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What have we learned from petrophysical evaluation of the Vaca Muerta formation during the last 7 years of unconventional shale play exploration and development?

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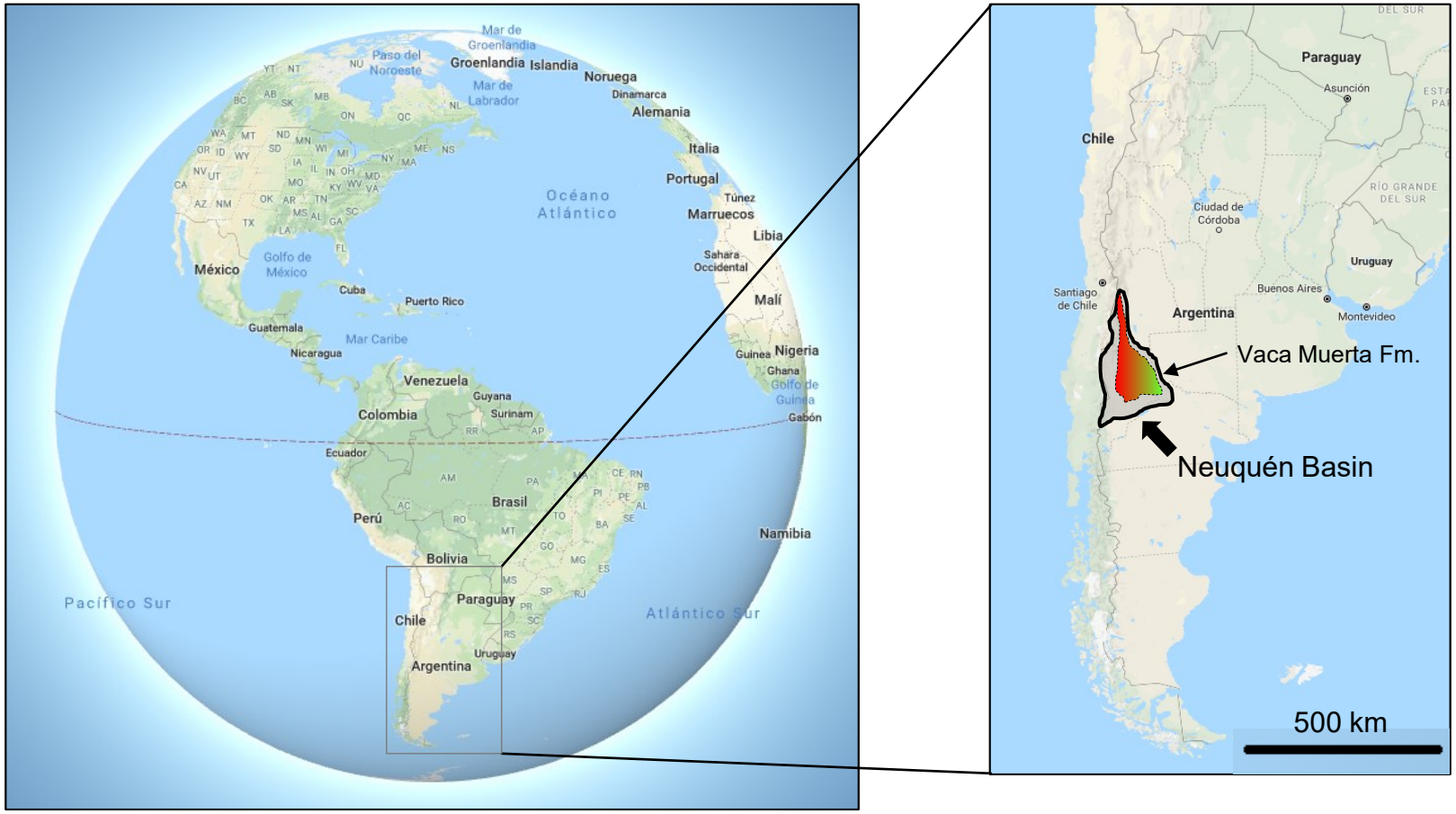
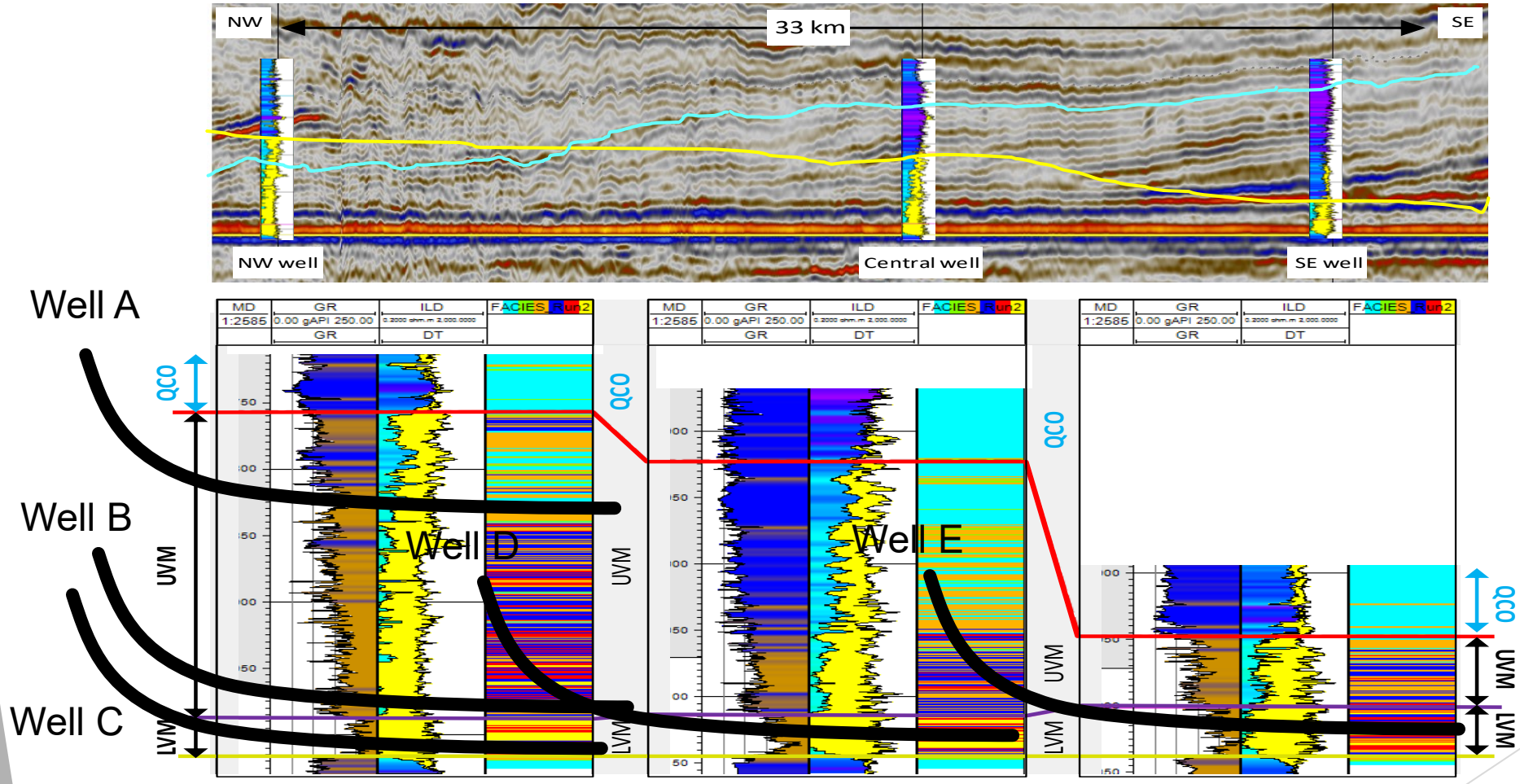
Introduction



