Semi-parametric clustering of well log data from the Fort Worth Basin, Texas

AASPI Consortium Meeting

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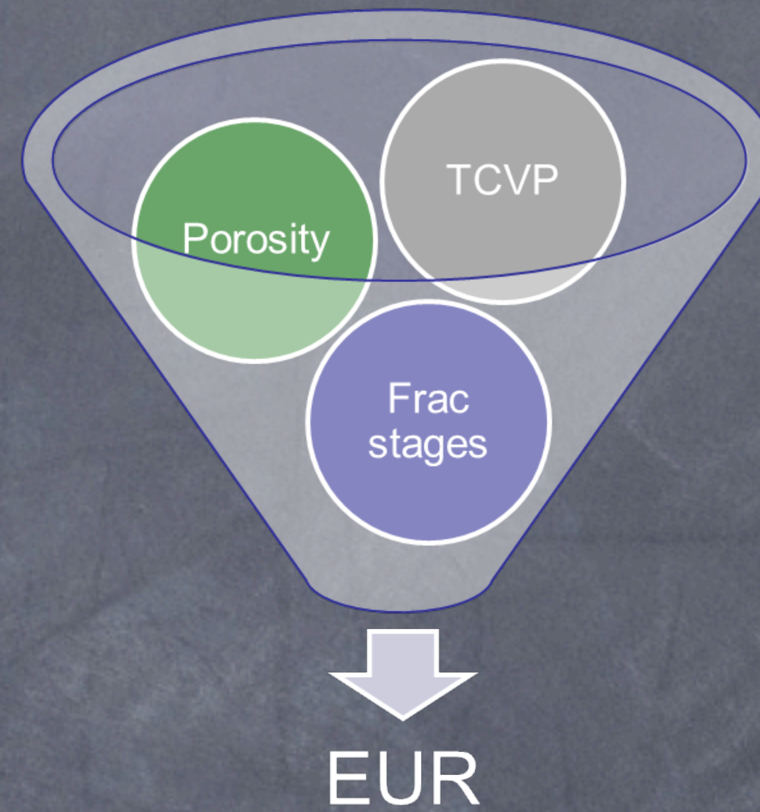
Outline

- GOAL
- AVO INVERSION
- RESULTS
- ANALYSIS
- CONCLUSIONS

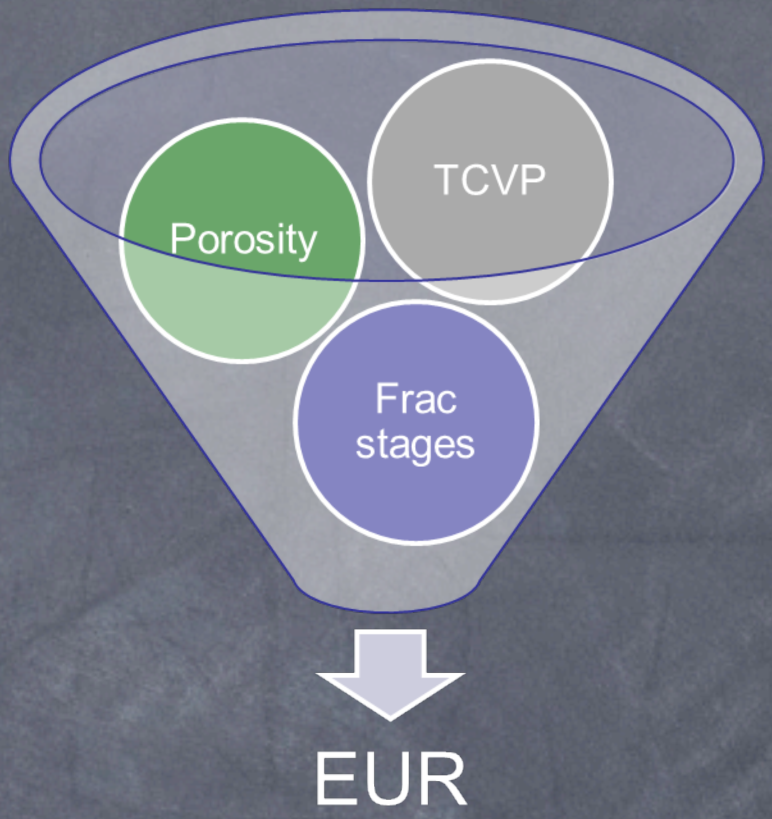
Goal

- Using a multivariate analysis, develop a predictive tool for EUR based on geological and engineering parameters



Goal

- Using a multivariate analysis, develop a predictive tool for EUR based on geological and engineering parameters

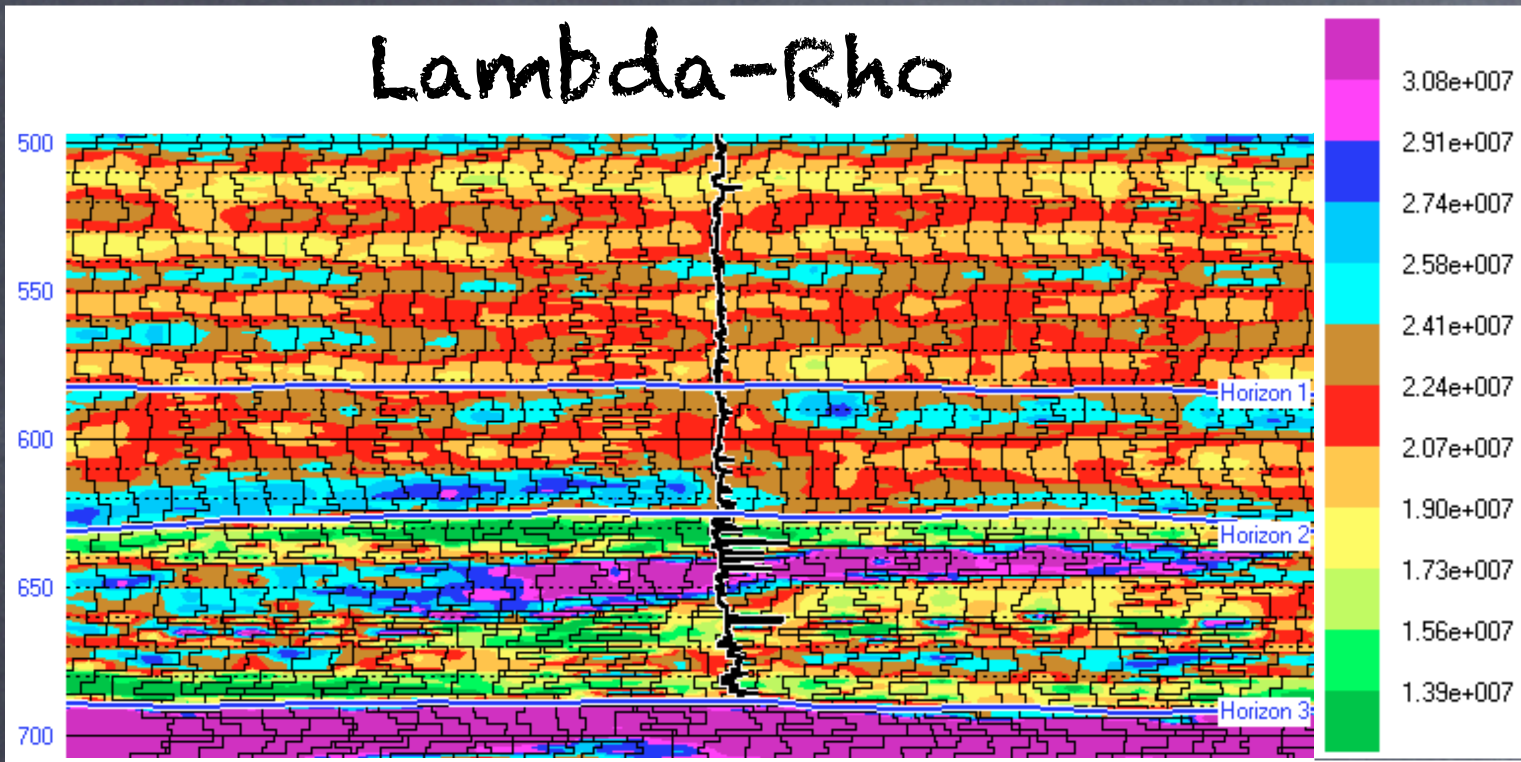


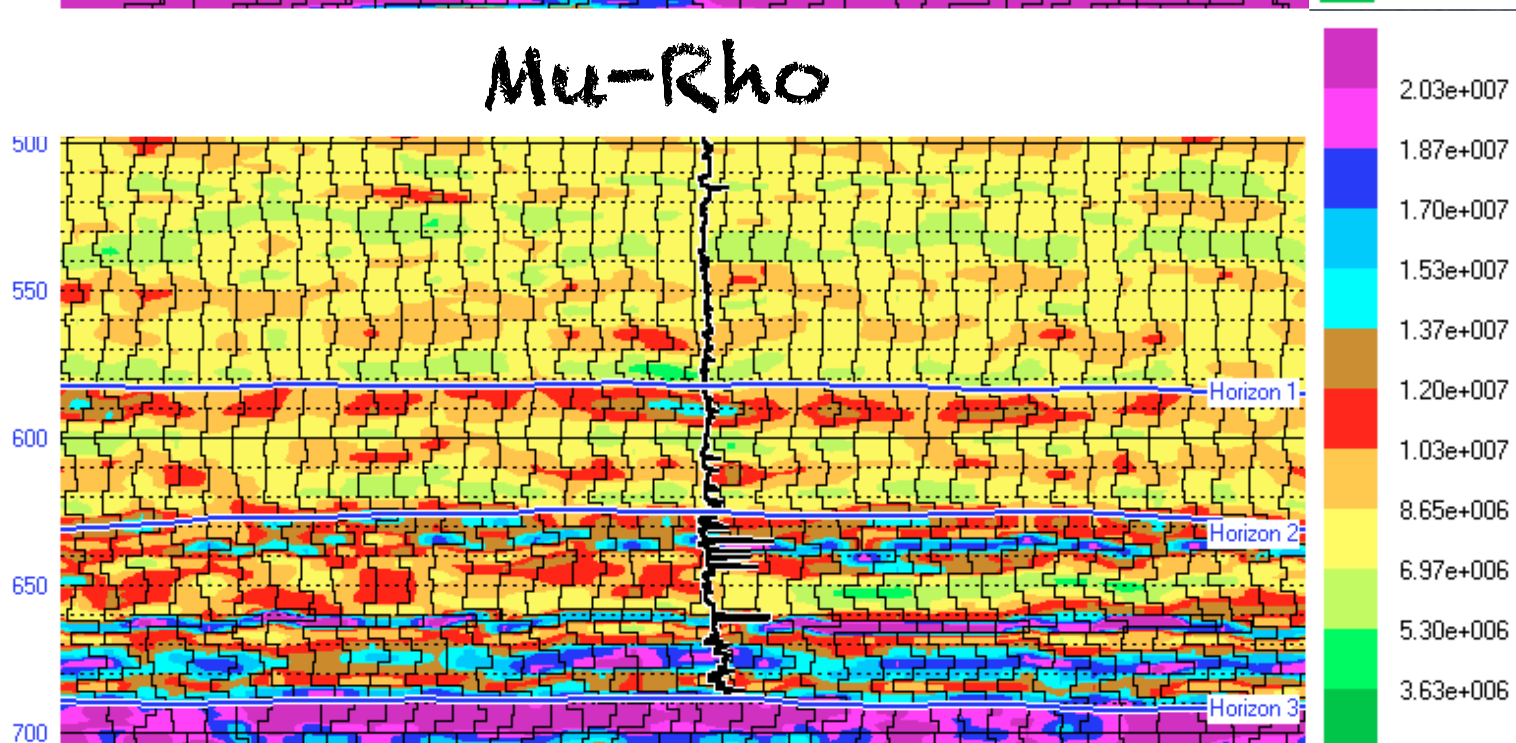
- Use of seismic clustering techniques to identify heterogeneity and formation evaluation in the Barnett Shale

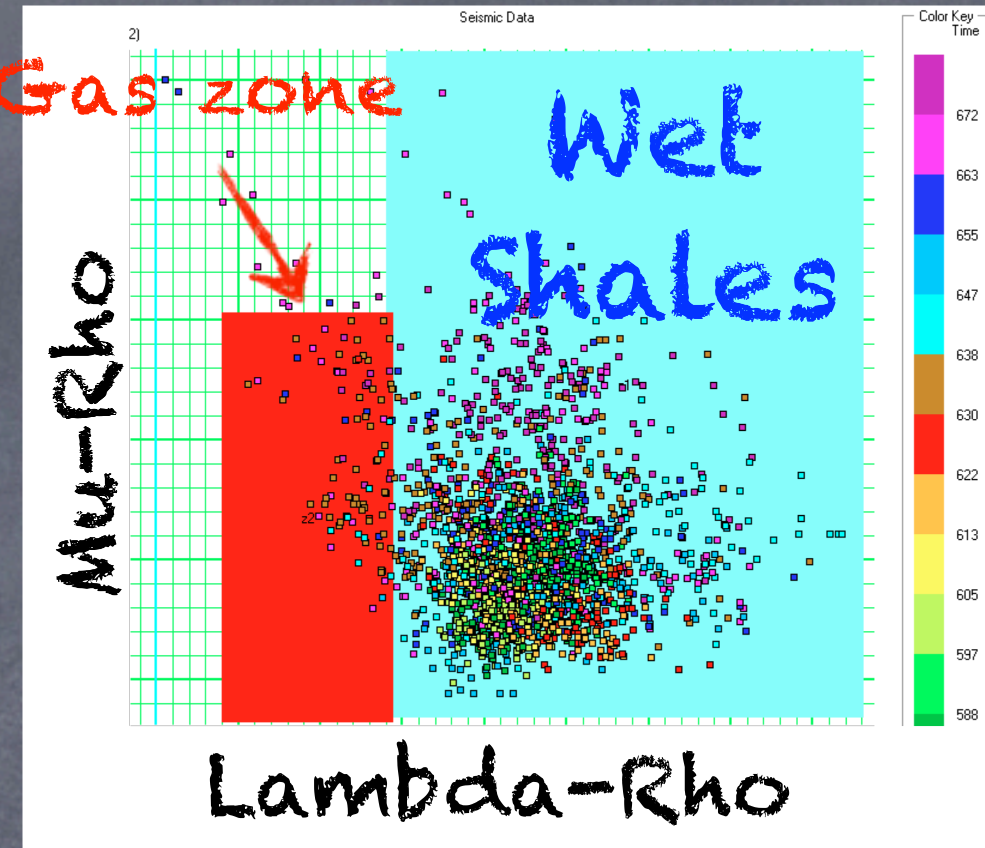
Semi-parametric clustering of well log data from the Fort Worth Basin, Texas

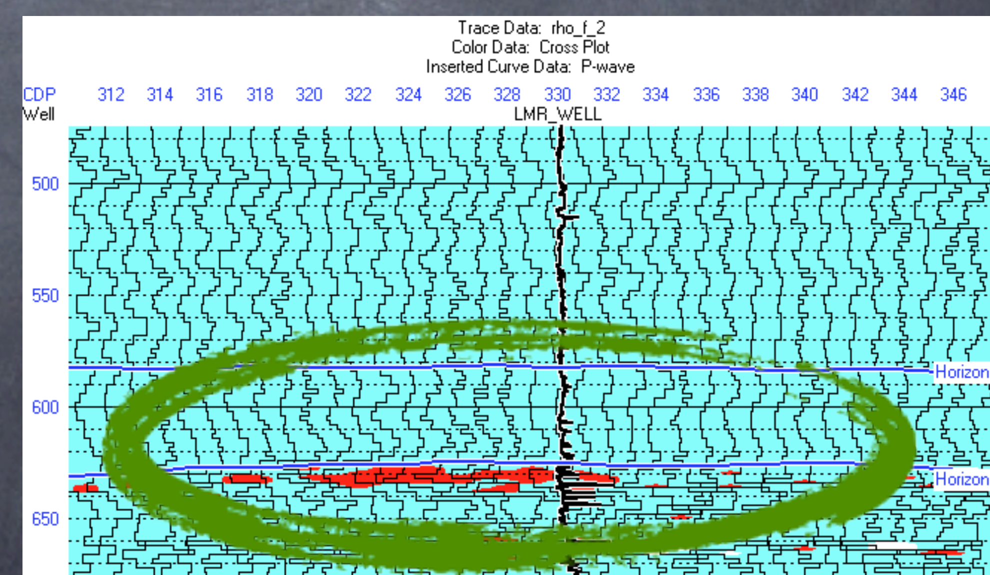
LAMBDA-RHO / MHU-RHO INTEGRATION

Introduction









Images from H&R Strata Manual

Methodology

Lamé Parameters

V_S

Shear wave

$$V_S = \sqrt{\frac{\mu}{\rho}}$$

Dipole log

Original Rock

$$\lambda\rho = Z_P^2 - 2Z_S^2$$

$$\mu\rho = Z_S^2$$

μ = Rigidity (Lame moduli)

