Applied Petroleum Source Rock Evaluation and High-Resolution Sequence Stratigraphy for Unconventional Reservoirs in La Luna Formation (Cenomanian-Santonian), Northwest Maracaibo Basin, Venezuela (Preliminary results)*

Andreina Liborius-Parada[1], Richard P. Philp[1], and Roger Slatt[1]

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[1]Geology and Geophysics, The University of Oklahoma, Norman, Oklahoma (andreinaliborius@ou.edu)

Abstract

Since the early 2000s, the exploration of unconventional reservoirs has become very important around the world for their high source of energy and for their high economic value. Venezuela's oil wealth has a world class hydrocarbon source rock that symbolizes one of the most prolific places for oil accumulation in Venezuela and around the world. This source rock is the so-called La Luna Formation (Cretaceous in age) located in eastern Venezuela, Maracaibo Basin.

One of the theories that make it one of the best source rocks in the world is its relationship with an extensive transgression and dysaerobic water column that created the best conditions for the preservation and the productivity of this high organic matter source rock. One of the worldwide oceanic anoxic events (OAE2) developed in the Cretaceous at the same time as deposition of the La Luna Formation in northern South America. However, local variations in depositional and diagenetic conditions have manifestly affected the preservation and dilution of the organic source material to some degree. This generates small-scale variability in the depositional environments creating a better-quality source rock variation within the sequence that can be more prospective than others. To understand the variability of the depositional conditions, variations in organic matter source, thermal maturity, and depositional environments, the use of biomarkers was critical in this study.

The methodology was based on the integration of elemental proxies, source rock evaluation and biomarker analysis using gas chromatography (GC), gas chromatography-mass spectrometry (GC-MS), and a high-resolution sequence stratigraphic characterization to unravel the stratigraphic origin and migration pathways of presently existing petroleum systems.

The La Luna Formation was characterized with TOC values ranging from 3.85-9.13 wt%, showing a Type II kerogen, a “Good-to-Excellent” oil generation potential and a thermal maturity of 0.78% Ro on average. Biomarker analyses revealed variations in redox conditions and a predominance of marine organic matter deposited under anoxic and high-water salinity conditions. The observed facies association and

biomarker analyses identified the depositional environment as shallow marine, middle carbonate shelf, in a transgressing sea. These assessments indicate a good potential for an unconventional resource, where good organic matter content generated high prospectivity towards the Maracaibo Basin.

Selected References

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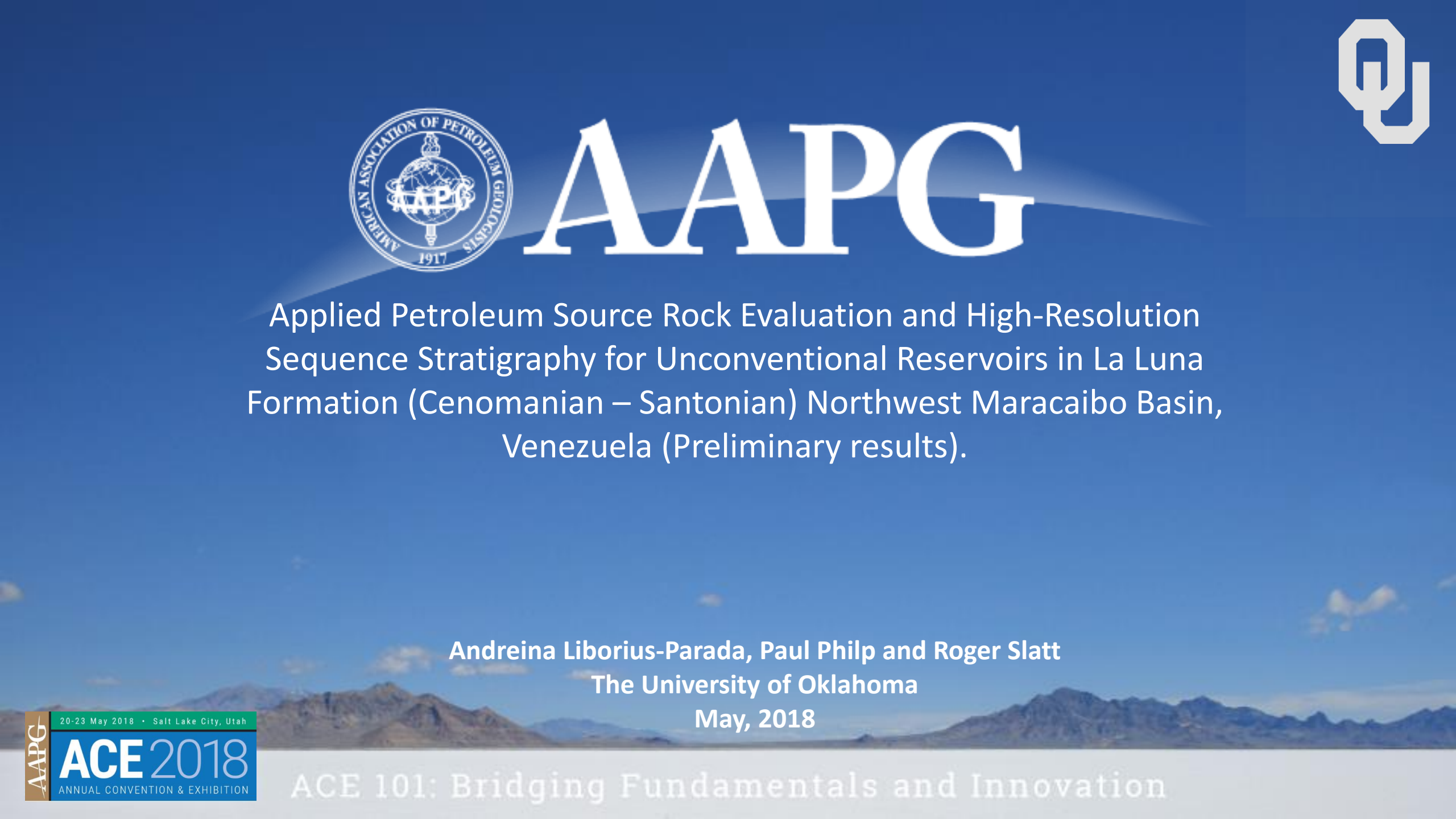

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Andreina Liborius-Parada, Paul Philp and Roger Slatt
The University of Oklahoma
May, 2018

20-23 May 2018 • Salt Lake City, Utah
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ACE 101: Bridging Fundamentals and Innovation

WELCOME

La Luna stratotype.
Flanco Perijanero, Venezuela

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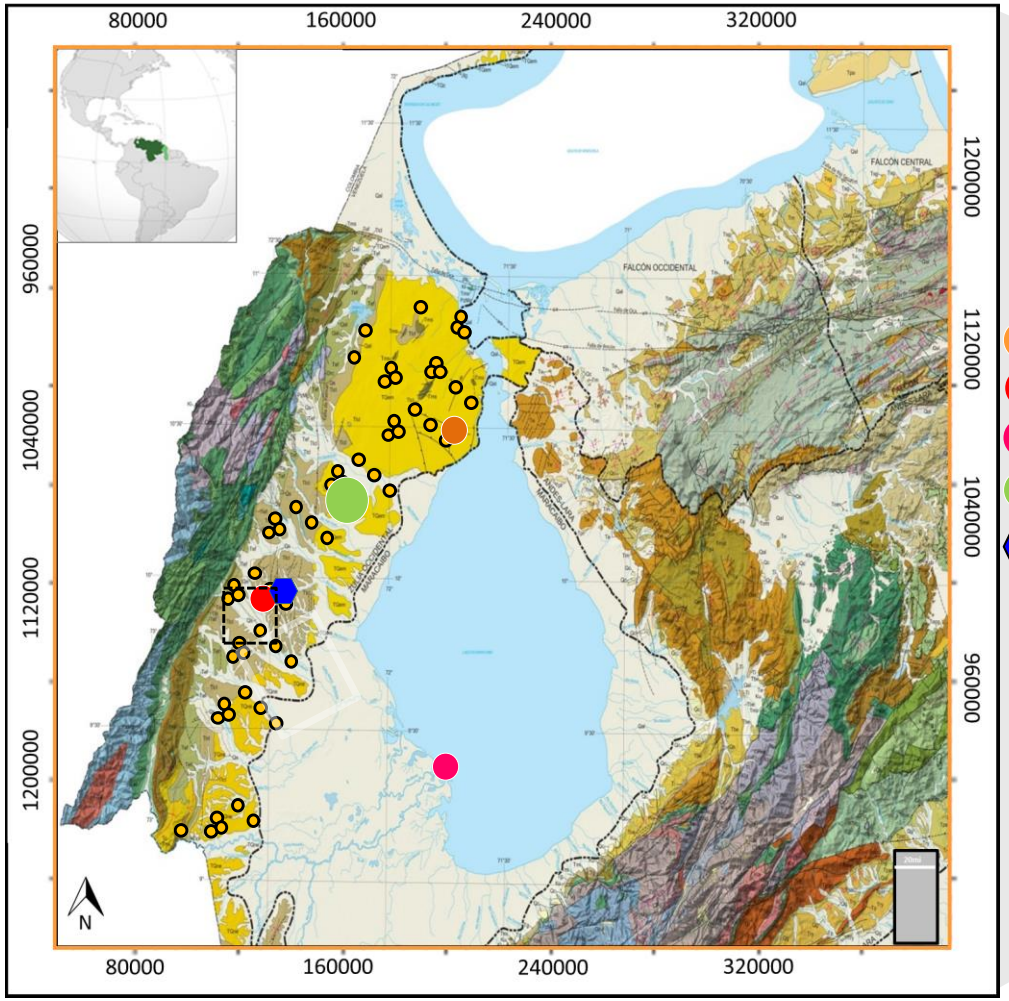
Key Parameters to Evaluate a potential source rock

- TOC
- Maturity
- Areal extension
- Brittleness
- Lithofacies

La Luna stratotype, Venezuela

Location and dataset

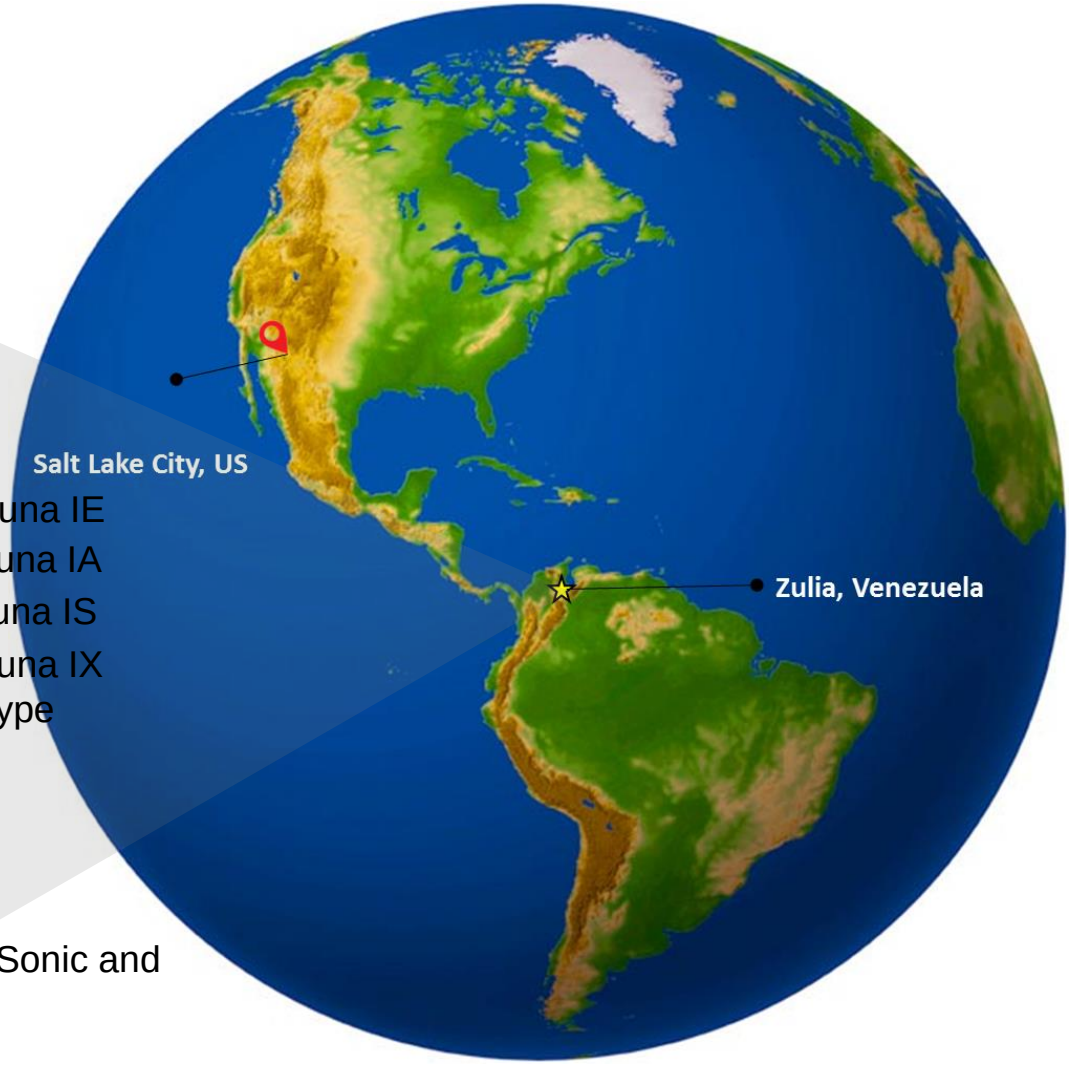


Cores

- 282 ft. core for La Luna IE
- 220 ft. core for La Luna IA
- 112 ft. core for La Luna IS
- 345 ft. core for La Luna IX
- La Luna Fm. stratotype

