Origin, Evolution and Petroleum Systems of the Lower Magdalena and San Jacinto basins of NW Colombia

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Hocol S.A.

October 8, 2021

Agenda

- Introduction and tectonic models
- Origin and Evolution of the San Jacinto basin
- Origin and Evolution of the Lower Magdalena Valley basin
- Petroleum systems
- Concluding remarks

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First oil in Colombia was apparently found in northern San Jacinto!

y from Barranquilla to Puerto Colombia, a
s Volcanes" to investigate the fires which
ere there were gas emmissions and strong

he area but the workers couldn't drill more

"The first exploring well in Colombia (and Latin America?) was really drilled in 1883. It was called Tubará (?) and the pioneers were Manuel María Palacio and David López assisted by geologist Luis Striffler. The work was done at open cut, that is to say pure oil minery. The drilling rig was a wooden structure 10 meters high; in its top there was a crown block with steel cable tied to a drop hammer that when hammered entered the earth's crust. The result: a production capacity of 50 barrels per day."

(summary by Victor E. Pérez, 2001 at http://www.palacio.org/Hablamos/00000015.htm)

Manuel María Palacio Vargas, brothers & associates started forming a private company at the end of the 19th century and in 1906 they formed in Canada the Atlantic Oil Co. Ltd., with a capital of 2MM USD and with geologist Eugene Coste they drilled the first Perdices wells (1/1A) finding 40° API oil at 750'.

(source: http://tubara.homestead.com/Historia.html) - more historical research has to be done to verify this info

Striffler

Manuel Ma. Palacio

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First oil in Colombia was apparently found in northern San Jacinto!

Anderson, 1926

Tubará or Las Perdices Wells?

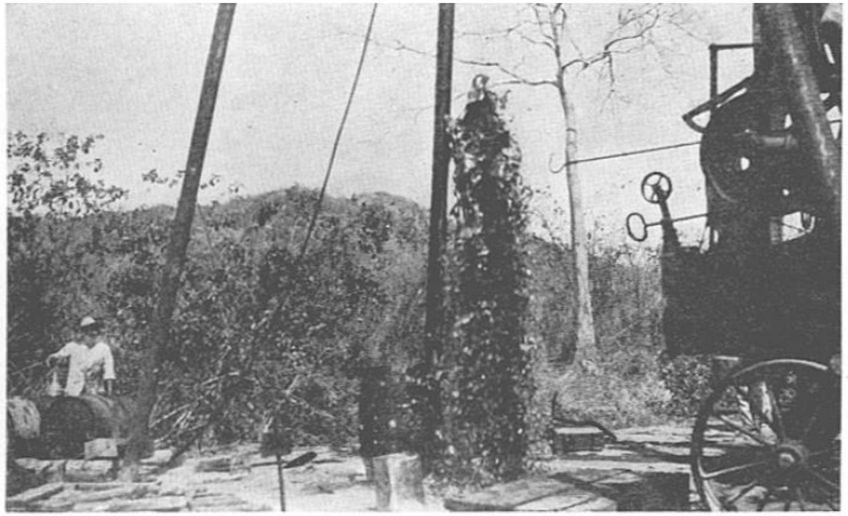


FIG. 3.—Flowing oil well near Puerto Colombia, May, 1922

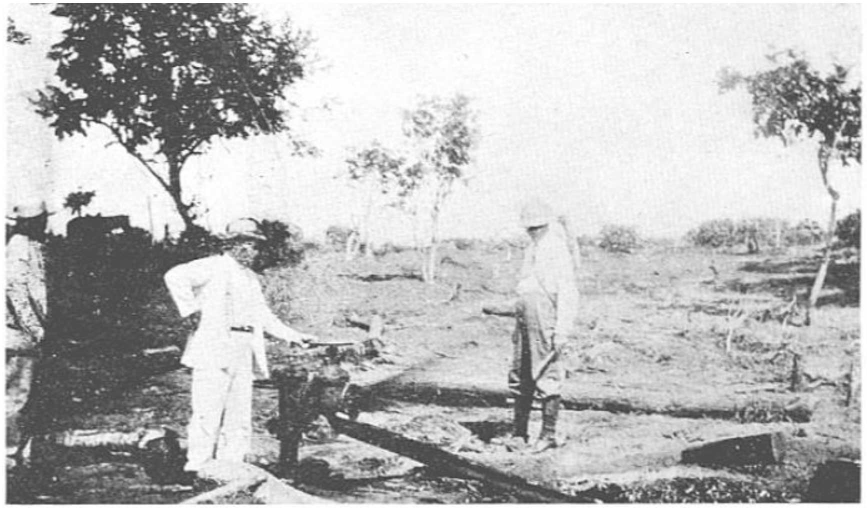


FIG. 4.—Flowing oil well near San Sebastian, Sinu Valley, March, 1915

CLASSIFICATION OF COLOMBIAN TERTIARY

Periods	Magdalena Valley	Cartagena District	Sinú River Region	Lower Sogamoso	Upper Magdalena	Plateau Region
Pliocene	Galapa group	La Popa group	Escondido group	Honda beds	Honda beds	?
Miocene	Tuberá group	Turbaco group	San Antonio group (Beck)	Oponcito group	Barzalosa beds	Miocene group (Berry)
Oligocene	San Juan group	?	Bombo shales (Beck)	?	?	?
Eocene	Carmen group	Arjona group	Tofeme-Coloso group	La Paz series	Guaduas beds	Guaduas beds
Cretaceous	Upper Cretaceous	?	?	Guadalupe group	Guadalupe group	Guadalupe group

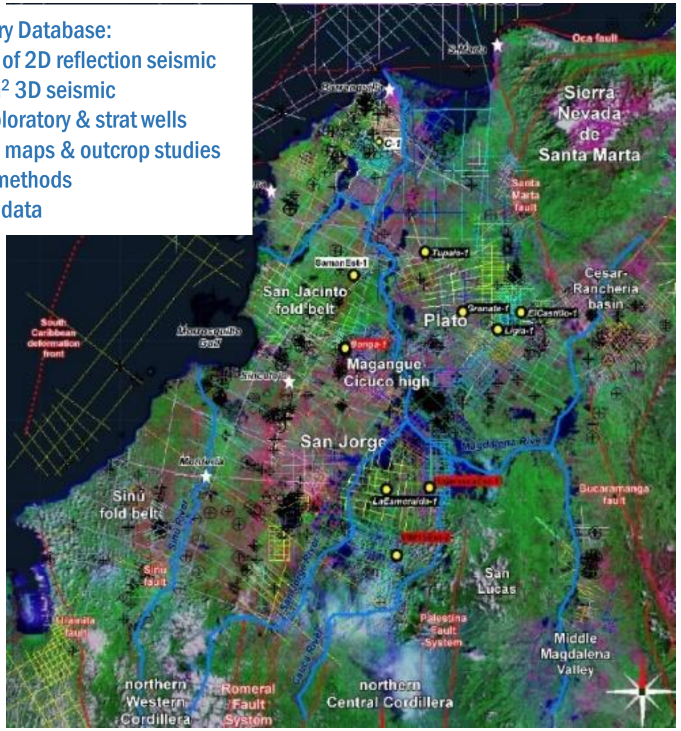
"The commercial deposits of oil thus far developed in Colombia are not only actually found in Tertiary rocks, but both presumably and by evidence originated in these rocks"

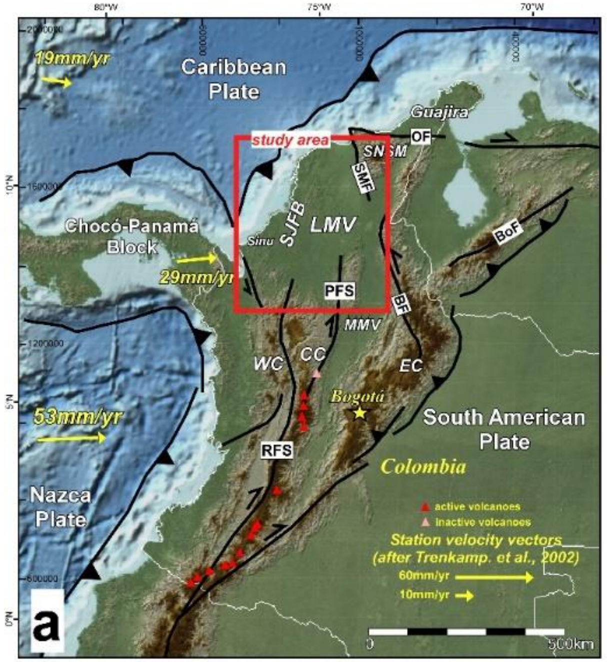
Anderson, 1926

Location and database

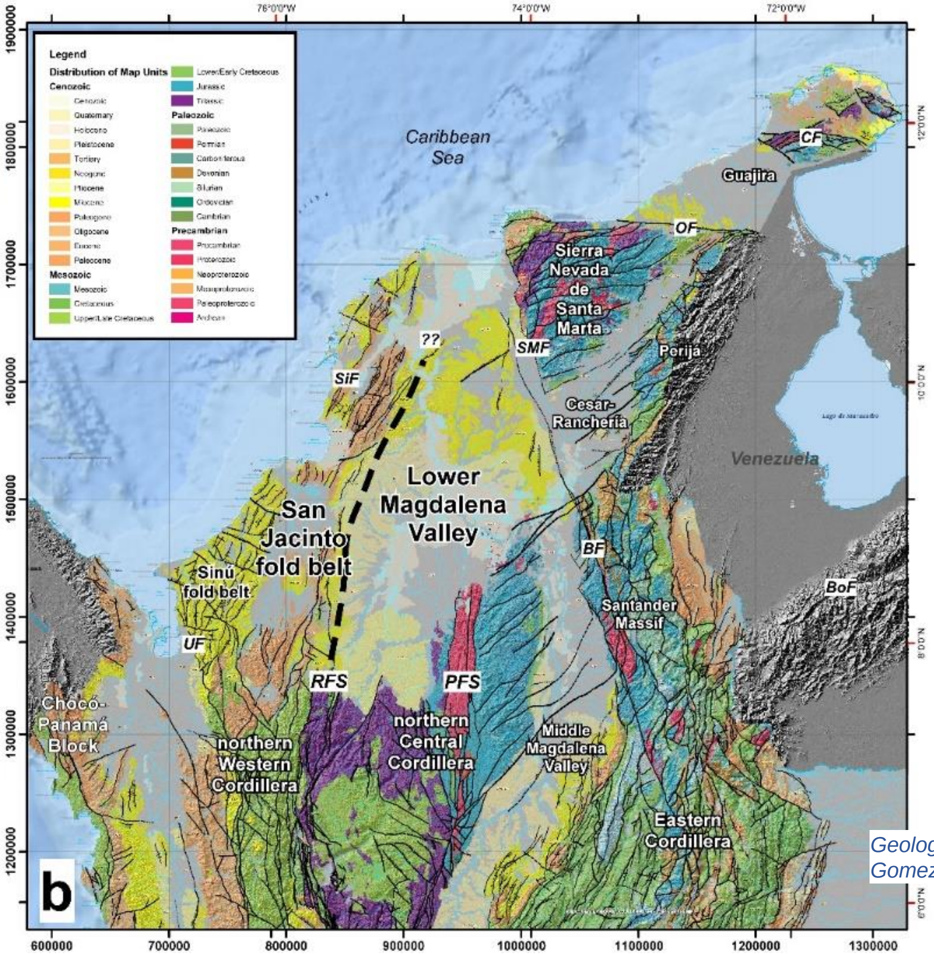
The Lower Magdalena Valley & San Jacinto fold belt are two not very well-understood basins located in onshore NW Colombia, which were formed by the complex interaction of several tectonic plates and which contain commercial hydrocarbons.

Big industry Database:
~ 30K km of 2D reflection seismic
>3000 km^2 3D seismic
~ 250 exploratory & strat wells
geological maps & outcrop studies
potential methods
seismicity data





Mora et al., 2017a (JSAMES)



Geology after Gomez et al., 2015

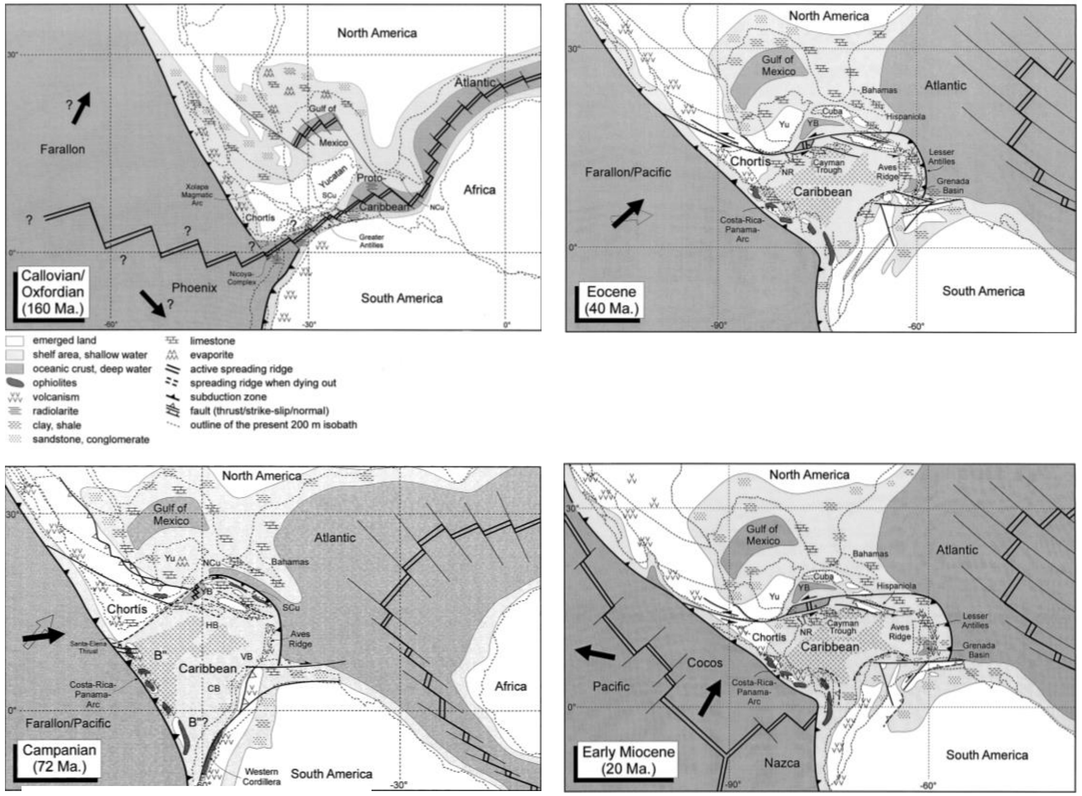
Most used acronyms in this study:

LMV: Lower Magdalena Valley basin
SJFB: San Jacinto fold belt
RFS: Romeral Fault System
PFS: Palestina Fault System
SiF: Sinú Fault
WC: Western Cordillera
CC: Central Cordillera
SNSM: Sierra Nevada de Santa Marta
SMF: Santa Marta Fault
BF: Bucaramanga Fault
OF: Oca Fault
UF: Uramita Fault
CR: Cesar-Ranchería basin
MCH: Magangué-Cicuco High

Proposed tectonic models of N Colombia

2 models proposed for origin of the Caribbean: Allochthonous vs autochthonous.

-Autochthonous: “in situ” origin of the Caribbean Plate, formed farther to the W but nearly in its current location between the Americas (Meschede & Frisch, 1998; James, 2006).



Meschede & Frisch, 1998

There have even been proposals of the Colombian Caribbean as a passive margin since the Cretaceous.

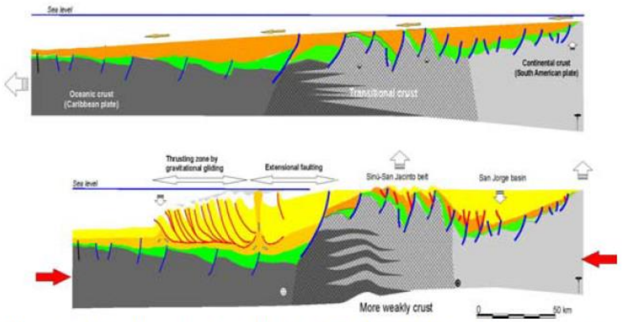


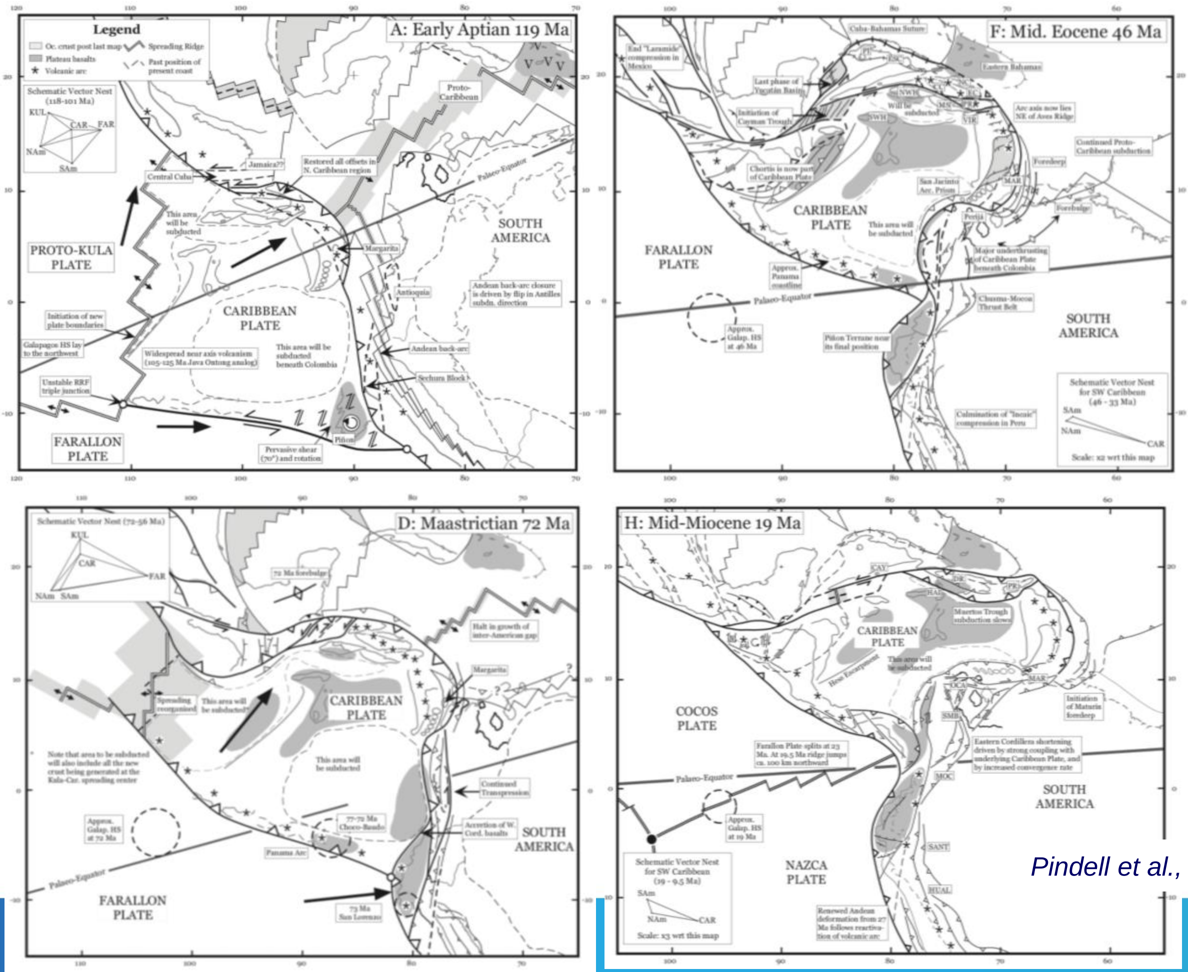
Figure 3. Schematic evolution for the CMC. *Above*: passive margin during the Cretaceous? to Lower Tertiary times. *Below*: Present context showing the Sinú-San Jacinto belt uplifted by a concentration of the deformation on the most weakly transitional crust.

Rosello & Cossey, 2012

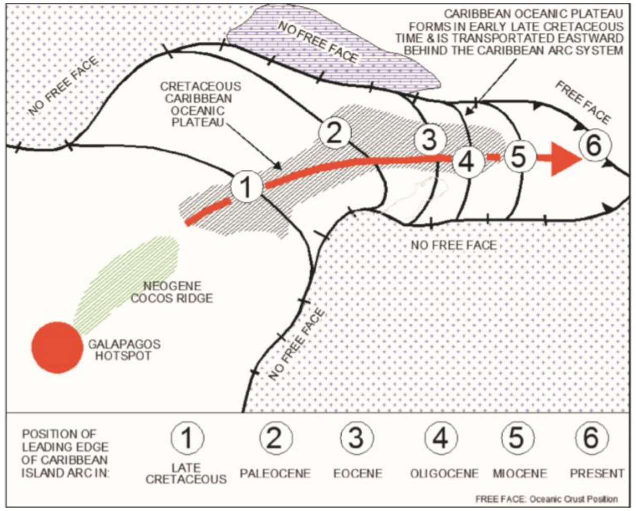
Proposed tectonic models of N Colombia

2 models proposed for origin of the Caribbean: Allochthonous vs autochthonous.

-Allochthonous or “Pacific”: long-distance displacement of the plate which was formed in the Pacific and migrated to occupy its current position between the Americas (Burke, 1988; Pindell & Kennan, 2009 among others).



Pindell et al., 2007

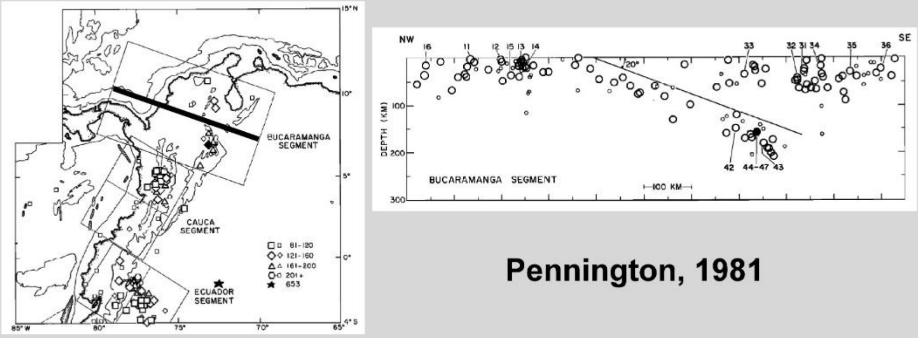


Mann, 1999

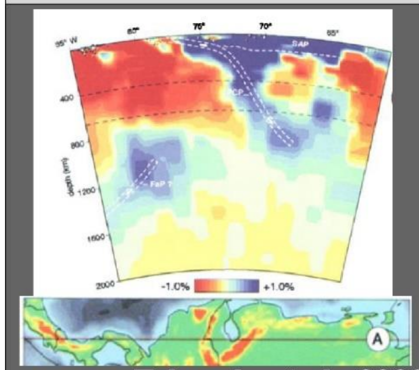
Some previous studies

- Seismology (Pennington, 1981) showed possible subduction of the Caribbean Plate beneath NW South America.

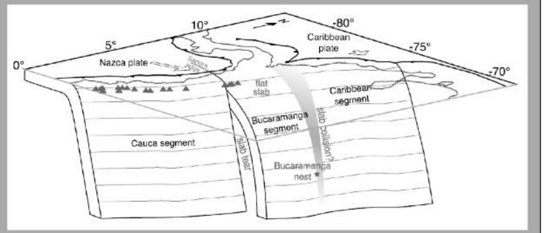
- **Different sources of data such as GPS (tectonic plate movement vectors), seismologic, tomographic y gravimetric have confirmed such a subductions (allochthonous model is more supported).**



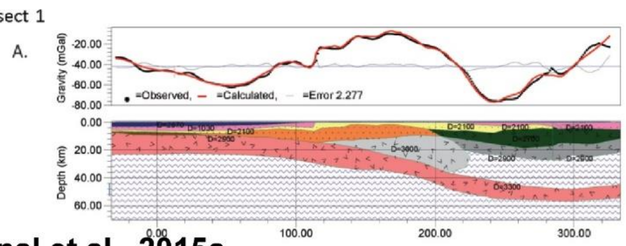
Pennington, 1981

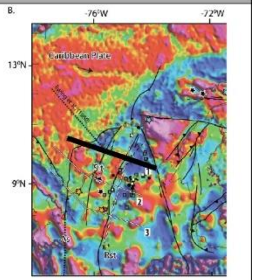


Taboada et al., 2000

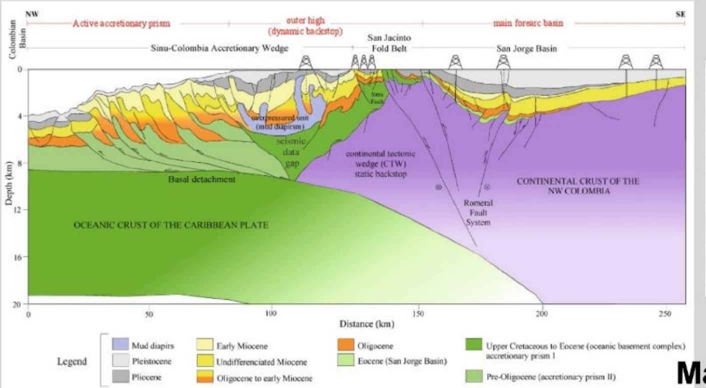


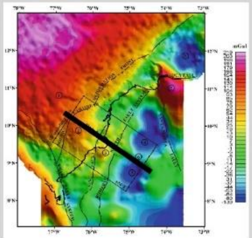
Syracuse et al., 2016





Bernal et al., 2015a

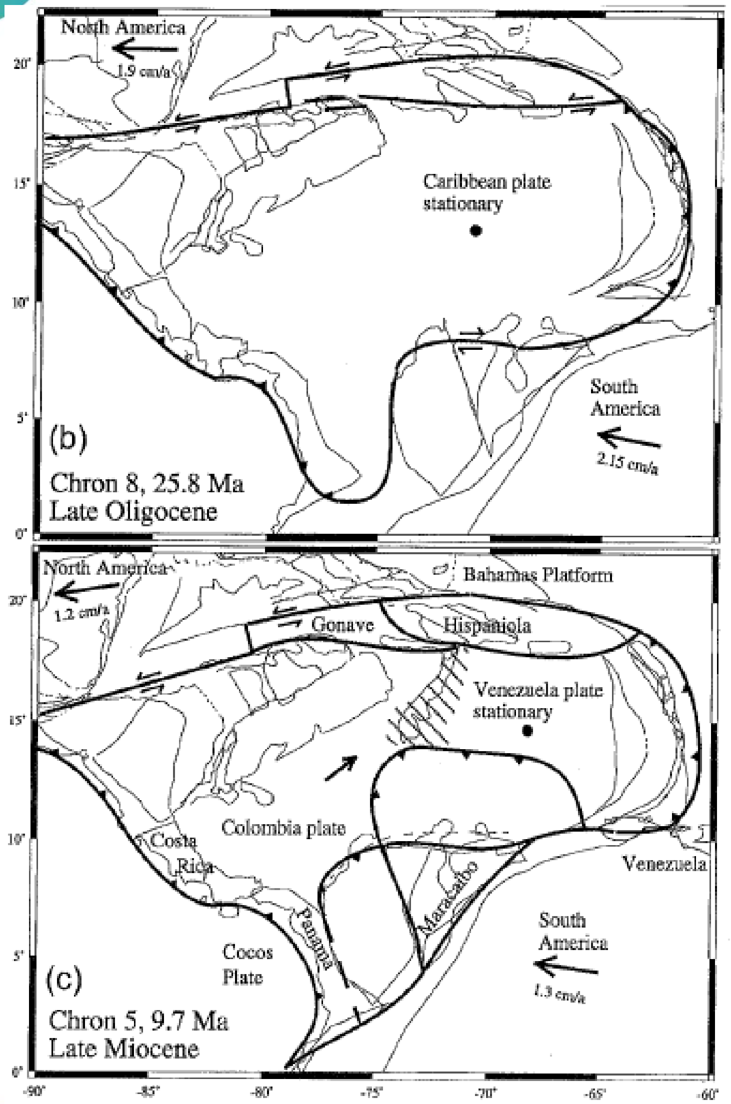




Mantilla et al., 2009

GPS Data (tectonic plate displacement vectors)

Müller et al., 1999



- For reconstructions it is better to try to use the mantle reference frame (e.g. mid-Atlantic ridge).
- Within this reference frame, South America is rapidly moving towards the W and it's over-thrusting the Caribbean and Pacific plates

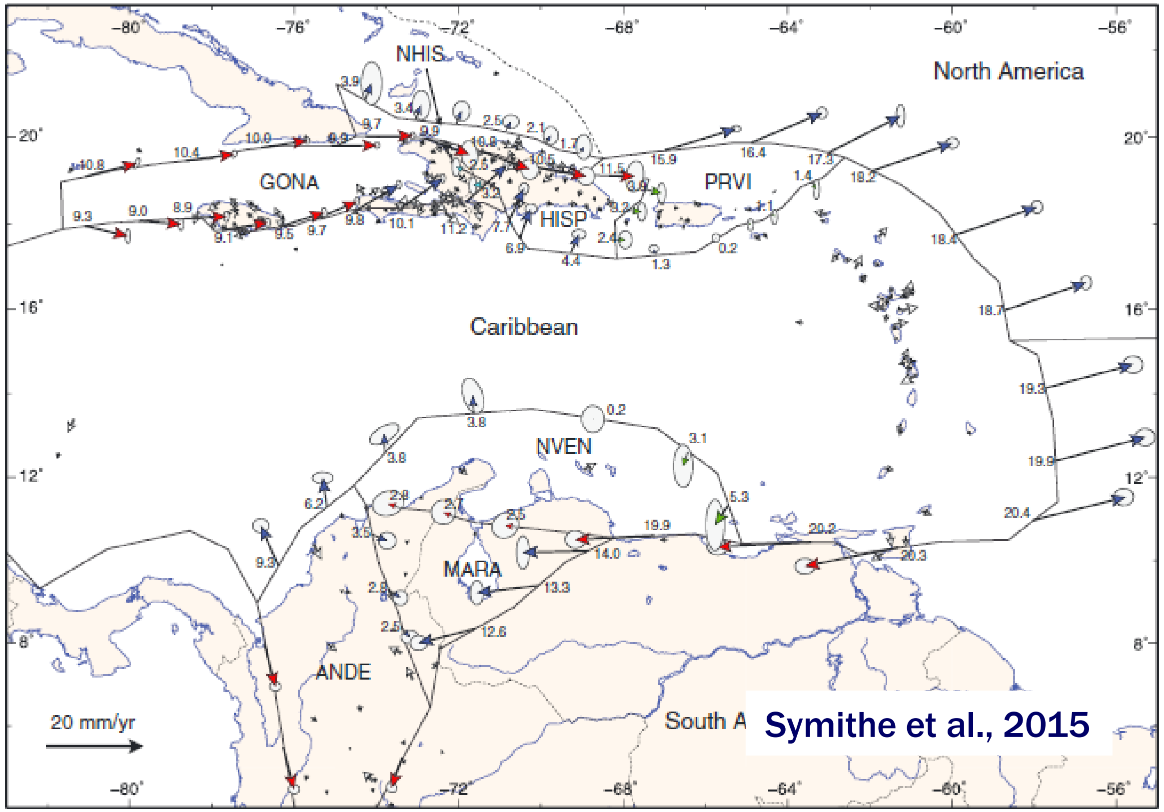
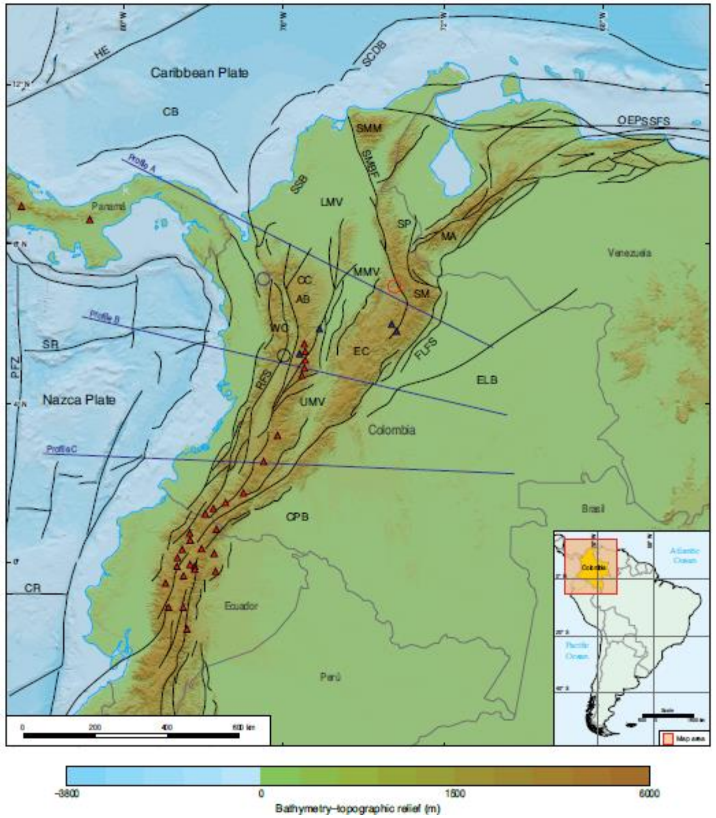
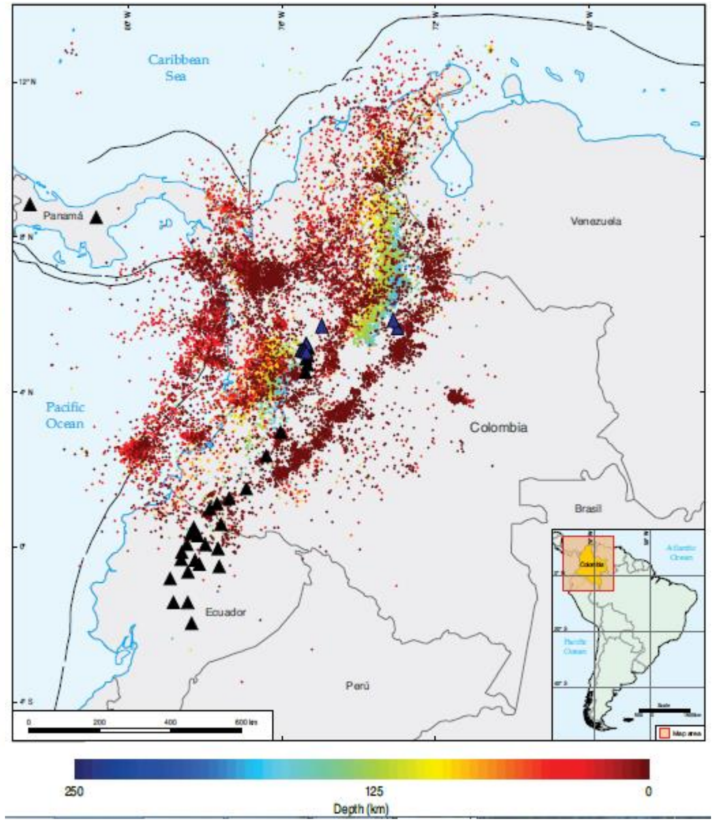


Figure 8. Best fit model geometry with block boundaries as solid black lines and predicted relative block motions as arrows with velocity indicated in mm/yr with their 95% confidence ellipse according to the parameters listed in Table 2. Red = strike slip (i.e., slip direction with ± 30° from fault strike), blue = reverse or transpressional, green = normal of transtensional. Residual velocities are shown with grey arrows. We omitted their error ellipses for a sake of readability, see Figures 9 and 10 for a close up view on Hispaniola and the Lesser Antilles. The thin dashed line indicates the boundary of the Bahamas Platform.

