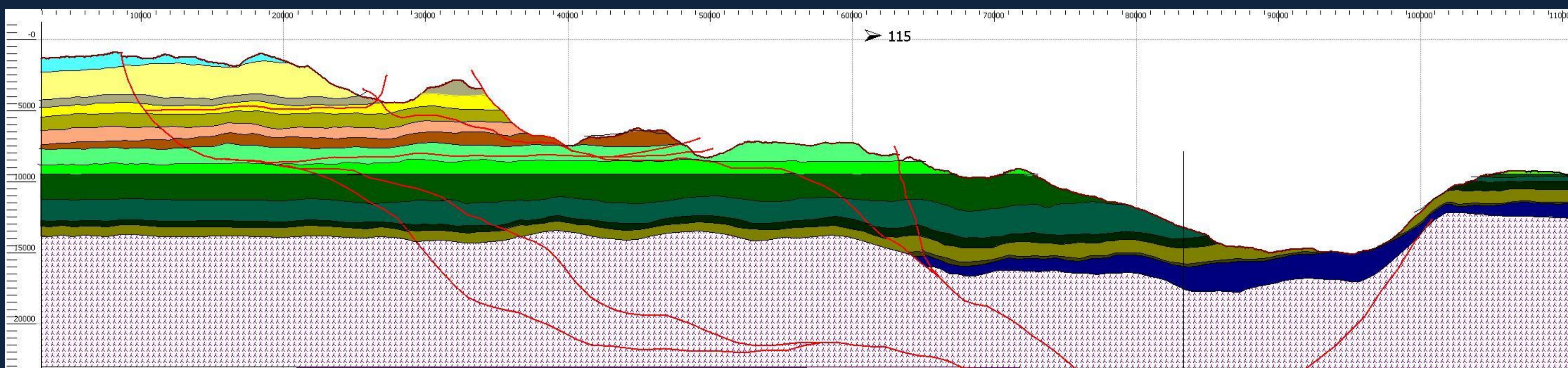

- Main displacement along the La Salina fault (LSF)
- Minor deformation propagated along the frontal thrust
- Passive roof duplex (backthrust) in the footwall of LSF
- Basement-involved deformation , possible inverted structure to east





**Shortening: ~ 27 Km**
**~ 25 %**

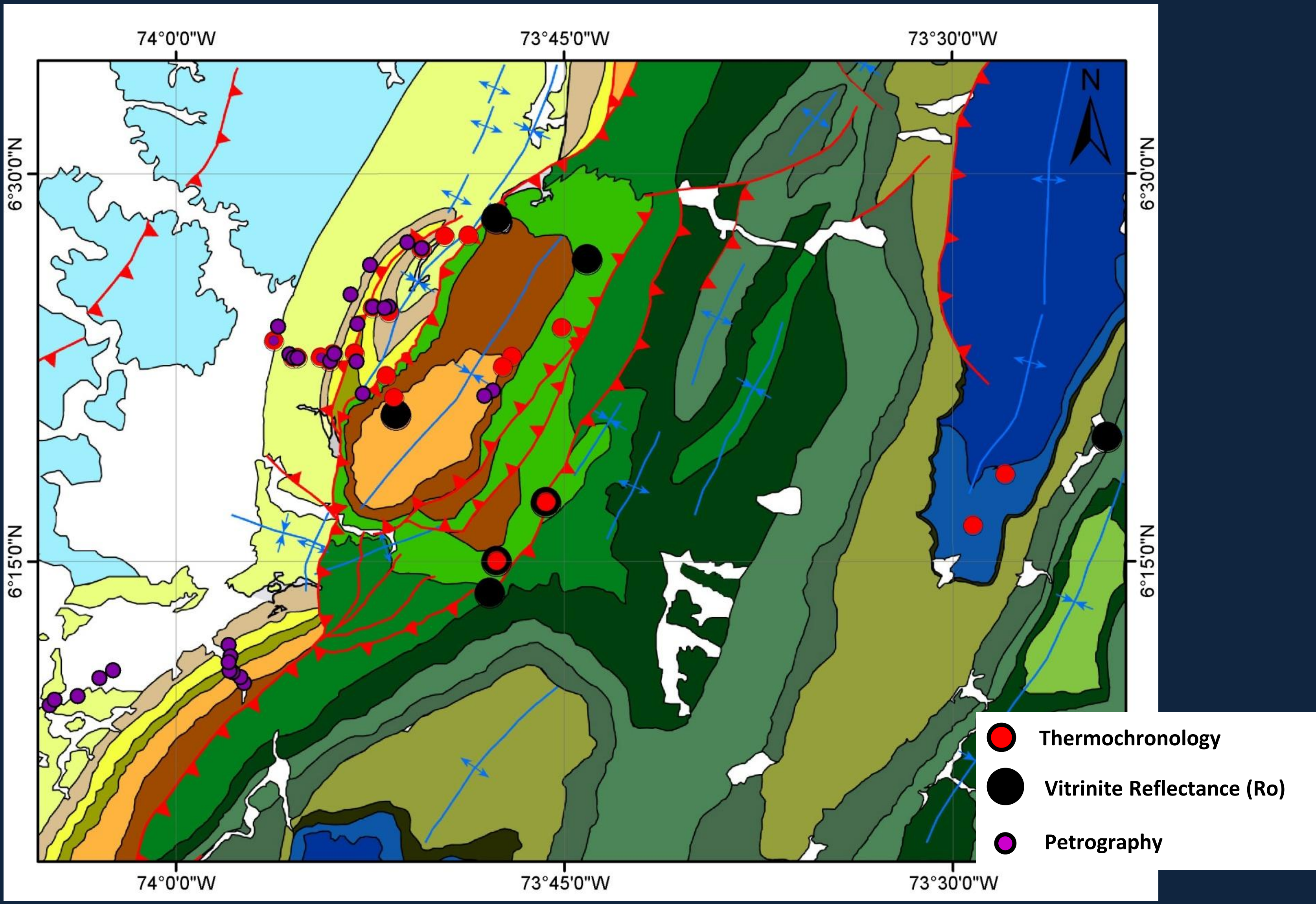



5 Km

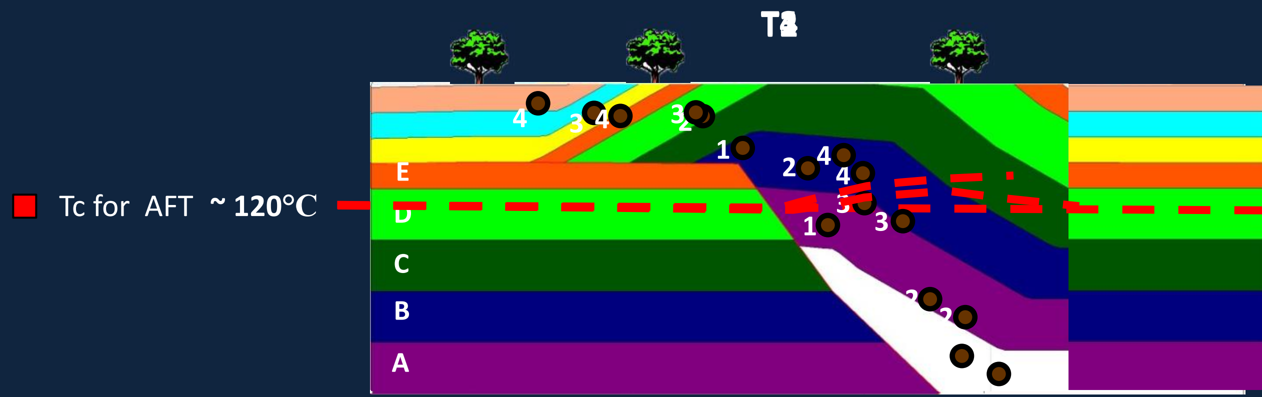
10 Km

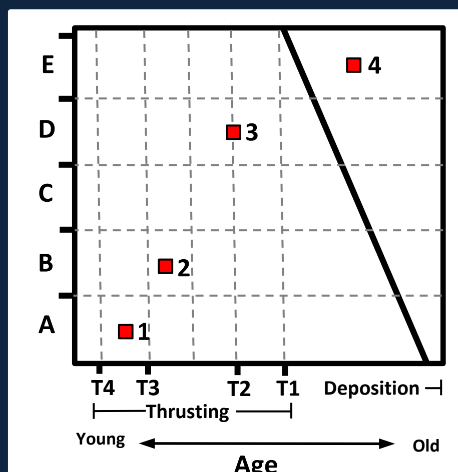
# Sampling

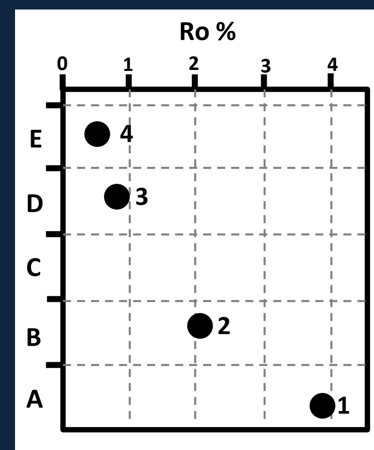


74°0'0"W
73°45'0"W
73°30'0"W
6°30'0"N
6°15'0"N
N
Thermochronology
Vitrinite Reflectance (Ro)
Petrography

