

Structural Evolution of La Florida Anticline and Petroleum System in a Foreland Fold Belt, Eastern Cordillera Foothills, Colombia*

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Abstract

The La Florida anticline is located in the Llanos Foothills, a prolific sub-Andean petroleum province on the southeastern flank of the Eastern Cordillera of Colombia. The giant Cusiana and Cupiagua fields are located along structural strike in hanging-wall anticlinal traps to the northeast of the La Florida anticline. The traps were formed during the Late Oligocene-Early Miocene “thin-skinned” and Miocene-Holocene “thick-skinned” deformation of the Eastern Cordillera. The source rocks are Gachetá Formation Late Cretaceous organic-rich black marine mudstones. Reservoir rocks include upper Eocene Mirador Formation sandstones and Paleocene Barco Formation estuarine sands. Cap rocks are Oligocene Carbonera marine shales C8. Well ties and horizon mapping were based on a rich seismic data volume (322 km² 3D high-resolution seismic and 540 2D seismic profiles, Pacific Energy/Frontera) and 7 wells. Volume-balanced forward and retrodeformed structural modeling, and 1D basin models suggest that migration pathways were available for the La Florida anticline at the time of maximum oil expulsion (6 – 8 Ma). Structural traps are Andean age (3 – 6 Ma) fault-bend folds with transpressive displacement. Fracture attribute analysis (Ant-tracking, Chaos and Variance) indicates possible up-plunge sealing fault (4-way closure) for anticlinal trap permitting accumulation of hydrocarbons. The La Florida anticline has an active petroleum system (source, reservoir, seal, timing of charge, and trap formation) like the adjacent Cusiana giant field. The Medina anticline to the southwest of La Florida is isolated from the active Foothills source pods by a major sealing thrust fault. Hydrocarbon accumulations in the Medina structure are therefore limited or non-existent.

References Cited

- Bachu, S., Ramon, J. C., Villegas, M. E., and Underschultz, J. R., 1995, Geothermal regime and thermal history of the Llanos Basin, Colombia: AAPG bulletin, v. 79, no. 1, p. 116-128.
- Bande, A., Horton, B. K., Ramirez, J. C., Mora, A., Parra, M., and Stockli, D. F., 2012, Clastic deposition, provenance, and sequence of Andean thrusting in the frontal Eastern Cordillera and Llanos foreland basin of Colombia: Geological Society of America Bulletin, v. 124, no. 1-2, p. 59-76.

- Bayona, G., Cortes, M., Jaramillo, C., Ojeda, G., Aristizabal, J. J., and Reyes-Harker, A., 2008, An integrated analysis of an orogen-sedimentary basin pair: Latest Cretaceous-Cenozoic evolution of the linked Eastern Cordillera orogen and the Llanos foreland basin of Colombia: Geological Society of America Bulletin, v. 120, no. 9-10, p. 1171-1197.
- Branquet, Y., Cheilletz, A., Cobbold, P. R., Baby, P., Laumonier, B., and Giuliani, G., 2002, Andean deformation and rift inversion, eastern edge of Cordillera Oriental (Guatèque-Medina area), Colombia: Journal of South American Earth Sciences, v. 15, no. 4, p. 391-407.
- Campos, H., and Mann, P., 2015, Tectonostratigraphic evolution of the Northern Llanos Foreland Basin of Colombia and implications for its hydrocarbon potential: Petroleum geology and potential of the Colombian Caribbean Margin, v. 108, p. 517-546.
- Carrillo, E., Mora, A., Ketcham, R. A., Amorcho, R., Parra, M., Costantino, D., Robles, W., Avellaneda, W., Carvajal, J. S., and Corcione, M. F., 2016, Movement vectors and deformation mechanisms in kinematic restorations: A case study from the Colombian Eastern Cordillera: Interpretation, v. 4, no. 1, p. T31-T48.
- Cazier, E. C., Hayward, A. B., Espinosa, G., Velandia, J., Mugniot, J. F., and Leel Jr, W. G., 1995, Petroleum geology of the Cusiana field, Llanos Basin foothills, Colombia: AAPG bulletin, v. 79, no. 10, p. 1444-1462.
- Cediel, F., Shaw, R. P., and Cceres, C., 2003, Tectonic assembly of the northern Andean block: The Circum-Gulf of Mexico and the Caribbean: Hydrocarbon habitats, basin formation, and plate tectonics, v. 79, p. 815-848.
- Colletta, B., Hebrard, F., Letouzey, J., Werner, P., and Rudkiewicz, J. L., 1990, Tectonic Style and Crustal Structure of the Eastern Cordillera (Colombia) from a Balanced Cross-Section: Petroleum and Tectonics in Mobile Belts, v. 47, p. 81-100.
- Cooper, M. A., Addison, F. T., Alvarez, R., Coral, M., Graham, R. H., Hayward, A. B., Howe, S., Martinez, J., Naar, J., and Peñas, R., 1995, Basin development and tectonic history of the Llanos Basin, Eastern Cordillera, and middle Magdalena Valley, Colombia: AAPG bulletin, v. 79, no. 10, p. 1421-1442.
- Cortés, M., Colletta, B., and Angelier, J., 2006, Structure and tectonics of the central segment of the Eastern Cordillera of Colombia: Journal of South American Earth Sciences, v. 21, no. 4, p. 437-465.
- Dahlen, F. A., 1990, Critical taper model of fold-and-thrust belts and accretionary wedges: Annual Review of Earth and Planetary Sciences, v. 18, no. 1, p. 55-99.
- de la Parra, F., Mora, A., Rueda, M., and Quintero, I., 2015, Temporal and spatial distribution of tectonic events as deduced from reworked palynomorphs in the eastern Northern Andes: AAPG Bulletin, v. 99, no. 08, p. 1455-1472.

De Toni, B., and Kellogg, J., 1993, Seismic evidence for blind thrusting of the northwestern flank of the Venezuelan Andes: *Tectonics*, v. 12, no. 6, p. 1393-1409.

DeCelles, P. G., 2004, Late Jurassic to eocene evolution of the Cordilleran thrust belt and foreland basin system, western USA: *American Journal of Science*, v. 304, no. 2, p. 105-168.

Delgado, A., Mora, A., and Reyes-Harker, A., 2012, Deformation partitioning in the Llanos foreland basin during the Cenozoic and its correlation with mountain building in the hinterland: *Journal of South American Earth Sciences*, v. 39, p. 228-244.

Dengo, C. A., and Covey, M. C., 1993, Structure of the Eastern Cordillera of Colombia - Implications for Trap Styles and Regional Tectonics: *AAPG Bulletin*, v. 77, no. 8, p. 1315-1337.

Egbue, O., and Kellogg, J., 2012, Three-dimensional structural evolution and kinematics of the Piedemonte Llanero, Central Llanos foothills, Eastern Cordillera, Colombia: *Journal of South American Earth Sciences*, v. 39, p. 216-227.

Erslev, E. A., 1991, Trishear Fault-Propagation Folding: *Geology*, v. 19, no. 6, p. 617-620.

G. mez, E. a., Jordan, T. E., Allmendinger, R. W., and Cardozo, N., 2005, Development of the Colombian foreland-basin system as a consequence of diachronous exhumation of the northern Andes: *GSA Bulletin*, v. 117, no. 9-10, p. 1272-1292.

Horton, B. K., Saylor, J. E., Nie, J., Mora, A., Parra, M., Reyes-Harker, A., and Stockli, D. F., 2010b, Linking sedimentation in the northern Andes to basement configuration, Mesozoic extension, and Cenozoic shortening: Evidence from detrital zircon U-Pb ages, Eastern Cordillera, Colombia: *GSA Bulletin*, v. 122, no. 9-10, p. 1423-1442.

Jaramillo, C., Rueda, M., Bayona, G., Santos, C., Florez, P., Parra, F., and Demchuk, T. D., 2009, Biostratigraphy breaking paradigms: dating the Mirador Formation in the Llanos Basin of Colombia: Geological problem solving with microfossils: a volume in honor of Garry D. Jones. Tulsa (OK): SEPM (SEPM Special Publication No. 93), p. 29-40.

Jimenez, L., Mora, A., Casallas, W., Silva, A., Tesón, E., Tamara, J., Namson, J., Higuera-Díaz, I. C., Lasso, A., and Stockli, D., 2013, Segmentation and growth of foothill thrust-belts adjacent to inverted grabens: the case of the Colombian Llanos foothills: *Geological Society, London, Special Publications*, v. 377, no. 1, p. 189.

Martinez, J. A., 2006, Structural evolution of the Llanos foothills, Eastern Cordillera, Colombia: *Journal of South American Earth Sciences*, v. 21, no. 4, p. 510-520.

McQuarrie, N., 2002, The kinematic history of the central Andean fold-thrust belt, Bolivia: Implications for building a high plateau: *Geological Society of America Bulletin*, v. 114, no. 8, p. 950-963.

Mora, A., 2015, Petroleum systems of the Eastern Cordillera, foothill basins, and associated Llanos basin: Impacts on the prediction of large-scale foreland and foothill petroleum accumulationsIntroduction: Petroleum Systems of the Llanos Basin: AAPG Bulletin, v. 99, no. 8, p. 1401-1406.

Mora, A., Casallas, W., Ketcham, R. A., Gomez, D., Parra, M., Namson, J., Stockli, D., Almendral, A., Robles, W., and Ghorbal, B., 2015, Kinematic restoration of contractional basement structures using thermokinematic models: A key tool for petroleum system modeling Kinematic Restoration of Contractional Basement Structures Using Thermokinematic Models: AAPG Bulletin, v. 99, no. 8, p. 1575-1598.

Mora, A., Garcia, D., Reyes-Harker, A., Parra, M., Blanco, V., Sanchez, N., de la Parra, F., Caballero, V., Rodriguez, G., and Ruiz, C., 2019a, Tectonic evolution of petroleum systems within the onshore Llanos basin: Insights on the presence of Orinoco heavy-oil analogues in Colombia and a comparison with other heavy oil provinces worldwide: AAPG Bulletin, v. 103, no. 5, p. 1179-1224.

Mora, A., Parra, M., Strecker, M. R., Kammer, A., Dimaté, C., and Rodríguez, F., 2006, Cenozoic contractional reactivation of Mesozoic extensional structures in the Eastern Cordillera of Colombia: Tectonics, v. 25, no. 2.

Mora, A., Parra, M., Strecker, M. R., Sobel, E. R., Hooghiemstra, H., Torres, V., and Jaramillo, J. V., 2008, Climatic forcing of asymmetric orogenic evolution in the Eastern Cordillera of ColombiaClimatic forcing of orogenic evolution: GSA Bulletin, v. 120, no. 7-8, p. 930-949.

Mora, A., Parra, M., Strecker, M. R., Sobel, E. R., Zeilinger, G., Jaramillo, C., Da Silva, S. F., and Blanco, M., 2010b, The eastern foothills of the Eastern Cordillera of Colombia: An example of multiple factors controlling structural styles and active tectonics: GSA Bulletin, v. 122, no. 11-12, p. 1846-1864.

Parra, M., Mora, A., Jaramillo, C., Strecker, M. R., Sobel, E. R., Quiroz, L., Rueda, M., and Torres, V., 2009a, Orogenic wedge advance in the northern Andes: Evidence from the Oligocene-Miocene sedimentary record of the Medina Basin, Eastern Cordillera, ColombiaOrogenic wedge advance in the northern Andes, Colombia: GSA Bulletin, v. 121, no. 5-6, p. 780-800.

Parra, M., Mora, A., Jaramillo, C., Torres, V., Zeilinger, G., and Strecker, M. R., 2010, Tectonic controls on Cenozoic foreland basin development in the north-eastern Andes, Colombia: Basin Research, v. 22, no. 6, p. 874-903.

Parra, M., Mora, A., Sobel, E. R., Strecker, M. R., and González, R., 2009b, Episodic orogenic front migration in the northern Andes: Constraints from low temperature thermochronology in the Eastern Cordillera, Colombia: Tectonics, v. 28, no. 4.

Ramirez-Arias, J. C., Mora, A., Rubiano, J., Duddy, I., Parra, M., Moreno, N., Stockli, D., and Casallas, W., 2012, The asymmetric evolution of the Colombian Eastern Cordillera. Tectonic inheritance or climatic forcing? New evidence from thermochronology and sedimentology: Journal of South American Earth Sciences, v. 39, p. 112-137.

Ramon, J. C., and Fajardo, A., 2006, Sedimentology, sequence stratigraphy, and reservoir architecture of the Eocene Mirador Formation, Cupiagua field, Llanos Foothills, Colombia: Giant hydrocarbon reservoirs of the world: From rocks to reservoir characterization and modeling, v. 88, p. 433-469.

Reyes-Harker, A., Ruiz-Valdivieso, C. F., Mora, A., Ramírez-Arias, J. C., Rodriguez, G., de la Parra, F., Caballero, V., Parra, M., Moreno, N., Horton, B. K., Saylor, J. E., Silva, A., Valencia, V., Stockli, D., and Blanco, V., 2015, Cenozoic paleogeography of the Andean foreland and retroarc hinterland of ColombiaPaleogeography of the Northern Andes: AAPG Bulletin, v. 99, no. 8, p. 1407-1453.

Rowan, M. G., and Linares, R., 2000, Fold-Evolution Matrices and Axial-Surface Analysis of Fault-Bend Folds: Application to the Medina Anticline, Eastern Cordillera, Colombia: AAPG Bulletin, v. 84, no. 6, p. 741-764.

Sánchez, N., Mora, A., Parra, M., Garcia, D., Cortes, M., Shanahan, T. M., Ramirez, R., Llamosa, O., and Guzman, M., 2015, Petroleum system modeling in the Eastern Cordillera of Colombia using geochemistry and timing of thrusting and deformationPetroleum Systems Modeling Colombia: AAPG Bulletin, v. 99, no. 8, p. 1537-1556.

Sarmiento-Rojas, L. F., Van Wess, J. D., and Cloetingh, S., 2006, Mesozoic transtensional basin history of the Eastern Cordillera, Colombian Andes: Inferences from tectonic models: Journal of South American Earth Sciences, v. 21, no. 4, p. 383-411.

Saylor, J. E., Horton, B. K., Stockli, D. F., Mora, A., and Corredor, J., 2012, Structural and thermochronological evidence for Paleogene basement-involved shortening in the axial Eastern Cordillera, Colombia: Journal of South American Earth Sciences, v. 39, p. 202-215.

Suppe, J., 1983, Geometry and kinematics of fault-bend folding: American Journal of science, v. 283, no. 7, p. 684-721.

Tamara, J., Mora, A., Robles, W., Kammer, A., Ortiz, A., Sanchez-Villar, N., Piraquive, A., Rueda, L. H., Casallas, W., Castellanos, J., Montana, J., Parra, L. G., Corredor, J., Ramirez, A., and Zambrano, E., 2015, Fractured reservoirs in the Eastern Foothills, Colombia, and their relationship with fold kinematics: AAPG Bulletin, v. 99, no. 8, p. 1599-1633.

Teixell, A., Ruiz, J.-C., Teson, E., and Mora, A., 2015, The structure of an inverted back-arc rift: Insights from a transect across the Eastern Cordillera of Colombia near Bogotá: Petroleum geology and potential of the Colombian Caribbean Margin, v. 108, p. 499-516.

Tesón, E., Mora, A., Silva, A., Namson, J., Teixell, A., Castellanos, J., Casallas, W., Julivert, M., Taylor, M., Ibáñez-Mejía, M., and Valencia, V. A., 2013, Relationship of Mesozoic graben development, stress, shortening magnitude, and structural style in the Eastern Cordillera of the Colombian Andes: Geological Society, London, Special Publications, v. 377, p. SP377.310.

Toro, J., Roure, F., Bordas-Le Floch, N., Le Cornec-Lance, S., and Sassi, W., 2004, Thermal and kinematic evolution of the Eastern Cordillera fold and thrust belt, Colombia: Deformation, fluid flow, and reservoir appraisal in foreland fold and thrust belts, v. AAPG Hedberg Series, no. 1, p. 79-115.

Vergara S, L. E., and Rodríguez Ch, G., 1997, The Upper Cretaceous and Lower Paleocene of the Eastern Bogota Plateau and Llanos Thrust belt, Colombia: Alternative Appraisal to the Nomenclature and Sequence Stratigraphy: *Geología Colombiana - An International Journal on Geosciences*; Vol 22 (1997).

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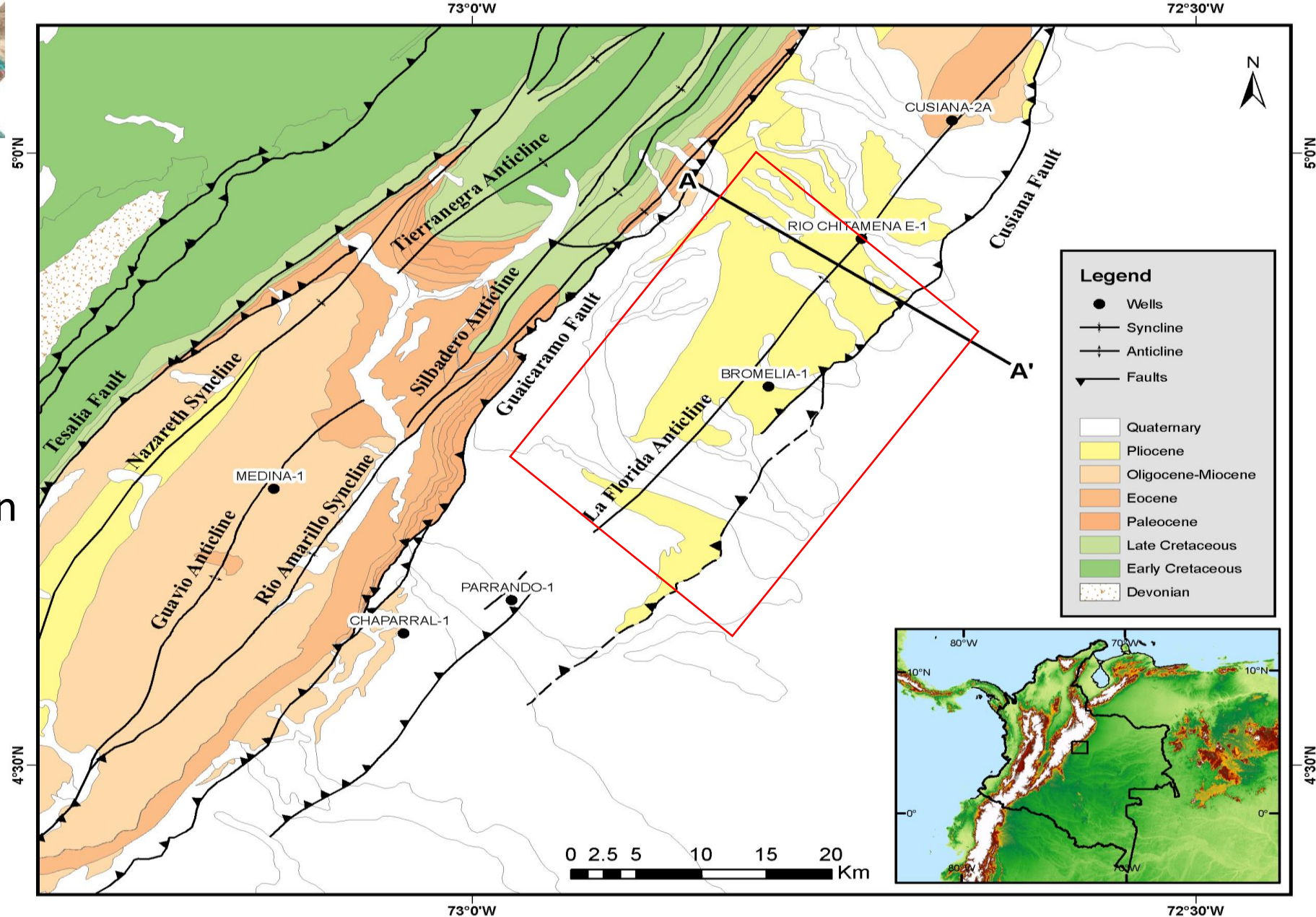


Outline:

- Overview
- Aim of Research
- Tectonic and Stratigraphic Setting
- Data & Methods
- Seismic Interpretation
- Retro-deformed Model
- Burial History
- Conclusions

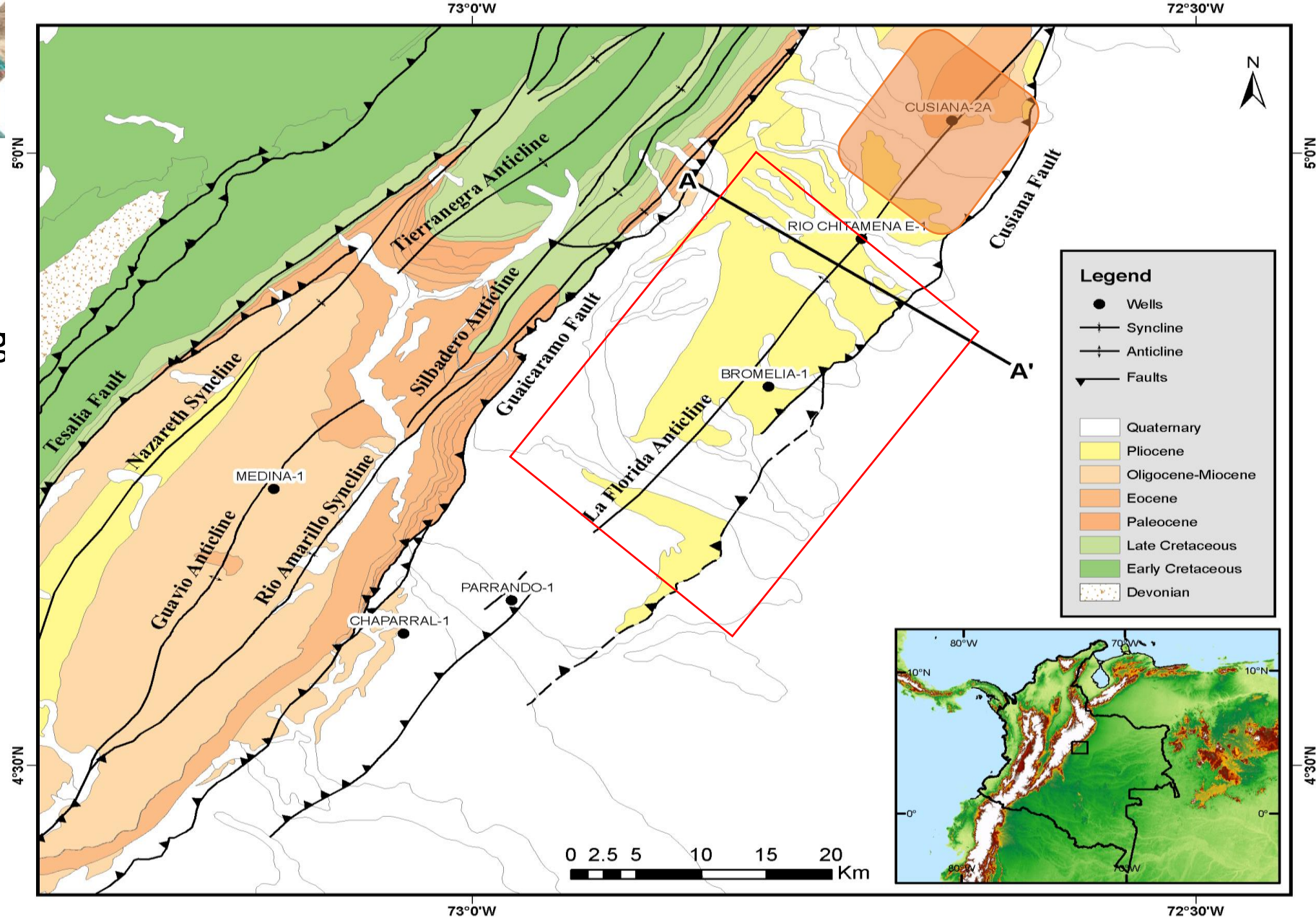
Overview:

- **La Florida Anticline** is located in the foothills zone of Llanos basin on the Eastern flank of Eastern Cordillera.



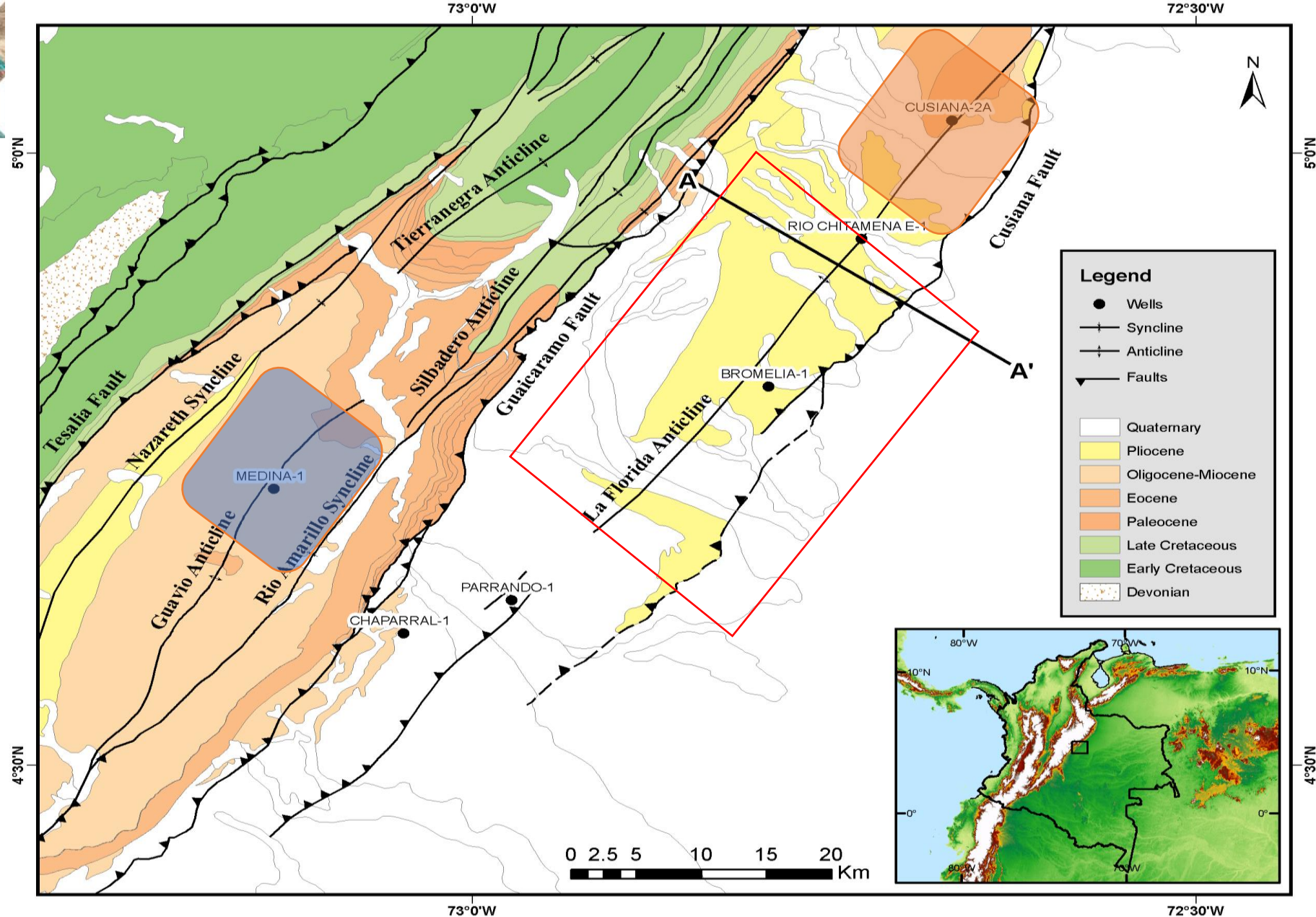
Overview:

- To the Northeast along strike is the giant Cusiana oilfield.



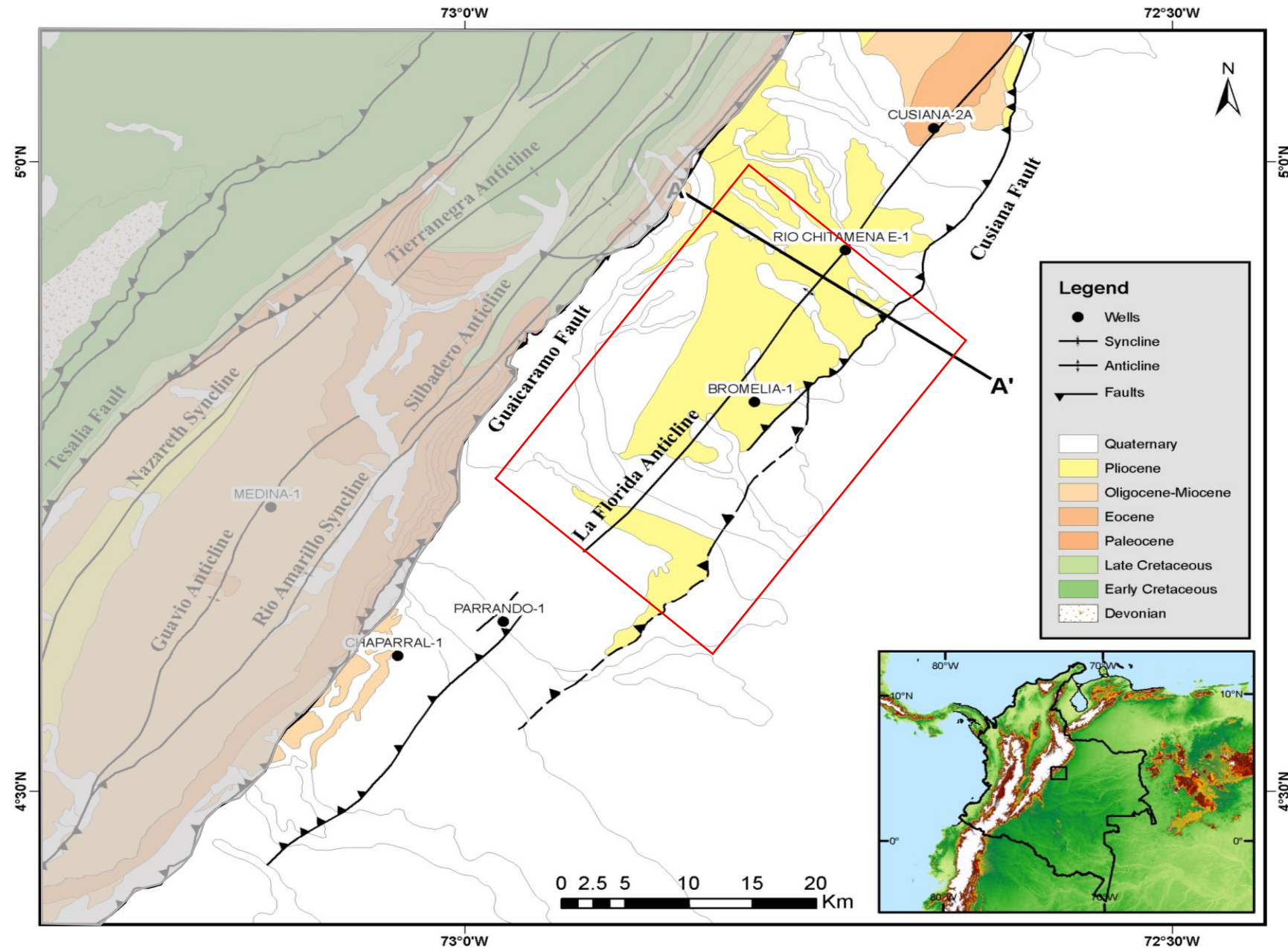
Overview:

- Just to the Southwest is **the Guavio Anticline** in Medina basin, a large anticline with 4-way closure and seal but no commercial hydrocarbons.



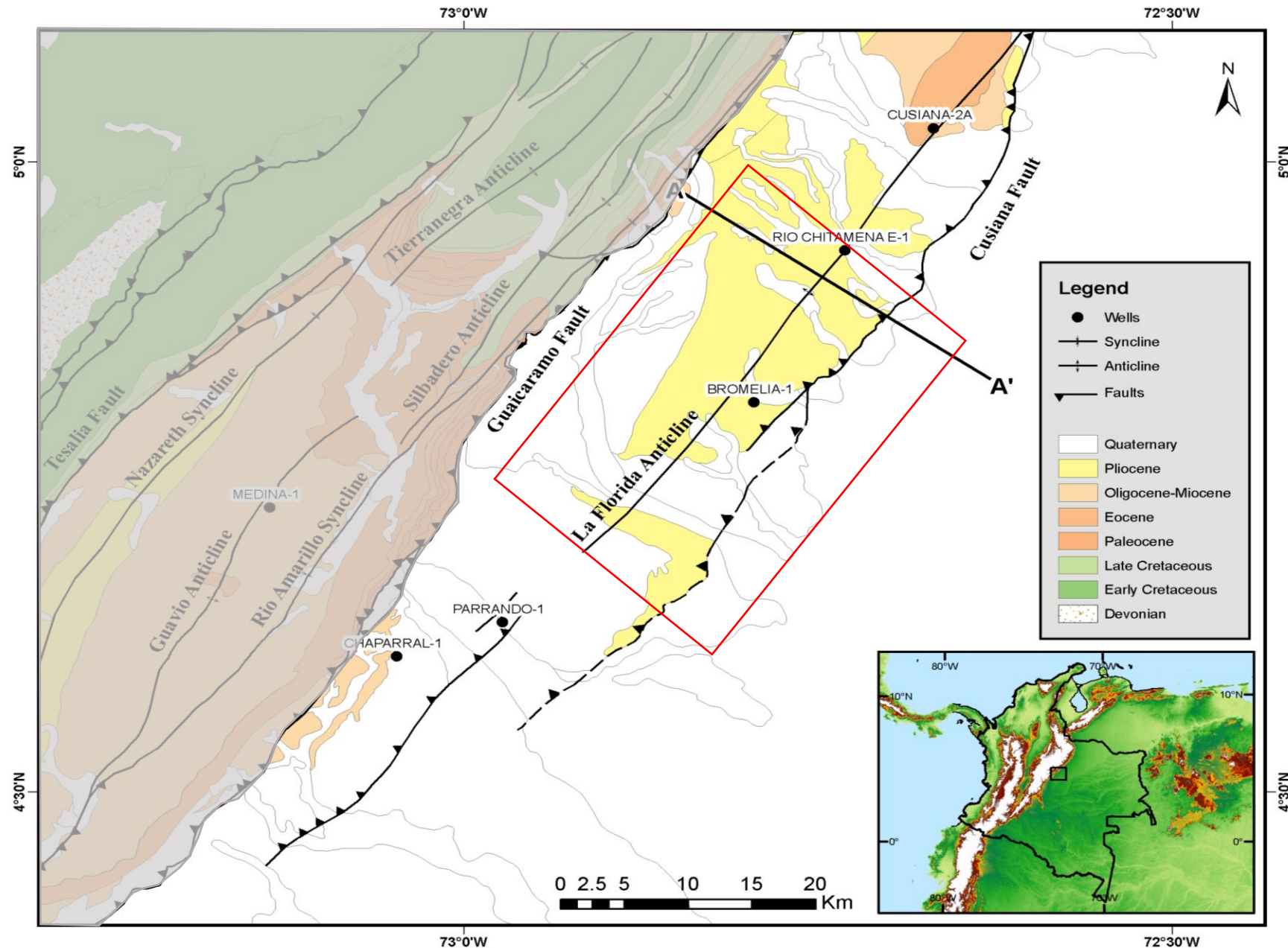
Overview:

- **Llanos basin** is the biggest oil province in Colombia.
- up to 70 fields producing ~ 1600 Mbbl (Tamara et al, 2015; Sánchez et al, 2015).



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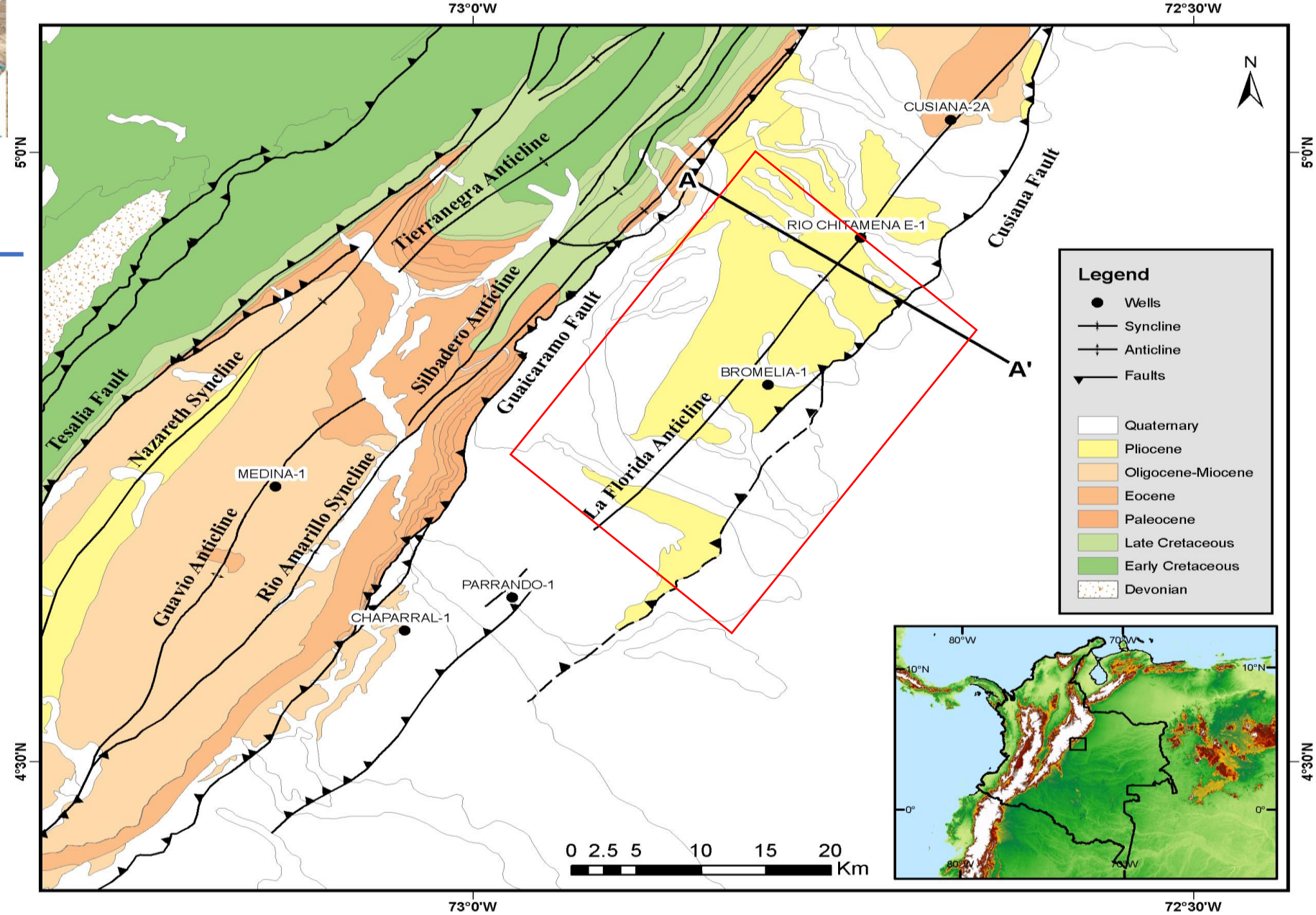
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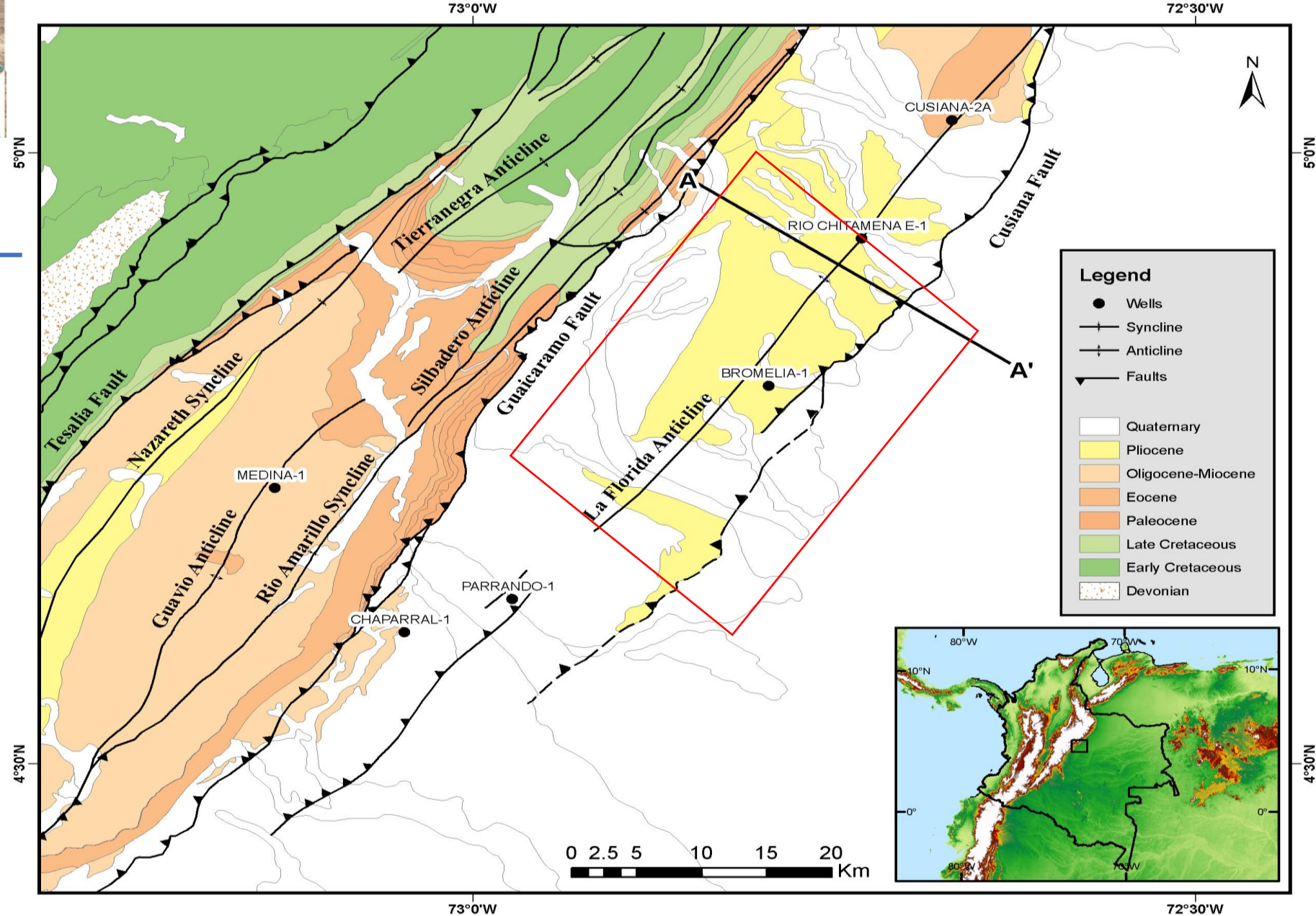
Aim of Research:

- How does the **thin-skinned** and **thick-skinned** structural evolution of an Andean foreland basin effect the evolution of the **petroleum system**?



