Thin Sweet Spots Identification in the Duvernay Formation of North Central Alberta*

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Abstract

The Duvernay Shale liquids play, running along the foothills east of the Rocky Mountains, possesses all the prerequisites of being a successful unconventional play, and has gained attention of the oil and gas industry in Alberta, Canada. Even though the net shale isopachs range between 25 m and 60 m for the most part within the play, at places it thins out. Considering the poor vertical resolution of the available seismic data, it is not possible to identify and characterize the thin Duvernay sweet spot zones using seismically-derived attributes. In a case study taken up recently, we found it challenging characterizing the thin Duvernay reservoir zone, and consequently developed a workflow that successfully addressed the challenge and identified the thin sweet spots. The workflow entailed extracting the P- and S- reflectivities from prestack seismic data using Fatti et al.'s approximation to the Zoeppritz equations, and then subjecting them to thin-bed reflectivity inversion. The latter process removes the time-varying effect of the wavelet from the data and the output of the inversion process can be viewed as spectrally-broadened seismic data, retrieved in the form of broadband reflectivity which can be filtered back to any desired bandwidth. This usually represents useful information for interpretation purposes. Filtered thin-bed reflectivity, obtained by convolving the reflectivity with a wavelet of a known frequency band-pass, not only provides an opportunity to study reflection character associated with features of interest, but also serves to confirm its close match with the original data. These P- and S-reflectivities with higher bandwidth were inverted into P- and S-impedances using model-based impedance inversion. This workflow enabled us to differentiate between the Upper and Lower Duvernay intervals. Sweet spots were identified based on the constrained volume that was created using multi-attribute analysis.

References Cited

Fatti, Jan L., George C. Smith, Peter J. Vail, Peter J. Strauss, and Philip R. Levitt, 1994, Detection of gas in sandstone reservoirs using AVO analysis: A 3-D seismic case history using the Geostack technique: Geophysics, v. 59/9, p. 1362-1376.

Rokosh, C.D., S. Lyster, S.D.A. Anderson, A.P. Beaton, H. Berhane, T. Brazzoni, D. Chen, Y. Cheng, T. Mack, C. Pana, and J.G. Pawlowicz, 2012, Summary of Alberta's shale- and siltstone-hosted hydrocarbons: Alberta Geological Survey Open File Report 2012-06.

Thin sweet spot Identification in the Duvernay Formation of North Central Alberta

Ritesh K. Sharma and Satinder Chopra

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(Talk delivered at AAPG Annual Convention & Exhibition, Calgary on 21st June, 2016)

Duvernay Formation

The Devonian Duvernay shales are proven source rocks for many of the large Devonian oil and gas pools in Alberta including the Leduc discovery in 1947.

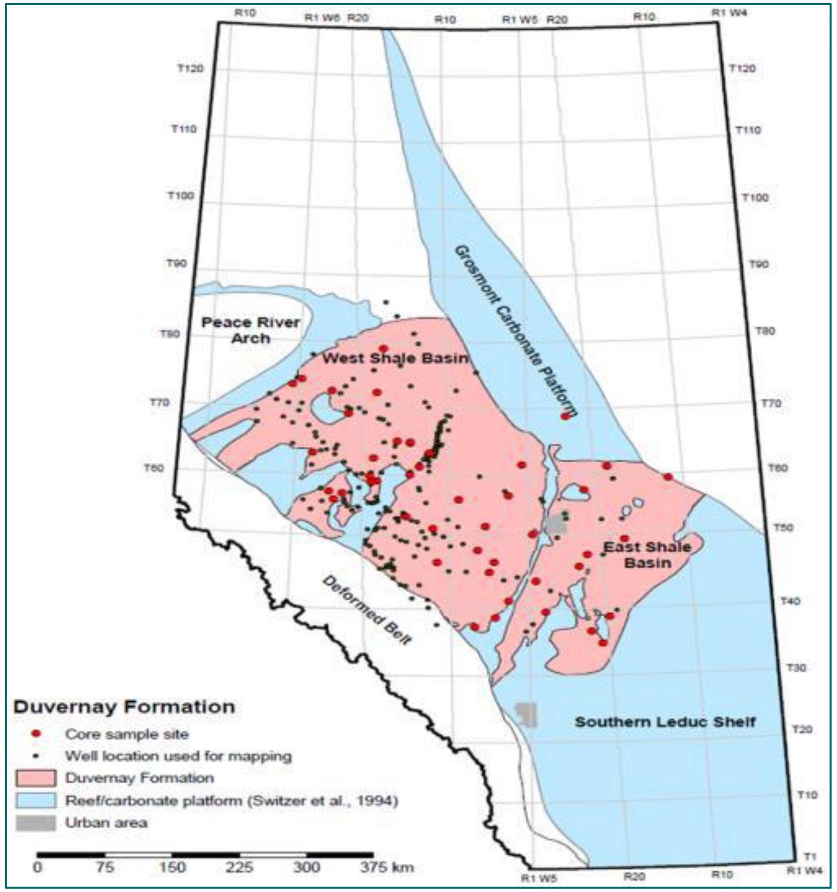
The Duvernay shale basin spans approx. 50,000 sq. miles, with an estimated 7,500 sq. miles within the thermally mature or wet gas window.

Holds an estimated 443 trillion cubic feet of gas and 61.7 billion barrels of oil (Source: AER).

Duvernay Formation

In Alberta, the Duvernay shales are found in the East Shale Basin and West Shale Basin, both of which differ in the geological setting and their characteristics.

The present case study focuses on a dataset from central Alberta and situated in the West Shale Basin.



Index map showing the Duvernay Formation in the province of Alberta (After Rokosh et al., 2012)

Characteristics of Duvernay

Lithology: Fine grained and silica (quartz) rich. Fine grained rocks have increased total surface area which leads to a higher absorbed gas component in organic rich rocks. More brittle and favorable for fracking.

TOC: Measure the organic matter that was preserved in the rock. TOC varies from 1-20% .

Thickness: required for storage and ultimate economic of the play. Varies from 10-70m.

Effective Porosity: Pore space required for storage of hydrocarbon once generated from the organic material contained in the rock. Varies between 3 and 5%.

Pressure Gradient: Over-pressured reservoirs allow for increased storage. It is over pressured nature.

Characteristics of Duvernay

Element	Desired	Duvernay
Lithology	Fine grained/silica-rich	Fine grained/silica-rich
Thickness	> 40m	10-70m
TOC	> 1%	1-20%
Effective Porosity	> 2.5%	3-15
Pressure Gradient	> 0.5 psi/ft	0.68-0.81 psi/ft
Areal Extent	Large	7,500 square miles

Some key elements for characterization of shale plays

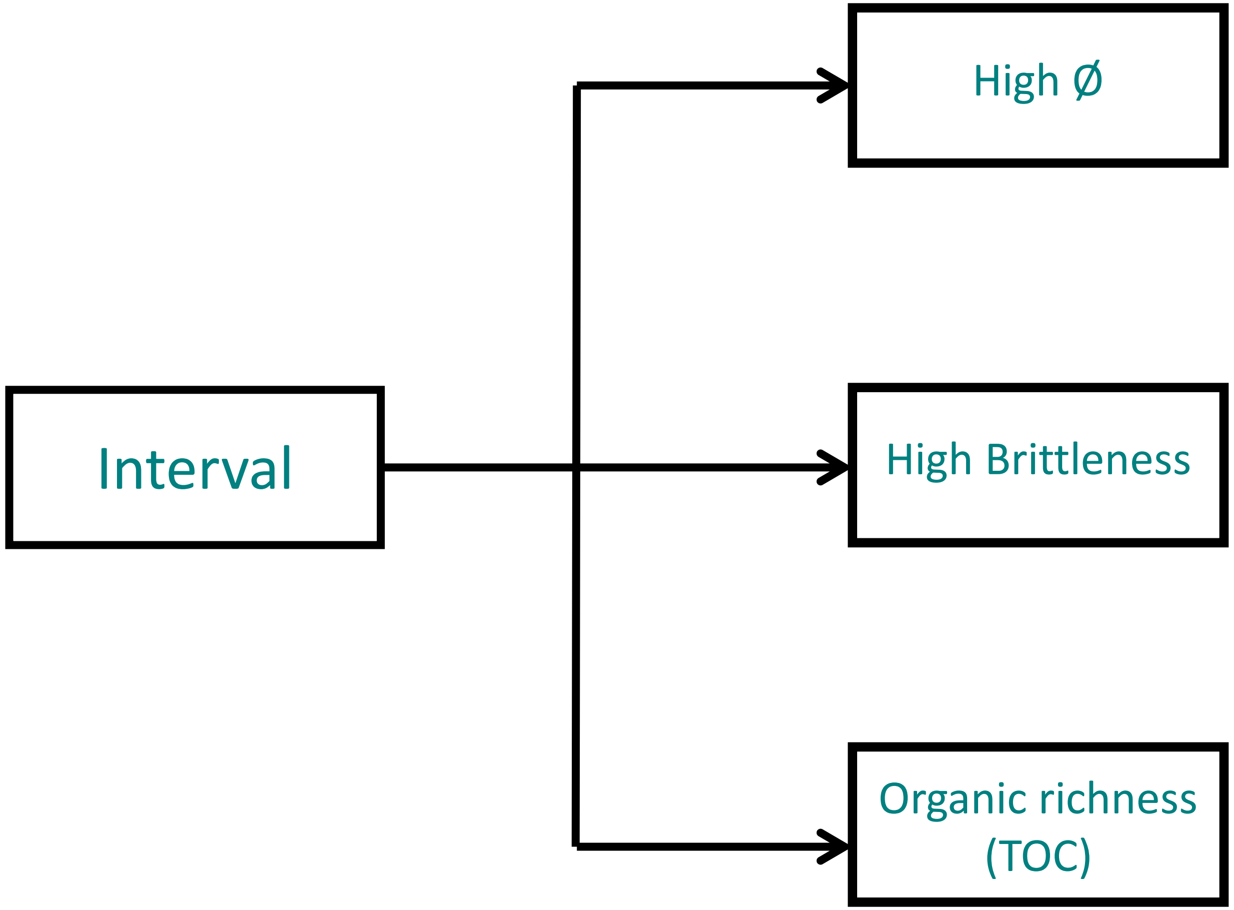
1. Mineralogy
2. Organic richness
3. Maturation
4. Porosity/permeability
5. Faults/fractures
6. Brittleness
7. Pore-pressure/stress
8. Thickness
9. Oil/gas-in-place

Can be determined using lab testing of samples, geochemical analysis, and log measurements

Can determine using **seismic data** and log measurements

Estimated with knowledge of various parameters

Sweet spot identification



“High porosity is a prerequisite for better reservoir quality . ”

“Brittle rocks frac much better than ductile rocks and enhance the permeability of those zones. ”

“Higher the TOC, better the potential for hydrocarbon generation”

Use of seismic for sweet spot identification

1. Properties that help seismic to identify sweet spots.

   "Changes in the porosity of shale formations influence V_P, V_S, and ρ, thus should be detected on the seismic response."

2. Such influence can be detected on different pairs of attributes

$$I_P - I_S,\ \lambda\rho - \mu\rho \text{ and } I_P - \frac{V_P}{V_S} \text{ etc.}$$

Location of brittle shale pockets

1. Brittleness of a rock formation can be estimated from the computed Poisson's ratio (strength) and Young's modulus (stiffness) well log curves.

2. Brittle rocks exhibit high Young's modulus and low Poisson's ratio (PR).

$$E = I_S^2 \left(\frac{3I_P^2 - 4I_S^2}{\rho (I_P^2 - I_S^2)} \right)$$

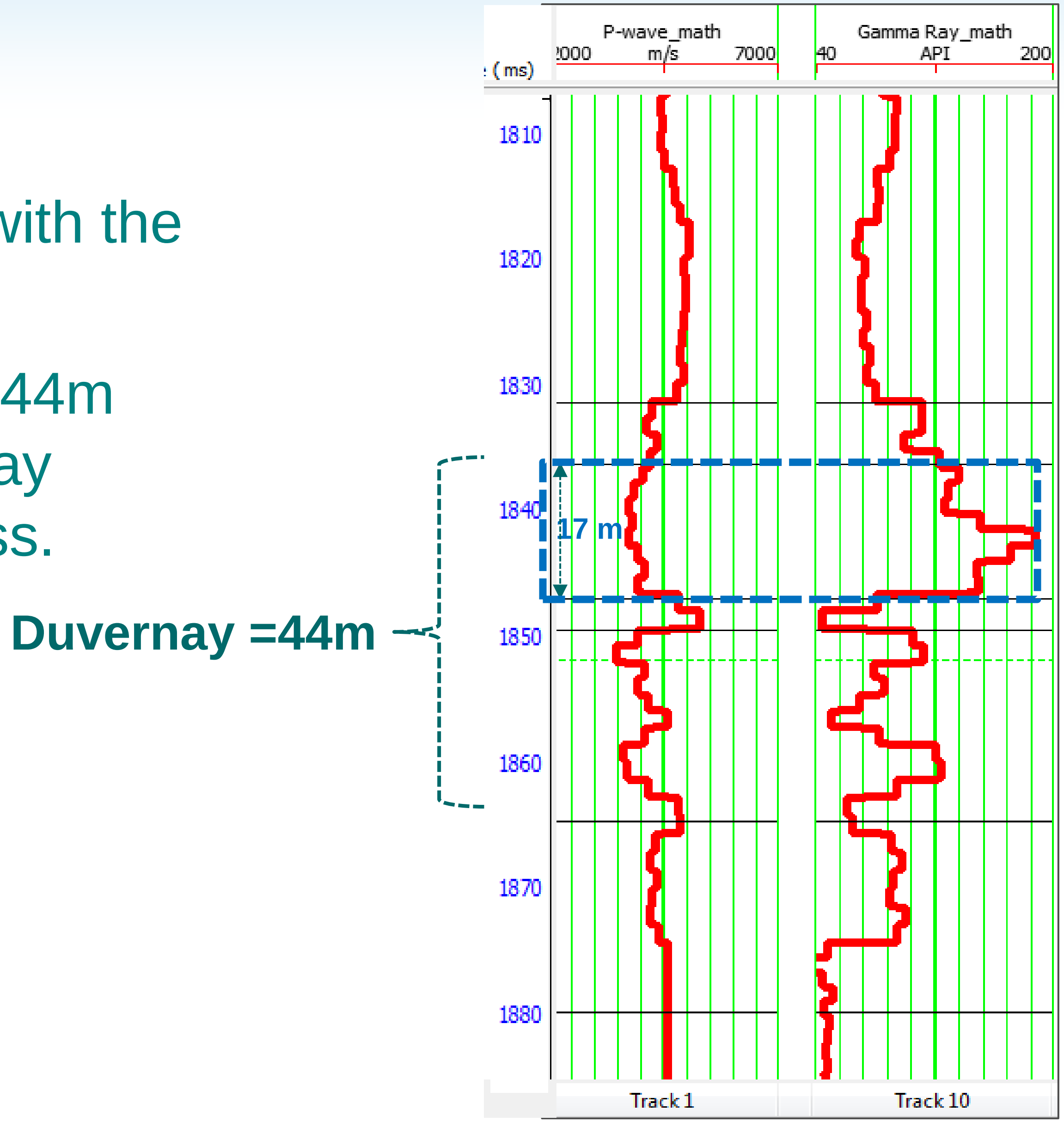
$$\sigma = \frac{I_P^2 - 2I_S^2}{2(I_P^2 - I_S^2)}$$