# Thermochronology and Vitrinite Reflectance



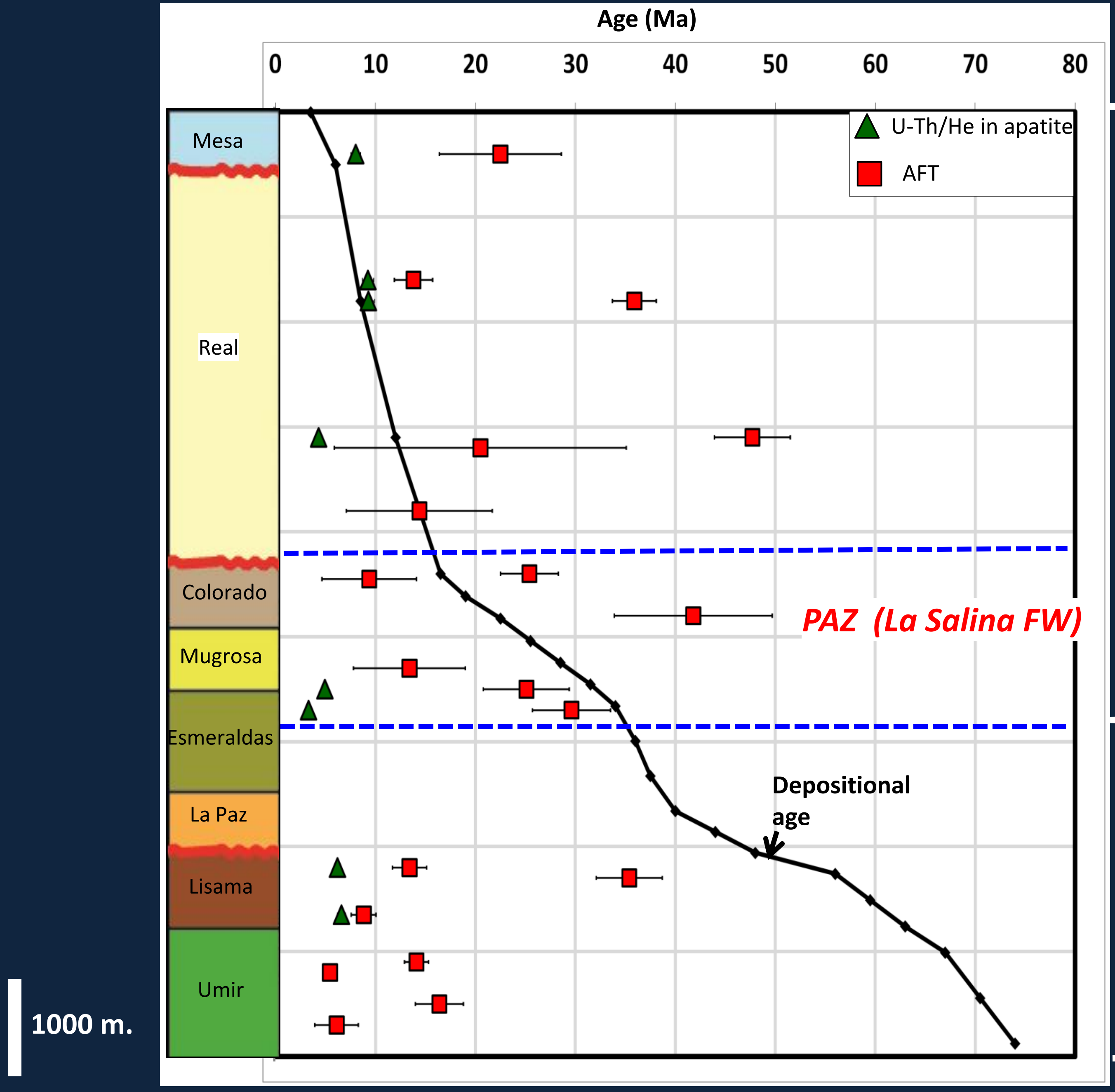

**Thermochronometers:** Information about time and thermal history

- **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-temperatute

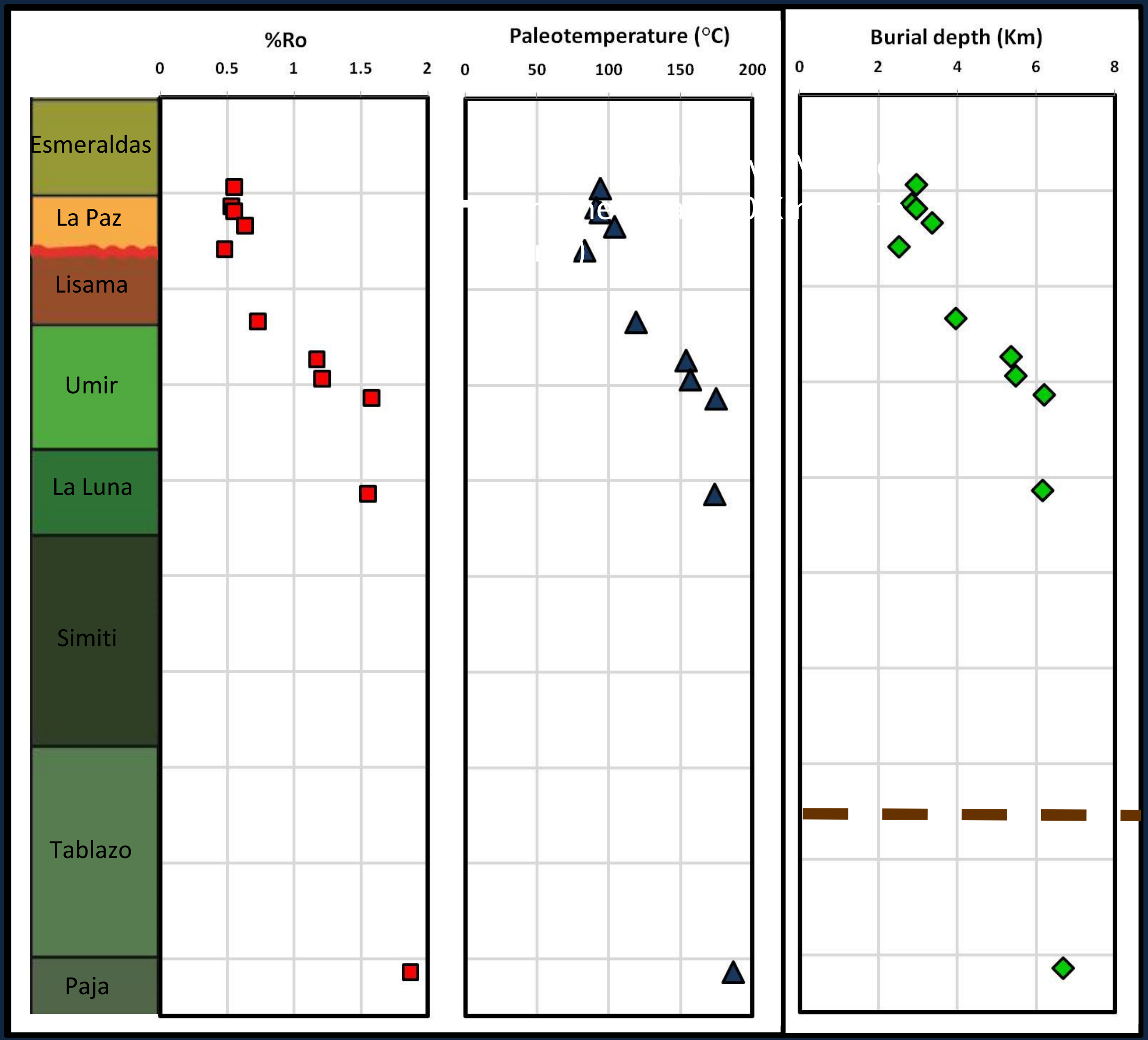
# Thermochronology




La Salina fault