λ = Incompressibility

V_P

Compressional wave

$$V_P = \sqrt{\frac{\lambda + 2\mu}{\rho}}$$

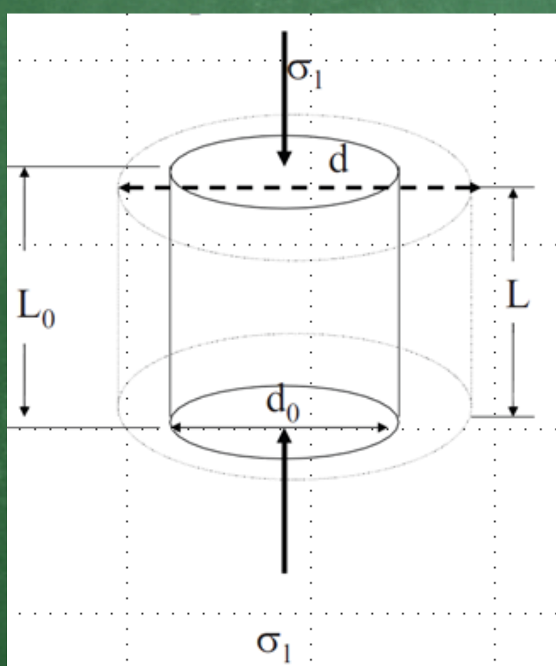
Sonic log

Modified from Goodway, 2009

Appendix

STATIC MODULI AND MODULI RATIO DEFINITIONS IN TERMS OF LAME PARAMETERS

Young's Modulus



$$E = \frac{\mu(3\lambda + 2\mu)}{(\lambda + \mu)}$$

$$V_p = \sqrt{\frac{\lambda + 2\mu}{\rho}}$$

P-wave Velocity

$$V_s = \sqrt{\frac{\mu}{\rho}}$$

S-wave Velocity

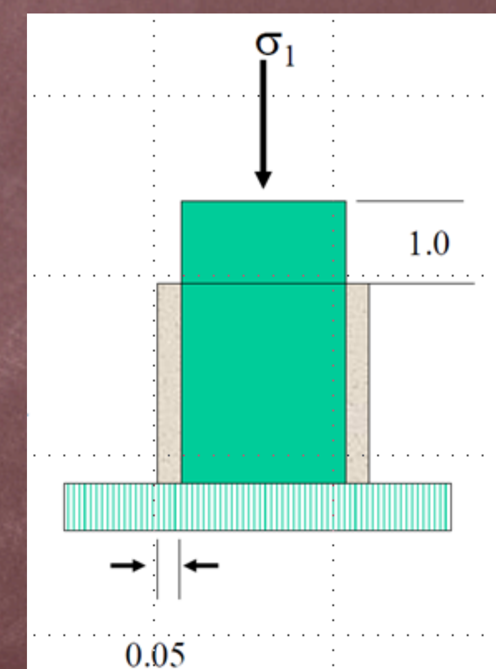
$$M = \lambda + 2\mu$$

P-wave Modulus

$$\frac{E}{1+\nu} = 2\mu$$

Young - Poisson Relation

Poisson's ratio

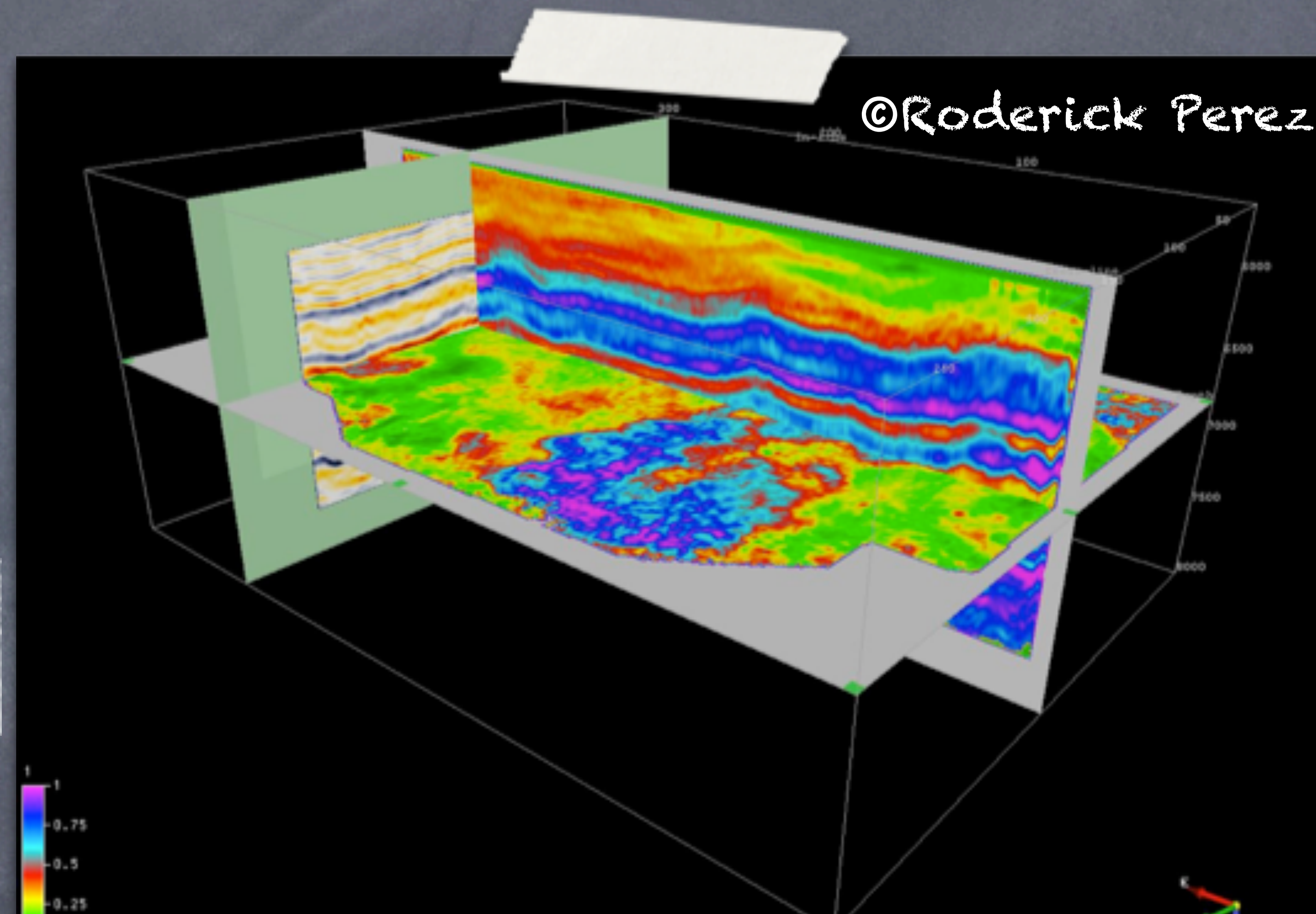


$$\nu = \frac{\lambda}{(2\lambda + 2\mu)}$$

Methodology

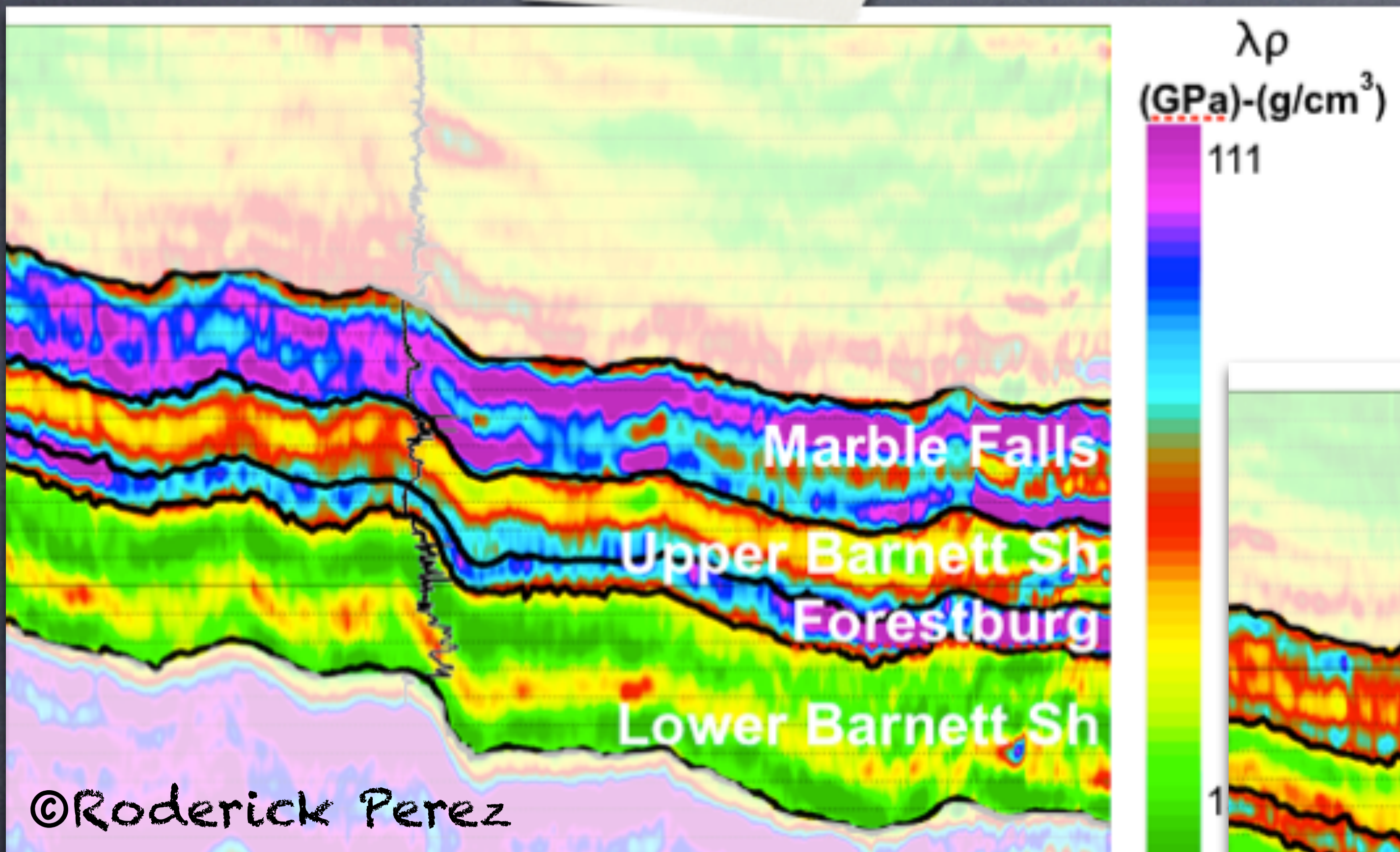
AVO Inversion

- Angle Gathers
  - R_p reflect. → Z_p Imped.
  - R_s reflect. → Z_s Imped.
- → Lambda-Rho / Mu-Rho
- → Cross-plots

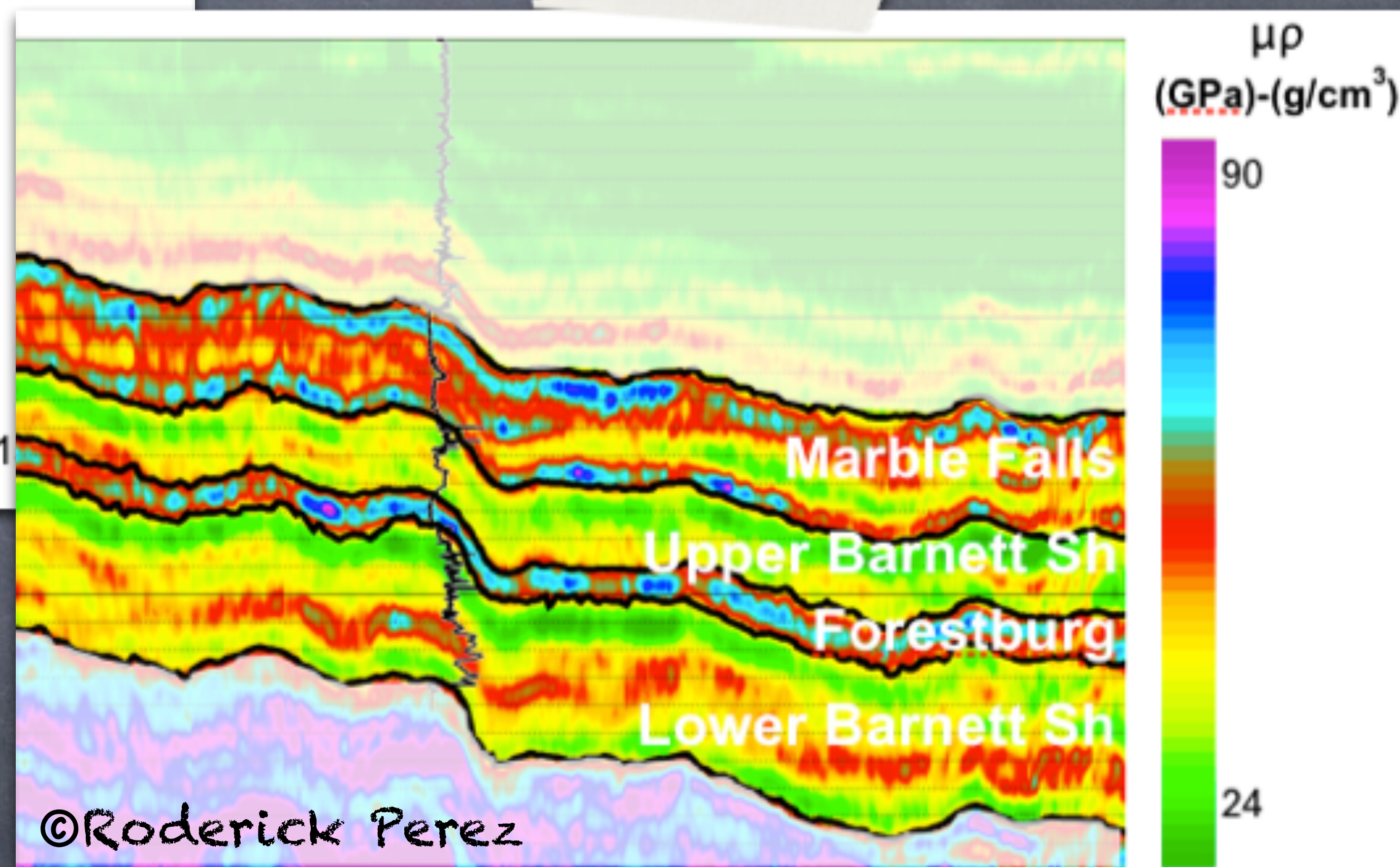


Lambda-Rho & Mu-Rho from the area of study

Results



Lambda-Rho from representative inline of area of study



Mu-Rho from representative inline of area of study

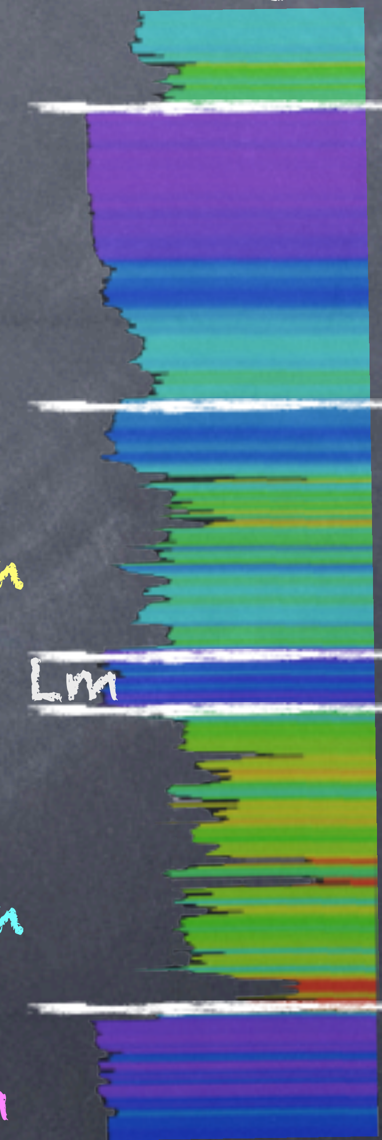
Methodology

Cross-plots

	V_p ft/s	V_s ft/s	Rho kg/m^3	$\lambda\rho$ 10^8	$\mu\rho$ 10^8
Shale	12,600	8,000	2.55	41.6	15.9
Lime stone	20,000	10,500	2,7	80	90

GR

0 300



Methodology

Cross-plots

Mu- Rho

$10*10^8$

	Vp	Vs	Rho	$\lambda\rho$	$\mu\rho$
	ft/s	ft/s	kg/m^3	10^8	10^8
Shale	12,600	8,000	2.55	41.6	15.9
Lime stone	20,000	10,500	2,7	80	90

