

Application of LMR and Clustering Analysis in Unconventional Reservoirs*

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Search and Discovery Article #40879 (2012)

Posted February 13, 2012

*Adapted from presentation at AAPG Geoscience Technology Workshop, "International Shale Plays," Houston, Texas, October 11-12, 2011

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General Comments

- 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 (Lambda-Mu-Rho) 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).

References

Goodway, B., 2009, Connecting active and passive seismic to describe geomechanical rock properties: Recorder, v. 34/2, p. 7-9.

Roy, A., R. Perez, and K.J. Marfurt, 2011, Formation Evaluation of Barnett Shale by Kohonen Self Organizing Maps – An Example from North East Fort Worth Basin: AAPG Search and Discovery Article #90124. Web accessed 31 January 2011, <http://www.searchanddiscovery.com/abstracts/html/2011/annual/abstracts/Roy.html>

Application of LMR and Clustering Analysis in Unconventional Reservoirs

AAPG - GTW
International Shale Plays

October 11th, 2011

Roderick Perez
The University of Oklahoma

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Outline



- GOAL
- LMR INVERSION
- RESULTS
- ANALYSIS
- CONCLUSIONS



Goal





Goal



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



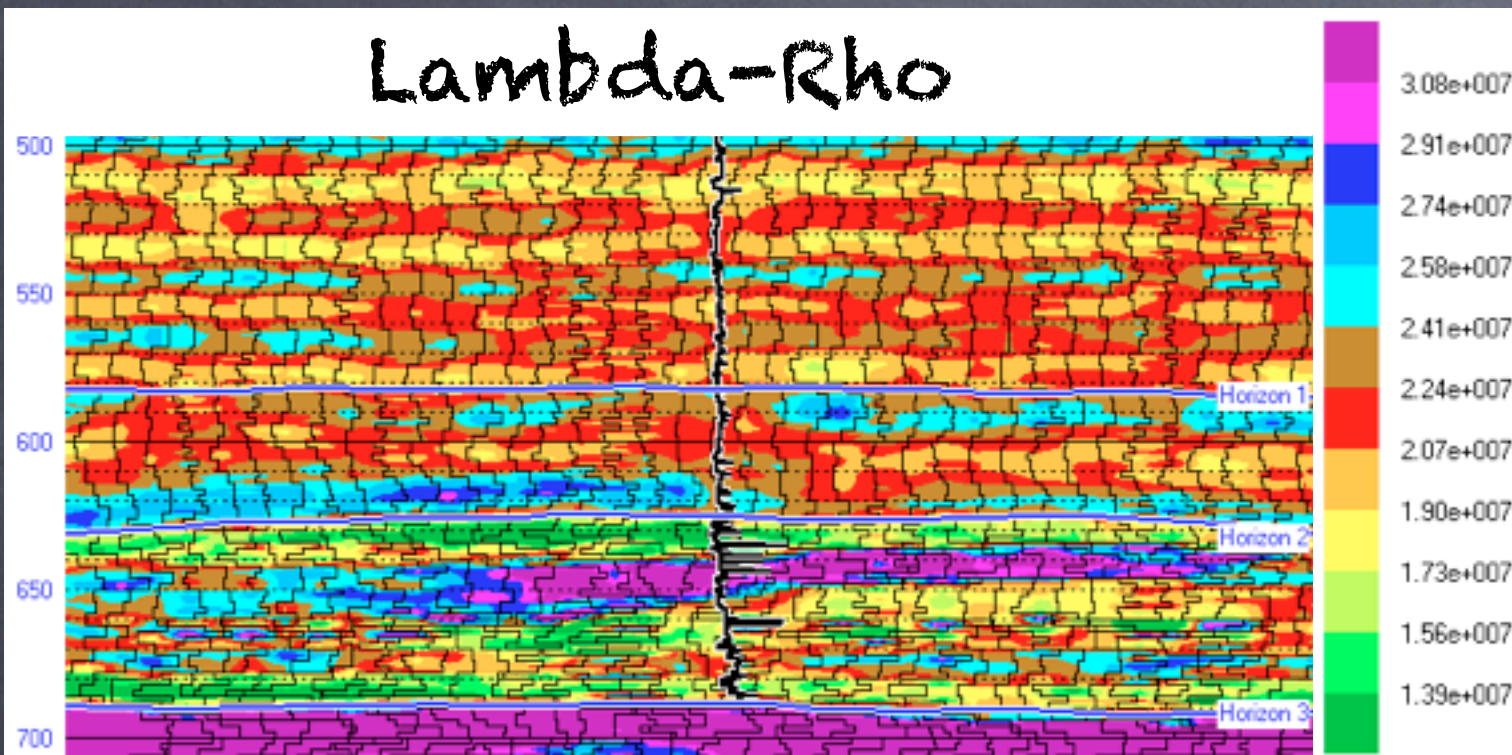
Application of LMR and Clustering Analysis in
Unconventional Reservoirs

LAMBDA-RHO / MHU-RHO
INTEGRATION

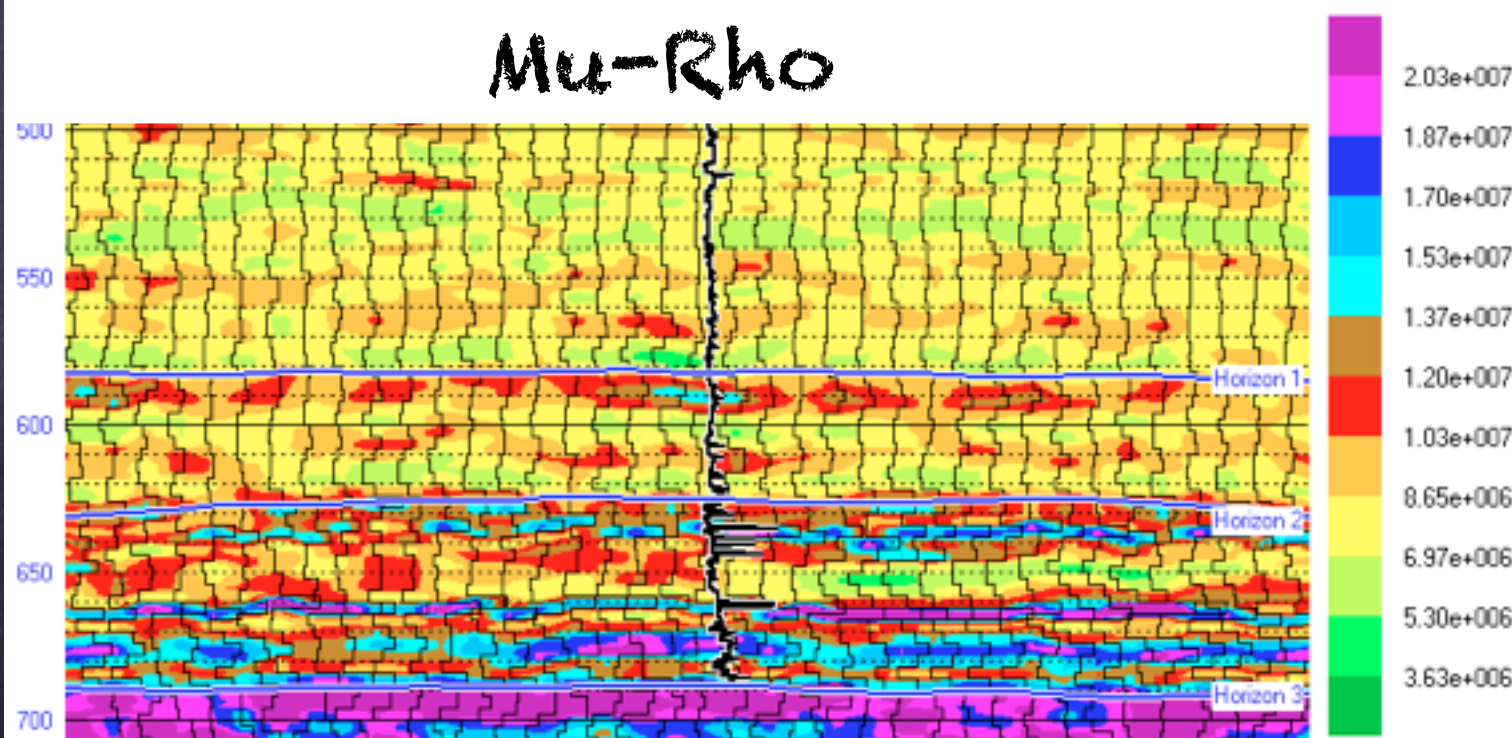


Introduction

Lambda-Rho

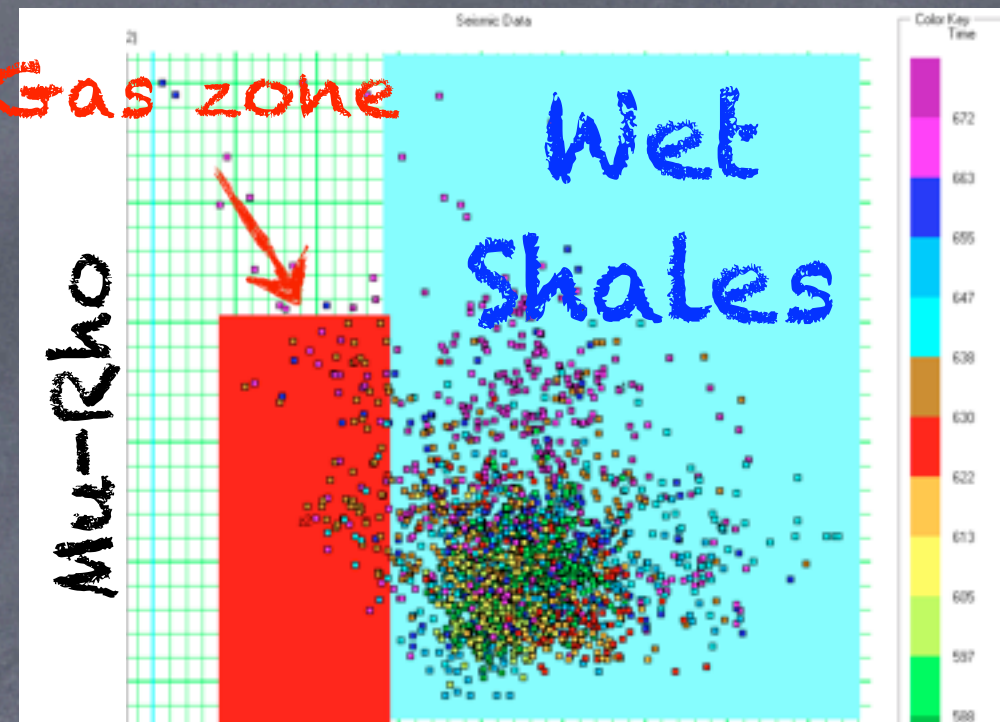


Mu-Rho

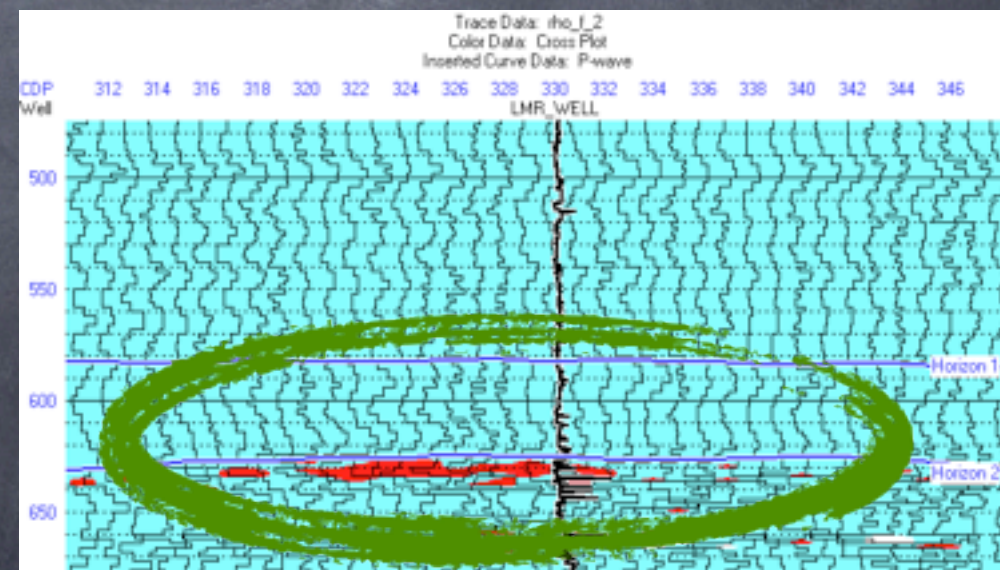


Gas zone

Mu-Rho



Lambda-Rho



Images from H&R Strata Manual



Methodology

Lamé Parameters

V_s

Shear wave



Original
Rock

V_p

Compressional wave



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

Dipole log

$$\lambda \rho = Z_p^2 - 2Z_s^2$$
$$\mu \rho = Z_s^2$$

μ = Rigidity (Lame moduli)
 λ = Incompressibility

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

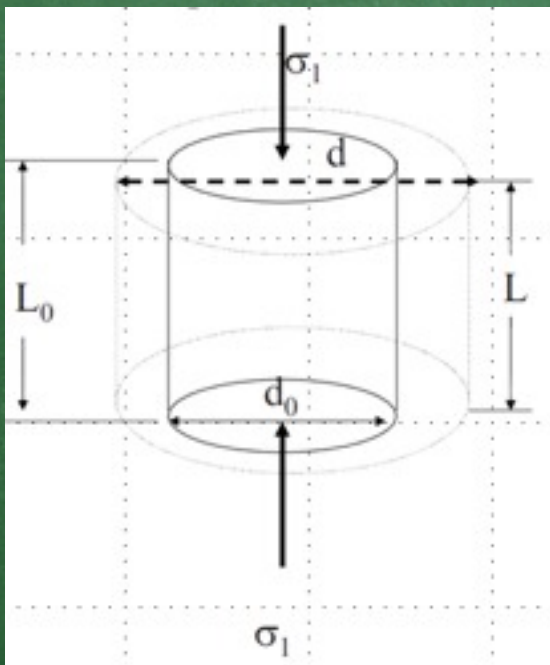
Sonic log



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

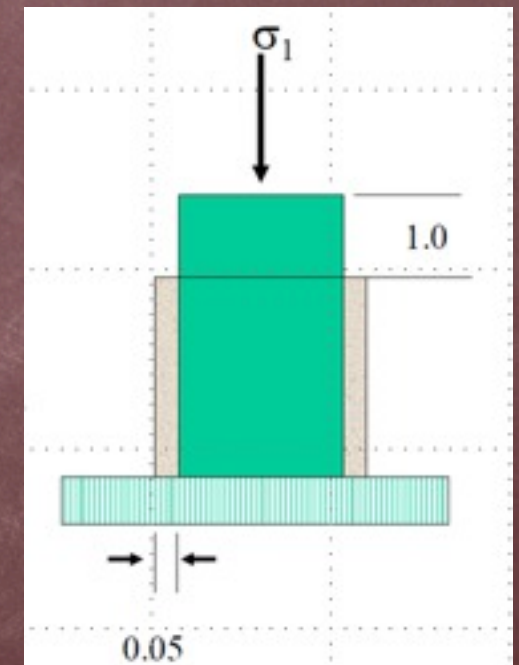
$$M = \lambda + 2\mu$$

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.

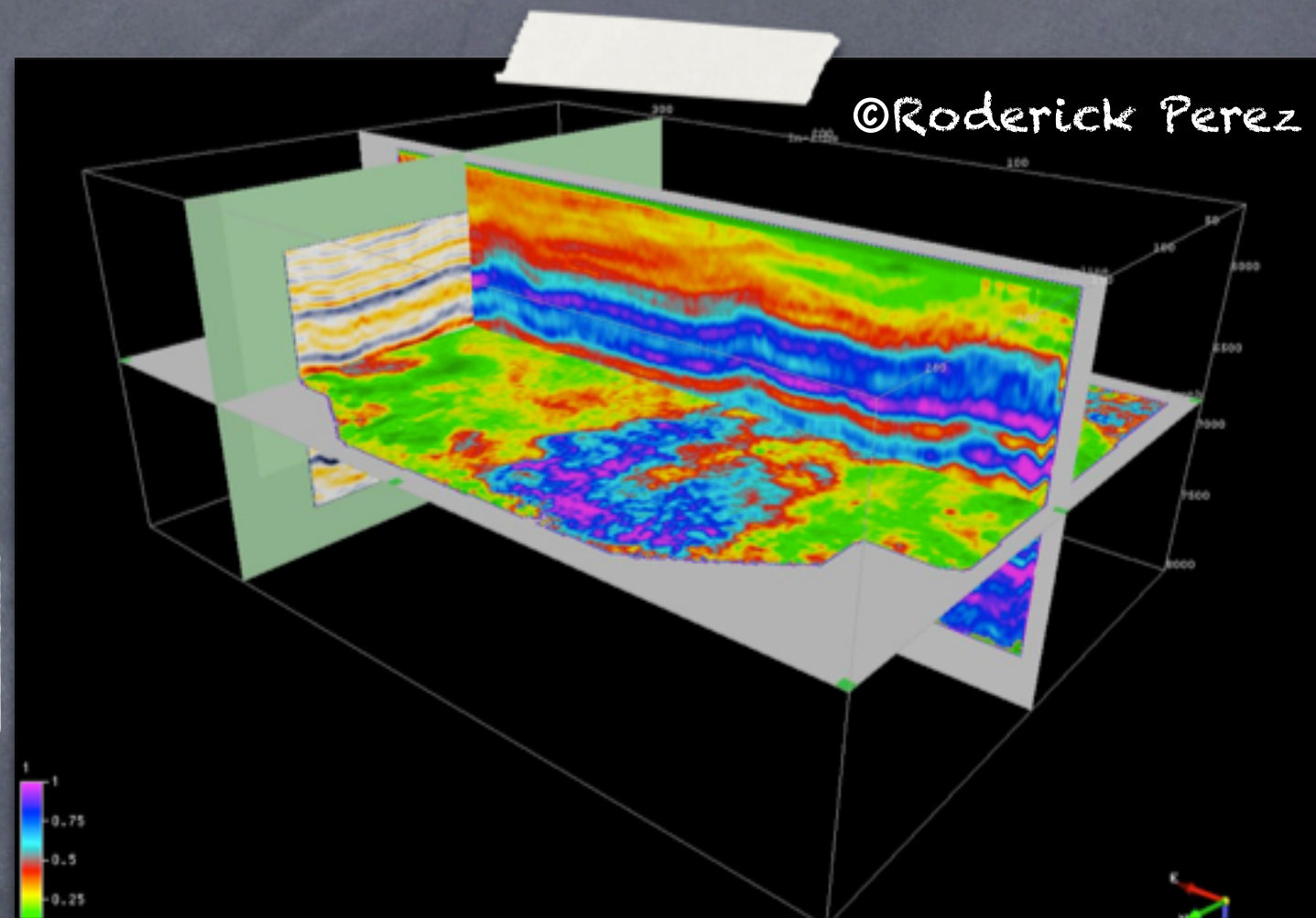
R_s reflect.

Z_p Imped.

Z_s Imped.

Lambda-Rho / Mu-Rho

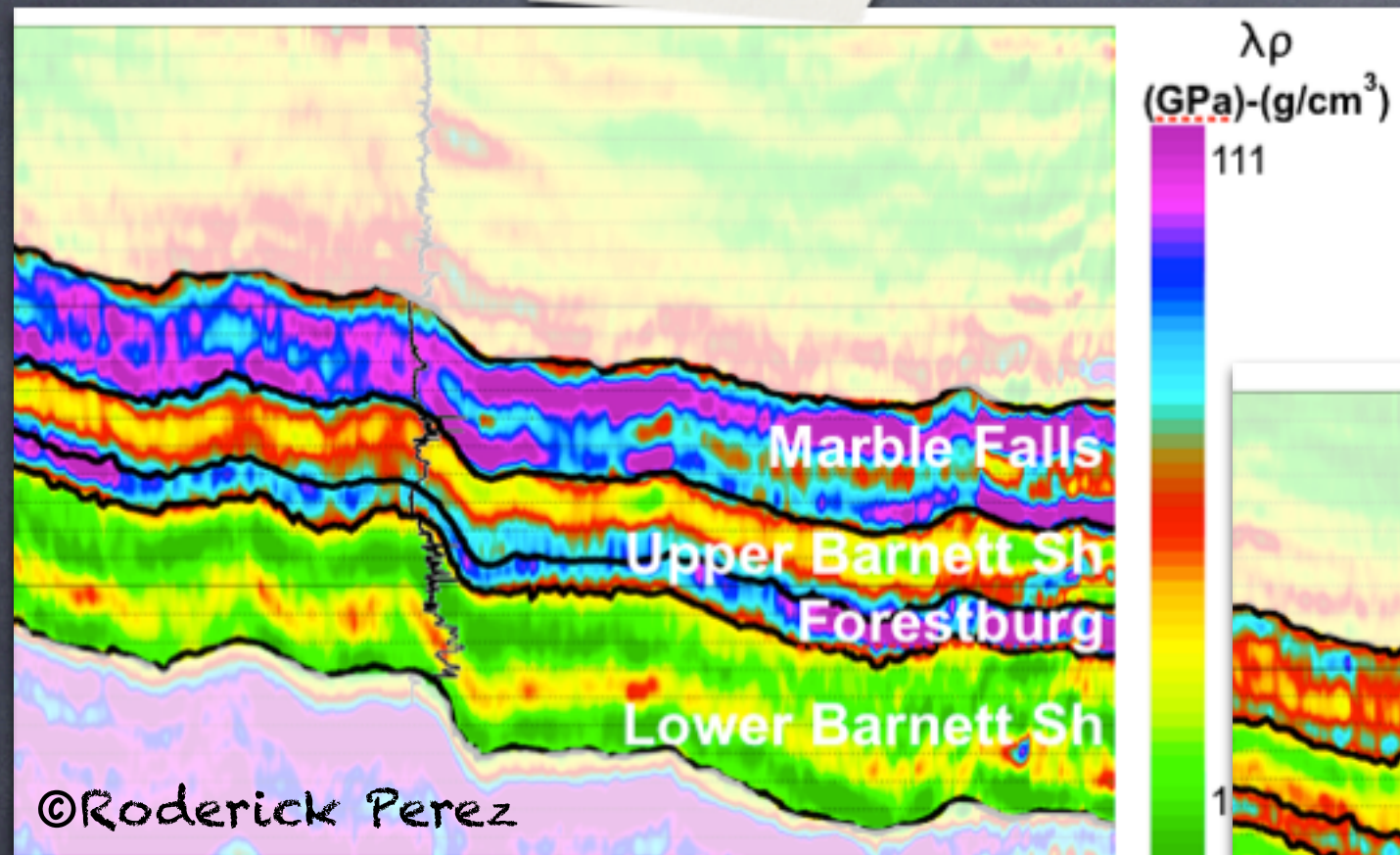
Cross-plots



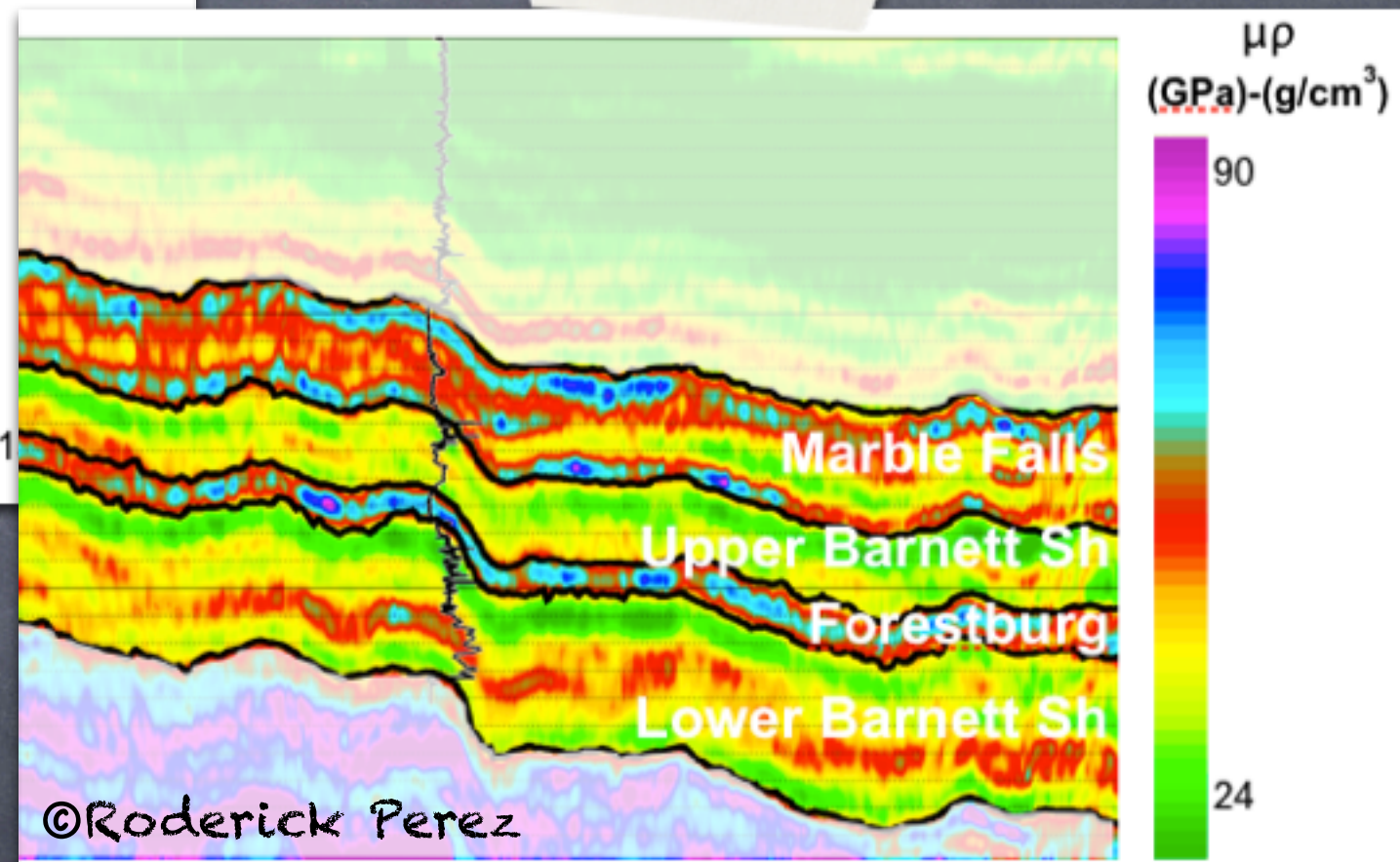
Lambda-Rho & Mu-Rho from the
area of study



