

Petroleum System Analysis of the Nicaraguan Rise and Colombia Basin: A Regional Overview from Seismic and Well Data*

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Abstract

The Caribbean region covers only 0.4% of the world's surface but has an extremely complex tectonic history due to the interaction of the North American, South American and Pacific plates. To reevaluate the prospectivity of this area, we have used 8500 km of vintage 2D seismic data acquired in the early 1980s and 3000 km of high-resolution, deep-penetration 2D seismic data acquired in 2007. The seismic data set was tied to 27 existing exploration wells and five ODP and DSDP wells containing a complete set of geochemical, geological, and geophysical logs. We have also integrated our interpretation with previous work by Bowland (1993) using UT lines from the early 1980s that effectively expand our study area to cover a 621,000 km² area of the Nicaraguan Rise and Colombian basin. Main results include:

- 1) The sediment deposition controlled by tectonic events is represented by localized horst and grabens in the Nicaraguan Rise, and major depocenters in Jamaica offshore, Panama offshore, and Colombia Basin.
- 2) We identify key petroleum system elements and processes using geological, geophysical, and geochemical data integrated into a 3D petroleum system model that includes an early and late Eocene / Oligo-Miocene (!) petroleum system.
- 3) Early and Late Eocene source rocks identified in the Nicaraguan Rise include clayey, calcareous limestone, and pelagic shale containing kerogen type II and III with a TOC between 0.85% and 3.74%.
- 4) Potential reservoirs include transitional to deep-marine environments with clastic pinchouts; dolomitized, shallow-marine carbonate complexes; and reefal buildups.
- 5) Potential seal rocks include gray calcareous shale, siltstone, and silty shale deposited above regional and local unconformities and as intraformational facies changes.
- 6) Thermal history modeling based on paleo-heat flows, burial histories, and transformation ratio maps shows that the initiation of hydrocarbon generation began during the early Oligocene (35 Ma) at ~69 mW/m² with an average hydrocarbon expulsion of 7.15 MMBOE per km² between Eocene source rock intervals.
- 7) Our proposed model predicts vertical migration in the Nicaraguan Rise with a predicted generation-accumulation efficiency of 3.5%.

Selected References

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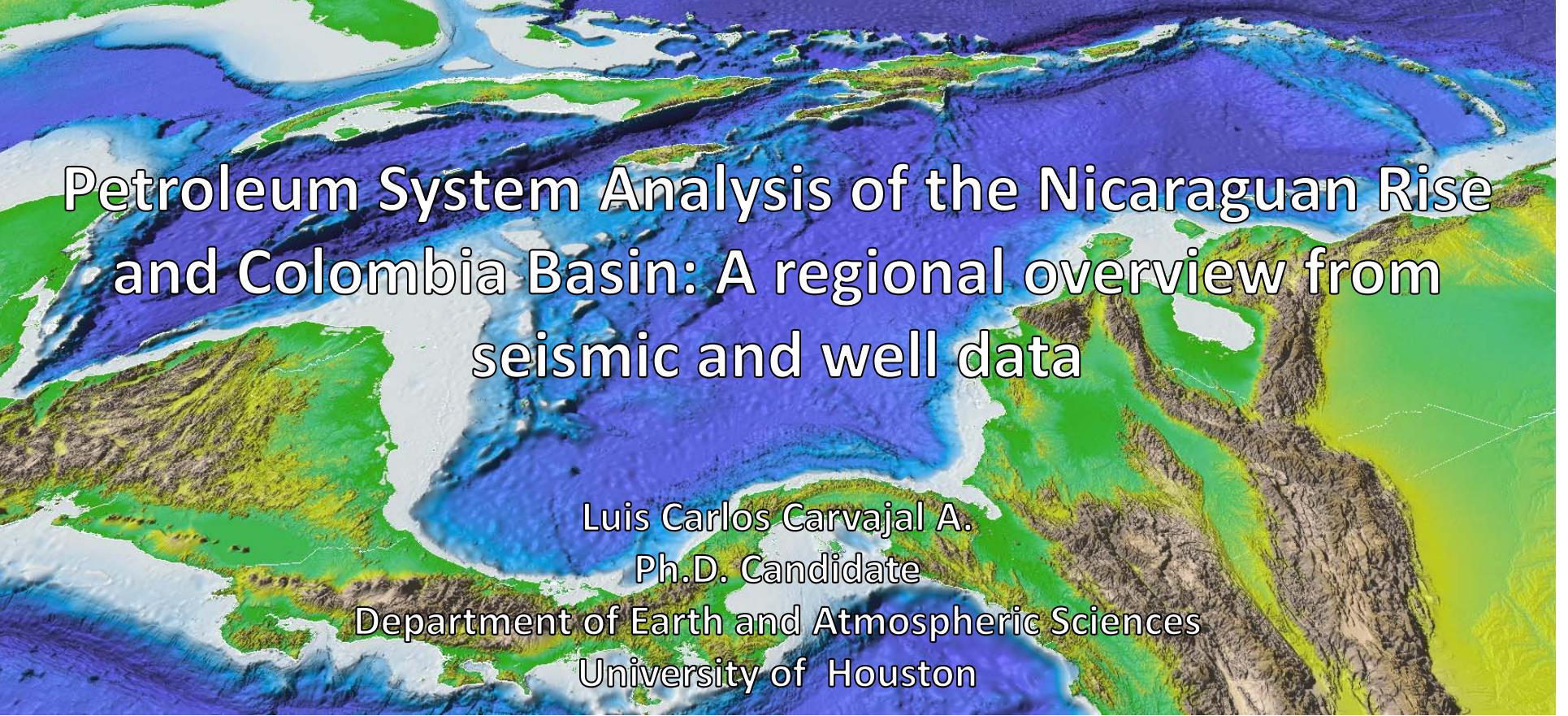
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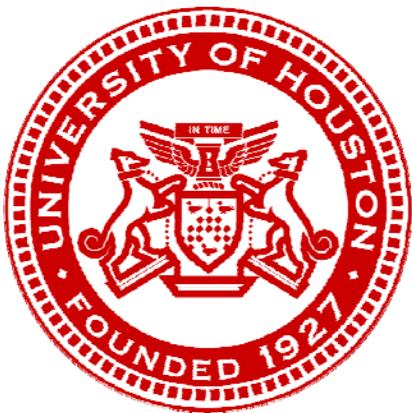
Department of Earth and Atmospheric Sciences
University of Houston



GTW - Carbonate Plays around the World –
Analogues to Support Exploration and Development
February 5th - 2015



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Talk Overview

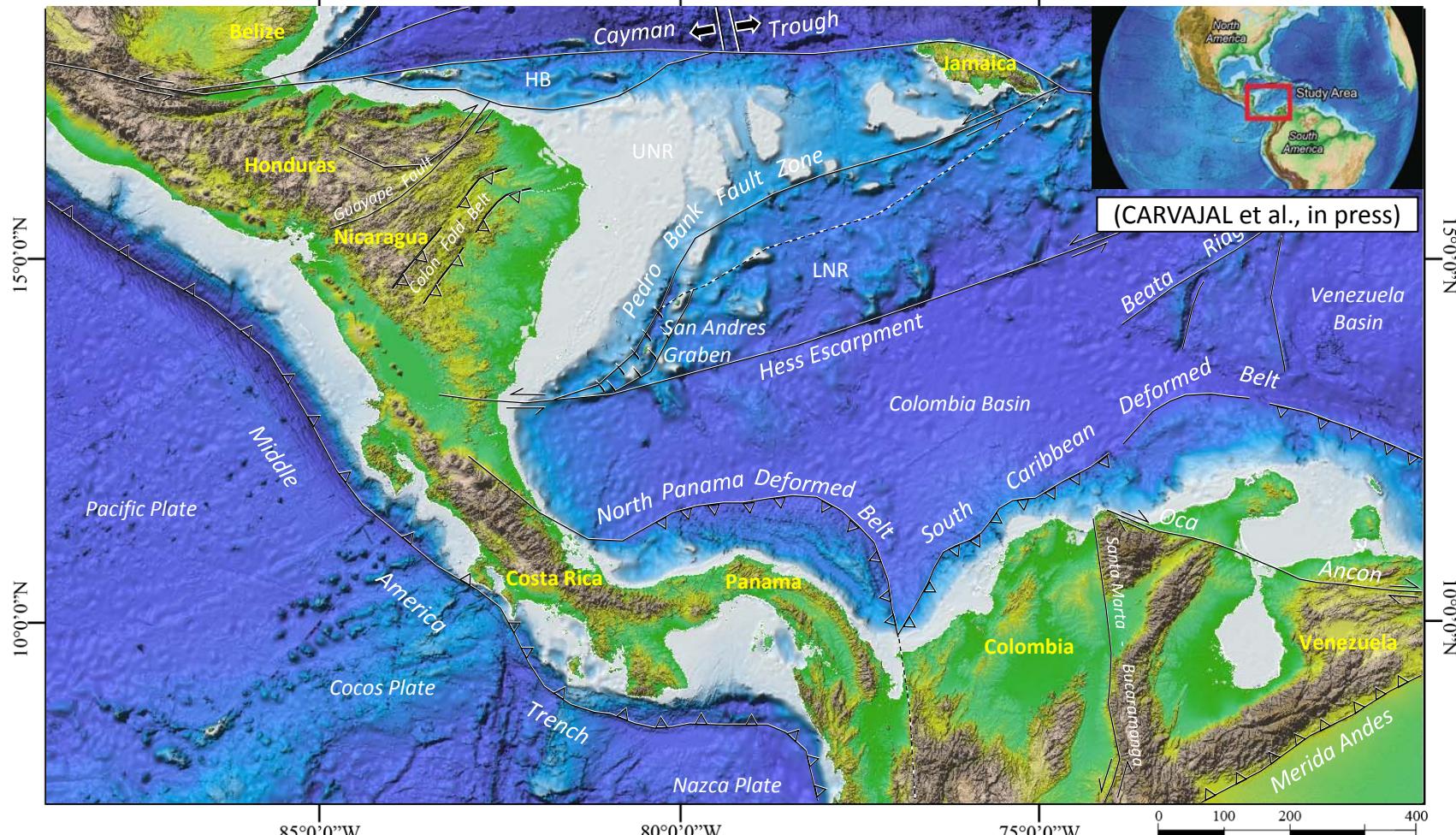


Objective

By integrating all available data into the 3D basin model, and following the petroleum system classification of Magoon and Dow (1994), we propose a known Early & Late Eocene / Oligo-Miocene (!) petroleum system in the Nicaraguan Rise.

PART I

Regional Setting

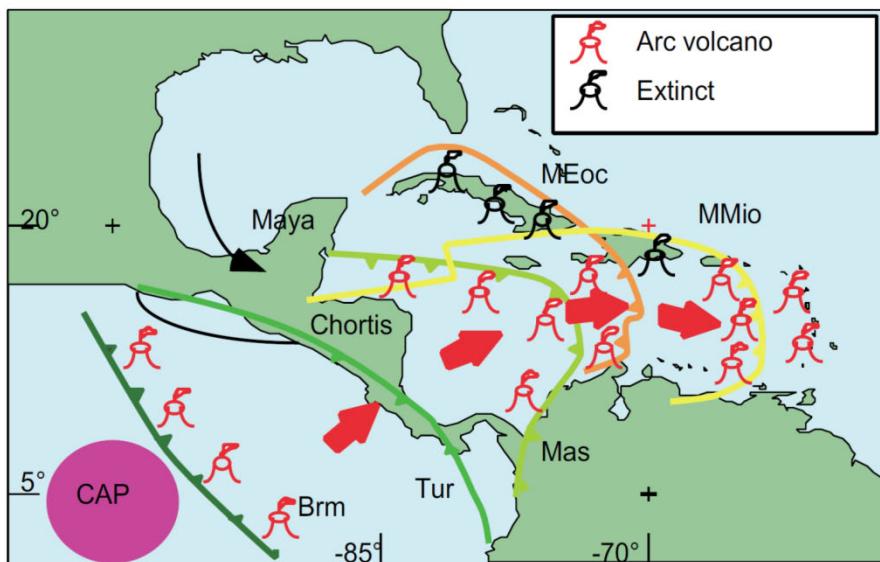


- Regional Strike-Slip Faults
- Extensional Regime in the South and compressional in the North
- Active spreading center in the Cayman Trough

Caribbean Tectonic Evolution

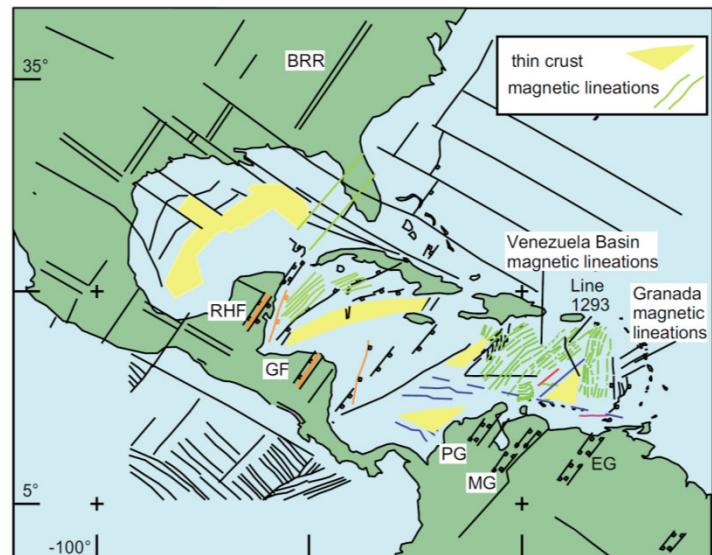
Tectonic Evolution Models

Pacific Model (allochthonous)



James Pindell, 1982

Inter-American Model (in-situ)