Aim of Research:

- Is **La Florida anticline** a hydrocarbon trap?
- On one side is the **dry Guavio** structure. On the other side is the **giant Cusiana** oil field.





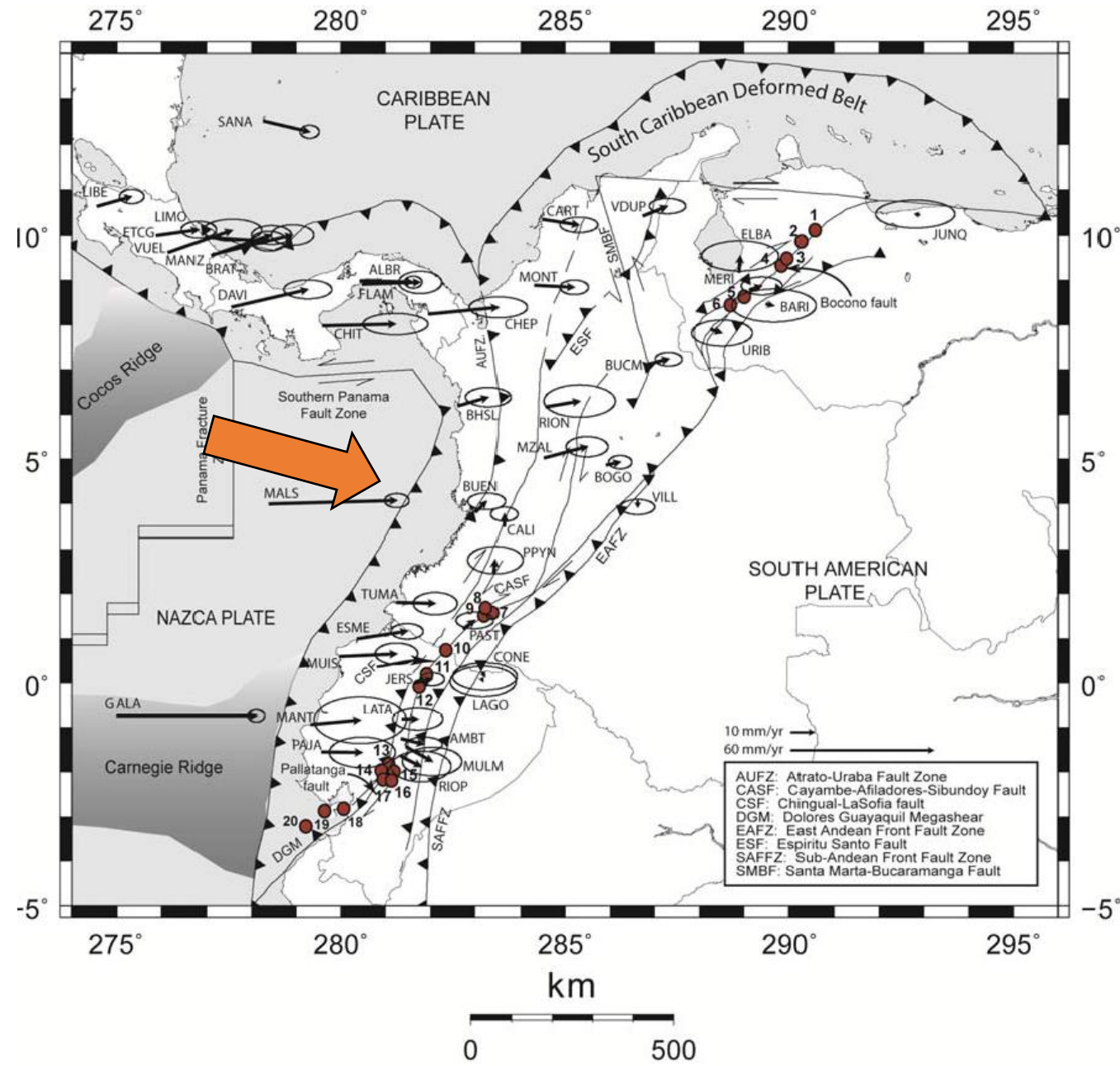
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Tectonic and Stratigraphic Setting

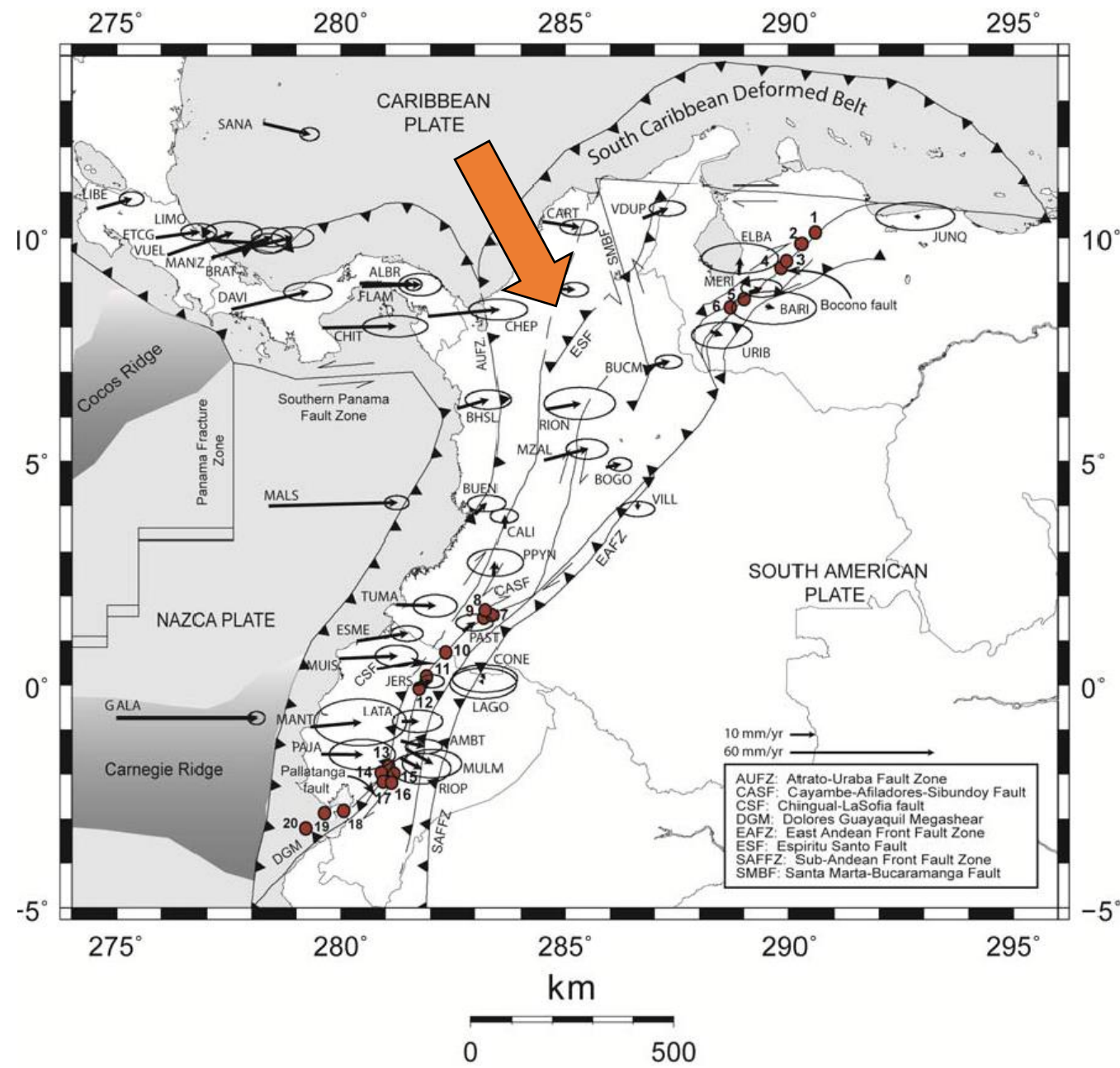
- Tectonic Setting:
 - Oblique subduction of **Nazca plate** beneath **South American plate**
 - Oblique subduction of the Caribbean beneath North Andes.
 - Collision of Panama microplate and North Andes.



Tectonic and Stratigraphic Setting

- Tectonic Setting:

- Oblique subduction of Nazca plate beneath South American plate.
- Oblique subduction of the **Caribbean** beneath **North Andes**.
- Collision of Panama microplate and North Andes.

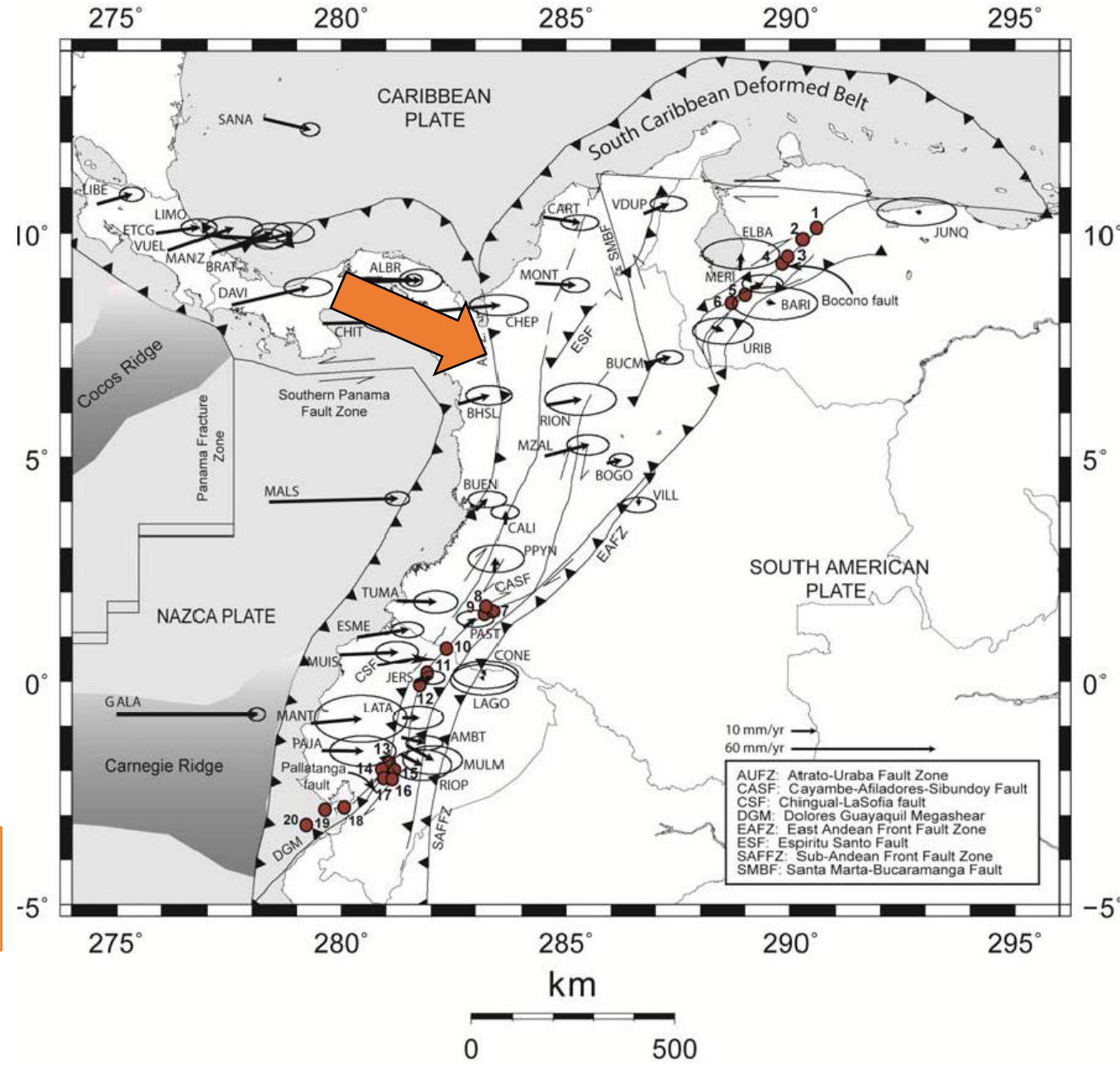


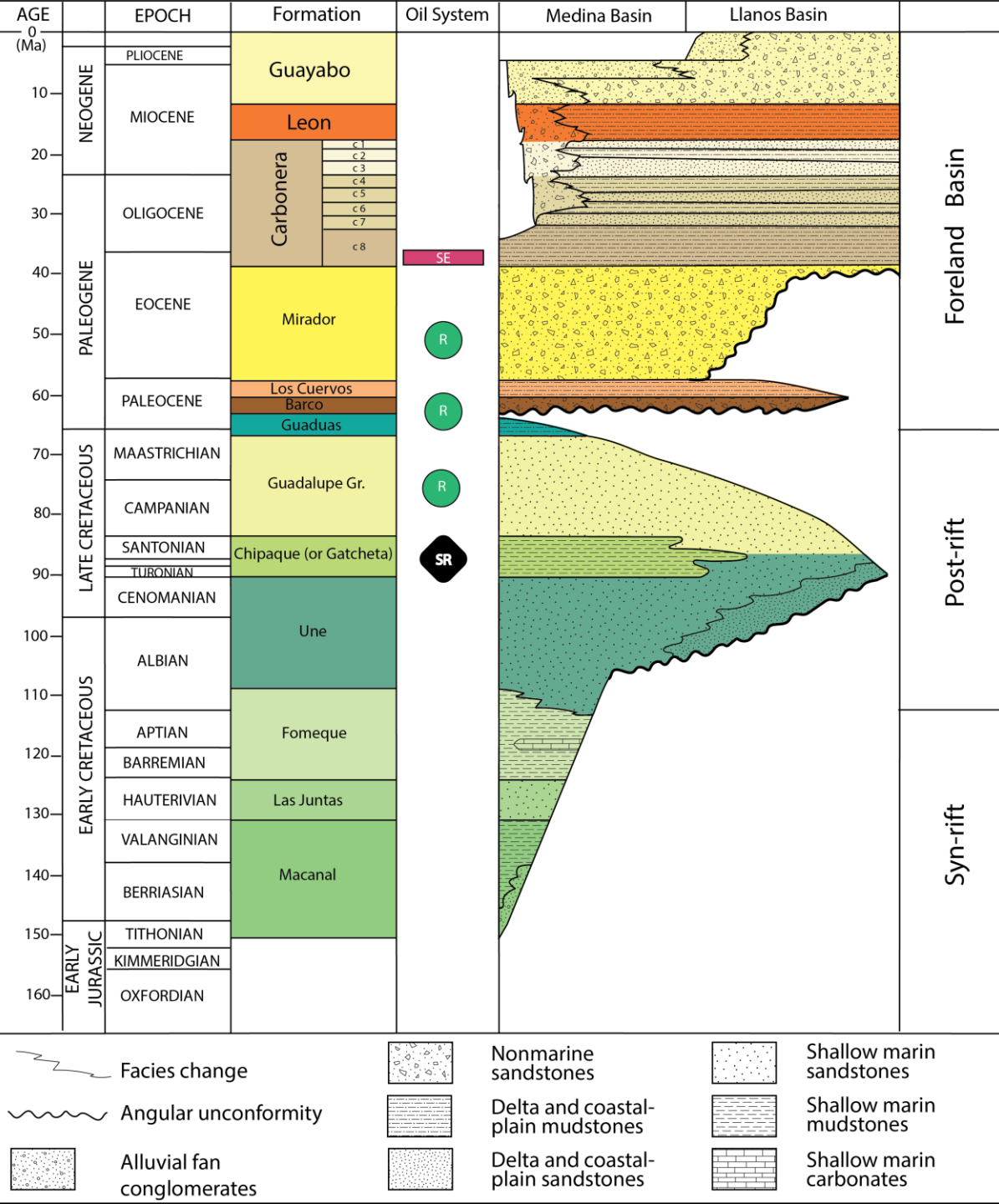
- Convergence of Nazca and South America (Active margin).
- Convergence of the Caribbean and North Andes.
- Collision of **Panama Choco arc** and **North Andes**.

Geological map of the northern Andes region, showing tectonic plates, faults, and seismicity. The map includes the Caribbean Plate, South Caribbean Deformed Belt, South American Plate, and Nazca Plate. Key features include the Cocos Ridge, Panama Fracture Zone, Southern Panama Fault Zone, Carnegie Ridge, and various faults like the Bocono fault, Atrato-Uraba Fault Zone, and Sub-Andean Front Fault Zone. Seismicity is marked with red dots and numbered 1 through 20. An orange arrow points to the area around station ALBR. A scale bar indicates 0 to 500 km, and a velocity scale shows 10 mm/yr and 60 mm/yr.

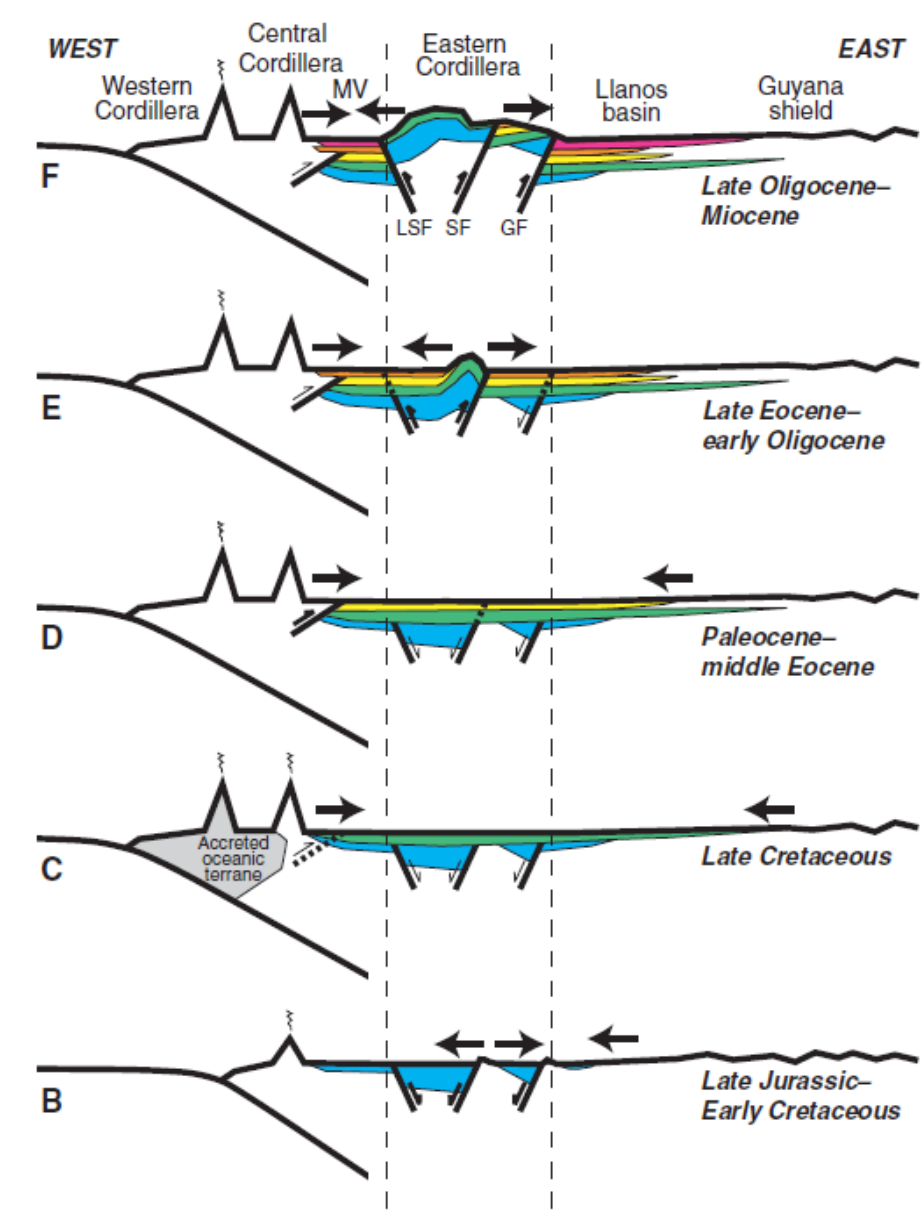
Legend:

- AUFZ: Atrato-Uraba Fault Zone
- CASF: Cayambe-Afiladores-Sibundoy Fault
- CSF: Chingual-LaSofia fault
- DGM: Dolores Guayaquil Megashear
- EAFZ: East Andean Front Fault Zone
- ESF: Espiritu Santo Fault
- SAFFZ: Sub-Andean Front Fault Zone
- SMBF: Santa Marta-Bucaramanga Fault



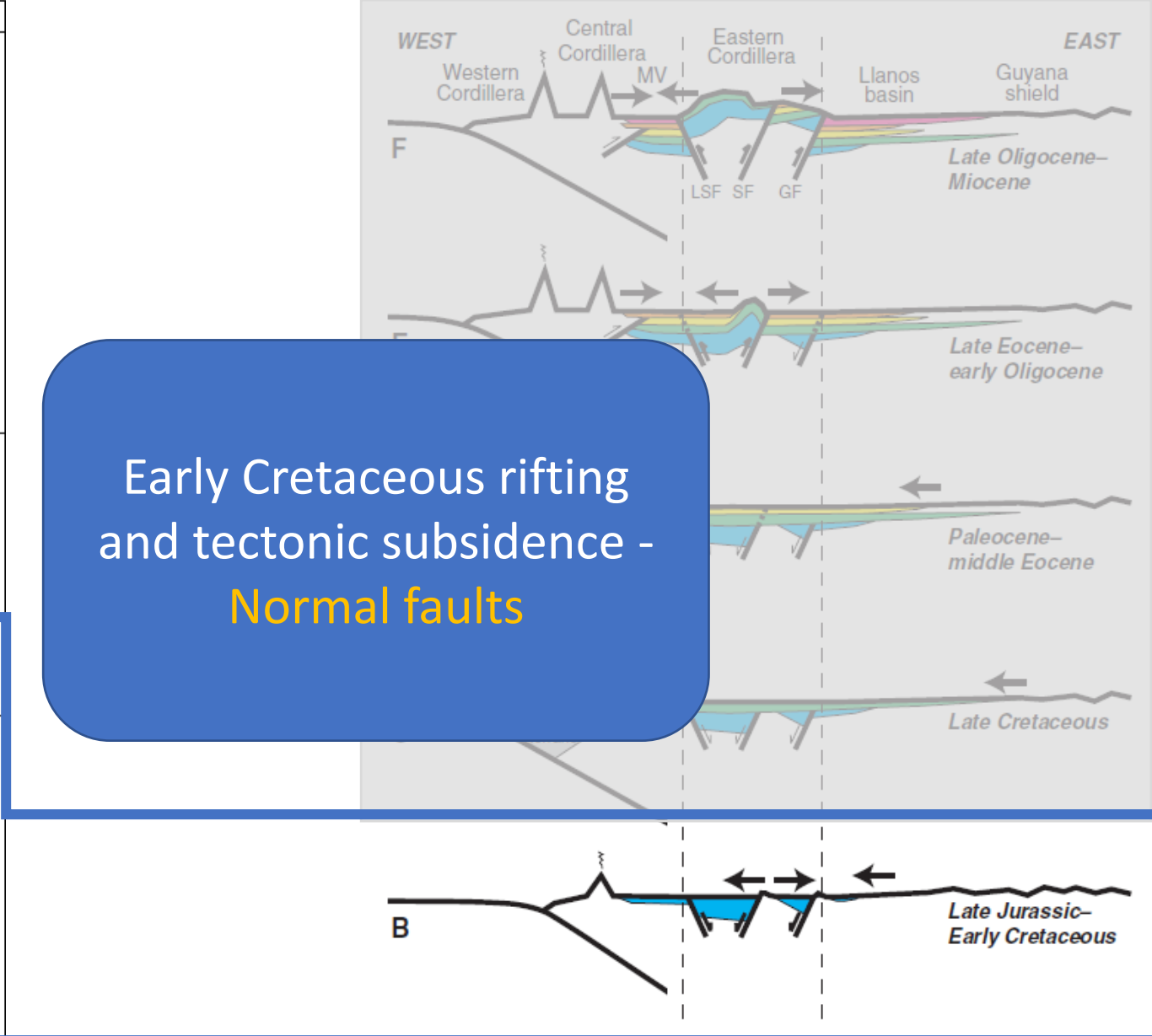
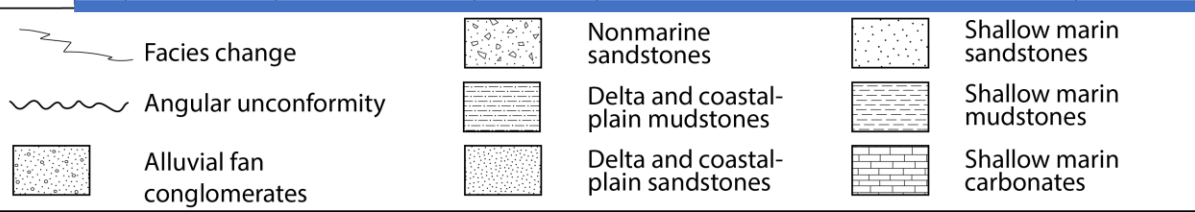
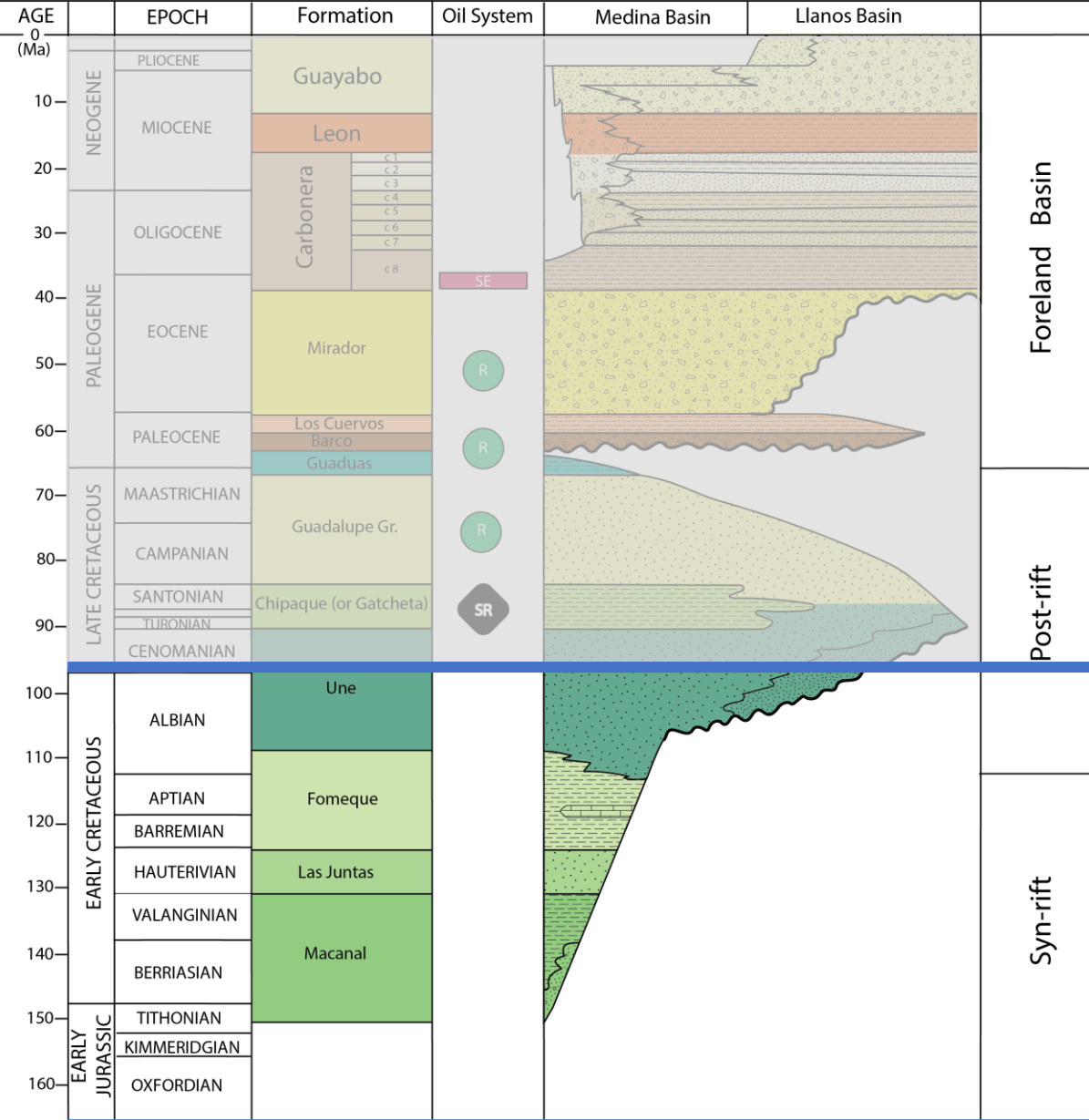


Sediments deposition during the Tectonic evolution events



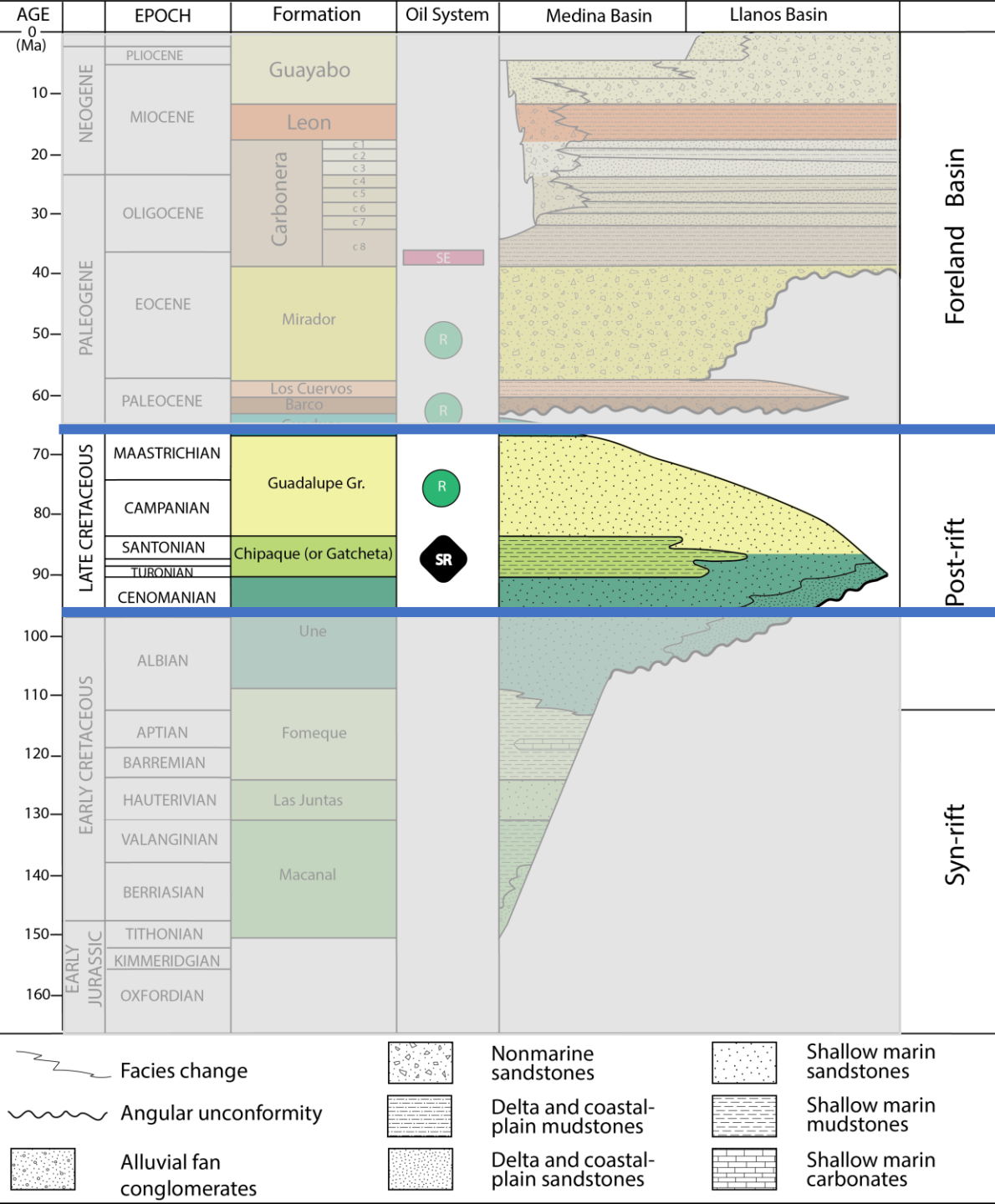
Horton et al 2010



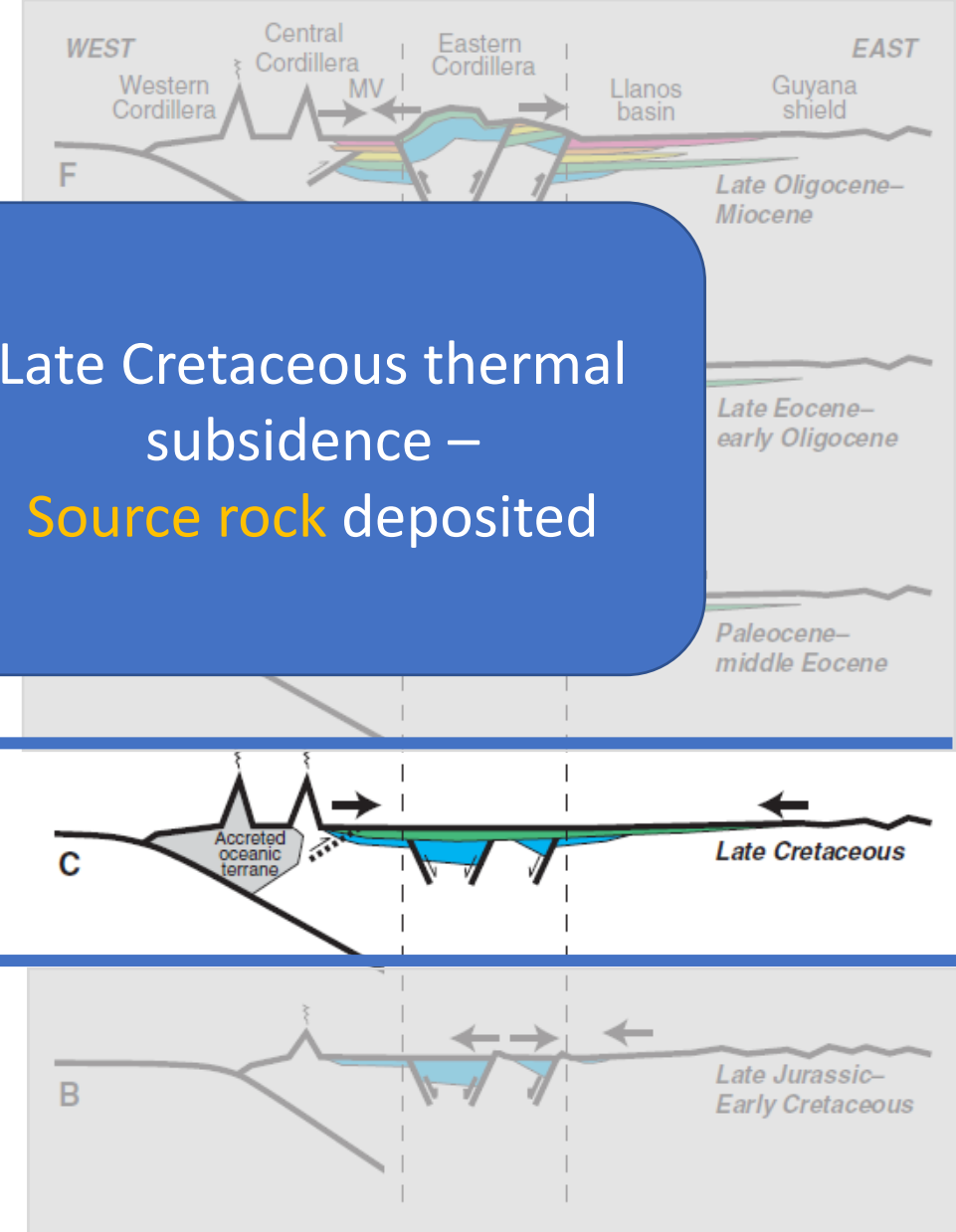


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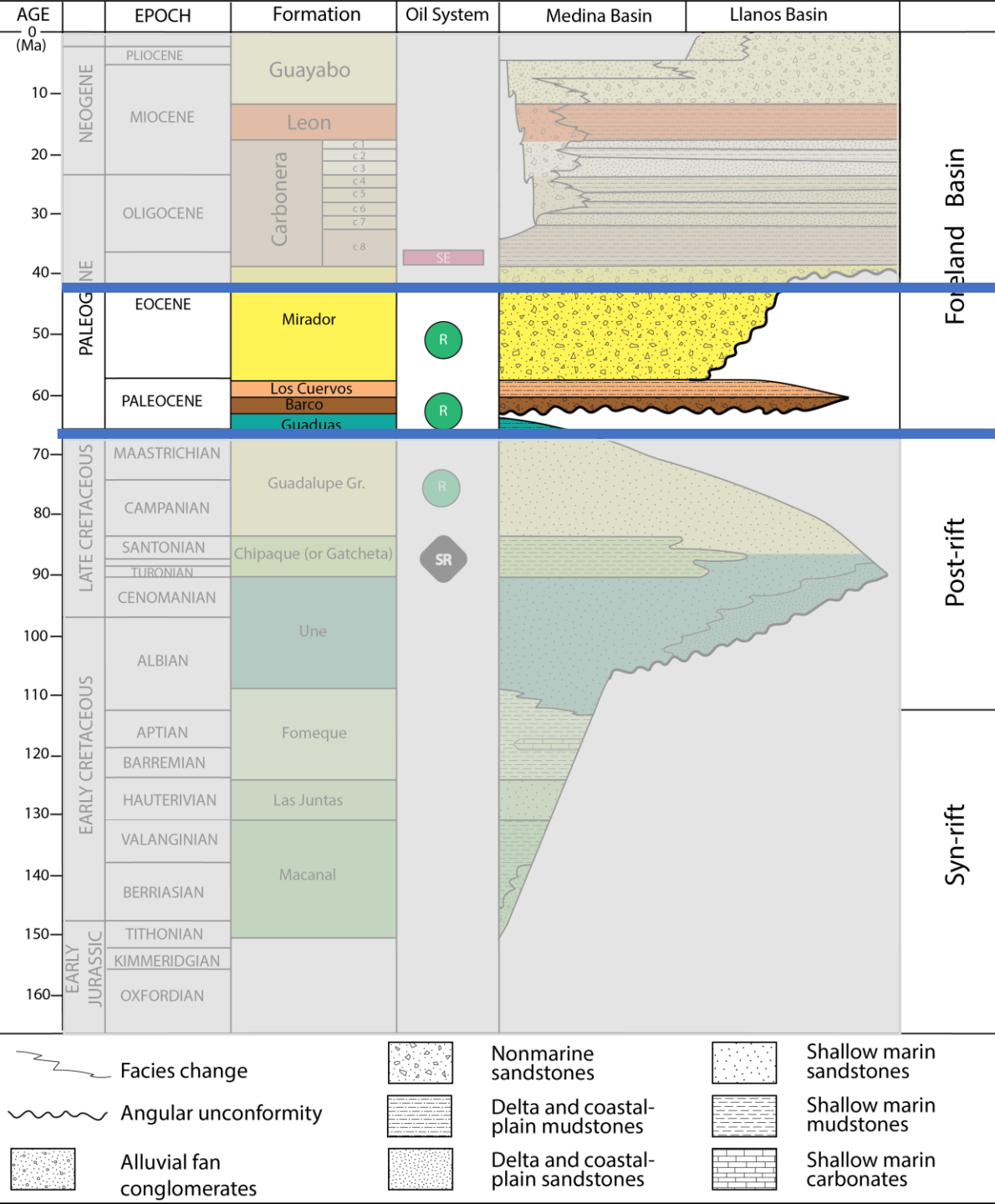