$$E\rho = I_S^2 \left(\frac{3I_P^2 - 4I_S^2}{(I_P^2 - I_S^2)} \right)$$

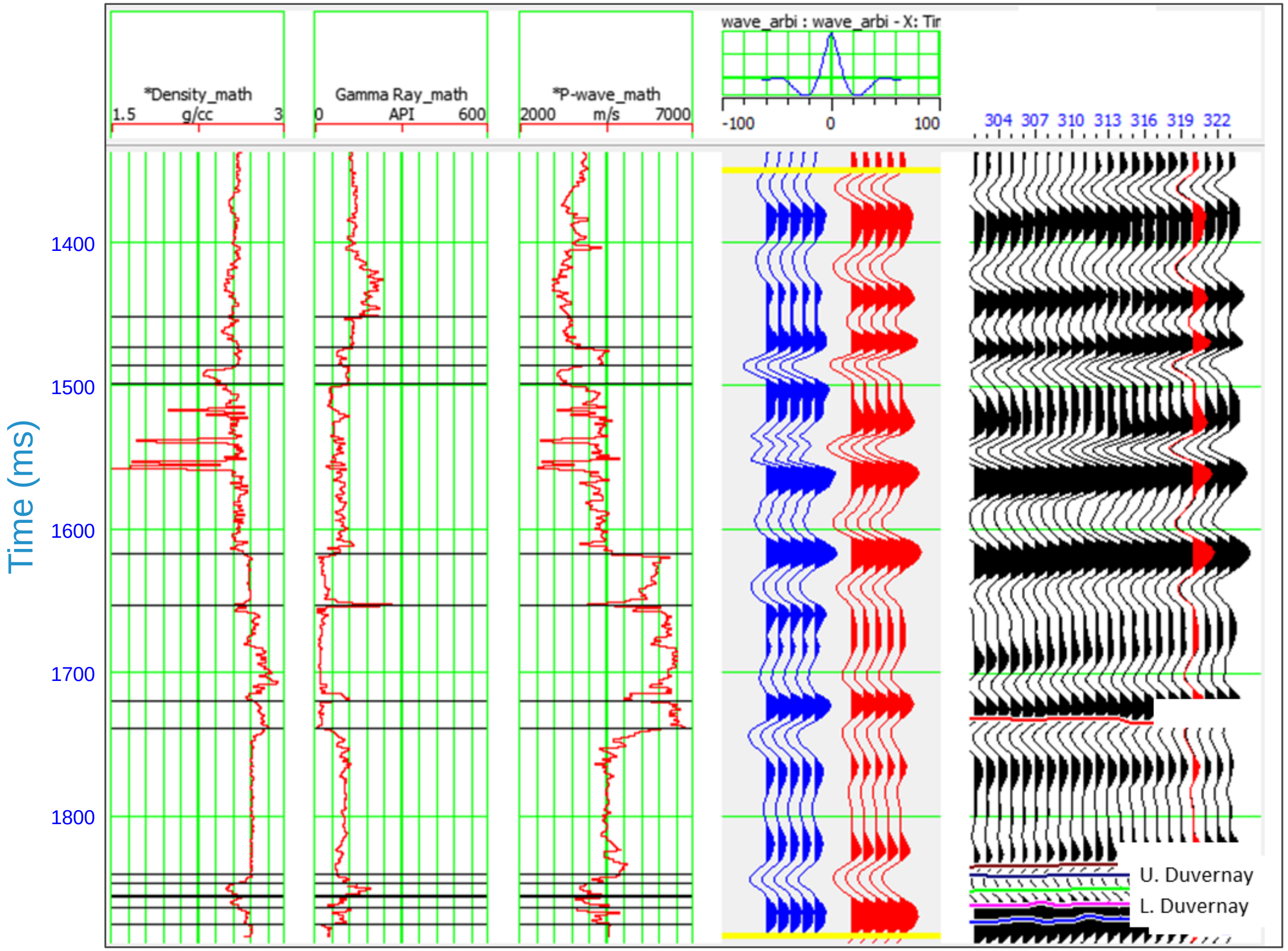
3. Once P-impedance and S-impedance attributes are determined, different rock parameters can be computed from them.

Characterization of Duvernay

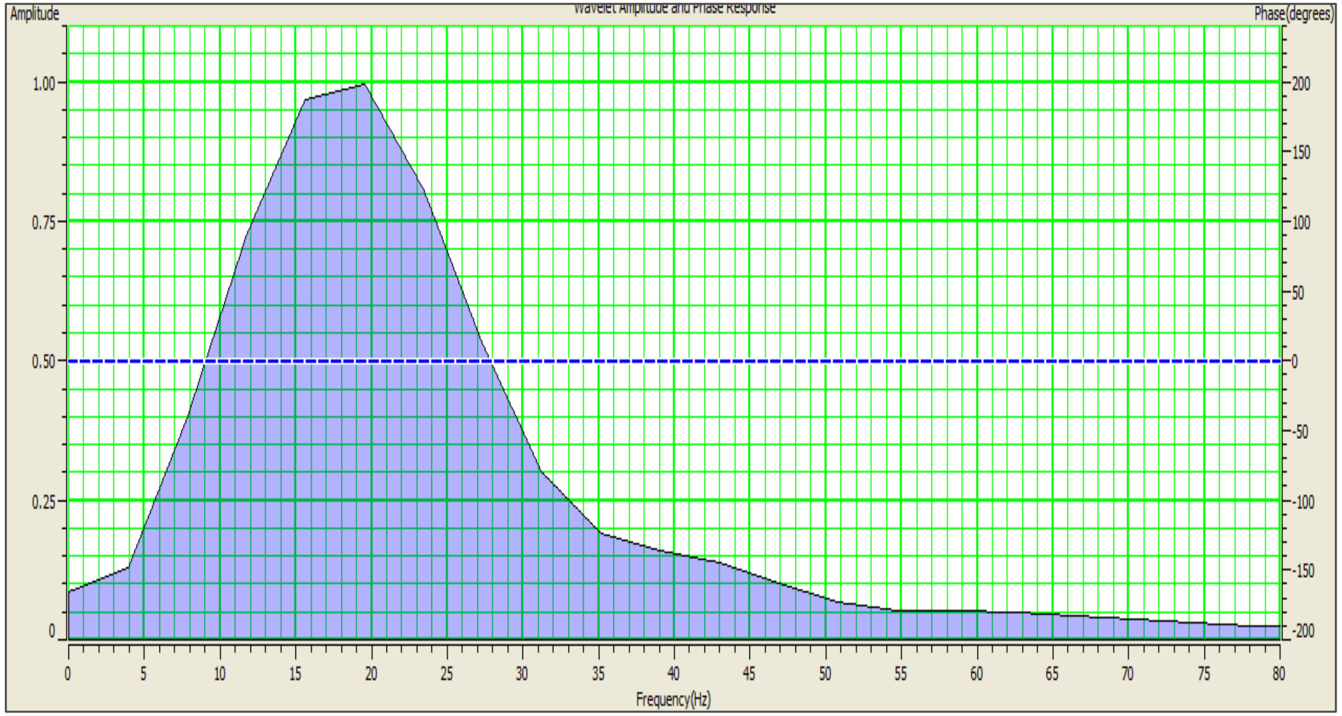
- We begin our characterization exercise with the appropriate well-log curves.
- Even though the Duvernay Formation is 44m thick, the thickness of the Upper Duvernay (productive zone) is only 17m in thickness.



Well-to-seismic ties



Well-to-seismic ties

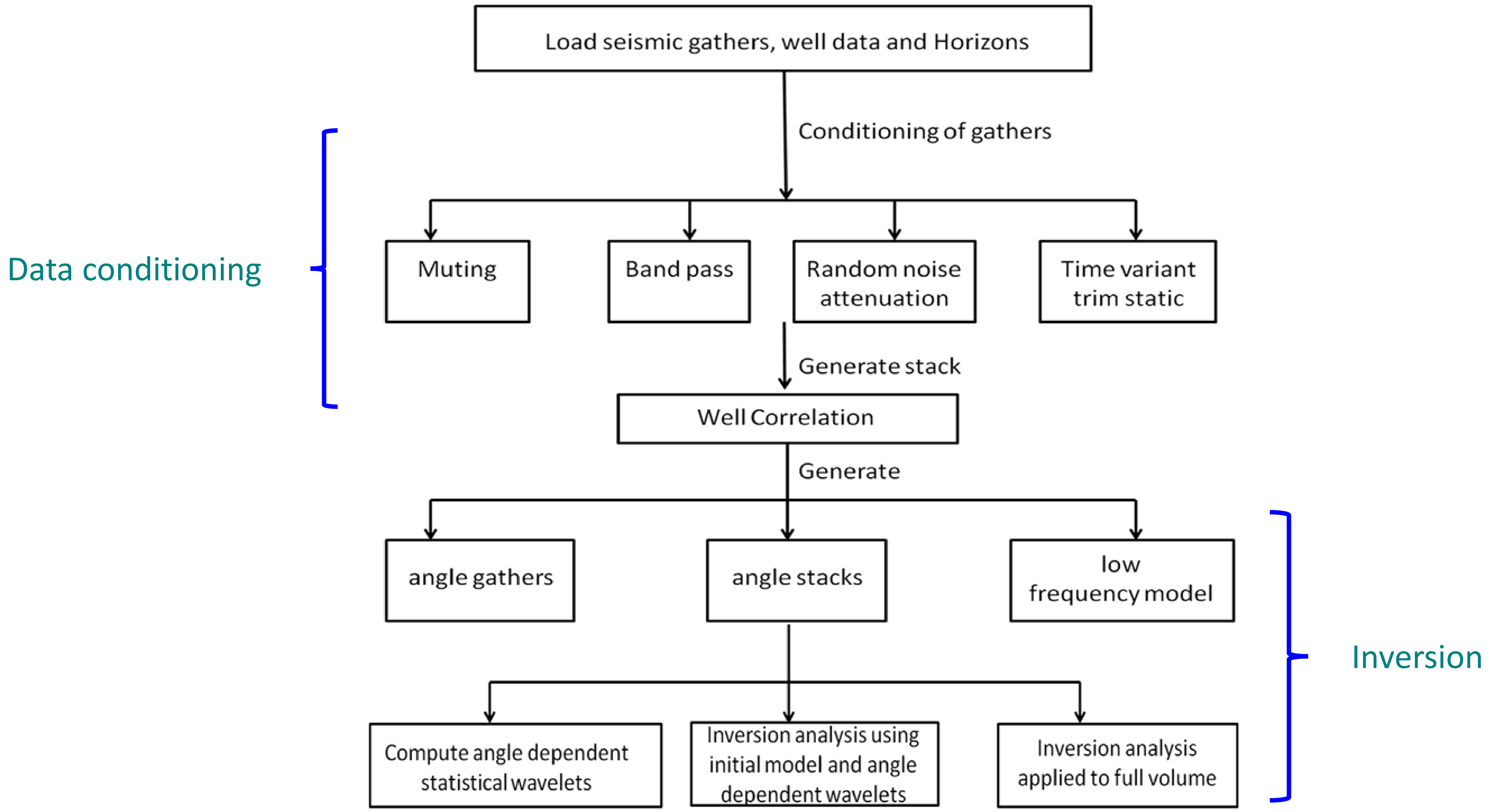


Amplitude spectra of a statistical wavelet (shown above) indicates that the dominant frequency in the data is 20 Hz.

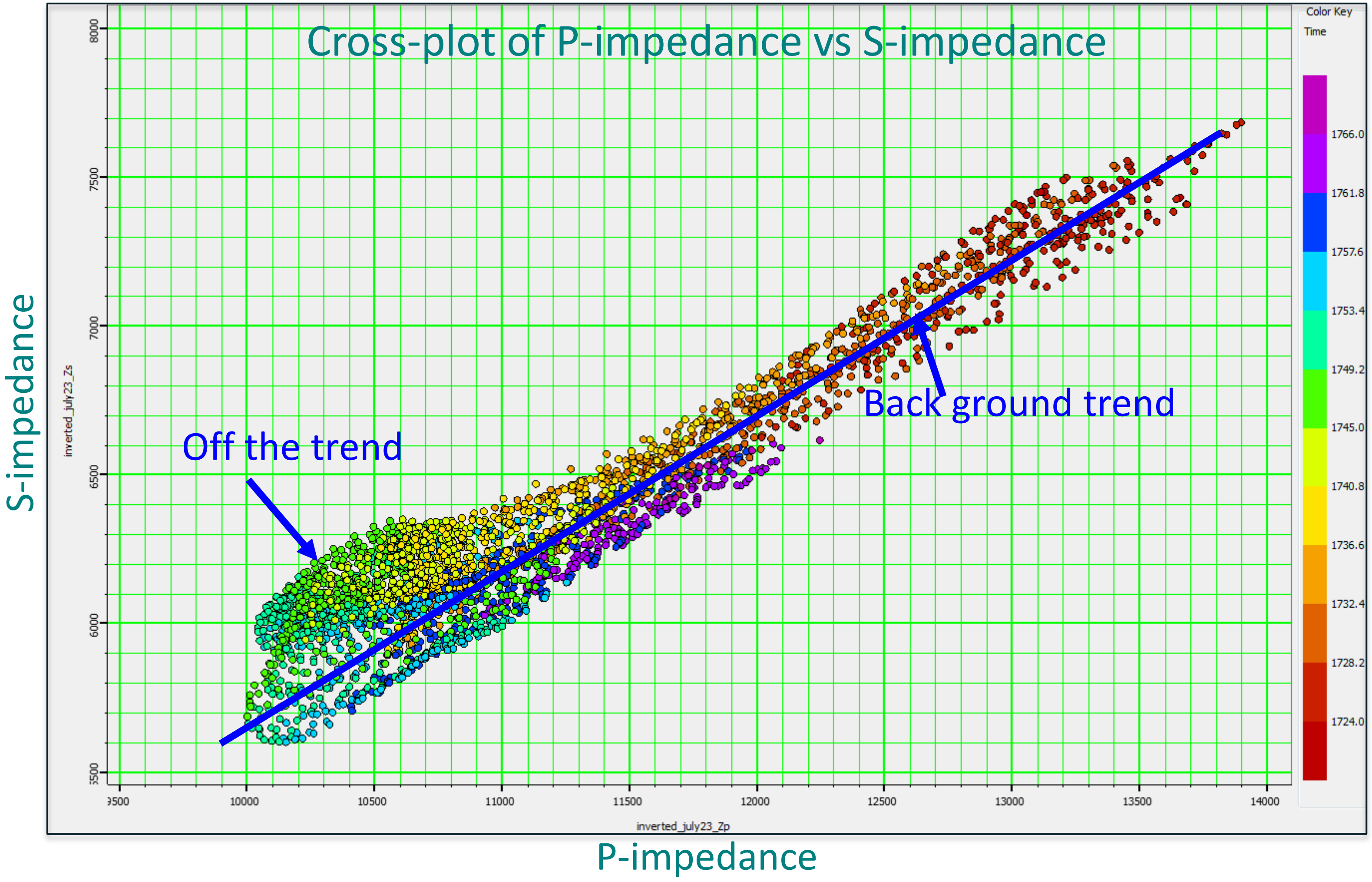
This implies the vertical resolution for this data set is approximately 48m (V_P = 3800 m/s).

It is therefore challenging to characterize a 17m thick formation.