Results



Lambda-Rho from representative inline of area of study



Mu-Rho from representative inline of area of study



Methodology

Cross-plots

	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

Marble
Falls Lm

Upper
Barnett Sh

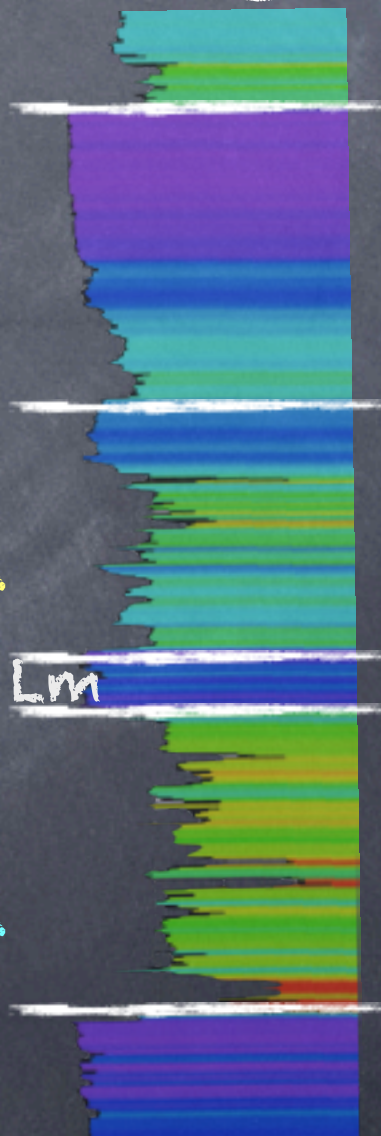
Forestburg Lm

Lower
Barnett Sh

Viola Lm

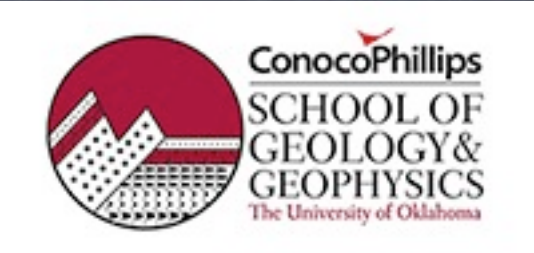
GR

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

Marble Falls Lm

Upper Barnett Sh

Forestburg Lm

Lower Barnett Sh

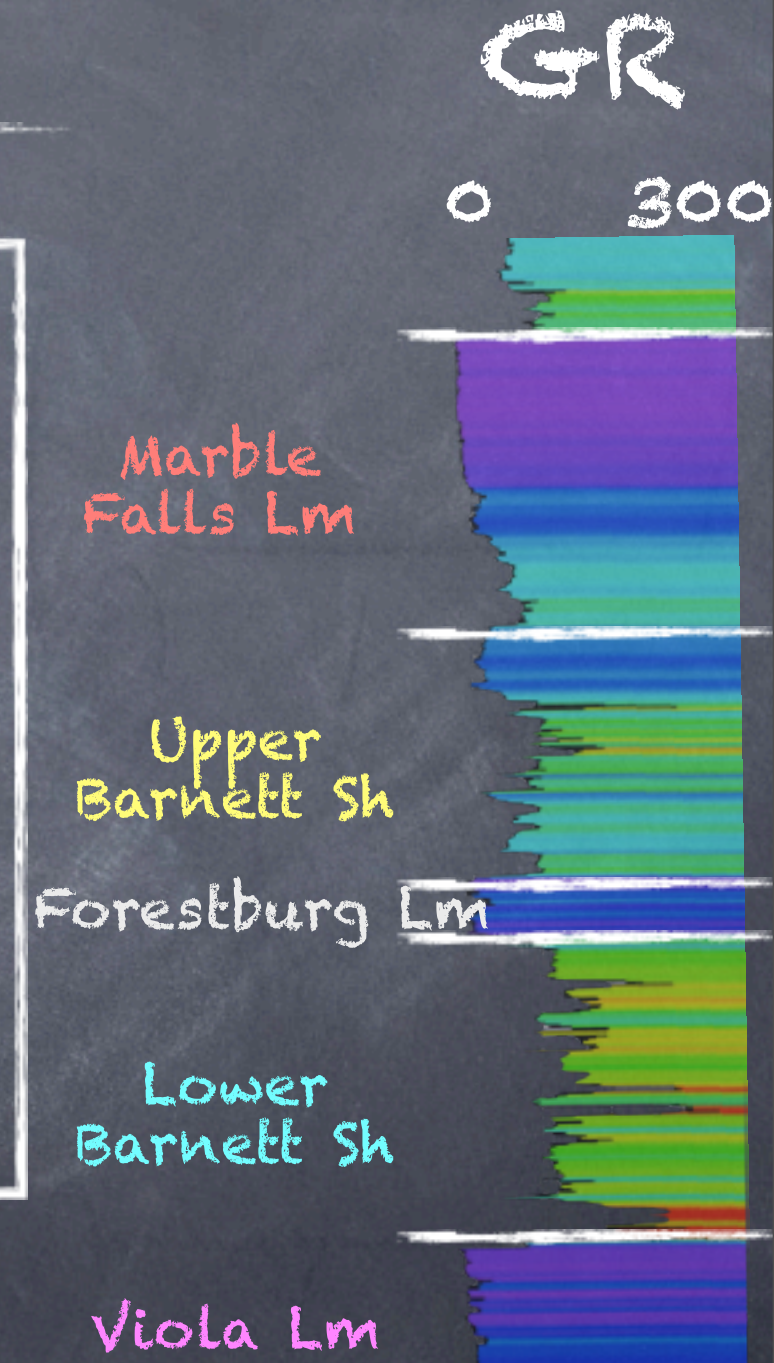
Viola Lm



Methodology



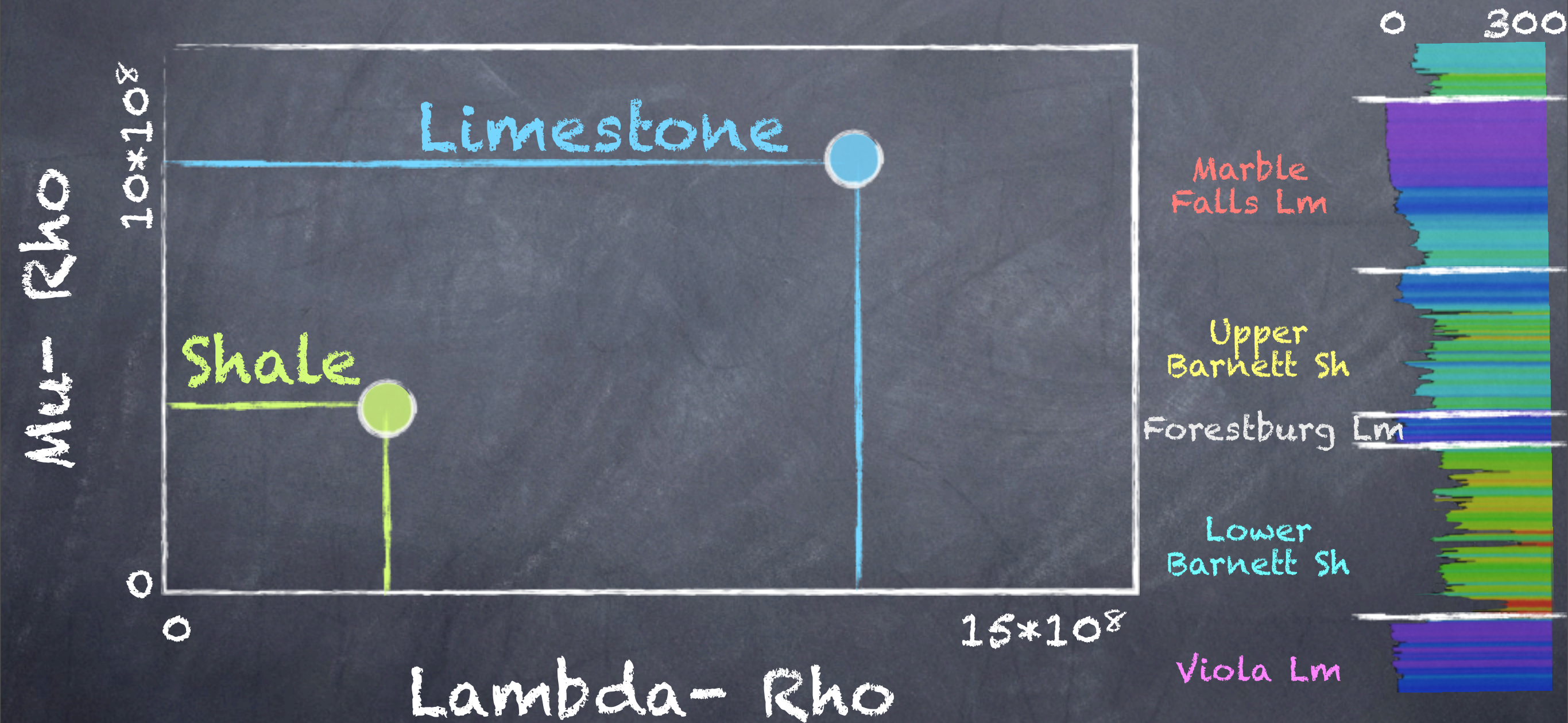
Cross-plots





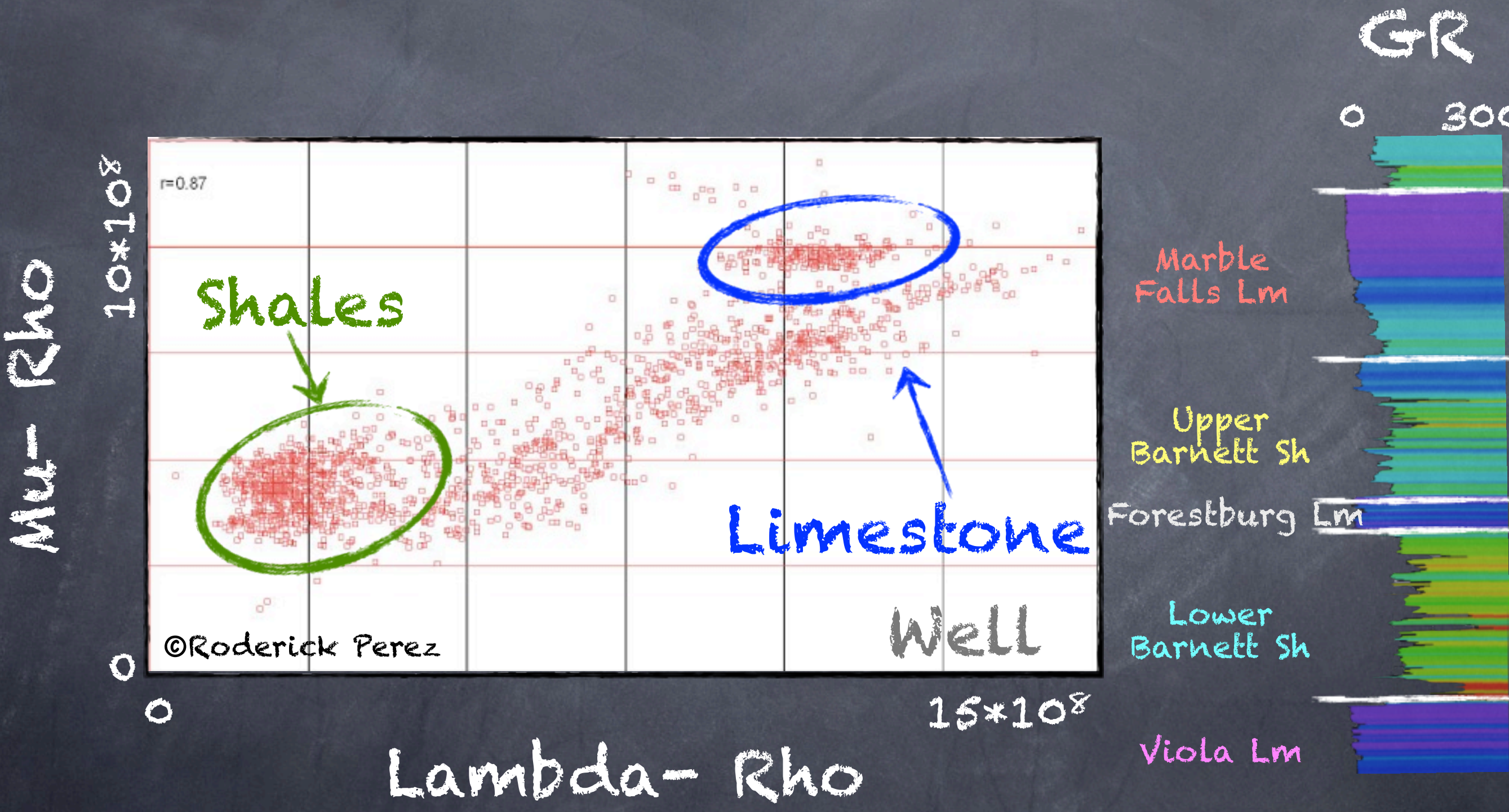
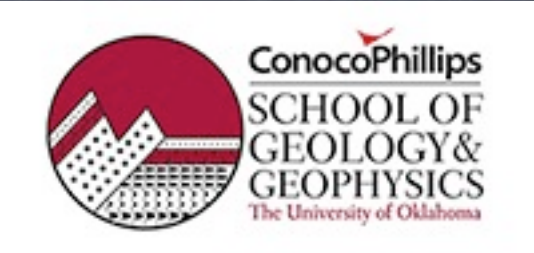
Methodology

Cross-plots



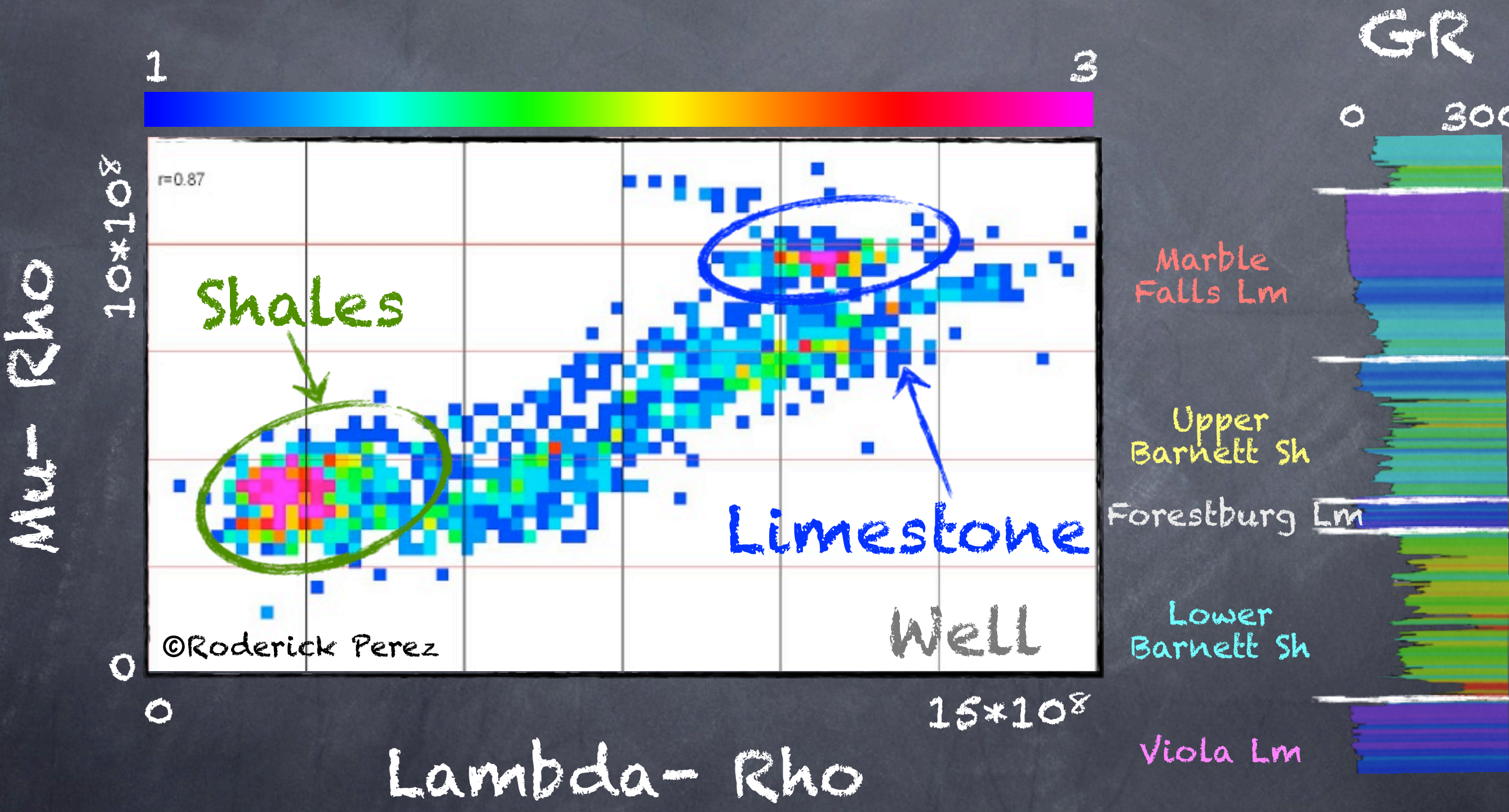
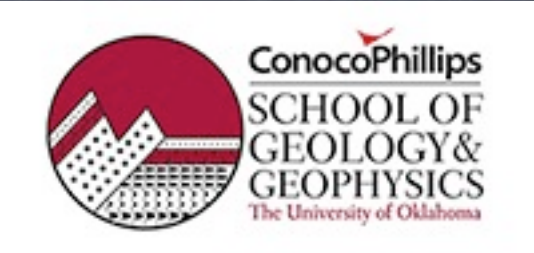


Methodology



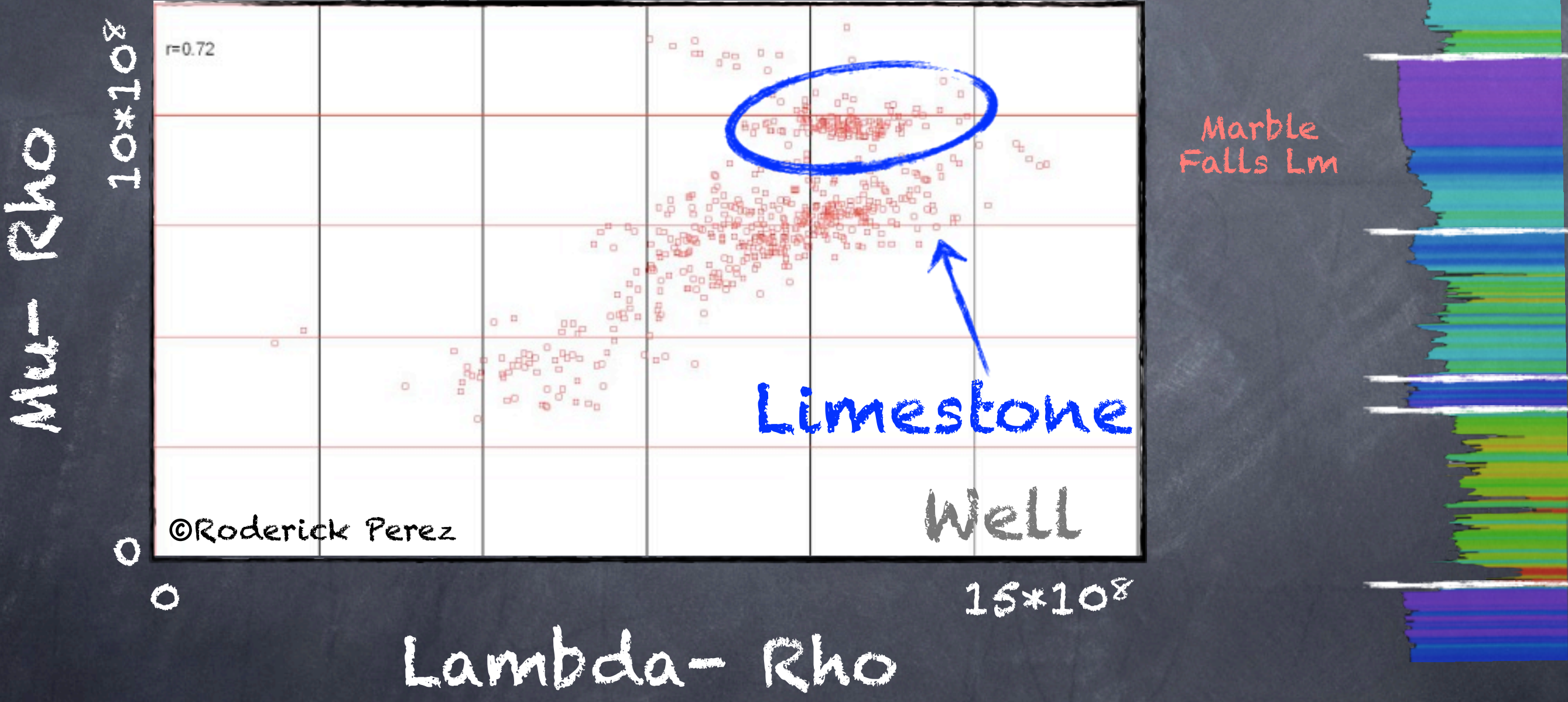
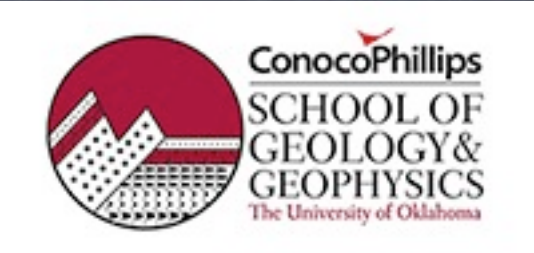