Late Cretaceous thermal subsidence –
Source rock deposited

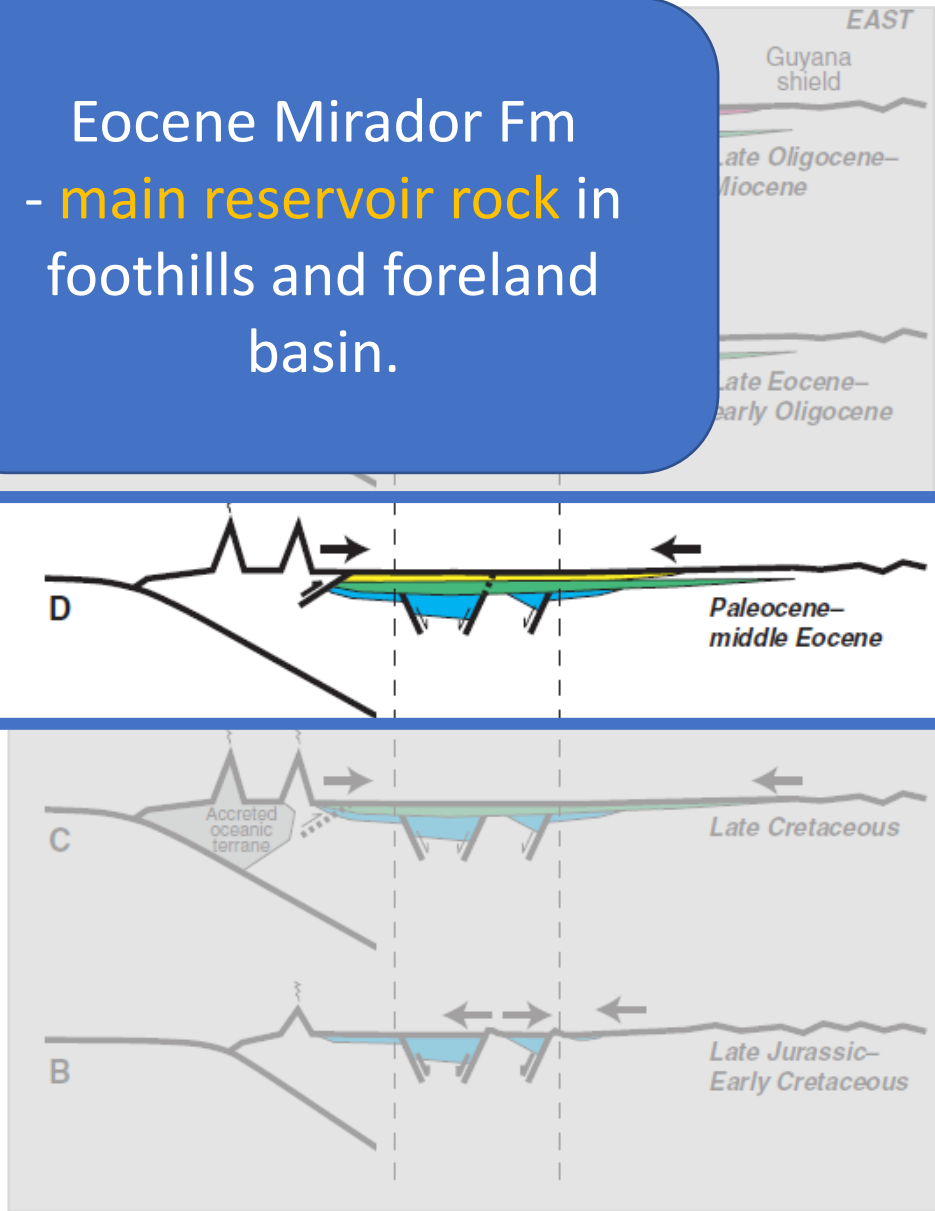


Horton et al 2010



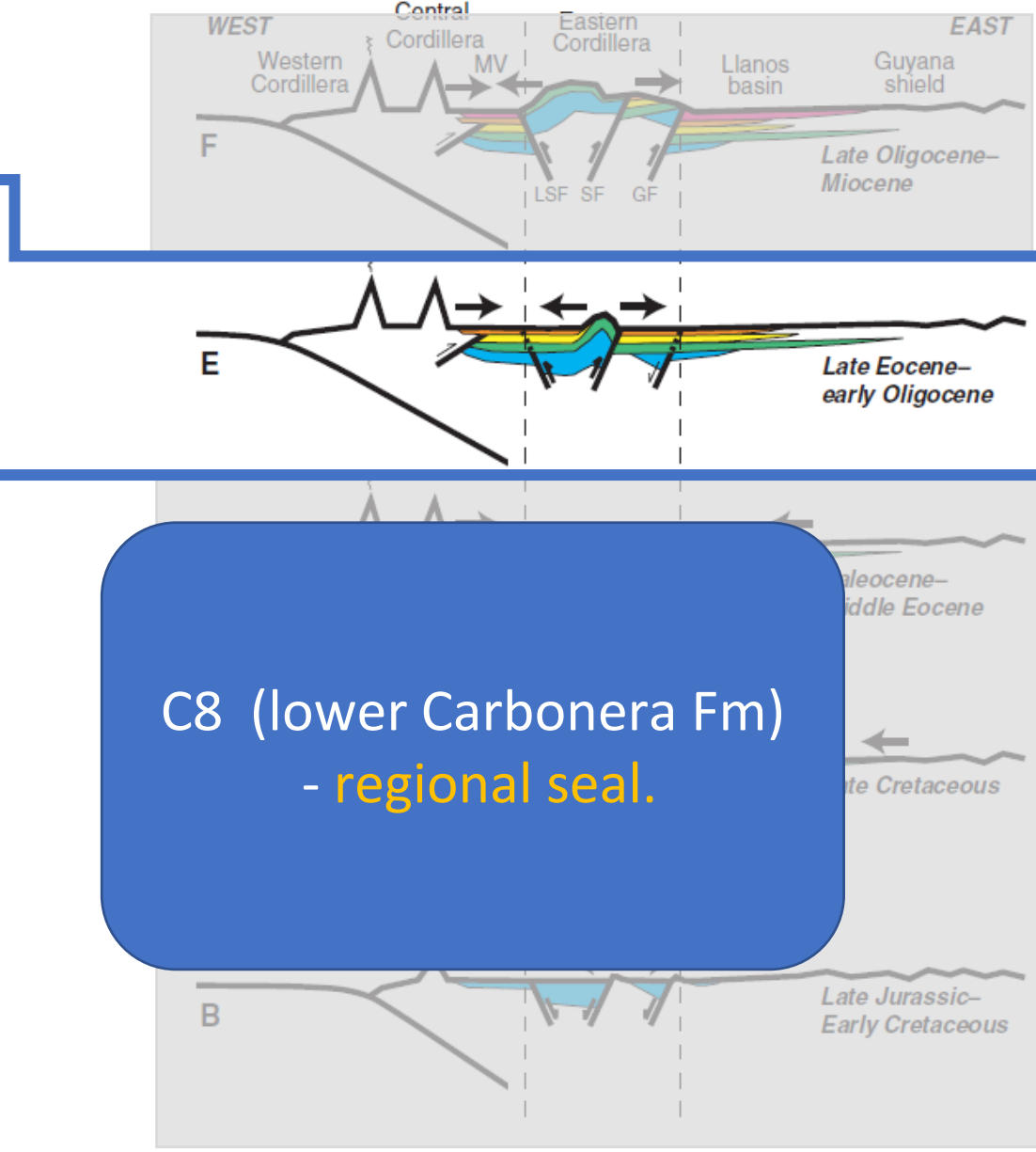
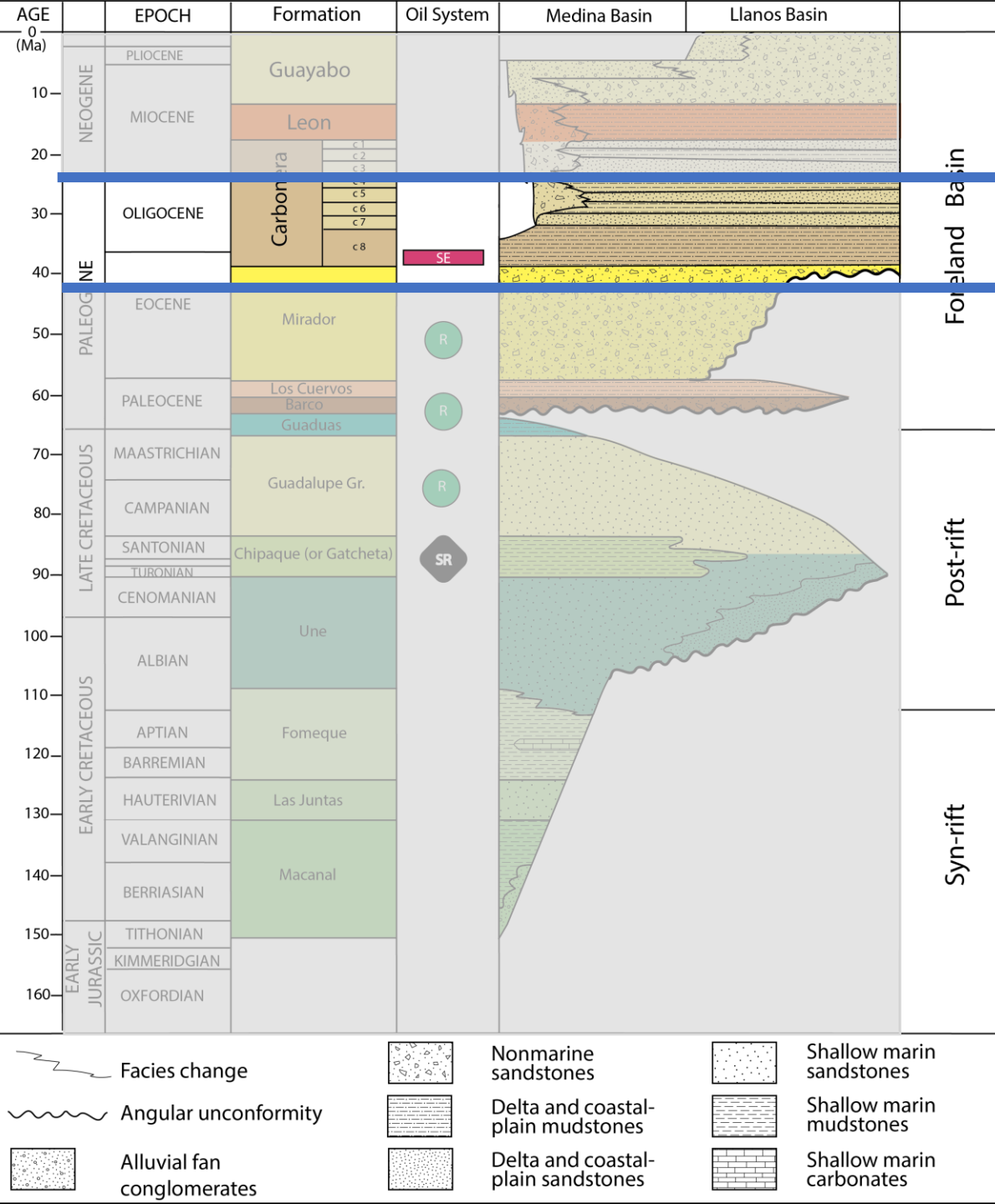


Eocene Mirador Fm
- **main reservoir rock** in foothills and foreland basin.



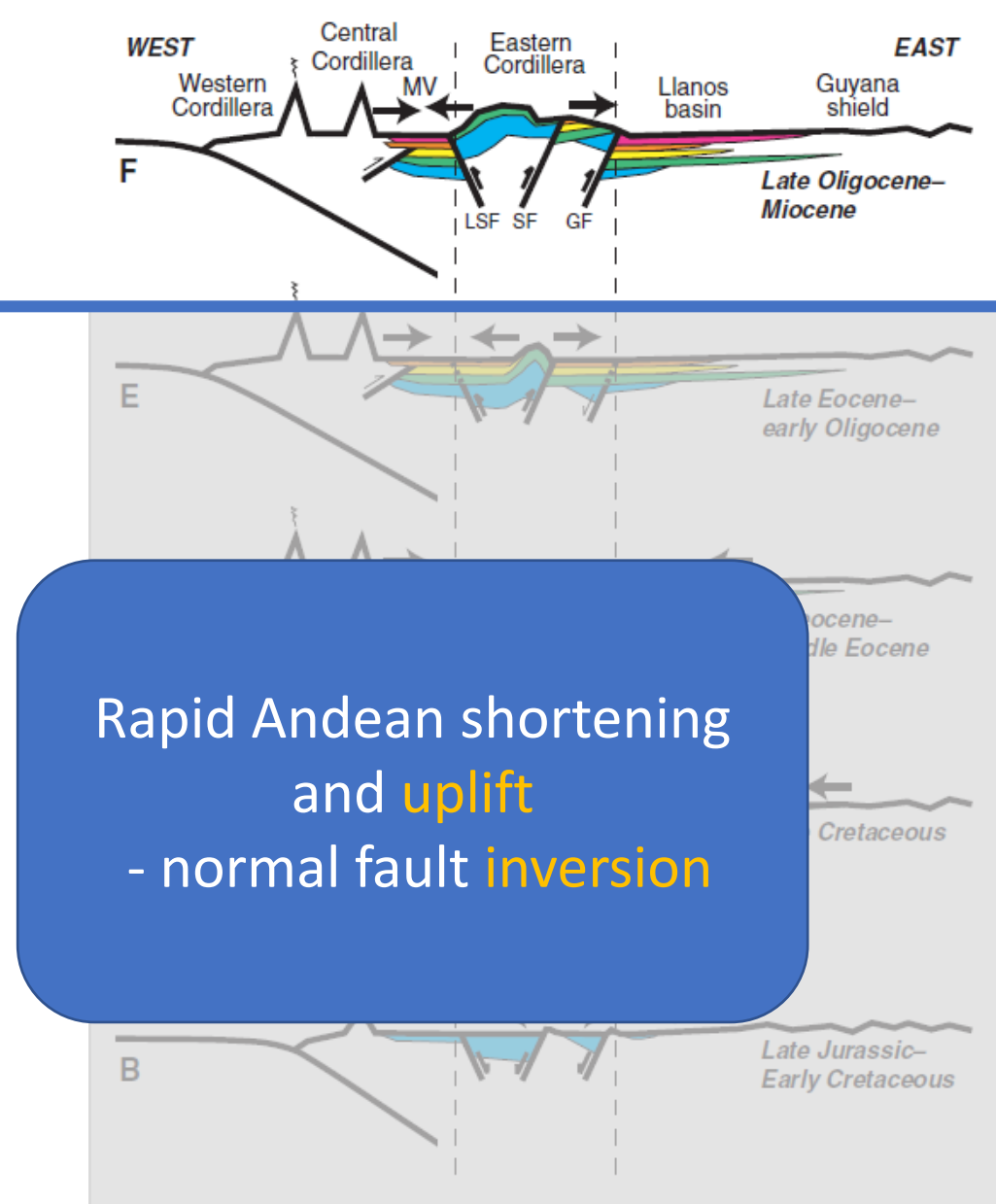
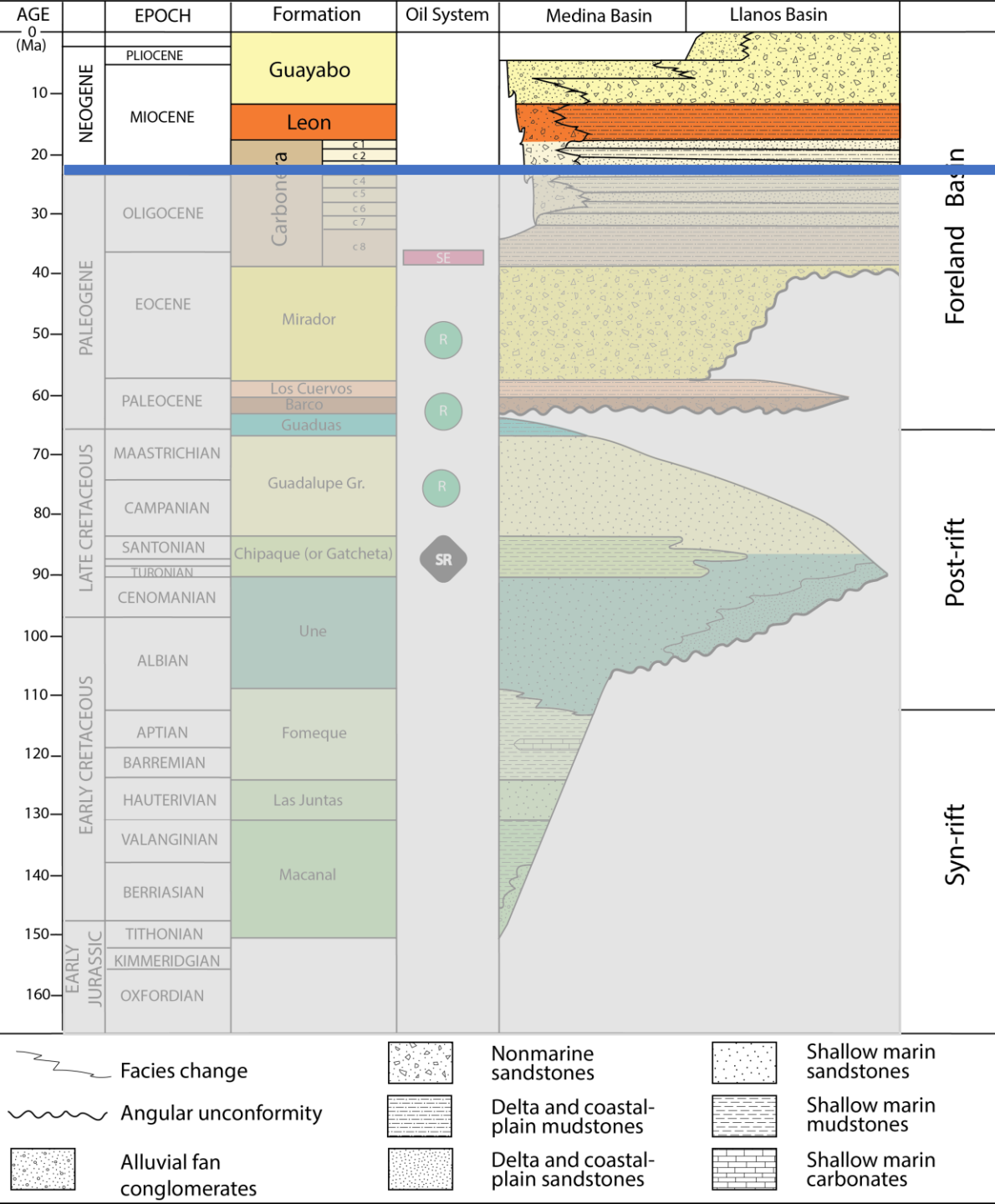
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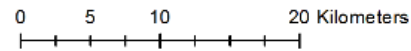
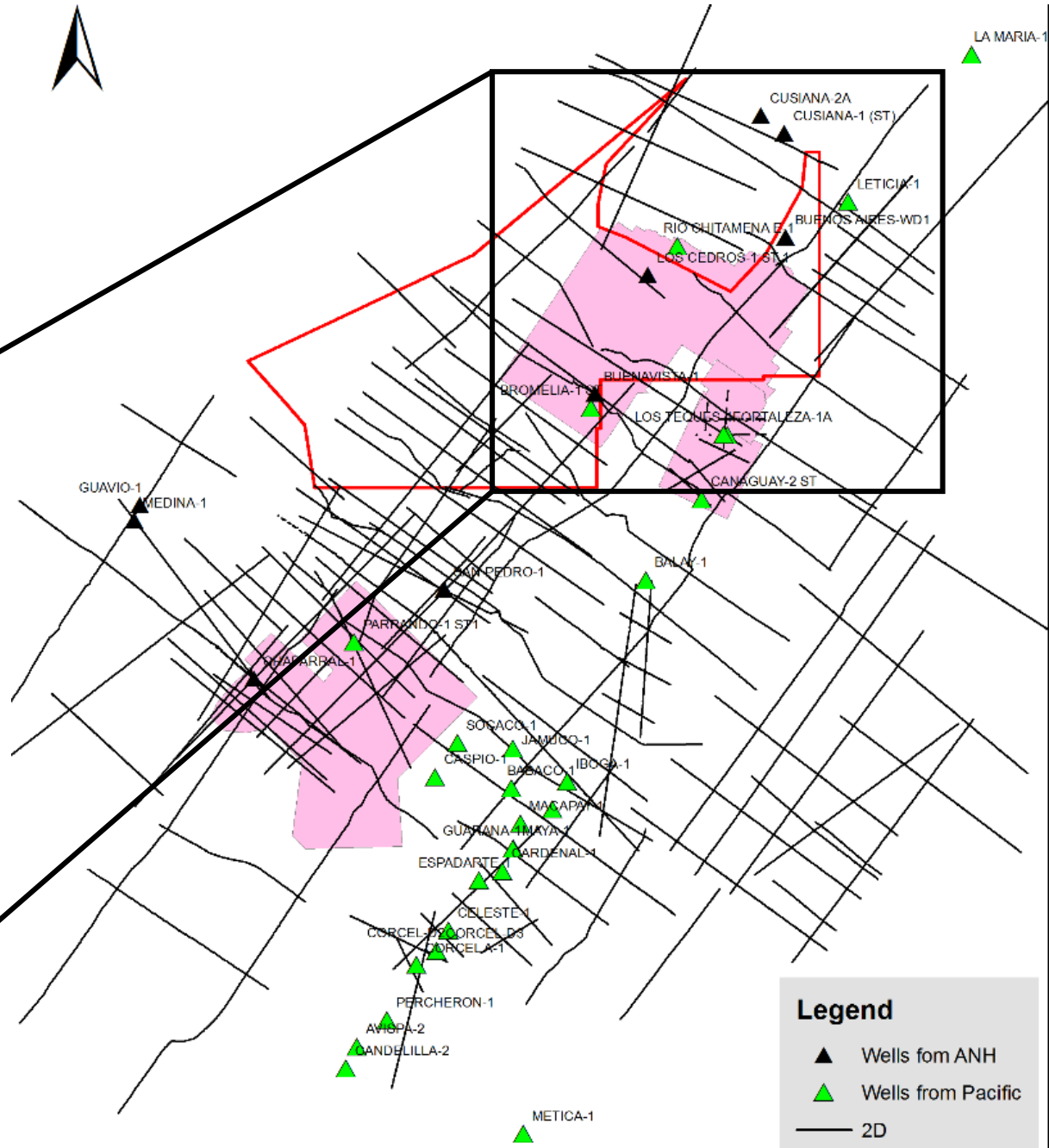
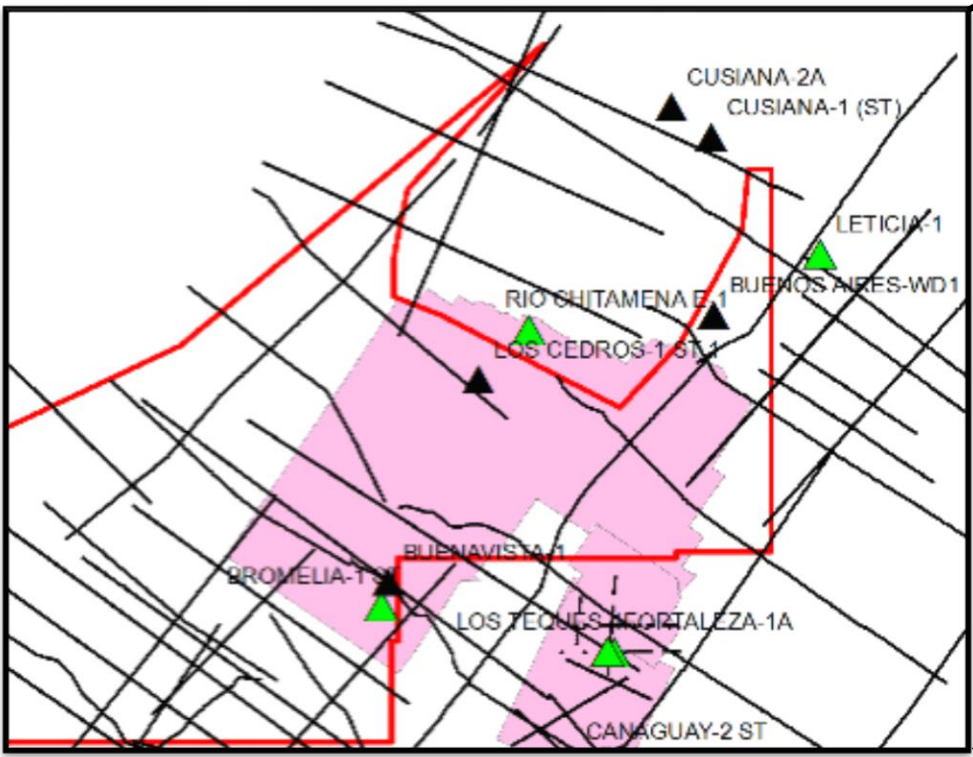


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 28 wells with logs
  Old wells.



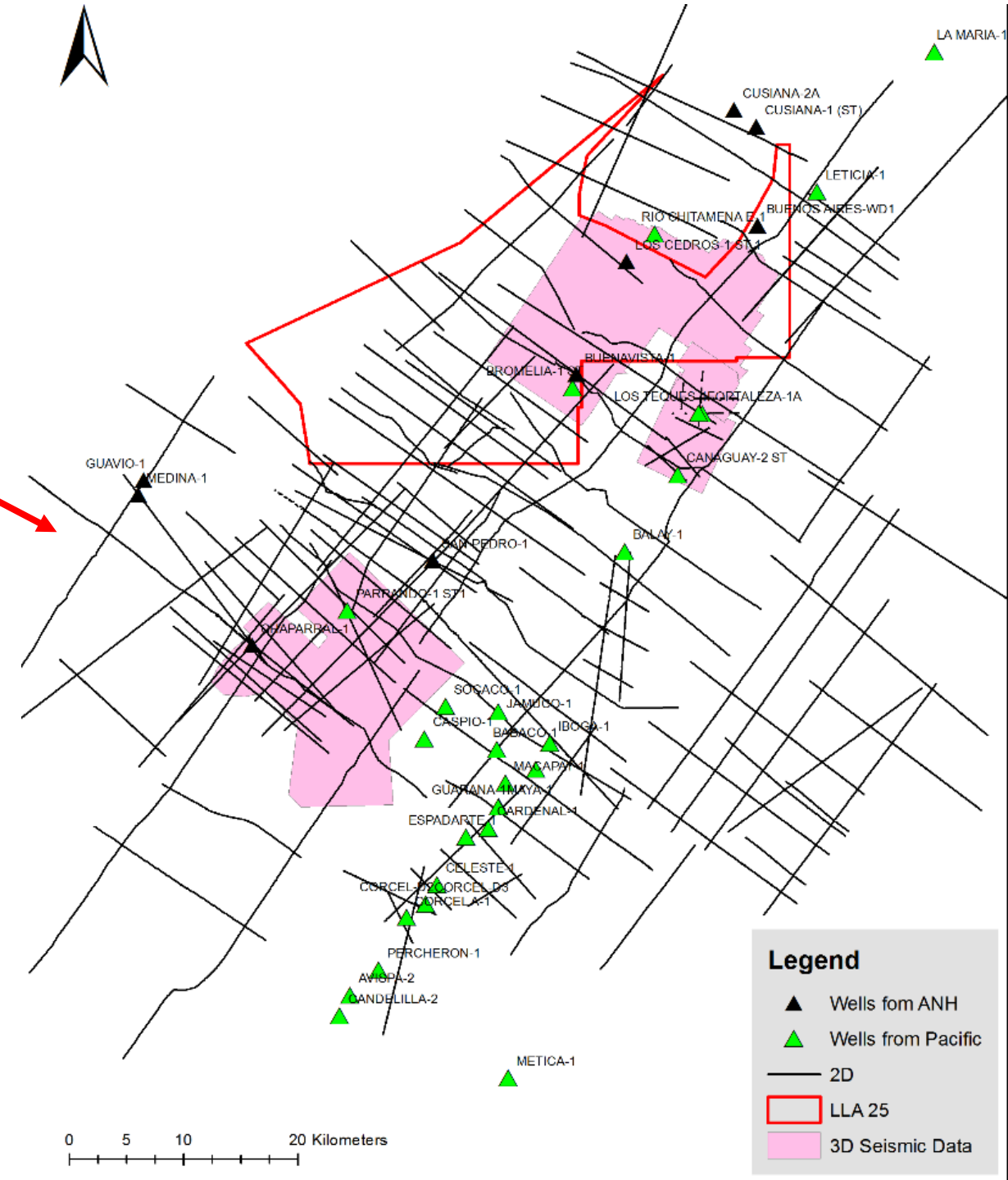
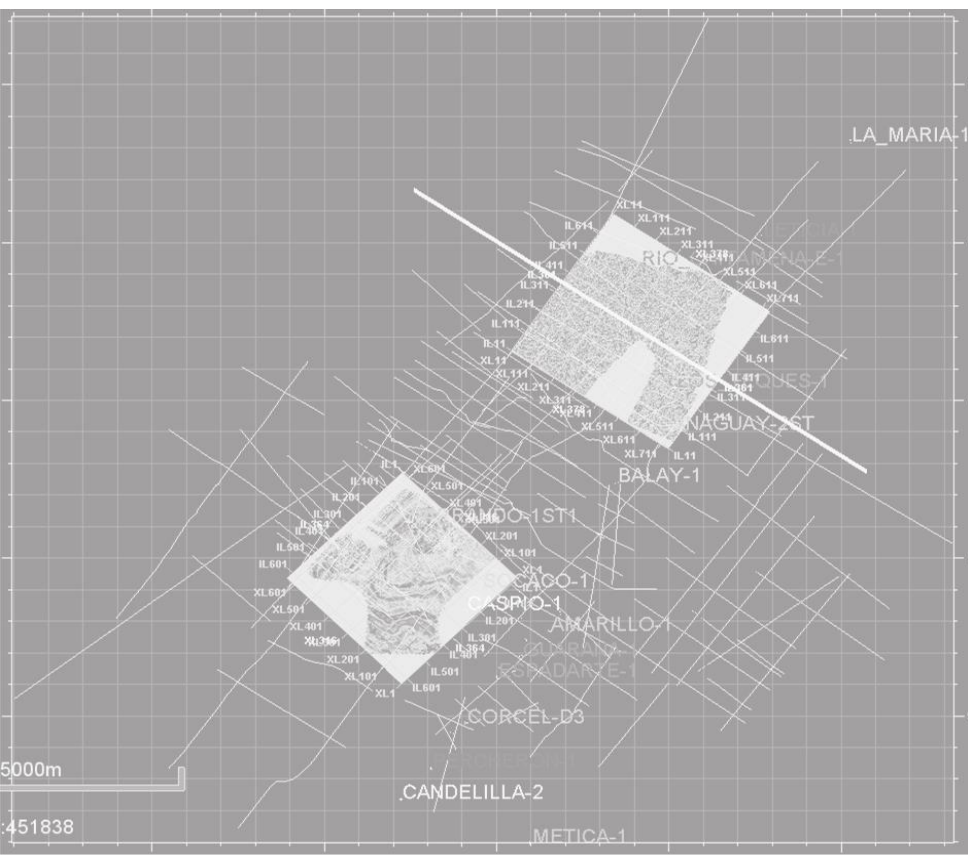
Legend

-  Wells fom ANH
-  Wells from Pacific
-  2D
-  LLA 25
-  3D Seismic Data

Seismic data:

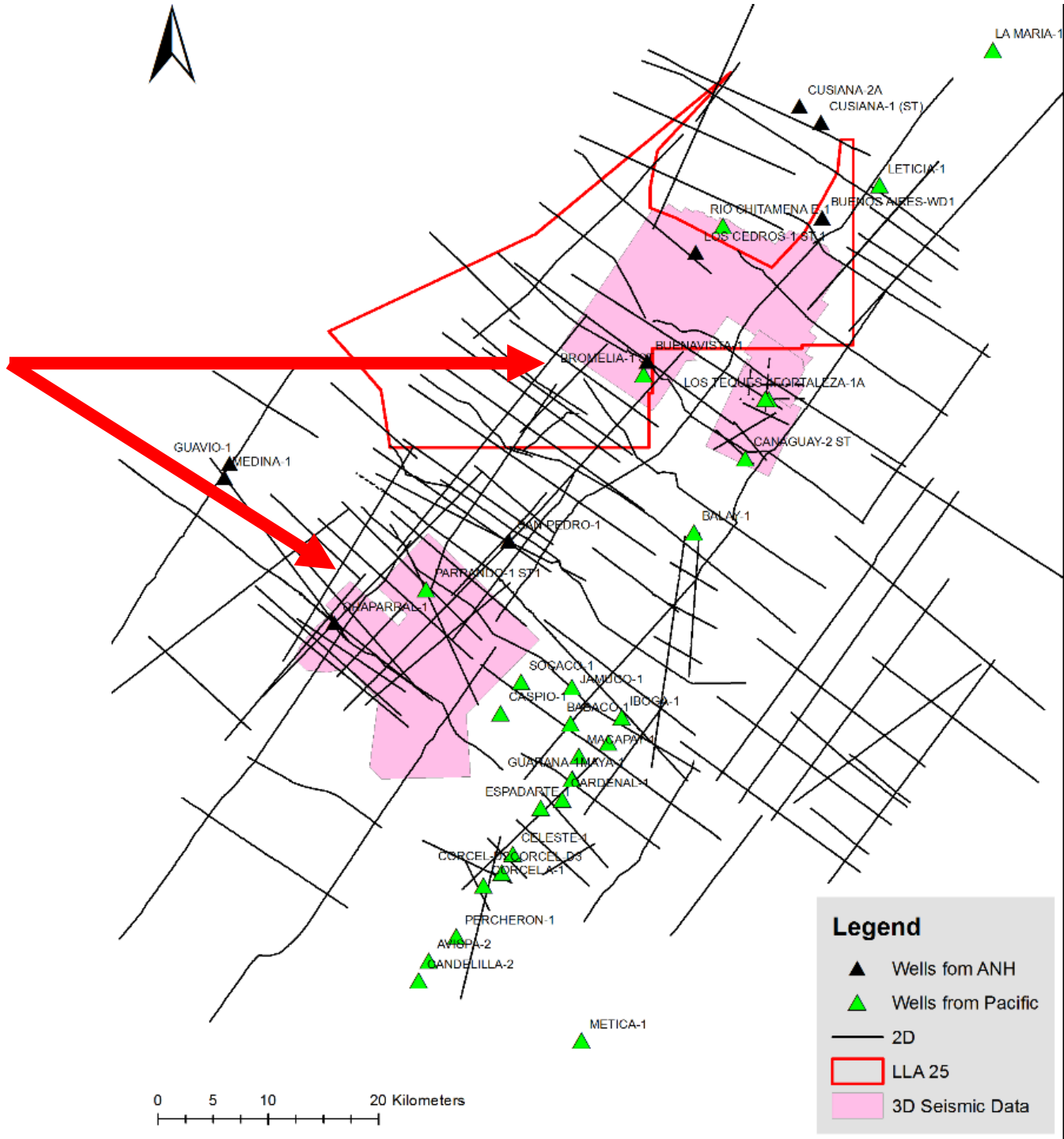
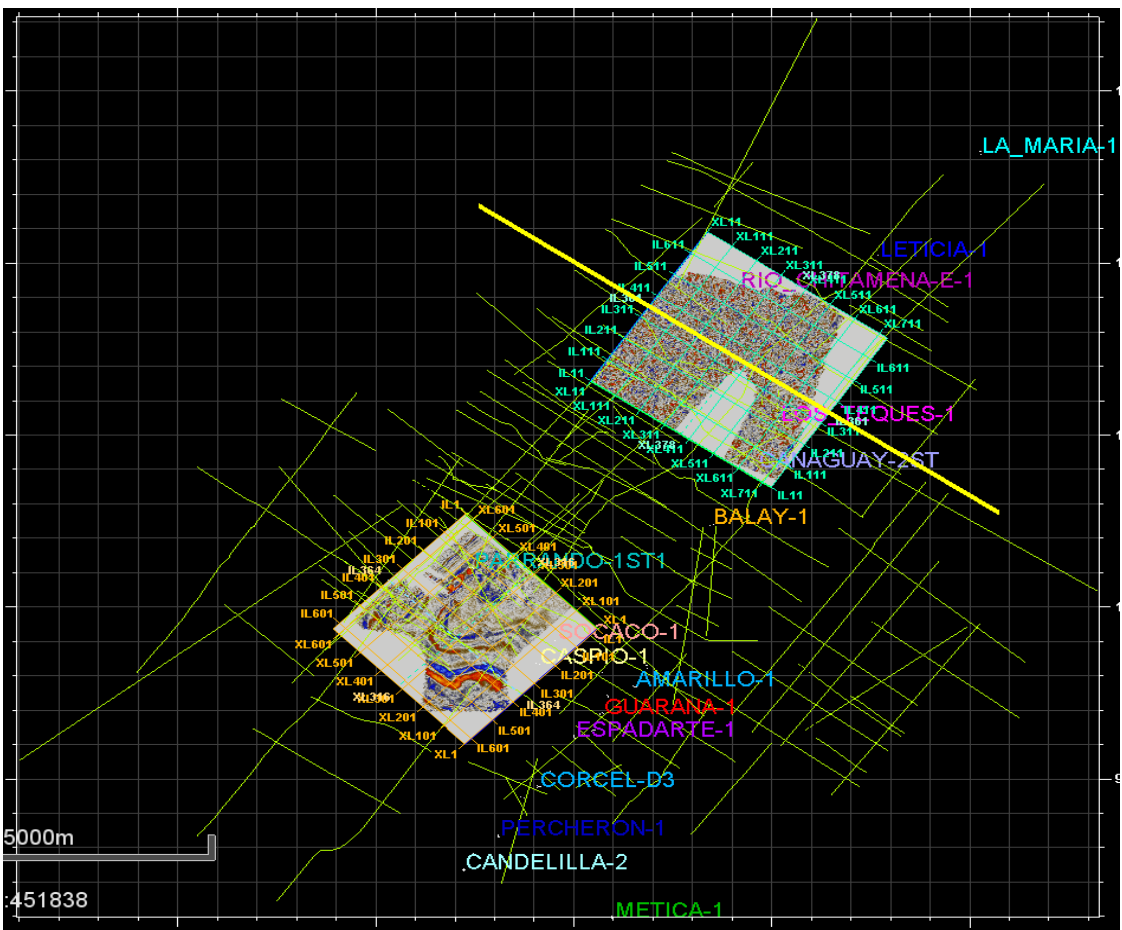
— 194 2D seismic profiles (SGY files).