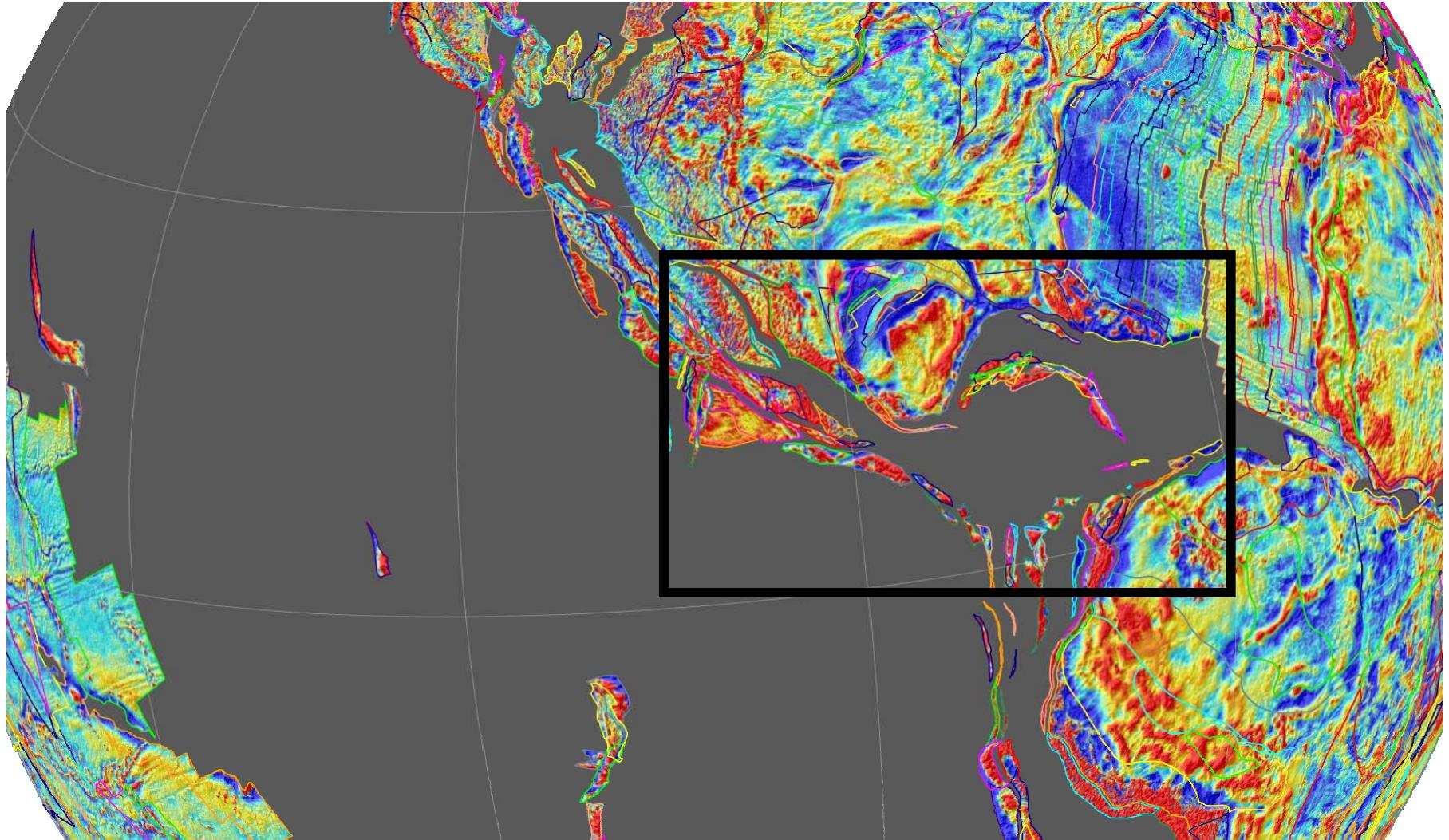


Keith James, 2006

- Migration of the Caribbean Plate from the Pacific since Jurassic and thickened into an igneous oceanic plateau in the Cretaceous.

- Caribbean formed due to the separation of North America and South America since Jurassic.

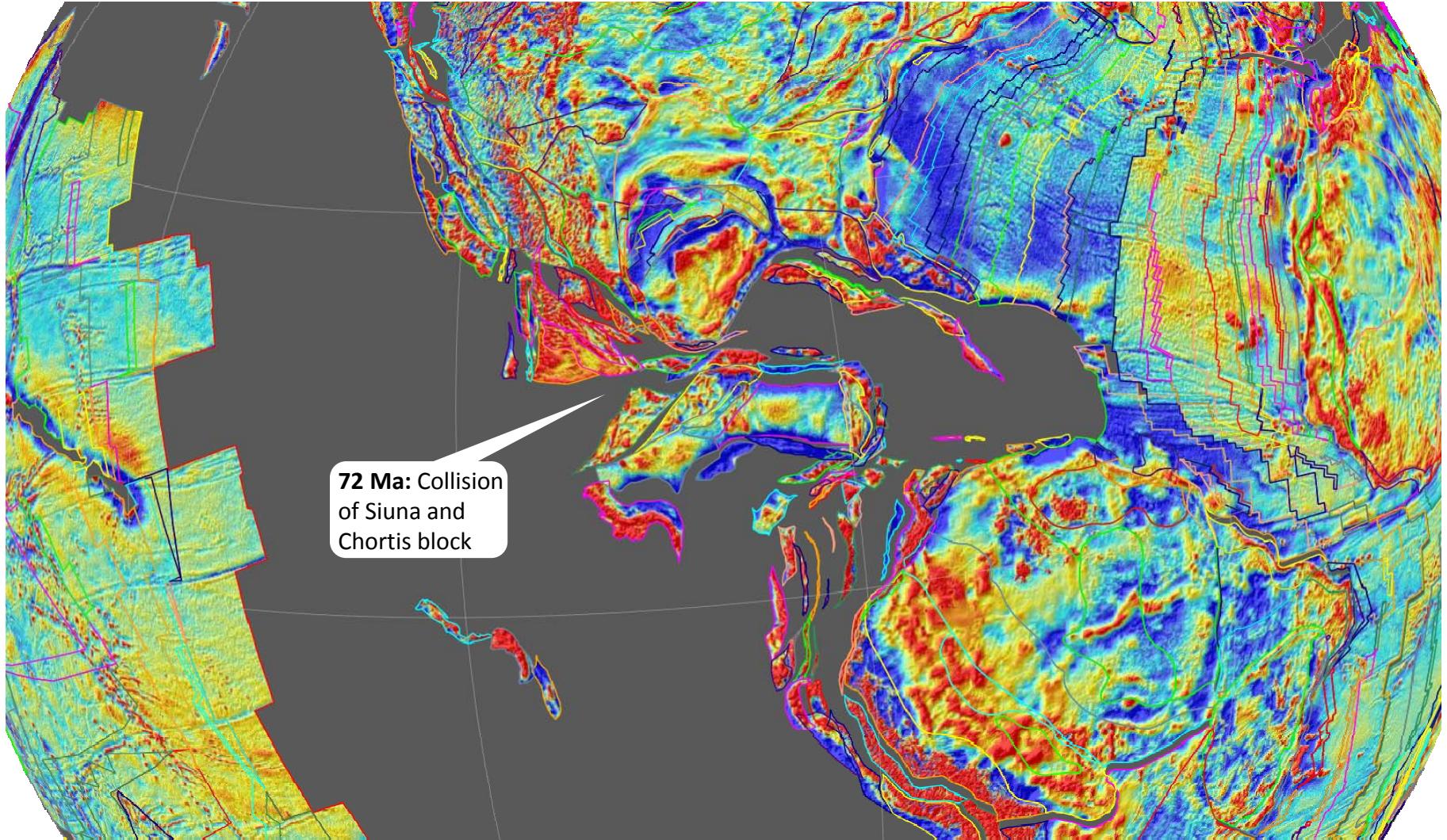
Main Tectonic Phases of the Caribbean 100 Ma



