RESERVOIR CHARACTERIZATION PROJECT

Rock Physics Modeling of Tight Gas Sands
Lajas – Neuquén Basin

Atilas Silva
Master's Student

COLORADO SCHOOL OF MINES

Topics

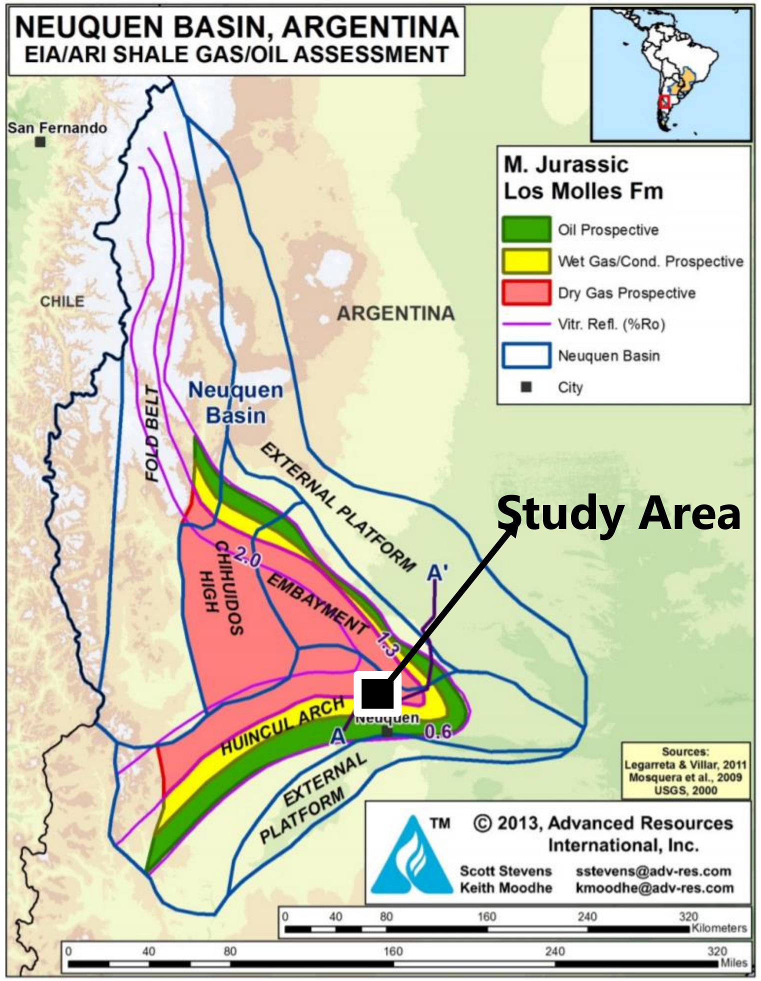
- Objectives
- Location and geologic setting
- Data available
- Rock physics modeling
- Conclusions and future work

Research Objectives

- Develop a rock physics model that can best represent the seismic response of the tight sand of the study area
- Construct rock physics templates aiming to quantitatively predict the seismic response as a function of key rock properties (porosity, pore aspect ratio, gas saturation, fracture density, pore pressure, etc.)
- Identify sweet spots in the seismic inversion data

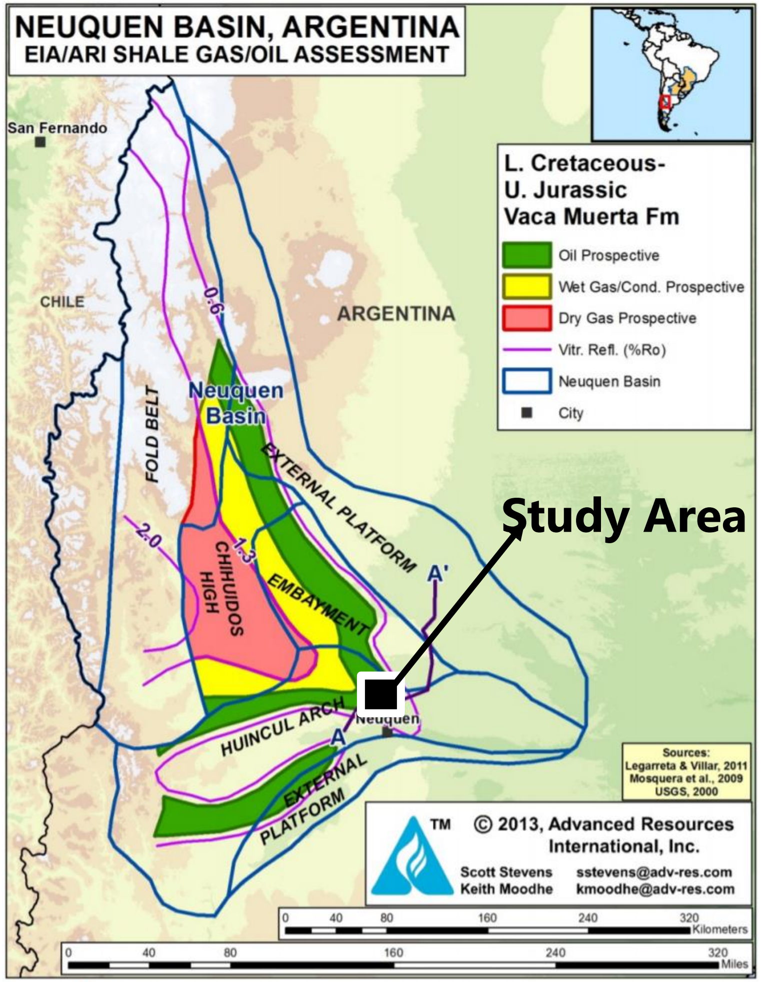
Thermal Maturity Map

Los Molles

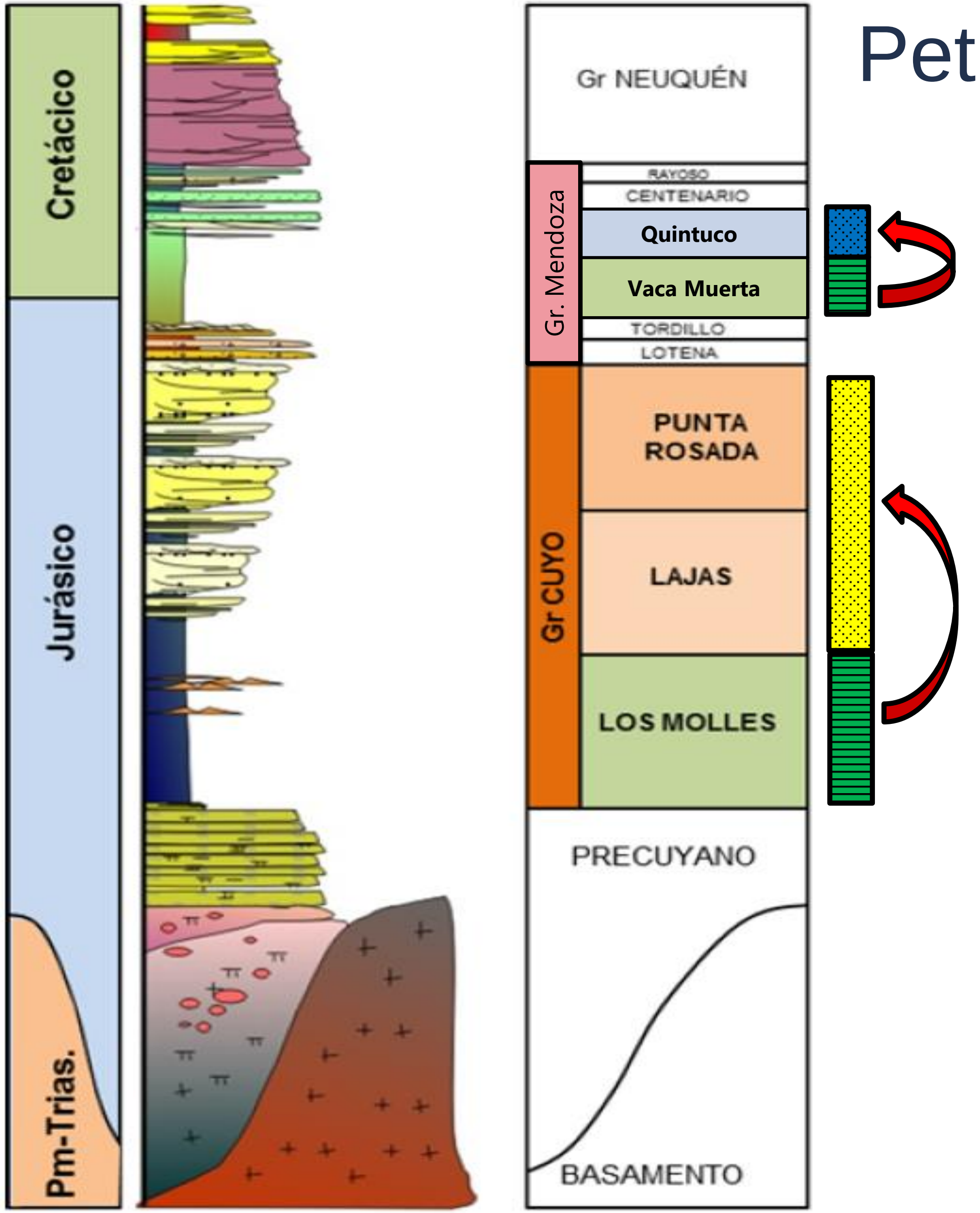


Source: ARI, 2013.

Vaca Muerta



Source: ARI, 2013.



Modified from Lucia Lamberghini et al. 2017.

Petroleum Systems in the area

RCP
In pursuit of new ideas

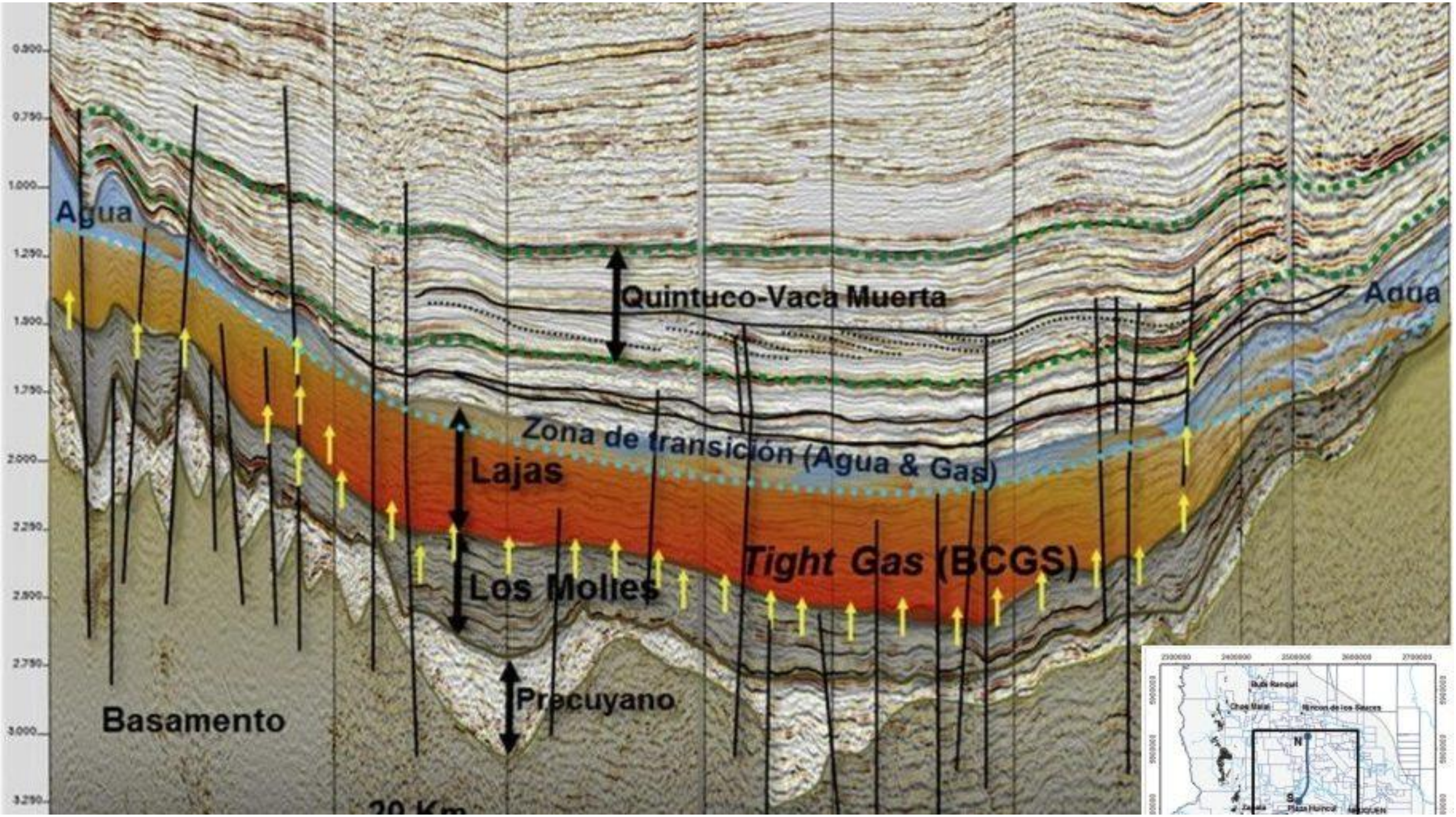
Conventional

- Carbonates from the Quintuco Formation
- **Vaca Muerta** Source Rock

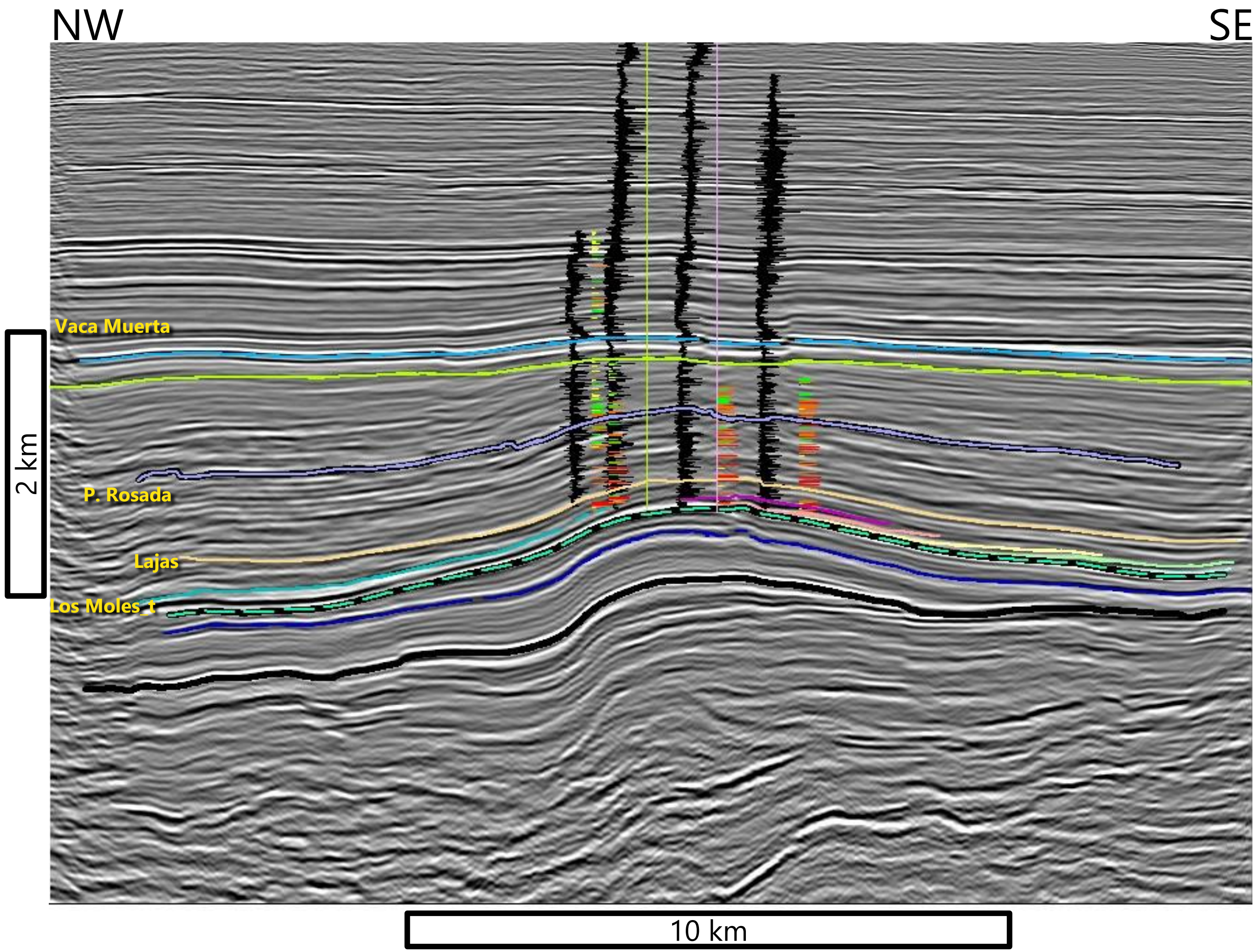
Unconventional

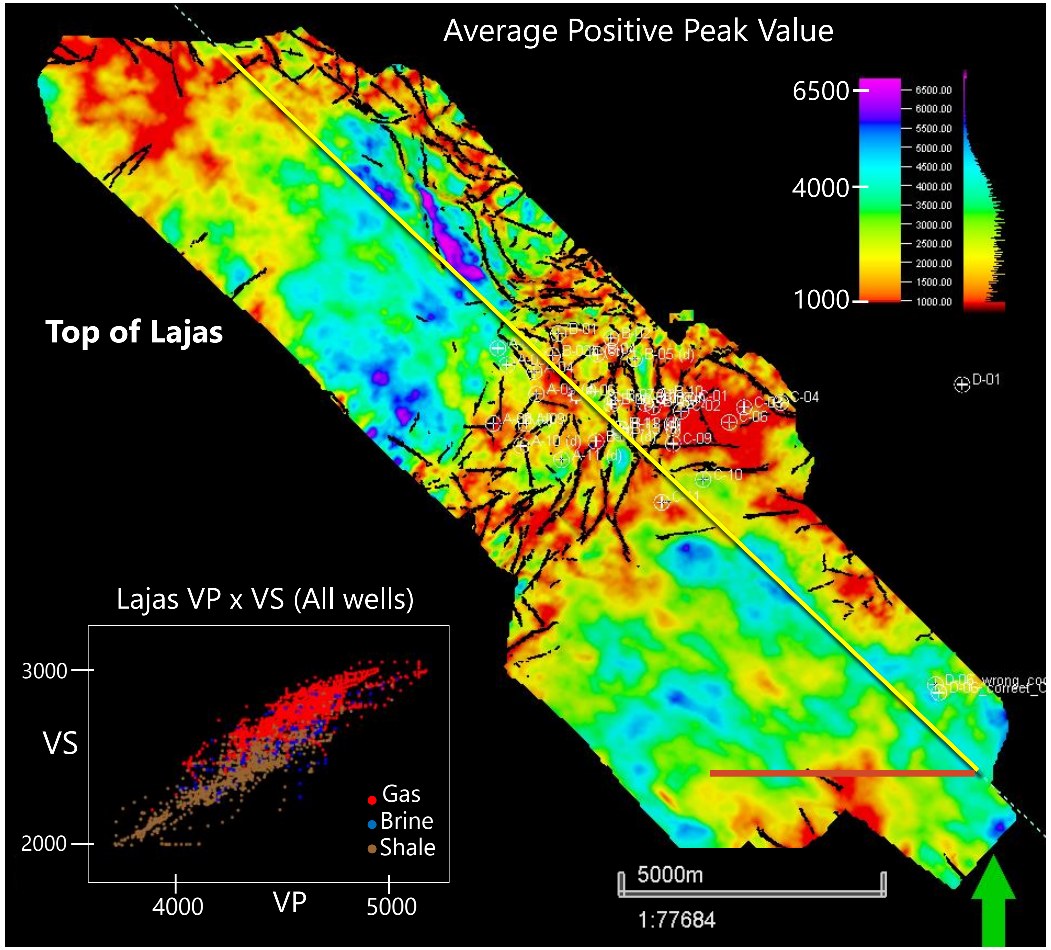
- Tight Sands
- **Lajas e Punta Rosada**
- Ranging from 900 to 1500m of thickness
- Porosity: 4 to 10%
- Permeability: < 0.1 mD
- **Los Molles** Source Rock

Overpressurized tight sands

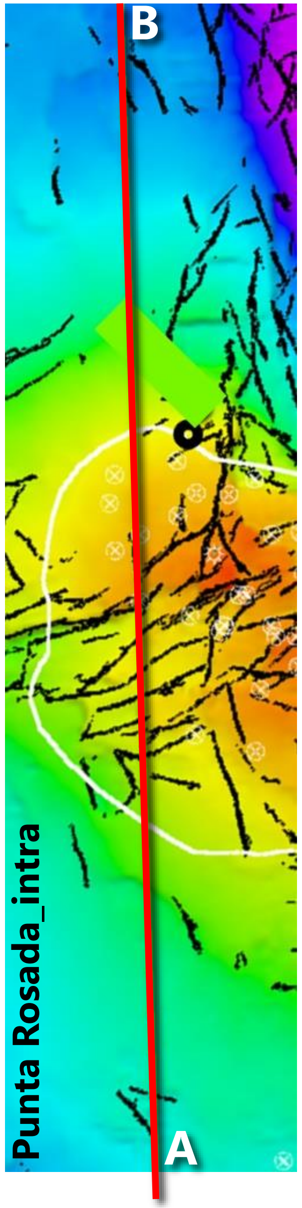


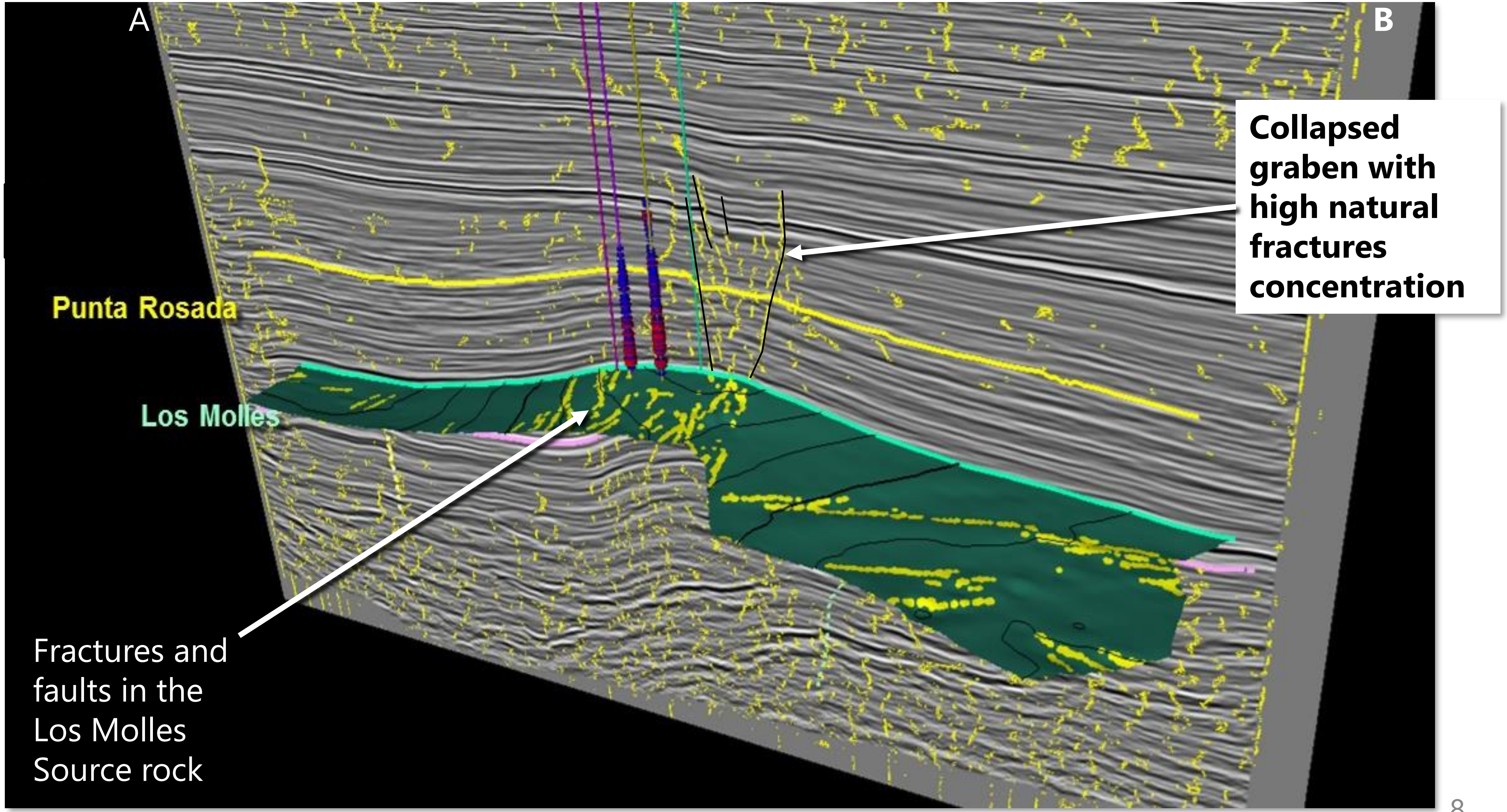
Martin, 2019 (allaboutshale.com)


NW
SE
Vaca Muerta
P. Rosada
Lajas
Los Moles_t
2 km
10 km


Average Positive Peak Value
Top of Lajas
6500
4000
1000
Lajas VP x VS (All wells)
3000
2000
VS
4000
VP
5000
Gas
Brine
Shale
5000m
1:77684