Methodology



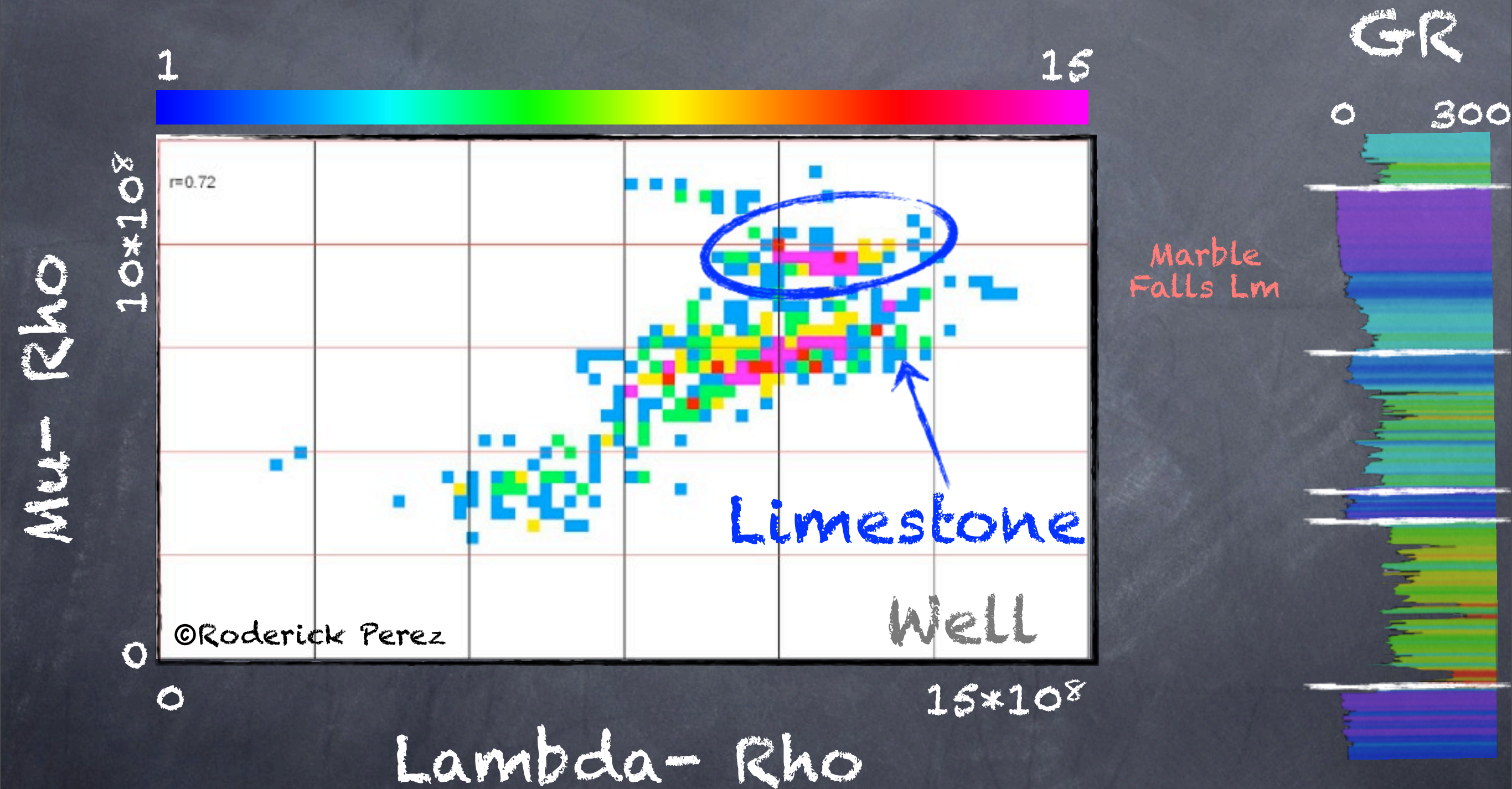


Methodology



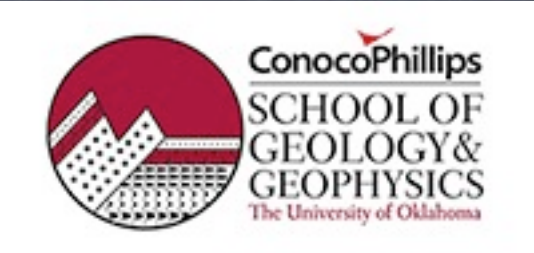


Methodology



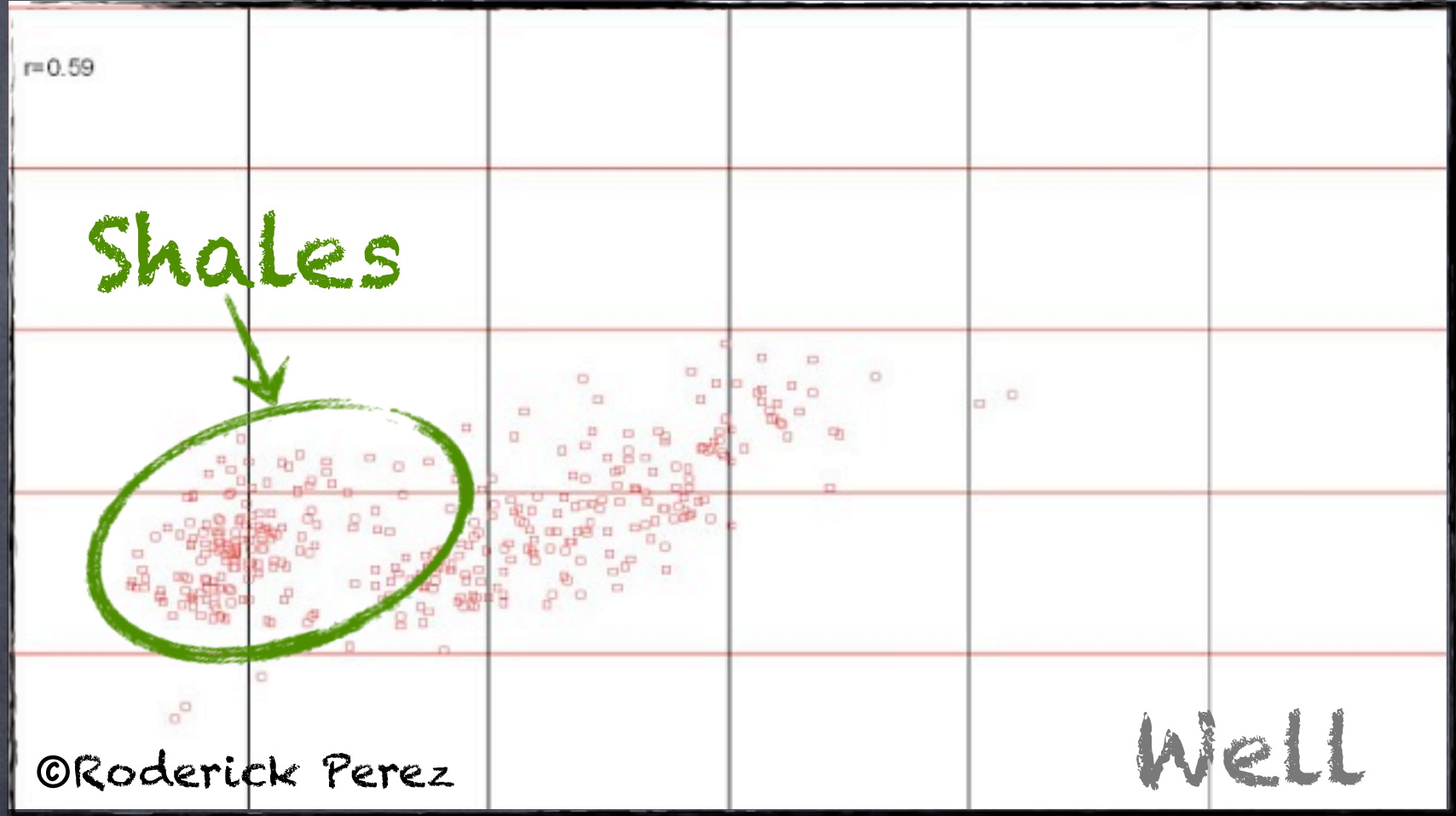


Methodology



Mu - Rho

10×10^8



Well

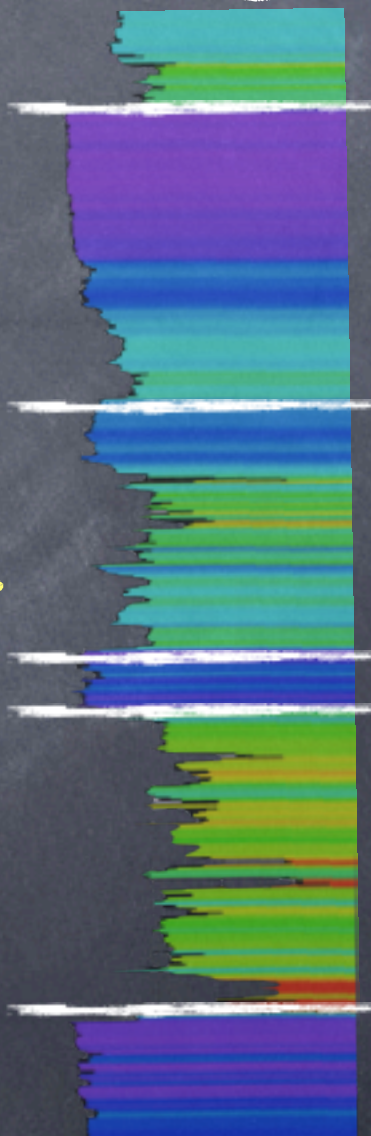
15×10^8

Lambda - Rho

GR

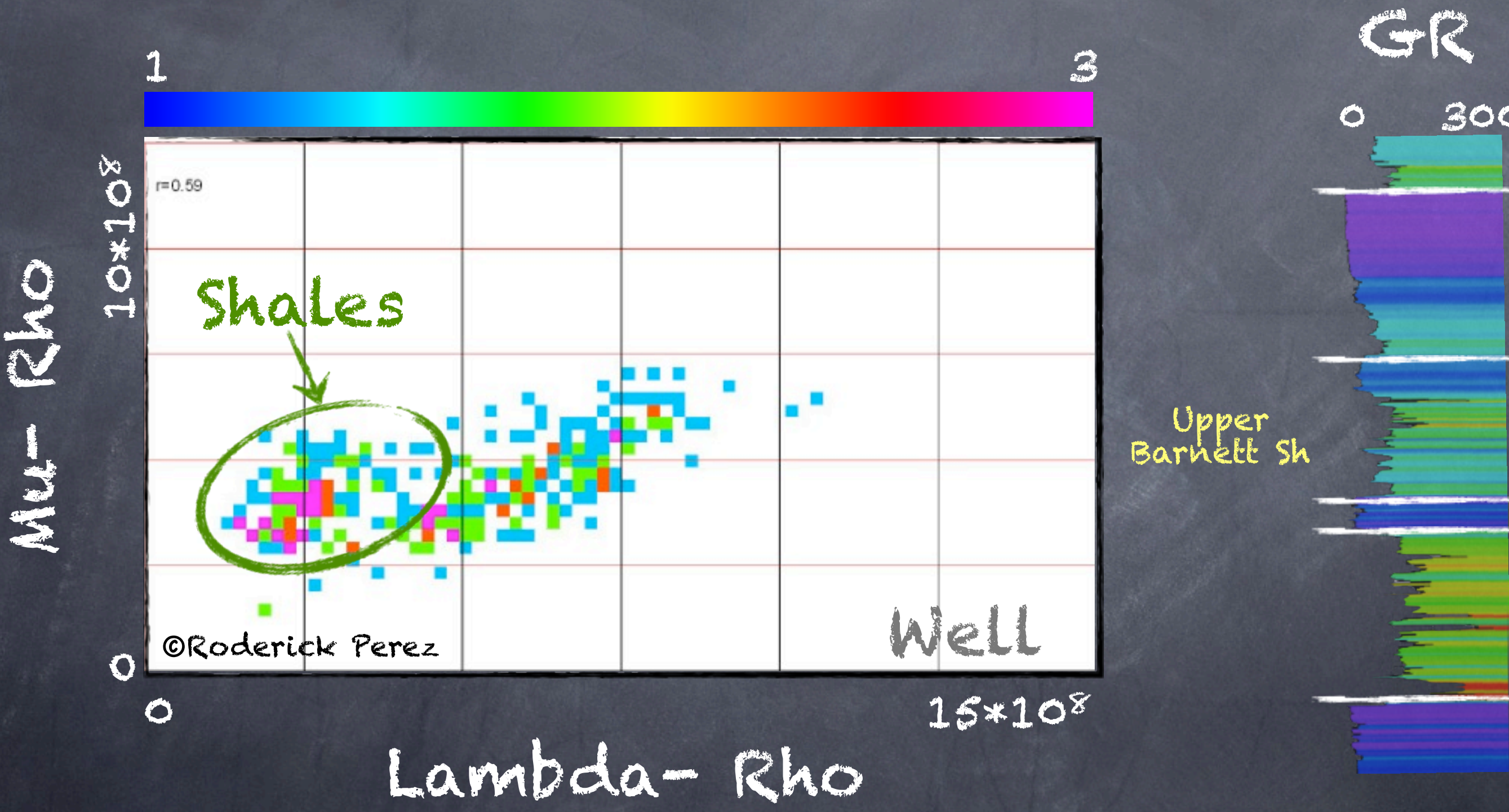
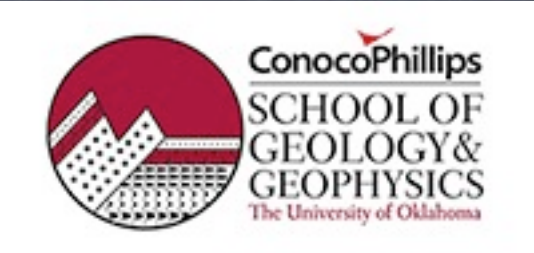
0 300