Reconstructions courtesy of PLATES

Main Tectonic Phases of the Caribbean

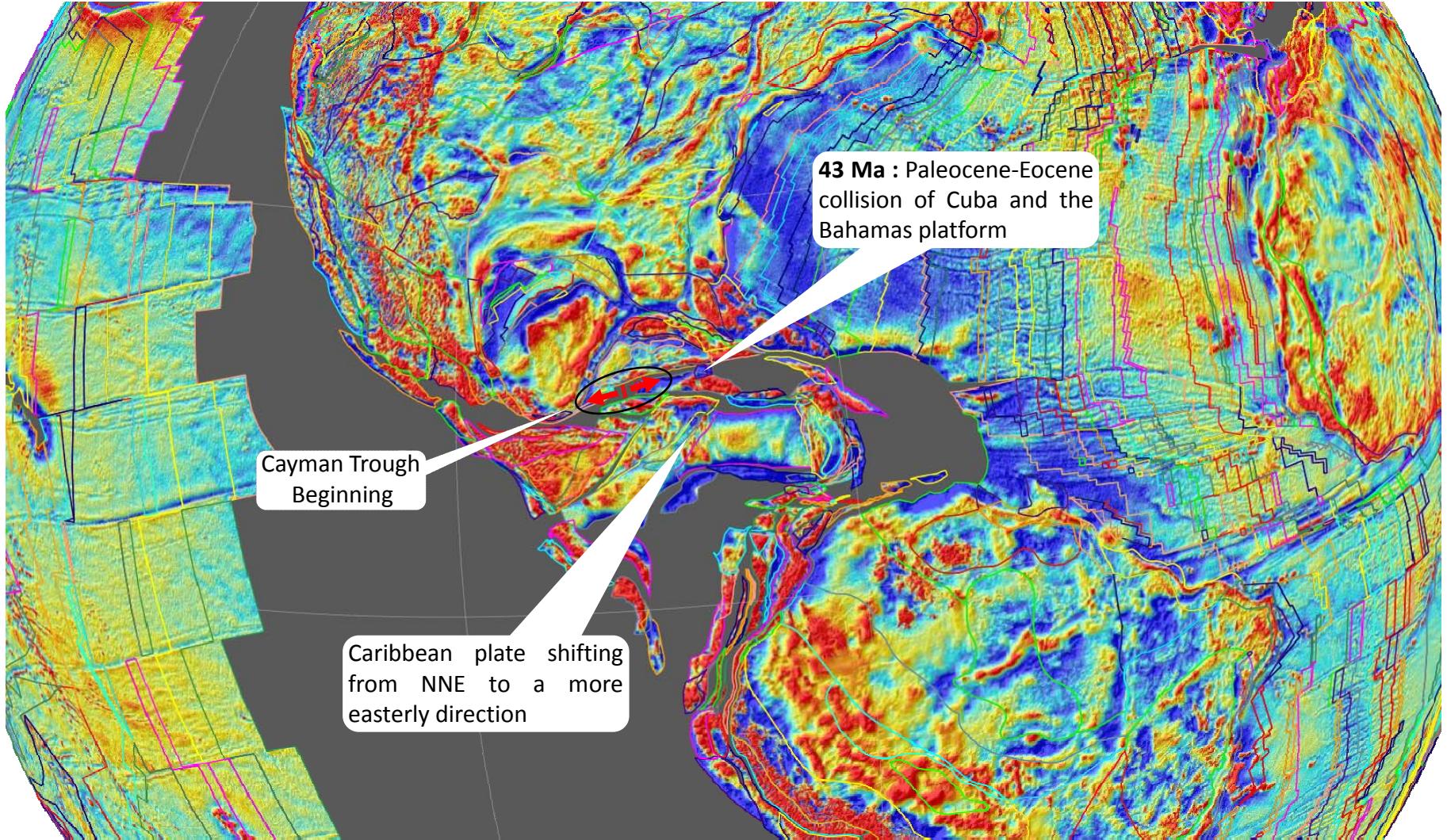
70 Ma



Reconstructions courtesy of PLATES

Main Tectonic Phases of the Caribbean

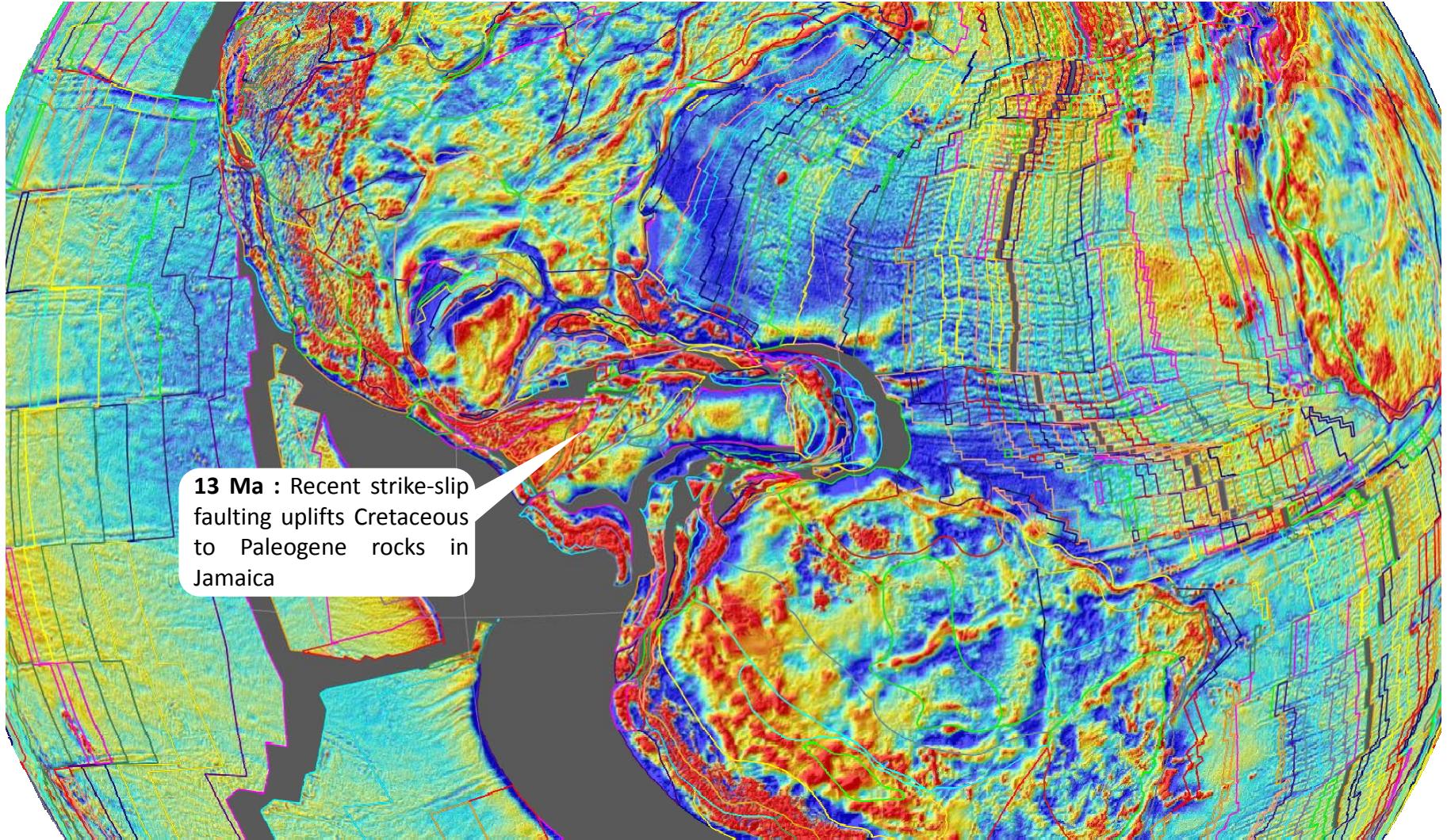
40 Ma



Reconstructions courtesy of PLATES

Main Tectonic Phases of the Caribbean

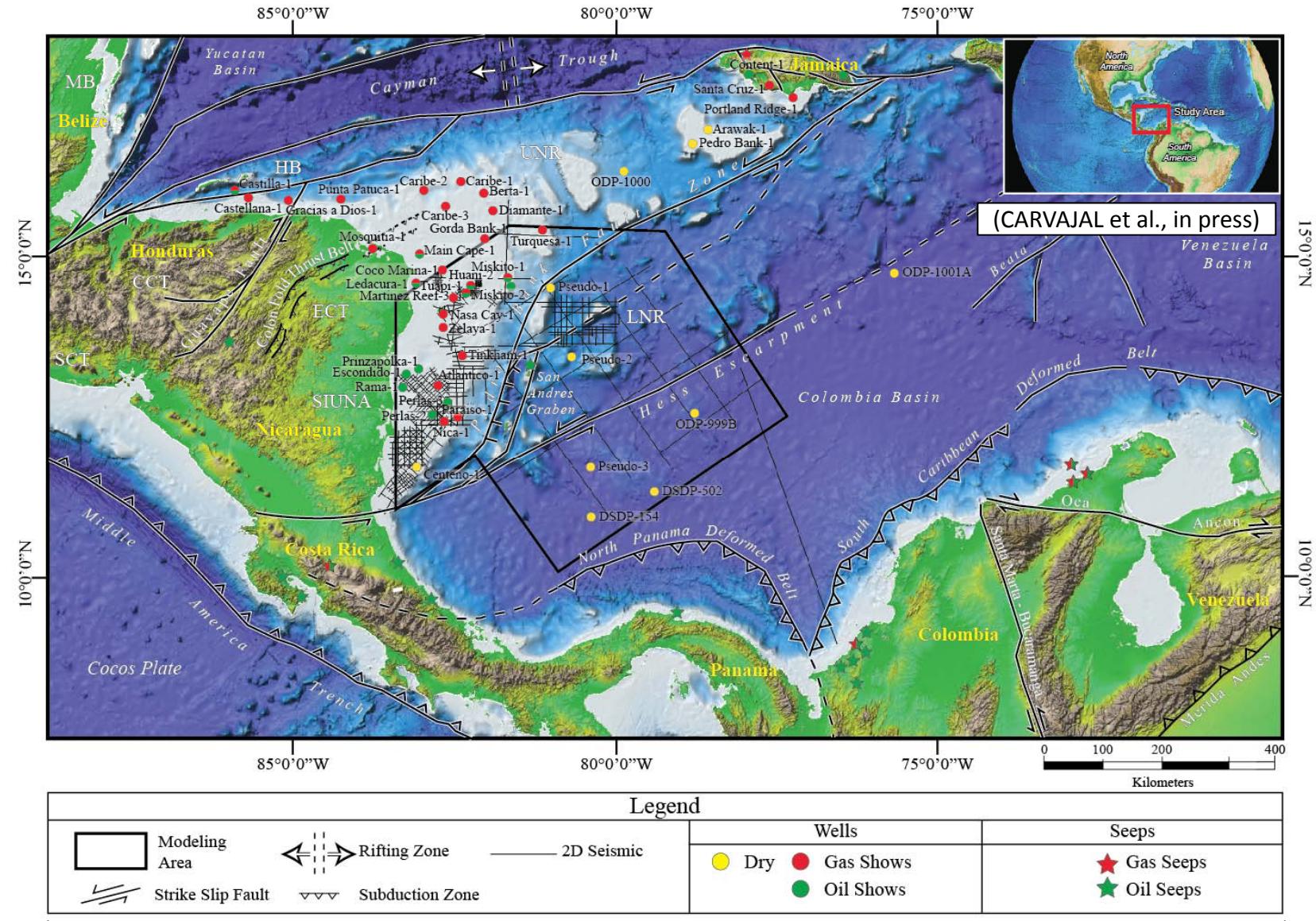
13 Ma



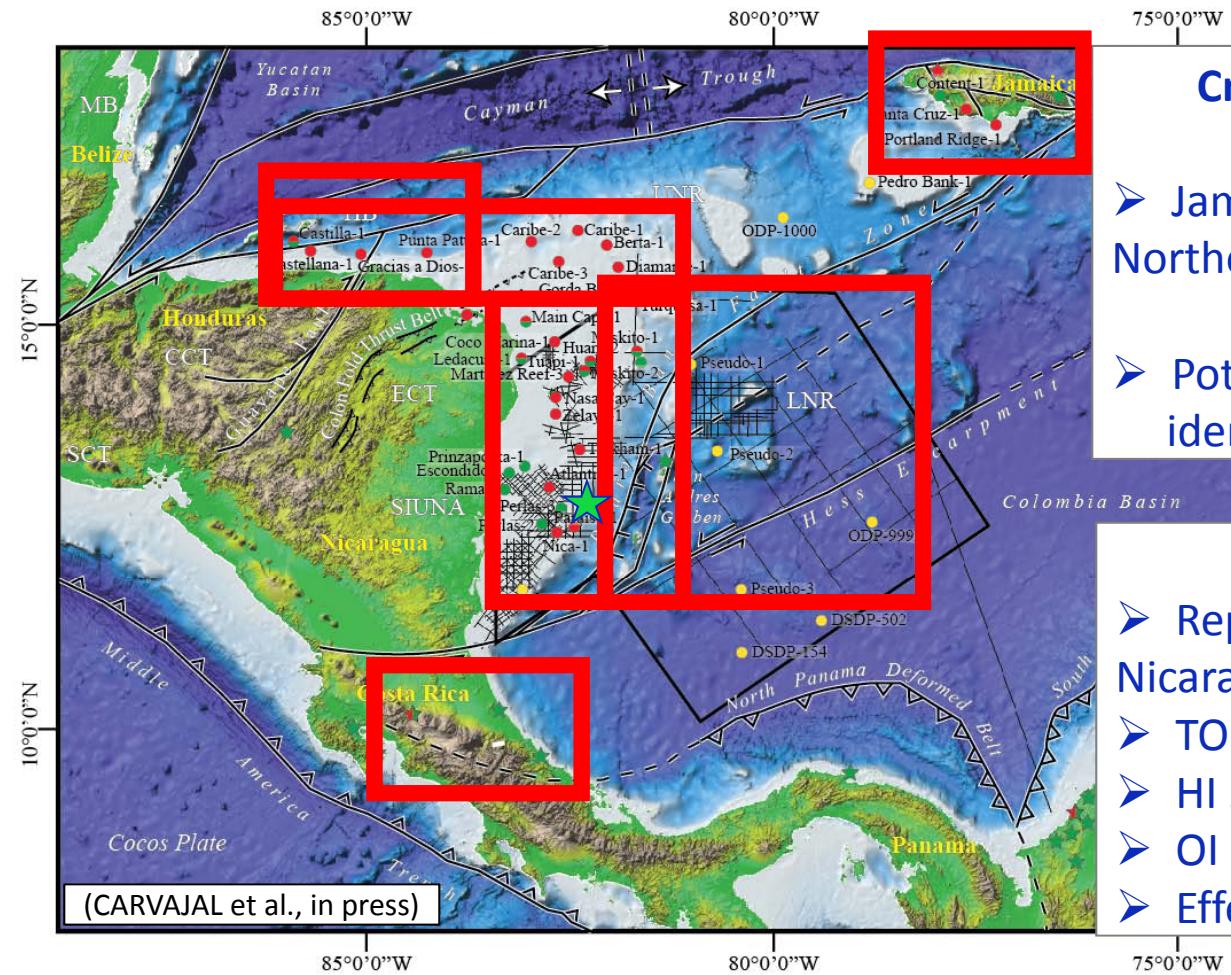
Reconstructions courtesy of PLATES

PART II

Data Set



Source Rock Outcrops



Cretaceous Source Rocks

- Jamaica, Honduras, Costa Rica, Northern Colombia
- Potential Cretaceous sediments identified in seismic

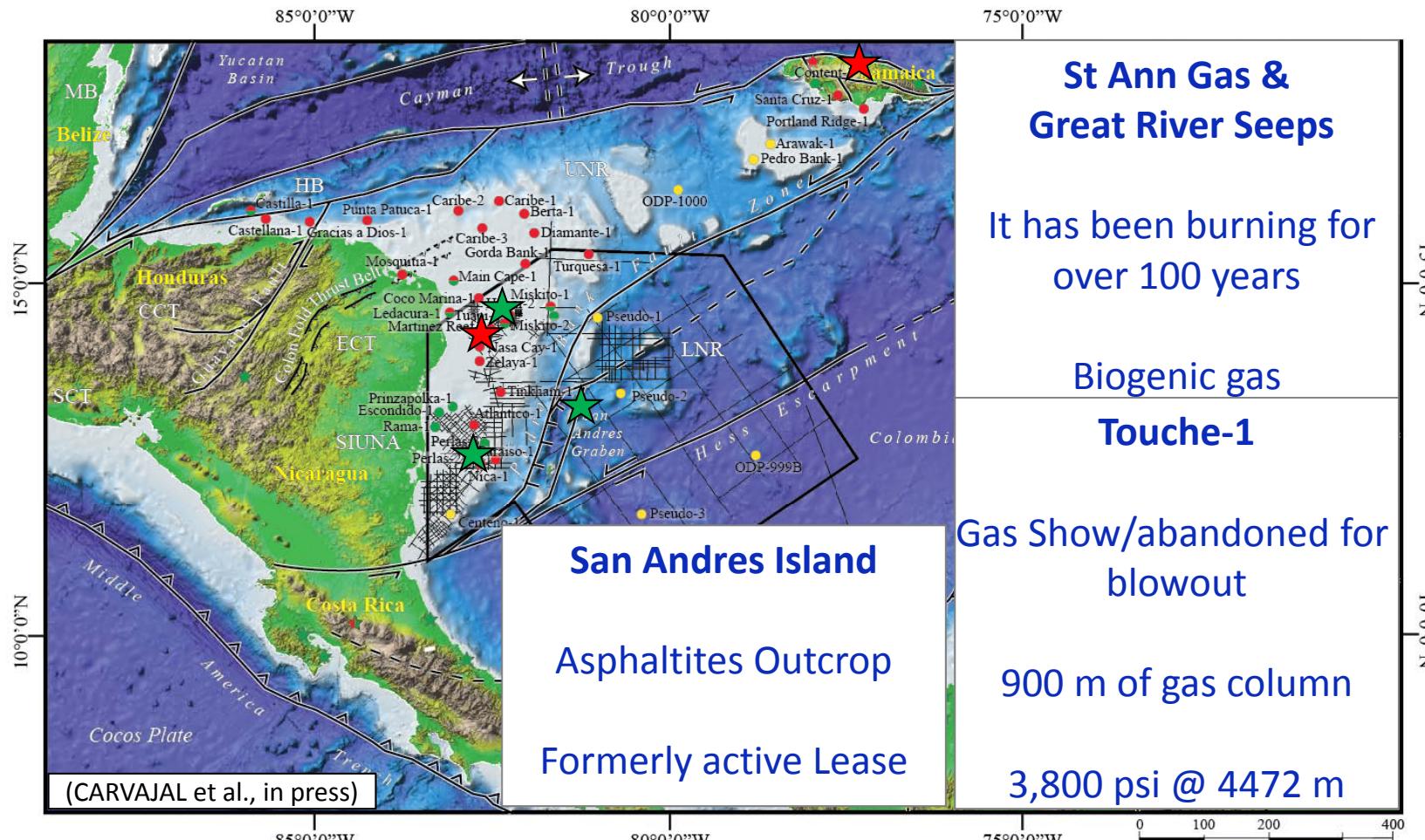
Eocene Source Rocks

- Reported Honduras, Nicaraguan offshore
- TOC 0.85 to 3.4%
- HI 280 to 450 mgHC/g TOC
- OI up to 380 mgCO₂g/TOC
- Effective Thickness 70-400m

Legend

Modeling Area	Rifting Zone	2D Seismic	Wells	Seeps
Strike Slip Fault	Subduction Zone		● Dry ● Gas Shows ● Oil Shows	★ Gas Seeps ★ Oil Seeps

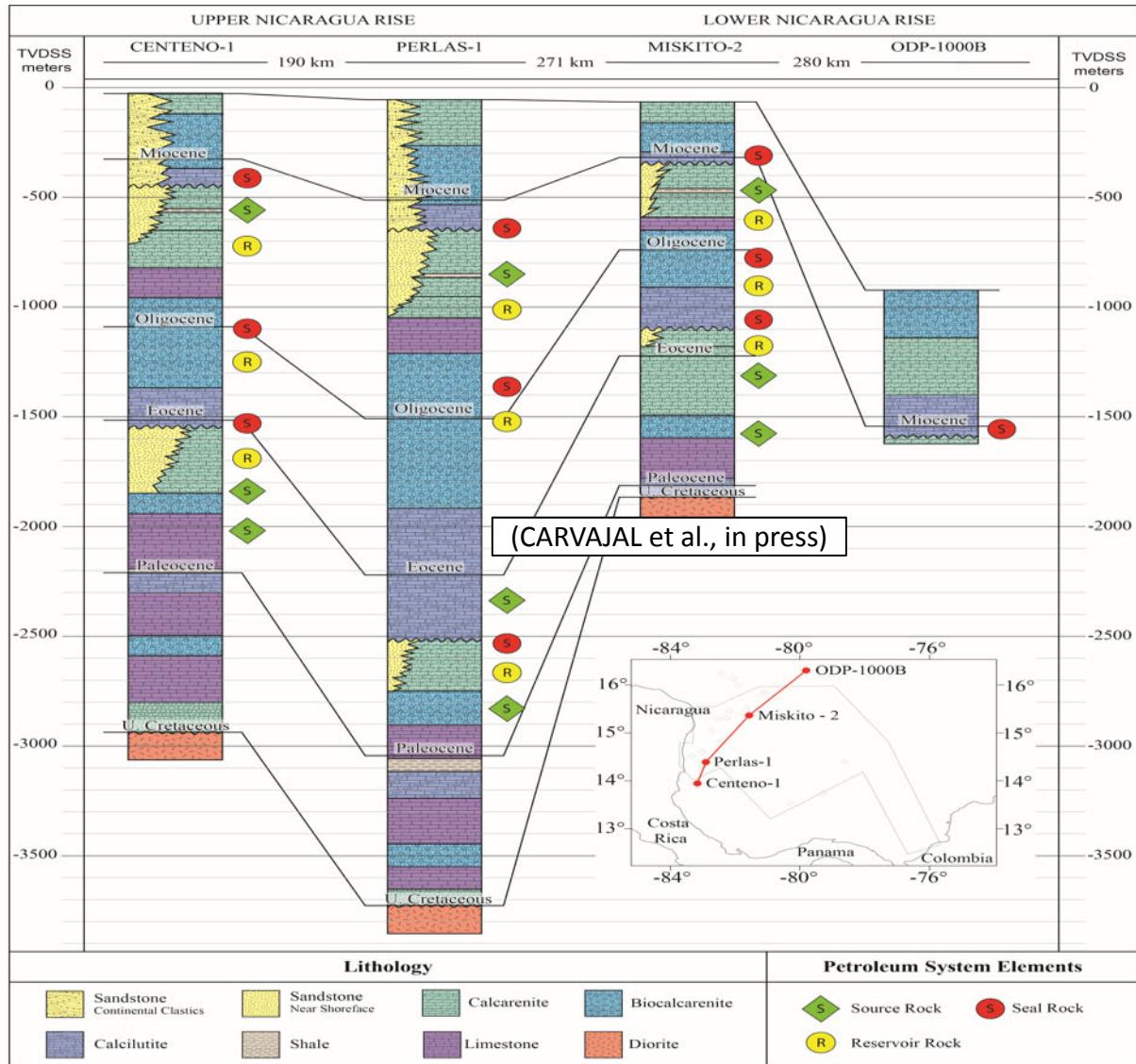
Hydrocarbon Occurrences



Legend		
Modeling Area	Rifting Zone	2D Seismic
Strike Slip Fault	Subduction Zone	Wells: Dry (Yellow), Gas Shows (Red), Oil Shows (Green) Seeps: Gas Seeps (Red Star), Oil Seeps (Green Star)