Natural Fracture Network



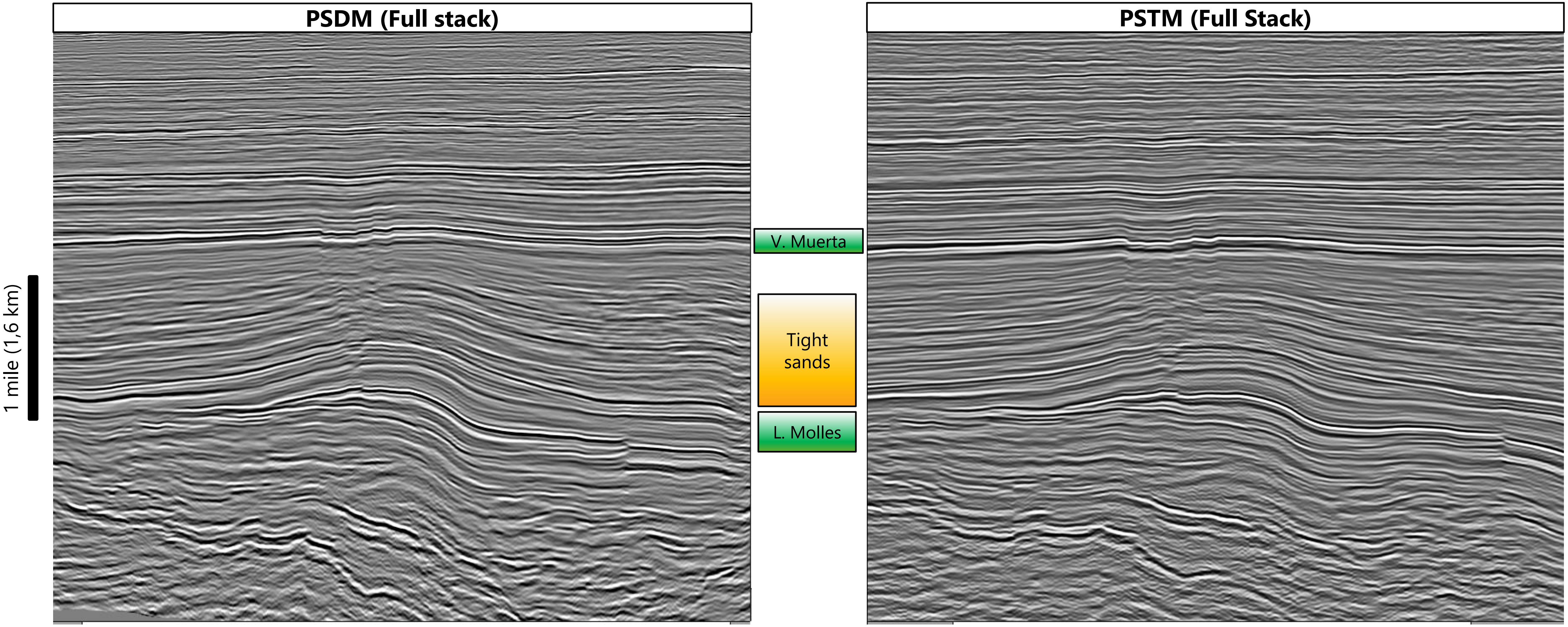


Data Available

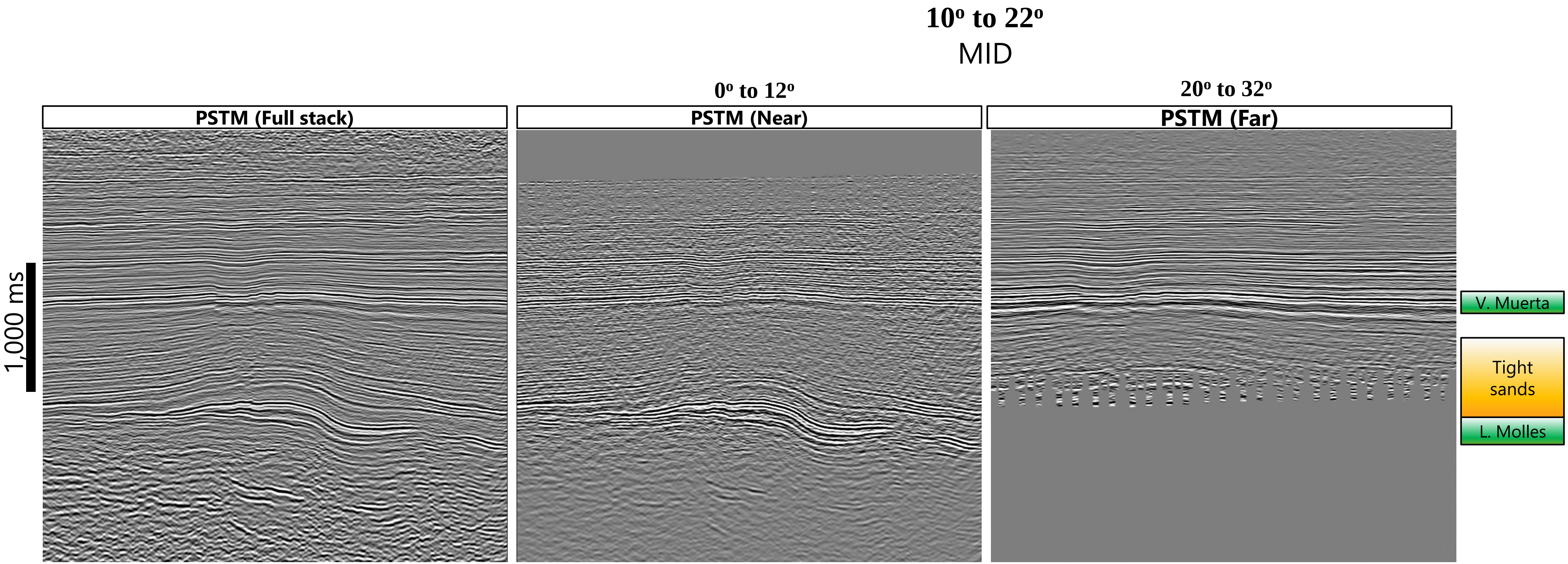
- Seismic
  - PSDM and PSTM
  - Full Stacks
  - Angle Stacks (Problem in the Far Stack)

- 29 Wells

Processed in 2015



Processed in 1998



ROCK PHYSICS MODELING

Lajas Formation

Seismic response for Sandstones

RCP
In pursuit of new ideas

- High porosity sandstone:
  - Mineral composition
  - Porosity
  - Fluid type

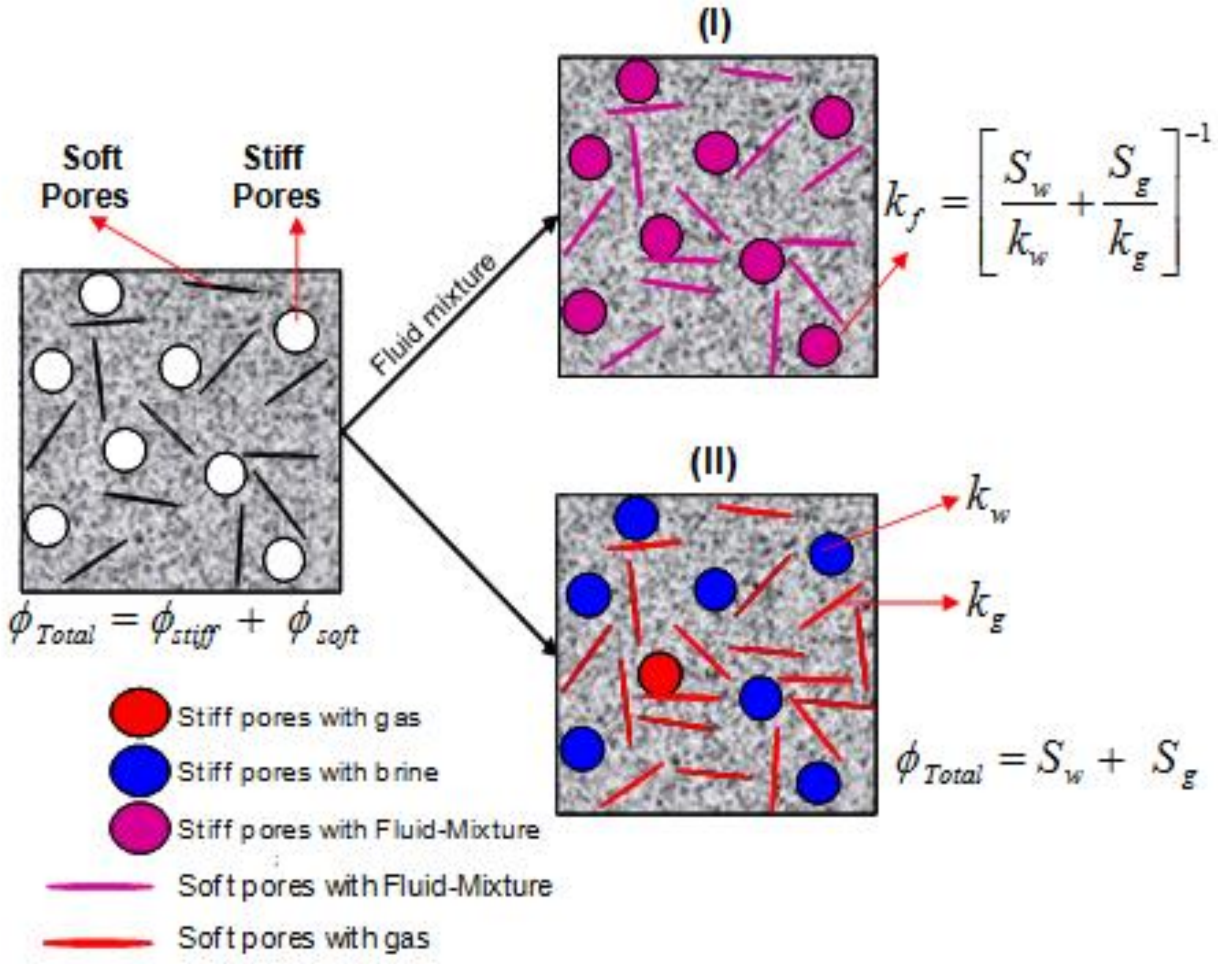
Seismic response for Sandstones

RCP
In pursuit of new ideas

- High porosity sandstone:
  - Mineral composition
  - Porosity
  - Fluid type

- Tight sandstone:
  - Most influenced by **Pore structure**.
  - An increase in velocity is mainly due to the closure of micro-cracks and compliant pores.

Inclusion-based Rock Physics Models

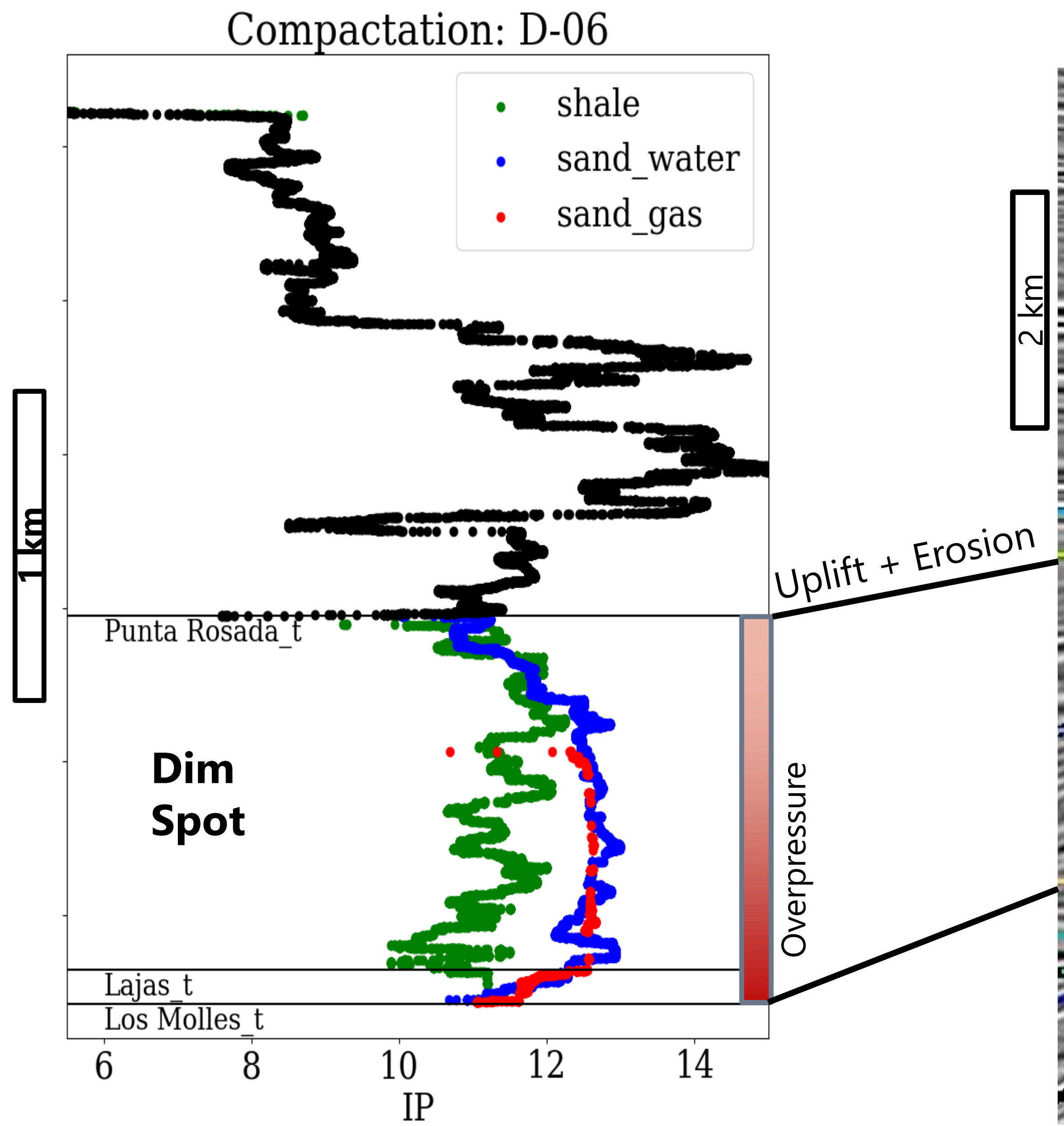


Effective medium approximations based on inclusions with different pore shapes can model the elastic moduli of low porosity rocks

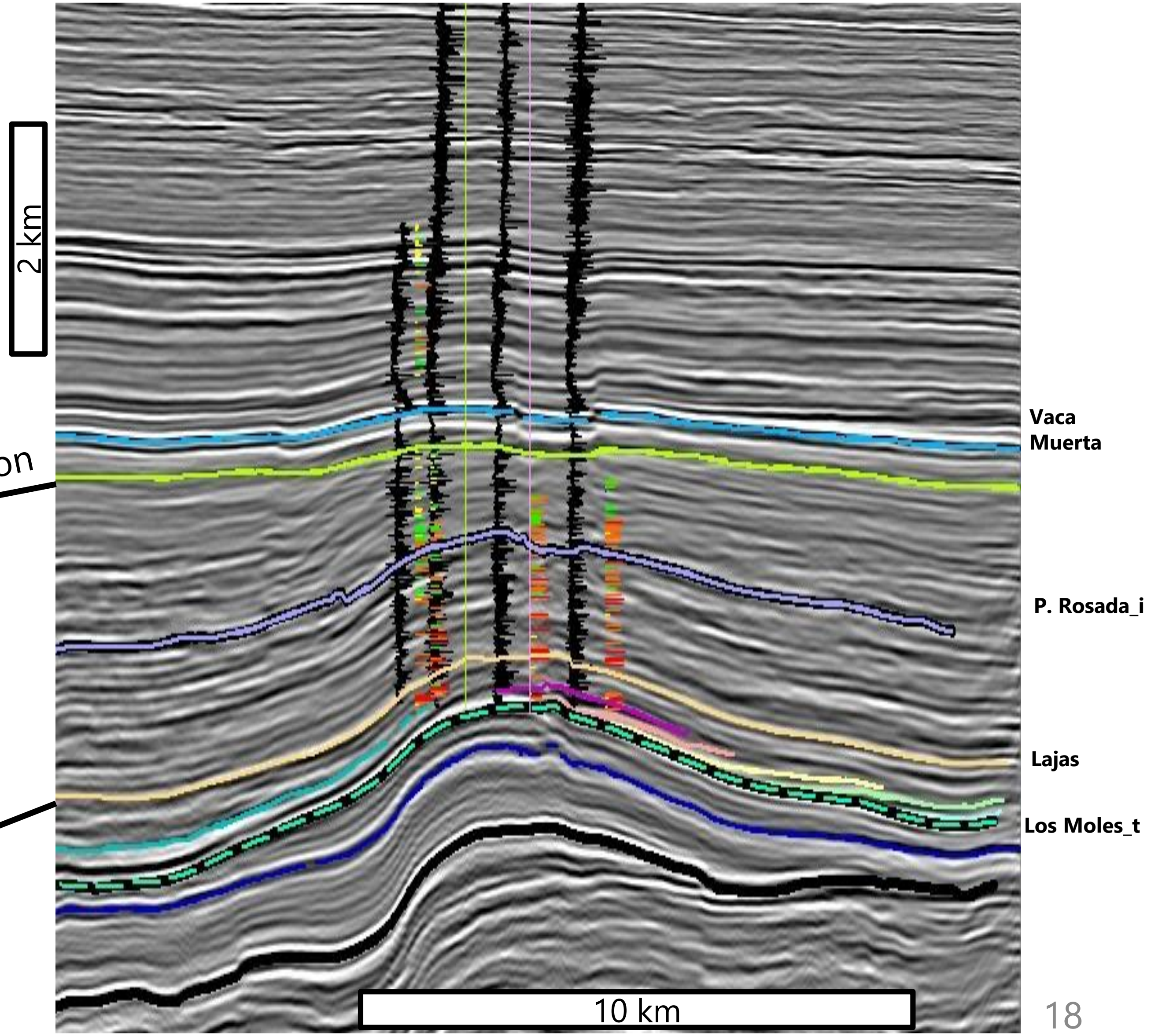
Ruiz and Cheng, 2010

Reservoir Characteristics

Compaction



Compactation: D-06
shale
sand_water
sand_gas
1 km
Punta Rosada_t
Dim Spot
Lajas_t
Los Molles_t
6
8
10
12
14
IP
Overpressure
Uplift + Erosion

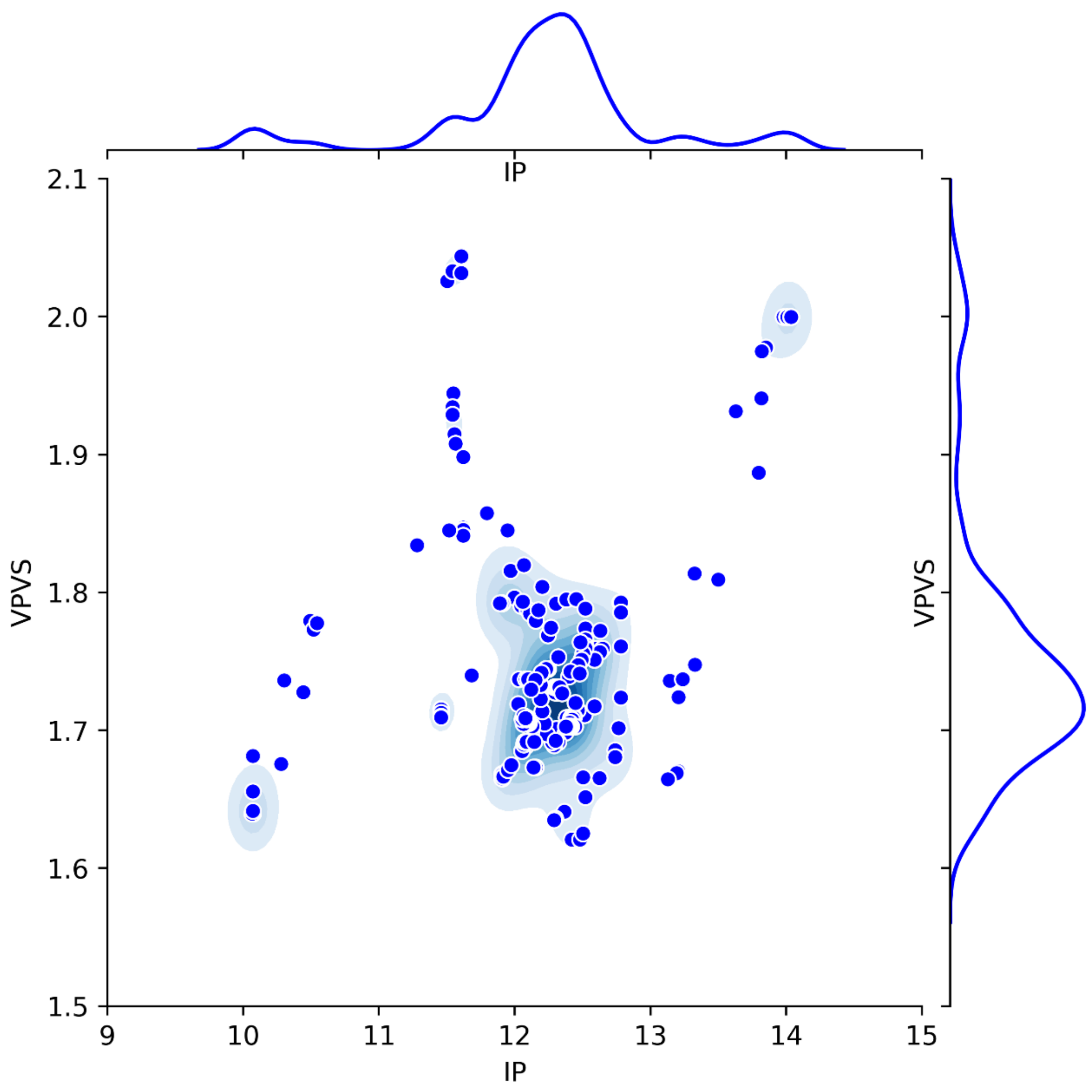


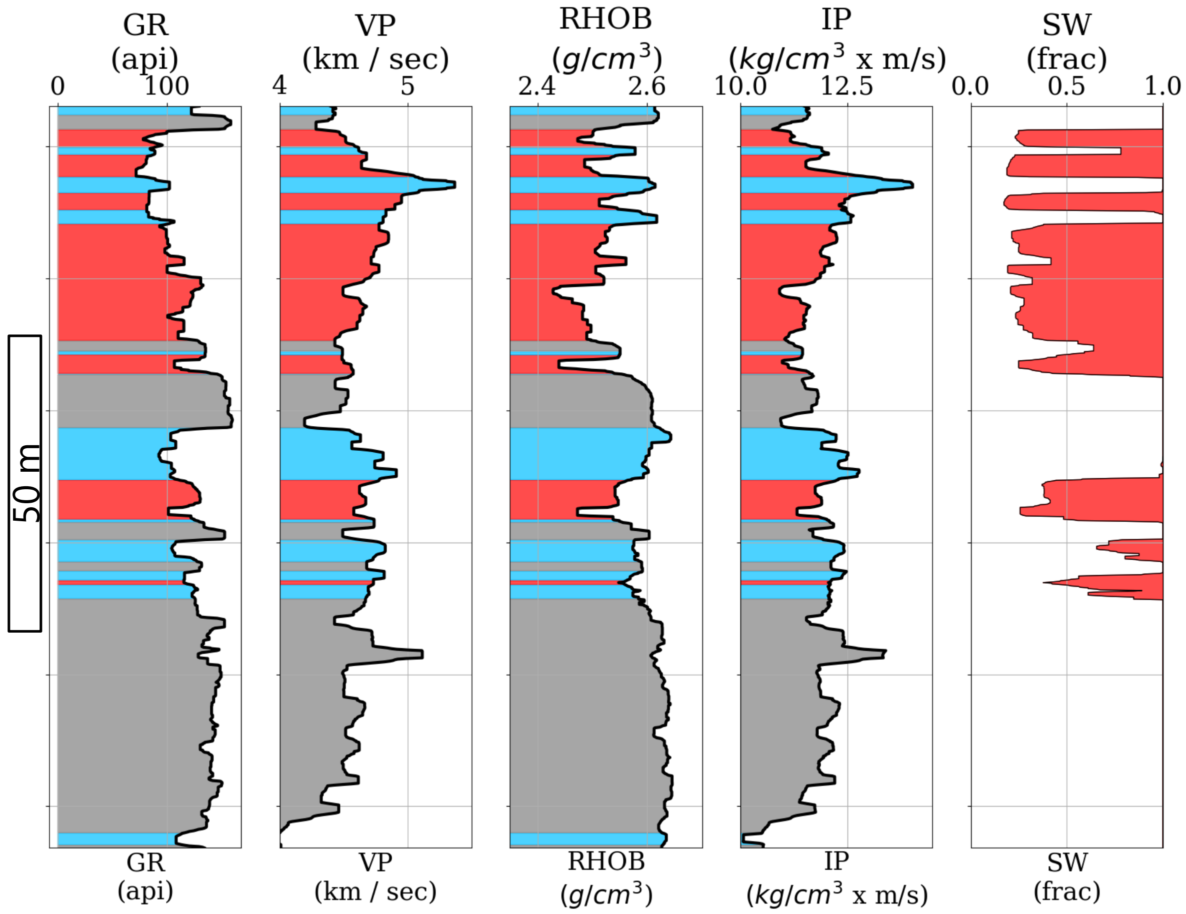
2 km
Vaca Muerta
P. Rosada_i
Lajas
Los Moles_t
10 km

Well A-10

Reservoir Cut-offs

	Gas	Brine	Shale
Clay	< 20%		> 20%
PHIe	> 4%		--
Sw	< 50%	> 50%	--





Well A-10

Reservoir Cut-offs

	Gas	Brine	Shale
Clay	< 20%		> 20%
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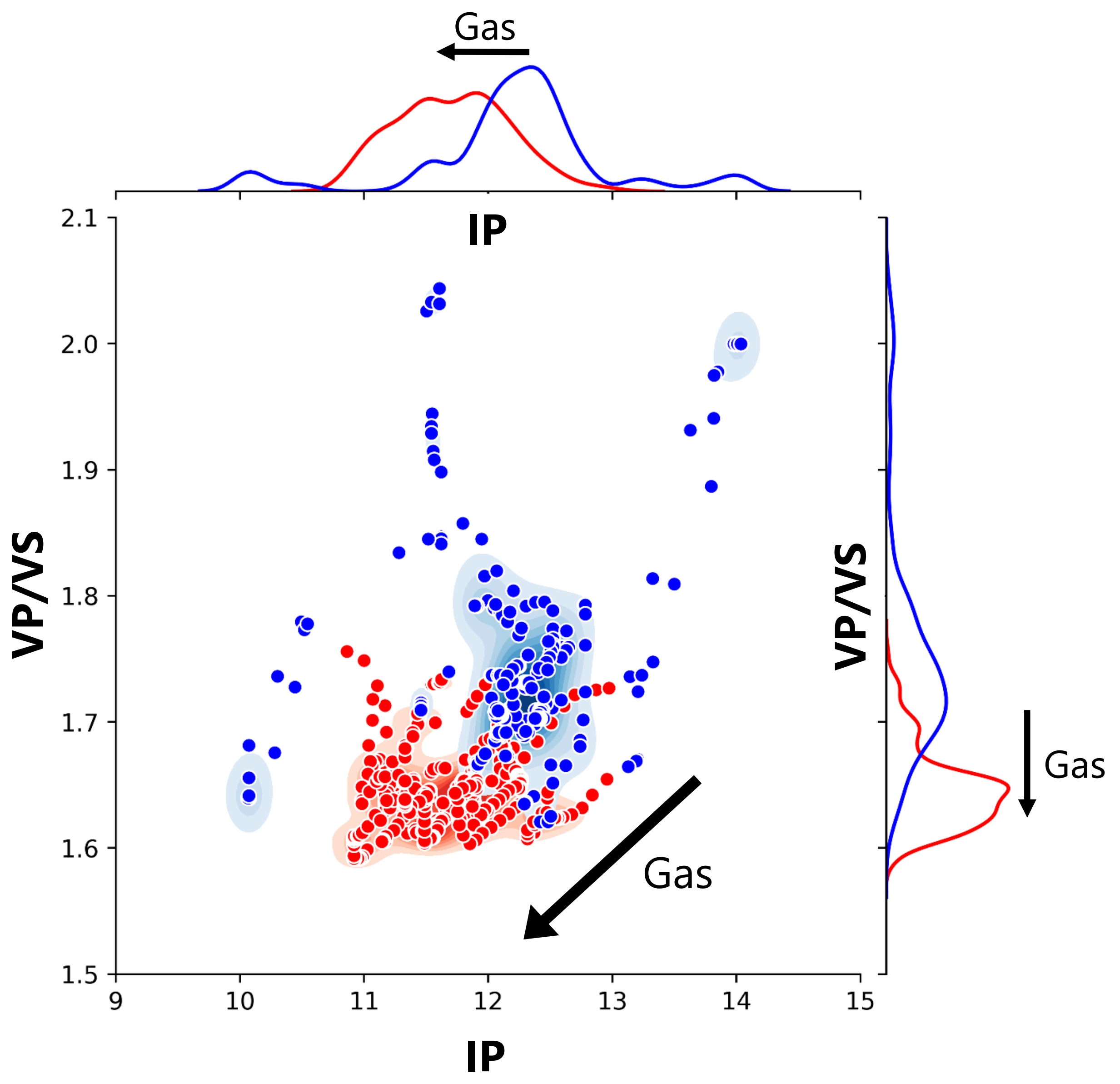