Outline

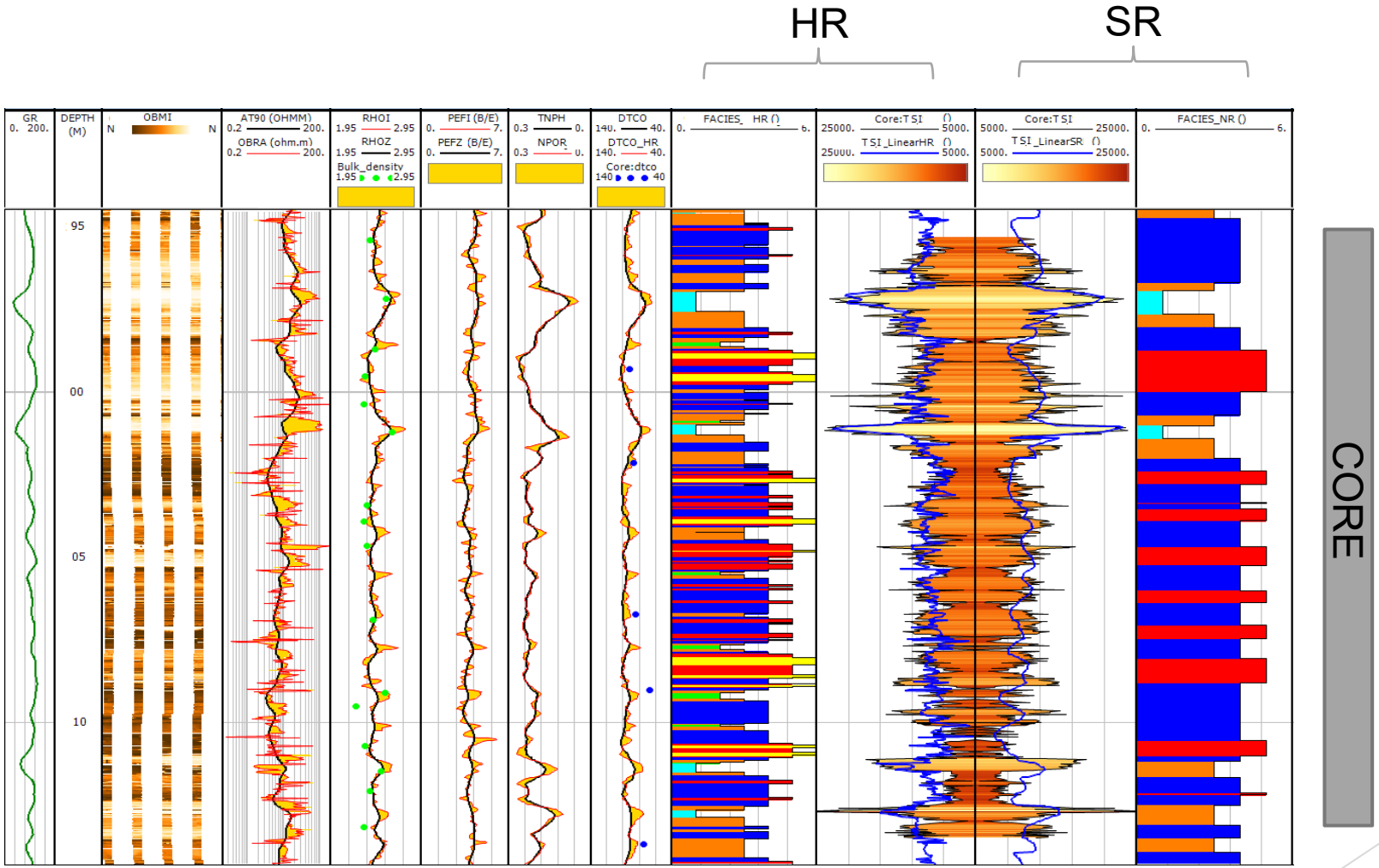
- Introduction
- Reservoir heterogeneity
- Mineralogy
- Maturity (solid & liquid)
- Water saturation
- Pore system characterization
- Data analytics
- Summary

Reservoir heterogeneity



from Sagasti et al., 2014

Standard vs High resolution synthetic TSI



From Sagasti et al., 2014

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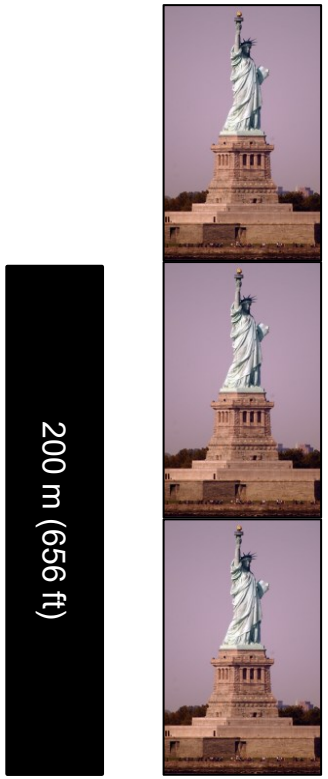
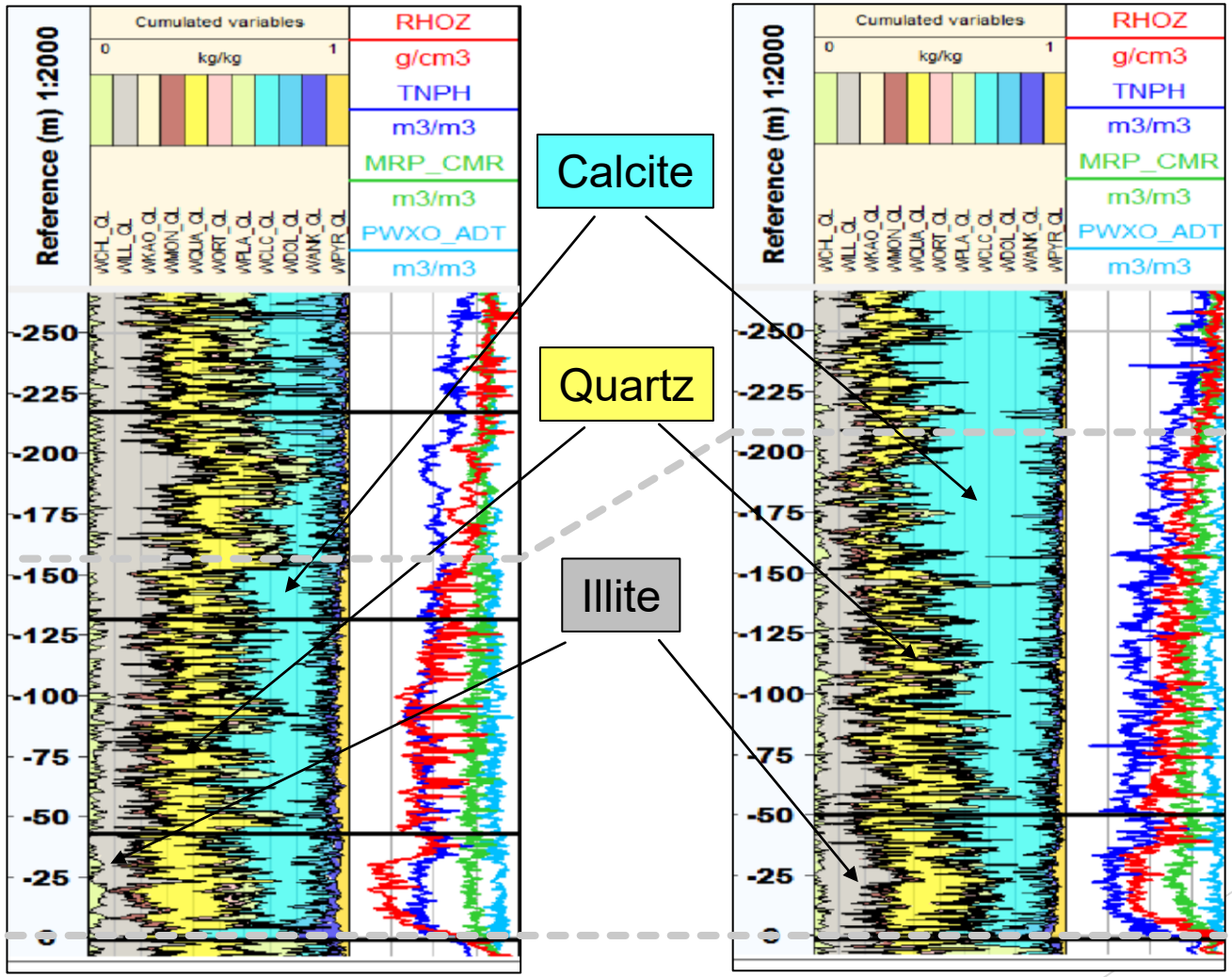
Mineralogy