Regional Stratigraphy

Generalized Stratigraphic Column



Cretaceous
Basement (Granite, Diorite, Andesite, Basalt), deep horizons suggest sedimentary structures

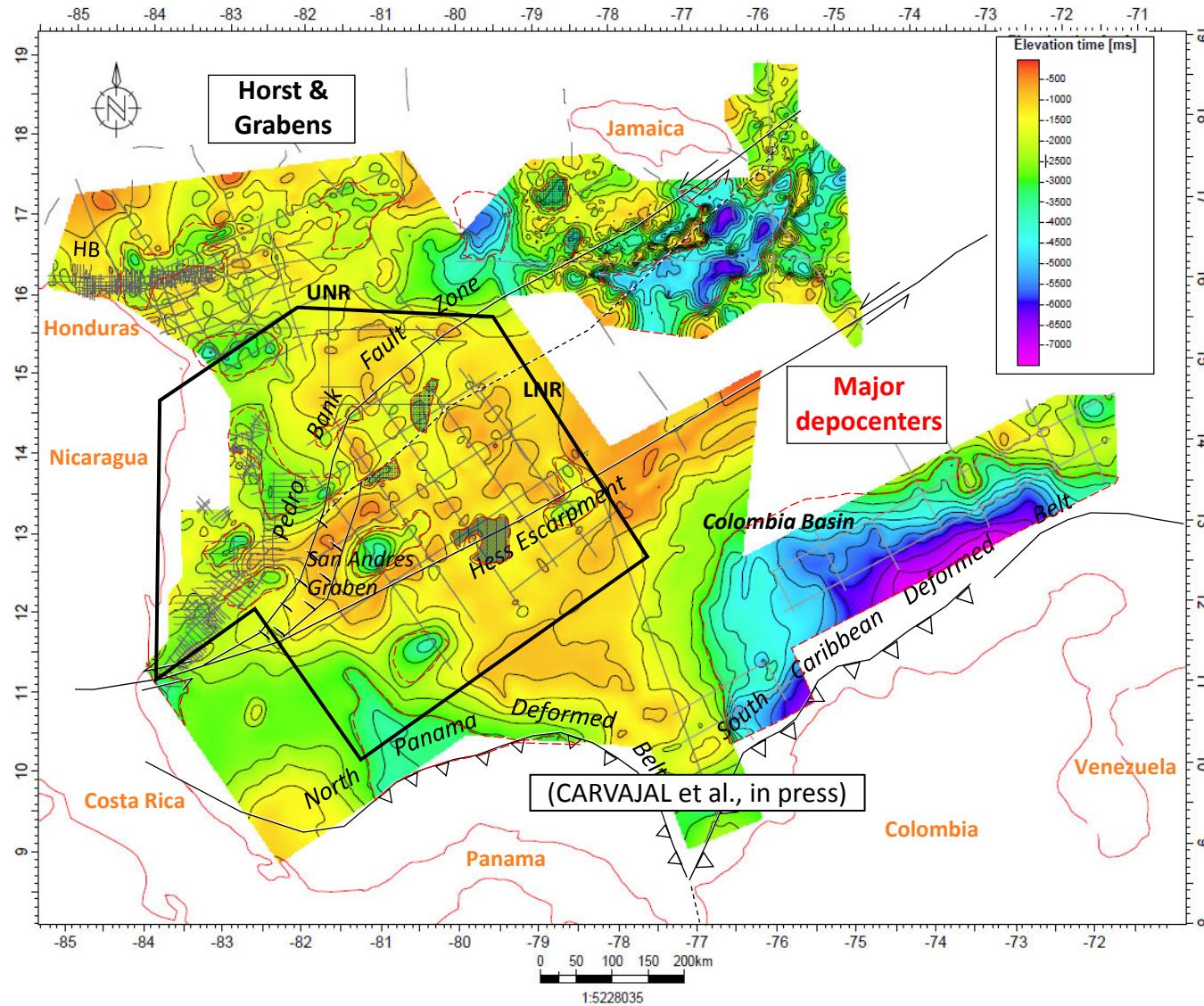
Paleocene
Volcanic ash and tuffs / Calcareous Shales

Eocene
No volcanic content
Limestones/ Organic-Rich Shales

Oligocene
Shallower carbonates

Miocene
Sandstones / conglomerates / Marine Shales

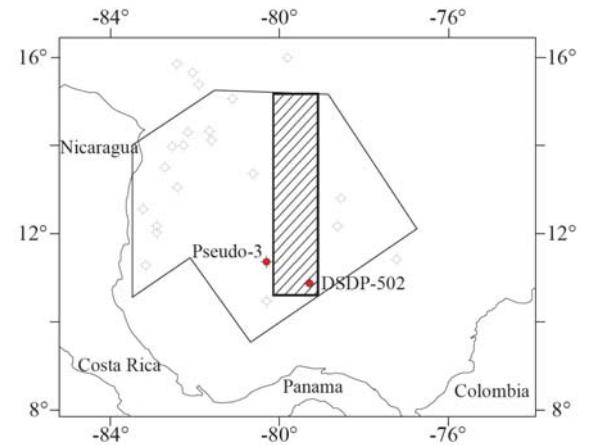
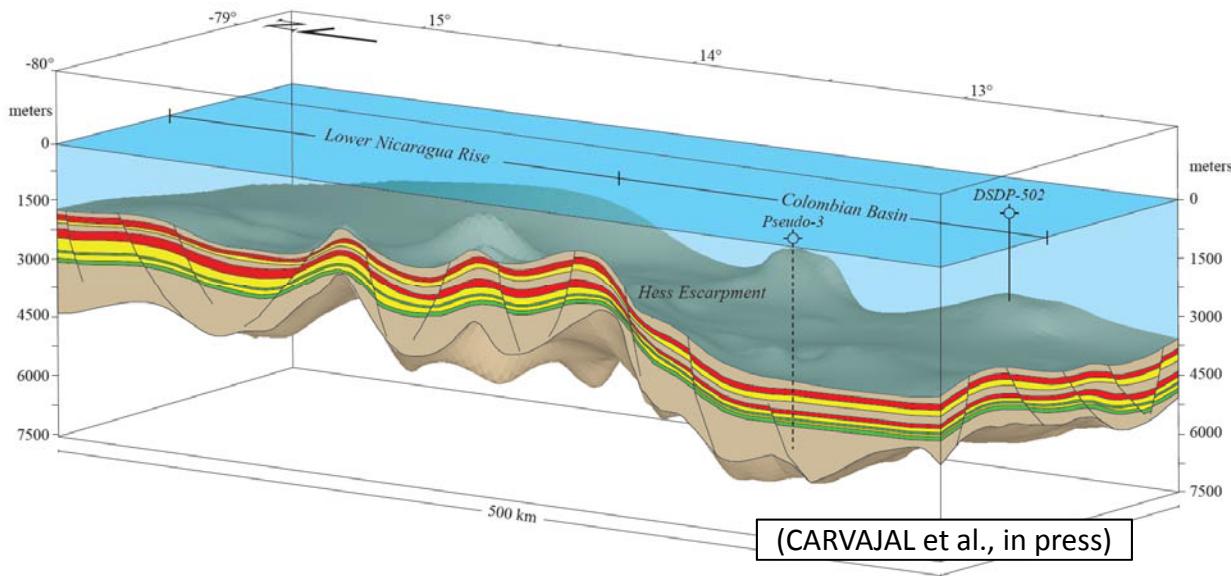
Regional Thickness Map



- Sediment Thickness ranges from 4 Km to 13 Km
- Main depocenters bounded by basement highs
- A variety of basin types are identified through the Nicaraguan Rise.

Boundary Conditions

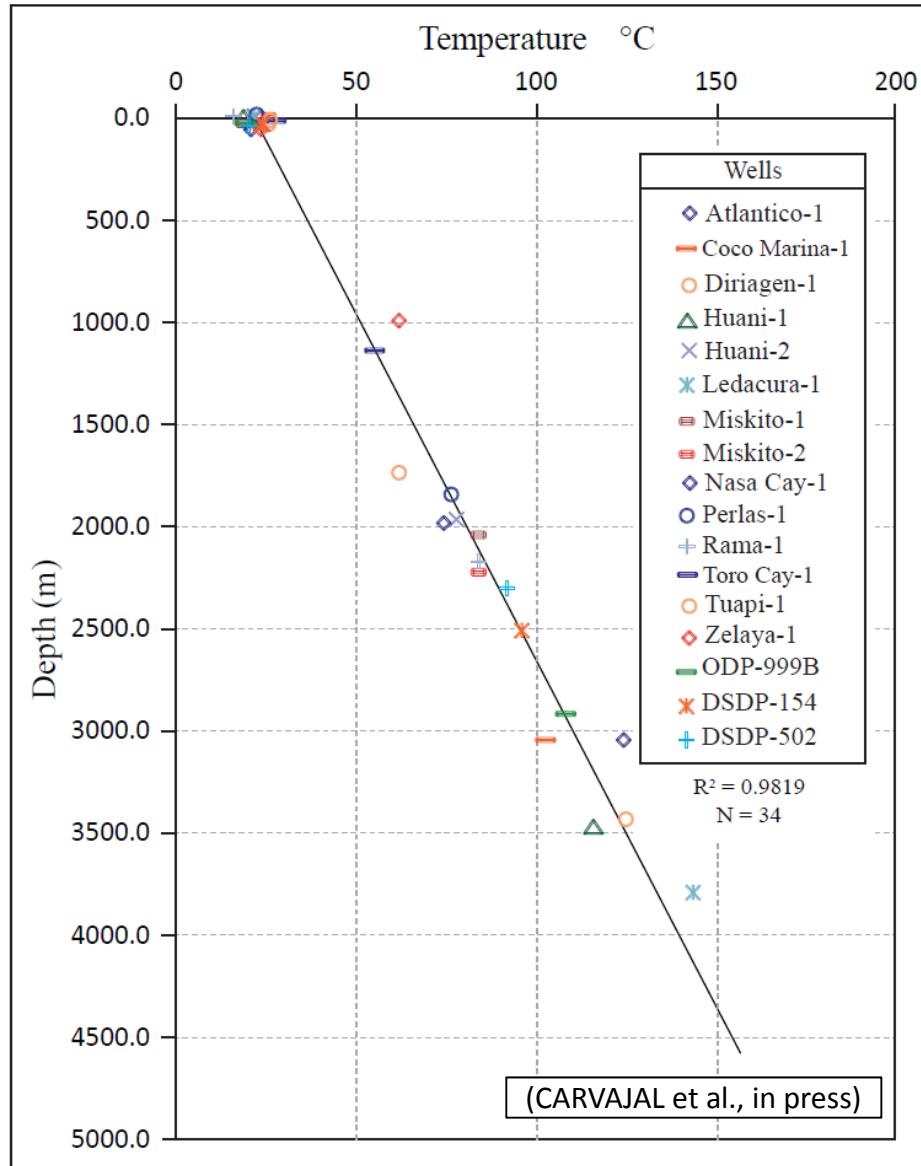
Petroleum System Model



Age (Ma)	Layer	Lithology	Age Intervals		PSE
0-12.82	1	Limestone/Calcareite/Dolomite	Sea Floor-Upper Miocene		Overburden Rock
12.82-14.2	2	Calcilitute/ Shale	Upper Miocene-Middle Miocene		Seal Rock
14.2-15.97	3	Sandstone/Dolomite	Middle Miocene-Early Miocene		Reservoir Rock
15.97-23.03	4	Calcareite/Limestone	Early Miocene-Late Oligocene		
23.03-28.4	5	Calcilitute/Shale	Late Oligocene-Early Oligocene		Seal Rock
28.4-45.6	6	Calcareite/Sandstone	Early Oligocene-Upper Eocene		Reservoir Rock
45.6-48.6	7	Organic Shale/Shaly Limestone	Upper Eocene-Middle Eocene		Source Rock
48.6-53.3	8	Calcareite/Sandstone	Middle Eocene-Early Eocene		Reservoir Rock
53.3-55.8	9	Organic Shale	Early Eocene-Paleocene		Source Rock
55.8-75	10	Limestone/Calcareite	Paleocene-Late Cretaceous		Underburden Rock

- Extraction of a 3D volume
- Major Petroleum elements
- 2 source rocks were modeled