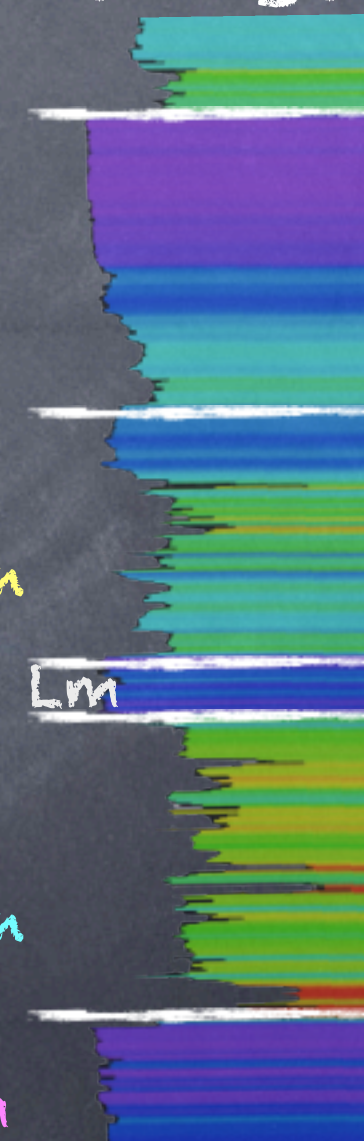
0

0 $15*10^8$

Lambda- Rho

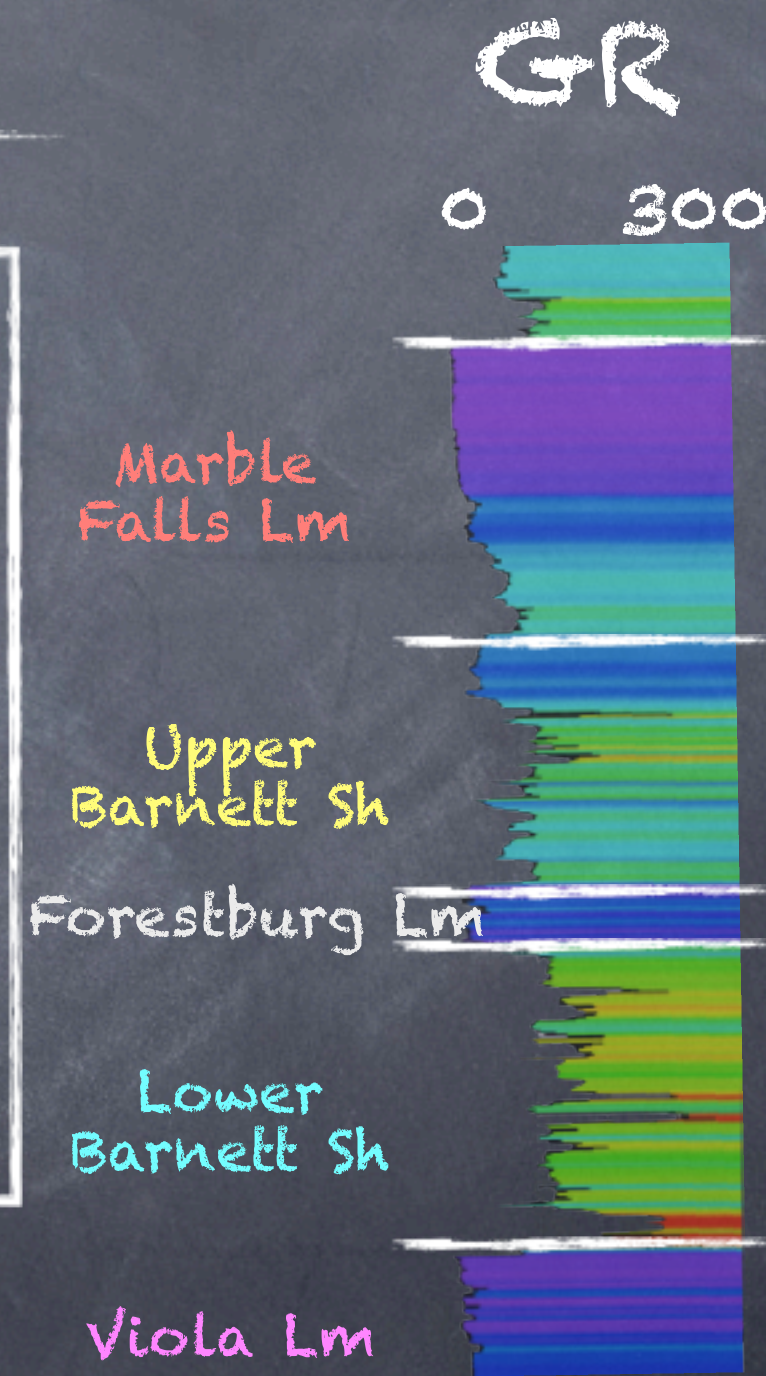
GR

0 300



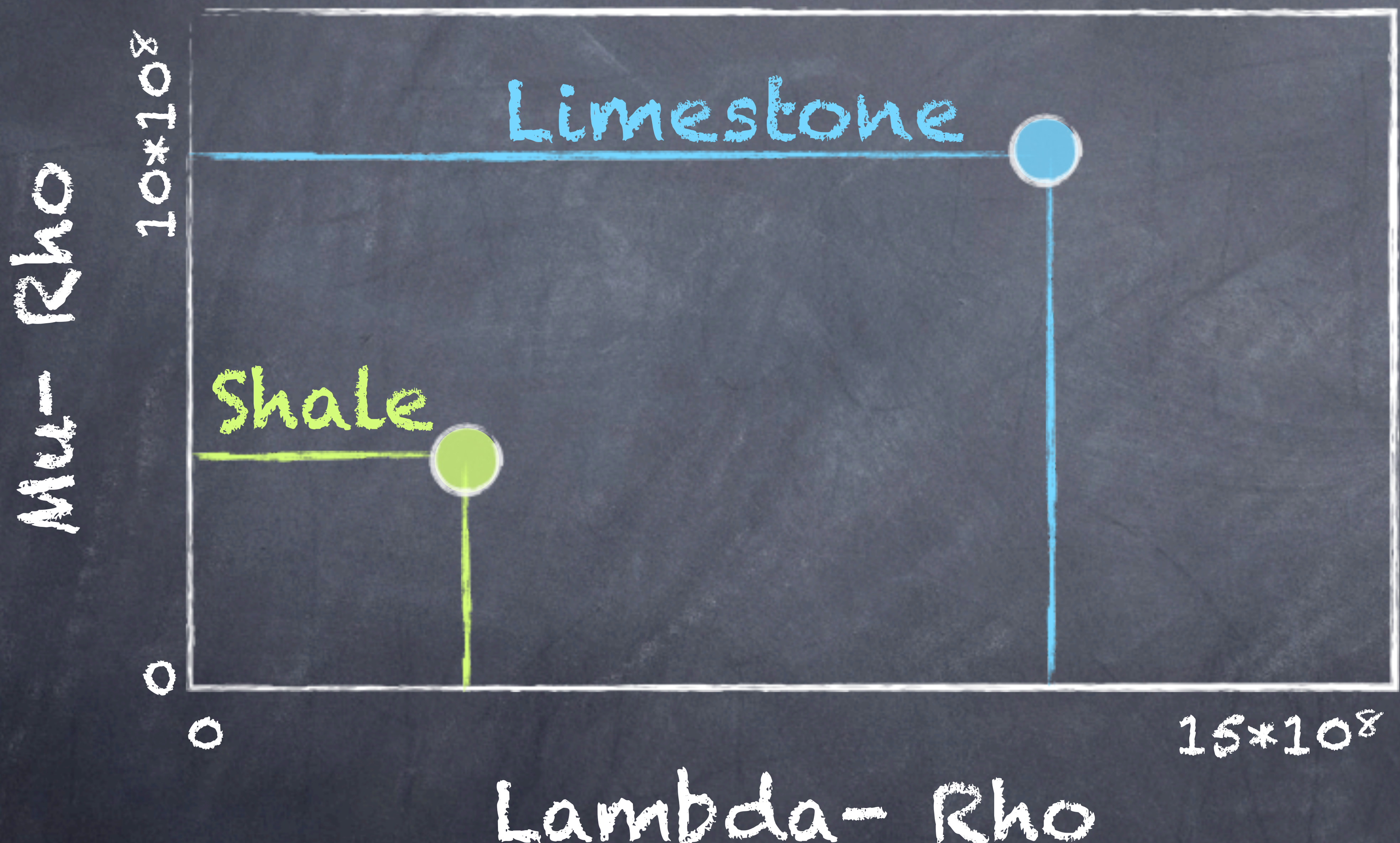
Methodology

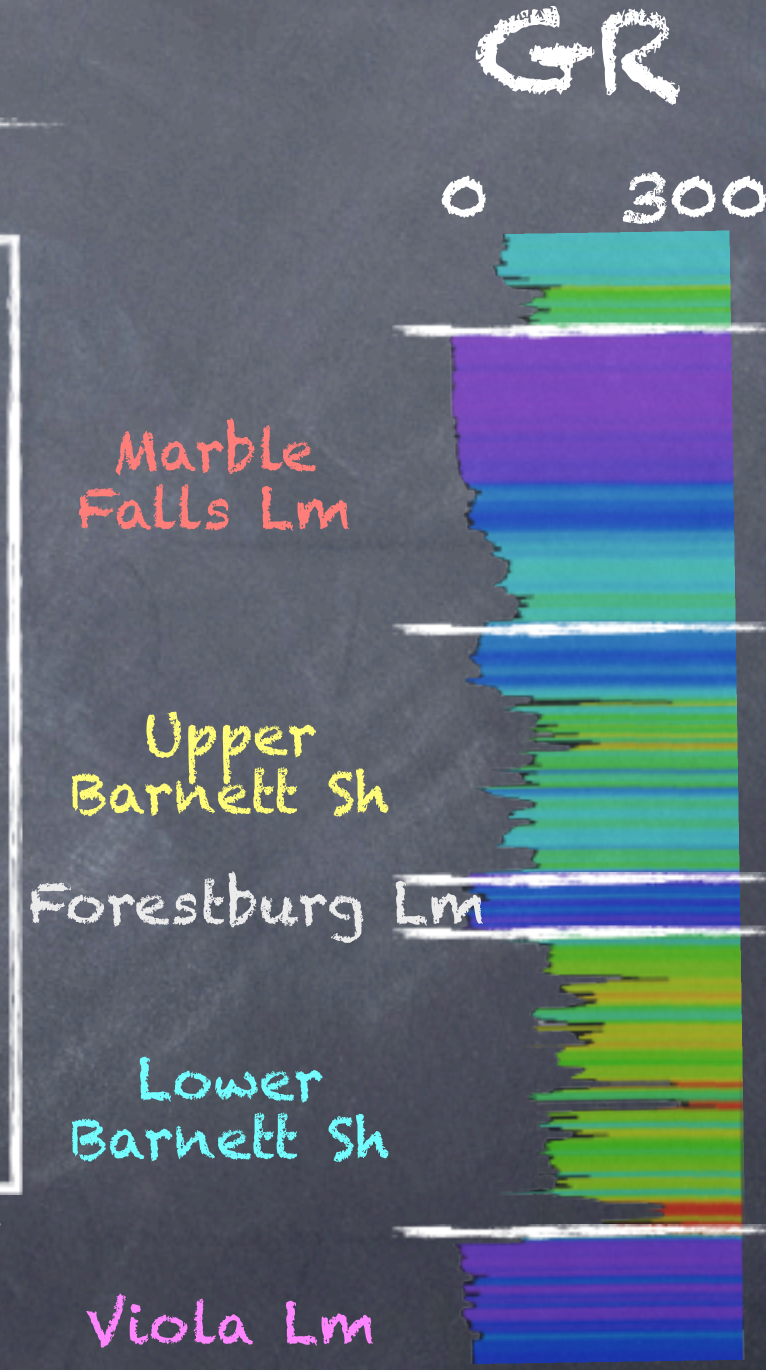
Cross-plots



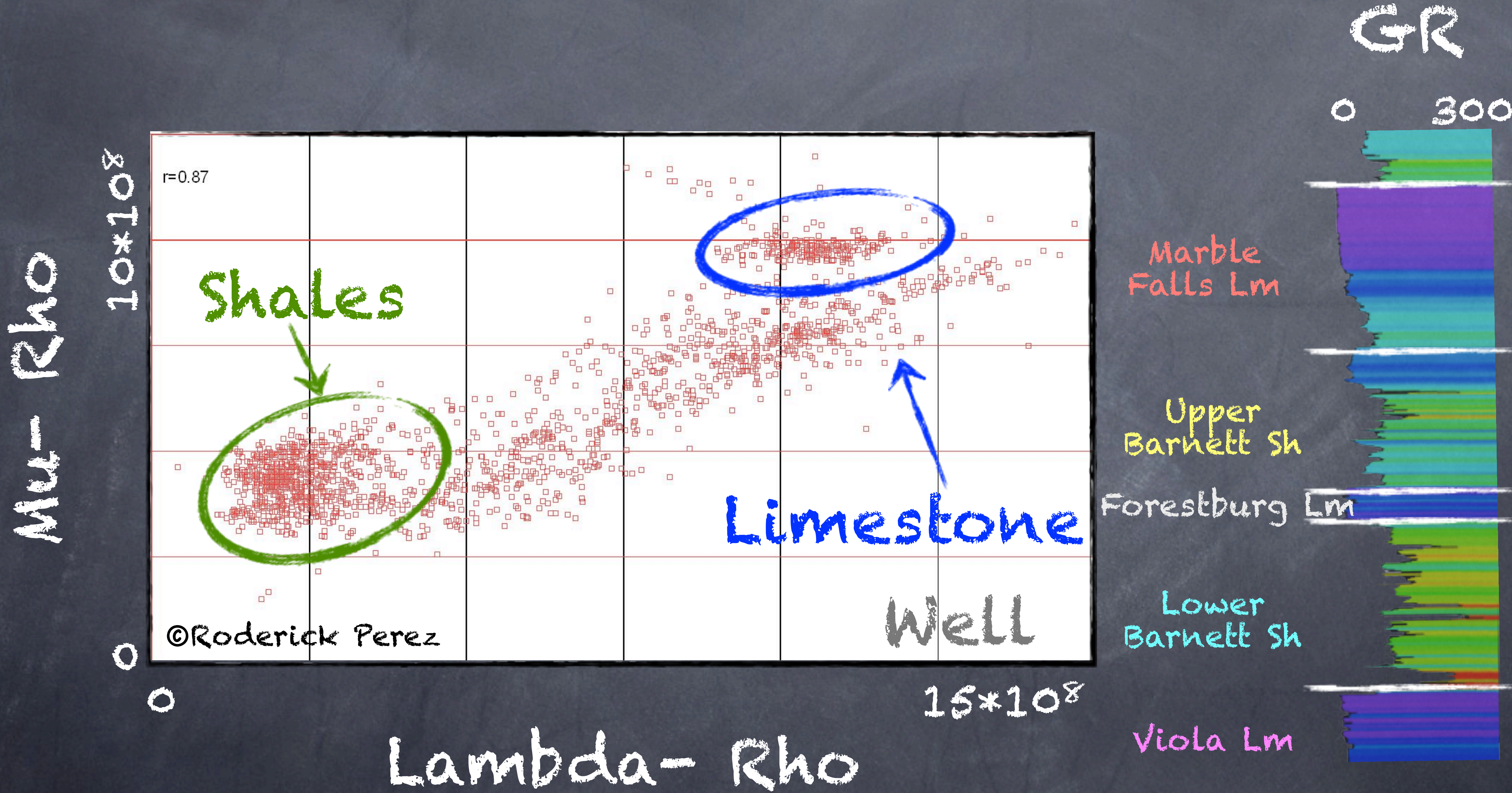
Methodology

Cross-plots

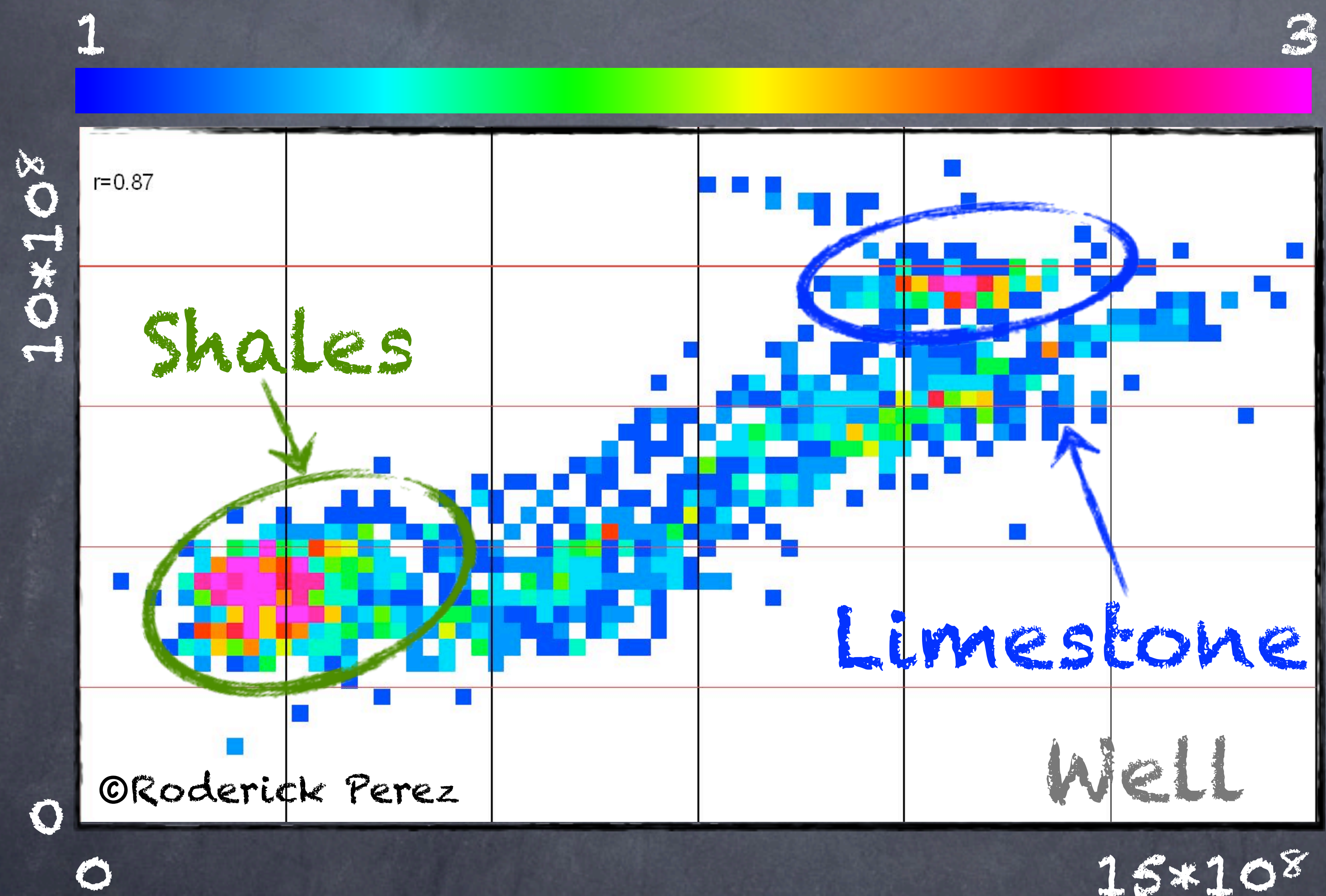


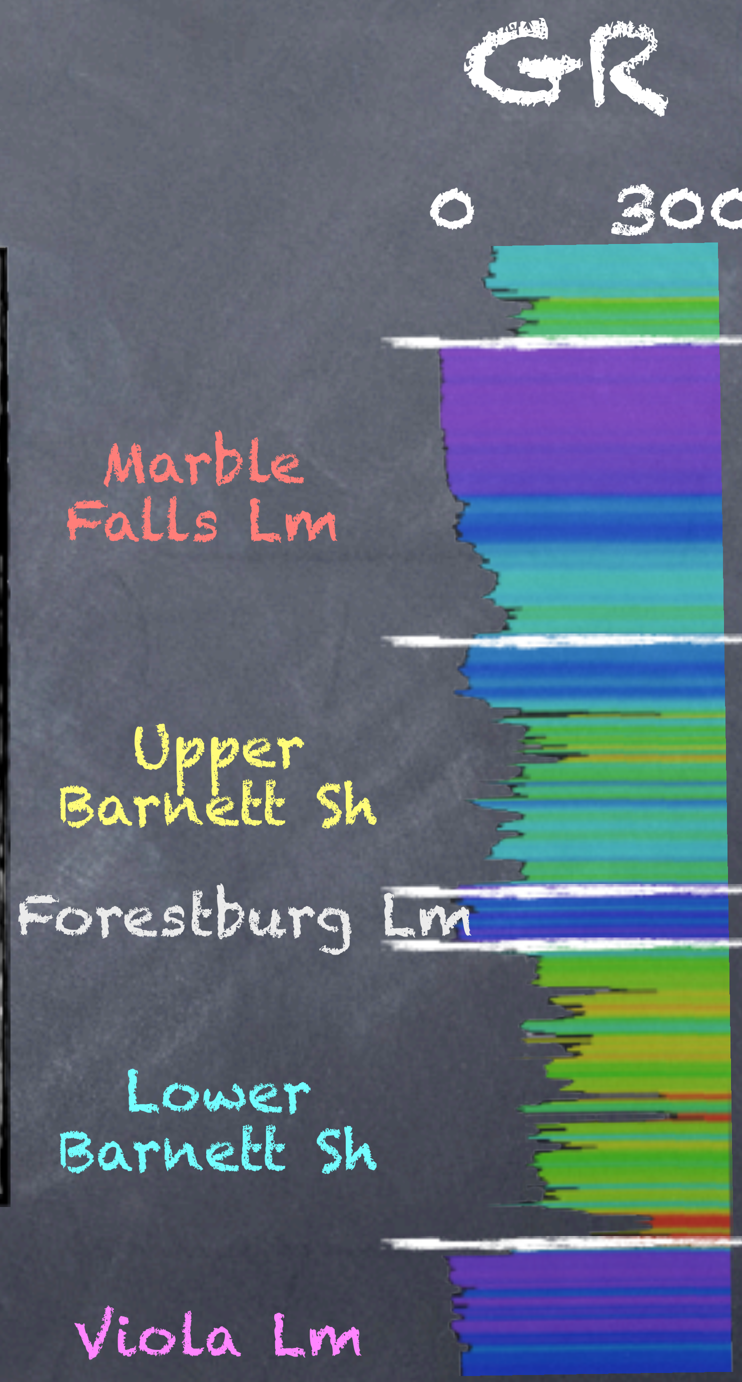


Methodology

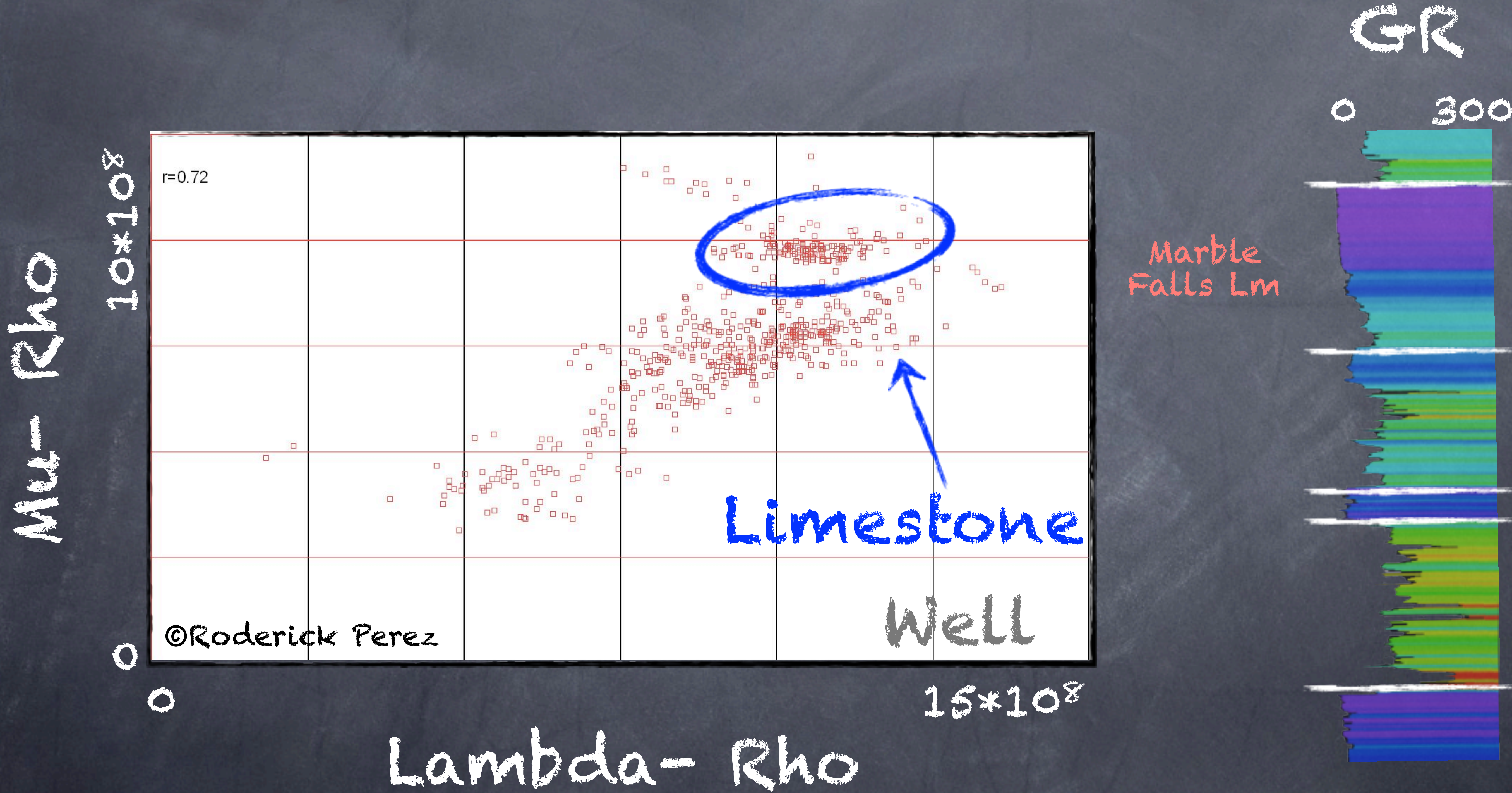


Methodology

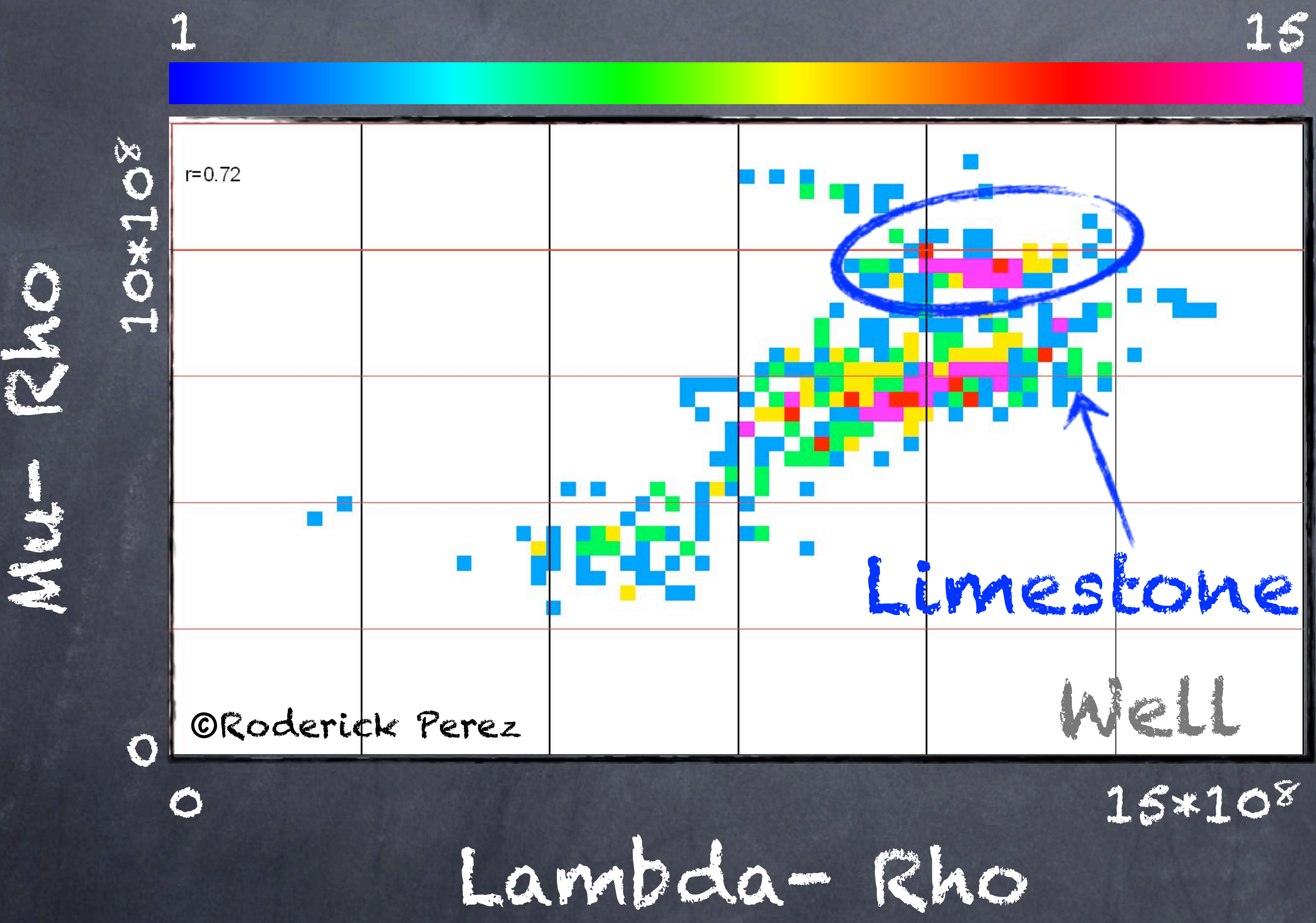


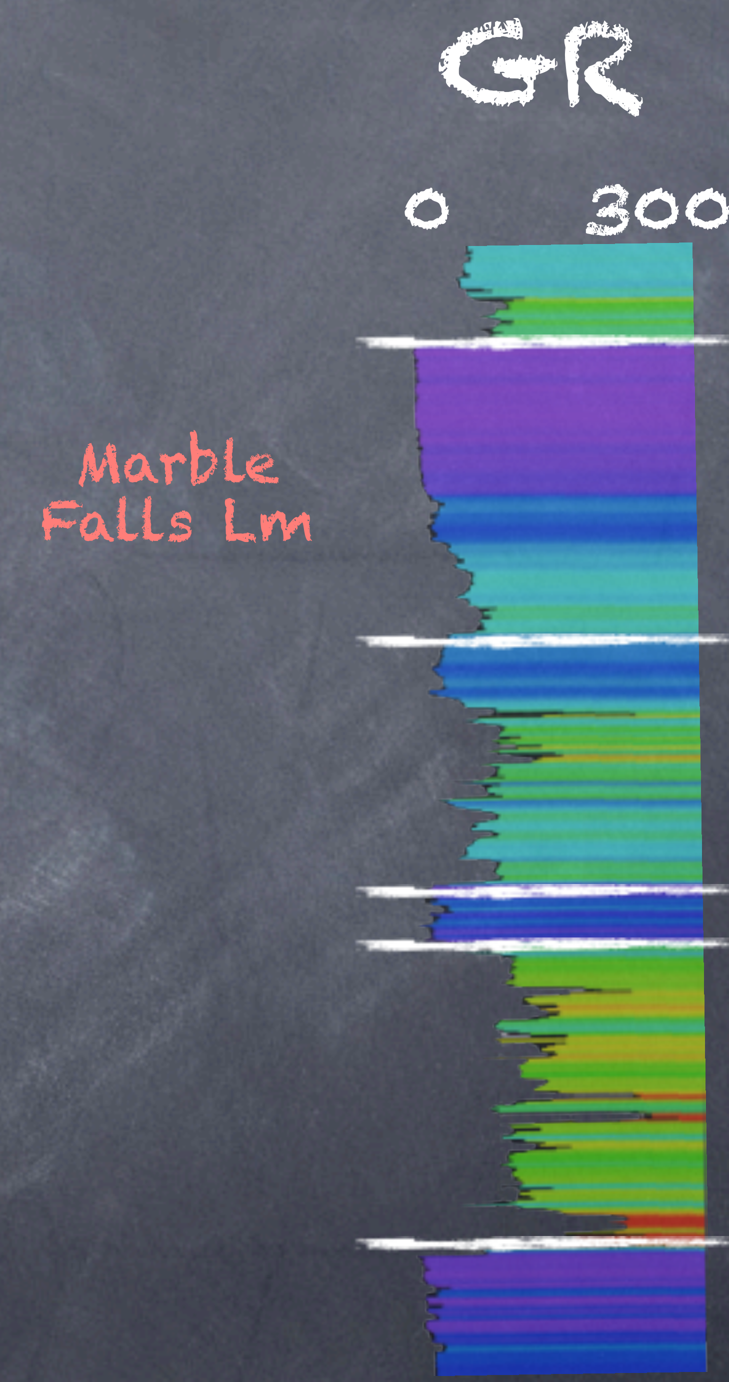


Methodology