Modified from Mossé et al., 2017

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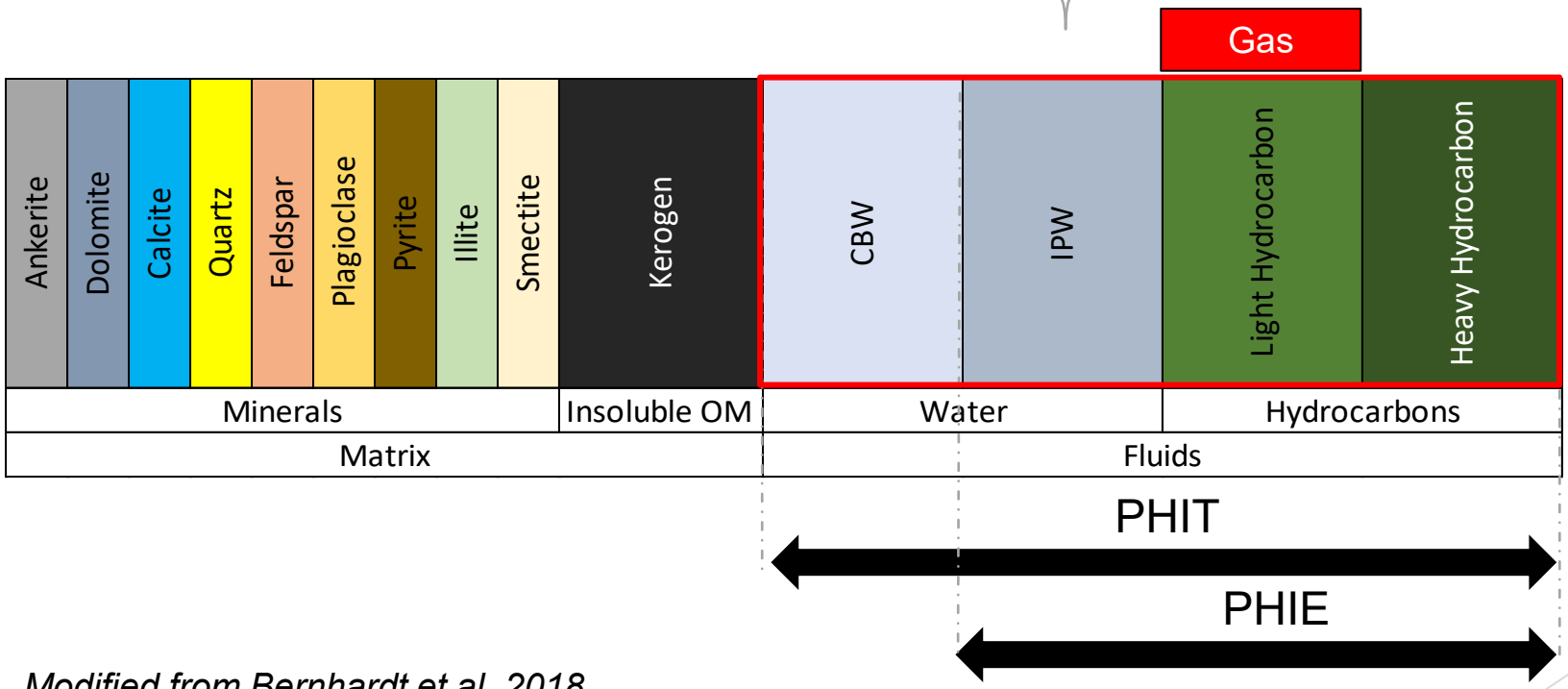
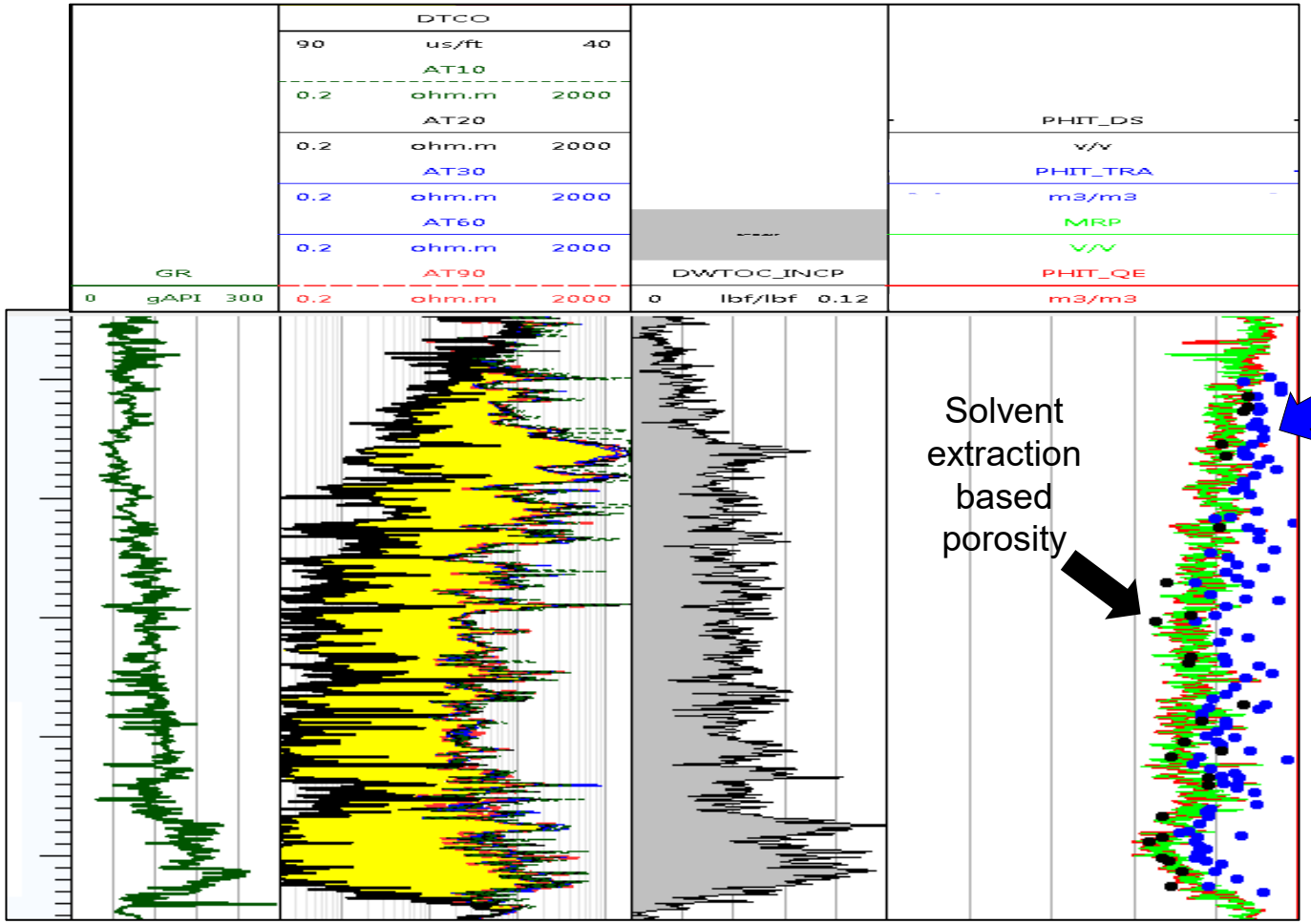
Petrophysical model

