Cenozoic Paleogeographic Reconstruction of the Foreland System in Colombia and Implications on the Petroleum Systems of the Llanos Basin*

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Abstract

This study shows the implications of the evolution of uplifted areas, sediment sources and depocenters of the eastern Colombian foreland basin system on the timing of hydrocarbon migration. This work is based on the integration of data from several works developed during the Ecopetrol Project "Cronologia de la deformación en las Cuencas Subandinas" which included new data and field mapping of facies and thickness distribution, balanced geological cross sections, paleocurrent measurements, conglomerate and sandstone petrography, biostratigraphy, vitrinite reflectance data as well as the novel dating techniques of Zircon-UPb geochronology and bed rock thermochronology. Data indicating timing of deformation and uplift gathered in previous studies were taken into account in this study.

The main results of this work conclude that the Cenozoic evolution of the foreland system includes three stages: (1) A compressive phase that uplifted the Central Cordillera and affected the Magdalena Valley and the northern portions of the Eastern Cordillera south of the Santander Massif. This phase begins in the Late Cretaceous with a maximum intensity in the Late Paleocene and Early Eocene, (2) a phase of tectonic quiescence of slow deformation rate in the Middle Eocene, and (3) a renewed compressive deformation beginning in the Late Eocene lasting until the Oligocene and Miocene.

The paleogeographic reconstruction also shows the variations and locations of the sediment provenance domains based on the UPb signal from the Central Cordillera (UPb ages younger than 150 Ma), the evolution and facies distribution along the Magdalena and Llanos basins and the extension, timing of uplift and exhumation of the source areas of sediment. This work allows estimating the precise timing of exhumation of the Eastern Cordillera which is fundamental to assessing the timing of cessation of oil generation and migration from the kitchens previously located on this range. Also, the paleogeographic evolution is important to estimating the extension of the kitchen areas at different times and defining the extension and configuration of the reservoirs and seals of the Llanos and Magdalena basins. From our assessments it appears that the Oligocene is the most important time for the generation of heavy oils now present in the Llanos Basin.

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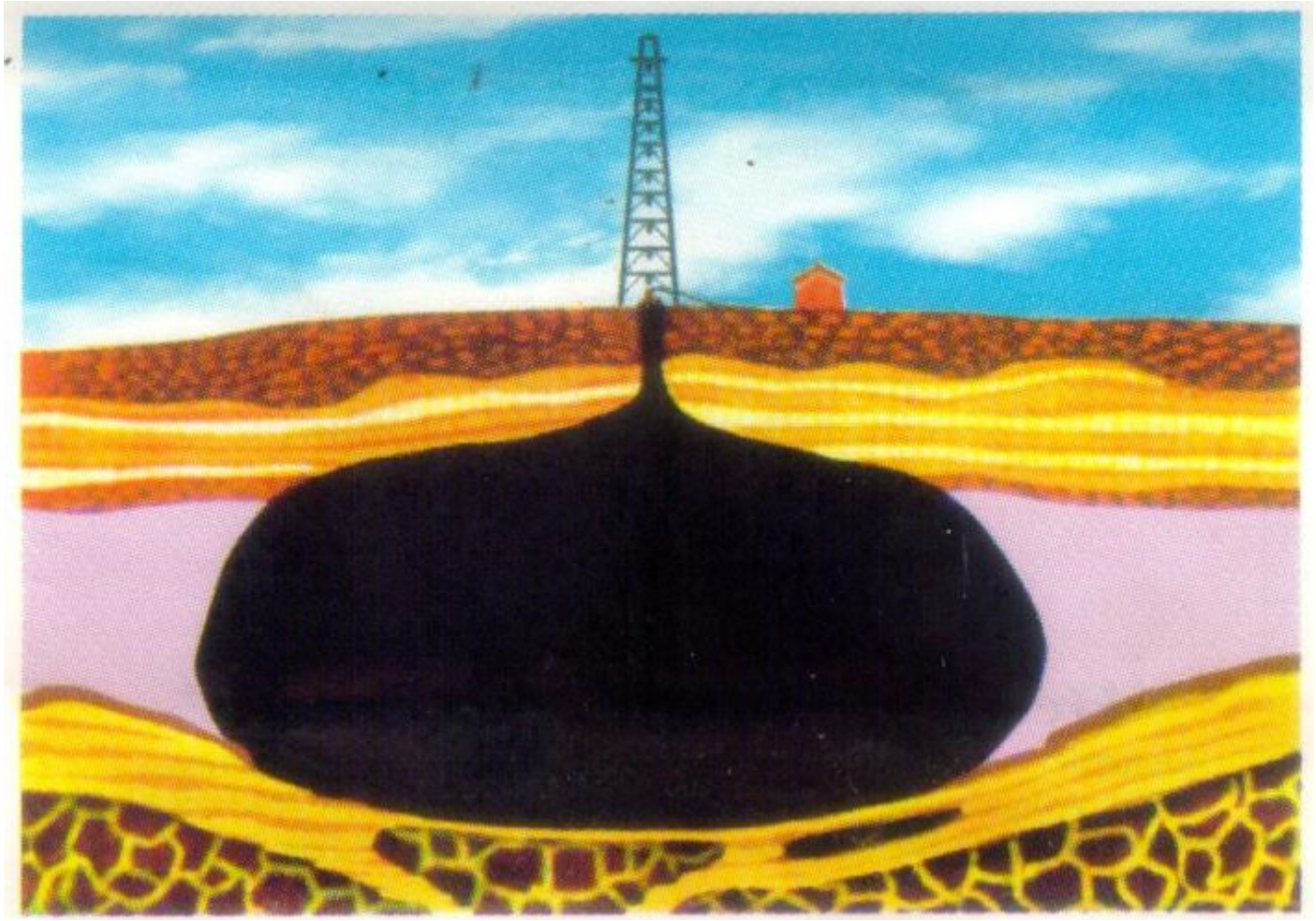
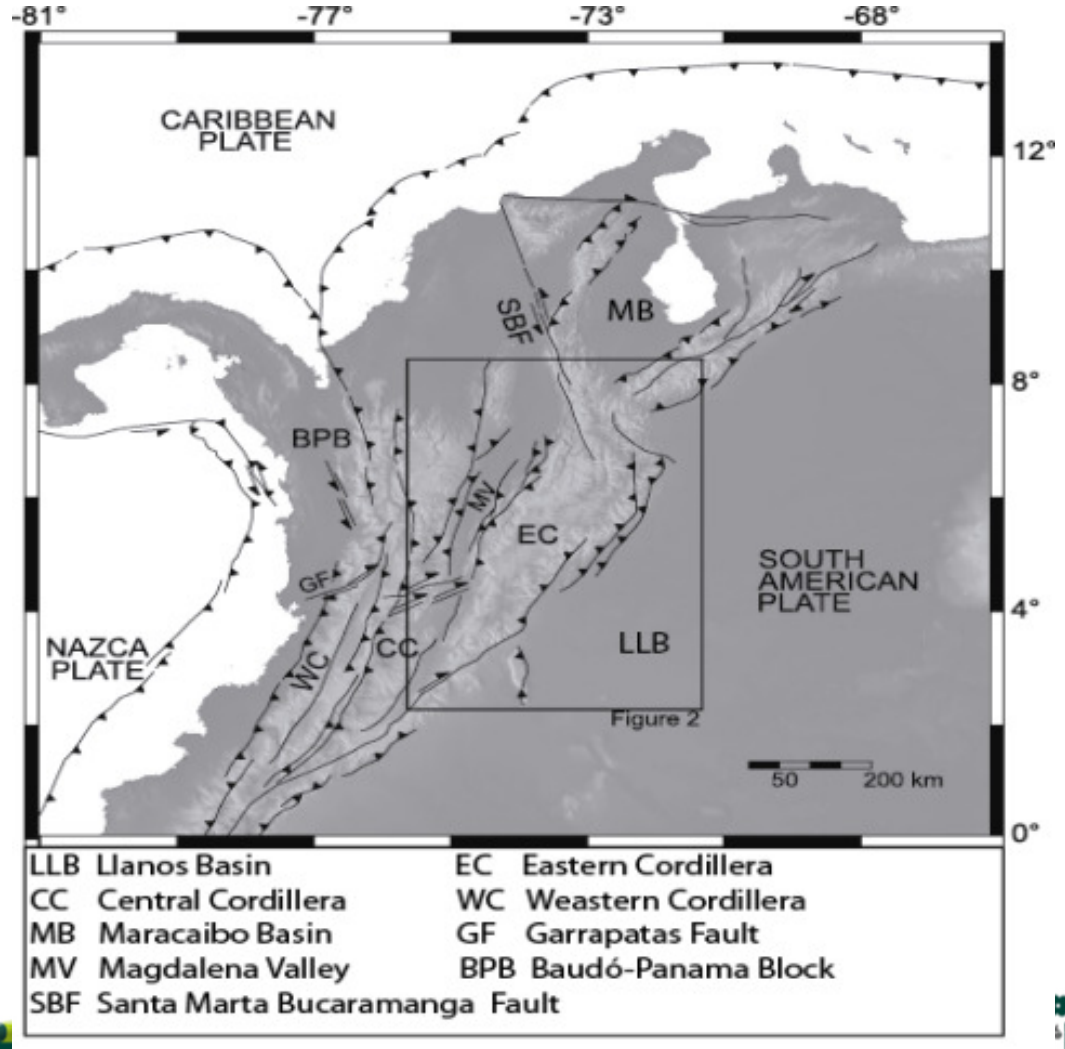