Borehole Temperature



Today's Geothermal Gradient

$3.35 \text{ }^\circ\text{C} / 100 \text{ m}$

Today's Heat Flow

$45 - 65 \text{ mW/m}^2$

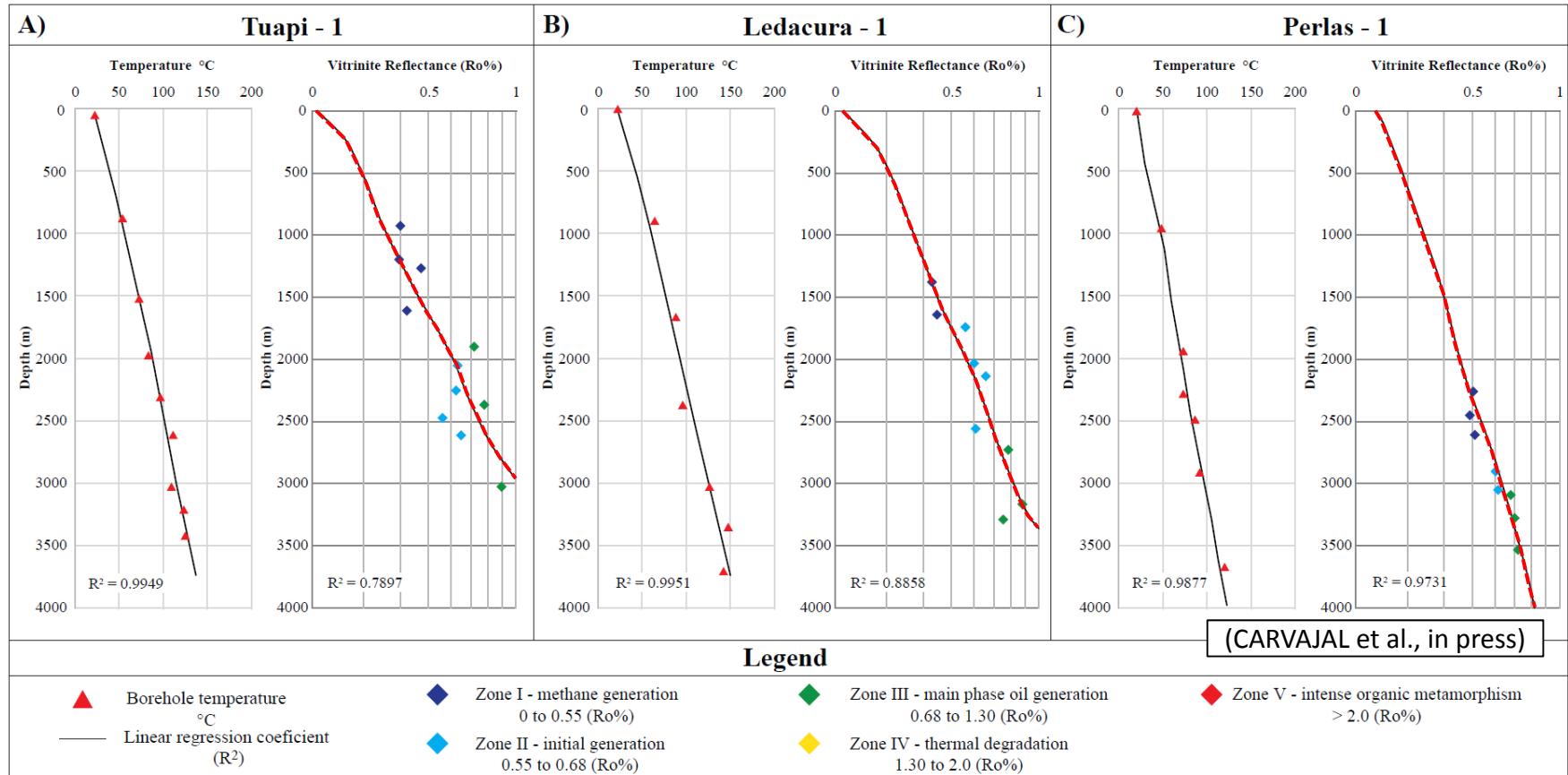
Sediment-Water Interface

(SWIT) based on Wygrala
(1989) and motion Plate of the
Caribbean

$30 \text{ }^\circ\text{C} \text{ to } 22.39 \text{ }^\circ\text{C}$

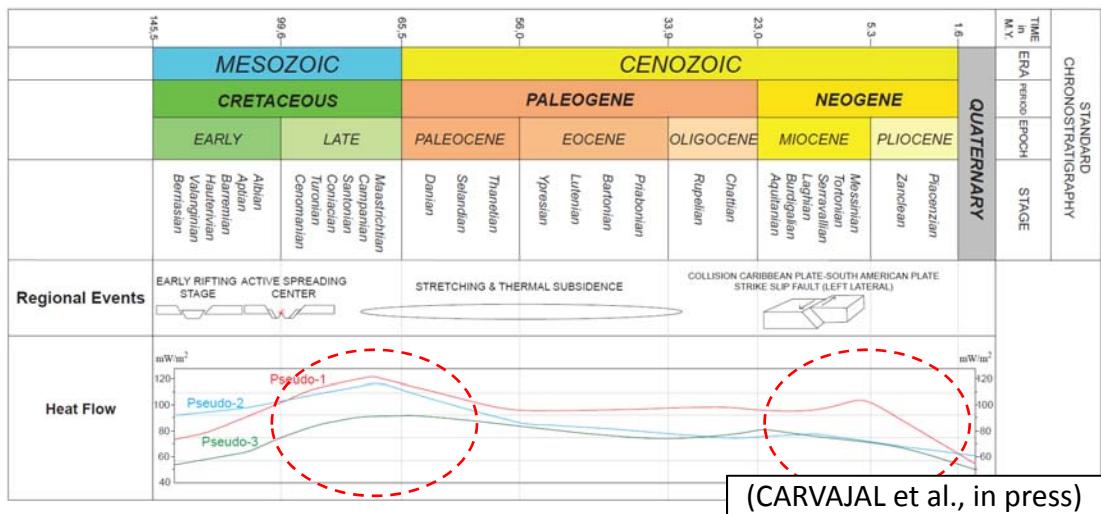
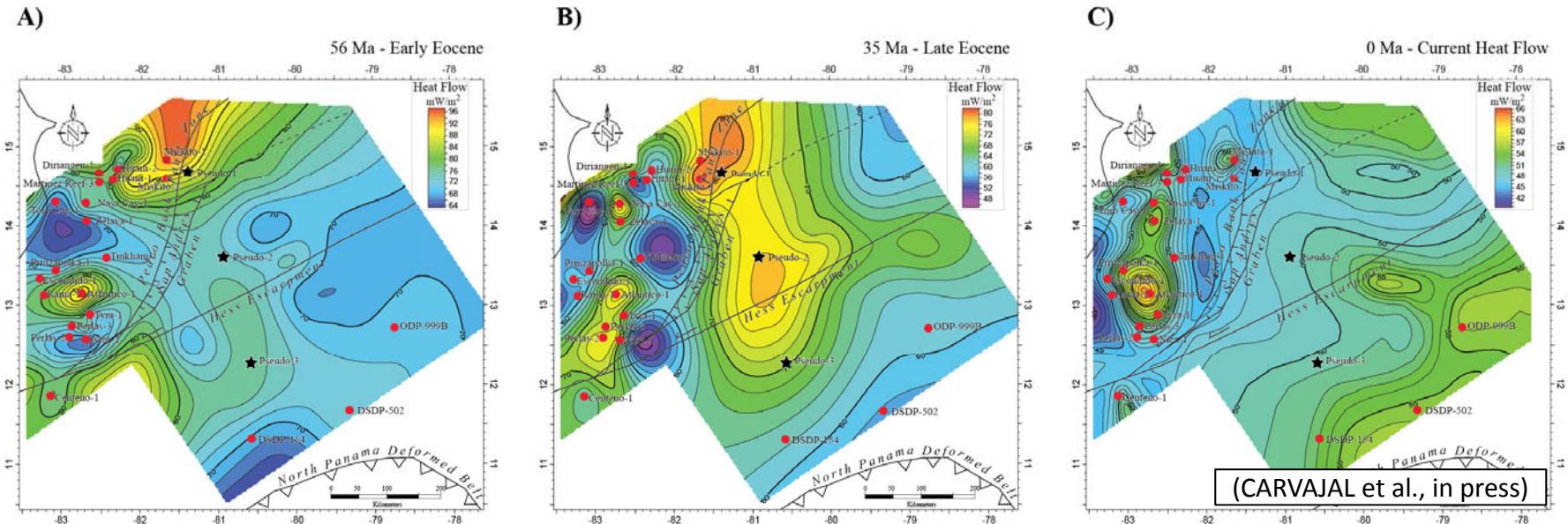
Vitrinite Reflectance was used
to calibrate Paleo Heat Flows

Vitrinite Reflectance (Ro%) Calibration



- Calibration of Vitrinite Reflectance to recreate Paleo-Heat flows
- VR% samples are within zones II, III and IV

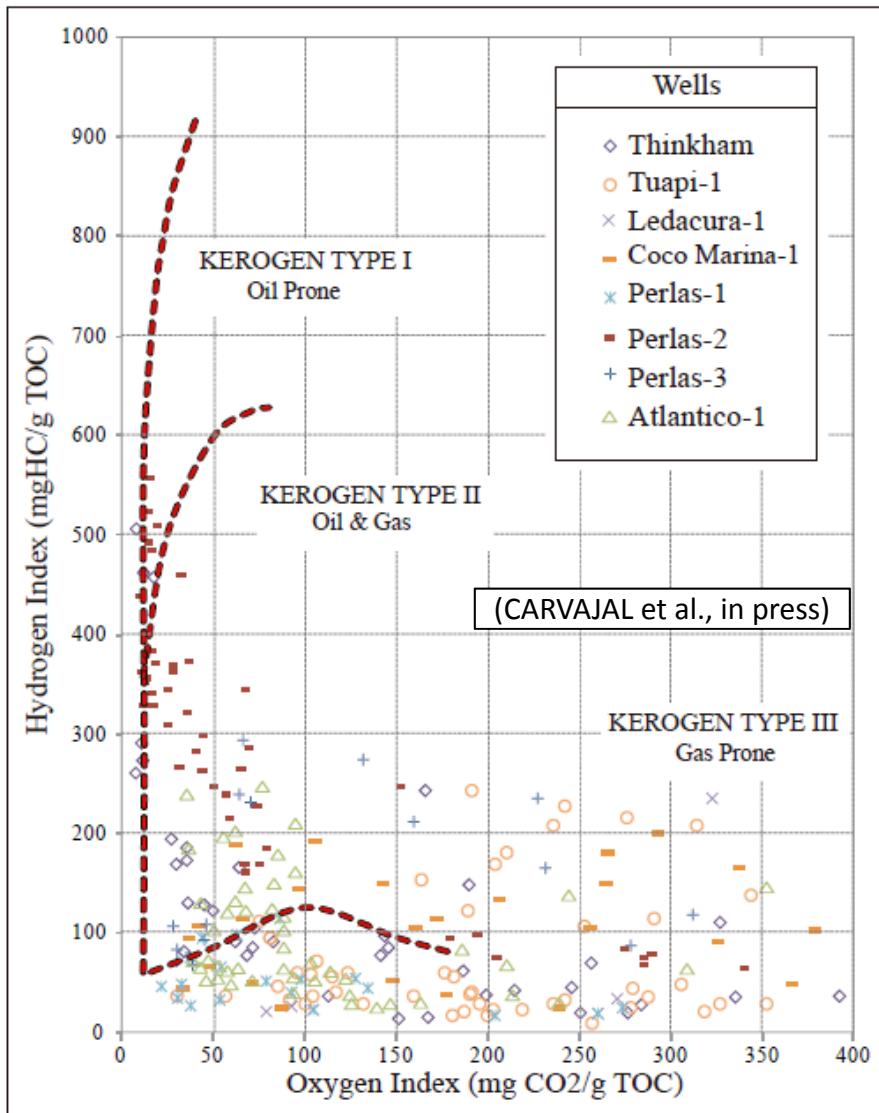
Paleo Heat Flows linked to Major Tectonic Events



- 12 PHF maps were calculated from punctual VR calibrations.
- Two PHF peaks are identified in most of the pseudo-wells.
- Closer areas to Strike-slip faults > HF during Miocene

Petroleum Play Elements

Source Rocks



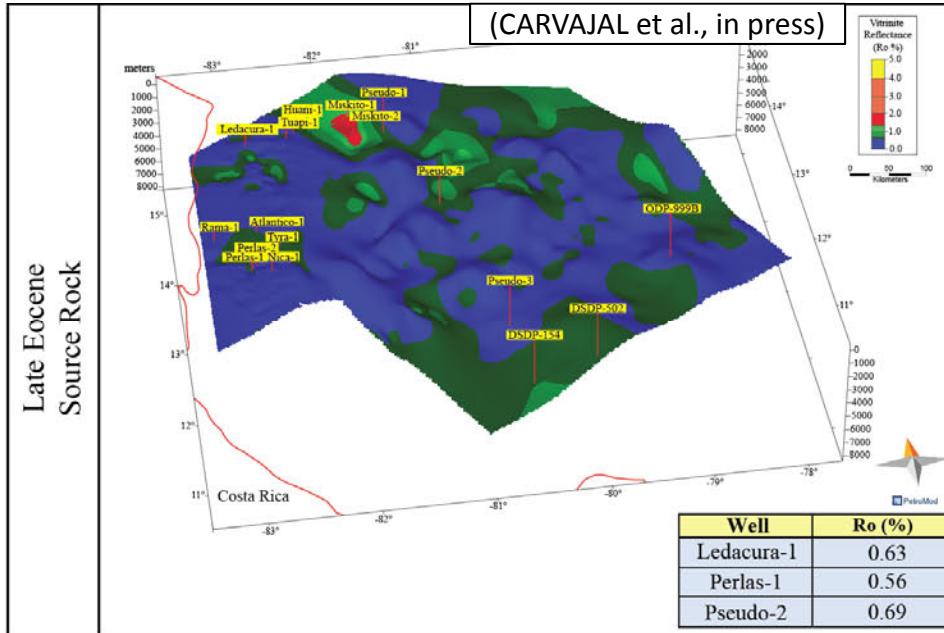
Early Eocene & Late Eocene Source Rocks

- Limestones, Carbonatic Shales, and Rich Organic Shales
- TOC% 0.85 – 3.47
- H.I 30-300 mgHC/gTOC
- O.I 50-280 mgHC/gTOC
- Kerogen Type II & III from Eocene intervals
- Organic matter deposited in transitional environments
- High content of Oxygen
- Medium-low generation potential

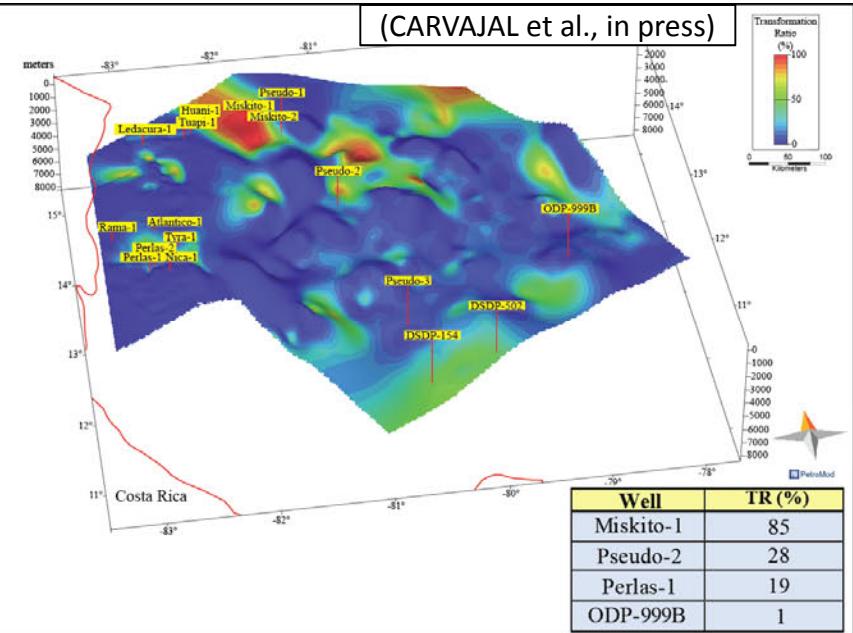
Source Rock Modeling Results



Vitrinite Reflectance Ro(%)