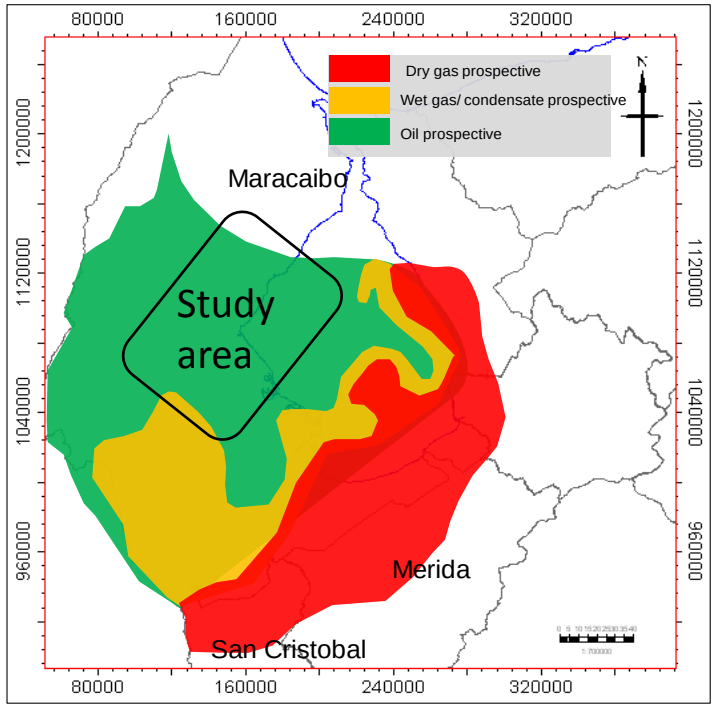
Well logs

- GR; GR core
  GR spectral
  Density; Neutron; Sonic and Resistivity.

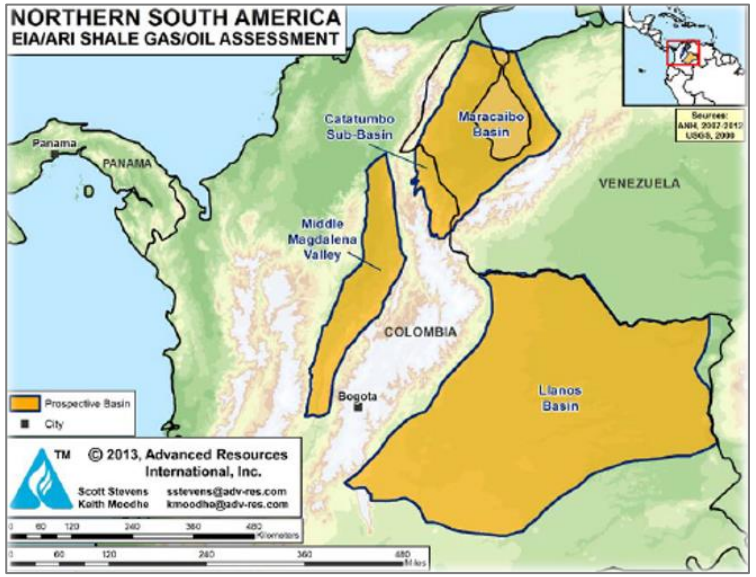


Taken from fotosearch.com

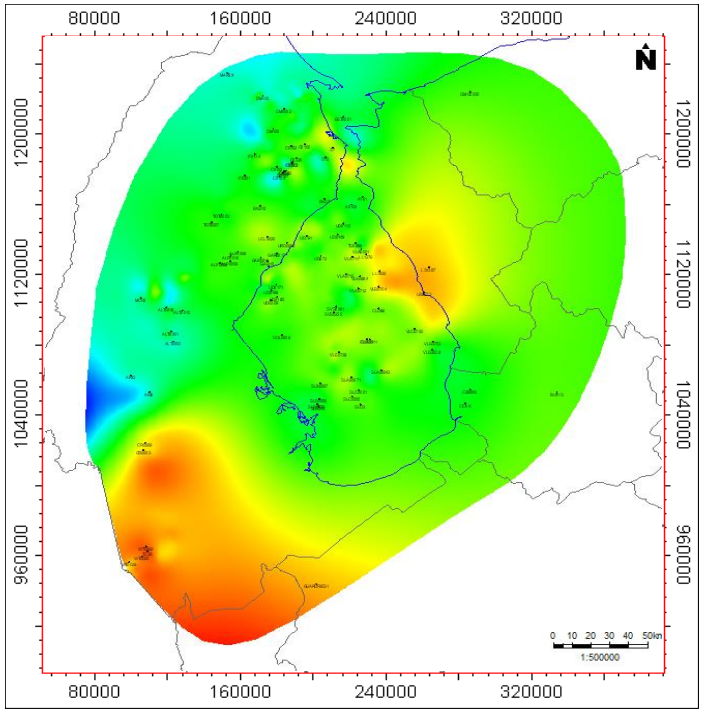
Motivation of study



Prospective Area for Shale Exploration in the Maracaibo/Catatumbo Basin (Modified from EIA, 2013)



Prospective Area for Shale Exploration in the Maracaibo/Catatumbo Basin (EIA, 2013)



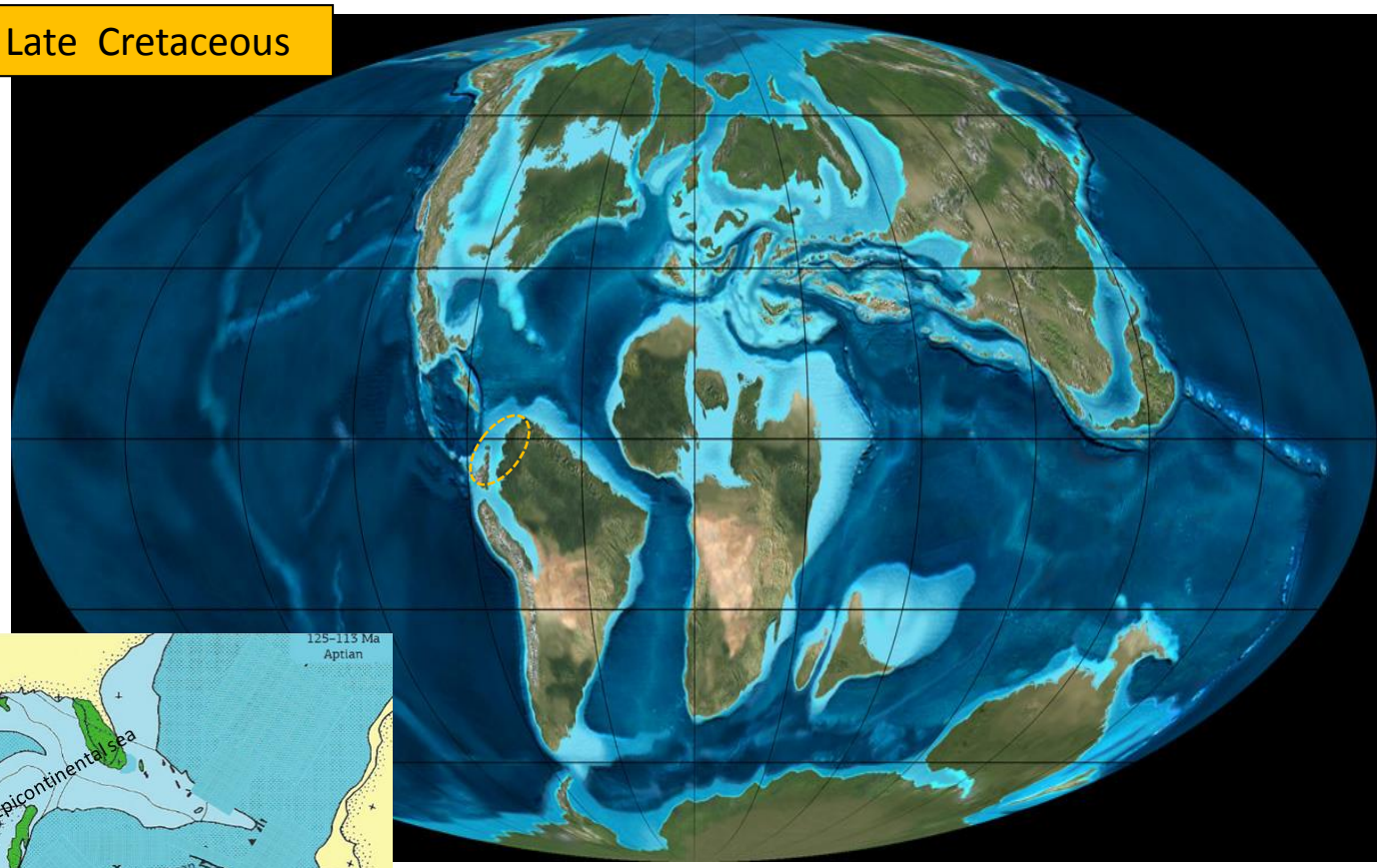
Thickness map of La Luna Formation, Venezuela. (PDVSA, 2013)

The Upper Cretaceous (Cenomanian-Santonian) La Luna Formation, is the primary source rock in the basin and time-equivalent with the Eagle Ford Shale in Texas, **appears to be the most prospective target for shale oil and gas exploration.** The black calcareous La Luna Shale ranges from **100 to over 500** feet thick across the basin with an extension of **23,000 square miles**, thinning towards the south and east

La Luna Formation, Venezuela

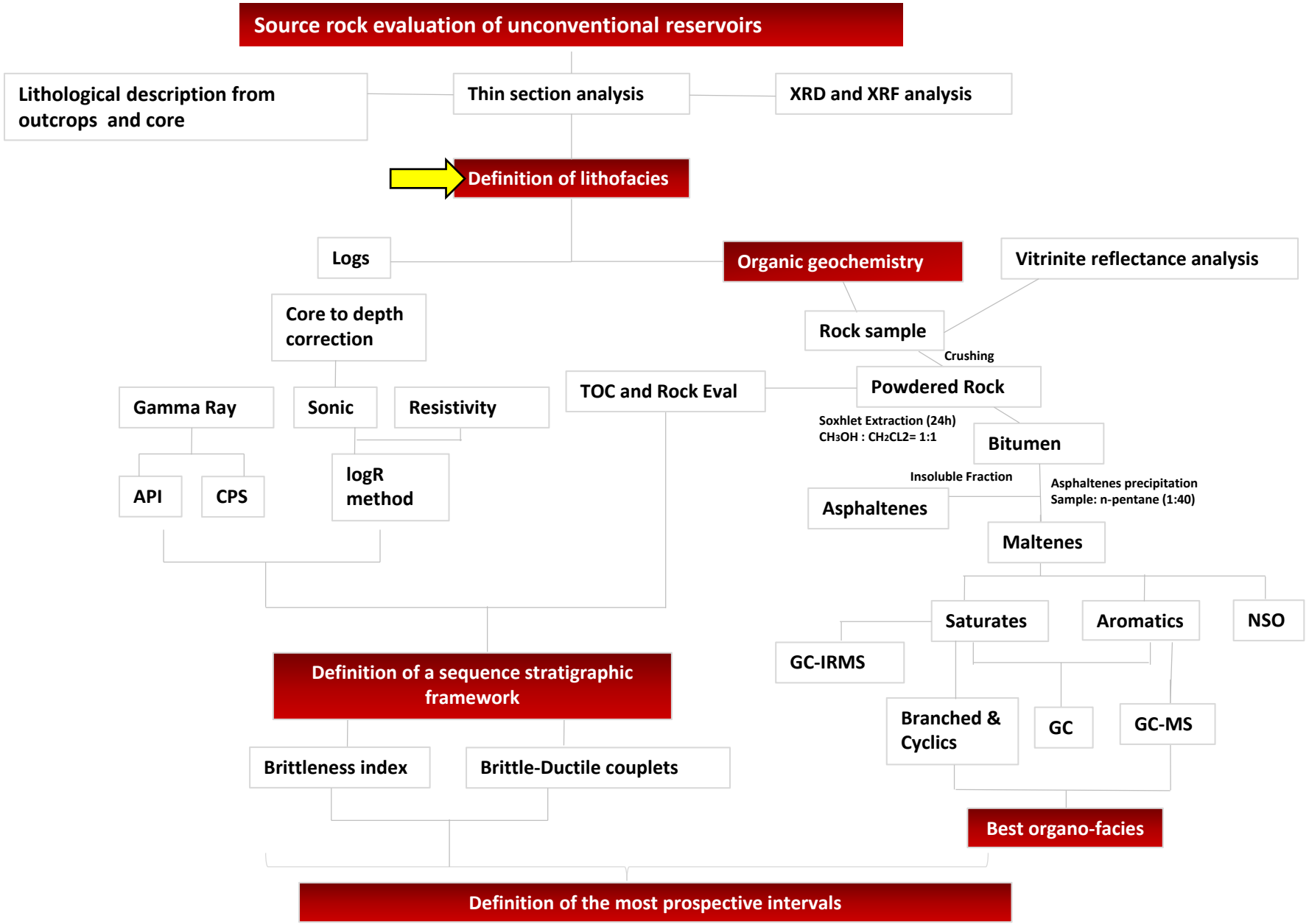
Era	Period	Epoch	Geological events	Sed. Deposits	Units	
CENOZOIC	TERTIARY	Eocene	-Cretaceous sea withdrew (Marine regression) -Shelf seas	-Fluvial meandering rivers	Mirador Fm	
		Paleocene		-Deltaic Province: deltaic settings interdigitated with fluvio-deltaic and beach deposits	Orocue Fm	Los Cuervos
						Barco
MESOZOIC	CRETACEOUS	UPPER Ma	-Regressive conditions. -Start of the Alpine Orogeny. - Maximum marine Transgresion	-Neritic settings, near to the shore with sea periods.	Colon Fm	Mitojuan
		Camp				Tres esquinas
		Santonian		-Open marine platform to restricted platform	La Luna Fm	
		Conia	-Maximum flooding Surface -Deep seas			
		Turonian		Sedimentological settings that shows the progress of the transgression and deepening.		
		Ceno				
		LOWER Albian	-Cretaceous transgression over the continental margin of Venezuela. -The geometry of the ocean scatterings centers is changed. - The tectonic styles in the plate boundaries are changed	-Shelf Environment -Fluvio-deltaic environments -Shallow marine environments	Cogollo Group	Maraca Fm.
						Lisure Fm.
						Apon Fm.