"Jet" Petroleum System, by

Outline

Study Area location
Previous work
Cenozoic evolution
Conclusions

Study Area Location



Includes…

- Central Cordillera
- Middle Magdalena Valley
- Eastern Cordillera
- Llanos Basin

New pieces of information form outcrops and core data from…

- Basement
- Sedimentary sequence

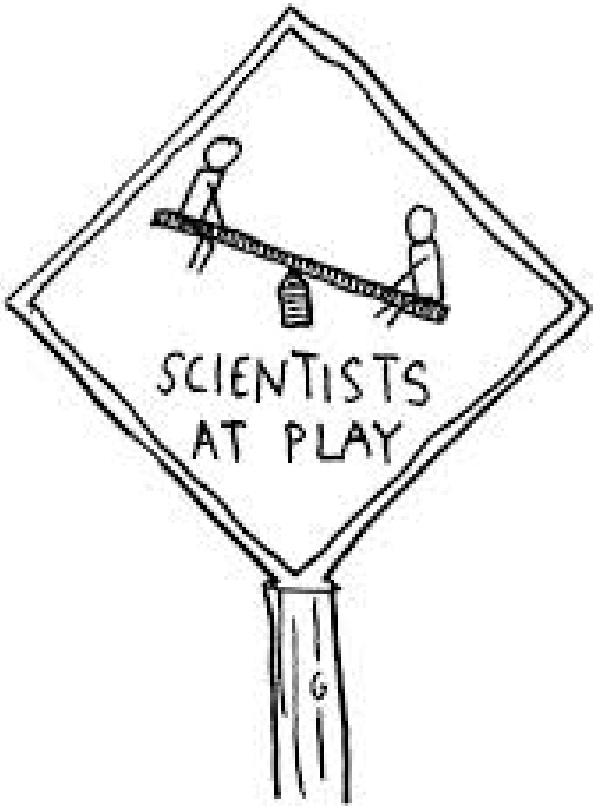
PREVIOUS WORK IN THE AREA BY ECOPETROL

▪ Subcuenca Apiay – Ariari (GEX)	1990
▪ Proyecto Nell	1993-1994
▪ Beicip – Franlab & ECP	1995
▪ Sistemas Petrolíferos Llanos Orientales	1997
▪ Evaluación Regional del Meta	1998
▪ Flujo Regional de Fluidos	2003-2006
▪ Modelo estratigráfico Llanos Piedemonte	2000
▪ Crudos Pesados a Nivel Nacional	2001-2002
▪ Evolución Estructural – Sarmiento	2001
▪ Estratigrafía del Bloque Caño Sur	2005
▪ Evaluacion Oportunidades Exploratorias Bloque Caño Sur	2006

▪ Evaluación Post Perforación Pozos	2006
▪ ANH Crudos Pesados	2006
▪ Altos estructurales y fallas asociadas a componentes de rumbo	2009
▪ Soporte Geológico a Caño Sur	2007
▪ Cronología de la Deformación en Cuencas Subandinas	2008-2011.
▪ Reconstrucción Geométrica Cuenca Llanos – ECP	2010.
▪ Modelo Estratigráfico Llanos Sur Preliminar – ECP	2010.
▪ Geometría de la Cuenca Llanos Sur – ECP	2011.
▪ Modelamiento Geológico de Áreas Complejas – Piedemonte y Llanos – ICP	2003-11

OTHER RELEVANT SCIENTIFIC WORK

Morales, L	1958
Fabre, A	1983
McCourt et al	1984
Etayo, F	1985
Forero, A	1990
Colleta, et al	1990
Dengo, Covey	1993
Villamil, T	1999
Cooper et al	1995
Touissaint, J.F.	1999
Restrepo, P	2004
Gomez, E	2001, 03, 05
Parra, et al	2009, 11, 12
Bayona et al	2003-1012
Horton, et al	2010

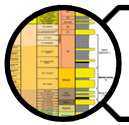


New data in the game…

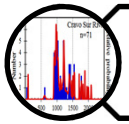
(mainly quantitative data)

TECHNOLOGICAL SUPPORT / RECENT TECHNIQUES

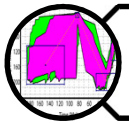
Technological Support



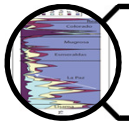
Biostratigraphy
Biostratigraphic zonation