Two 3D seismic volumes.



Seismic data:


 Two 3D seismic volumes.



Legend

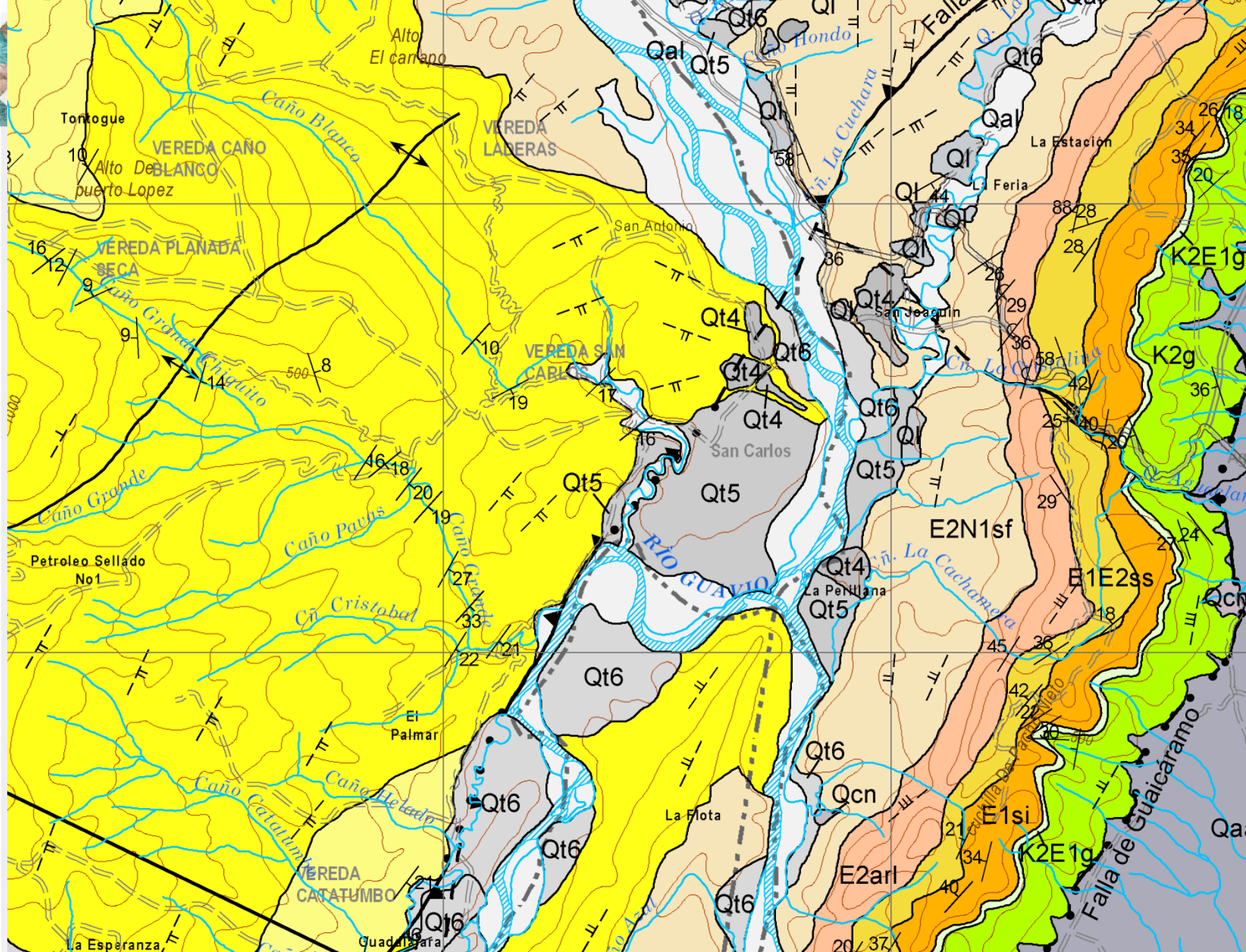
- ▲ Wells fom ANH
- ▲ Wells from Pacific
- 2D
- LLA 25
- 3D Seismic Data



Surface geology

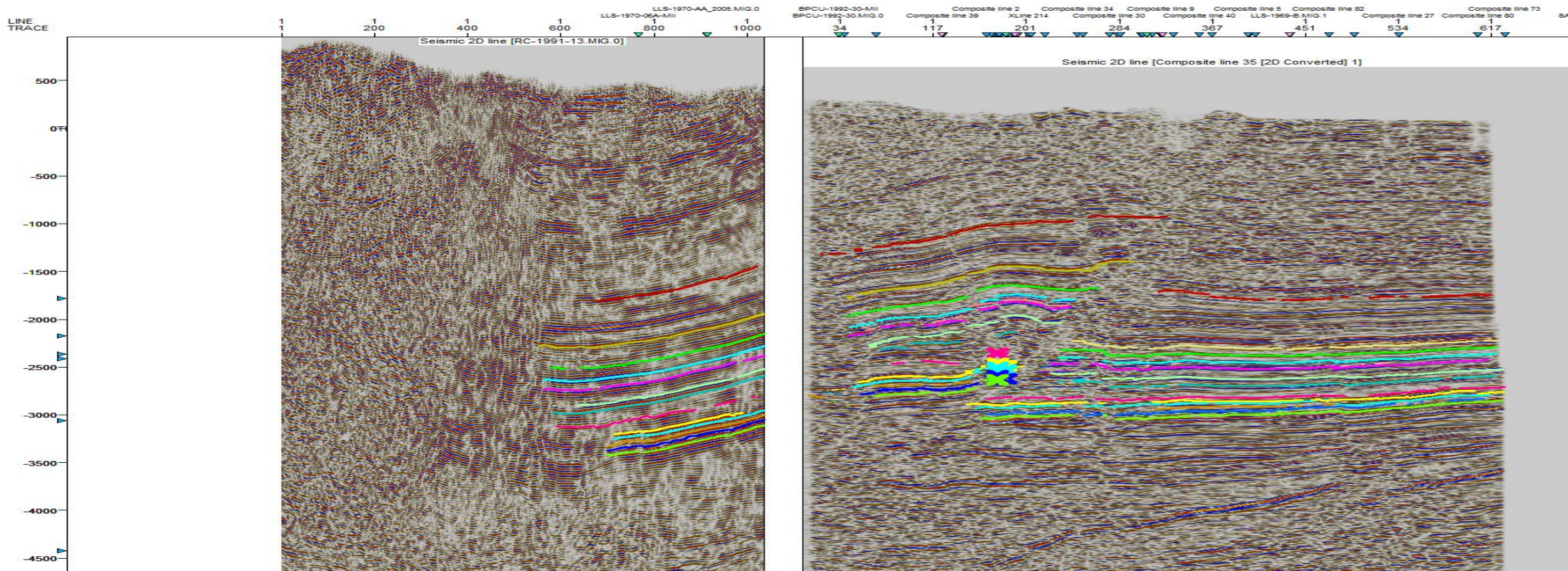
(Colombian
Geological Survey)

used to constrain
geologic cross-
sections NW of the
Guaicaramo fault.



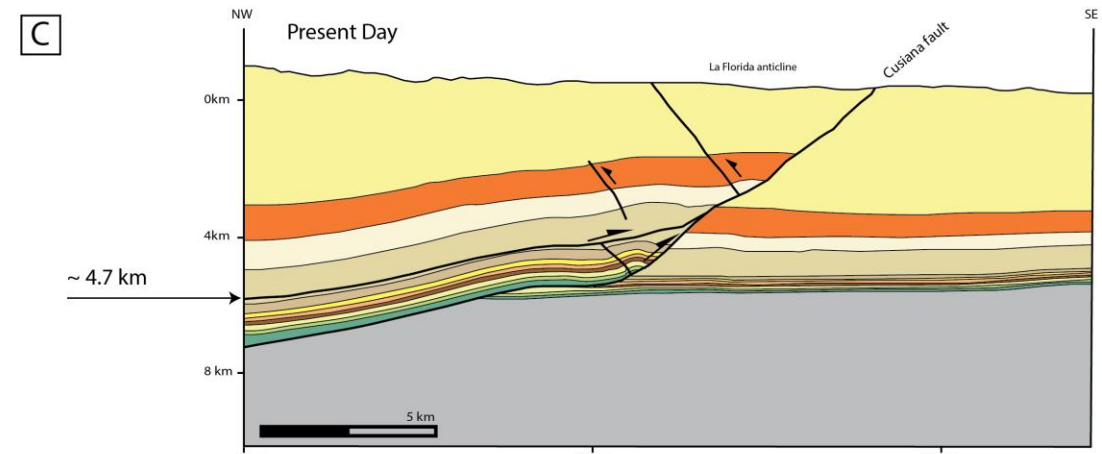
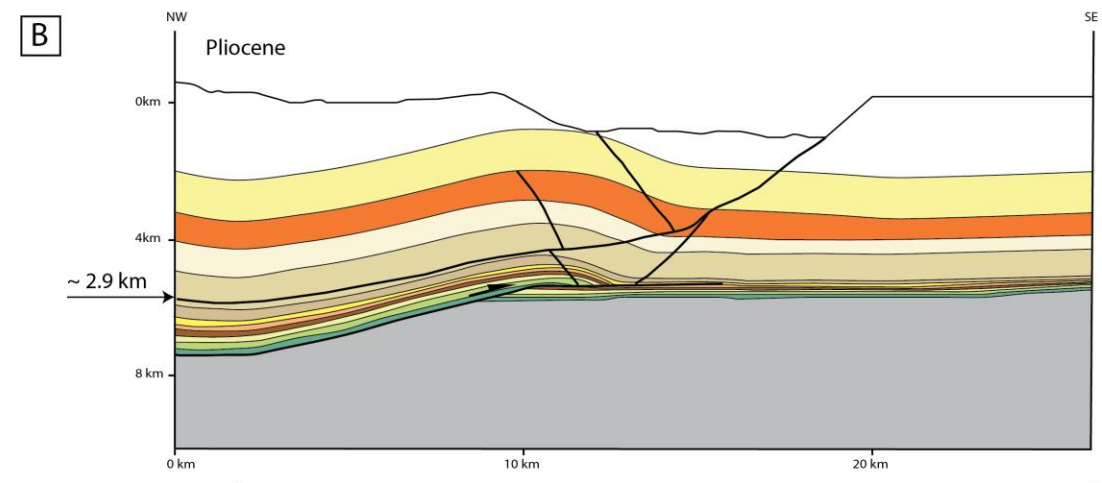
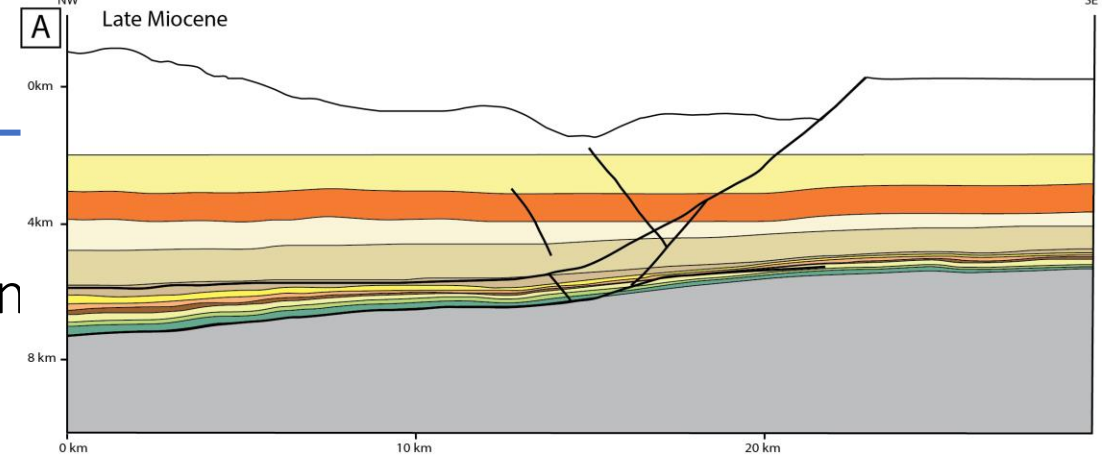
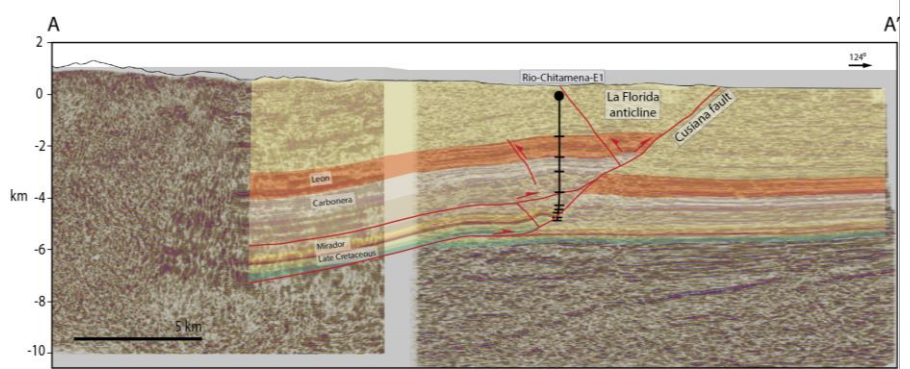
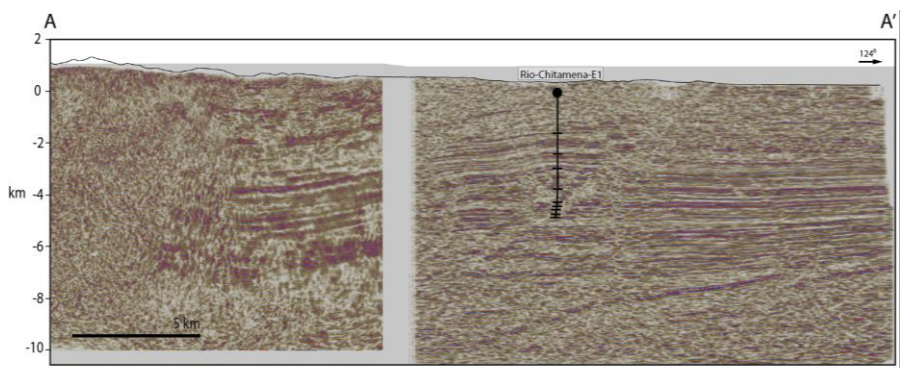
I. Seismic Interpretation

Created synthetic seismograms, seismic-ties, picked horizons with well control - **Petrel** (Schlumberger).



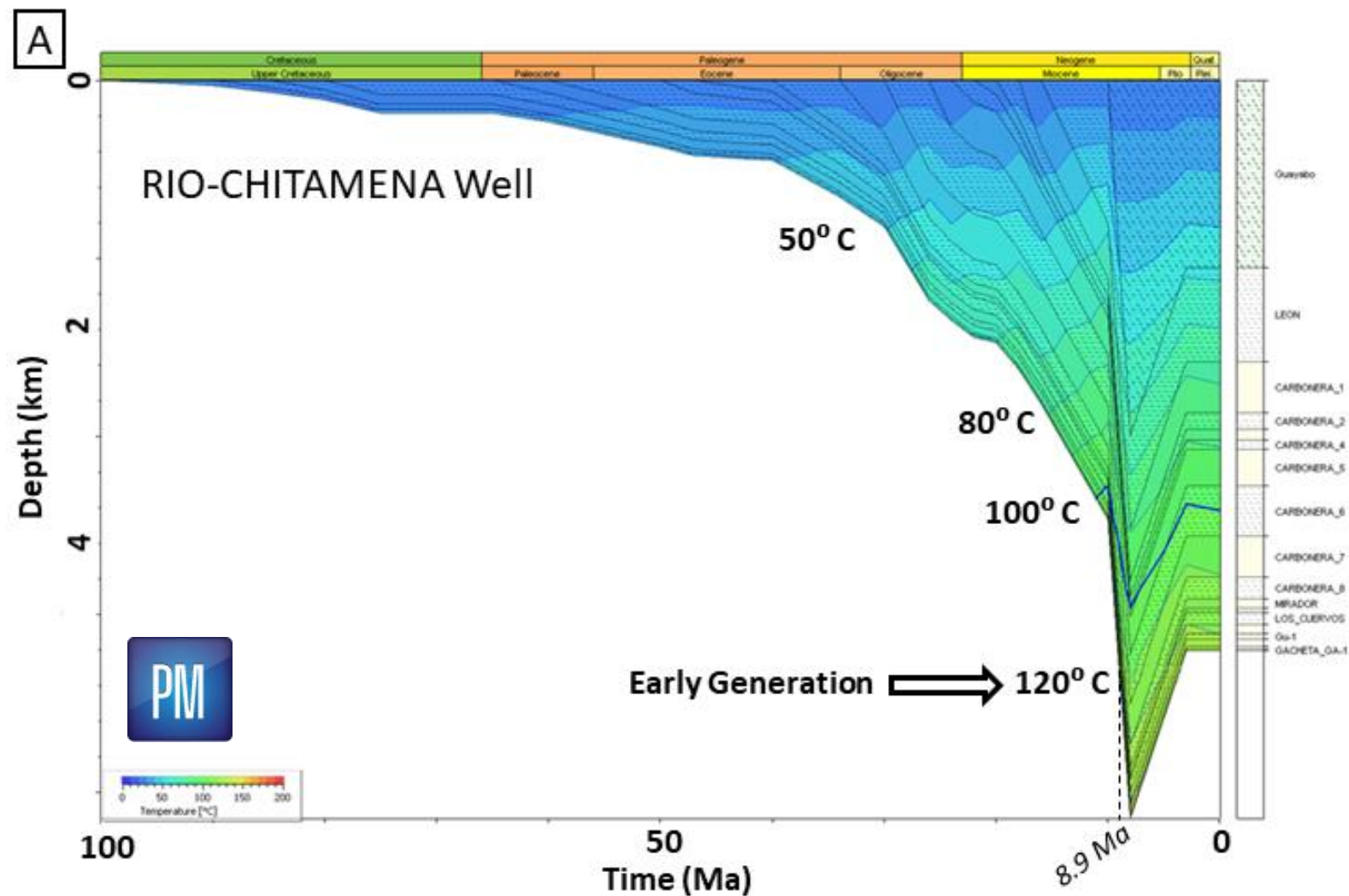
II. Cross-Section Construction and Kinematic Restoration

Constructed cross-sections and retrodeformed sections assuming volume conservation (Suppe et al 1983) - **Move** (Midland Valley).



1-D Burial Models

Estimated source rock burial history and timing of critical moment with **PetroMod** (Schlumberger).



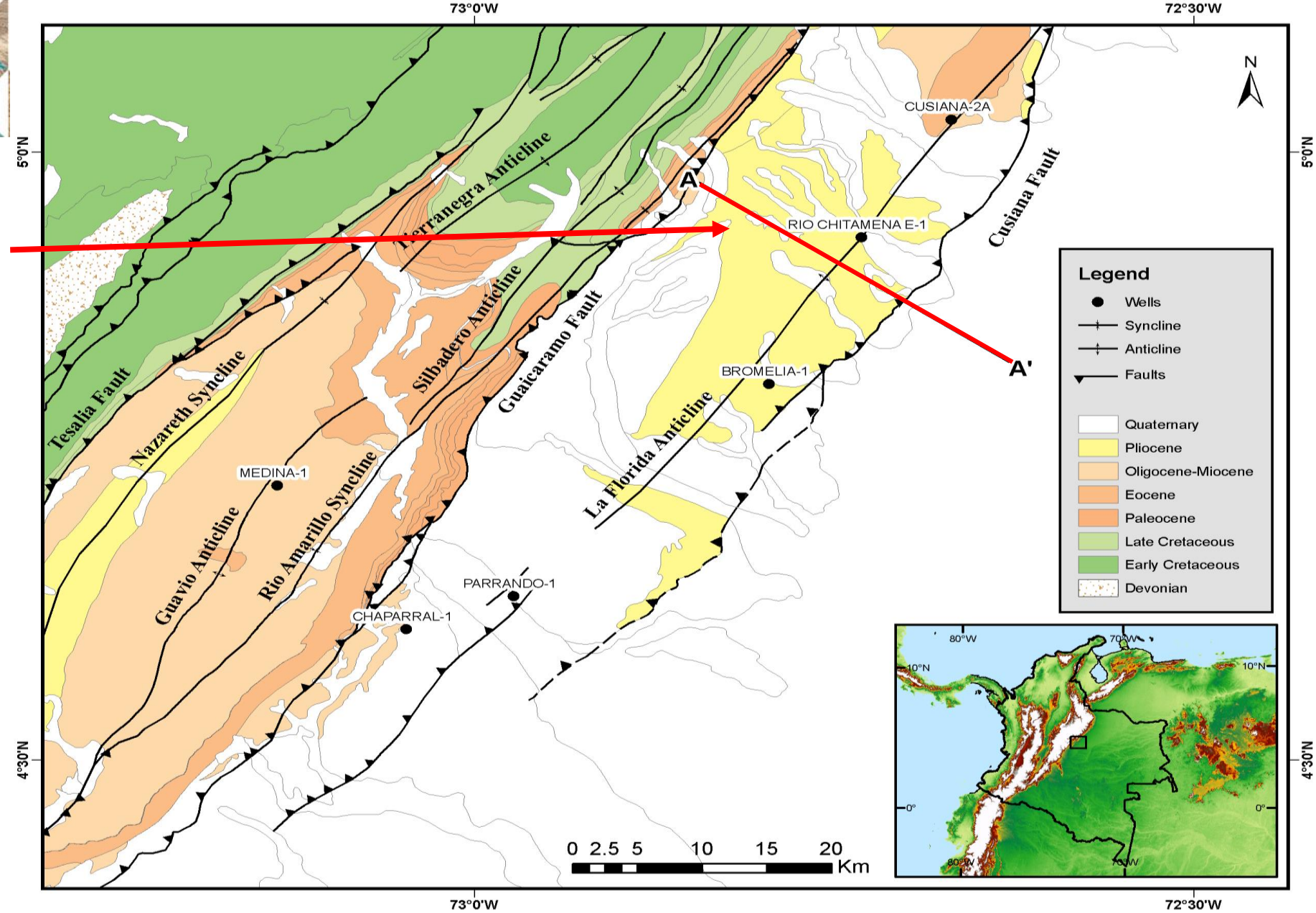


Outline:

- Overview
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- **Seismic Interpretation**
- Retro-deformed Model
- Burial History
- Conclusions



- Cross-section A – A'
combined dip line from
3-D volume and 2-D
seismic line.

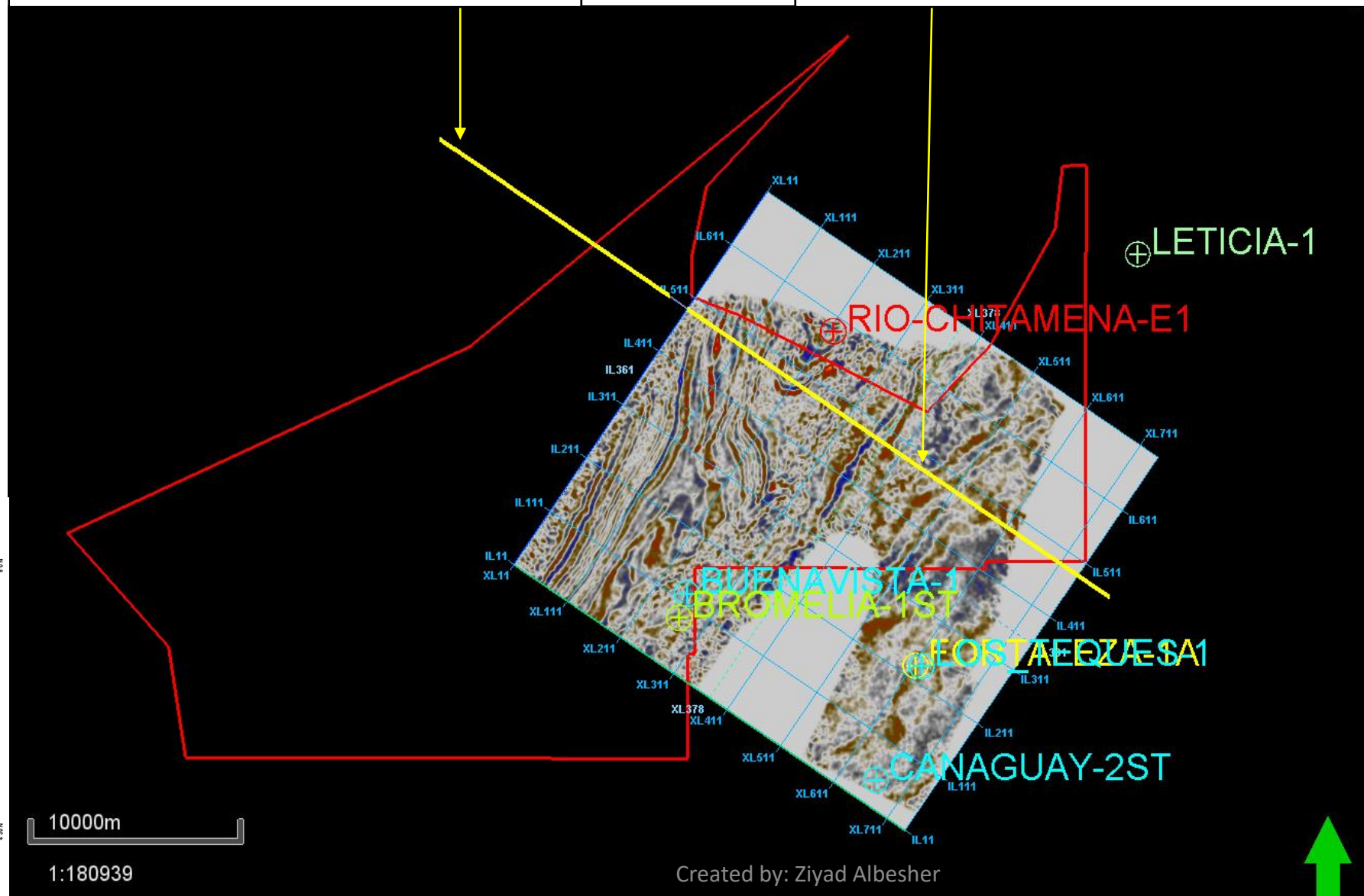
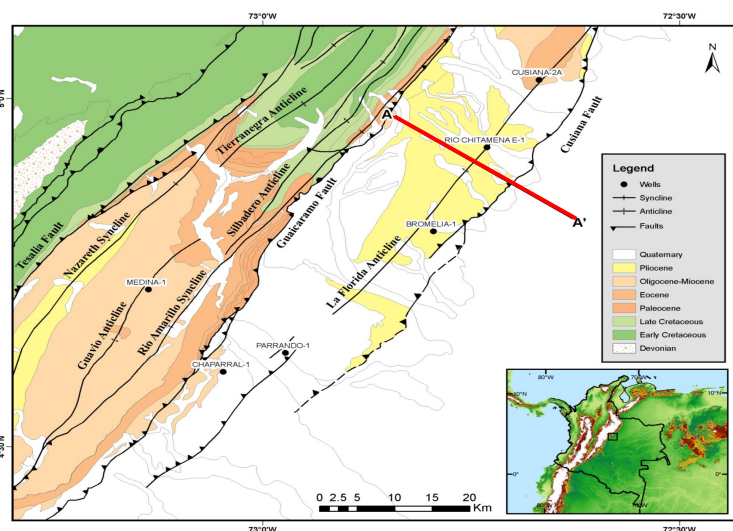


- Cross-section A – A'
combined dip line from
3-D volume and 2-D
seismic line.

Total Length: 36 km

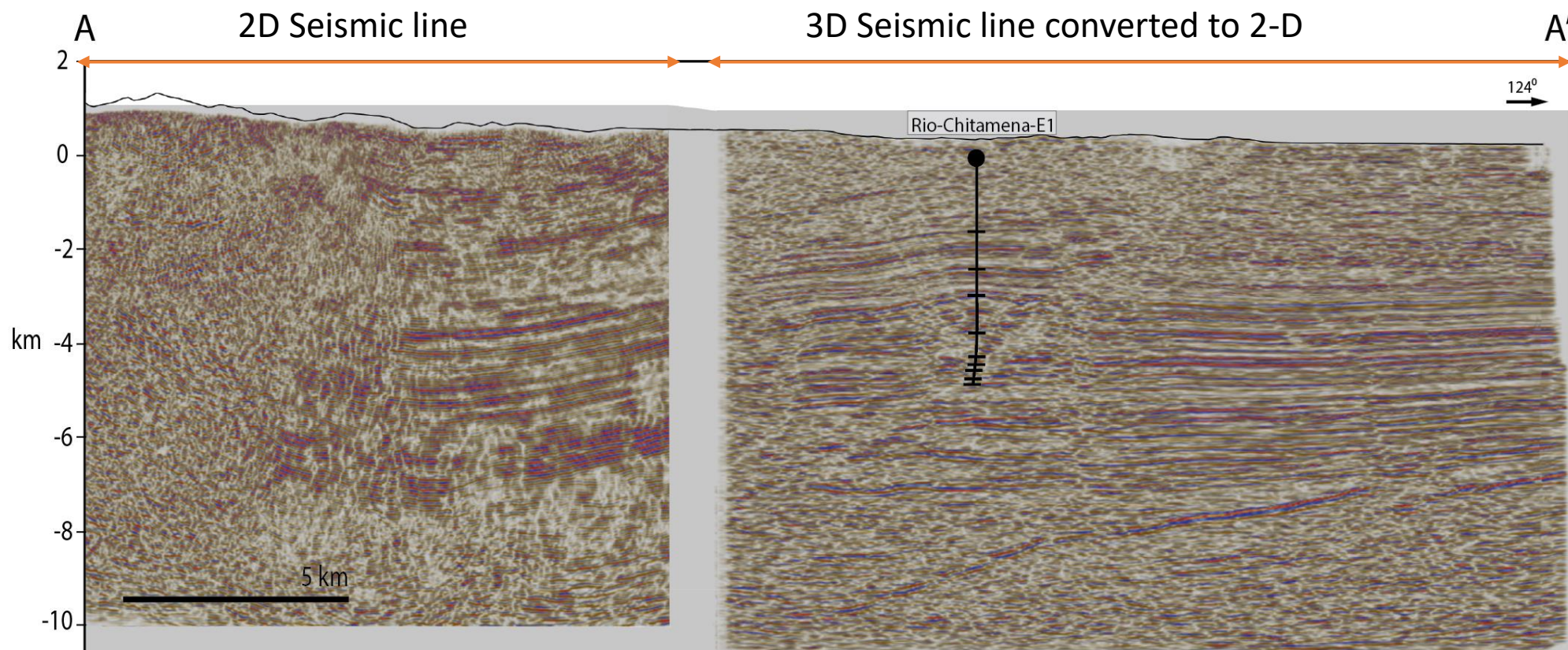
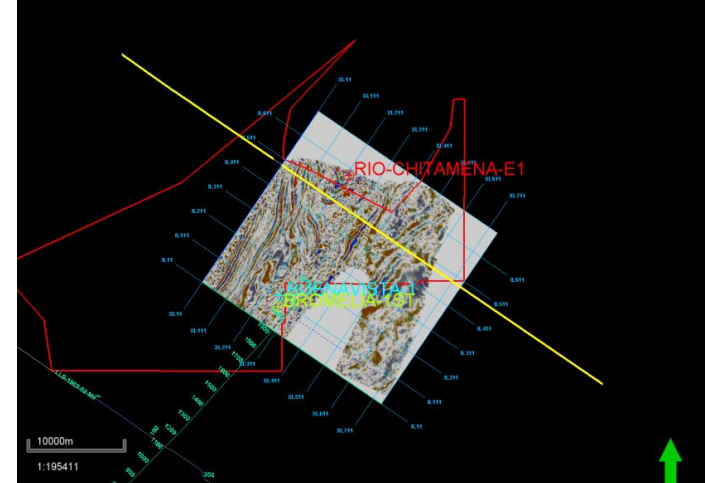
2D Seismic line [RC-1991-13.MIG]

3D Seismic line [Composite line]



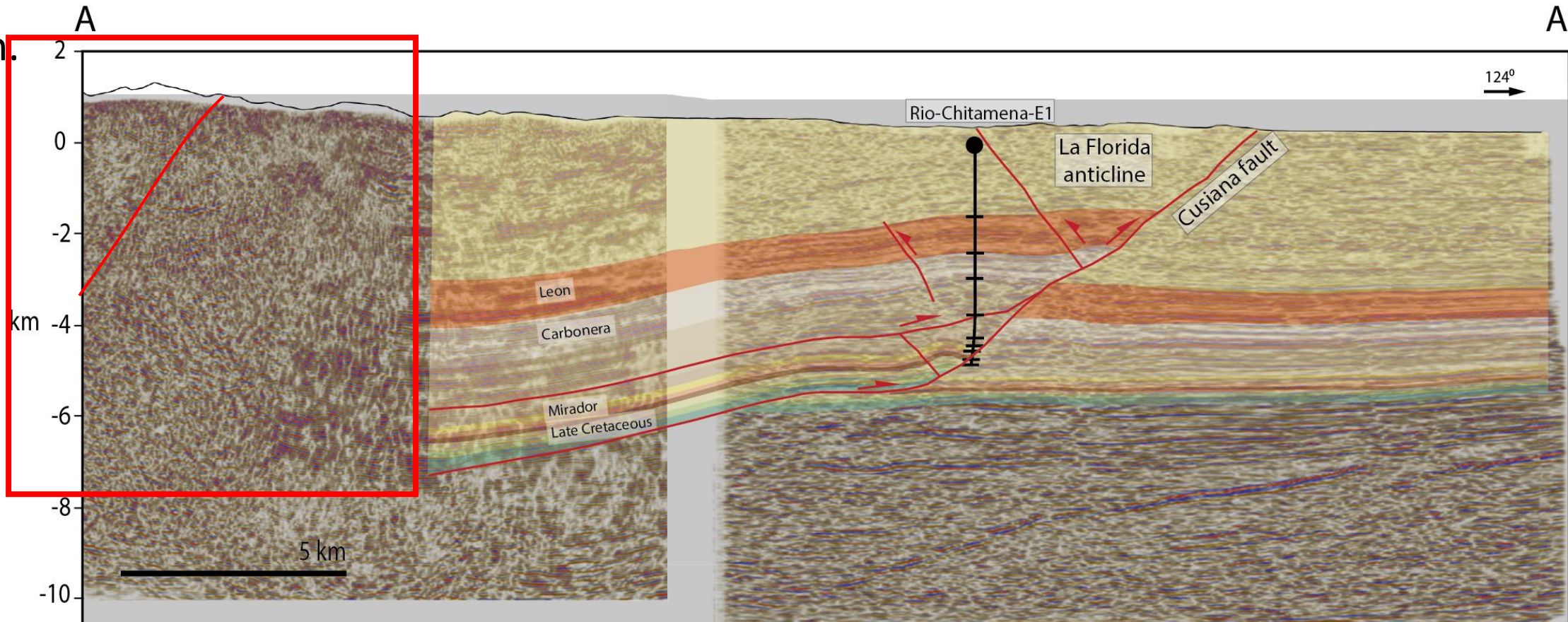
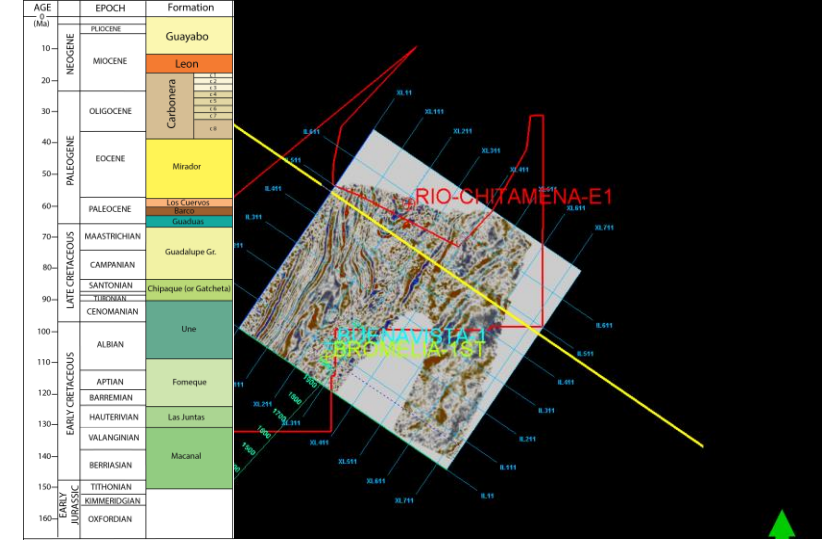
Seismic Interpretation

- **Rio Chitamera well** was projected ~ **3 km** onto cross-section along the anticlinal axis to constrain dips and formation tops.