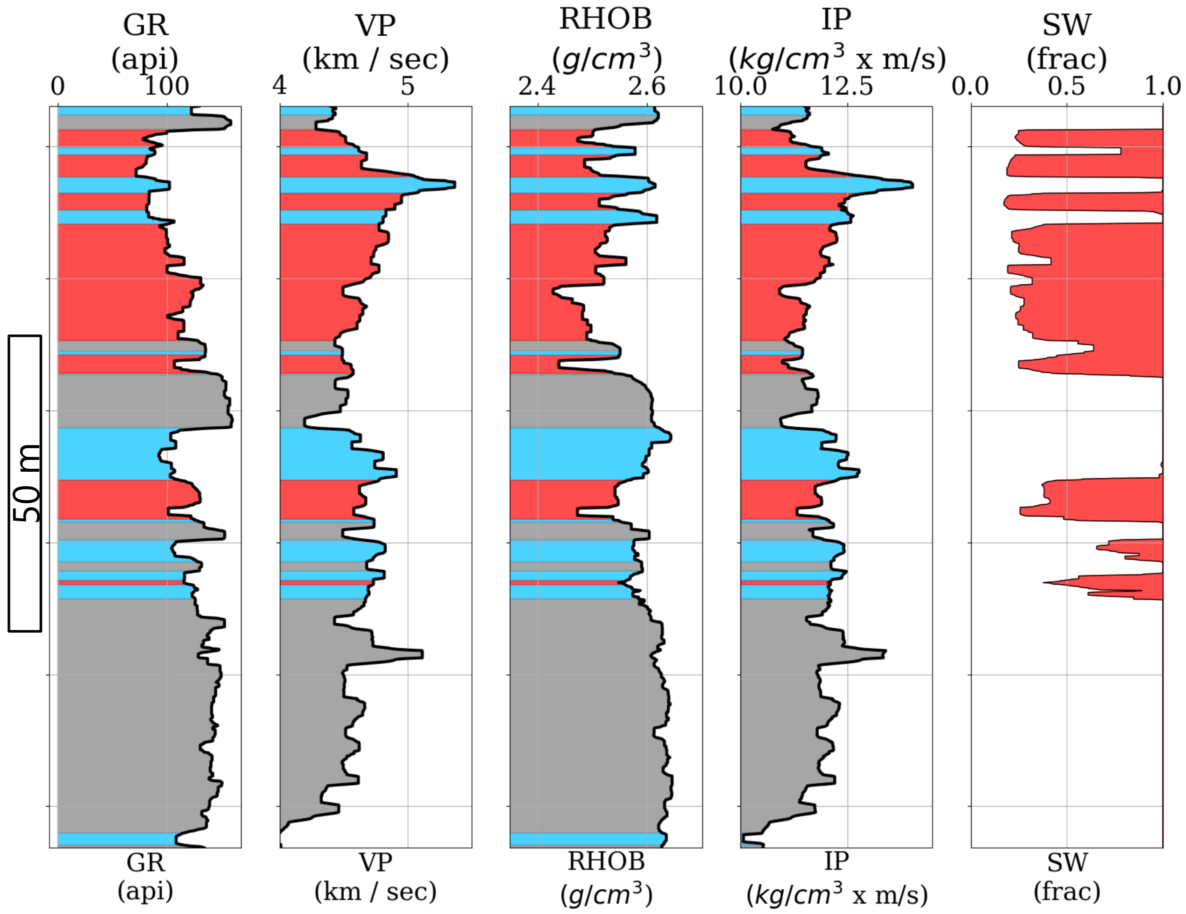

Well A-10

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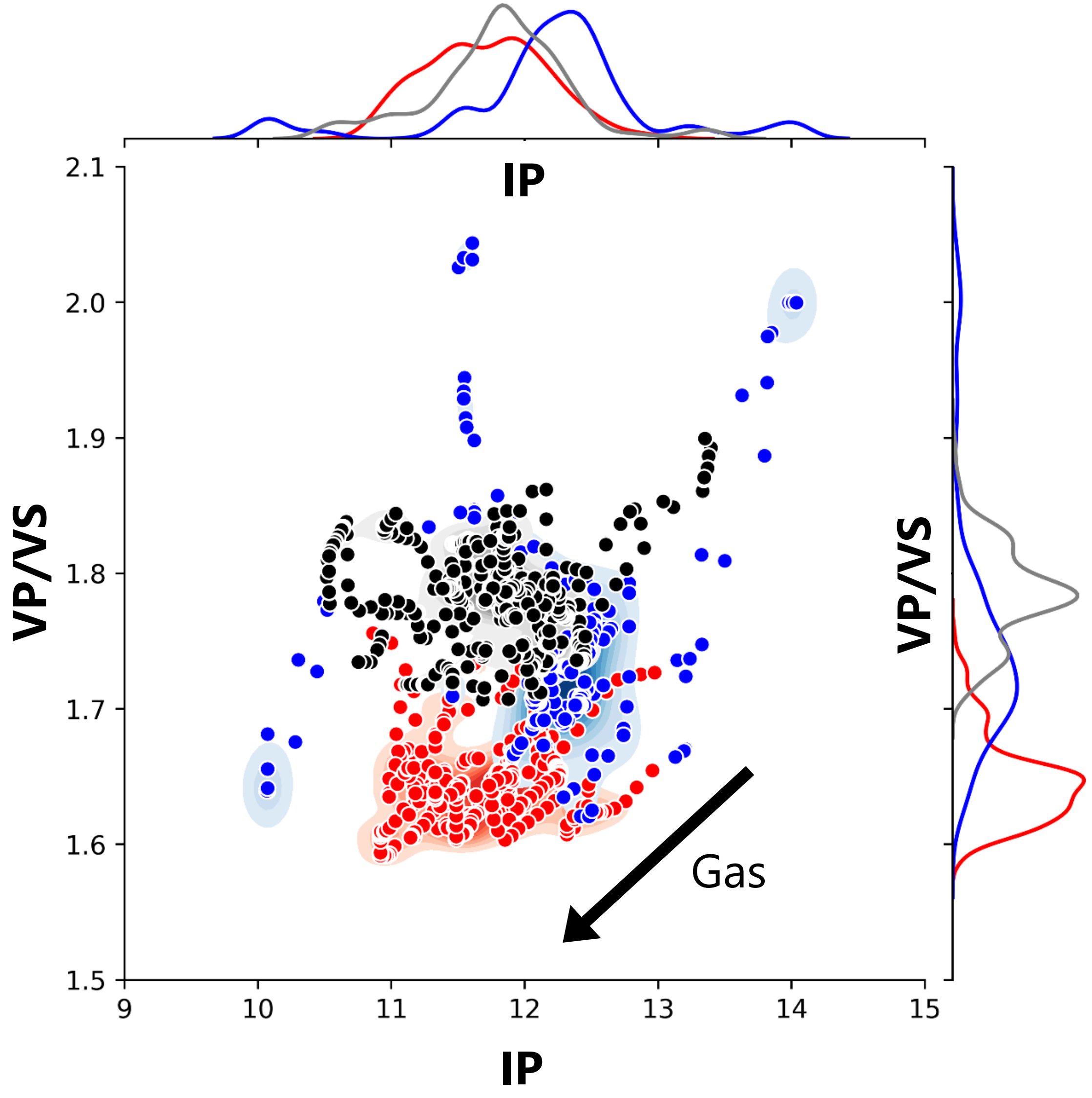
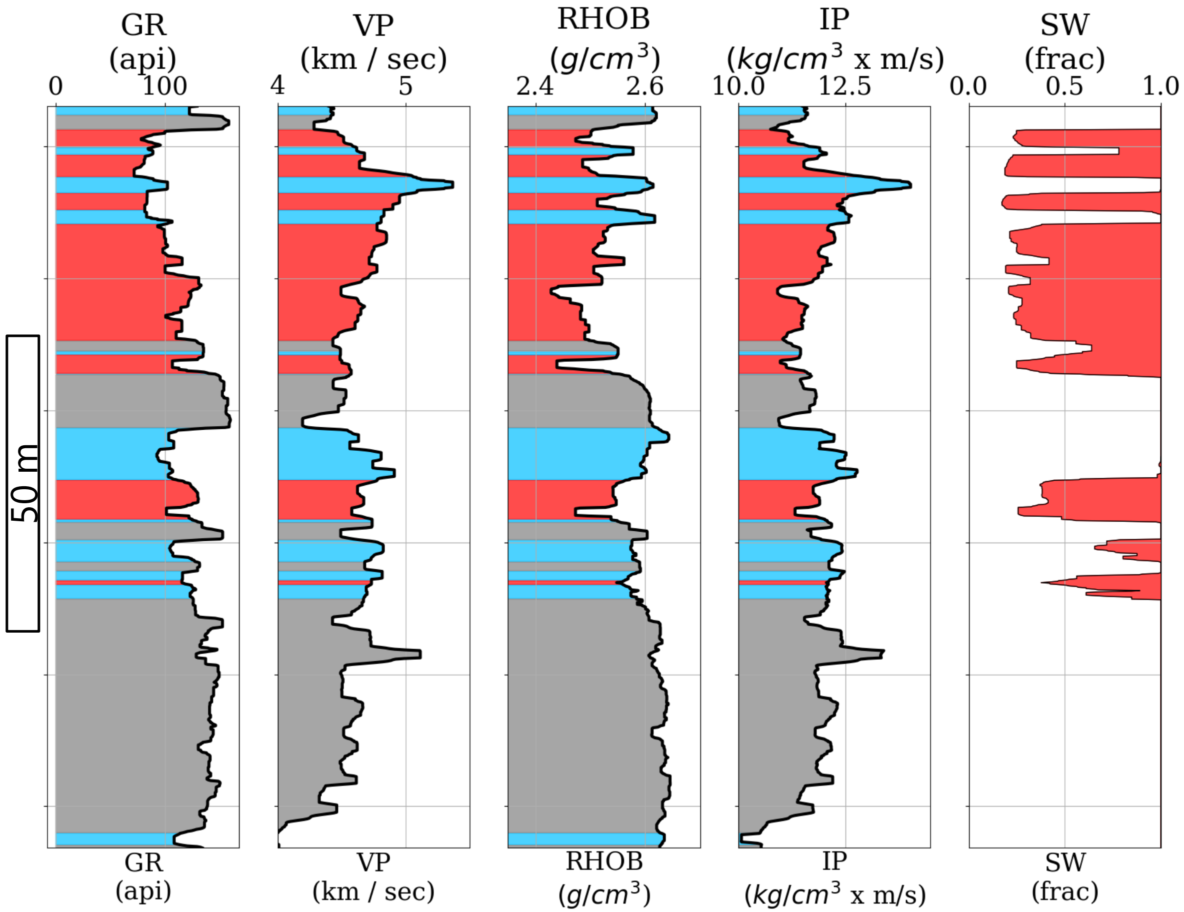


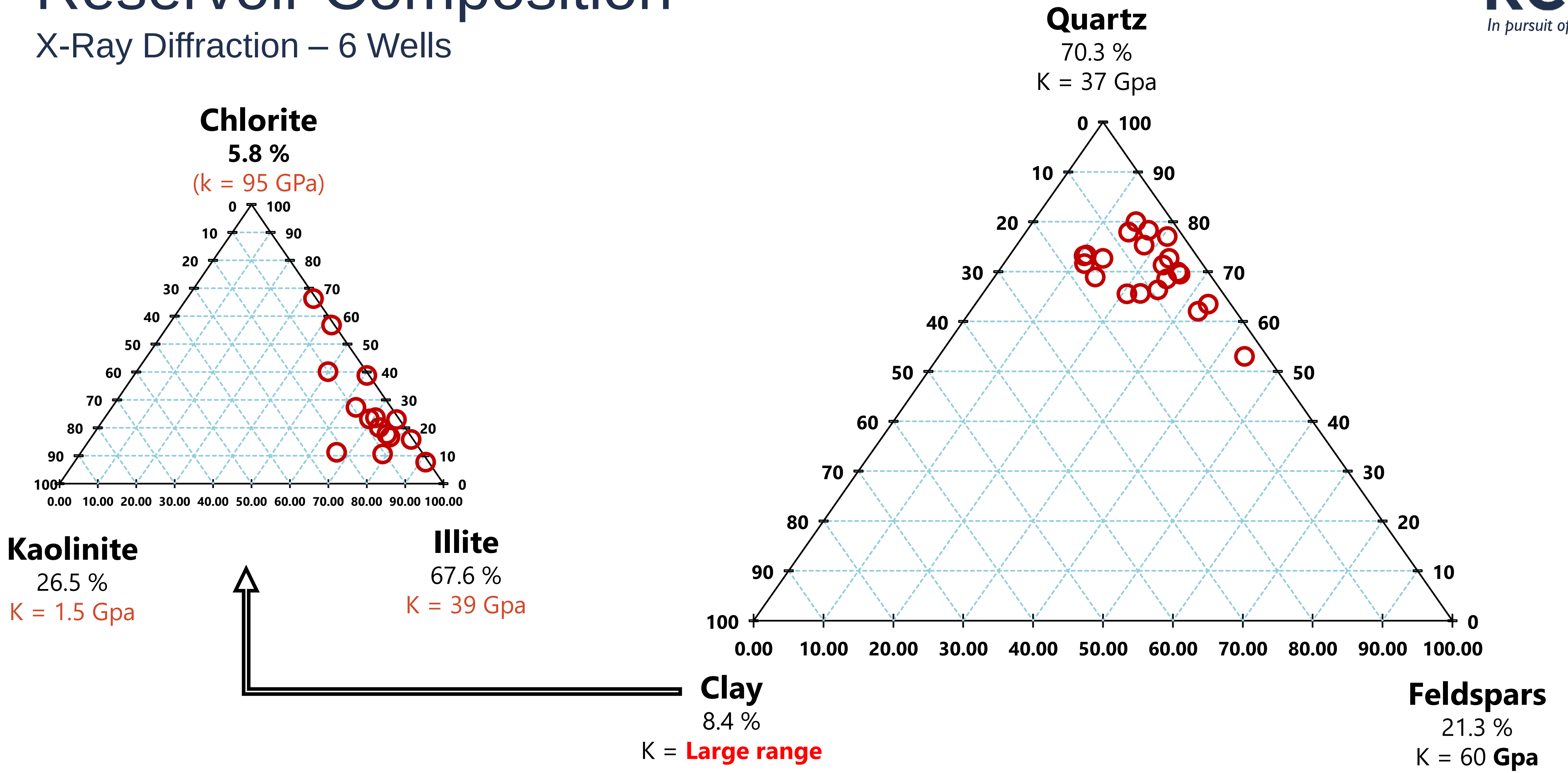


Rock Physics Model

- Composition
- Homogeneous Matrix
- Dry Frame / Gassmann
- Aspect Ratio Analysis
- Clay Sensitivity
- SW Sensitivity

Reservoir Composition

X-Ray Diffraction – 6 Wells



Reservoir Composition

X-Ray Diffraction – 6 Wells

RCP
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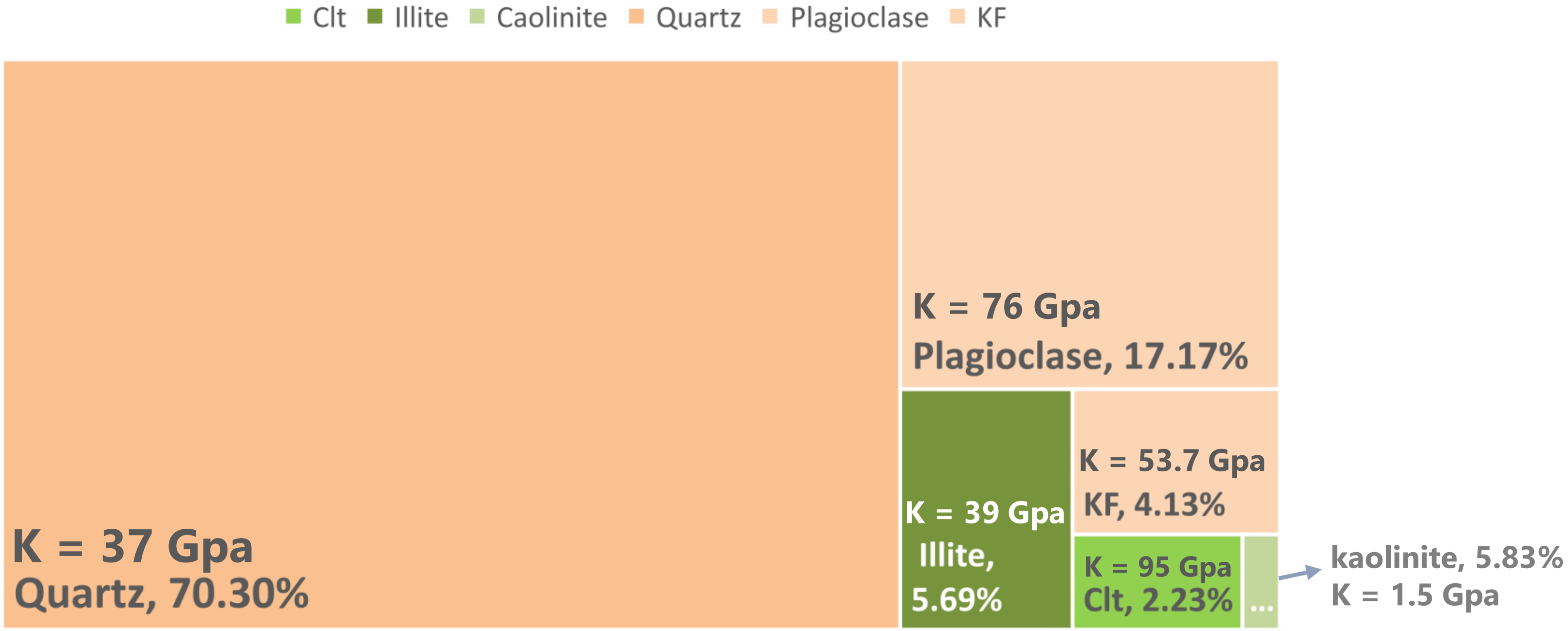
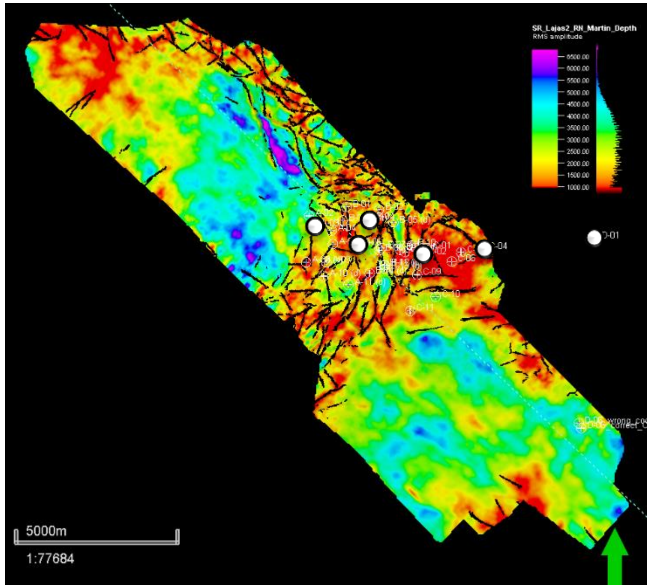




Two Homogeneous medium

(Voigt-Reuss-Hill)

Silicate Background (91.6%)

QTZ + PLG + KF

K = 44.2 Gpa
$\mu = 39$ GPa
$\rho = 2.64\ g/cm^3$

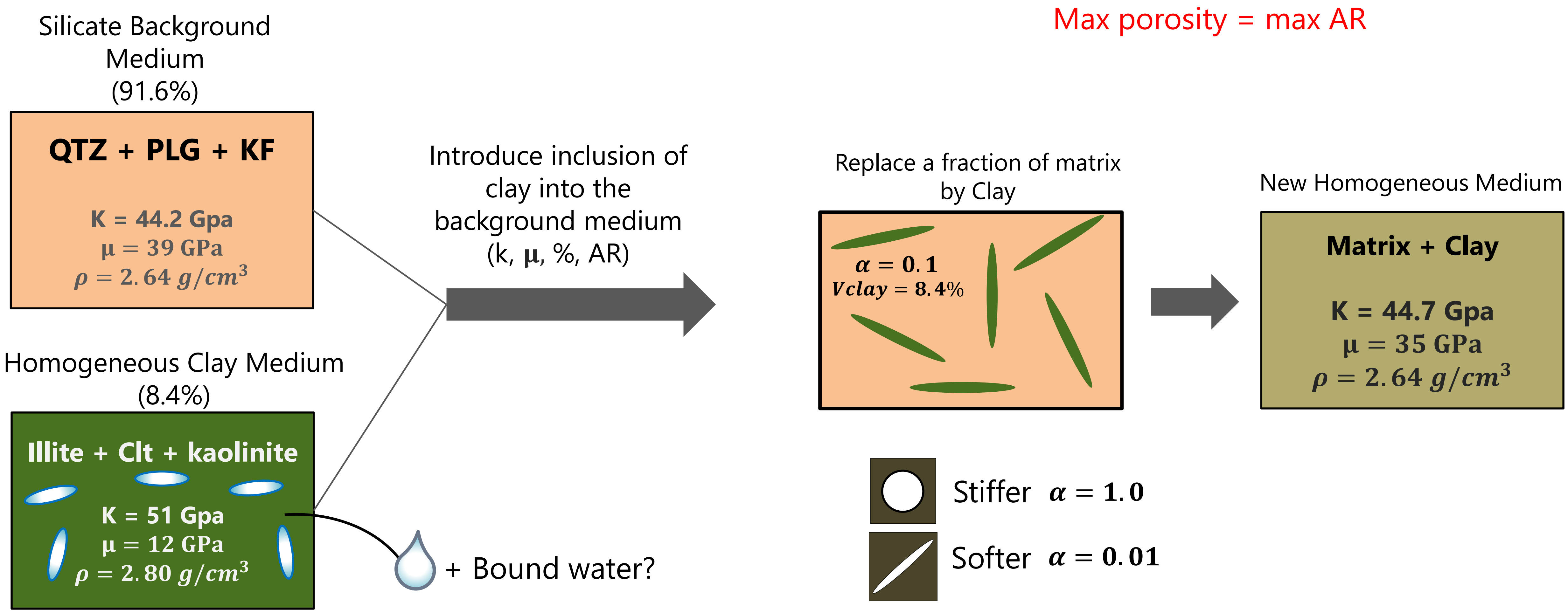
Homogeneous Clay (8.4%)

Illite + Clt + kaolinite

K = 51 Gpa
$\mu = 12$ GPa
$\rho = 2.80\ g/cm^3$

Kuster–Toksöz, 1974

Adding inclusions of clay into silicate background medium



Clay

RCP
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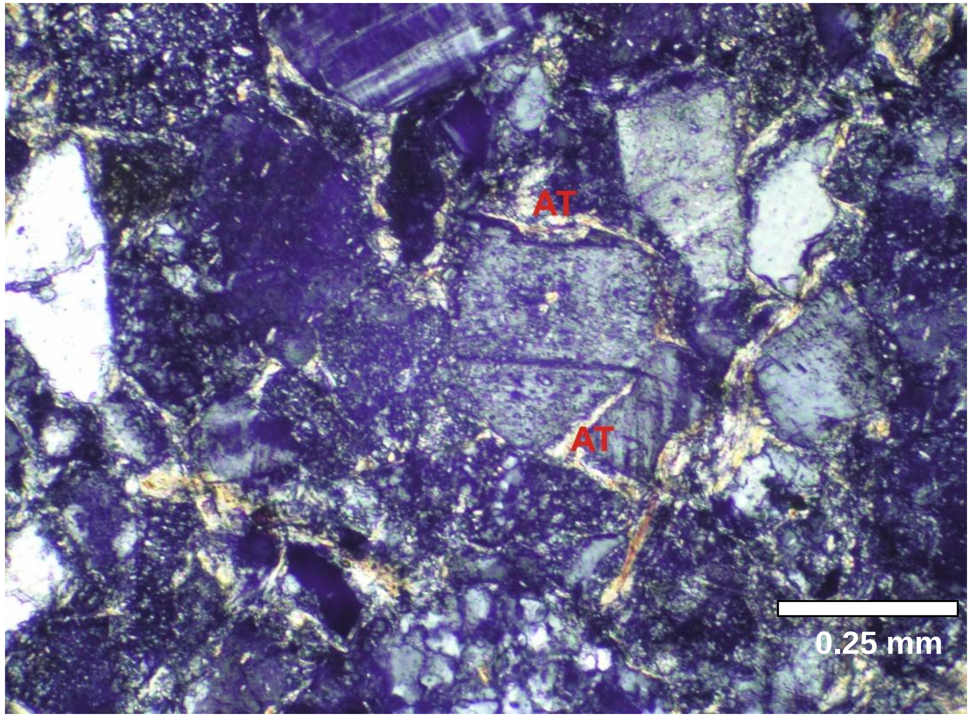
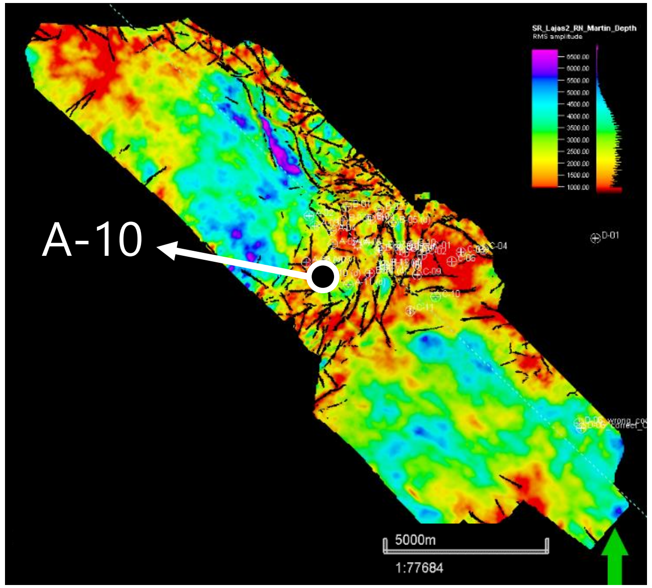


A-10: Early inter-grain clay.

