Unconventional Resources Assessment of La Luna Formation in the Middle Magdalena Valley Basin, Colombia*

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Abstract

La Luna Formation, a Cretaceous sequence in the Middle Magdelana Valley Basin (MMVB) of Colombia, is described as calcareous shales and limestones, black in color, with high foraminifera (Globigerina) content, and with calcareous and phosphate concretions. Formation members are named Galembo (calcareous shales with limestone layers and nodules), Pujamana (claystone, mudstone, gray shale, and cherts) and Salada (black shales, black mudstones, black calcareous claystone, black limestone layers, and concretions with pyrite). The total organic carbon (TOC) values for Galembo range from 1.09% to 11.90% and for Salada from 2.15% to 11.90 with Type IIS kerogen. Liquid hydrocarbons would be present in the northern and central part of MMVB, and condensates and dry/wet gases are related to the southern MMVB areas. Biomarker analyses reveal variations in redox and predominant marine organic matter deposited under anoxic and high water salinity conditions. The average SEM total area porosity for Galembo is 8.5% and 8.11% for Salada members. The depositional environment is shallow marine, restricted middle shelf. Four major third order stratigraphic cycles corresponding to the three La Luna Formation members are proposed during an overall sea level rise towards the La Luna Formation top. This primary assessment indicates a good potential for a shale oil/gas system, where good organic matter content is present, the formation reached maturity levels for hydrocarbon generation and has relatively high porosity for oil and/or gas storage. The thicknesses in outcrop vary from 180–720 ft. for Galembo, 300–400 ft. for Salada and 500 ft. for the transitional Pujamana member.

Selected Reference

Jarvie, D.M., R.J. Hill, T.E. Ruble, and R.M. Pollastro, 2007, Unconventional shale-gas Systems: The Mississippian Barnett Shale of North-Central Texas as One Mode for Thermogenic Shale-gas Assessment: AAPG Bulletin, v. 91, p. 475–499. doi: 10.1306/12190606068.

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in the Middle Magdalena Valley basin, Colombia.

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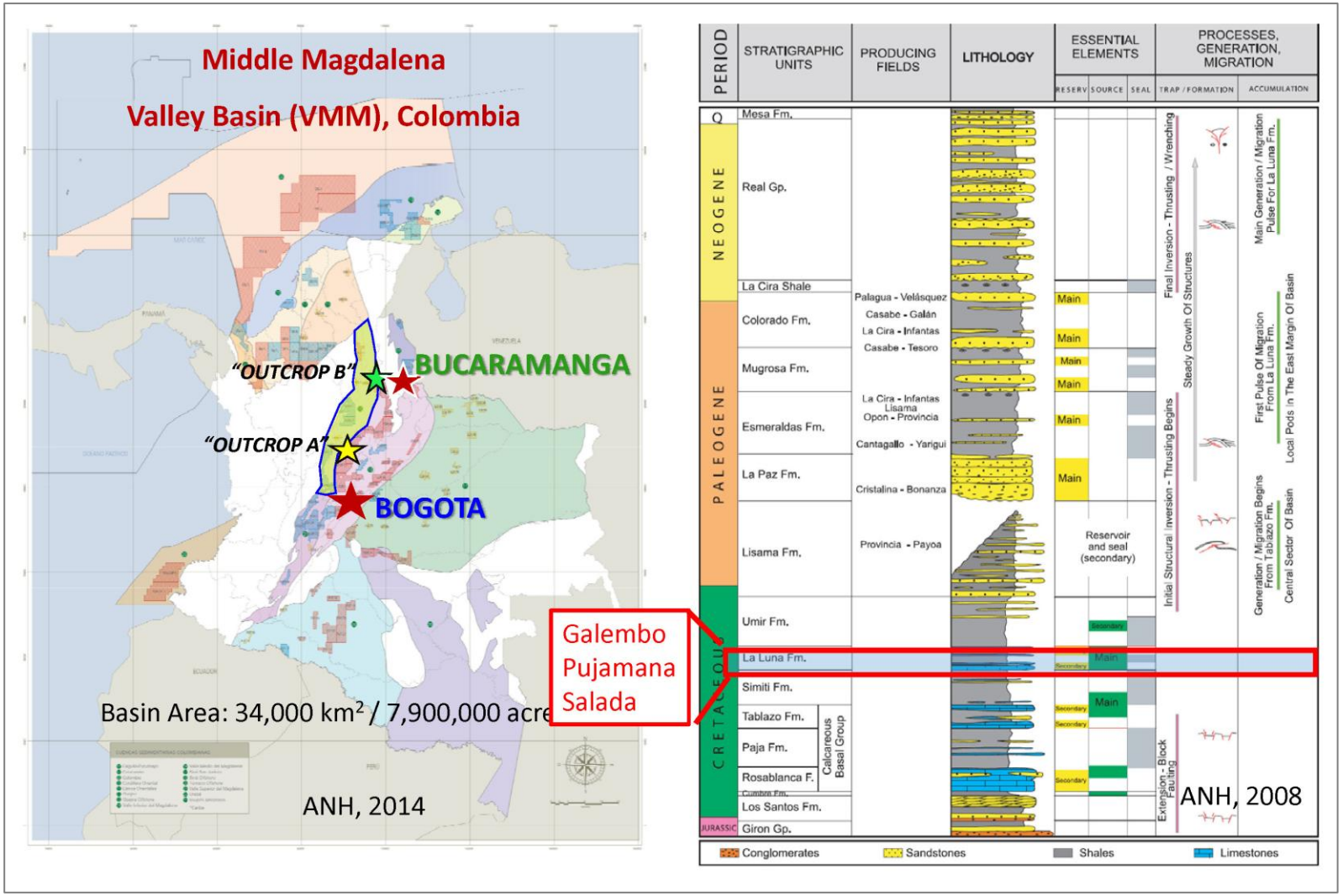
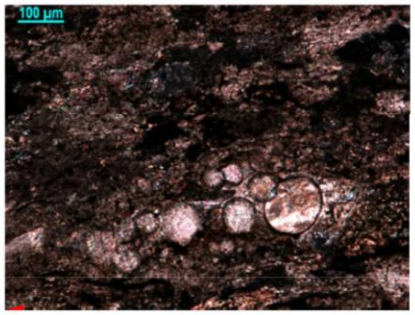