Figure (A) Areas of carbonate platforms during the early Aptian-Albian (in green). Dot et al., 2015



(B) Paleographic maps from Late cretaceous. Ron Blakey, Colorado Plateau Geosystems Inc., 2012.

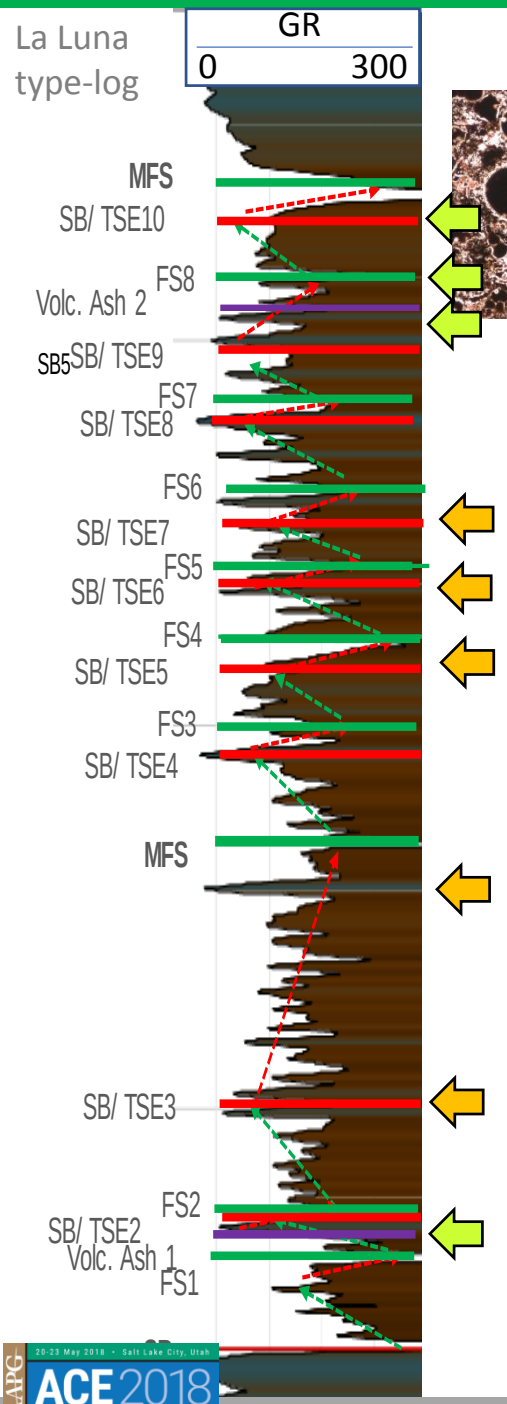
Methodology

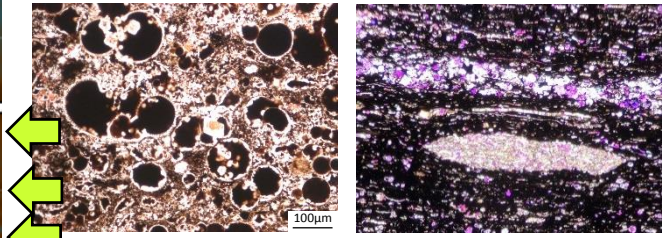


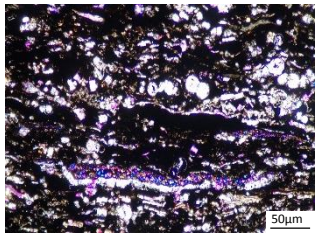
Flow chart for source rock evaluation of unconventional gas shales (Modified from Slatt, et al., 2012 and Michelli-Romero & Philp, 2014).

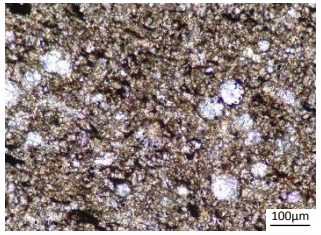
Mineralogical Facies

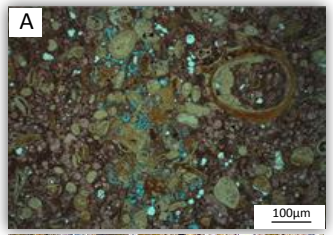
La Luna type-log

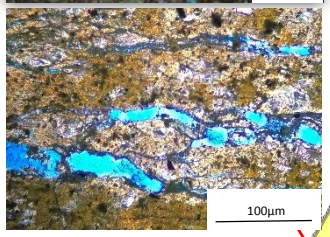












Quartz and Feldspar

Carbonate dominated Lithotype

Carbonates

Clay dominated Lithotype

Clay

Cores

- 282 ft. core for La Luna IE
- 220 ft. core for La Luna IA
- 112 ft. core for La Luna IS
- 345 ft. core for La Luna IX
- La Luna Fm. stratotype

Based on the ternary plot classification from Gamero-Diaz et al, 2012.

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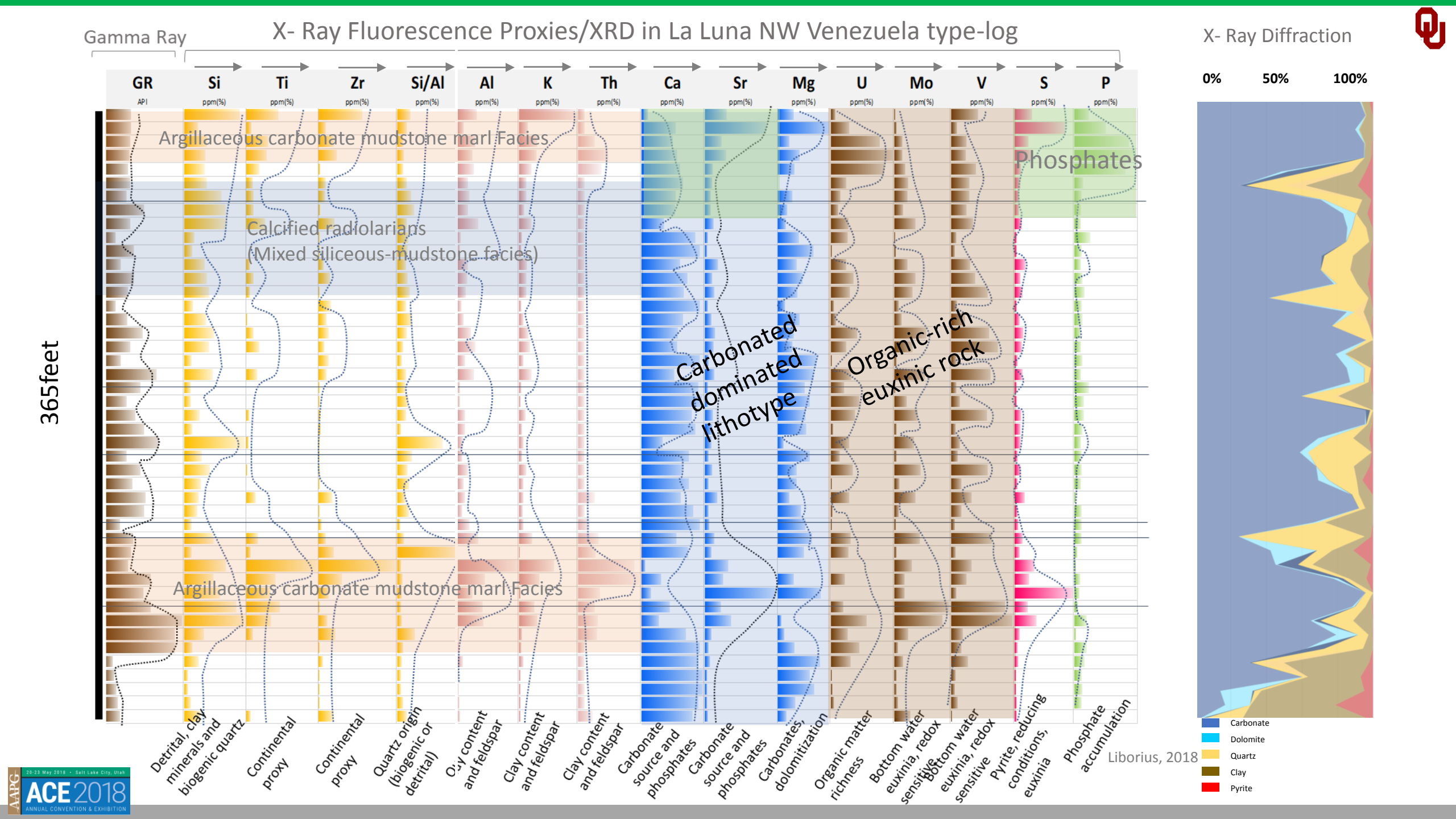
Gamma Ray
X- Ray Fluorescence Proxies/XRD in La Luna NW Venezuela type-log
X- Ray Diffraction
0%
50%
100%
GR
API
Si
Ti
Zr
Si/Al
Al
K
Th
Ca
Sr
Mg
U
Mo
V
S
P
ppm(%)
Argillaceous carbonate mudstone marl Facies
Phosphates
Calcified radiolarians
(Mixed siliceous-mudstone facies)
Carbonated dominated lithotype
Organic-rich euxinic rock
Argillaceous carbonate mudstone marl Facies
365feet
Detrital, clay minerals and biogenic quartz
Continental proxy
Continental proxy
Quartz origin (biogenic or detrital)
Clay content and feldspar
Clay content and feldspar
Clay content and feldspar
Carbonate source and phosphates
Carbonate source and phosphates
Carbonates, dolomitization
Organic matter richness
Bottom water euxinia, redox sensitive
Bottom water euxinia, redox sensitive
Pyrite, reducing conditions, euxinia
Phosphate accumulation
Carbonate
Dolomite
Quartz
Clay
Pyrite
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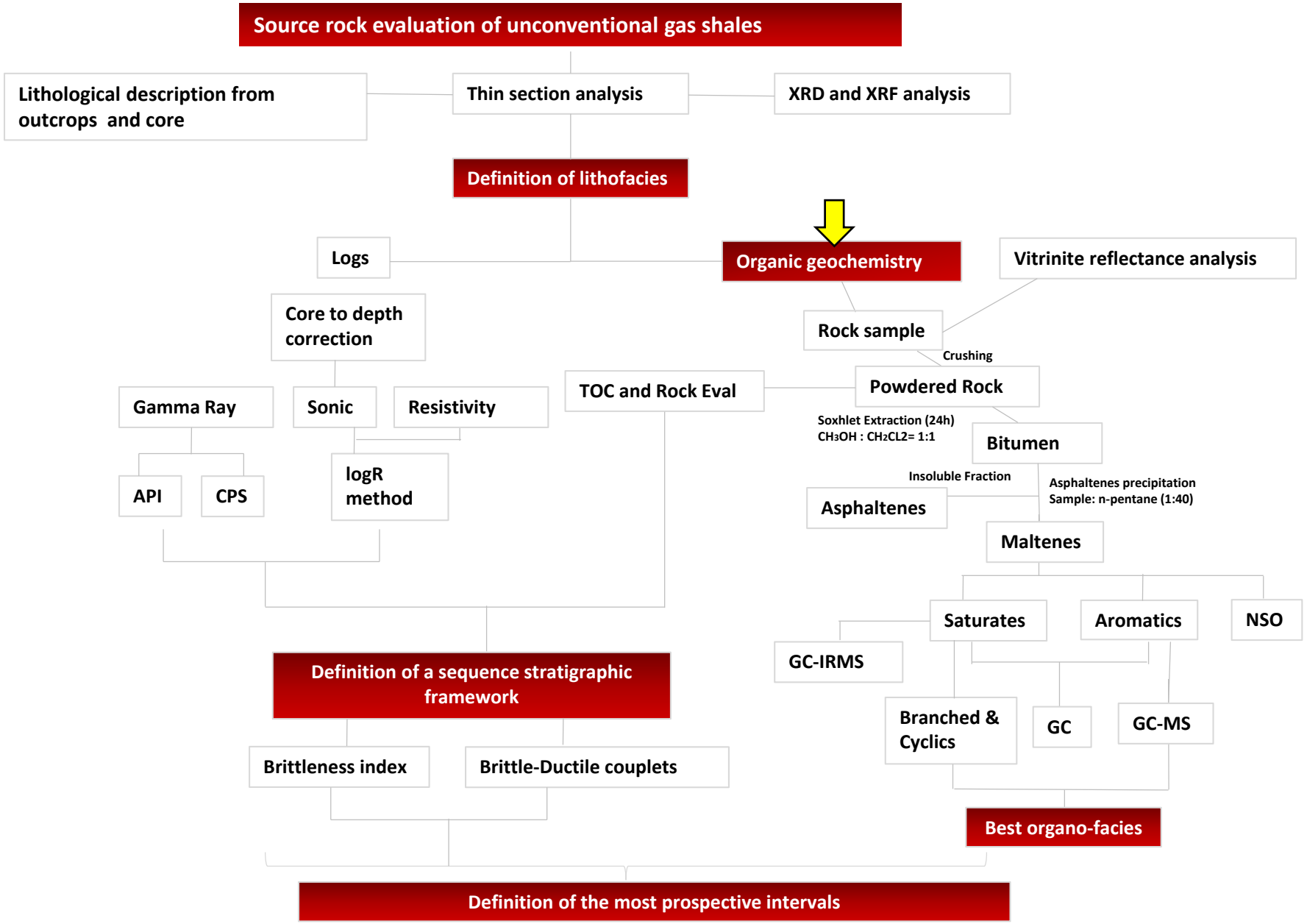
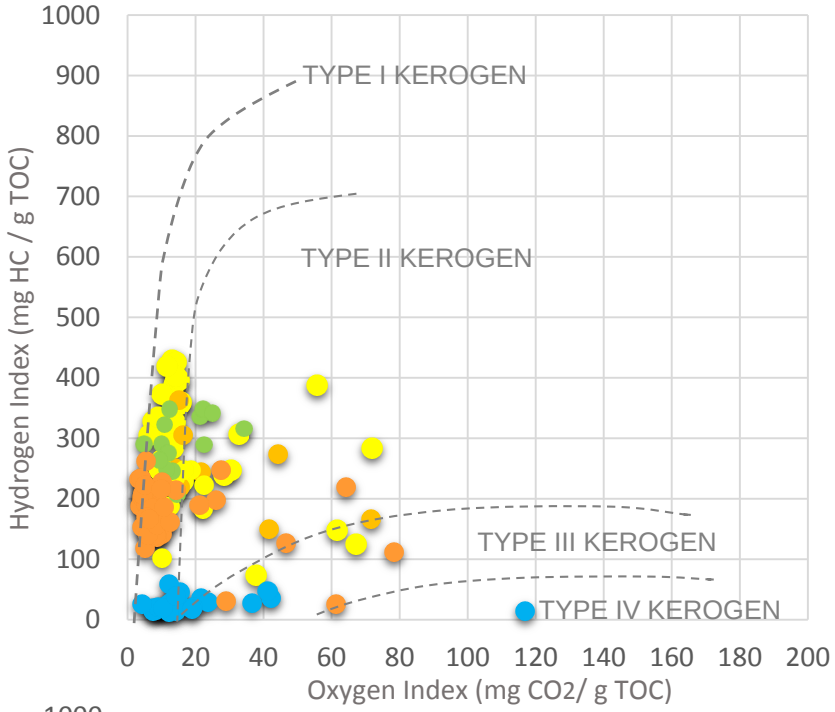
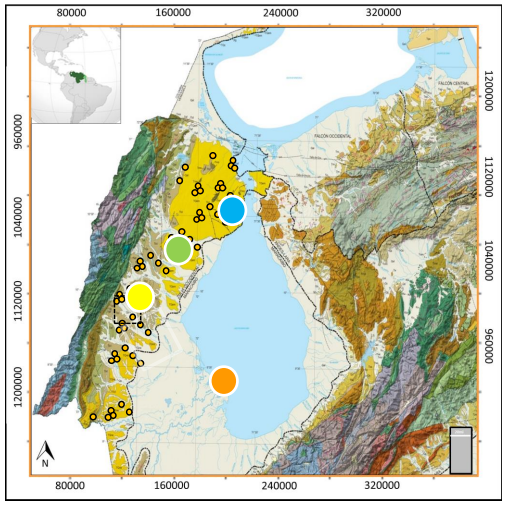
Methodology