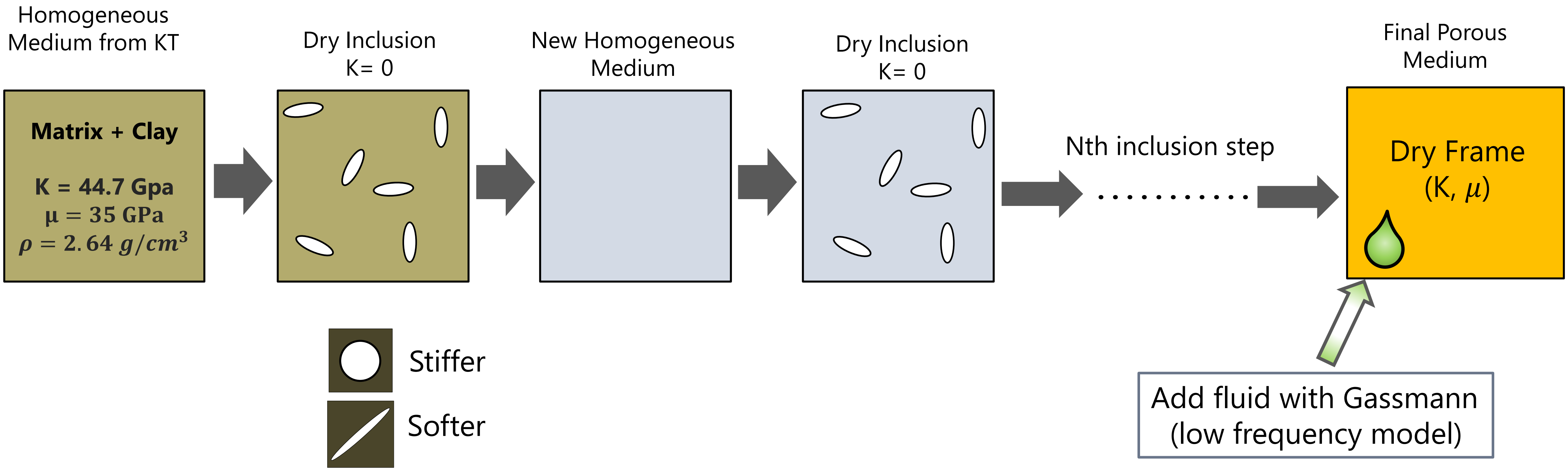


Differential Effective Medium (DEM)

Berryman (1992)

Dry Frame (Add void inclusions)

Add inclusions interactively to avoid violating the Kuster and Tuksoz (1974) premises.



Elastic Moduli Boundaries

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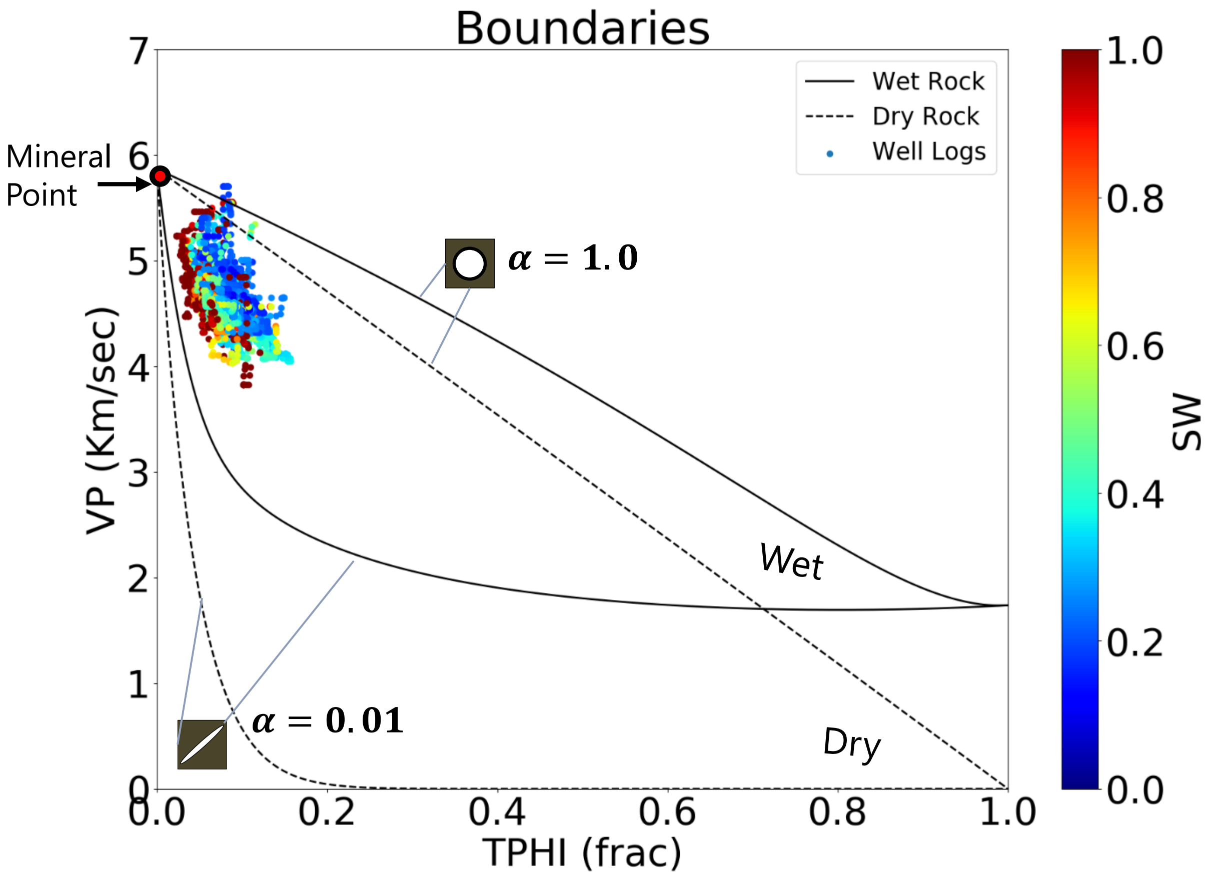

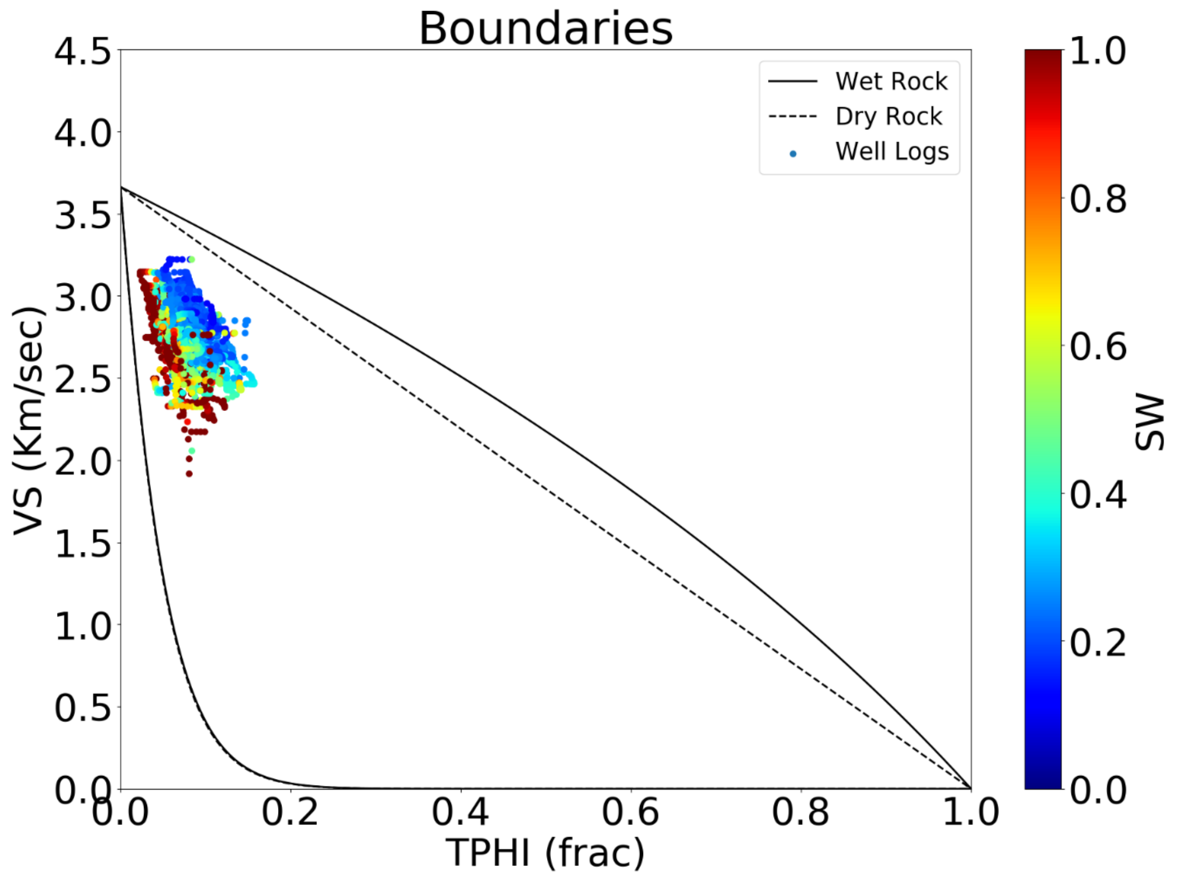

IP x Vp / Vs (Boundaries)

RCP
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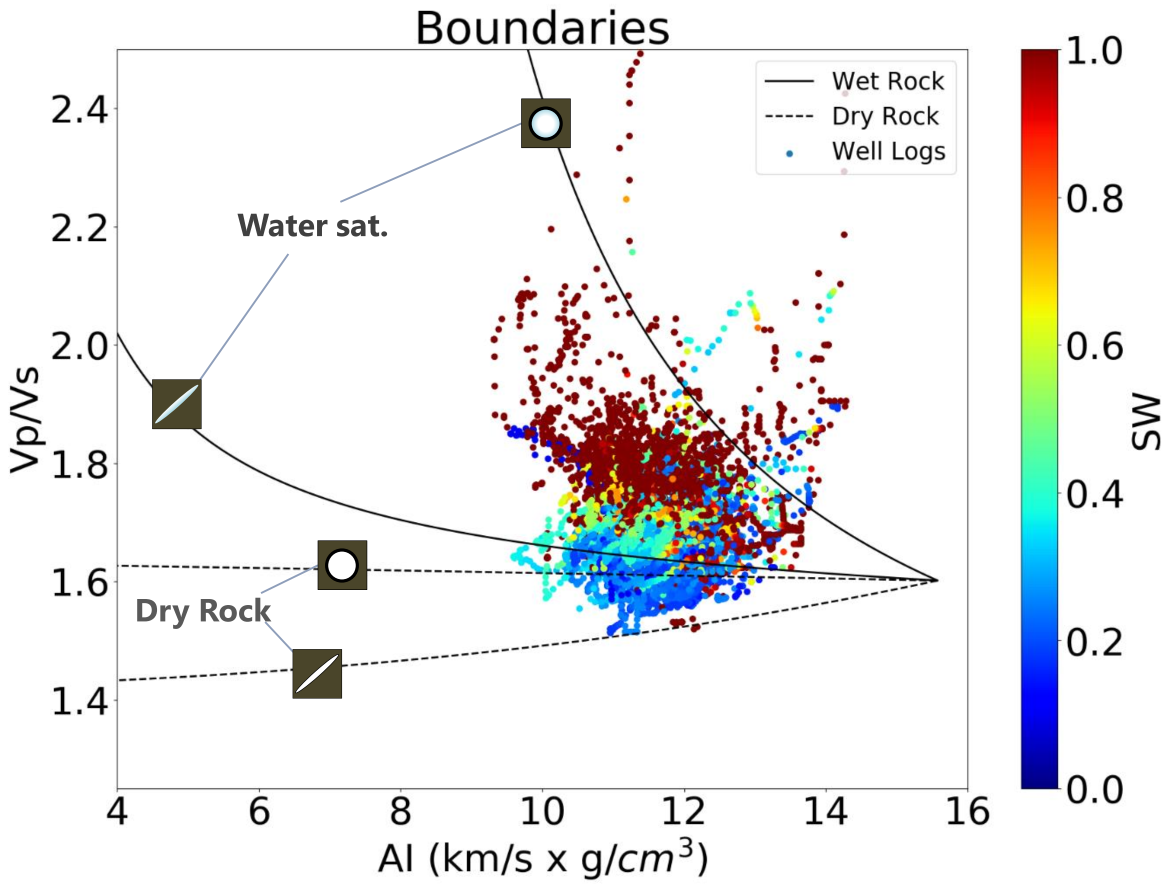
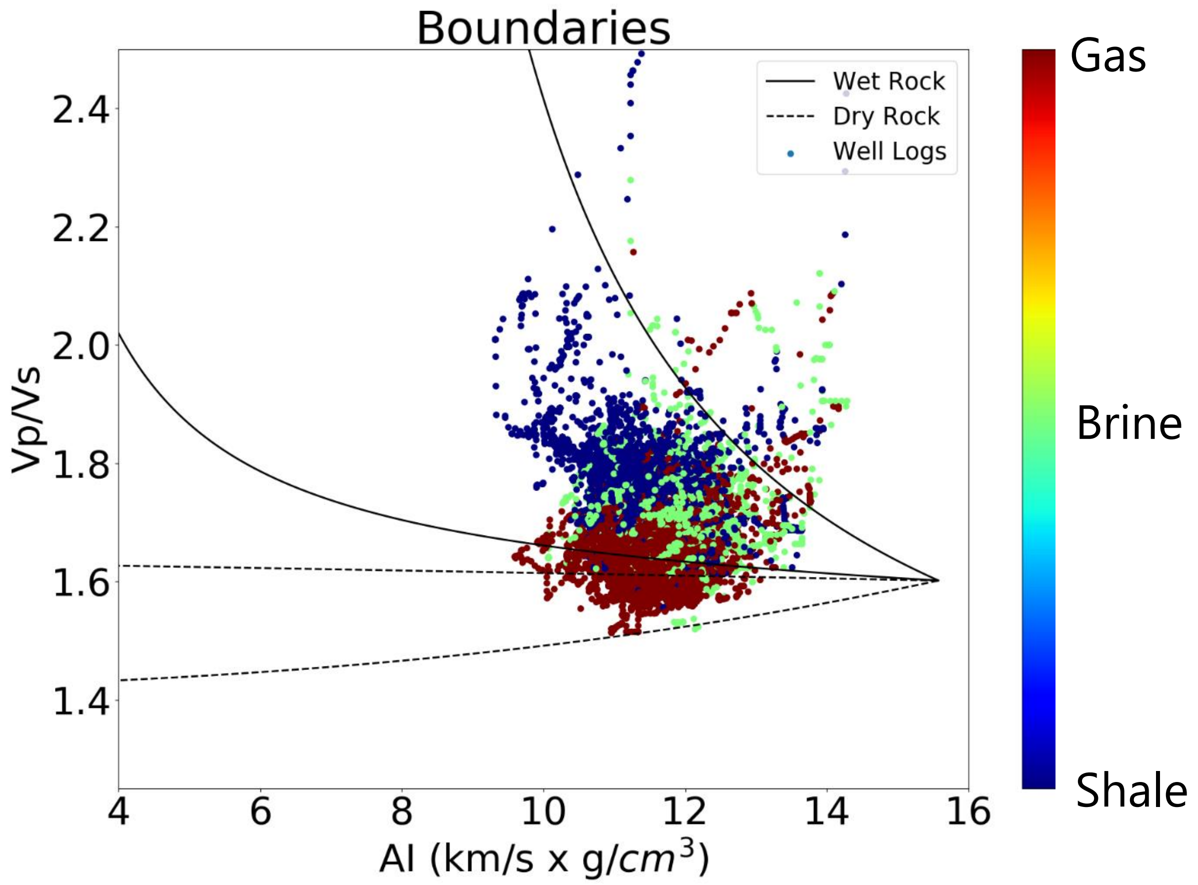
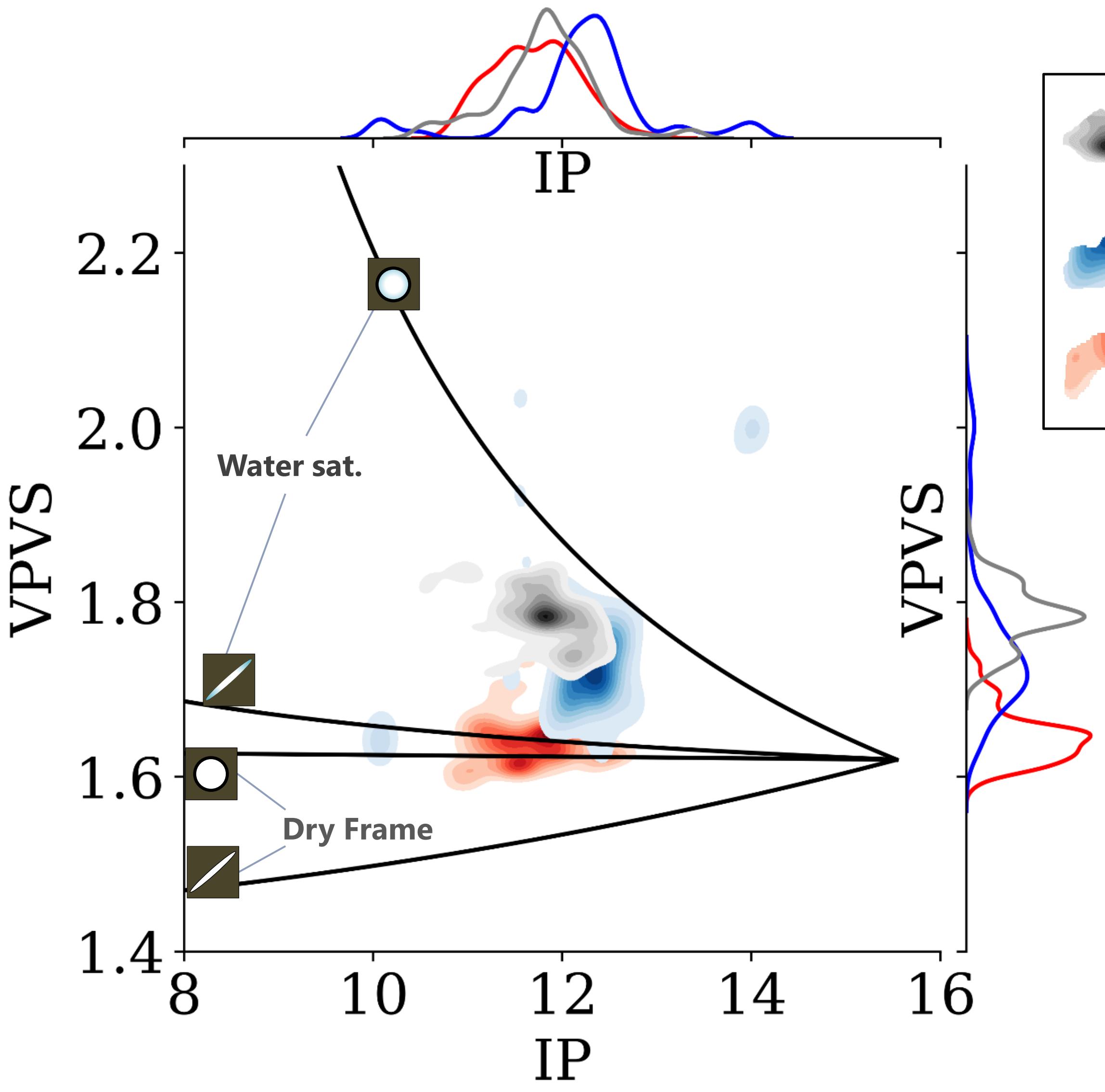
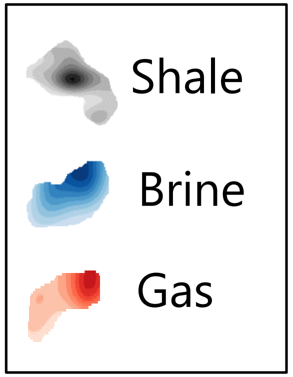