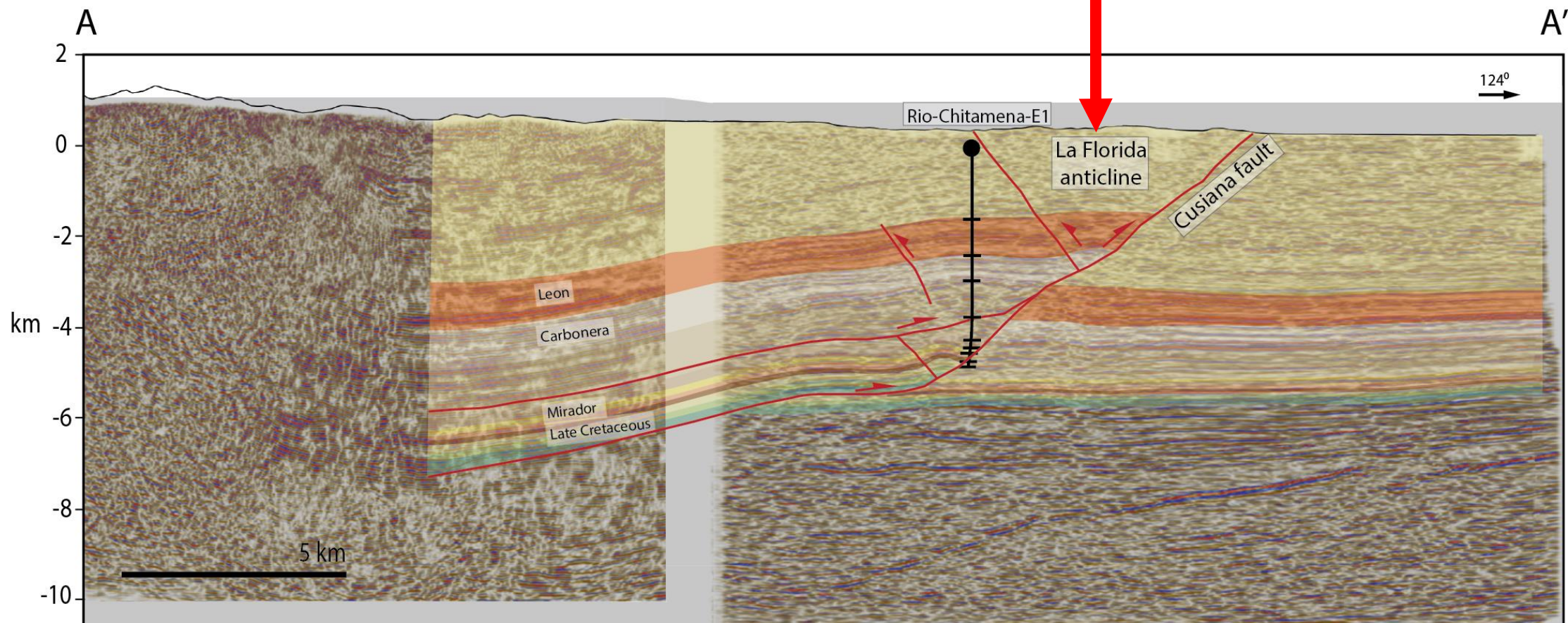
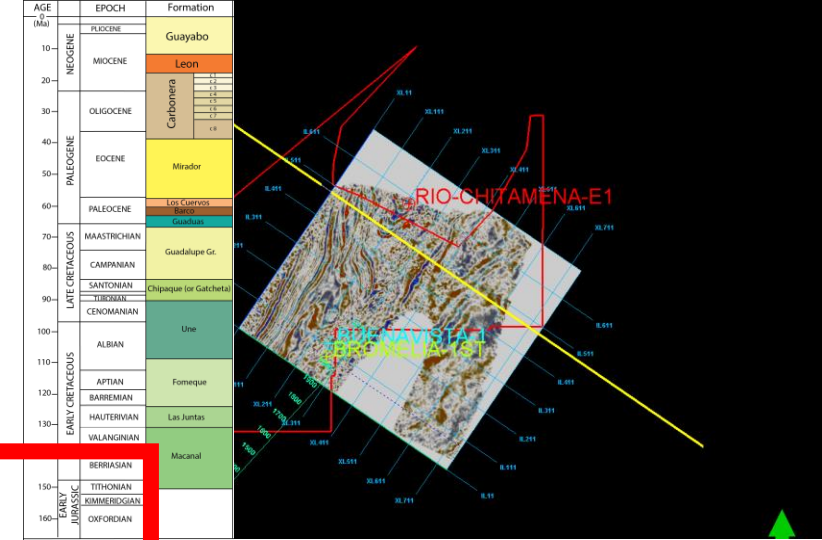


Results:

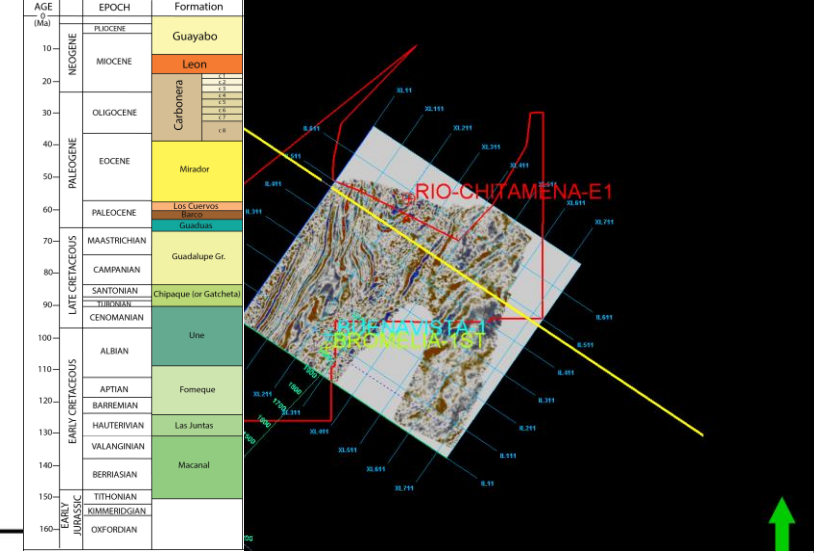
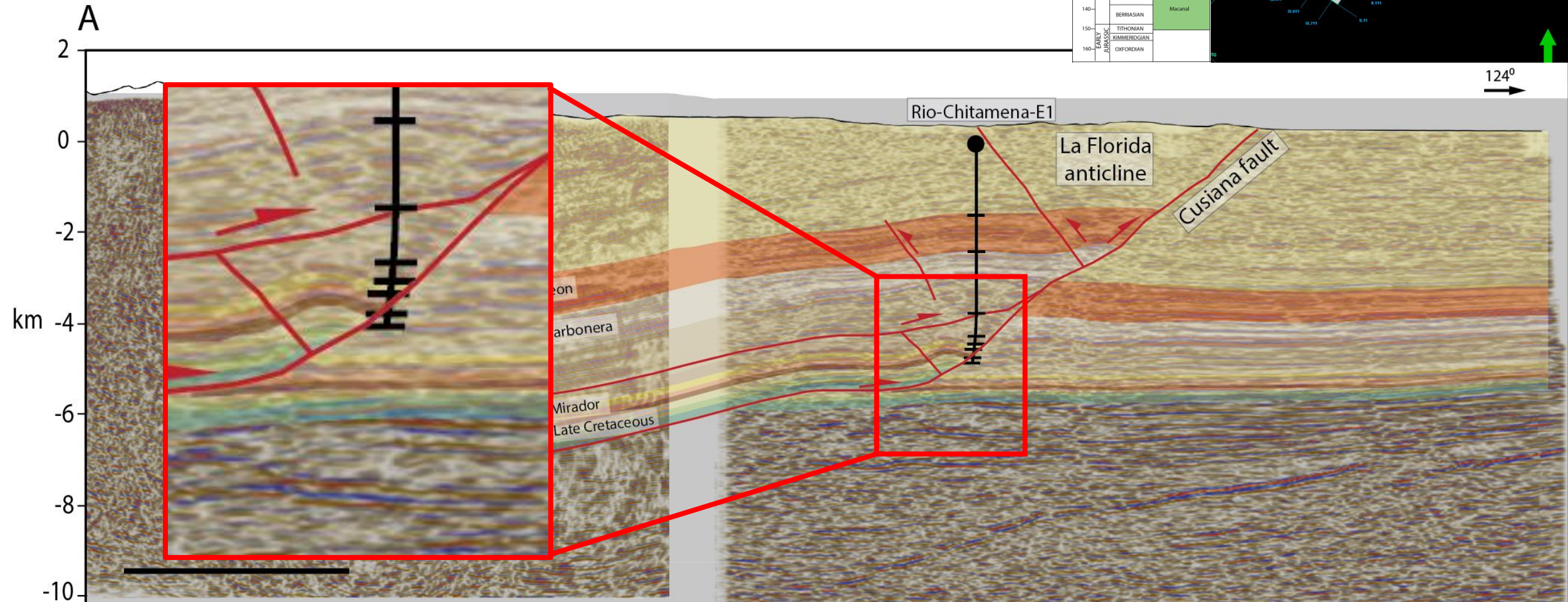
1. Guaicaramo thrust (west side of section) is poorly imaged due to energy dispersal from intense hanging wall and fault plane deformation.



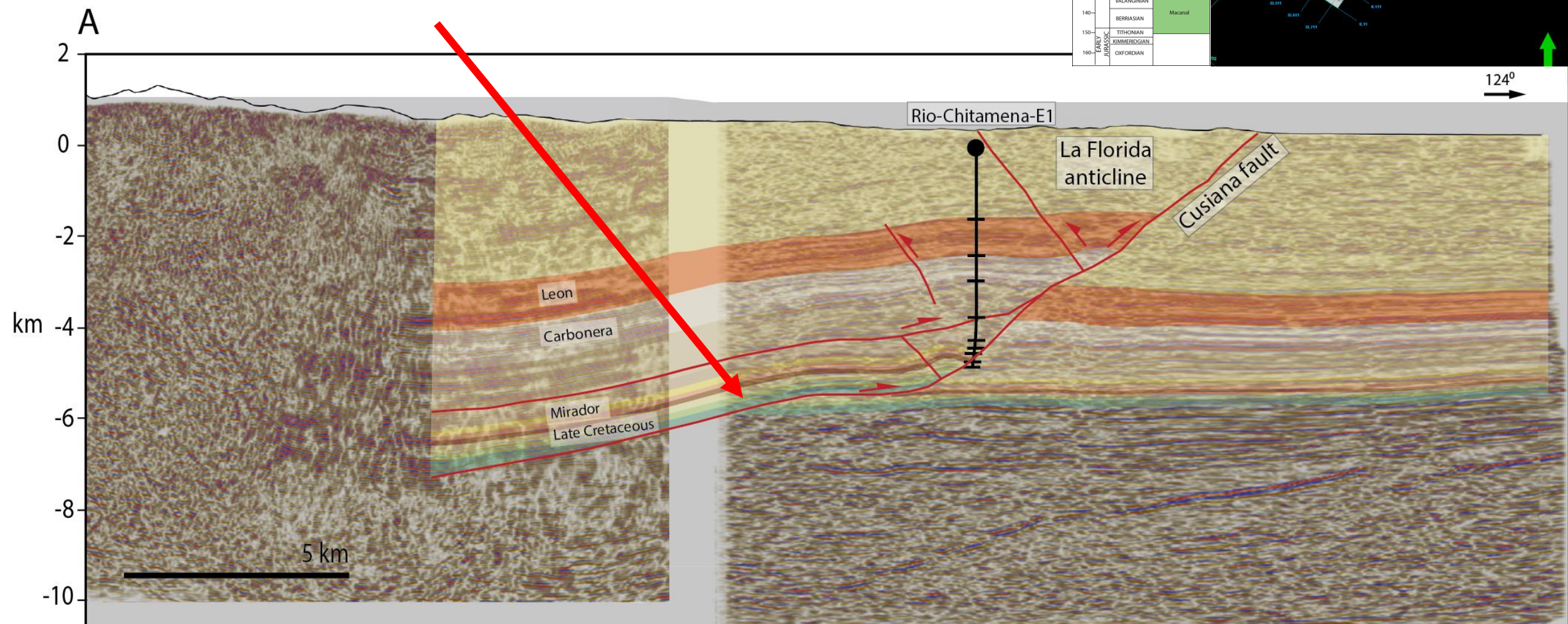
2. Florida anticline is a **gentle fold** with low relief produced by **thin-skinned thrusting** from detachments in the Lower Carbonera Fm and mid Cretaceous.



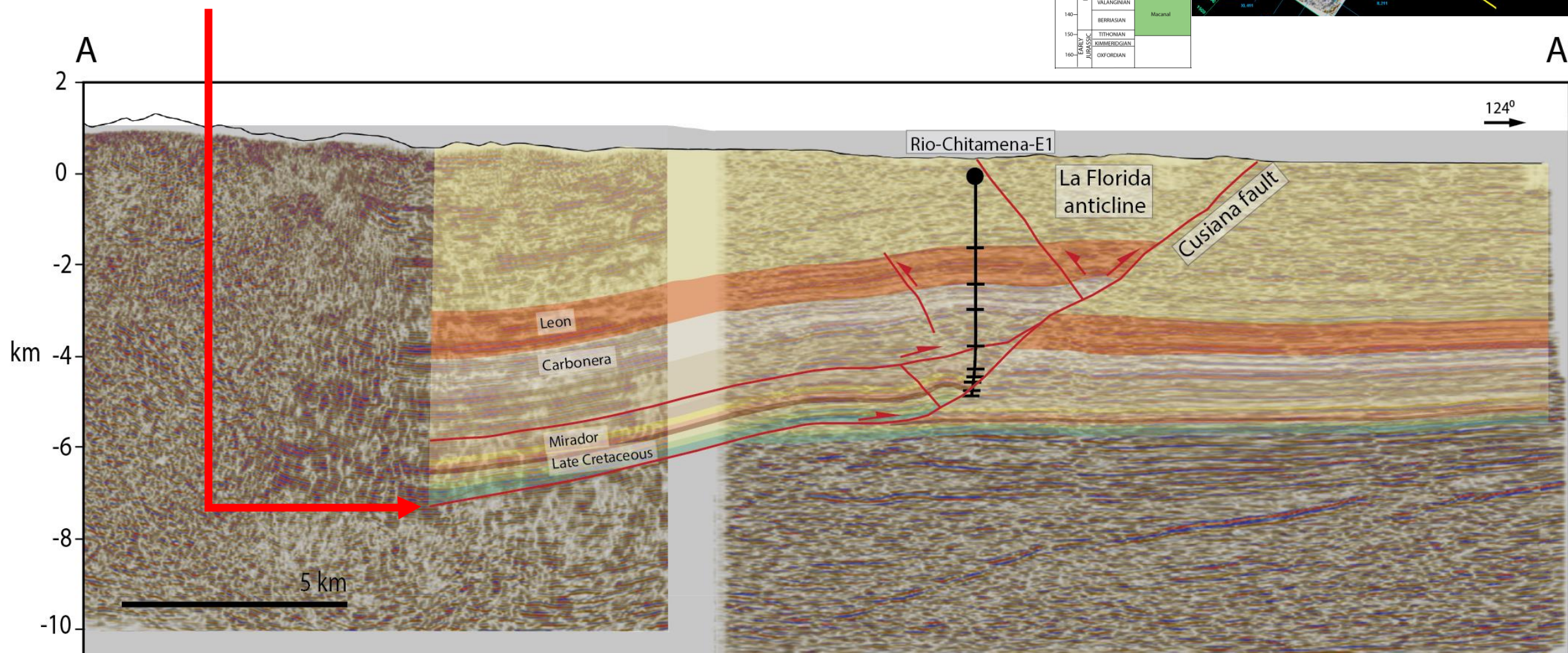
3. **Magnitude of folding** is higher in Early Oligocene to Early Cretaceous units.



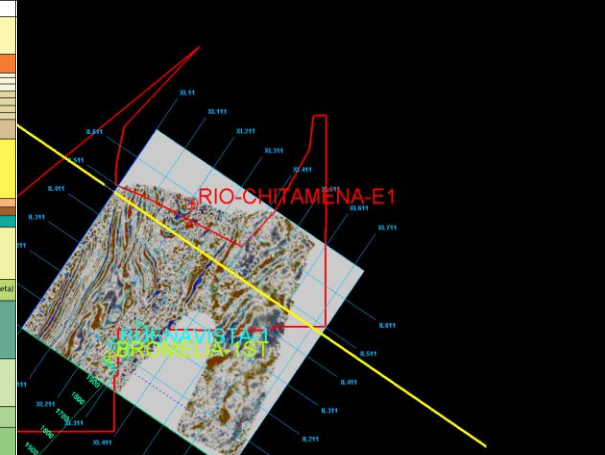
4. NW thickening of Cretaceous units due to normal faulting and thermal subsidence.



5. The **lower Cusiana thrust fault ramps up** to the surface from a mid-Cretaceous detachment.

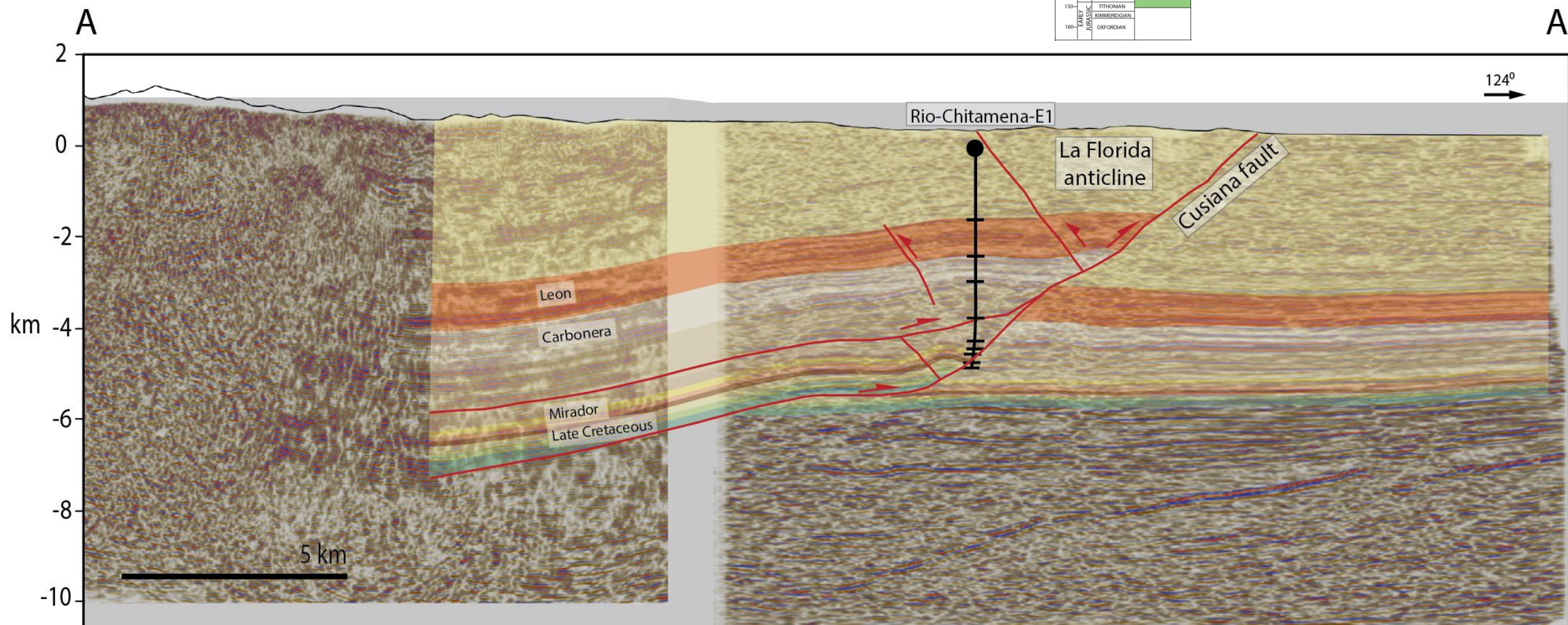
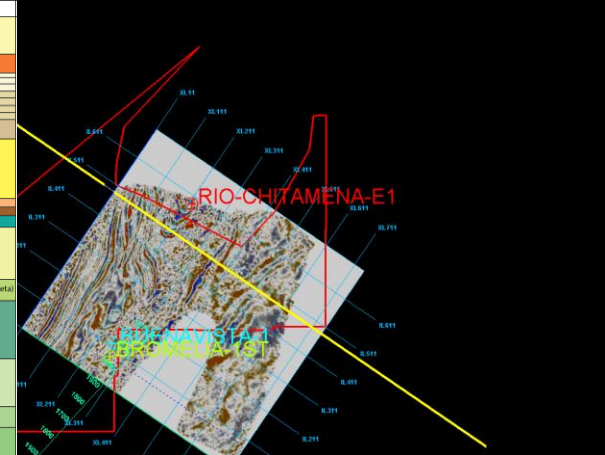


AGE (Ma)	EPOCH	Formation
0-5	PLIOCENE	Guayabo
5-23	MIOCENE	Leon
23-66	OLIGOCENE	Carbonera
66-23	PALEOCENE	Mirador
66-56	PALEOCENE	Los Cuervos
56-66	MAASTRICHTIAN	Guadalupe
66-80	CAMPANIAN	Guadalupe Gc.
80-90	SANTONIAN	Chiquique (or Gatcheta)
90-100	TIBERIAN	Ure
100-110	ALBIAN	Ure
110-120	APTIAN	Fomeque
120-130	BARREMIAN	Las Juntas
130-140	HAUTERIVIAN	Macanal
140-150	VALANGINIAN	Macanal
150-160	BERRIASIAN	Macanal
160-180	TITHONIAN	
180-200	KIMMERIDGIAN	
200-250	OXFORDIAN	



6. **Lack of growth strata** on the hanging wall of Cusiana fault indicates late Miocene-Pliocene age for La Florida anticline.

AGE (Ma)	EPOCH	Formation
0-5	PLIOCENE	Guayabo
5-23	MIOCENE	Leon
23-66	OLIGOCENE	Carbonera
66-23	Eocene	Mirador
66-56	PALEOCENE	Los Cuervos
56-66	MAASTRICHTIAN	Guadalupe
66-100	CAMPANIAN	Guadalupe Gc.
100-145	SANTONIAN	Chiquique (or Gatcheta)
145-160	CENOMANIAN	Una
160-180	ALBIAN	Fomeque
180-200	APTIAN	Las Juntas
200-252	HAUTERIVIAN	Macanal
252-252	VALANGINIAN	
252-252	BERRIASIAN	
252-252	TITHONIAN	
252-252	KIMMERIDGIAN	
252-252	OXFORDIAN	





Outline:

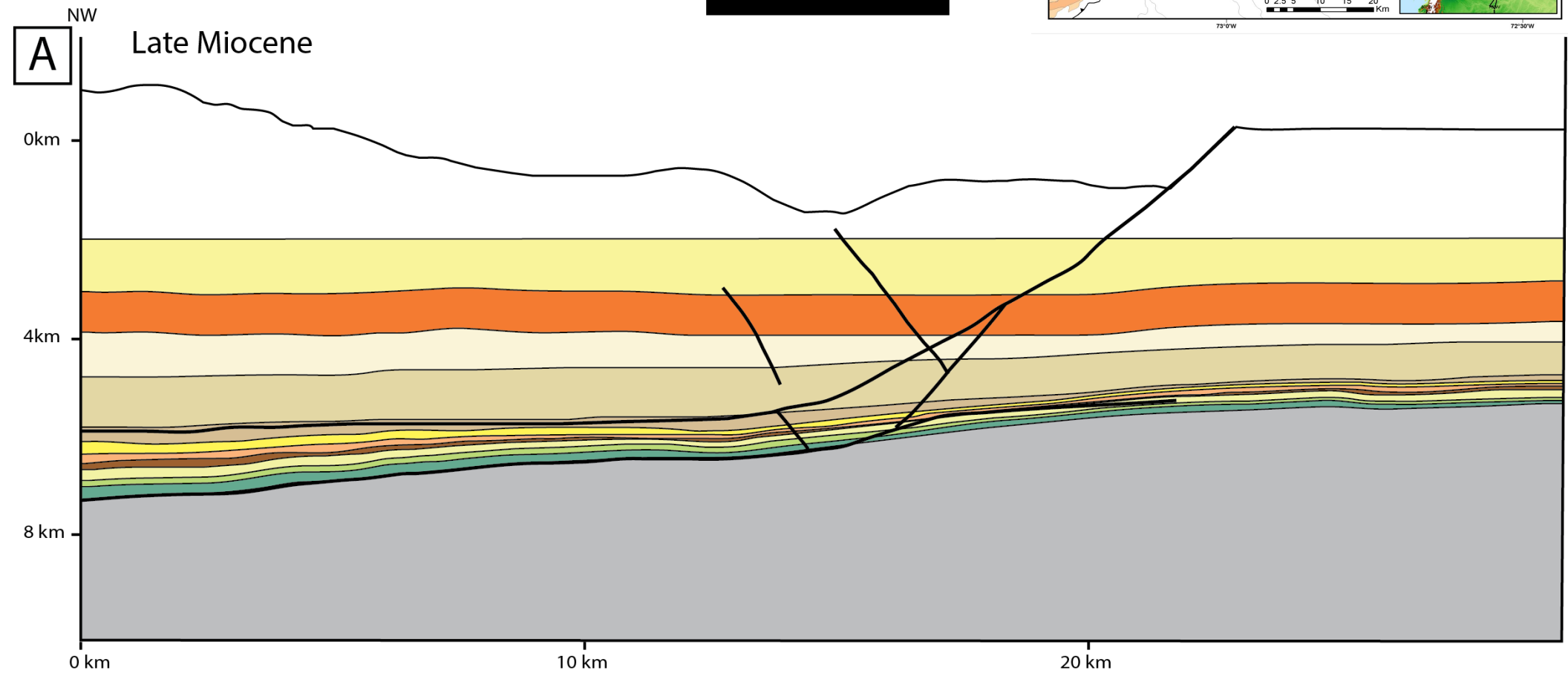
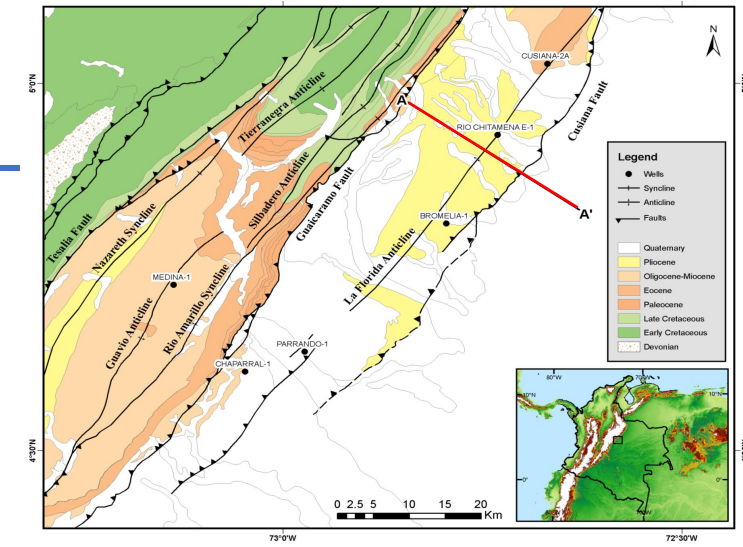
- Overview
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- **Retro-deformed Model**
- Burial History
- Conclusions



Retro-deformed Model

1. Profile was retro-deformed to **7 Ma** prior to Andean uplift (**6-3 Ma**).

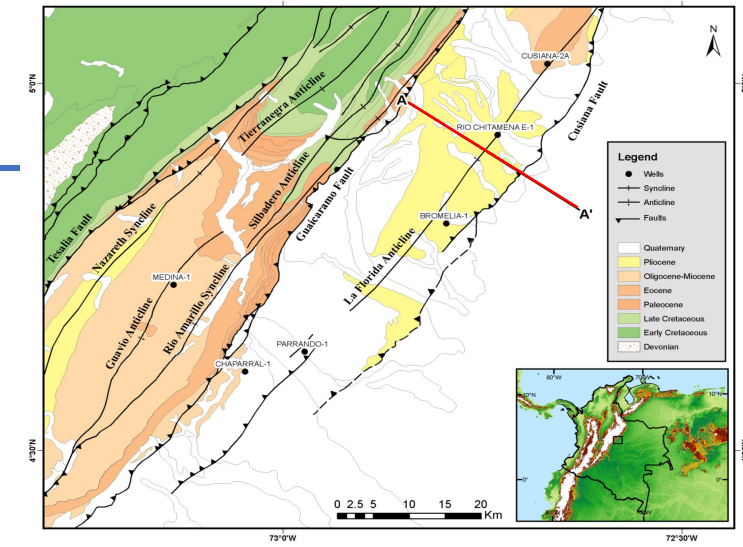
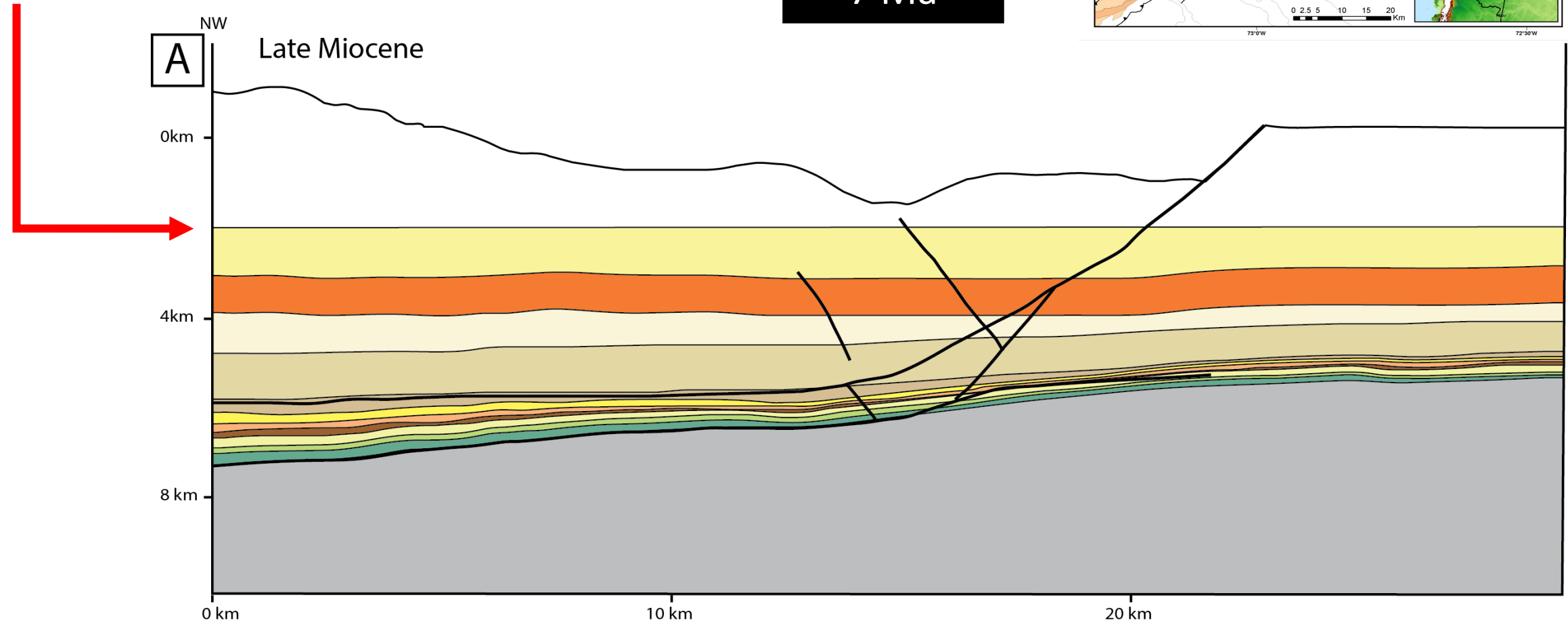
7 Ma



Retro-deformed Model

2. The **upper part** of section represents late Miocene
mid - **Guayabo Fm.**

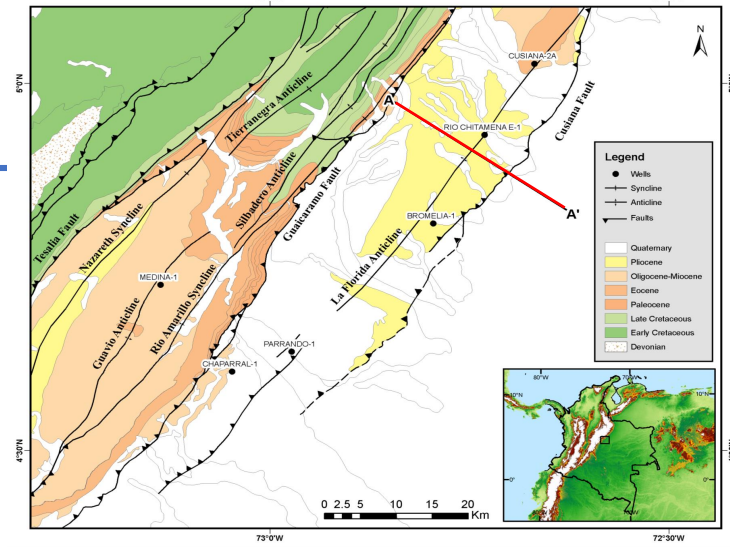
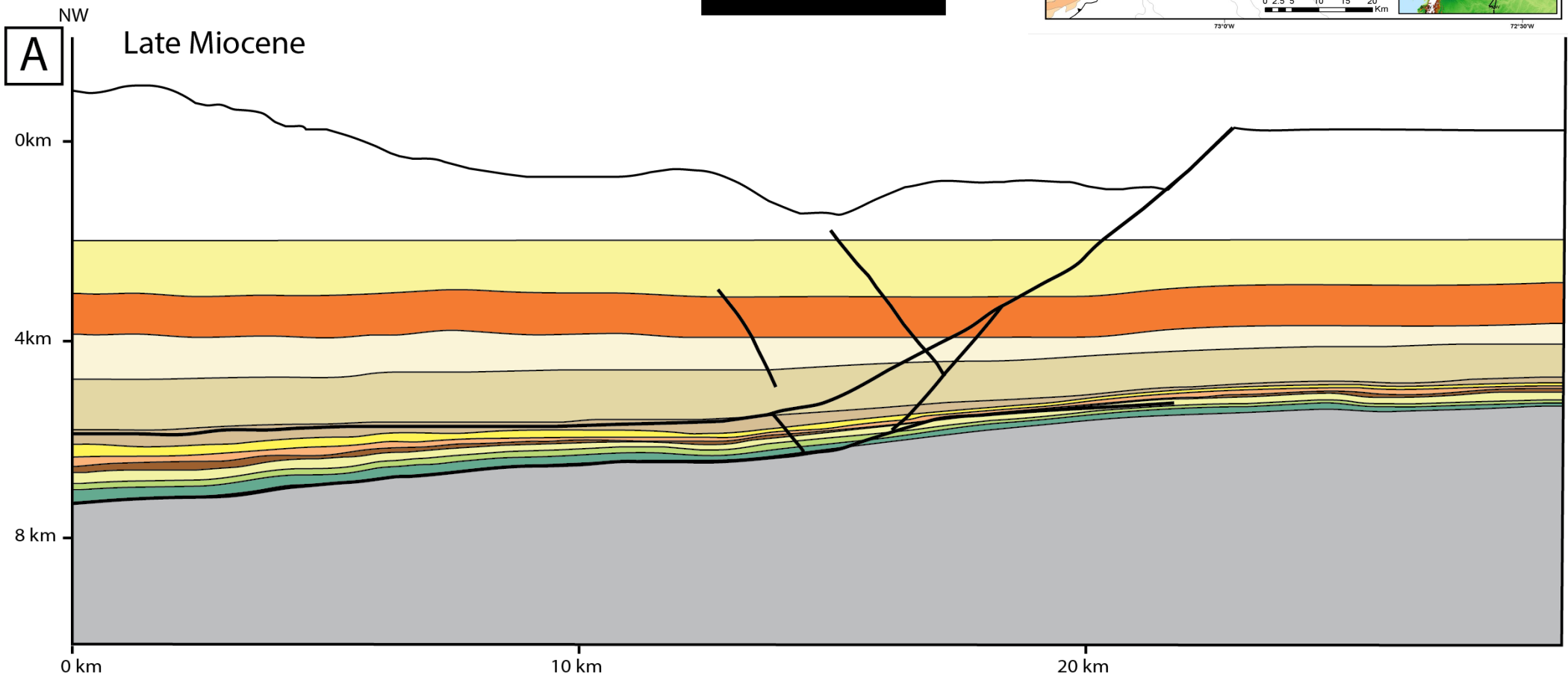
7 Ma

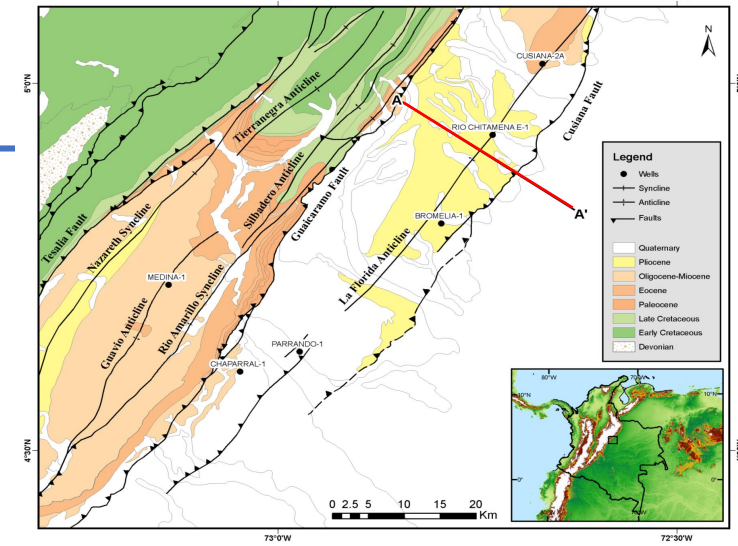


Retro-deformed Model

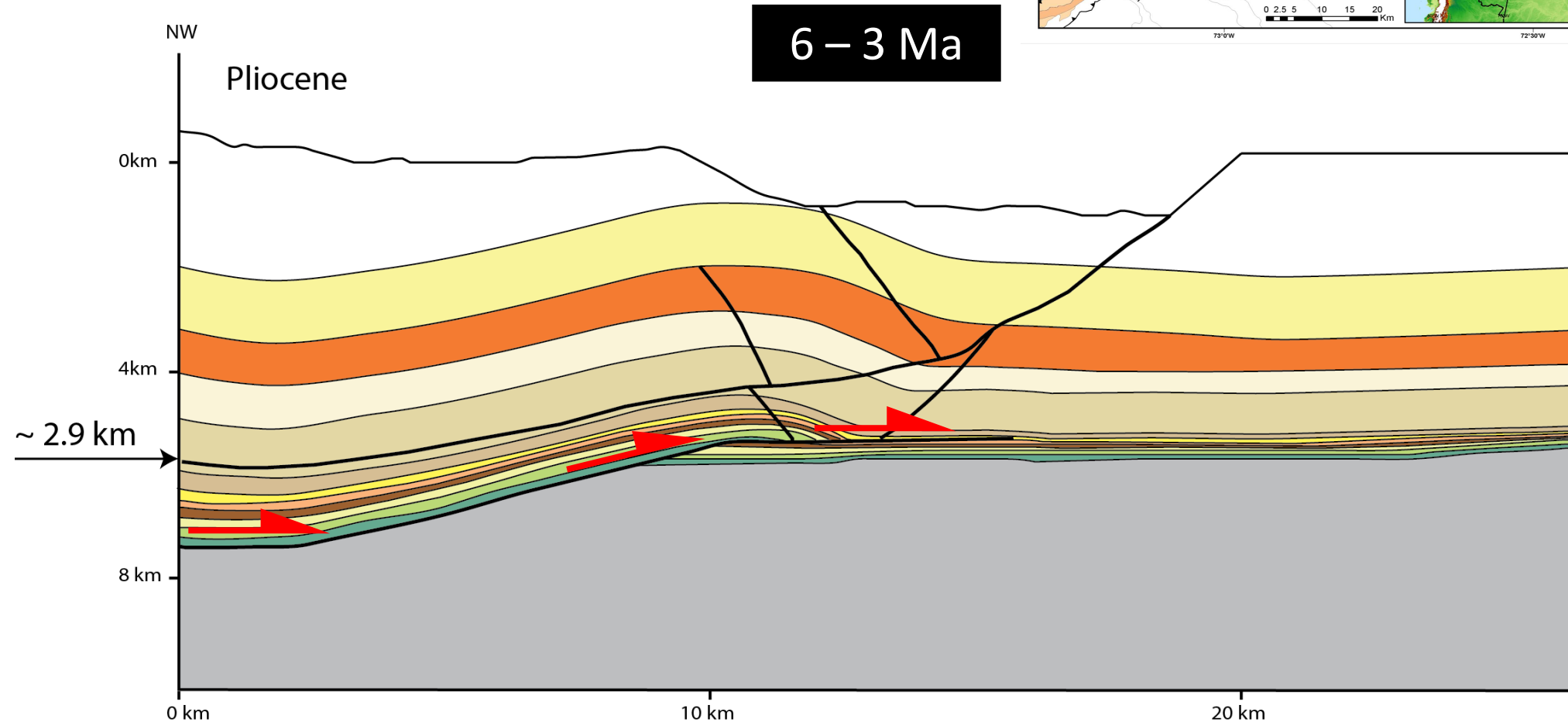
3. Units generally thin southeastward toward the Llanos basin.