Flow chart for source rock evaluation of unconventional gas shales (Modified from Slatt, et al., 2012 and Michelli-Romero & Philp, 2014).

Source Rock Potential and maturity



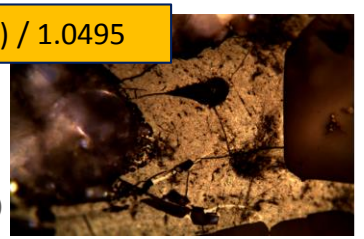


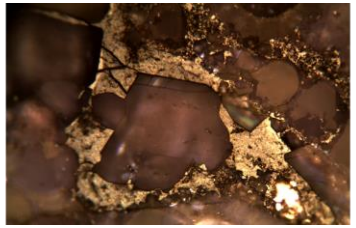
Ro = (BRo + 0.2443) / 1.0495

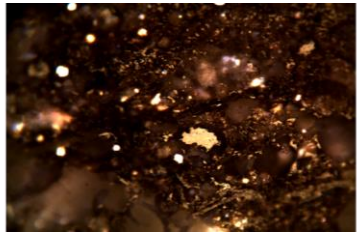
From Landis C. R. and Castano J. R. (1995).

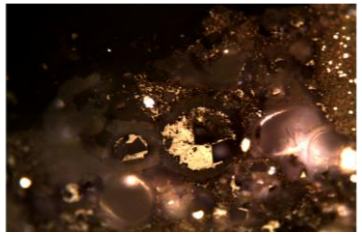
Cores
(Approximated location)

- La Luna IE
- La Luna IA
- La Luna IS
- La Luna IX


Grainy bitumen, 1.01%Ro


Grainy bitumen, 1.08%Ro


Bitumen, 1.20%Ro

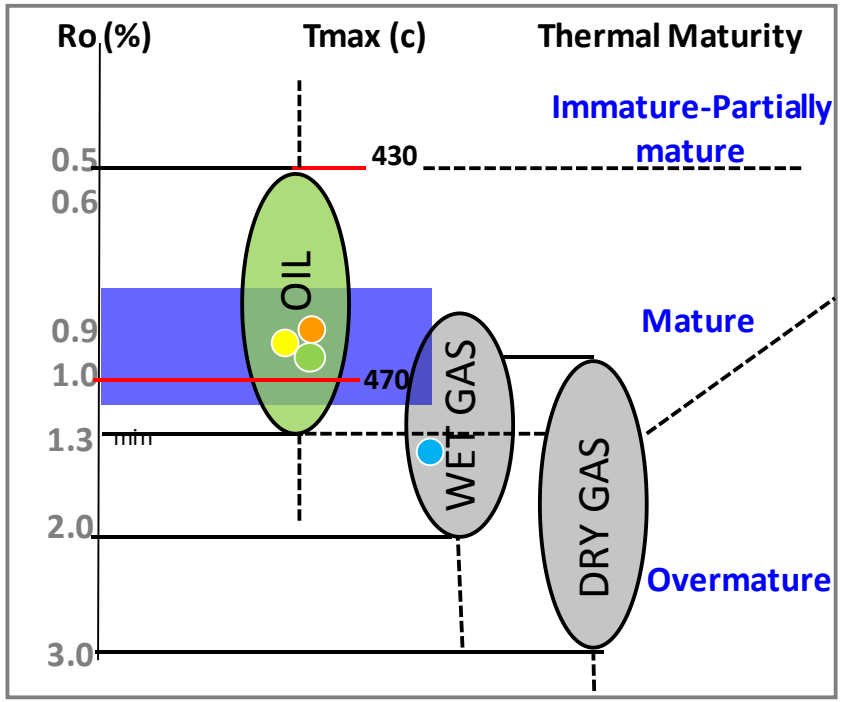

Grainy bitumen, 1.17%Ro

$$MPI\,1 = 1.5 \times \frac{[2 - MP + 3 - MP]}{[P + 1 - MP + 9 - MP]}$$

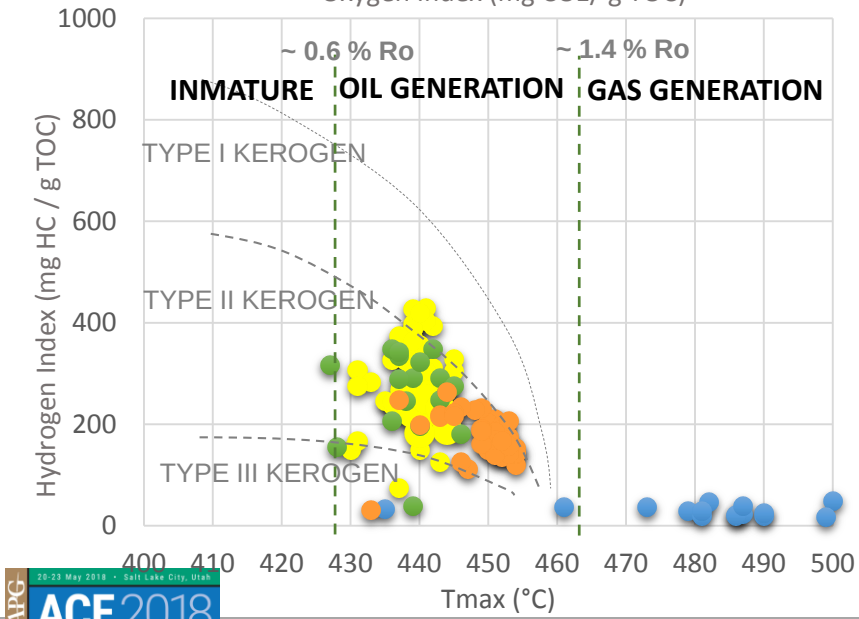
For 0.65 to 1.35%R_o:

R_c = 0.60 MPI-1 + 0.40

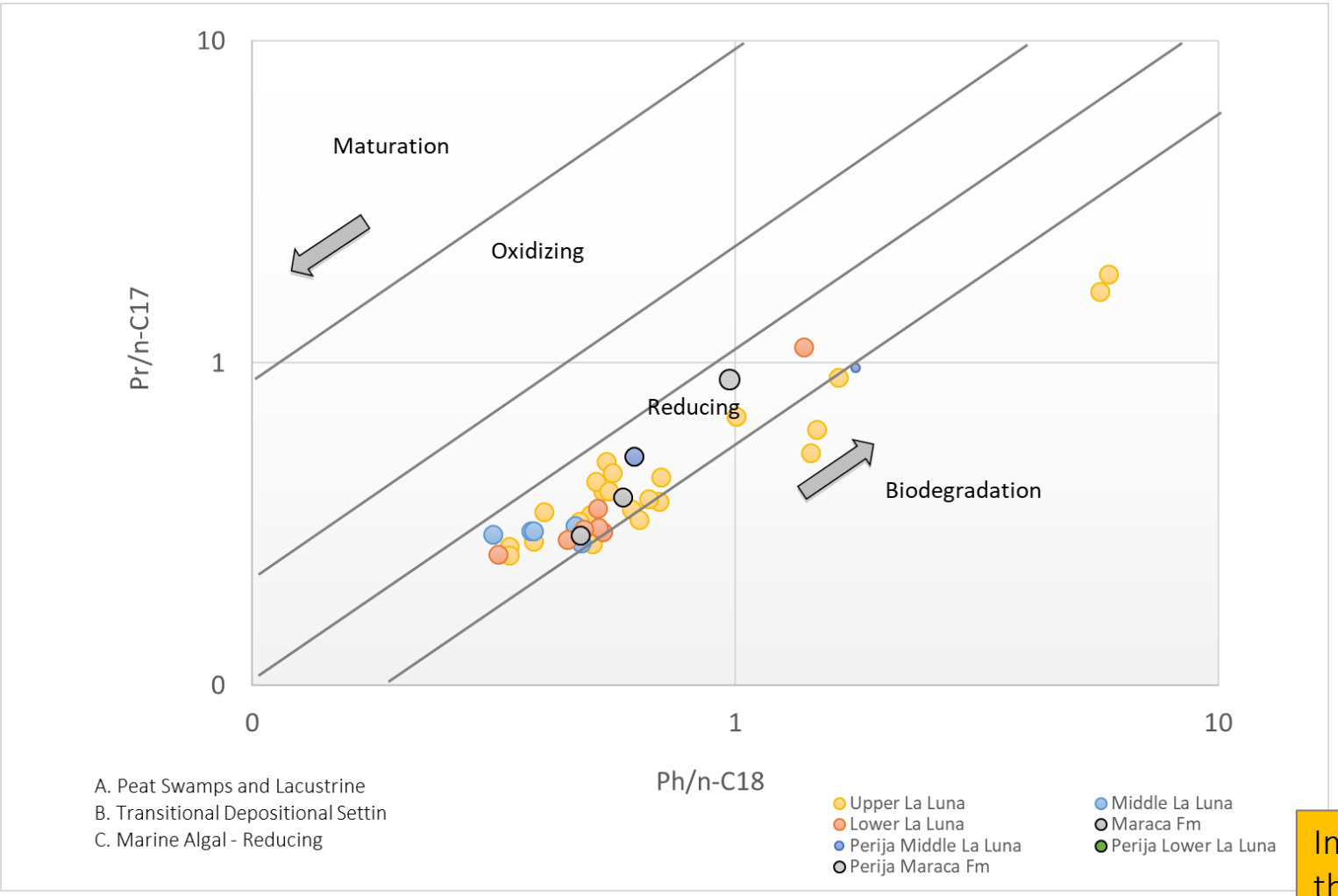
Ro calculated from MPI-1: 1.1 on average