Presenter's notes: Location of the basin in the middle part of Colombia. Yellow polygon in the map.
Present day morphology is a valley rounded by regional strike slip faulting with reverse tectonics component.
Location of two outcrops visited: Outcrop A in 2011 and Outcrop B in 2012. (Presenter's notes continued on next slide.)

(Presenter’s notes continued from previous slide.)

Image on the left: General stratigraphic column of the basin.
Highlighted in blue the La Luna Formation in the Upper Cretaceous section.
Upper lithologies are the conventional Tertiary fluvial deposits which are sourced from the La Luna.
Other possible shale plays in the formation stratigraphically below the La Luna Formation.

OUTCROP B. Salada (Lower) member



This member measured thickness is 328ft

Intercalations of dark shales with siliceous cherts and claystone lamina. Calcareous nodules around 0.5 inches in diameter are abundant. **Limestones and marlstones with calcareous and phosphatic nodules.**

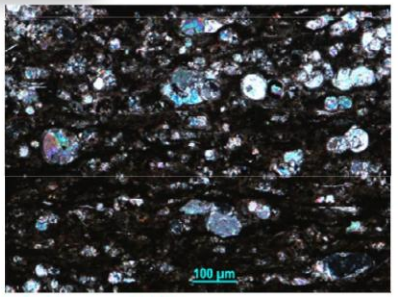
- Muddy laminated dark gray and thin bedded **foraminiferal wackestones** and calcareous mudstones with **small nodules of pyrite.**
- Foraminifera (Globigerina) and fecal pellets
- This facies ranges from predominately a clay rich interval to diluted carbonate intervals.

Presenter's notes: La Luna Formation Salada Member in Outcrop B.