**Hangingwall**

La Salina fault
**Footwall**

# Vitrinite reflectance

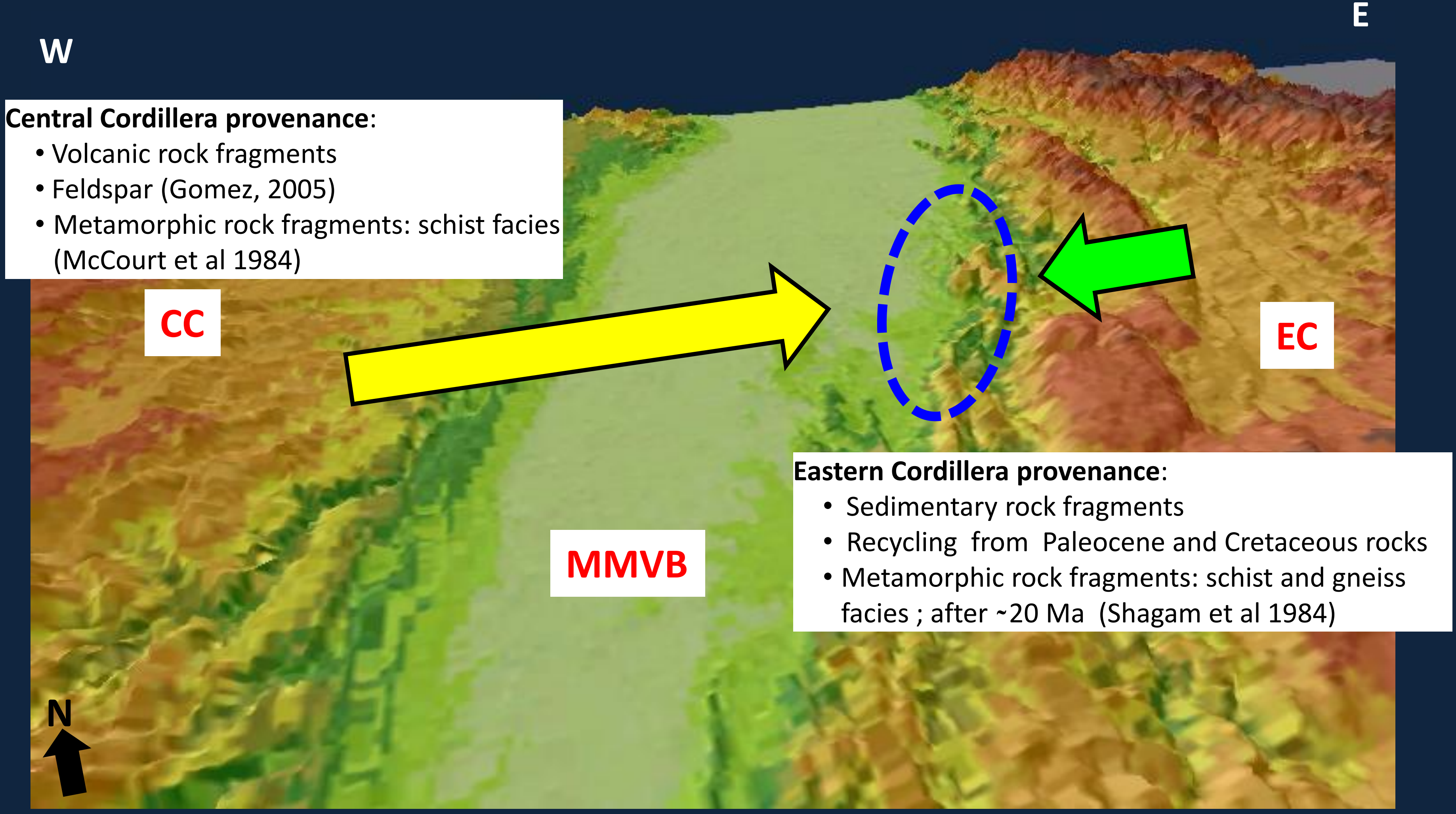



- Kinetic model : Burnham and Sweeney, 1990 (normal heating rate of 1°C/Ma)
- Geothermal gradient: 25°C/km

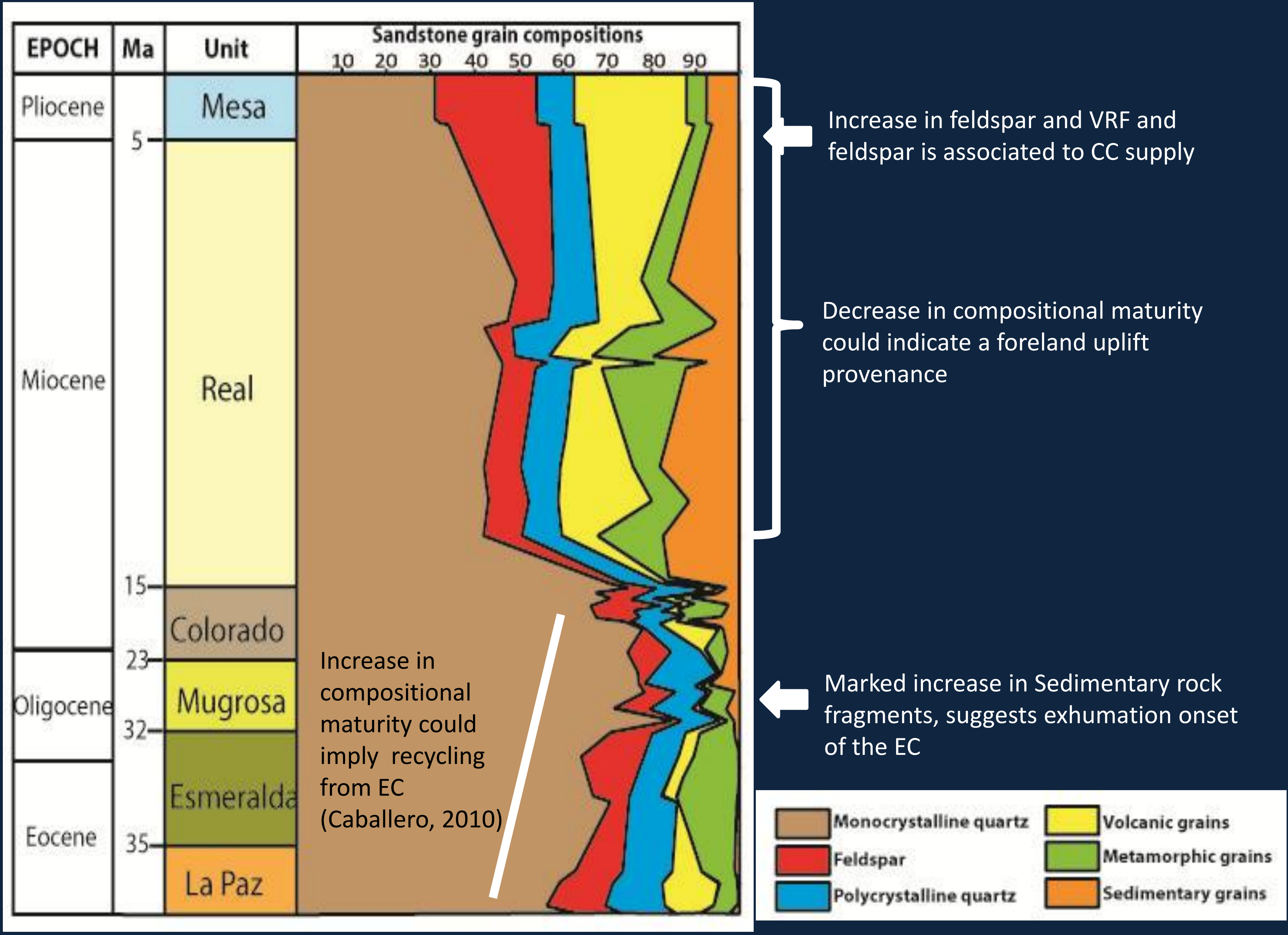
Different structural blocks

1000 m.