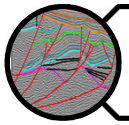
U-Pb geochronology



Thermocronology
Apatite, Zircon, Apatite-Helium FT

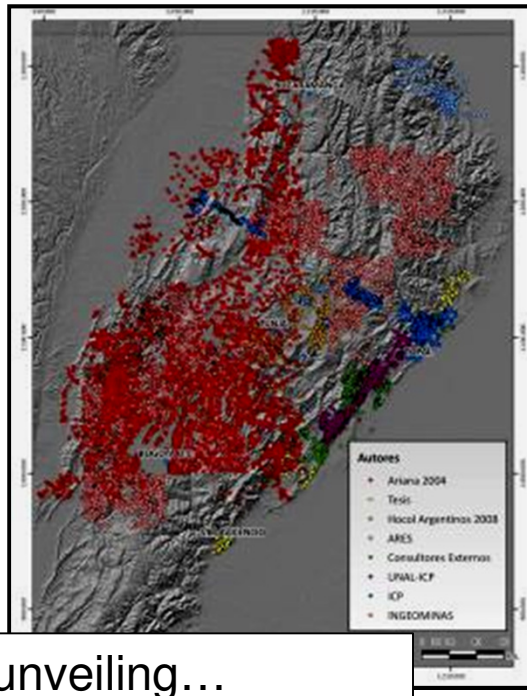


Sedimentary petrography



Seismic information

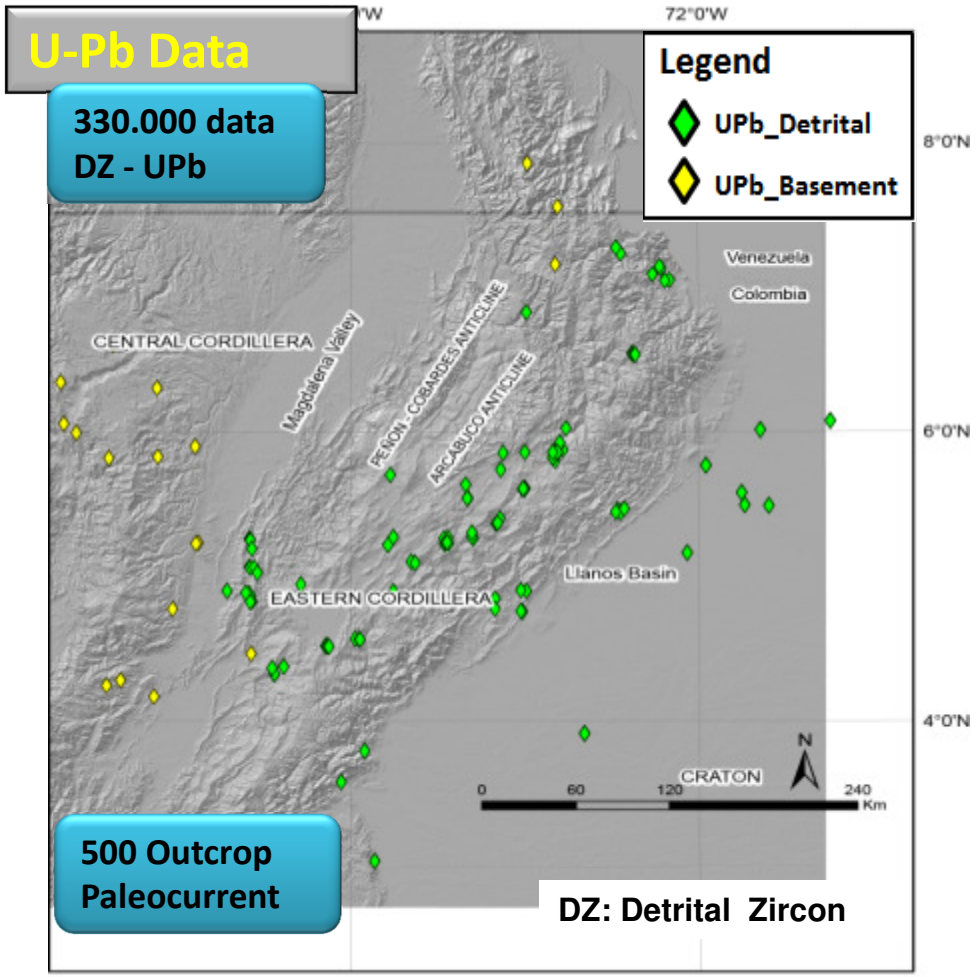
Core descriptions and facies analysis



For unveiling…

- Location of uplifted terrains
- Location of depocenters
- Facies changes
- Provenance of sediments

TECHNOLOGICAL SUPPORT / RECENT TECHNIQUES



U-Pb geochronology from…

- Basement and Sedimentary rocks of Central and Eastern Cordillera.
- Cenozoic rocks of Magdalena Valley, Eastern Cordillera and Llanos basin.

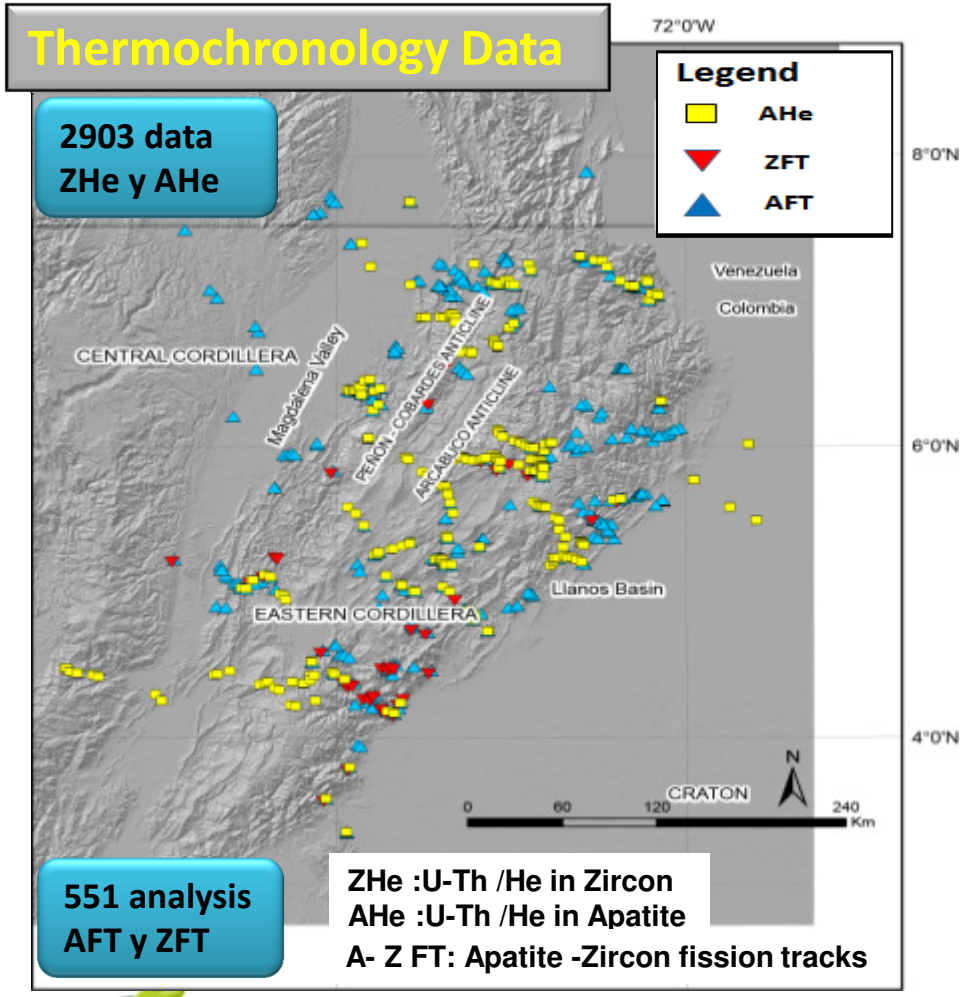
Additional data…

- Paleocurrent measurements
- Clasts counting
- Conventional petrography

Output…

- Sediment supply location
- Uplifted blocks vs geological time
- Direction of provenance

❑ TECHNOLOGICAL SUPPORT / RECENT TECHNIQUES



Uplift timing

Tools:

- Apatite Fission Tracts
- Zircon Fission Tracts
- Apatite-Helium dating

Aditional data

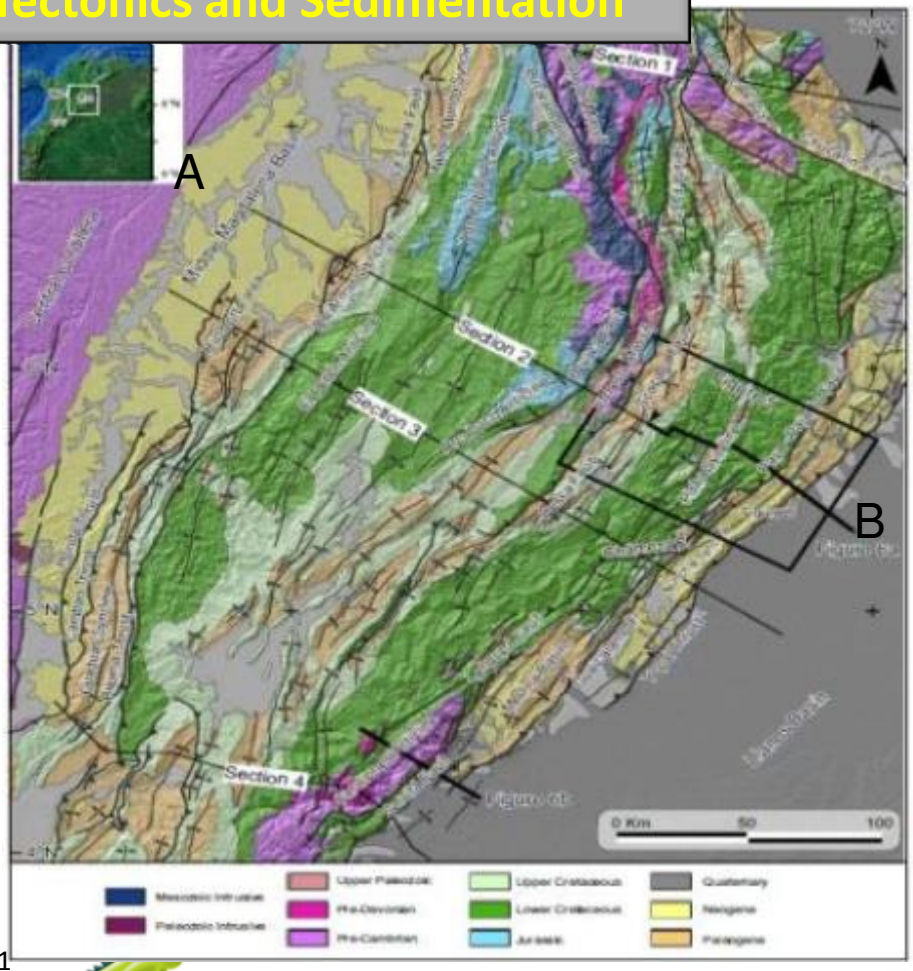
- Biostratigraphy (Cenozoic rocks)