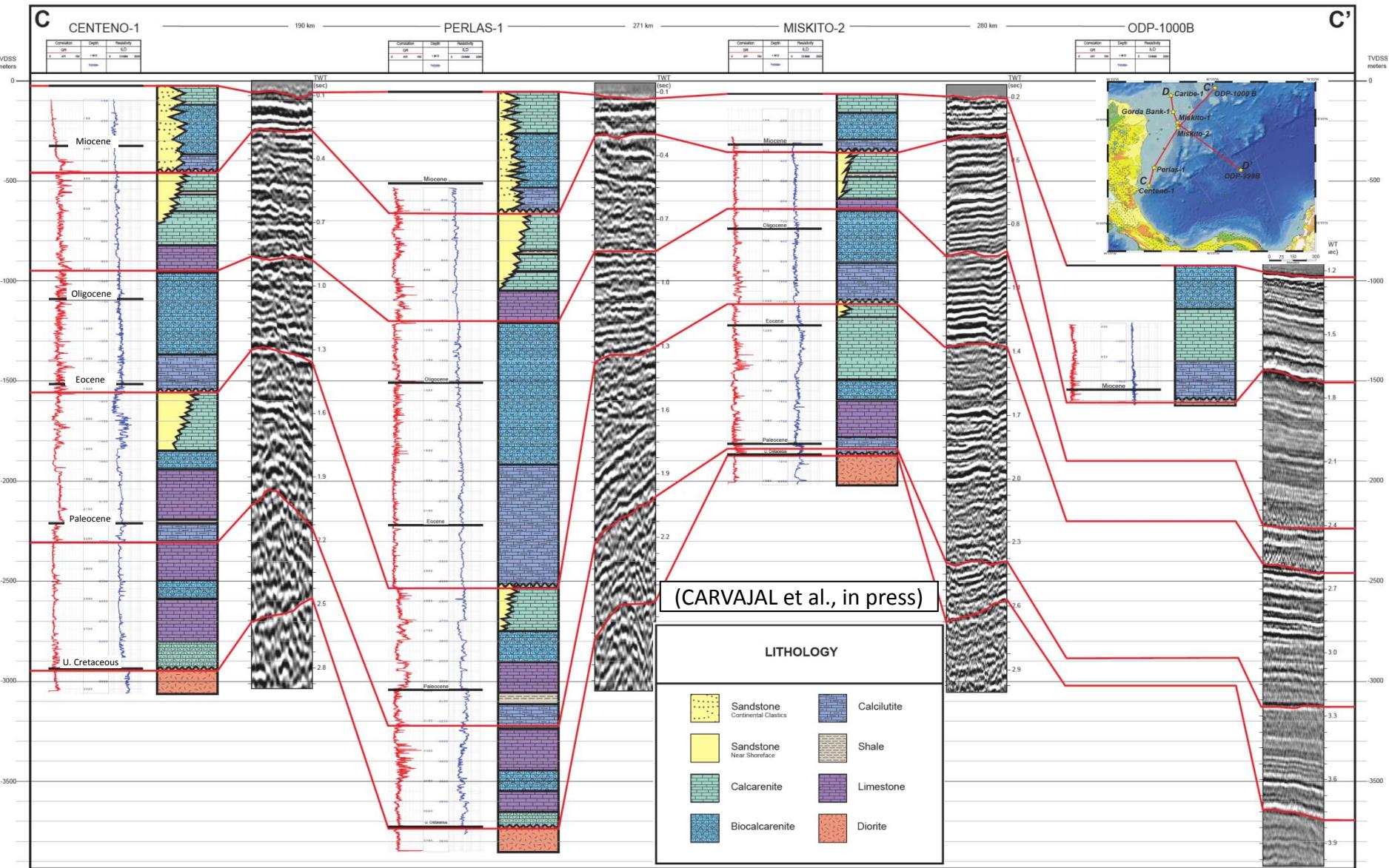


Transformation Ratio TR(%)

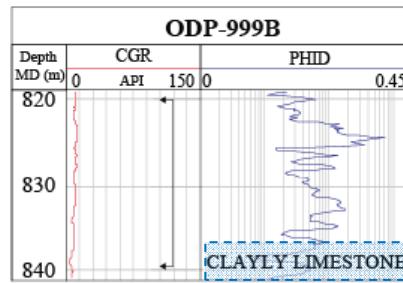
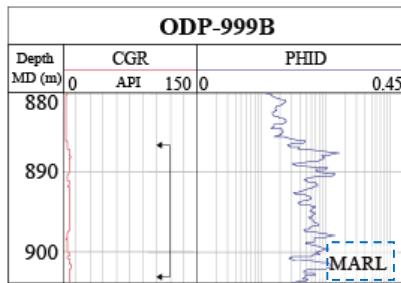
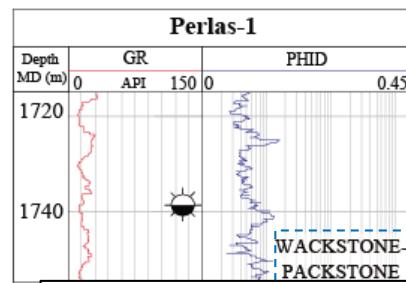
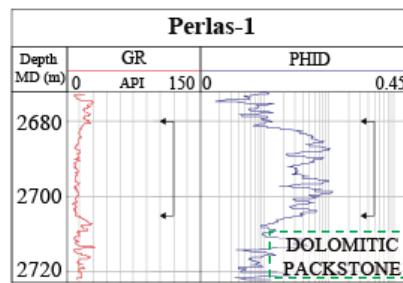
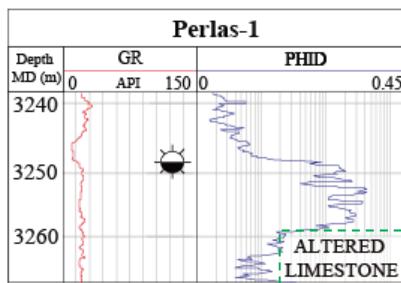
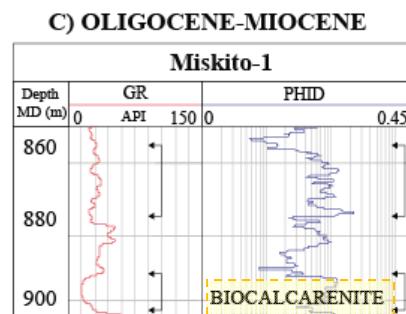
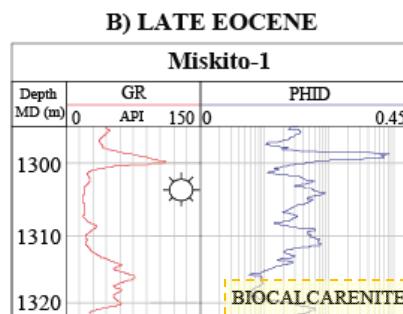
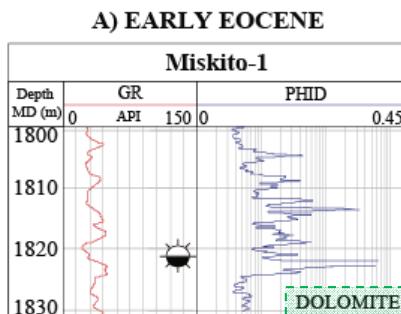


- 65% of the source rocks are within Zones III, IV
- High transformation ratio is observed in local basins and regional depocenters
- Gilsonite presence in Miskito-2 matches with high TR and VR
- Tuapi-1 shows thermogenic gas from generation Zones IV and V

Reservoir Rocks



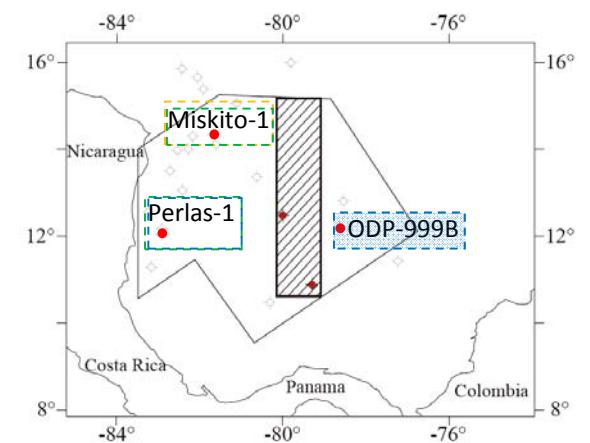
Reservoir Rocks



GR - Gamma ray

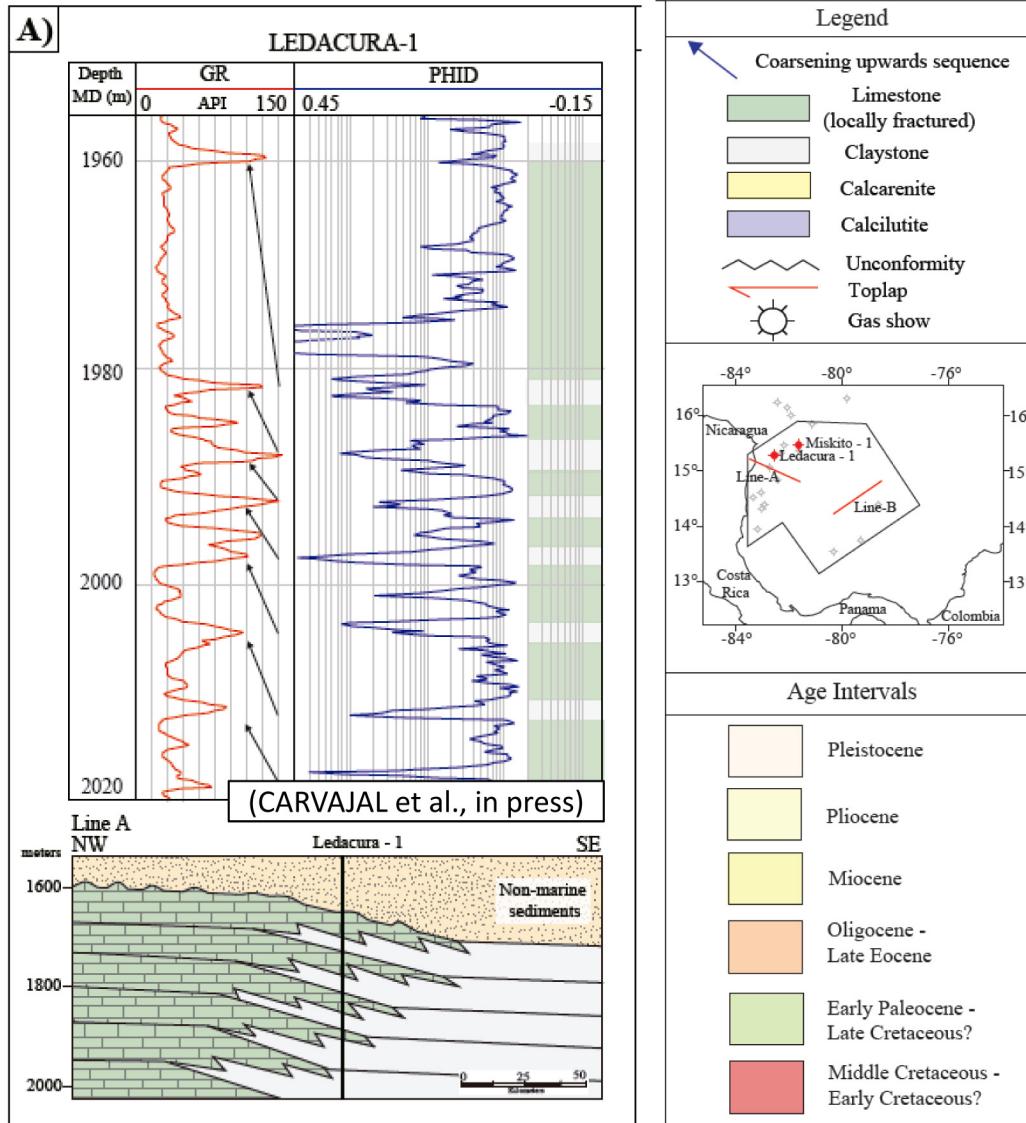
CGR - Corrected gamma ray for uranium contribution