Seismic tomography and seismicity





Vargas, 2020

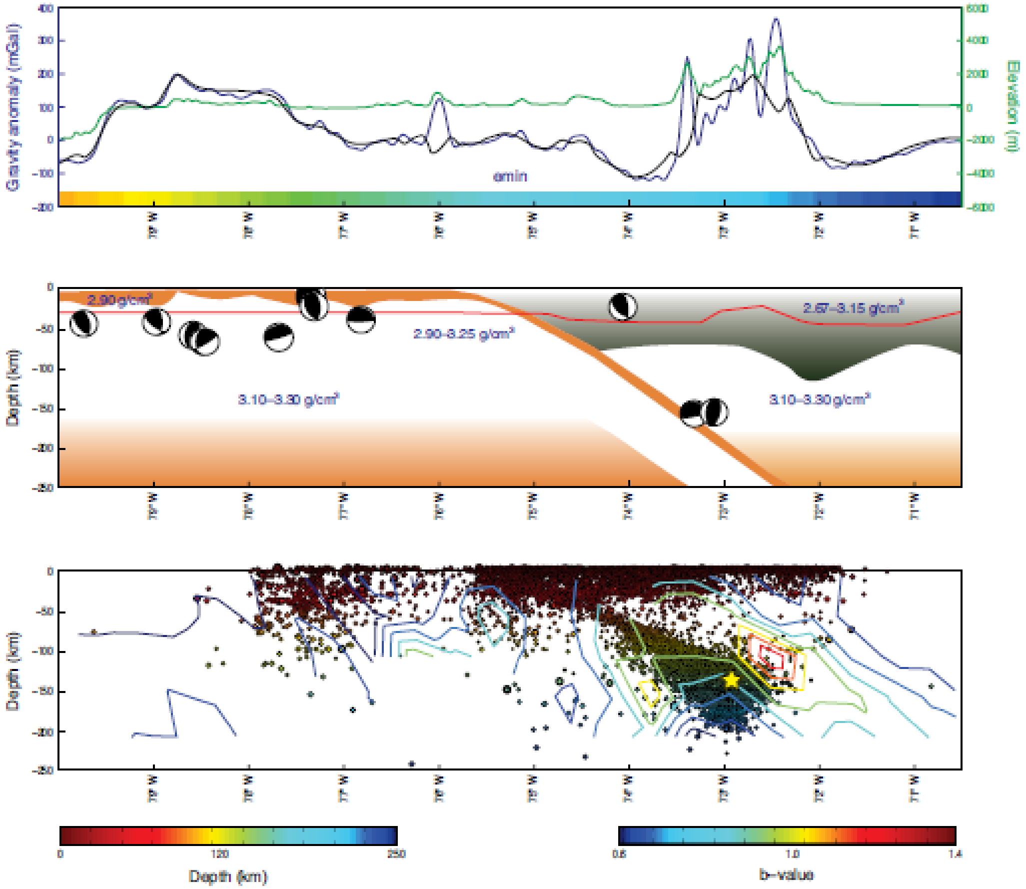


Figure 12. Profile A in the north is indicated in Figure 1. The upper panel represents the free–air anomaly observed (blue line) and calculated (black line). Exaggerated topography is represented with green lines. The colored band located in lower part of this panel represents the variation of the emin along the profile (see Figure 6). Middle panel shows the proposed model of subduction based on density variations and thickness of the crust and the lithosphere–asthenosphere boundaries reported by Poveda et al. (2015) and Blanco et al. (2017). Focal mechanisms are vertical projections on the section. Lower panel shows seismicity in a corridor 50 km wide and the iso–lines of b–values. The red line in the middle panel corresponds to the Curie point depth isotherm. Yellow star in the lower panel shows the approximate location of the Bucaramanga nest.

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Seismic tomography

Van Benthem et al., 2013

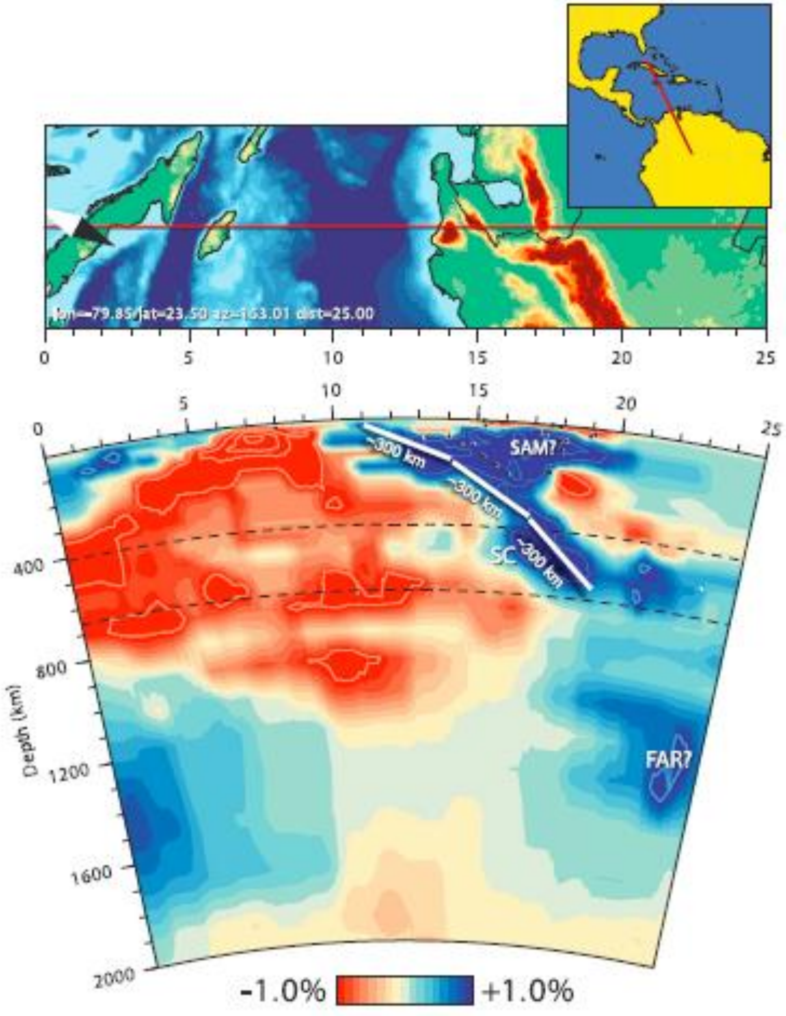
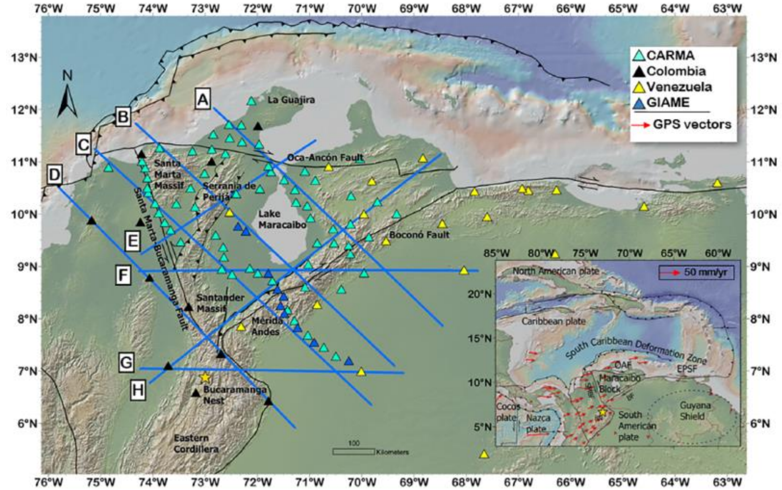


Figure 7. Tomographic section showing the South Caribbean (SC) anomaly. For figure layout, see the caption of Figure 5. We measure around 900 km of South Caribbean slab length. The angle of subduction is 40°. In the upper 400 km, the Nazca slab is also visible. In the lower mantle, the southern Great Arc of the Caribbean anomaly and Farallon anomalies are visible.

Cornthwaite et al., 2021



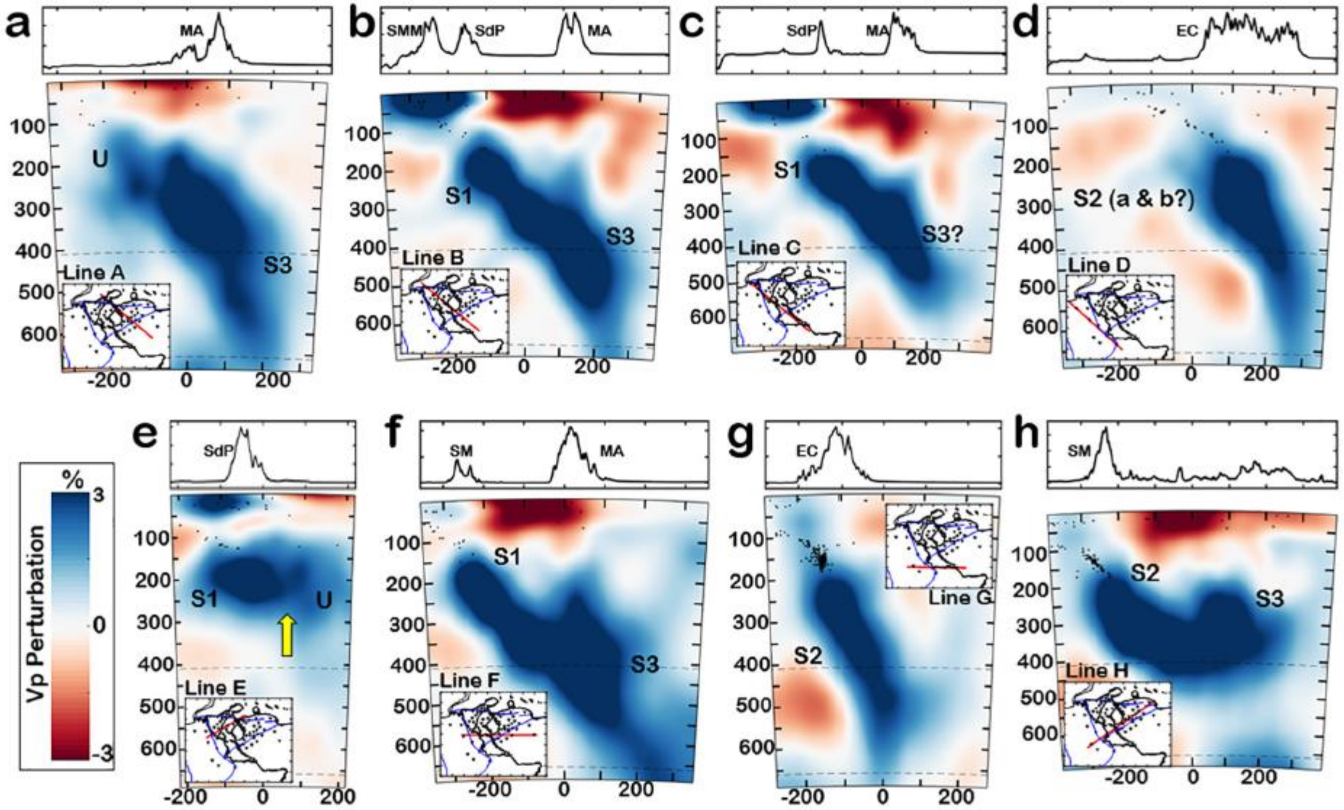
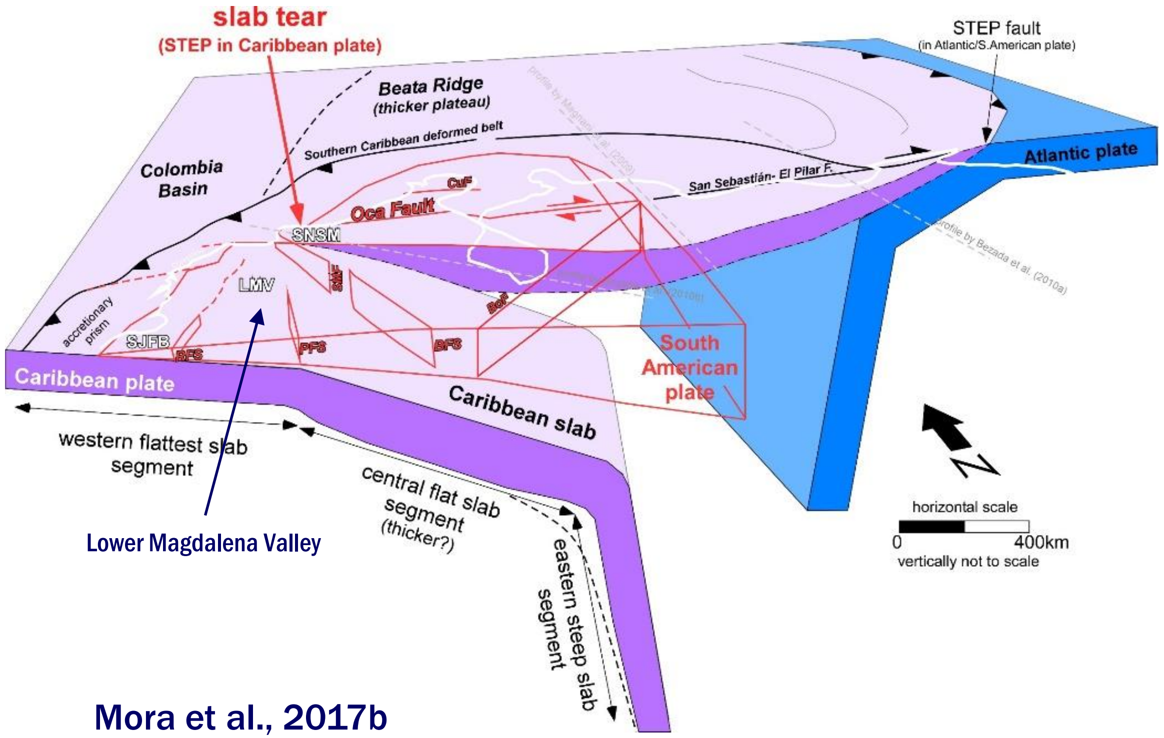


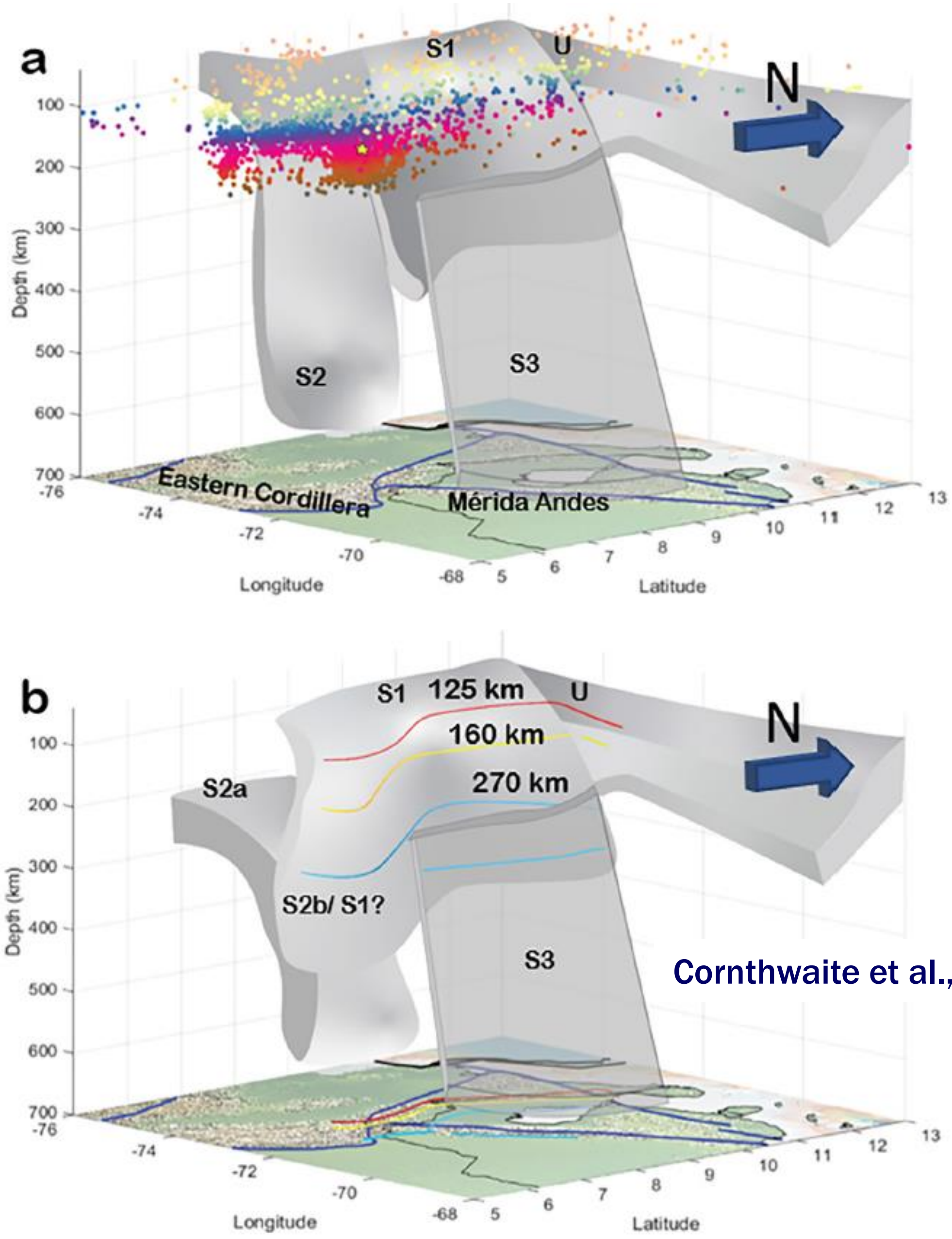
Figure 6. Cross-sections of velocity models. Black dots are seismicity as in Figure 4. S1 is the attached CAR. S2 is a southern segment possibly comprised of 2 plates. S3 is an anomaly atop the CAR we interpret as a broken segment of the CAR. Yellow arrow: Location where intermediate depth seismicity ends.

Recent tectonic models of N South America

- The allochthonous model implying Caribbean subduction beneath South America is much better supported than the "in situ" model.



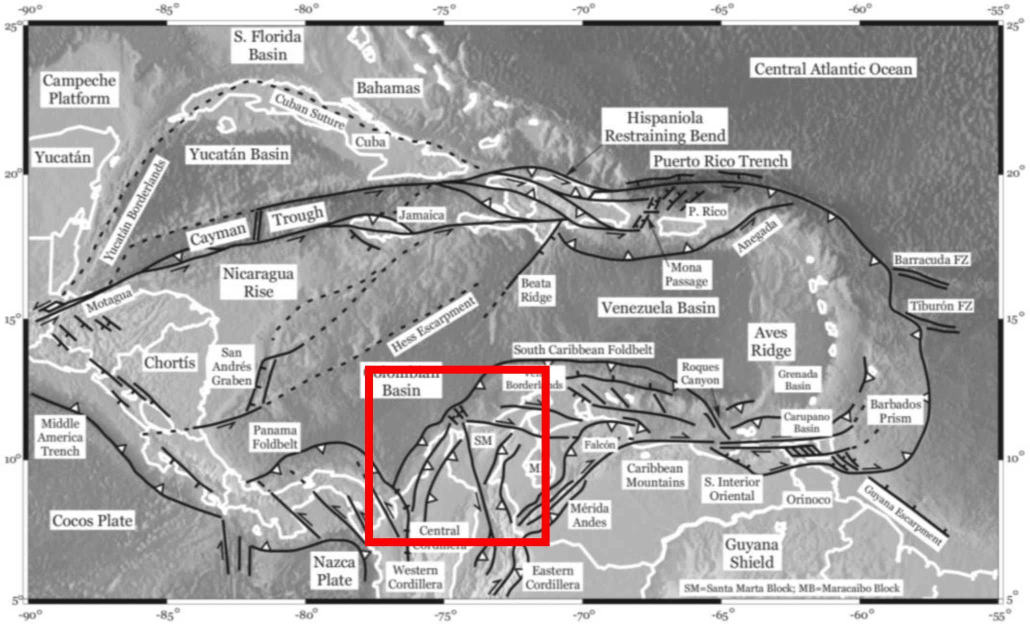
Mora et al., 2017b



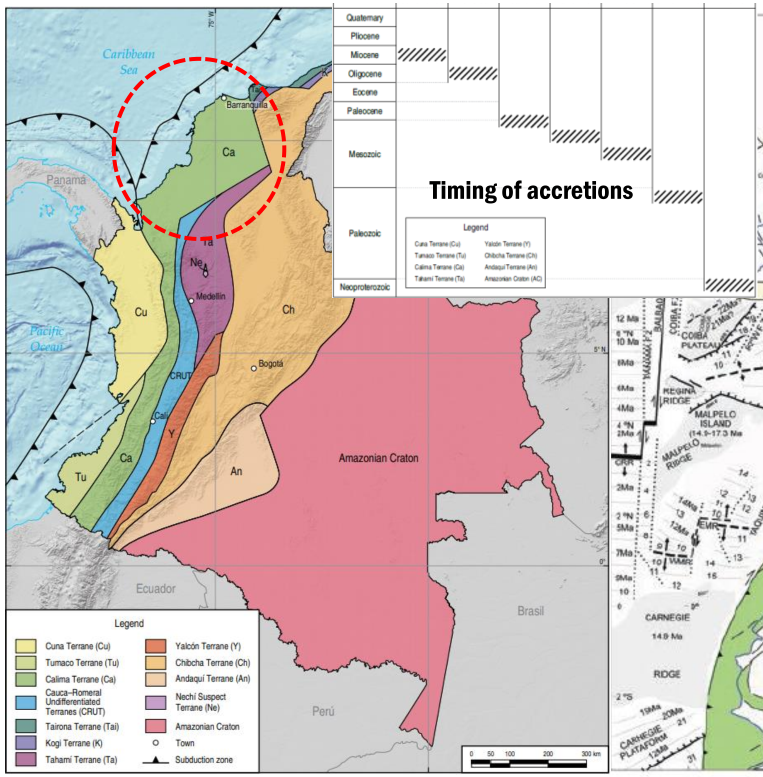
Cornthwaite et al., 2021

Tectonic setting of N South America

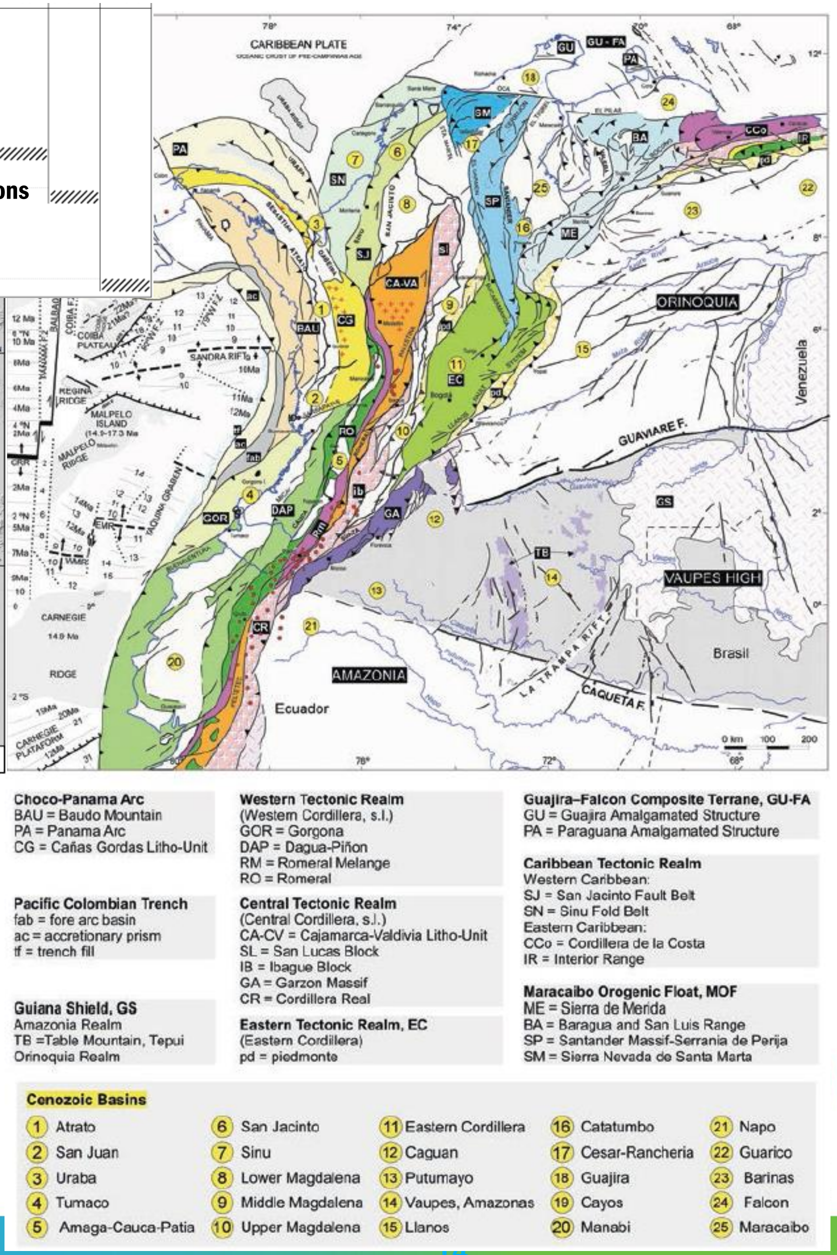
Cediel, 2019



Pindell et al., 2009

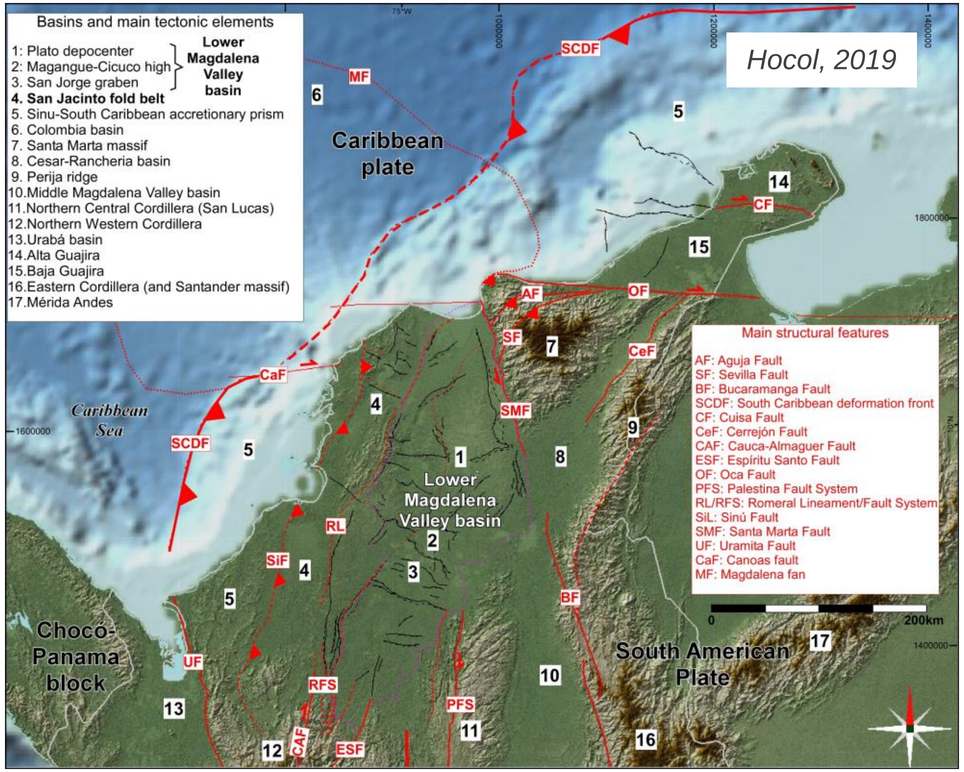


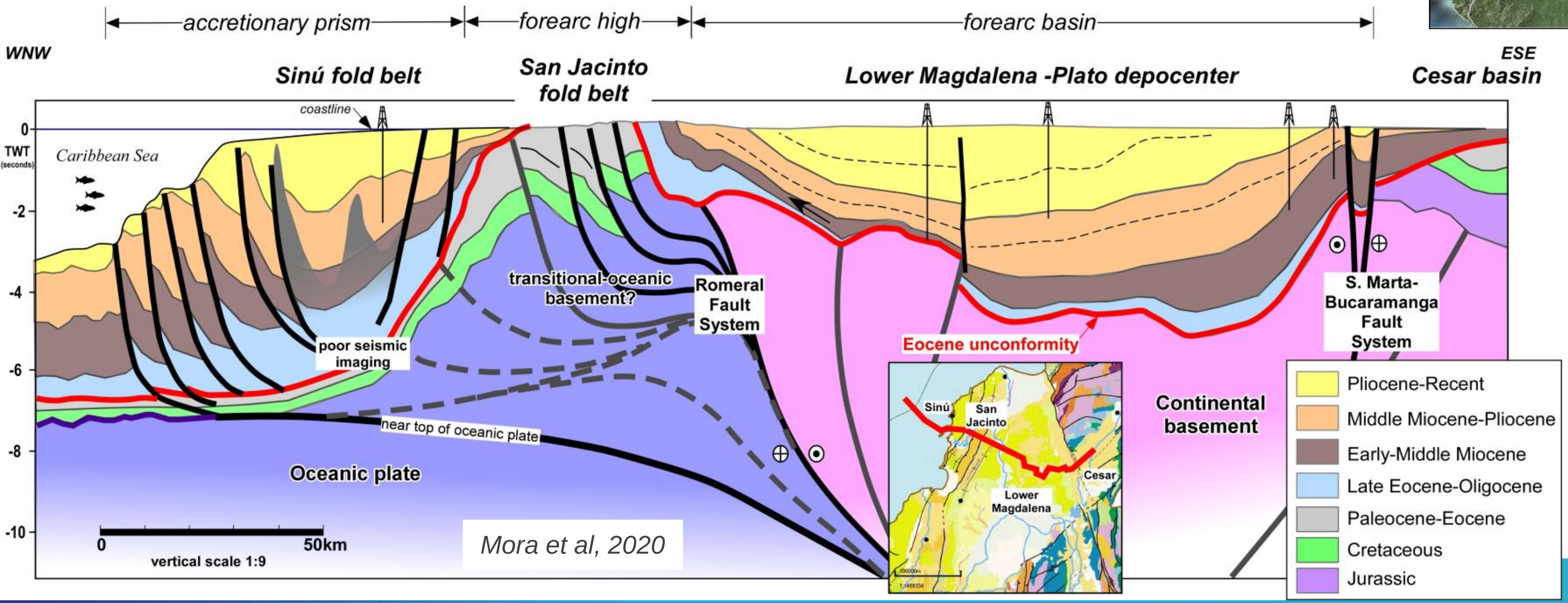
Restrepo & Toussaint, 2020



- **Several accretion espisodes have formed a complex melange of different litho-tectonic terranes in the Andes.**
- **Two main tectonic schemes have been proposed: a less-detailed, more simple by Toussaint & Restrepo (2020, should be adjusted in the N-red circle) and a more complex and detailed (Cediel, 2019).**

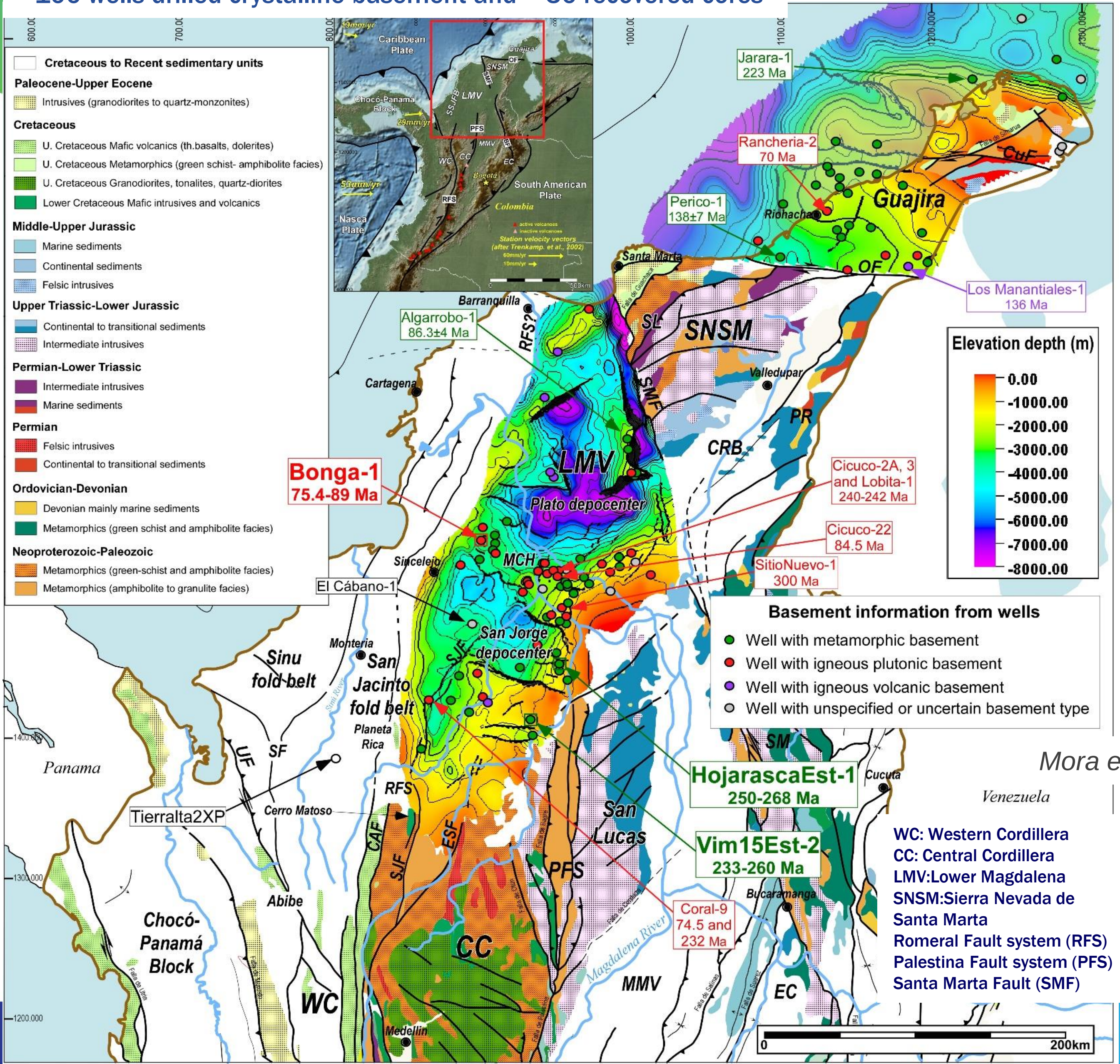
Tectonic setting of N Colombia





Basement in N Colombia

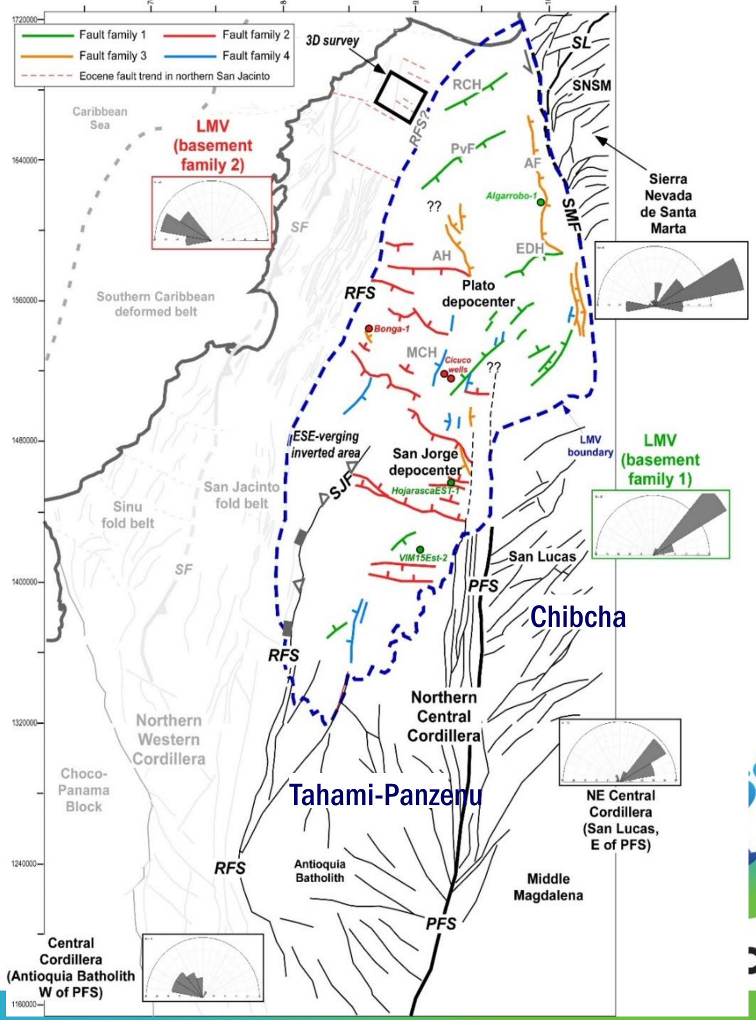
~100 wells drilled crystalline basement and ~ 30 recovered cores



Mora et al., 2017a

WC: Western Cordillera
CC: Central Cordillera
LMV:Lower Magdalena
SNSM:Sierra Nevada de Santa Marta
Romeral Fault system (RFS)
Palestina Fault system (PFS)
Santa Marta Fault (SMF)

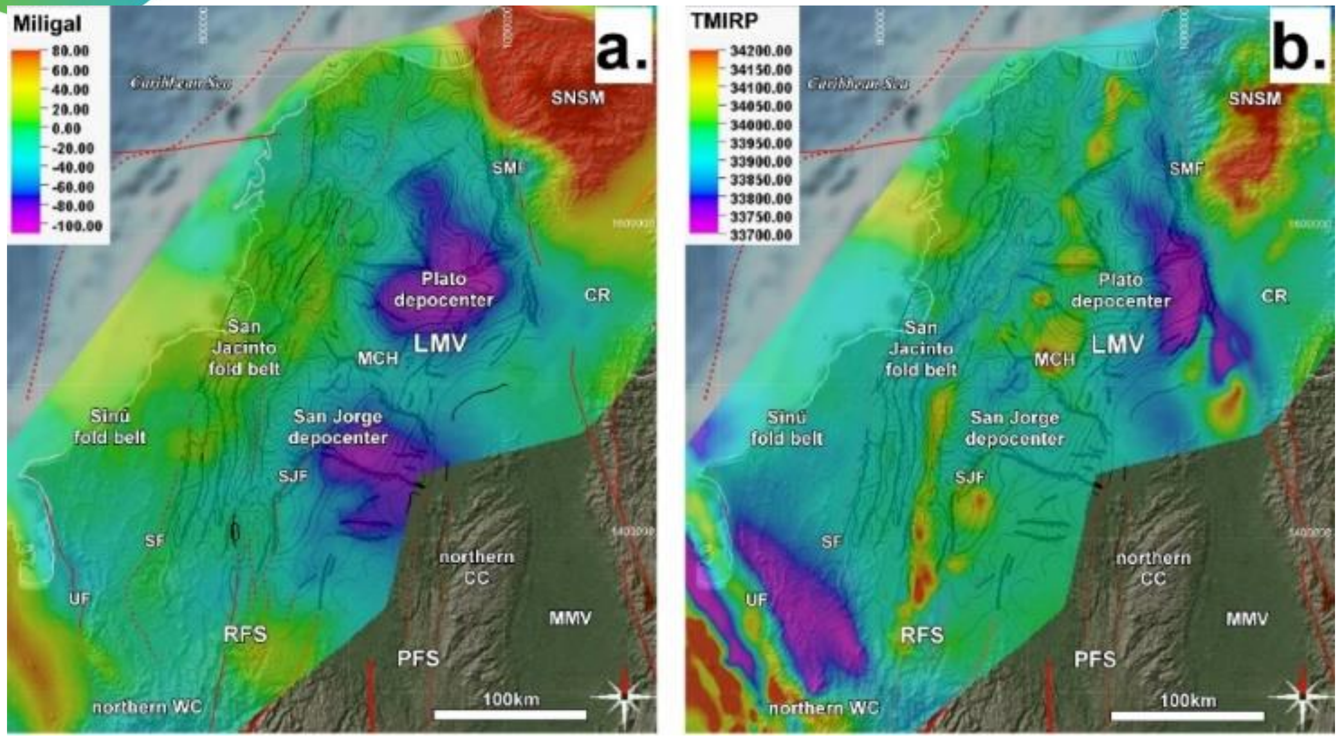
- The basement of LMV is northward extension of basement terranes in the northern CC; San Jacinto appears to be the possible extension to the N of an oceanic terrane.
- The origin of the basement fabrics has been related to Jurassic rifting and oblique convergence in the forearc which caused extension, strike-slip and block rotation.