OUTCROP B. Pujamana (Middle) Member





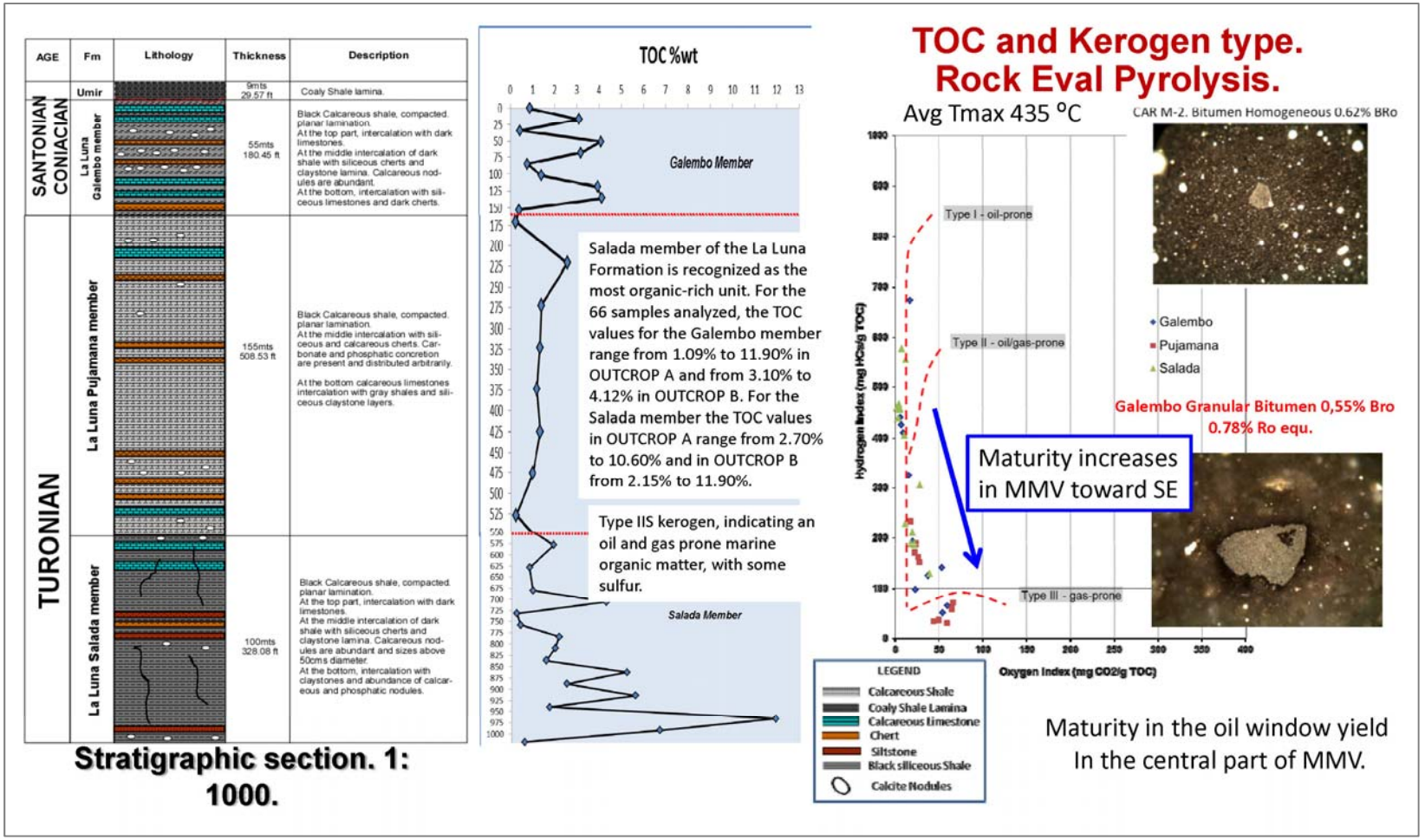


Claystone layers, siliceous mudstone layers and chert interbeds. Some layers filled with hydrocarbons. ~500ft gross thickness

- Intercalations of **bentonite thin layers** (possible deposit from weathering of volcanic ashes), cherts, phosphate layers, siliceous mudstones and claystones. Abundant foraminifera observed in thin section.
- Muddy laminated wackestones and calcareous dark gray shales at the top.
- **Phosphatic layers** occur at the base of this member.

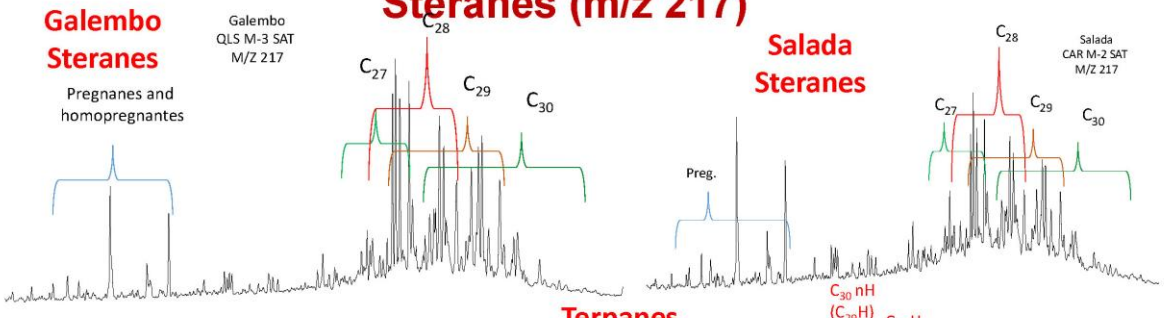
Presenter's notes: Upper pictures showing the silica rich lithologies in the Pujamana Member, possible more transitional environment with layers filled with hydrocarbons.
Lower left image: Panoramic view of Pujamana in Outcrop B. Stratigraphic top at the right of the picture. Total gross thickness around 500 ft.