Upper Barnett Sh



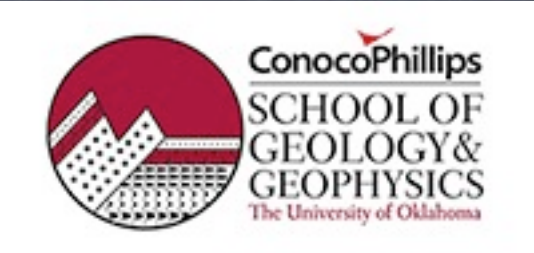


Methodology



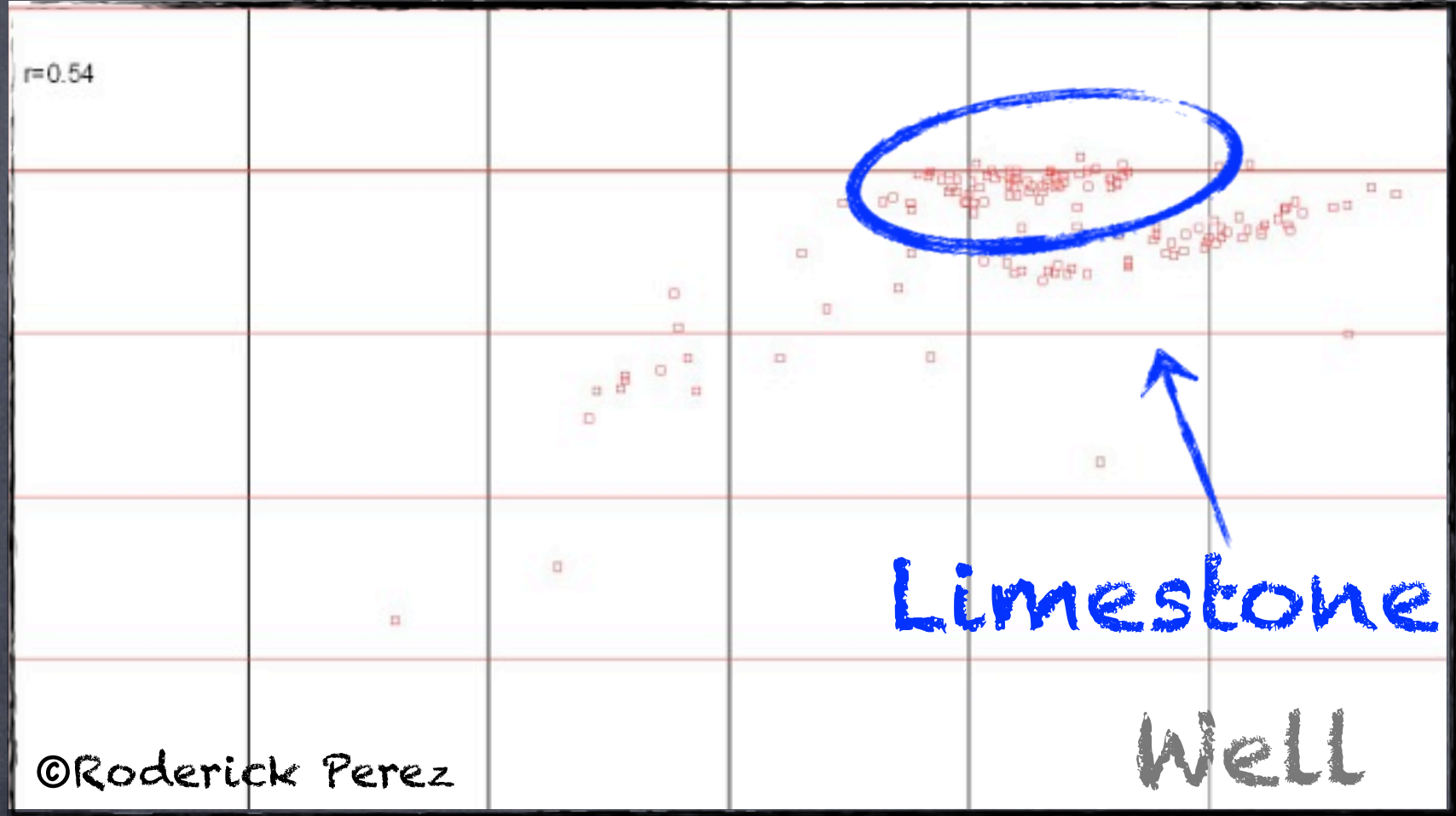


Methodology



Mu - Rho

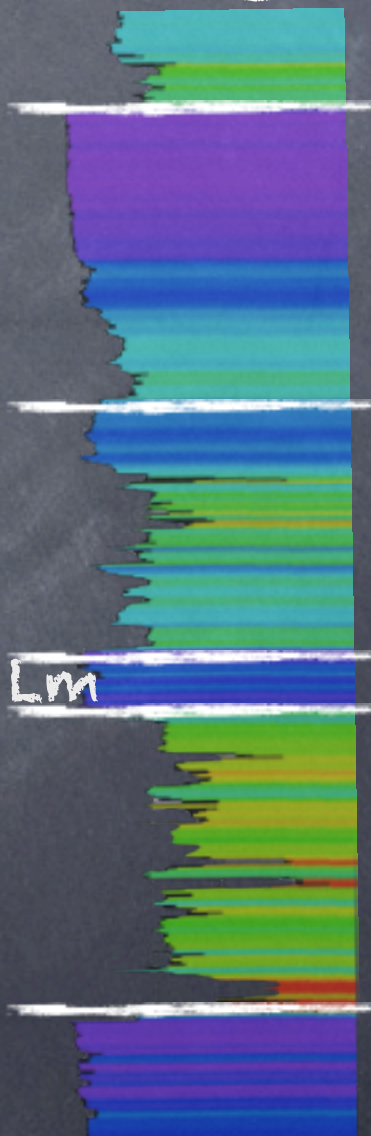
10×10^8



Limestone Well

GR

0 300

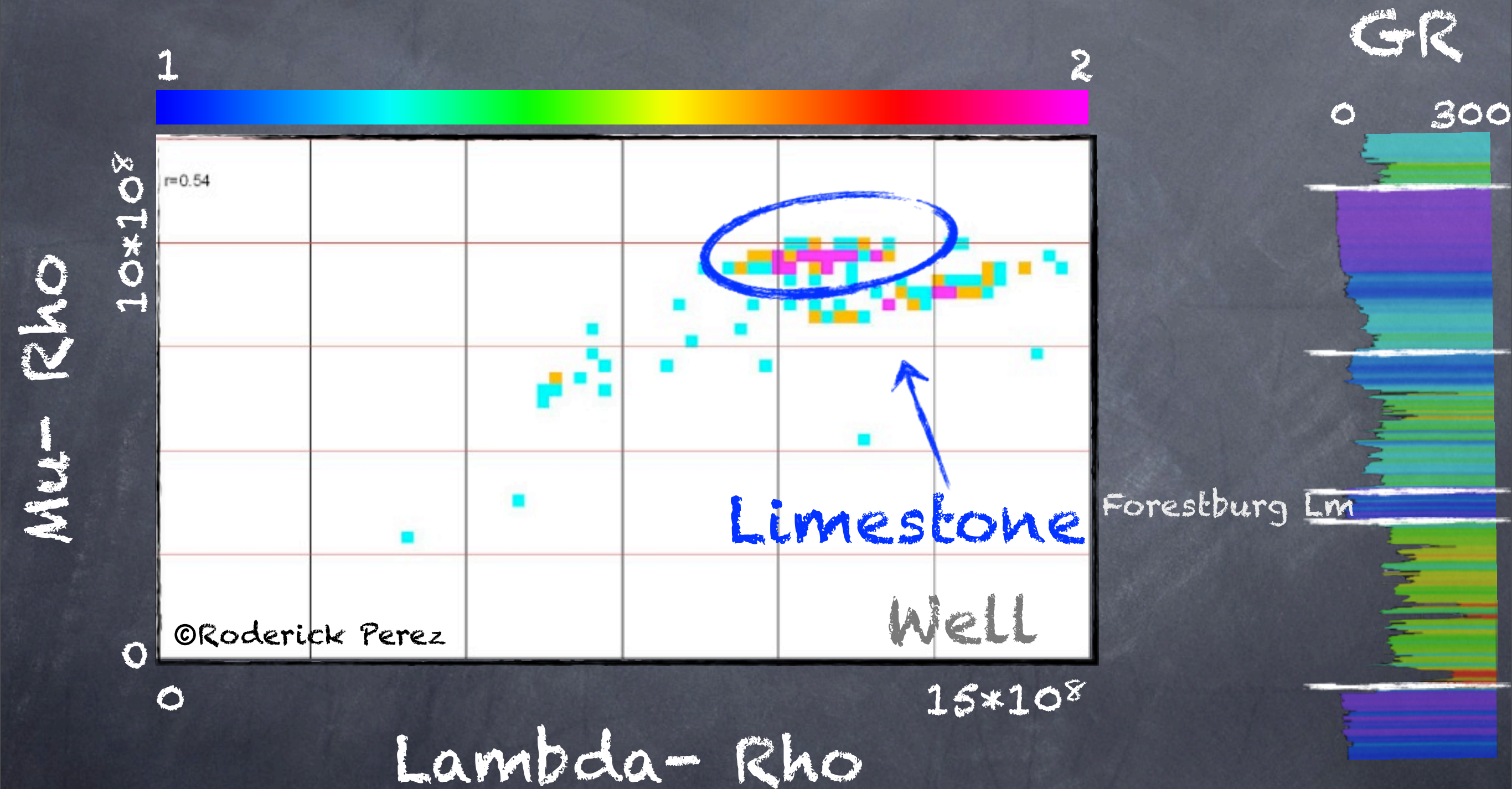


Forestburg Lm

Lambda - Rho

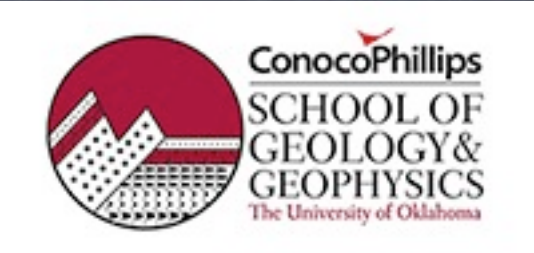


Methodology



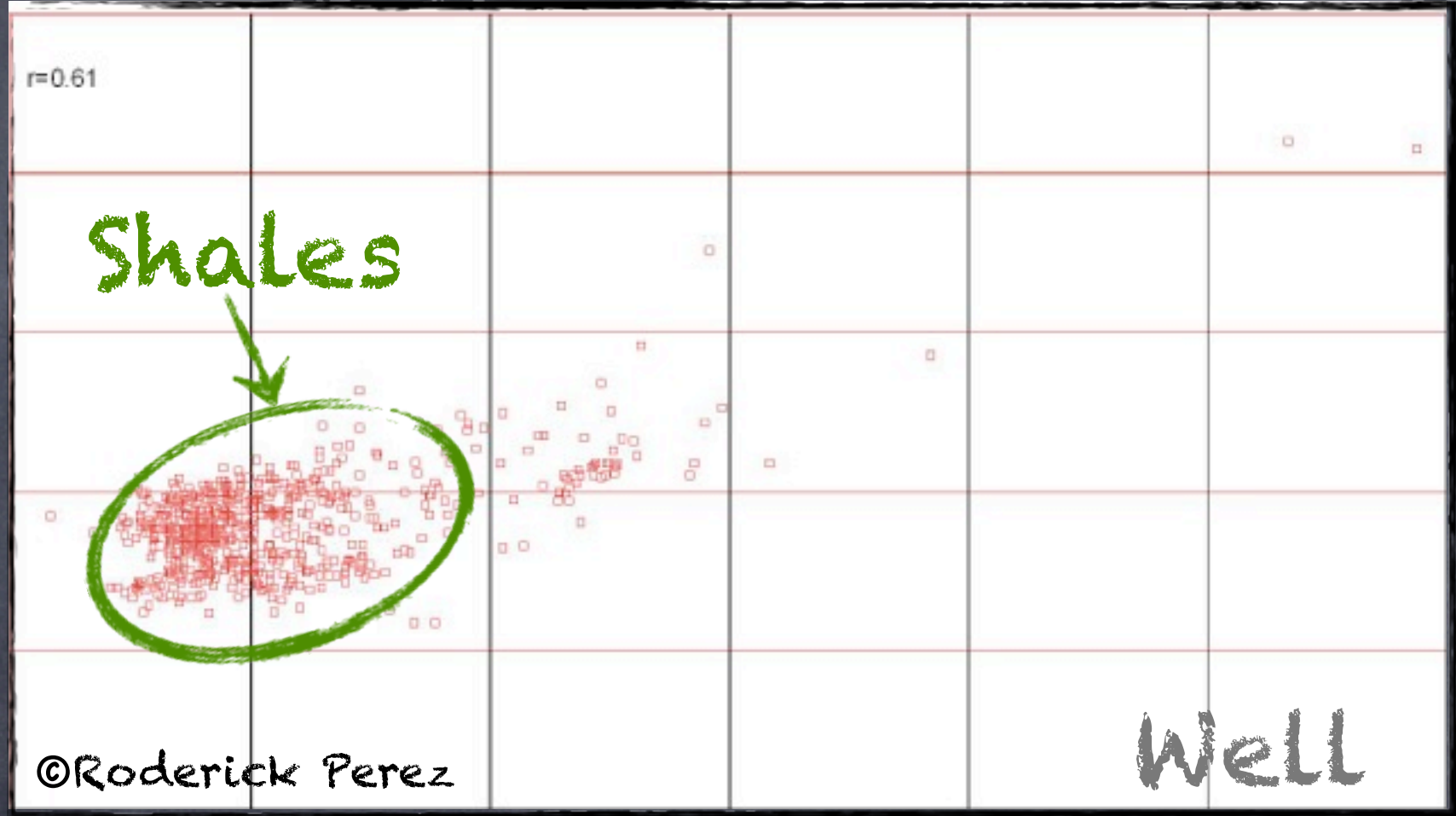


Methodology



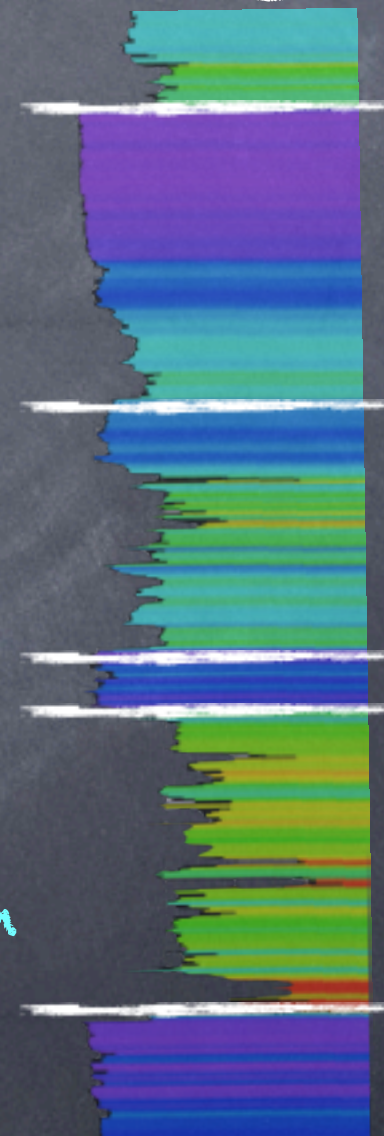
Mu - Rho

10×10^8



GR

0 300

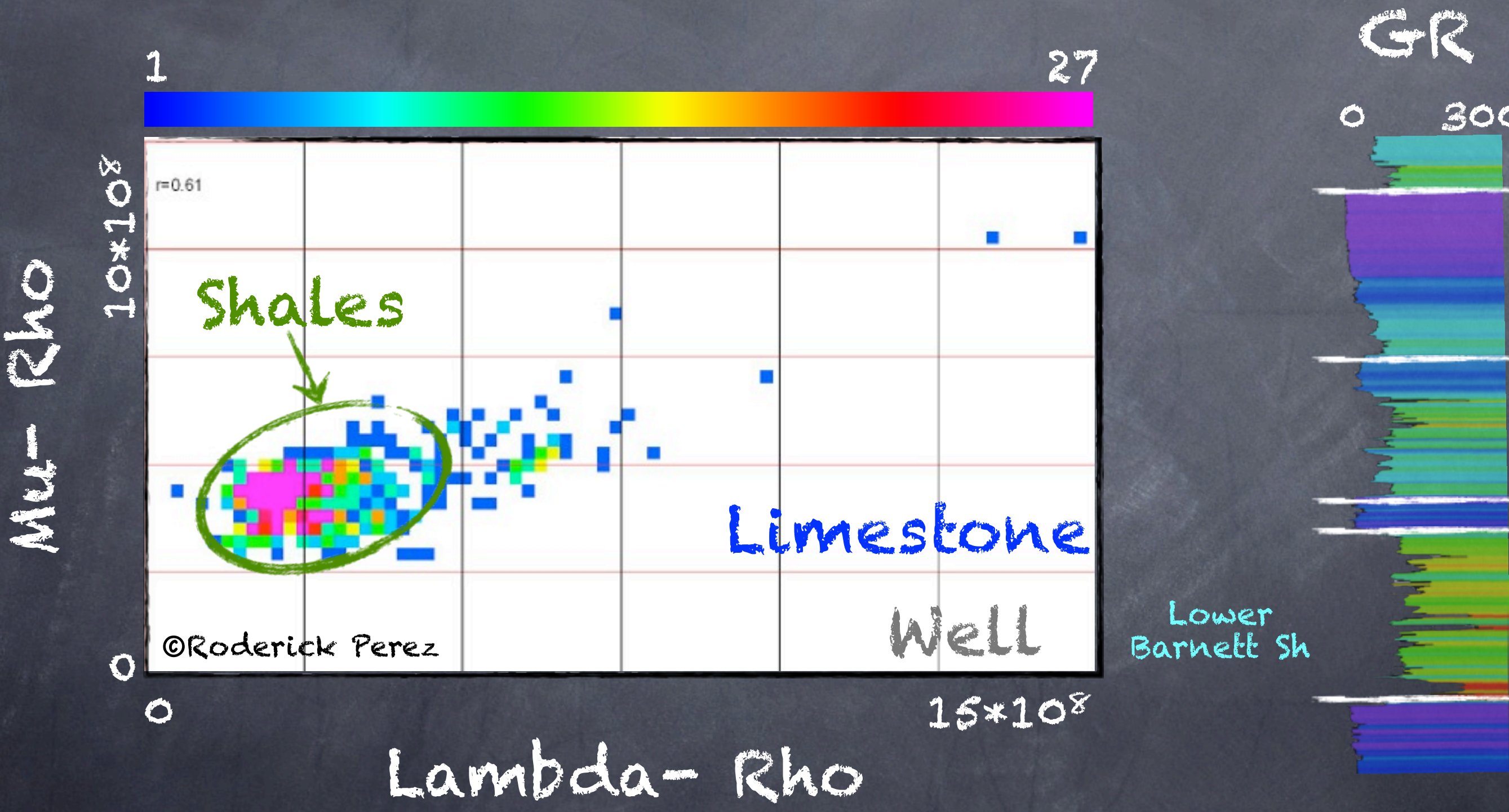
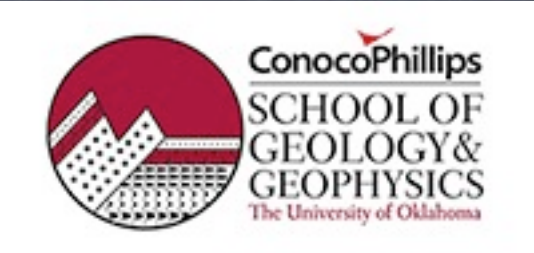


Lower Barnett Sh

Lambda - Rho

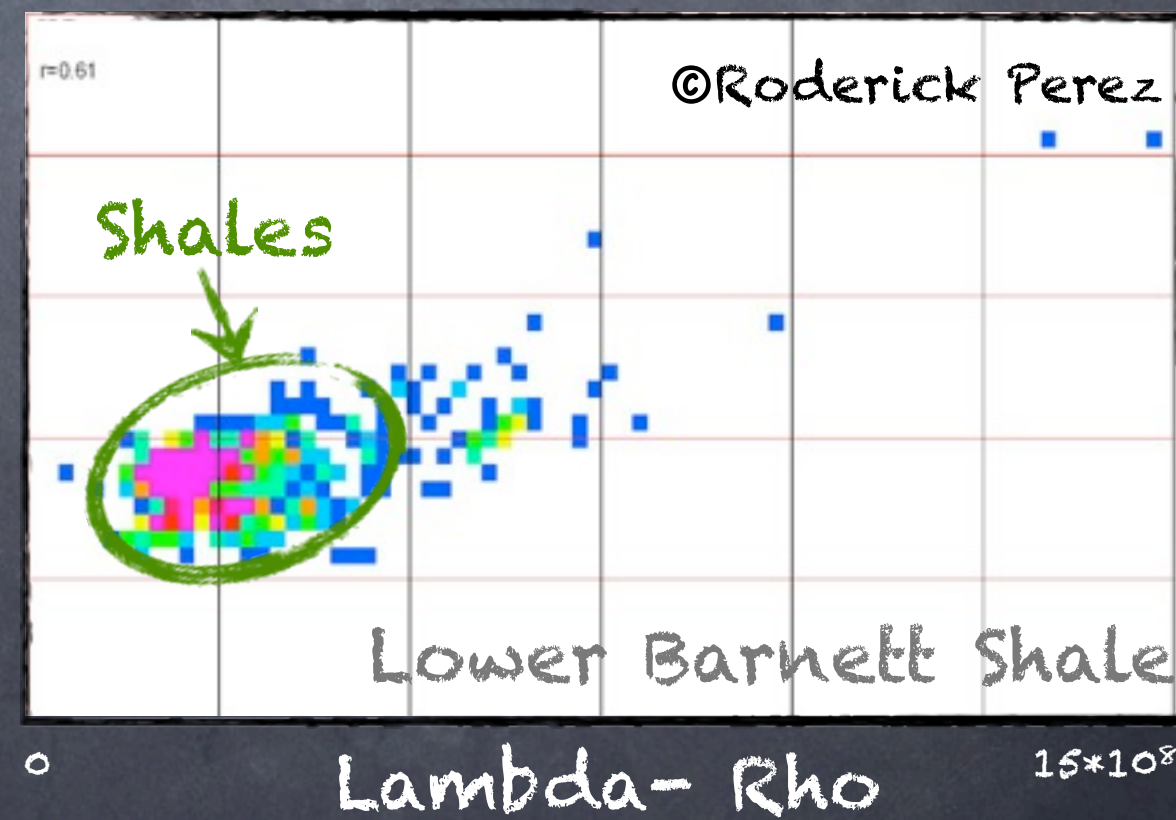
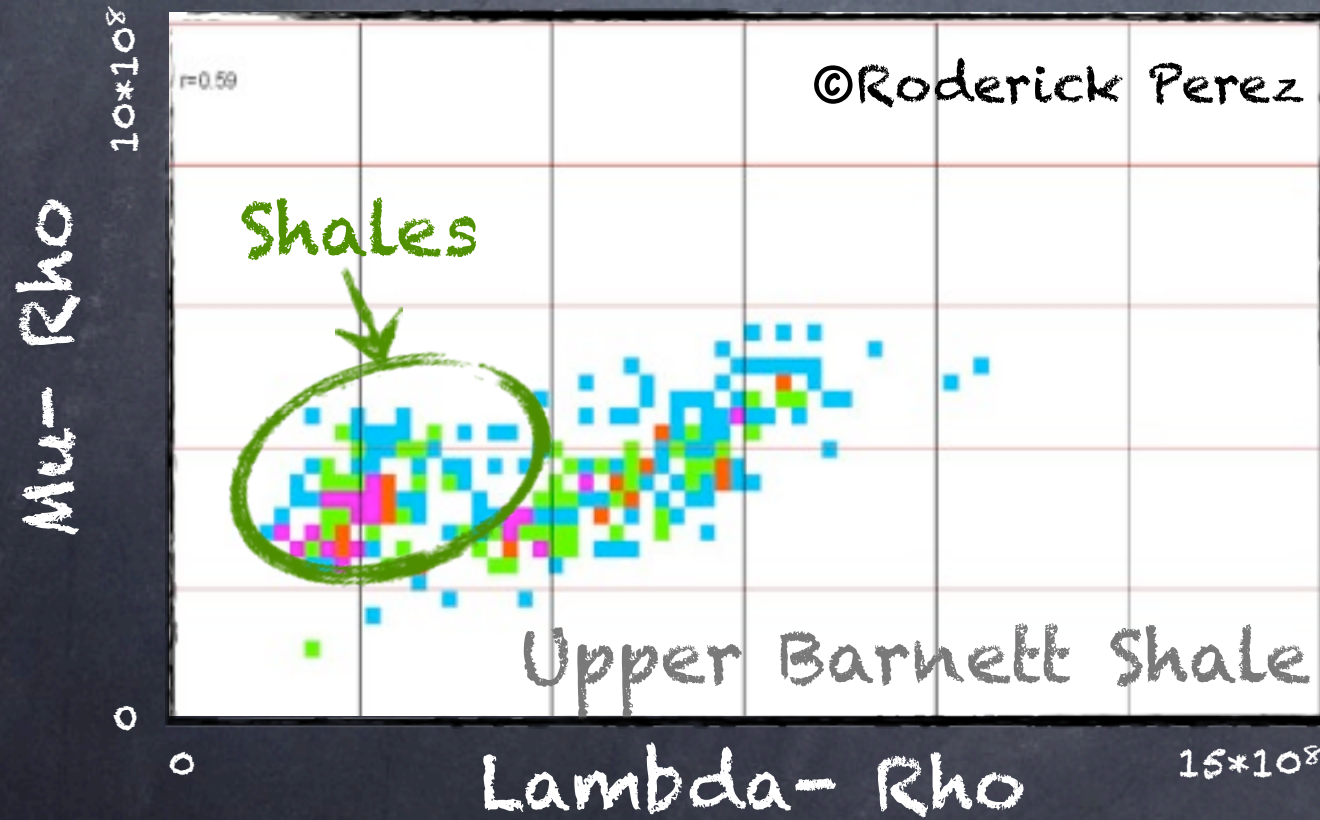
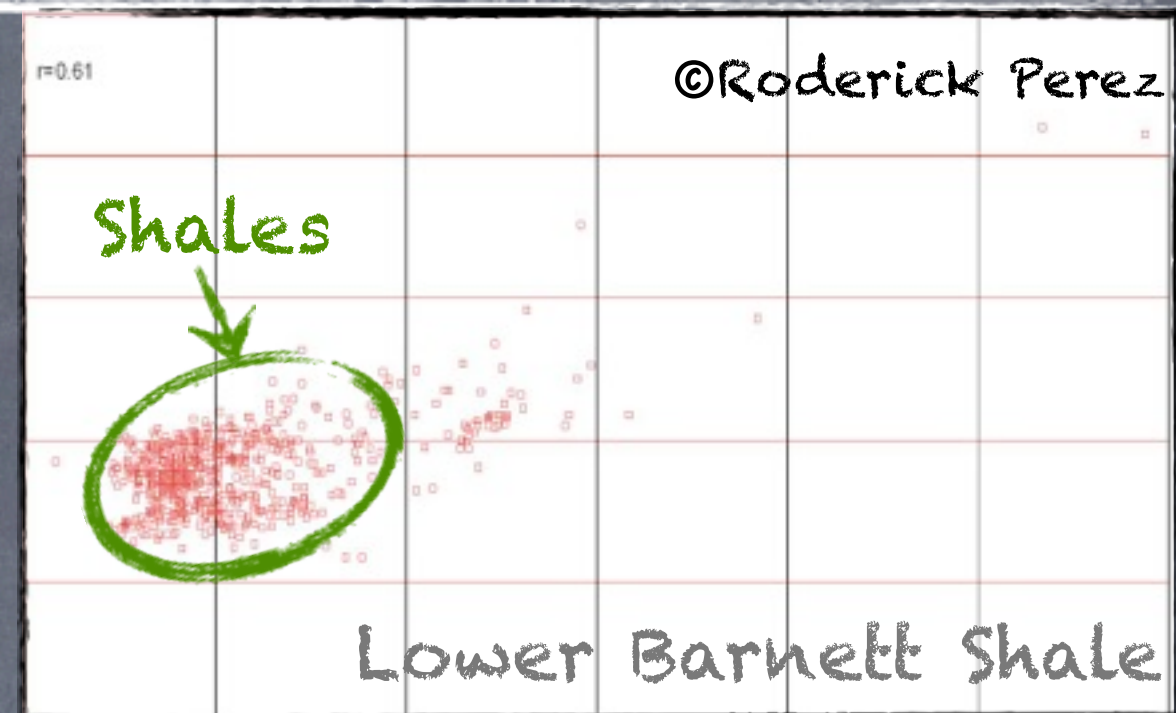
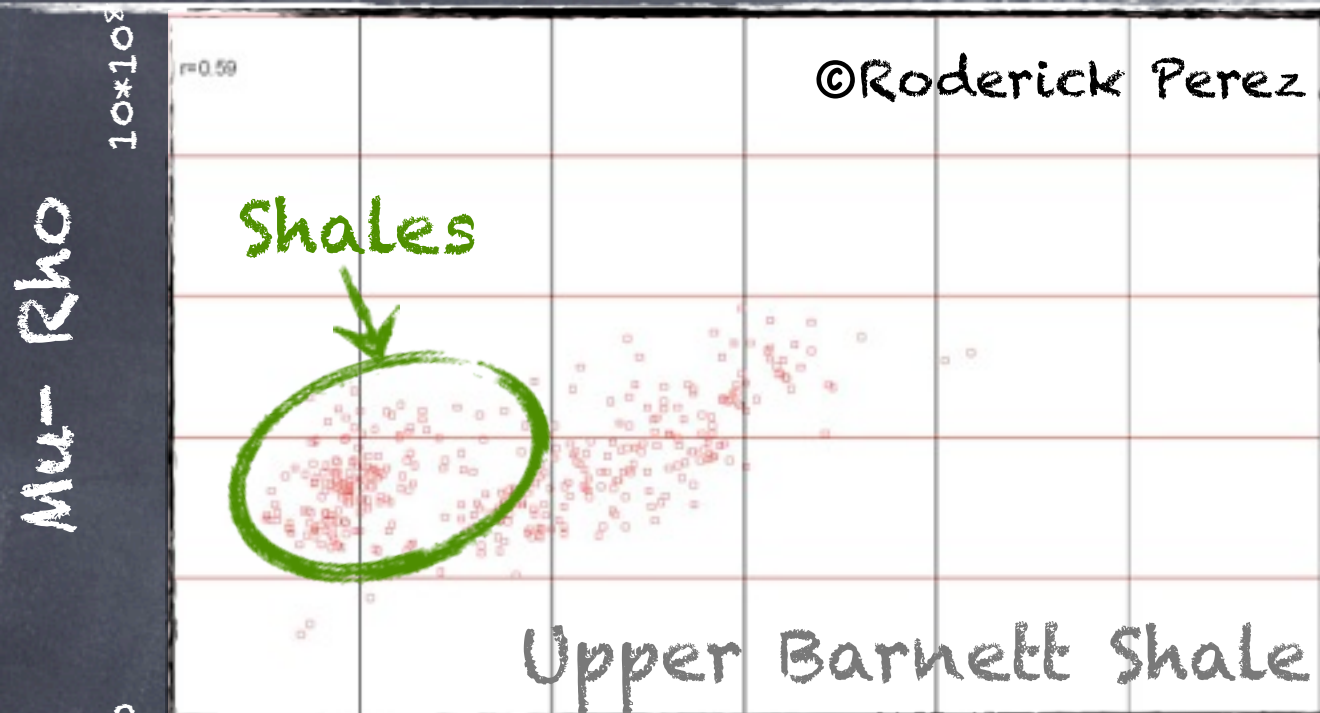