Thermal maturity scale of La Luna IX. Tmax and Ro (%) taken from Kuuskra et al (2011)



Evaluation in redox conditions



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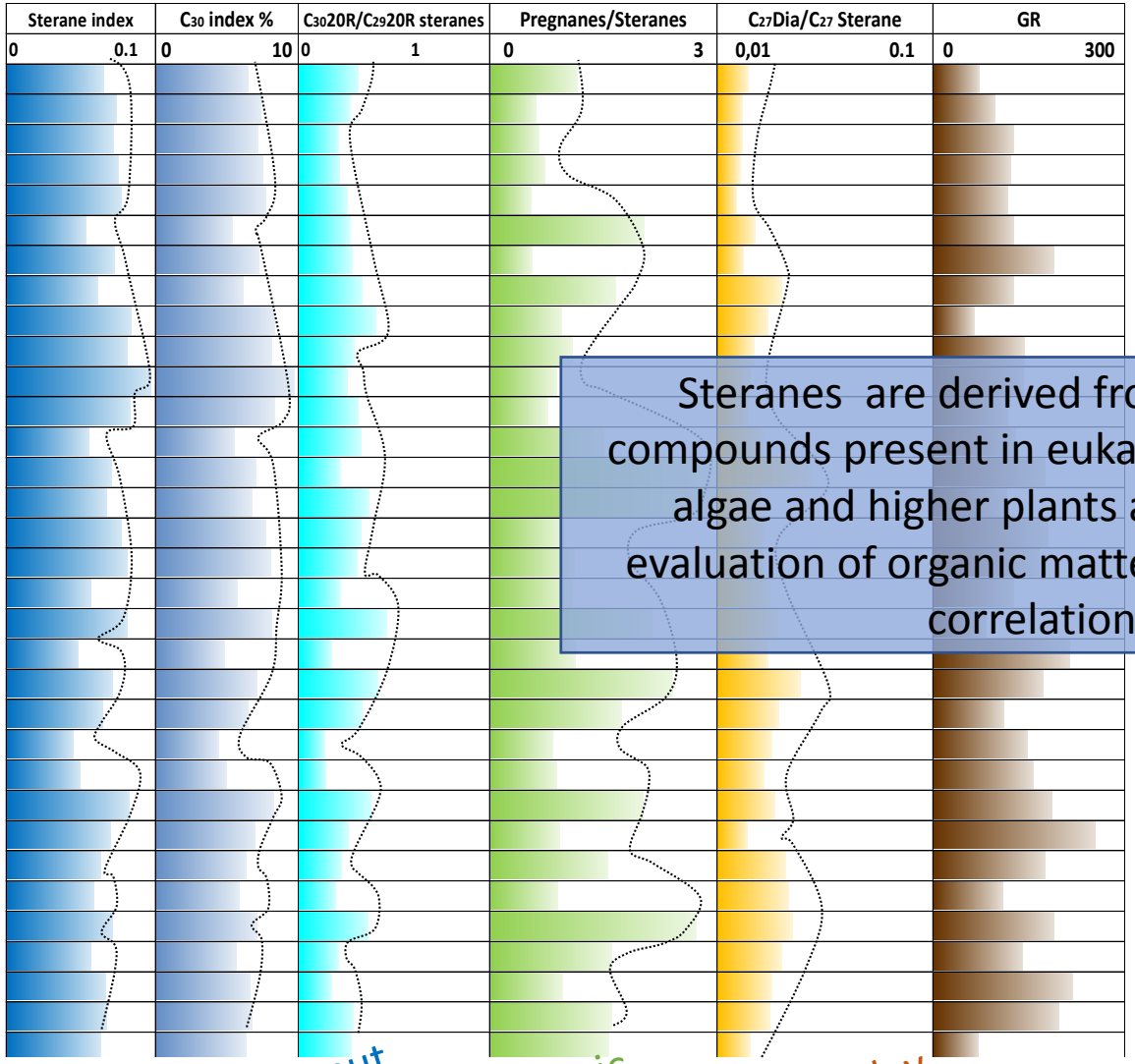
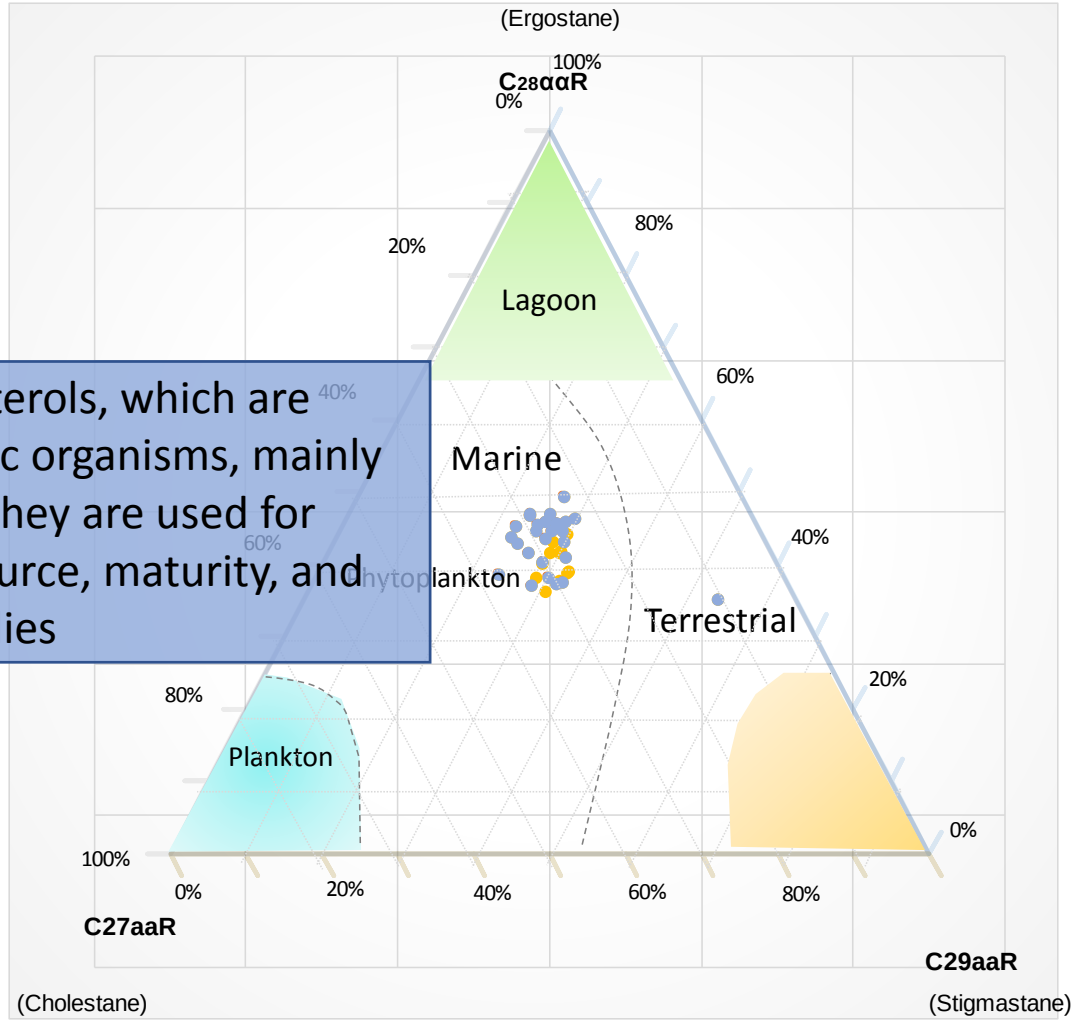
Important parameters used to evaluate the variations in redox conditions, organic matter source, maturity, and alteration in source rock extracts.

Steranes



Steranes are derived from sterols, which are compounds present in eukaryotic organisms, mainly algae and higher plants and they are used for evaluation of organic matter source, maturity, and correlation studies



Derived from lipid membranes of eukaryotic cells.

- C_{27} -> Plankton and marine invertebrates
- C_{28} -> Fungi and protozoa
- C... -> Higher plants