# Sandstone Petrography



# Sandstone Petrography




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

Increase in feldspar and VRF and feldspar is associated to CC supply

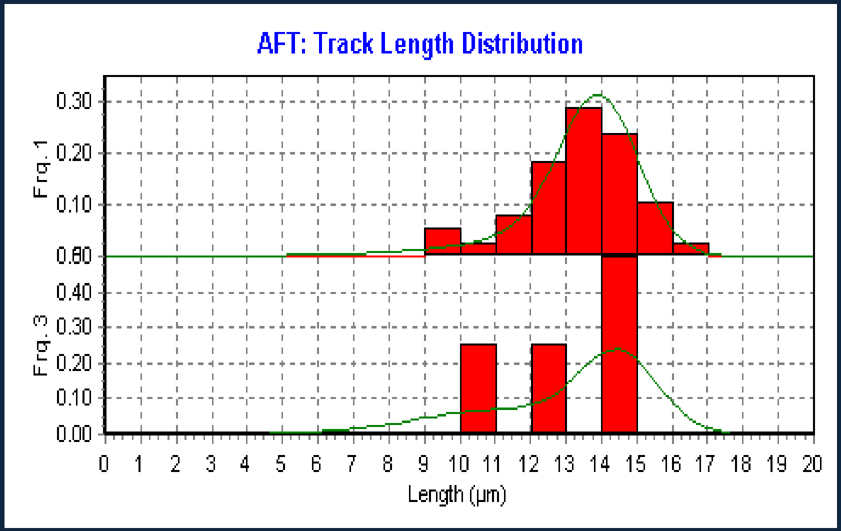
Decrease in compositional maturity could indicate a foreland uplift provenance

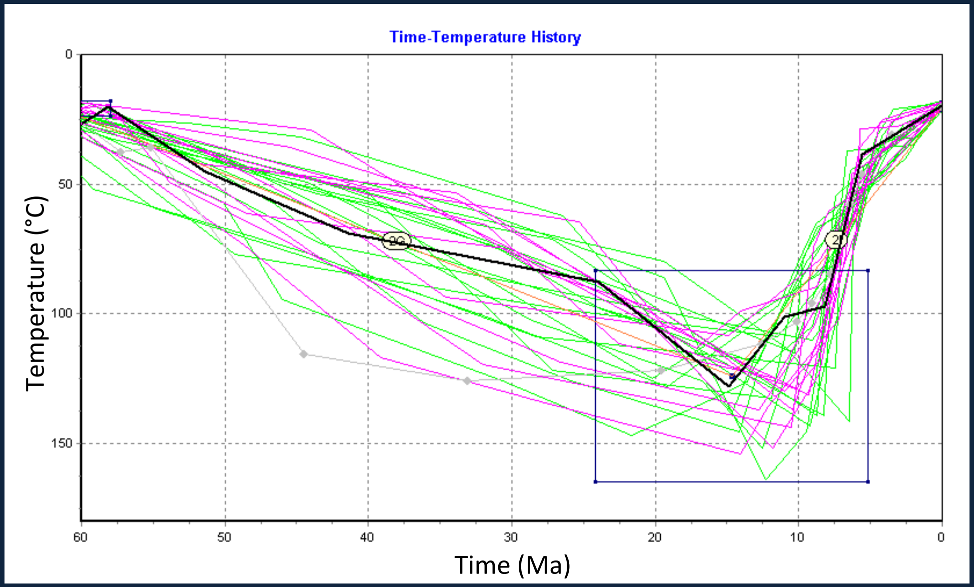
Marked increase in Sedimentary rock fragments, suggests exhumation onset of the EC

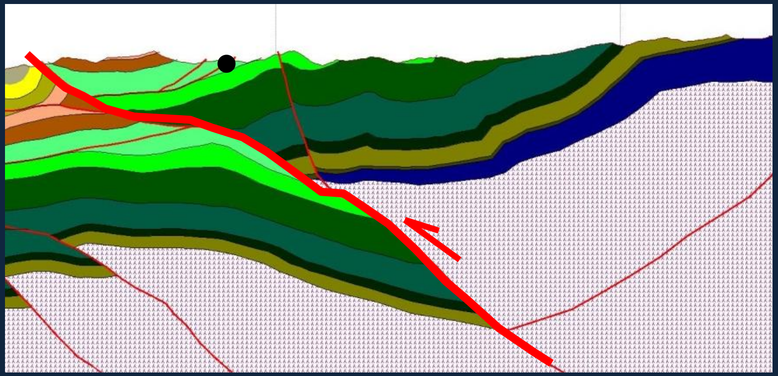
# Thermal modeling

**Thermochronometers:**

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



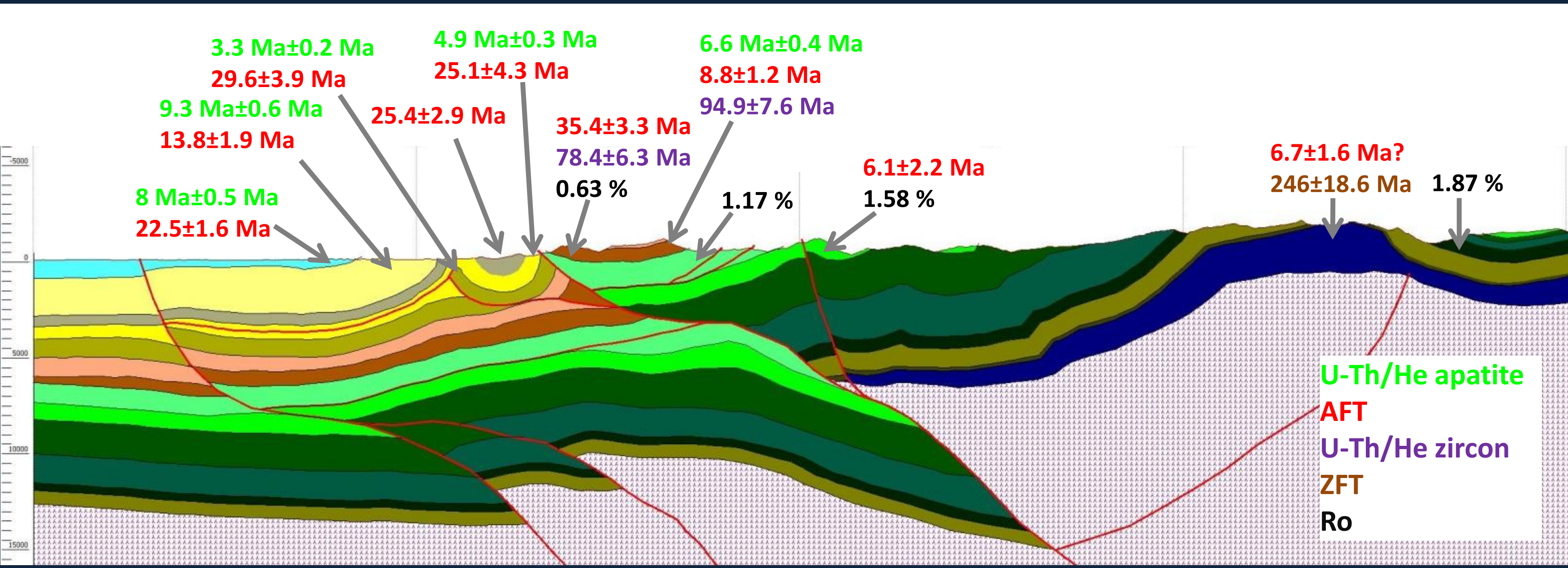
Software**: HeFTy 1.6.7 (Ketcham, 2009)**

Structural analysis

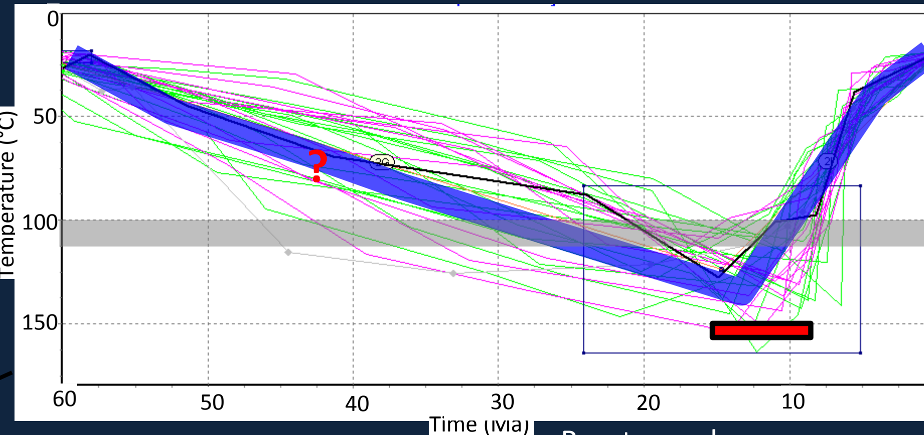
Themochronology and vitrinite reflectance