Methodology





Shale Comparison





Mineralogy

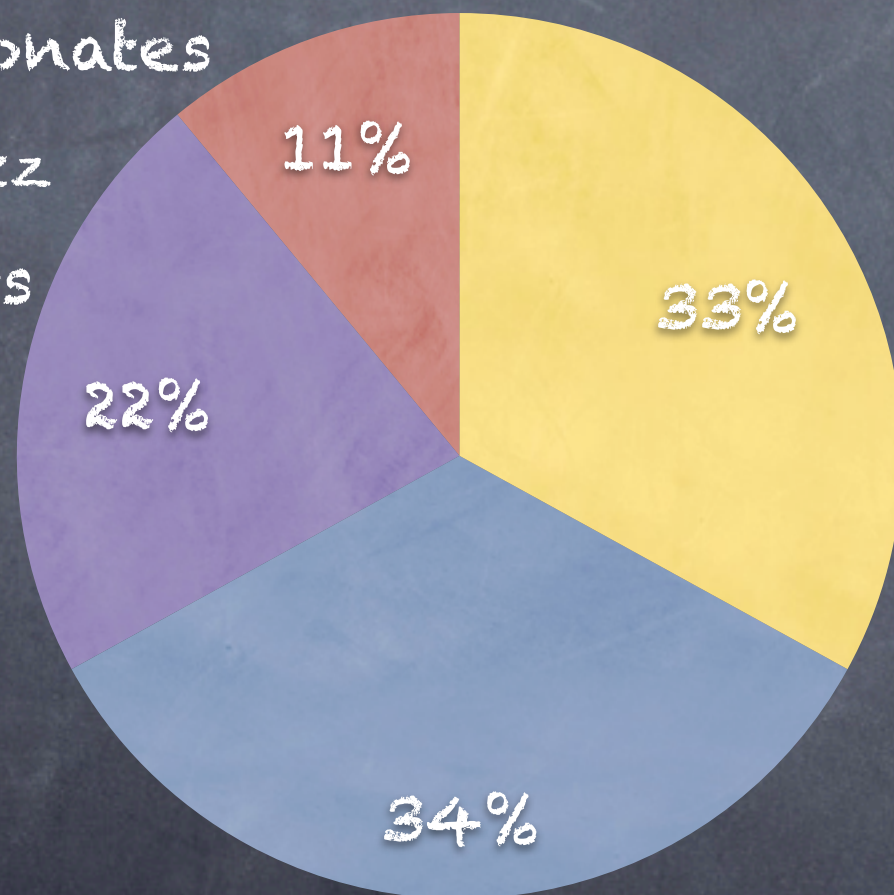
Upper Barnett Shale Lower Barnett Shale

● Clays

● Carbonates

● Quartz

● Others

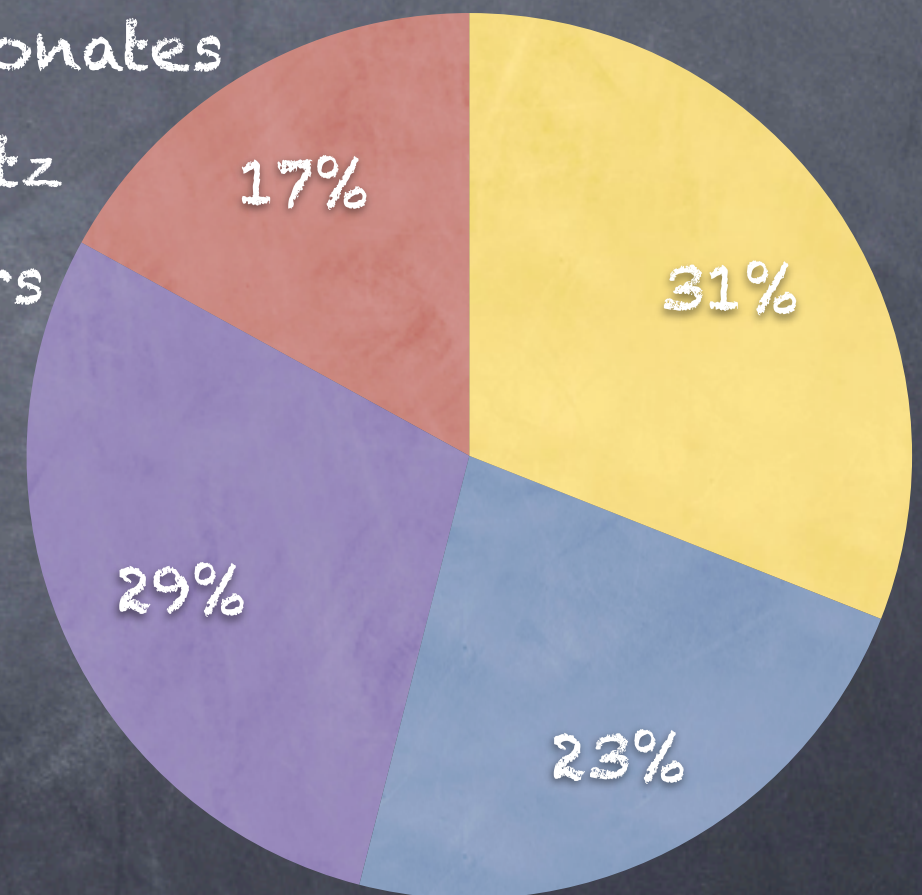


● Clays

● Carbonates

● Quartz

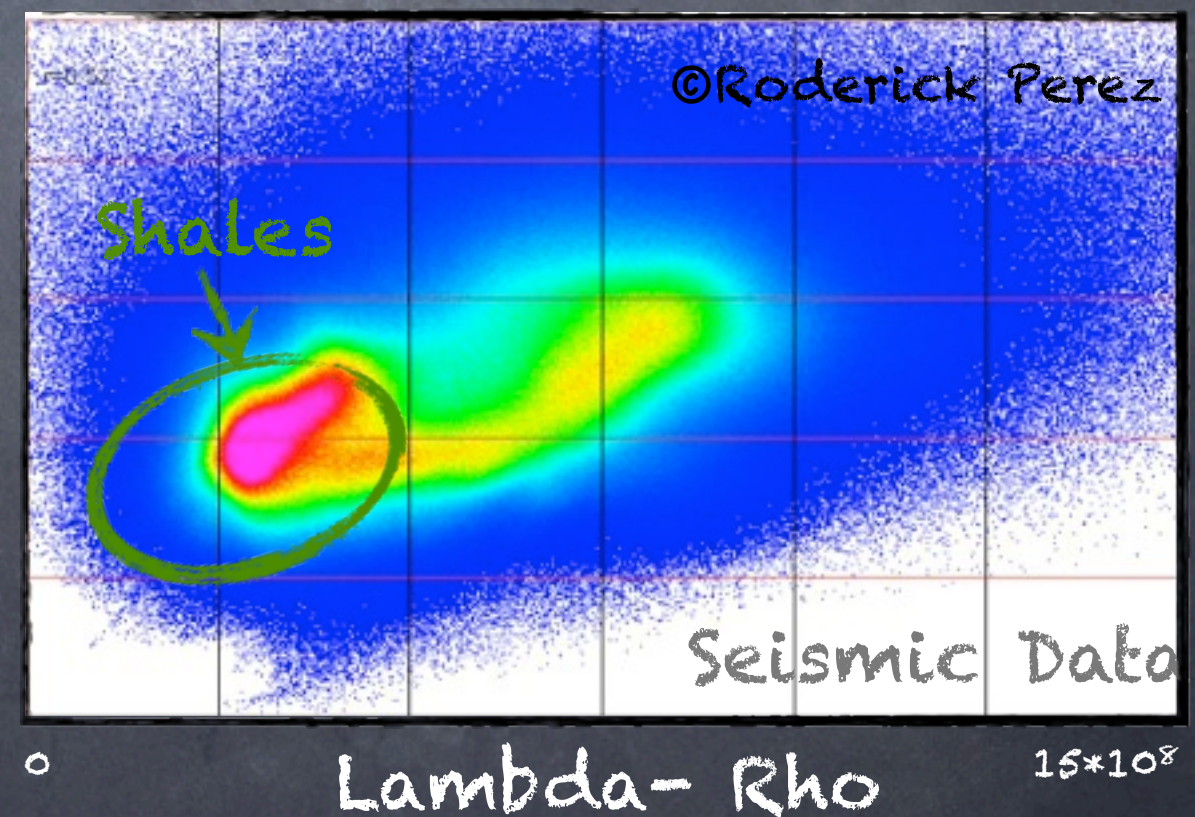
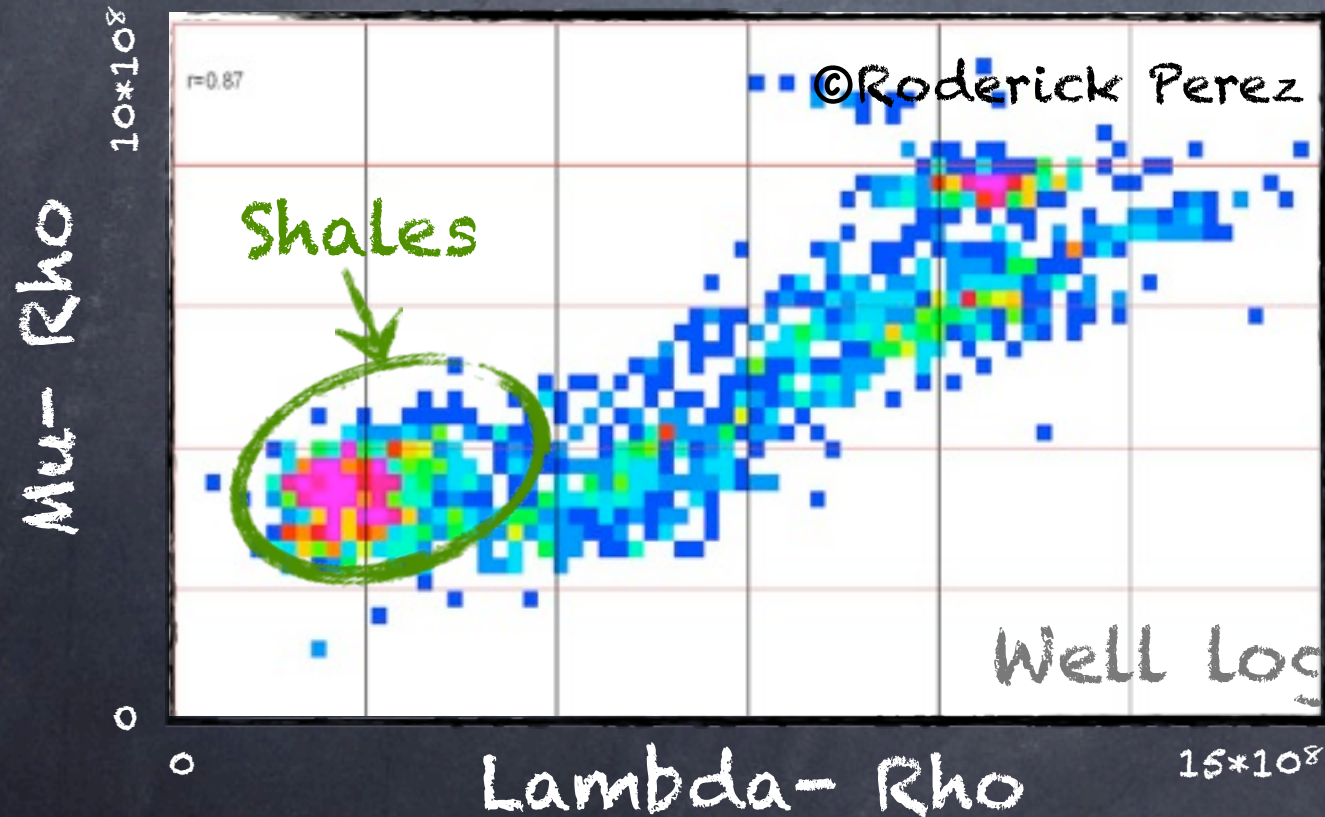
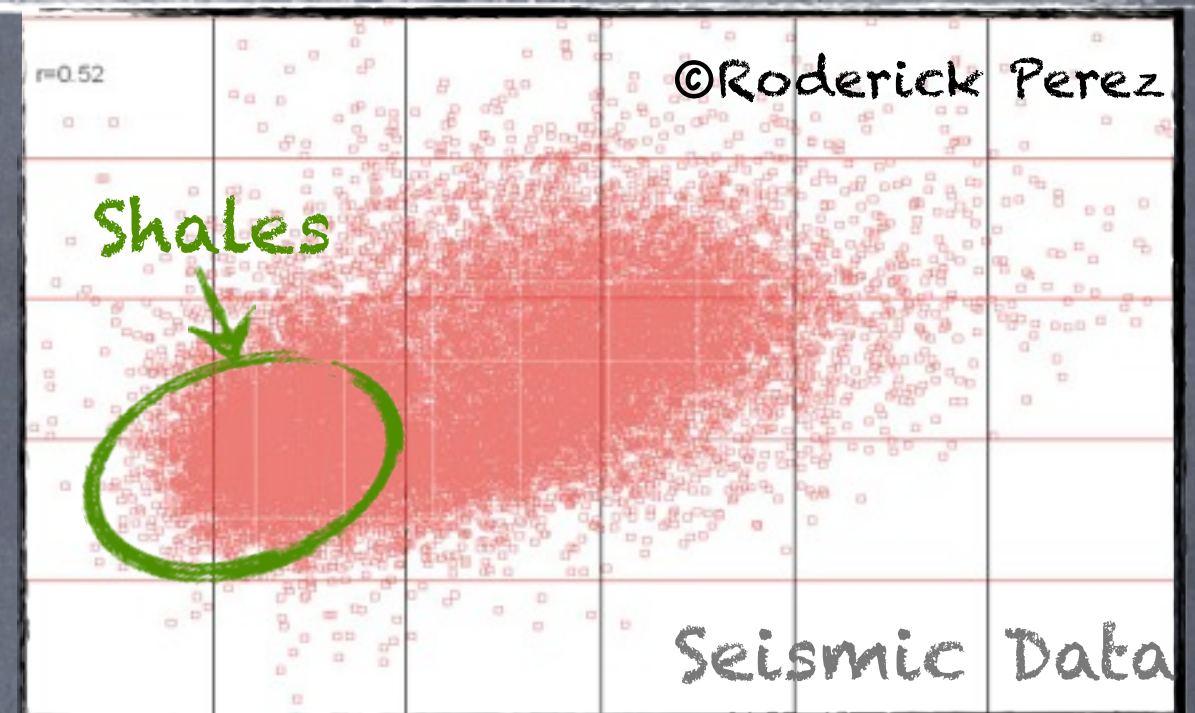
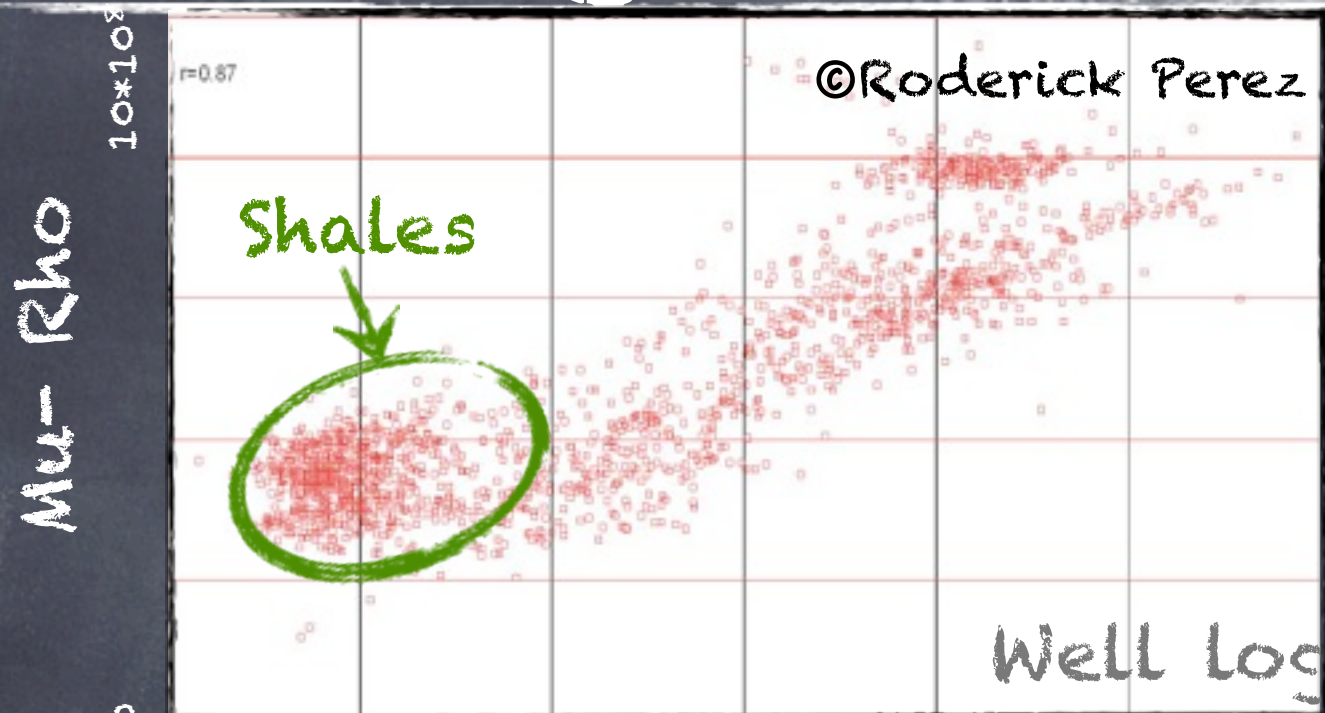
● Others