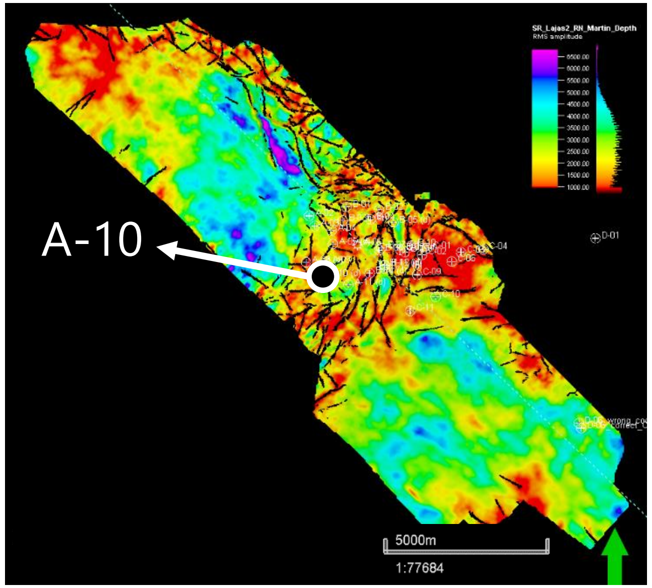


Well A-10

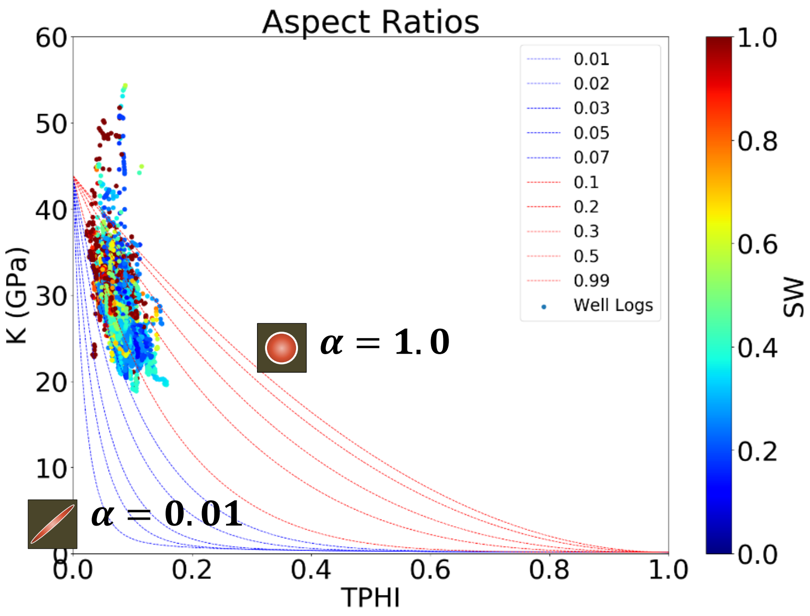
RCP
In pursuit of new ideas



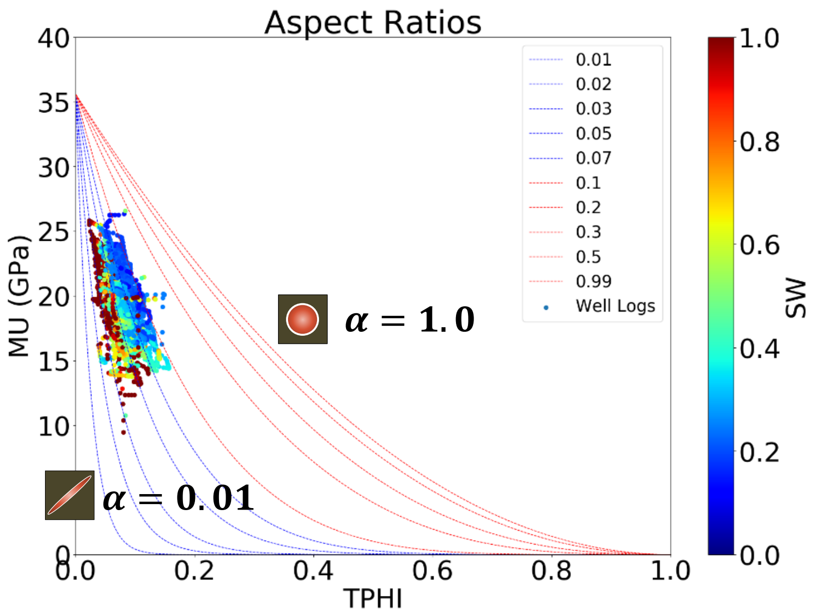




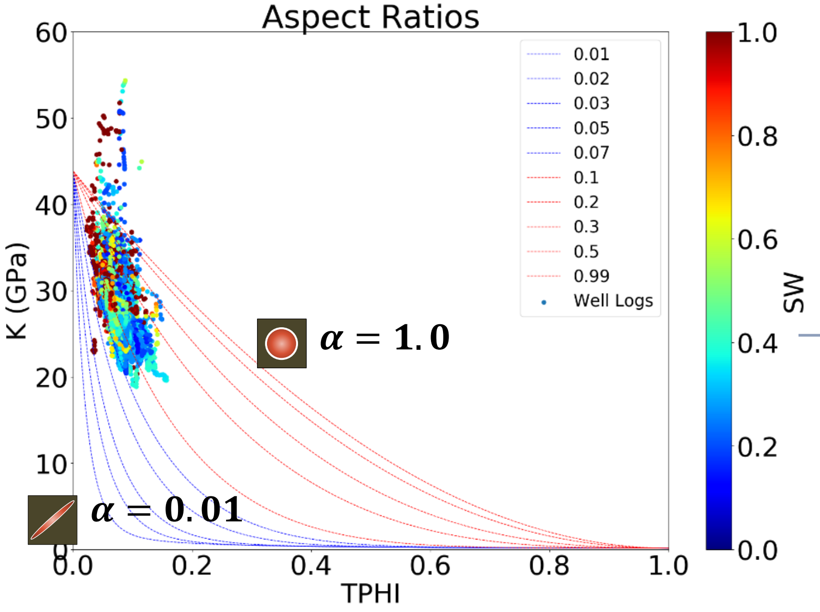
SW: 0 to 100%



Gas Saturated Medium

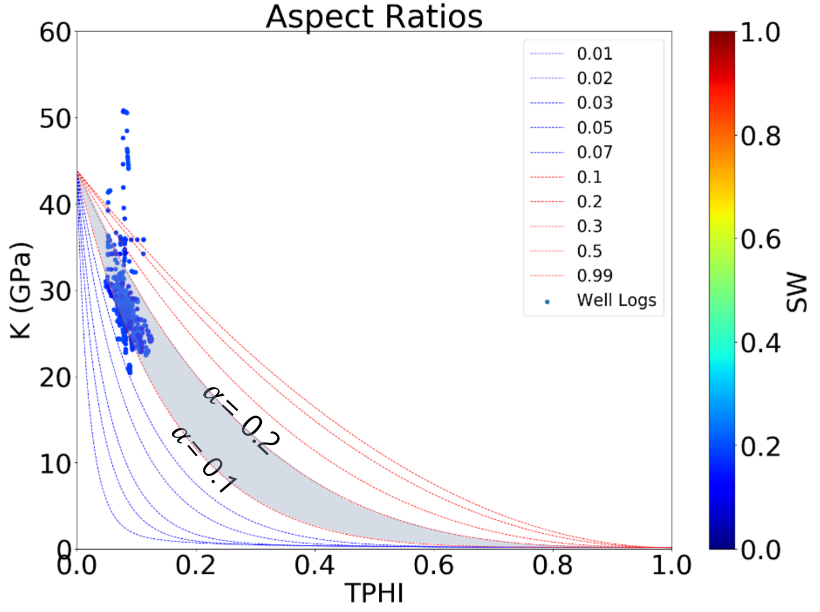


SW: 0 to 100%



Gas Sandstones

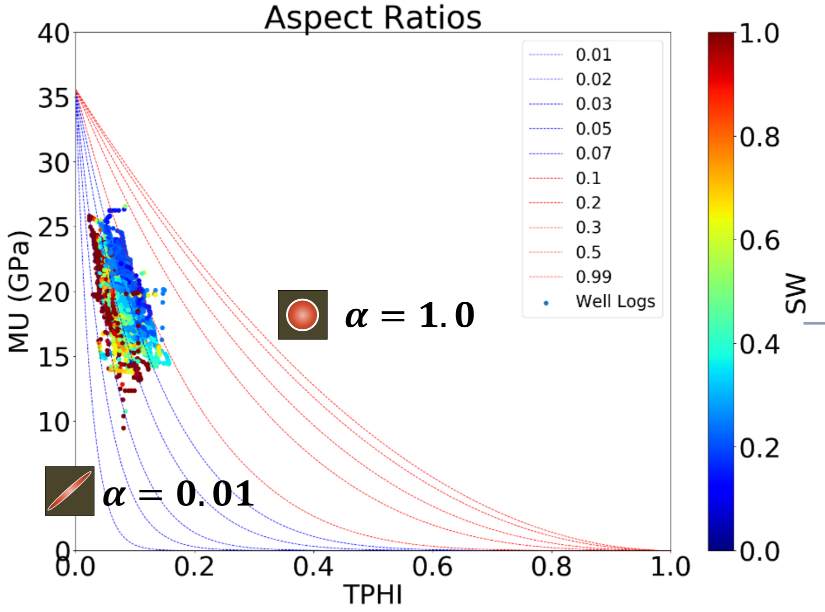
SW: 0 to 20%

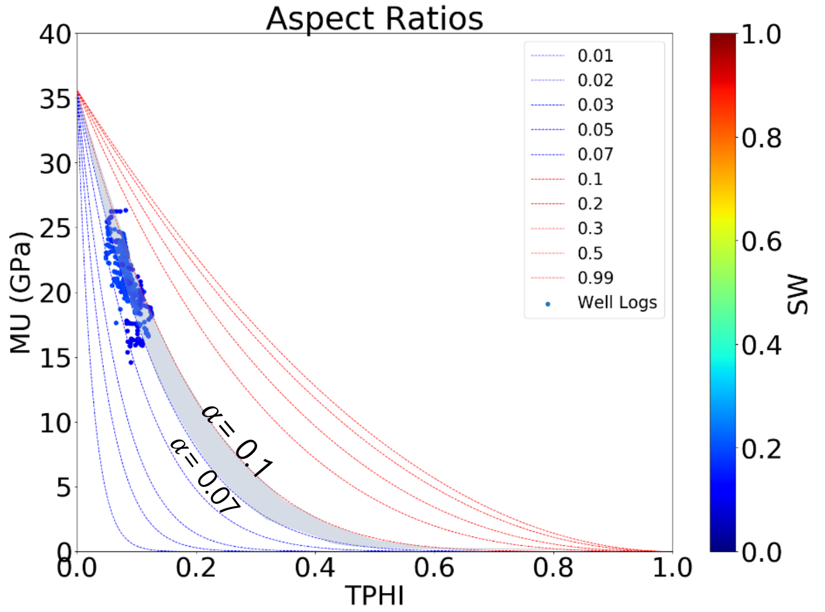


RCP
In pursuit of new ideas

Gas Saturated Medium

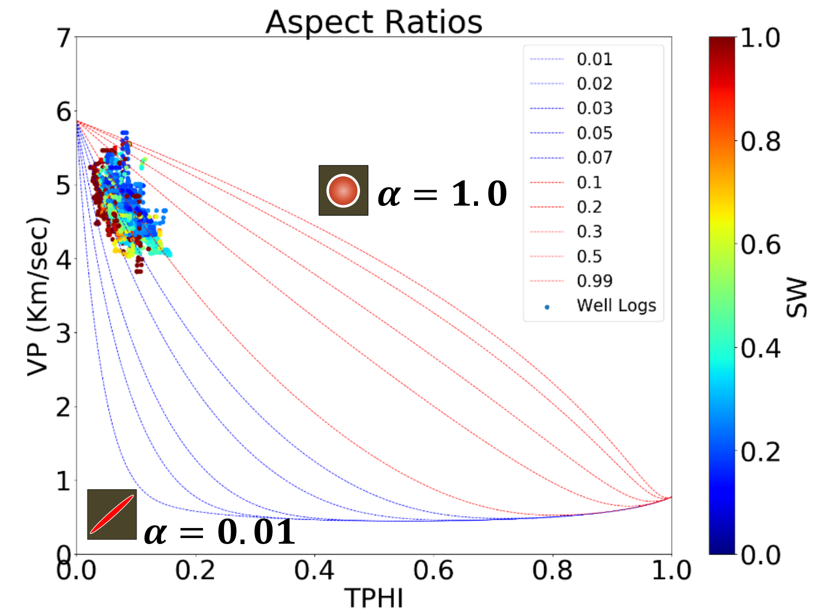
α= 0.07 to 0.2

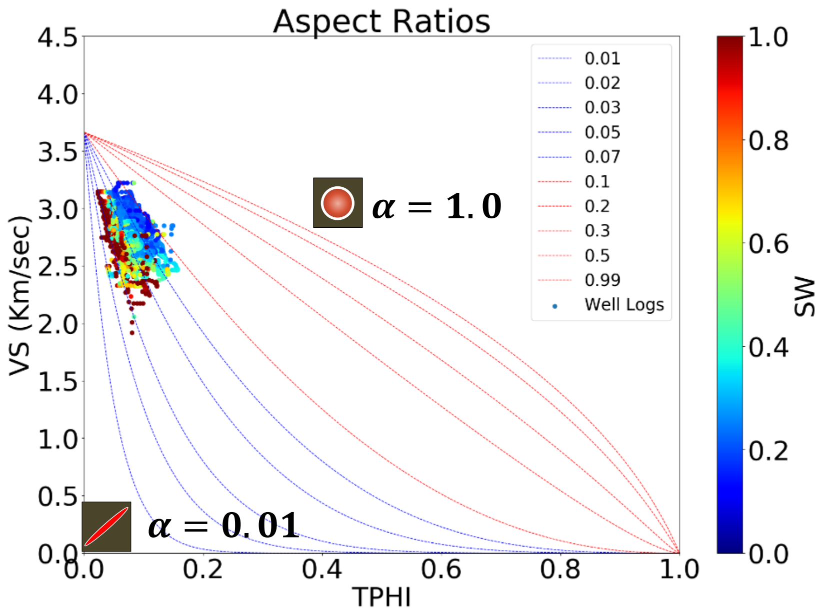




SW: 0 to 100%

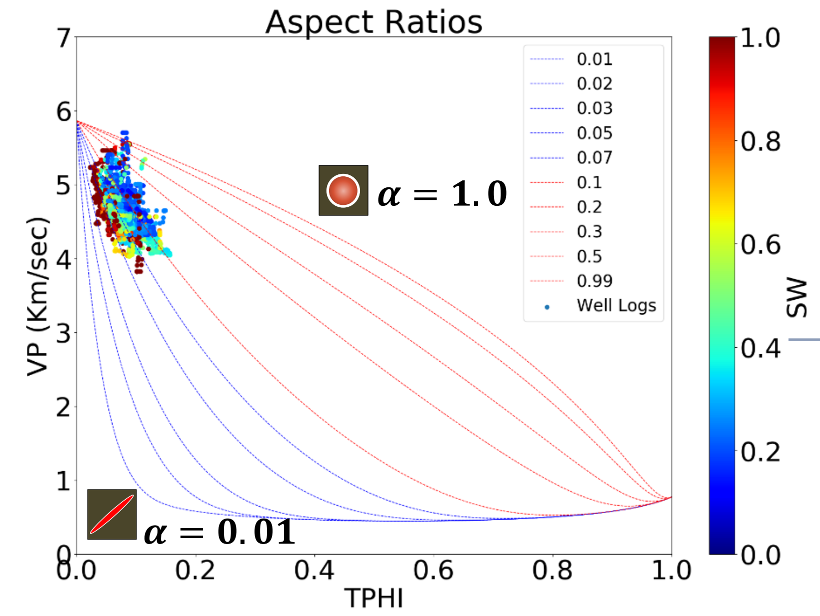
RCP
In pursuit of new ideas

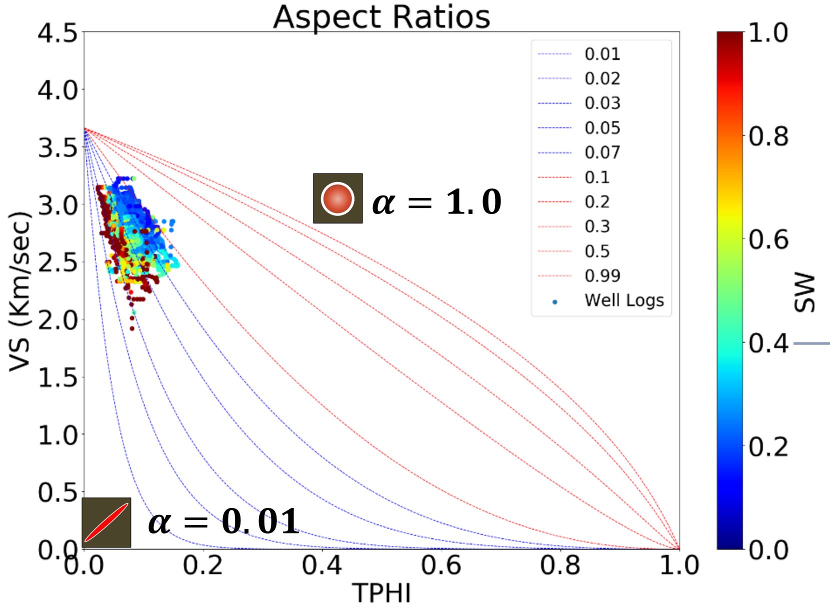




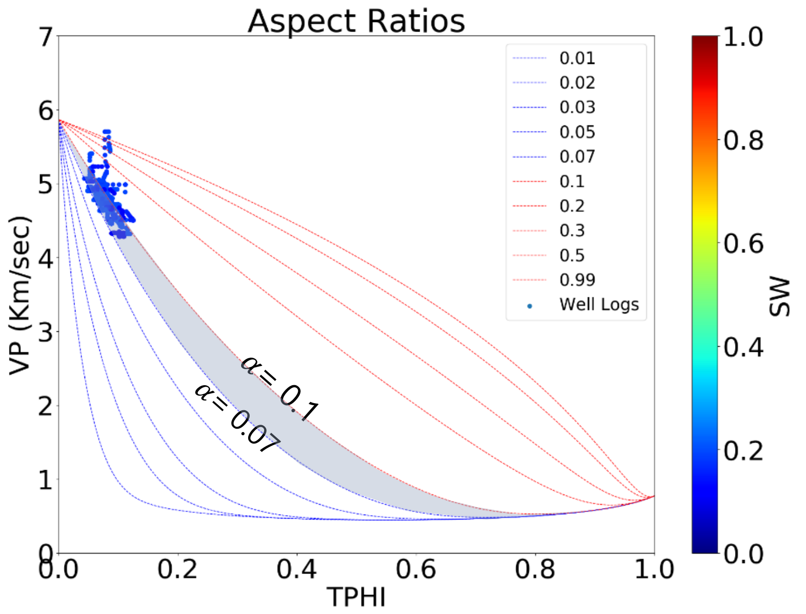
Gas Saturated Medium

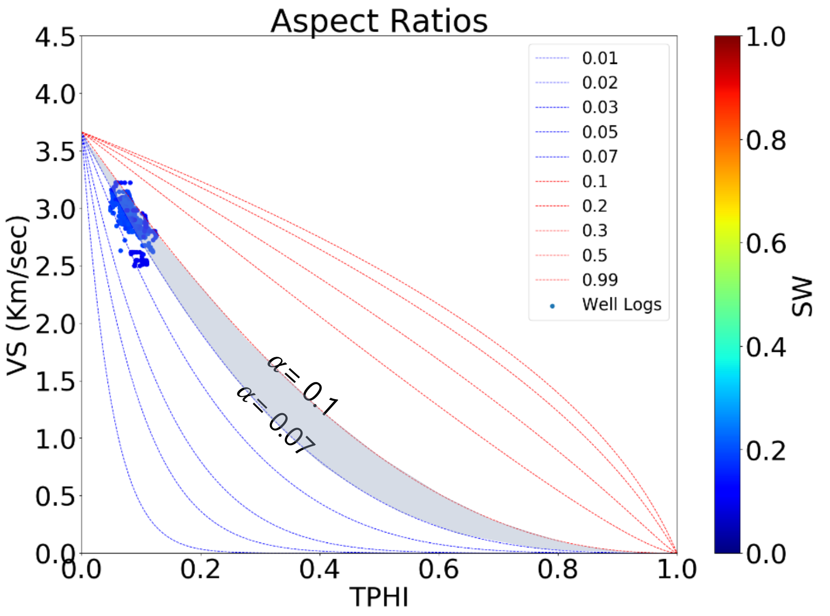
SW: 0 to 100%





Gas Sandstones
SW: 0 to 20%

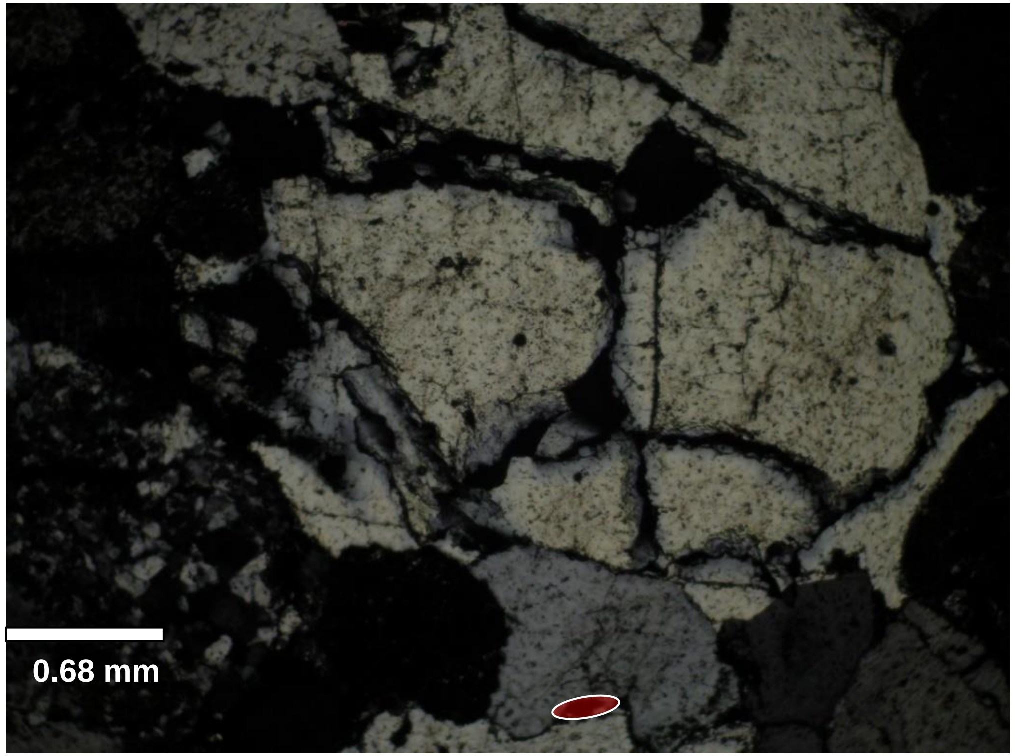




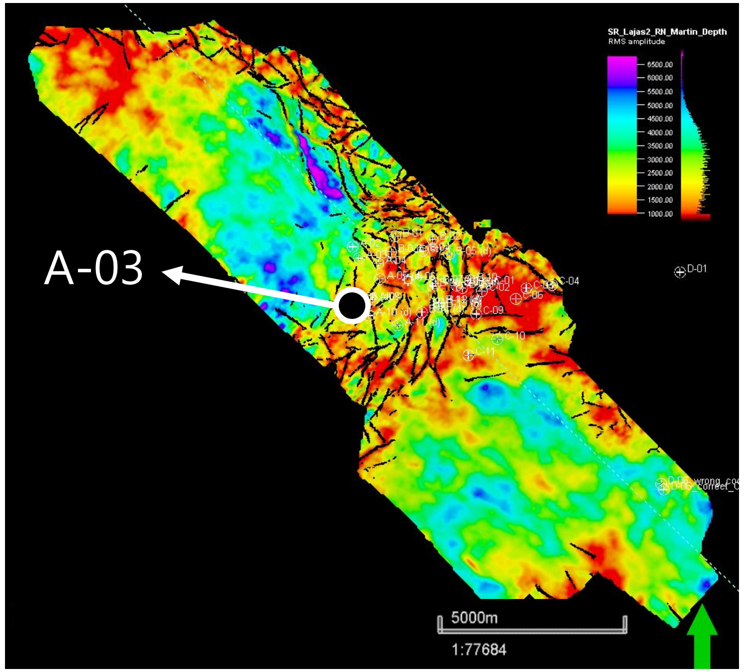
Gas Saturated Medium

α = 0.07 to 0.1

α = 0.2 (average)

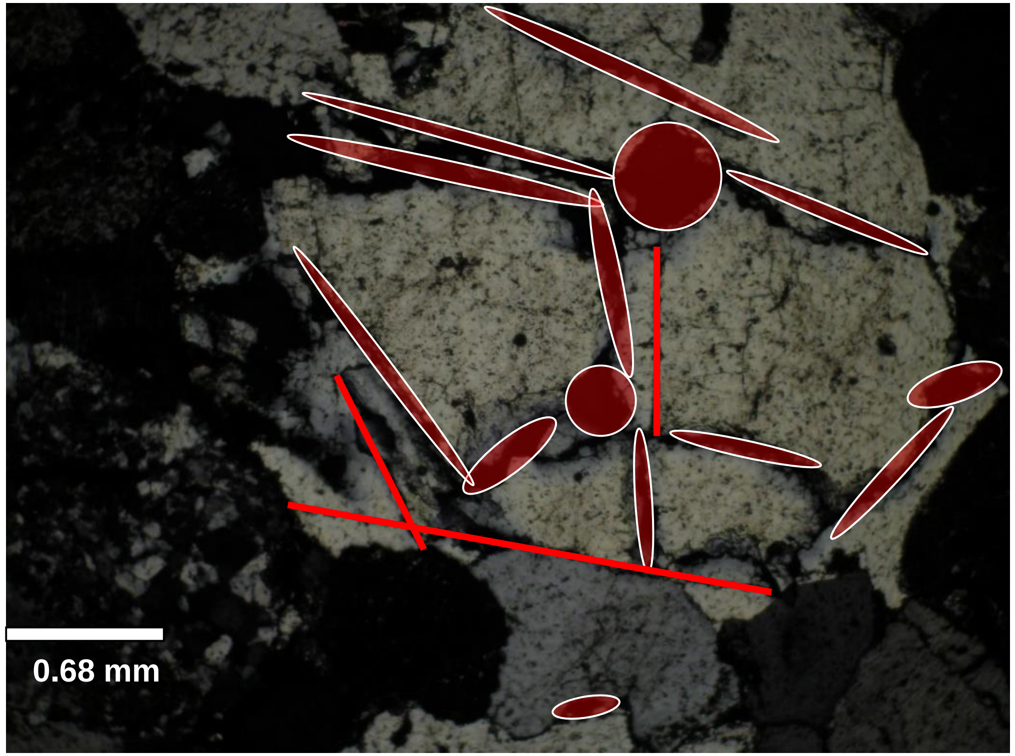


A-03. Dissolution of Feldspars and microfractures

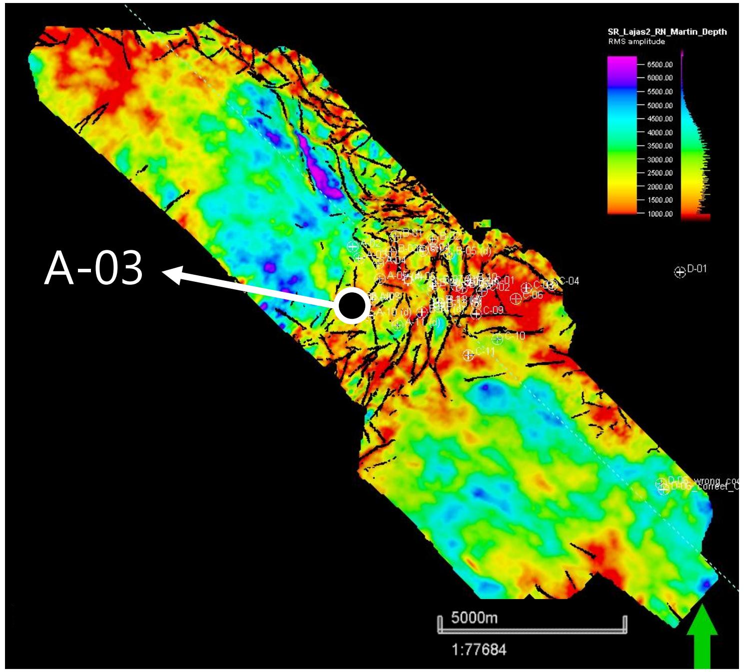


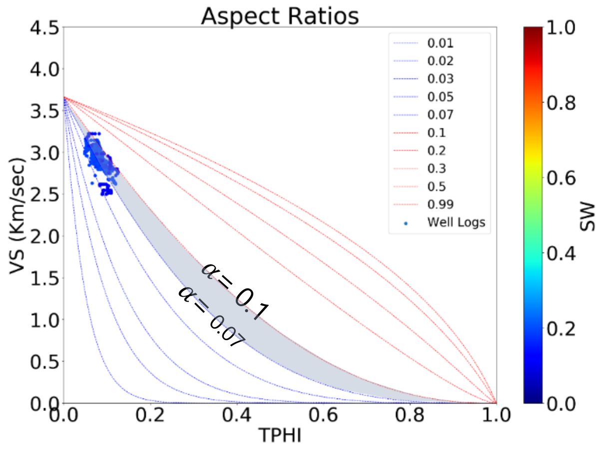
RCP
In pursuit of new ideas

α = 0.15 (average)



A-03. Dissolution of Feldspars and microfractures

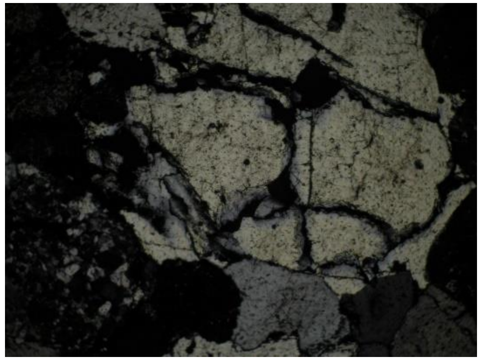




α= 0.07 to 0.2

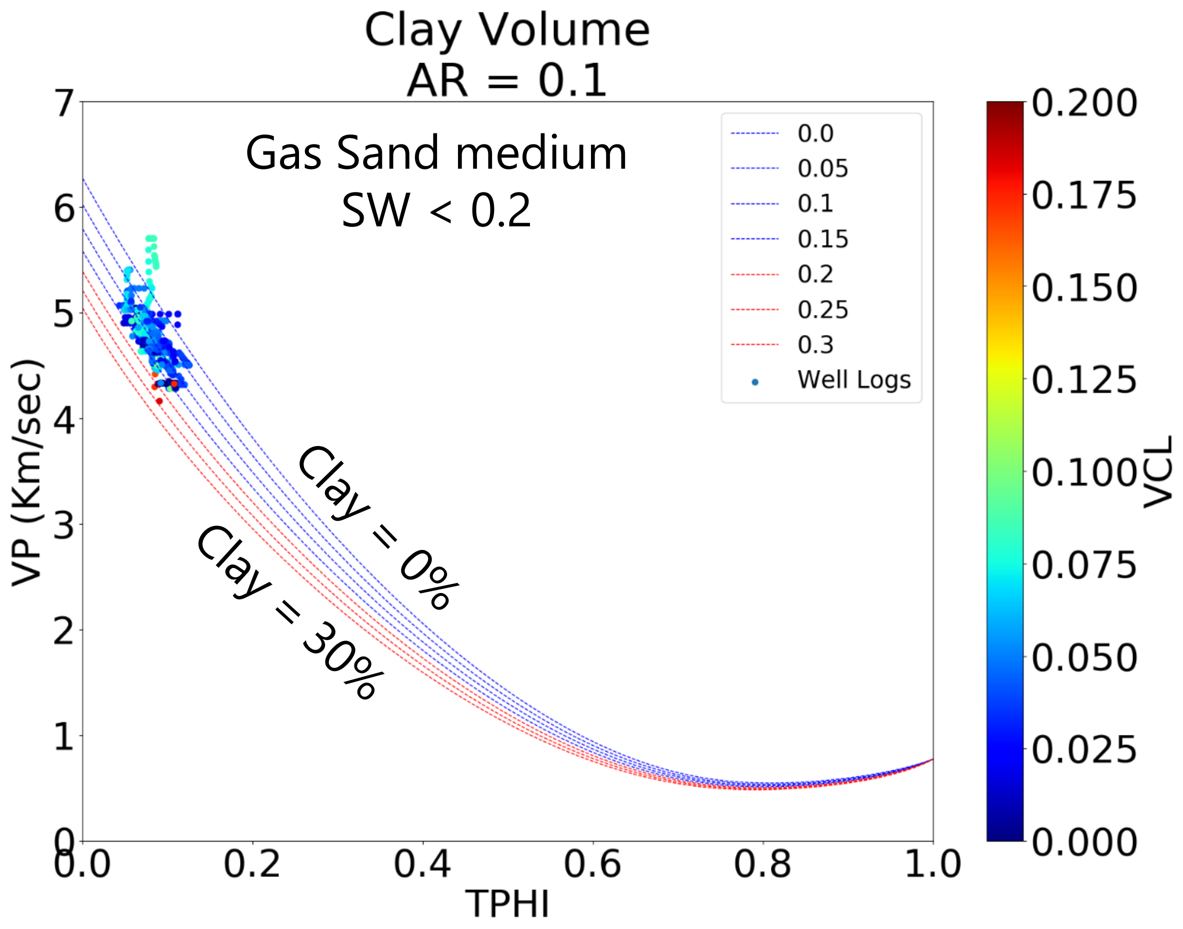
Best fit for the model
(based on xplot analysis)