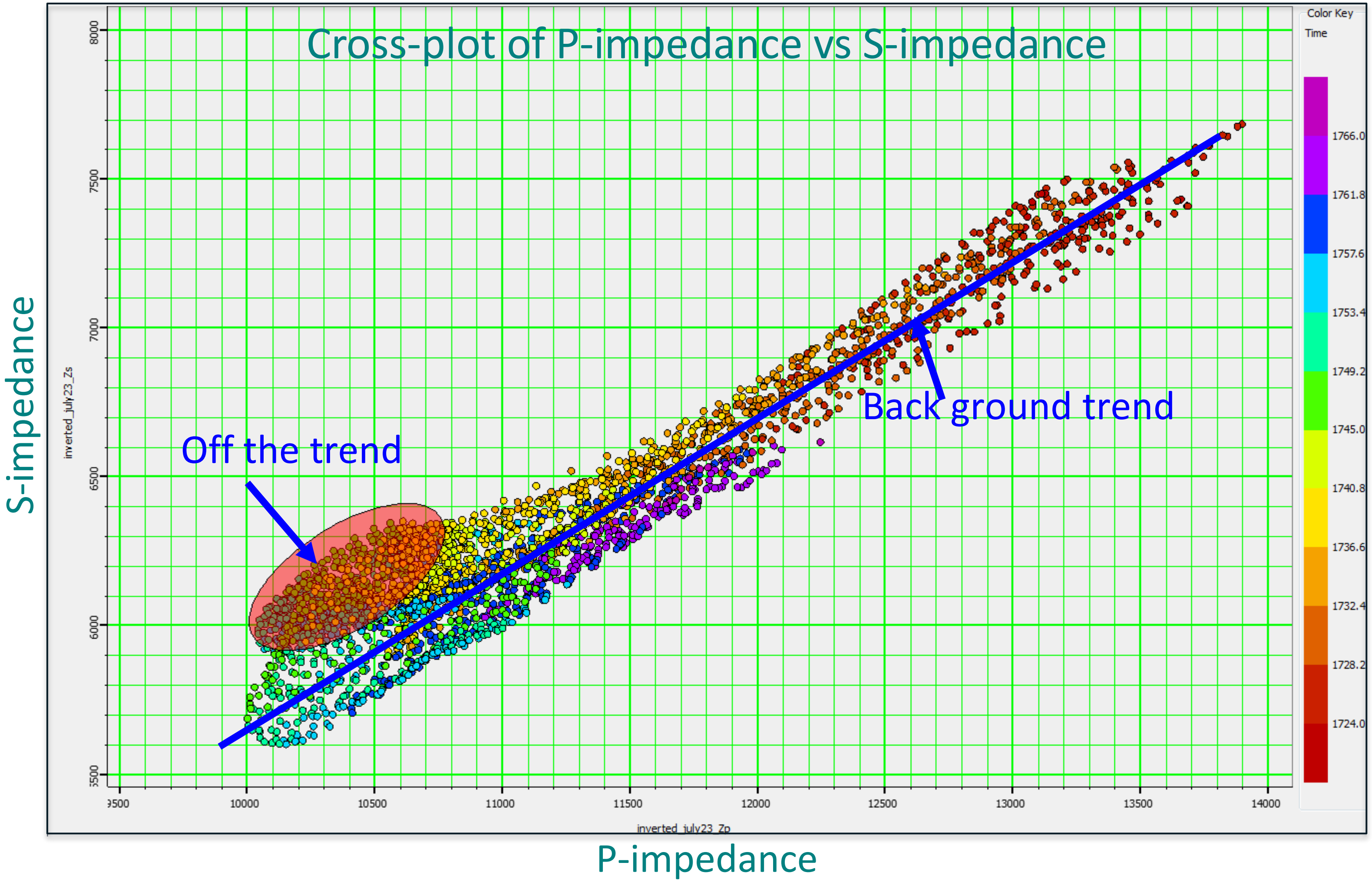
Workflow for simultaneous inversion



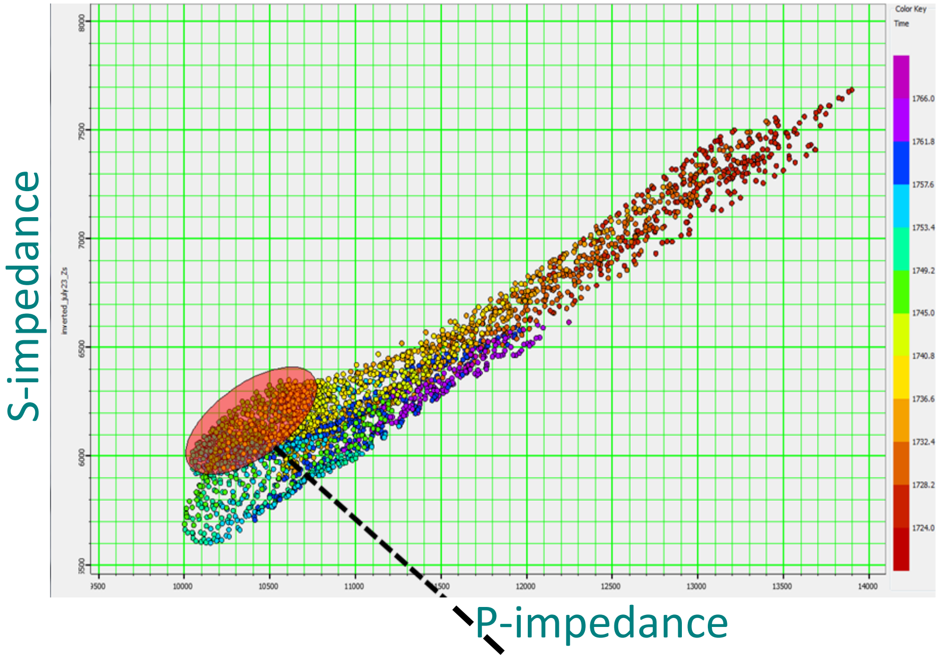
Simultaneous inversion output



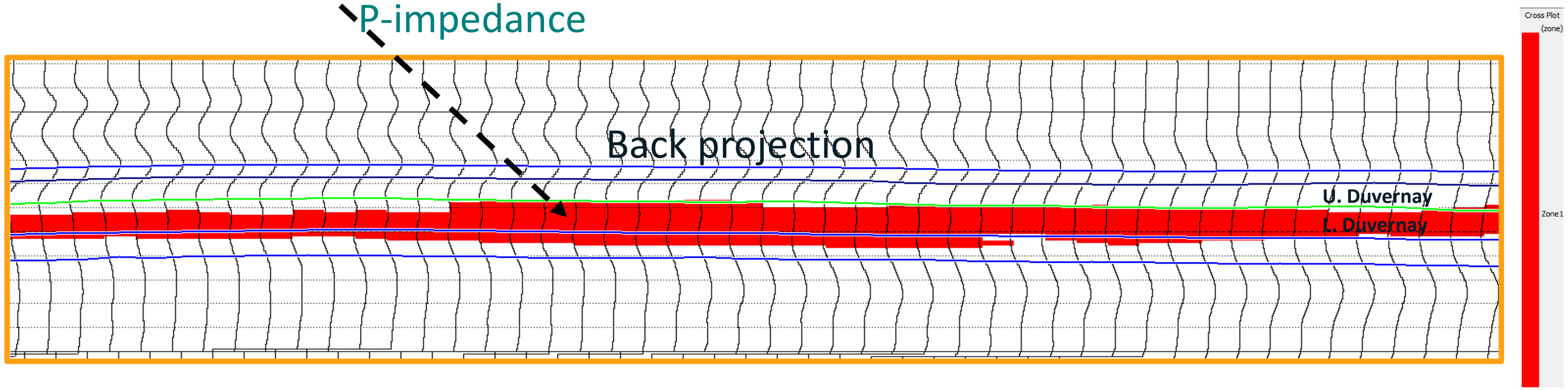
Simultaneous inversion output



Crossplot of P-impedance vs S-impedance

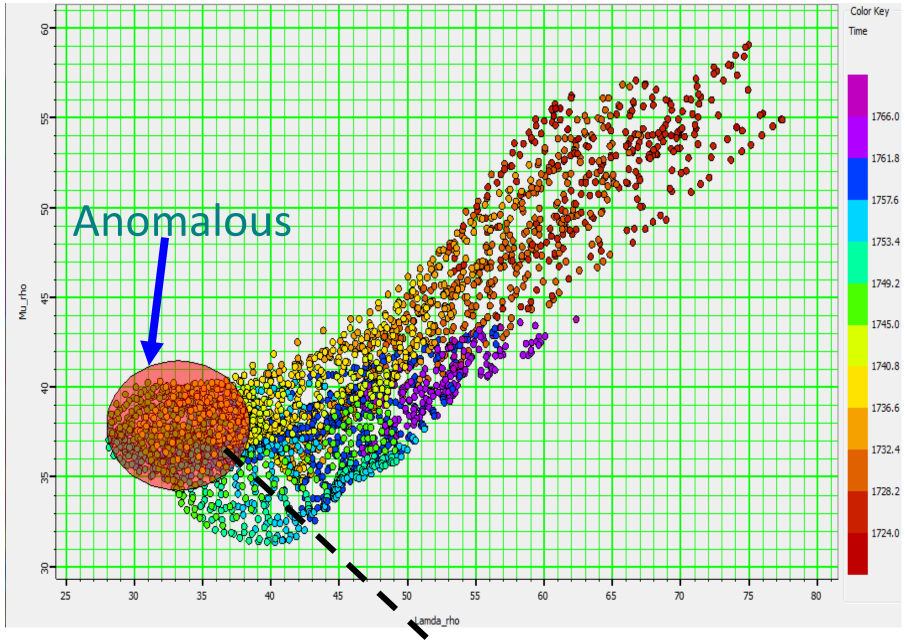


Back projection indicates that the anomalous points are coming from Lower Duvernay formation which is not expected.

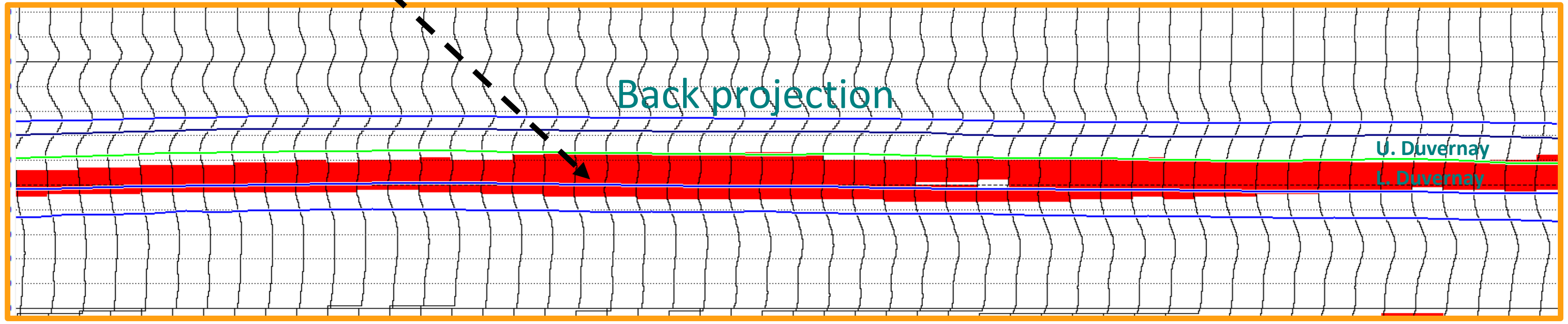


Crossplot of Lambda-rho vs Mu-rho

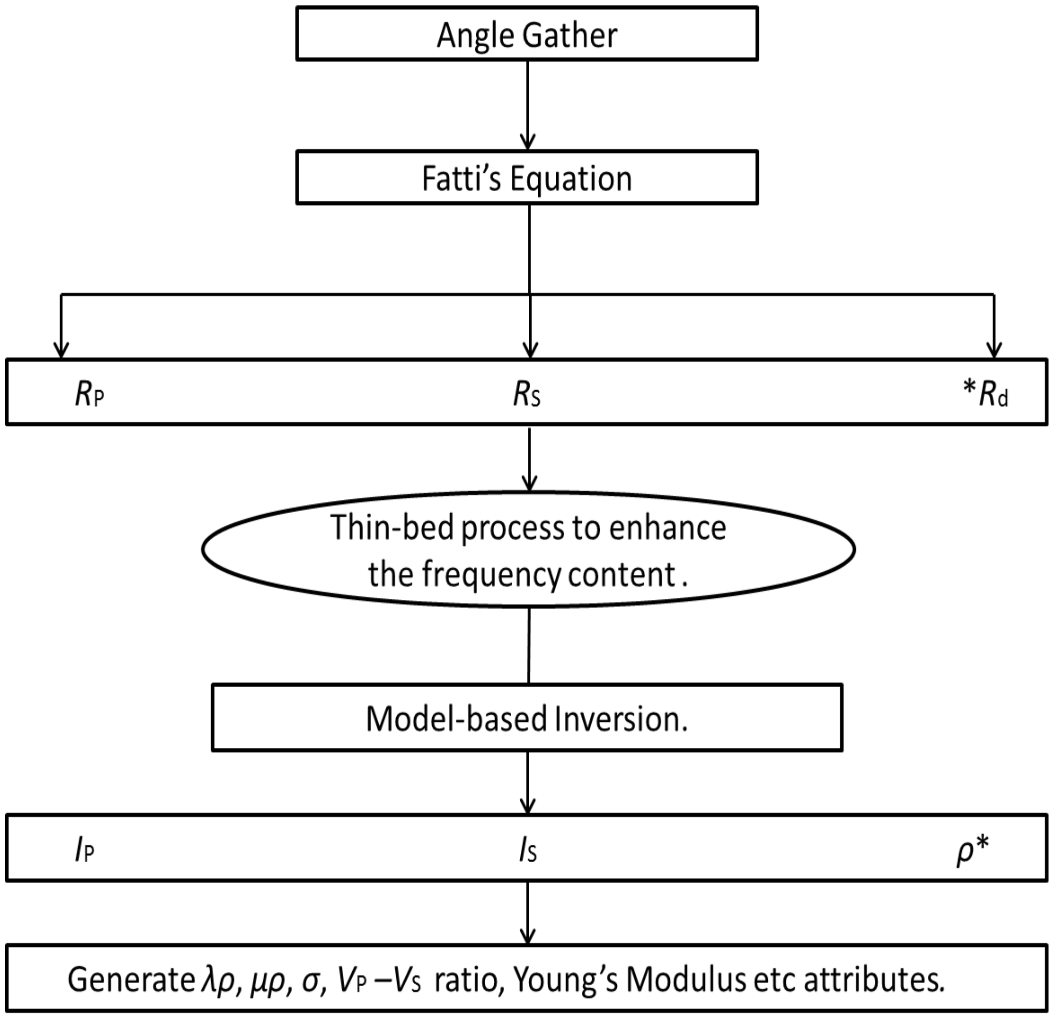
Cross-plot of λρ vs μρ



Similarly, back projection indicates that anomalous points are coming from Lower Duvernay formation.