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

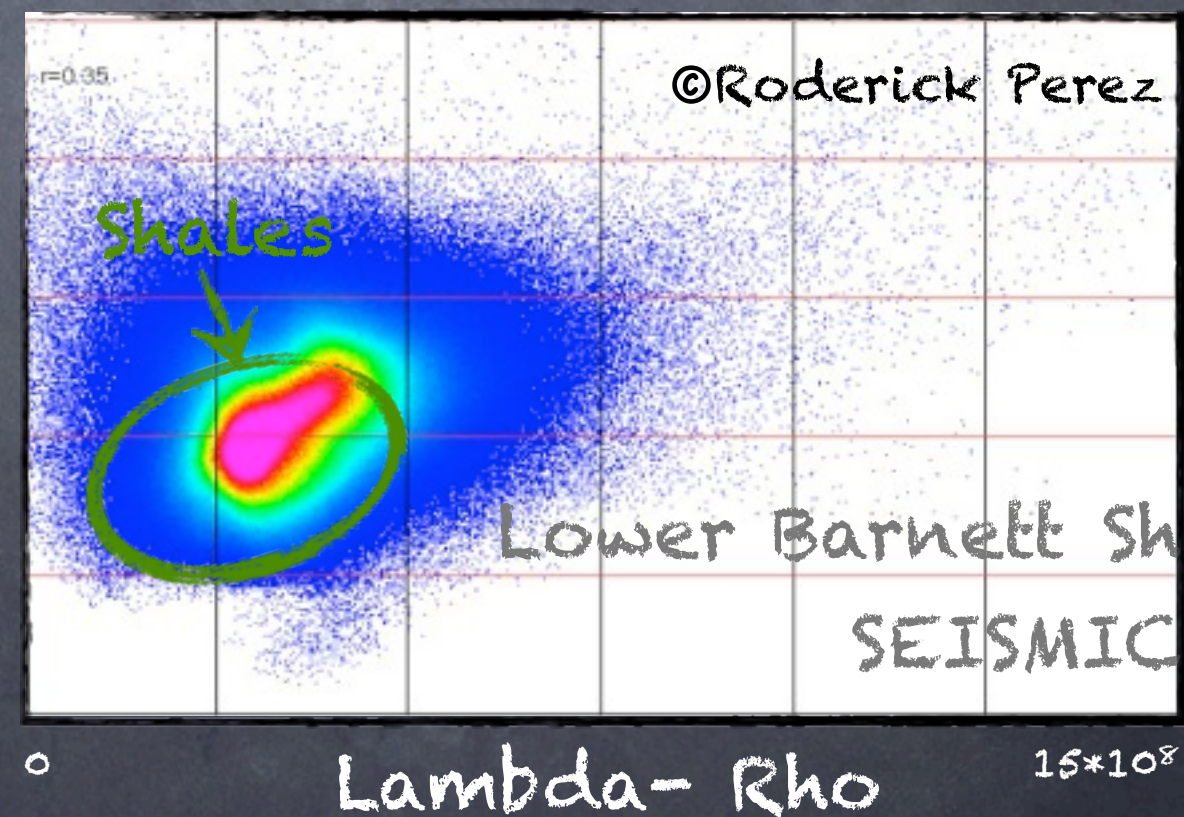
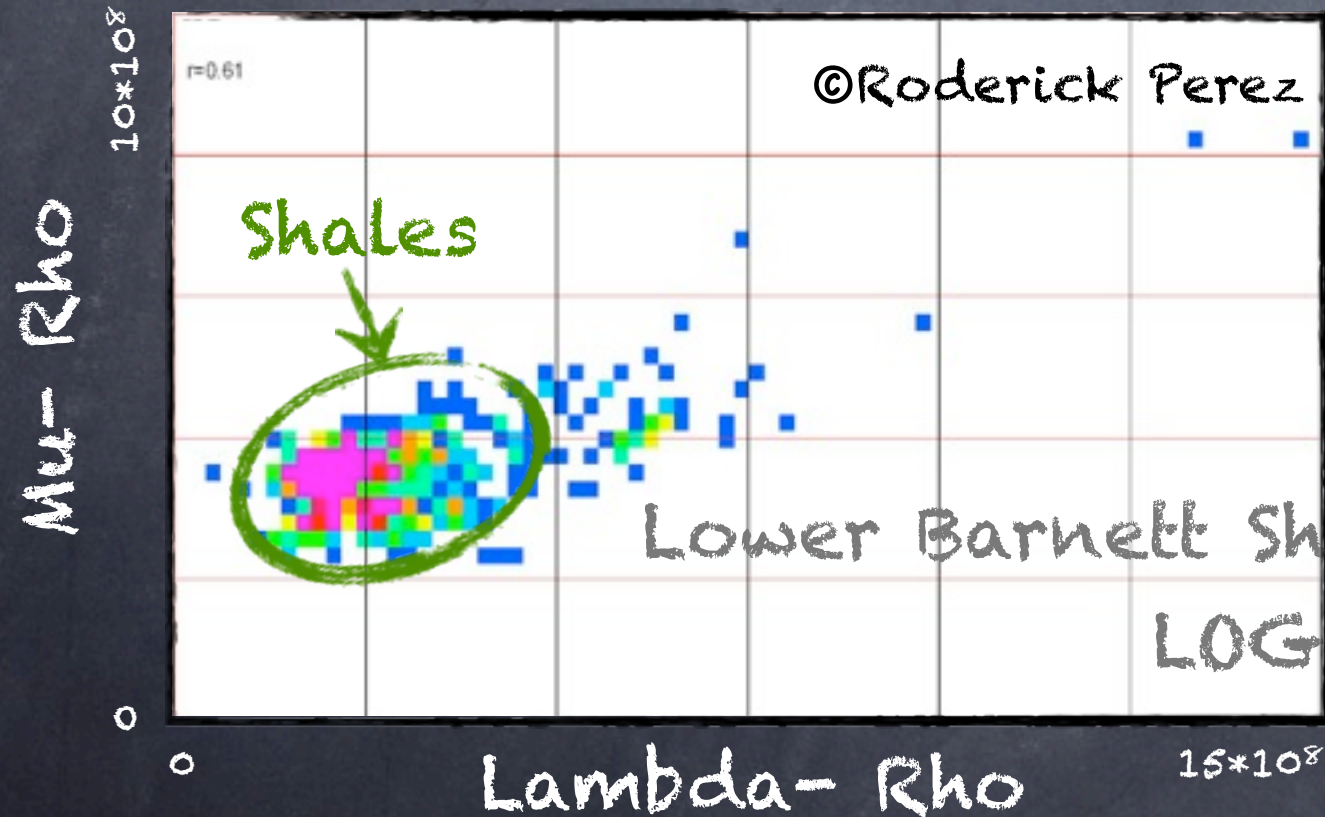
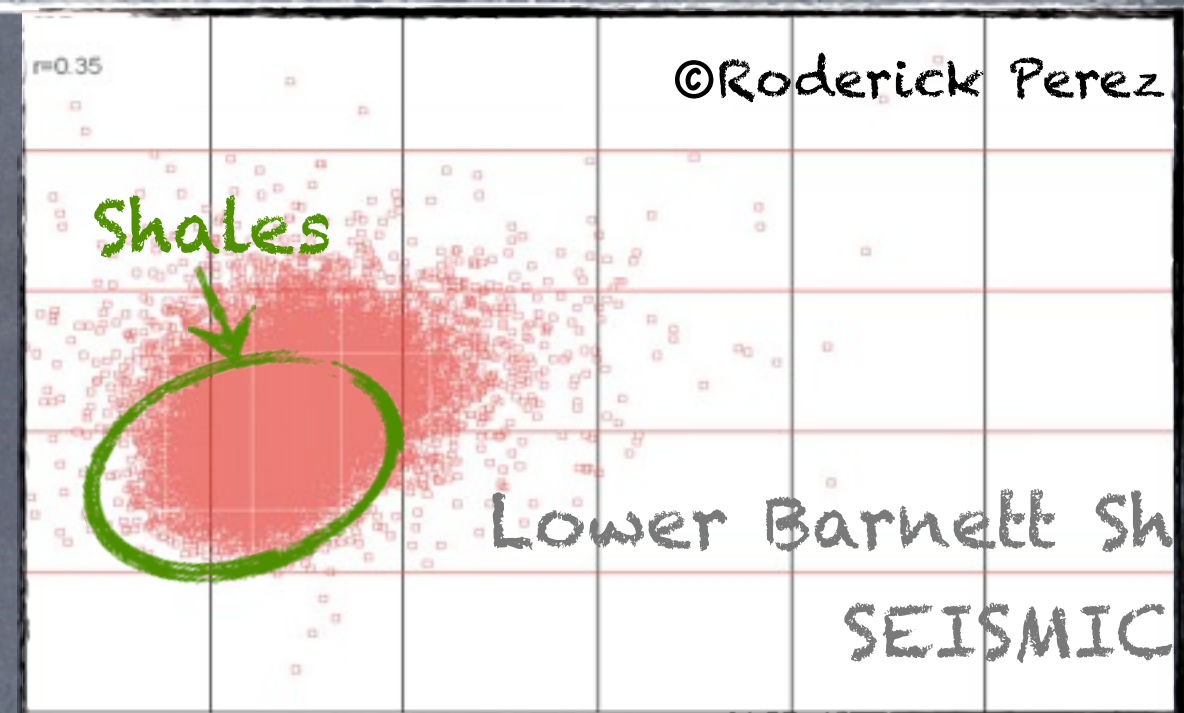
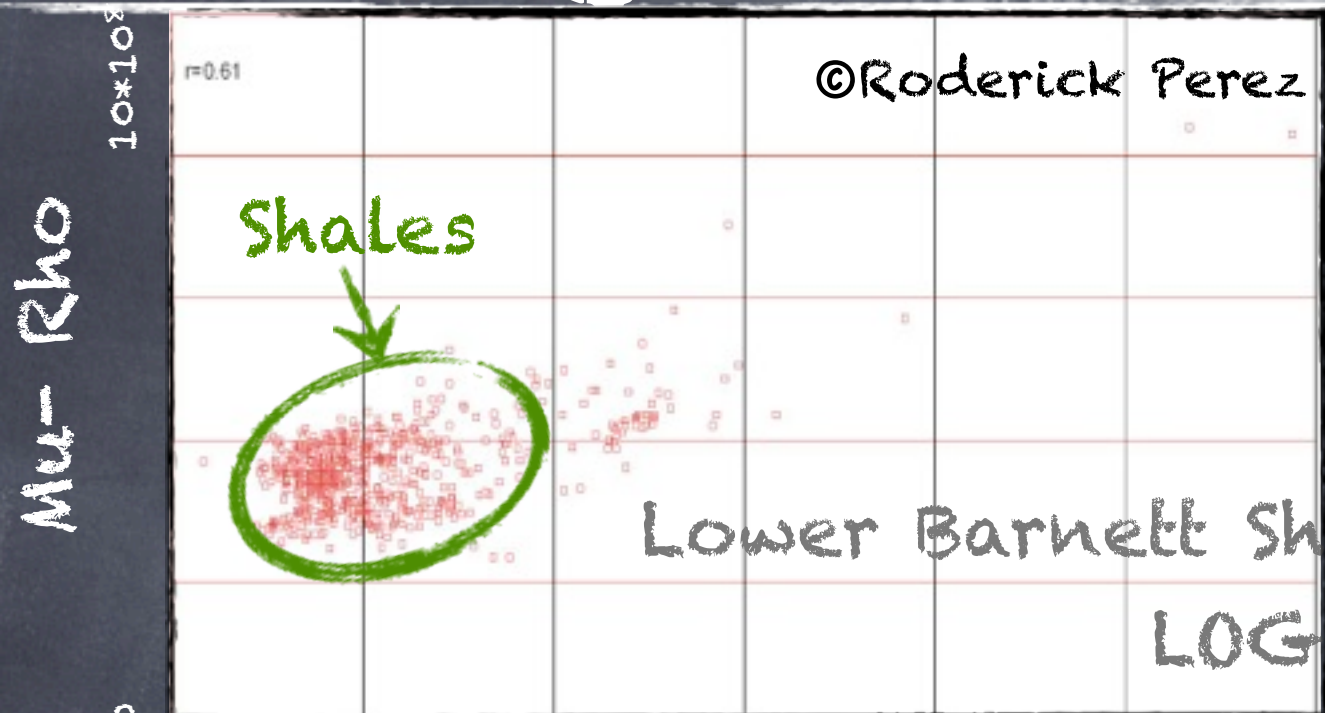


Logs vs. Seismic



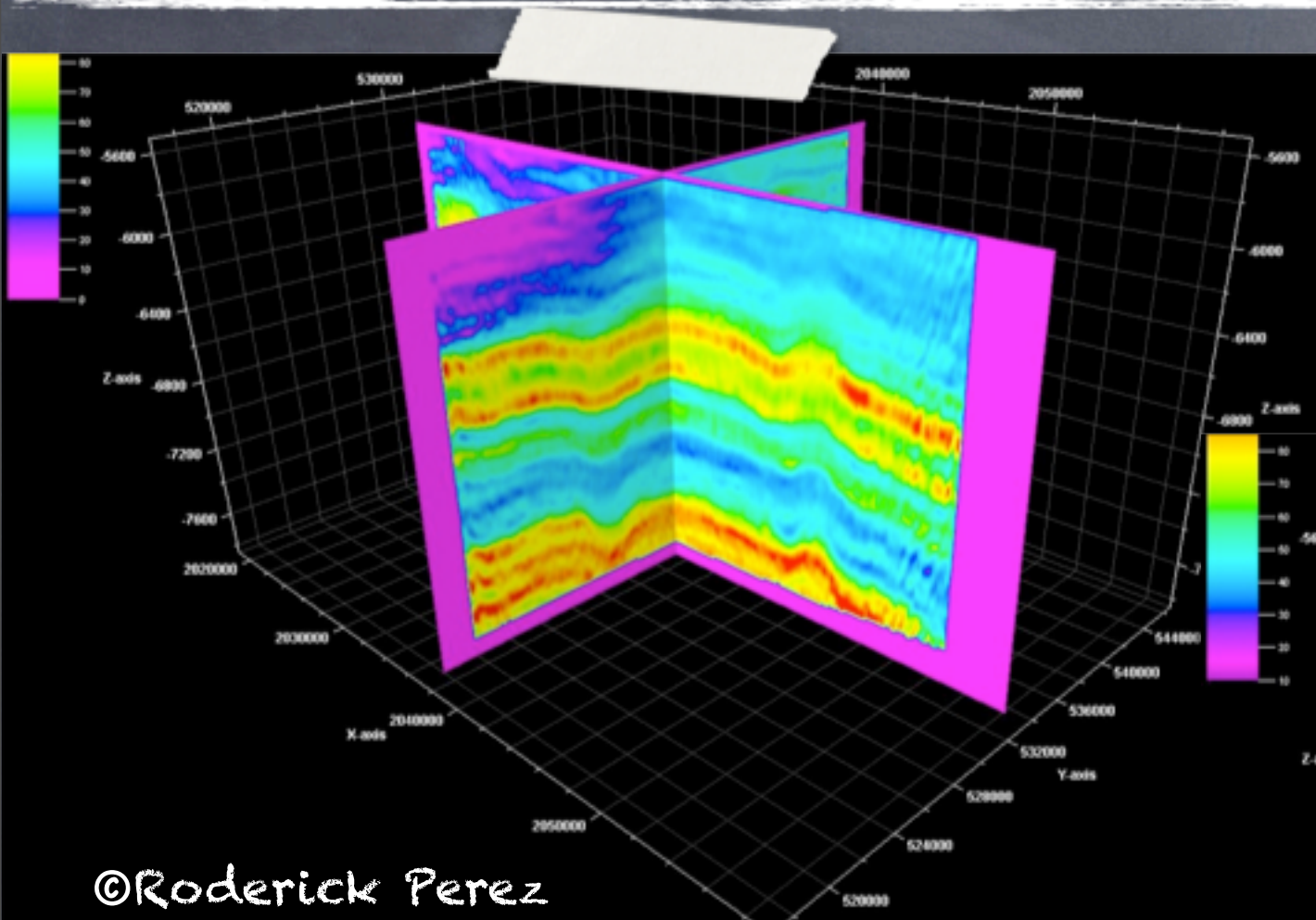


Logs vs. Seismic



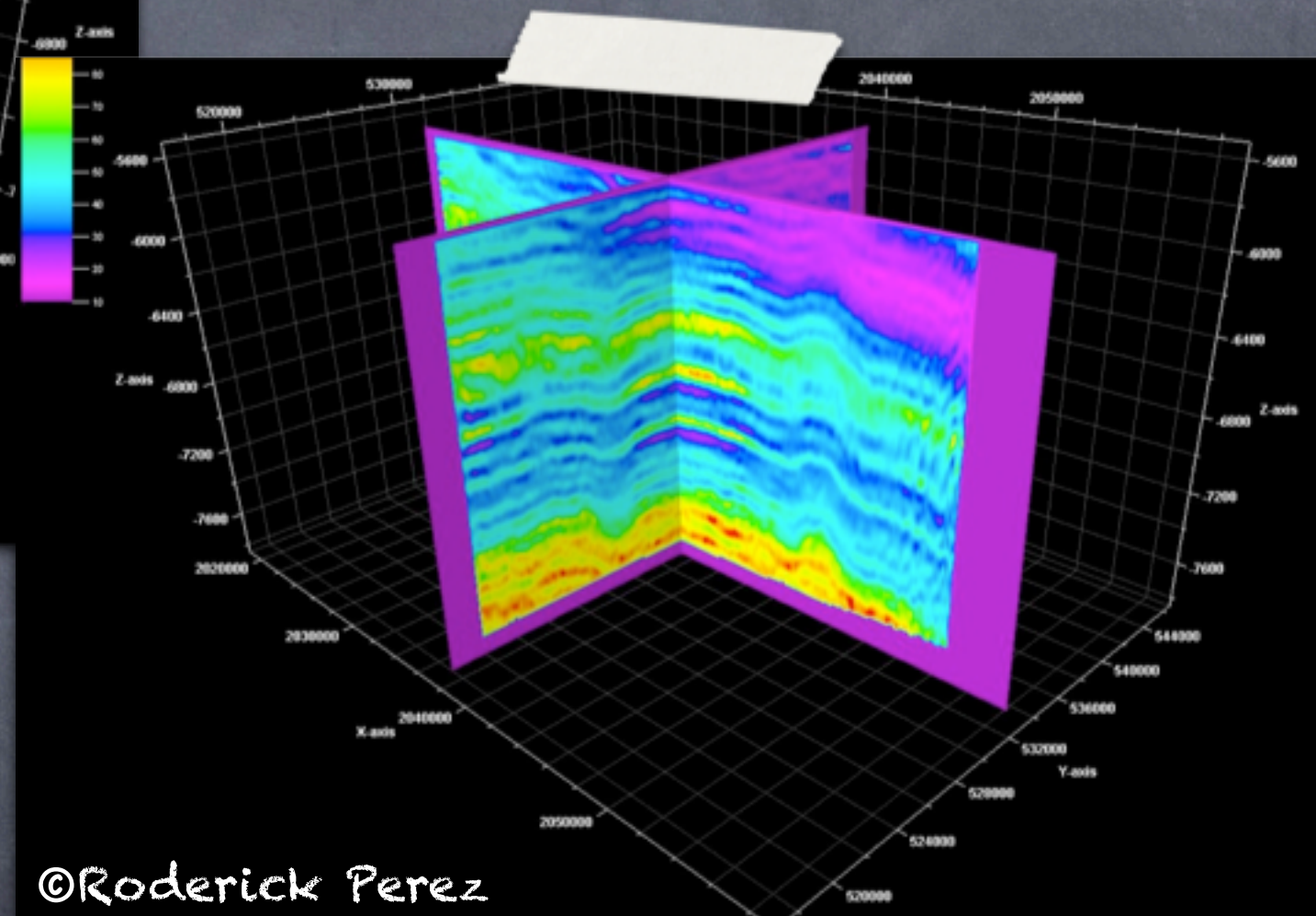


Clustering Analysis



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Lambda-Rho



©Roderick Perez

Mu-Rho

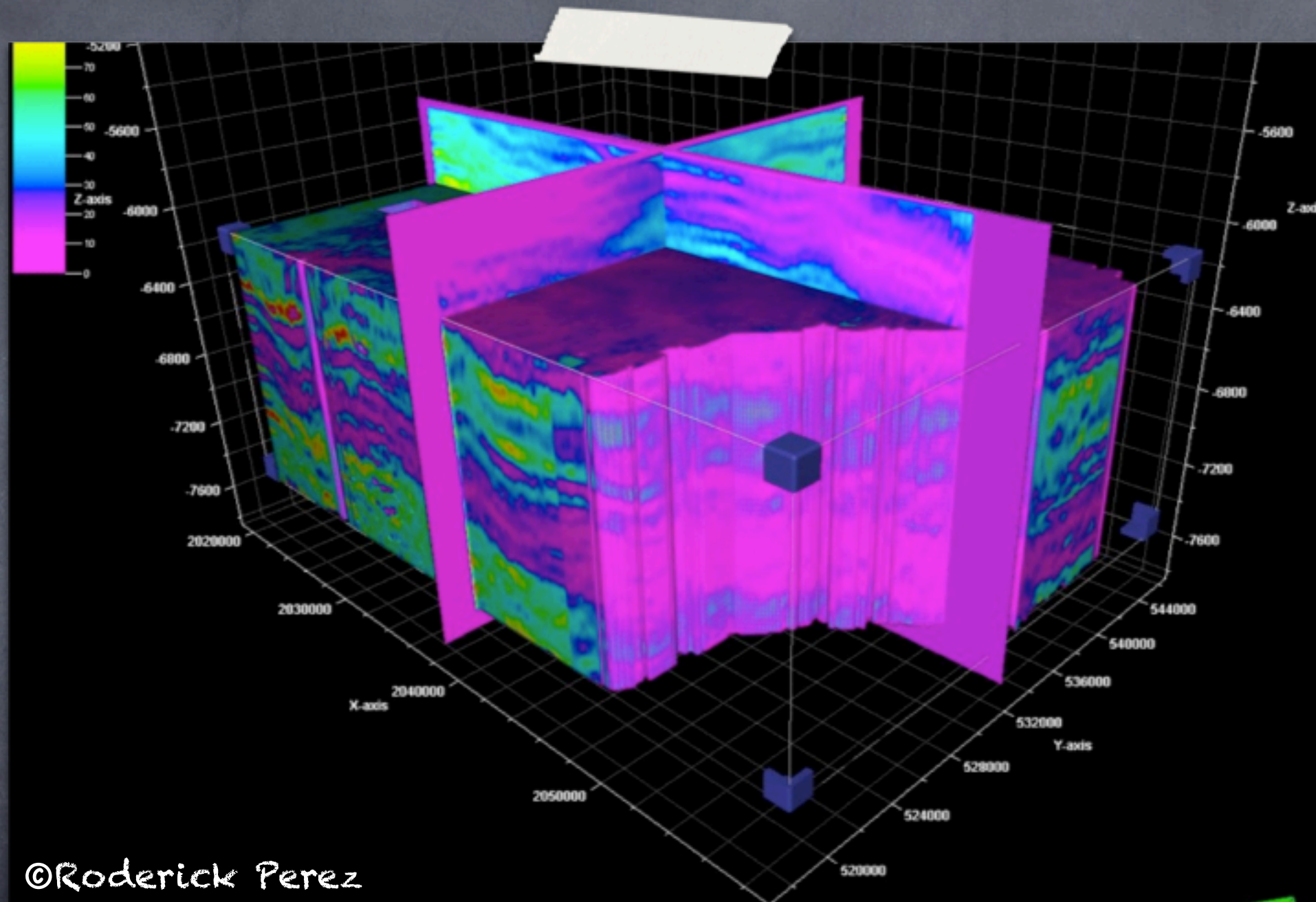
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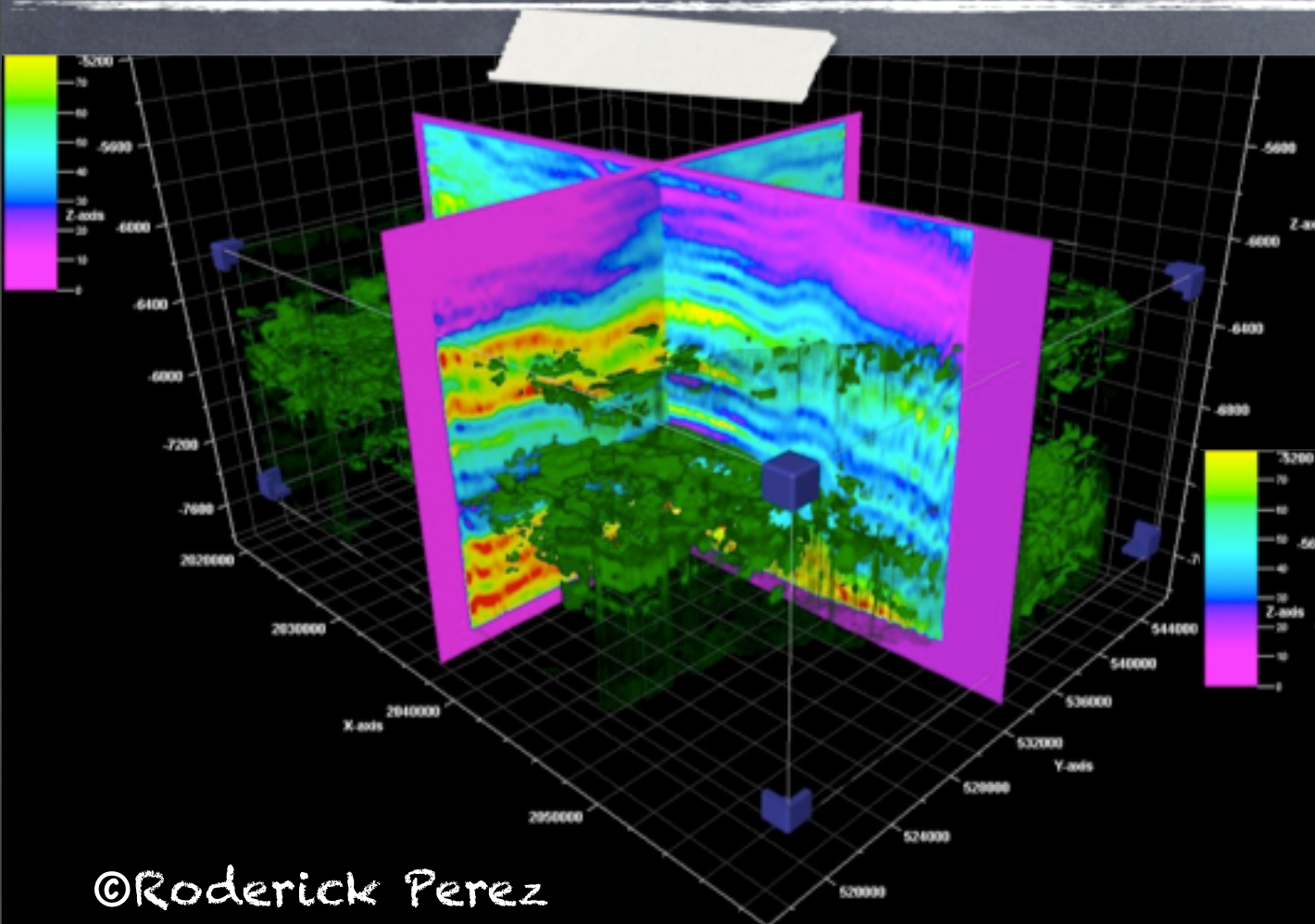
Clustering Analysis



Lambda-Rho / Mu-Rho X-plot volume

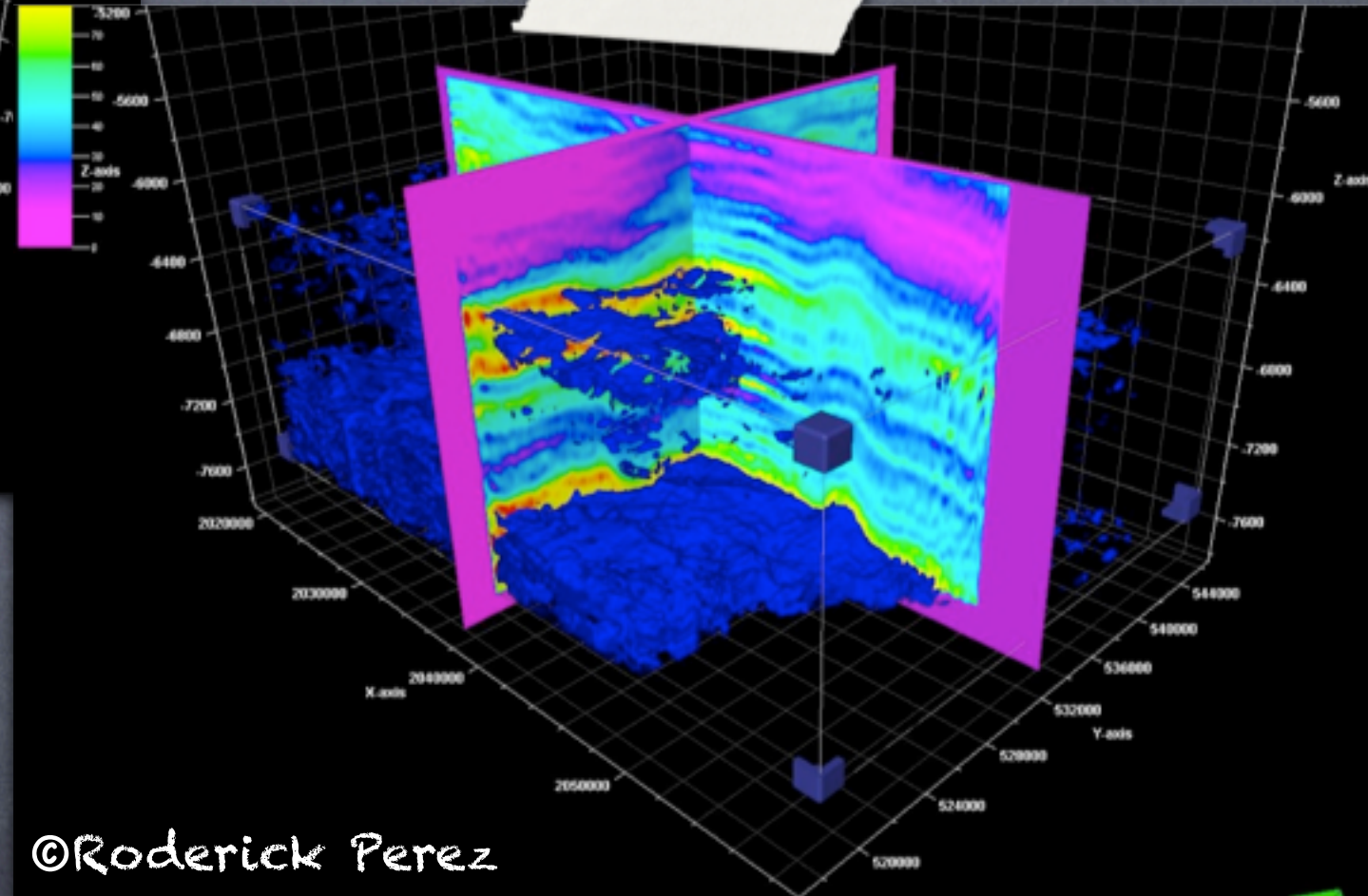


Clustering Analysis



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Shales



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Limestone



Self Organizing Maps

Main features to identify
Compartmentalization in
Barnett shale

Zone of Analysis
11 strata slices from
each of the $\lambda\rho$ and $\mu\rho$
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