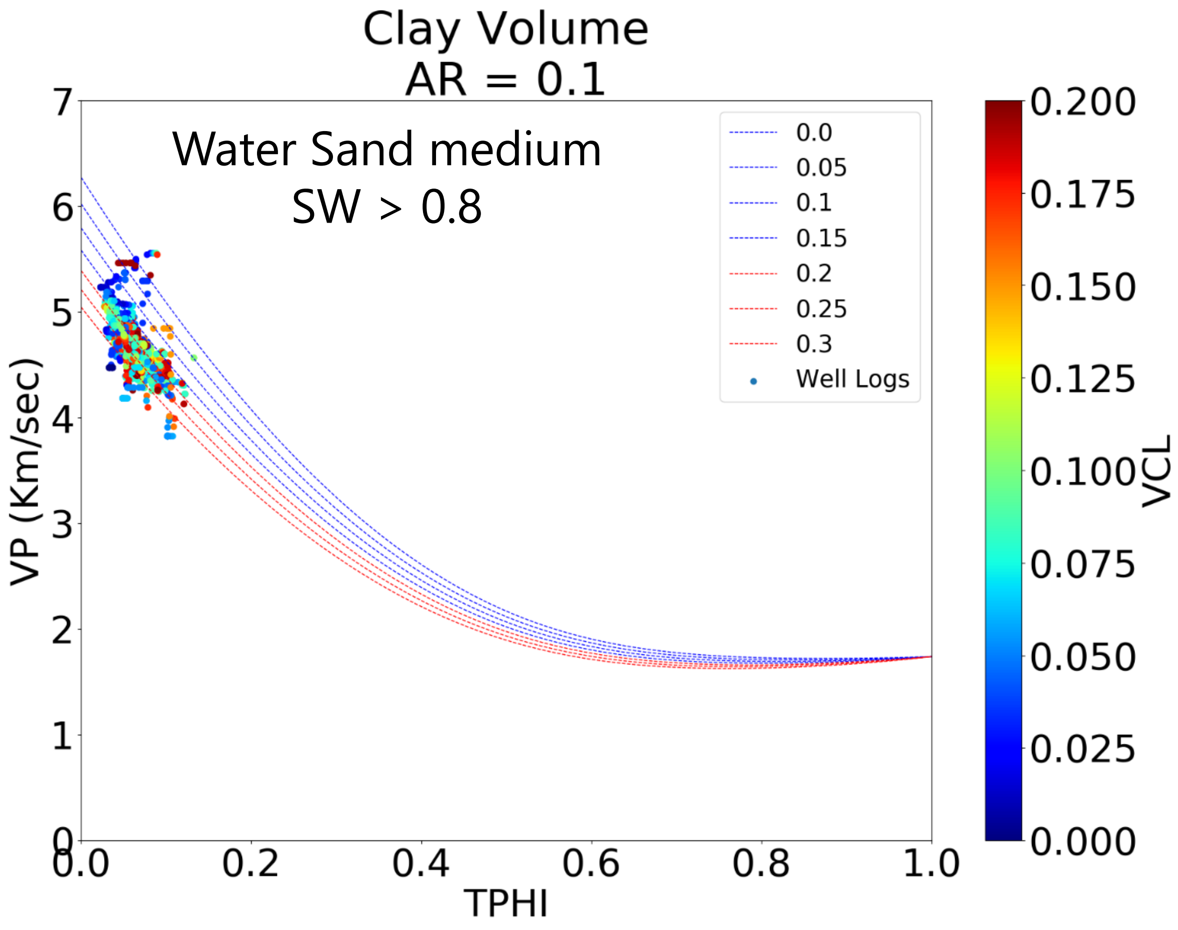
α_ref= 0.1



α= 0.15

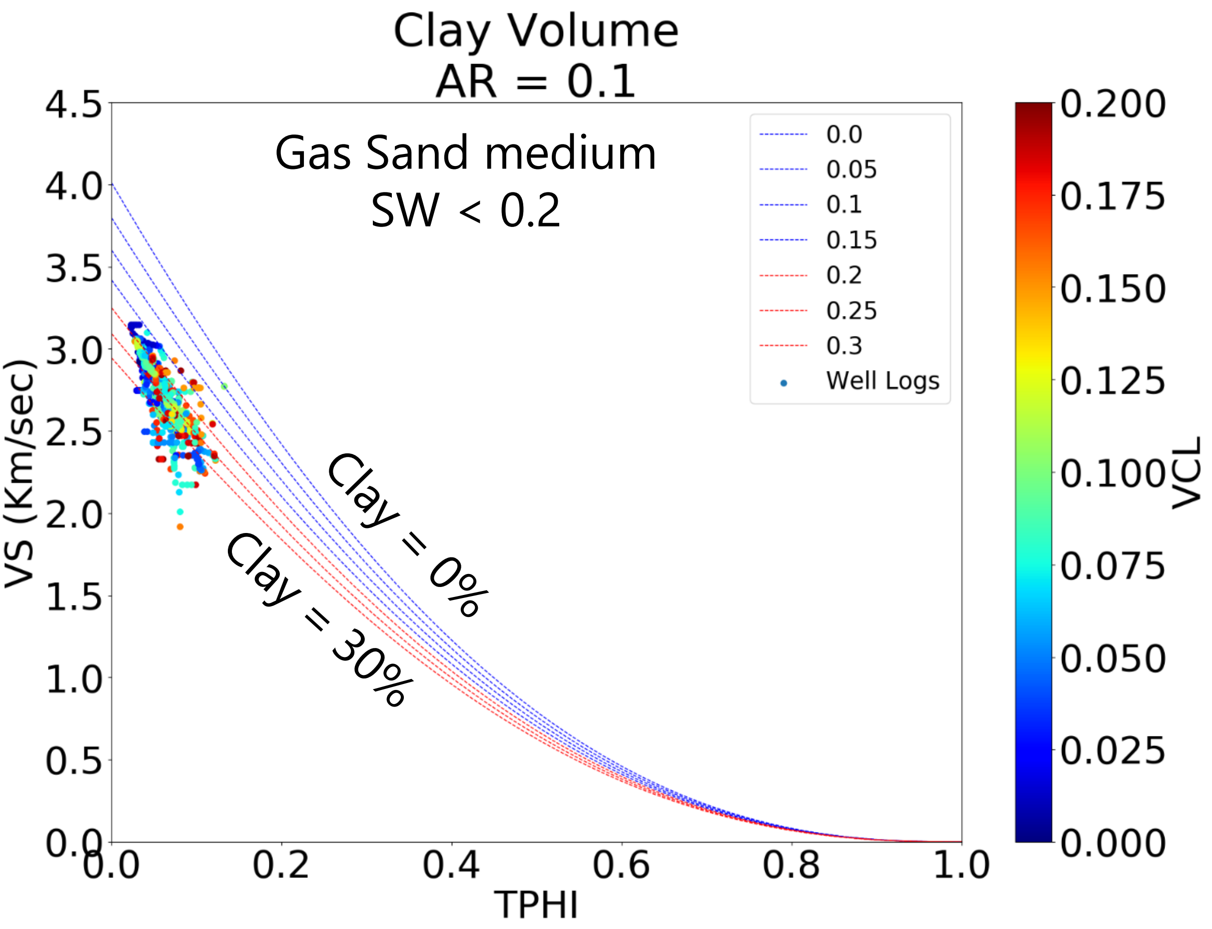
Clay Analysis - VP

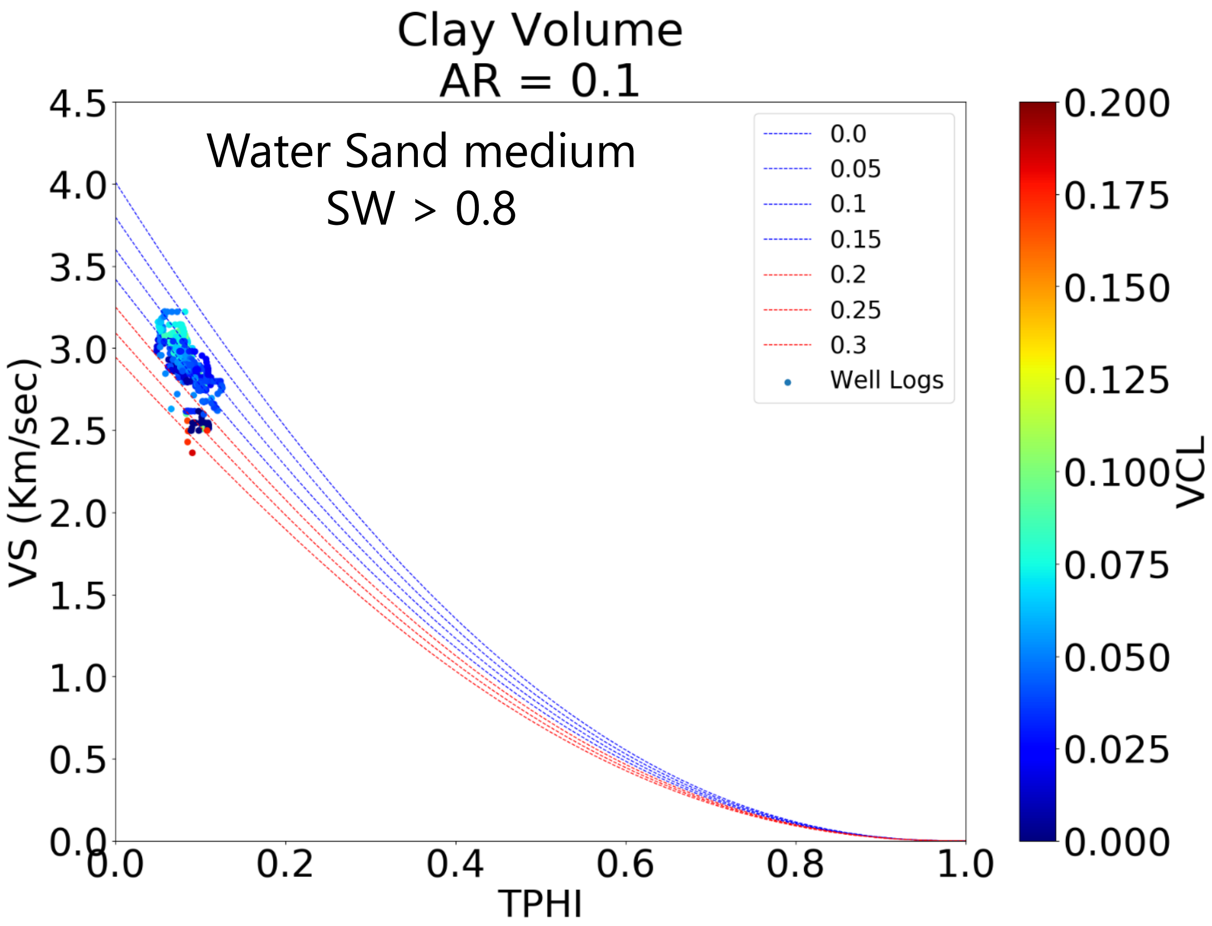




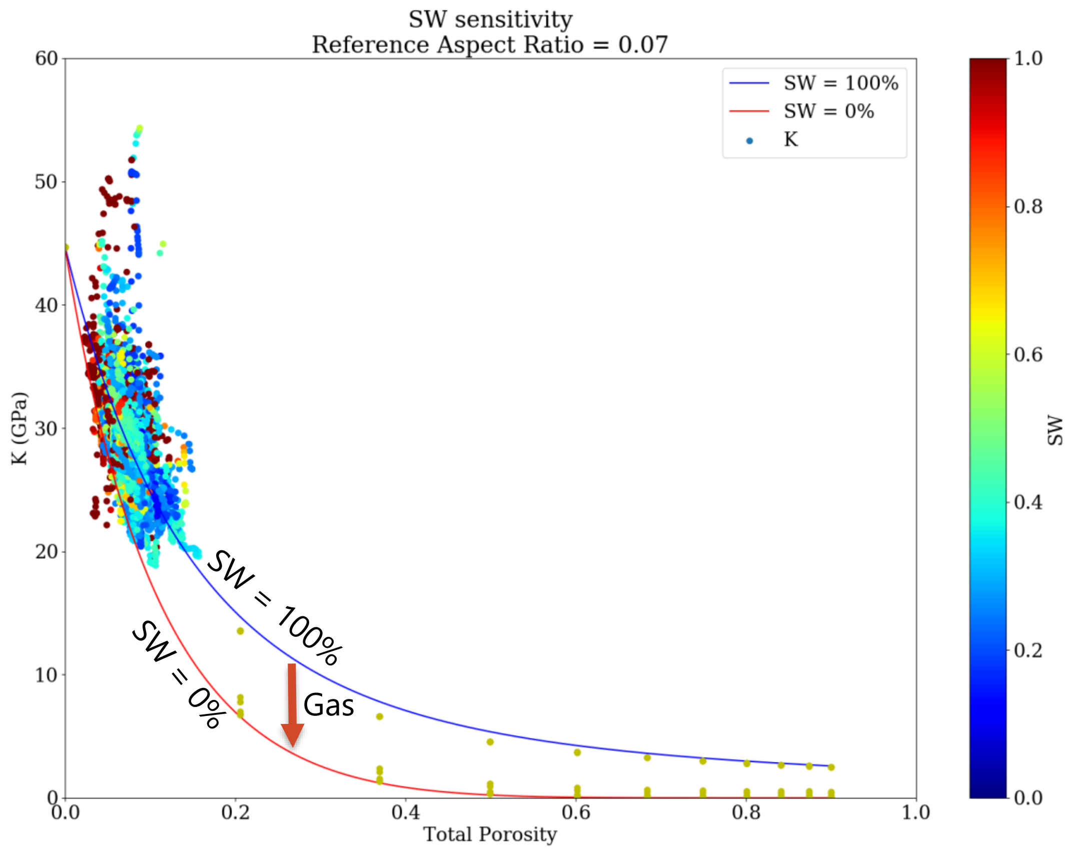
Clay Analysis - VS

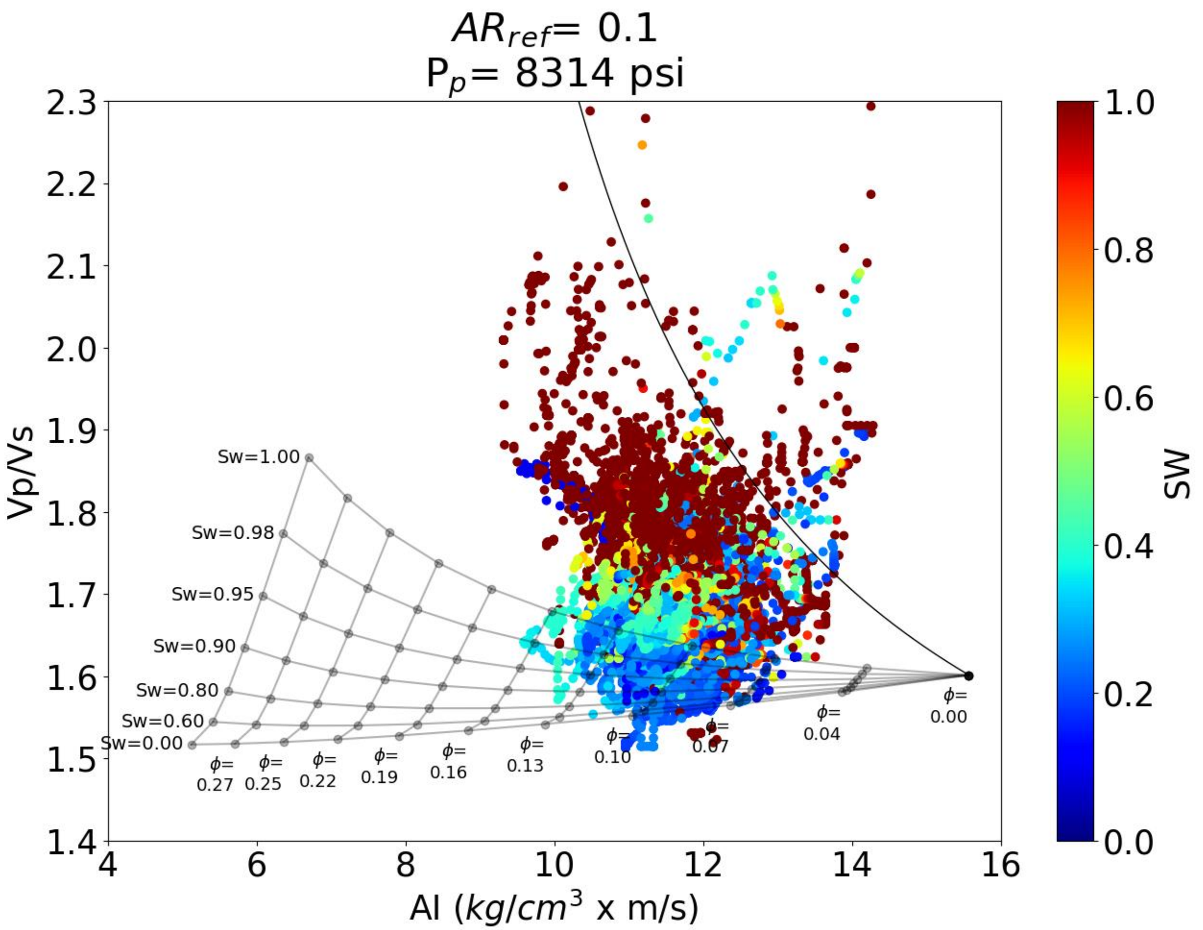
RCP
In pursuit of new ideas

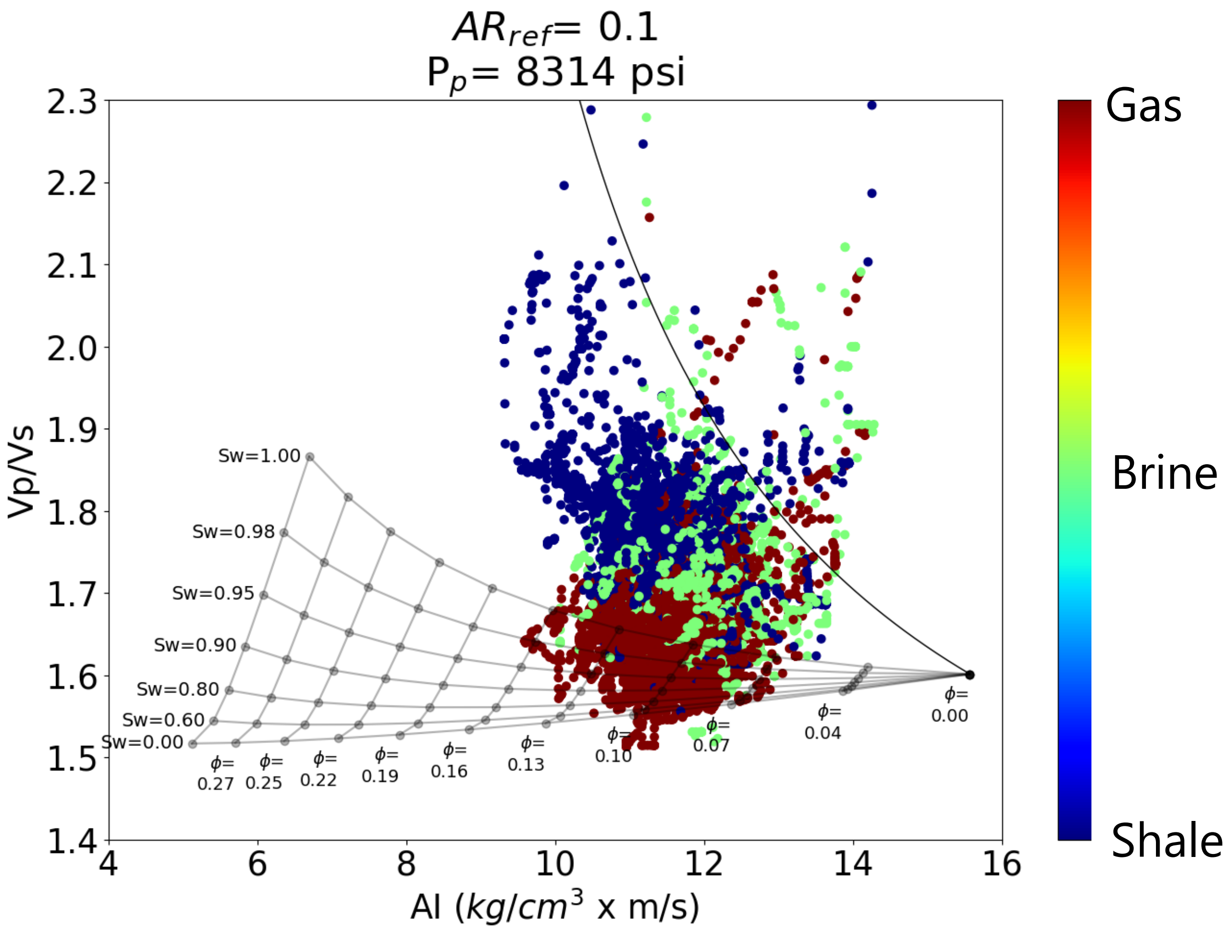


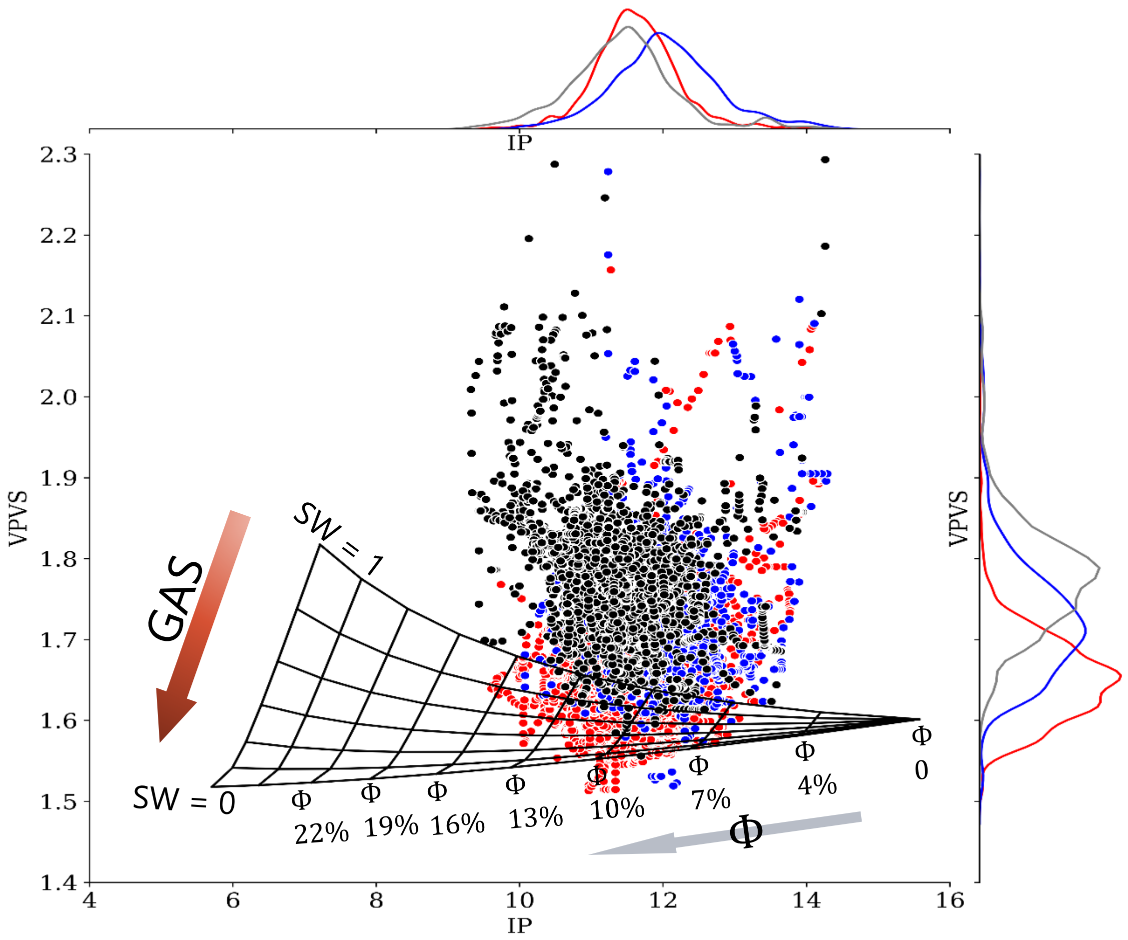


Water Saturation Sensitivity




AR_{ref}= 0.1
P_p= 8314 psi
Vp/Vs
AI (kg/cm^3 x m/s)
SW
Sw=1.00
Sw=0.98
Sw=0.95
Sw=0.90
Sw=0.80
Sw=0.60
Sw=0.00


AR_{ref}= 0.1
P_p= 8314 psi
Vp/Vs
AI (kg/cm^3 x m/s)
Gas
Brine
Shale



IP
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
VPVS
GAS
SW = 1
SW = 0
Φ 22%
Φ 19%
Φ 16%
Φ 13%
Φ 10%
Φ 7%
Φ 4%
Φ 0
Φ
4
6
8
10
12
14
16
IP
VPVS

Conclusions and Future Works

In pursuit of new ideas

- Pre stack inversion is necessary to identify the gas zones
- The rock physics model based in the pore shape can model the seismic response of the tight sand of the Lajas Formation.

Conclusions and Future Works

In pursuit of new ideas

- Improve the model
  - Effect of pressure on the Dry Frame
  - Clays properties
  - Bounded water (irreplaceable constituent of the matrix)
- Punta Rosada Fomation
- Post and Pre stack Inversion

AFL

Anadarko Petroleum Corporation

Apache

CGG

Chevron

CIMAREX

CNOOC

DAWSON Dawson Geophysical Company

devon

drillinginfo better, faster decisions

eog resources

ExxonMobil

Great Western OIL & GAS COMPANY

HALLIBURTON Landmark

HighPoint RESOURCES

شركة نفط الكويت Kuwait Oil Company

ikon Science

LUMINA

Lundin Petroleum

NANOSEIS

OptaSense®

OXY

OIL AND GAS INSTITUTE - National Research Institute

PDC ENERGY

PENN VIRGINIA CORPORATION

PIONEER NATURAL RESOURCES

REPSOL

Schlumberger

Shell

SIGMA³

中国石化 SINOPEC

Vecta Oil & Gas Ltd.