7 Ma

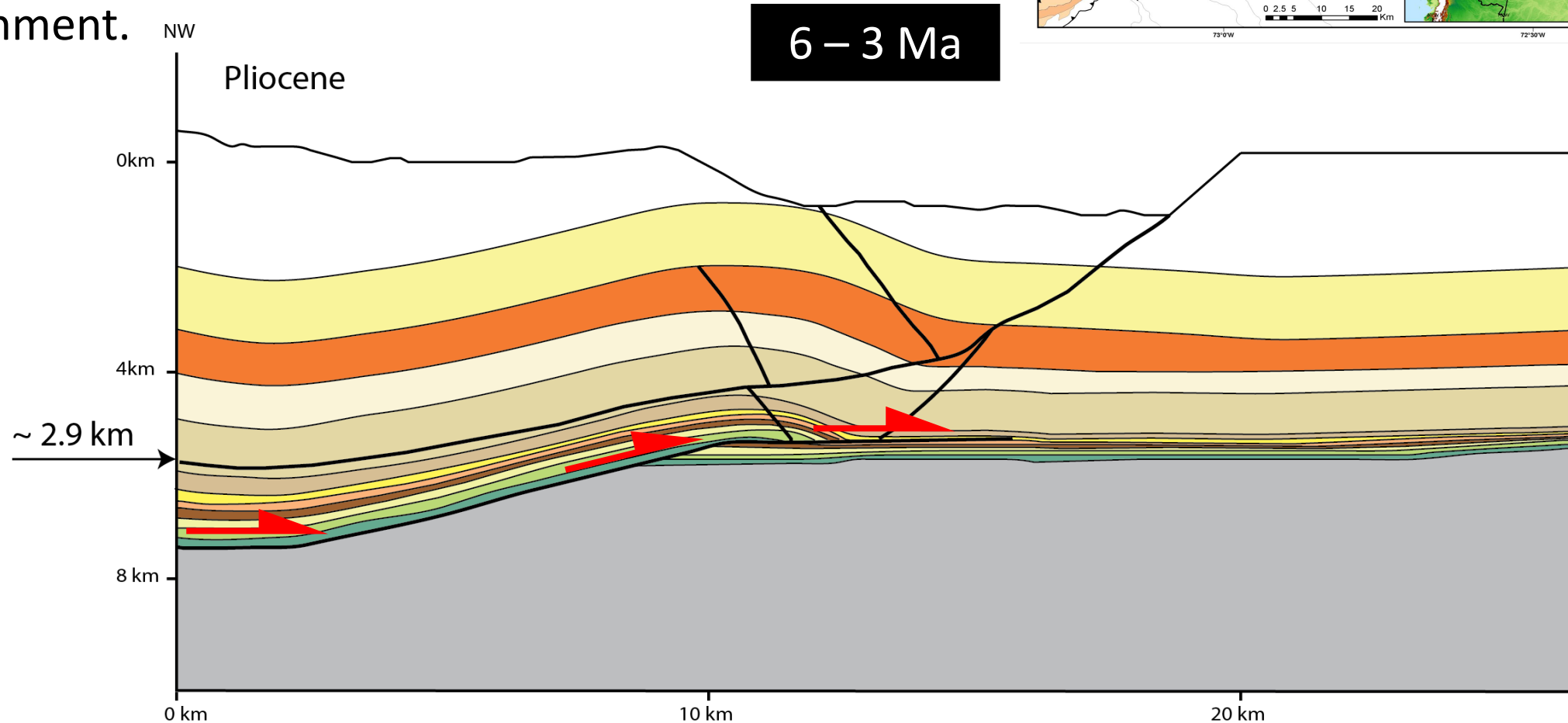
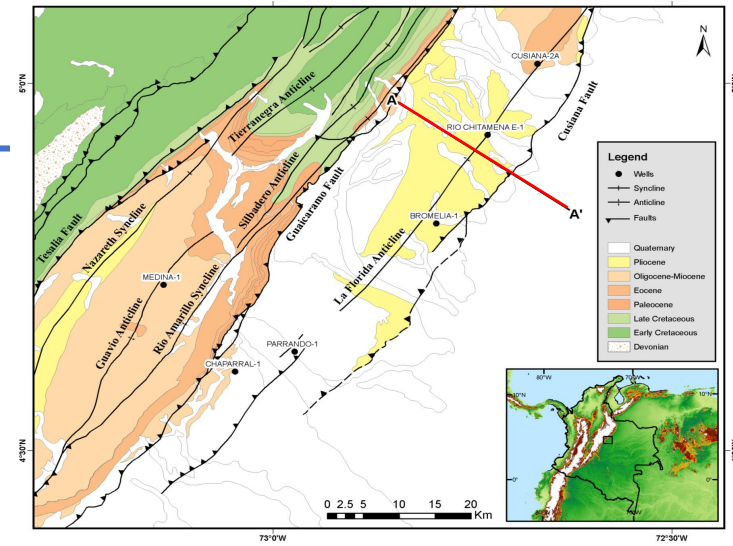




1. 6 to 3 Ma, **thermochronometric** data east of Guaicaramo fault (Bande et al., 2012) and **lack of growth strata** at La Florida suggest trap formation at **5 Ma** or younger.

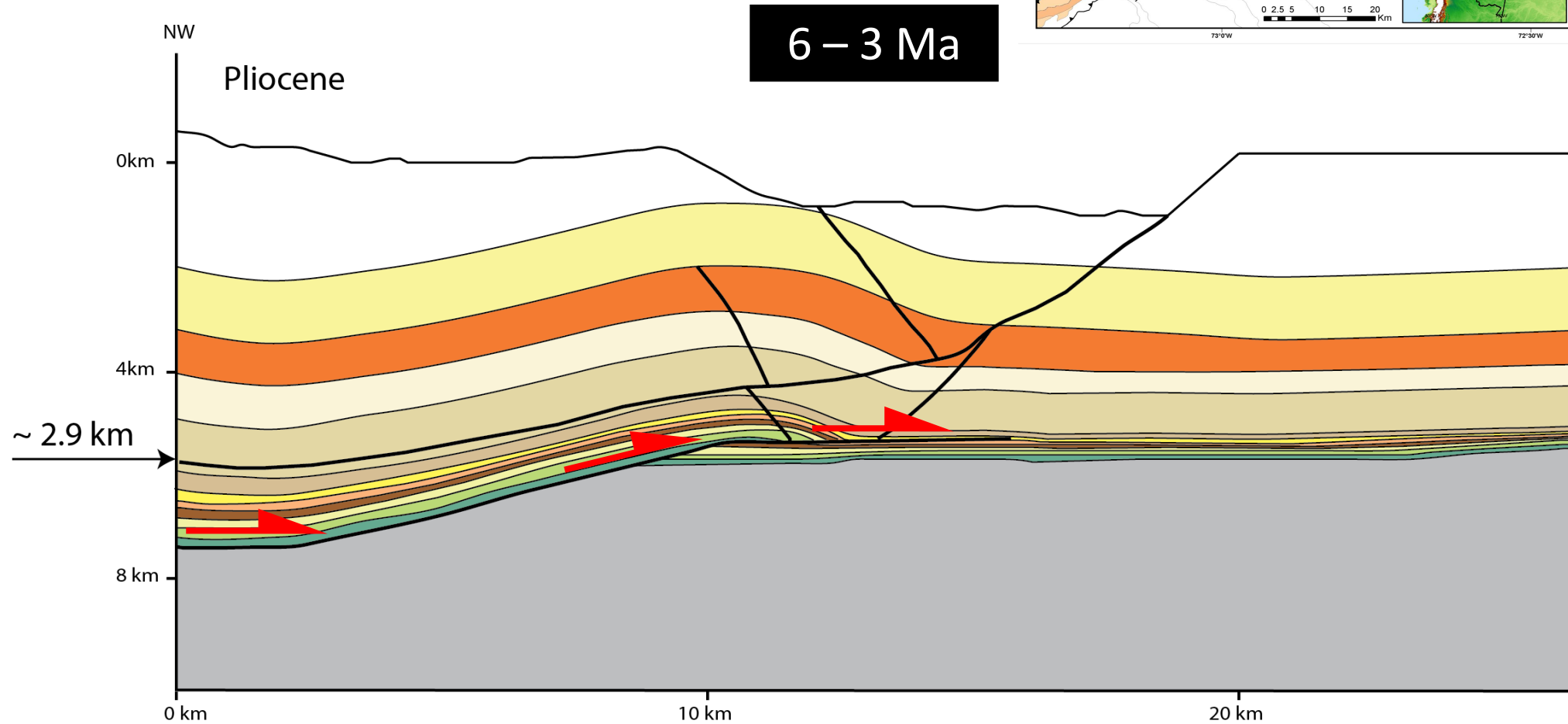
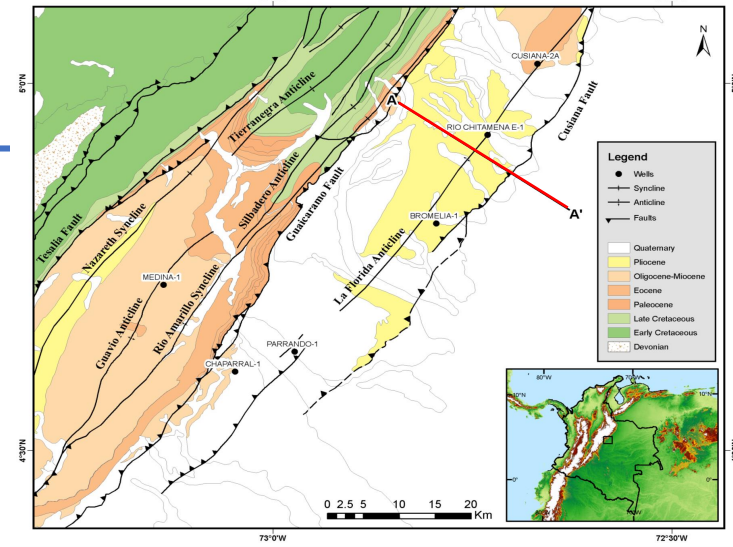


2. **Pliocene** time – initial La Florida anticline formed as a **fault-bend fold** by a **thin-skinned** thrust ramping up from a mid-Cretaceous detachment.



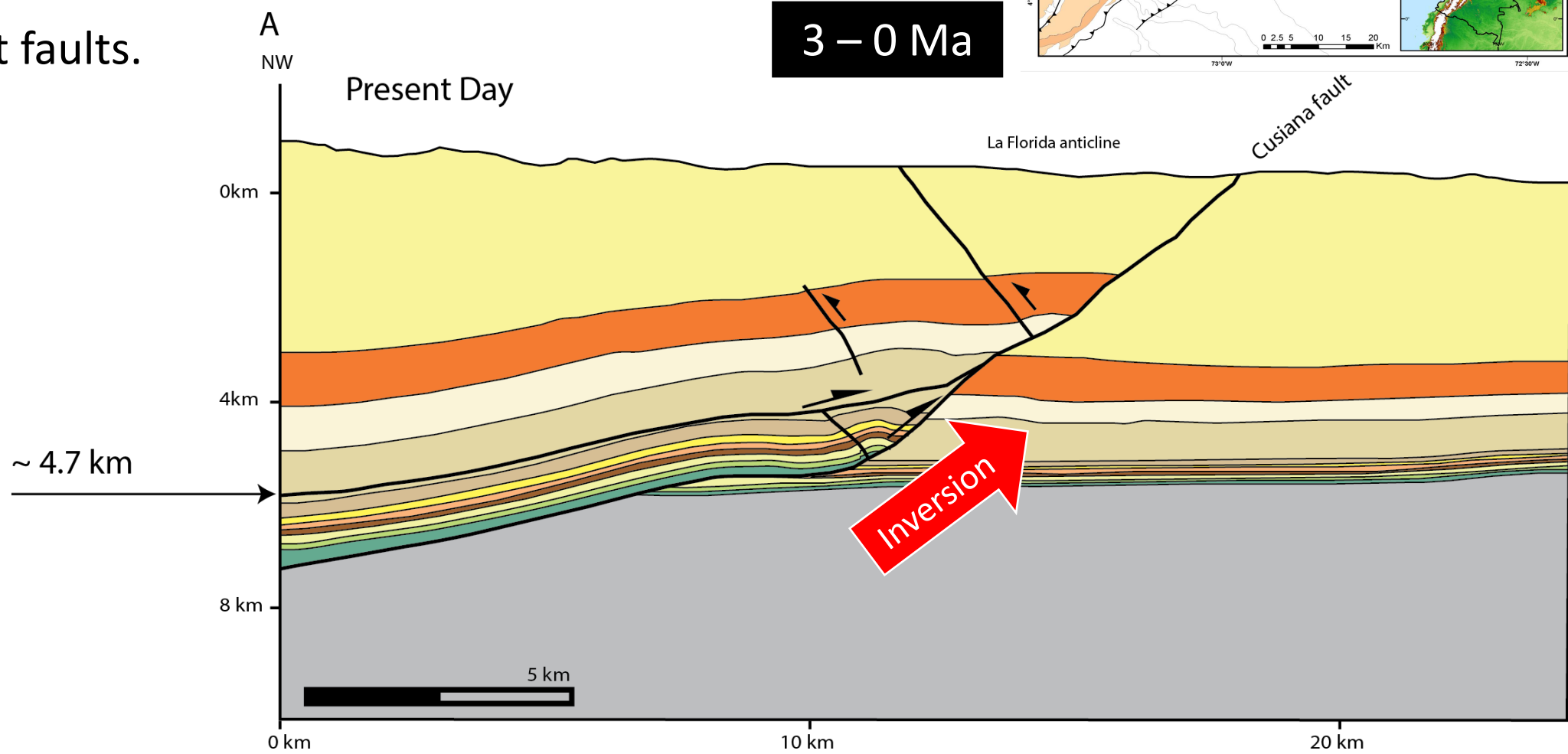
Retro-deformed Model

3. Shortening ~ 2.9 km, and ~ 60% of the total shortening.

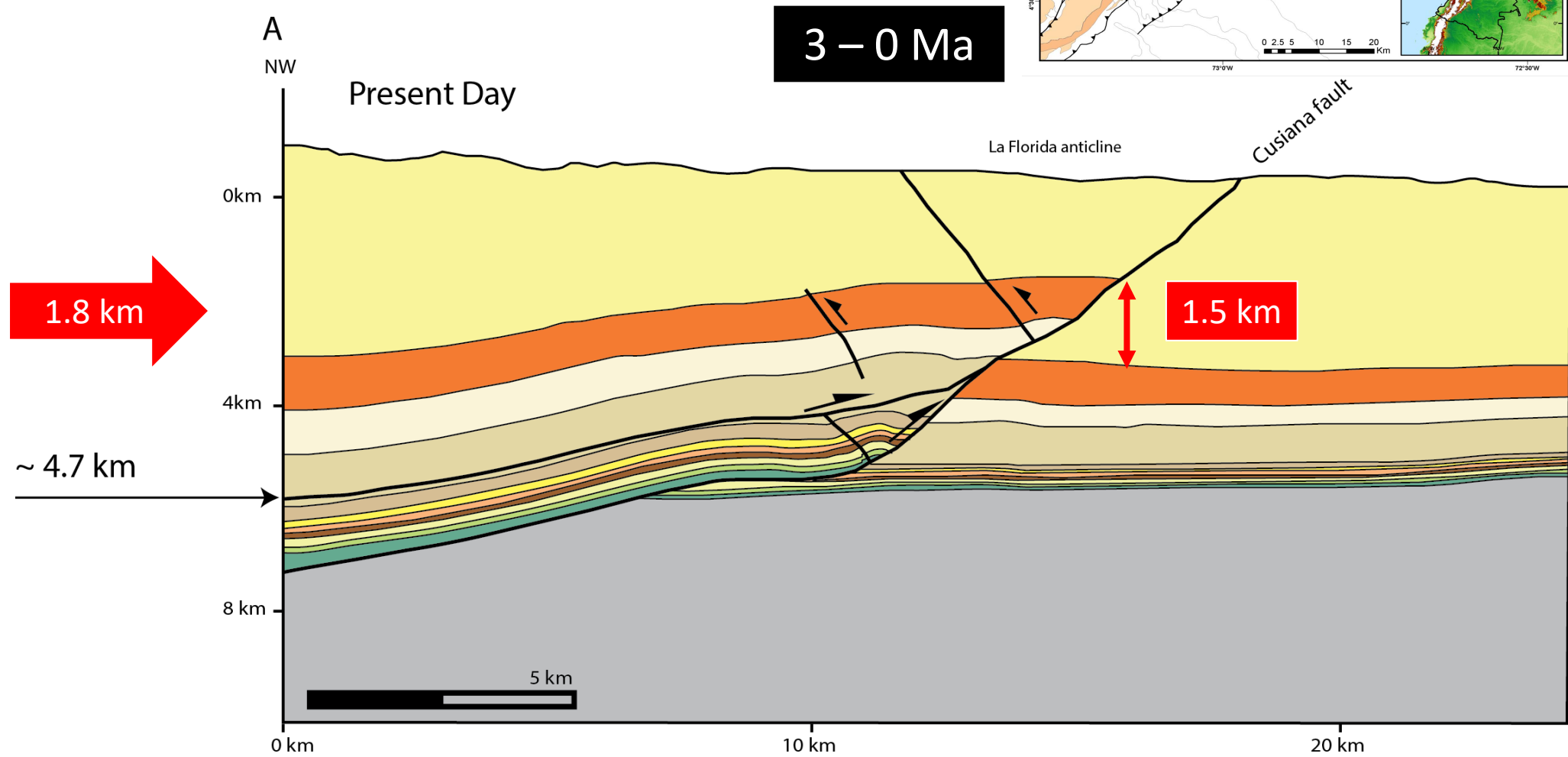


Retro-deformed Model

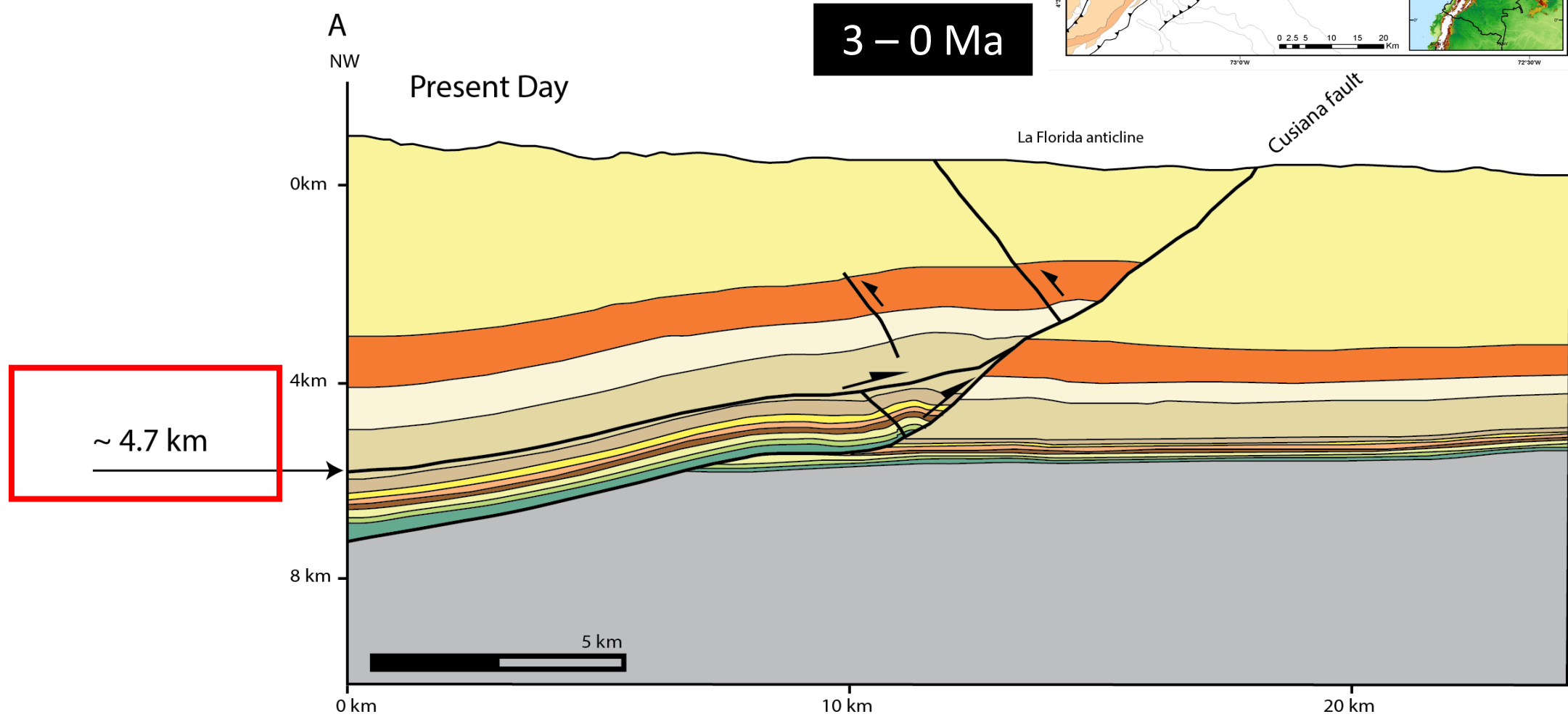
1. 3 Ma to Present – Cretaceous normal faults **inverted** (Cooper et al 1995) resulting in “**thick-skinned**” deformation on Cusiana and Guaicaramo thrust faults.



4. Cusiana normal fault inversion resulted in an additional **1.8 Km** of shortening and **1.5 Km** of structural relief.



5. Total shortening of La Florida anticline from late Miocene to Present ~ 4.7 km.



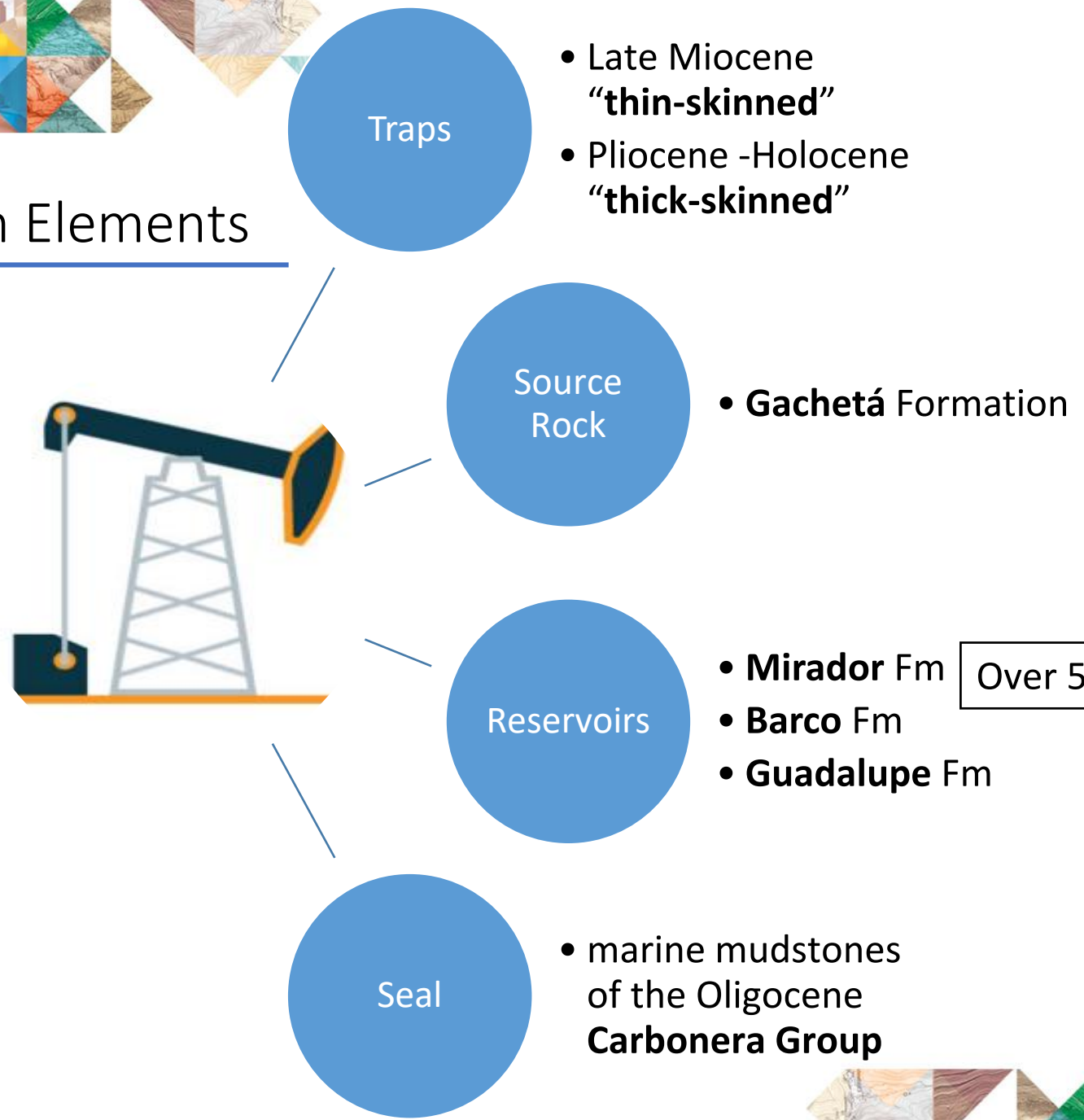


Outline:

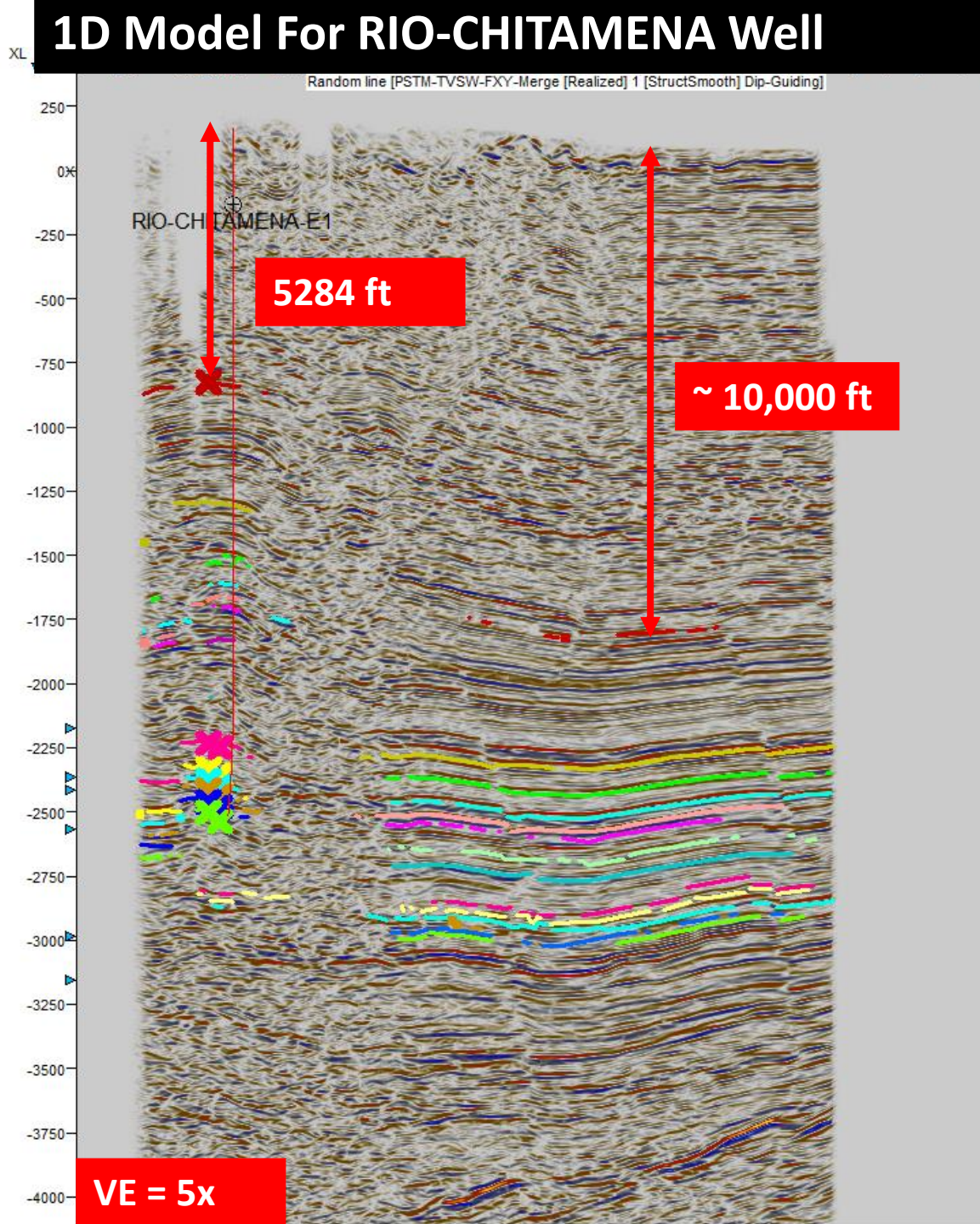
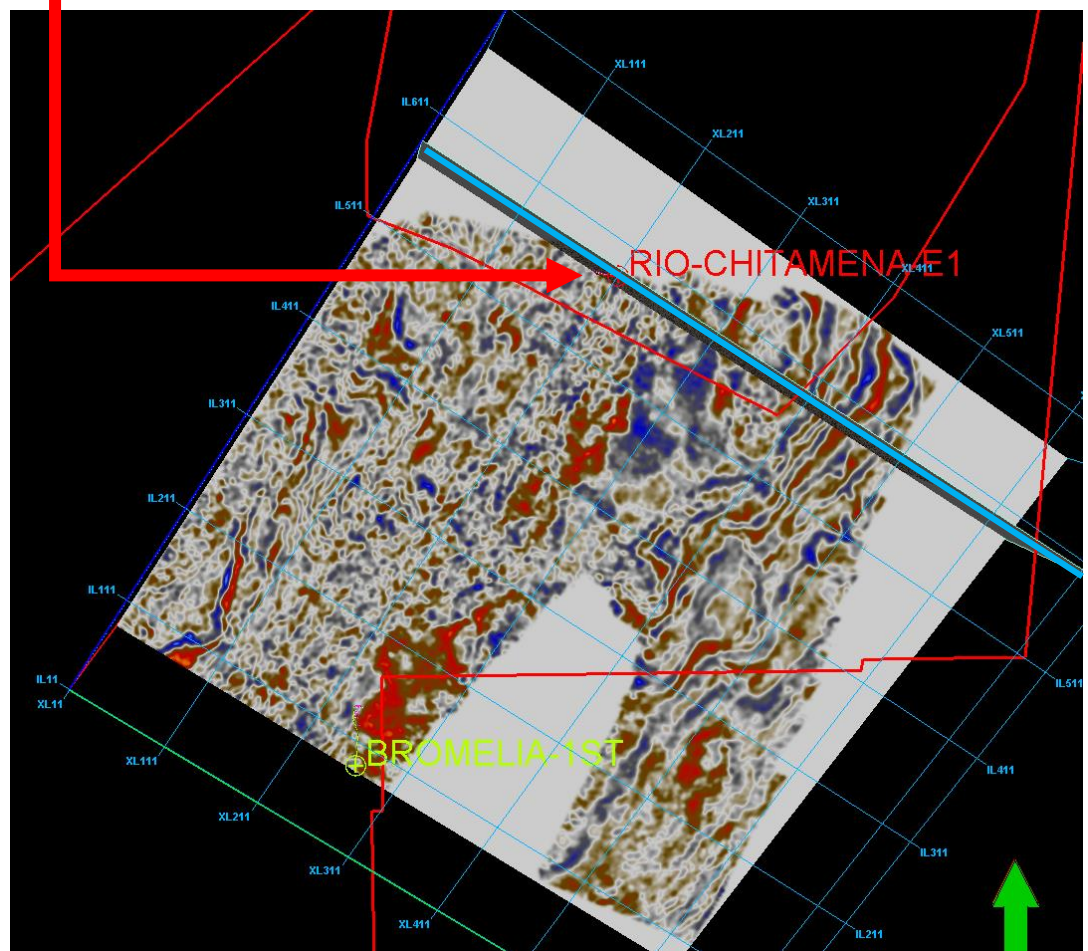
- Overview
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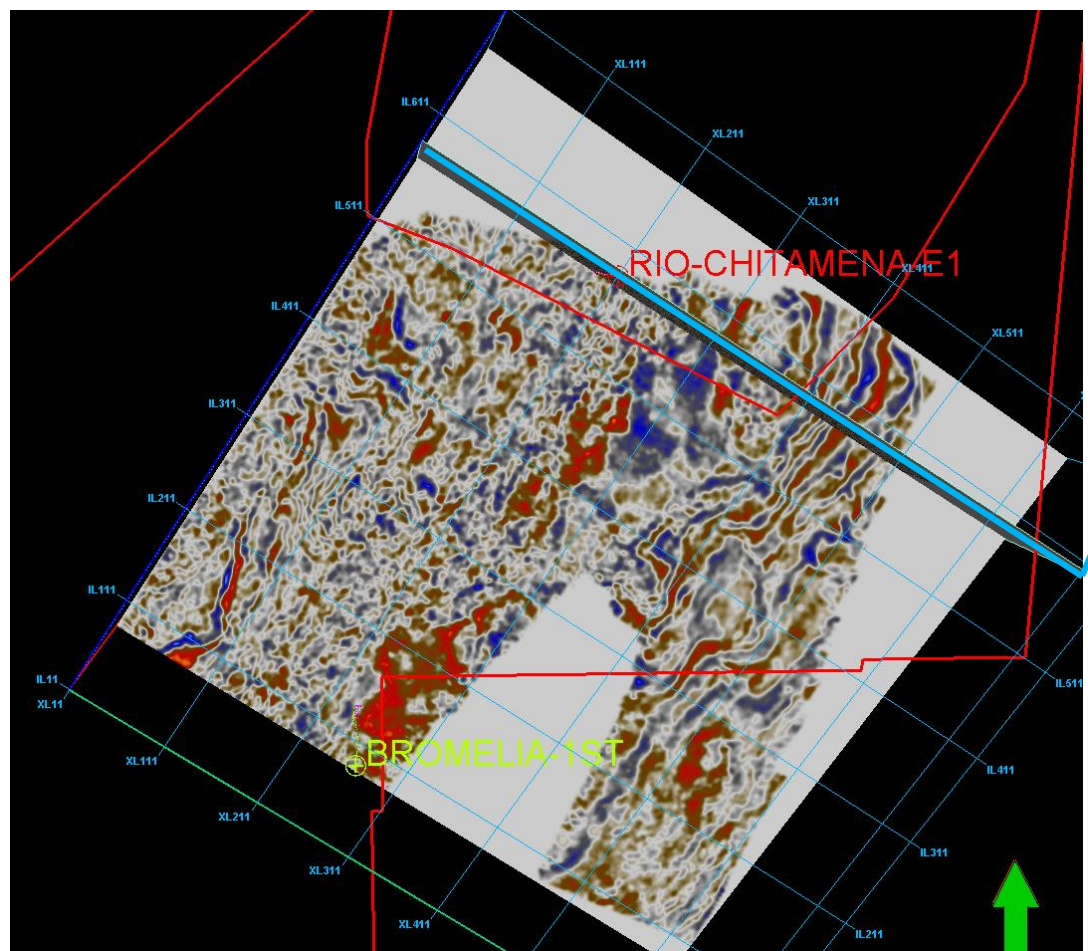
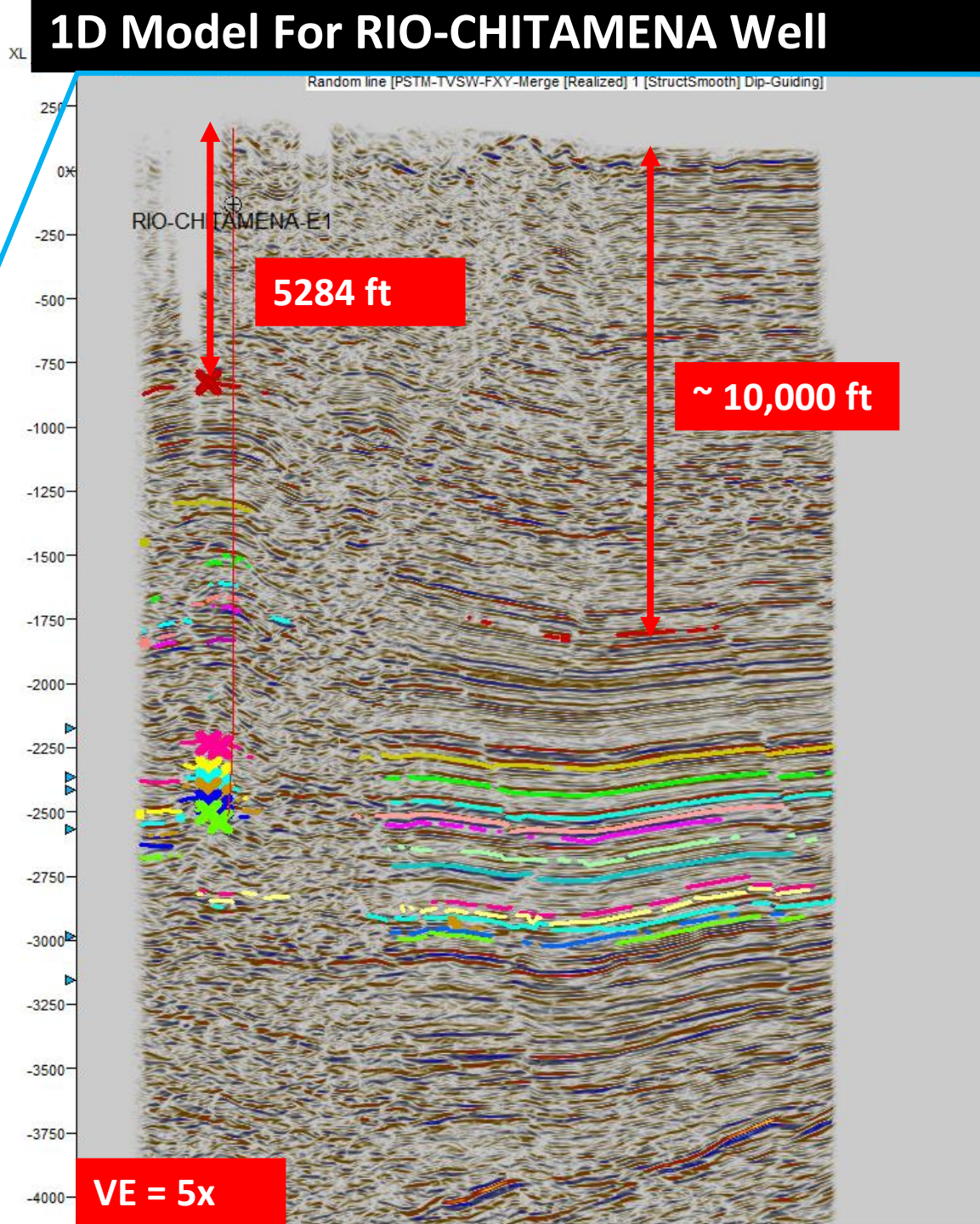
Petroleum System Elements



- Rio-Chitamera well is located in the hanging wall of Cusiana fault.