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

Output 2D seismic
Facies Map

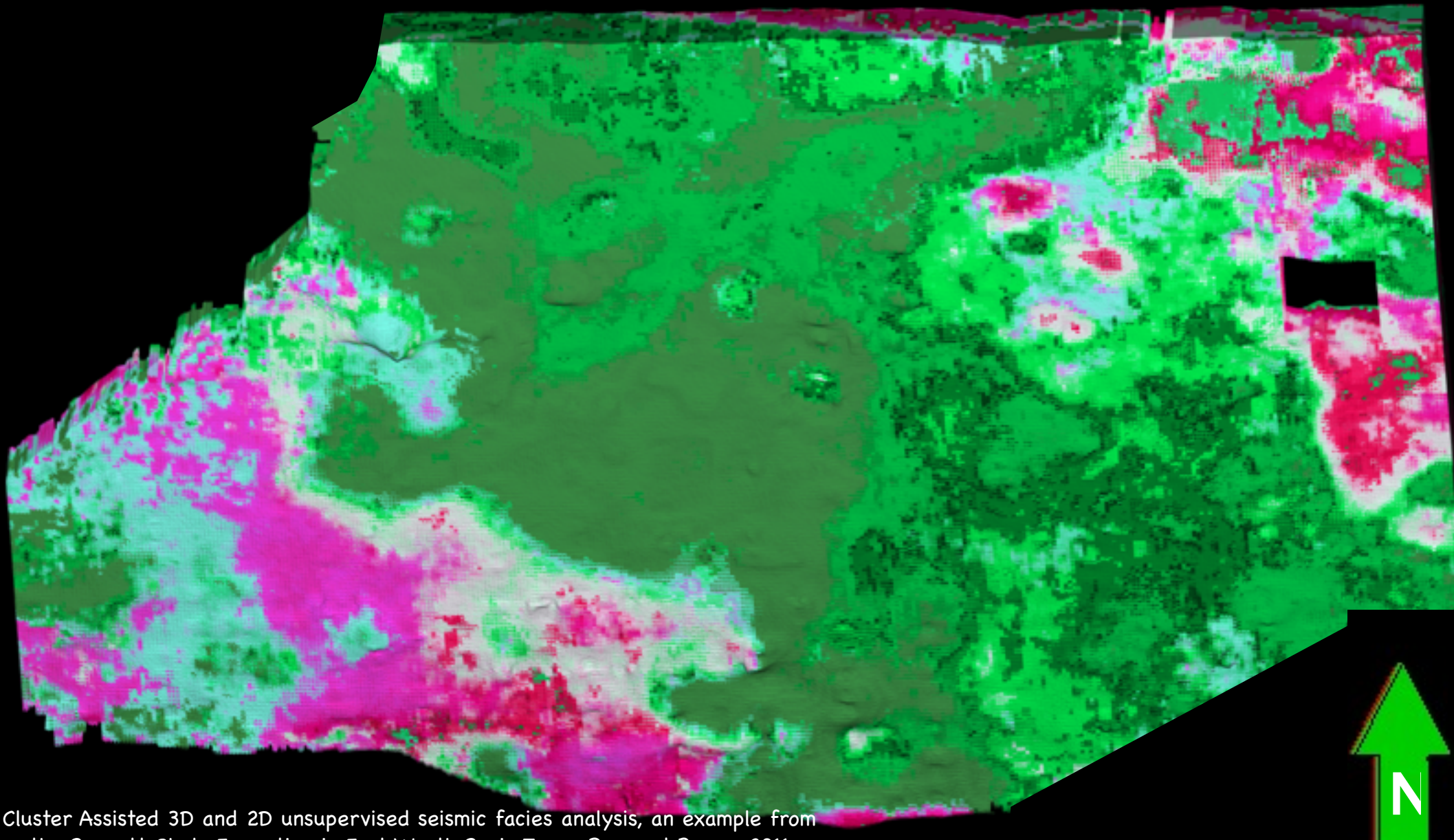
Output

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



Self Organizing Maps

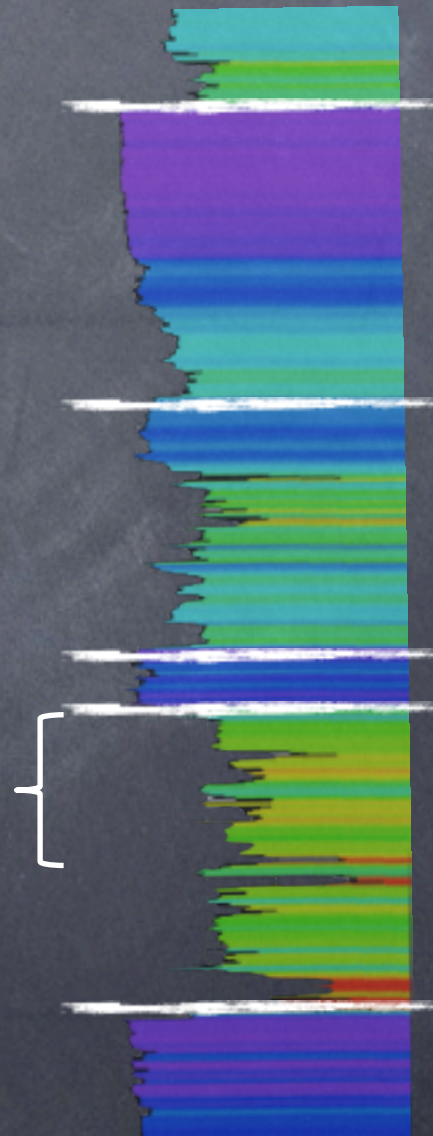
FACIES MAP



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

GR

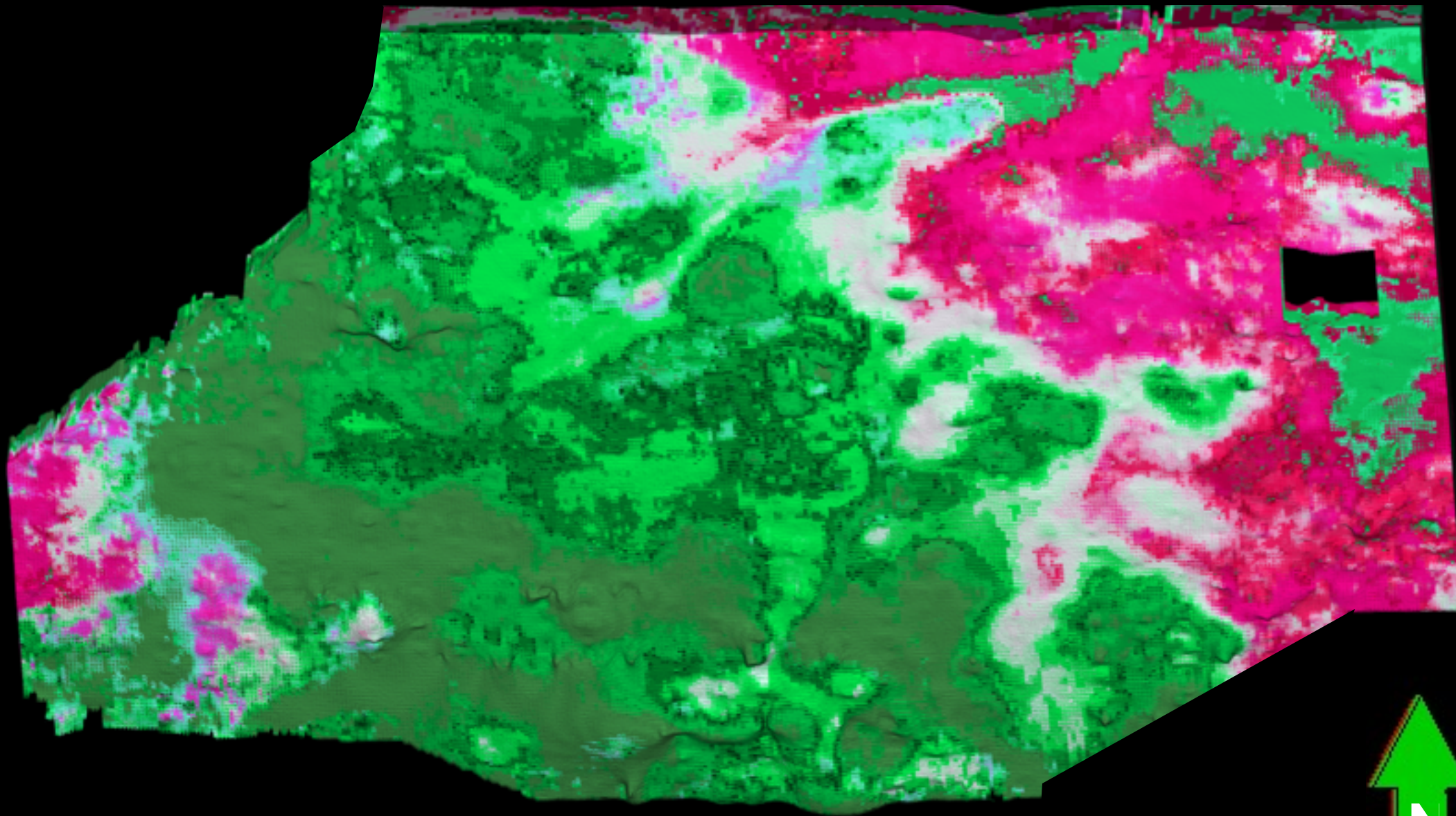
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Self Organizing Maps

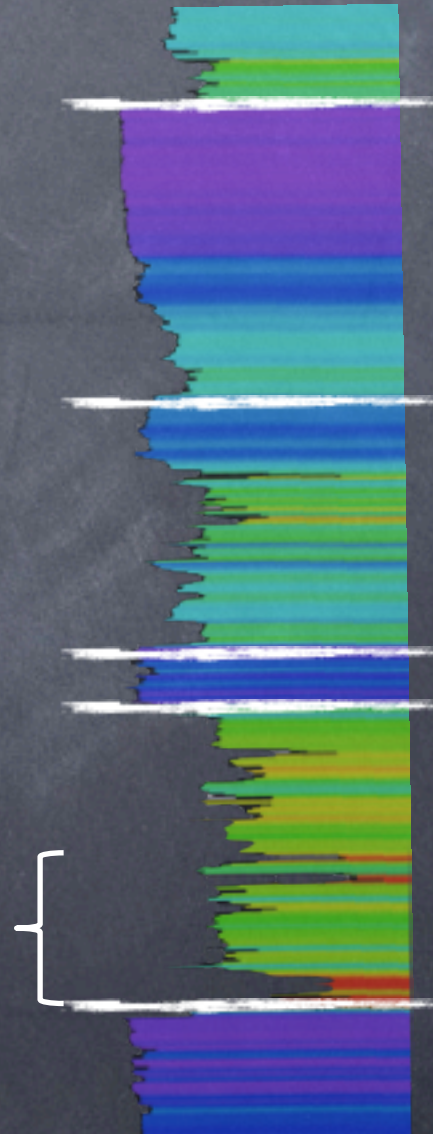
FACIES MAP



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

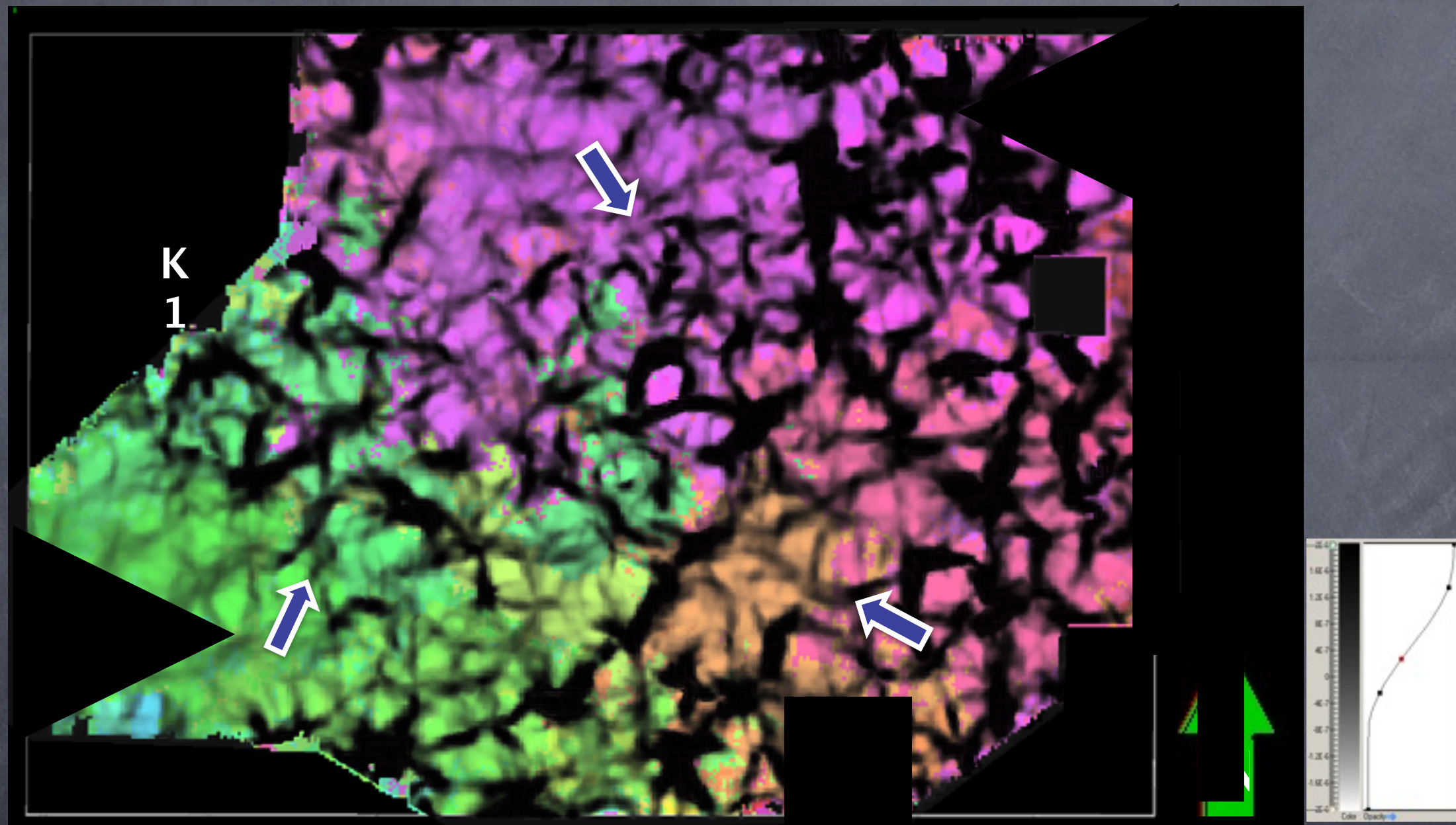
GR

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Co-rendered map



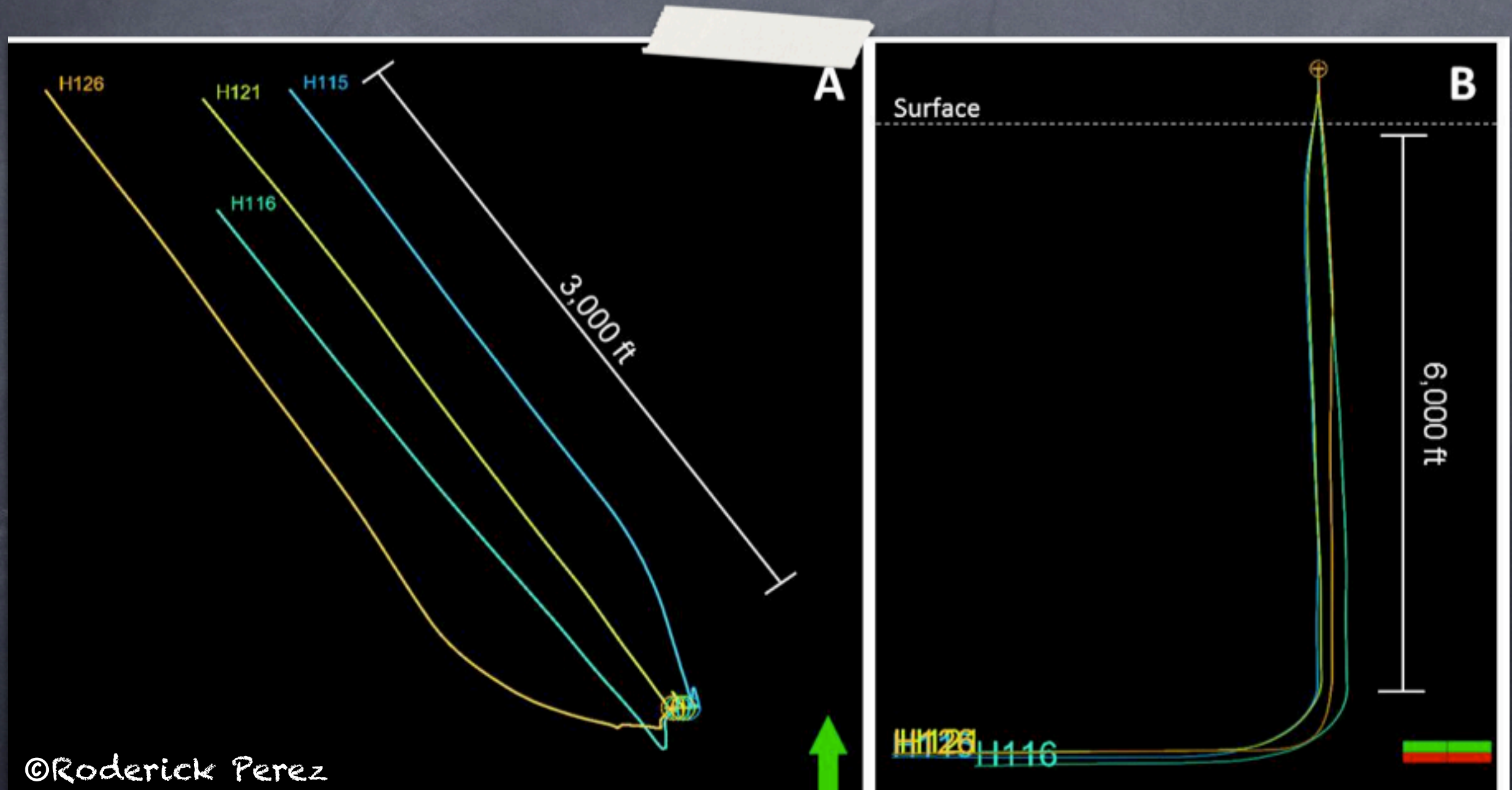
The 2D Multi-attribute map co-rendered with the principal positive curvature of the Viola lime