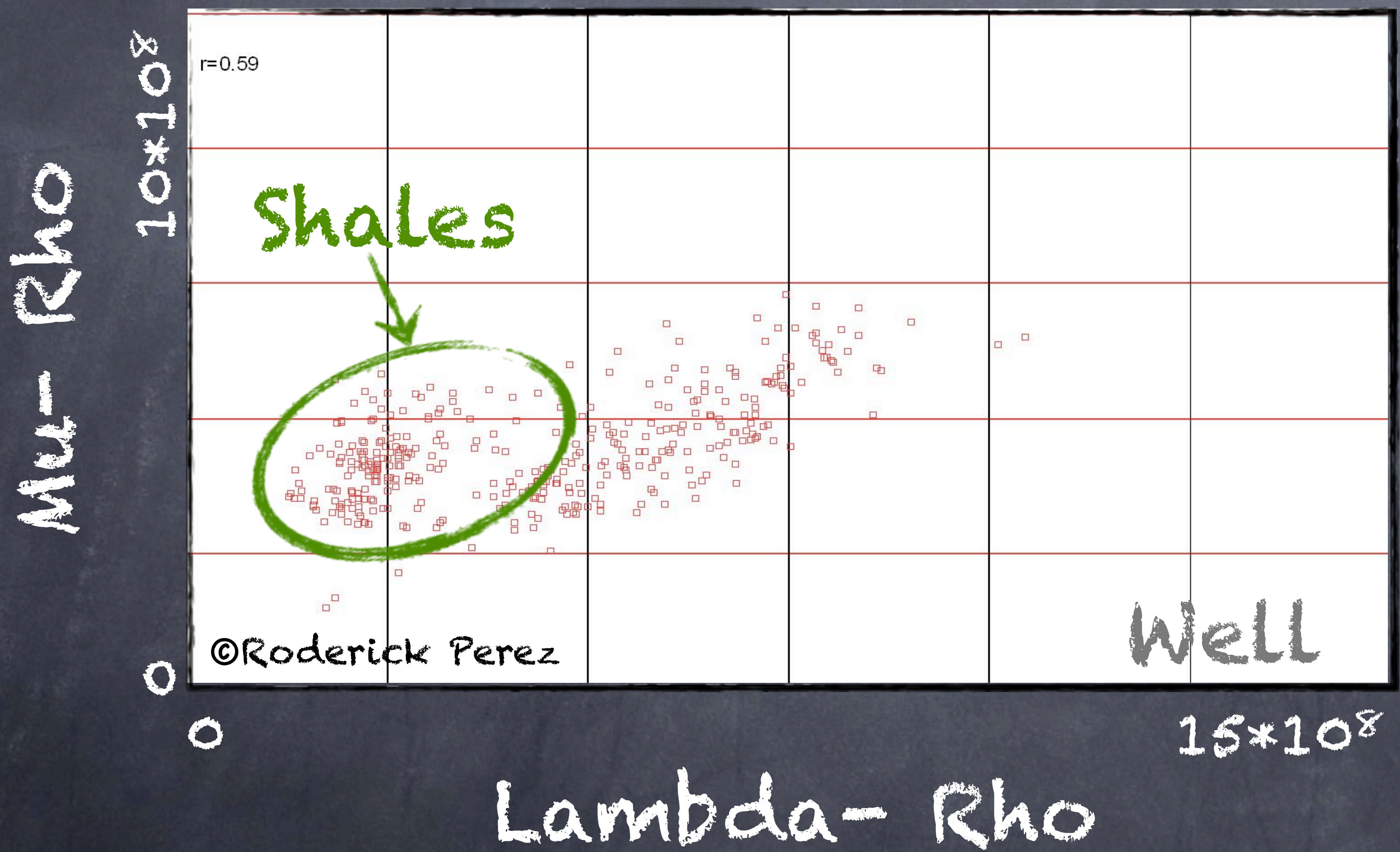


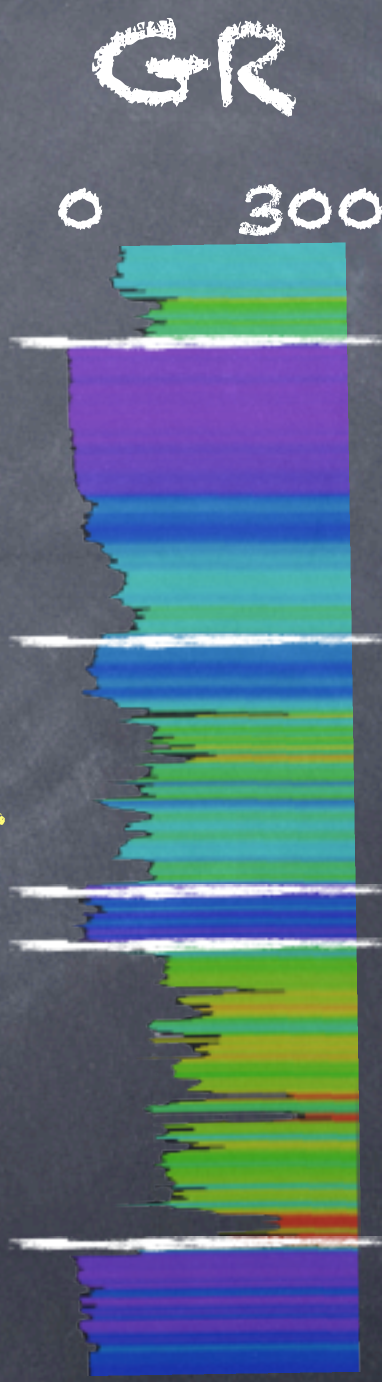
Methodology





Methodology





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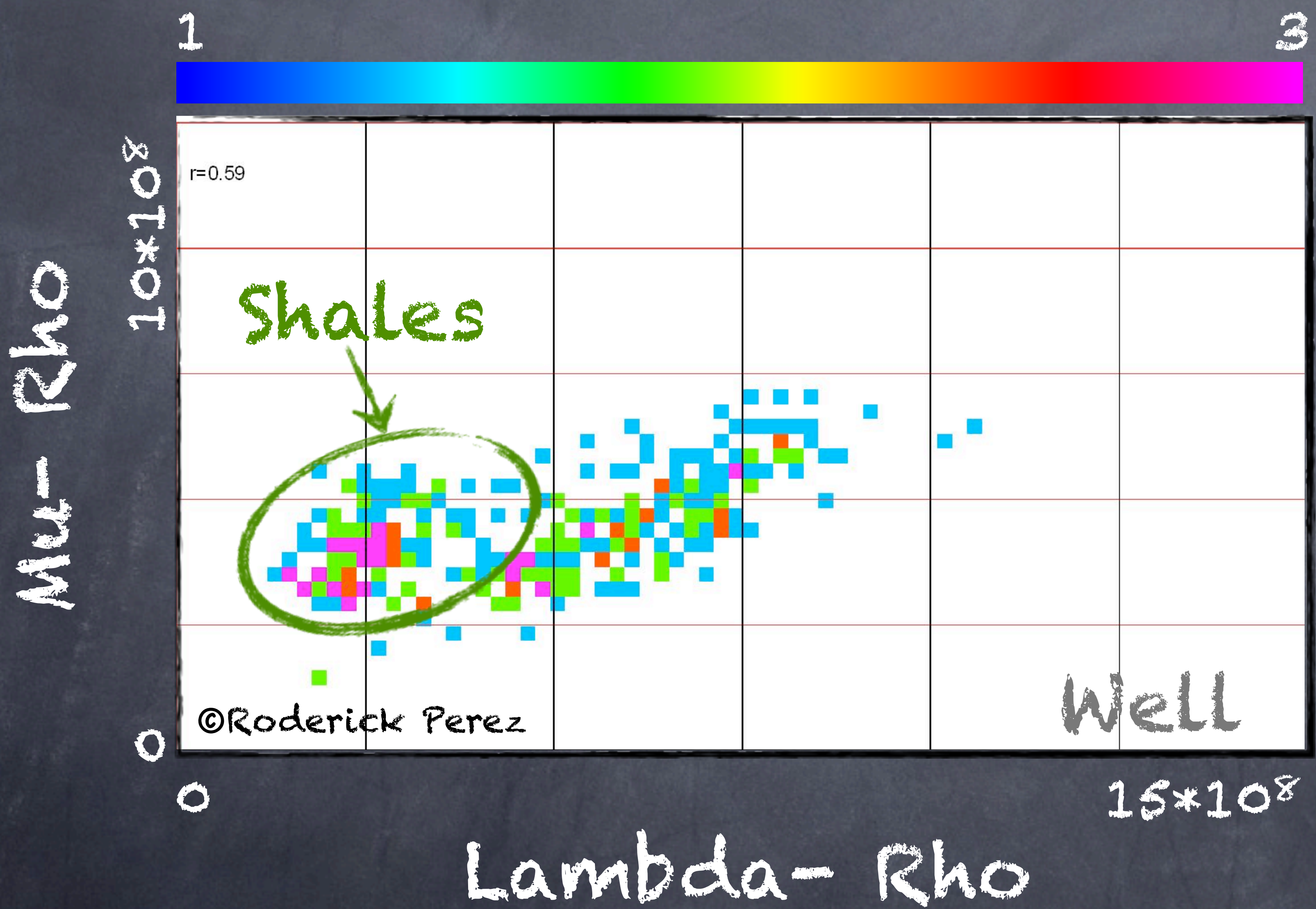

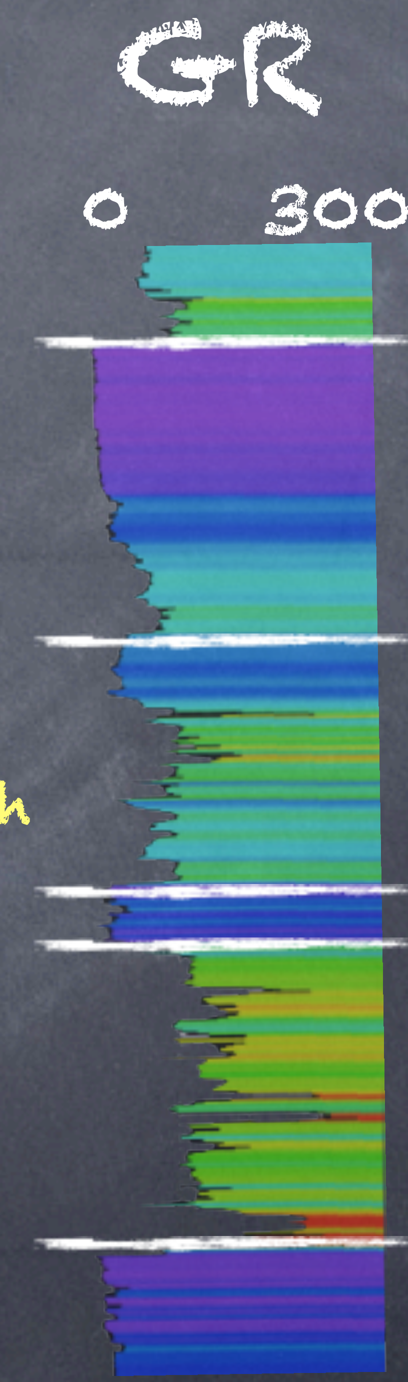

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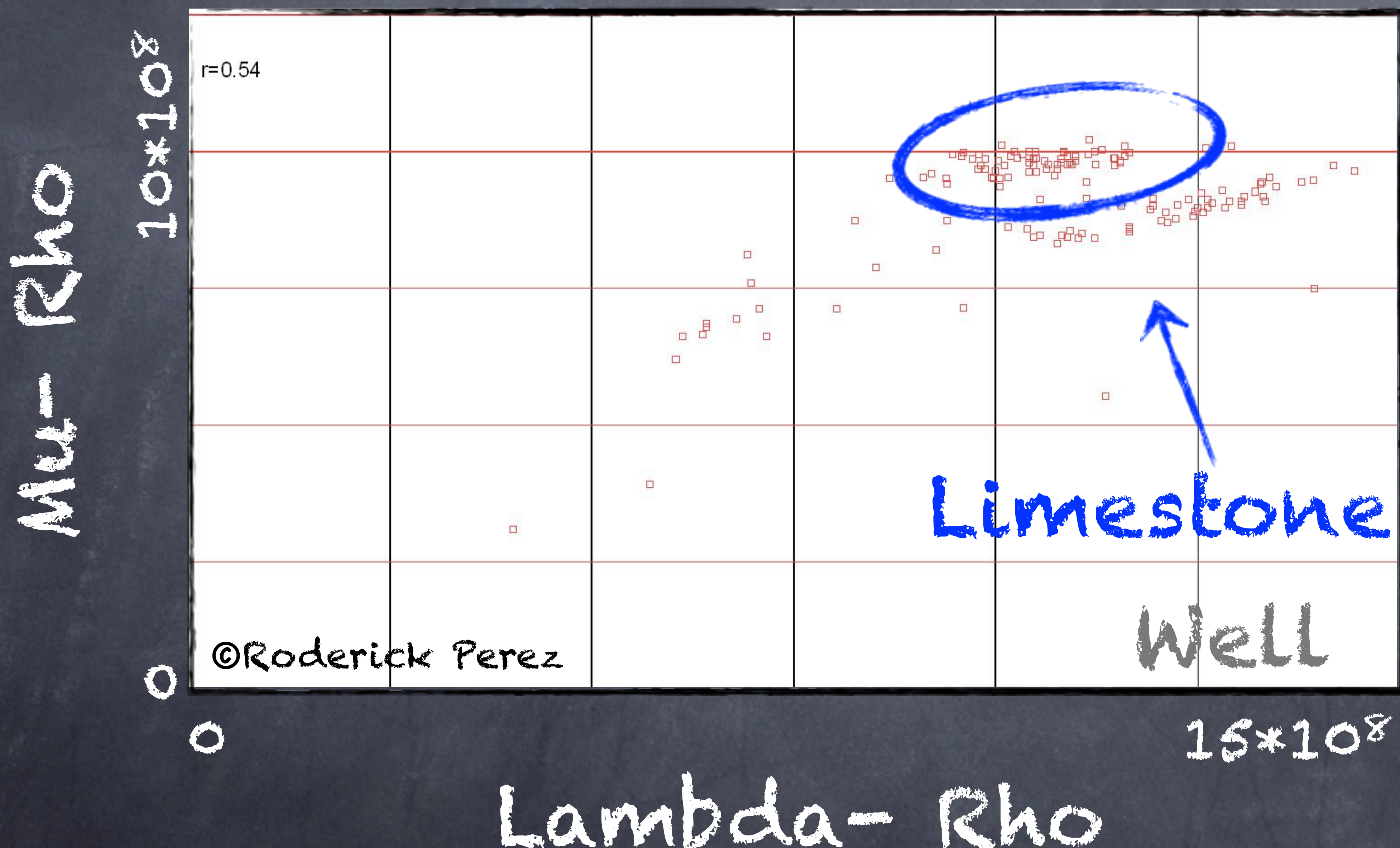

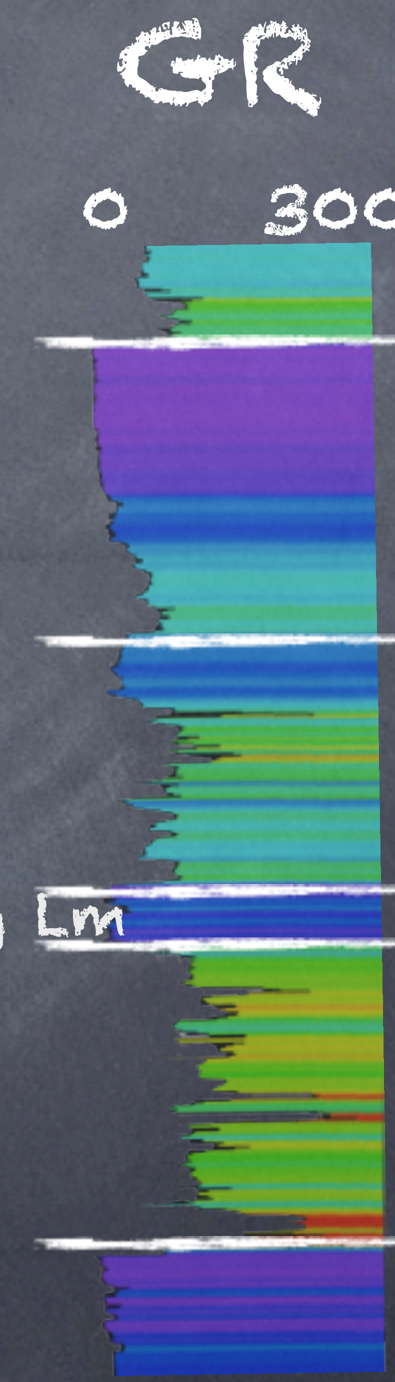

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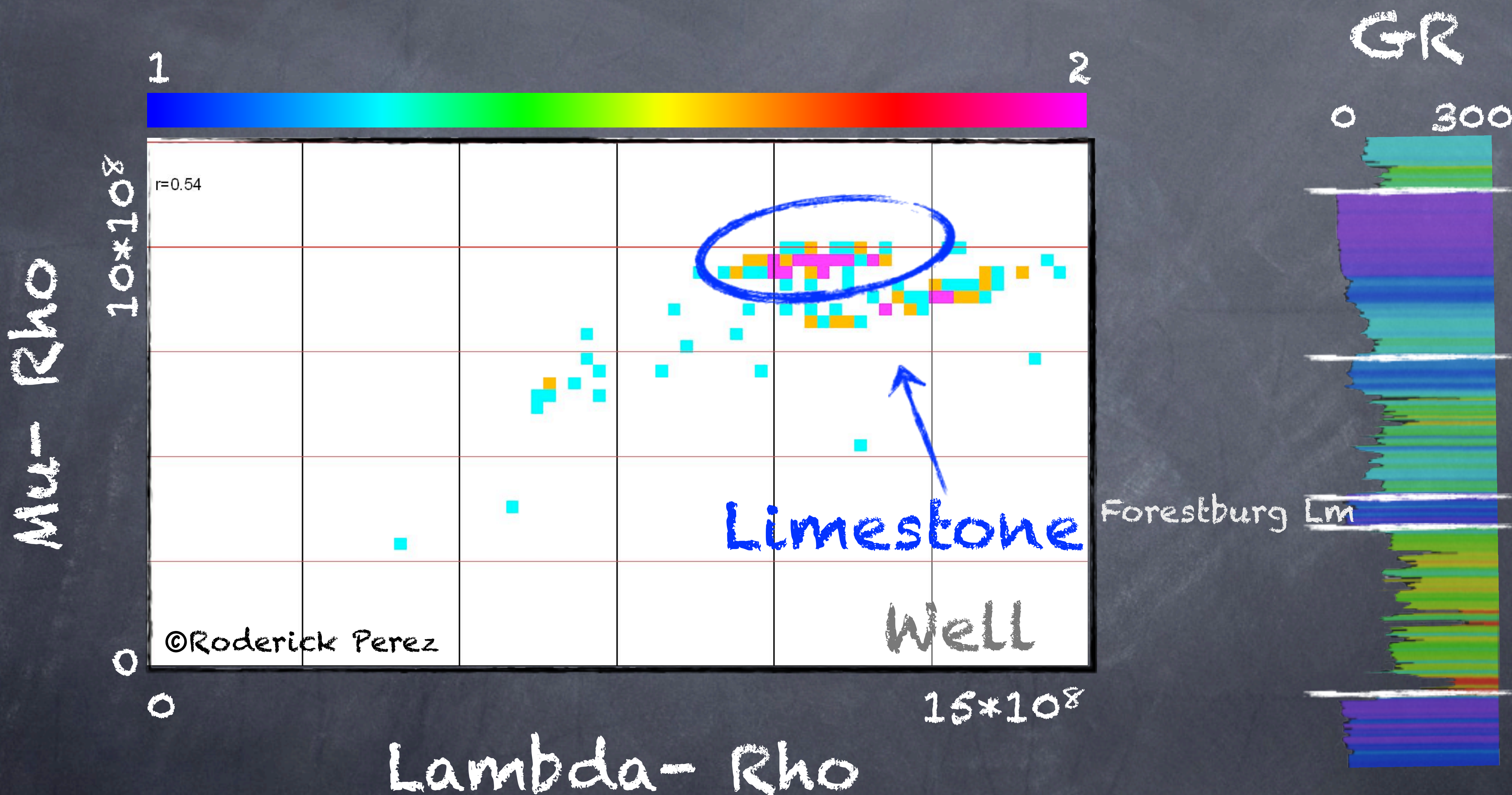

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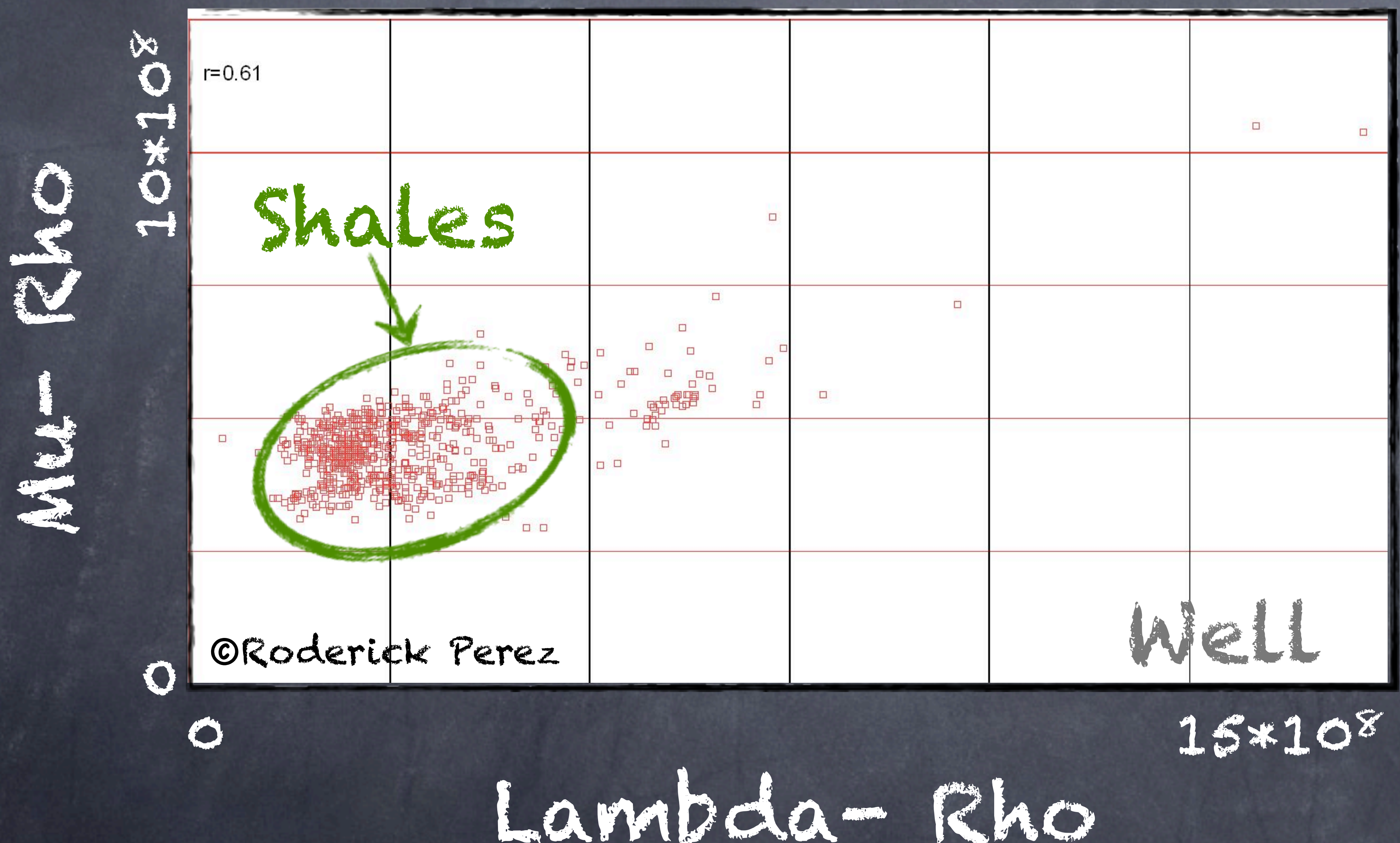