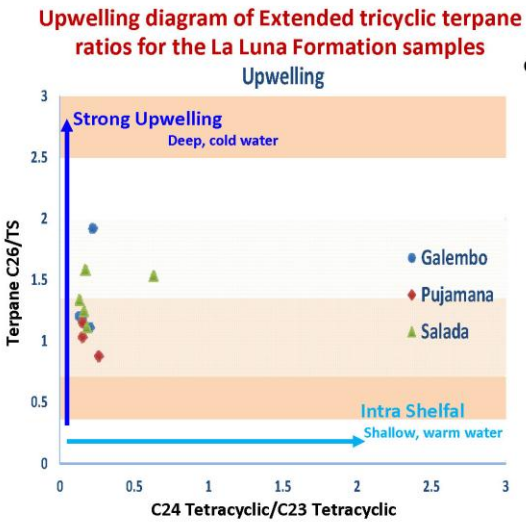
Lower right image: Thin section of Pujamana, abundant nanofossils of globigerina foraminifers.

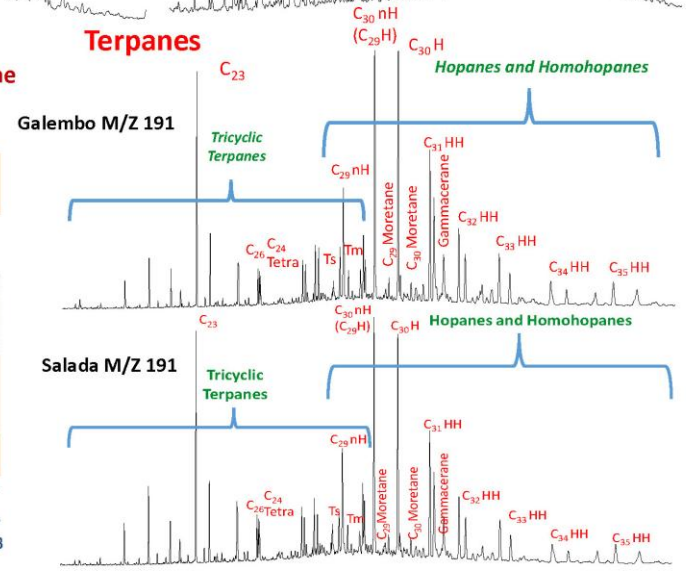


Presenter's notes: Left image: Stratigraphic column of Outcrop B with descriptions and thickness for each member.
Plot in the middle: TOC vs depth for Outcrop B. Higher values in the Salada Member.
Image in the left: Kerogen types two and three, oil and gas prone. The pictures correspond to solid bitumen reflectance, corrected to vitrinite reflectance for maturity interpretation. Both are oil window maturity.
The TOC curve and the stratigraphic column are aligned. The lithologies match with the curve, also with the member's subdivision.

OUTCROP B Biomarkers. Terpanes (m/z 191) and Steranes (m/z 217)