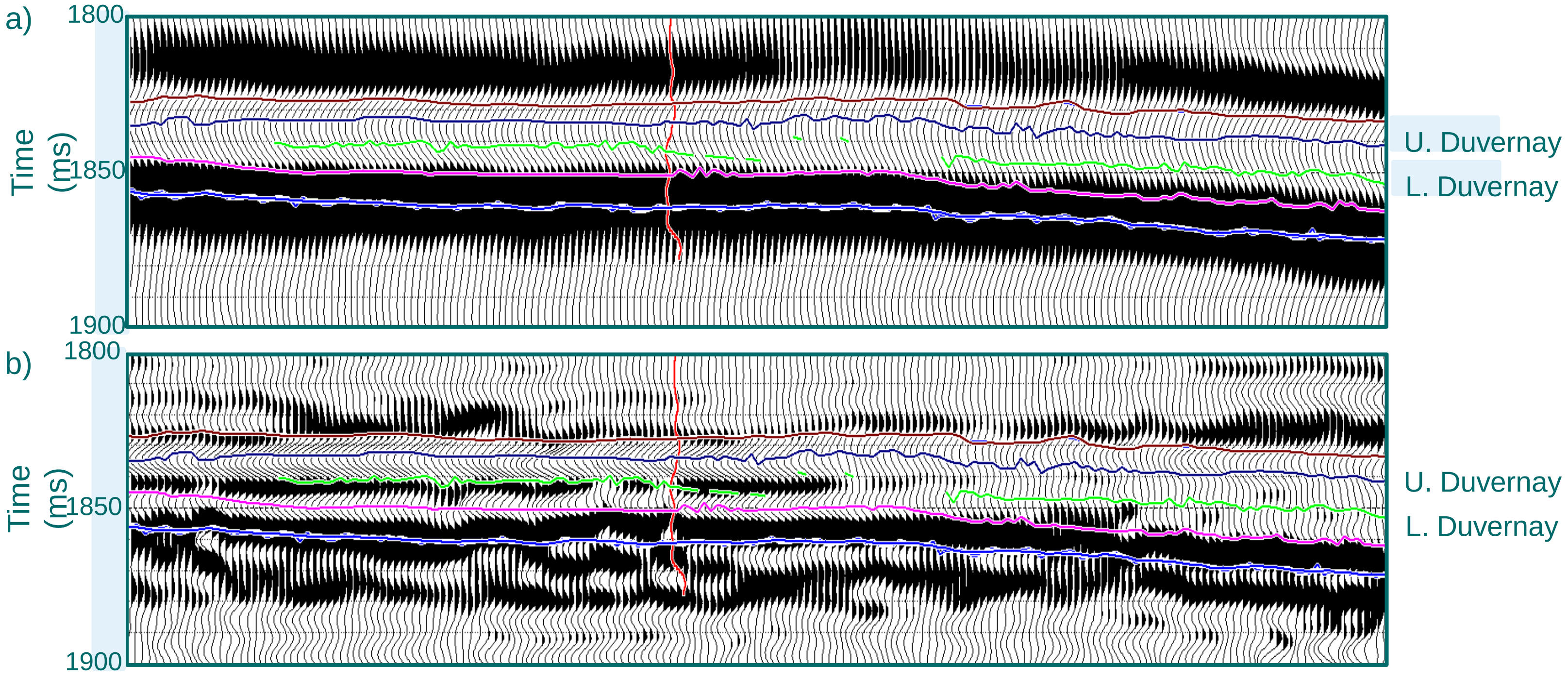


New approach followed



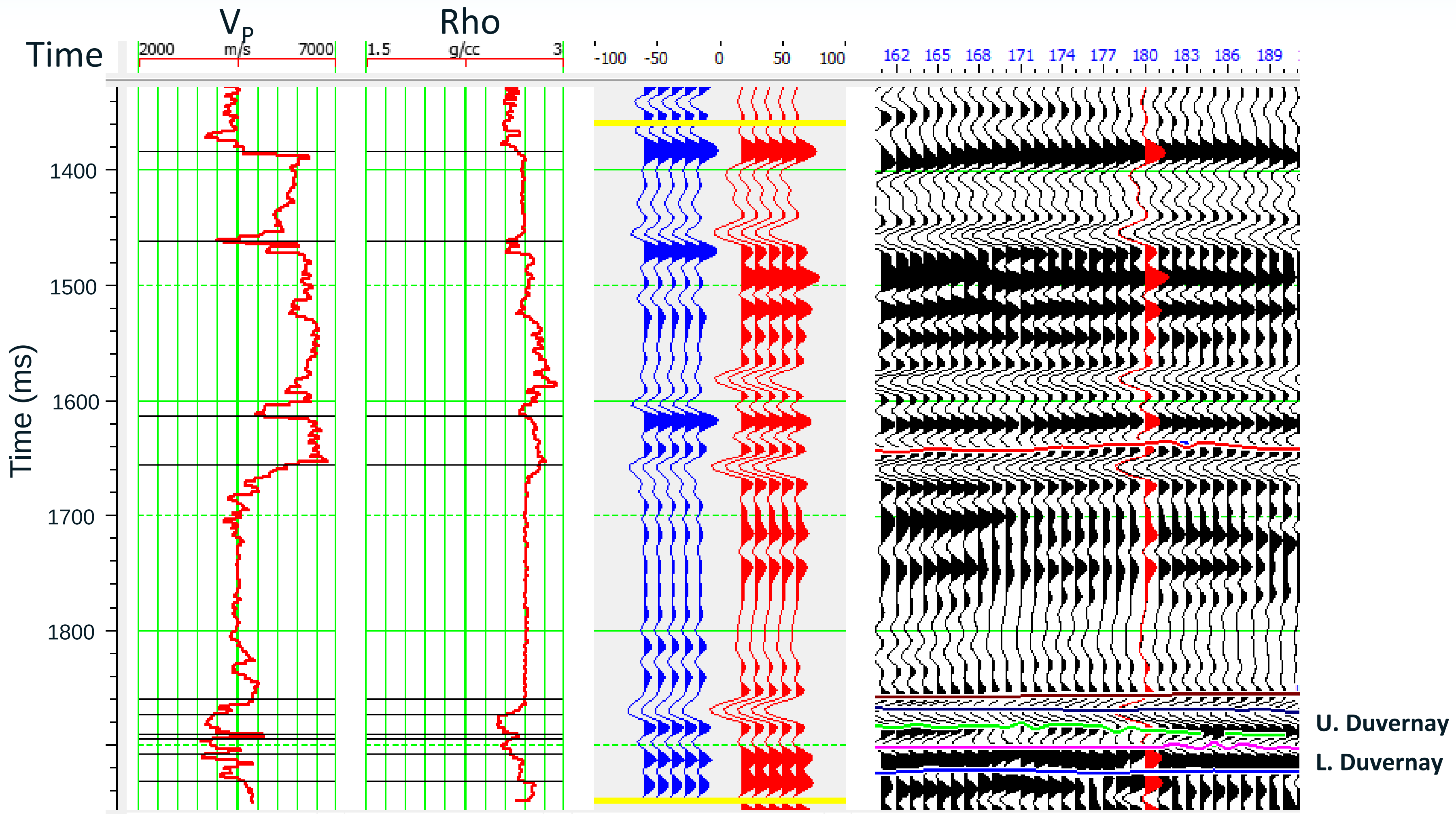
* Computation depends on the quality of input data.

New approach followed



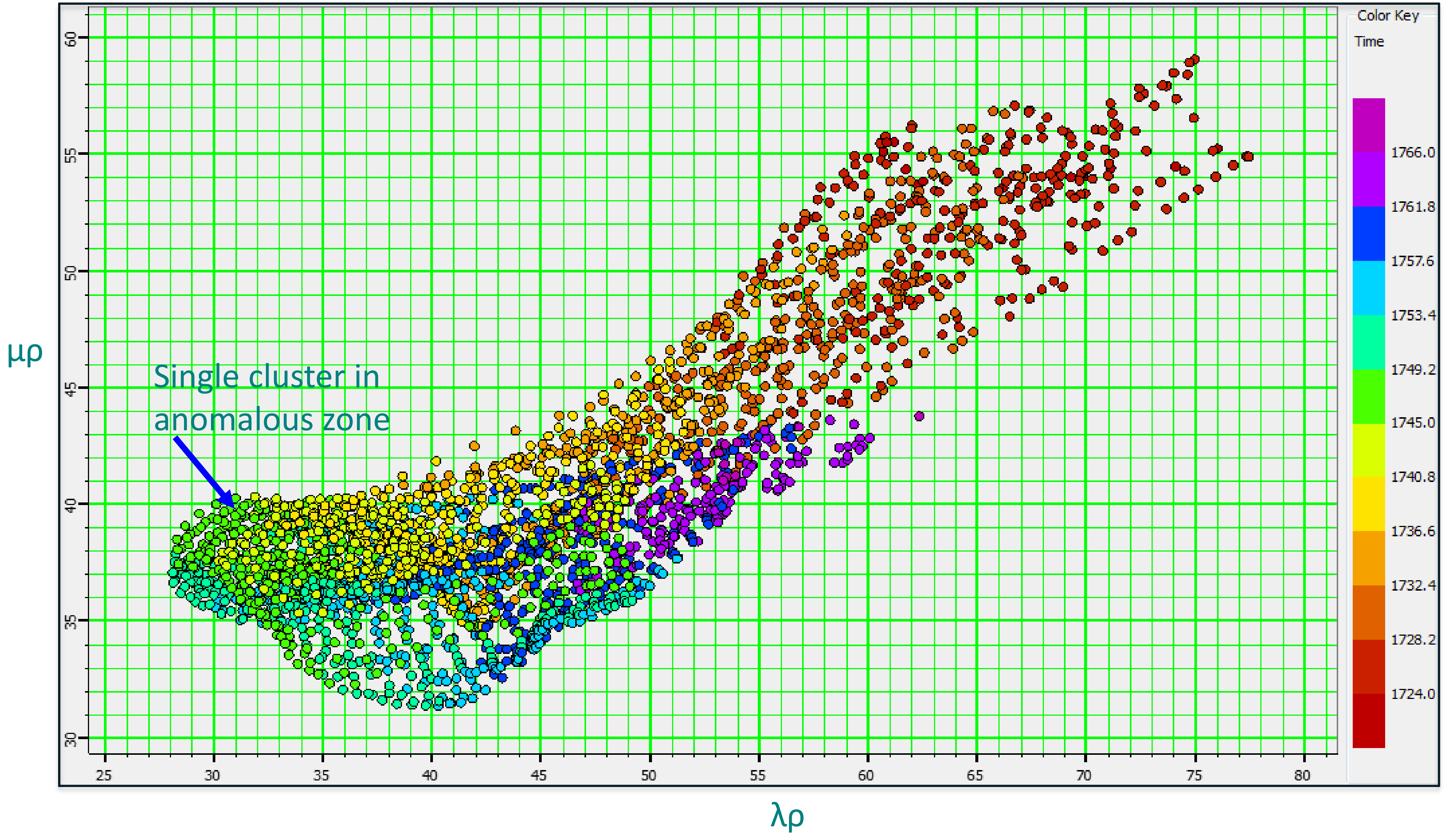
P-wave reflectivity section (a) before and (b) after thin-bed reflectivity inversion. Notice the extra events and more detailed information over the zone of interest.

Quality control

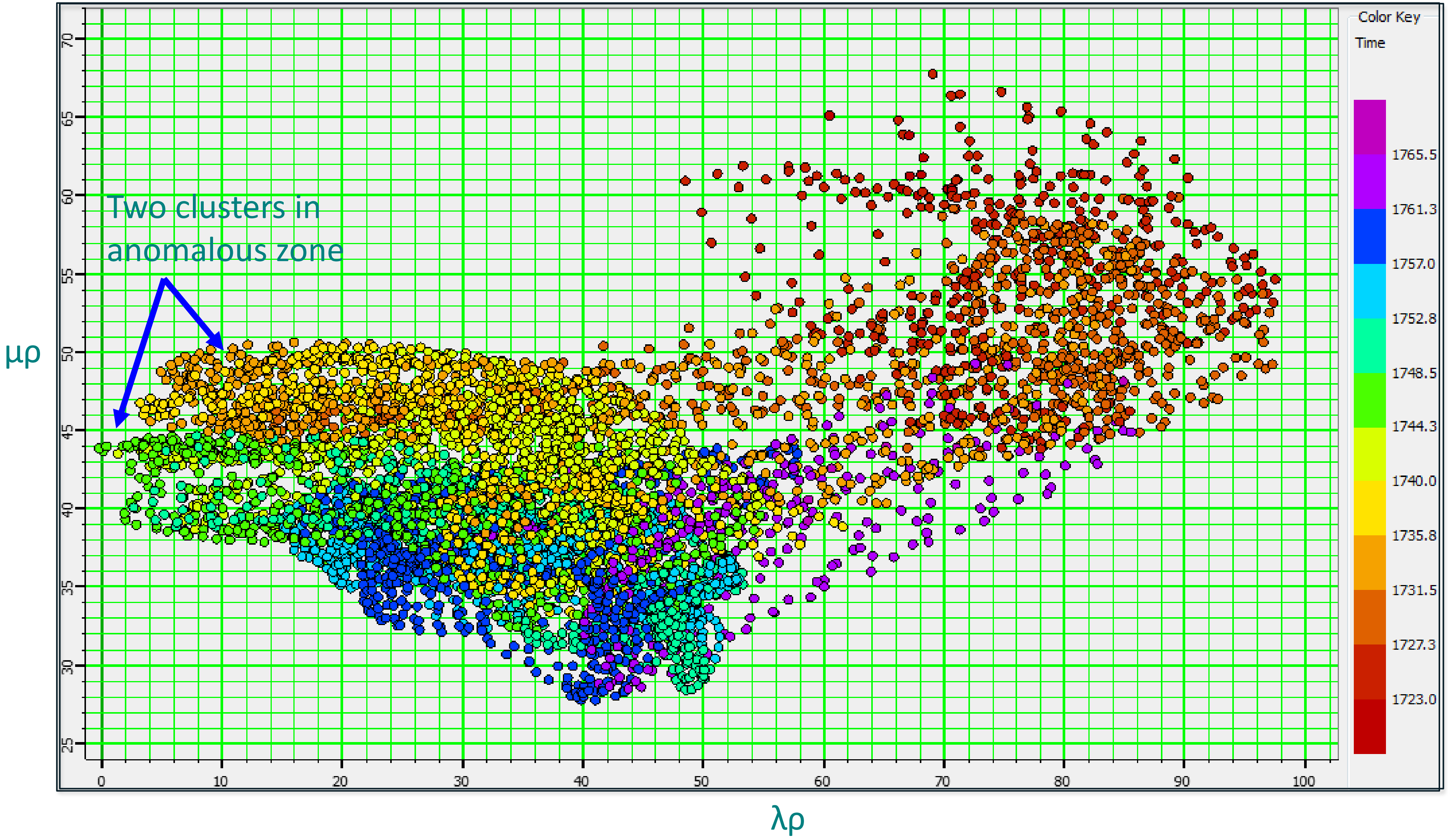


To check whether enhancement of frequencies is realistic or not, well-to-seismic tie is carried out

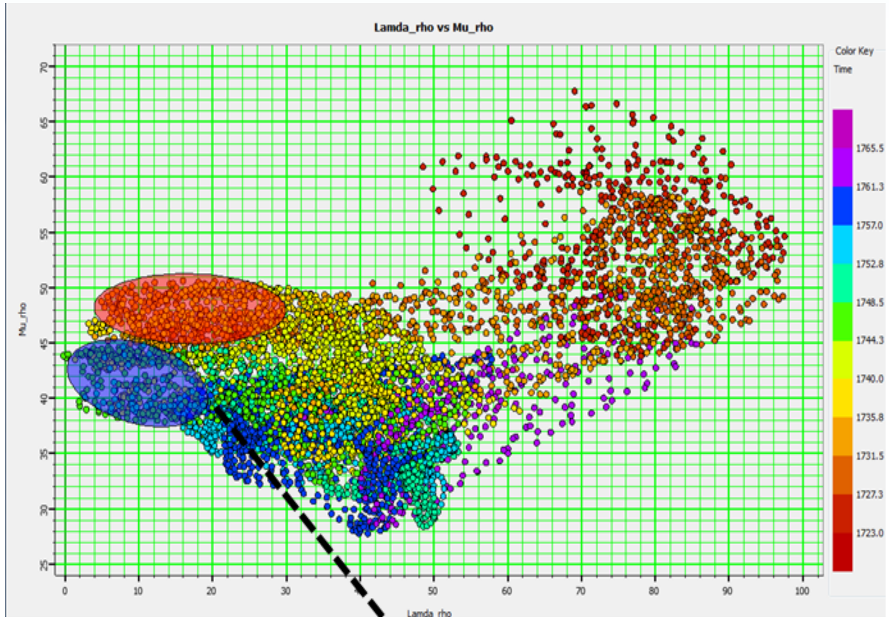
Lambda-rho vs Mu-rho crossplot (simultaneous inversion)



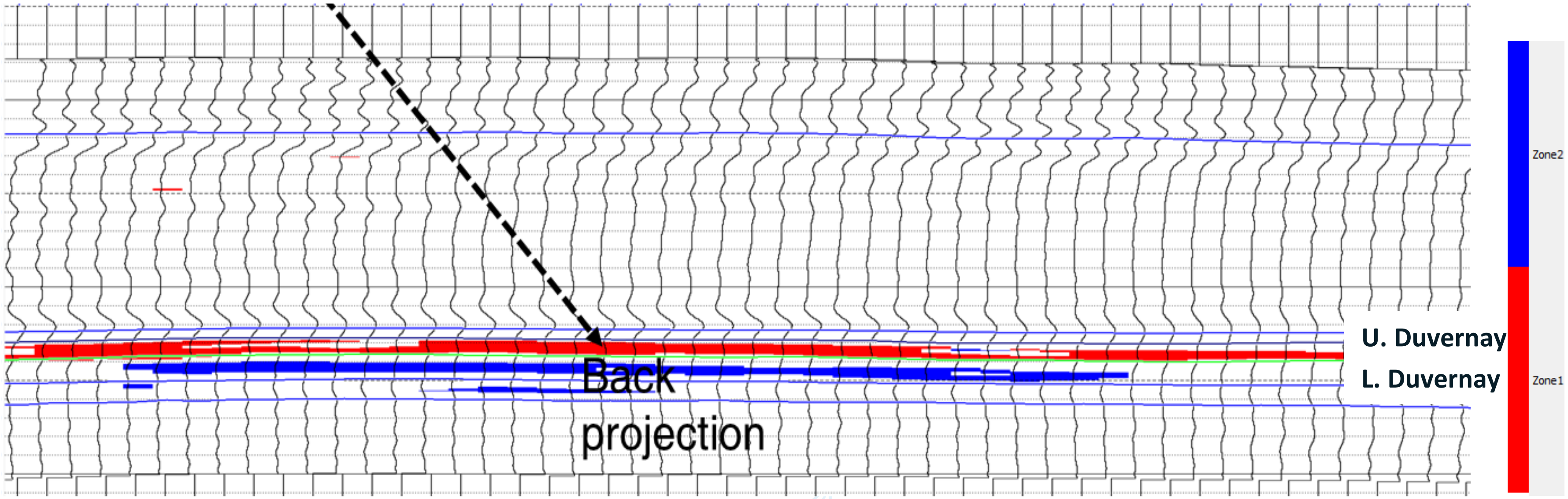
Lambda-rho vs Mu-rho crossplot (new approach)



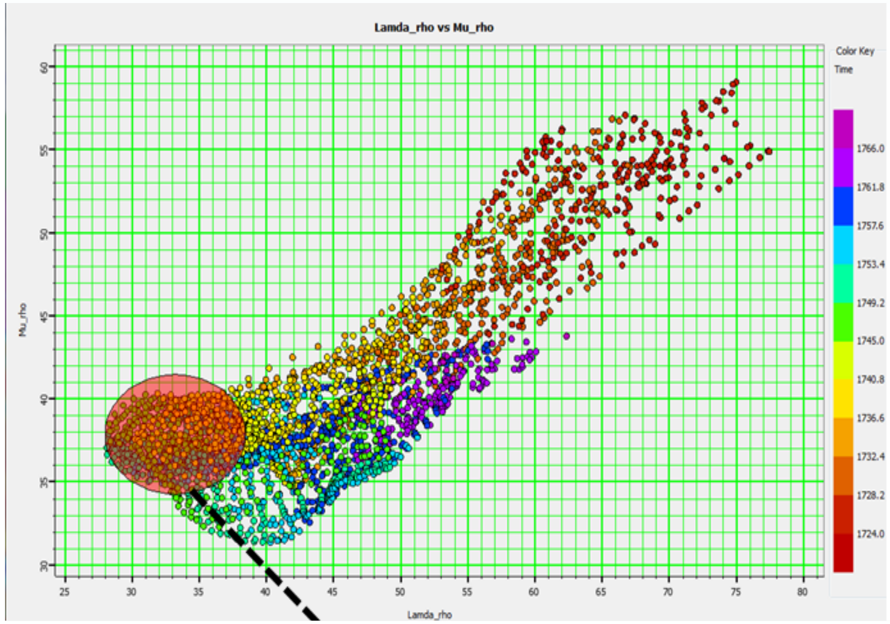
Lambda-rho vs Mu-rho crossplot (new approach)