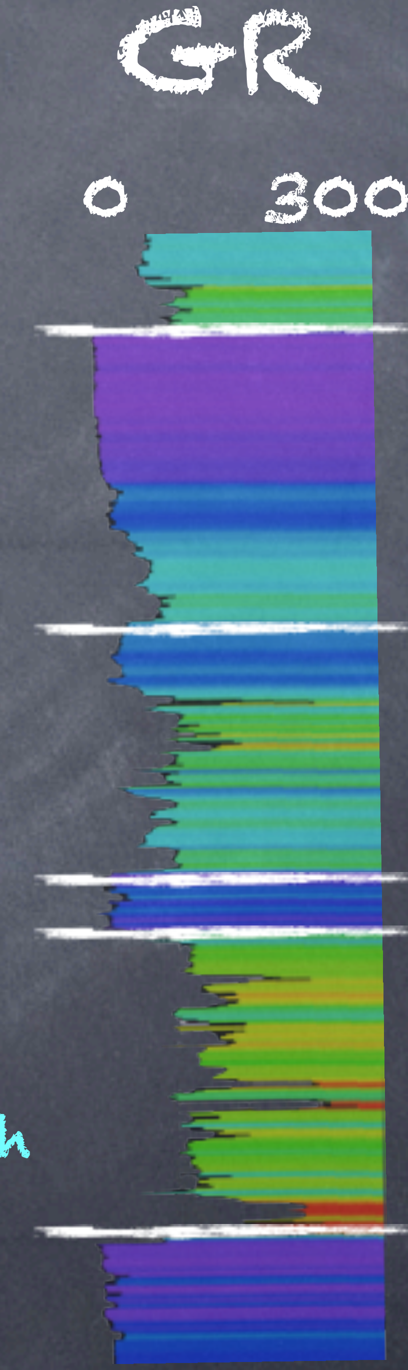

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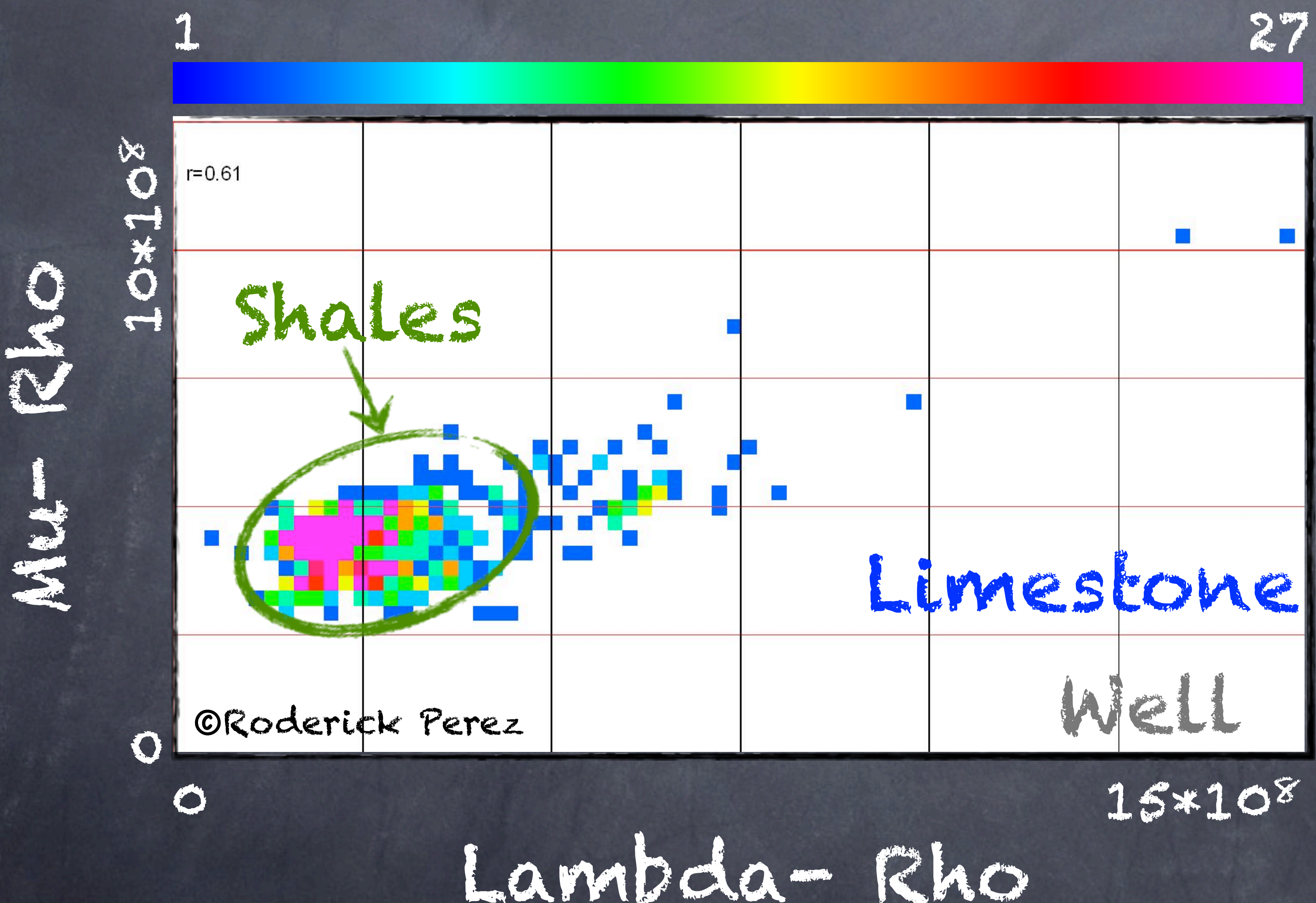
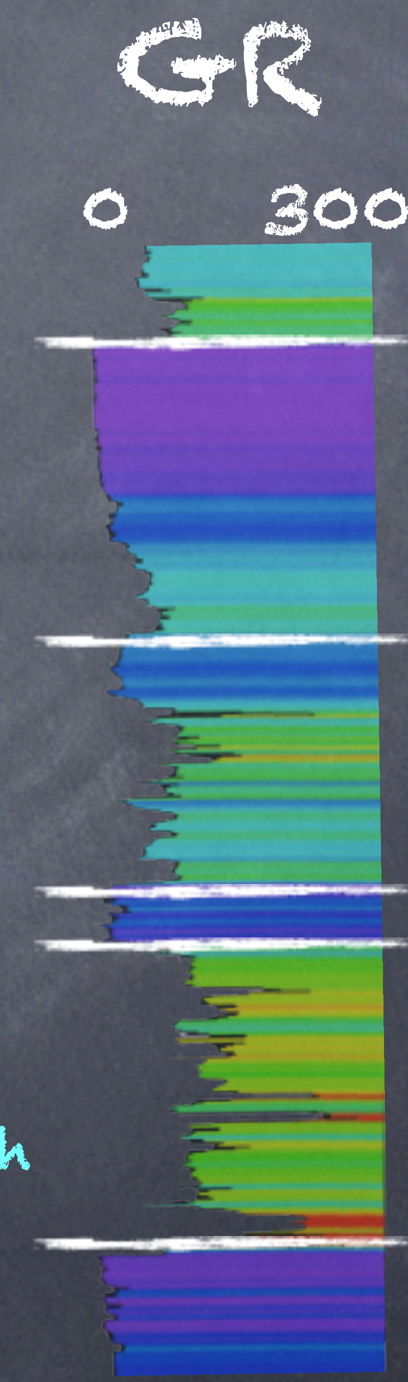
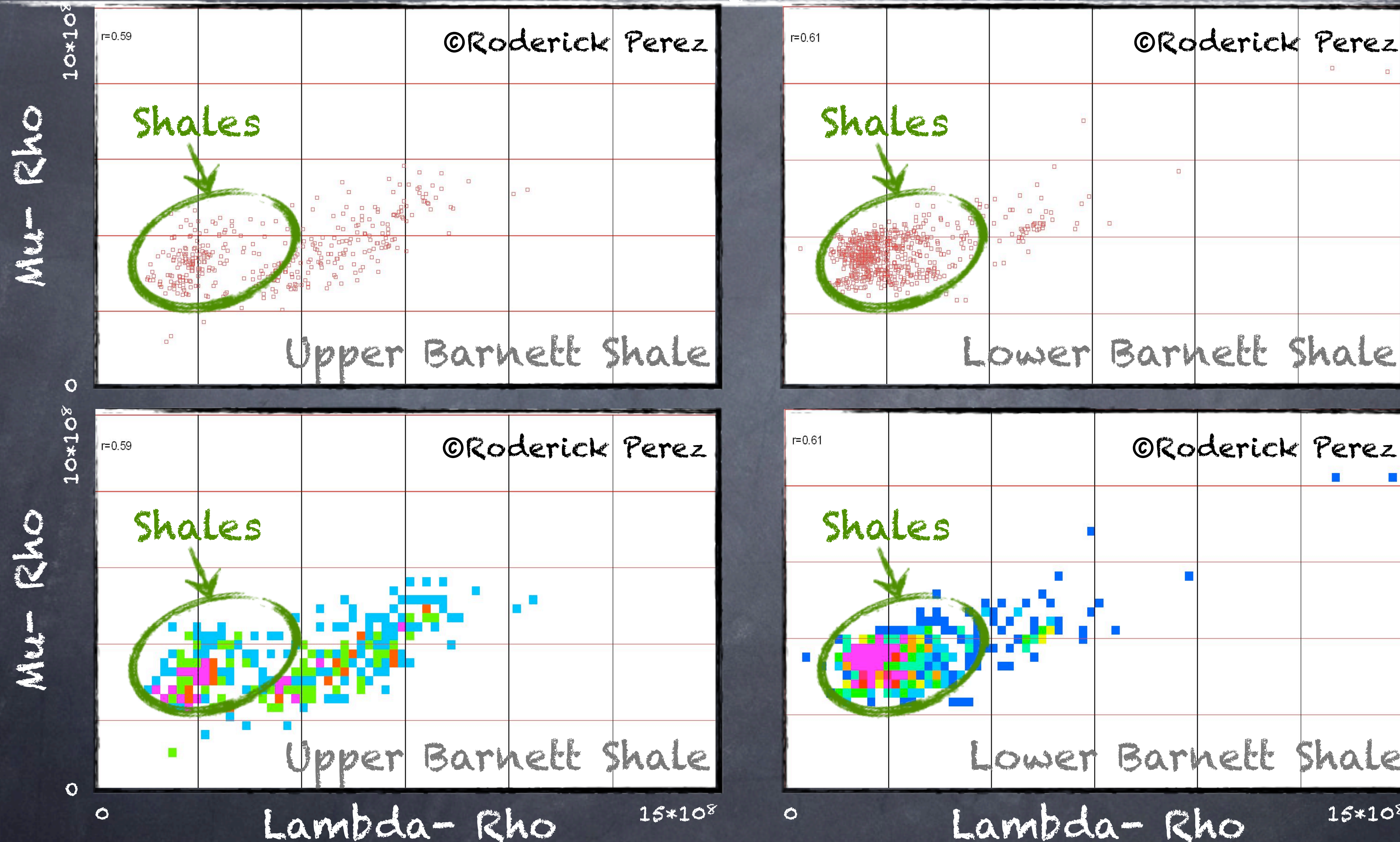


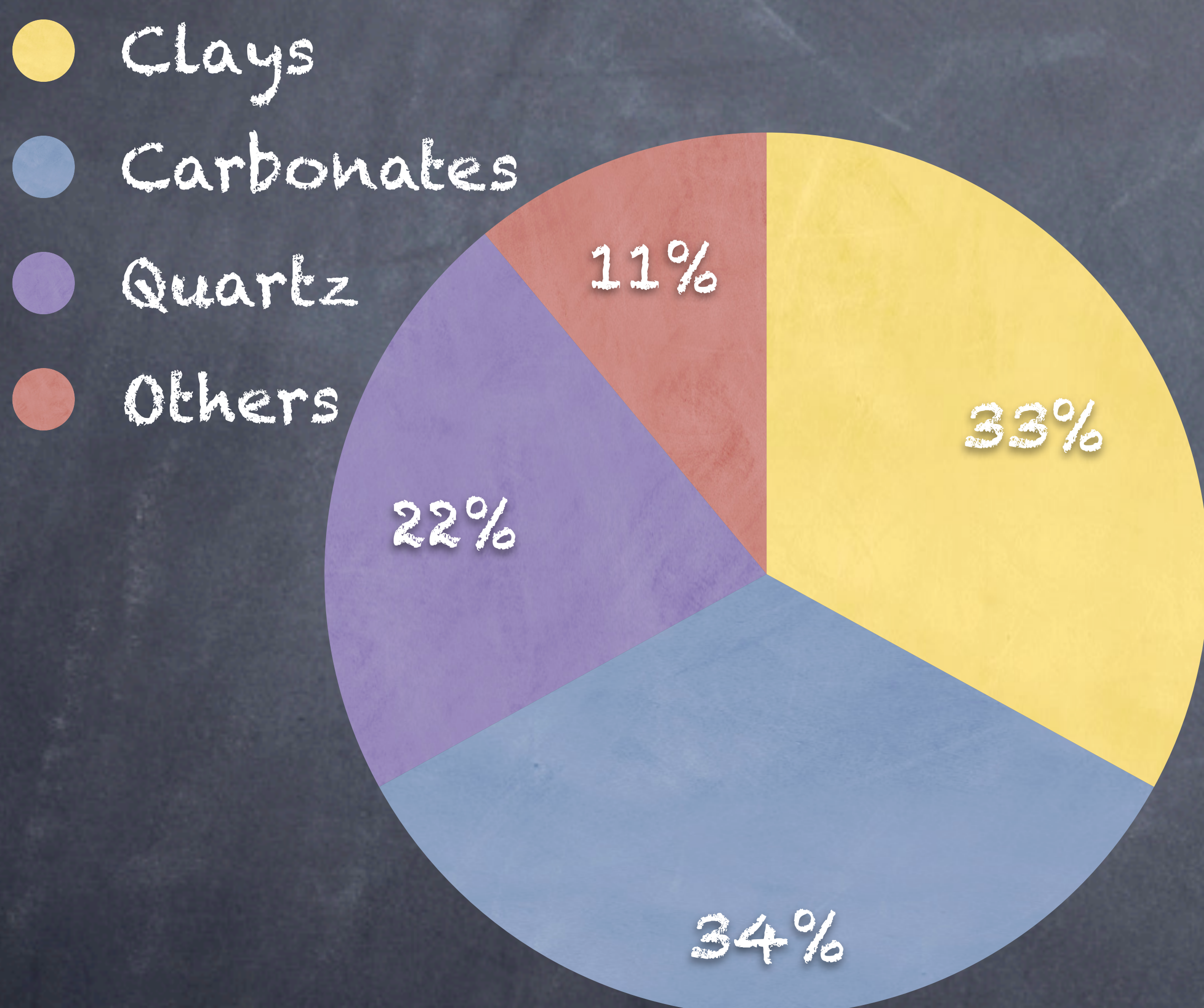


Shale Comparison

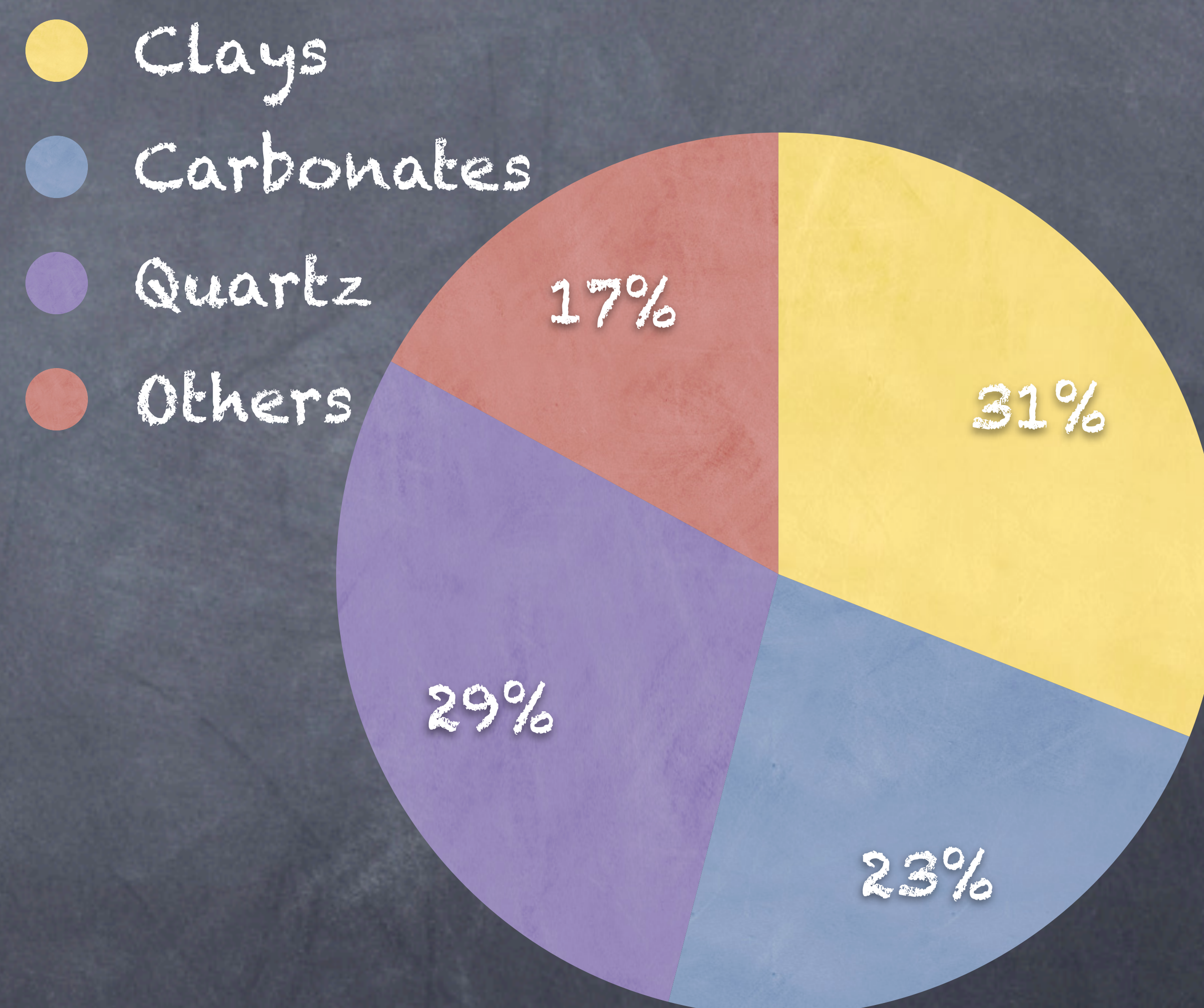


Mineralogy

Upper Barnett Shale

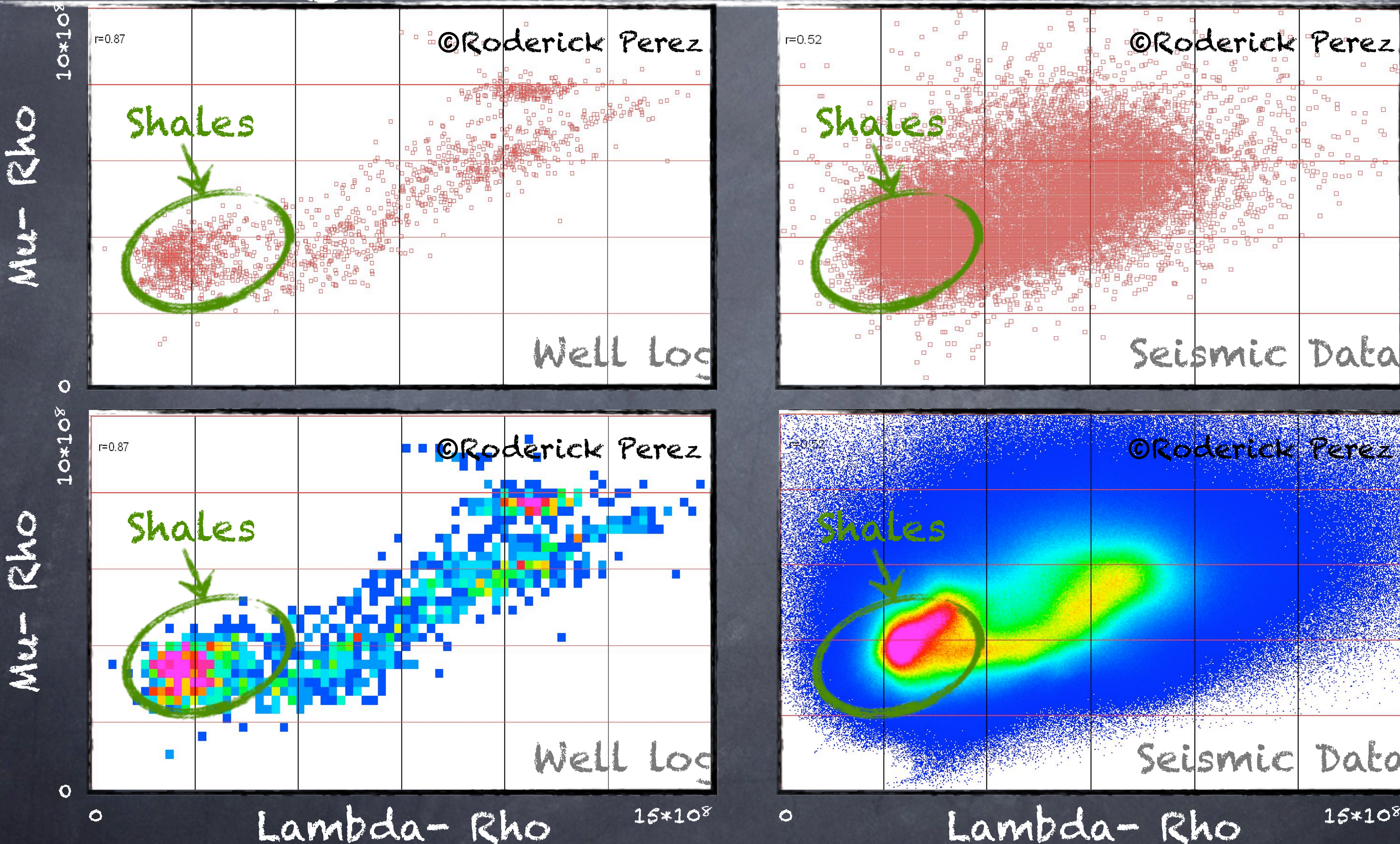


Lower Barnett Shale

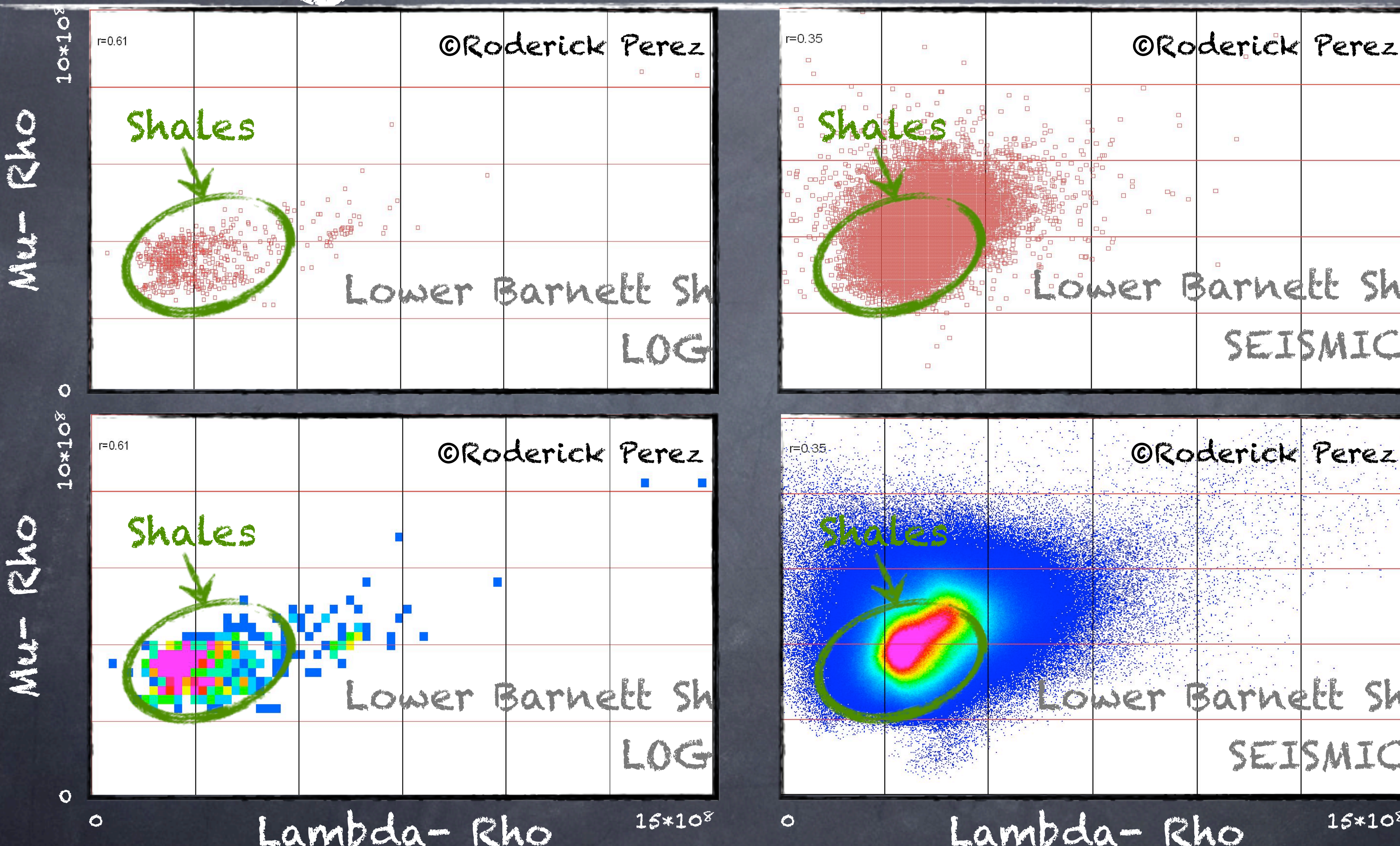


Average composition of the Upper and lower of the Barnett shale. PETROPHYSICAL MEASUREMENTS ON TIGHT GAS SHALE. ARGYRIOS KARASTATHIS, 2007.