Provenance petrography

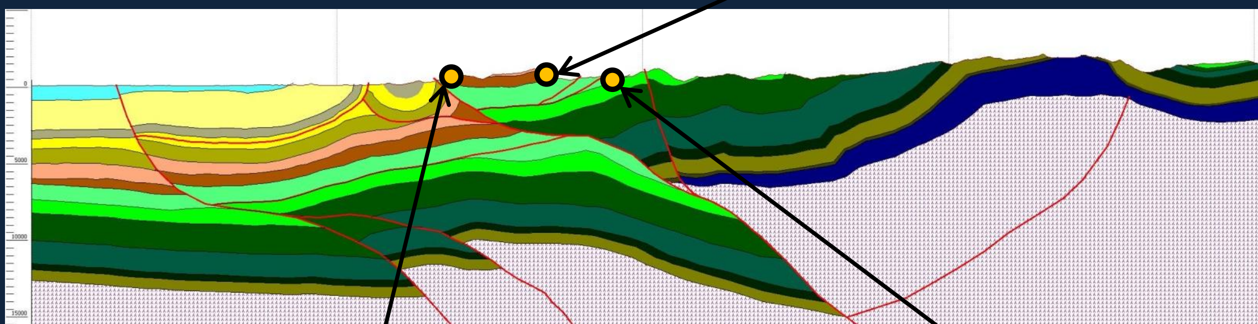
# Kinematic restoration



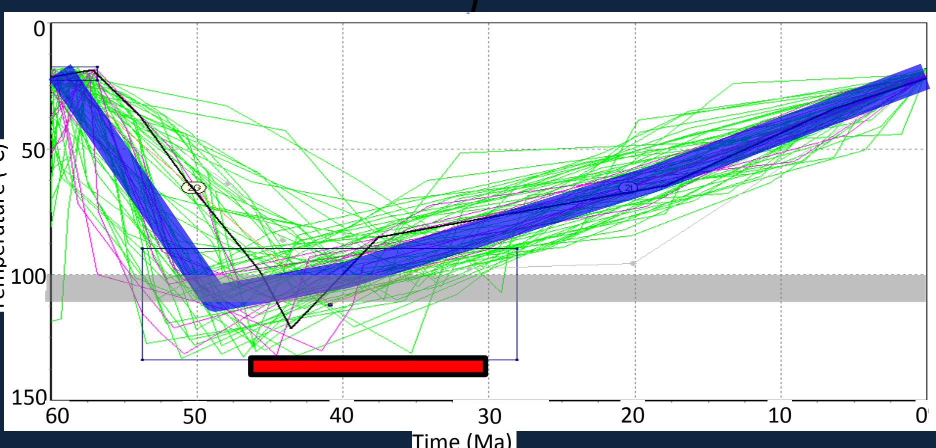
# Exhumation pattern
# "La Salina" fault hangingwall



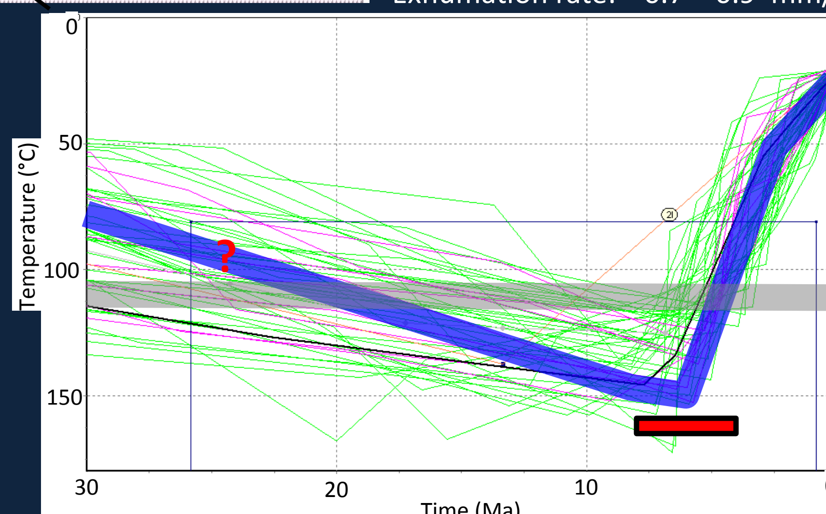

Reset sample
Cooling onset:: ~ 8 - 15 Ma



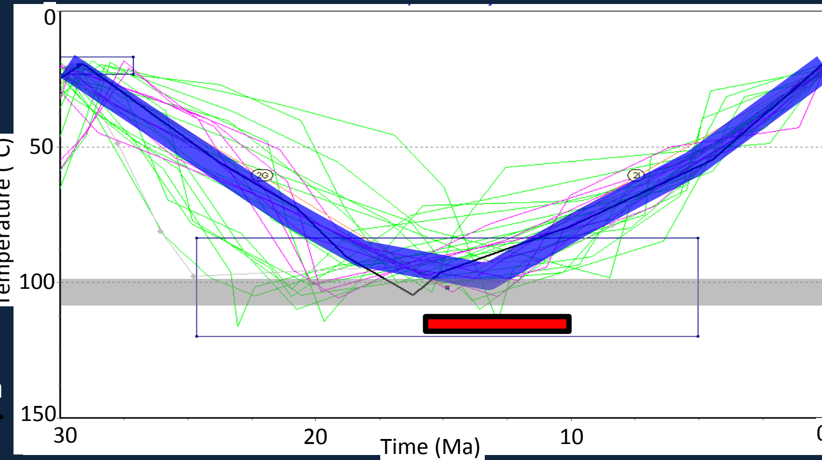
Reset sample
Cooling onset: ~ 4 - 8 Ma
Exhumation rate: ~ 0.7 – 0.9 mm/yr



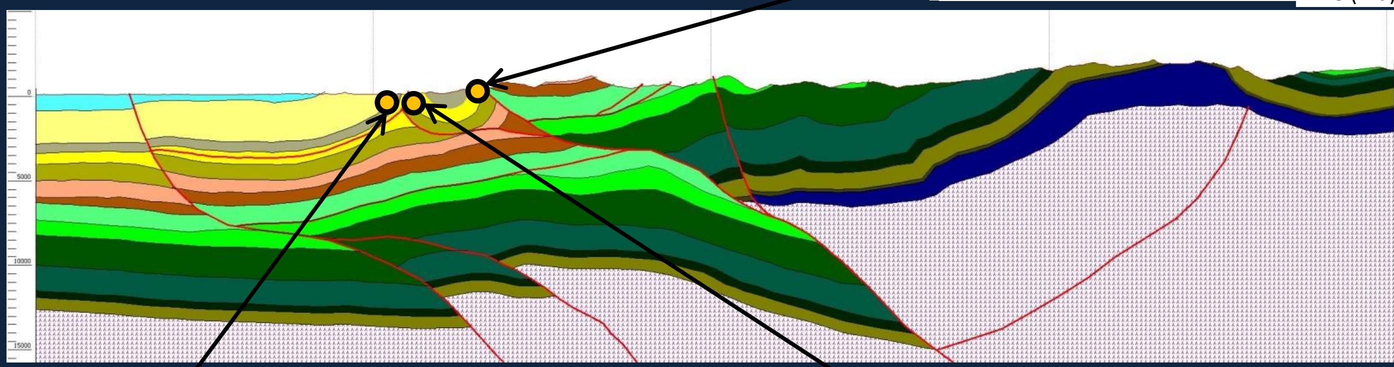

Partially reset sample?
Cooling onset: ~ 30 - 40 Ma



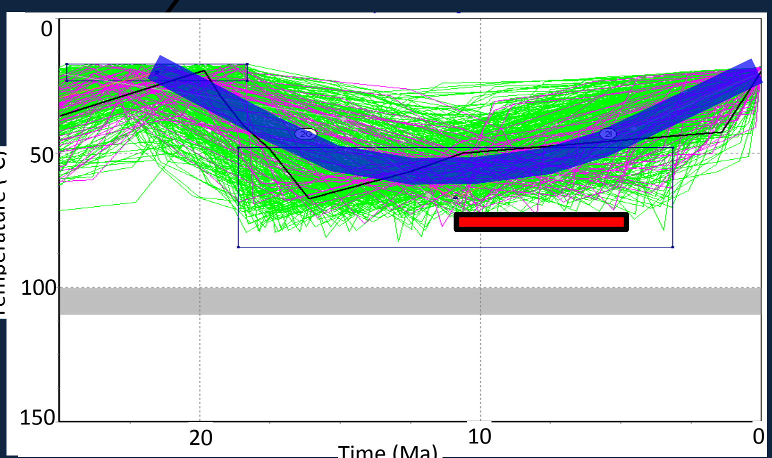
# Exhumation pattern
# “La Salina” fault footwall