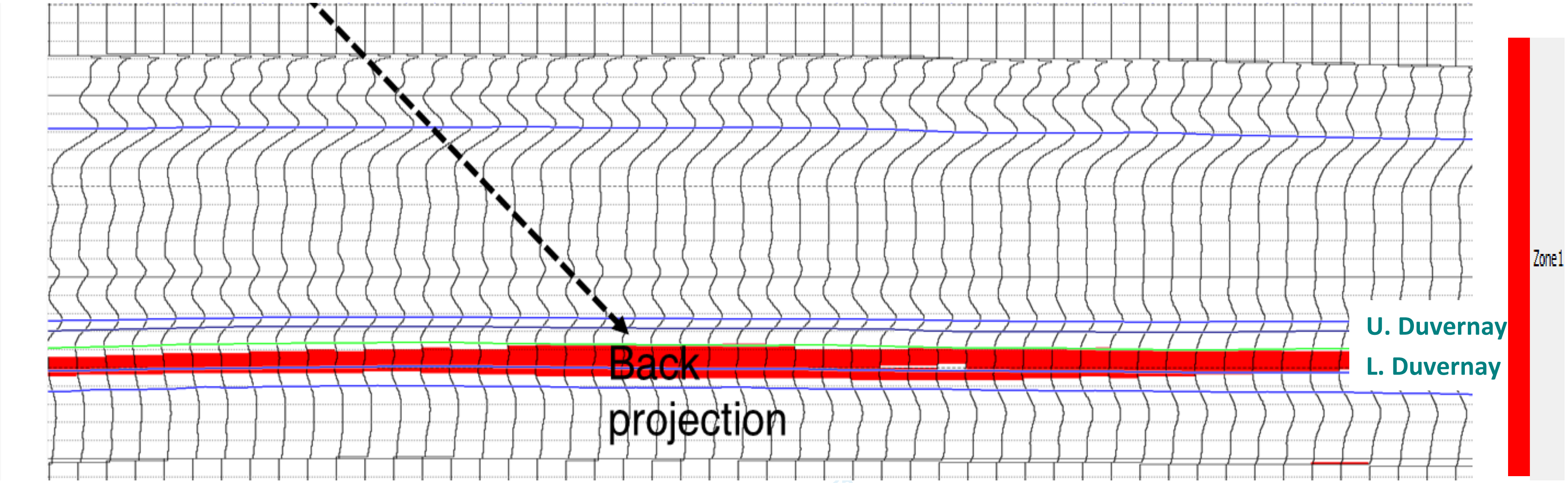
Here, we are able to differentiate between Upper and Lower Duvernay formations.



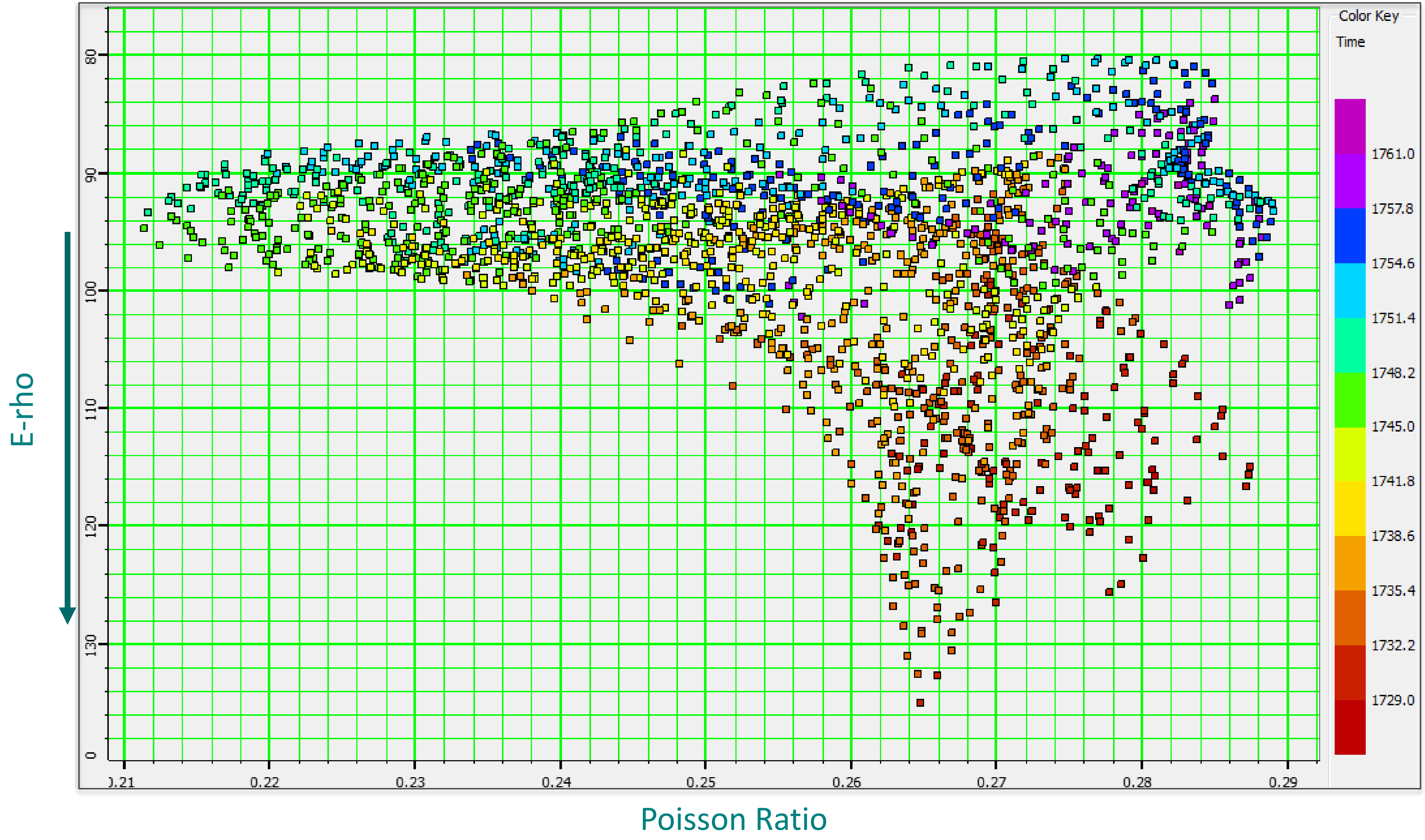
Lambda-rho vs Mu-rho crossplot (simultaneous inversion)



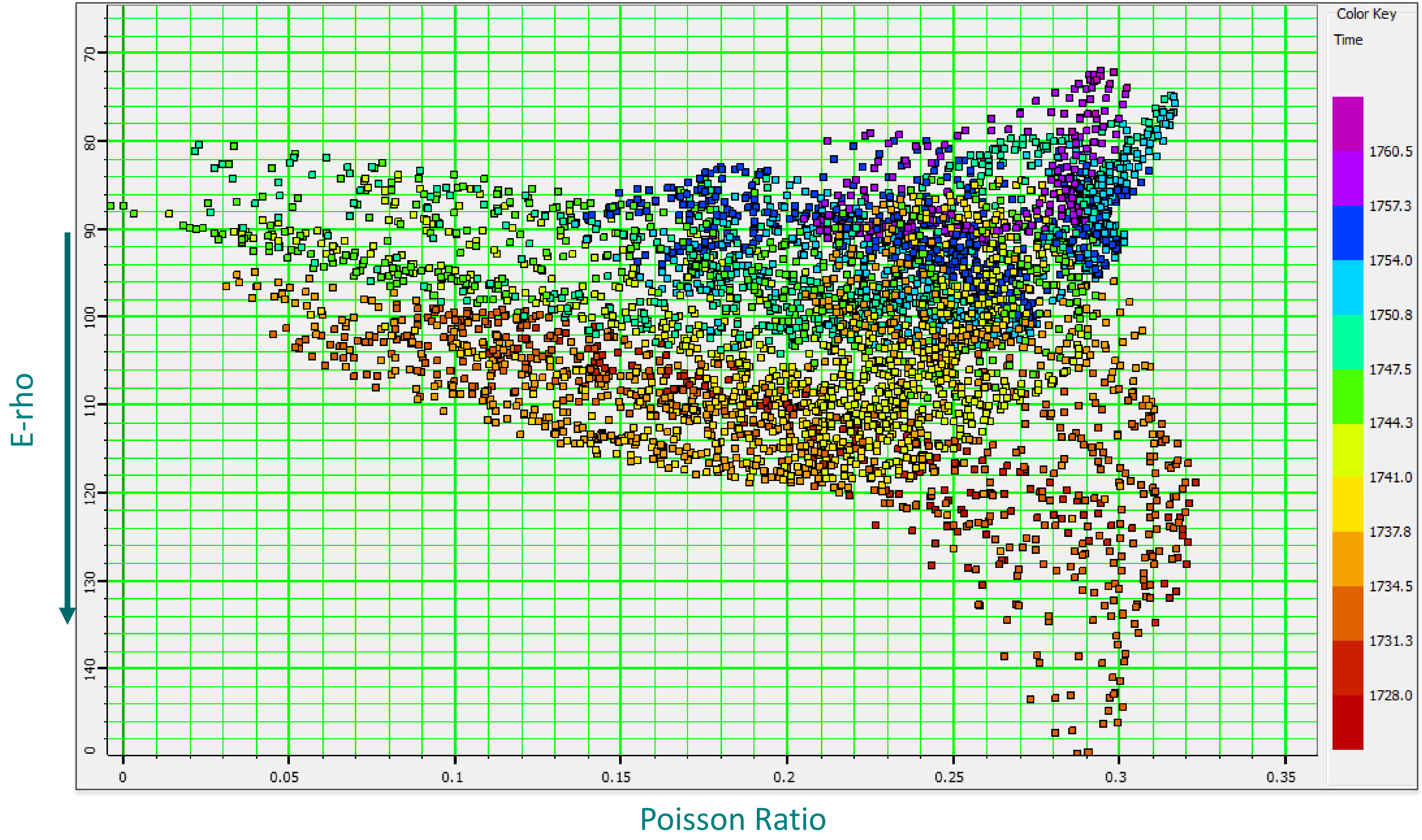
We were not able to differentiate between Upper and Lower Duvernay formations.



E-rho vs Poisson ratio crossplot (simultaneous inversion)

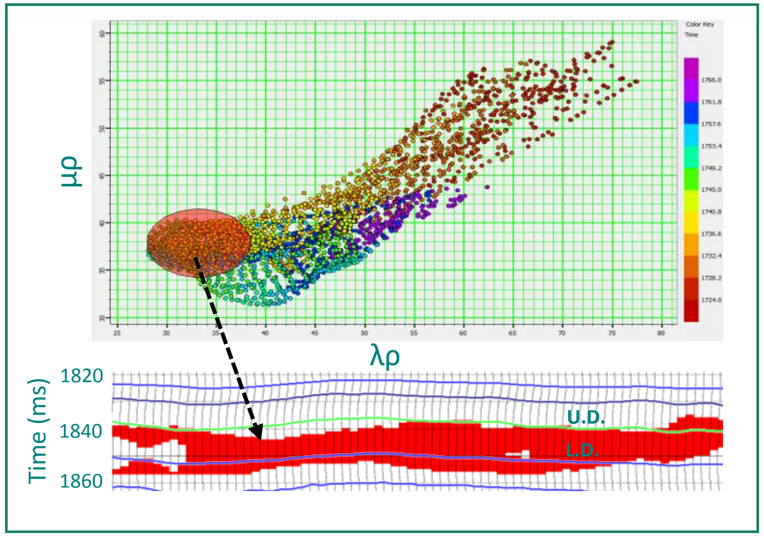


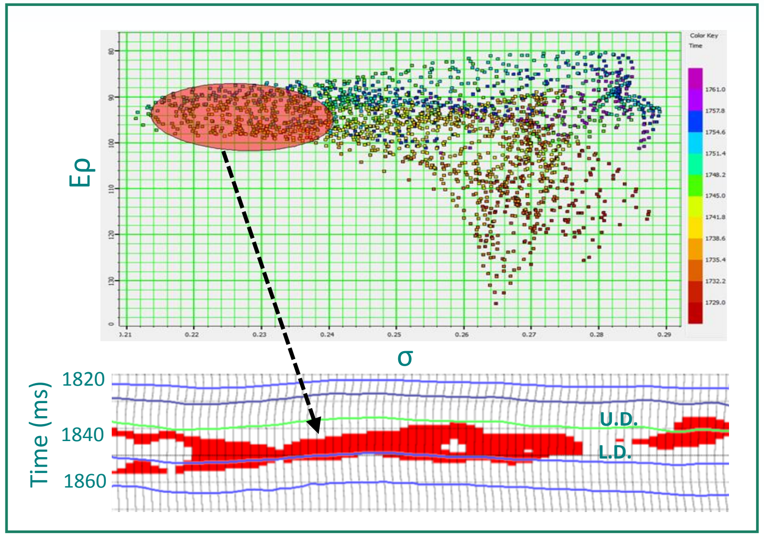
E-rho vs Poisson ratio crossplot (new approach)