PHID - Density-porosity



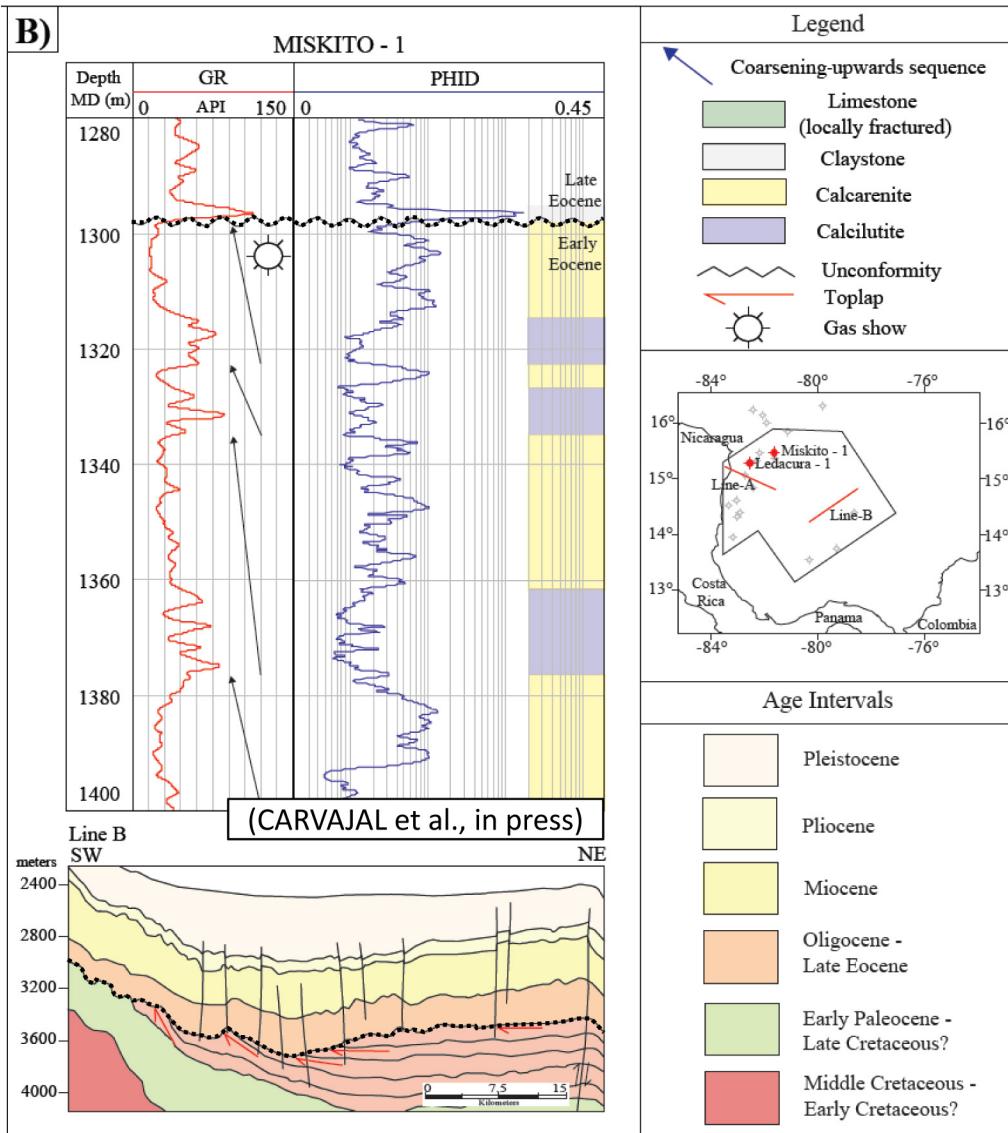
- Variety of reservoir rocks
- Transitional to Deep Marine environments
- Average porosities in carbonates approx. 15%
- Average porosities in Clastic rocks approx. 25%

Seal Rocks



- Local seal distribution
 - Reservoir-Seal pairs identified in proximal areas
 - Coarsening-upwards sequences
 - Regressive-transgressive intervals of limestone and mudstone
-

Seal Rocks



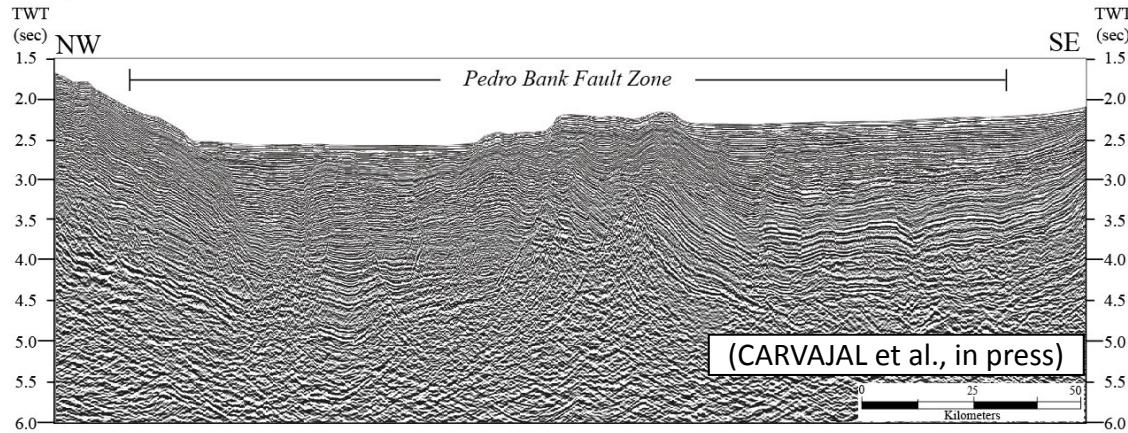
- Eocene unconformity followed by regional seal
- Eocene unconformity is a potential reservoir-seal pair

Highest risk factor

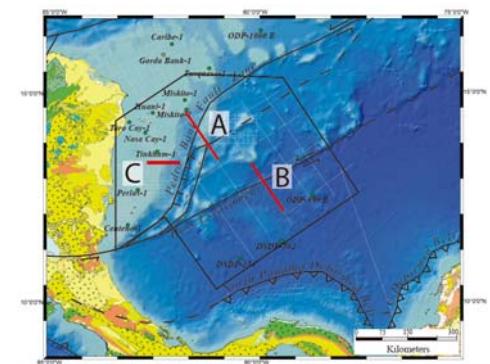
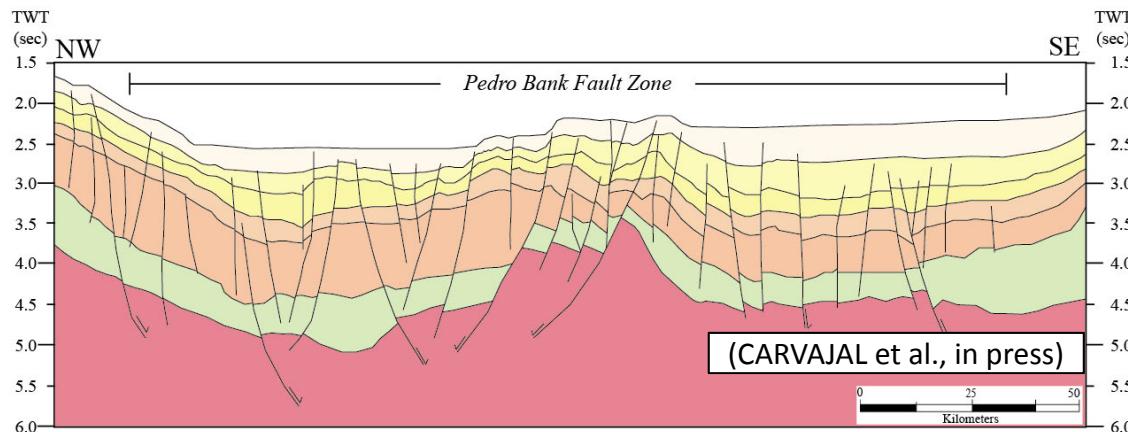
Petroleum Play Processes

Structural Traps

A)

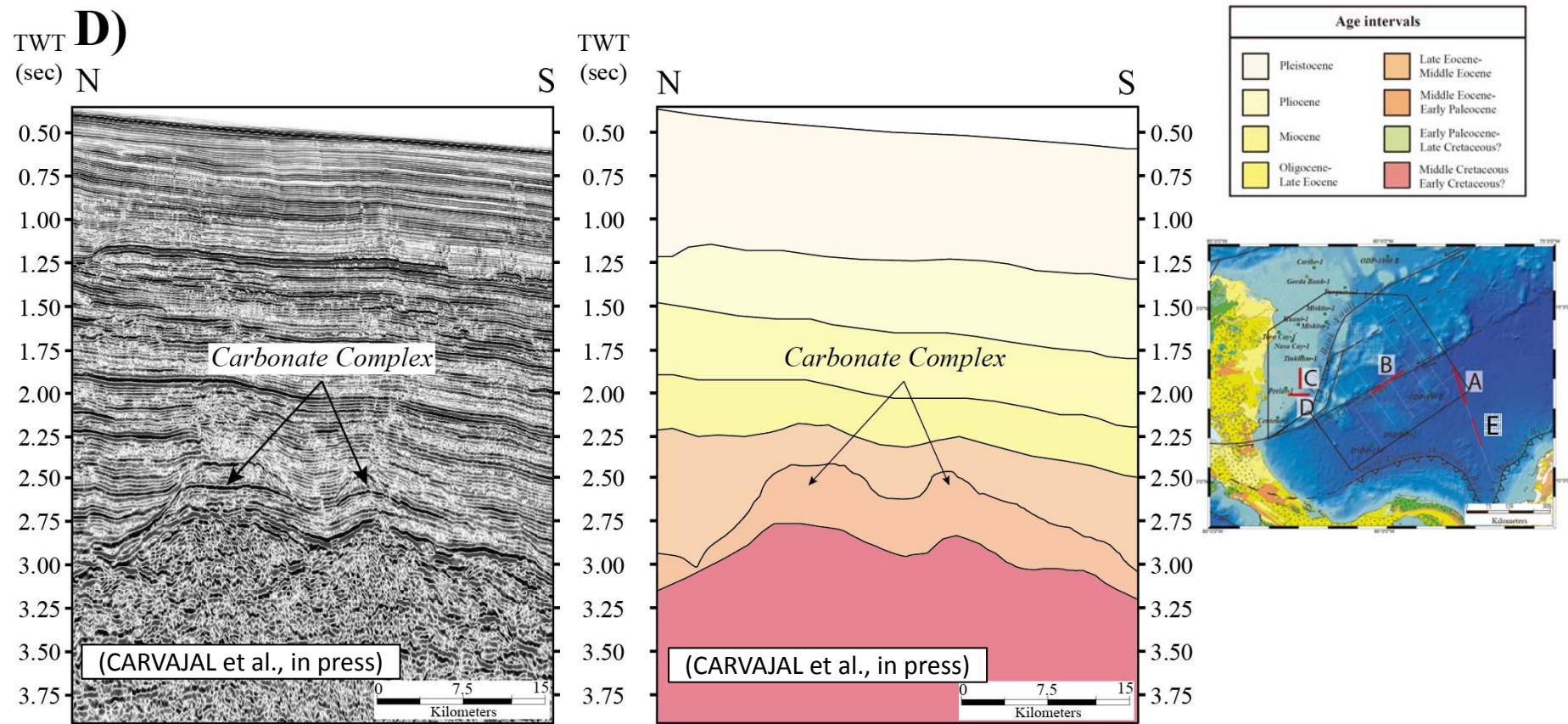


Age intervals	
Pleistocene	Late Eocene-Middle Eocene
Pliocene	Middle Eocene-Early Paleocene
Miocene	Early Paleocene-Late Cretaceous?
Oligocene-Late Eocene	Middle Cretaceous-Early Cretaceous?



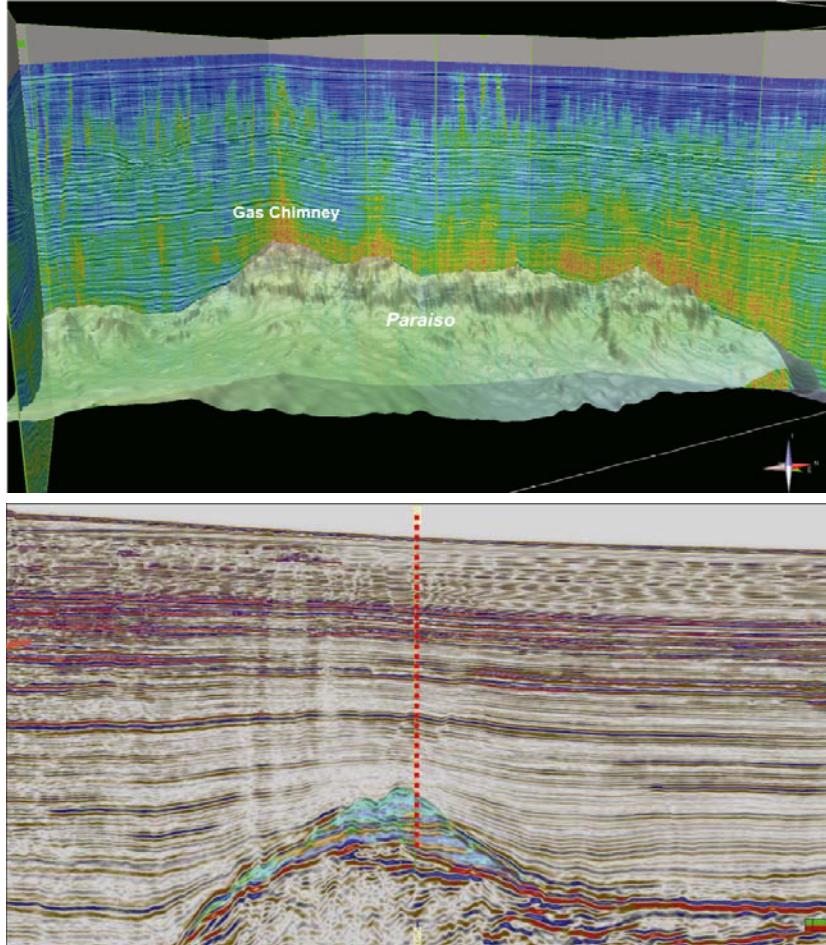
- Negative flower structures
- Block rotation
- Extensional regime syn-deposition of Cretaceous (?) - Paleocene sediments
- Growth strata along block rotation

Stratigraphic Traps

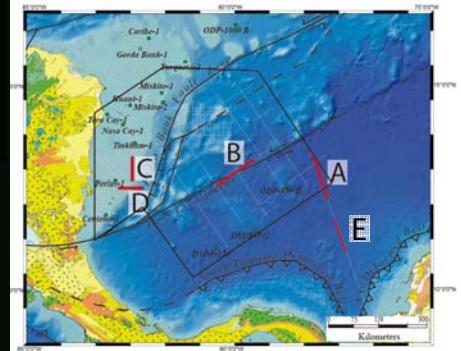
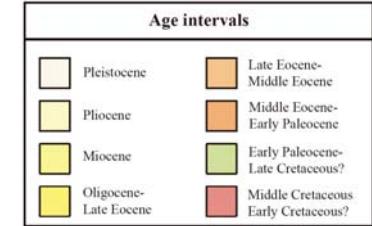
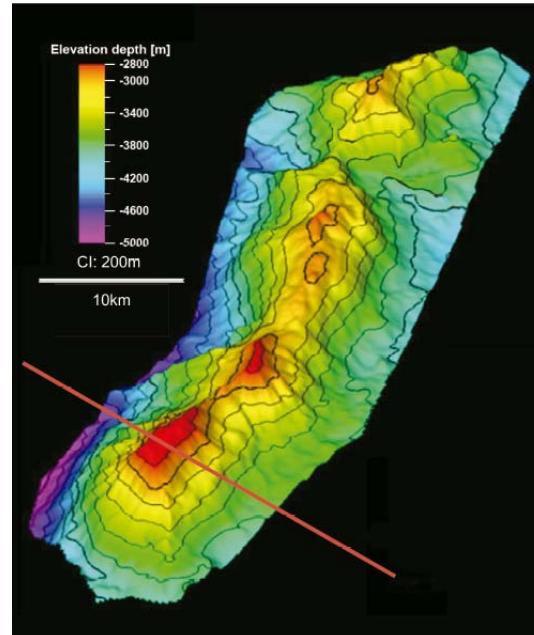