Output…

- Sediment supply location
- Uplifted blocks vs geological time
- Direction of provenance

❑ TECHNOLOGICAL SUPPORT / RECENT TECHNIQUES

Tectonics and Sedimentation

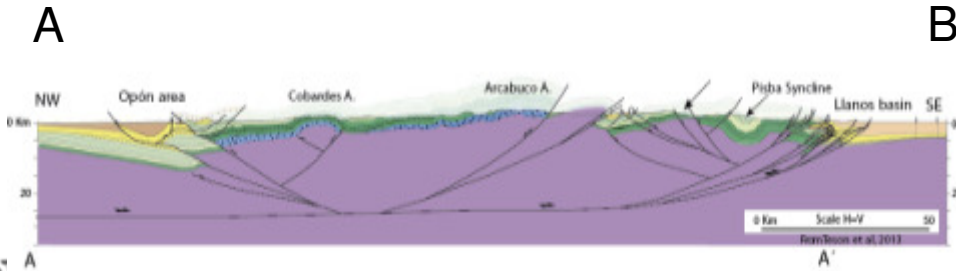


Paleotectonic Configuration based on:

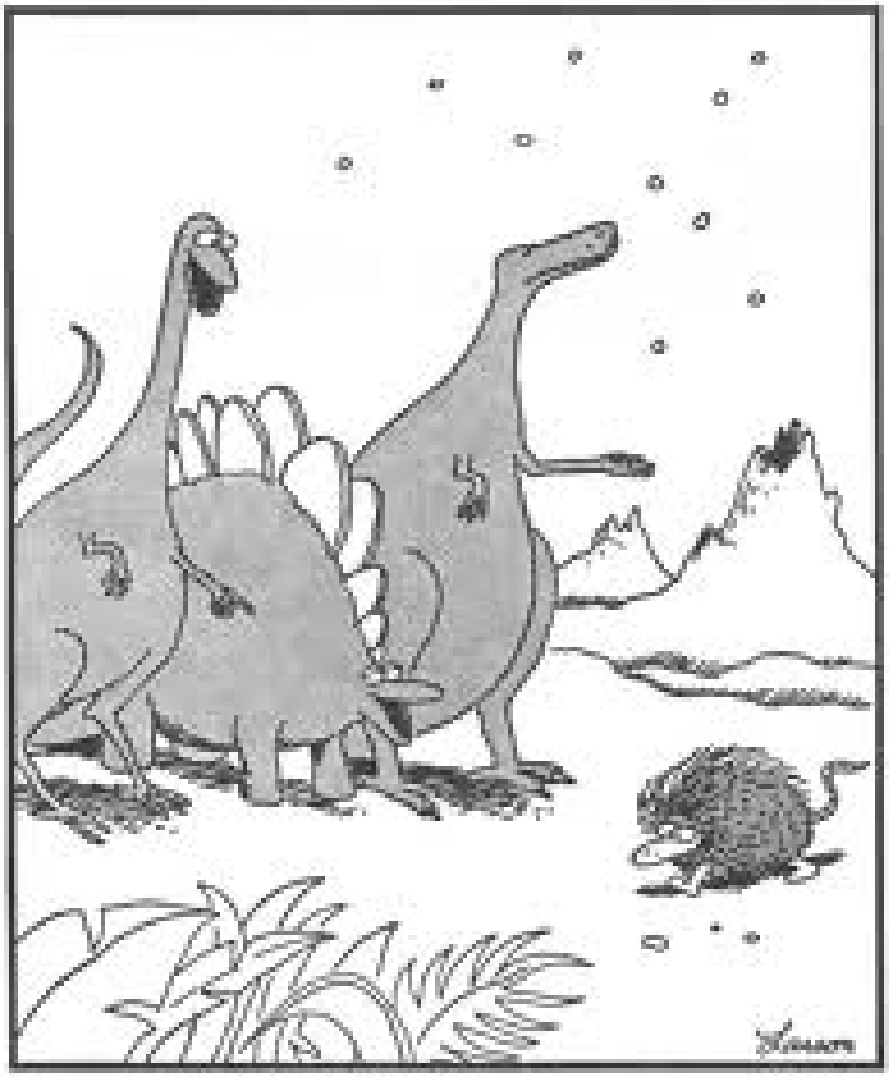
- Detailed field observations
- Structural Transects
- Seismic sections

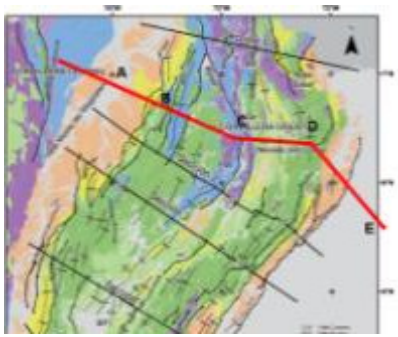
Paleo-Sedimentation (Cenozoic) based on:

- Core and outcrop description
- Well log facies analysis

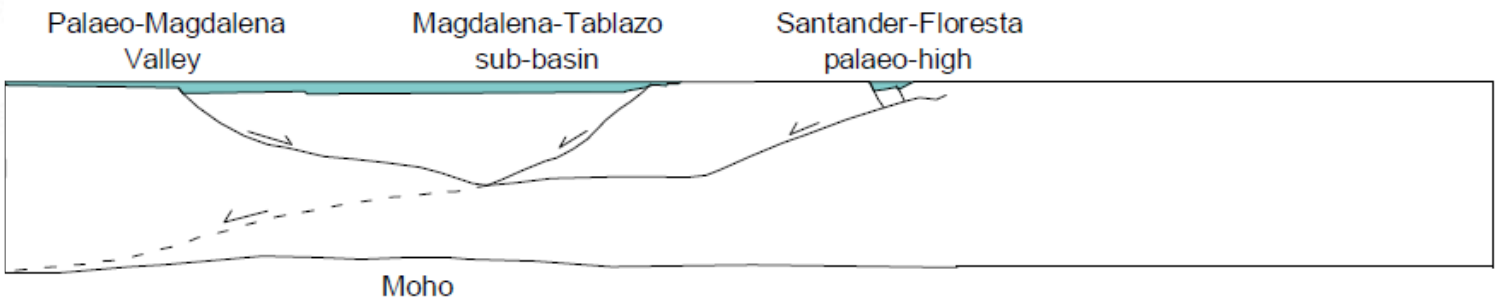


Cenozoic
Paleogeography

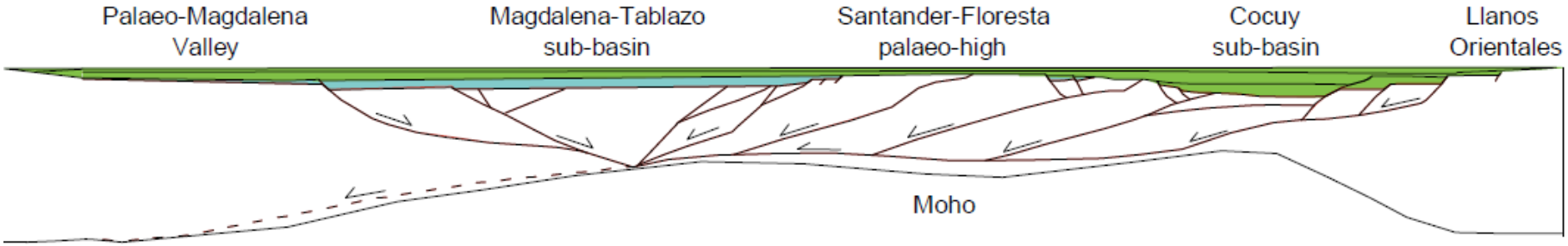




JURASSIC

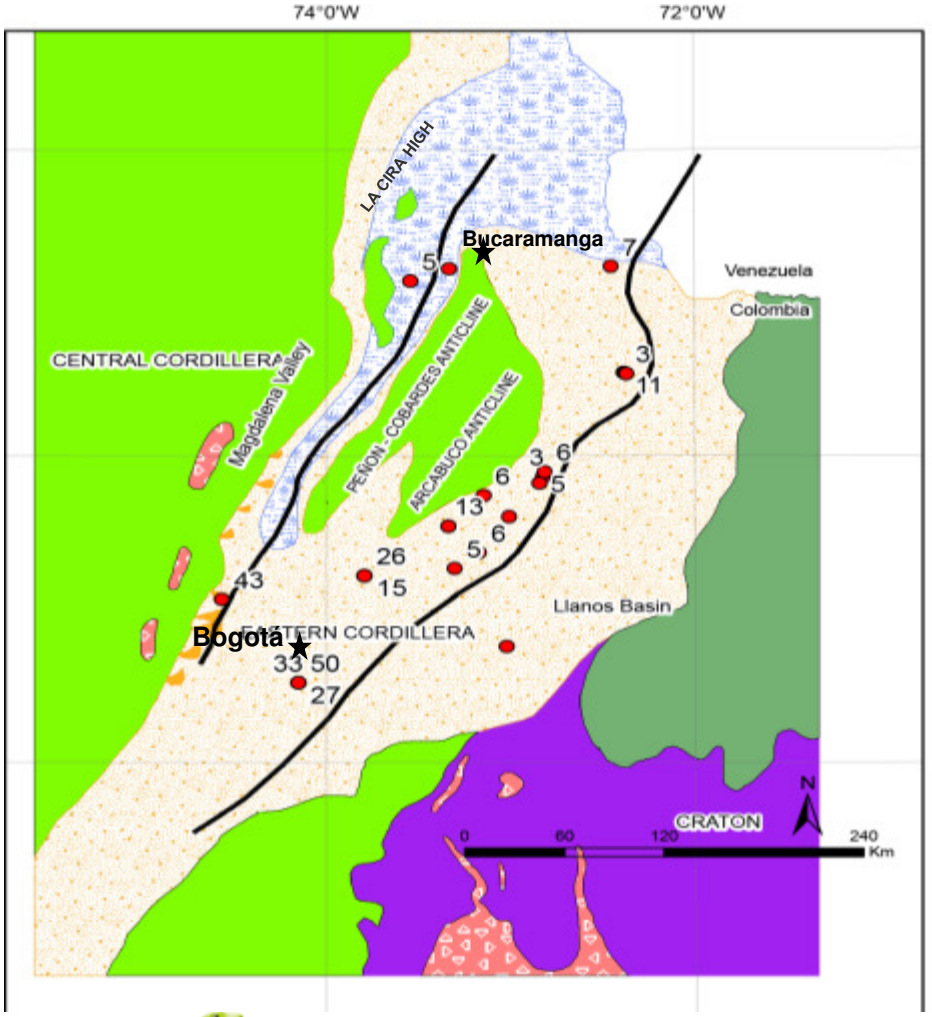


CRETACEOUS



Jurassic - Cretaceous tectonosedimentary evolution scheme for the Colombian Andes from Sarmiento (2006)

EARLY PALEOCENE PALEOGEOGRAPHY



LEGEND

Rocks exhuming

- Paleogene Rocks Exposed
- Jurassic Rocks Exposed
- Early Cretaceous Rocks Explosed
- Late Cretaceous Exposed
- pre-Cretaceous Rocks Exposed
- Christaline Basement Rocks

Deposit

- Lake or Marine Evidence
- Coastal Plain
- Alluvial Fan
- Fluvial Continental
- UPB_Samples
- Provenance divide

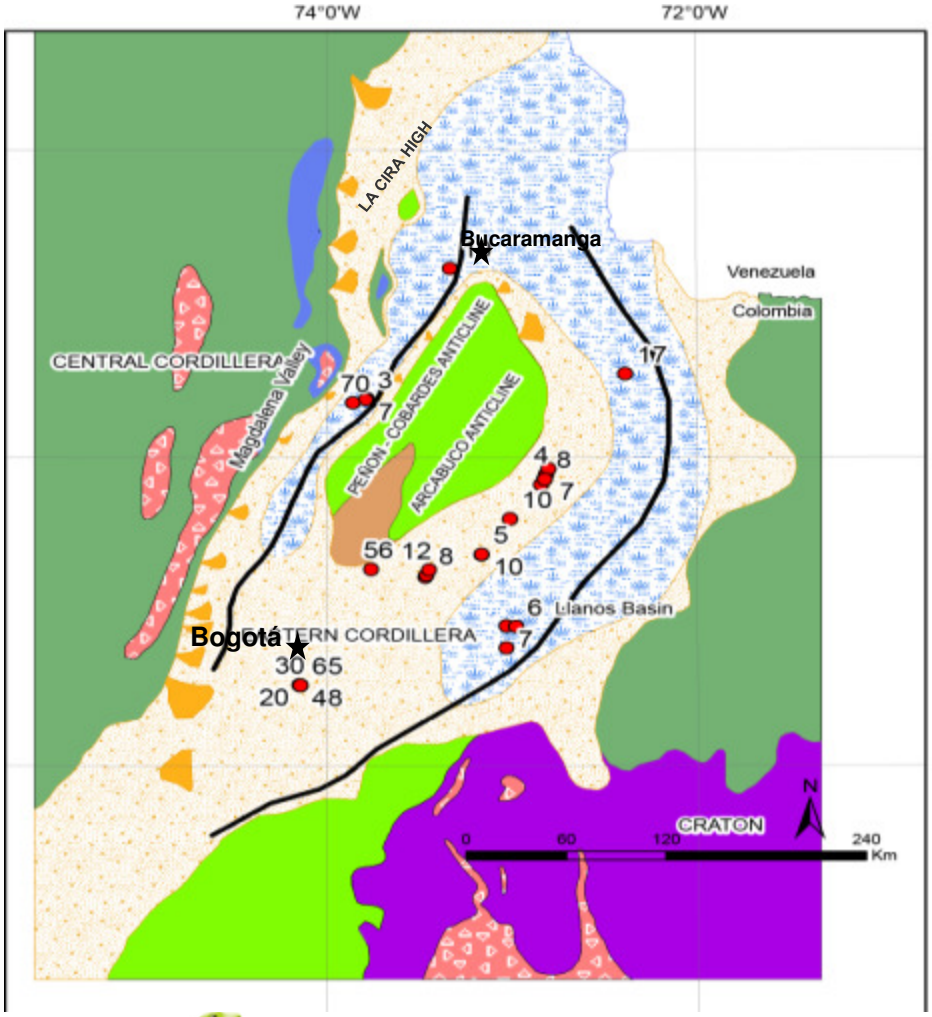
Uplifted areas (sources of sediment):

- Central Cordillera
- La Cira high
- Peñón-Cobardes, Arcabuco anticlines
- Craton

Features…

- Predominantly fluvial in Llanos Basin
- Transitional/deltaic in Middle Magdalena Valley.
- Facies and paleocurrents indicate a seaway towards NE.