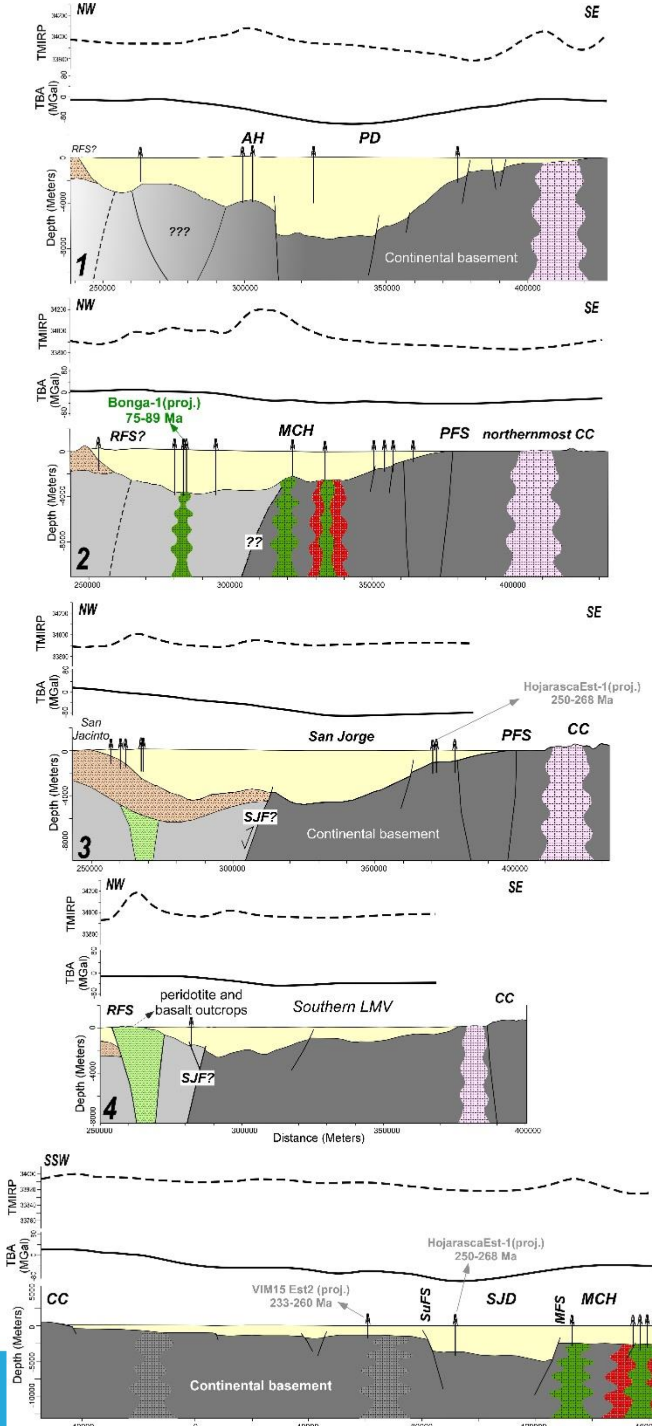


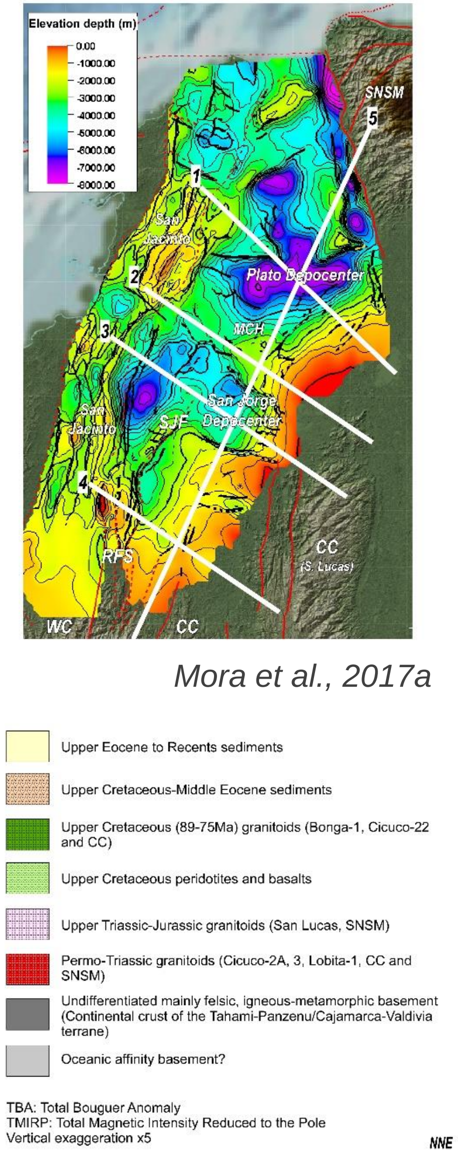
Potential Methods

aerogravimetría

aeromagnetometría







Mora et al., 2017a

Potential methods suggest a change in physical properties (mainly densities) of the basement towards the San Jacinto fold belt to the W:
Denser terrane with more transitional to oceanic affinity?

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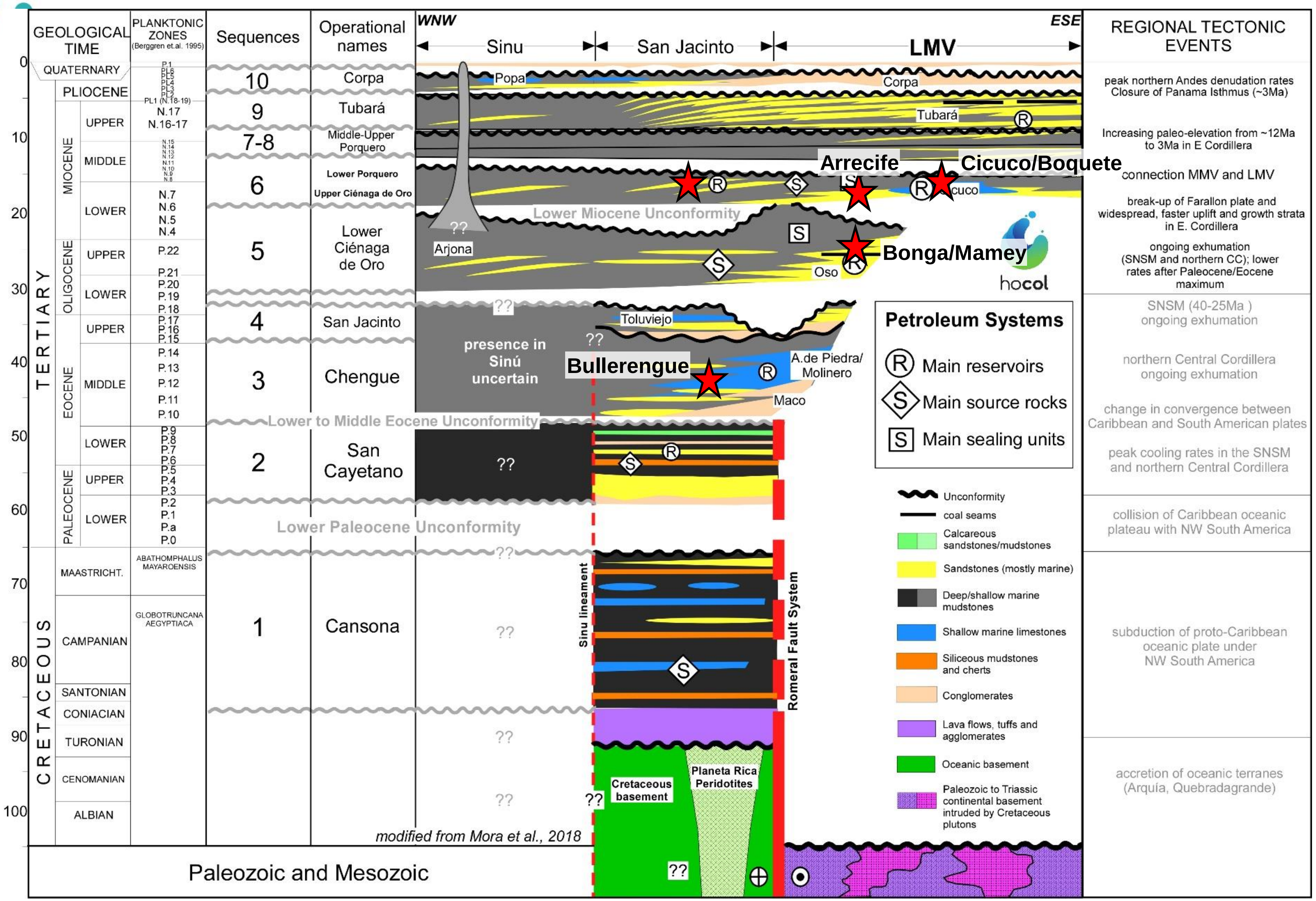
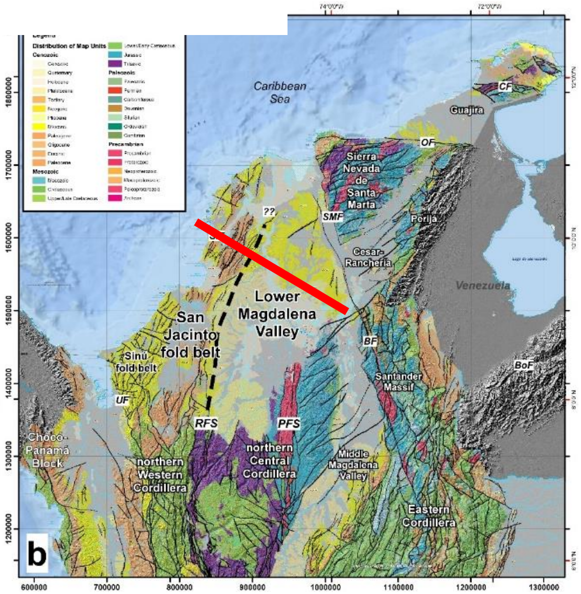
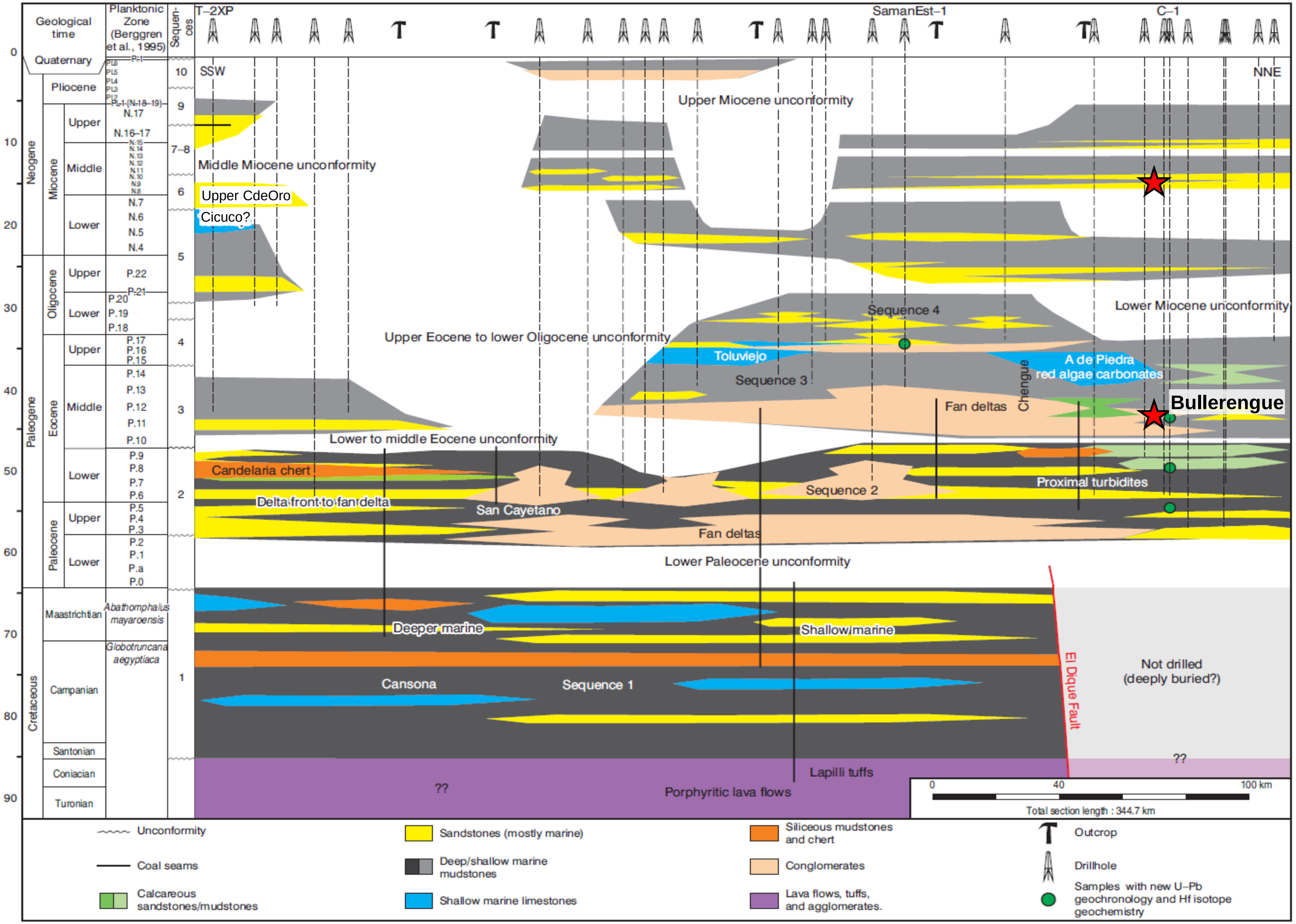
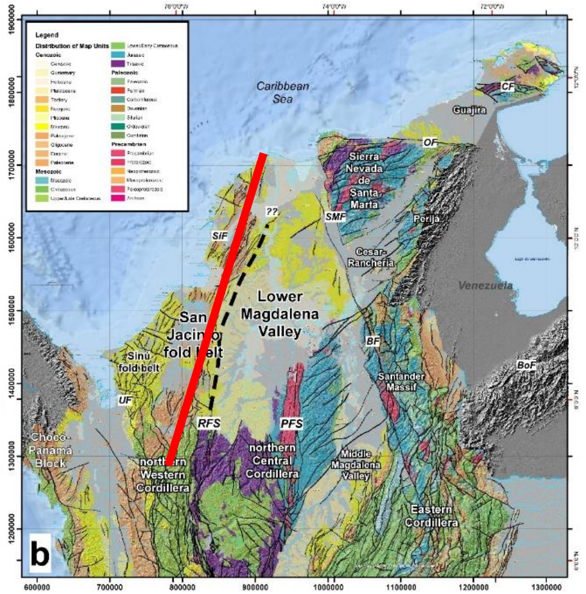
NW Colombia stratigraphic chart





San Jacinto stratigraphic chart (SSW-NNE)

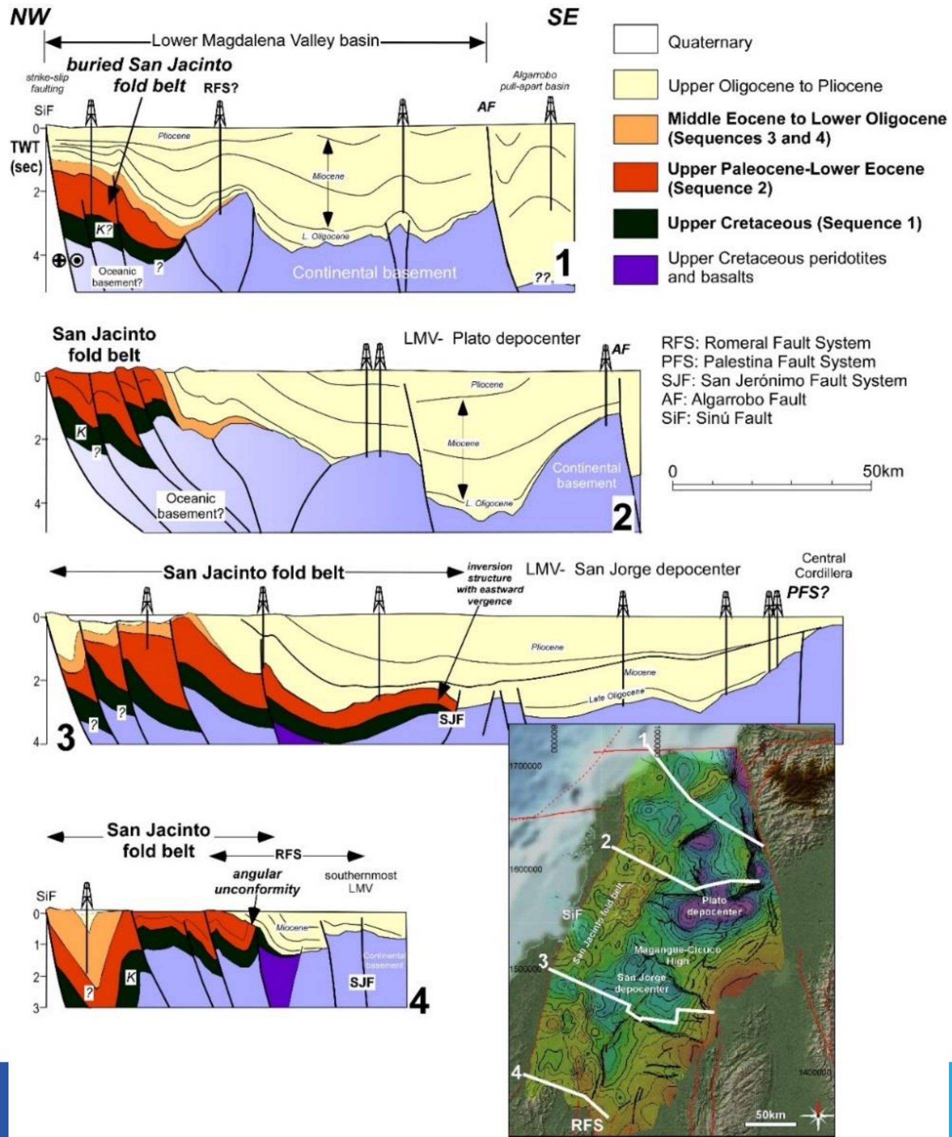


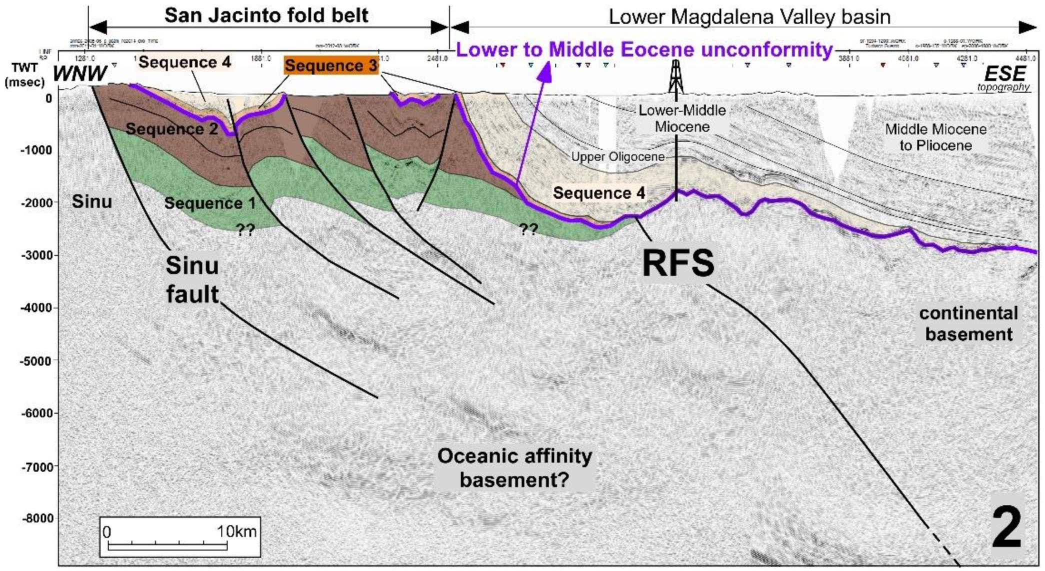


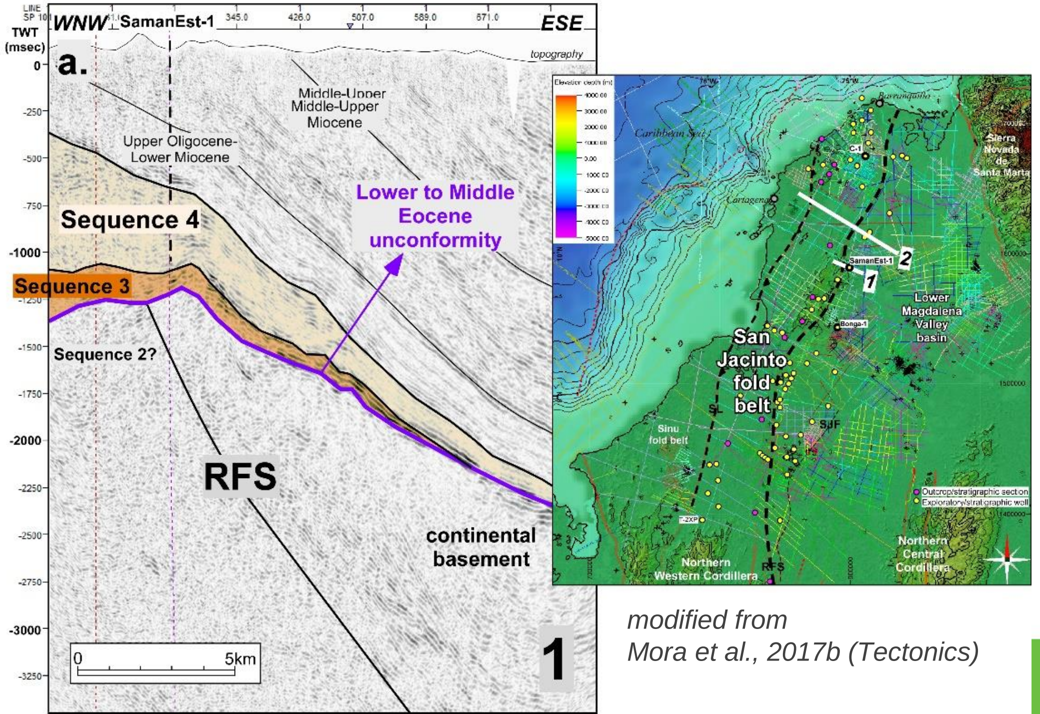
Mora et al., 2020

Structure & tectono-stratigraphy of the San Jacinto fold belt

- Angular unconformity below sequences 3 and 4 marks a major lower to middle Eocene tectonic event, related to the strike-slip activity of the RFS
- Sequences 3 and 4 are sealing the activity if the RFS
- RFS mostly inactive since Oligocene times, activity decreases to the N

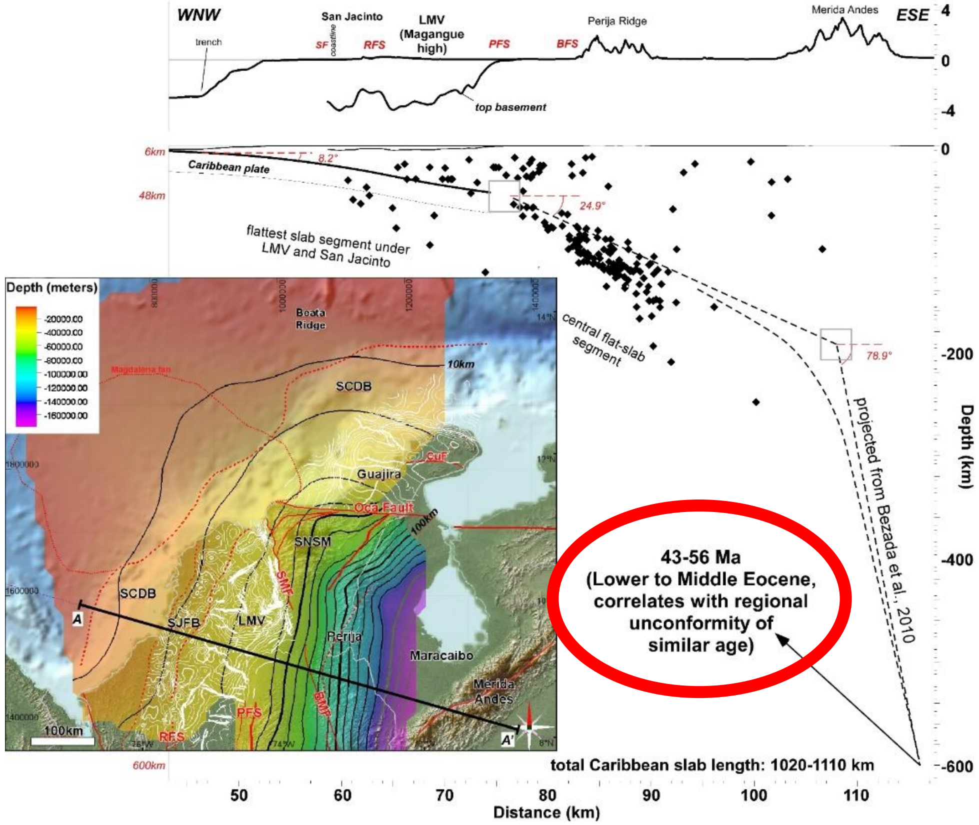






modified from
Mora et al., 2017b (Tectonics)

Subduction and paleo-tectonic reconstruction



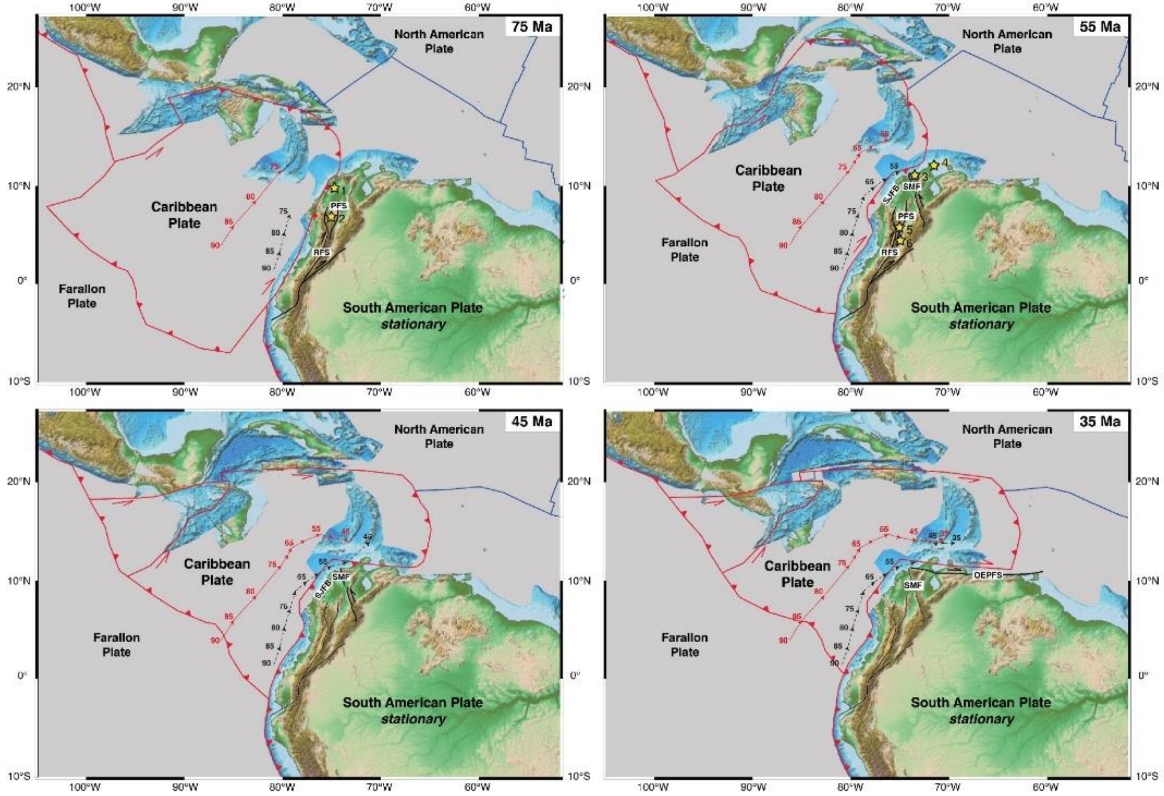
Mora et al., 2017b (Tectonics)

	Slab segment length (km) (± 15 km error)	Calculated age of slab entrance in the trench using mean plate velocities over the last 45 Ma	
		Boschman et al. 2014 19 mm/yr	Matthews et al. 2016 25 mm/yr
Western flat slab segment under SJFB and LMV	278-308	14.6-16.2 Ma	11.1-12.3 Ma
Central intermediate-depth flat slab segment	341-371	18-19.5 Ma	13.6-14.8 Ma
Eastern deepest and steepest slab segment	401-431	21.1-22.7 Ma	16-17.2 Ma
Western plus Central flat slab segments	619-679	32.6-35.7 Ma	24.8-27.2 Ma
All three slab segments	1020-1110	**53.7-58.4 Ma (56 ± 2 Ma)**	**40.8-44.4 Ma (43 ± 2 Ma)**
*Slab length by Van Benthem et al. (2013)**	*900*	***47,4 Ma***	***36 Ma***

** they interpret three slab segments, each one 300 km-long*

Paleo-tectonic reconstructions in Gplates

Arc magmatism was shut off at middle Eocene times (~45 Ma)



Matthews et al., 2016
Boschman et al., 2014
GPlates models

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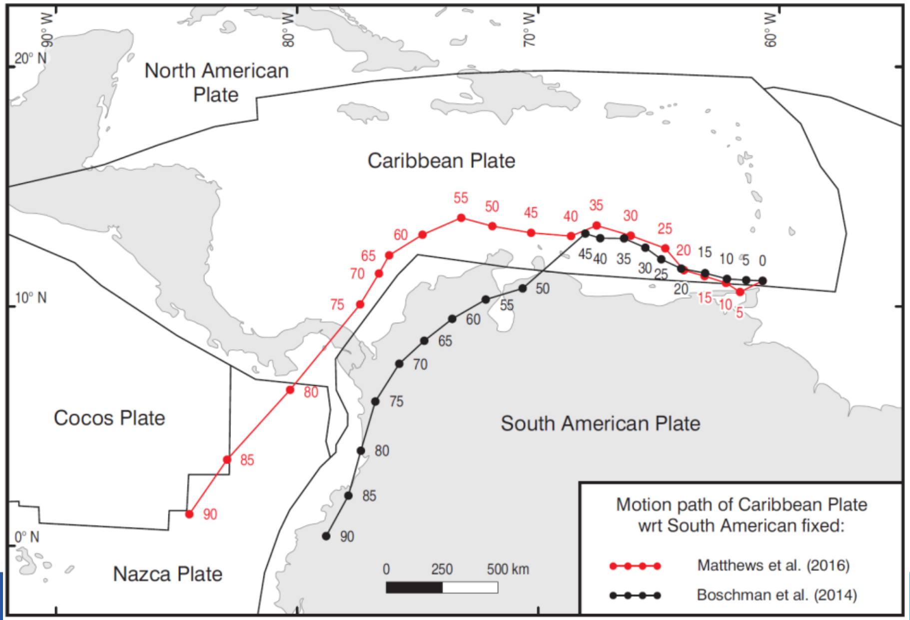
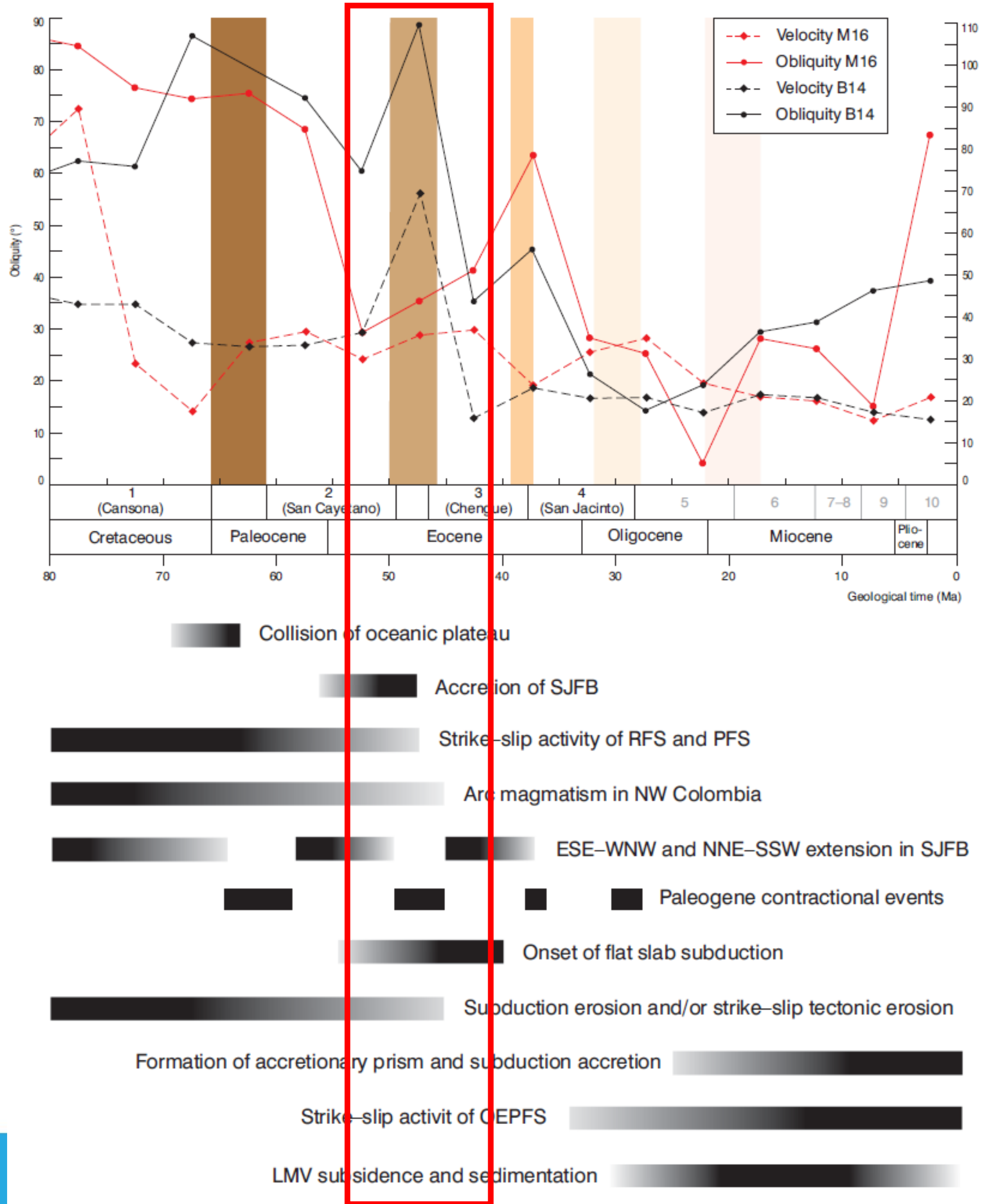
Plate convergence vs tectonic events & unconformities in San Jacinto

- A notorious decrease in convergence obliquity and velocity, related to the tectonic readjustement between the Caribbean and South America, coincides with the lower to middle Eocene unconformity, with the end of activity of major suture zones and with the end of arc magmatism.
- Such a readjustment would have influenced the onset of flat subduction, as well as the later onset of activity of the OEPFS and sedimentation in the LMV.
- Therefore we have linked the evolution of the convergence between the Caribbean and South American plates to the deposition of the pre-Oligocene forearc sequences in the San Jacinto fold belt.