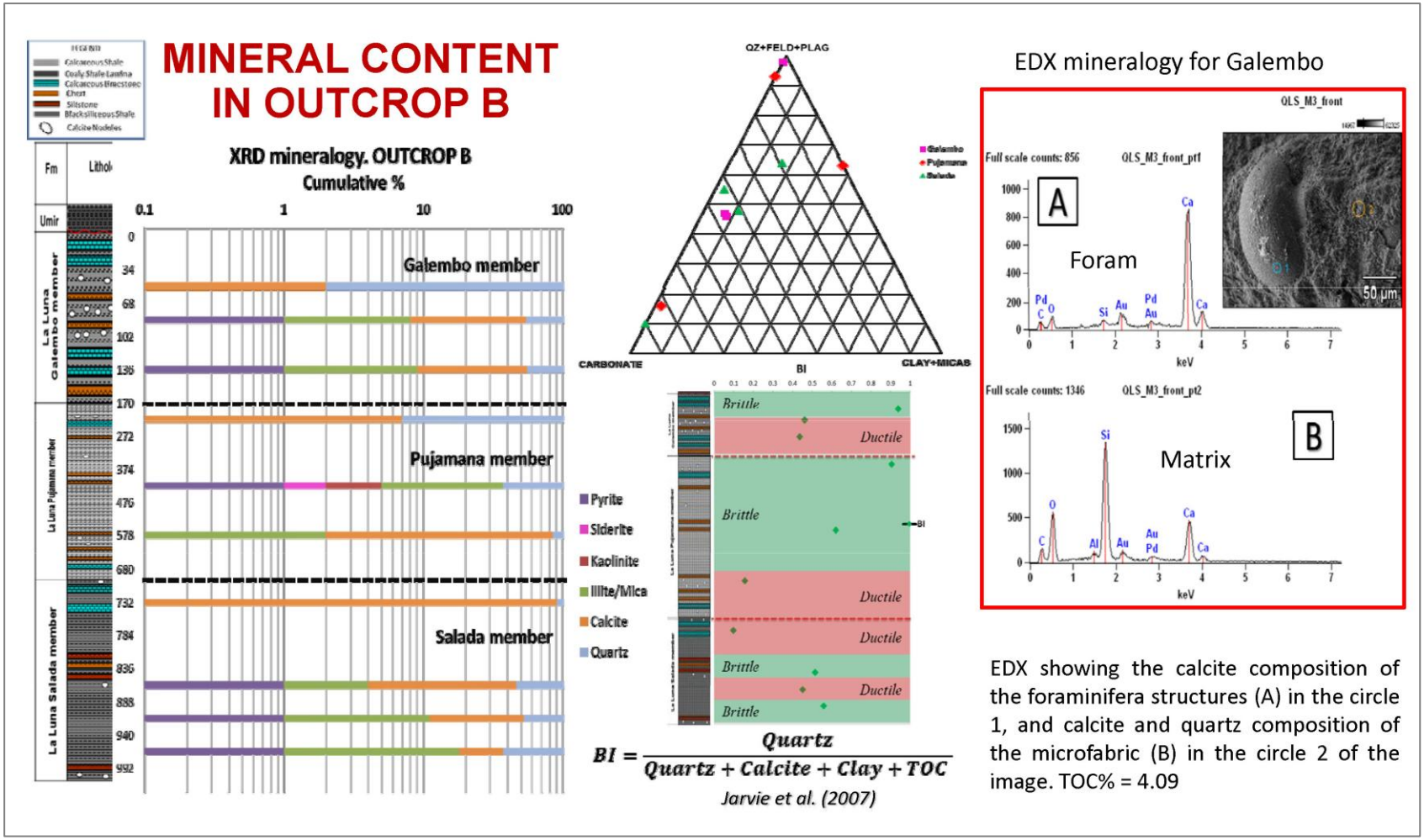






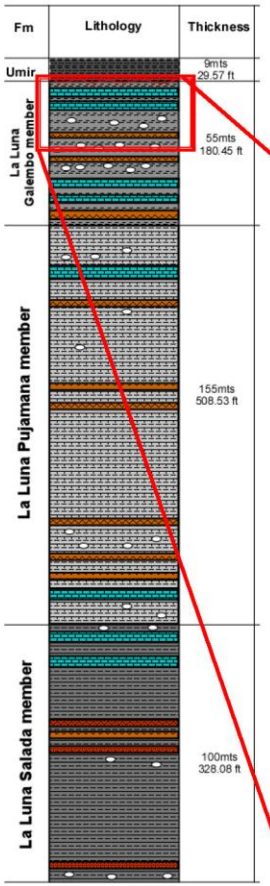
- The Biomarker analyses reveal variations in redox conditions and a predominant input of marine organic matter in a carbonate rich environment.
- Sterane and Terpane ratios suggest a predominance of anoxic conditions during deposition of the Galembo and Salada members.
- Based on biomarker ratios and litho-facies association:
  - ❖ The upper Galembo member is characterized by anoxic/suboxic conditions.
  - ❖ The lower Salada member shows a predominance of euxinic/anoxic conditions.
  - ❖ The middle Pujamana member is more suboxic with terrestrial input.