Measurement	Logs	Core
NMR Standard T2	x	x
Density / Neutron	x	
TRA (Retort based)		x
GRI (Solvent based)		x



Modified from Bernhardt et al, 2018

Porosity - Shale oil well



200 m

Retort based porosity

Solvent extraction based porosity

Porosity DA >> Porosity Retort

Modified from Ortiz et al., 2017

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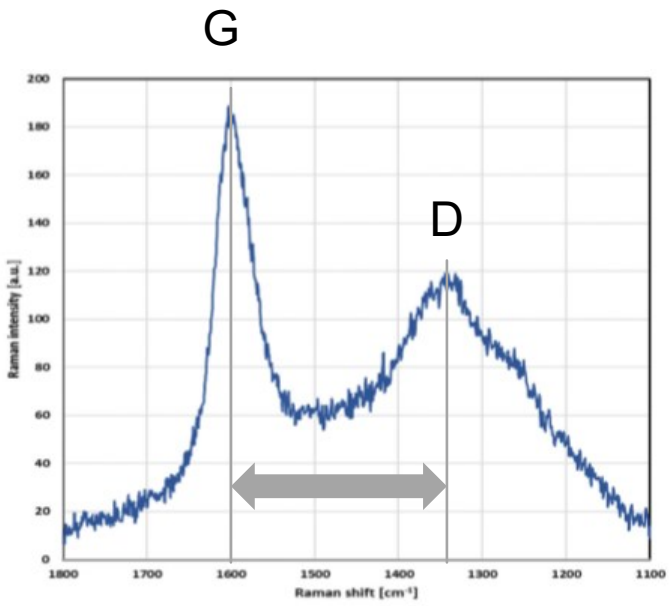
Maturity indicators

Indicator	Solid OM	Liquids
Vitrinite Reflectance	x	
Hydrogen Index	x	x
Tmax	x	
GOR		x
° API		x
Electrical Logs	x	x
C12 vs C13		x
Wetness (mud Logging)		x
Wetness (production)		x
DRIFT	x	
Raman Spectroscopy	x	

Raman Maturity



Modified from Ortiz et al., 2019

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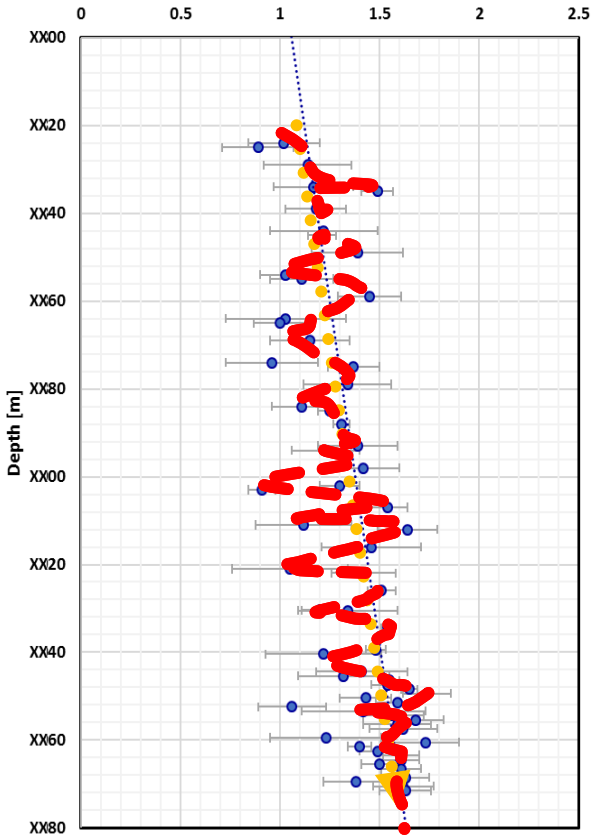
Raman Spectroscopy Based Maturity Profiling of the Vaca Muerta Formation, Neuquén Basin, Argentina

Alberto Ortiz[1], Bastian Sauerer*[2], Jean-Paul Lafournère[2], Pablo Saldungaray[2], Wael Abdallah[2]; 1. YPF S.A., 2. Schlumberger.

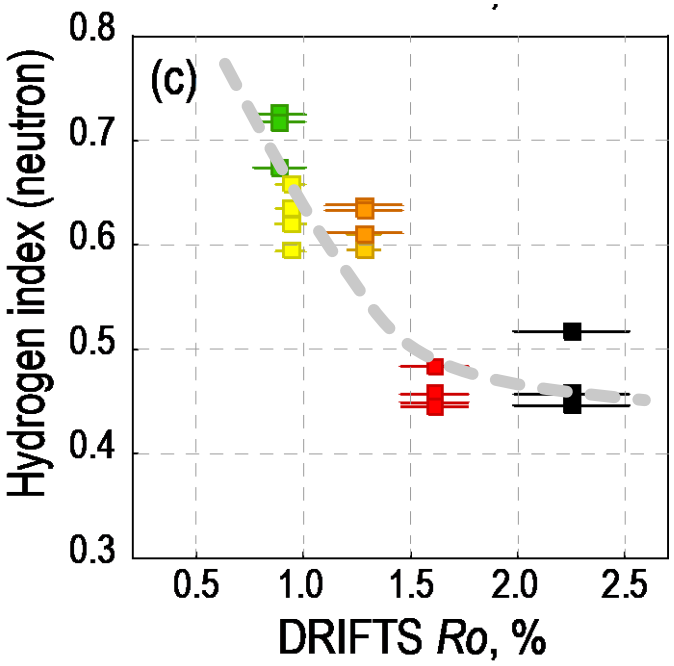
Vitrinite Reflectance Equivalent Maturity from Raman