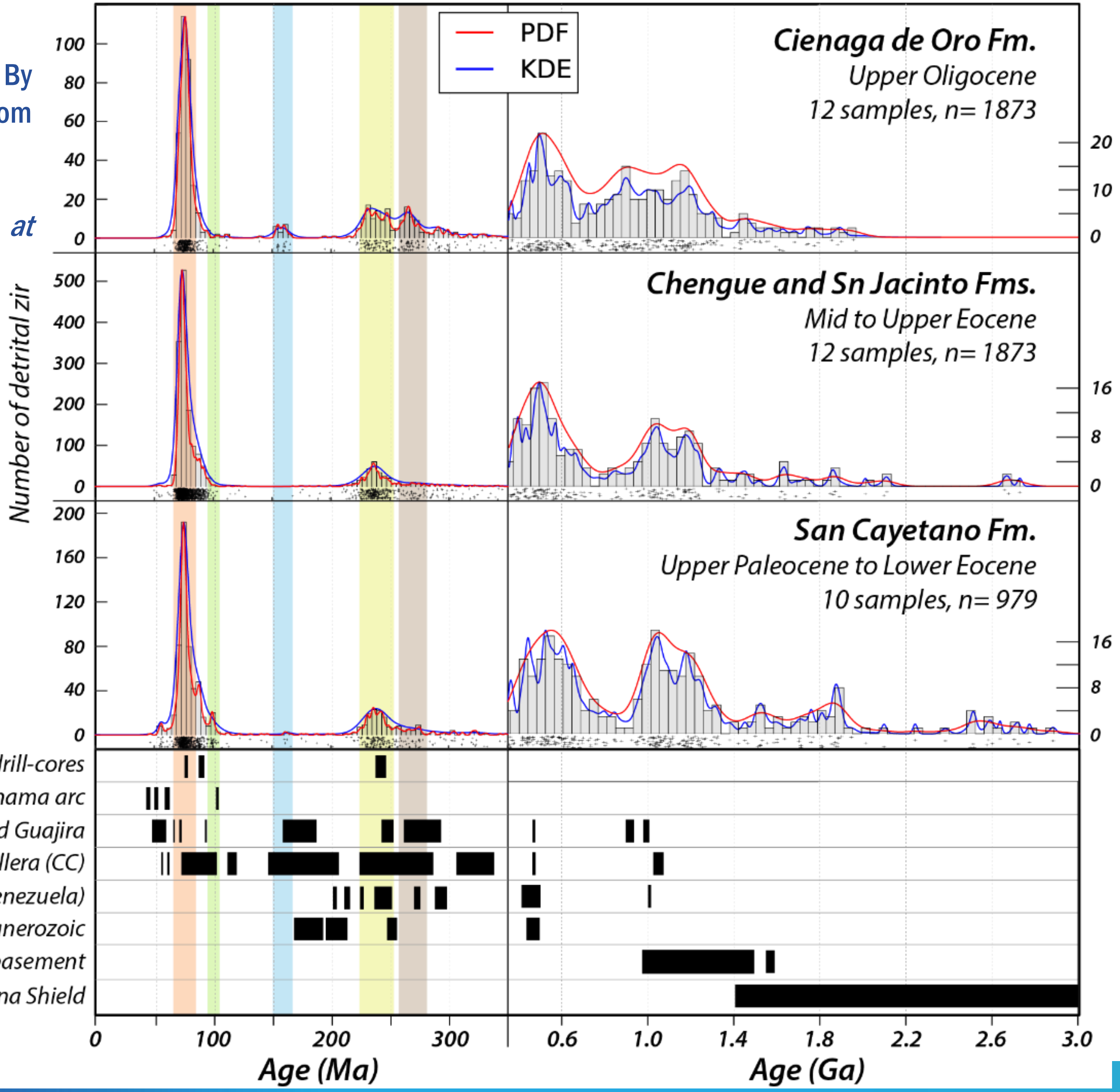




Recent U-Pb DZ geochronology

Samples collected By Ecopetrol, Hocol and from public databases

**Note change in scale at 350 Ma*

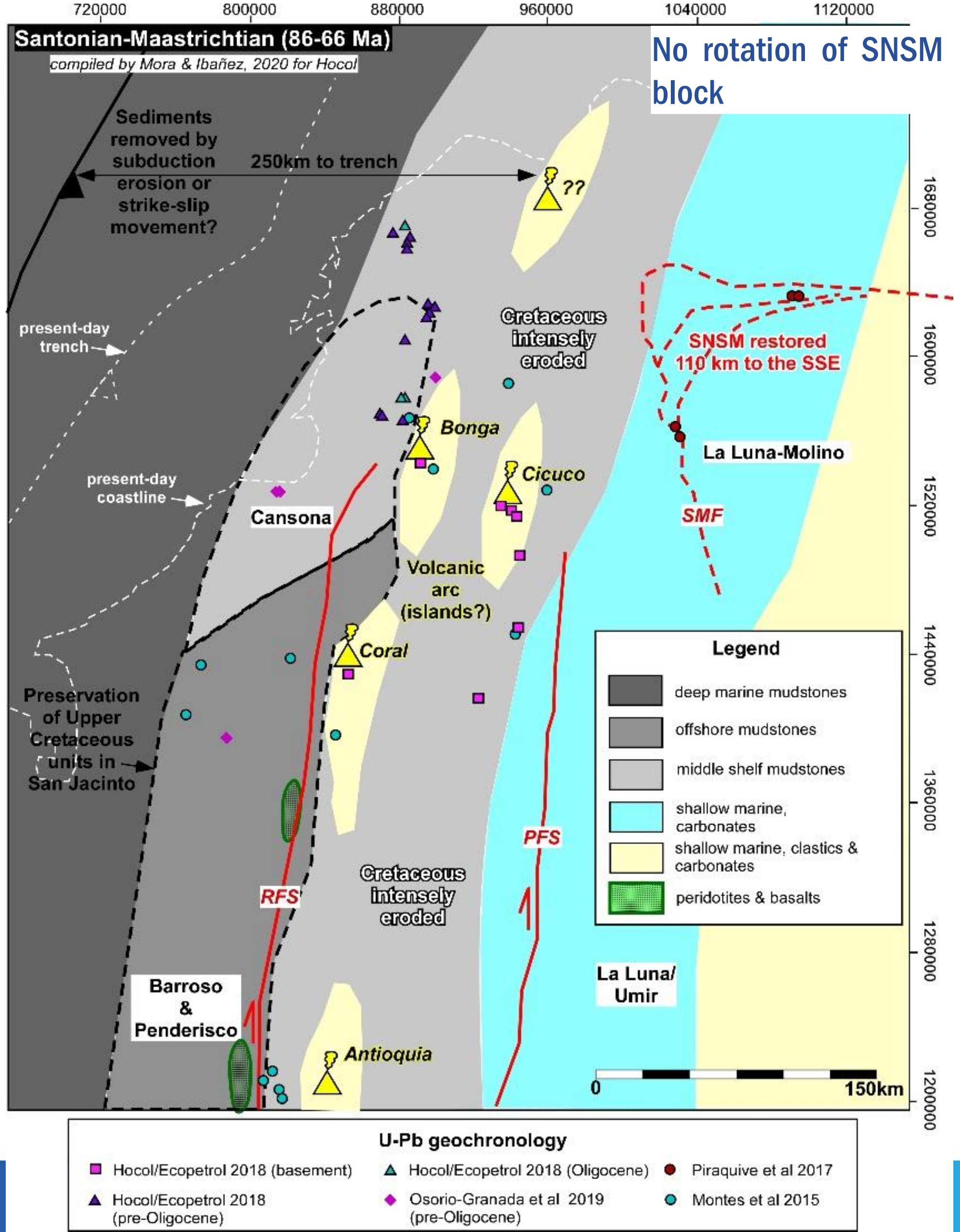


- Two main provenance peaks (Upper Cretaceous, 70-90 Ma and Permo-Triassic, 230-290 Ma), point to the northern termination of the Central Cordillera, the LMV basement and the Santa Marta massif as main source areas.

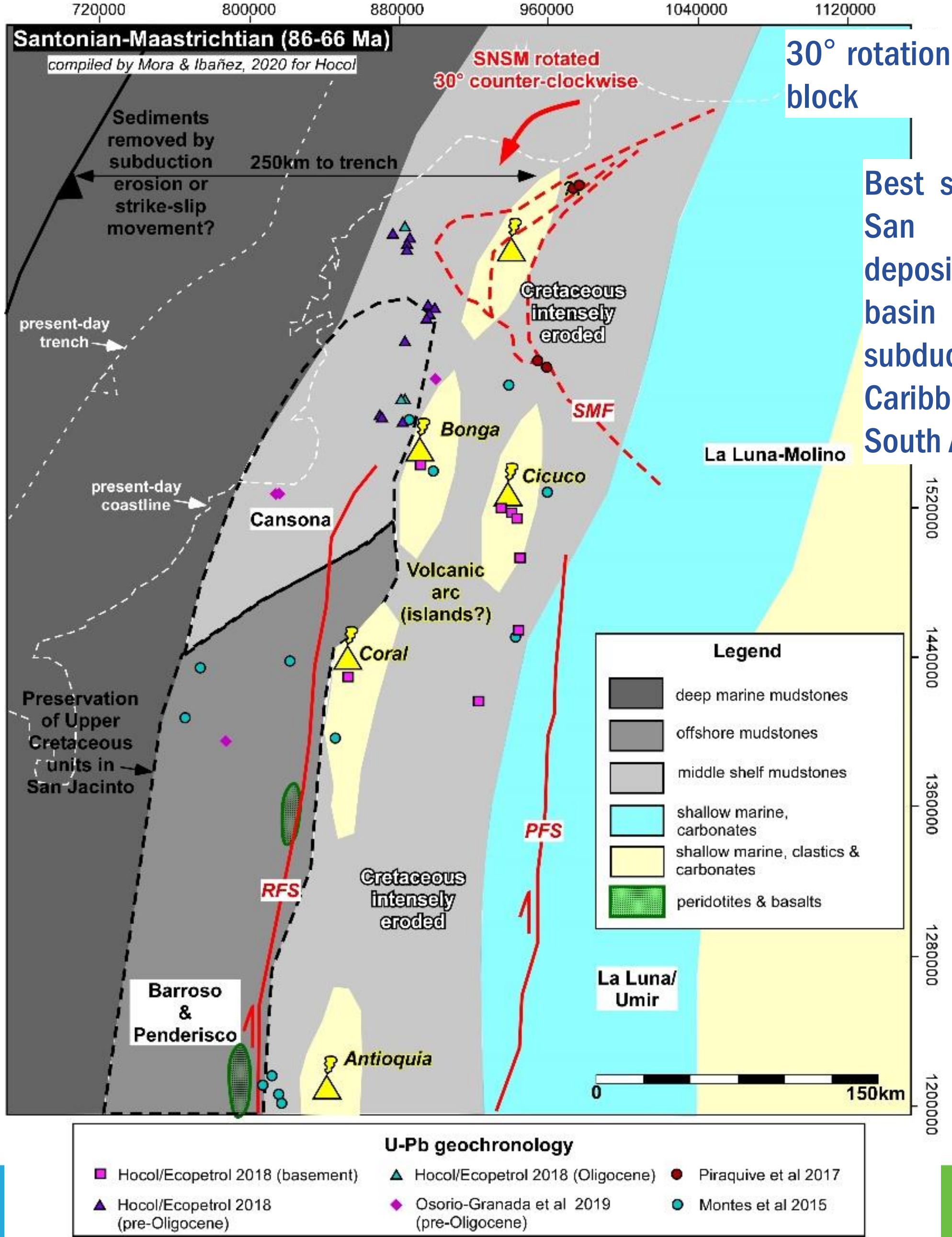
Compiled by Mora and Ibañez, 2020 for Hocol

hocol

Late Cretaceous tectonics & sedimentation



No rotation of SNSM block

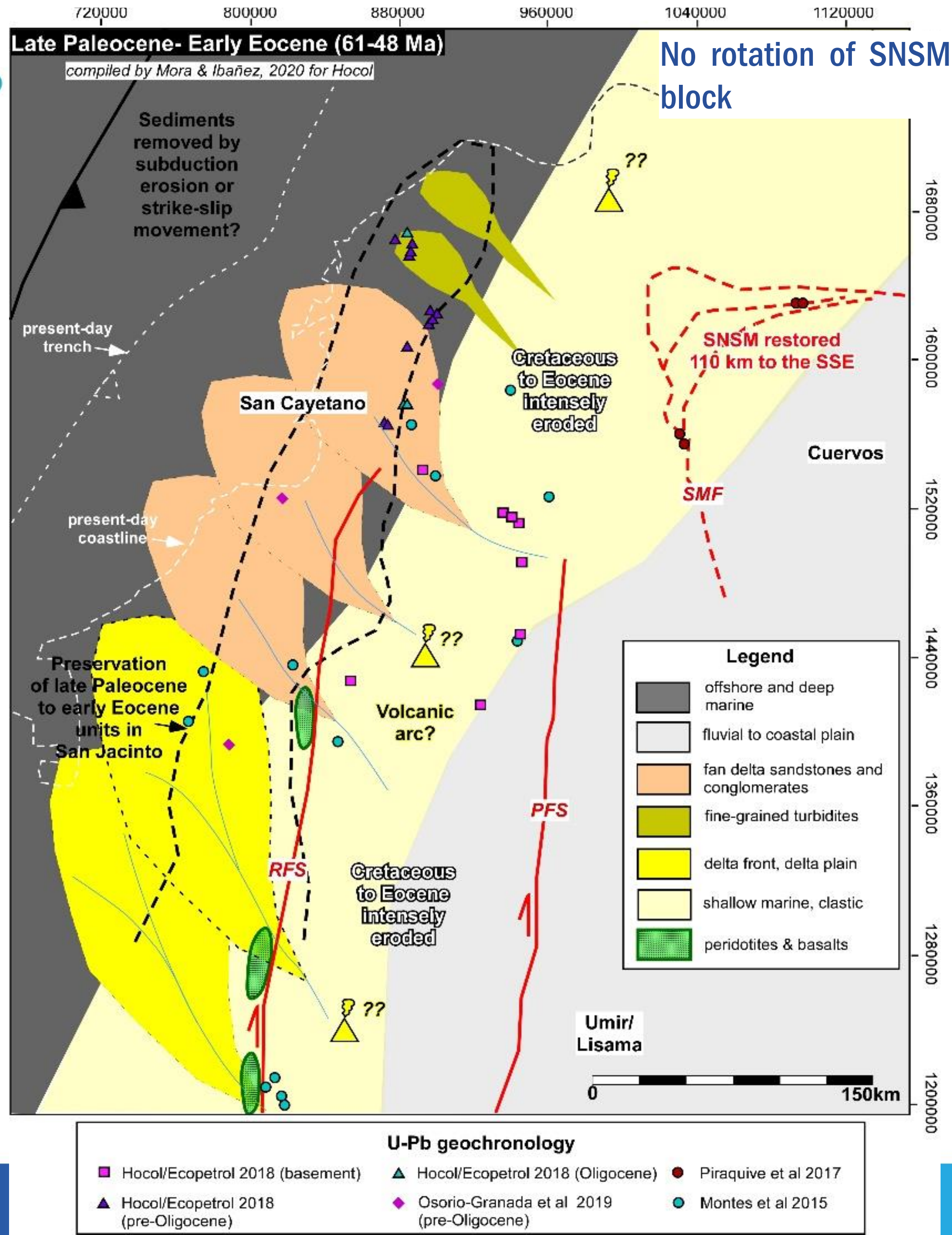


30° rotation of SNSM block

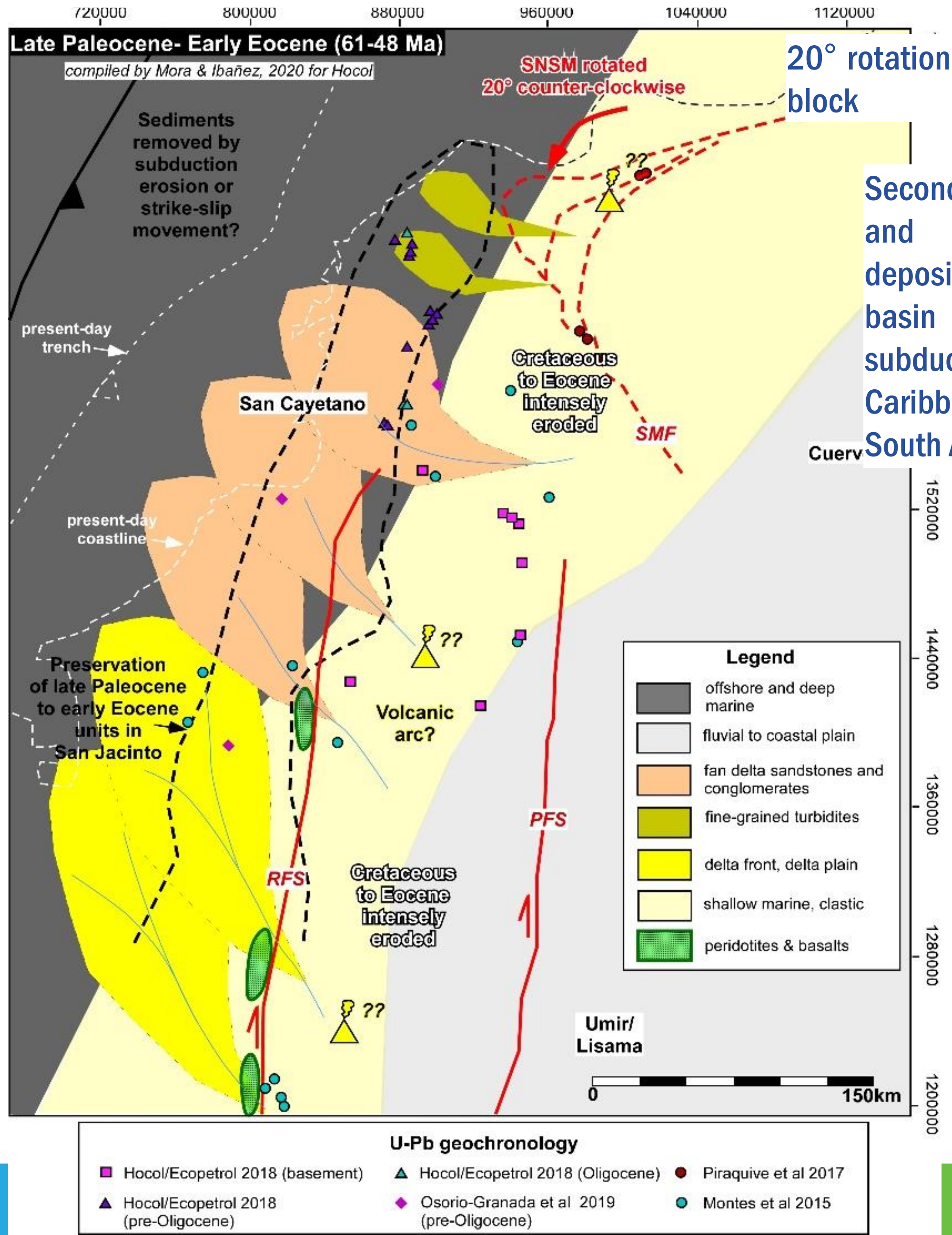
Best source rocks in San Jacinto were deposited in a forearc basin related to subduction of the Caribbean beneath South America

hocol

Late Paleocene- Early Eocene Tectonics & sedimentation



No rotation of SNSM block

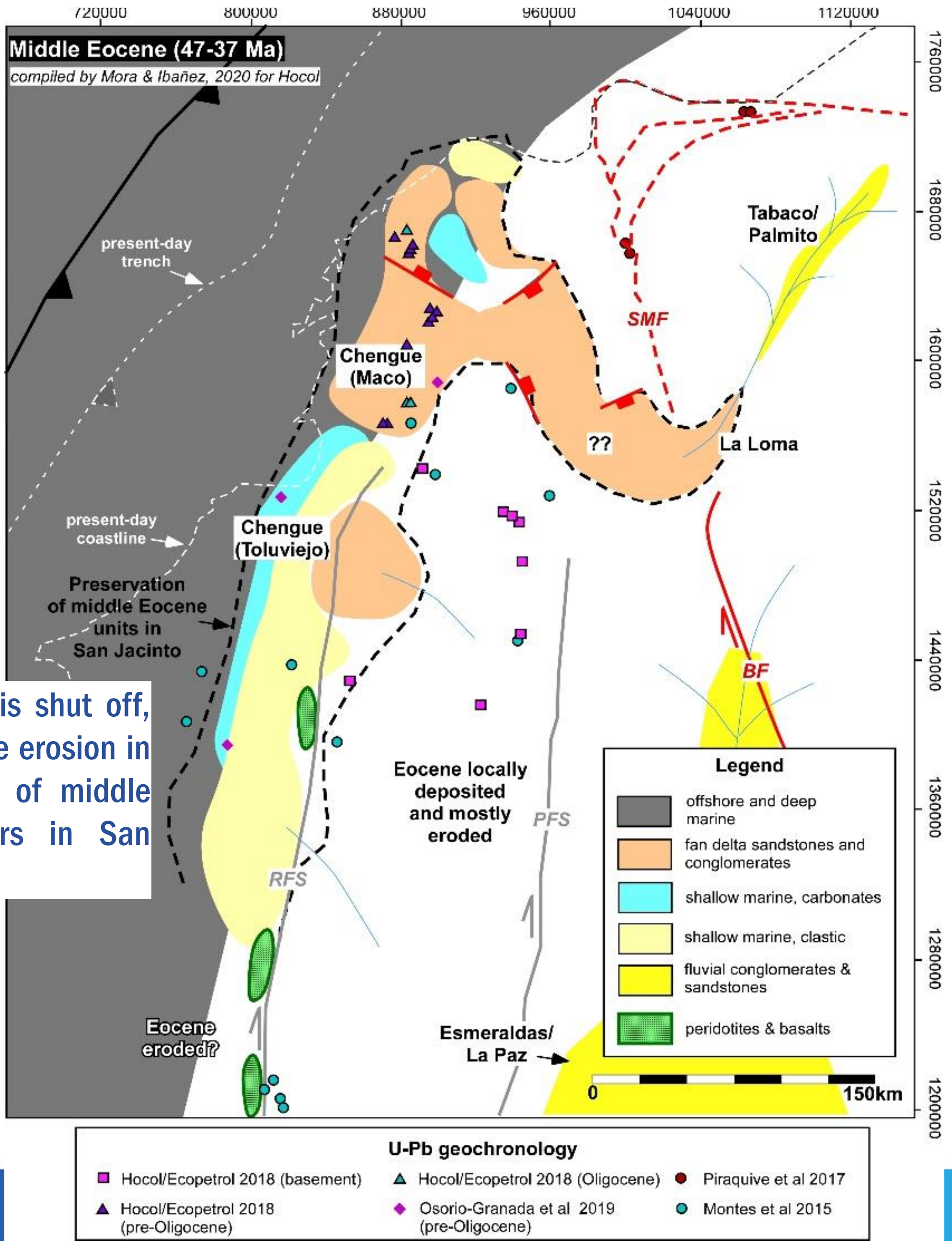


20° rotation of SNSM block

Secondary sources and reservoirs deposited in a forearc basin related to subduction of the Caribbean beneath South America

hocol

Middle Eocene-Early Oligocene Tectonics & sedimentation



Arc magmatism is shut off, uplift and intense erosion in LMV; deposition of middle Eocene reservoirs in San Jacinto

The San Jacinto fold belt is an intensely deformed, Cretaceous to Eocene forearc basin, related to the subduction of the Caribbean plate beneath South America, and its infill was strongly influenced by the tectonic evolution and plate re-adjustments (Mora et al 2017b, left).

Agenda

- Introduction and tectonic models
- Origin and Evolution of the San Jacinto basin
- Origin and Evolution of the Lower Magdalena Valley basin
- Petroleum systems
- Concluding remarks

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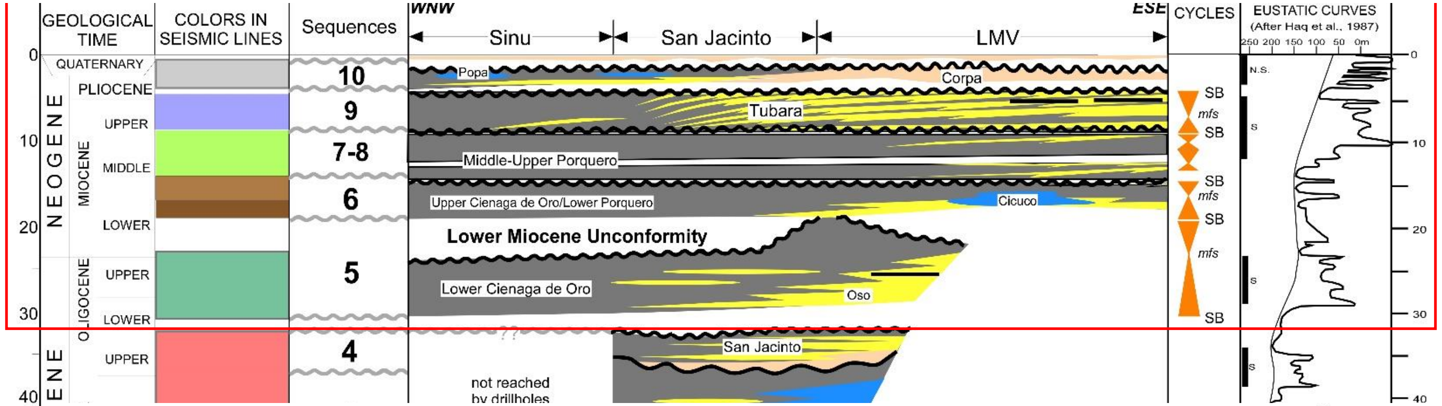
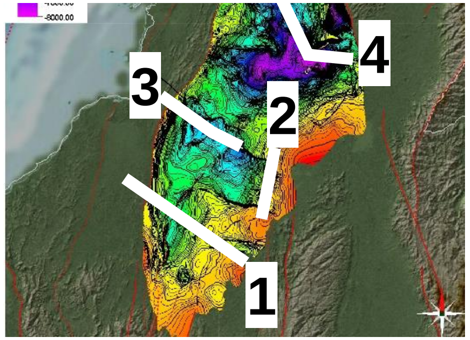
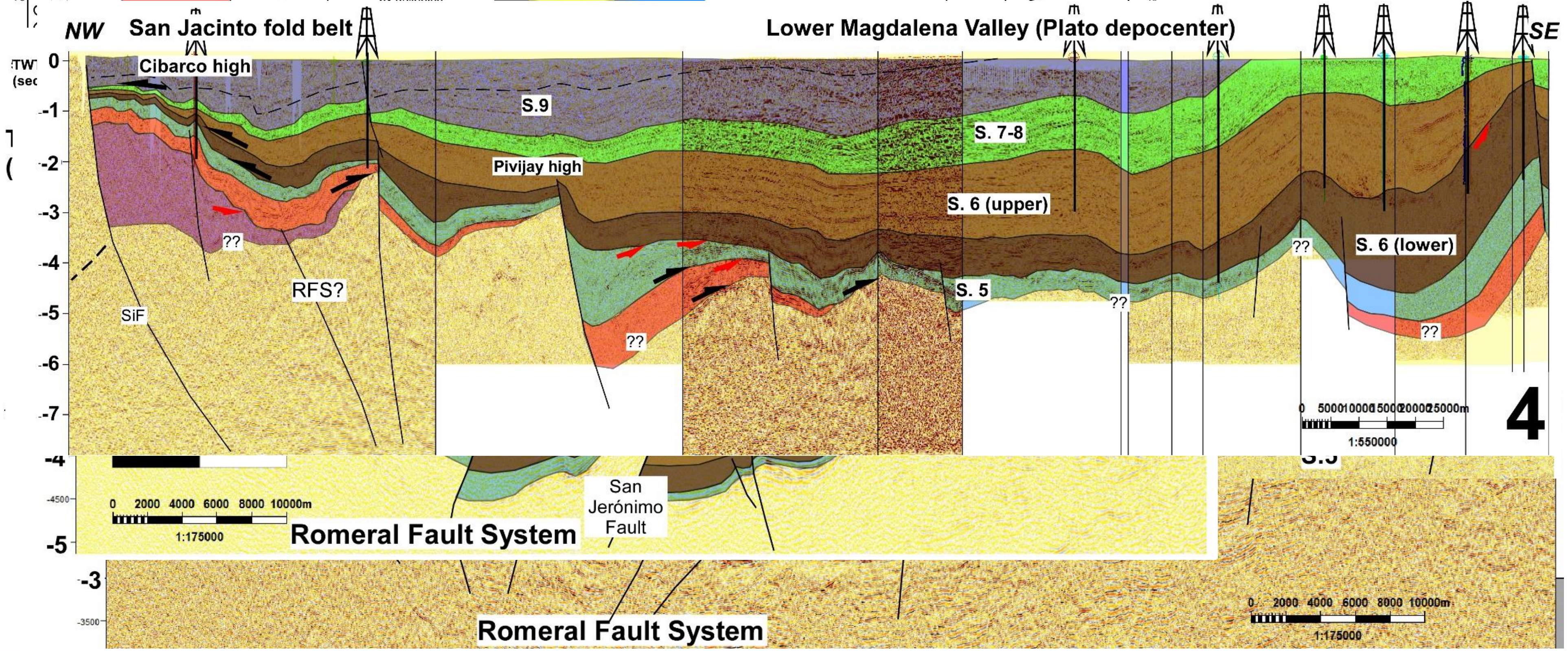
Oligocene to Recent stratigraphic sequences in the LMV





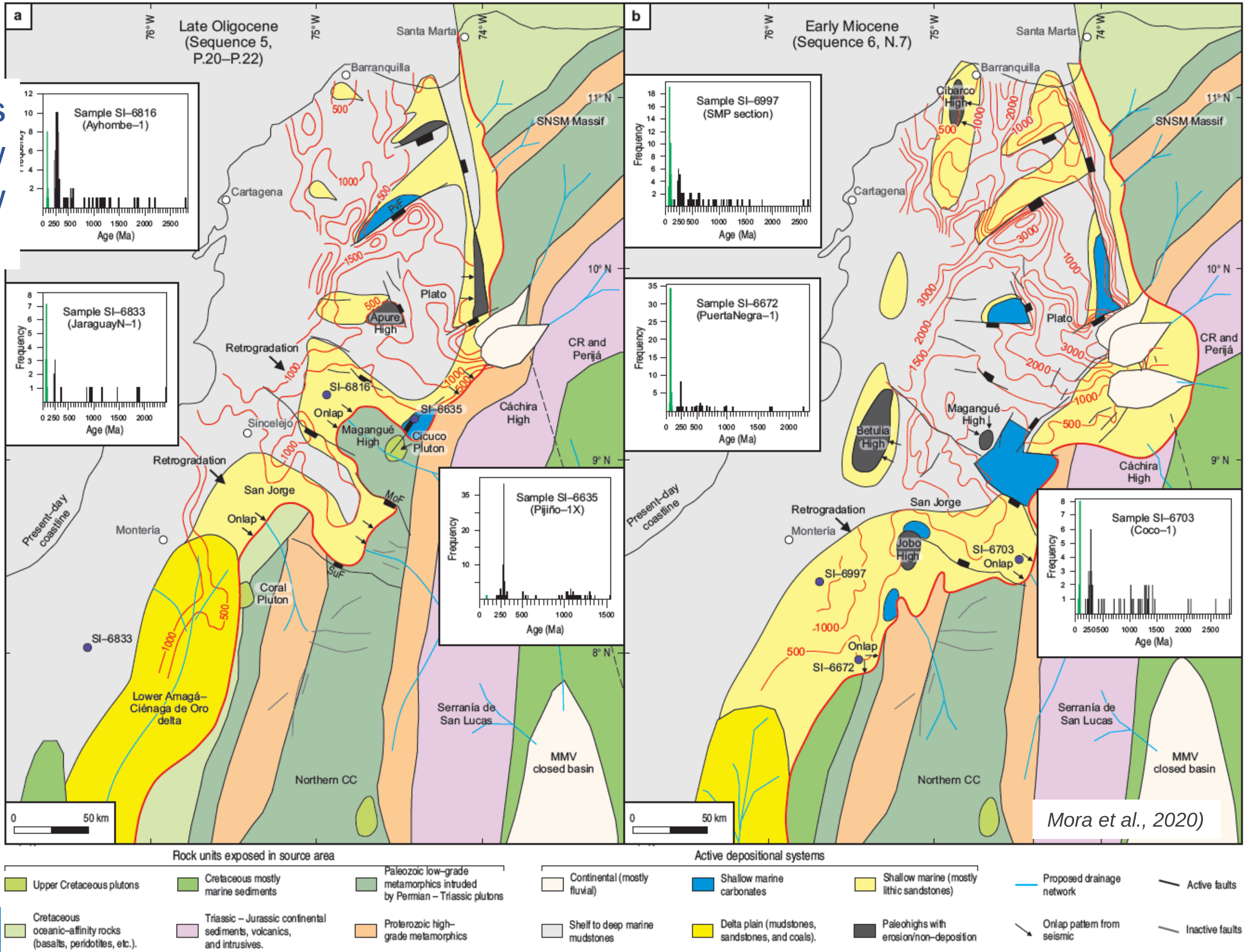


Mora et al., 2018)

truncation onlap/downlap

Oligocene- Early Miocene paleogeography

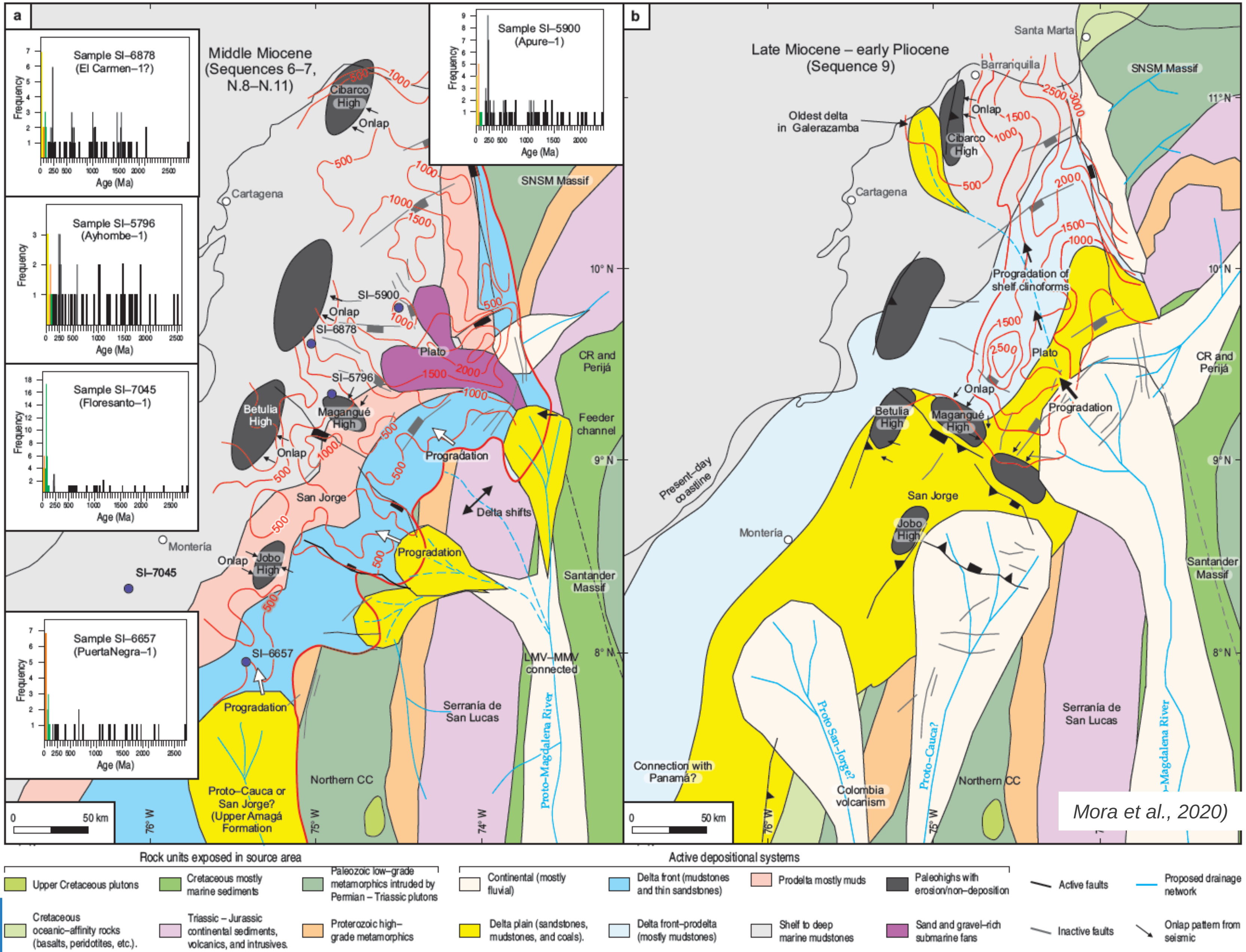
Facies distribution was initially controlled by basement paleotopography (basin segmentation).