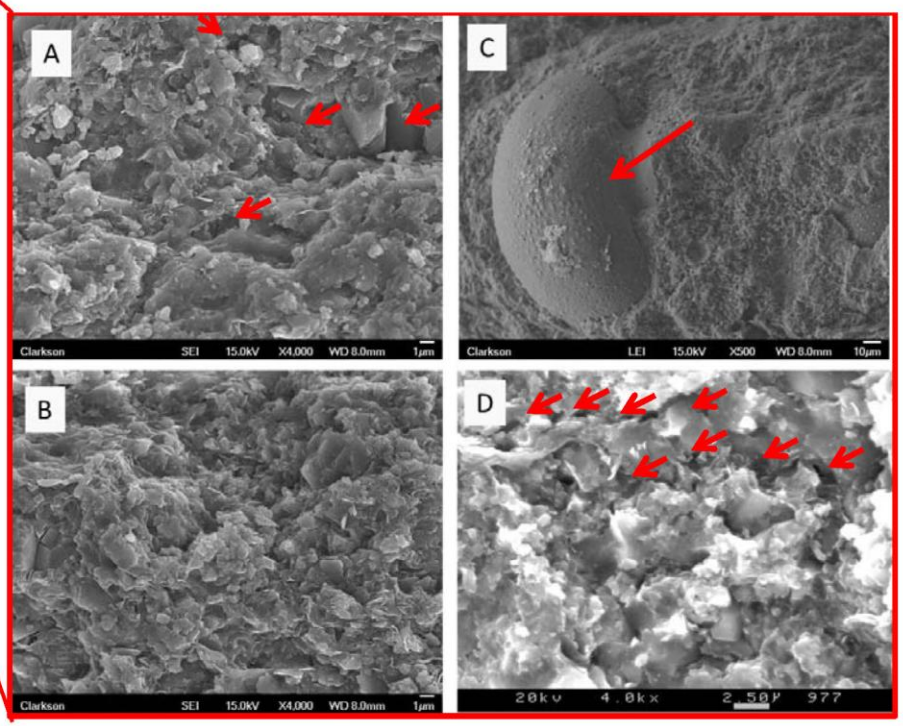
Presenter's notes: Biomarker analyses show typical carbonate marine source rocks with anoxia and upwelling.



Presenter's notes: Mineralogy content in the left image. Plot on logarithmic scale that shows abundance of calcite in most of the samples. Pyrite in purple color is present.
Ternary plot sowing abundance of carbonates and quartz rather than clay minerals.
Brittleness plot is generalized, but shows some samples very brittle and some very ductile.
The image on the right: EDX image of a Galembo sample, showing calcite and silica (B) and (A) is the fossil which is made of calcite.

Galembo member SEM microfabric and porosity characterization.