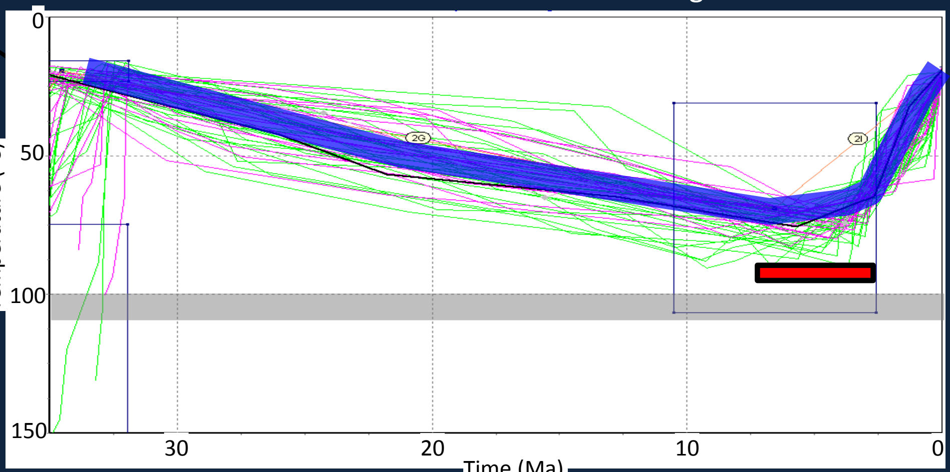



Partially reset sample?
Cooling onset: ~ 10 - 15 Ma



Partially reset sample
Cooling onset: ~ 3 - 6 Ma



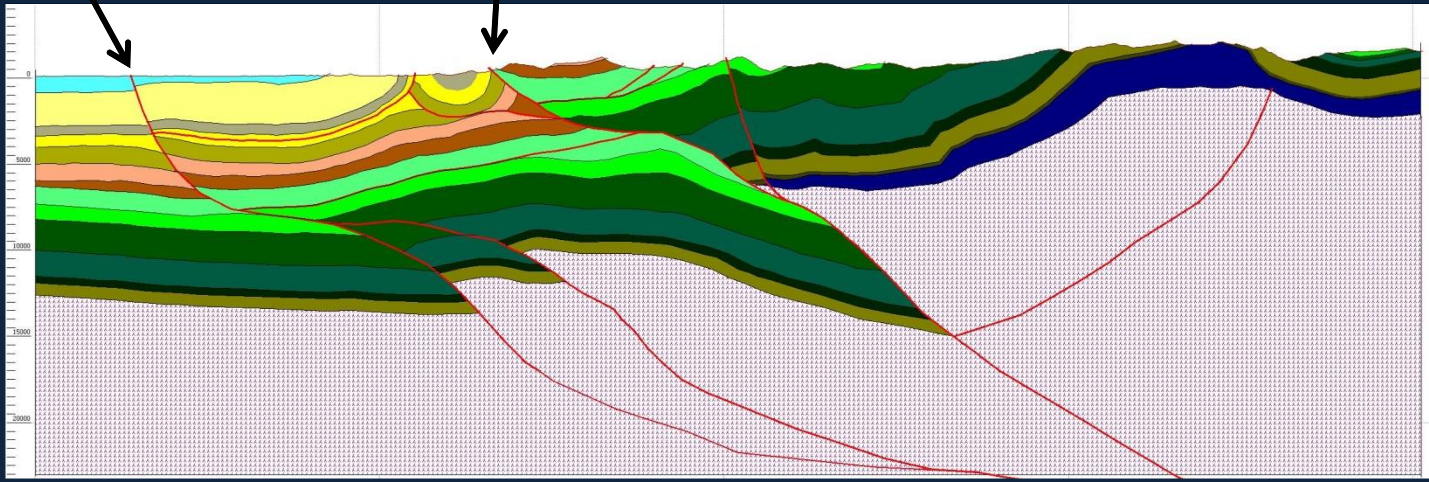




Partially reset sample
Cooling onset: ~ 5 - 10 Ma

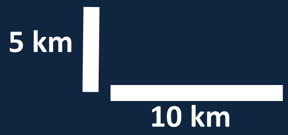
# Pliocene: ~ 0 - 5 Ma

Pliocene section fault cross-cut

Out of sequence event

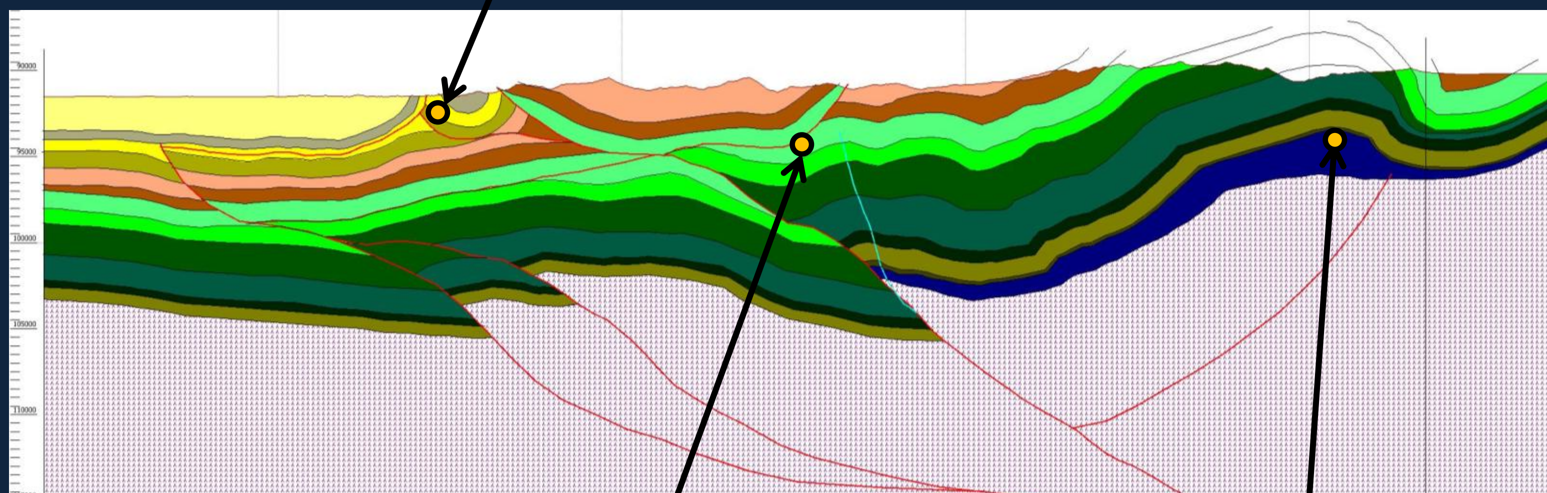


**Shortening: ~ 27 Km**
**~ 25 %**



# Pliocene-Late Miocene : ~ 5 - 6 Ma

Partially reset sample
Cooling onset: ~ 3 - 6 Ma



Reset sample
Cooling onset: ~ 4 - 8 Ma
Accelerated exhumation: ~ 0.7 – 0.9 mm/yr

AFT = 6.7 ± 1.6 Ma?