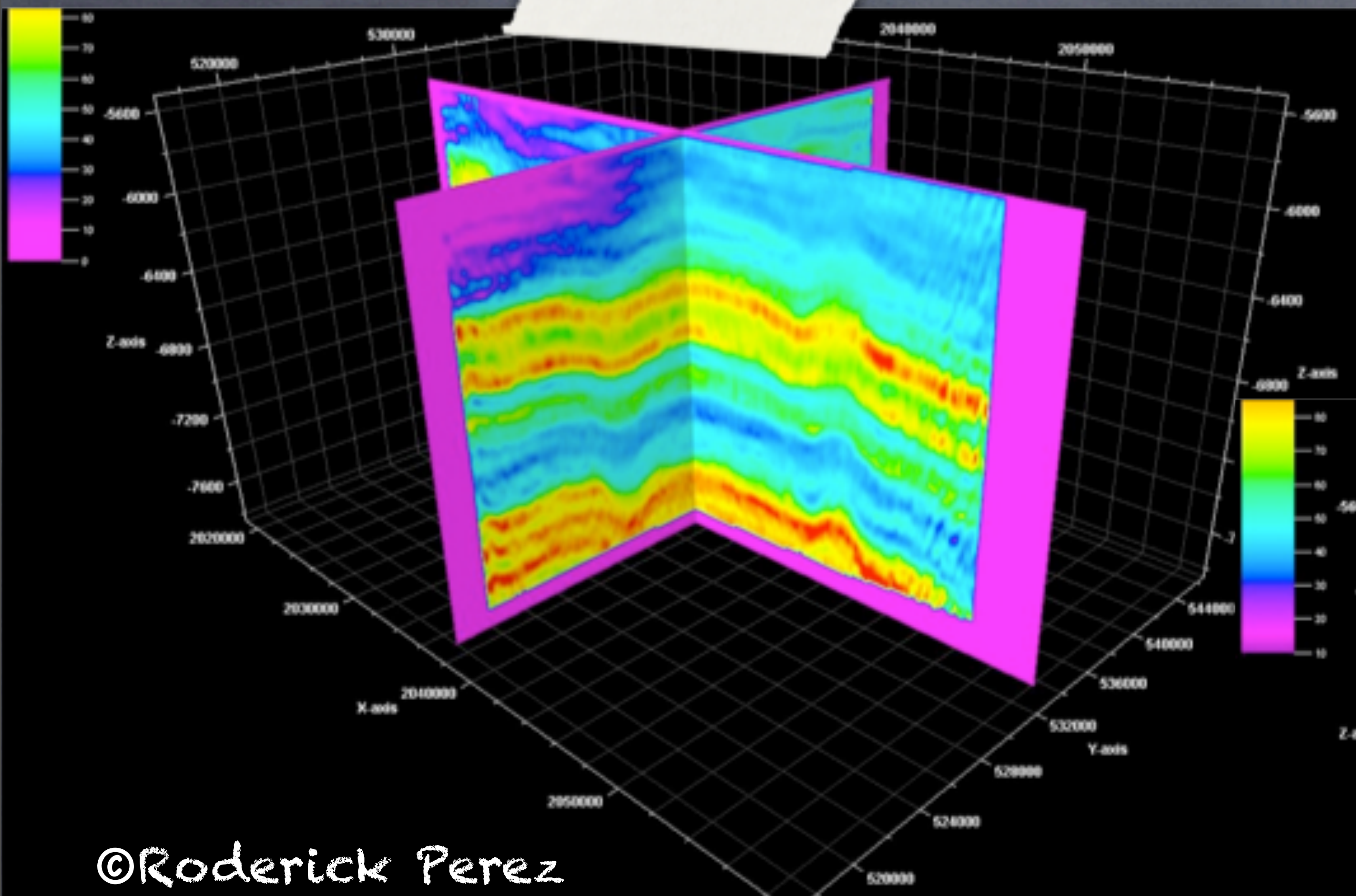
Logs vs. Seismic



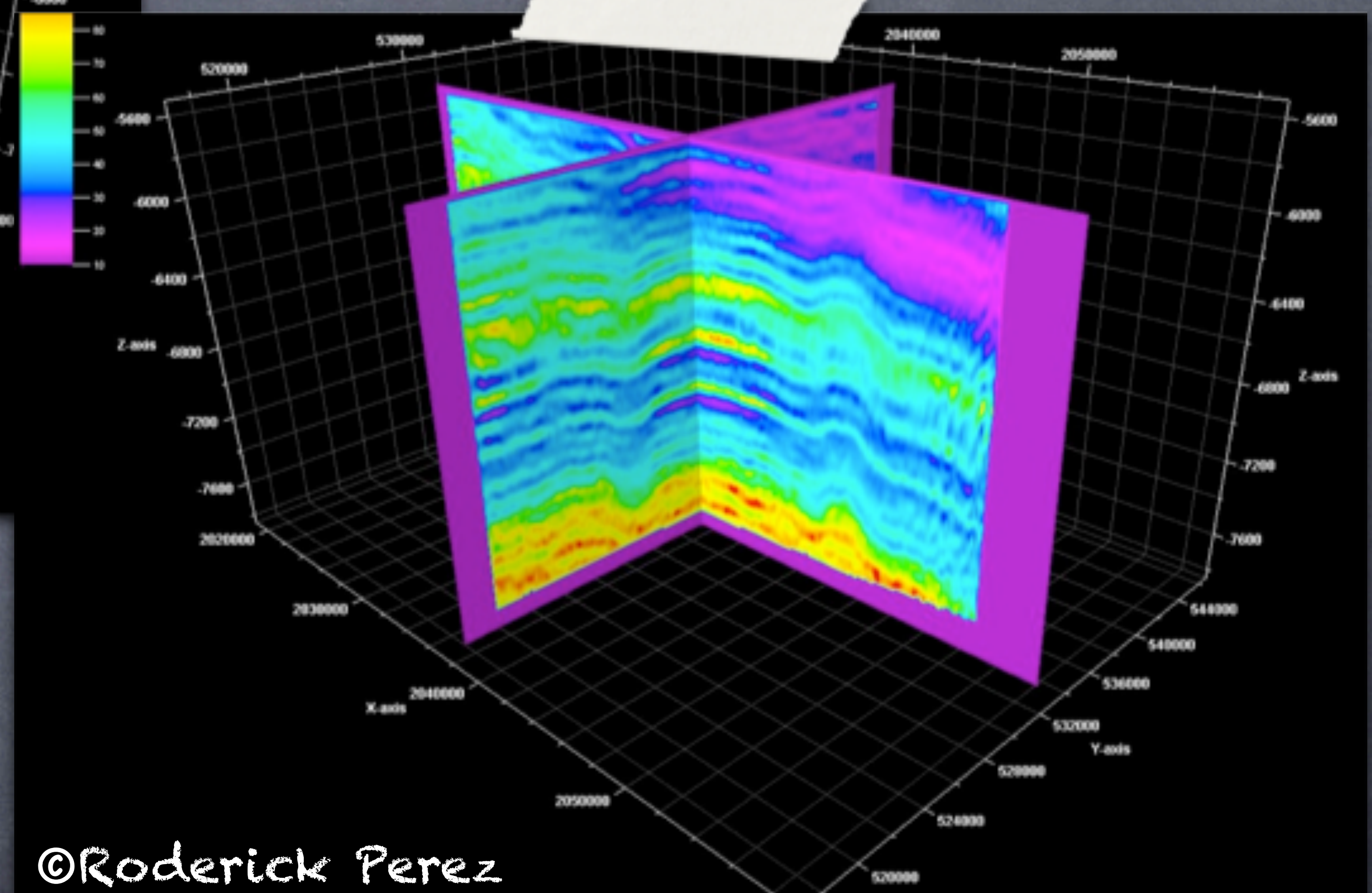
Logs vs. Seismic



Clustering Analysis



Lambda-Rho



Mu-Rho

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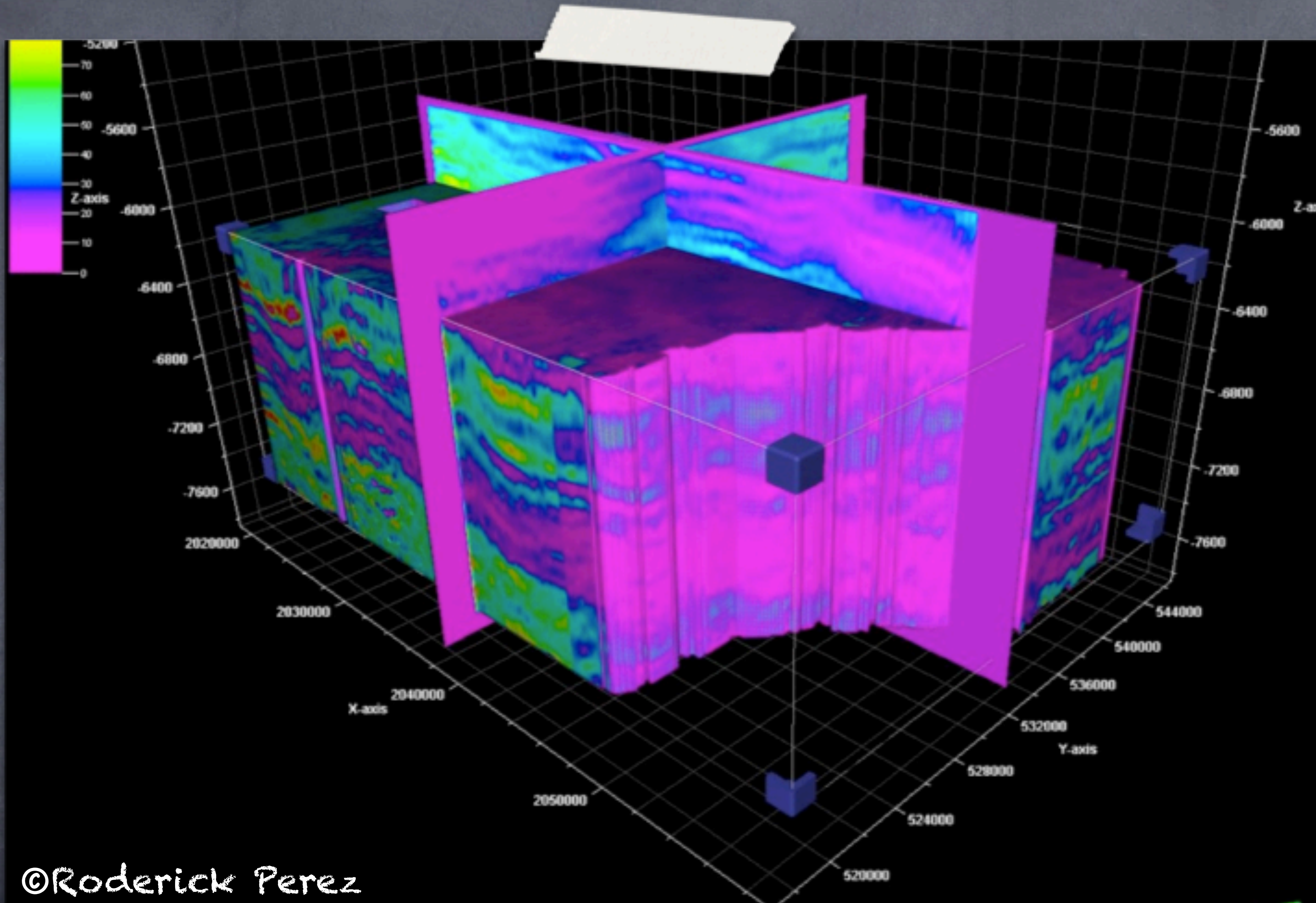
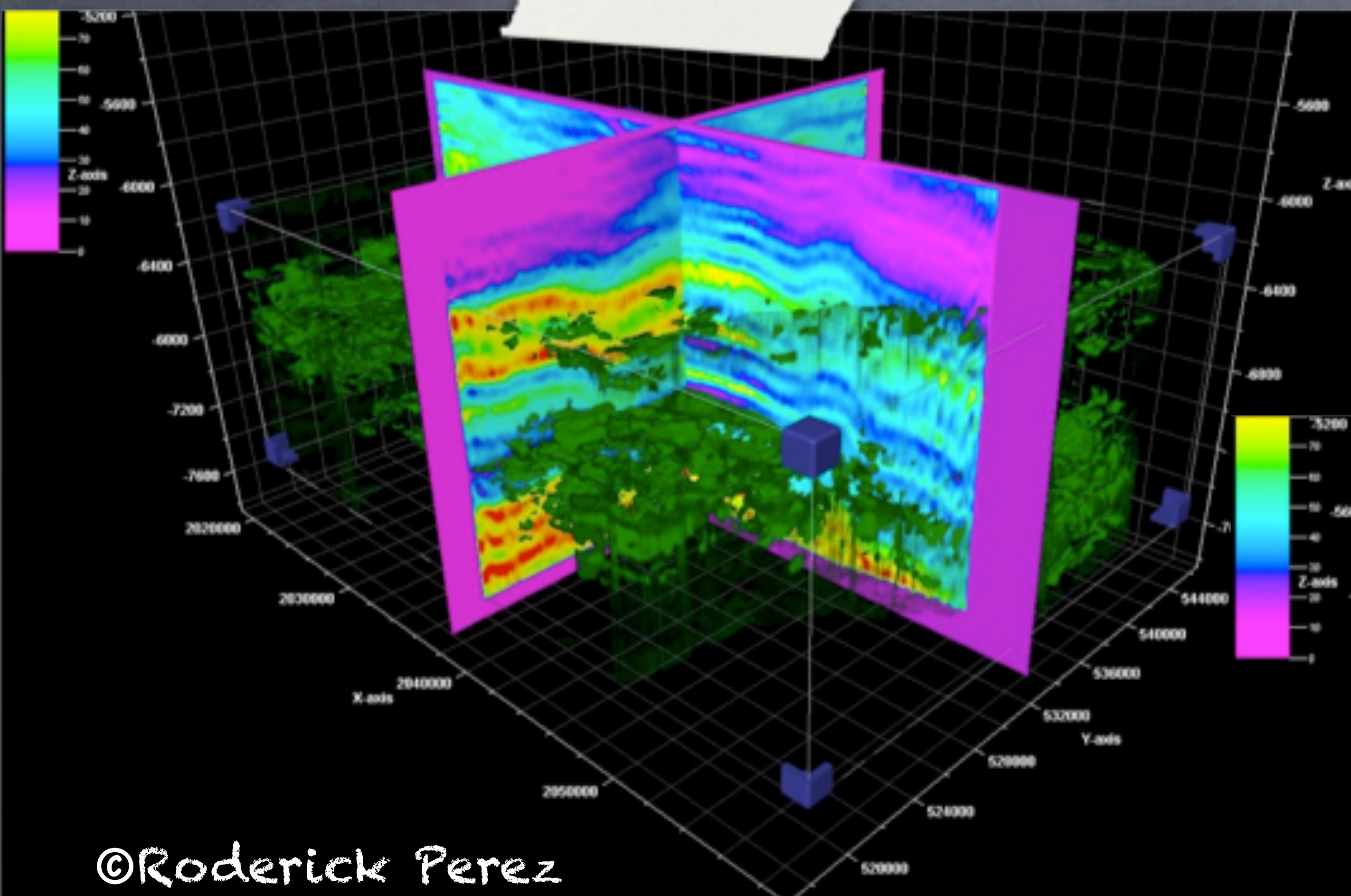
Clustering Analysis

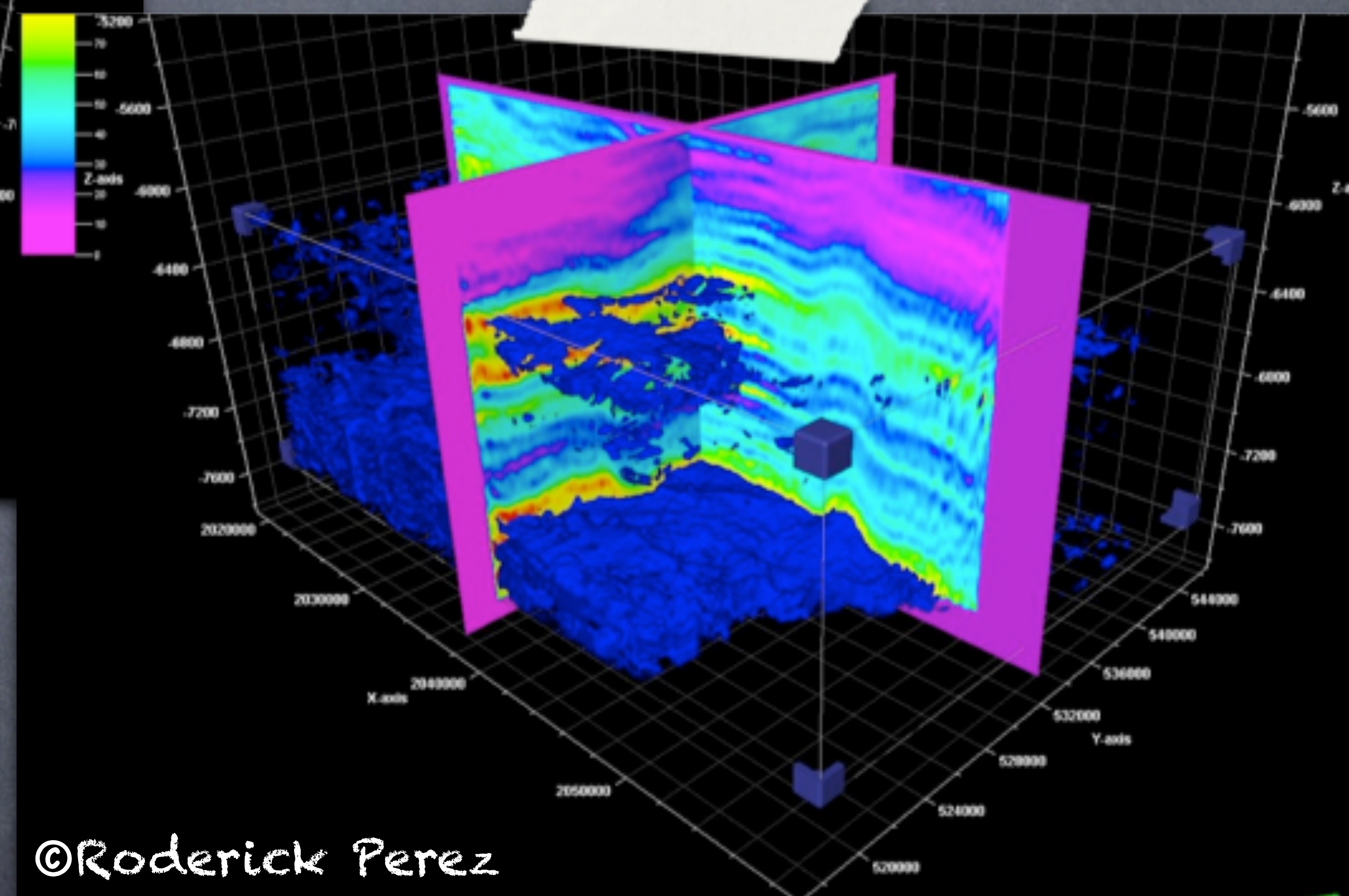


Lambda-Rho / Mu-Rho X-plot volume

Clustering Analysis

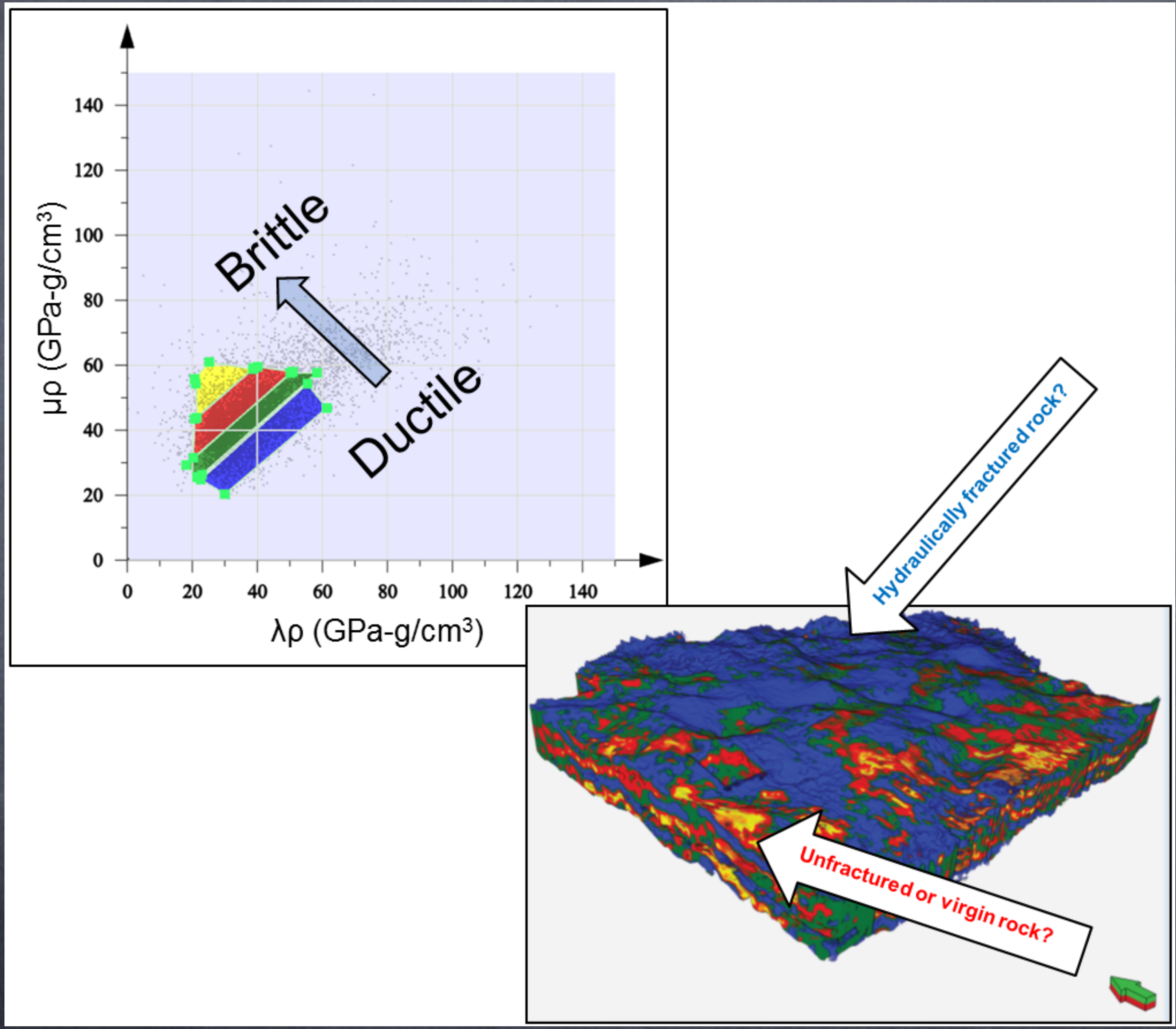


Shales



Limestone

Frac volume



140
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
μρ (GPa-g/cm³)
λρ (GPa-g/cm³)
Brittle
Ductile
Hydraulically fractured rock?
Unfractured or virgin rock?