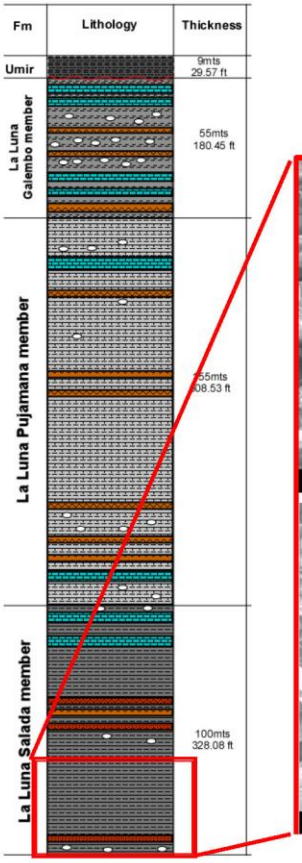


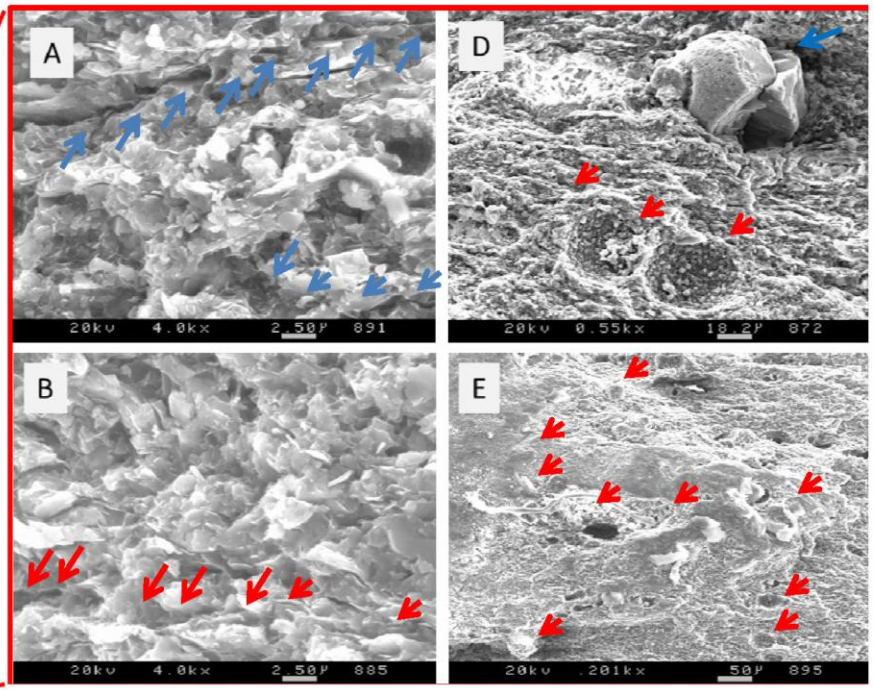
- **Galembo OUTCROP B. QLS M-3**

Clay floccules and interparticle porosity. Globigerina shell replacement with calcite Microchannel porosity indicated by the red arrows.
Clay flakes show more of a flocculated fabric; clay floccules are the dominate pore type (8.5% avg.).
TOC% = 4.09

Presenter's notes: SEM total porosity calculation for Galembo member: Average 8.5%.

Salada member SEM microfabric and porosity characterization.