Mora et al., 2020)

Red thin contours: isopachs in meters.
Red thick contour: sequence preservation boundary.
U-Pb detrital zircon geochronology from Montes et al. (2015).

Middle Miocene- Early Pliocene paleogeography



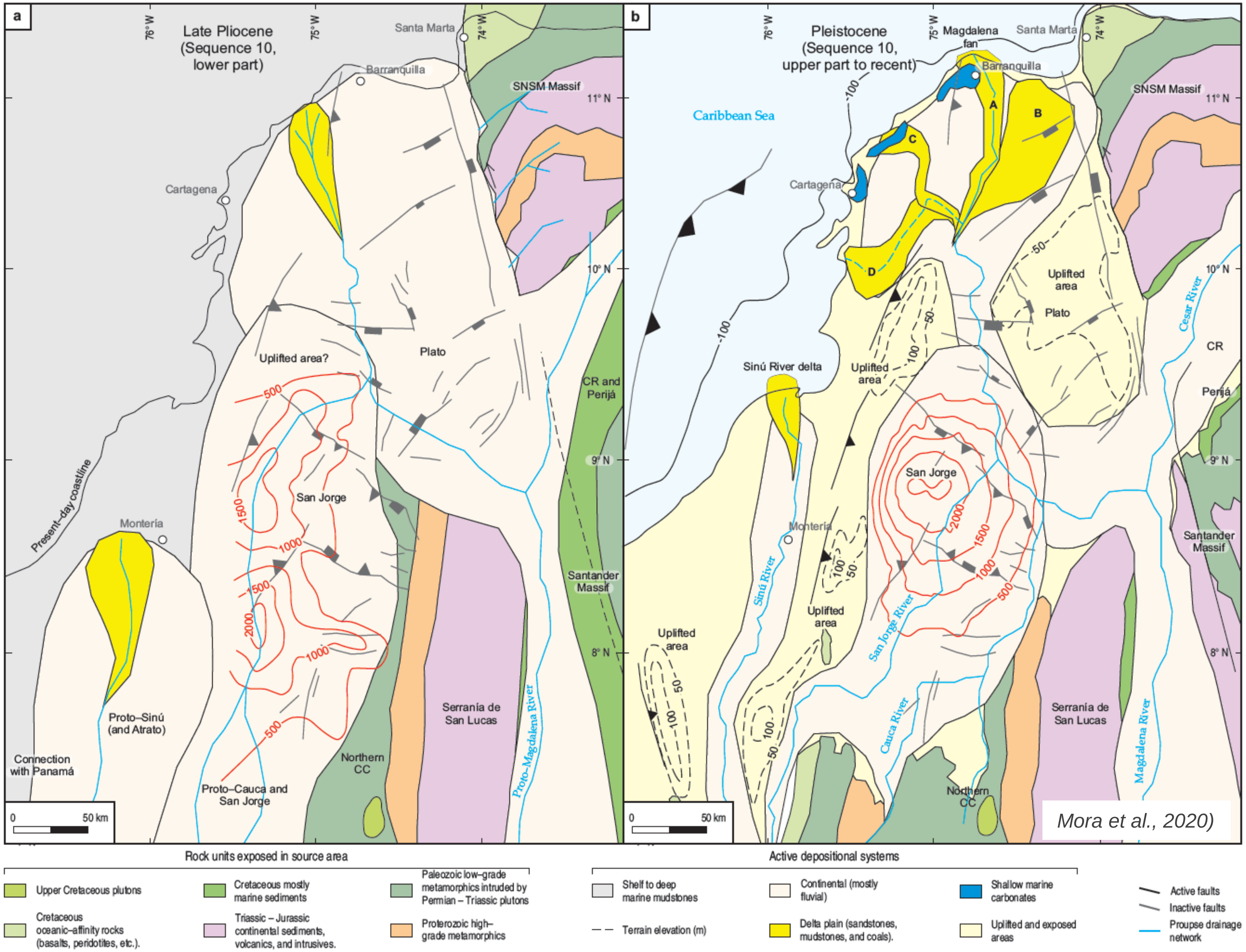
Mora et al., 2020)

Red thin contours: isopachs in meters.
Red thick contour: sequence preservation boundary.
U-Pb detrital zircon geochronology from Montes et al. (2015).

hocol

Late Pliocene-Pleistocene paleogeography

As the basin was filled, facies were more controlled by sediment supply and by uplift/subsidence pulses.

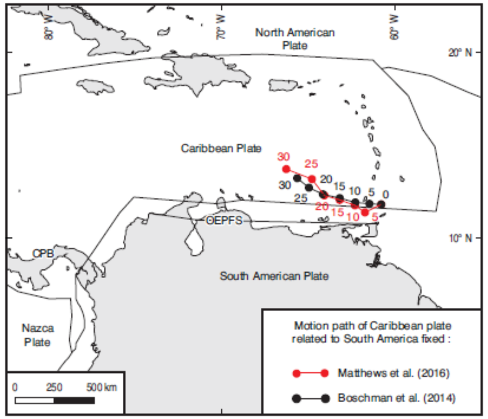


Red thin contours: isopachs in meters.
Red thick contour: sequence preservation boundary.
A-D in d represent Magdalena delta shifts (Romero et al. 2015).

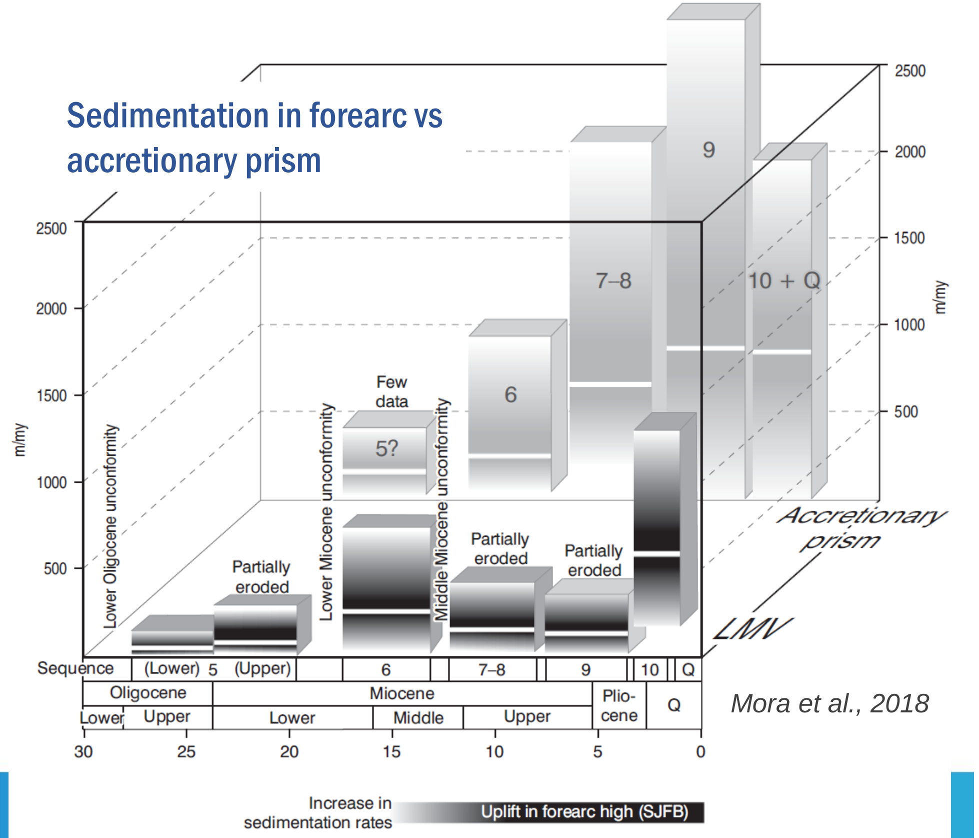
Plate convergence vs tectonic events & unconformities in LMV

While deposition took place in a low velocity and obliquity forearc setting, well data shows a notorious increase in both subsidence and sedimentation rates in early to middle Miocene times.

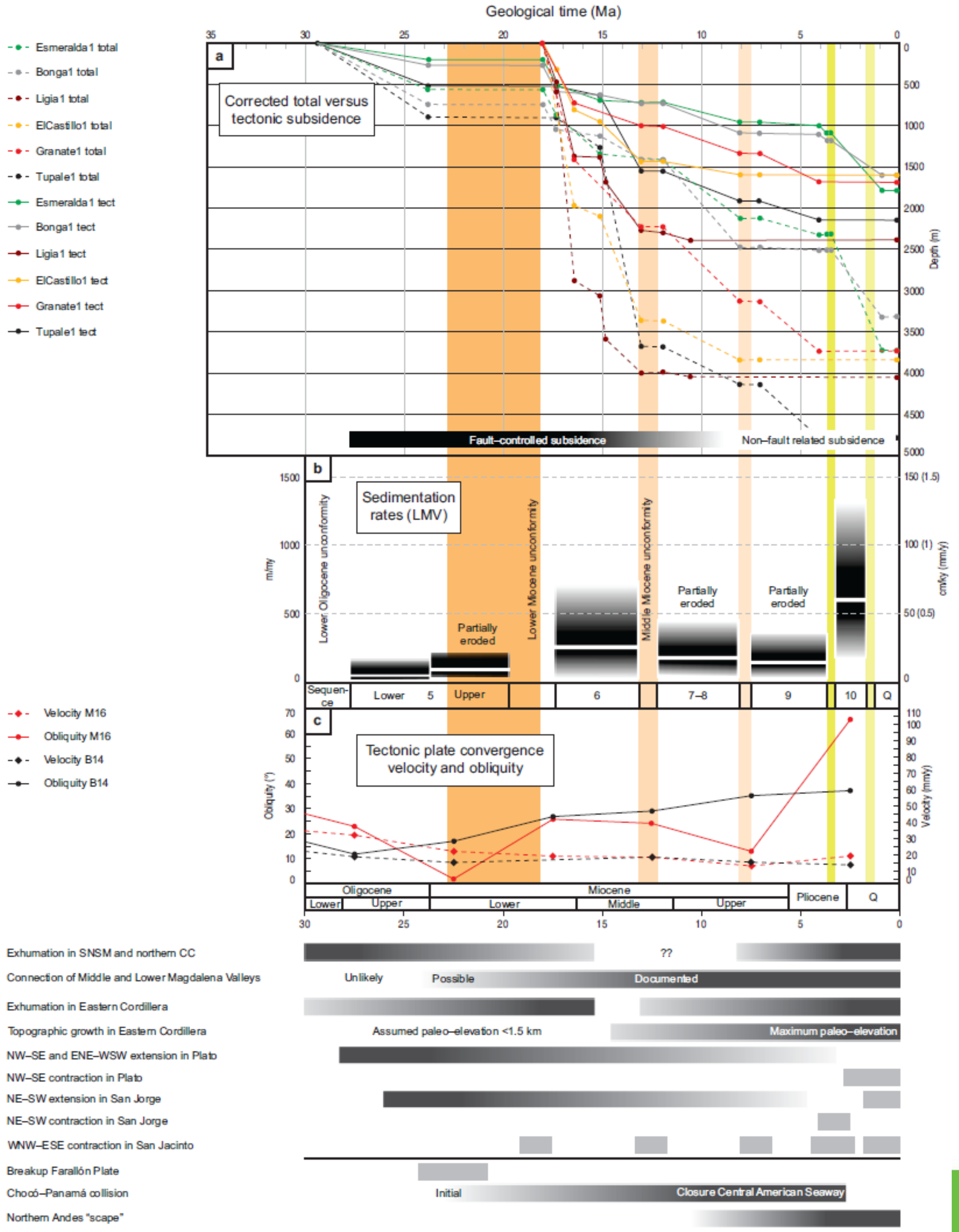
The LMV basin fill was more controlled by changes in the hinterland.



Sedimentation in forearc vs accretionary prism

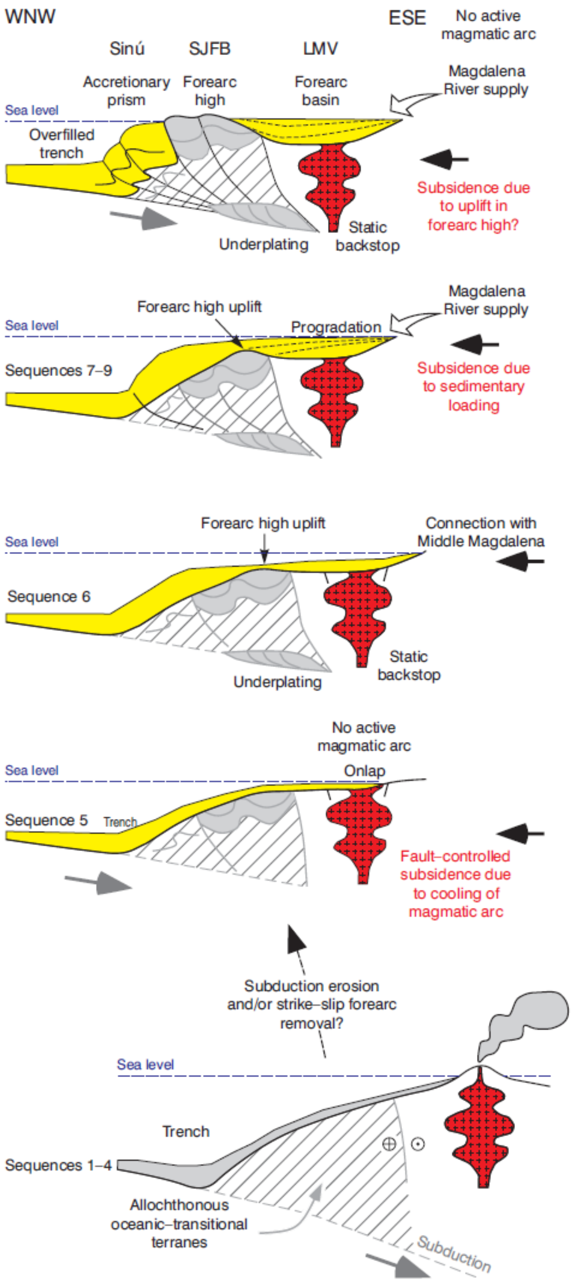


Mora et al., 2018



Controls in LMV formation & evolution

The LMV is a tectonically segmented, overfilled, amagmatic forearc basin whose formation and infill were controlled by sediment influx (connection MMV-LMV), basement structure and flat subduction.



Mora et al., 2018

Agenda

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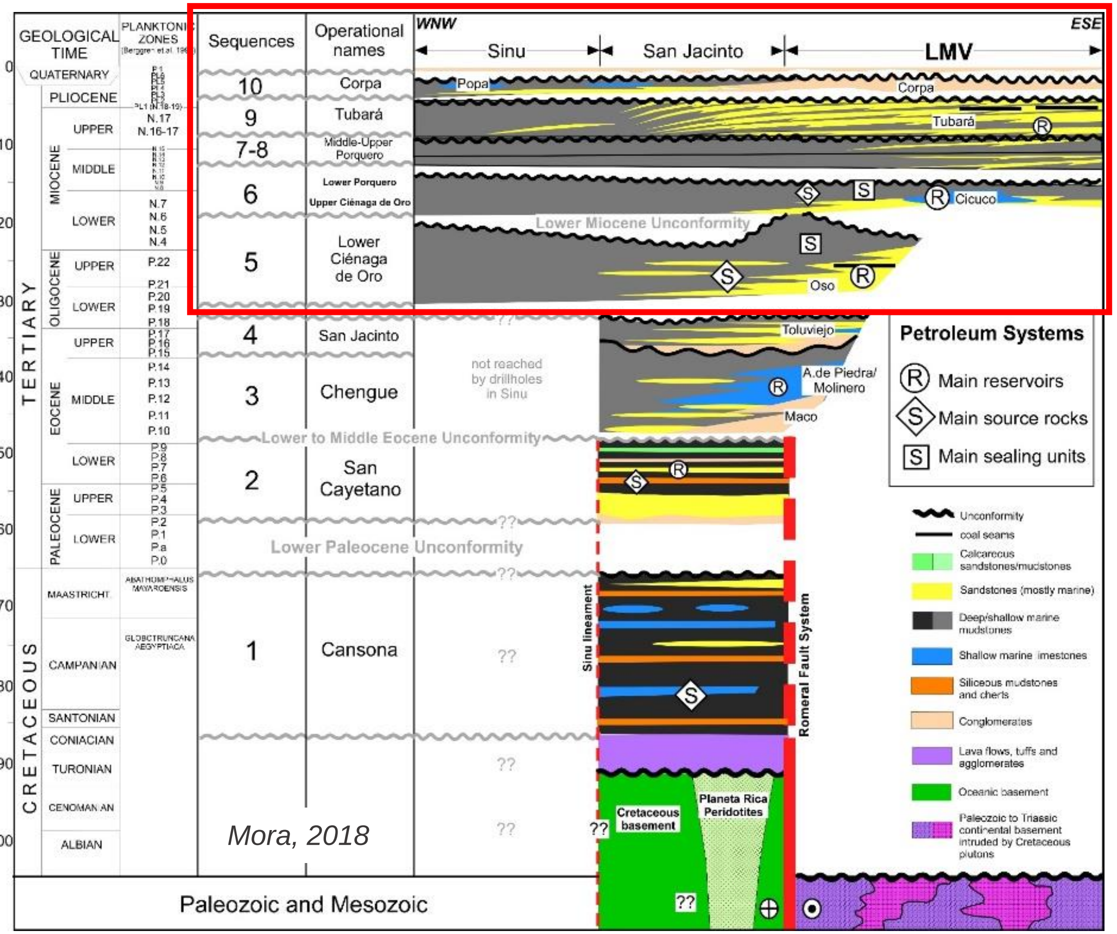
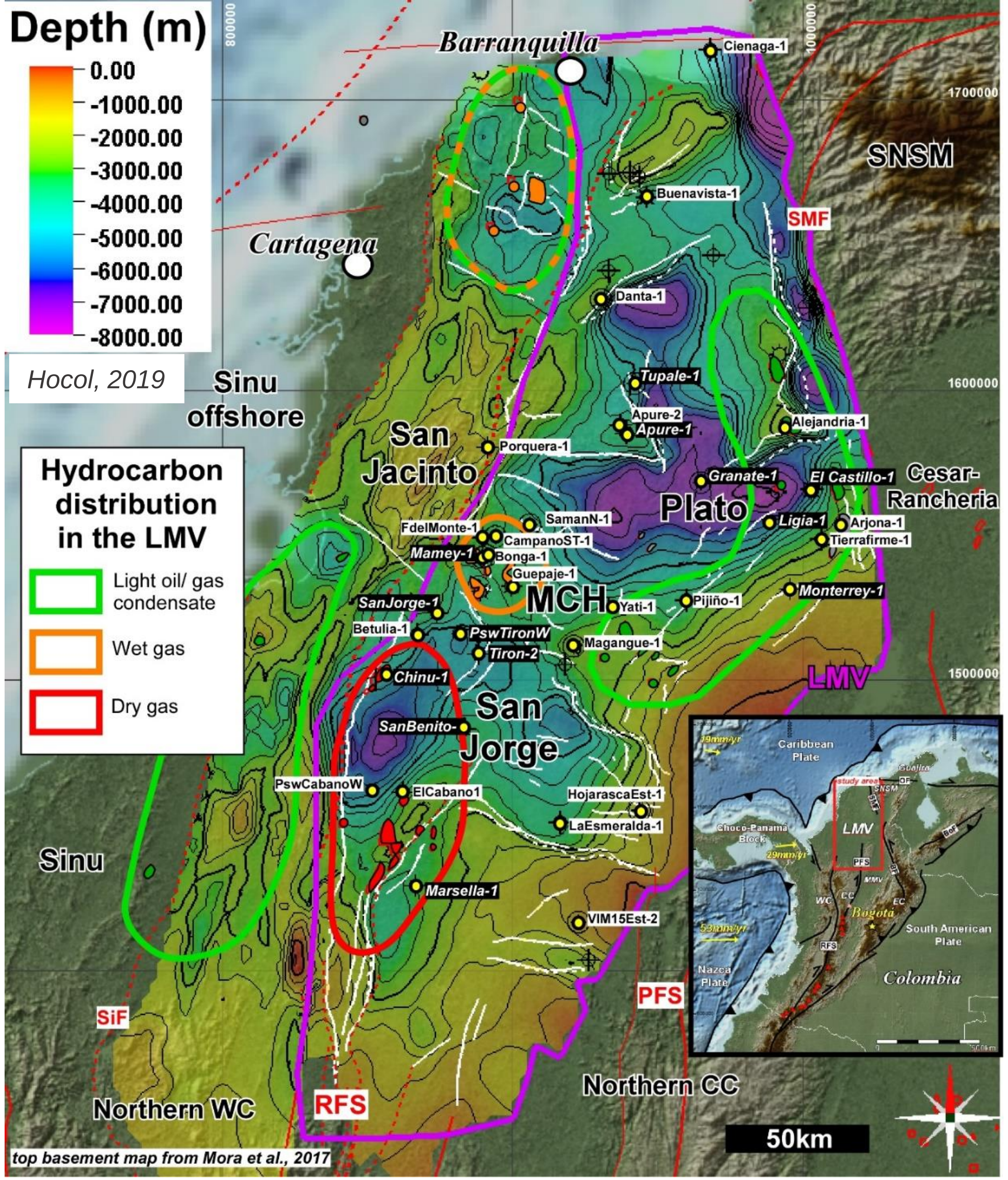
hocol

LMV basin modeling

Stratigraphic column & elements of petroleum systems

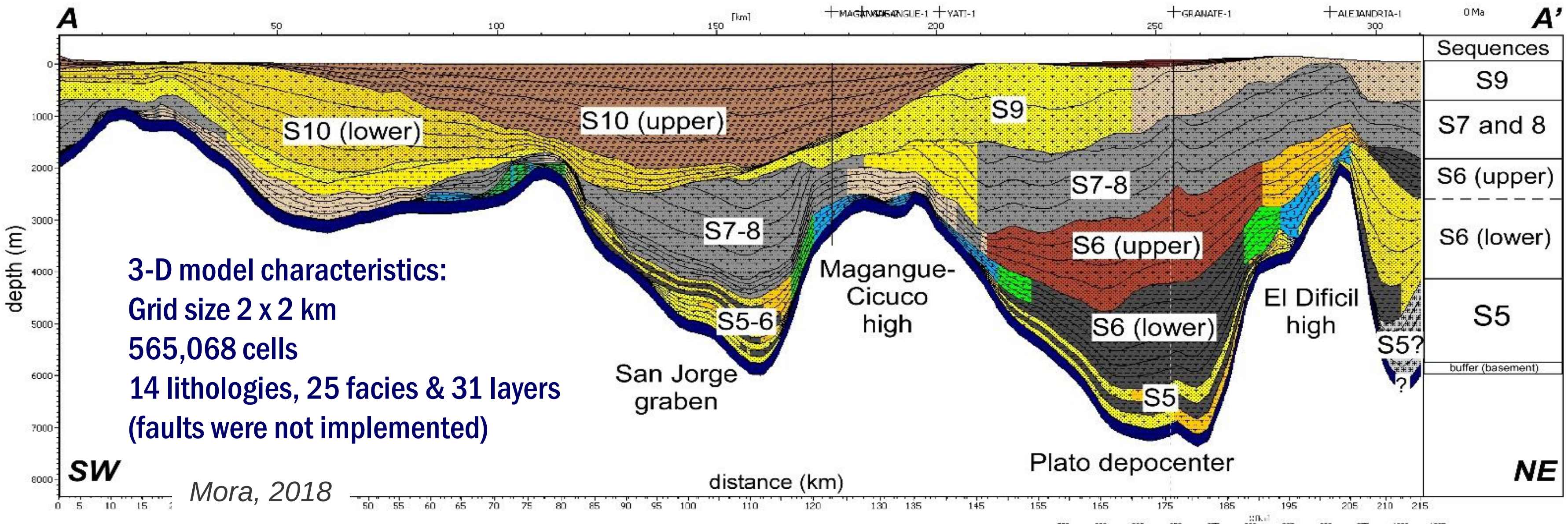
(map is being updated with new data)



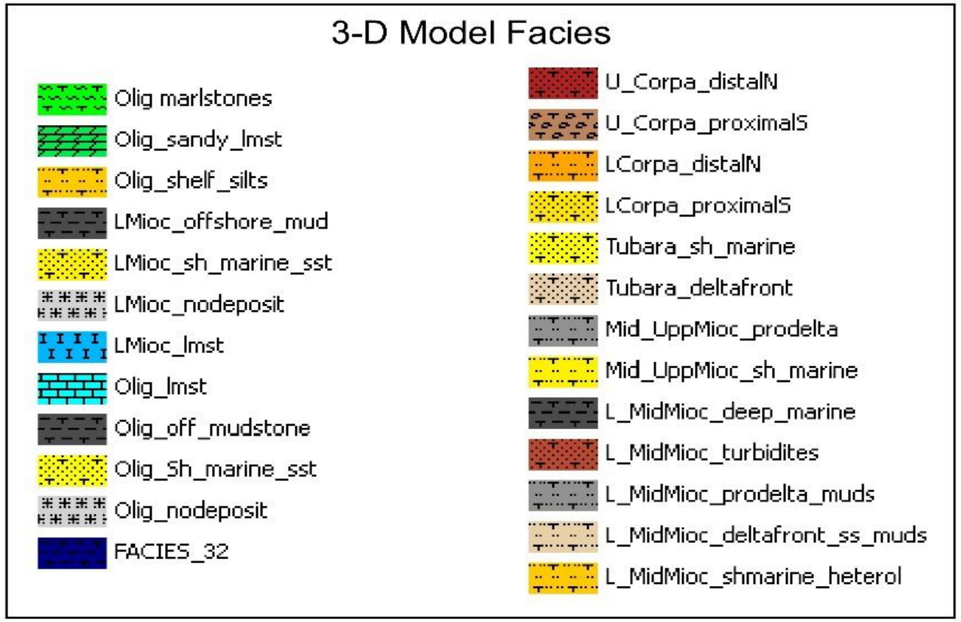


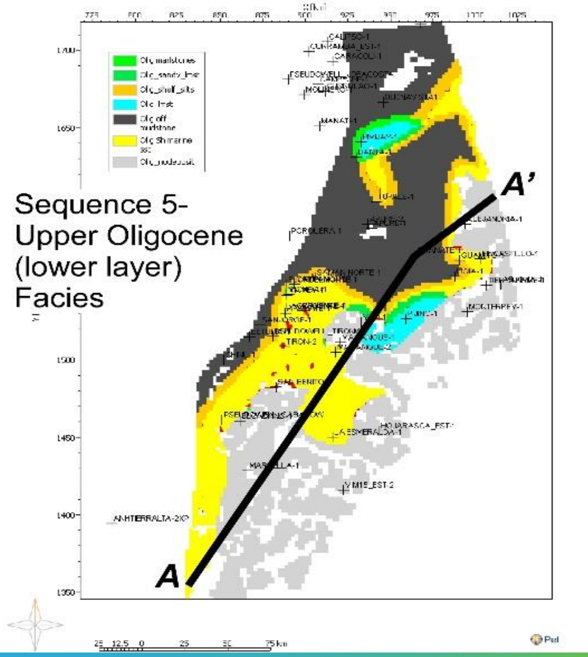
Wells with 1D models in black label and wells for calibration of the 3D model in white label; 3D model boundary in magenta

Tectono-stratigraphic model- facies and lithology distribution



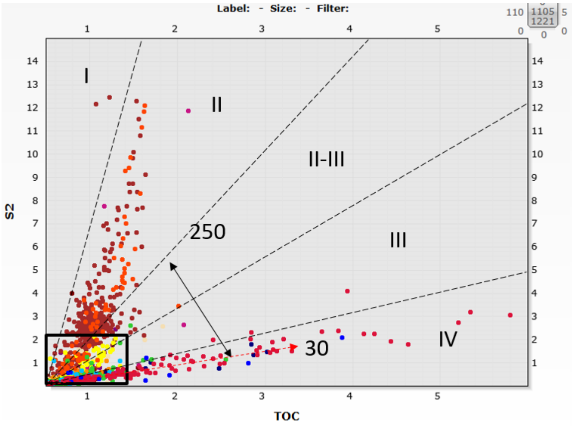
Mora, 2018

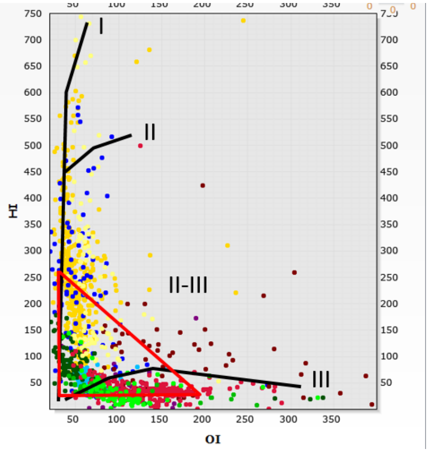


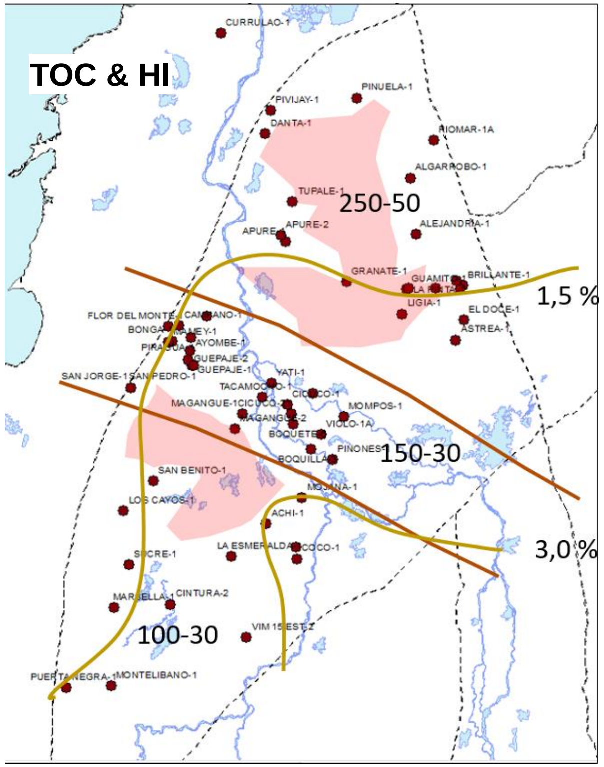


Summary of source rock characteristics (Hocol & ECP, 2017)

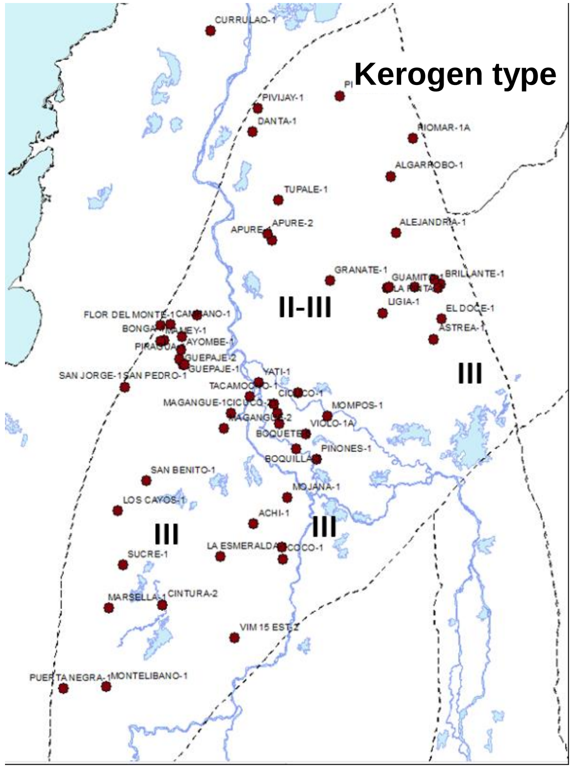
North (Plato)



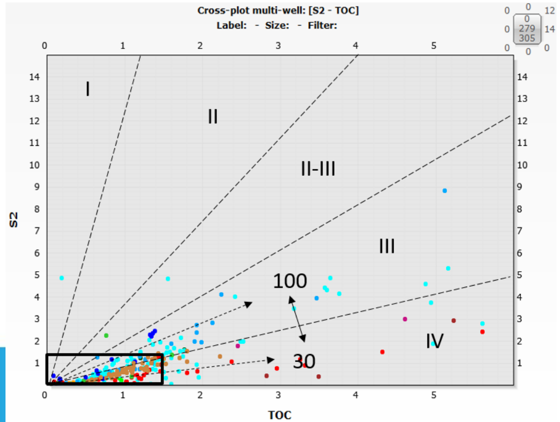


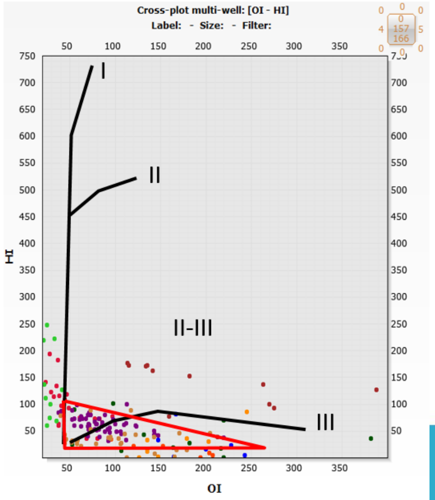


- Better quality source rocks in the N (Plato).
- Hence, formation of the LMV (segmentation into two main depocenters) controlled sedimentation and influenced facies and quality of source rocks.