Self Organizing Maps

ConocoPhillips SCHOOL OF GEOLOGY & GEOPHYSICS The University of Oklahoma

Main features to identify

Compartmentalization in Barnett shale

Zone of Analysis

11 strata slices from each of the λρ and μρ volumes within the bottom part of the lower Barnett shale

Cluster Assisted 3D and 2D unsupervised seismic facies analysis, an example from the Barnett Shale Formation in Fort Worth Basin Texas. Roy and Perez, 2011

Input

λρ

μρ

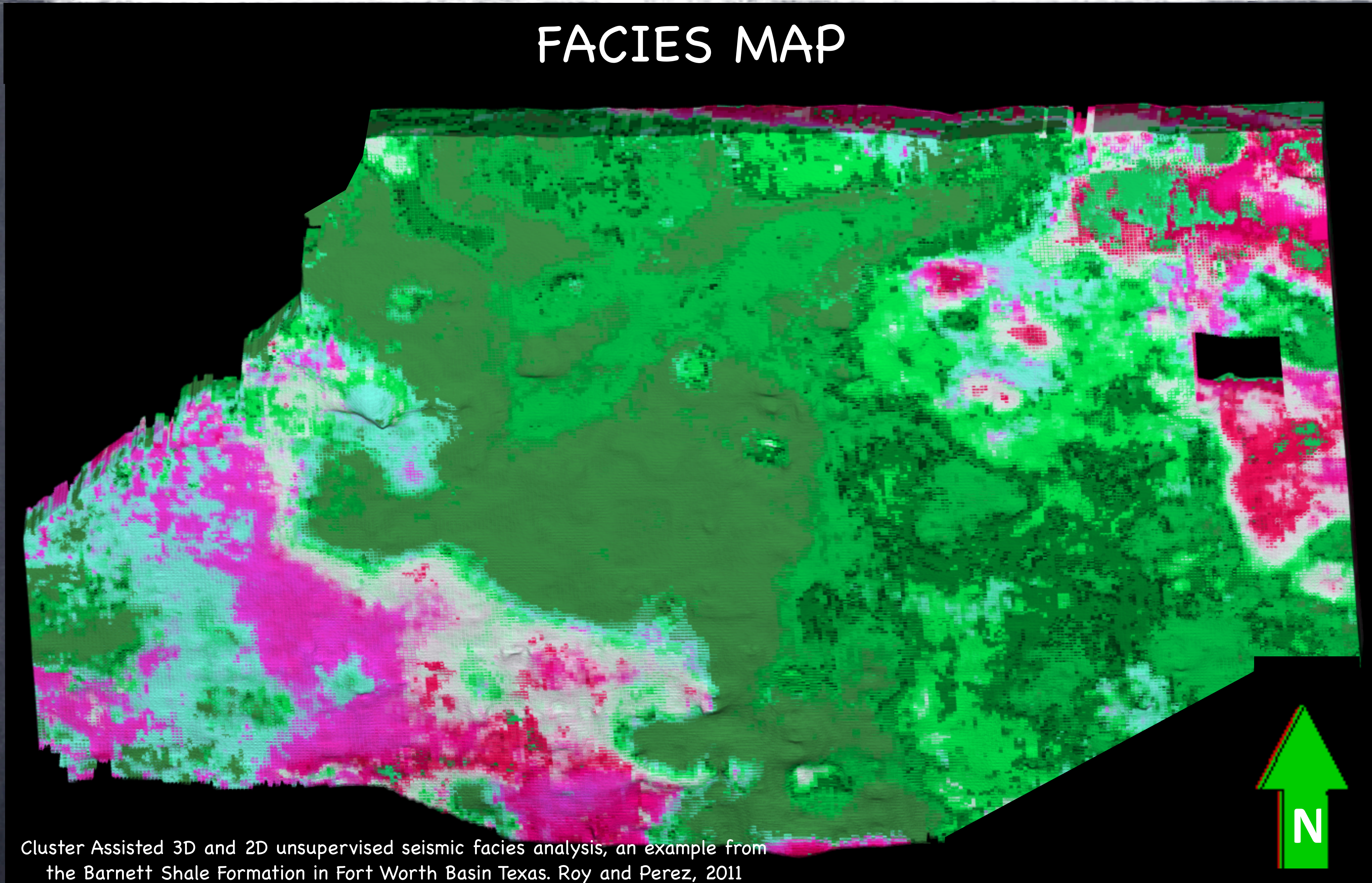
2D Multi-attribute analysis and coloring of the each sample location

Output 2D seismic Facies Map

Output

Co-rendering with the principal positive curvature of the top Viola surface

Self Organizing Maps



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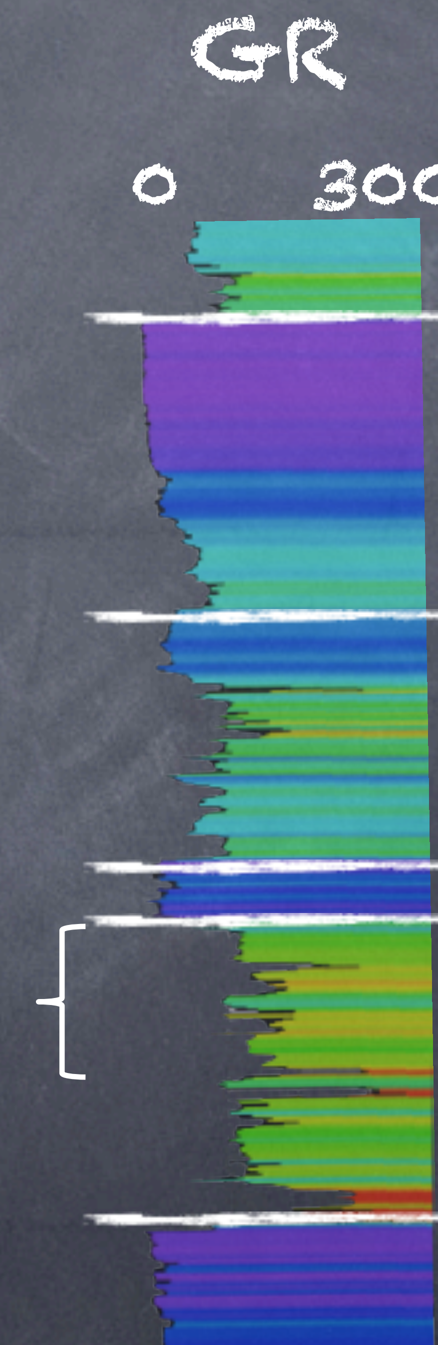
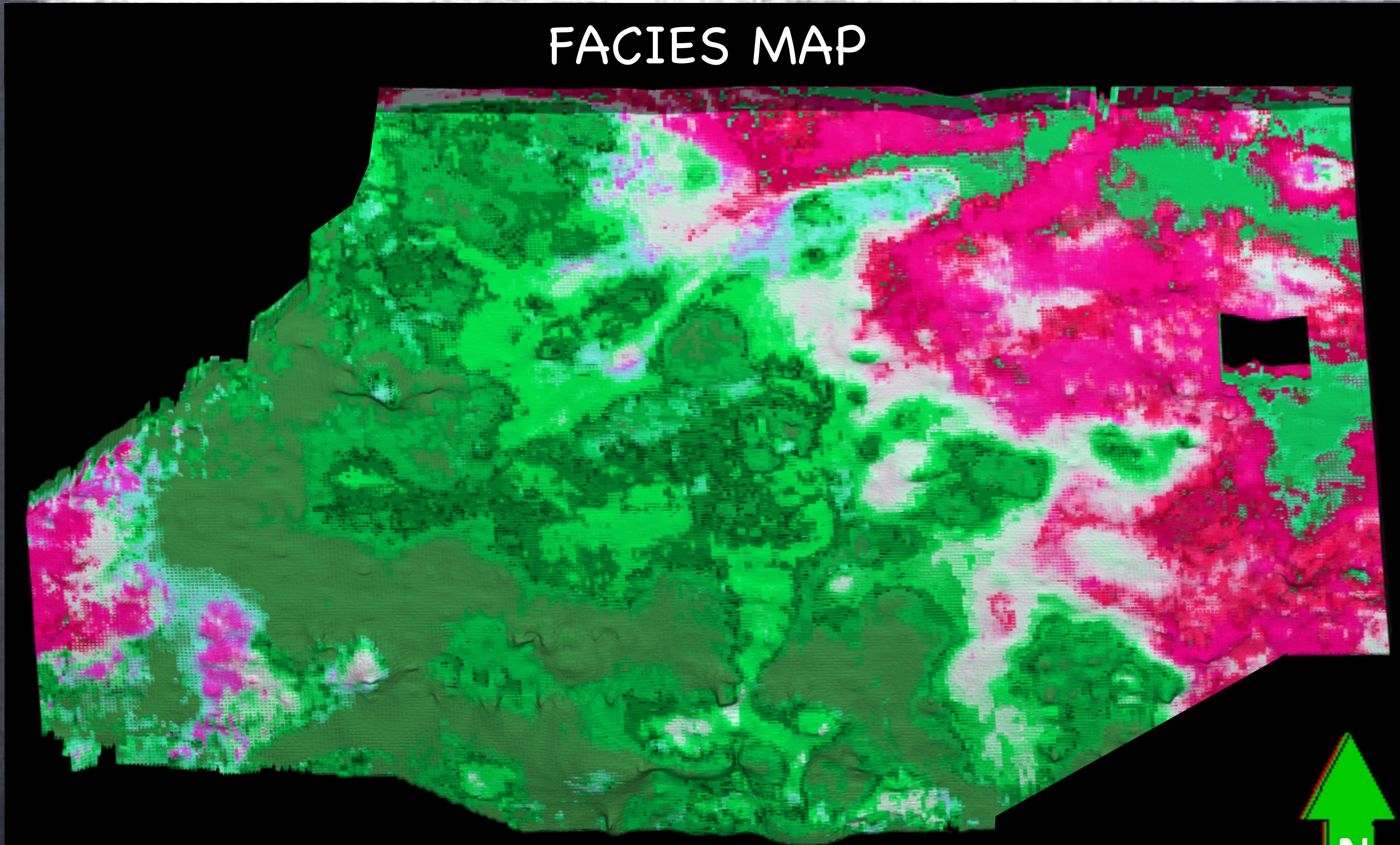


Self Organizing Maps



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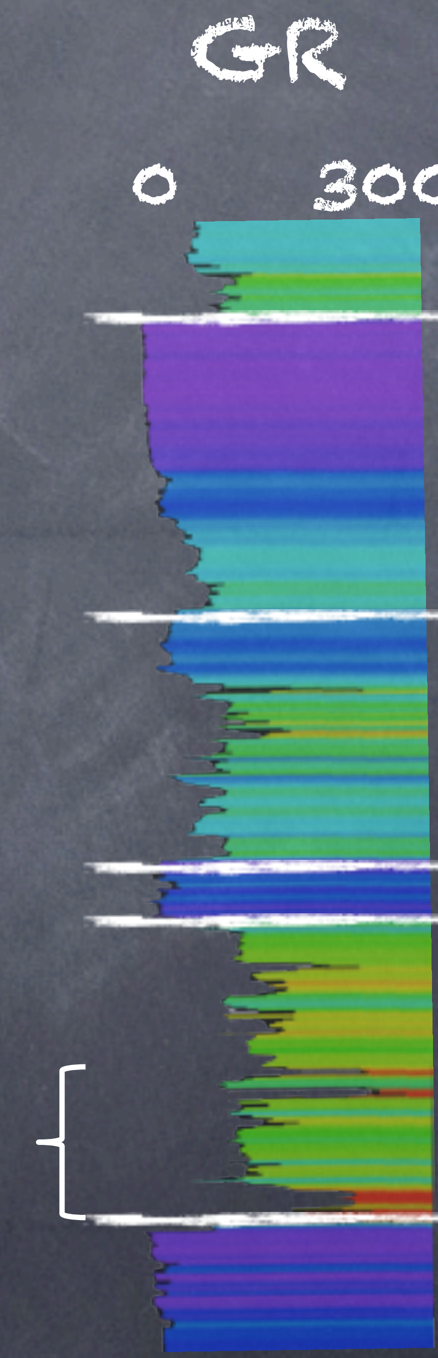
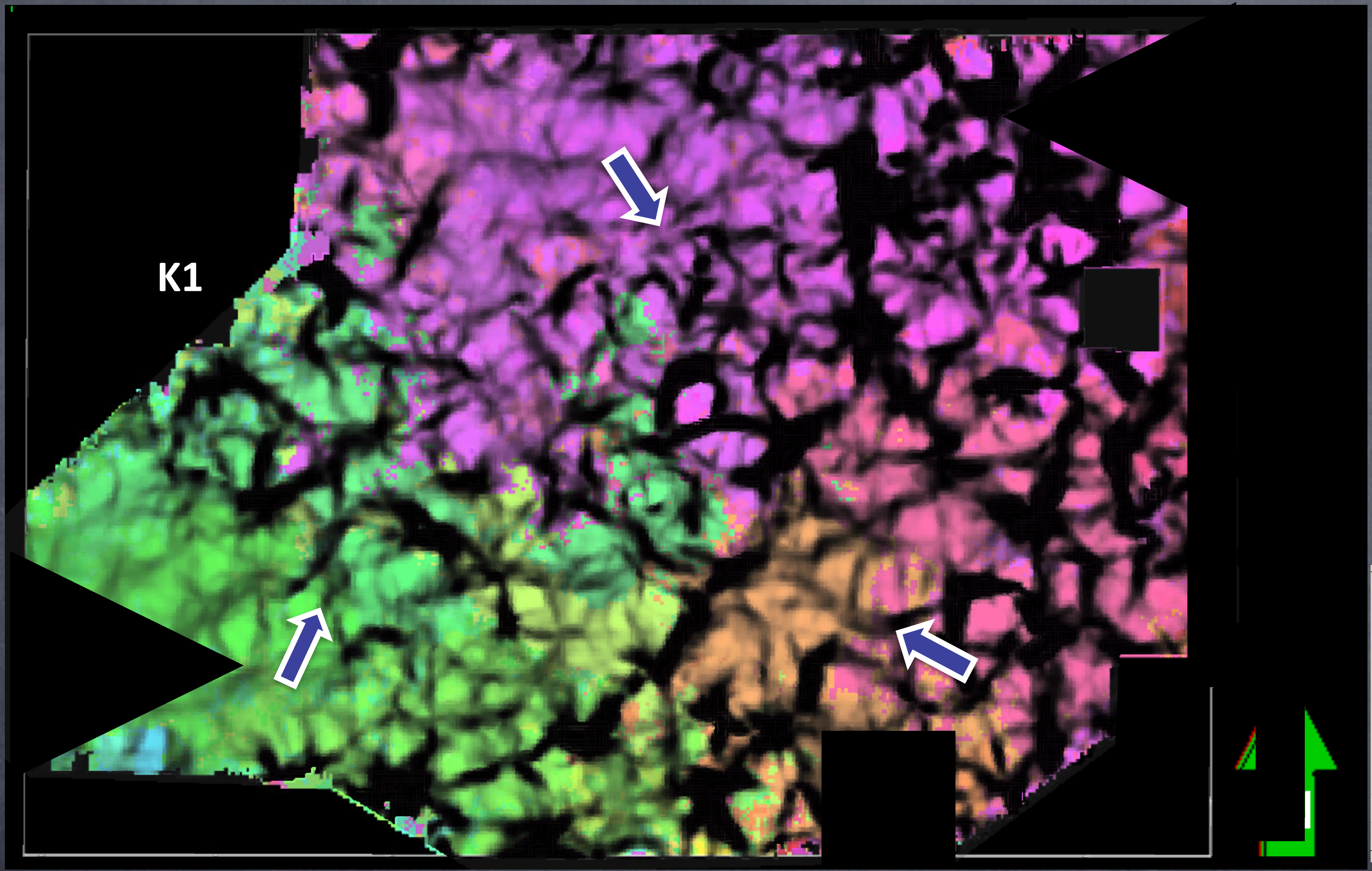
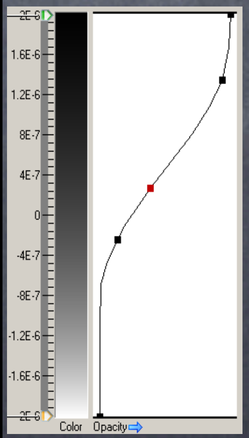


Co-rendered map



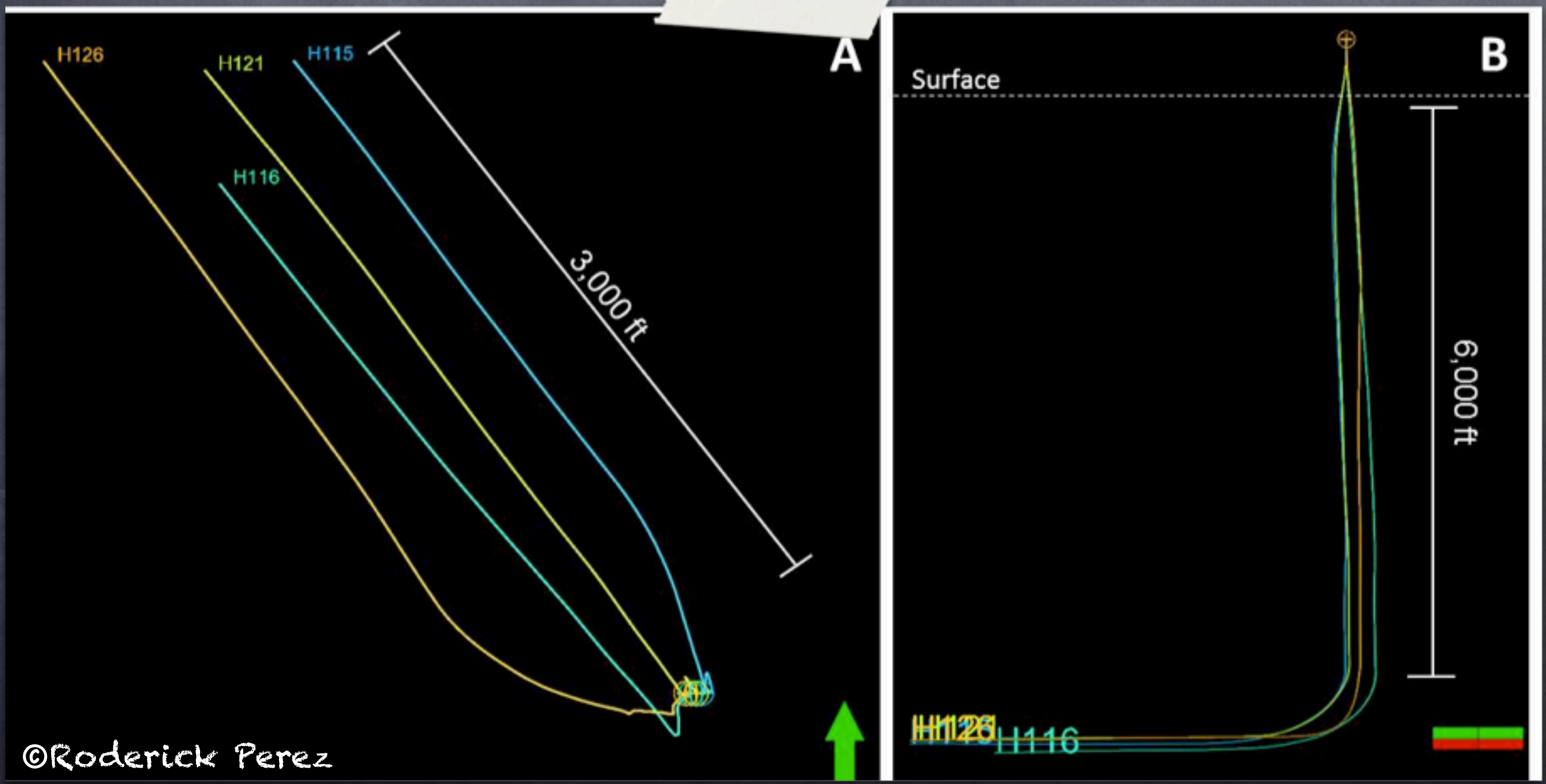


The 2D Multi-attribute map co-rendered with the principal positive curvature of the Viola lime

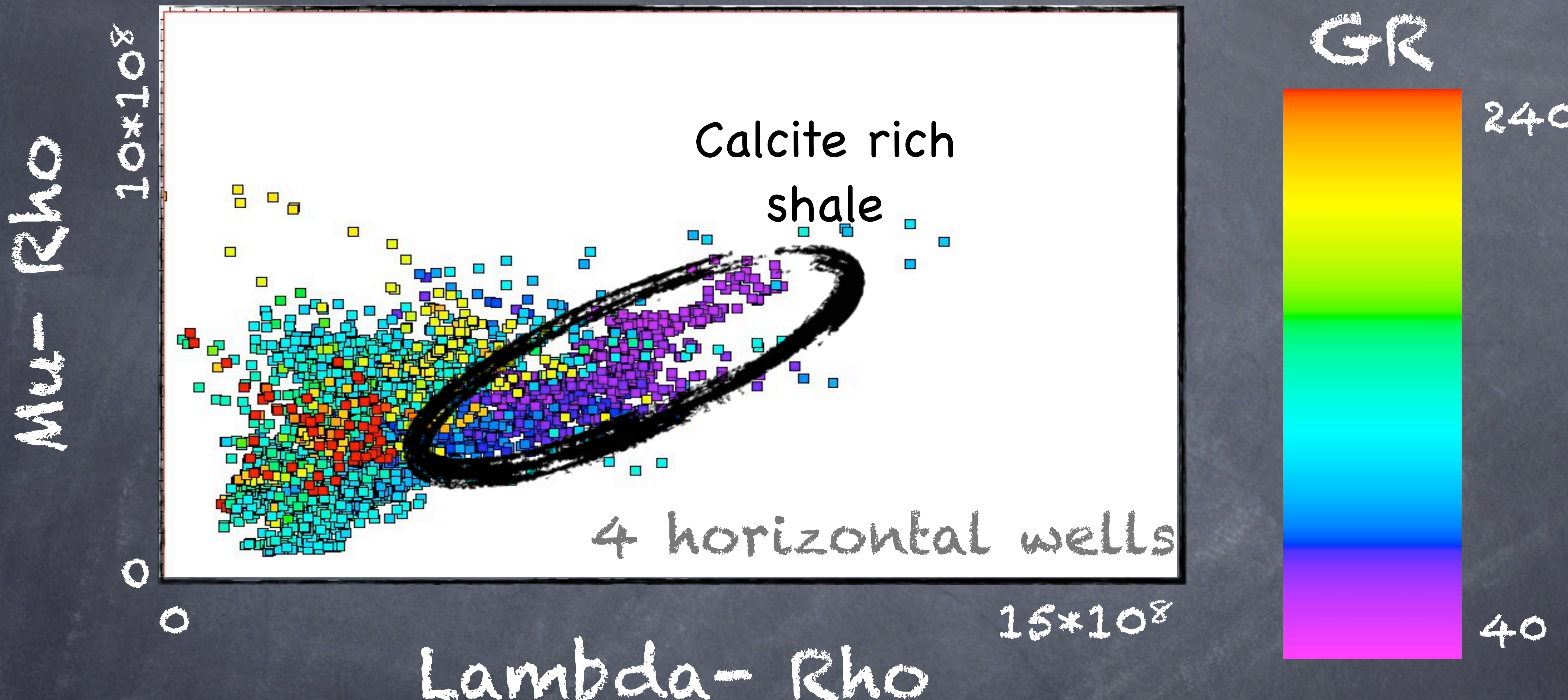
Cluster Assisted 3D and 2D unsupervised seismic facies analysis, an example from the Barnett Shale Formation in Fort Worth Basin Texas. Roy and Perez, 2011