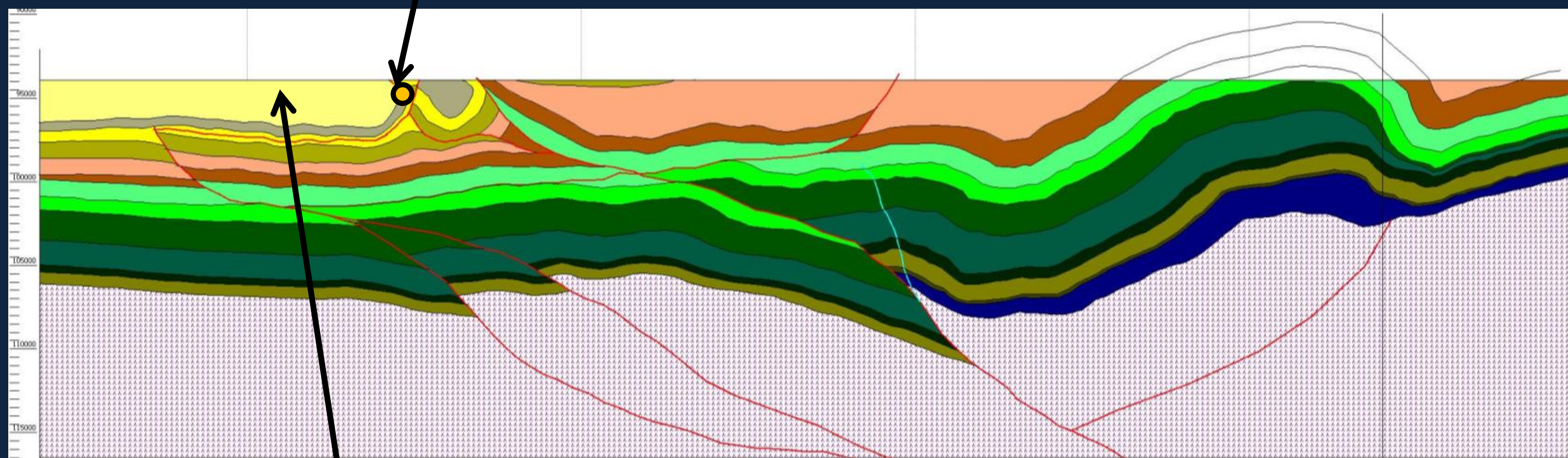
**Shortening: ~ 20 Km**
**~ 18 %**

**5 km**

**10 km**

# Late Miocene : ~ 6 - 8 Ma

Partially reset sample
Cooling onset: ~ 5 - 10 Ma



**Shortening: ~ 16 Km**
**~ 15 %**

Decrease in compositional maturity could indicates a foreland uplift provenance (Real group)