WHITING

wintershall

Back-up slides

Kuster and Toksöz (1974) derived expressions for P- and S- wave velocities by using a long-wavelength first-order scattering theory. A generalization of their expressions for the effective moduli K^*_{KT} and μ^*_{KT} for a variety of inclusion shapes can be written as (Kuster and Toksöz, 1974; Berryman, 1980b)

$$(K^*_{KT} - K_m)\frac{(K_m + \frac{4}{3}\mu_m)}{(K^*_{KT} + \frac{4}{3}\mu_m)} = \sum_{i=1}^{N} x_i(K_i - K_m)P^{mi}$$

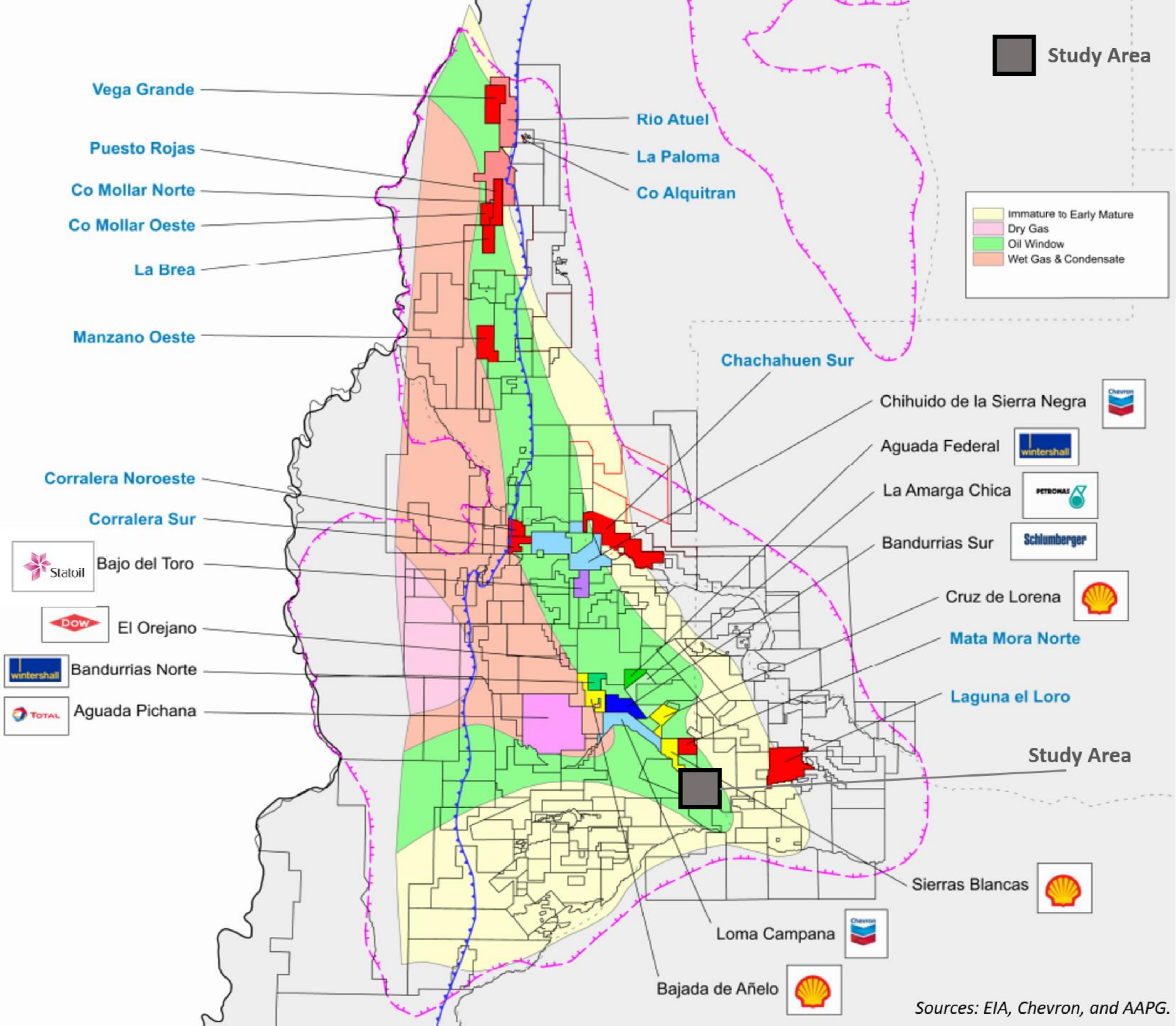
$$(\mu^*_{KT} - \mu_m)\frac{(\mu_m + \zeta_m)}{(\mu^*_{KT} + \zeta_m)} = \sum_{i=1}^{N} x_i(\mu_i - \mu_m)Q^{mi}$$

where the summation is over the different inclusion types with volume concentration x_i, and

$$\zeta = \frac{\mu}{6}\frac{(9K + 8\mu)}{(K + 2\mu)}$$

TABLE 4.7.1. Coefficients P and Q for some specific shapes. The subscripts m and i refer to the background and inclusion materials [from Berryman (1995)].

Inclusion Shape	P^{mi}	Q^{mi}
Spheres	$\dfrac{K_m + \frac{4}{3}\mu_m}{K_i + \frac{4}{3}\mu_m}$	$\dfrac{\mu_m + \zeta_m}{\mu_i + \zeta_m}$
Needles	$\dfrac{K_m + \mu_m + \frac{1}{3}\mu_i}{K_i + \mu_m + \frac{1}{3}\mu_i}$	$\dfrac{1}{5}\left(\dfrac{4\mu_m}{\mu_m + \mu_i} + 2\dfrac{\mu_m + \gamma_m}{\mu_i + \gamma_m} + \dfrac{K_i + \frac{4}{3}\mu_m}{K_i + \mu_m + \frac{1}{3}\mu_i}\right)$
Disks	$\dfrac{K_m + \frac{4}{3}\mu_i}{K_i + \frac{4}{3}\mu_i}$	$\dfrac{\mu_m + \zeta_i}{\mu_i + \zeta_i}$
Penny cracks	$\dfrac{K_m + \frac{4}{3}\mu_i}{K_i + \frac{4}{3}\mu_i + \pi\alpha\beta_m}$	$\dfrac{1}{5}\left(1 + \dfrac{8\mu_m}{4\mu_i + \pi\alpha(\mu_m + 2\beta_m)} + 2\dfrac{K_i + \frac{2}{3}(\mu_i + \mu_m)}{K_i + \frac{4}{3}\mu_i + \pi\alpha\beta_m}\right)$

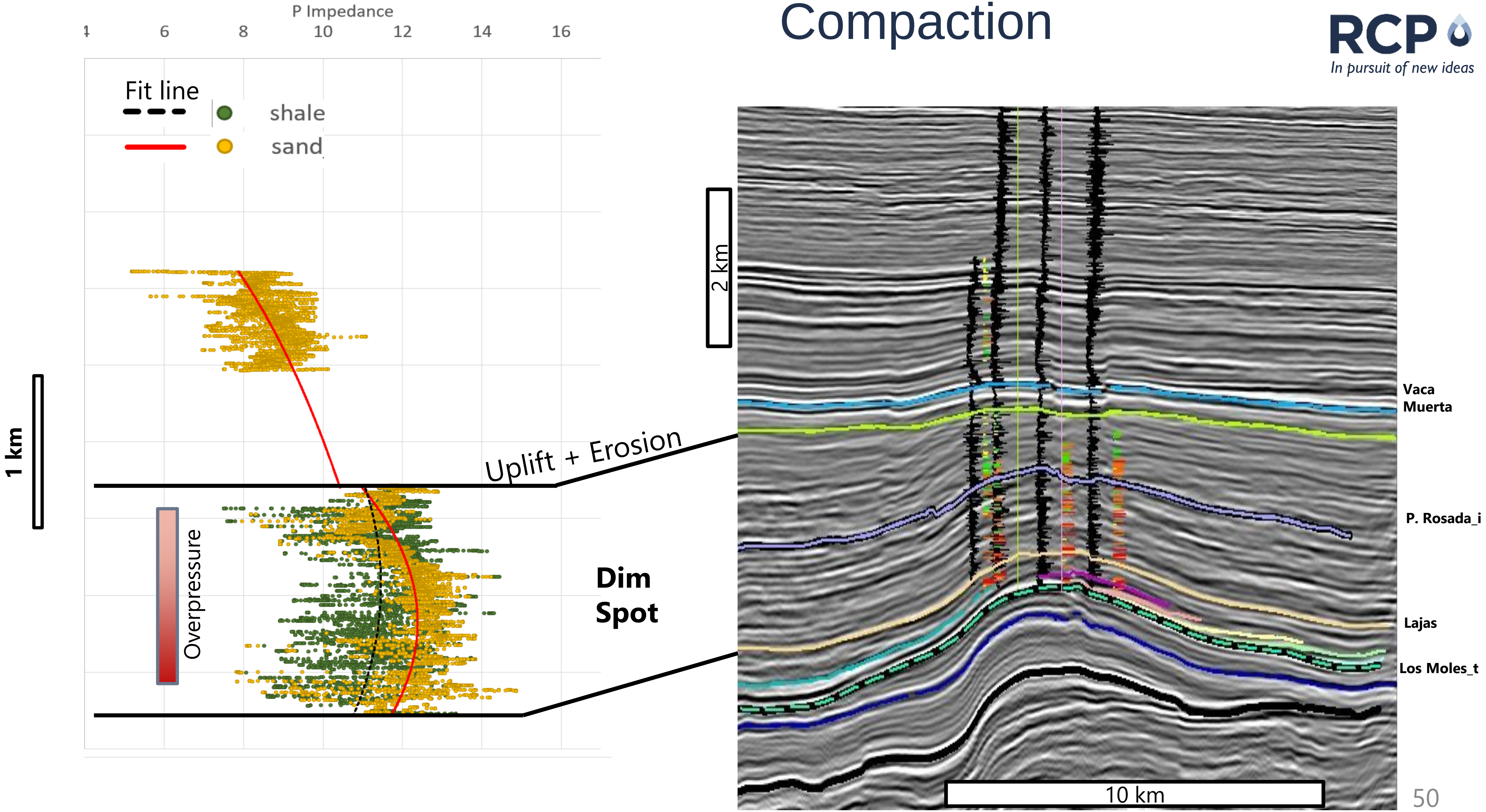


Sources: EIA, Chevron, and AAPG.

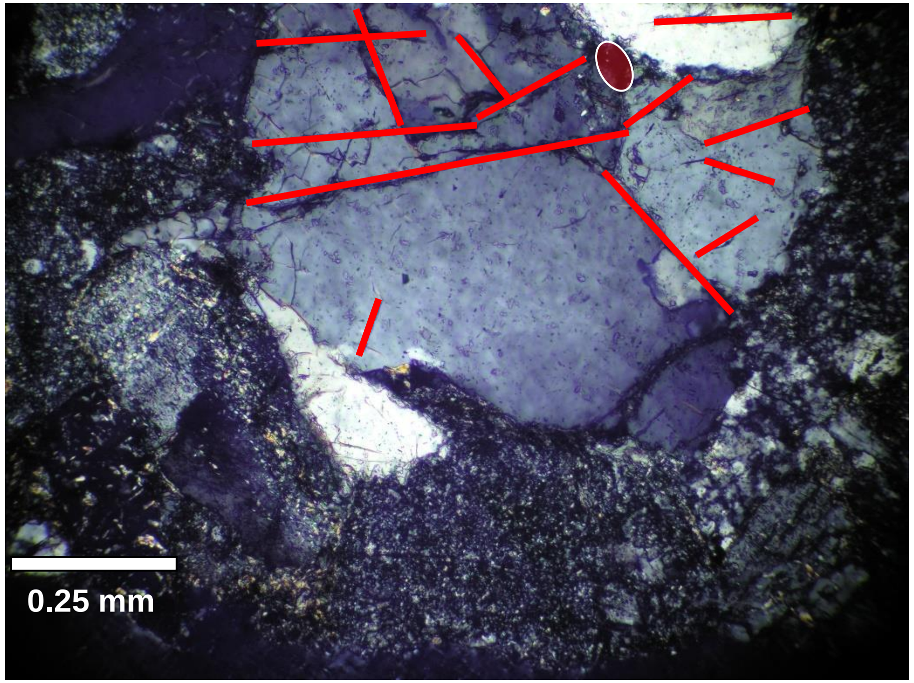
RCP
In pursuit of new ideas

Compaction

RCP
In pursuit of new ideas



$\alpha = 0.01$ **(average)**



A-06. Microfractures

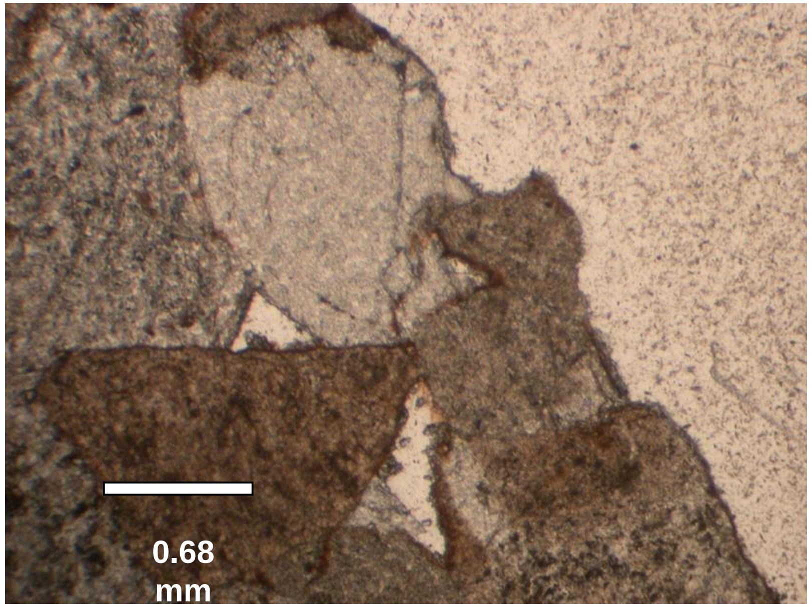


Foto 16: RN 1007 3620 x4 compactación.; crecimiento secundario de cuarzo.

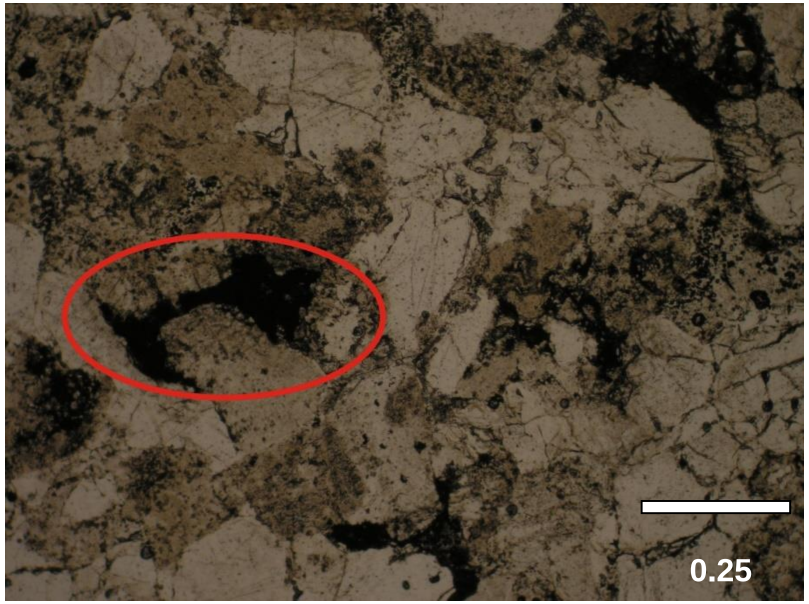


Foto 134 RN 1040 3332,50 x10 *voids* ocluidos con materia orgánica.

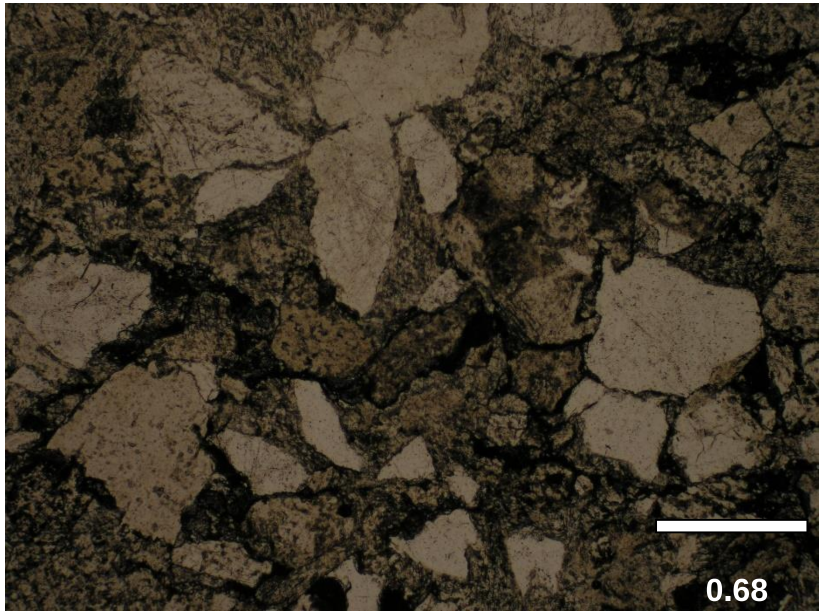


Foto 139 RN 252 3397,38 x4XN materia orgánica en fracturas.