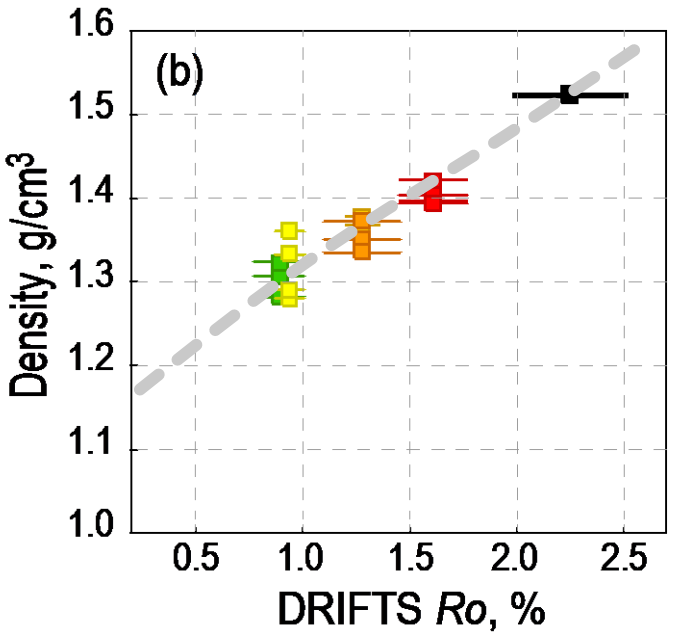
VACA MUERTA Formation



From Ortiz et al., 2019

Kerogen properties

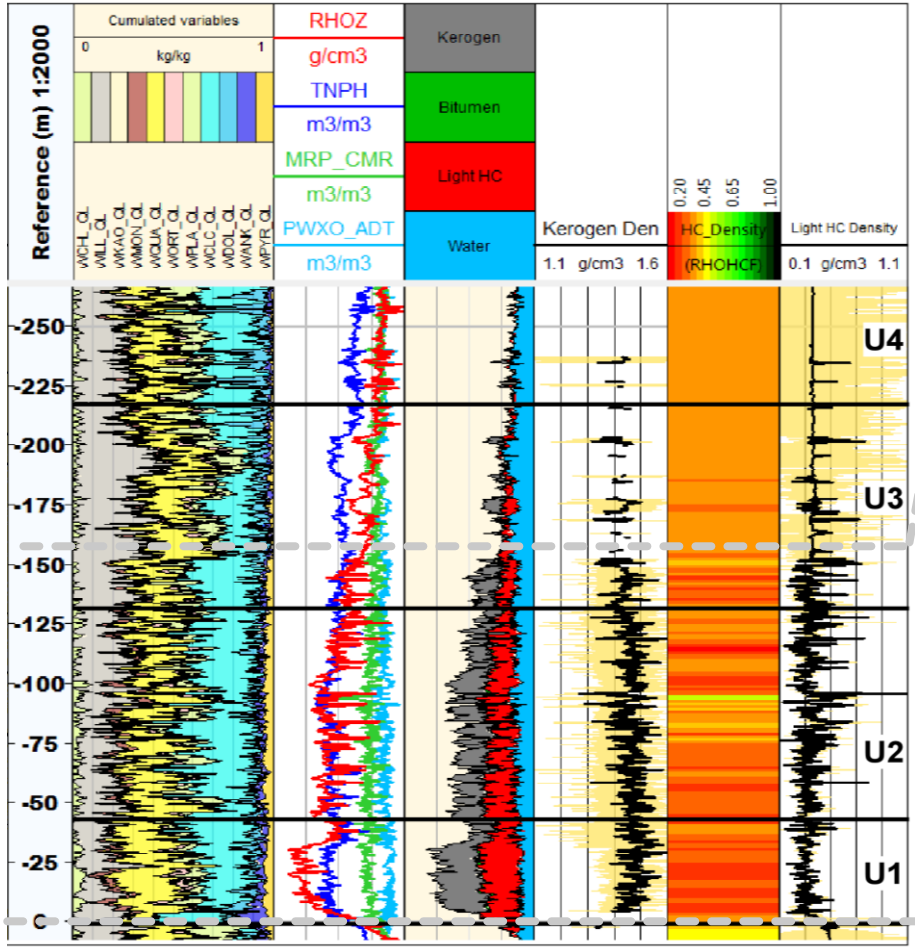




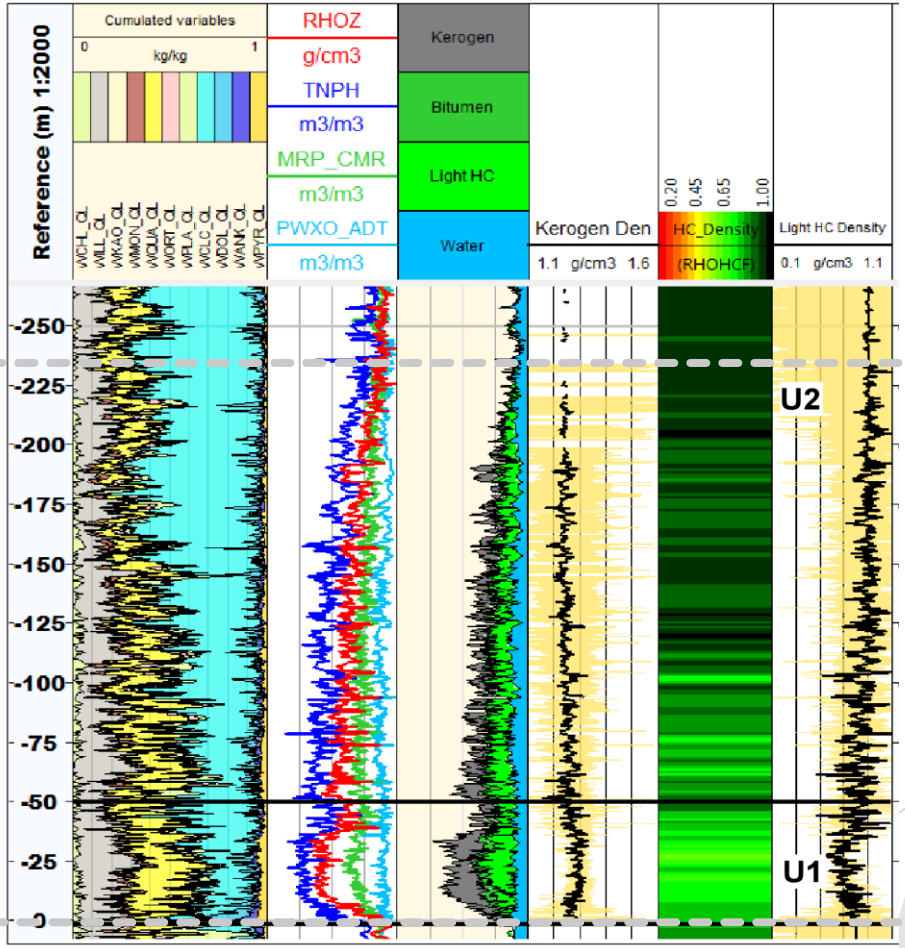
From Craddock et al., 2018

Maturity Inversion

Shale Gas well



Shale Oil well



Modified from Mossé et al,. 2016

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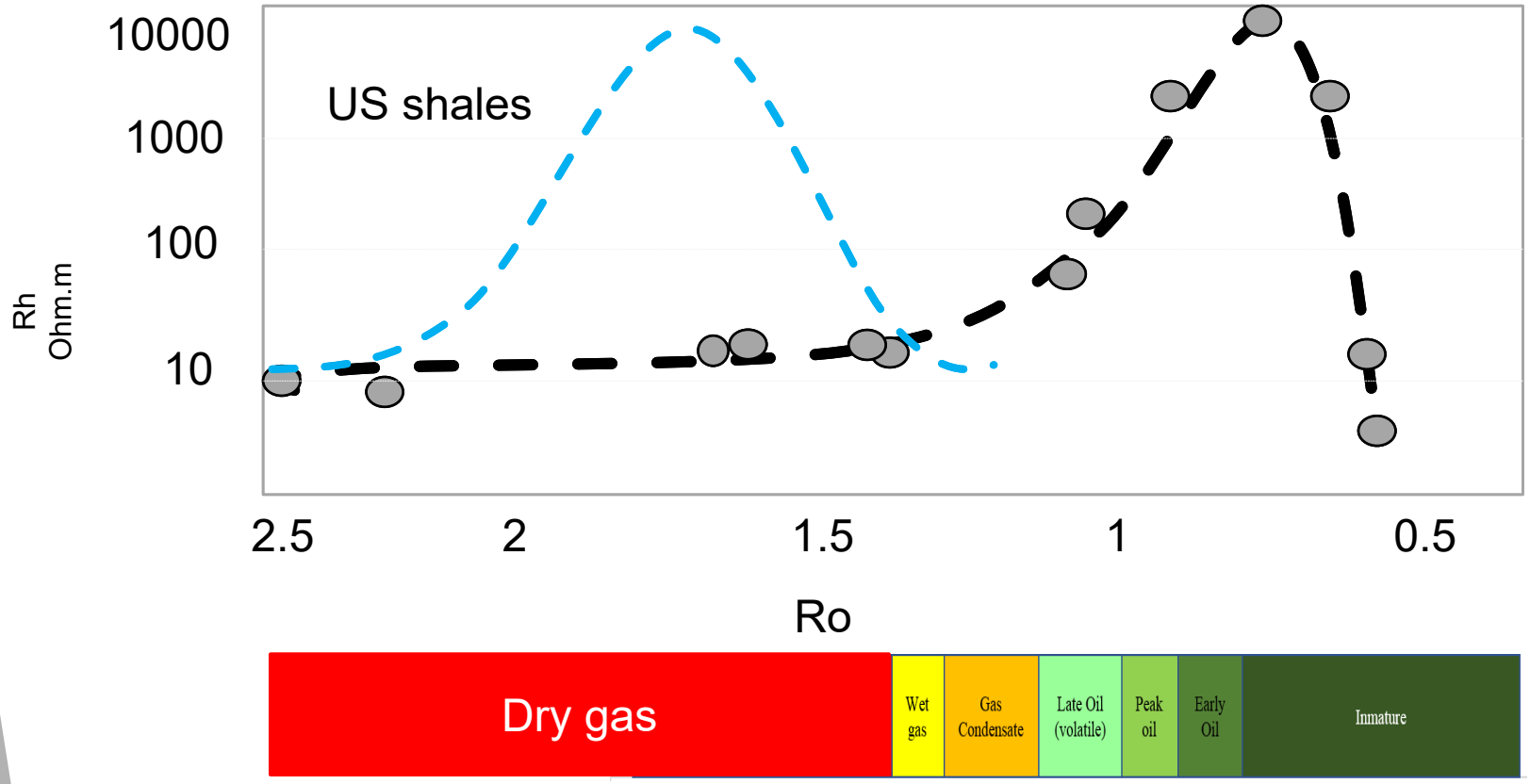
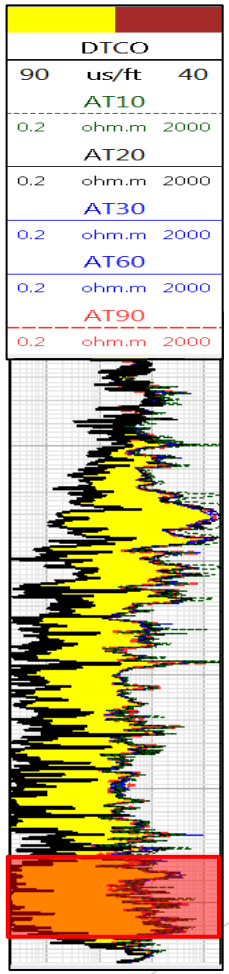
Water from logs & core

Measurement	Logs	Core	Comments
Dielectric	x		
NMR T1T2	x		
Resistivity Archie based	x		w/ caution
TRA (Tight Rock Analysis)		x	
GRI (Gas Research Institute)		x	