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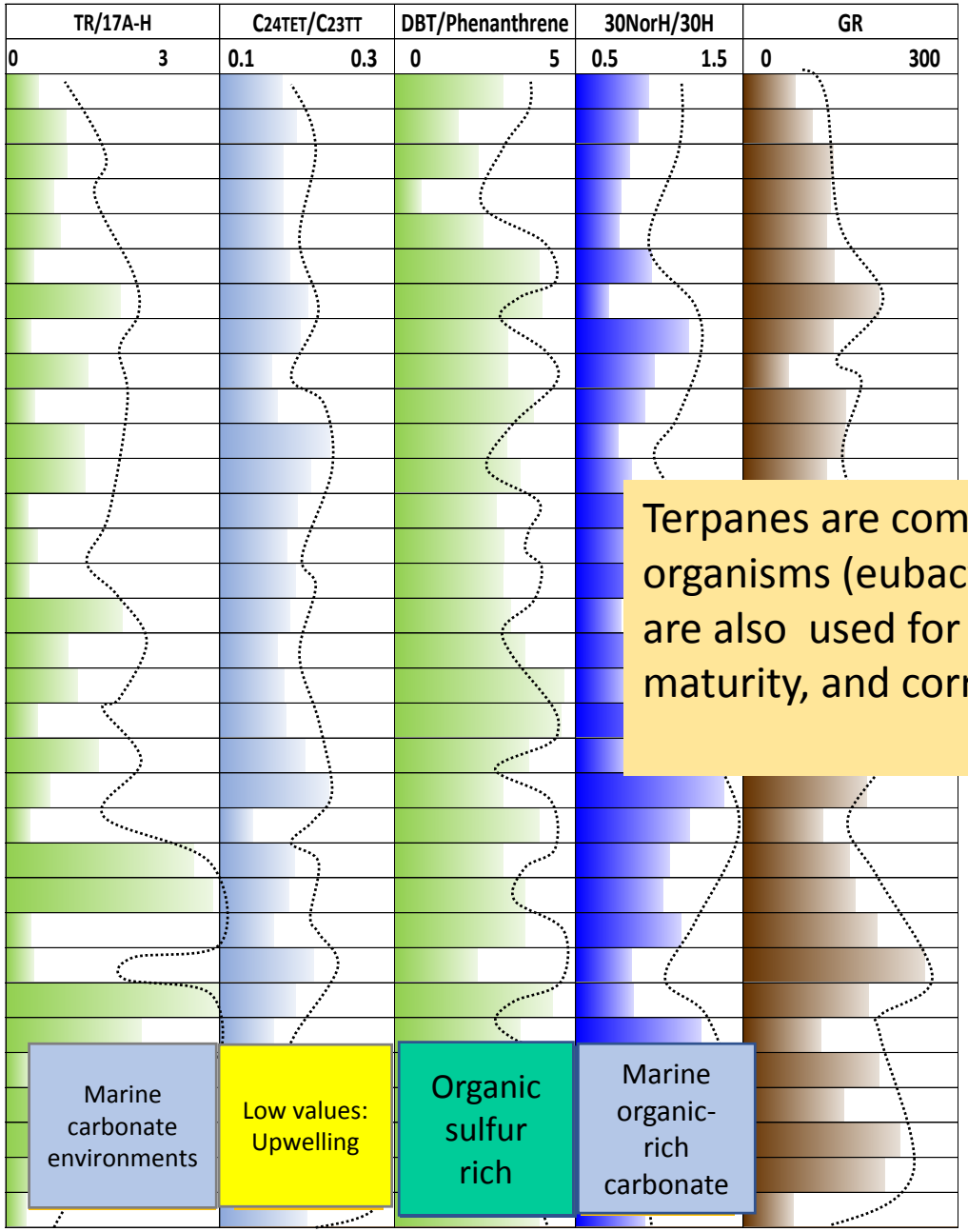
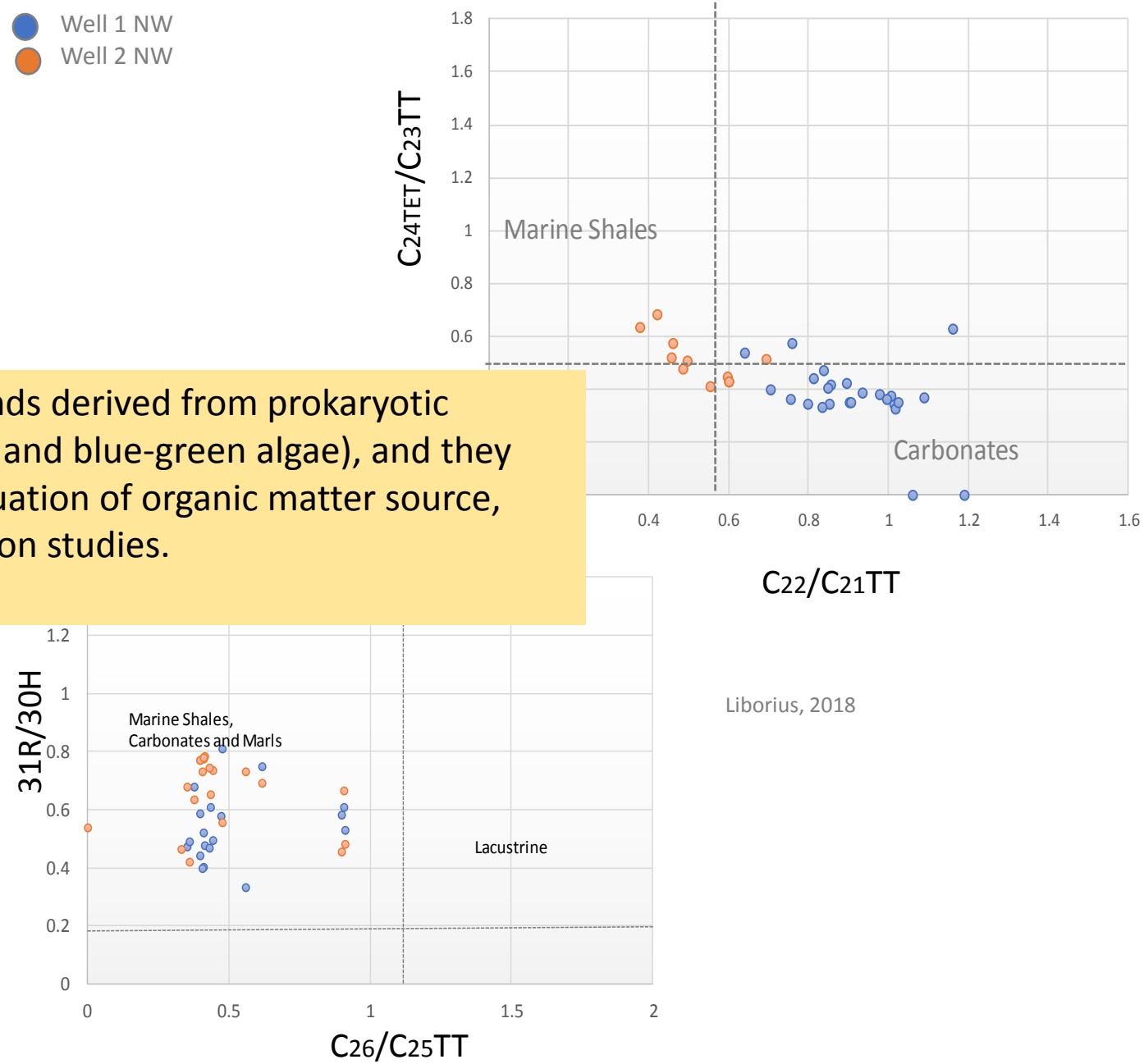
Marine organic input

Hypersaline anoxic conditions

Anoxia and low clay content

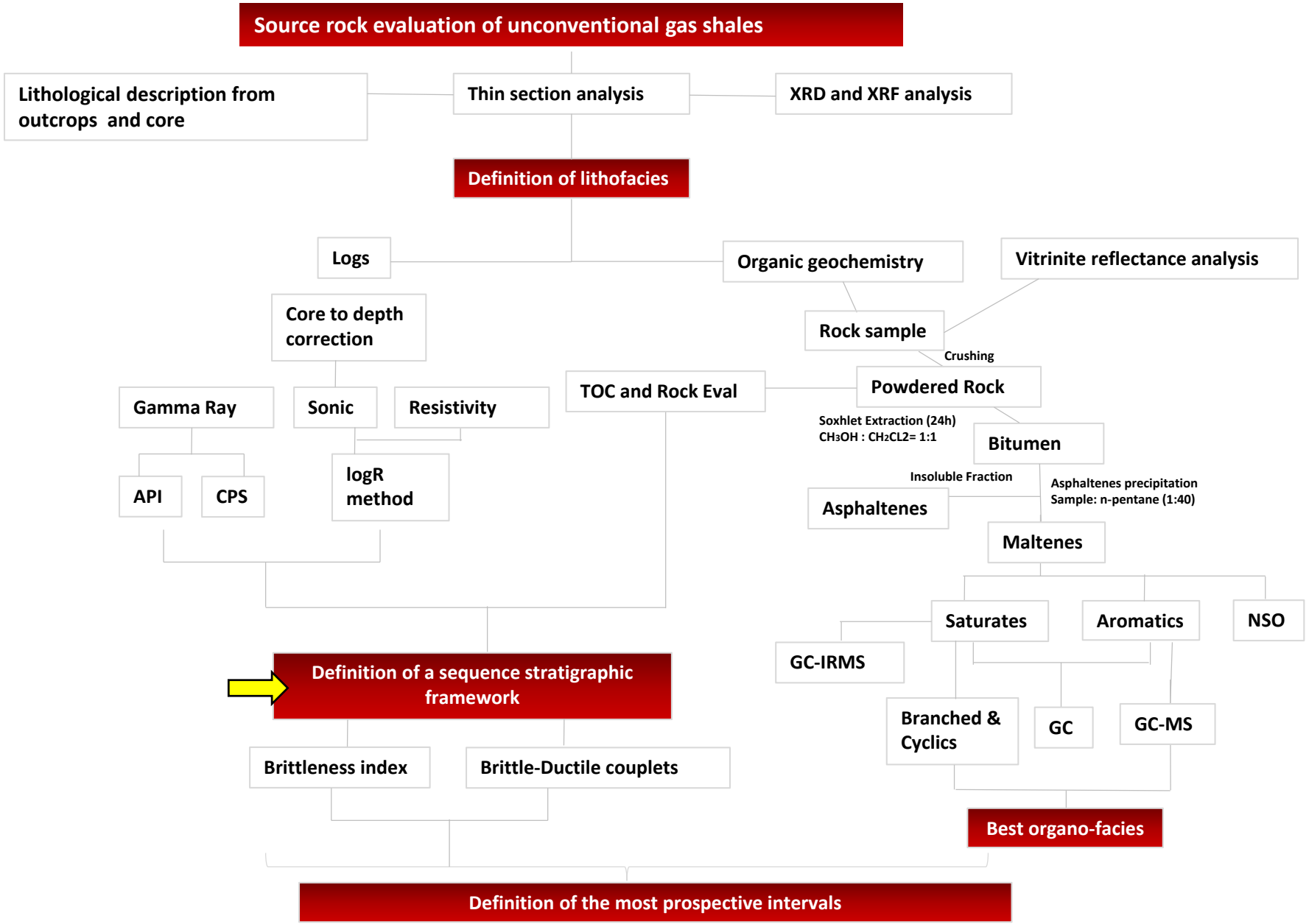


Terpanes are compounds derived from prokaryotic organisms (eubacteria and blue-green algae), and they are also used for evaluation of organic matter source, maturity, and correlation studies.



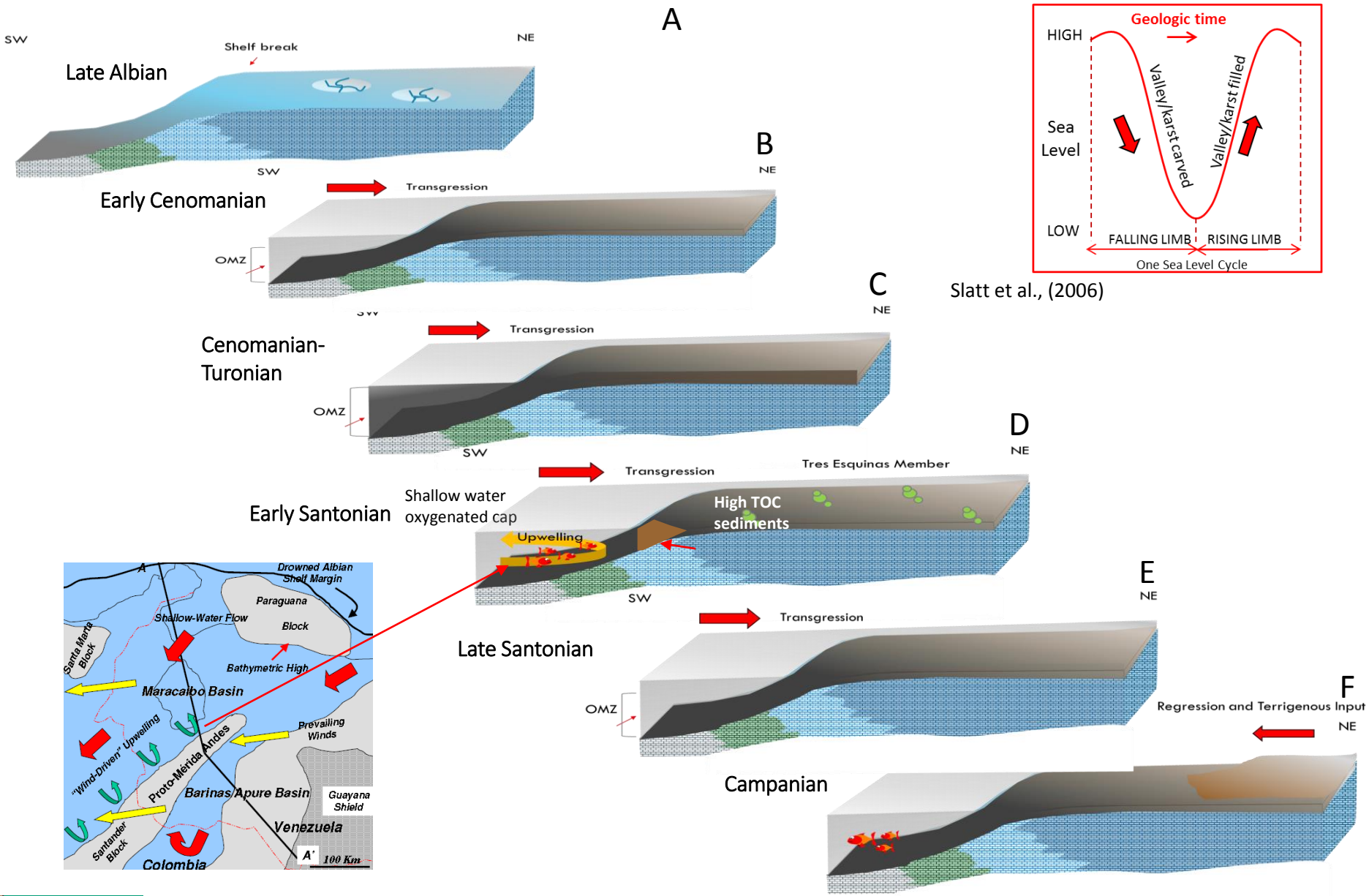
Liborius, 2018

Methodology

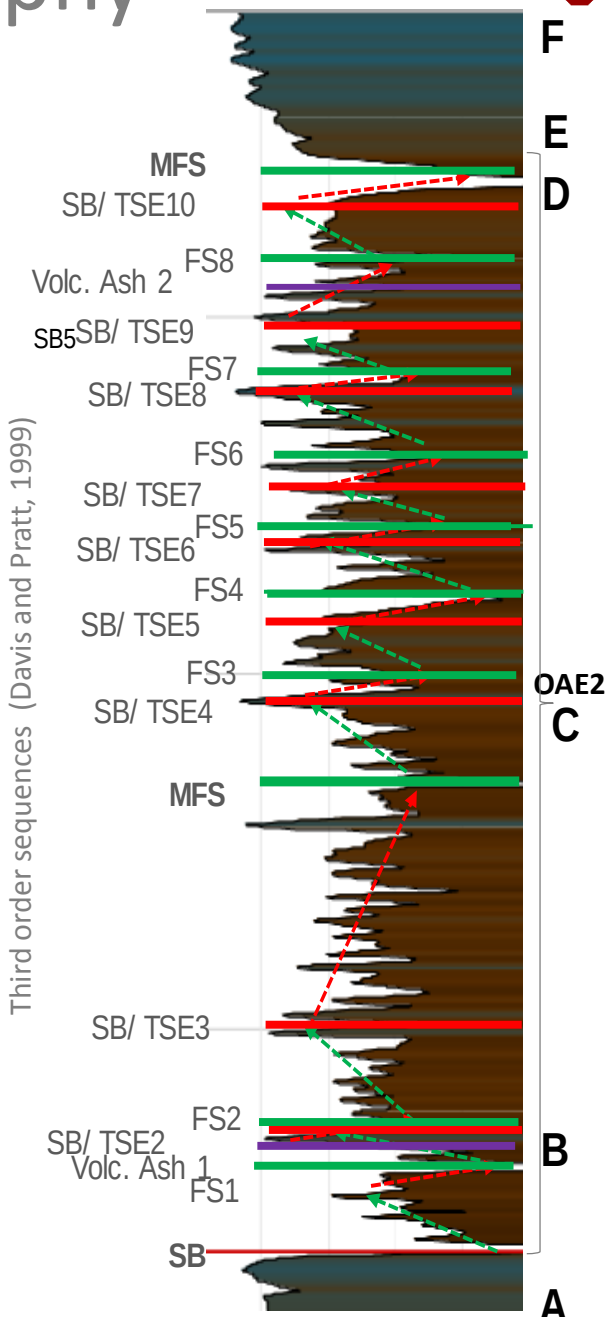


Flow chart for source rock evaluation of unconventional gas shales (Modified from Slatt, et al., 2012 and Michelli-Romero & Philp, 2014).