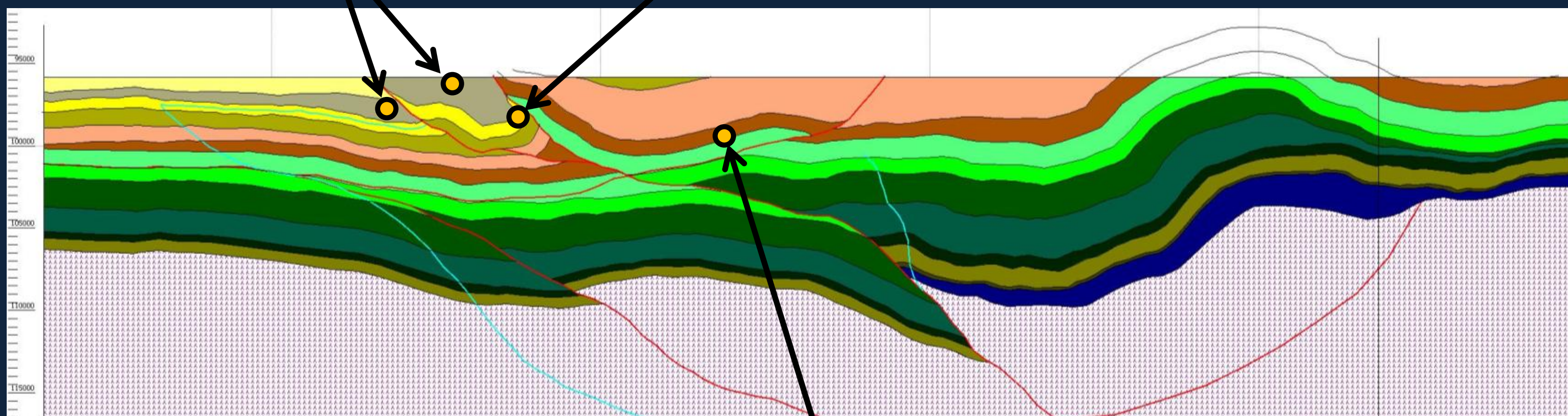
**5 km**

**10 km**

# Late Miocene : ~ 10 Ma

Difference in burial

Partially reset sample
Cooling onset: ~ 10 - 15 Ma



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

**Shortening: ~ 15 Km**
**~ 14 %**

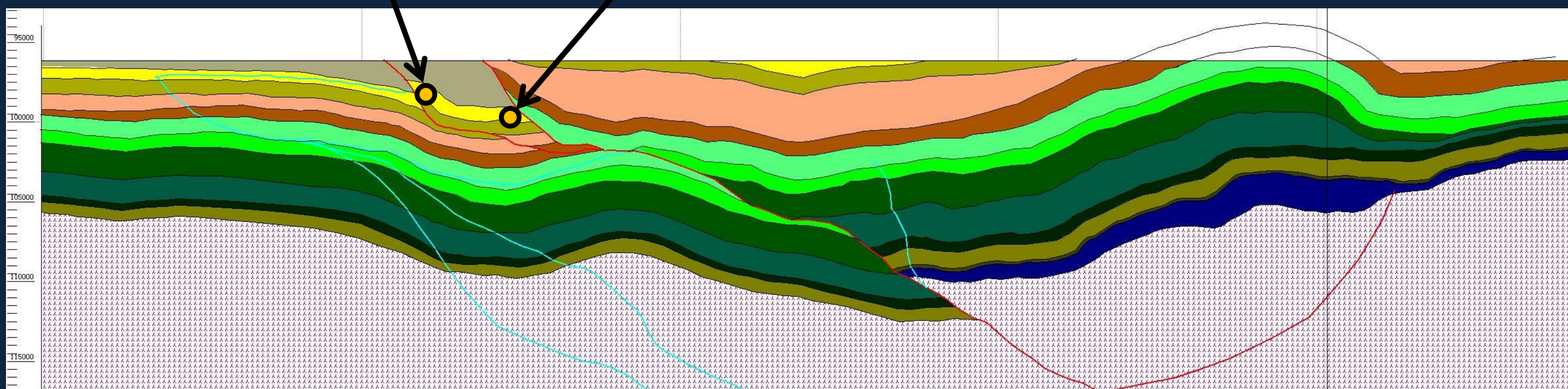
**5 km**

**10 km**

# Middle Miocene : ~ 15 Ma

Less burial

Partially reset sample
Cooling onset: ~ 10 - 15 Ma



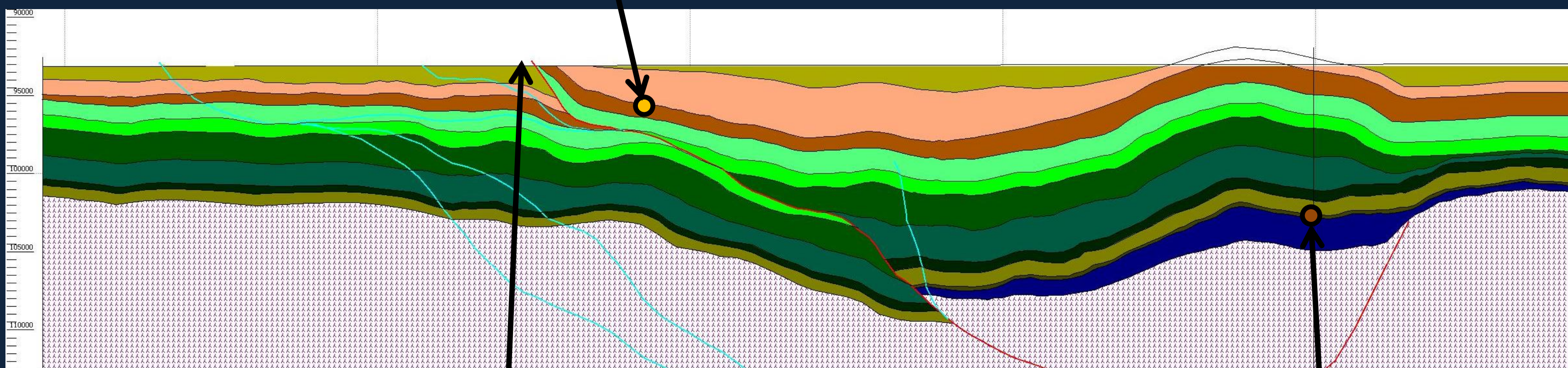
**Shortening: ~ 12 Km**
**~ 11 %**

5 km

10 km

# Early Oligocene: ~ 30 Ma

Partially reset sample
Cooling onset: ~ 30 - 40 Ma




**Shortening: ~ 10 Km**
**~ 9 %**

Marked increase in Sedimentary rock fragments

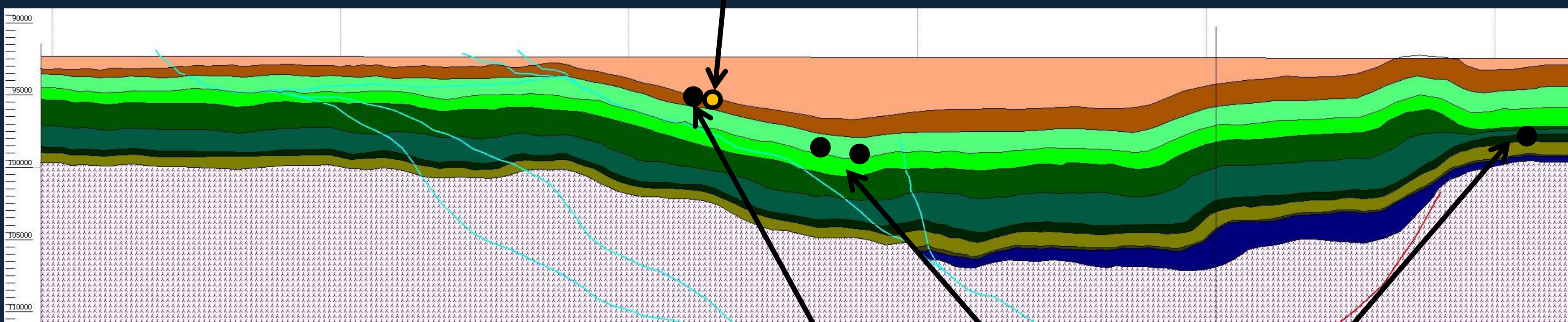
ZFT = ~246 Ma, no reset sample

**5 km**

**10 km**

# Middle Eocene: ~40 Ma

Partially reset sample
Cooling onset: ~ 30 - 40 Ma




~2-3 Km
~5-6 Km
~6-7 Km

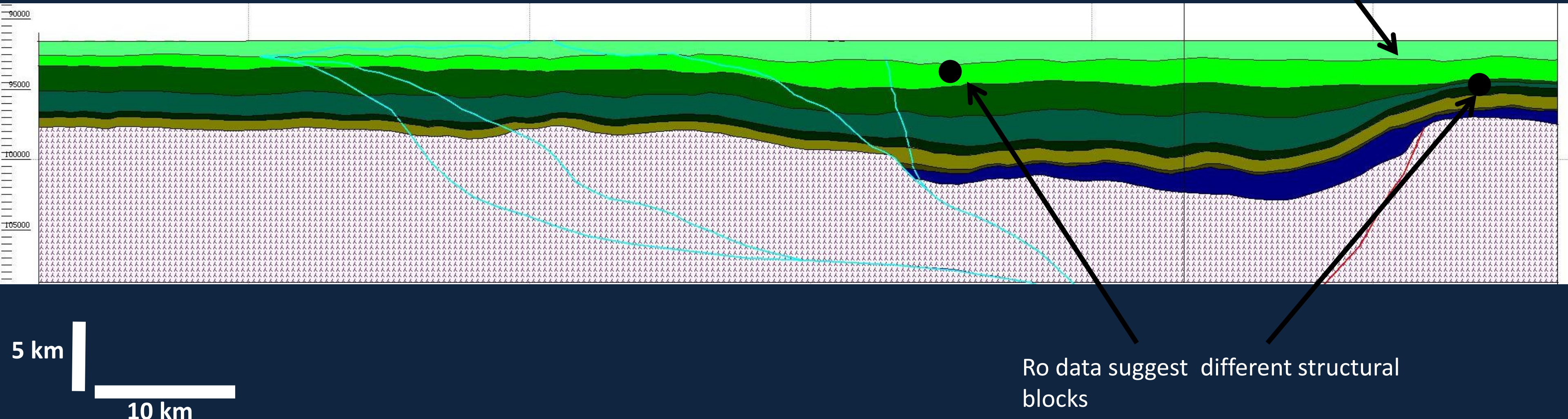
Max burial depth

**Shortening: ~ 2 Km**
**~ 2 %**

**5 km**
**10 km**

# 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?)

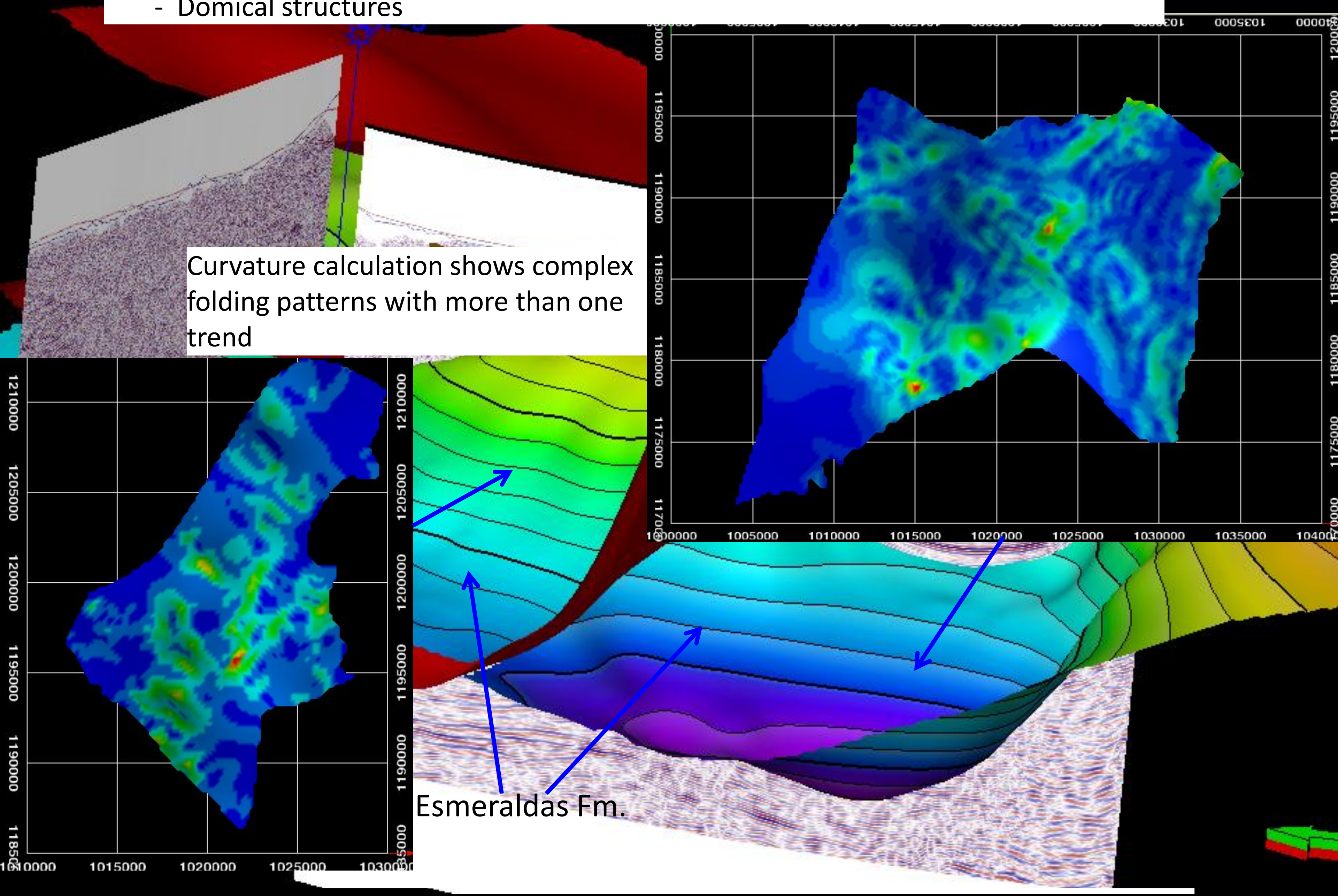
**Thermochronology**
- Onset of significant exhumation / cooling by ~6 Ma
- Other exhumation events at ~30-40 Ma and ~15 Ma

**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 Ma
- Eastern MMV basin: Tectonic wedging and backthrusting induced exhumation by ~15 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



# Acknowledgements

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