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



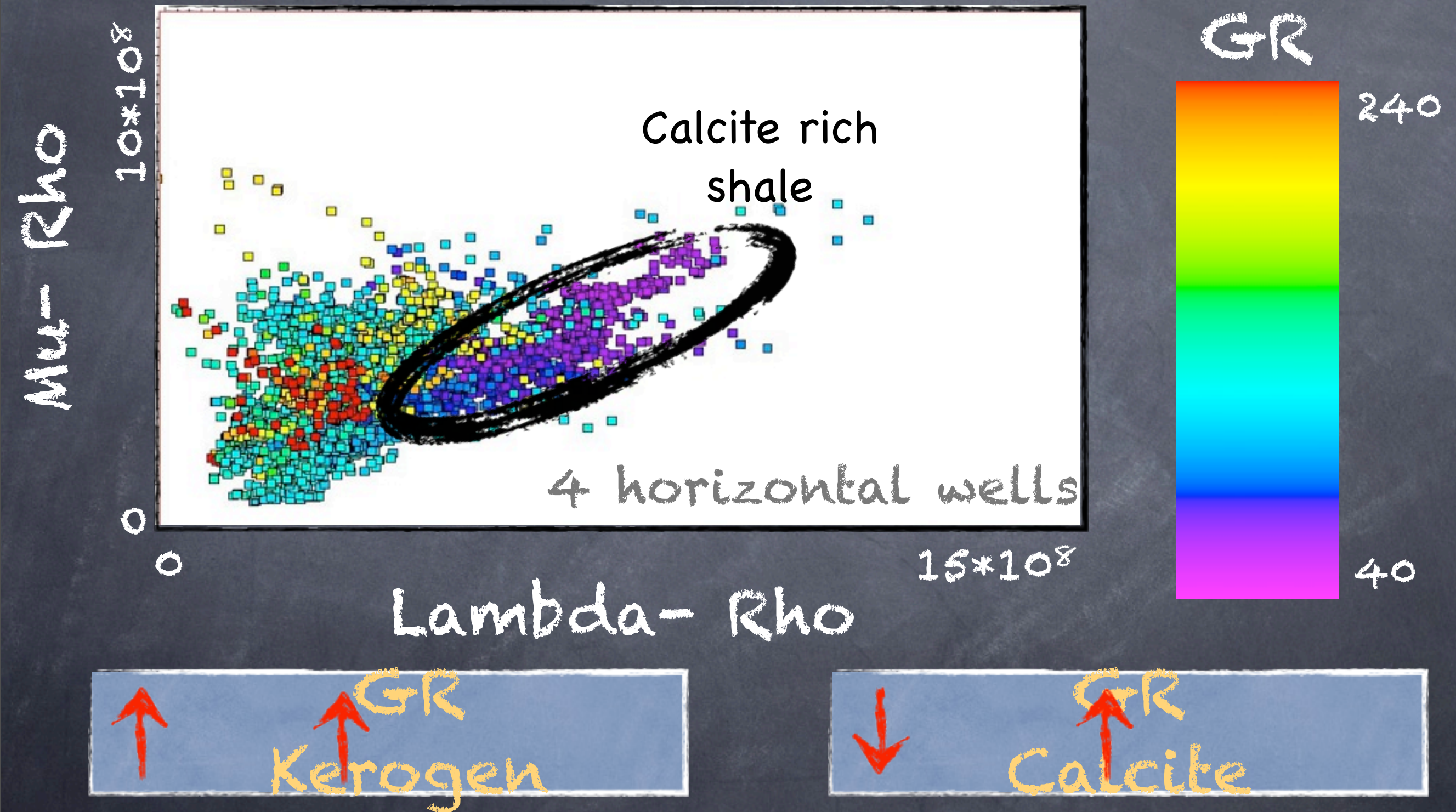
Results

LMR Inversion correlation to Production





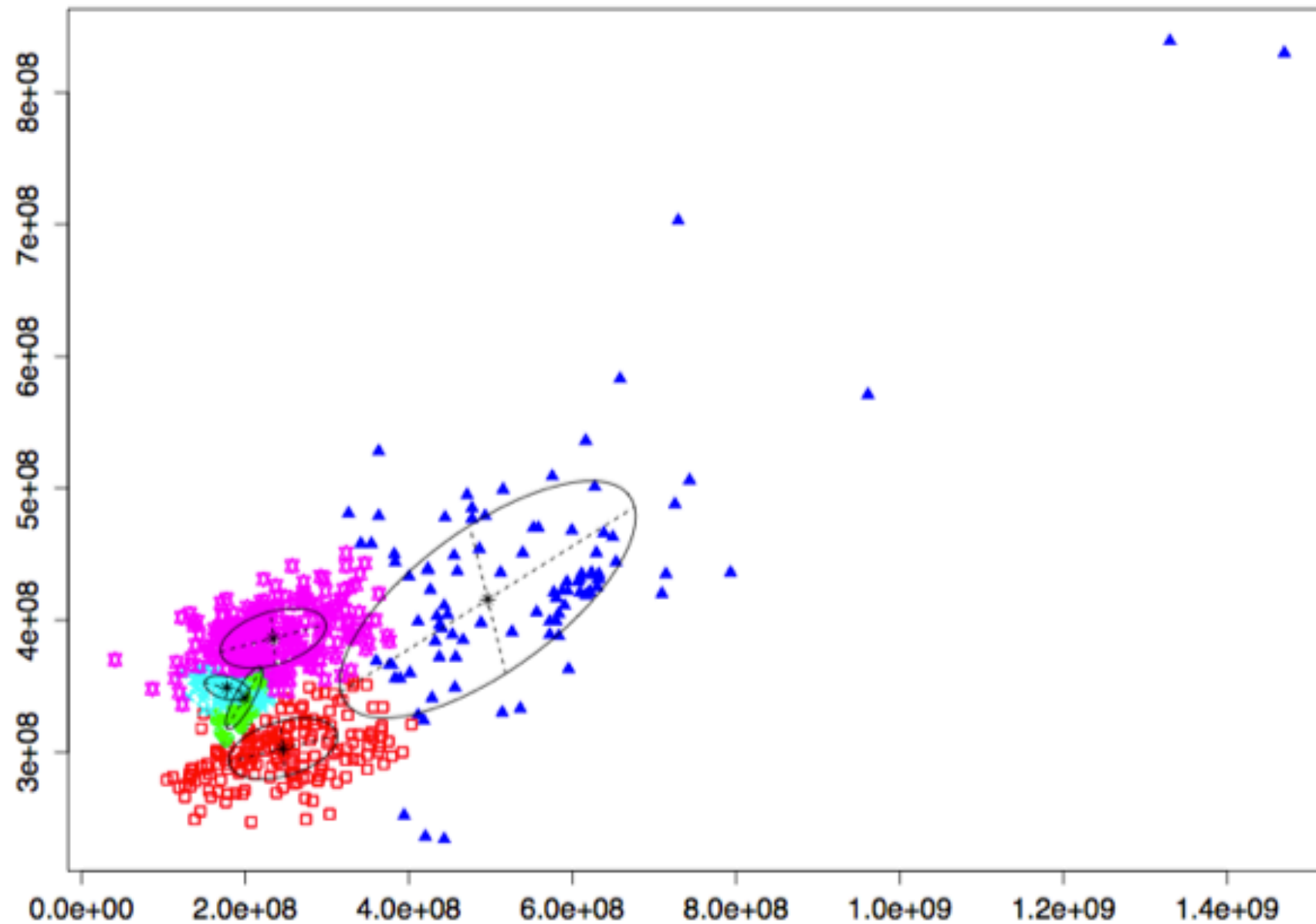
Results





Results

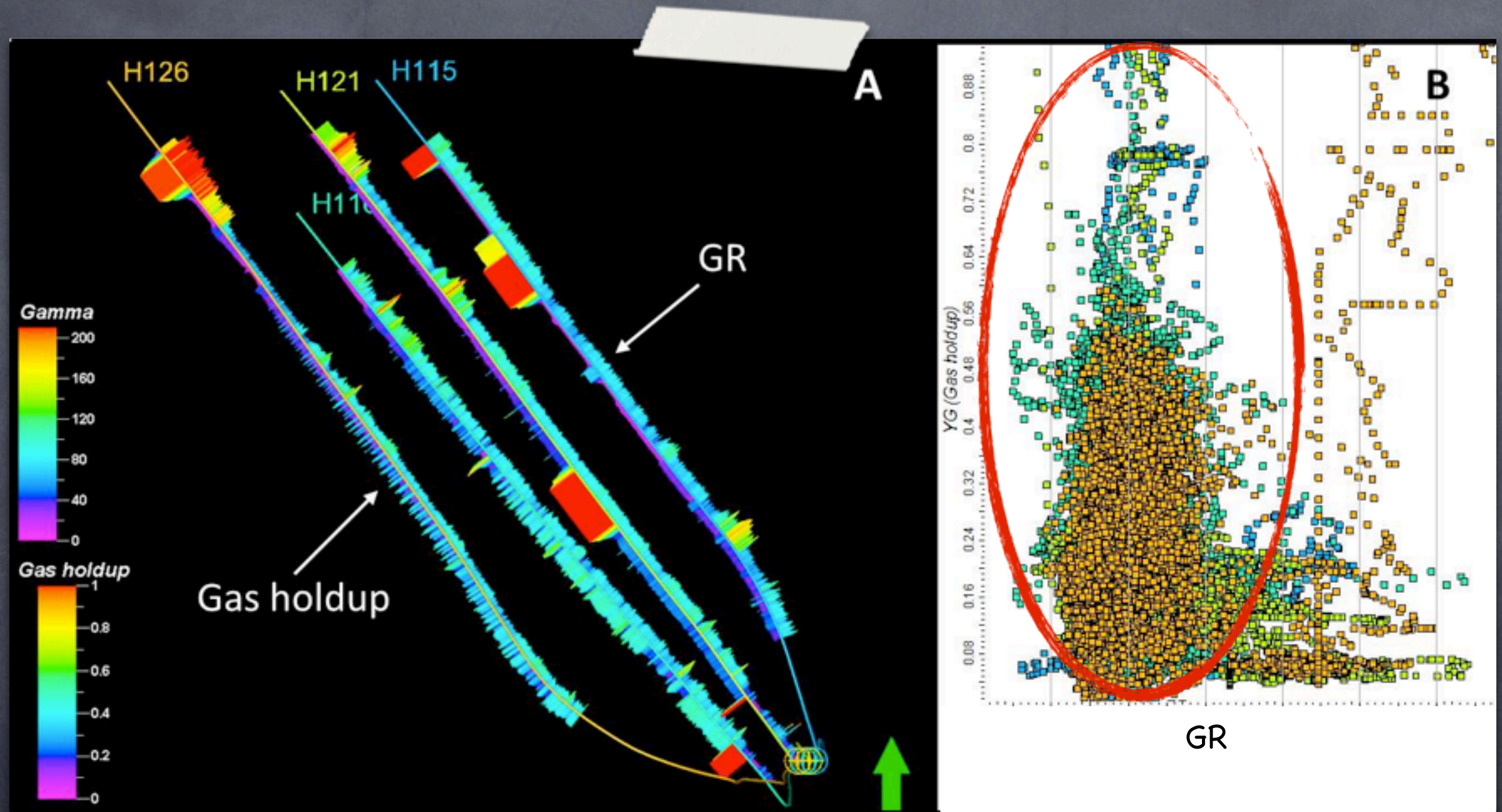
Mu-Rho



Lambda-Rho



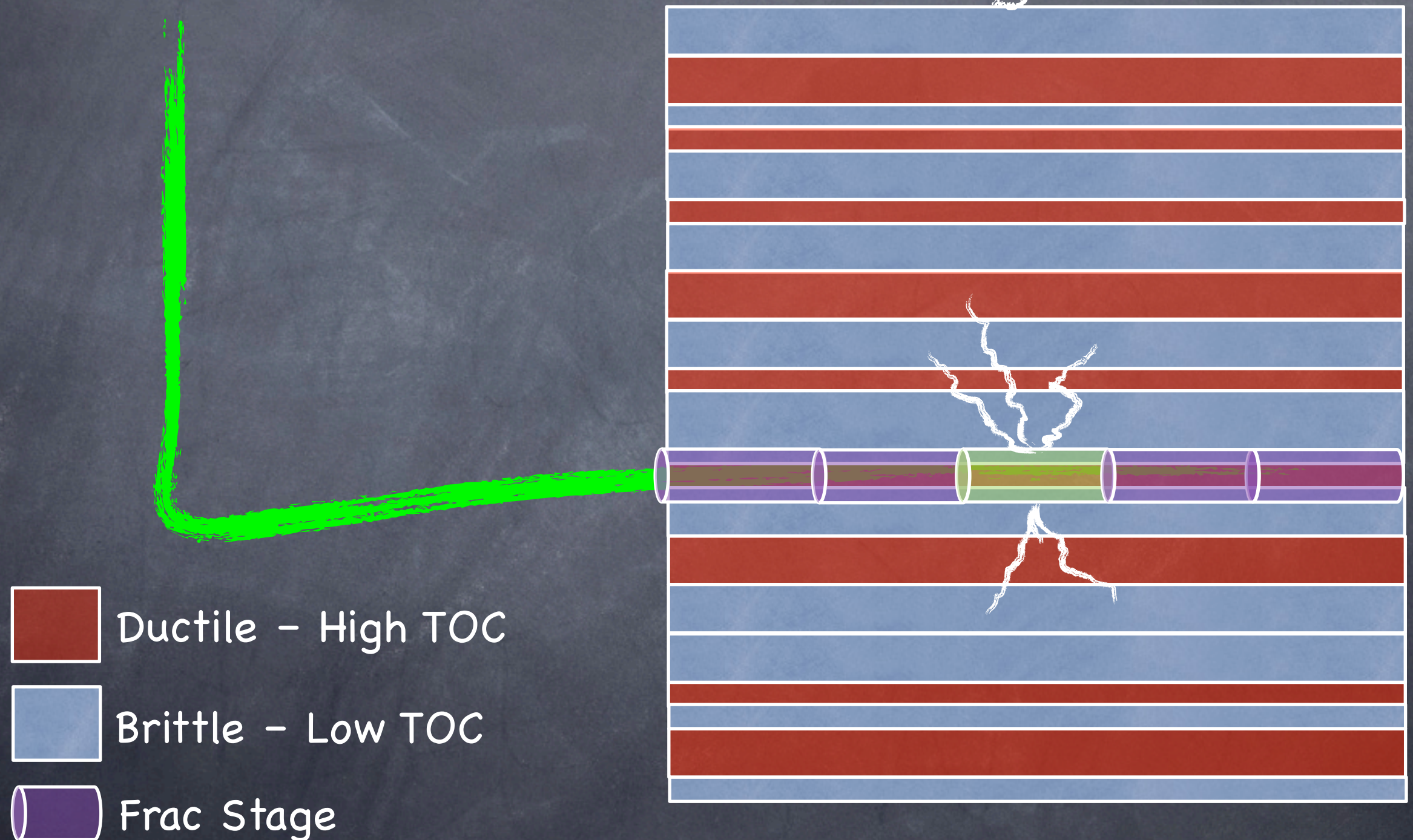
Results





Analysis

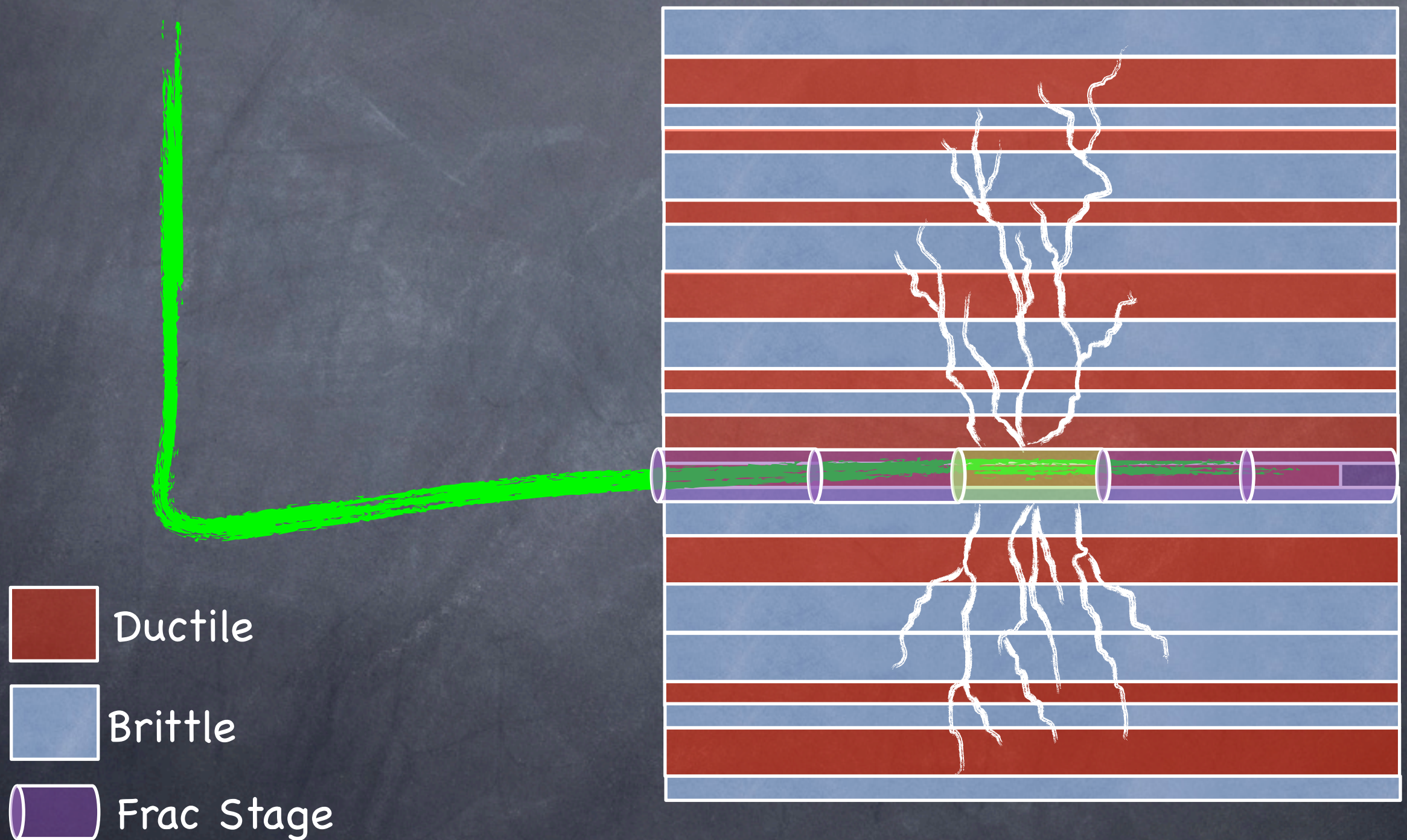
Scenario 1 Ductile - High TOC zone





Analysis

Scenario 2 Brittle - Low TOC zone





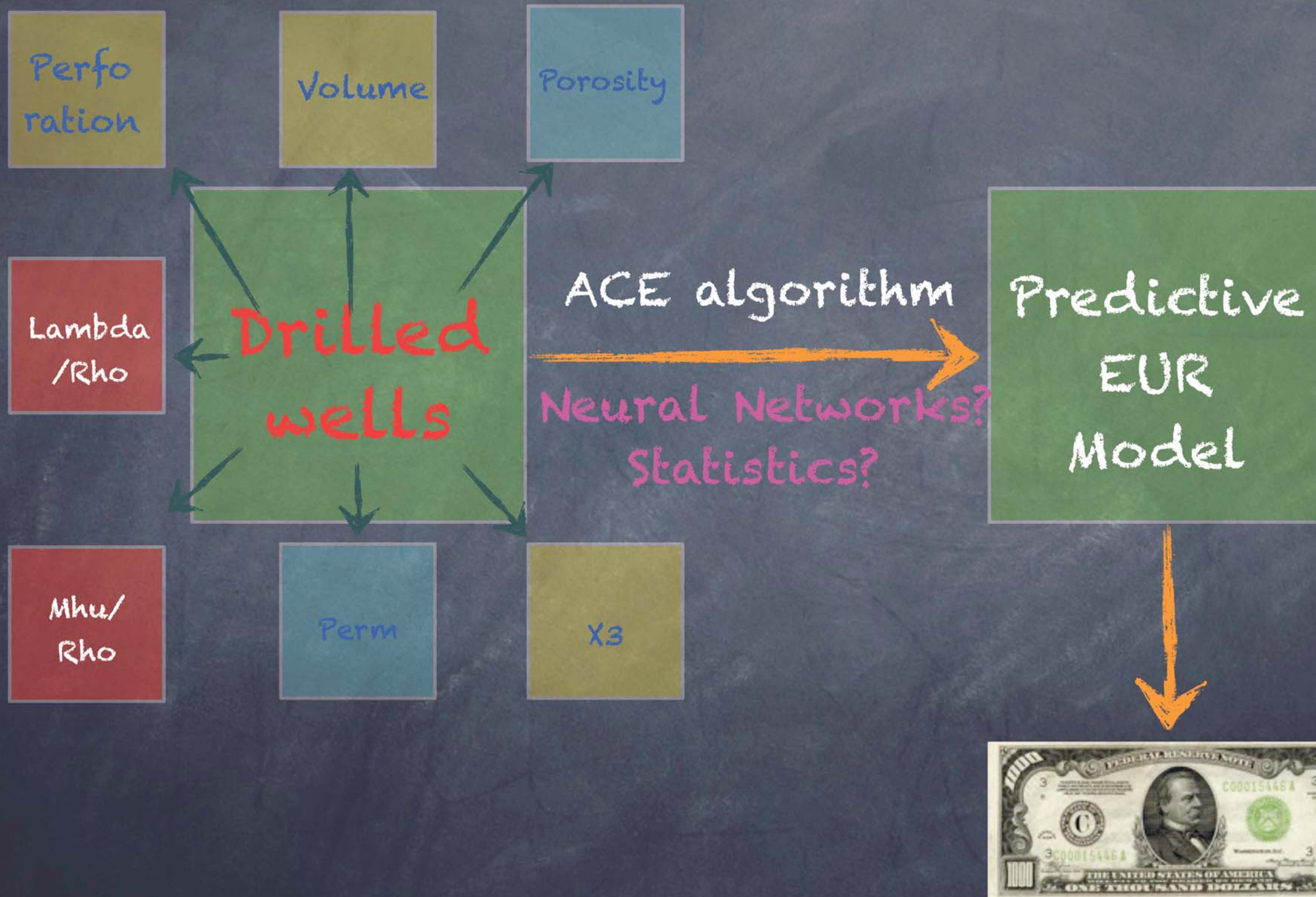
Conclusions



- 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

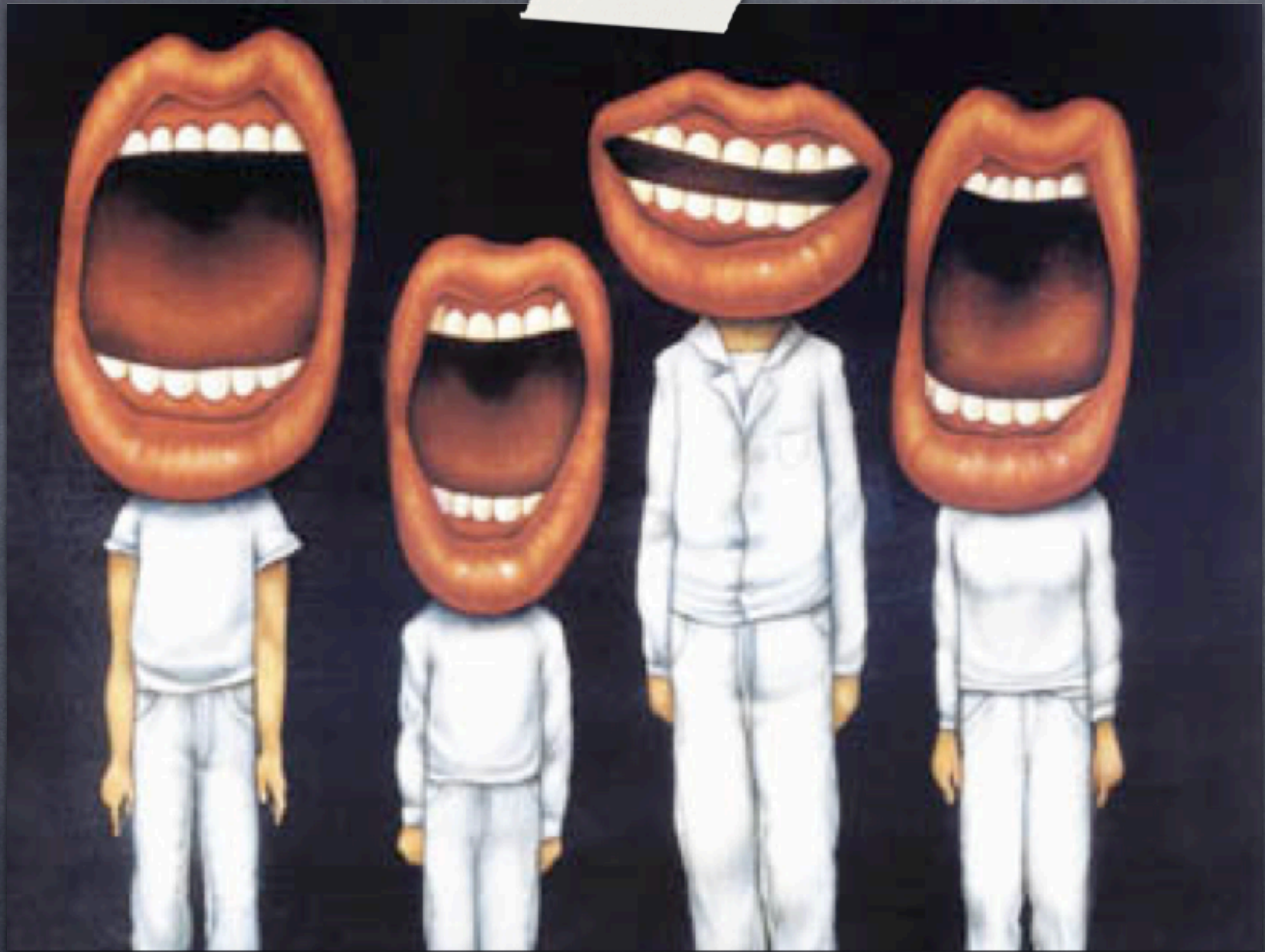




Acknowledgement



- Devon Energy for providing the data for this research.
- Dr. Kurt Marfurt for his support and suggestions.
- ALL AASPI members



Thanks