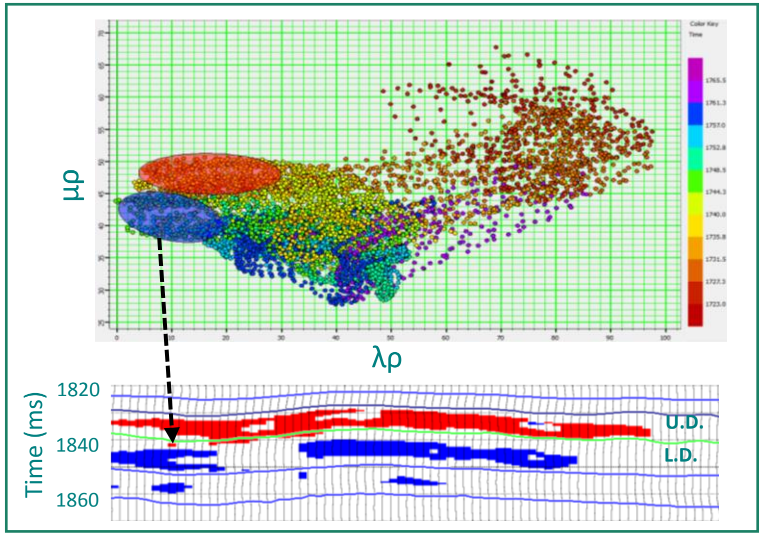
Constraining the data

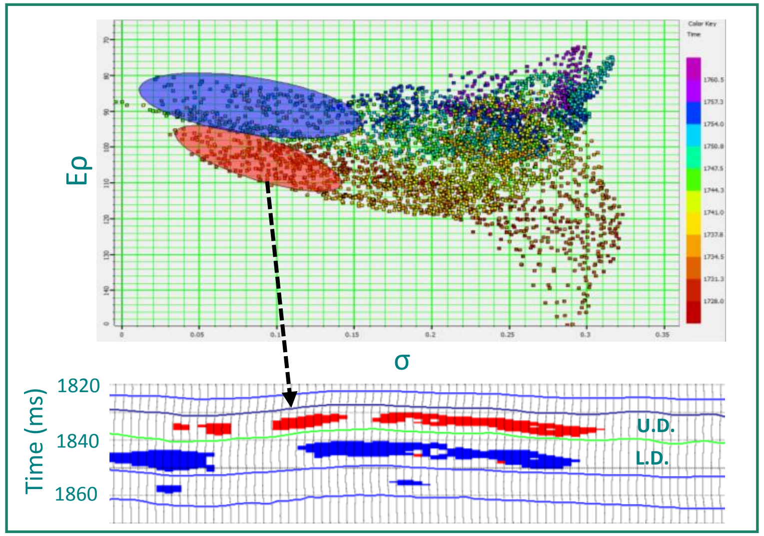
Simultaneous



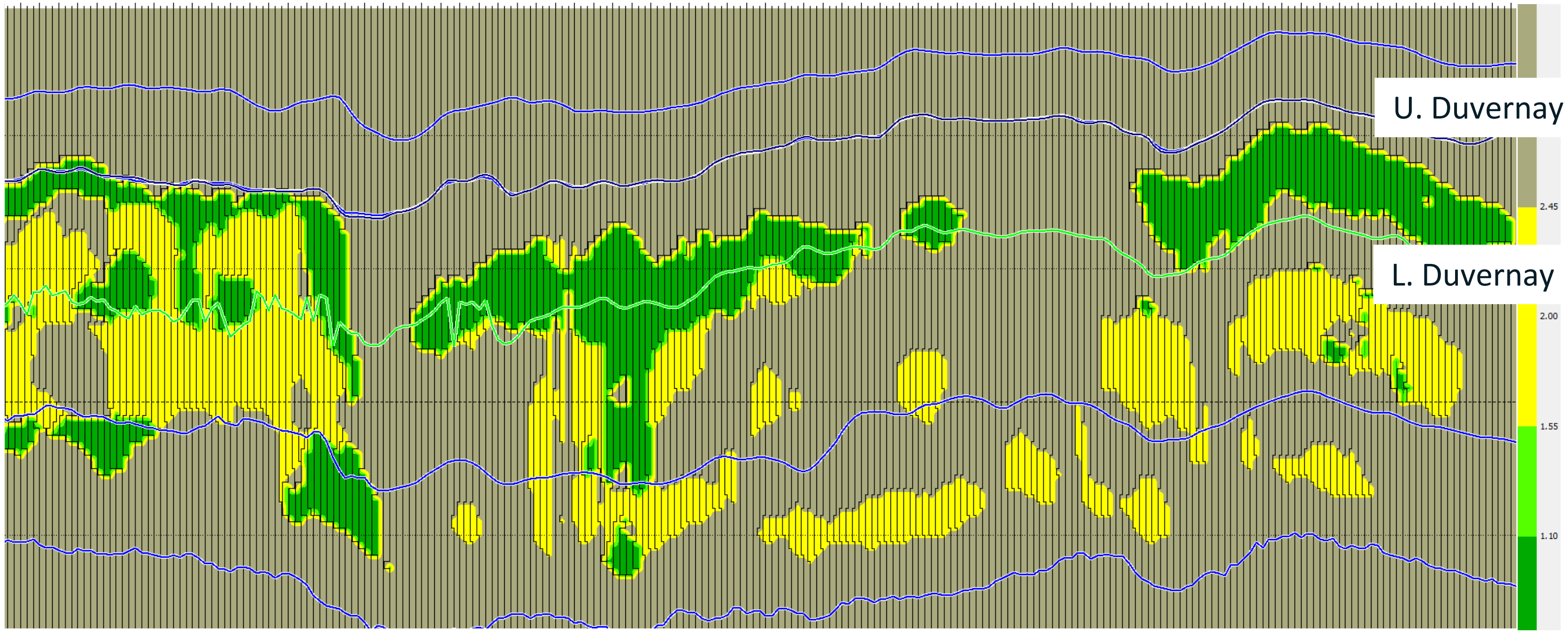


New approach



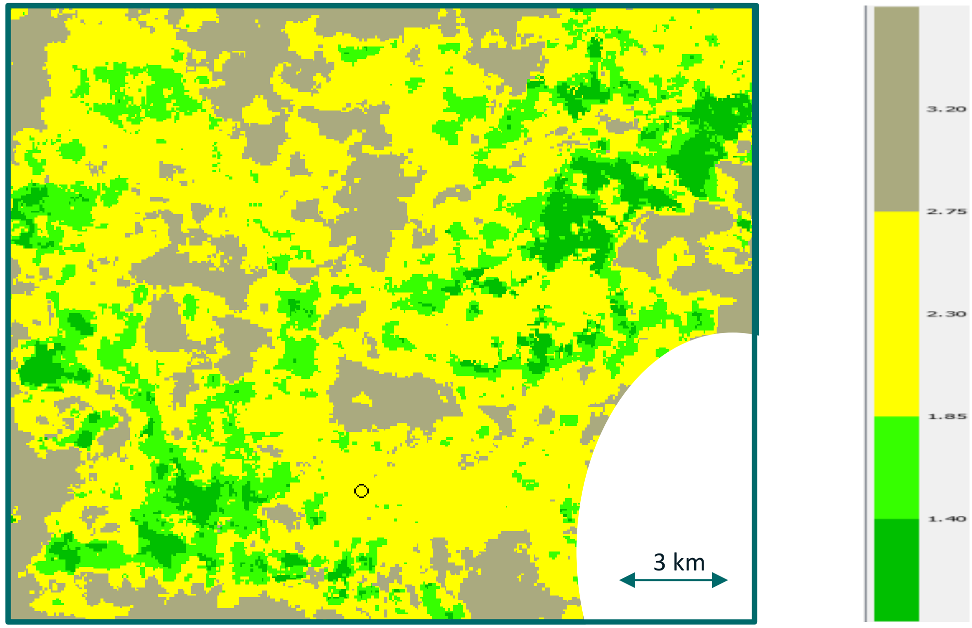


Constraining the data



By using a restricted range of values for each of the attributes (E-rho, Poisson's ratio, LR and MR) based on crossplots shown in the previous slides, and further subdividing the output into Upper Duvernay (green) and Lower Duvernay (yellow) the distribution is shown along an inline from the 3D survey.

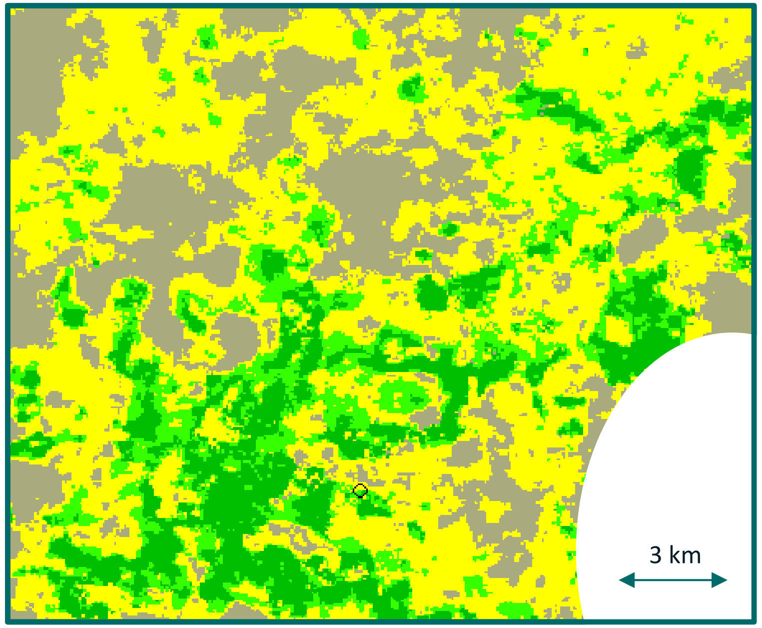
Constraining the data

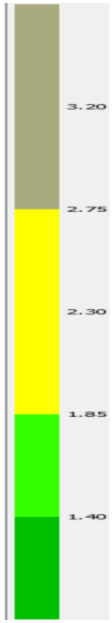


Horizon slice from the constrained attribute data over a 10 ms window below the Duvernay top marker.

It shows the distribution of the Upper (green) and Lower (yellow) Duvernay shales.

Constraining the data





Horizon slice from the constrained attribute data over a 10 ms window below the Duvernay top + 10ms marker.

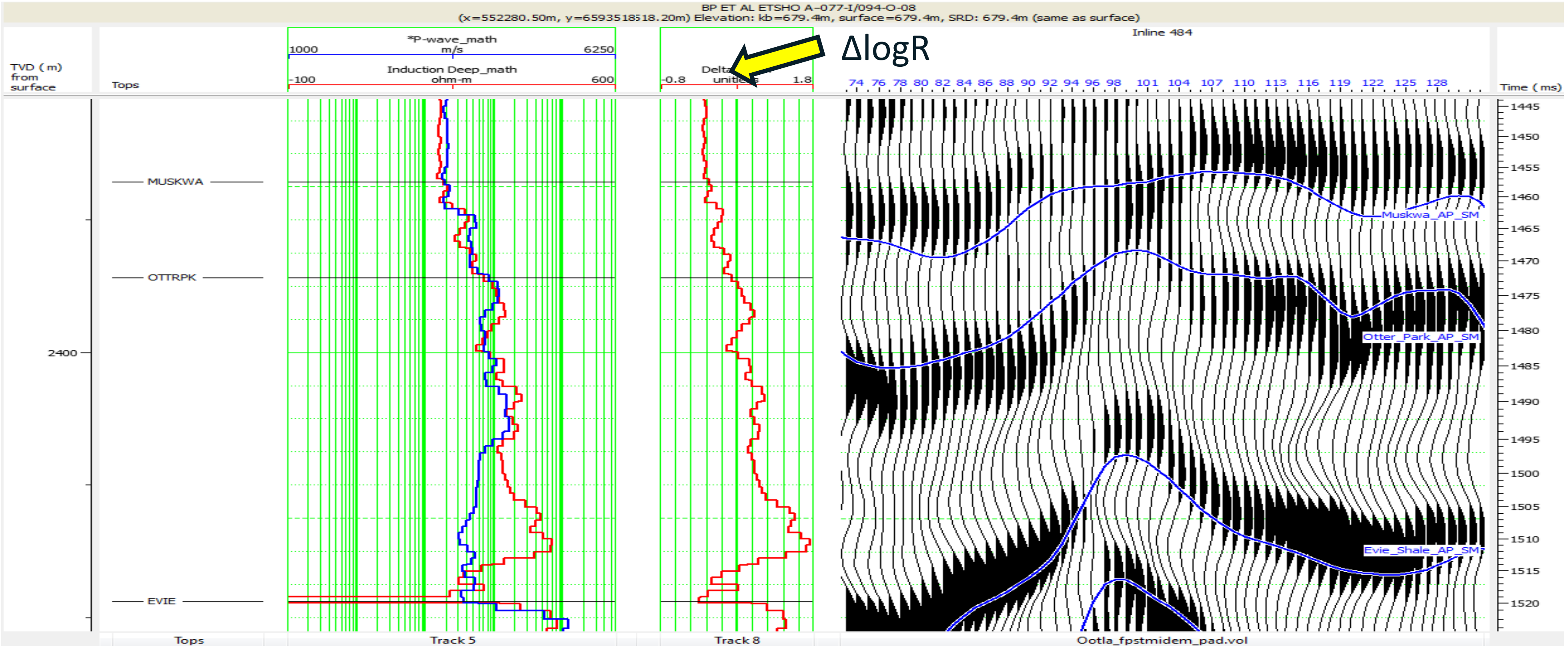
It shows the distribution of the Upper (green) and Lower (yellow) Duvernay shales in this window, which is lower than the one shown in the previous slide.

TOC estimation for Duvernay using seismic data

Passey et al. (1990) developed the ΔlogR technique for calculating TOC in organic-rich shales using well log curves.

This method is based on the porosity-resistivity overlay to locate hydrocarbon bearing shale pockets.

TOC estimation for Duvernay using seismic data



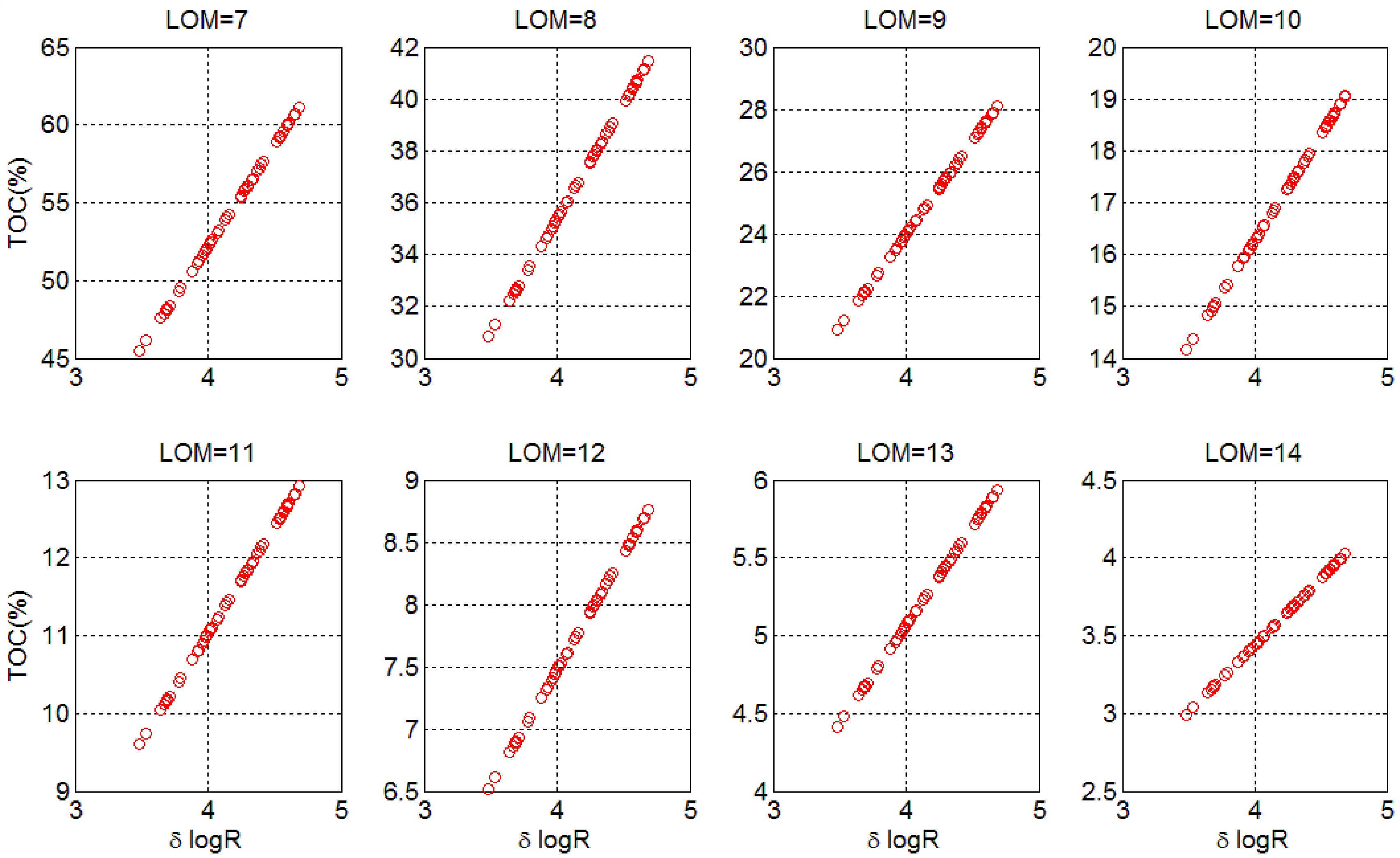
Compute ΔlogR based on the equation

$$\Delta logR = \log_{10}(R/R_{base}) + 0.02*(DT - DT_{base})$$

where R-Resistivity curve, DT-Sonic Curve

R_{base}, DT_{base} are resistivity and sonic values corresponding to overlapping zone.