LATE PALEOCENE PALEOGEOGRAPHY



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- UPB_Samples
- Provenance divide

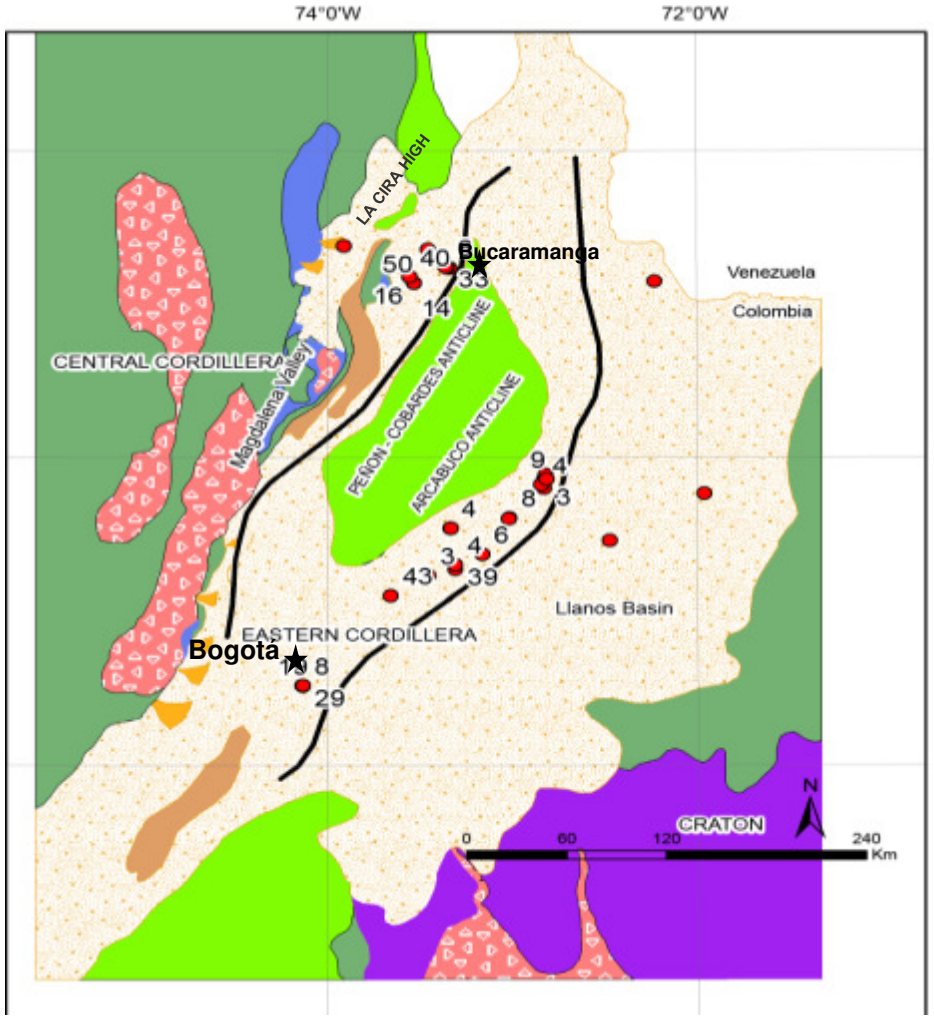
Sources of Sediment:

- Central Cordillera
- La Cira high
- Peñón-Cobardes, Arcabuco anticlines
- Craton
- **Exhumation at deeper levels**

Features…

- The provenance axis migrated to the east
- Overfilled configuration in the pre-Eastern Cordillera
- Fluvial to transitional from SW to NE.

EARLY EOCENE PALEOGEOGRAPHY



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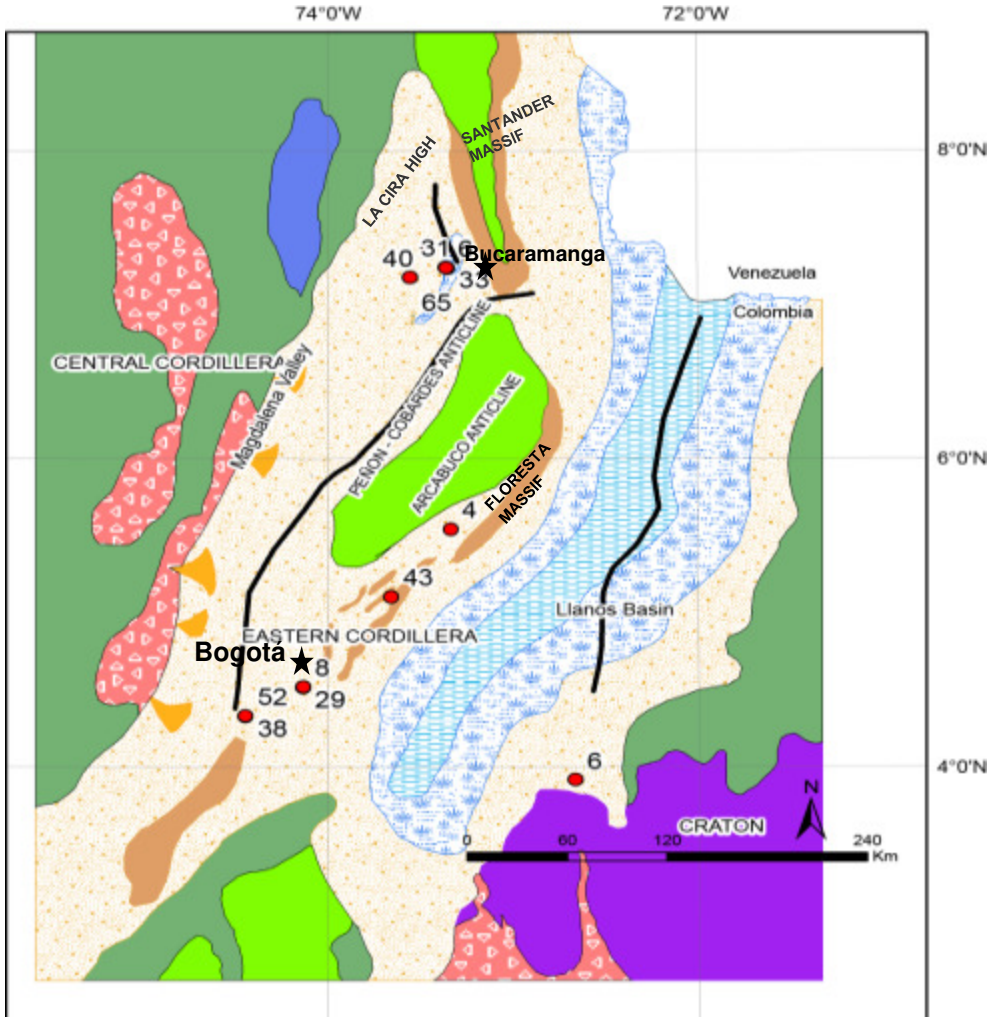
Deposit

- Lake or Marine Evidence
- Coastal Plain
- Alluvial Fan
- Fluvial Continental
- UPB_Samples
- Provenance divide

Features…

- Exhumation of the CC at deeper levels; it was the major source of sediment
- Inversion anticlines are another source
- Provenance axis migrated back to W
- Non-marine sedimentary environments
- It is the lowest sedimentation rate in the Cenozoic… period of tectonic quiescence