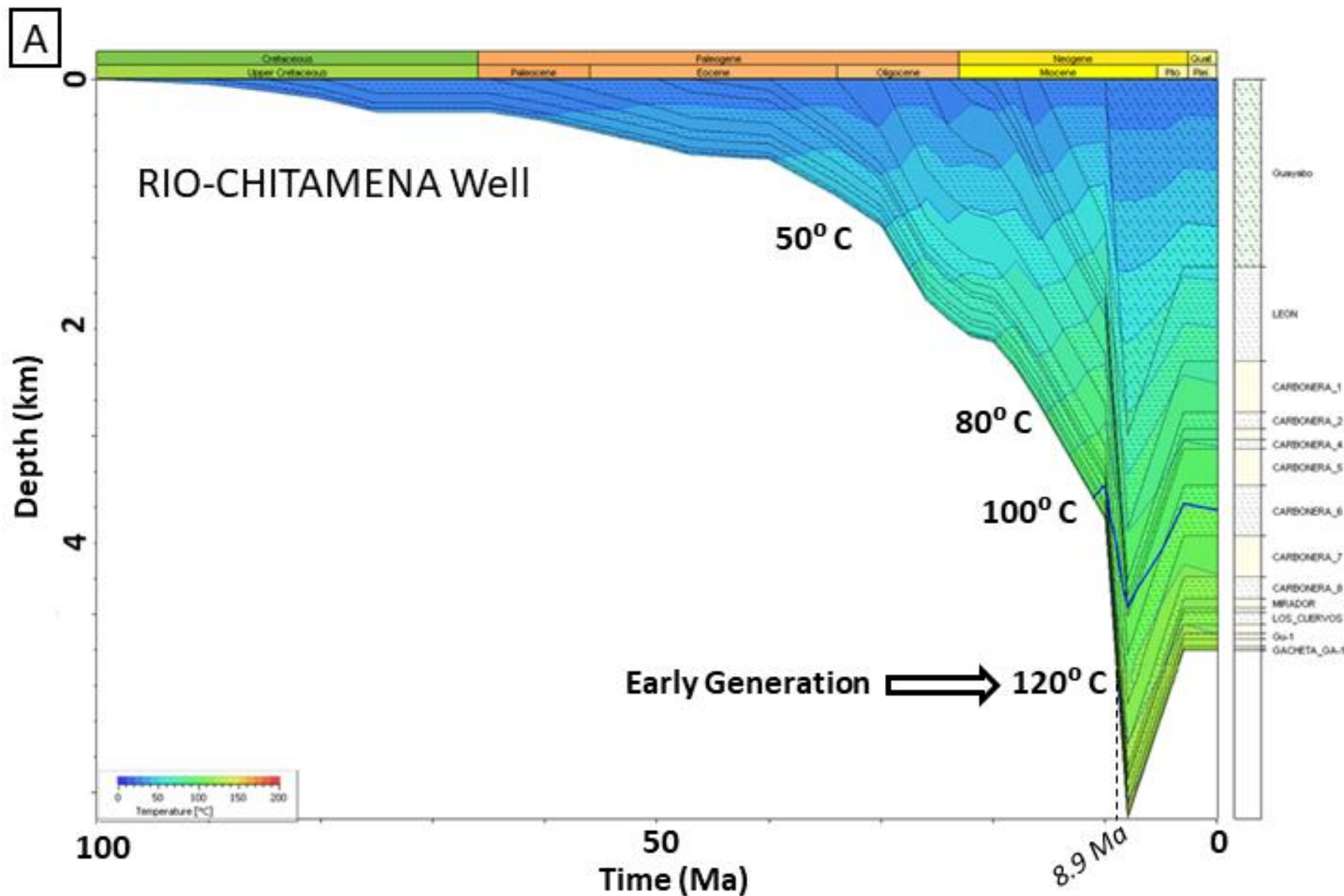


- **Guayabo Fm** thickness in the hanging-wall is **~5284 ft** - almost half was eroded.



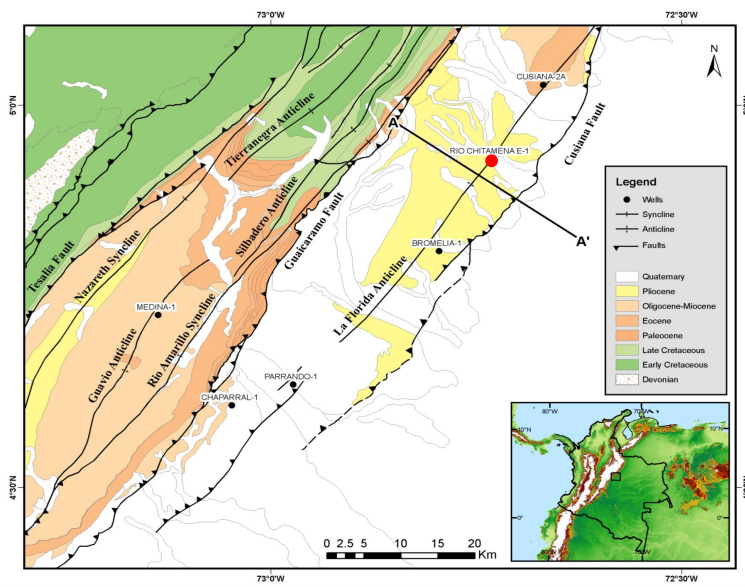
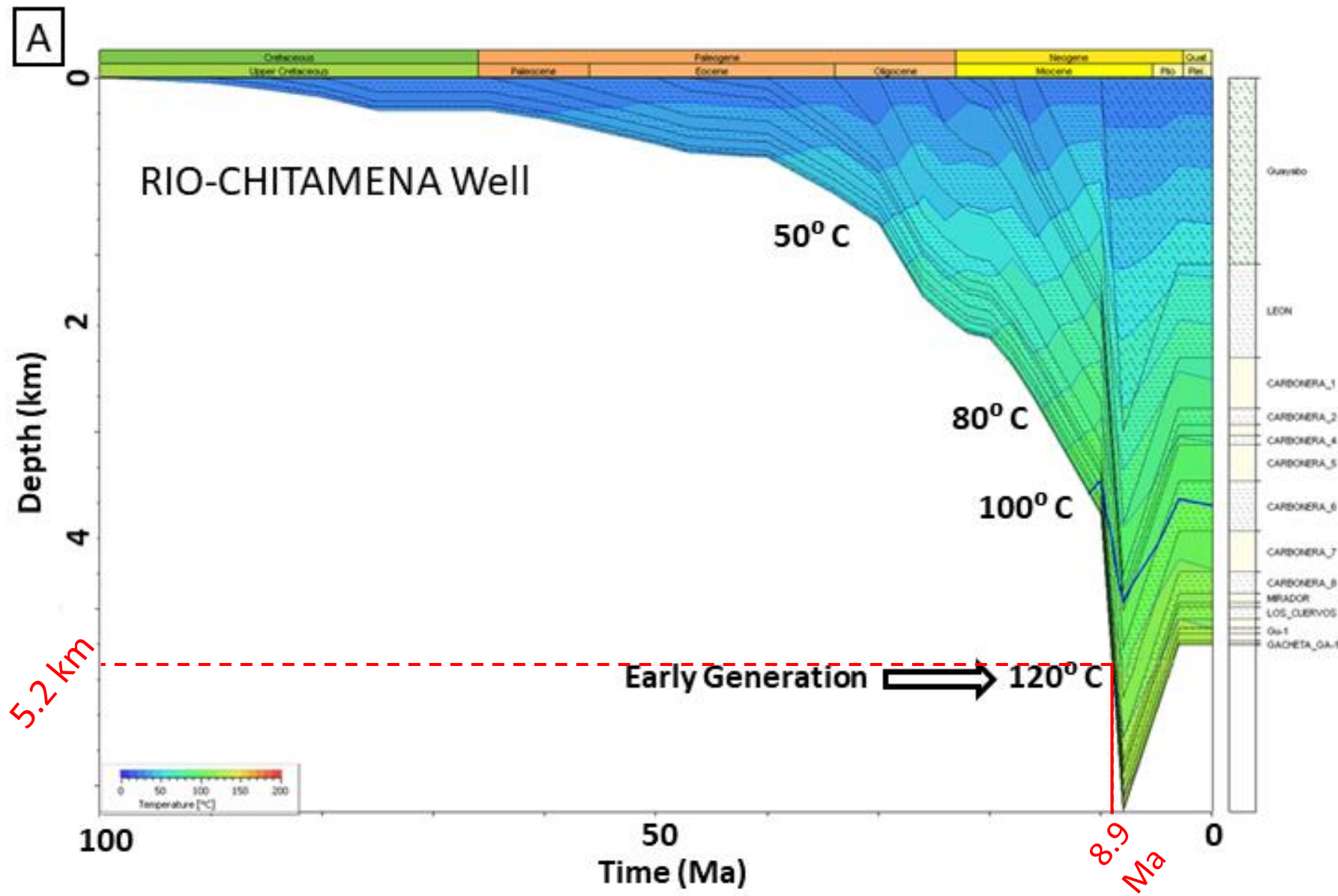
1D Model of Burial History

1. 35 mW/m^2 heat flow was assumed for 1-D burial model.



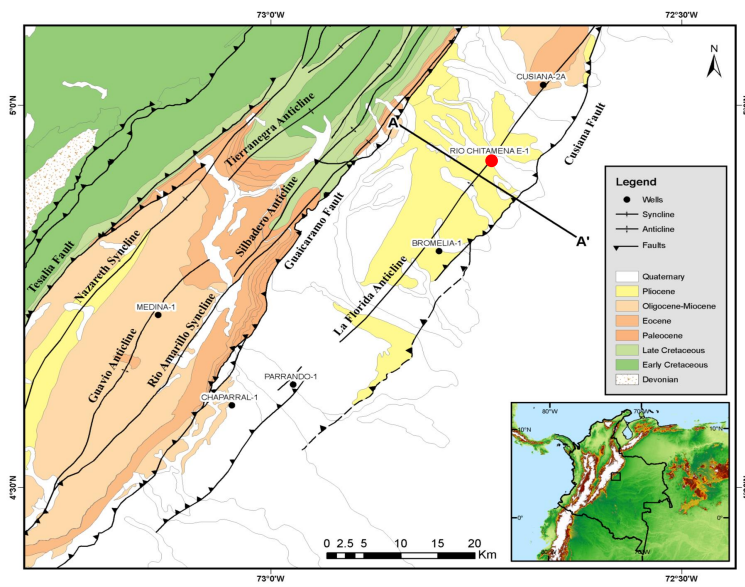
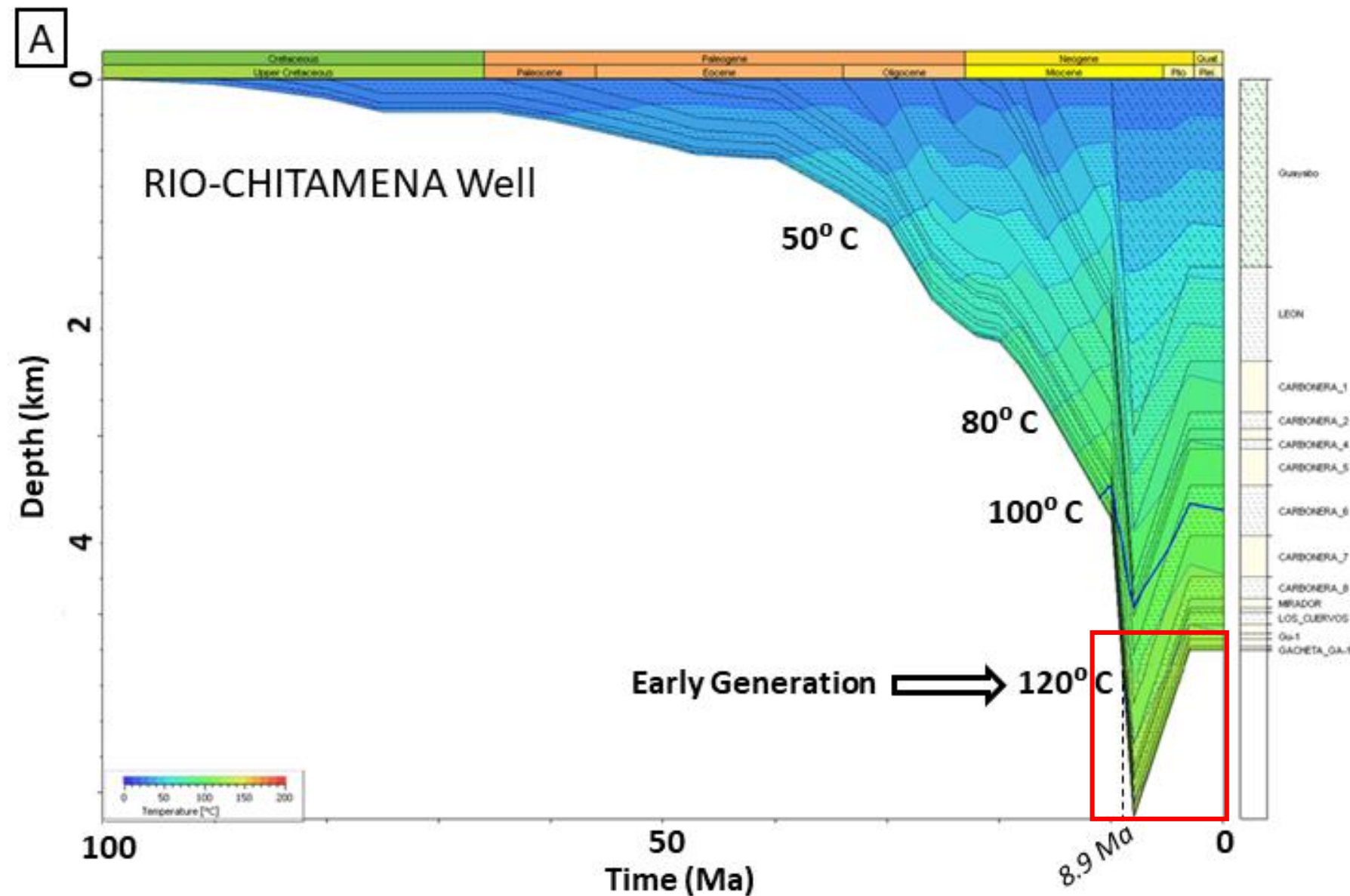
1D Model of Burial History

2. Source rock (SR) entered oil window ~ 8.9 Ma at a burial depth ~ 5.2 km.



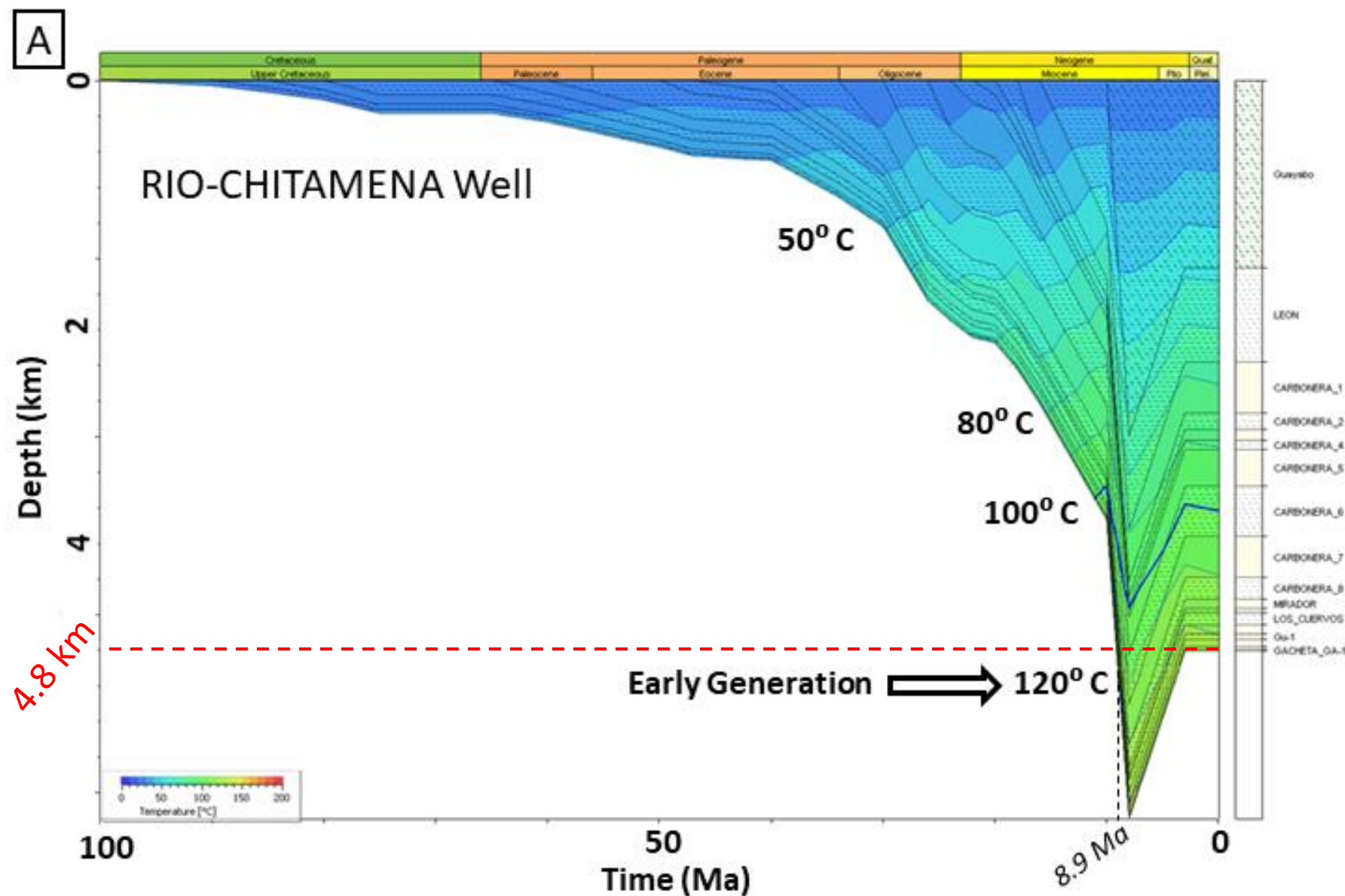
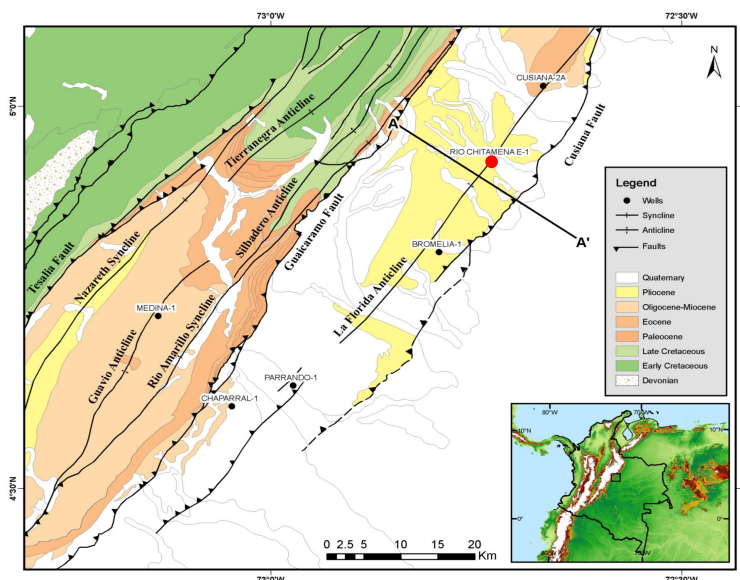
1D Model of Burial History

3. Present-day - source rock (SR) is still in oil window.

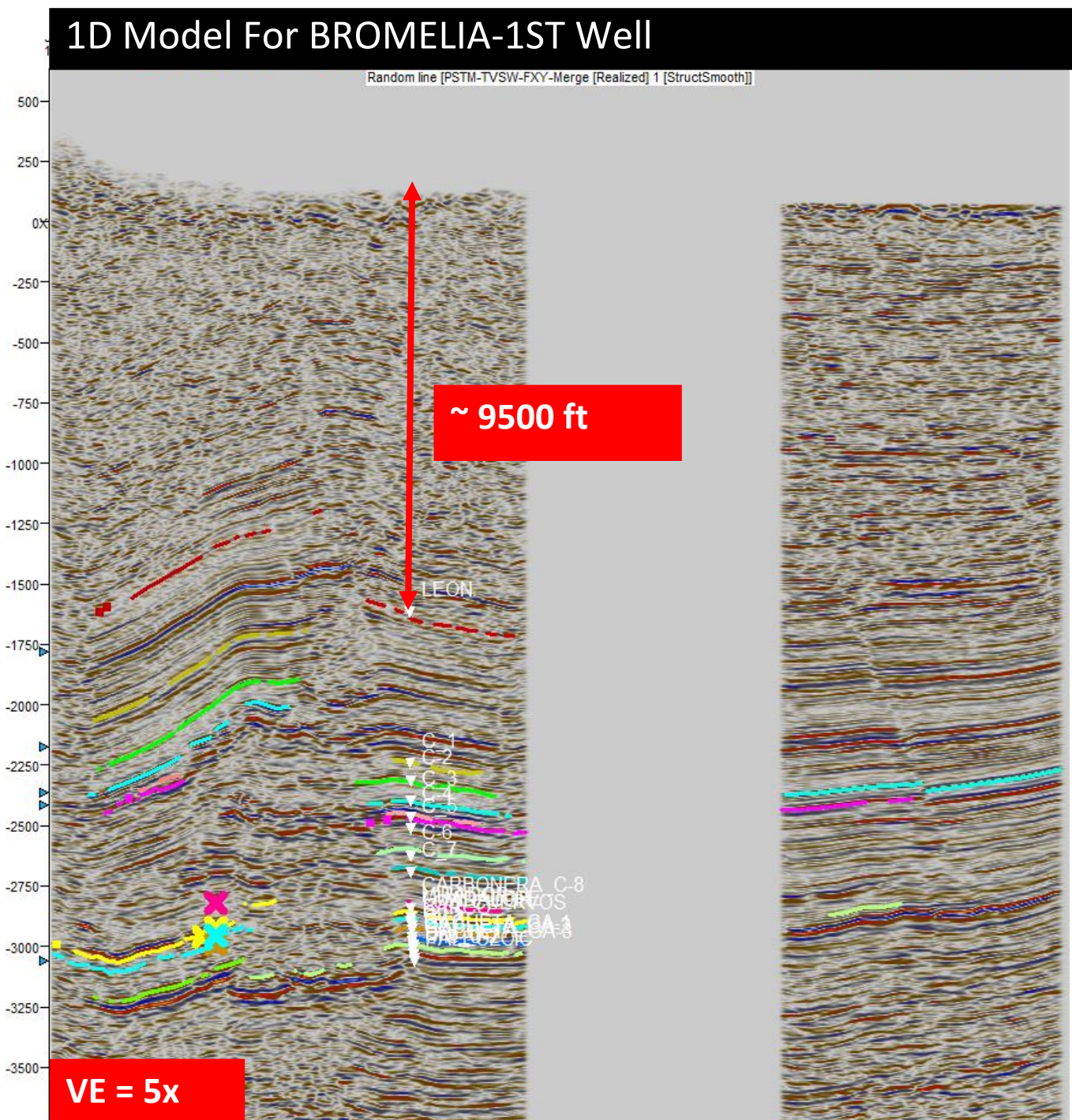
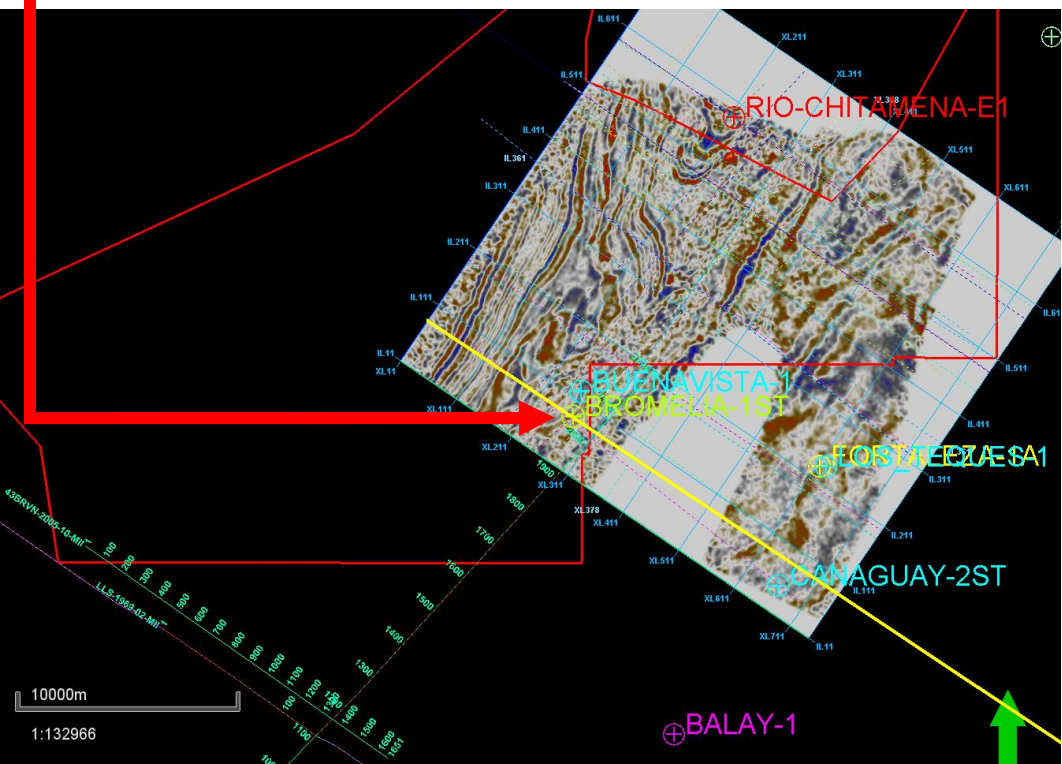


1D Model of Burial History

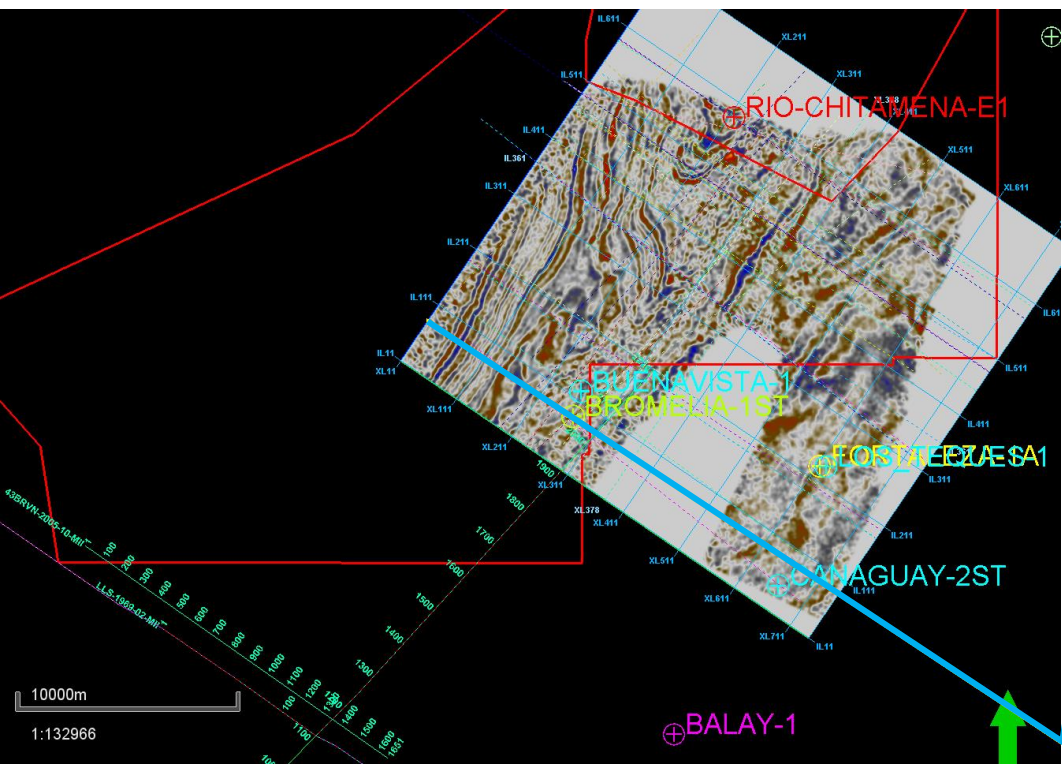
4. Present-day depth of
SR ~ 4.8 km.



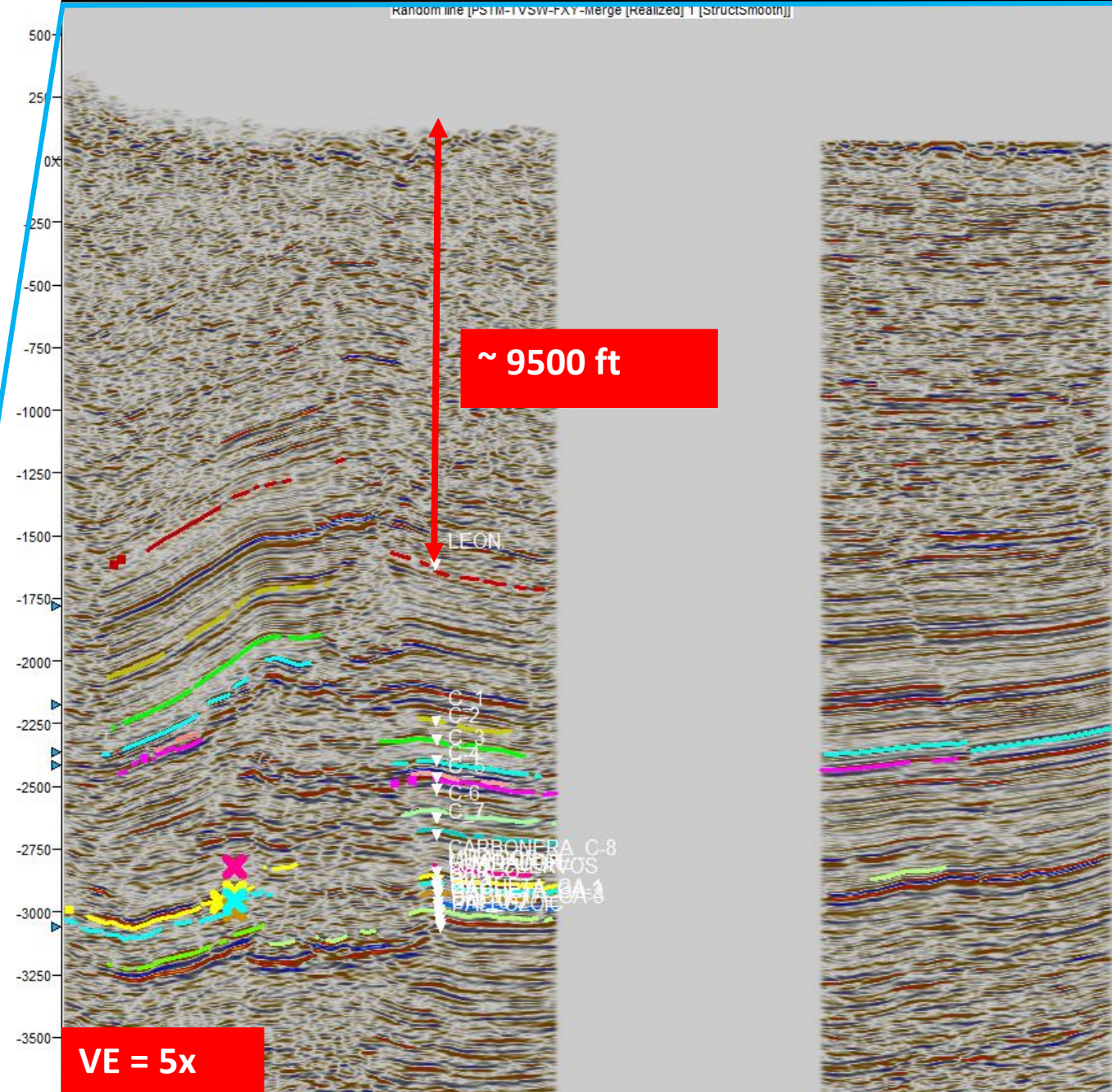
- Bromelia well is located in the **footwall** of the Cusiana fault.



- Bromelia anticline has low structural relief.



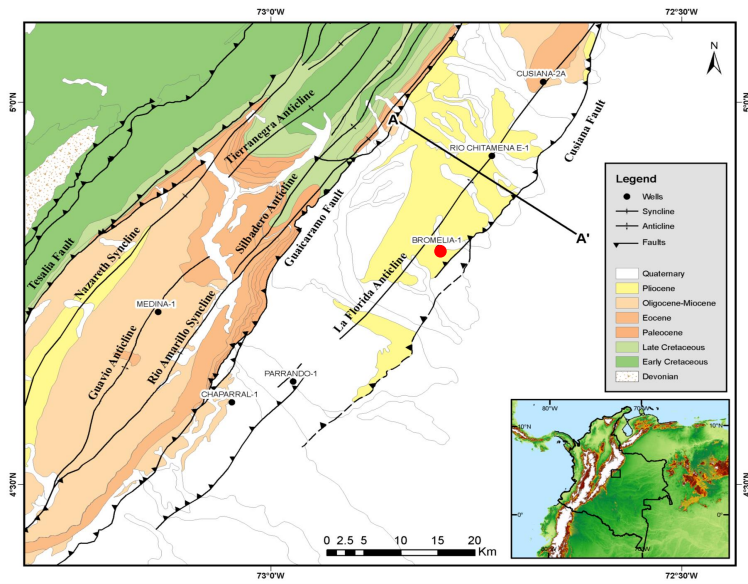
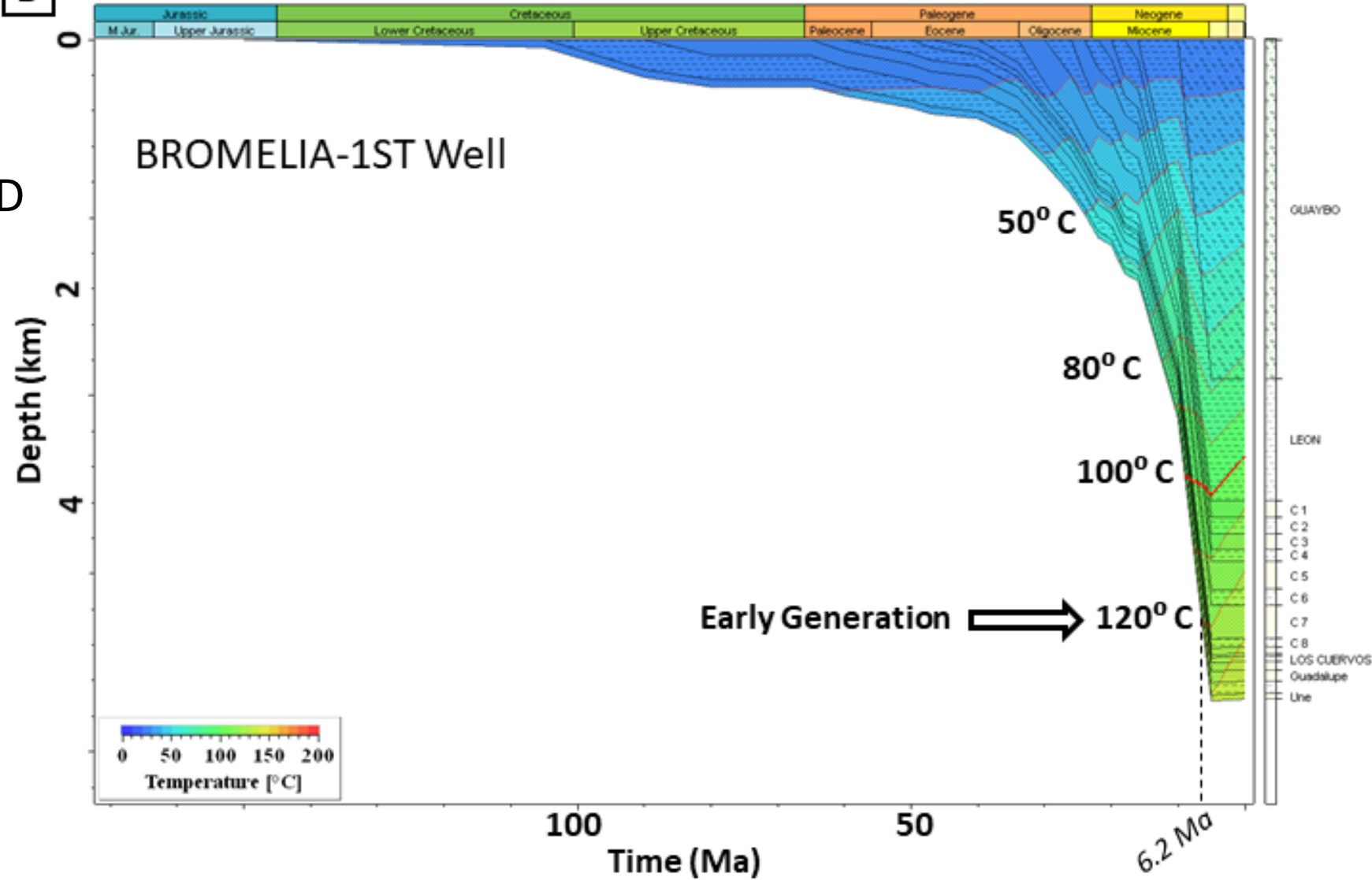
1D Model For BROMELIA-1ST Well



1D Model of Burial History

1. 35 mW/m^2 heat flow was assumed for the Bromelia 1-D burial model.