Depositional model and sequence stratigraphy



Slatt et al., (2006)



Depositional model of the La Luna Formation through one eustatic sea level cycle. Liborius, 2018.

S

265 km Strike line

N

MFS

SB

MFS

SB

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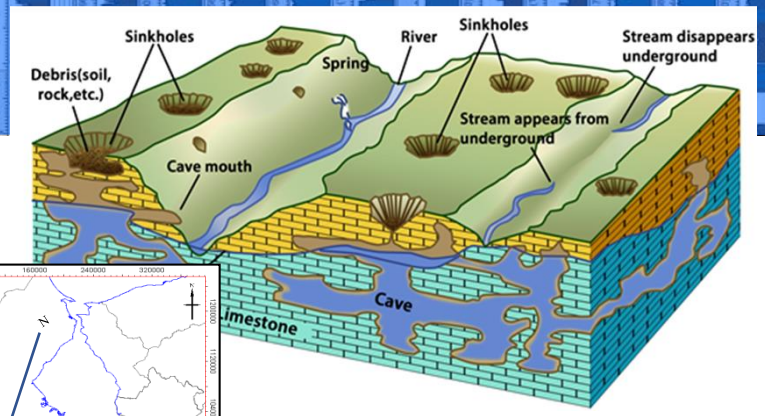
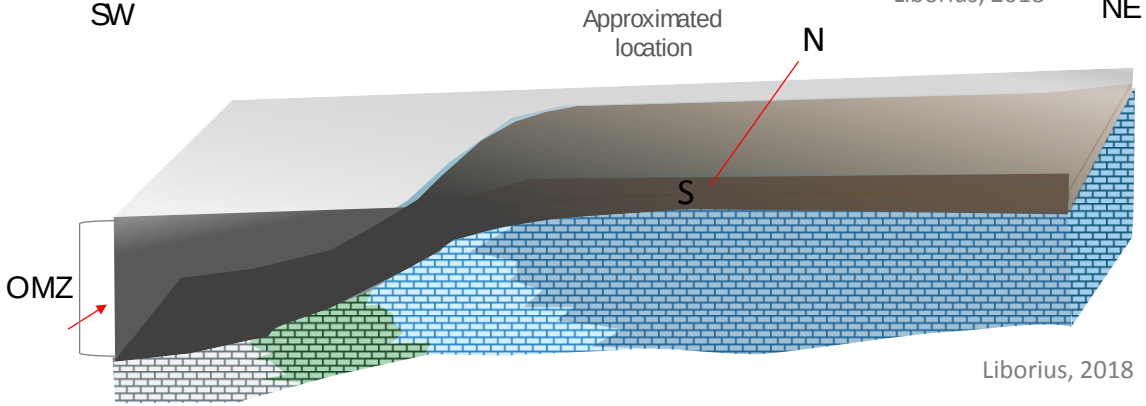