TOC estimation for Duvernay using seismic data



$$TOC = \Delta \log R * 10\text{^}(2.297 - 0.1688 * LOM)$$

TOC estimation for Duvernay using seismic data

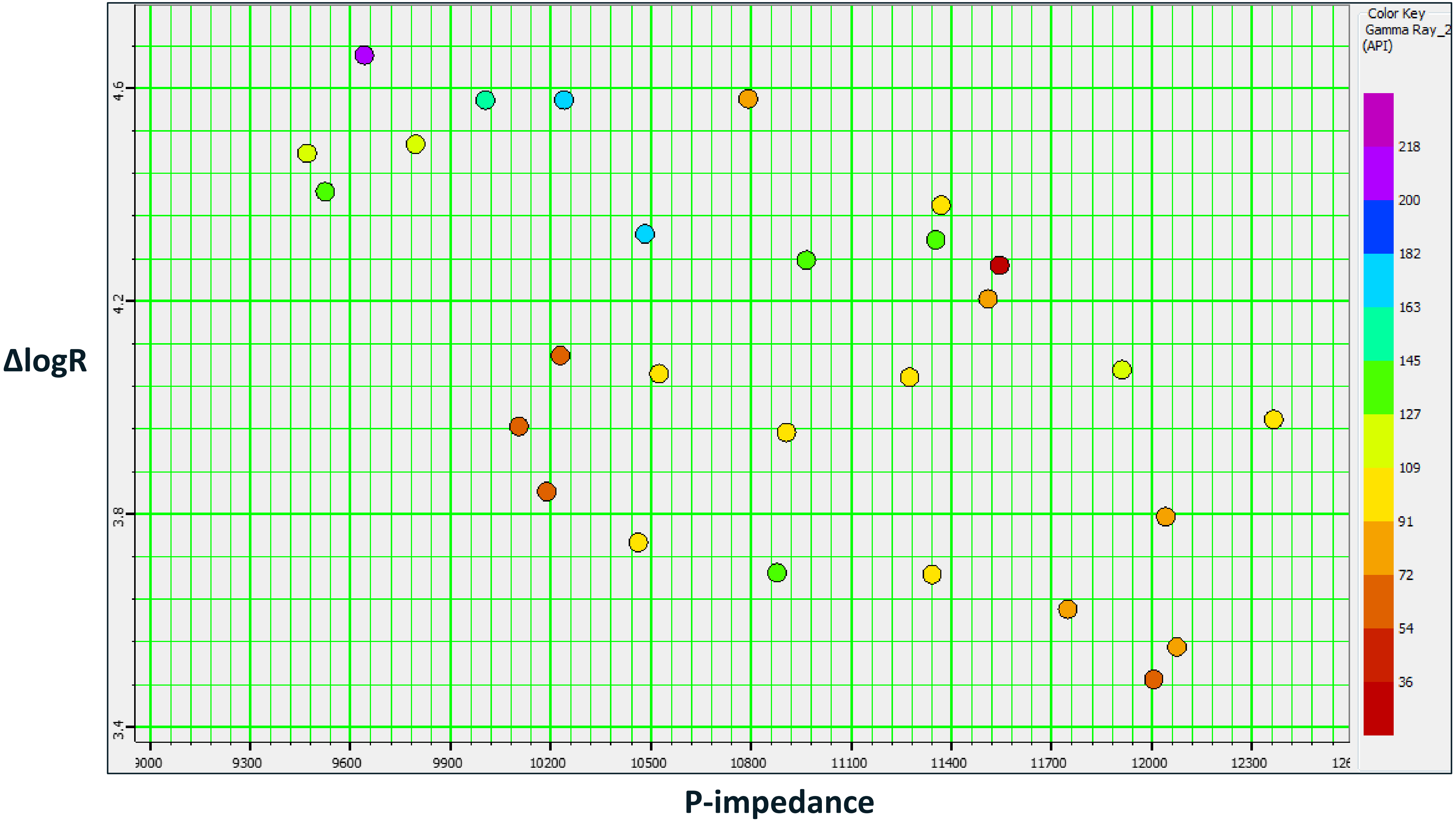
Methodology: Cross correlation analysis

1. ΔlogR vs different attributes generated from well data which can be derived from seismic data.

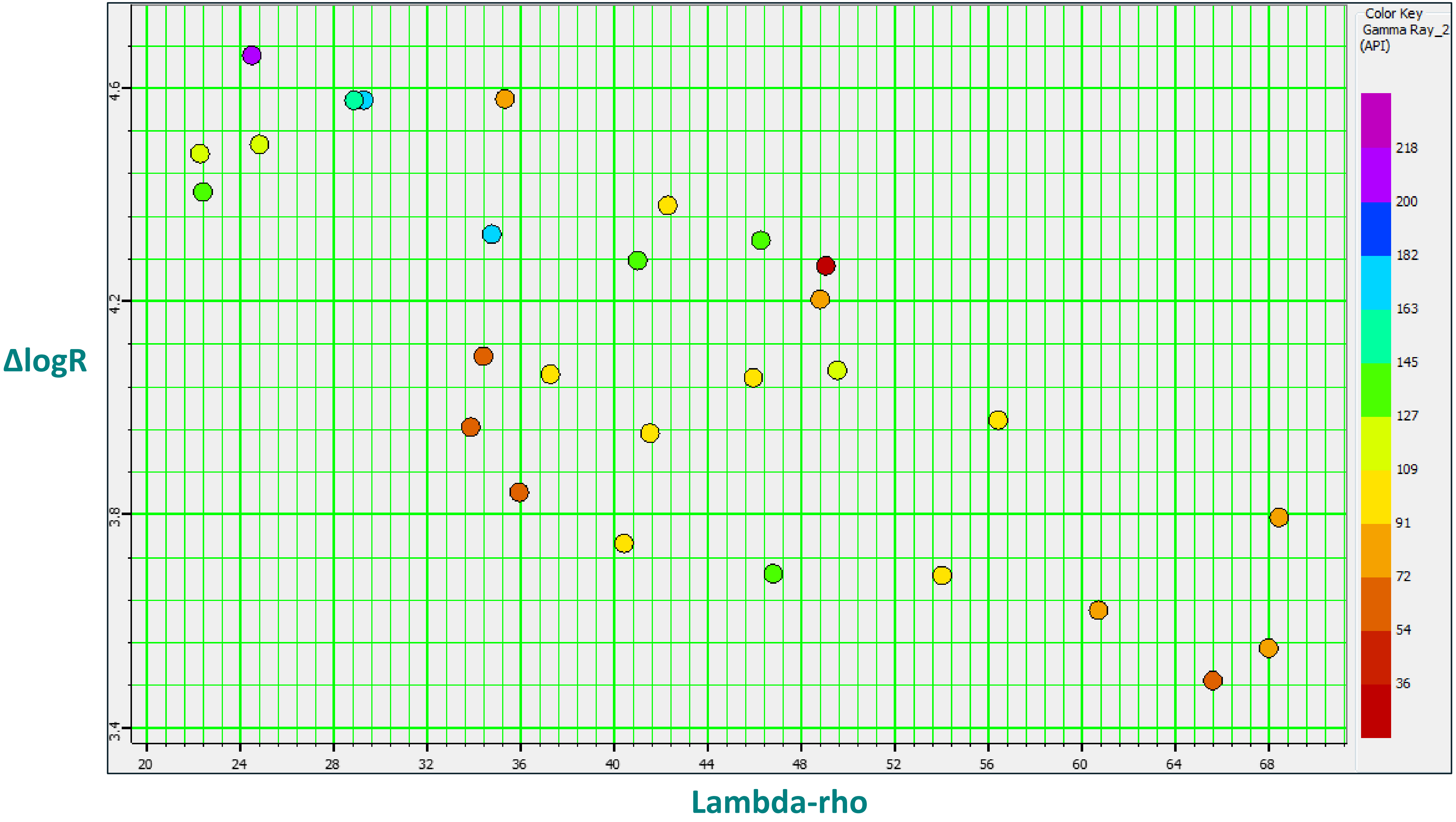
2. The attribute which shows the maximum correlation is selected and cross-plotted against ΔlogR for obtaining a relationship.

3. That relationship is then used for extracting ΔlogR volume from 3D seismic data.

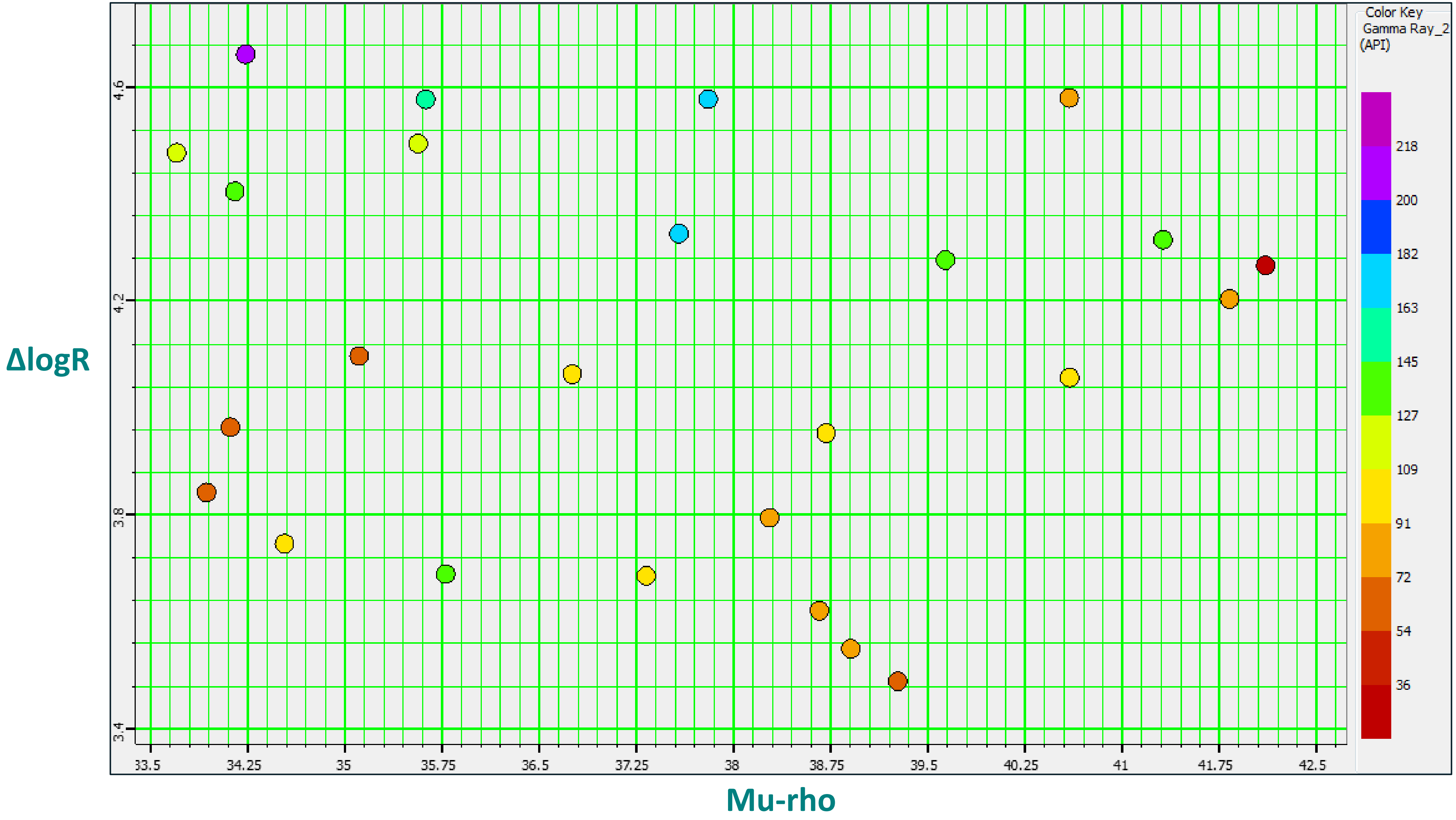
TOC estimation for Duvernay using seismic data



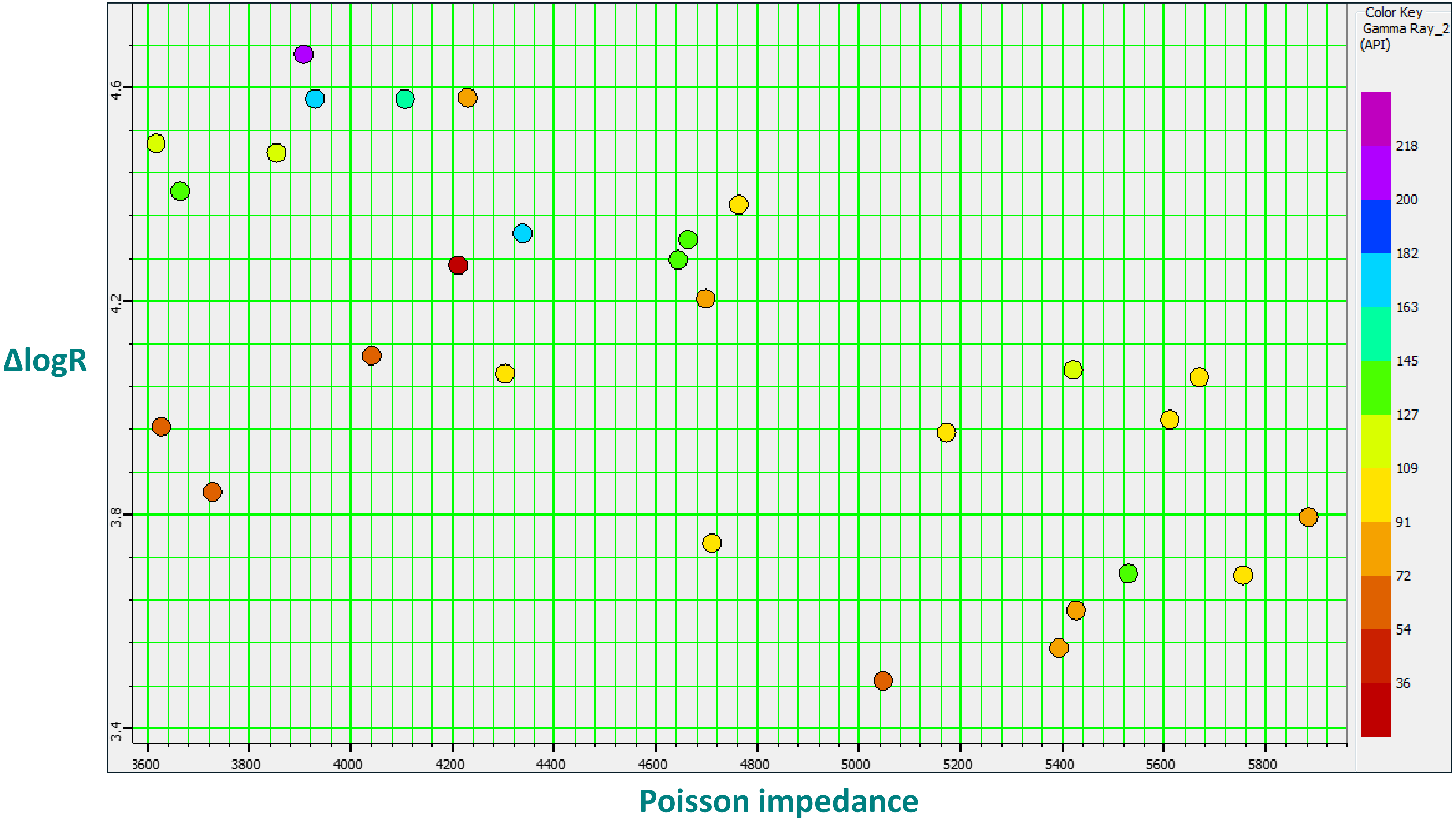
TOC estimation for Duvernay using seismic data



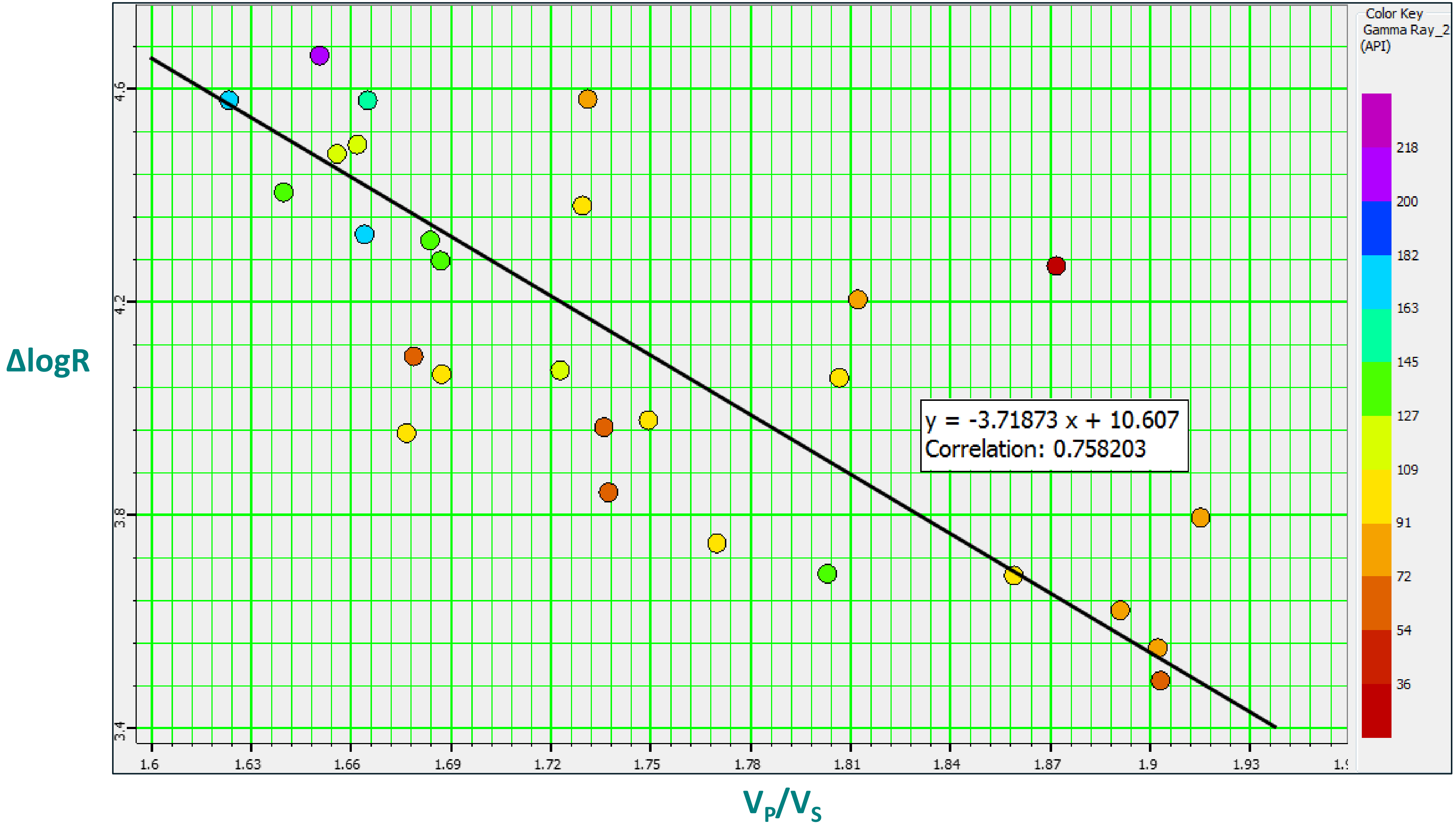
TOC estimation for Duvernay using seismic data