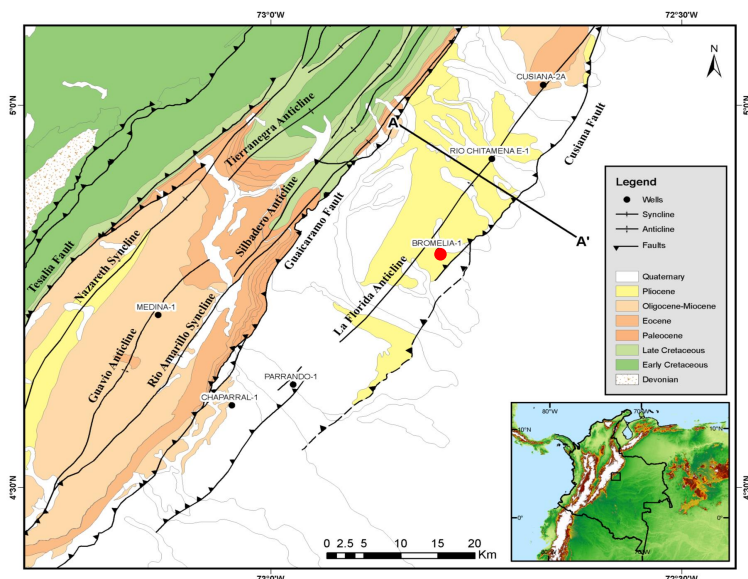
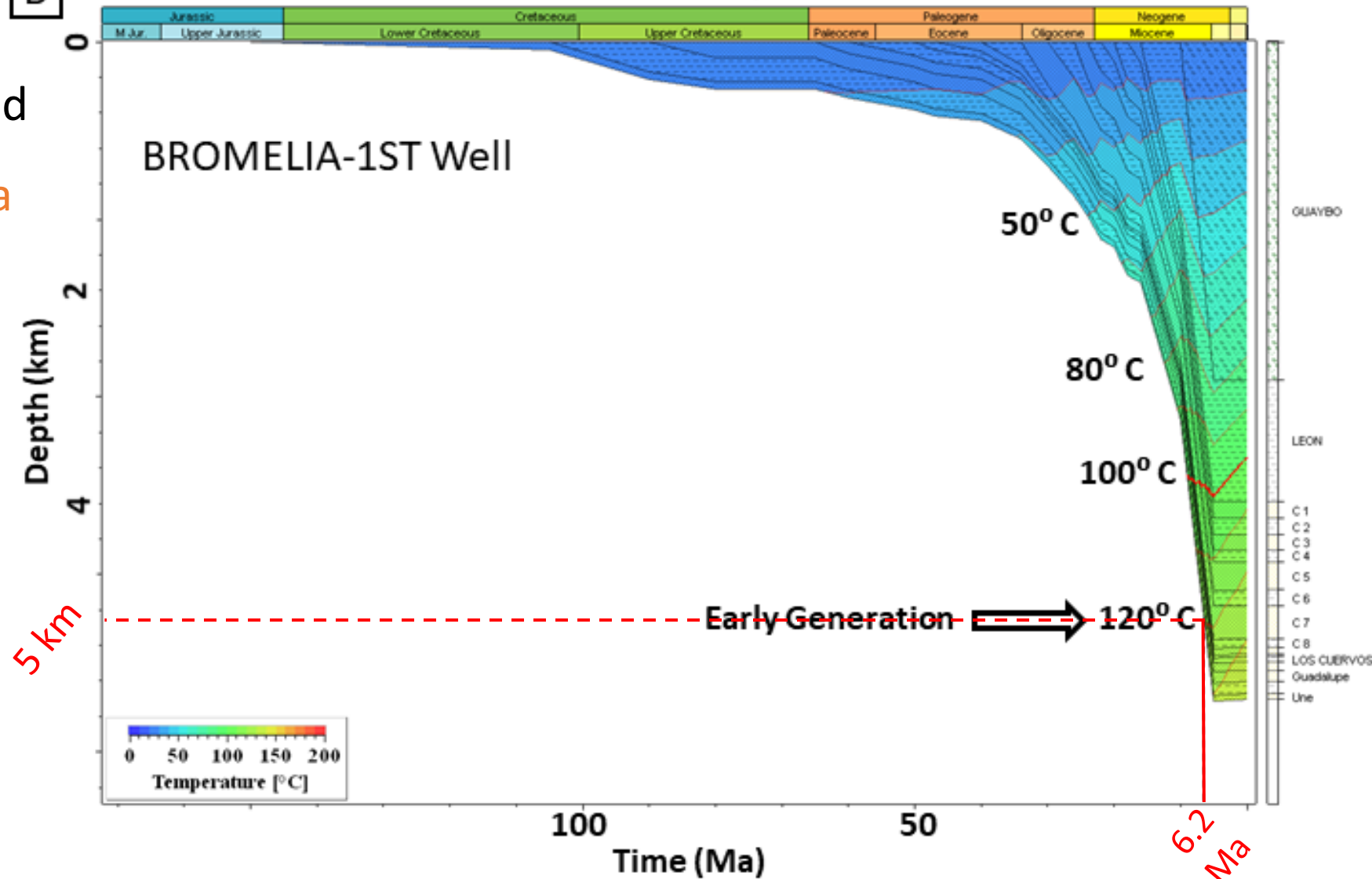
B



1D Model of Burial History

2. **Source Rock (SR)** estimated to enter **oil window** ~ **6.2 Ma** at depth of **5 km**.

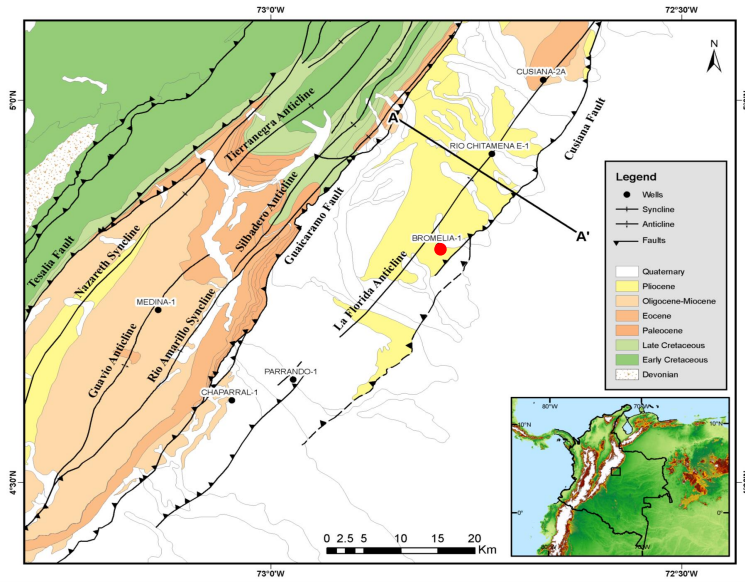
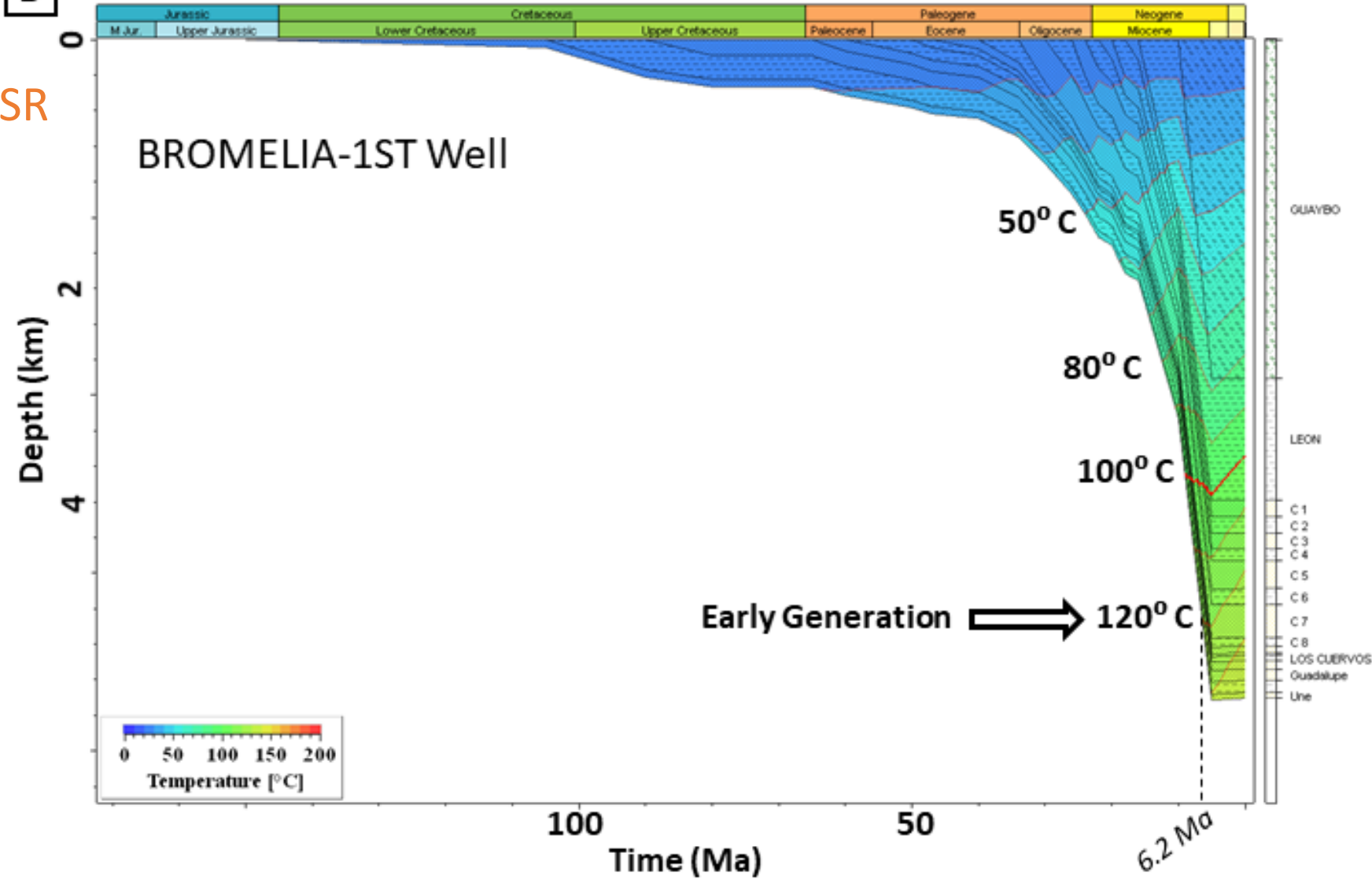
B



1D Model of Burial History

3. Present-day - source rock **SR**
is still in the **oil window**.

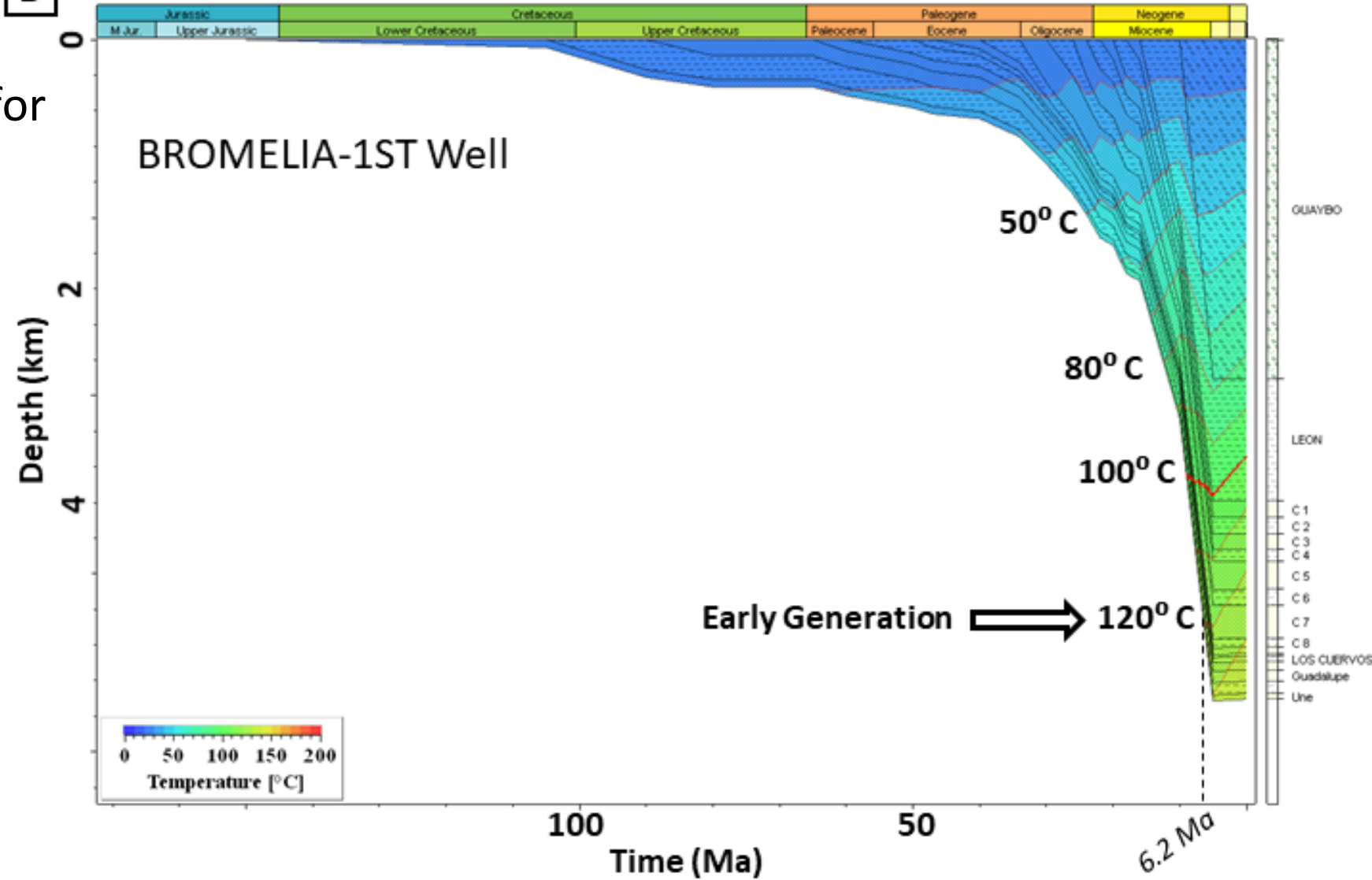
B



1D Model of Burial History

4. **No erosion** was assumed for **Guayabo Fm** over the footwall.

B





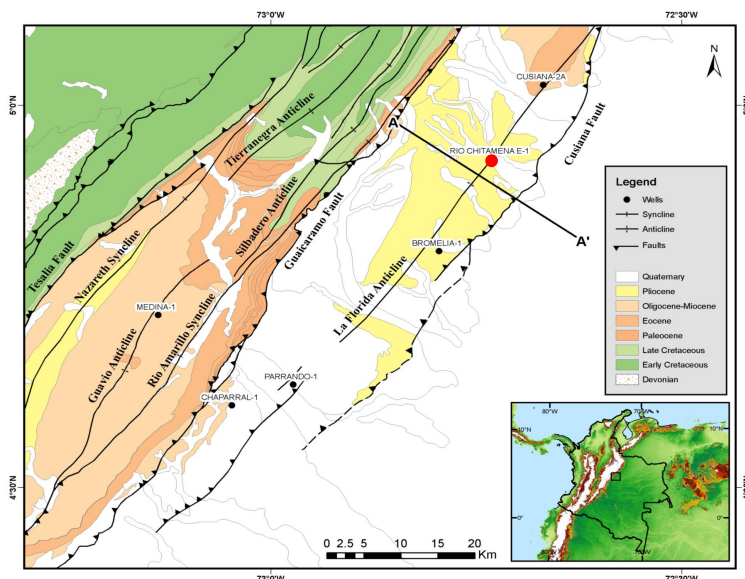
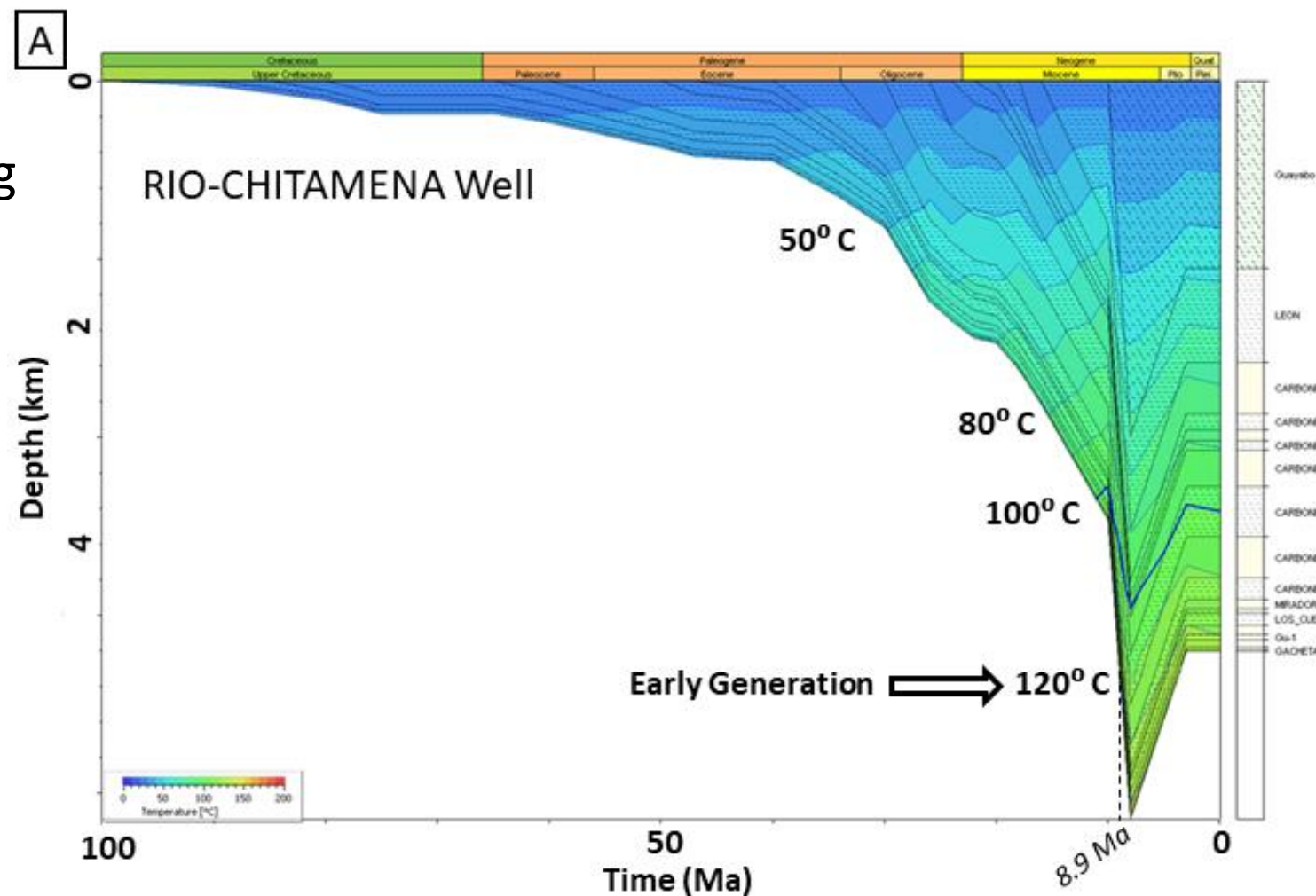
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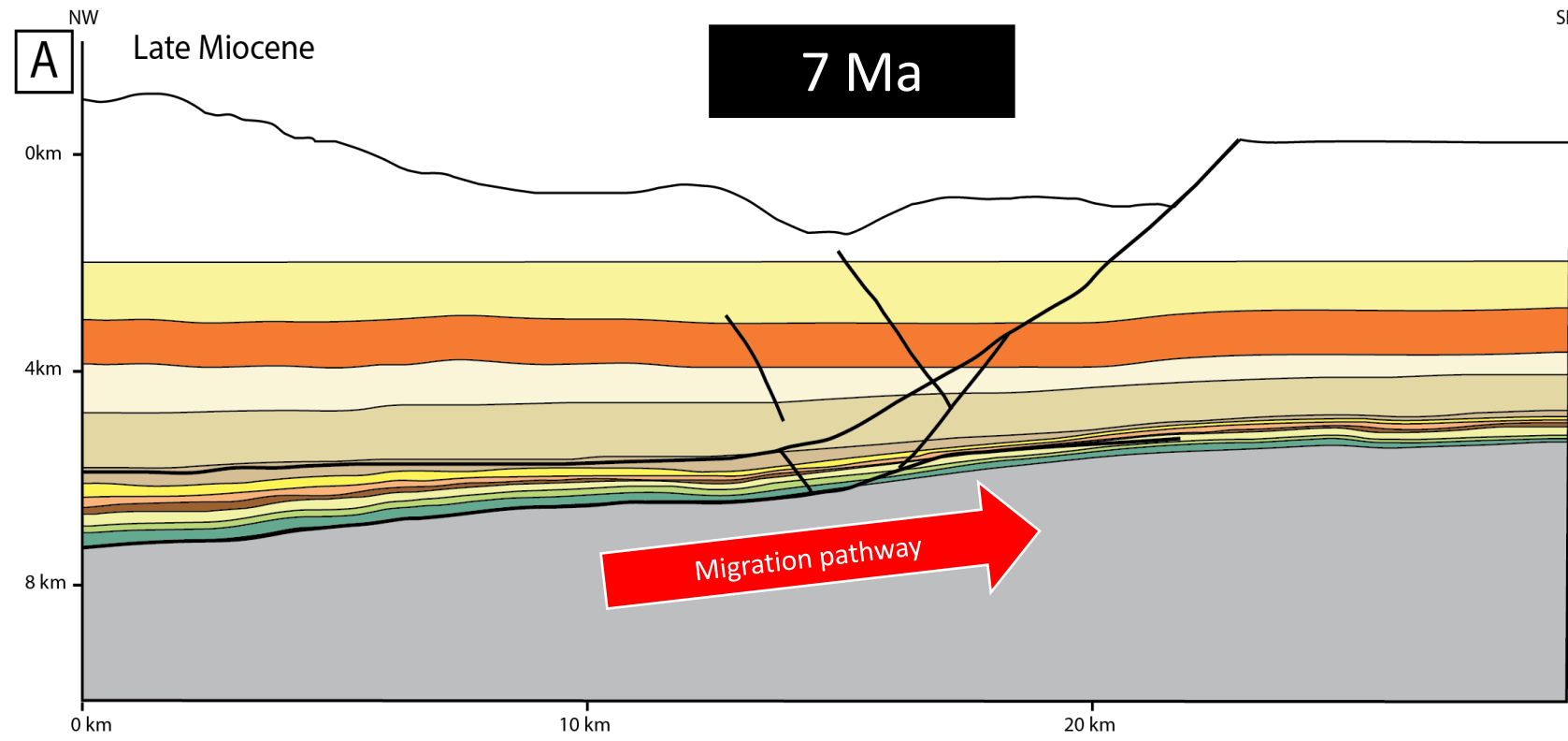
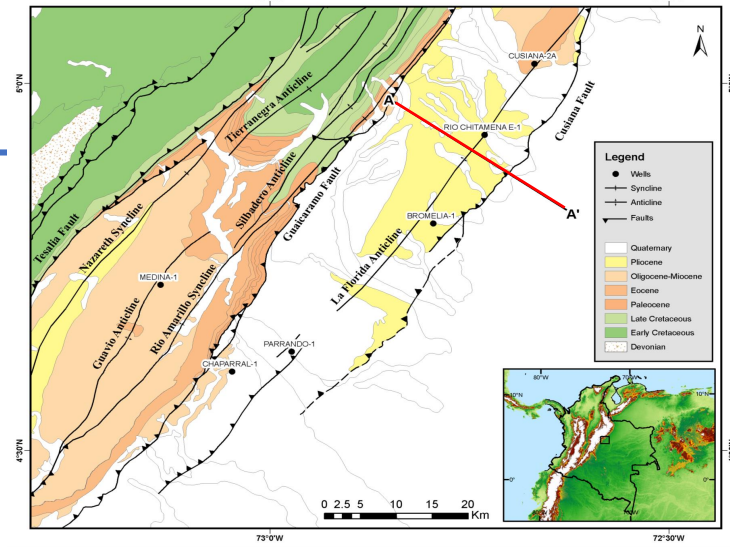
Conclusions

1. Our 1-D model predicts oil expulsion began ~9 Ma in the hanging wall rocks of the Cusiana thrust, similar to the Cusiana oilfield to the northeast at 8 Ma (Cazier et al 1995).

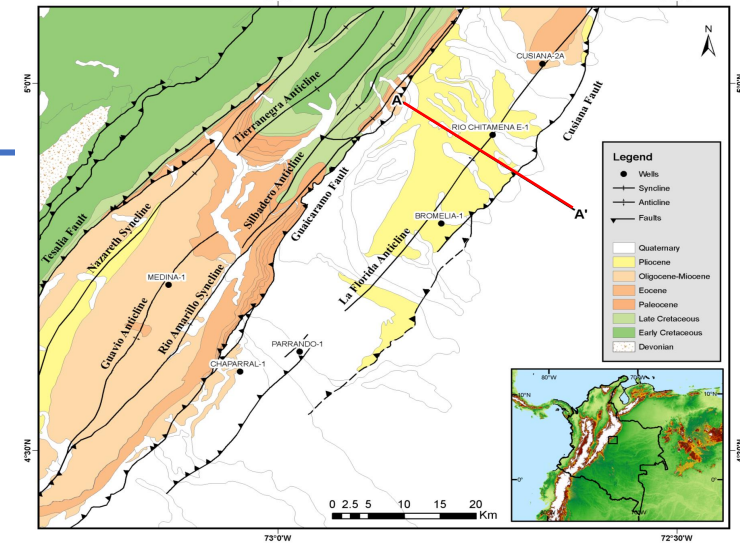
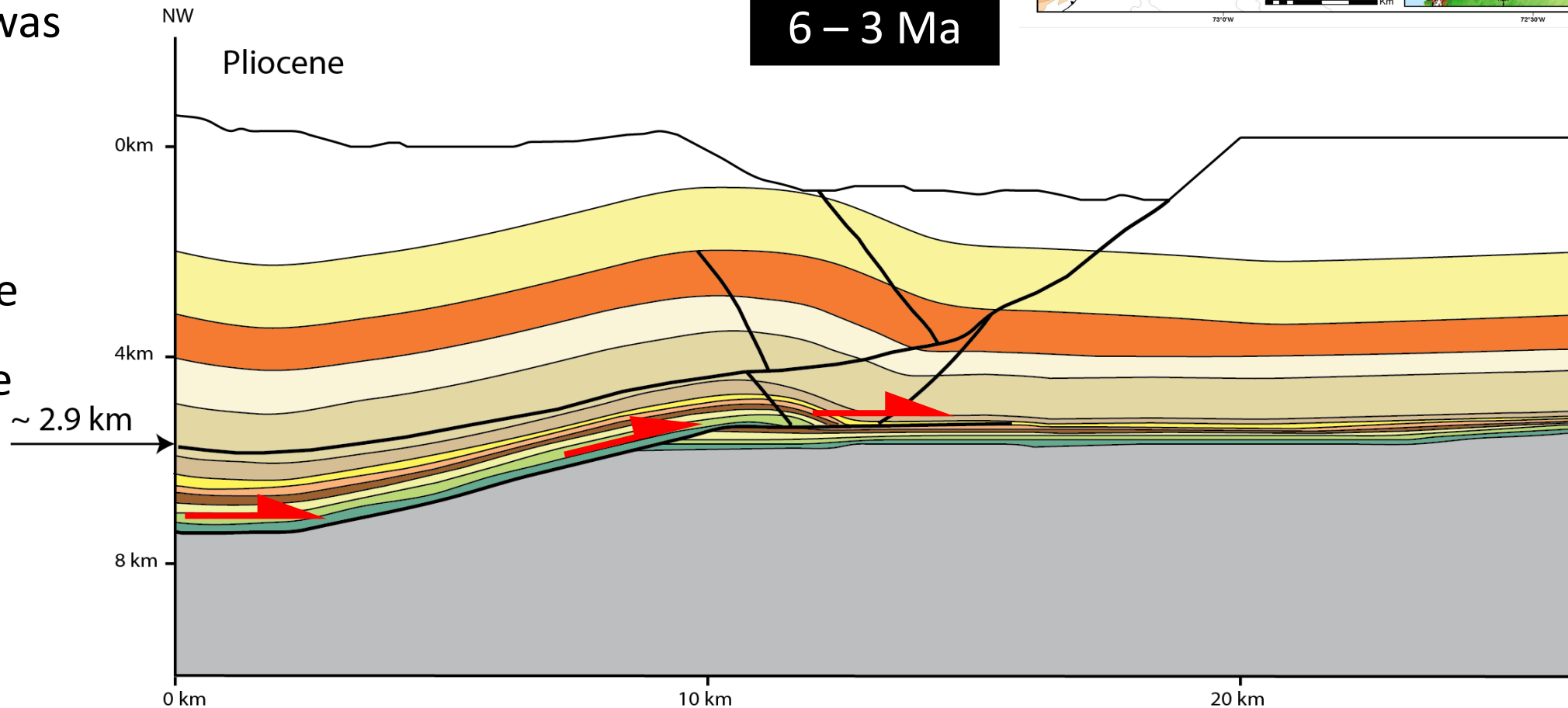


Conclusions

2. We predict that only 2-3 Ma of hydrocarbons may have escaped toward the foreland Llanos basin before the Florida trap formed.

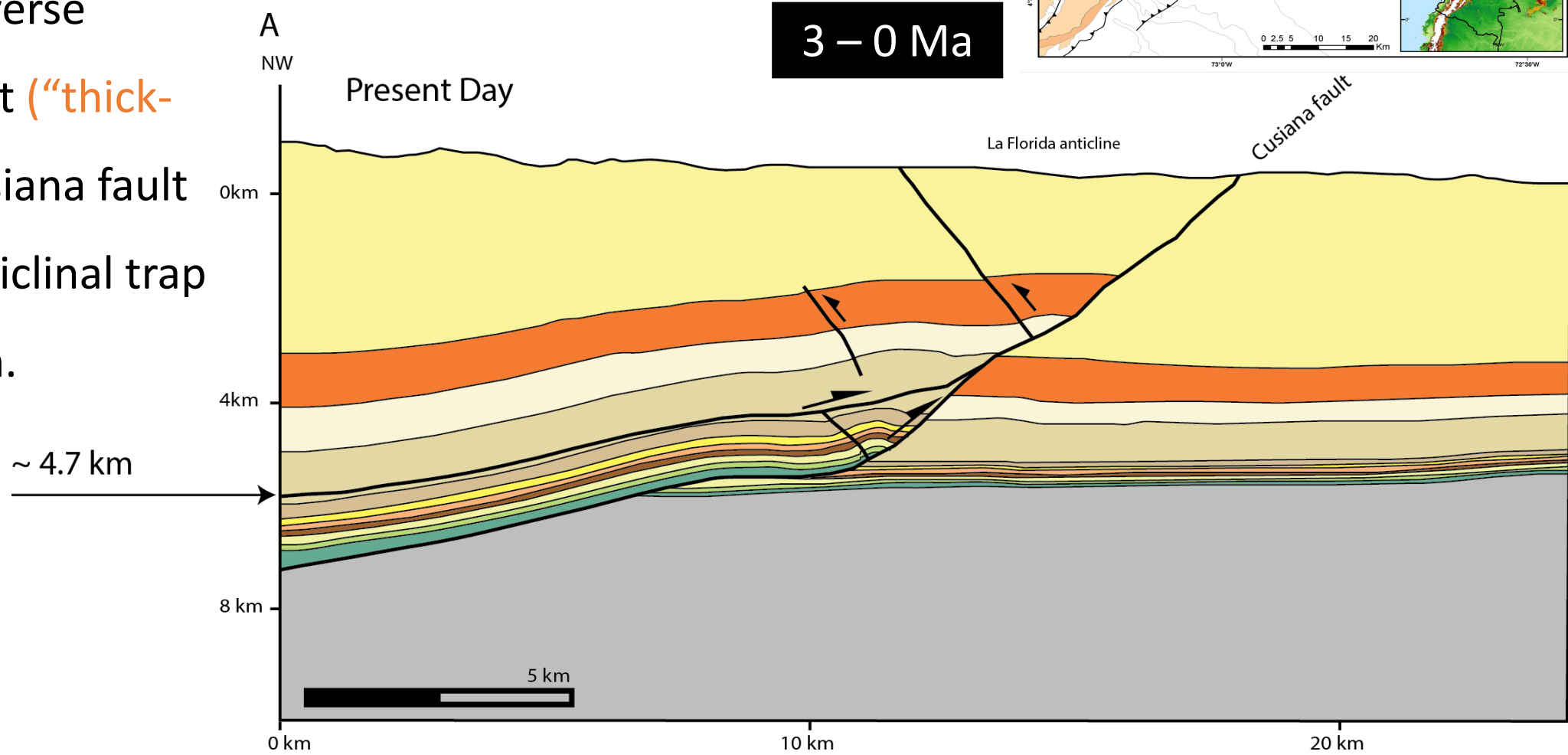


6 – 3 Ma



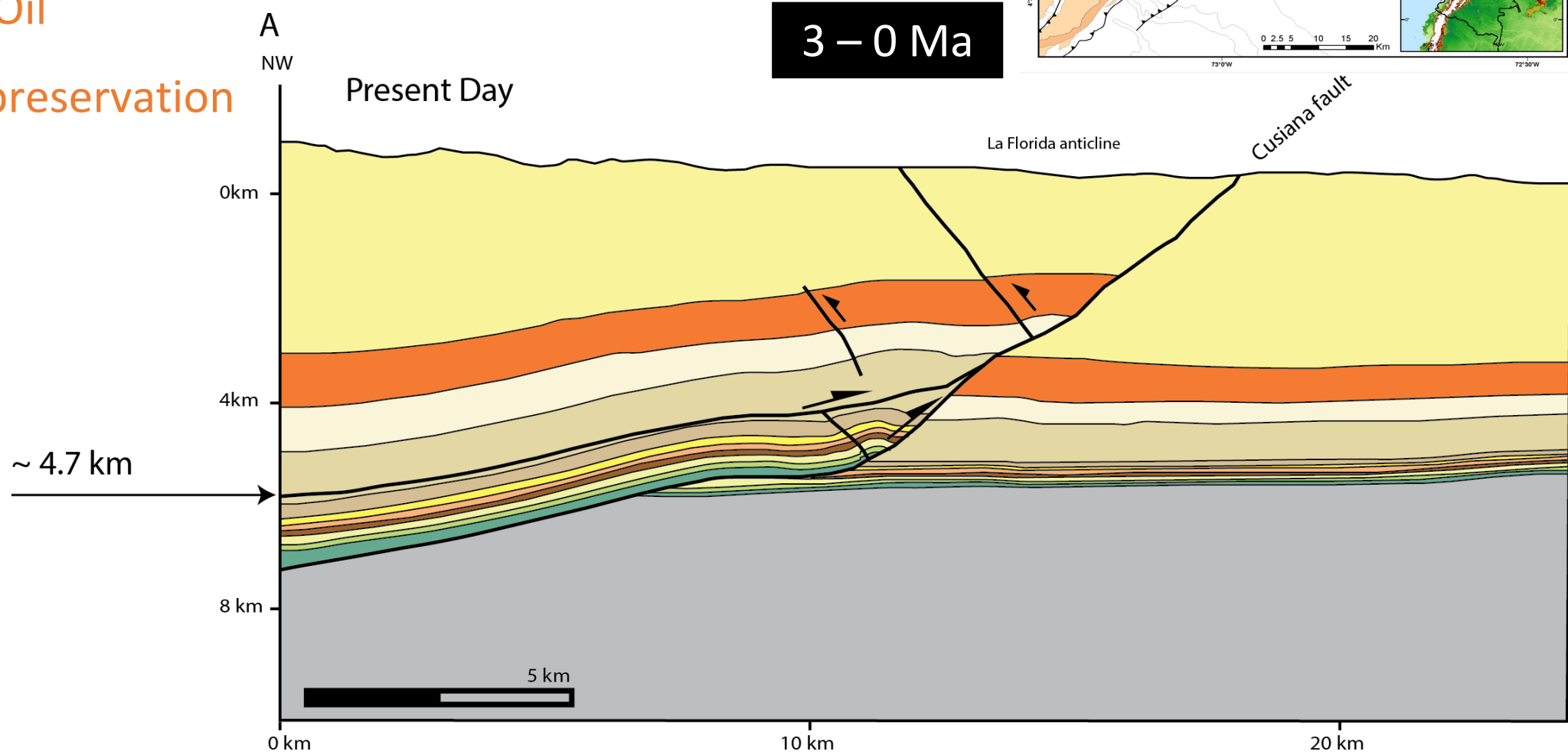
Conclusions

4. Subsequent reverse
inverse movement (“thick-
skinned”?) on Cusiana fault
preserved the anticlinal trap
in the Mirador Fm.

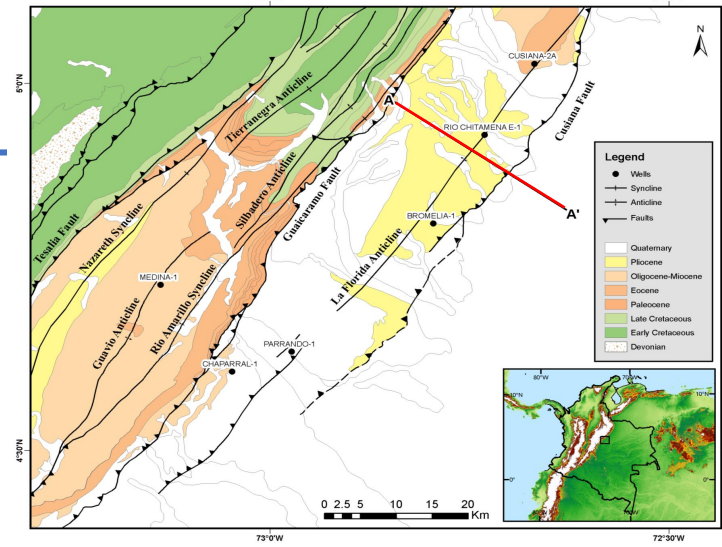


Conclusions

5. Present-day - Oil generation and preservation are continuing.

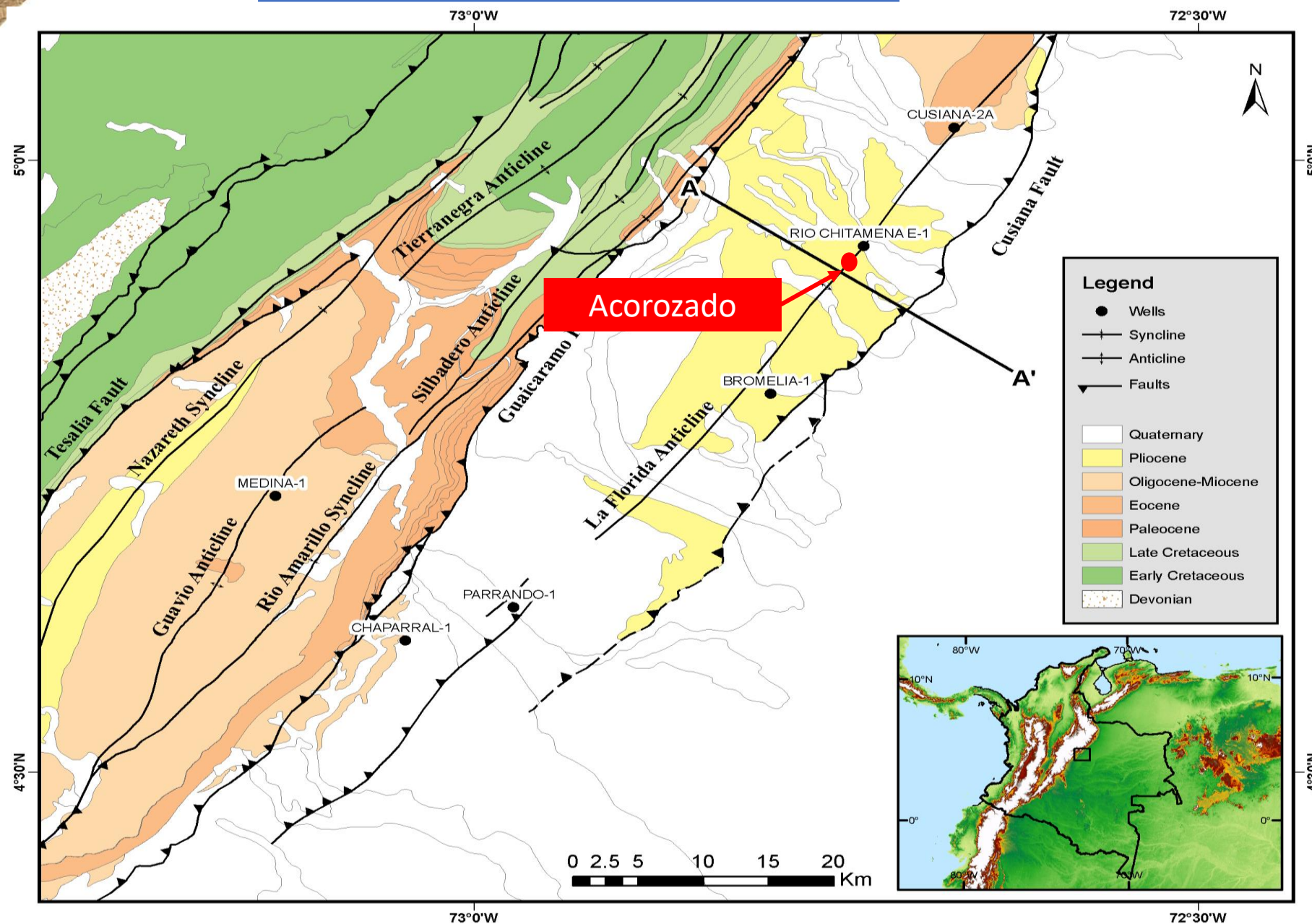


Risk factor - up-plunge
closure toward Rio
Chitamena. ~ 4.7 k



Announcement

Acorazado well - 1.3 km
northeast of our model,
Frontera announced
hydrocarbon shows.
Acorazado is being tested
for economic recovery.



Cusiana Field



Thank you