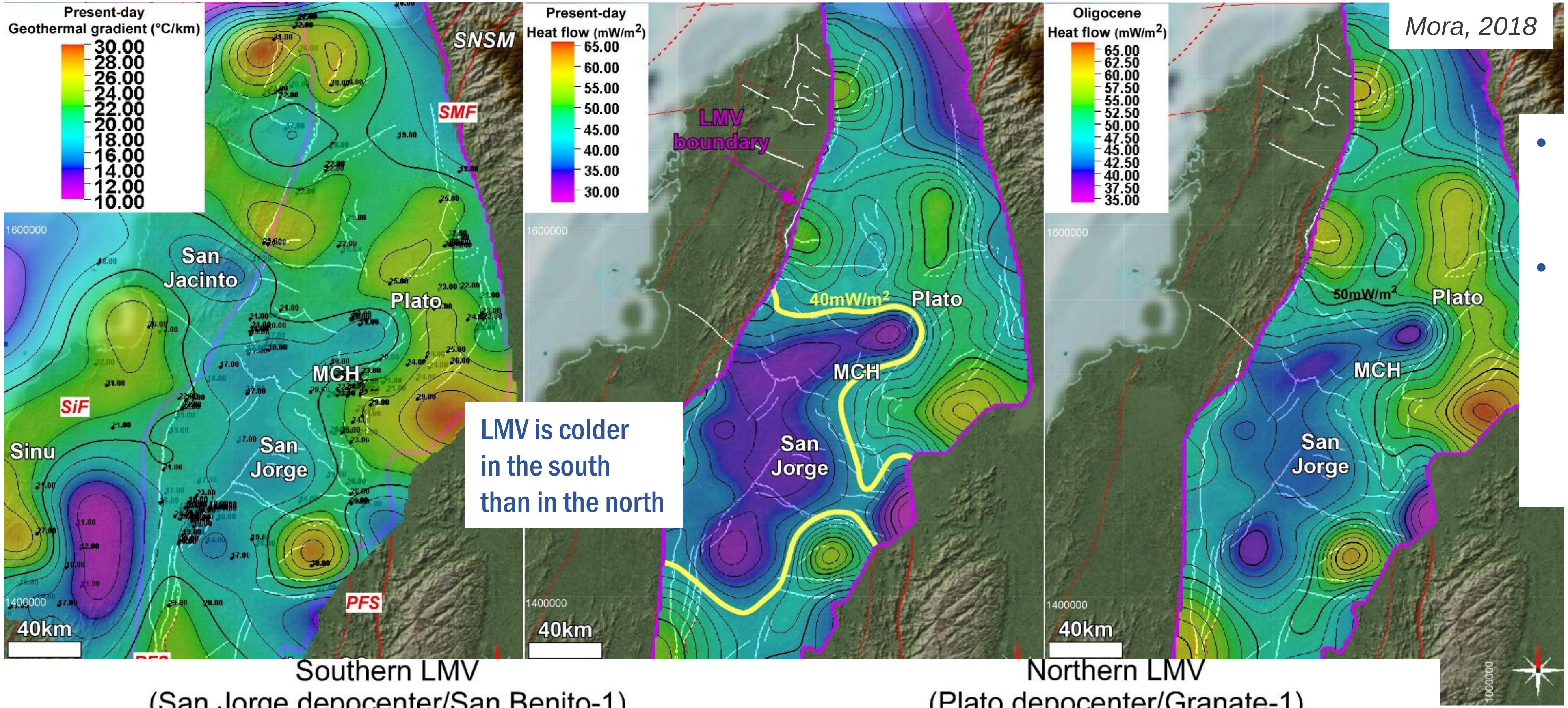
South (San Jorge)





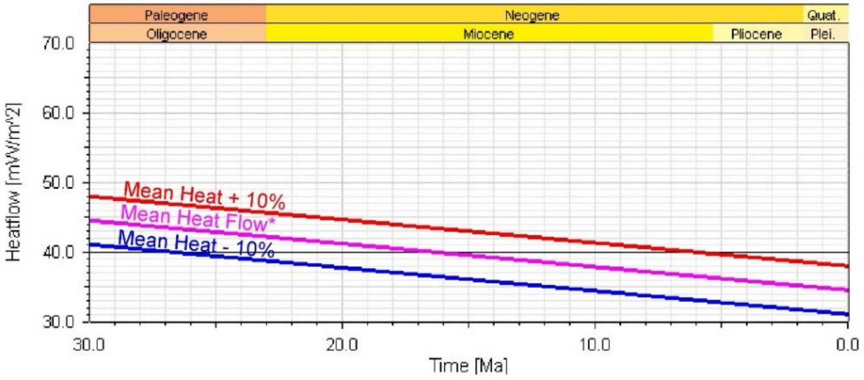
hocol

Lower boundary conditions: geotermal gradient & heat flow

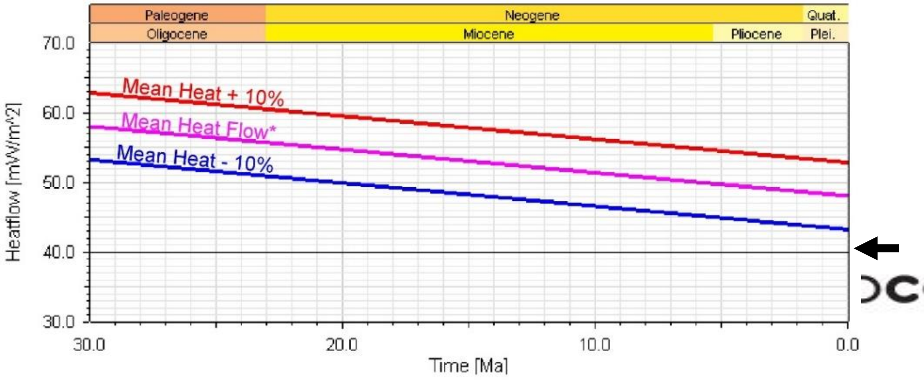


- LMV is colder in the S (San Jorge) than in the N (Plato).
- Again, formation of the LMV is controlling geothermal gradient and heat flow (possibly due to segmentation and differences in sedimentary infill, fluid flow and basement types?)

Southern LMV
(San Jorge depocenter/San Benito-1)



Northern LMV
(Plato depocenter/Granate-1)

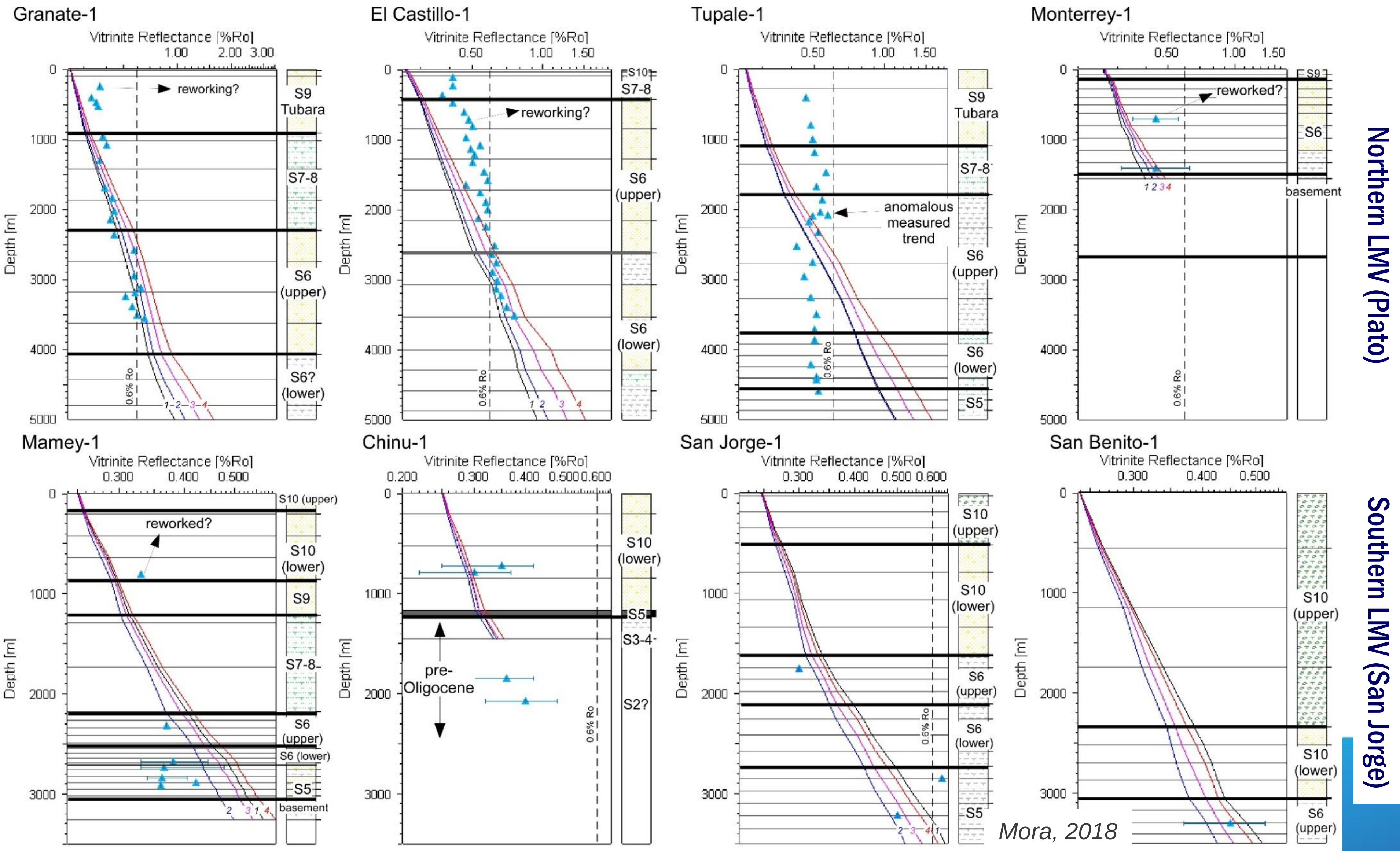


*Mean heat flow was obtained from the geothermal gradient, using thermal conductivity of ~2 W/m/K

Calibration: 1D extractions of vitrinite reflectance (Ro)

1: constant heat flow of 40 mW/m^2
2: low heat flow (mean – 10%)
3. mean heat flow
4. high heat flow (mean + 10%)
Blue triangles are measured Ro data

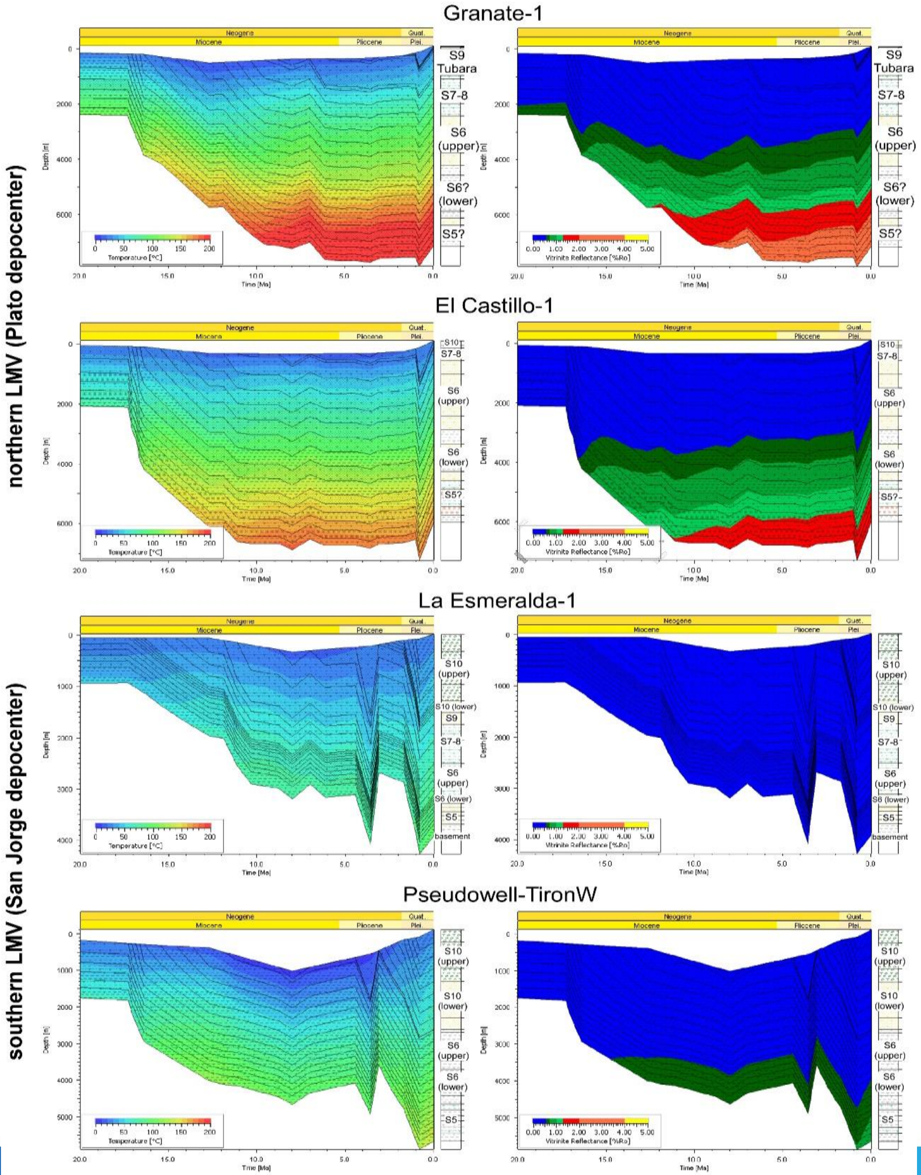
Anomalous Ro trend

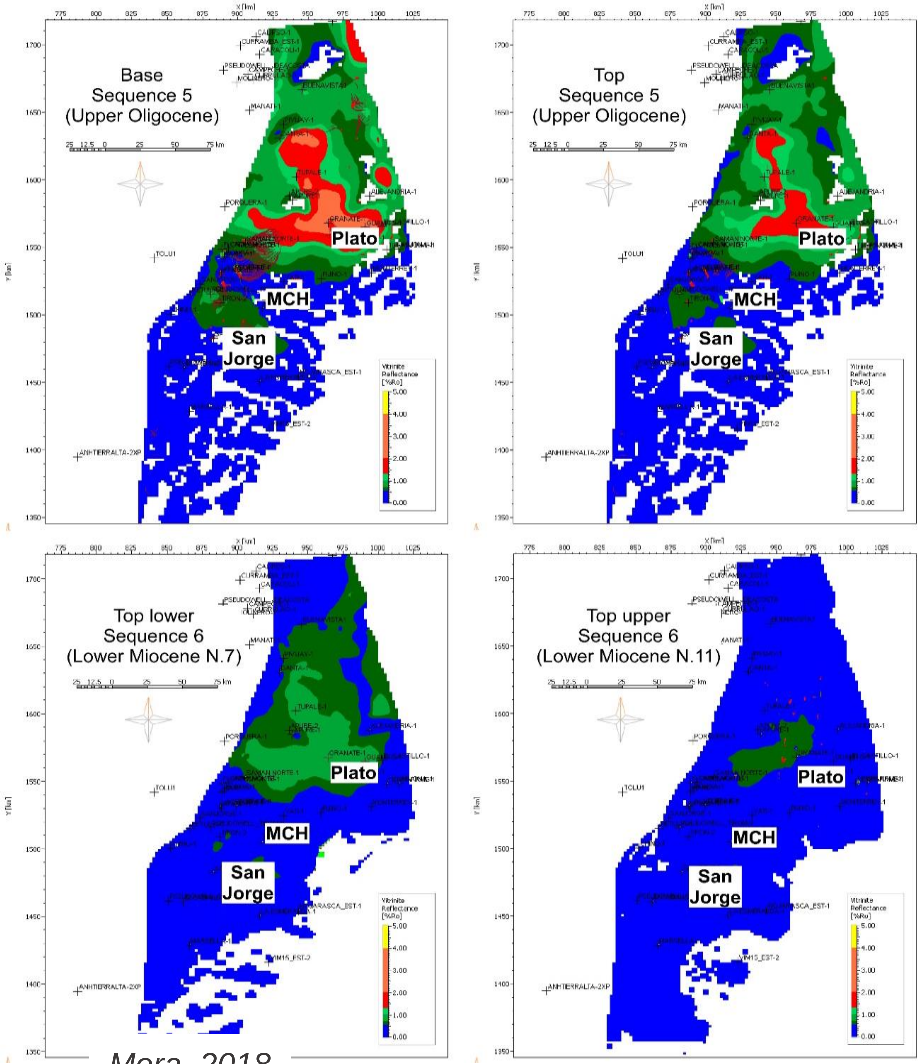


Mora, 2018

Calibration: 1D histories and model results for vitrinite reflectance (Ro)

Model results suggest that maturity is higher in the north (Plato) than in the south (San Jorge)

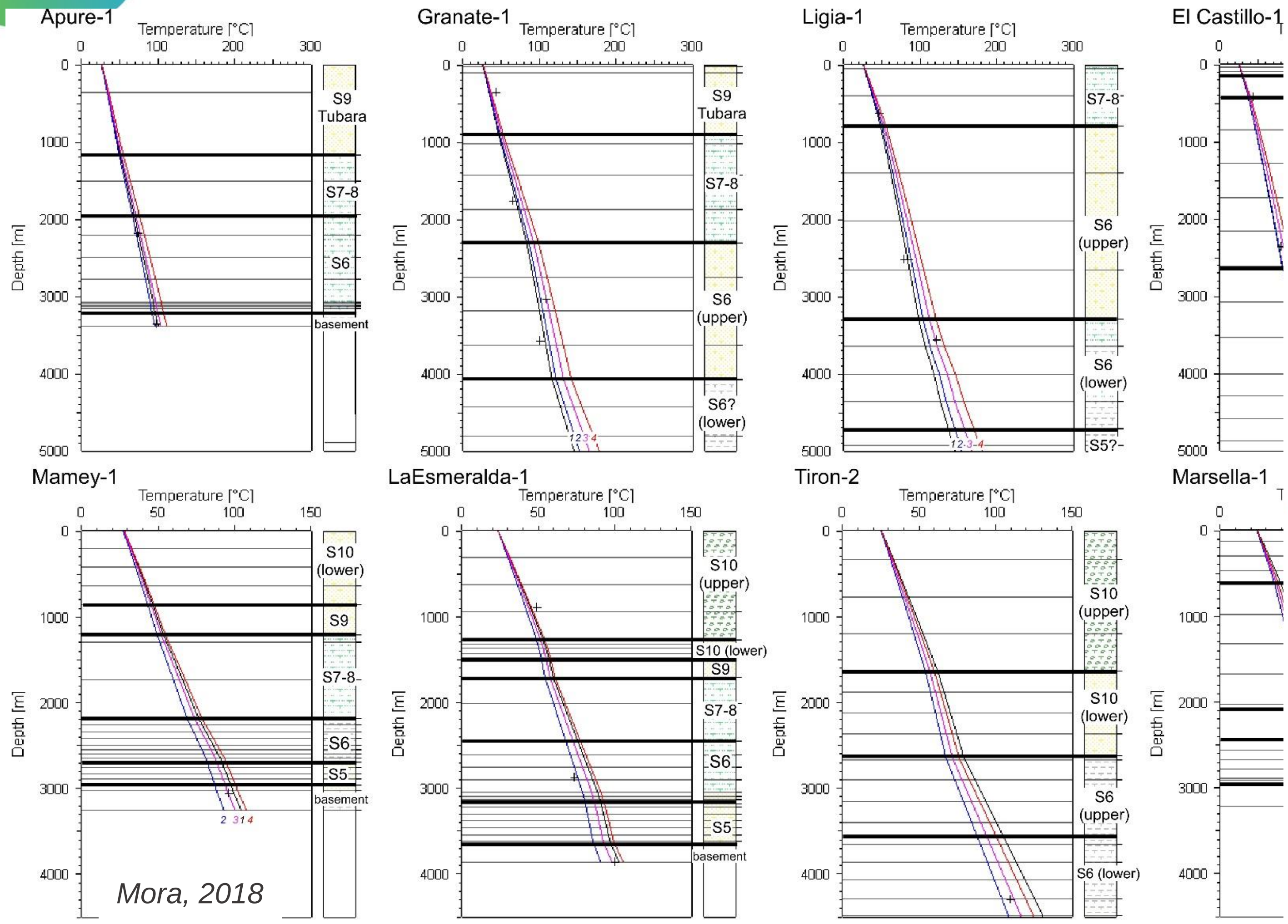




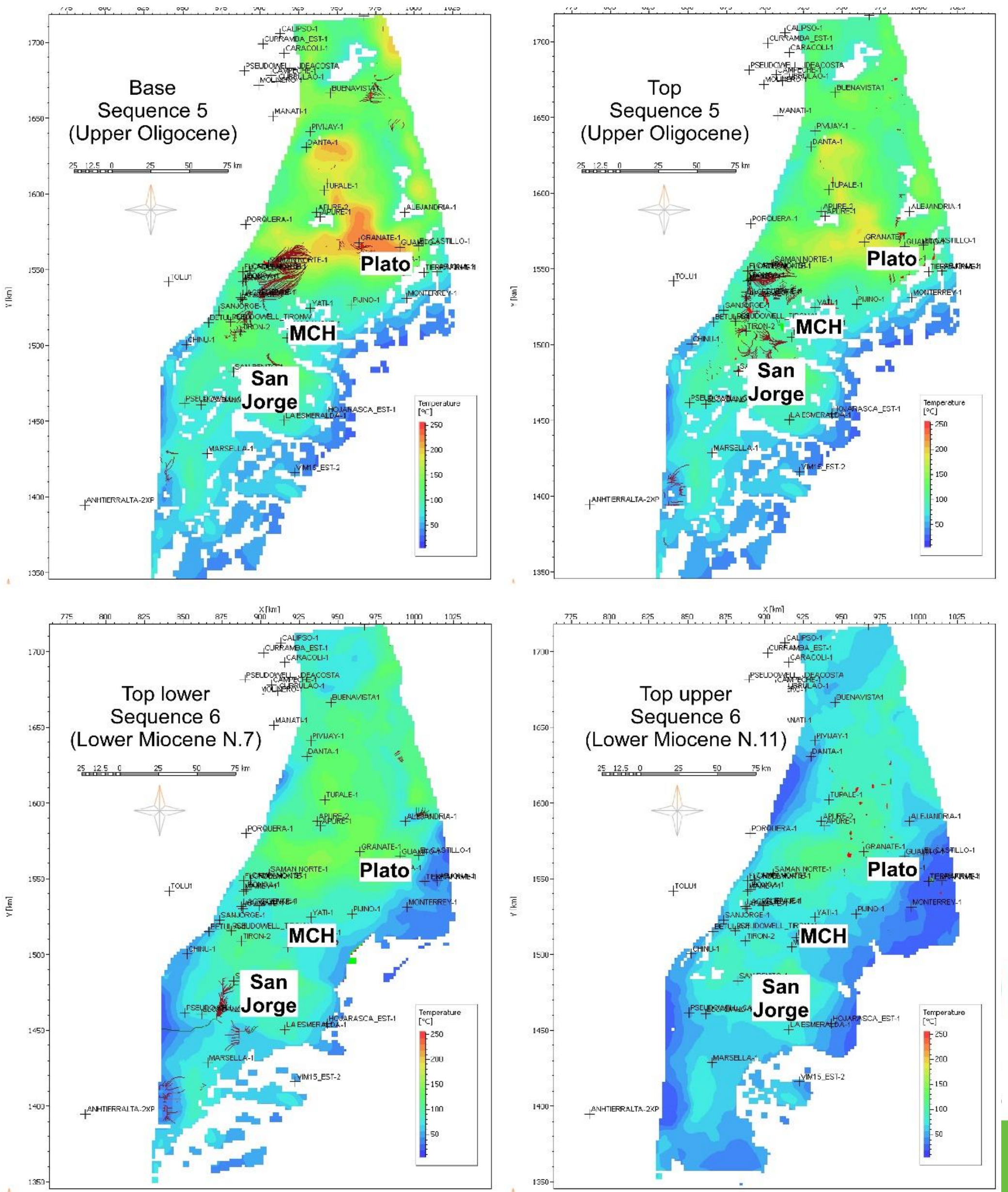
Mora, 2018

Calibration: 1D extractions and model results for Temperature

Model results suggest that temperature is higher in the north (Plato) than in the south (San Jorge)



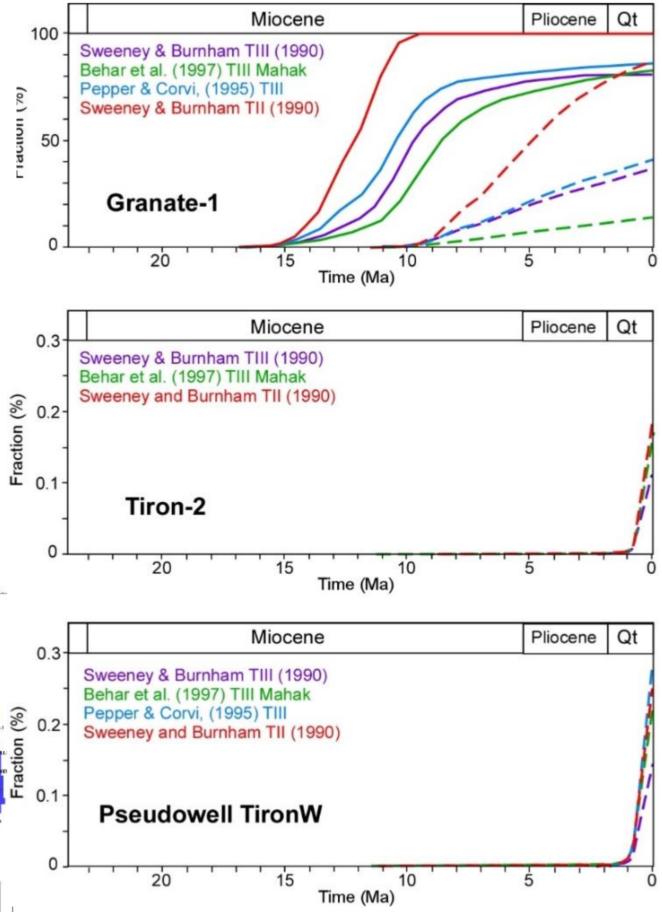
Mora, 2018



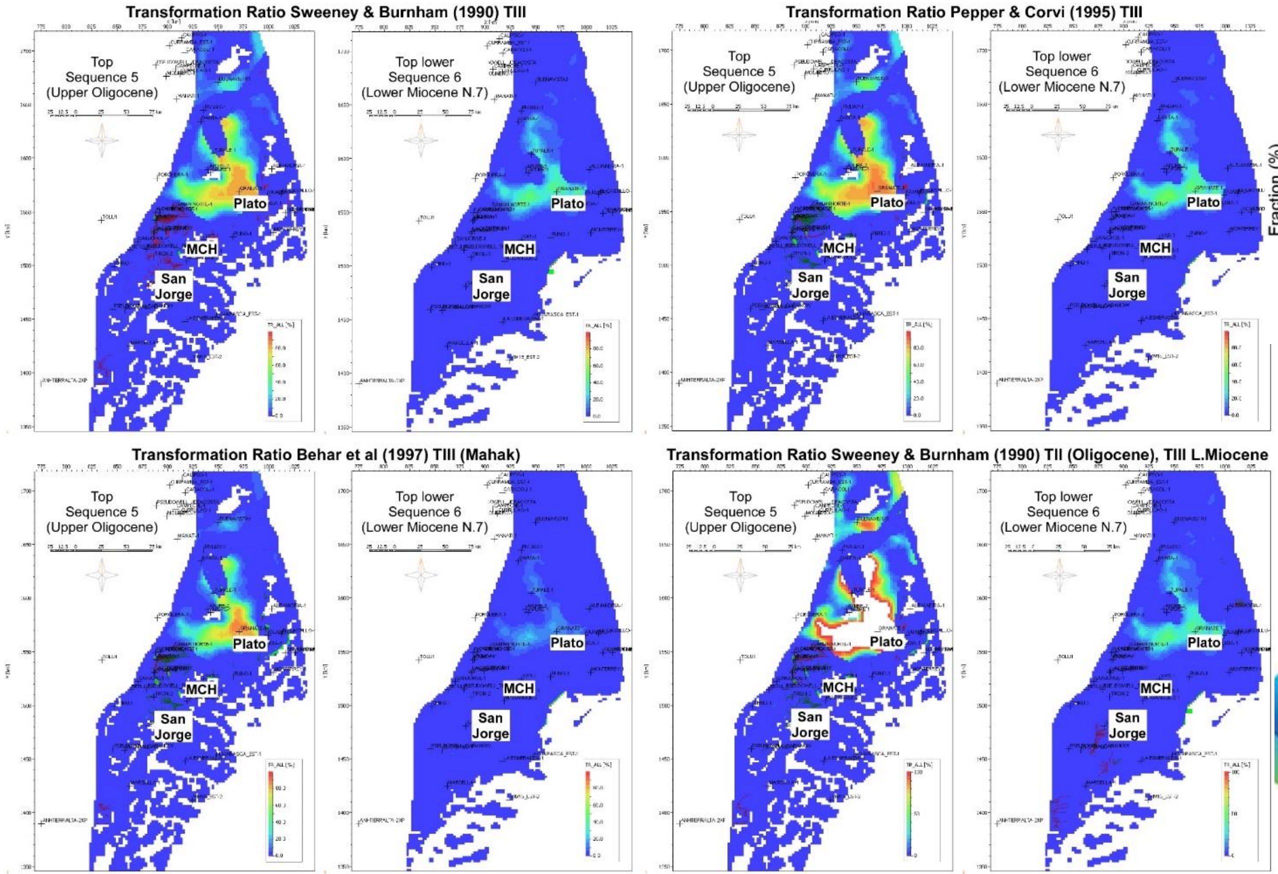
Transformation ratios predicted by the 3D model with different kinetics

>50% transformation occurred at ~10 Ma for upper Oligocene-lower Miocene source rocks, possibly related to better source rock qualities in the north (types III & II) and higher heat flow

In the south, only insignificant transformation occur, regardless of the kinetics used;
there must be other sources to explain the dry gas occurrences (biogenic gas or a pod of pre-Oligocene active source rock?)



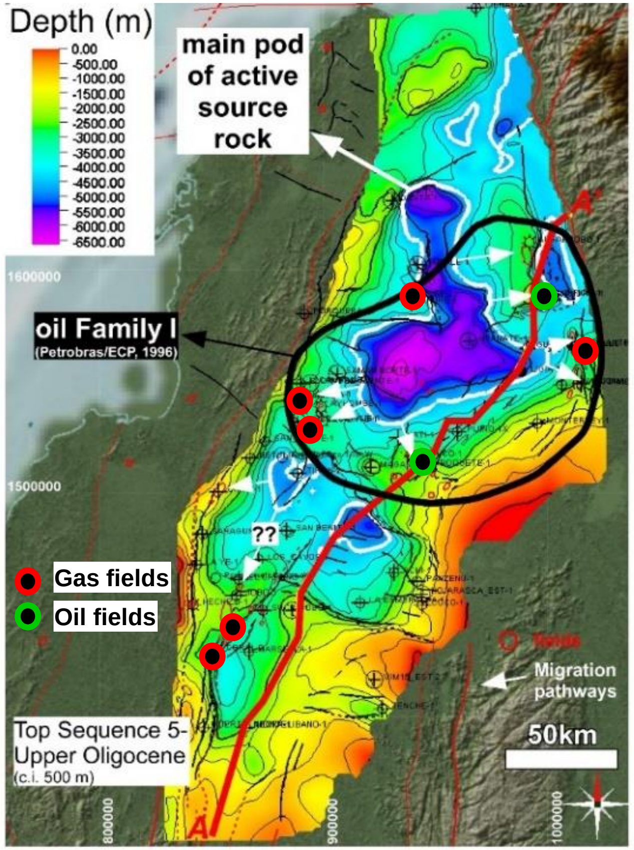
continuous lines: Oligocene-lower Miocene sources (Seq. 5)
dashed lines: lower to middle Miocene sources (Seq. 6)

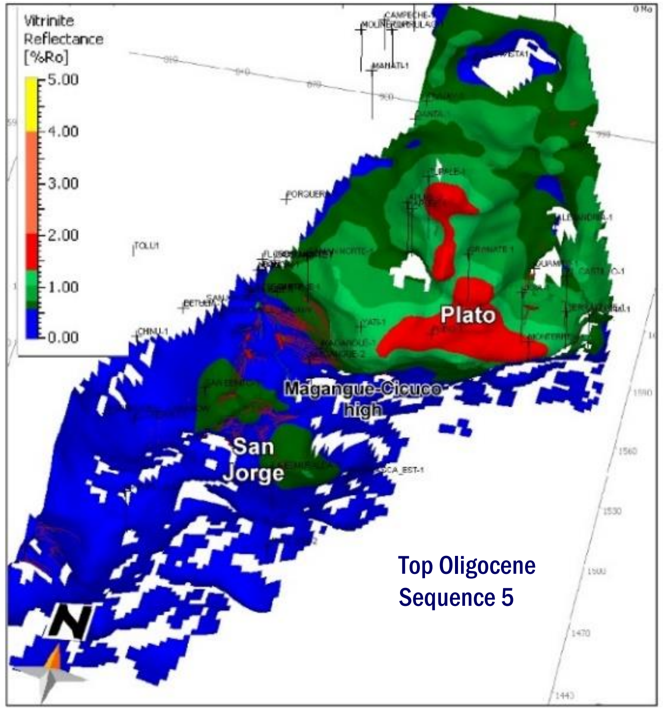


Mora, 2018

Petroleum systems in LMV

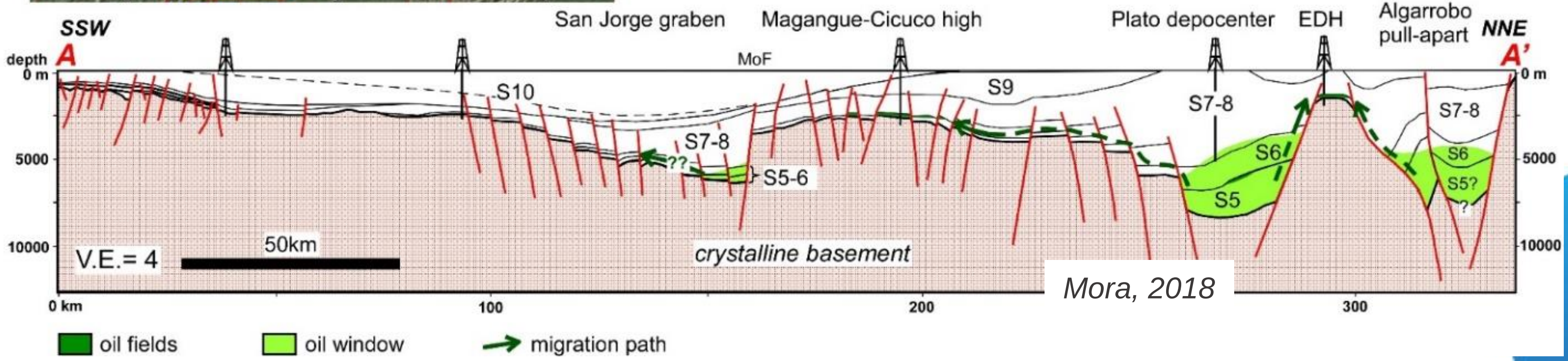
Better characterization of petroleum systems in the northern LMV, southern half requires more data and research.