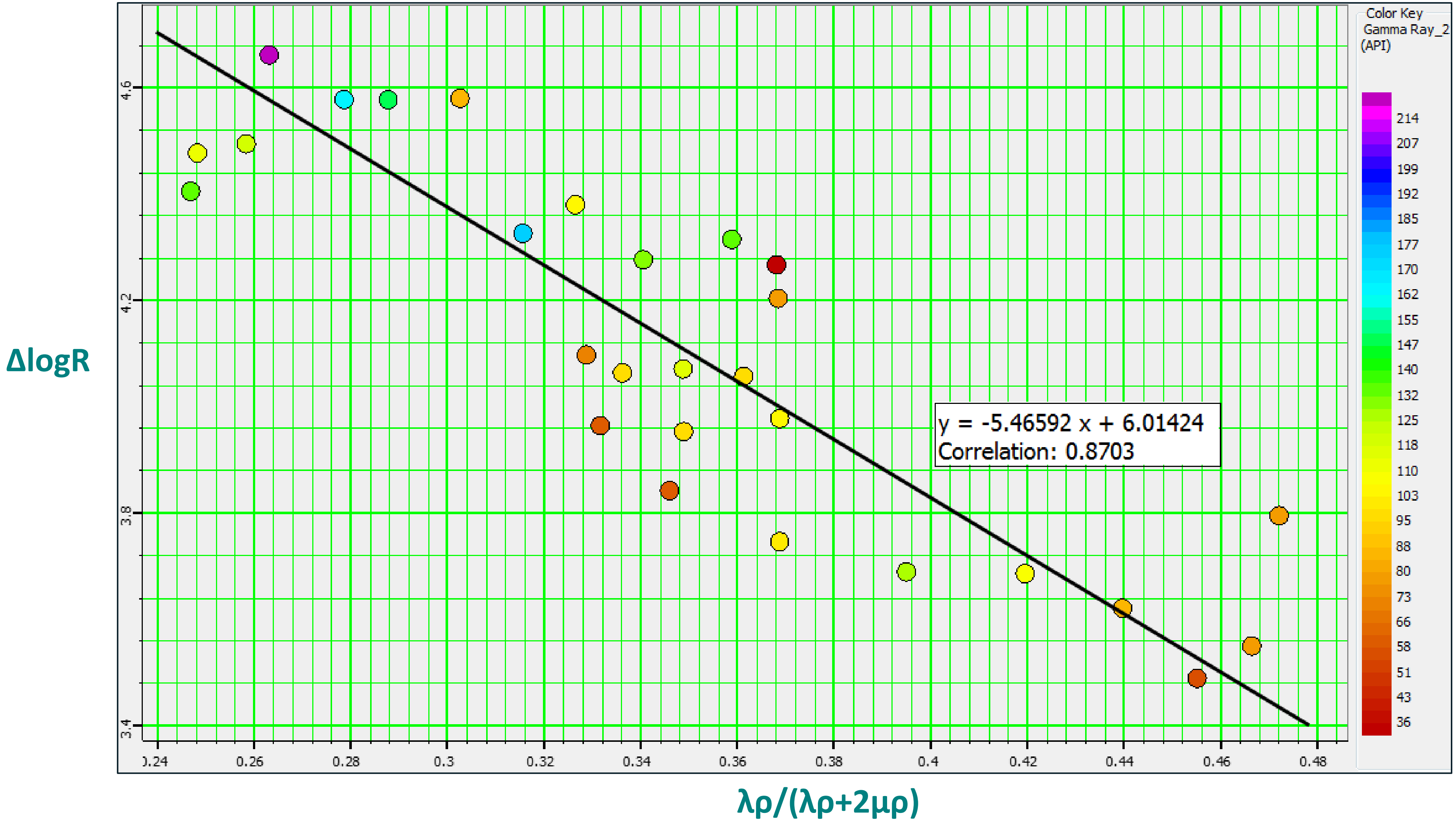
TOC estimation for Duvernay using seismic data



TOC estimation for Duvernay using seismic data



TOC estimation for Duvernay using seismic data

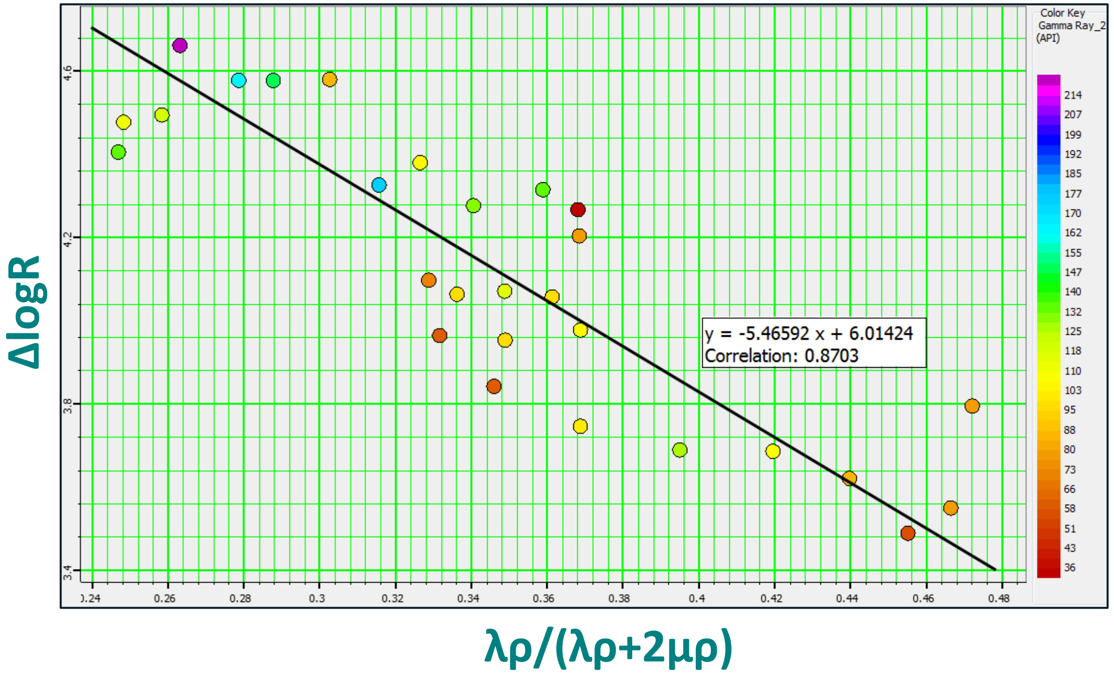


TOC estimation for Duvernay using seismic data

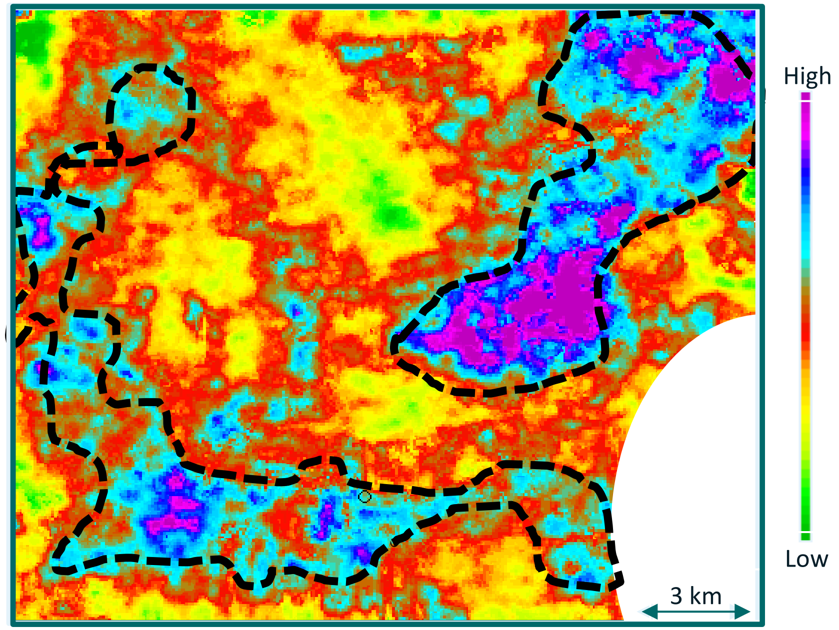
- 87% correlation is noticed between ΔlogR and λρ/(λρ+2μρ)

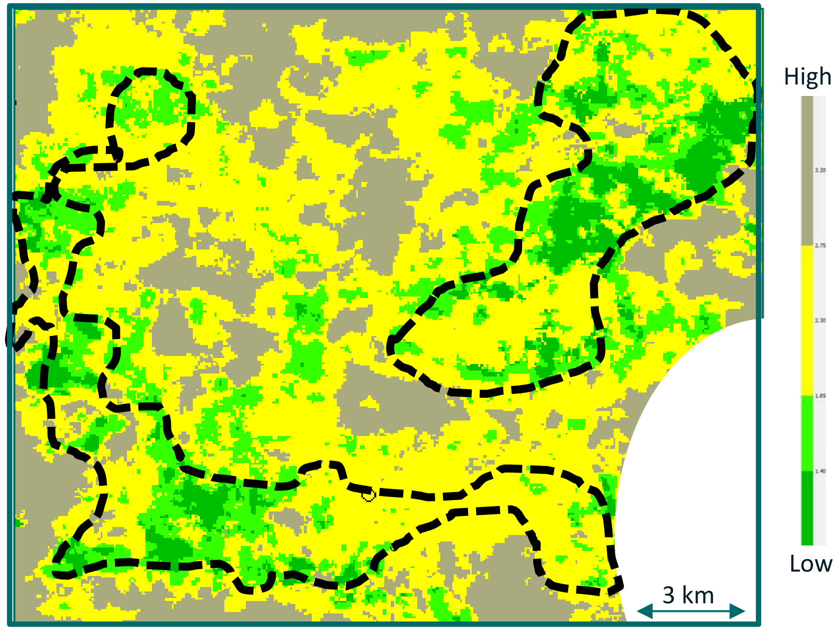
- Lambda-rho and Mu-rho volumes from seismic data were computed first.

- ΔlogR volume was derived using the relationship.



Identification of sweet spots in Duvernay formation

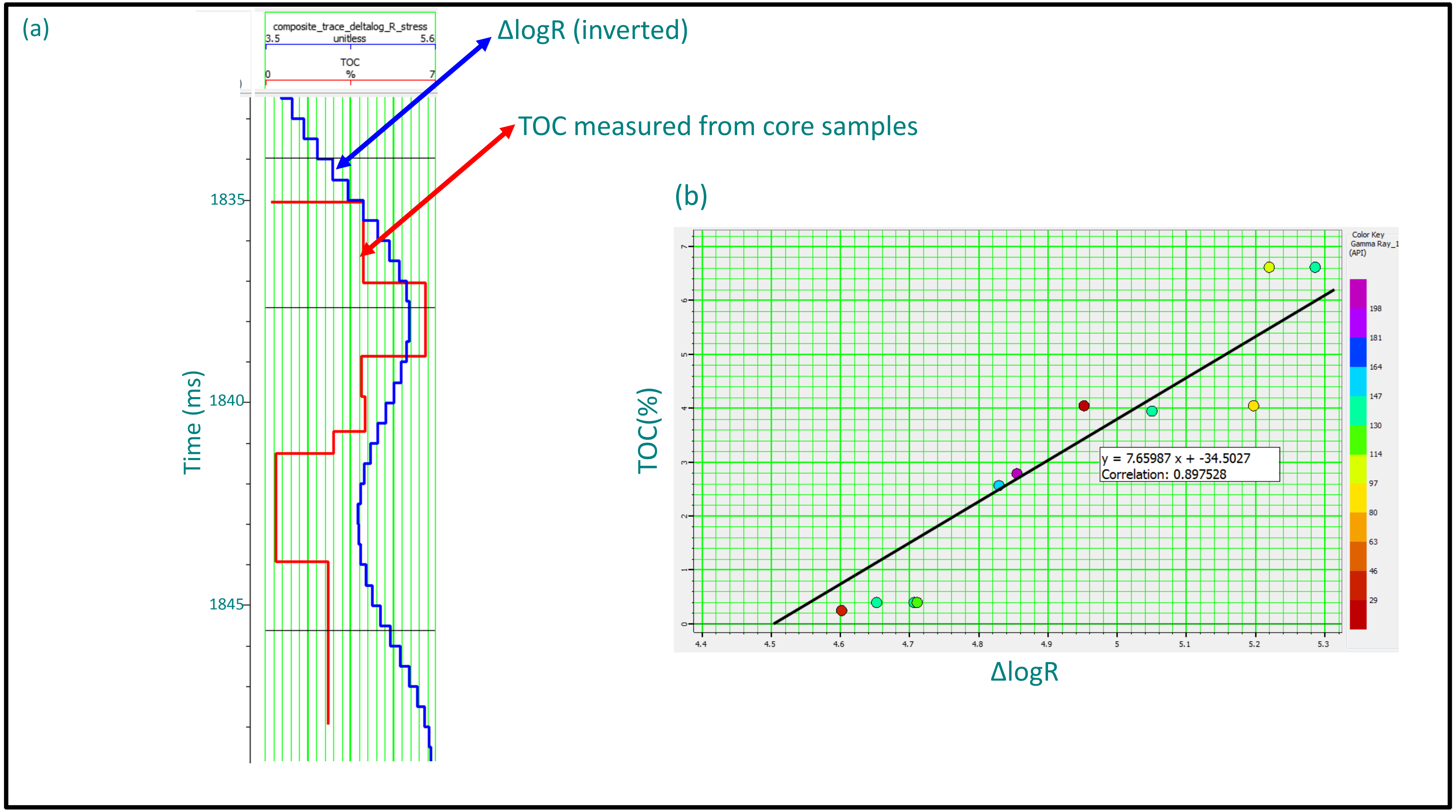




Horizon slice from the ΔlogR volume 10ms interval below the Duvernay top marker.

Notice the trend we see for high values of ΔlogR is not very different from what we see on the constrained volume display shown alongside.

Identification of sweet spots in Duvernay formation



This was a blind well test. (a) The match is seen as good as the increasing and decreasing trends seem to follow each other; (b) a crossplot between TOC and ΔlogR shows a correlation of 90%, which again lends confidence to the analysis.

Conclusions

1. An attempt has been made to characterize the Duvernay Formation using seismic data.

2. Derived some seismic attributes (λρ-μρ and Eρ-PR) using simultaneous inversion.

3. As the thickness of ZOI was far below the vertical resolution of the seismic data, simultaneous inversion was not found to be suitable for identifcation sweet spots in the Duvernay Formation.

Conclusions

4. We adopted a new workflow in which P-and S-reflectivities were processed through thin-bed reflectivity inversion before post-stack impedance inversion.

5. We were able to differentiate between Upper and Lower Duvernay using above workflow.

6. Additionally, ΔlogR volume was computed. A reasonably good match between ΔlogR and TOC measured at core sample, enhancing our confidence in the analysis.

Acknowledgements

Arcis Seismic Solutions, TGS, Calgary