LATE EOCENE PALEOGEOGRAPHY



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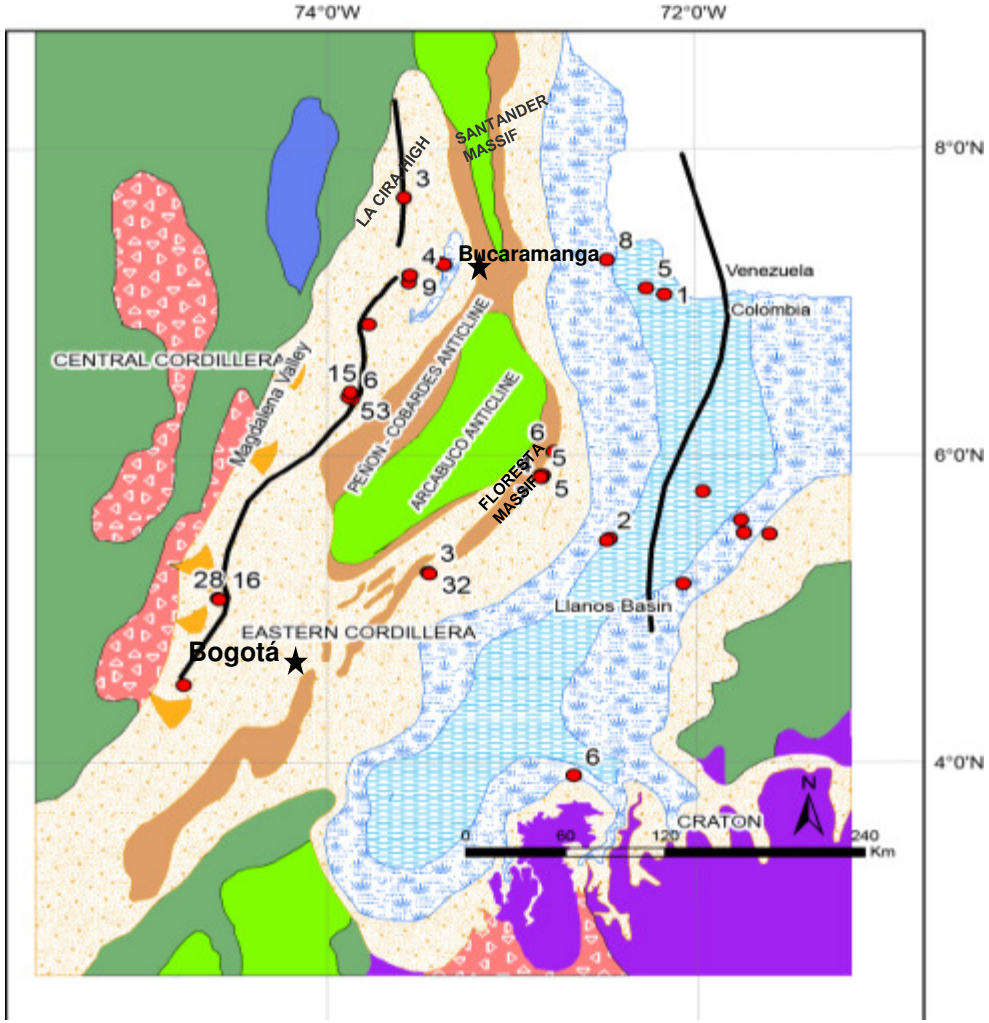
Deposit

- Lake or Marine Evidence
- Coastal Plain
- Alluvial Fan
- Fluvial Continental
- UPB_Samples
- Provenance divide

Features…

- Renewed tectonic activity
- Thrusting advance in the Floresta Massif
- Initial uplift of the Santander Massif
- Few tectonic activity in Central Cordillera. Activity migrated to the east
- Marine transgression in the Llanos
- Llanos basin began to separate from Magdalena Valley (uplifts in southern Eastern Cordillera)

EARLY OLIGOCENE PALEOGEOGRAPHY



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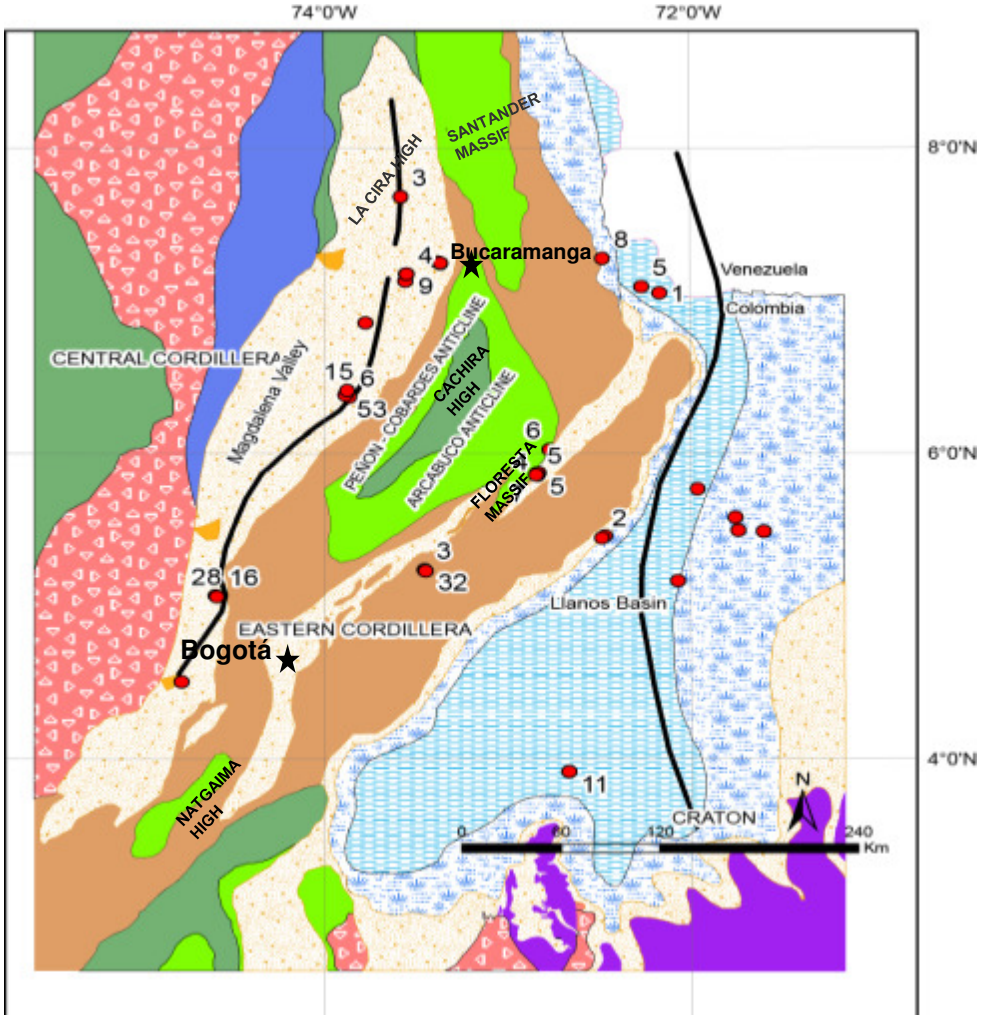
Deposit

- Lake or Marine Evidence
- Coastal Plain
- Alluvial Fan
- Fluvial Continental
- UPB_Samples
- Provenance divide

Features…

- Exhumation deeper than Late Eocene
- Oil kitchens in the Eastern Cordillera began to separate from the Llanos reservoirs (important moment for the hydrocarbon systems of the eastern basins)
- Initial exhumation of the Eastern Cordillera (source rocks out of oil window)
- Migration paths interrupted