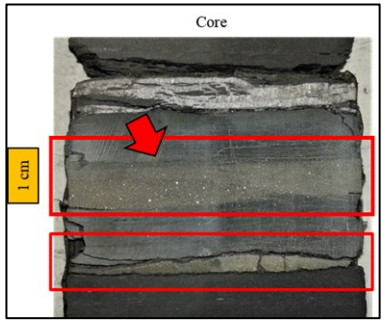
Horizontal res. in Lower VM



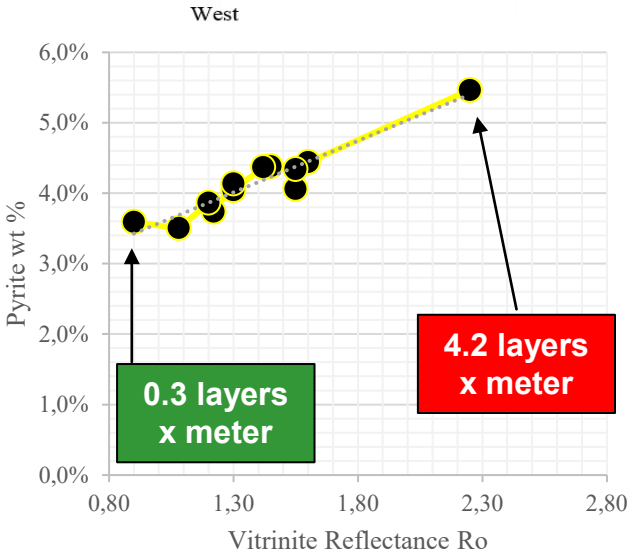
From Ortiz et al, 2018

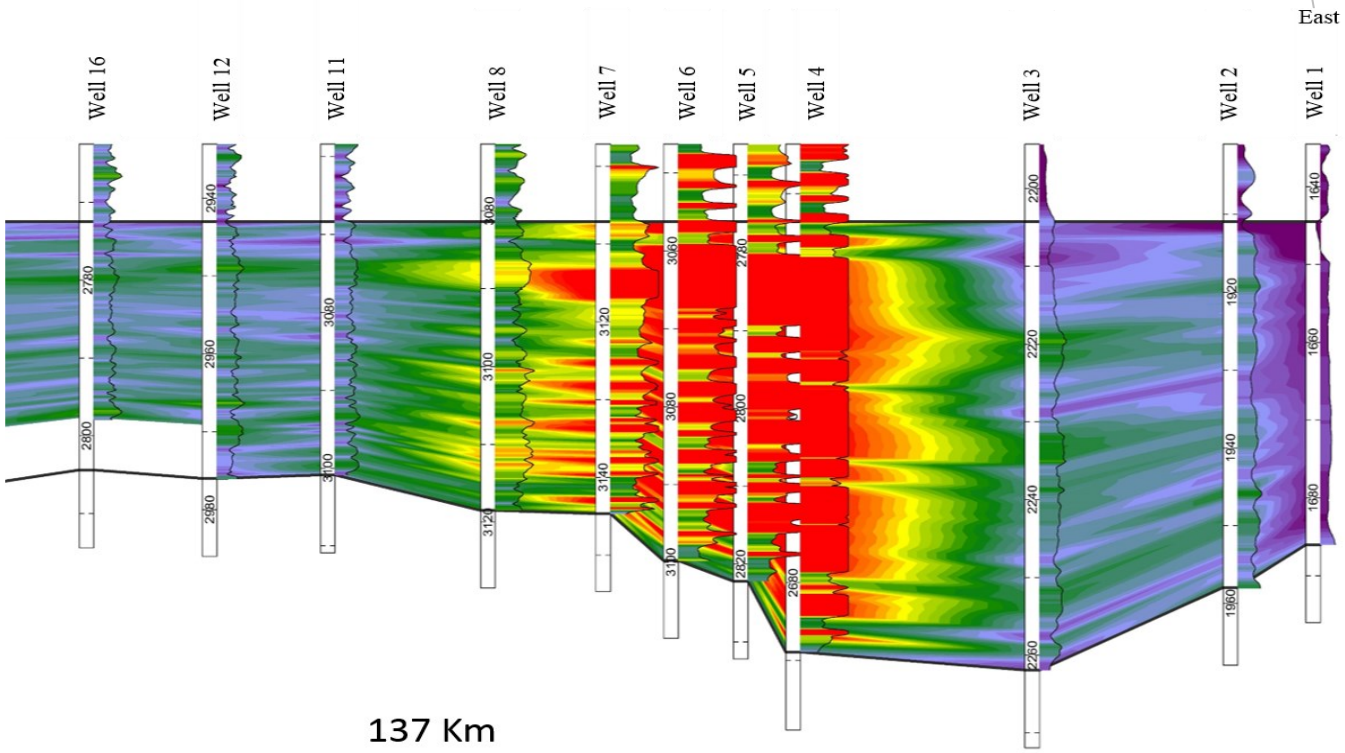


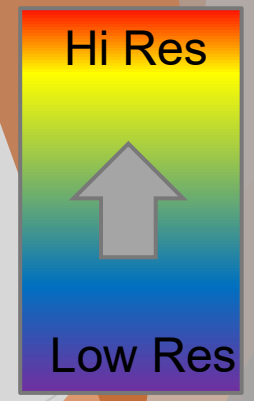
Resistivity reversal



Shale gas ← Shale oil







From Ortiz et al, 2018

RH and RV vs. Ro

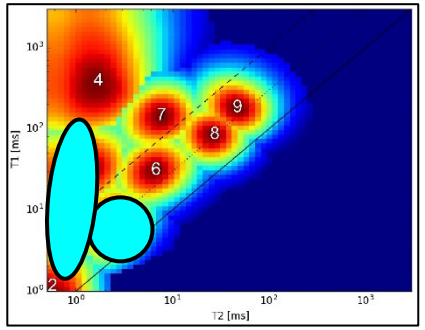
	Ro	RH	RV	RV/RH	Tool
		Ohm.m	Ohm.m	Ratio	
Well 19	2,25	8	N/A	N/A	Array induction
Well 18	1,60	17	144	9	3D induction
Well 17	1,55	20	N/A	N/A	Array induction
Well 16	1,55	19	N/A	N/A	Array induction
Well 15	1,45	18	156	9	3D induction
Well 14	1,42	13	N/A	N/A	Array induction
Well 13	1,30	10	N/A	N/A	Array induction
Well 12	1,30	20	N/A	N/A	Array induction
Well 11	1,22	18	N/A	N/A	Array induction
Well 10	1,20	51	203	4	3D induction
Well 9	1,08	75	N/A	N/A	Array induction
Well 8	0,90	71	323	5	3D induction
Well 7	0,87	214	N/A	N/A	Dual Induction
Well 6	0,70	>1000	N/A	N/A	Dual Induction
Well 5	0,50	>1000	N/A	N/A	Dual Induction
Well 4	0,37	>1000	N/A	N/A	Dual Induction
Well 3	<0,3	17	N/A	N/A	Dual Induction
Well 2	<0,3	16	N/A	N/A	Dual Induction
Well 1	<0,3	4	N/A	N/A	Dual Induction

- Clay conductivity
- Water
- ~~Laminated pyrite~~
- Ash beds
- Maturity (pore tortuosity & wettability)
- Resistivity anisotropy
- Shoulder beds effect
- Incipient graphitization