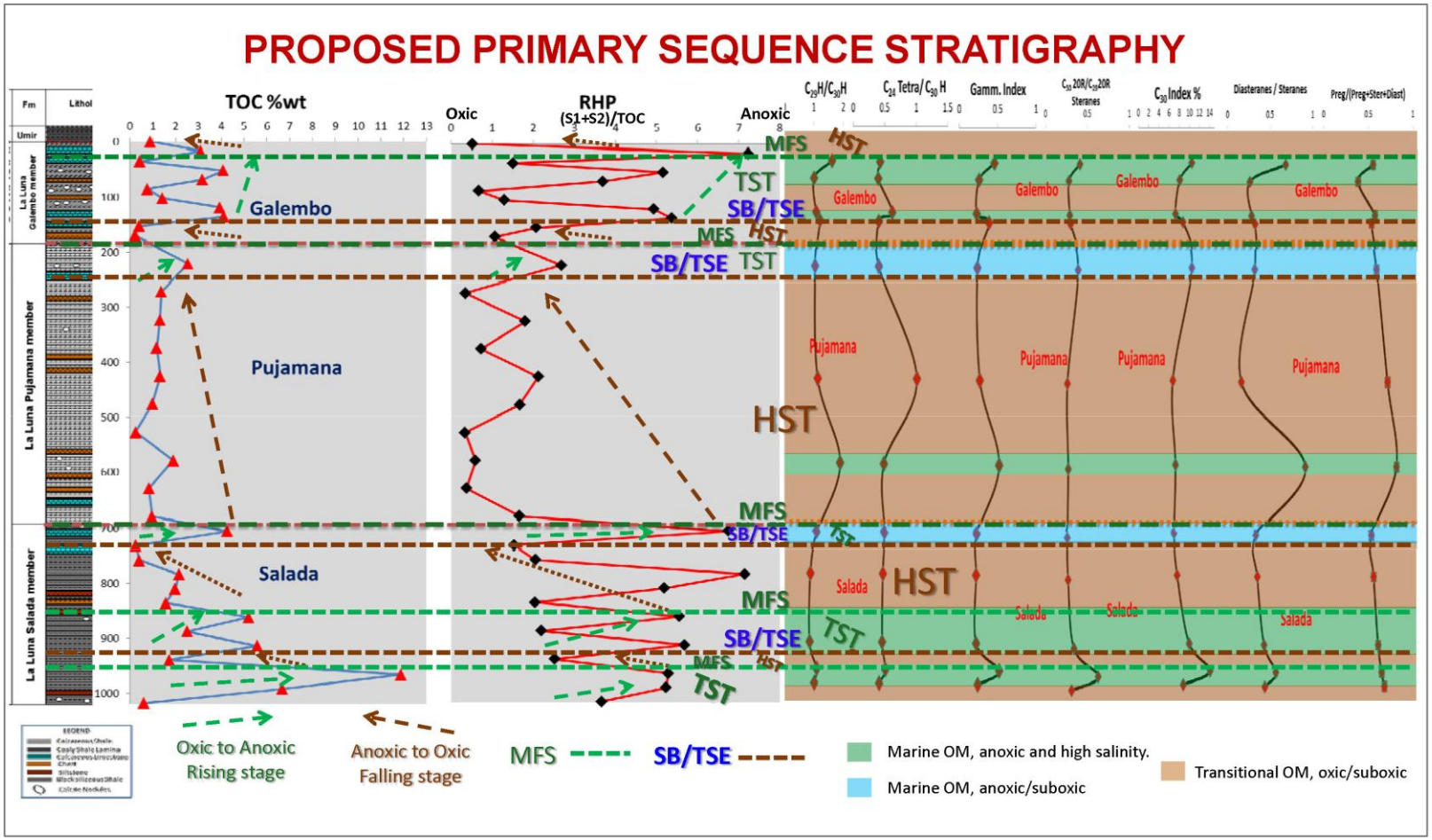




- Salada OUTCROP B. CAR M-3

Clay flakes show more of a **flocculated fabric**; clay floccules contain the dominate pore type.
Microchannel porosity in A and B indicated with arrows.
Fecal pellets in D and E.
Average porosity 8.11%; the average pore area is 0.083 μm^2.
TOC% = 11.90.

Presenter's notes: SEM total porosity calculation for Salada Member: Average 8.11%.



Presenter's notes: Sequence stratigraphy combining the TOC vs depth plot and relative hydrocarbon potential (RHP) with the biomarker relations plot.
RHP is obtained from the rock eval pyrolysis S1+S2 peaks and the TOC. High values are anoxia trends and TSTs.
The Outcrop B section was used for this analysis because it is the most complete section.
Four third order stratigraphic cycles are proposed. The La Luna Formation top is a HST towards the deposition of progradational deposits of the above Umir Formation.

Comparison of U.S. shale systems with La Luna Fm.

	Eagleford	Woodford	Haynesville	Bakken	Marcellus	La Luna MMVB
Depth (ft)	4,000 – 13,000	6,000 – 14,000	10,000 – 13,500	4,000 – 11,000	4,000 – 12,000	4,000 – 17,000
Net Shale pay Thickness (ft)	50 – 200	100 - 200	60 – 200	10 – 60	50 – 250	200 - 500
TOC (wt%)	2 – 9%	3 – 10%	2 – 5%	10 – 15%	3 – 15%	2 – 20%
Ro %	0.55 – 1.45%	0.53 – 3.0%	1 – 1.2%	0.45 – 0.80%	1.0 – 3.0%	0.60 – 3.0%
Hydrocarbon type	Oil – Gas	Oil – Gas	Gas	Oil	Gas	Oil – Gas
La Luna: 400 – 2200 ft		TOC: 1-3% Good >4% Very Good		Ro: 0.55- 1.0% Mature (Oil) 1.0-1.35% (oil and / or gas)) >1.35% (Dry gas)		

La Luna depth data: ANH, 2008.

Presenter's notes: The upper and lower La Luna members can be targeted as a separate shale systems.

Summary and Conclusions

- TOC%: Galembo member from 1.09% to 11.90%; Salada member ranges from 2.15% to 11.90%.

- Type IIS and III kerogen. Biomarker analyses reveal **predominant input of marine organic matter.** **Oil and gas prone.**
- Mixed organic matter input was recognized towards the deposition of the Pujamana member.

- La Luna Formation was deposited under **dysoxic/anoxic** episodic periods during **major transgressive-regressive cycle.**
- Galembo: SEM total porosity 8.5%.
- Salada: SEM total porosity 8.11%.

- Four major third order stratigraphic cycles were proposed.
  - The base of the lower Salada member: TST-HST-TST.
  - TST at the Salada member top .
  - Pujamana member deposition was interpreted as a HST (second sequence boundary and TSE)
  - Pujamana – Galembo boundary corresponds to deposition of TST
  - Galembo member occurred during a TST phase towards HST at the La Luna top.

❖ The Integration of biomarker ratios, lithofacies and relative hydrocarbon potential (RHP) indicate that the La Luna Formation was deposited under dysoxic/anoxic conditions and episodic periods of photic zone anoxia (PZA) during major transgressive-regressive cycles in a restricted middle shelf to upper slope. These sea-level changes affected the redox conditions and the extent of anoxia

- The Salada and Galembo members are good candidates for an unconventional shale resource play.
- Galembo member: 180 ft. to 720 ft Thickness.
- Salada member: 300 ft. to 400 ft thickness.
- Pujamana member: ~500ft. Thickness, may be a possible lithological barrier.

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