LATE OLIGOCENE PALEOGEOGRAPHY



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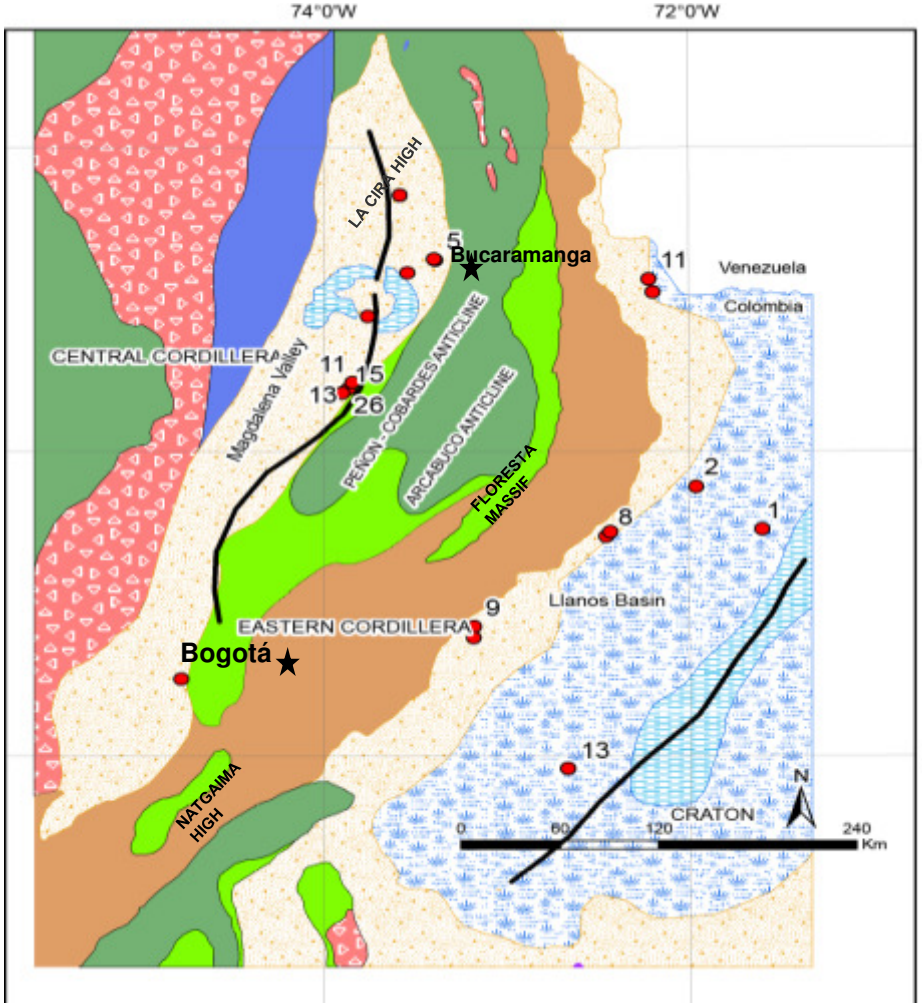
Deposit

- Lake or Marine Evidence
- Coastal Plain
- Alluvial Fan
- Fluvial Continental
- UPB_Samples
- Provenance divide

Features

- The orogenic front registered the most dramatic advance towards the E.
- Part of Neocomian graven was exhumed to configure the Eastern Cordillera.
- Uplift of the Natagaima, Cachira highs and the Santander Massif.
- Middle Magdalena Valley Basin configured as an isolated basin
- Ceased migration of oil towards Llanos Basin

EARLY TO MIDDLE MIOCENE



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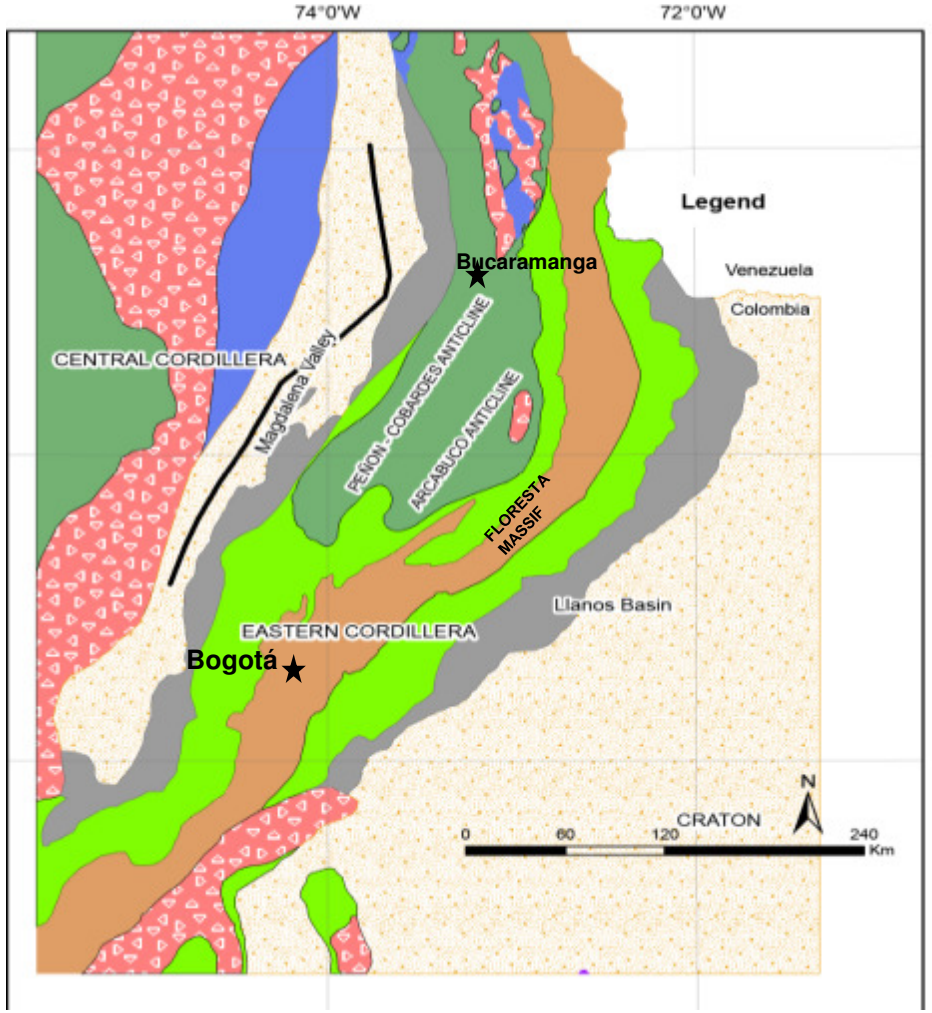
Deposit

- Lake or Marine Evidence
- Coastal Plain
- Alluvial Fan
- Fluvial Continental
- UPB_Samples
- Provenance divide

Features

- Exhumation of the Eastern Cordillera continued
- Exhumation of Jurassic and Basement rocks of the Cordillera and Santander Massiff,
- Exhumantion of Cretaceous rocks in eastern foothills and Paleogene rocks in the eastern orogenic front.
- Eastward movement of the depositional axis
- Lacustrine to marine environments dominate in Llanos Basin.

LATE MIOCENE PALEOGEOGRAPHY



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Deposit

- Lake or Marine Evidence
- Coastal Plain
- Alluvial Fan
- Fluvial Continental
- UPB_Samples
- Provenance divide

Features

- Depositional environments changed to alluvial to fluvial
- Highest sedimentation rates
- Increased tectonic activity in the Eastern Cordillera (maximum orogenic exhumation and erosion, shortening and uplift).
- Eastern Cordillera acquired the nowadays configuration.

Conclusion and considerations for oil exploration…

- Cenozoic evolution is intimately related with Mesozoic anisotropy of the basement
- Separation of two basins (Llanos Orientales / VMM) since Late Eocene time
- The critical moment for oil generation is during Early Oligocene; In Late Oligocene **the oil generation stopped because of exhumation of the kitchen**
- Main reservoirs were deposited in Paleocene and Eocene in Llanos (Barco, Mirador). In VMM reservoirs range from Paleocene to Oligocene