- Carbonate Build- ups
 - Regional expression of carbonate drowning
 - Miocene Carbonate Buildups

Stratigraphic Traps



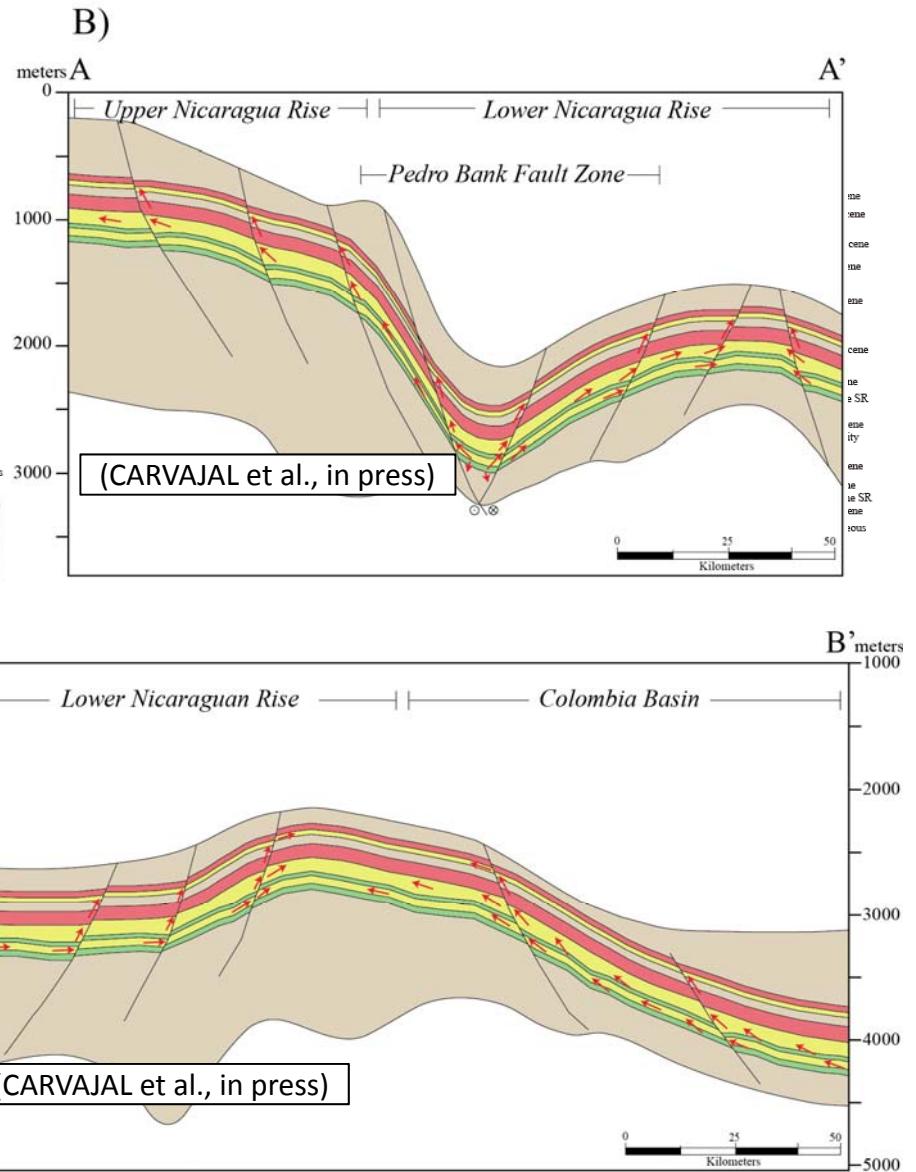
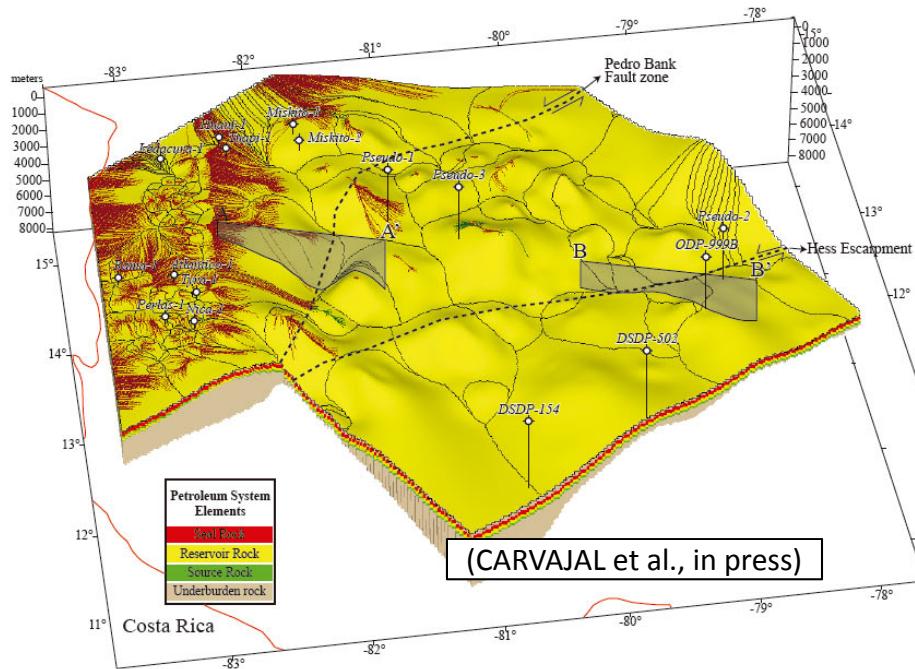
PARAISO-1 WELL



Taken from Noble Energy, 2013

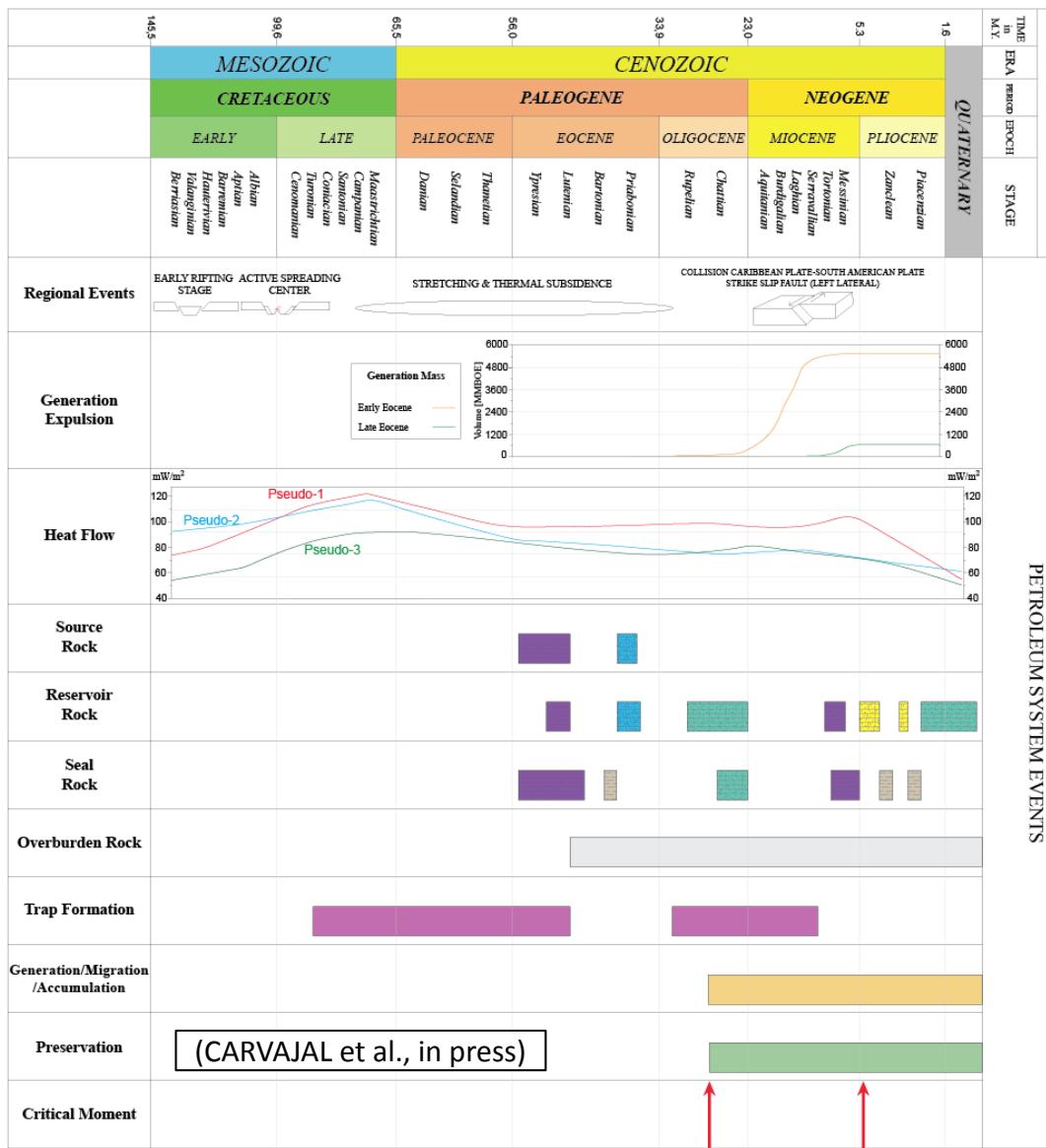
- Carbonate Build-ups
- Eocene Carbonate Build-ups
- Regional expression of carbonate drowning

Generation/Migration/Accumulation



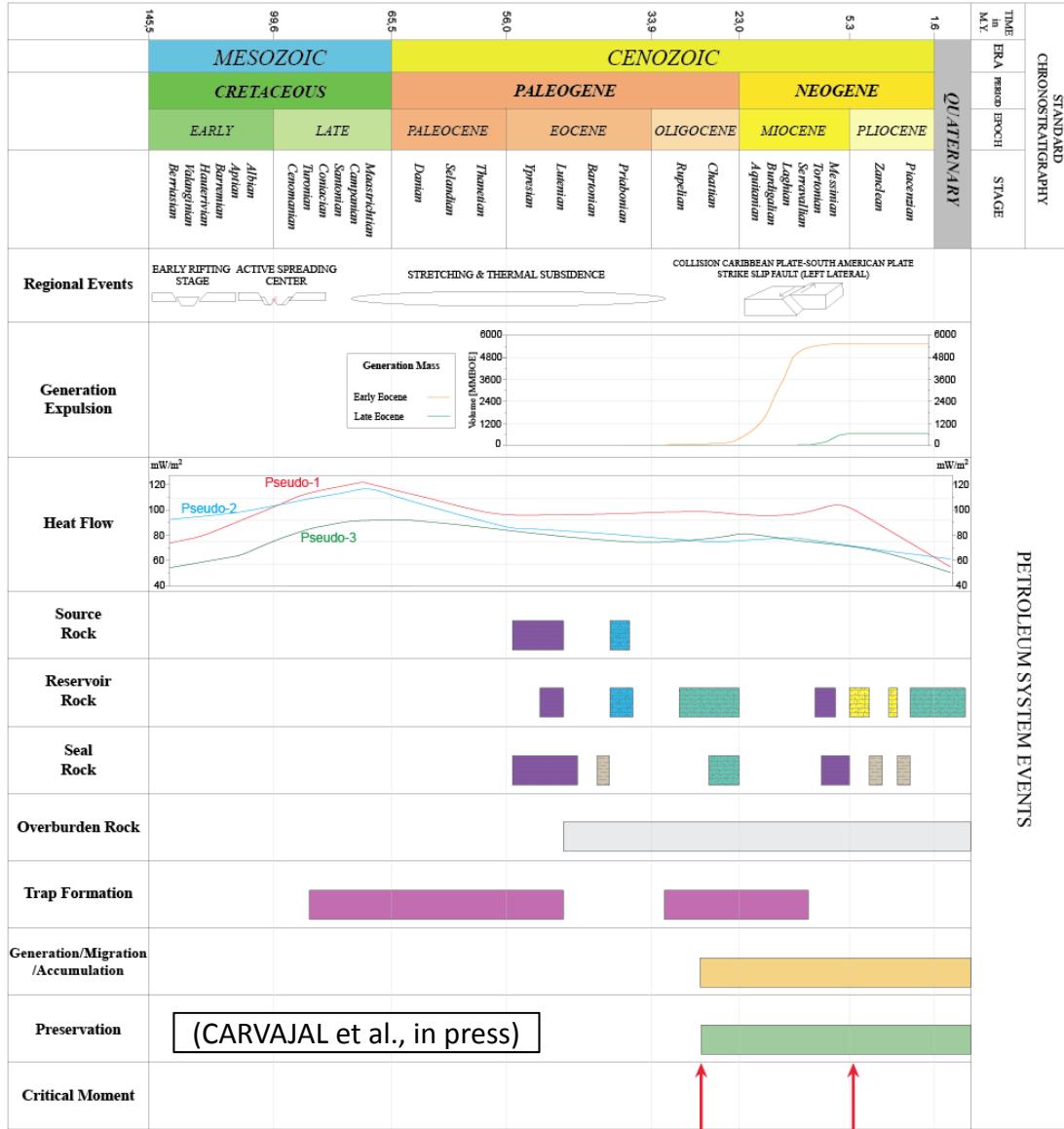
- Early Eocene source rock first expulsion in Middle Oligocene (26 Ma)
- Late Eocene source rock first expulsion in Early Pliocene (5.1 Ma)

Summary & Conclusions



- An Early & Late Eocene / Oligo-Miocene (!) petroleum system model is proposed.
- Two tectonic events matched with paleo-heat flow peaks interpreted from Ro(%).
- Early and Late Eocene intervals in offshore wells and mapped on the 2D seismic grid are proposed as potential source rocks.
- Reservoirs deposited from transitional to deep marine environments since the Paleocene.
- Seal rocks include shale deposited above regional and local unconformities, and as intraformational, siliciclastic-carbonate interbedding. Seal rocks are the highest risk factor.

Summary & Conclusions



- The complex geological history of the Caribbean region has facilitated widespread structural and stratigraphic traps for hydrocarbons.
- Our basin model indicates that generation and expulsion is variable along the NR, where we have identified two critical moments
- We predict that migration styles are vertically dominated.
- We calculate a total of 7.15 MMBOE of oil expulsion per km² for Eocene SR where 6.23 MMBOE per km² corresponds to Early Eocene SR, and 0.92 MMBOE per km² corresponds to Late Eocene SR.

Acknowledgements



MEM NICARAGUA

- AAPG Committee
- Lucia Torrado
- Dr. Adry Bissada
- Jack English (Chevron)

Thank You