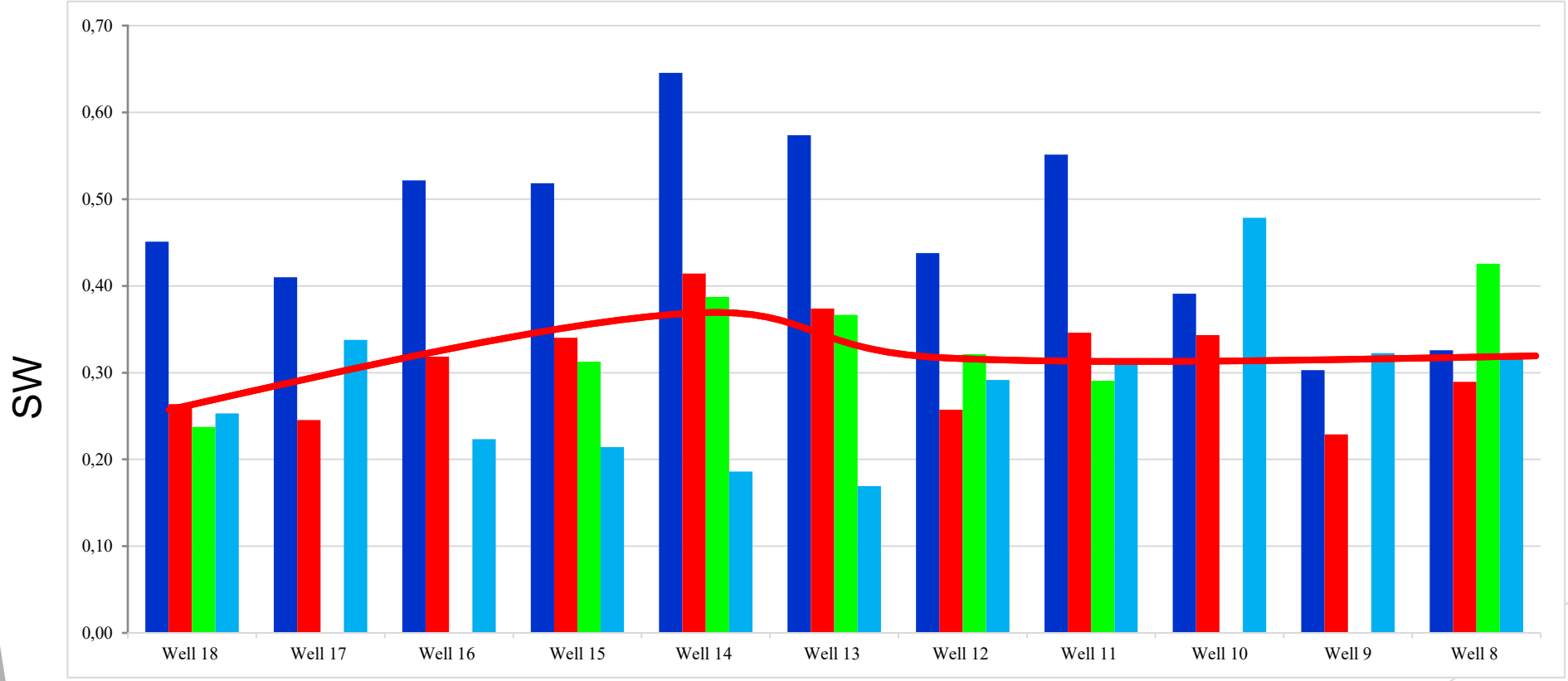
From Ortiz et al, 2018

Sw methods

Archie
Sigma
NMR
Dielectric



Shale gas ← → Shale oil



From Ortiz et al, 2018

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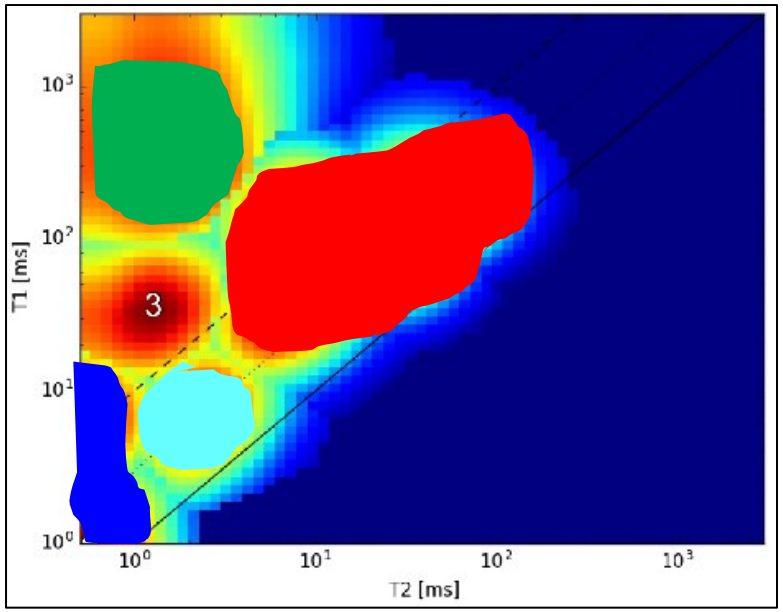
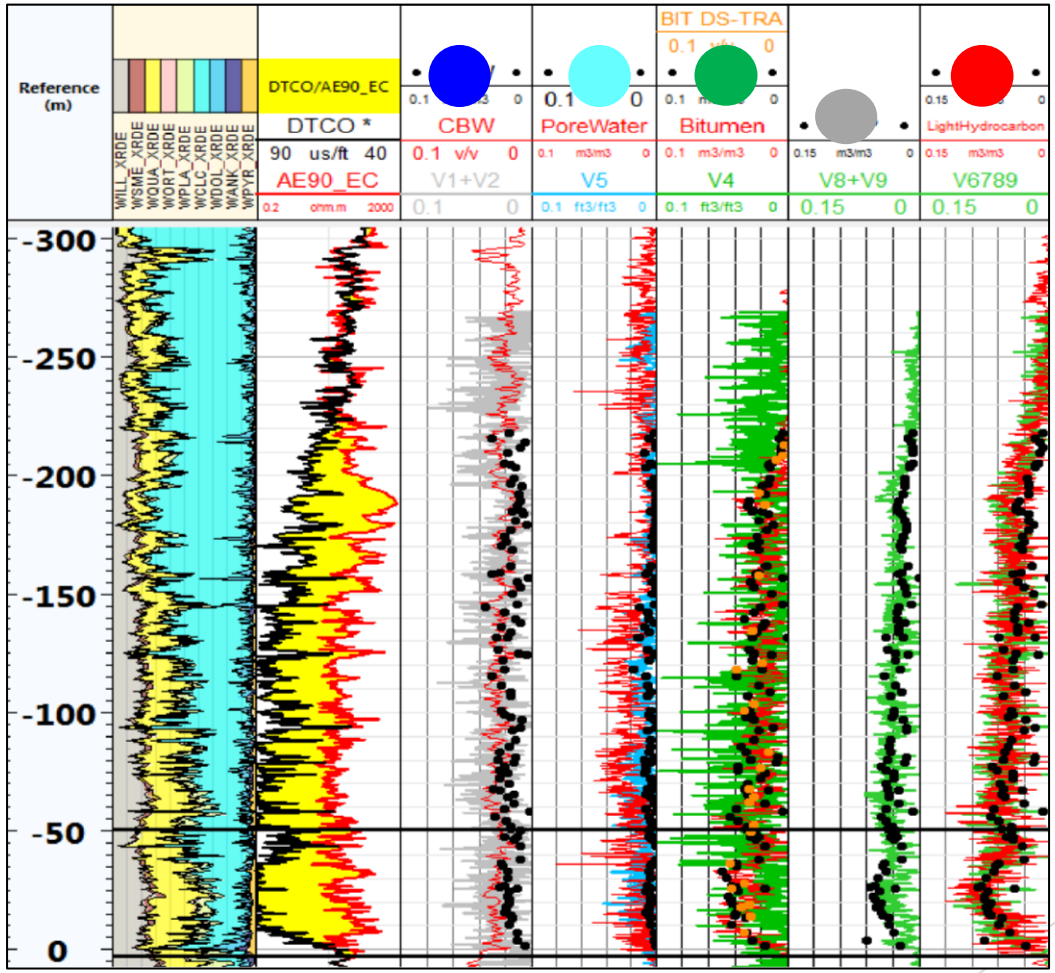
Pore system characterization

Measurement	Logs	Core
NMR T1T2	x	
SEM		x
NMR T1T2 low and high frequency		x
SGA		x

PSC shale oil well





From Ortiz et al., 2017

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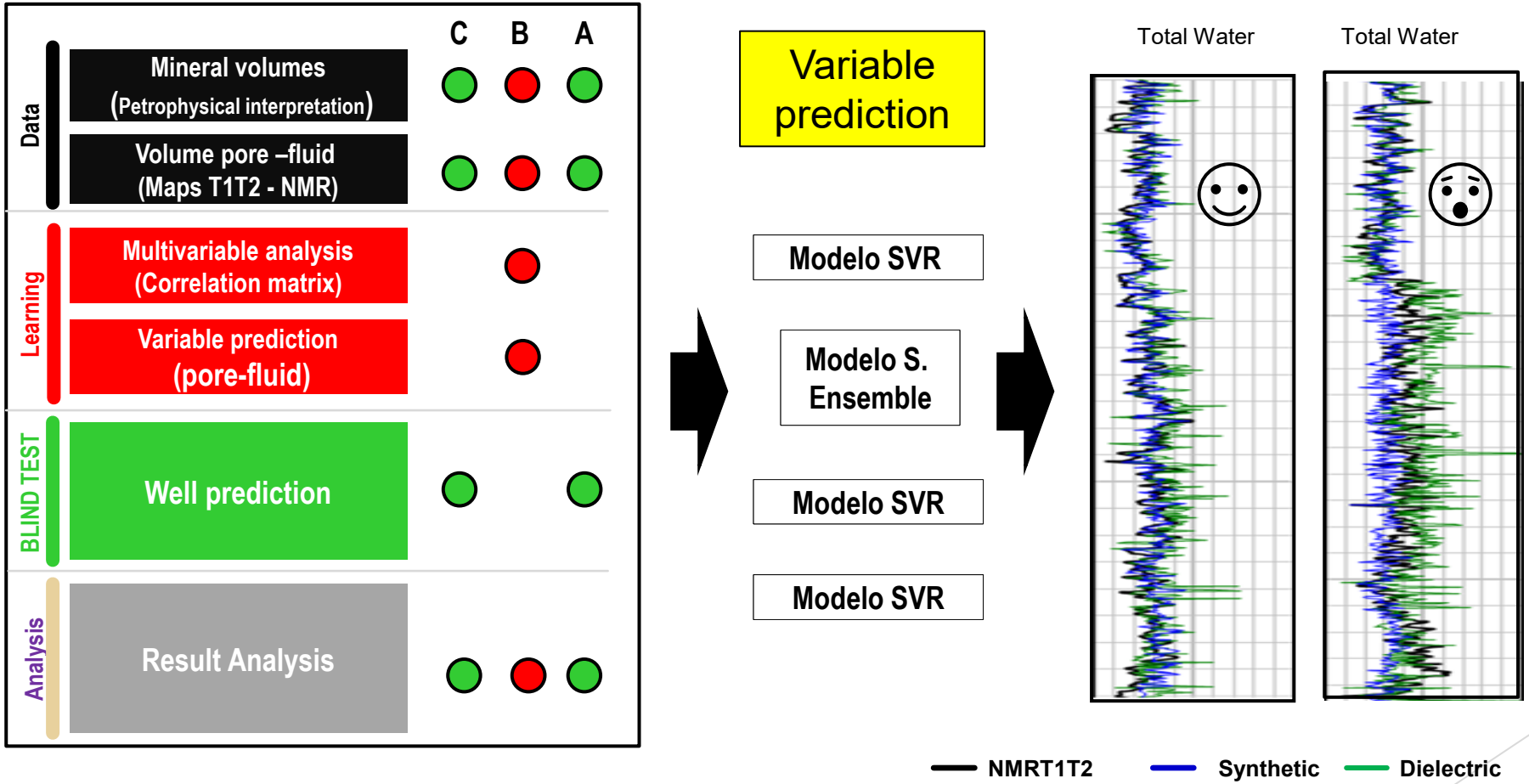
Data Analytics



Modified from Bernhardt et al 2018, CONEXPLO

Summary

- Heterogeneity at all scales must be considered when characterizing VM.
- Heavy oil components matter when calibrating core to log for porosity and oil in place estimation.
- Resistivity free methods such us dielectric or T1-T2 NMR are preferred for SW calculation.
- PSC matters but must be done with appropriate upscaling.
- Data Analytics could be a powerful tool to understand rock-fluid anomalies.

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- Luisa Crousse
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