Good correlation of model and main oil & gas fields in basement highs

S10: upper Pliocene to Pleistocene sequence (Corpa) = overburden
S9: upper Miocene to lower Pliocene sequence (Tubará) = overburden and secondary reservoir)
S7-8: middle to upper Miocene sequences (Middle-Upper Porquero) = top seal and overburden
S6: lower to middle Miocene sequence (upper Cienaga de Oro) = source and reservoir rocks
S5: upper Oligocene to lower Miocene sequence (lower Cienaga de Oro) = source and reservoir rocks

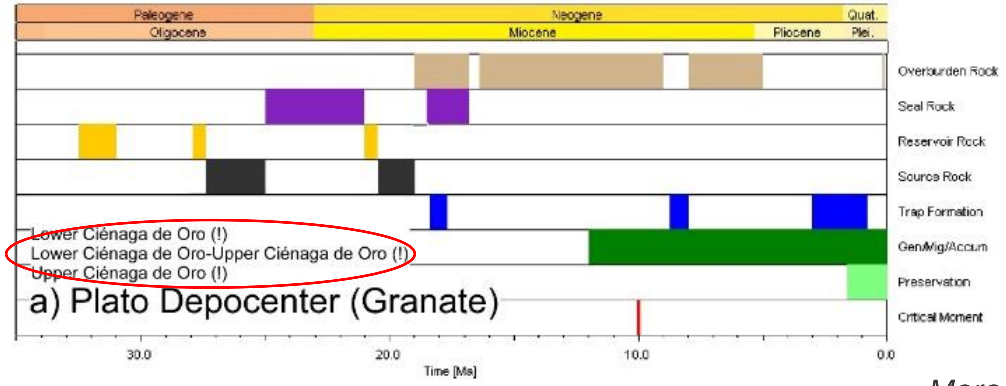


Mora, 2018

Petroleum systems in LMV- event charts

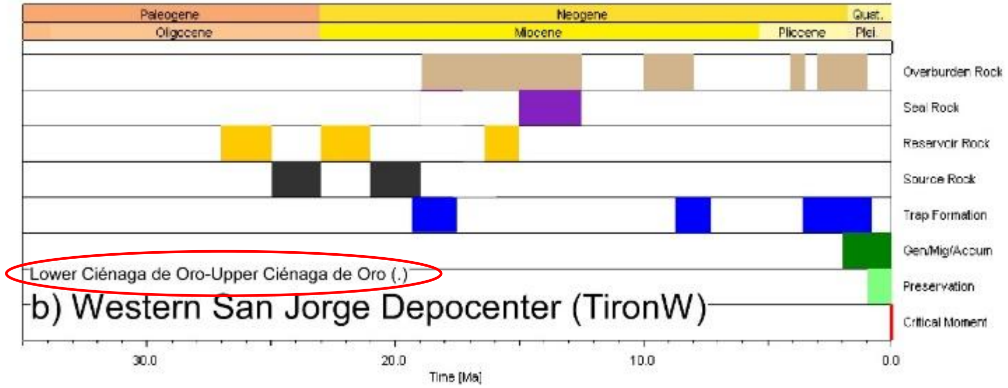
Petroleum system definition & nomenclature after Magoon & Dow, 1994:

known or proven p.s.: (!)
hypothetical p.s.: (.)
speculative p.s. (?)



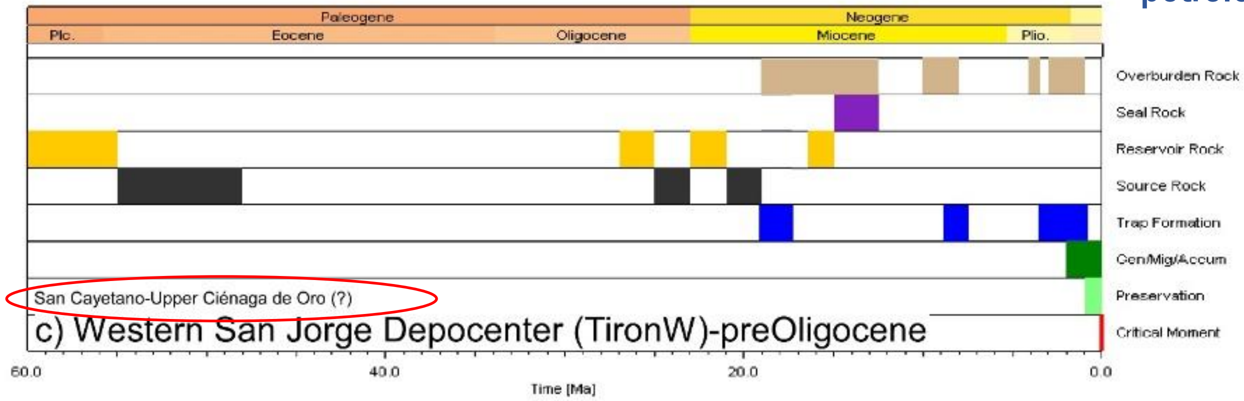
Known thermogenic petroleum systems in the north (Plato)

Mora, 2018



Hypothetical & speculative thermogenic petroleum systems in the south (San Jorge)

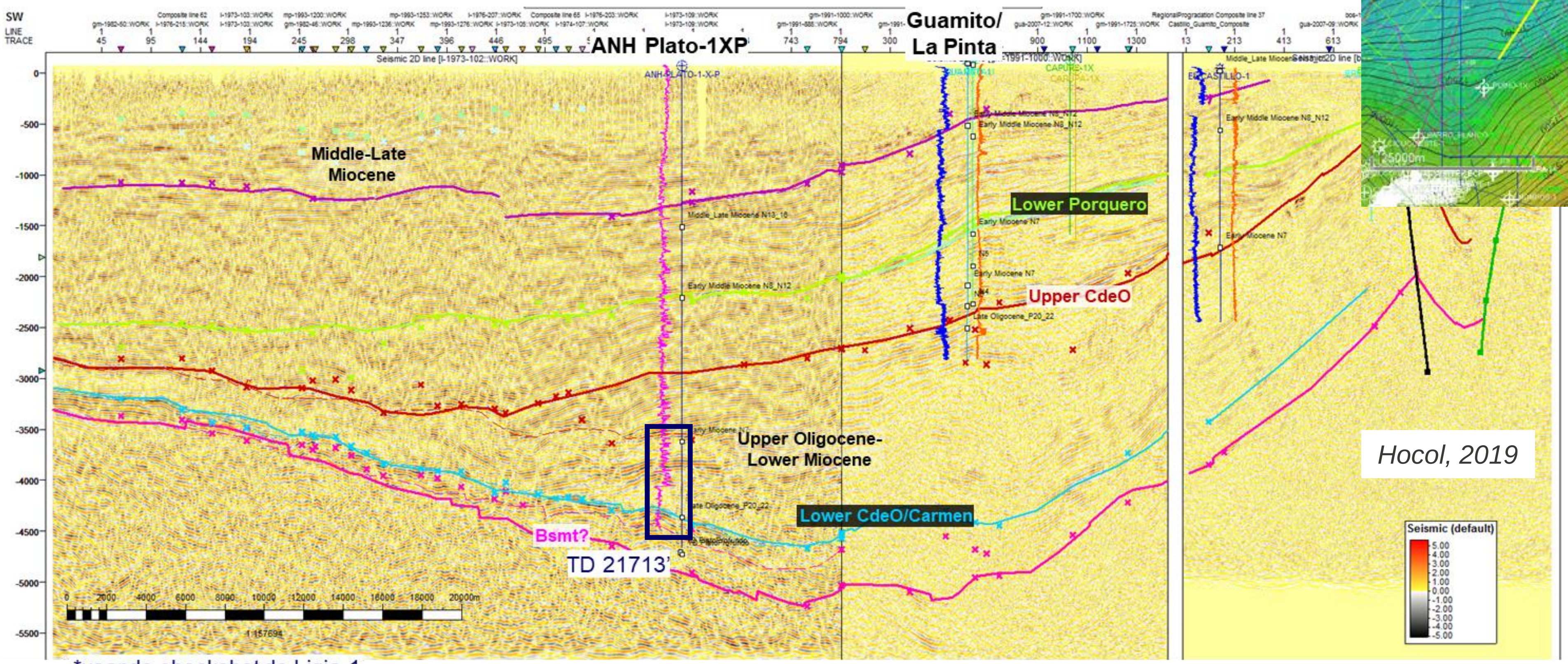
Possible biogenic petroleum systems?



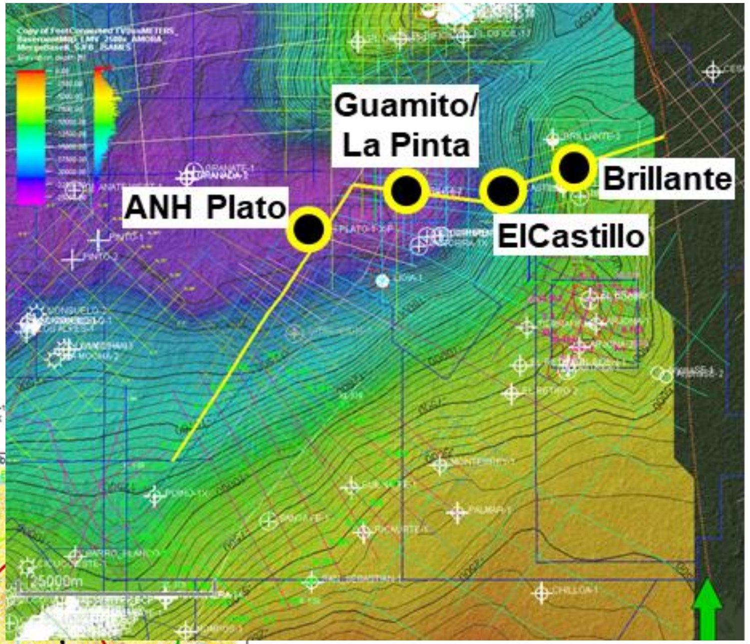
hocol

ANH Plato 1XP- 1D modeling

- Deepest well in the LMV, it found a stratigraphic succession very similar to Hocol's interpretation and modeling: Oligocene (to late Eocene?) at >21 K feet, no Cretaceous.

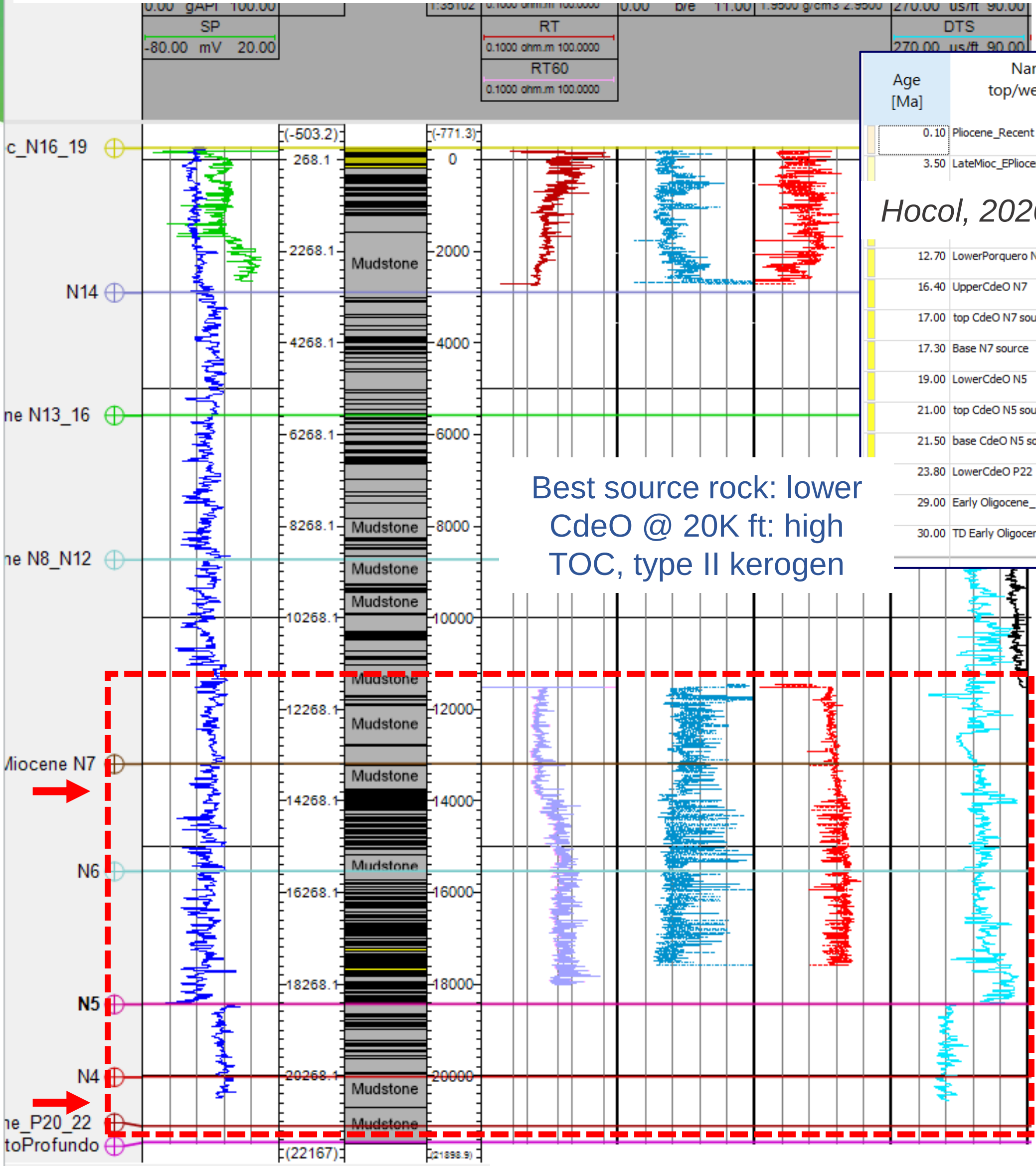


*usando checkshot de Ligia-1



hocol

ANH Plato 1XP- elogs & calibrations



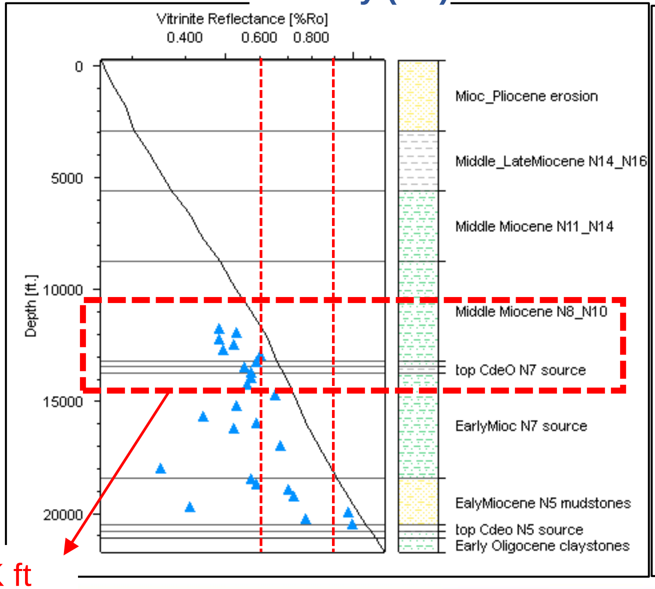
Best source rock: lower CdeO @ 20K ft: high TOC, type II kerogen

Input data (2 source rocks Upper CdeO @ 13.5 Kft & Lower CdeO @ 20.5Kft, using PetroMod t. II & III kinetics)

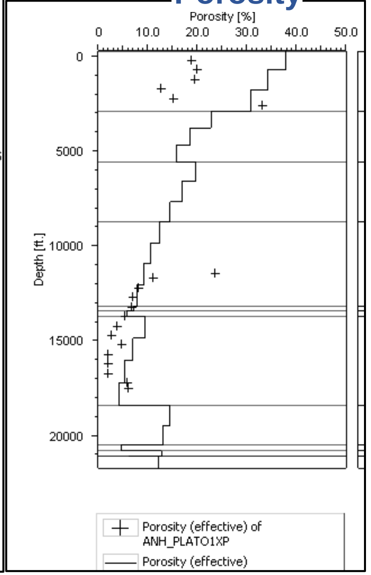
Hocol, 2020

Age [Ma]	Name top/well pick	Depth [ft.]	Thickness [ft.]	Event type	Name layer/event	Paleodeposition/ erosion [ft.]	Lithology	PSE	Kinetic	TOC [%]	HI [mgHC/gTOC]
0.10	Pliocene_Recent erosion	-263									
			0	Erosion		-150					
3.50	LateMioc_EPliocene_N16_N19	-263									
			3155	Deposition	Mioc_Pliocene erosion	150	Sandstone (clay rich)	Overburden Rock			
	… 5	2892									
			2680	Deposition	Middle_LateMiocene N14_N16		Shale (organic lean, silty)	Overburden Rock			
	… 4	5572									
			3153	Deposition	Middle Miocene N11_N14		Siltstone (organic lean)	Overburden Rock			
12.70	LowerPorquero N8_N10	8725									
			4456	Deposition	Middle Miocene N8_N10		Siltstone (organic rich, typical)	Seal Rock			
16.40	UpperCdeO N7	13181									
			269	Deposition	EarlyMiocene N7		Siltstone (organic rich, typical)				
17.00	top CdeO N7 source	13450									
			250	Deposition	top CdeO N7 source		Shale (organic rich, typical)	Source Rock	Burnham(1989)_TIII	1.00	250.00
17.30	Base N7 source	13700									
			4727	Deposition	EarlyMioc N7 source		Siltstone (organic rich, typical)_ANH Pl...	Seal Rock			
19.00	LowerCdeO N5	18427									
			2073	Deposition	EalyMiocene N5 mudstones		Sandstone (clay rich)	Reservoir Rock			
21.00	top CdeO N5 source	20500									
			300	Deposition	top Cdeo N5 source		Shale (organic rich, typical)	Source Rock	Burnham(1989)_TII	1.20	450.00
21.50	base CdeO N5 source	20800									
			289	Deposition	base LowerCdeO N5 source		Siltstone (organic rich, typical)				
23.80	LowerCdeO P22	21089									
			11	Deposition	LateOligocene P22 mudstones		Shale (organic rich, 3% TOC)				
29.00	Early Oligocene_	21100									
			613	Deposition	Early Oligocene claystones		Siltstone (organic lean)	none			
30.00	TD Early Oligocene_	21713									

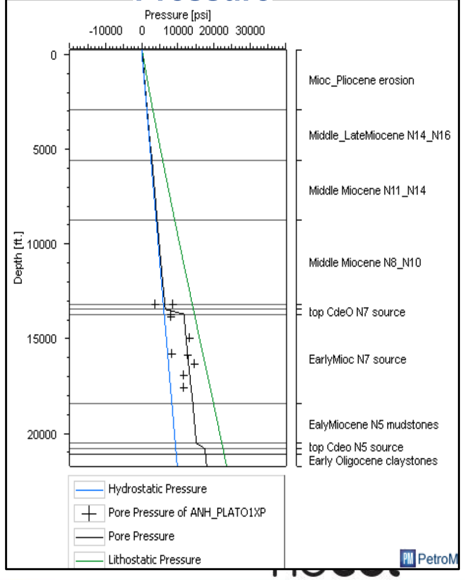
Maturity (Ro)



Porosity

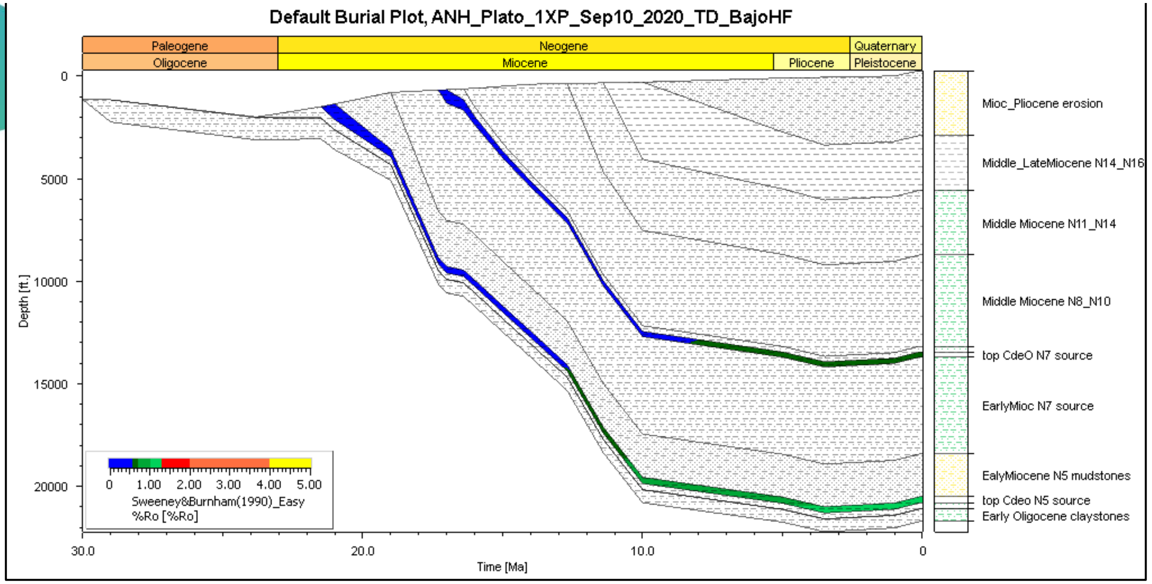


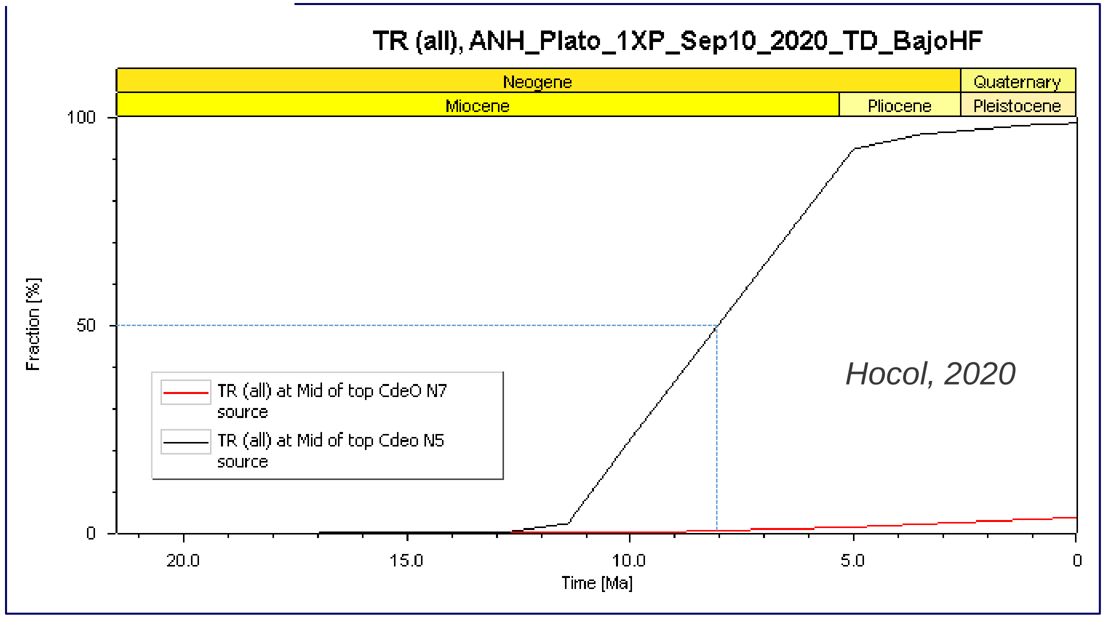
Pressure



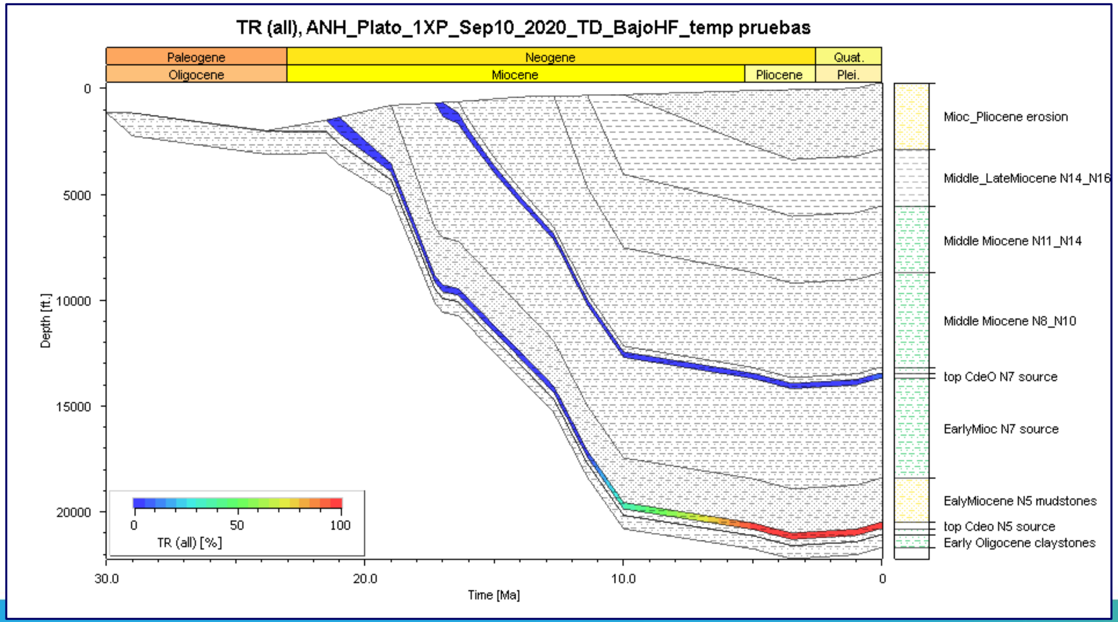
Early oil window from 12.5 to 13.5 K ft

ANH Plato 1XP- results 1D modeling Hocol





Maturity (Ro):
Entry into oil window
Middle Miocene (lower CDO N5)
Late Miocene (upper CDO N7)



The 1D model explains well thermogenic generation of liquid and gaseous hydrocarbons in the Plato depocenter (NO need of any Cretaceous sourcing!)

Transformation Ratios (TR)
100 %:
beginning of transformation
12Ma (Late Miocene, CDO N5)
type II kinetics

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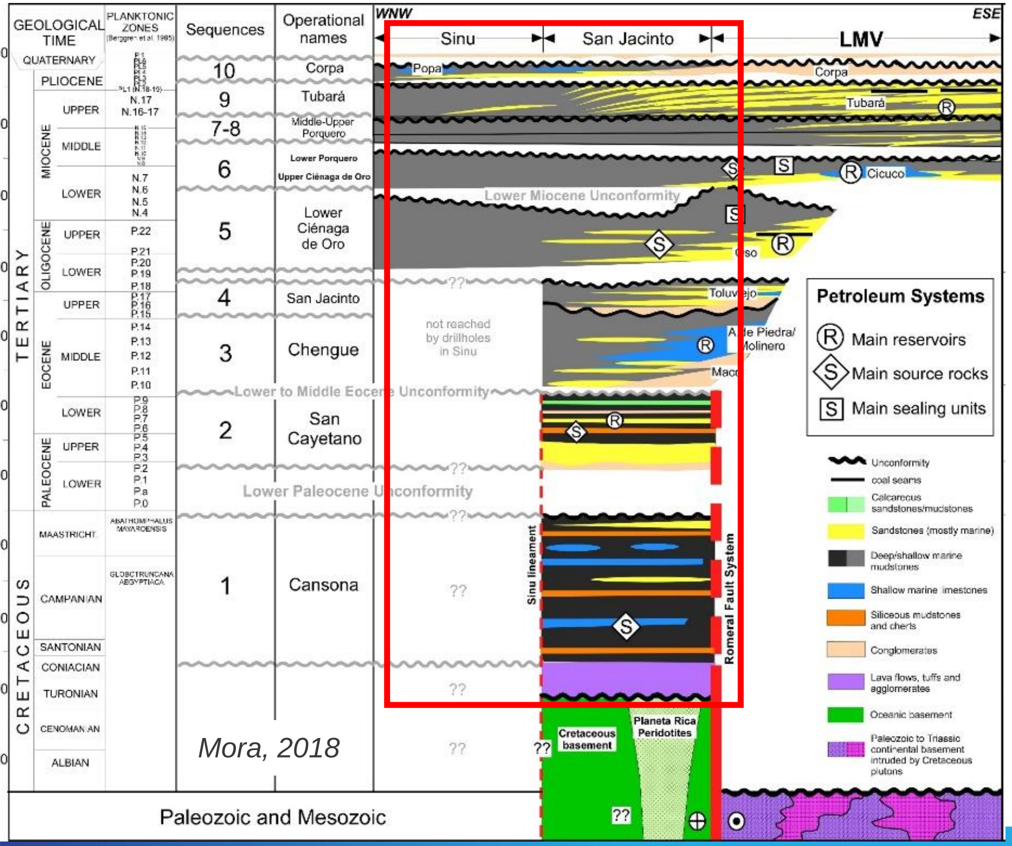
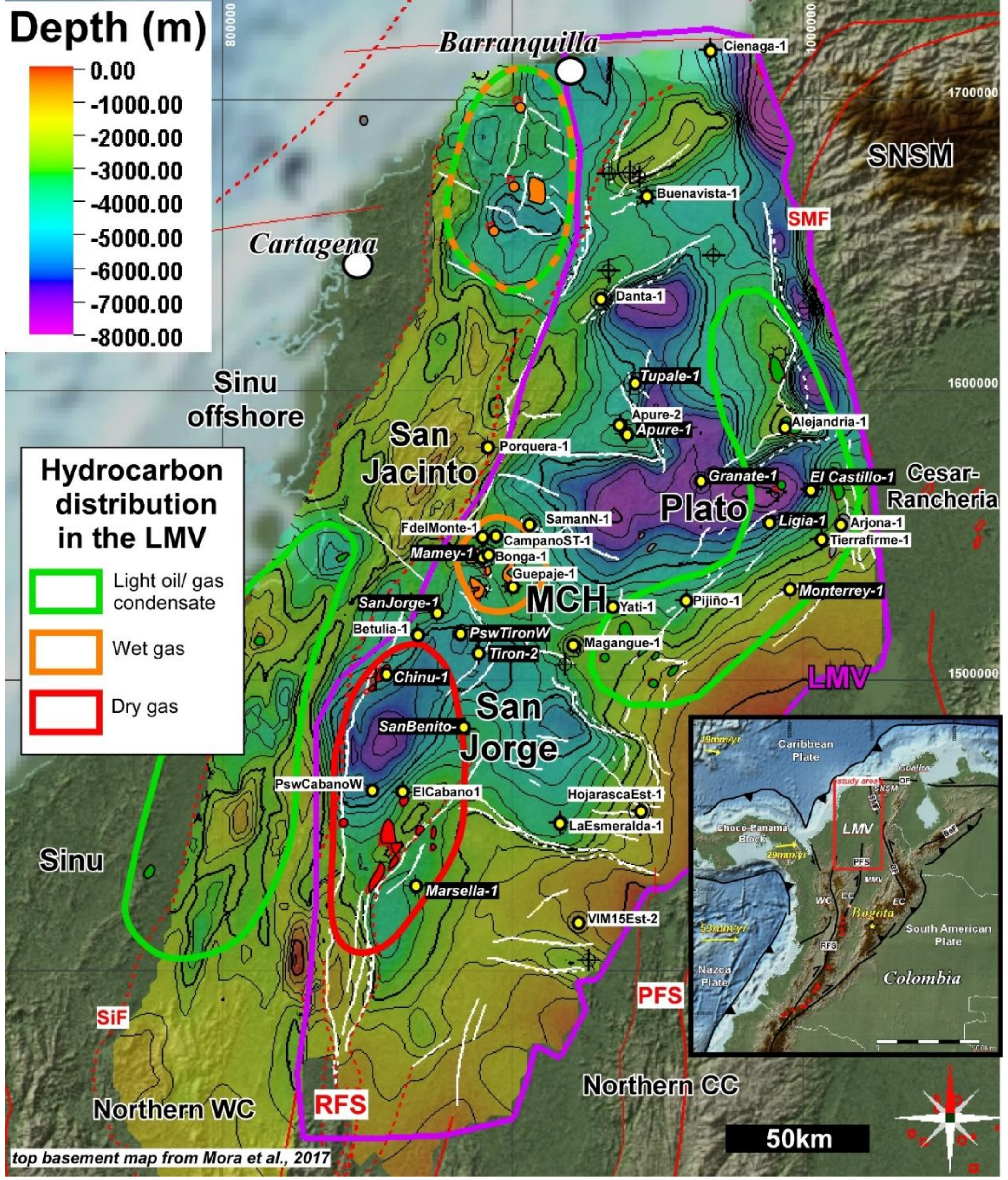
Sinú-San Jacinto petroleum systems

Complex and highly-deformed zone with few wells drilled and scattered and poorly-preserved outcrops. Several petroleum systems occur.

Source rocks: though some oil families have been proposed, there are several source rocks at different stratigraphic levels which haven't been properly characterized due to the scarcity of information (possible sources are Cansona, S. Cayetano, Chengue y San Jacinto?);

Reservoir rocks: only commercial production from Eocene Chengue reservoirs in the N San Jacinto but there are also other potential reservoir levels (S. Cayetano, San Jacinto, C de Oro, Porquero).