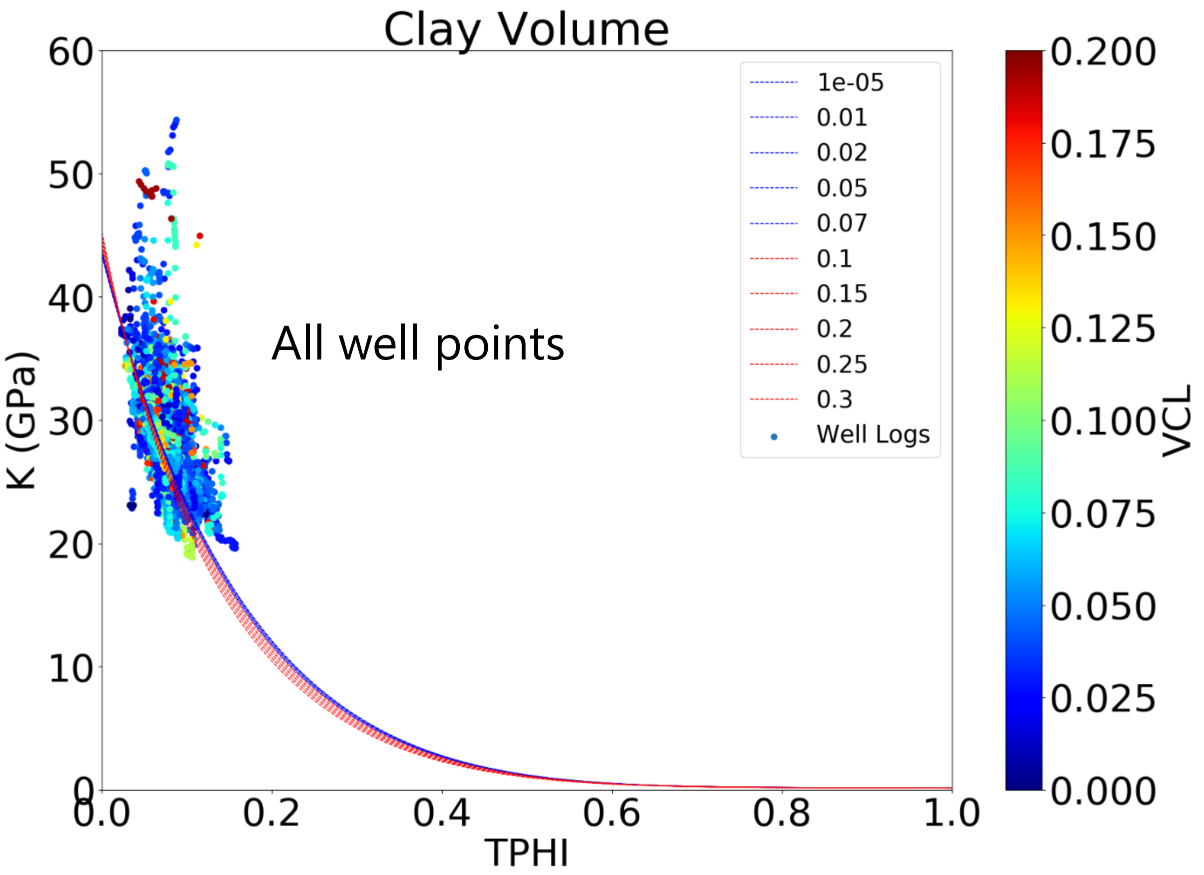
Clay Analysis

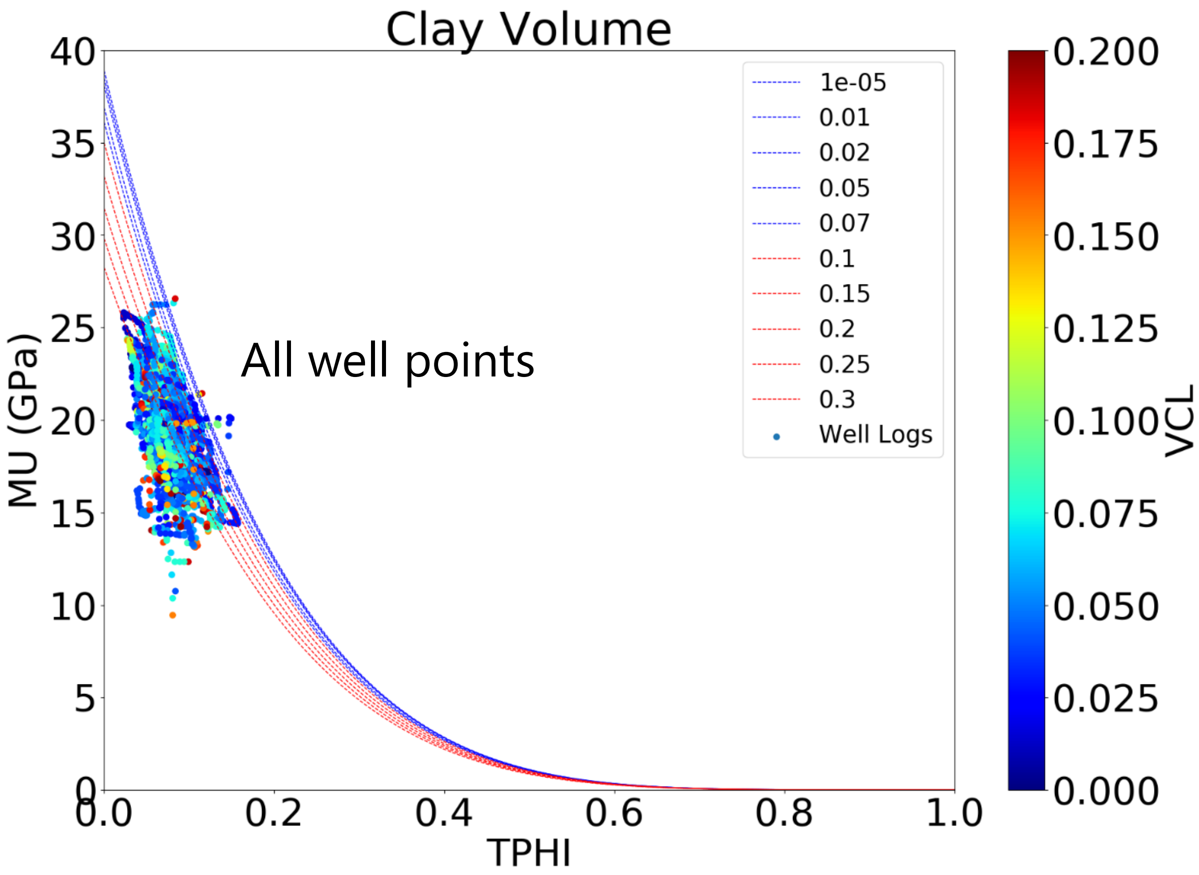
RCP In pursuit of new ideas

Water Saturated media

$\boldsymbol{\alpha}$ = 0.1

All well points





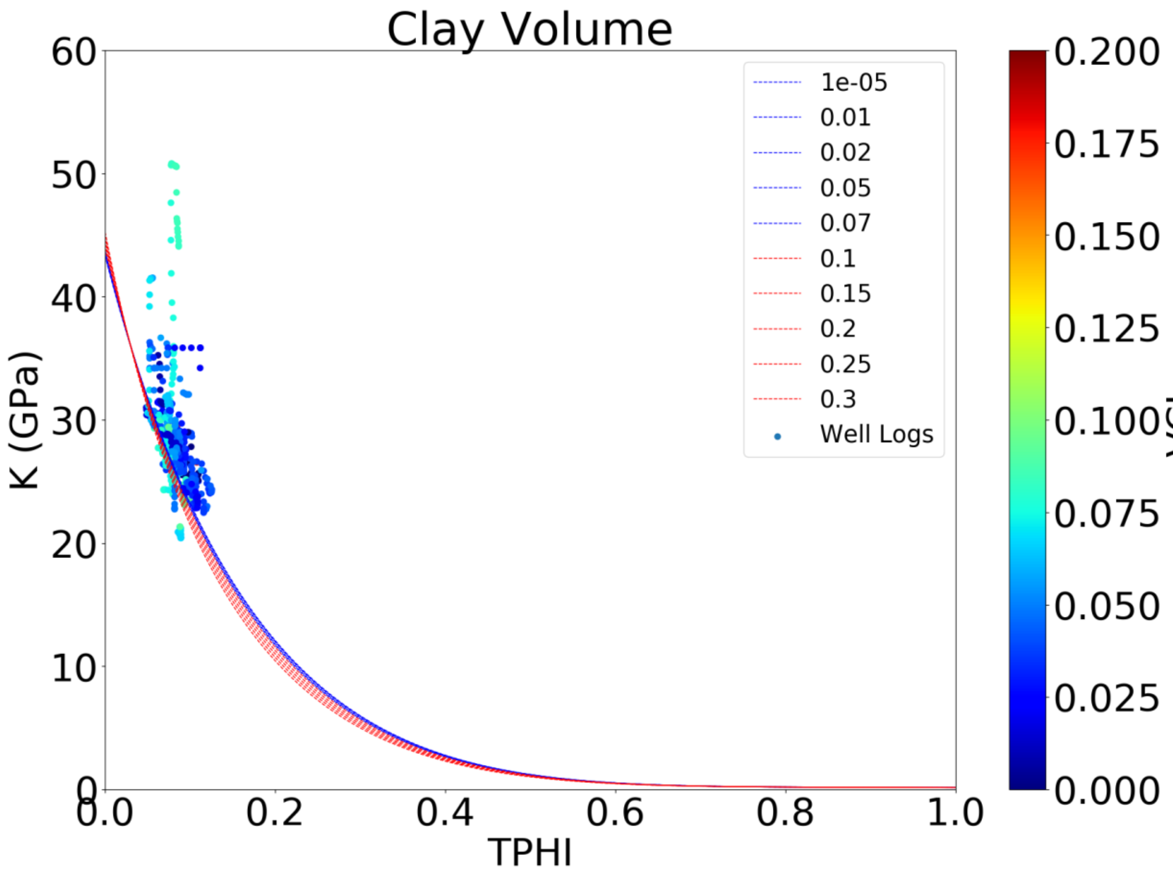
Clay Analysis

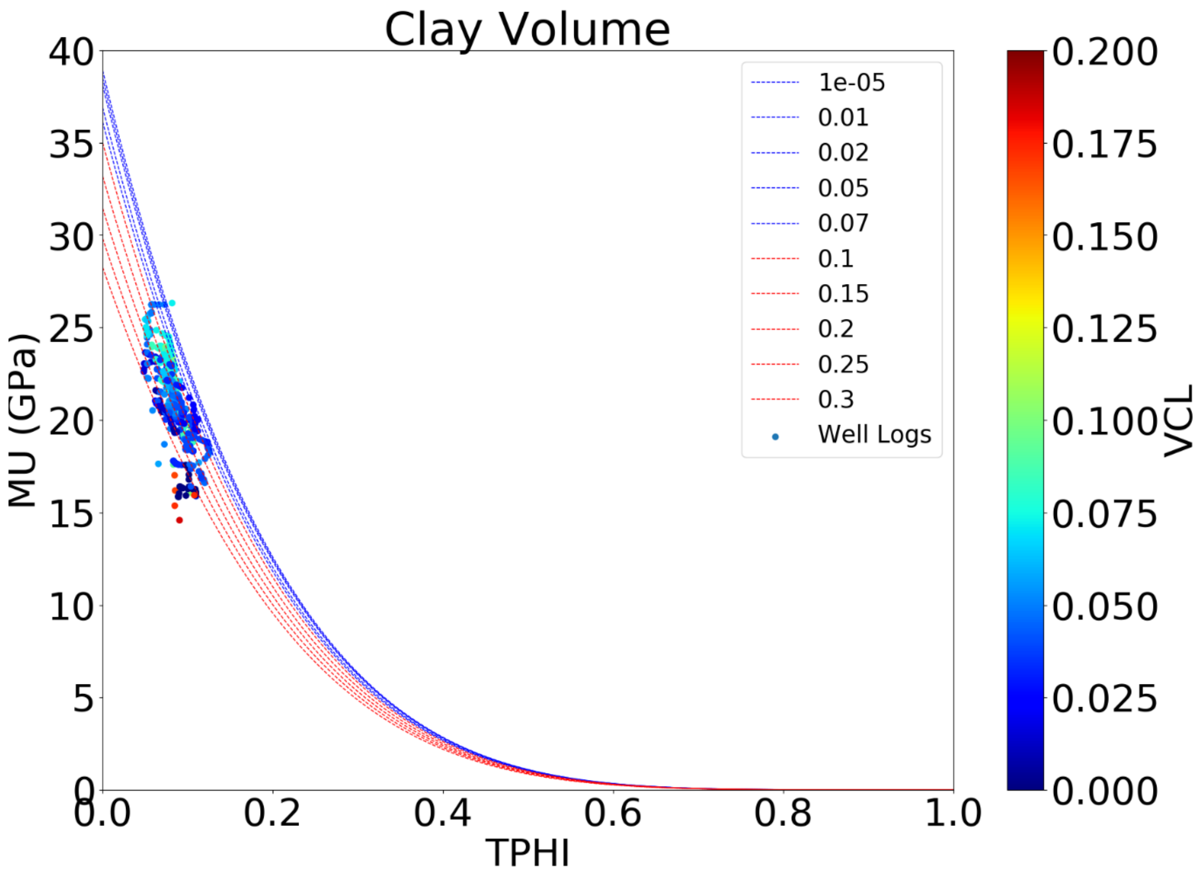
RCP
In pursuit of new ideas

Water Saturated media

α = 0.1

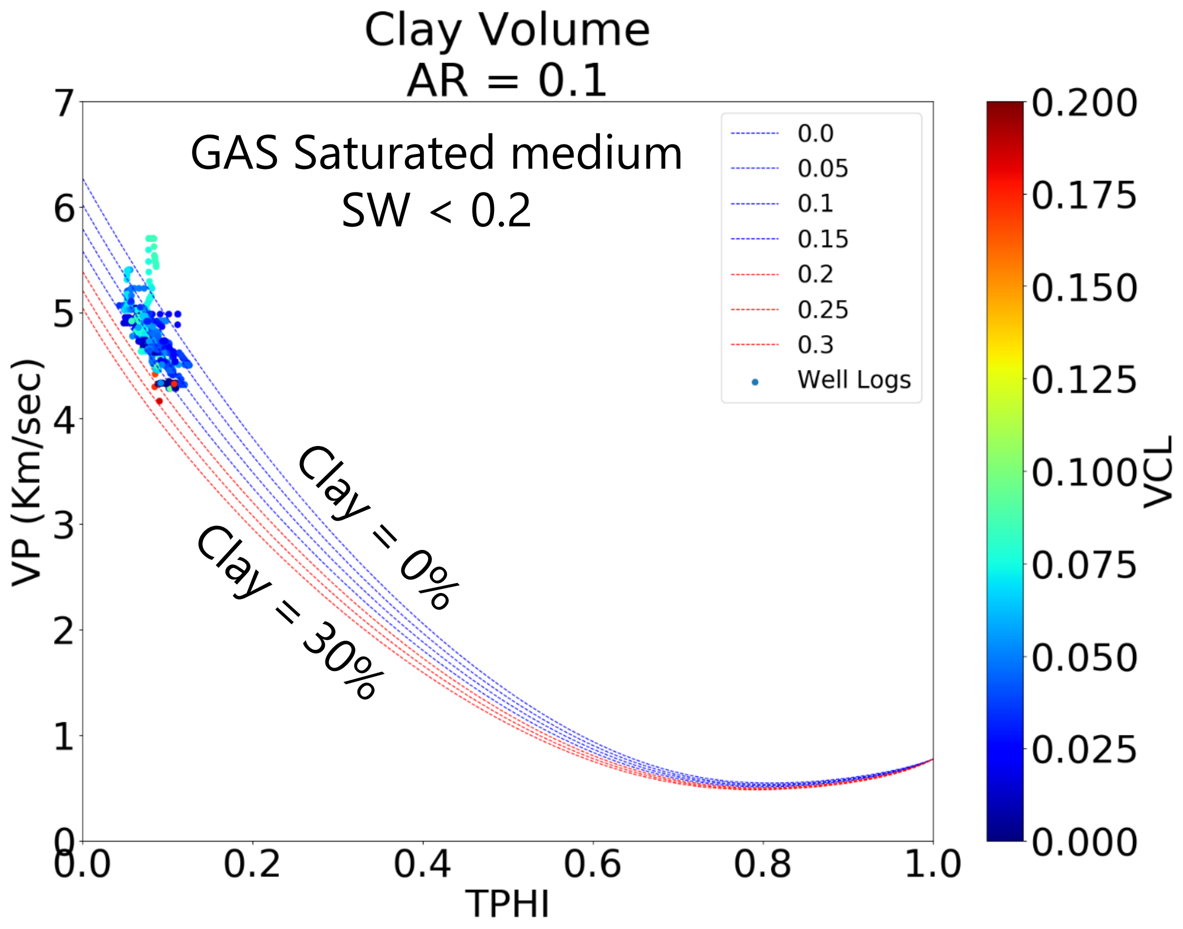
Well Points = Gas saturated

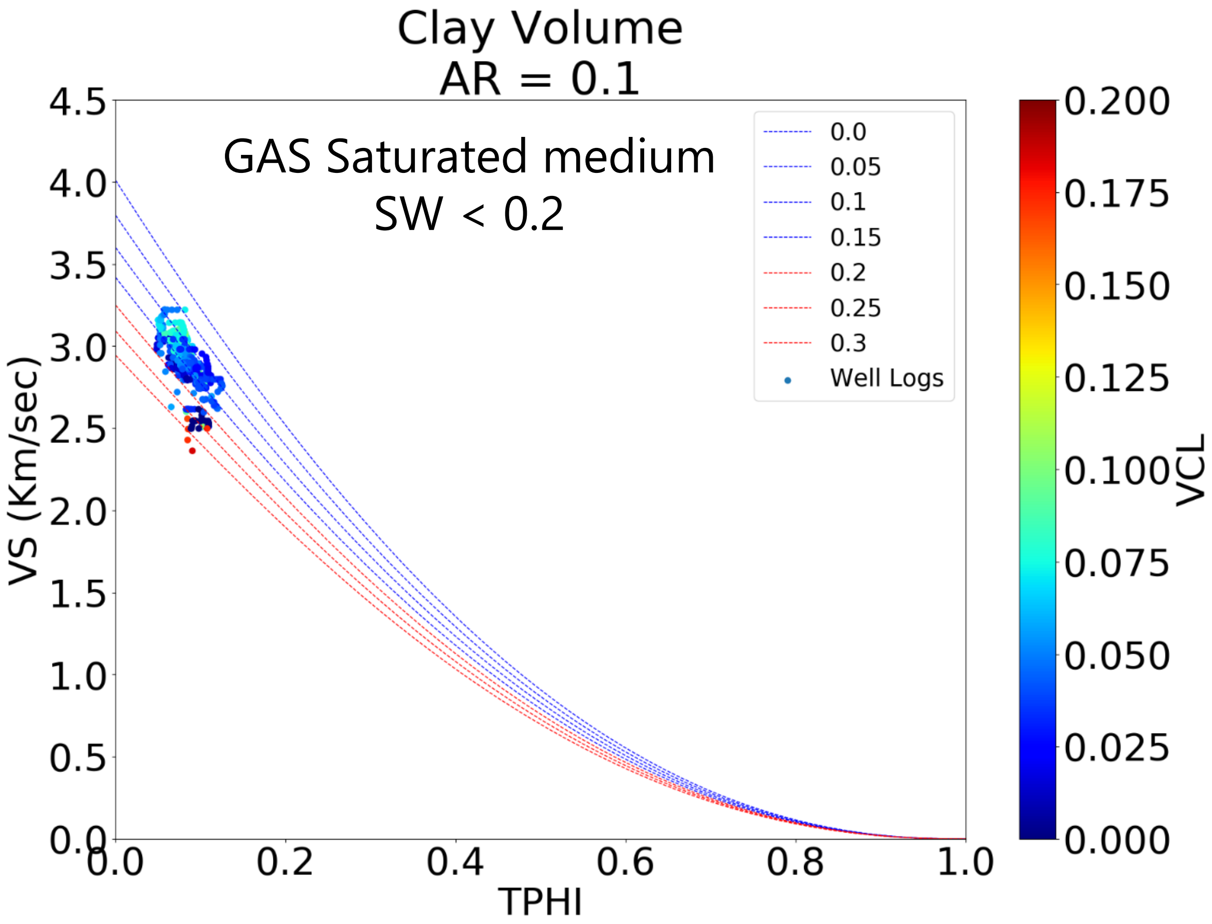




Clay Analysis

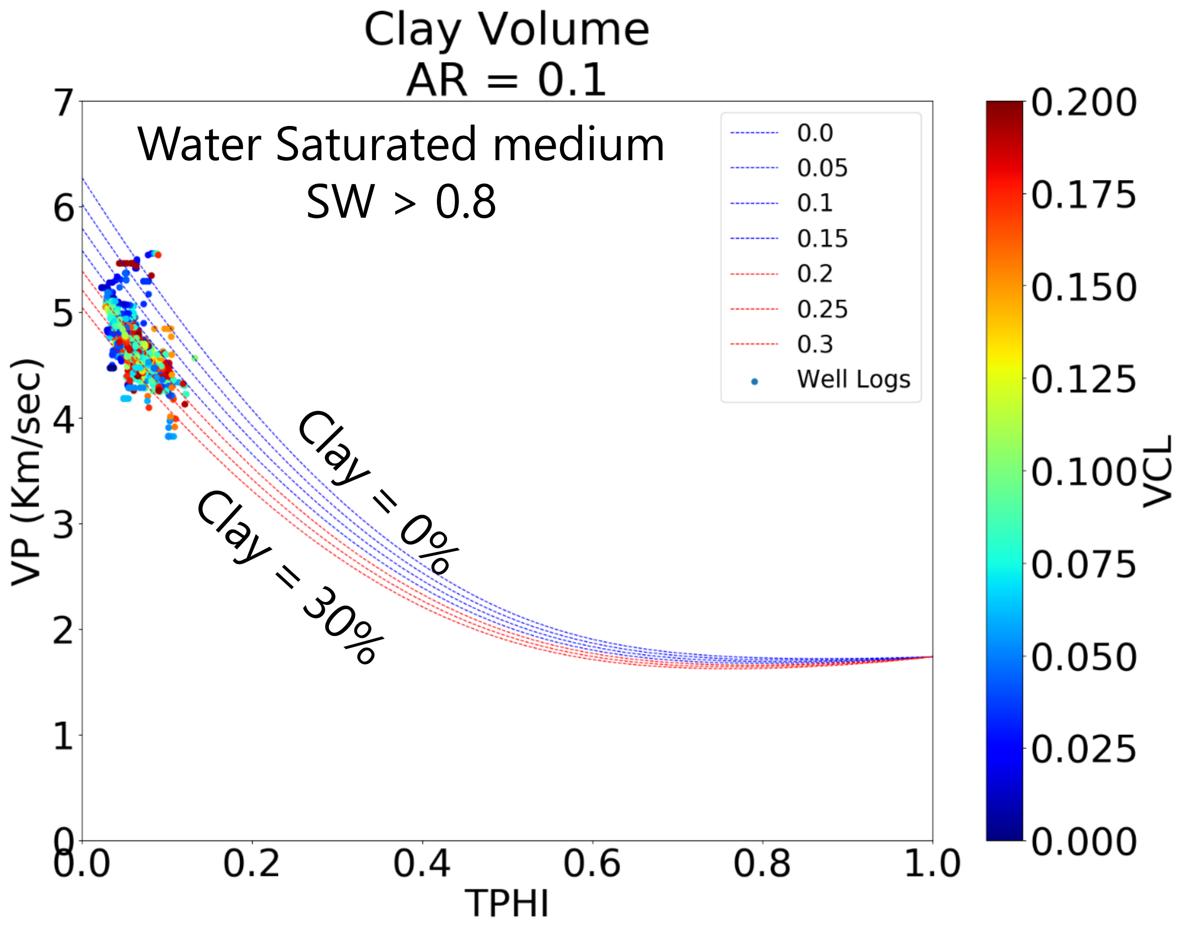
RCP In pursuit of new ideas

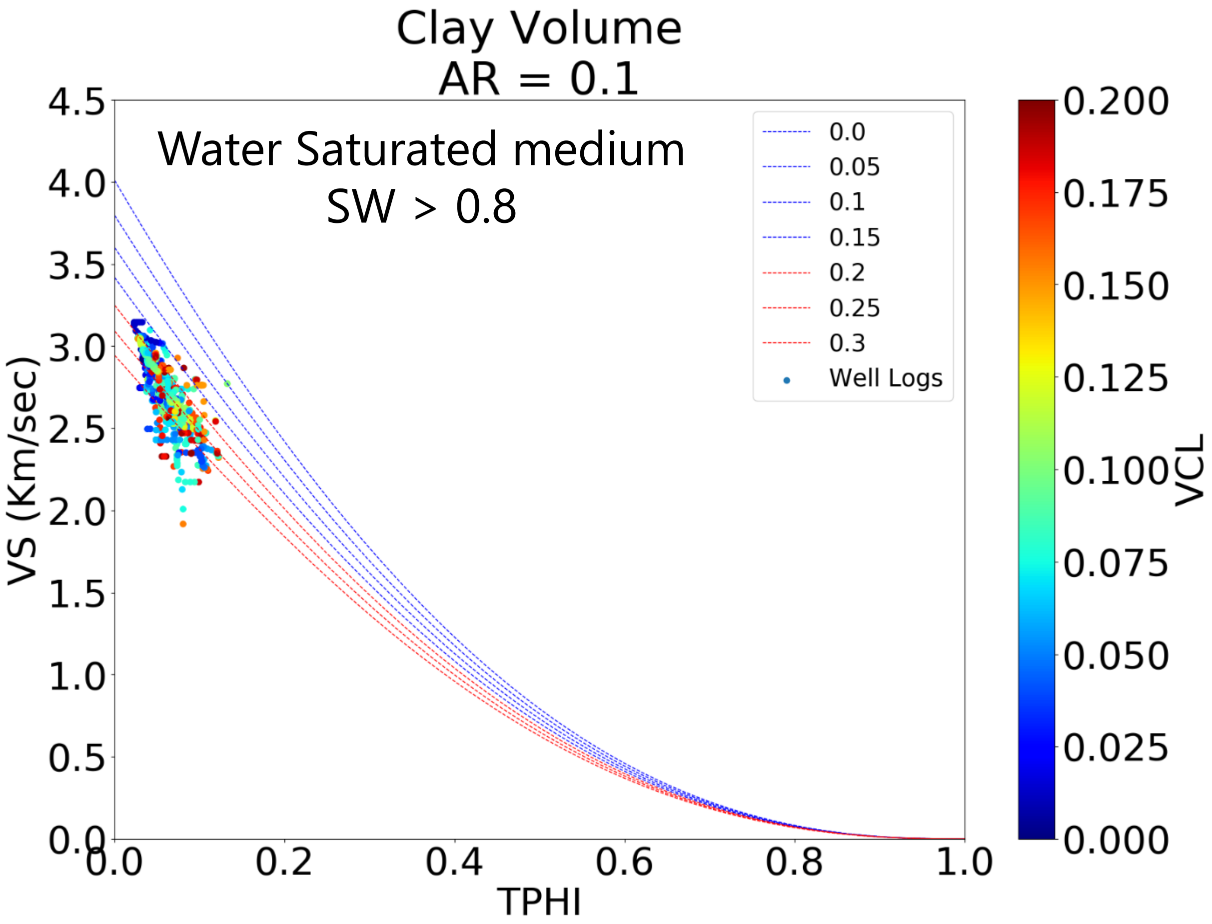


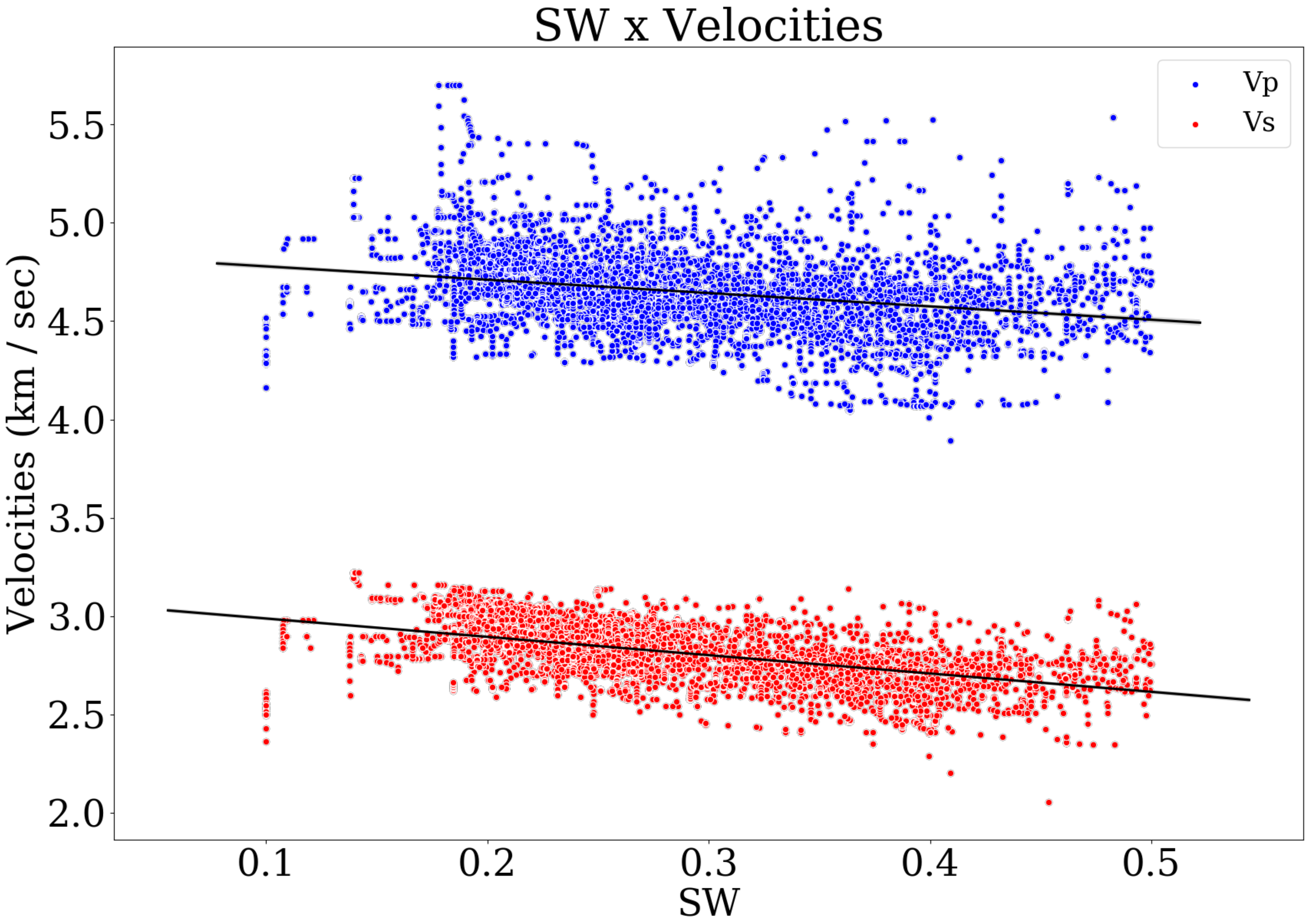


Clay Analysis

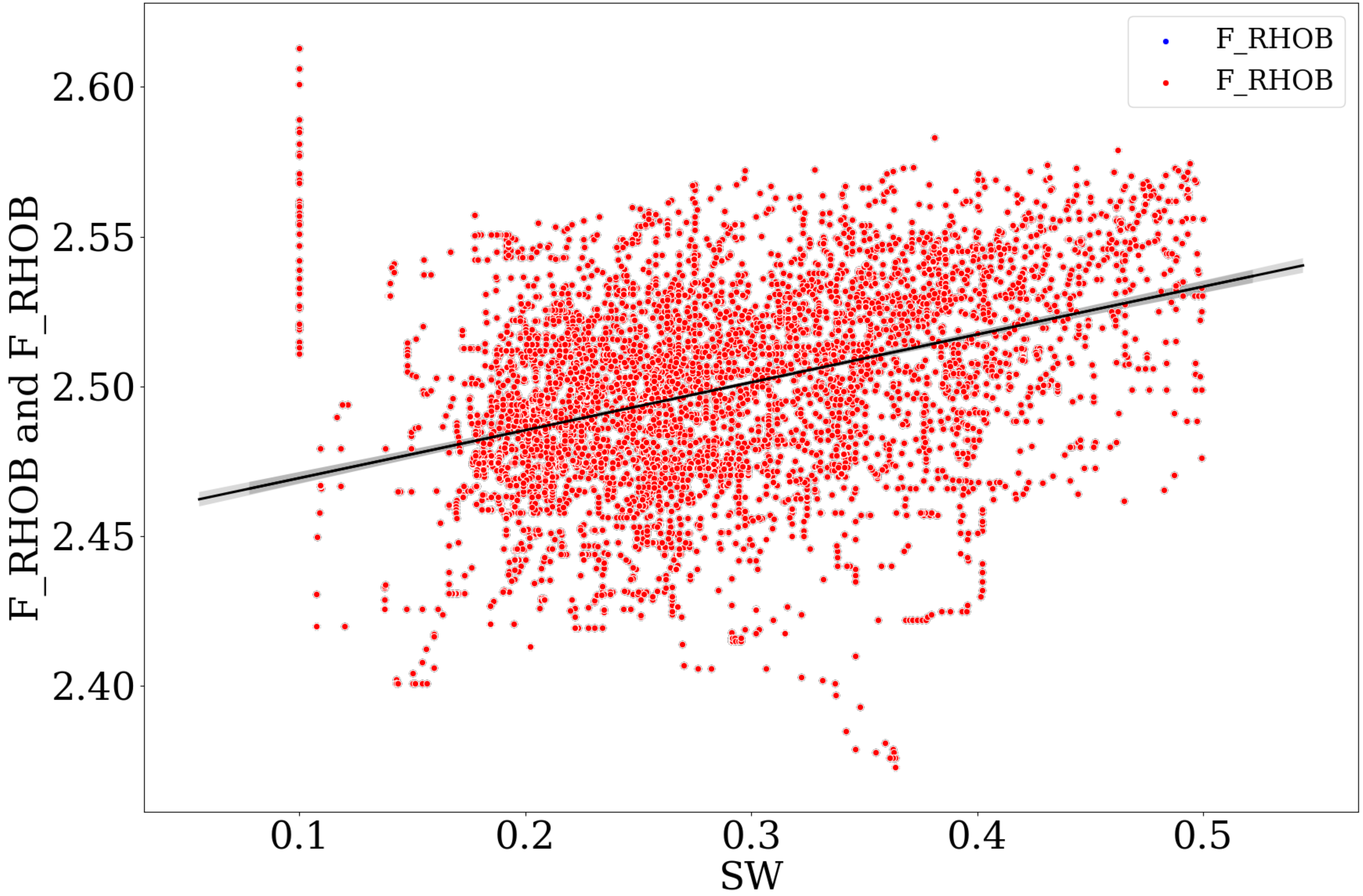
In pursuit of new ideas



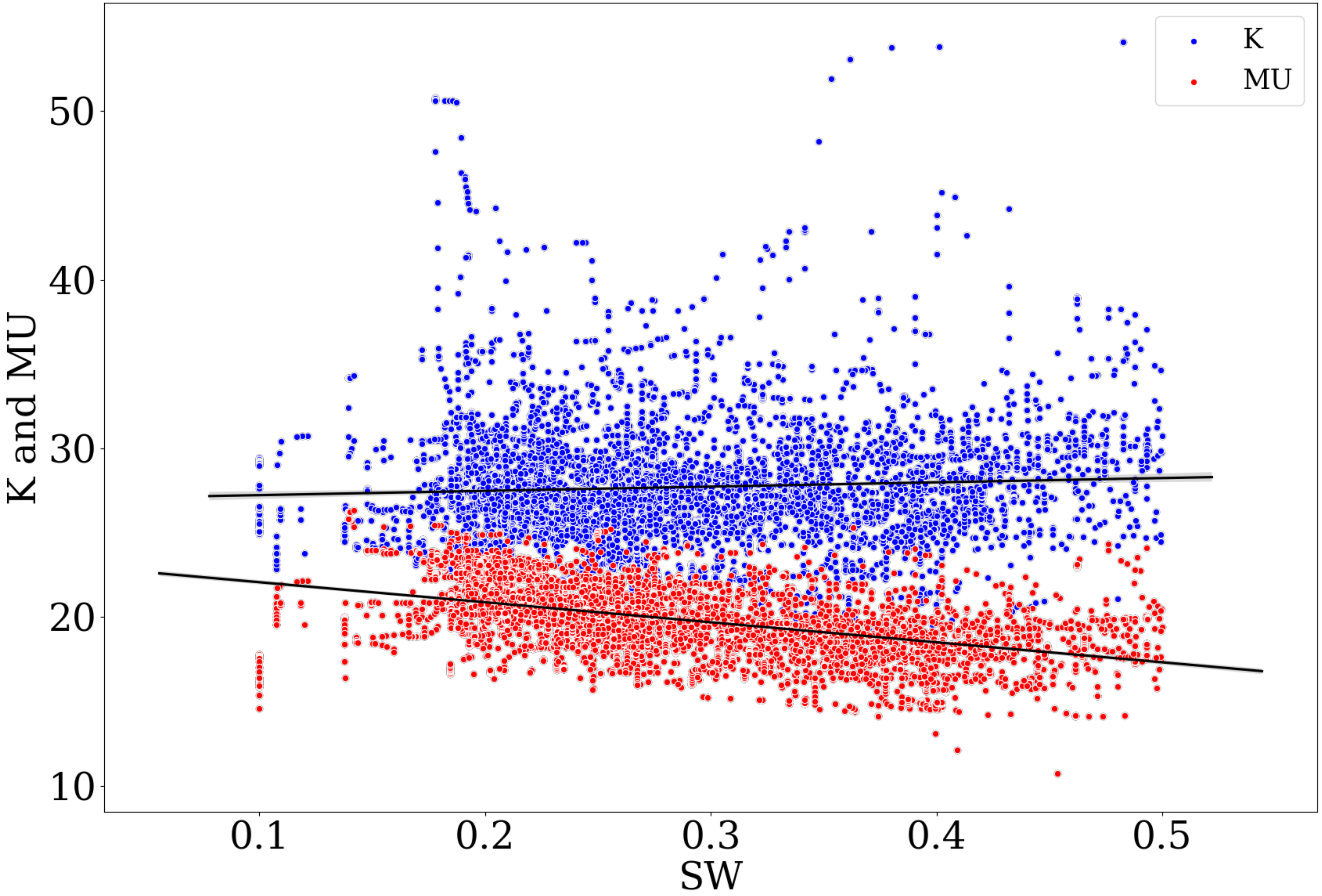




RCP
In pursuit of new ideas



rsuit of new ideas



K
MU
50
40
30
20
10
K and MU
0.1
0.2
0.3
0.4
0.5
SW