Results

LMR Inversion correlation to Production



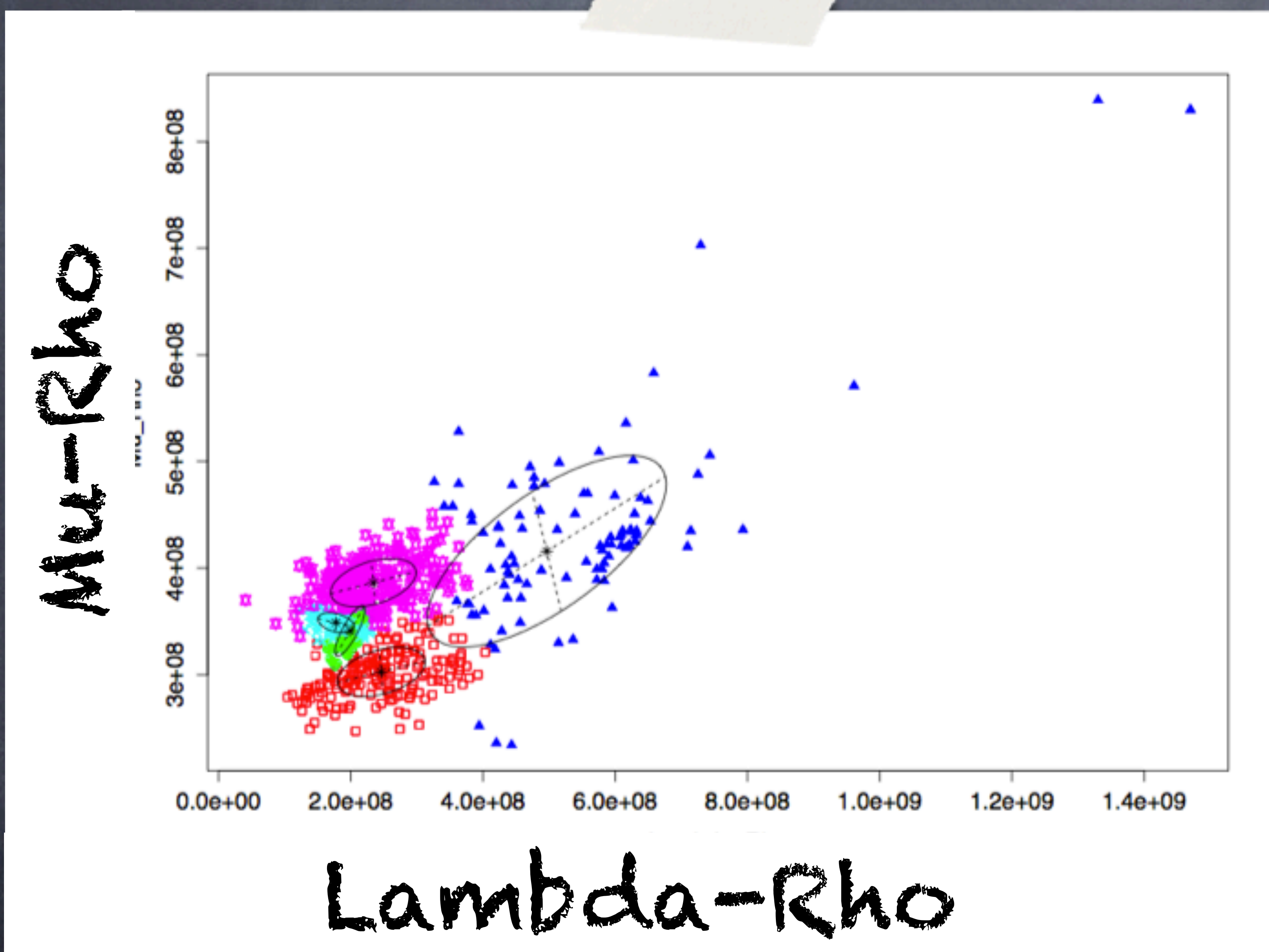
Results



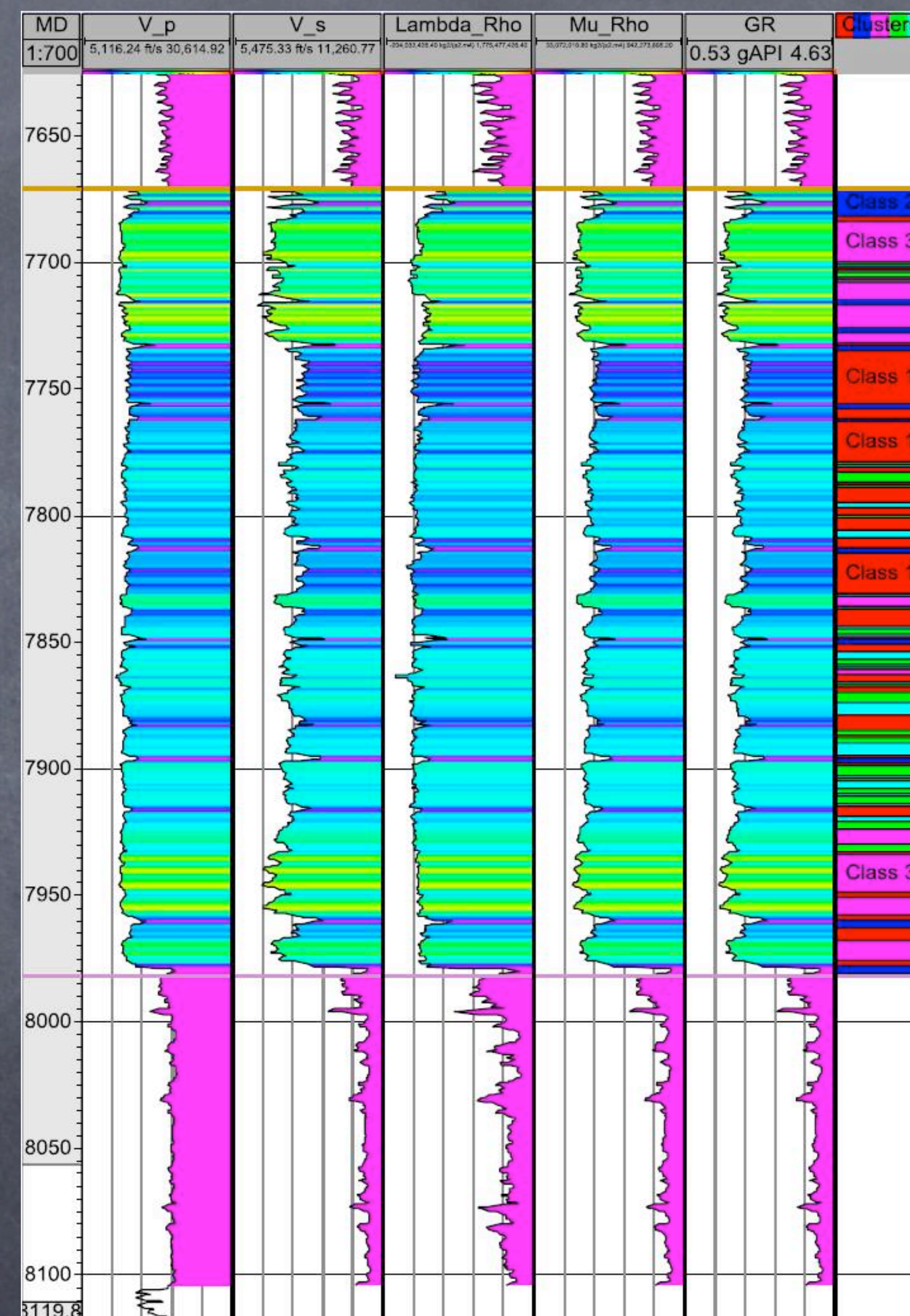
↑ GR ↑ Kerogen

↓ GR ↑ Calcite

Results

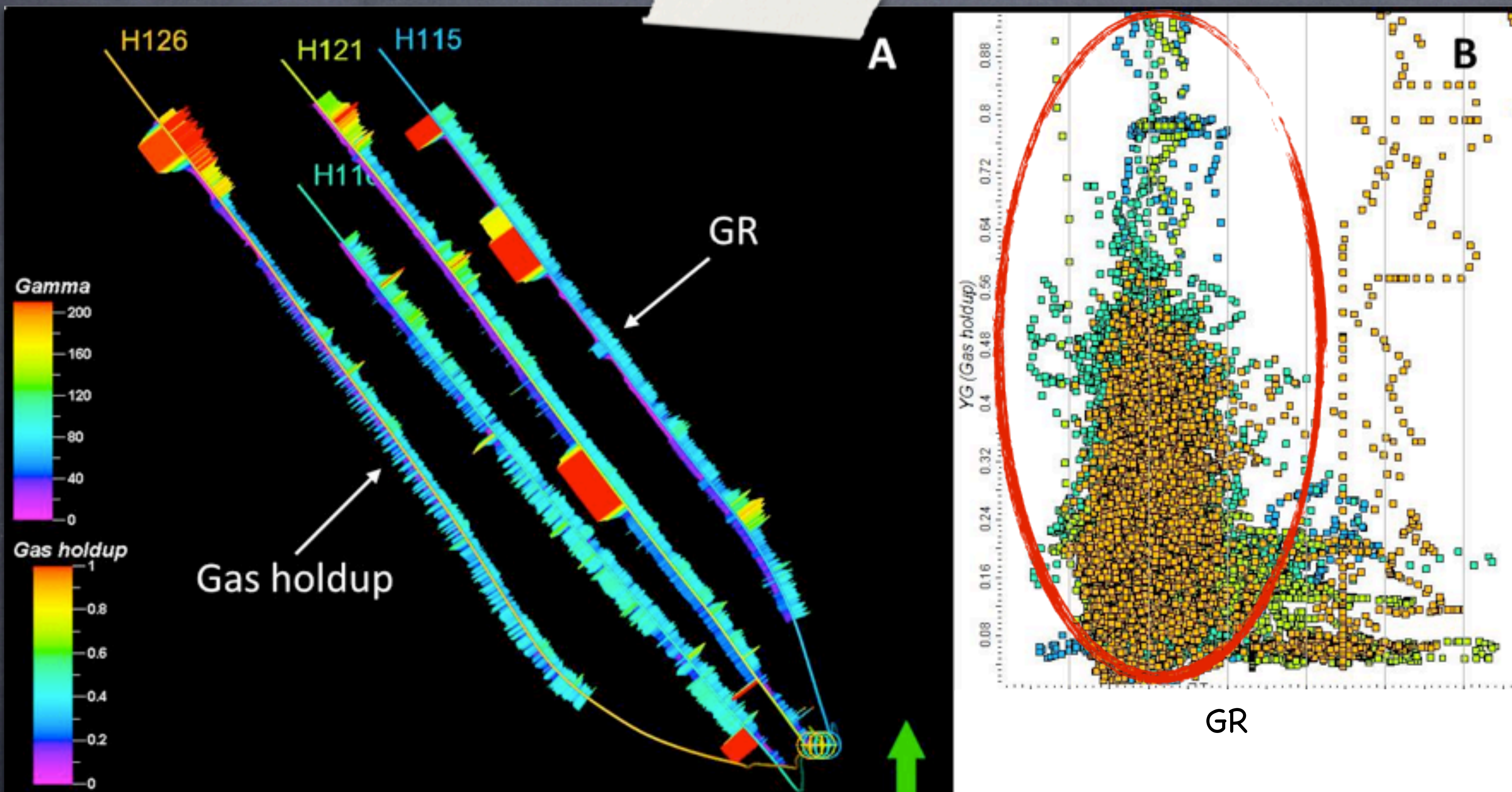


Mu-Rho
8e+08
7e+08
6e+08
5e+08
4e+08
3e+08
0.0e+00
2.0e+08
4.0e+08
6.0e+08
8.0e+08
1.0e+09
1.2e+09
1.4e+09
Lambda-Rho



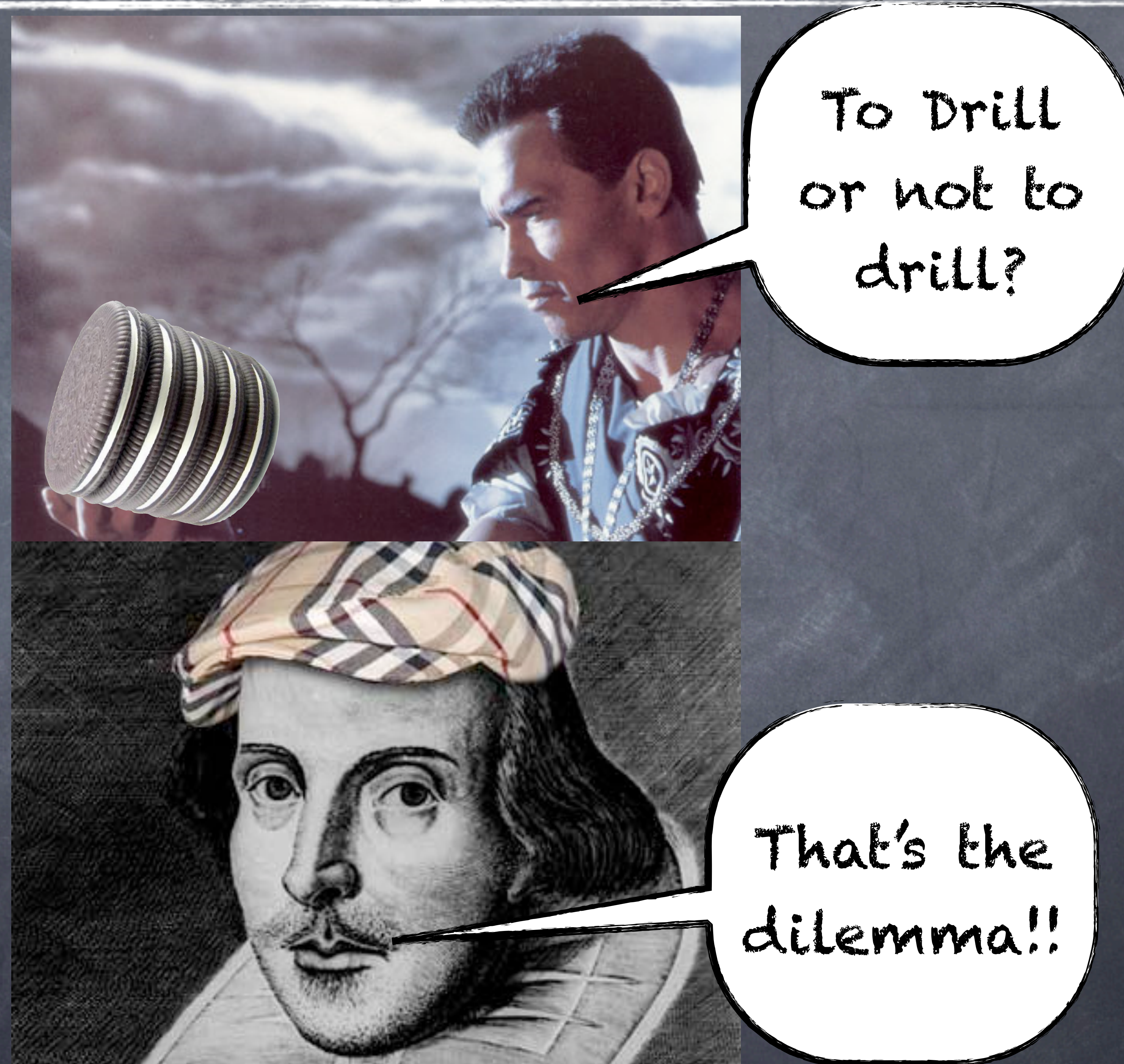
MD
1:700
V_p
5,116.24 ft/s 30,614.92
V_s
5,475.33 ft/s 11,260.77
Lambda_Rho
Mu_Rho
GR
0.53 gAPI 4.63
Clusters
7650
7700
7750
7800
7850
7900
7950
8000
8050
8100
8119.8
Class 2
Class 3
Class 1
Class 1
Class 1
Class 3

Results



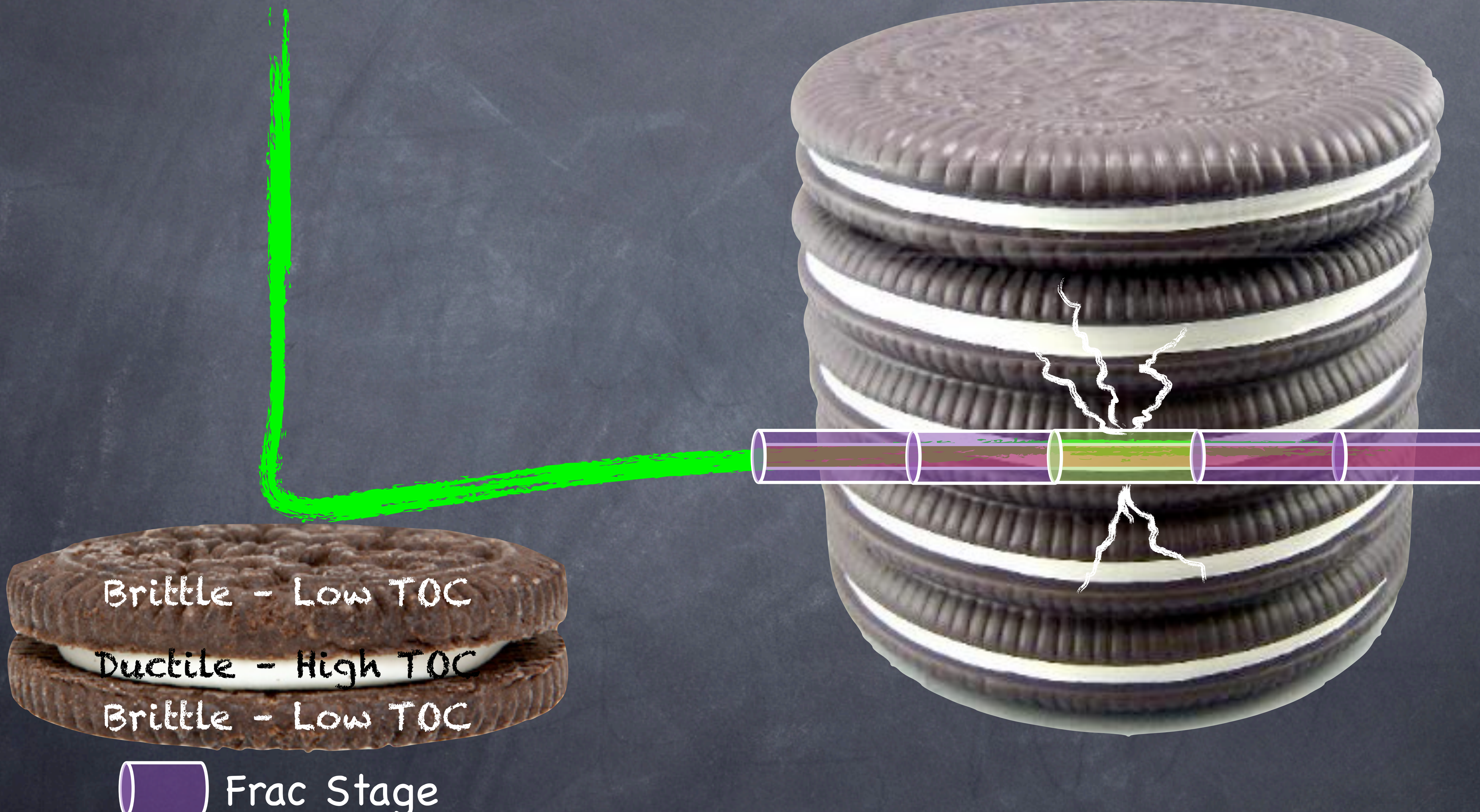
A
H126
H121
H115
H11
GR
Gamma
200
160
120
80
40
0
Gas holdup
1
0.8
0.6
0.4
0.2
0
Gas holdup
B
YG (Gas holdup)
0.08
0.16
0.24
0.32
0.4
0.48
0.56
0.64
0.72
0.8
0.88
GR

Analysis



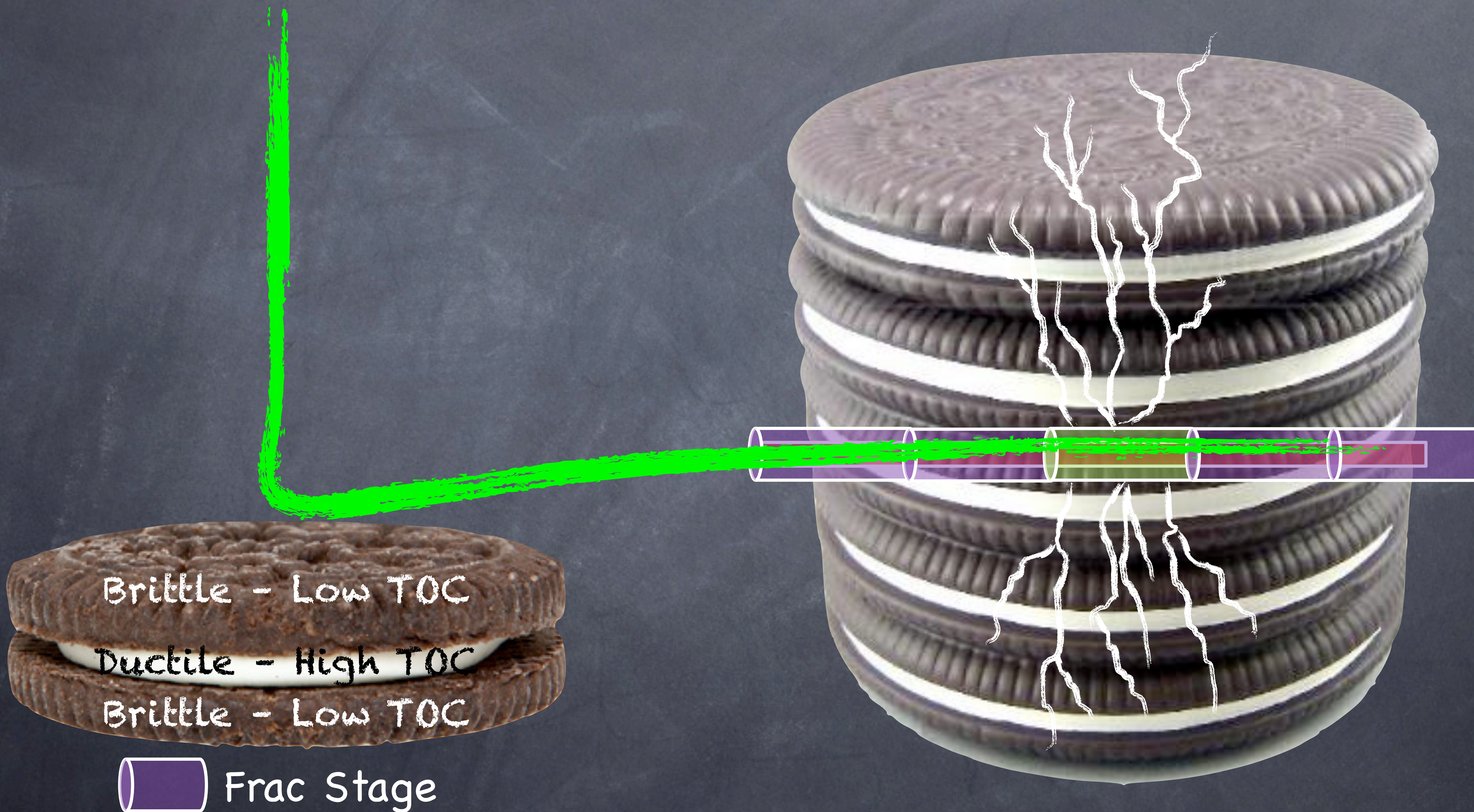
Analysis

Scenario 1   Ductile - High TOC zone



Analysis

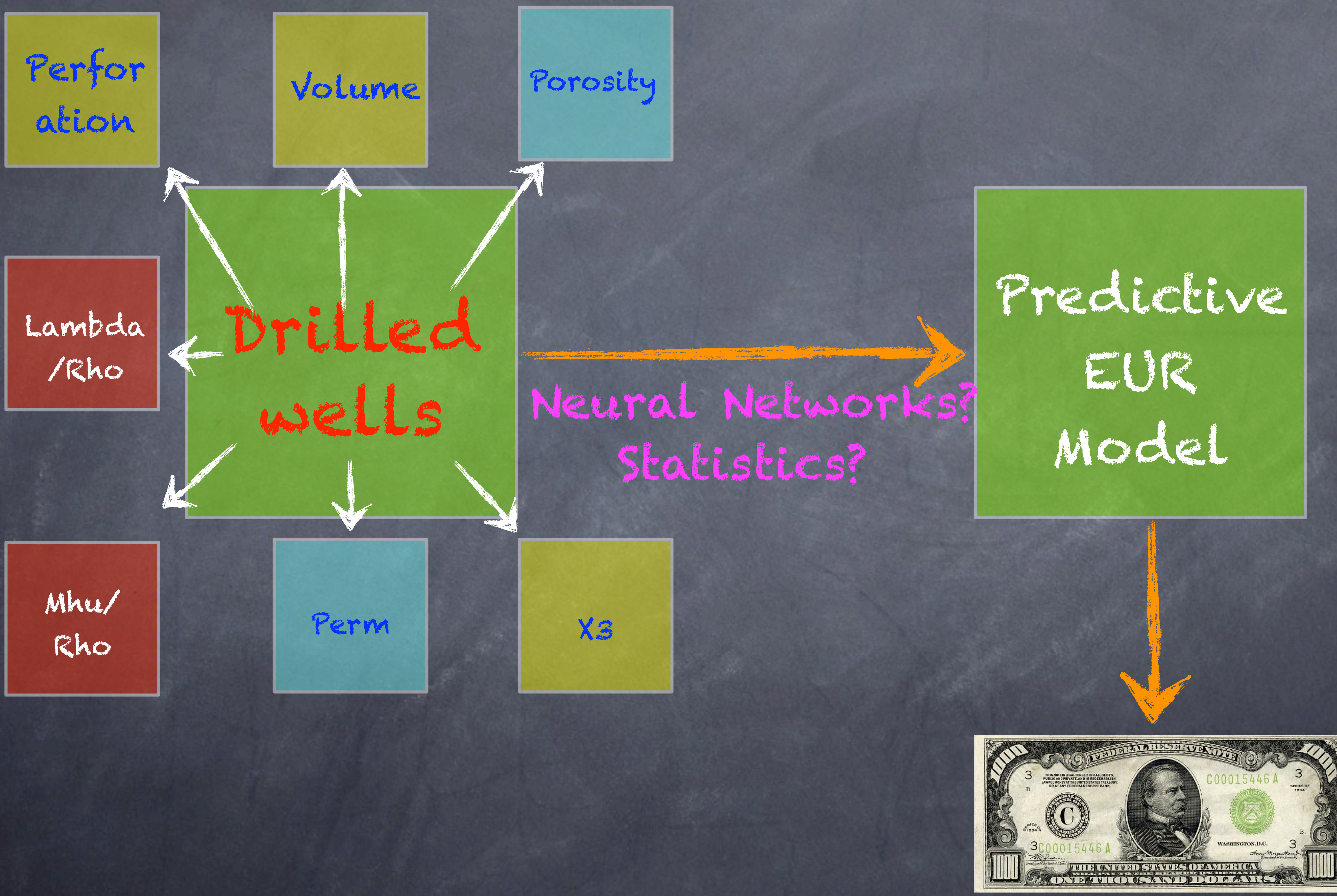
Scenario 2 Brittle - Low TOC zone



Conclusions

- EUR estimation is a multi-variable problem, divided in geological (Reservoir) and engineering (completion) variables
- Well log and seismic results show good correlation (calibration). LMR cluster analysis is useful to isolate brittle / ductile zones
- LMR X-plots reveal that the Upper Barnett is more brittle than the Lower Barnett (mineralogy)

Summary


Perforation
Volume
Porosity
Lambda/Rho
Drilled wells
Neural Networks?
Statistics?
Predictive EUR Model
Mhu/Rho
Perm
X3

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