Wells with 1D models in black label and wells for calibration of the 3D model in white label; 3D model boundary in magenta

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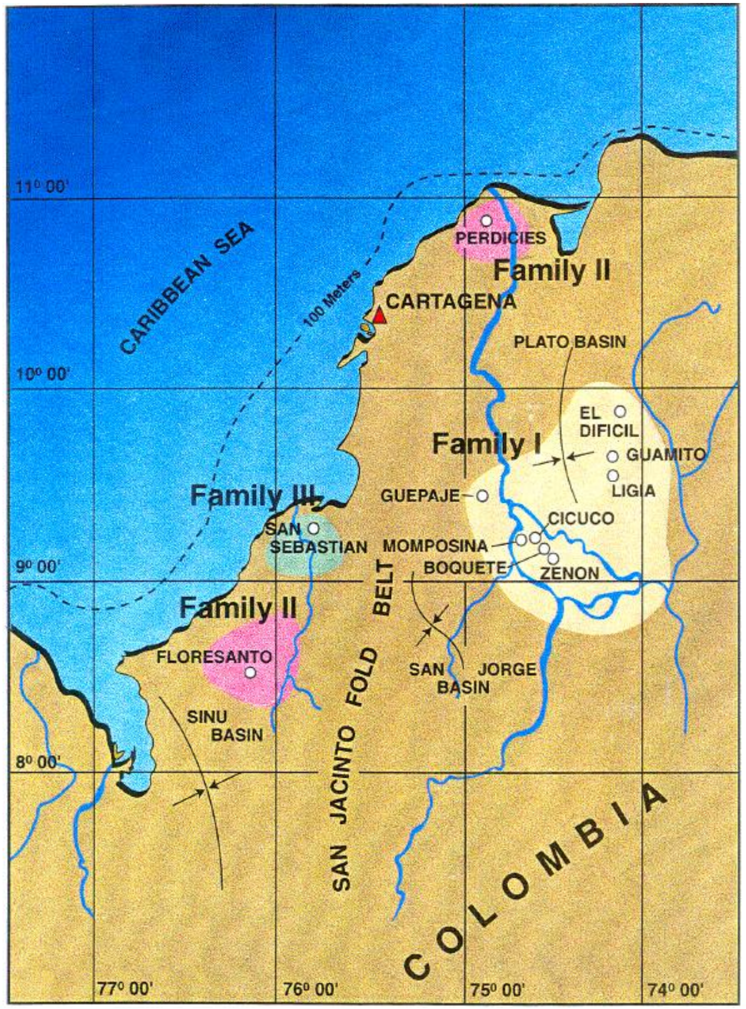
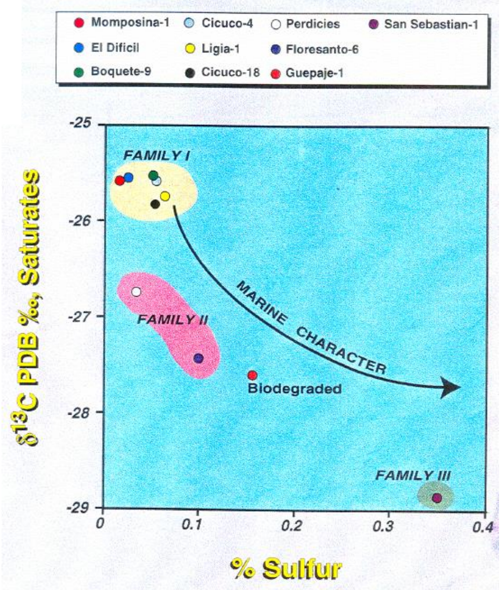
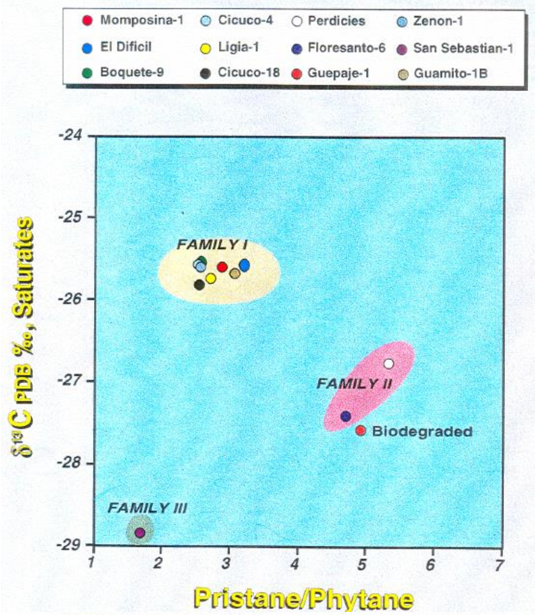
Petroleum systems in San Jacinto

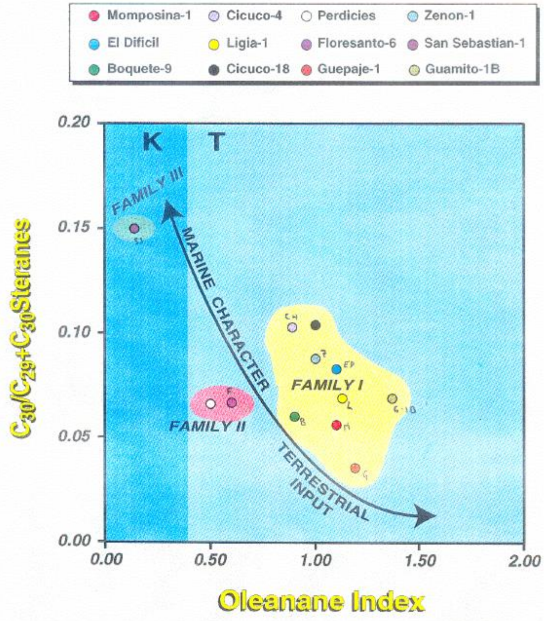
Oil families

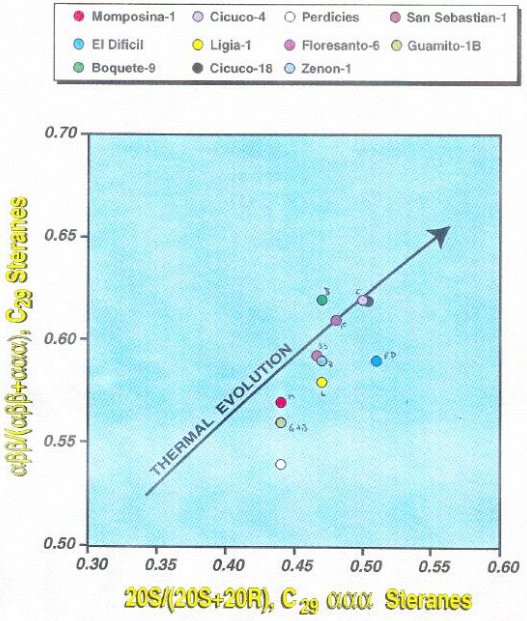
Petrobras/Ecopetrol, 1996











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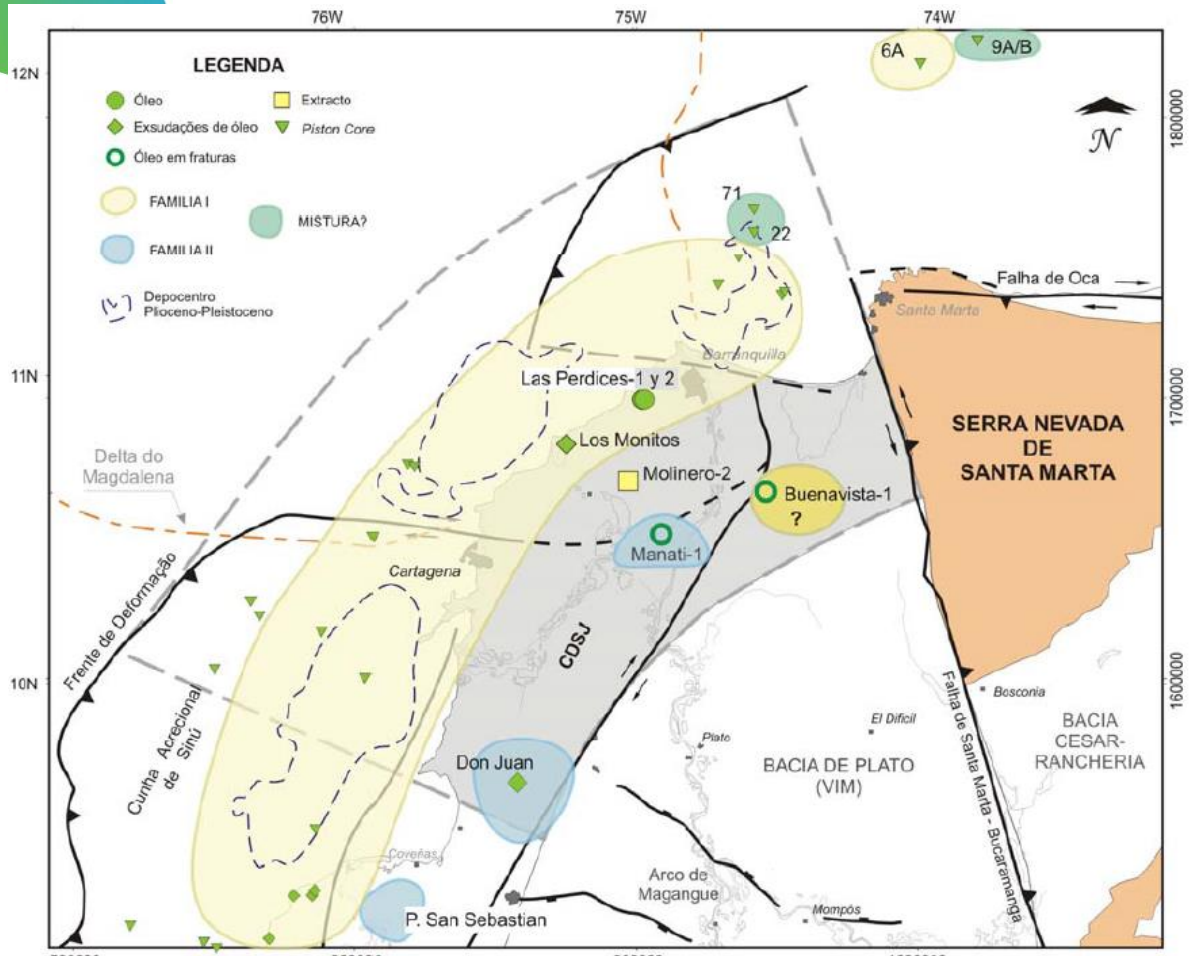
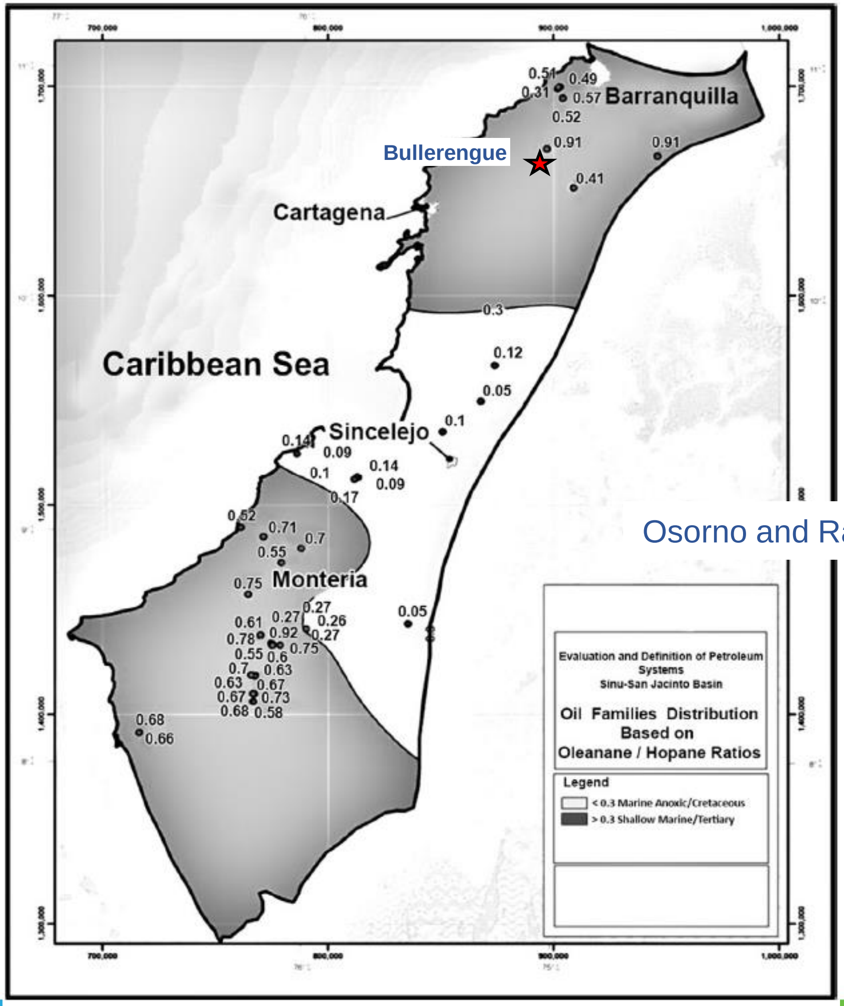
Petroleum systems in San Jacinto- proposed oil families

- Three P.S. proposed: Precansona-Precansona (?), Cansona-San Cayetano (.) and CdeO-CdeO-Porquero (.)
- Gases in the north would be thermogenic, and in the center and south biogenic or mixed.
- New data from Bullerengue field is being analysed (Chengue-Chengue (.)?)



Niño, 2005



Osorno and Rangel, 2015

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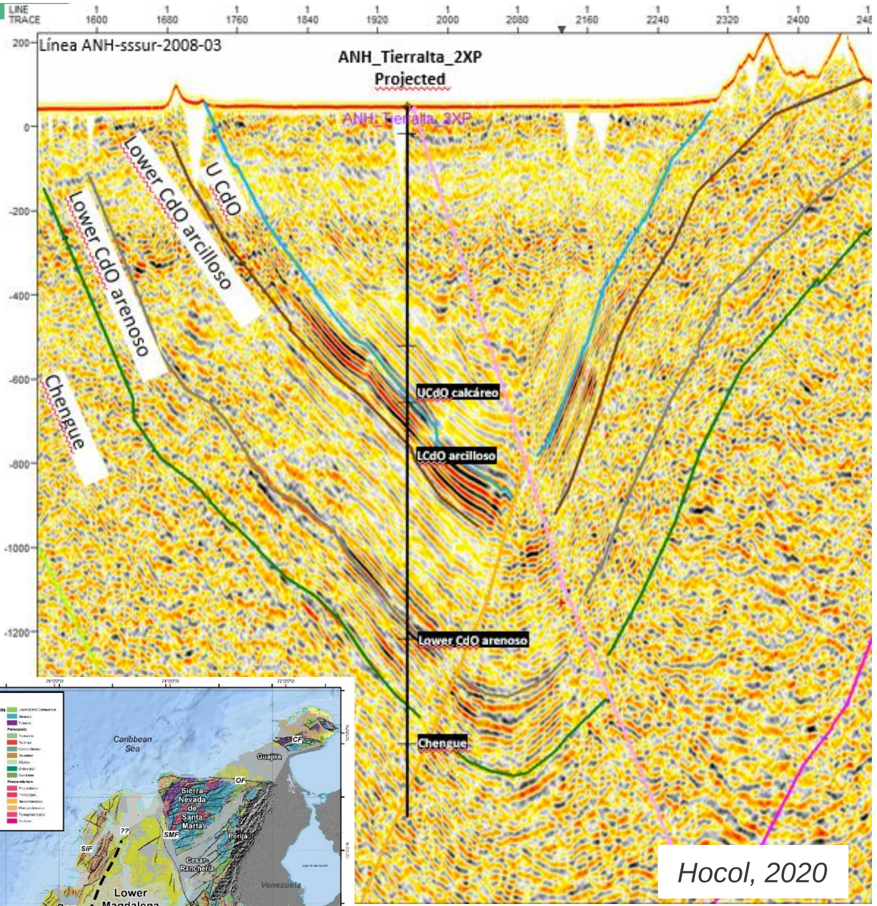
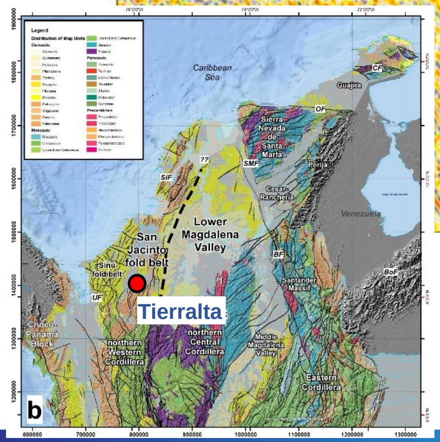
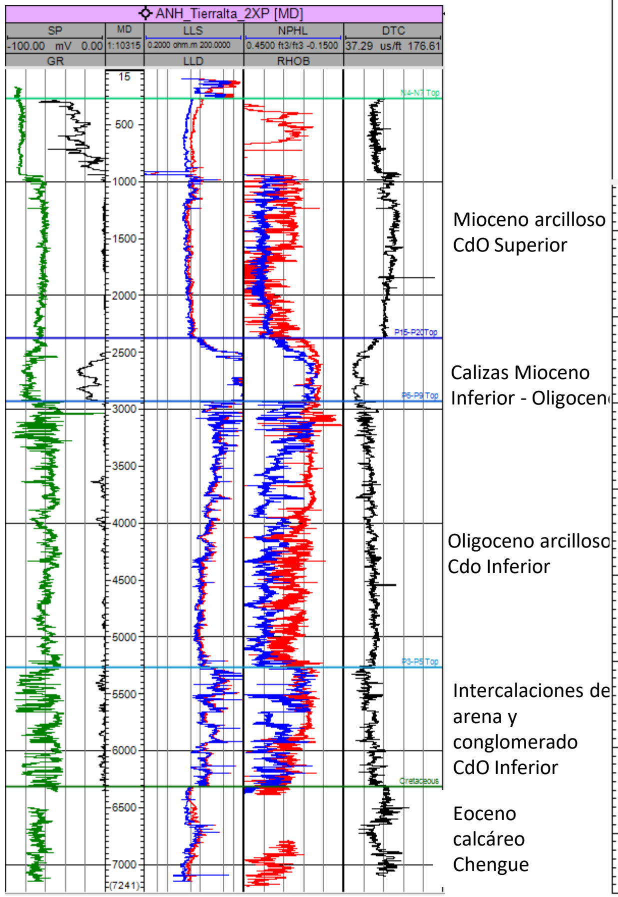
ANH Tierralta-2XP 1D modeling

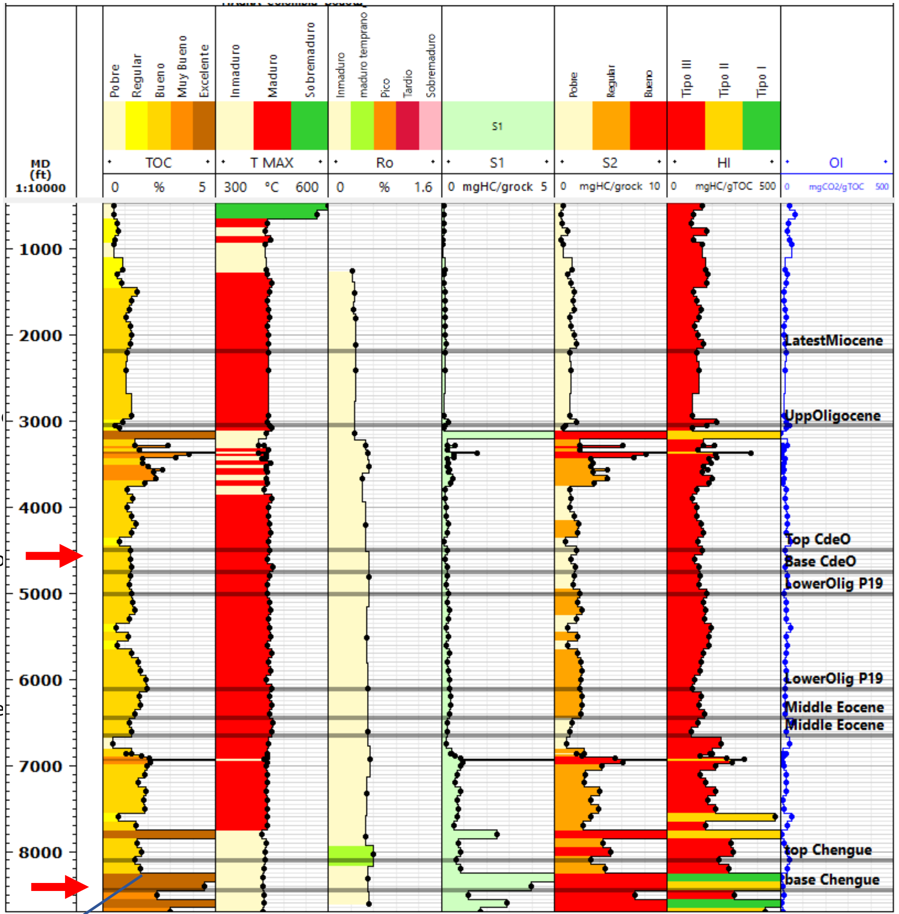
Drilled in the Saltillo Syncline, southern San Jacinto fold belt, initially reported Cretaceous rocks but this was later discarded.







Geochemical profile



Chengue (middle Eocene) appears to be a good source rock (high TOC, type II kerogen)

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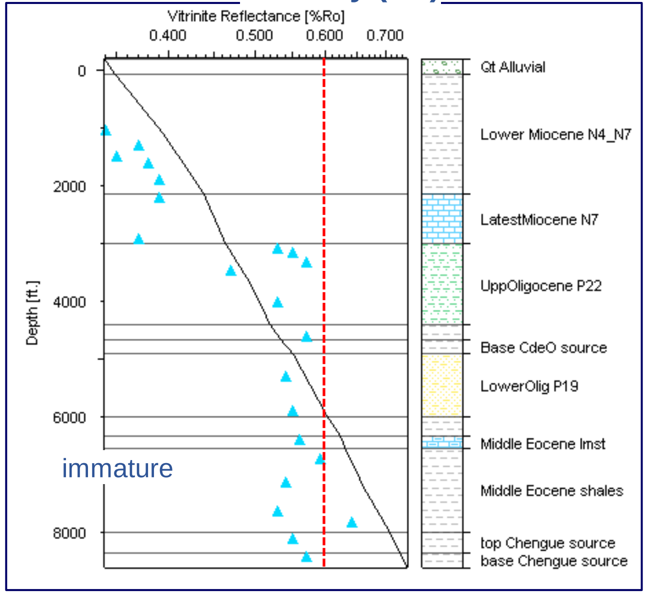
ANH Tierralta-2XP 1D modeling

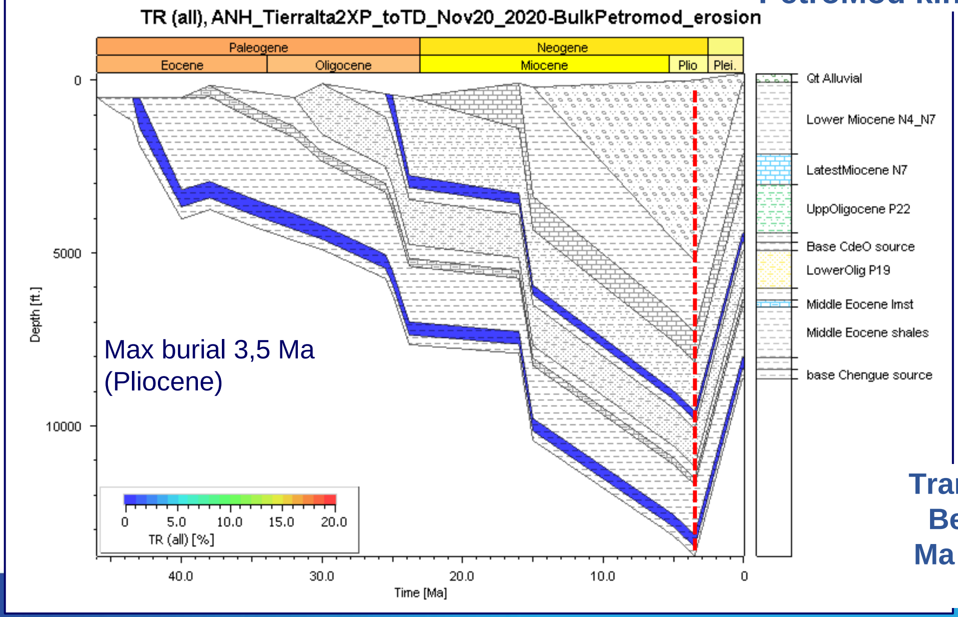
Input data (using two source rocks and bulk kinetics by GEMS, type II & III)

Age [Ma]	Name top/well pick	Depth [ft.]	Thickness [ft.]	Event type	Name layer/event	Paleodeposition/ erosion [ft.]	Lithology	PSE	Kinetic	TOC [%]	HI [mgHC/gTOC]
0.10	Qt erosion	-200	0	↑ Erosion	erosion	-500					
3.50	QT	-200	268	↓ Deposition	Qt Alluvial	500	Conglomerate (typical)_Tierralta	Overburden Rock			
15.00	UpperCdeO N4_N7	68	2115	↓ Deposition	Lower Miocene N4_...		Shale (organic rich, typical)_Tierralta	Overburden Rock			
16.00	UppCdeO Lmst N7	2183	869	↓ Deposition	LatestMiocene N7		Limestone (micrite)_Tierralta	Reservoir Rock			
23.80	LowerCdeO P22	3052	1448	↓ Deposition	UppOligocene P22		Siltstone (organic rich, typical)_Tierralta				
25.00	top CdeOP22 source	4500	250	↓ Deposition	Top CdeO source		Shale (organic rich, typical)	Source Rock	BulkKinetic_Tierralt...	2.40	186.00
25.50	base CdeO rouse	4750	260	↓ Deposition	Base CdeO source		Shale (organic rich, typical)				
30.00	SJacinto ssts P19	5010	1103	↓ Deposition	LowerOlig P19		Sandstone (clay rich)	Reservoir Rock			
32.00	SJacinto shales	6113	338	↓ Deposition	LowerOlig P19 shales		Shale (organic rich, typical)				
38.00	Chengue lmst	6451	199	↓ Deposition	Middle Eocene lmst		Limestone (shaly)	Reservoir Rock			
40.00	Chengue shales	6650	1450	↓ Deposition	Middle Eocene shales		Shale (organic rich, 3% TOC)				
43.00	top Chengue source	8100	350	↓ Deposition	top Chengue source		Shale (organic rich, 3% TOC)	Source Rock	BulkKinetic_Tierralt...	6.30	609.00
43.50	base Chengue source	8450	261	↓ Deposition	base Chengue source		Shale (organic rich, typical)				
46.00	TD	8711									

Maturity (Ro)

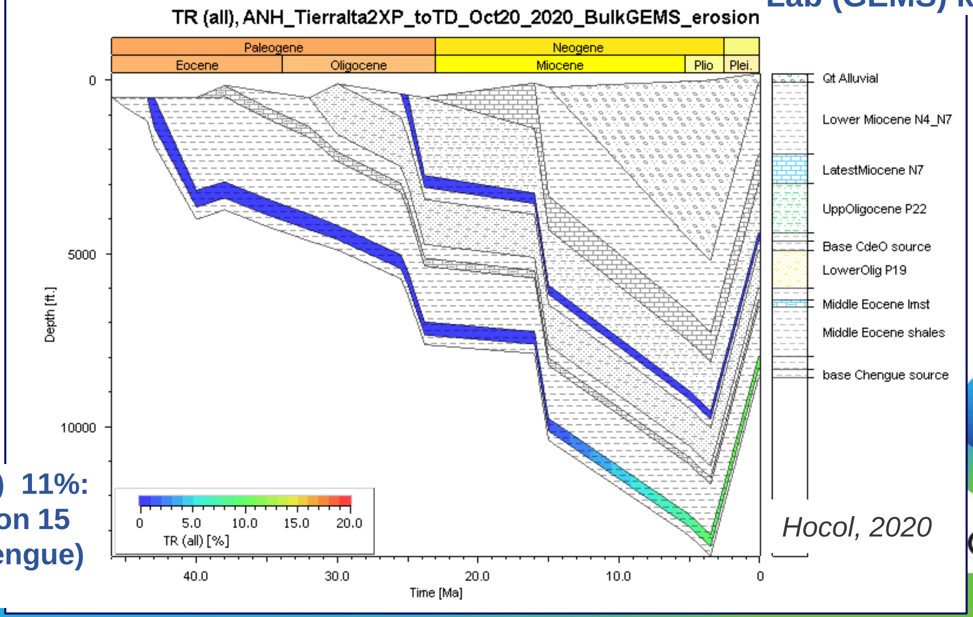


PetroMod kinetics



Transformation Rate (TR) 11%: Beginning transformation 15 Ma (Middle Miocene, Chengue) TII kinetics

Lab (GEMS) kinetics



Hocol, 2020

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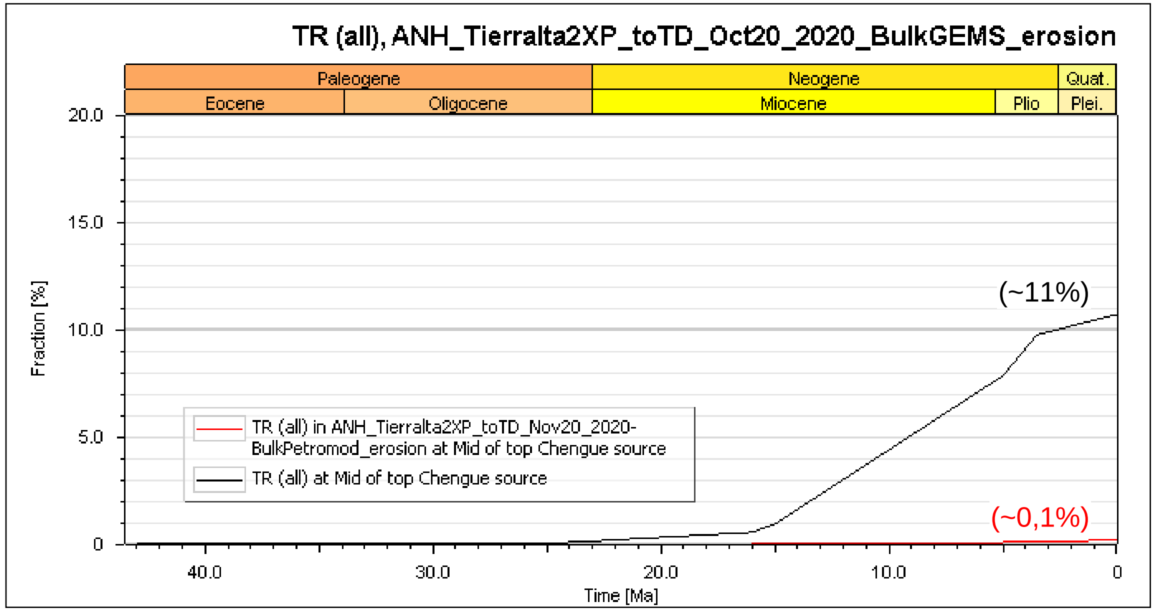
ANH Tierralta-2XP 1D modeling

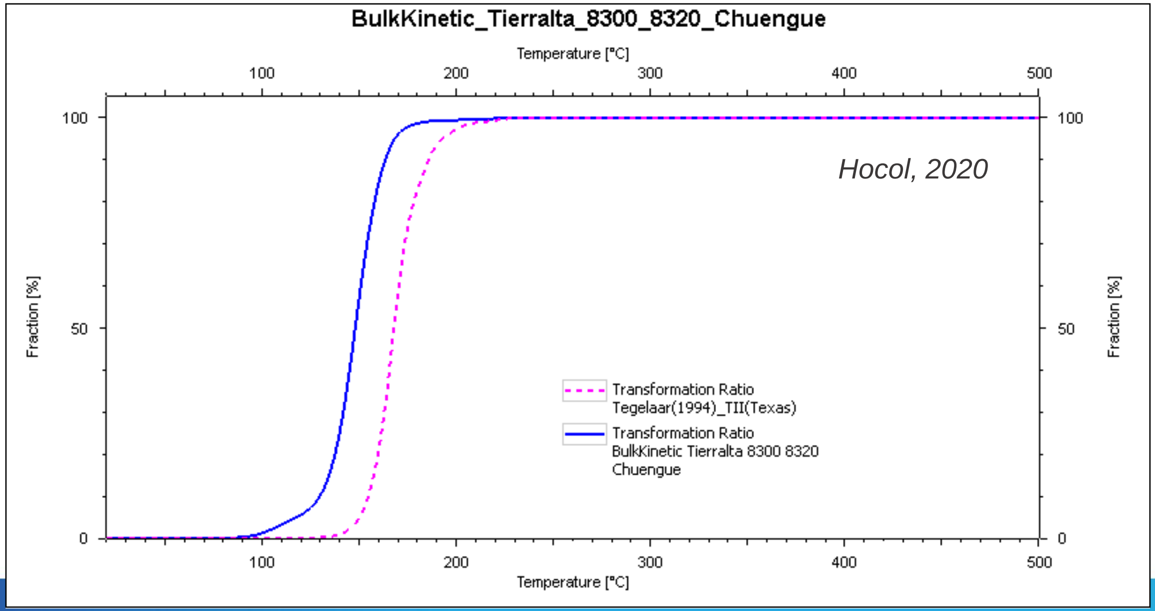
Lab bulk kinetics (GEMS) is more efficient than equivalent in software library

Transformation rates



Kinetics:

- **Bulk Petromod TII**
- **Bulk Gems TII**



The very few models performed in San Jacinto suggest low temperatures, maturities and transformation ratios, but we need more data to define and understand petroleum systems in this complex frontier area.

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Agenda

- Introduction and tectonic models
- Origin and Evolution of the San Jacinto basin
- Origin and Evolution of the Lower Magdalena Valley basin
- Petroleum systems
- Concluding remarks

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Concluding remarks LMV & San Jacinto

- The San Jacinto fold belt was a Cretaceous to Eocene, marine forearc basin formed by the oblique convergence between the Caribbean and South American plates, characterized by a normal subduction with an active magmatic arc. This forearc basin was later inverted and deformed, to become part of the forearc high of the convergent marging.

- The San Jacinto fold belt is frontier to emergent basin where Cretaceous to Eocene sequences are preserved and poorly understood (hypothetical to speculative) petroleum systems have been proposed.

- However, the only commercial production in the basin comes from Eocene Chengue reservoirs in the northern part of the fold belt (Bullerengue gas field), where at least one petroleum system can be proposed: Tertiary marine source rock (=Chengue or San Cayetano?-Chengue (.).

- In spite of the structural and stratigraphic complexities and of the limited amount of data in the basin, it may hold significant hydrocarbon resources and though ANH has helped considerably through stratigraphic drilling and seismic acquisition campaigns, successful exploration requires doing much more activities and investments focused on reconstructing in much more detail the evolution of the area.

Concluding remarks LMV & San Jacinto

- By contrast, the Lower Magdalena Valley basin is a younger (Oligocene to Recent), amagmatic forearc basin whose basement is the northward continuation of the basement terranes of the northern Central Cordillera, and the extensional reactivation of inherited basement faults was crucial for the tectonic segmentation of the basin with the formation of its two depocenters (Plato and San Jorge).

- Compared to San Jacinto, the LMV has remained more “protected” and much less deformed, in part due to its location more distant from the convergent margin; this has been favorable for petroleum systems including the preservation of the hydrocarbon accumulations (much better seal integrity).

- We have shown how the proposed formation and evolution of the basin controlled petroleum system elements (source, reservoir and sealing rocks) and processes (geothermal gradient/heat flow and maturity, migration and synchronism), though further data and studies are required to increase our understanding mostly in the southern part.

- This mature basin has significant remaining potential especially in stratigraphic traps, therefore exploration efforts must be focused on that direction.

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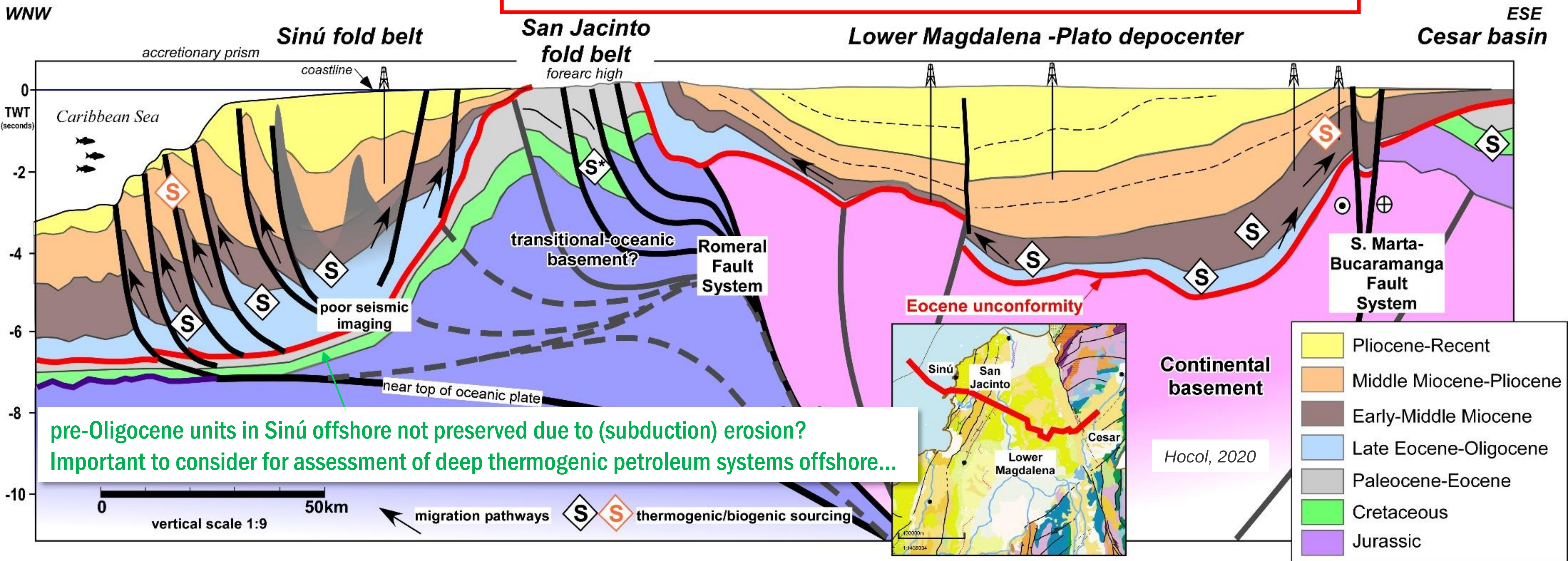
Basins and plays in N Colombia

Frontier basins	Emerging basin	Mature basin	Emerging basin
Oligocene?- Pleistocene plays; gas-prone area (shallow biogenic –deep thermogenic?)	new commercial, Eocene to Miocene plays; wet gas & condensate-prone area (north)	(commercial, > 300 MMBOE discovered) Oligocene to Miocene plays; light-oil, wet & dry gas-prone area (thermogenic to mixed)	Cretaceous to Paleocene plays; gas & oil?-prone area



pre-Oligocene units in Sinú offshore not preserved due to (subduction) erosion?
Important to consider for assessment of deep thermogenic petroleum systems offshore...

Thank you!-questions?

ANH- Miguel de Armas
Hocol Exploration Vicepresidency
All the assistants