After Grotzinger and Jordan, 2010

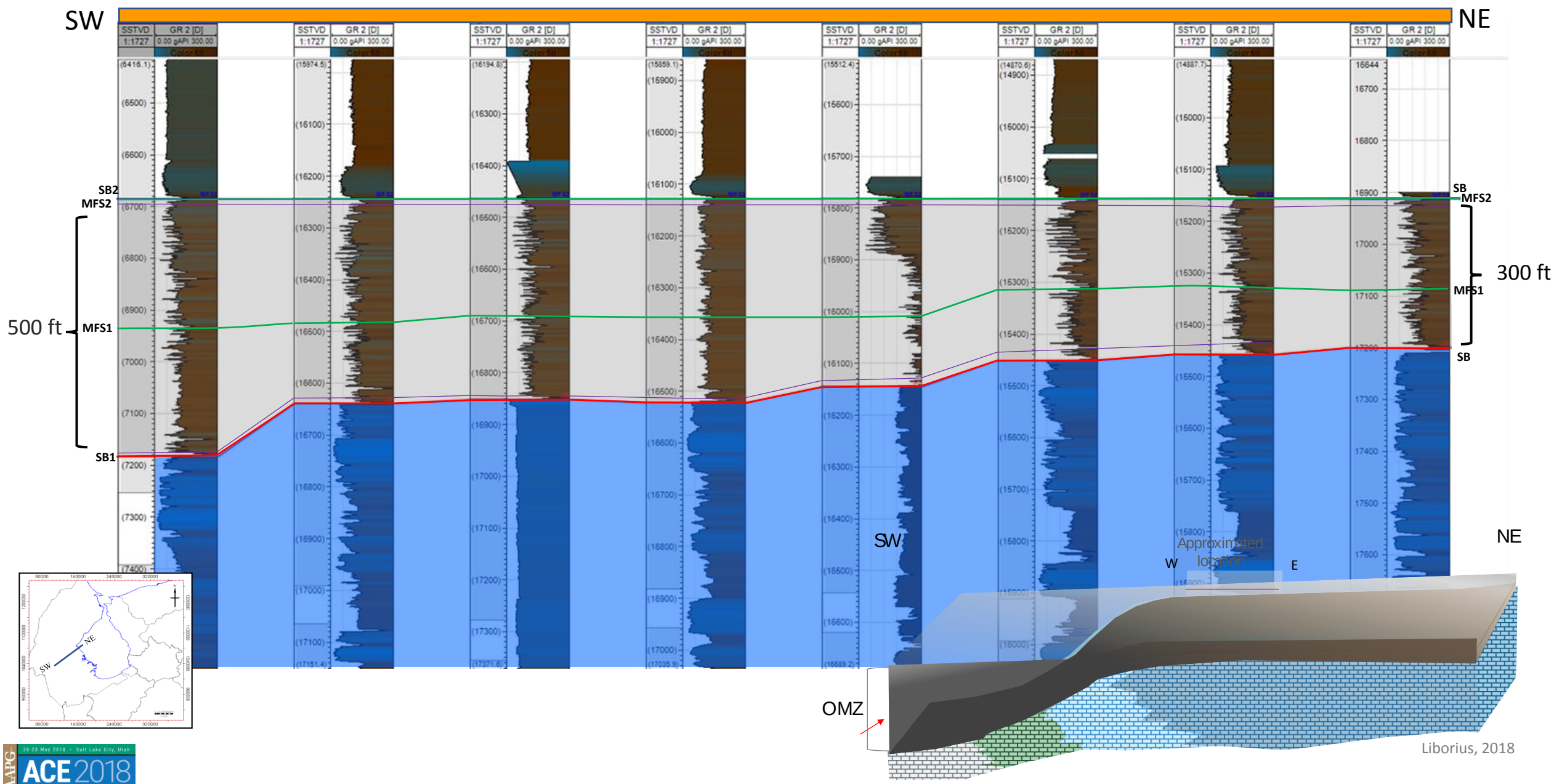
SW

Vertical scale

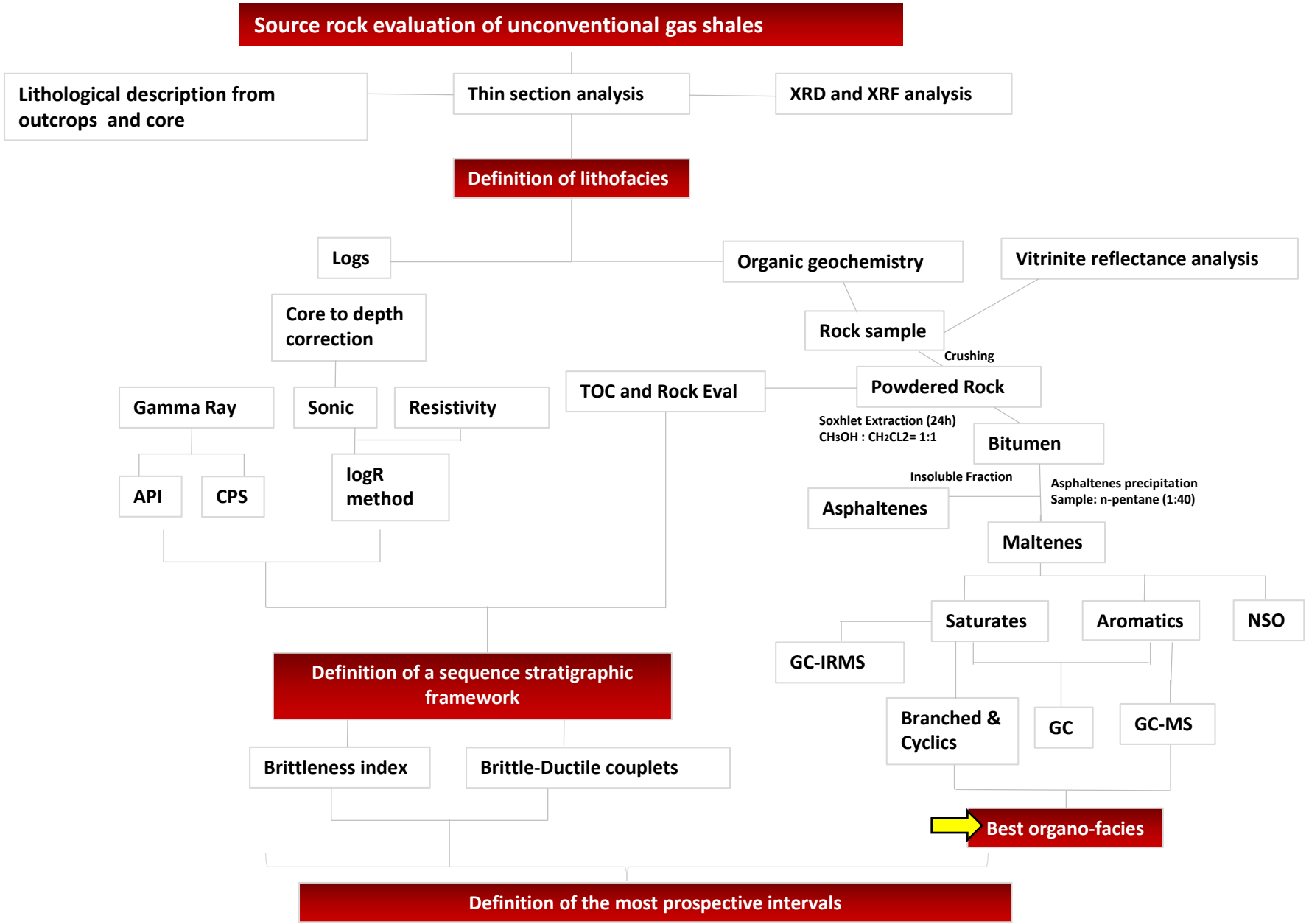
NE



Liborius, 2018

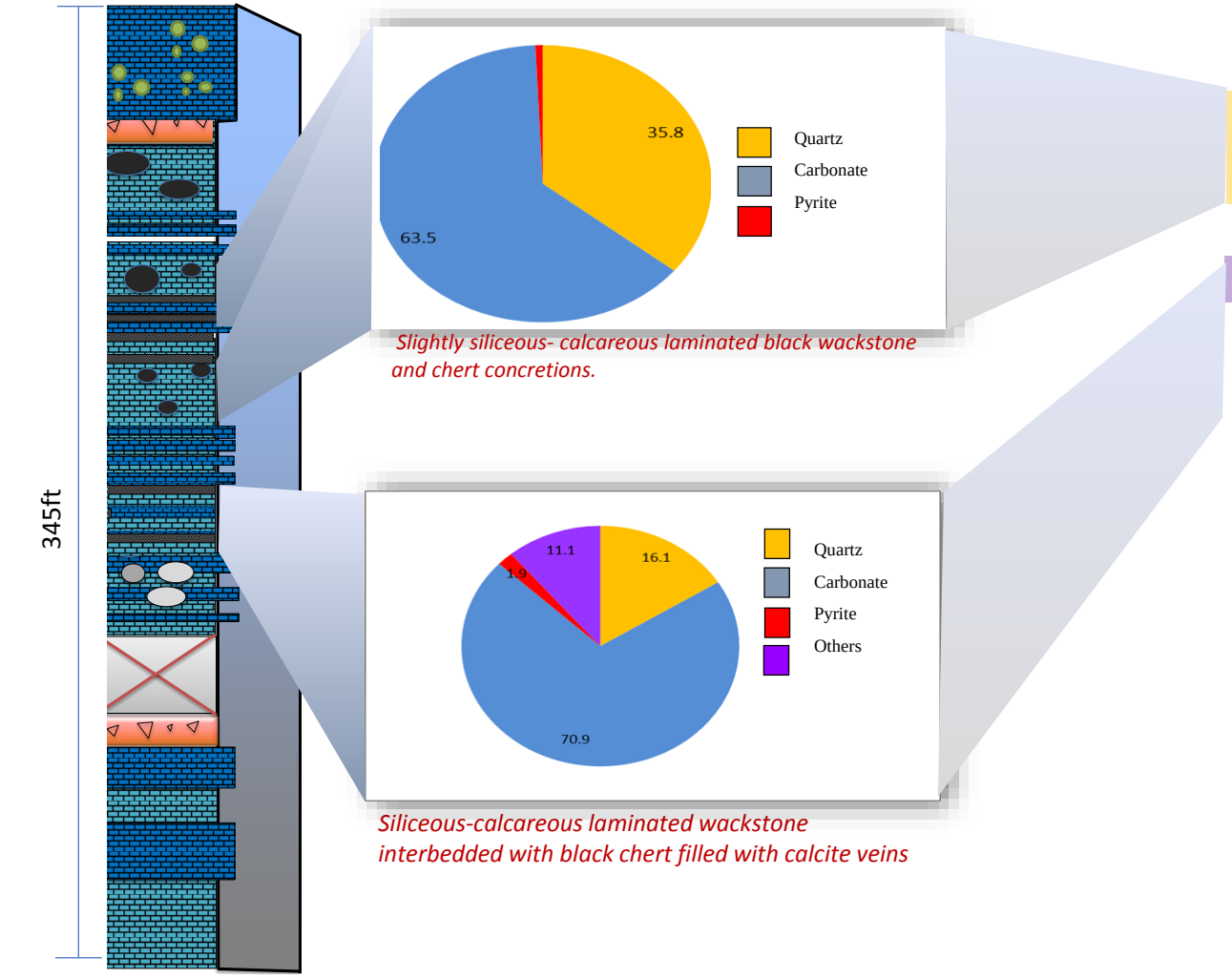

100 km Dip line
SW
NE
SSTVD
GR 2 [D]
1:1727
0.00 gAPI 300.00
SB2
MFS2
MFS1
SB1
SB
500 ft
300 ft
SW
NE
Approximated location
W
E
OMZ
Liborius, 2018

Methodology

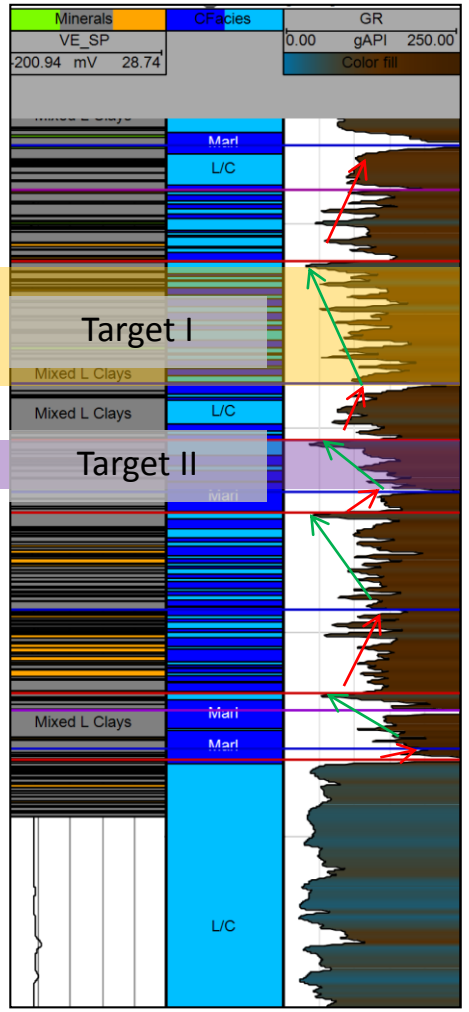


Flow chart for source rock evaluation of unconventional gas shales (Modified from Slatt, et al., 2012 and Michelli-Romero & Philp, 2014).

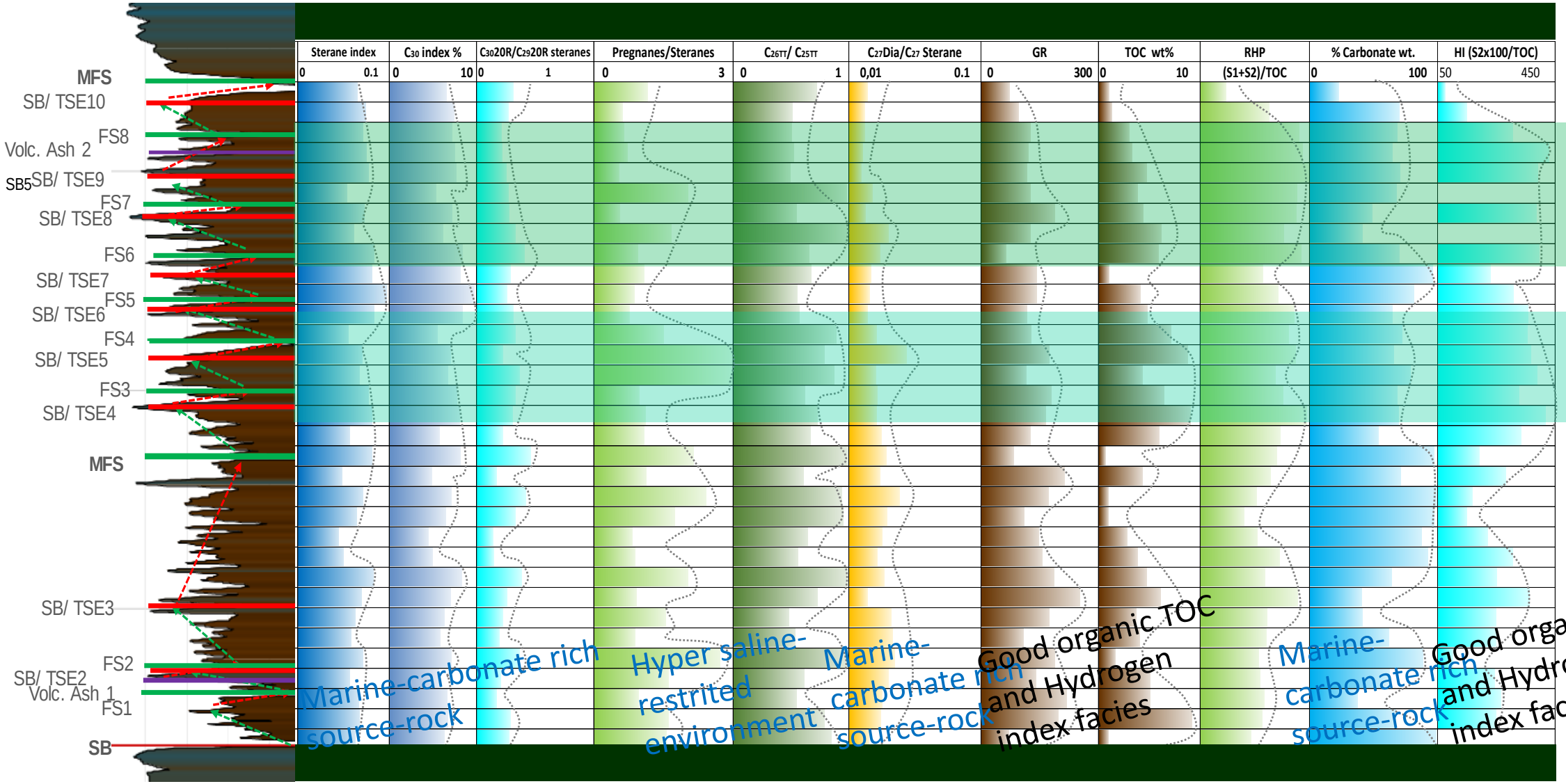
Preliminary definition of Targets in La Luna Northwest, Venezuela



Schematic stratigraphic column of core La Luna IX



Best organo-facies



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Key Parameters

- TOC
- Maturity
- Areal extension
- Brittleness
- Lithofacies

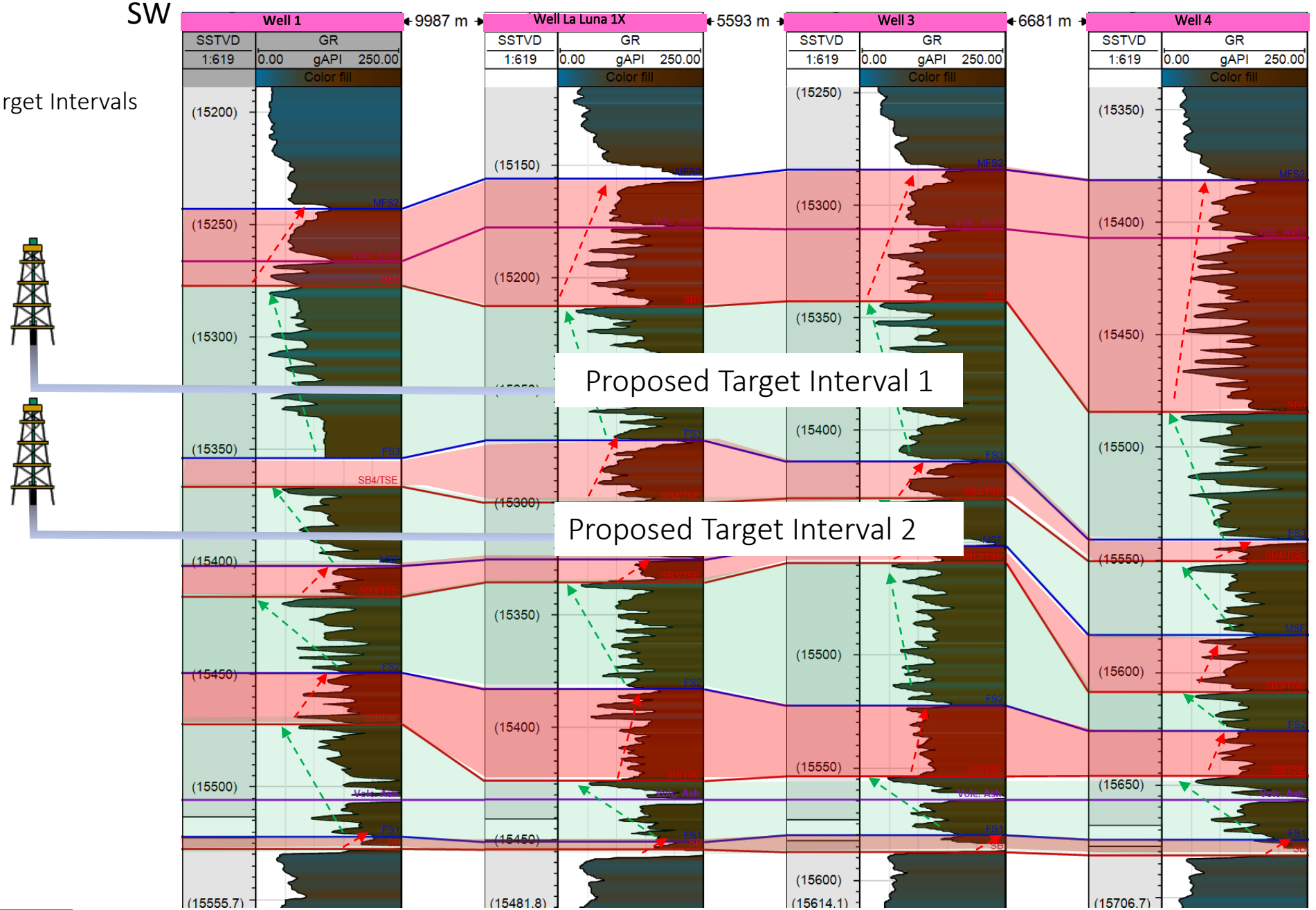

Excellent **QUALITY TOC**


Oil window


More than 23000 sq miles


High Brittleness index


Organic-rich lithofacies



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CONTACT INFORMATION
Andreina Liborius
andreinaliborius@ou.edu
https://www.linkedin.com/in/andreina-liborius