Seismic Screening for Hydrocarbon Prospects Using Rock-Physics Attributes*

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Abstract

The field of rock physics represents the link between qualitative geological parameters and quantitative geophysical measurements. Increasingly over the last decade, rock physics has become an integral part of quantitative seismic interpretation and stands out as a key technology in petroleum geoscience. Ultimately, the application of rock physics tools can reduce exploration risk and improve reservoir forecasting in the petroleum industry. In particular, rock-physics templates (RPT), in combination with seismic AVO inversion data, can be used to screen for hydrocarbon prospects during exploration. Rock-physics models are essential in that they help in converting elastic parameters from inversion data to reservoir parameters. Furthermore, the anatomy of rock physics crossplots and the trends observed in petrophysical/seismic data can be linked to geological processes (i.e. depositional and diagenetic). In this presentation, we will demonstrate the use of rock-physics templates to identify depositional facies and burial trends in geophysical data. We will also show how we can disentangle fluid trends (i.e. hydrocarbon saturation) from geological trends (lithology and porosity). We show examples from selected deep-water systems from the Norwegian Shelf and offshore West Africa.

References Cited

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Rimstad, K., P. Avseth, and H. Omre, 2012, Hierarchical Bayesian lithology/fluid prediction: A North Sea case study: Geophysics, v. 77/2, p. B69–B85, doi: 10.1190/geo2011-0202.1.

Seismic screening for hydrocarbon prospects using rock-physics attributes

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18/2-2015

Outline

- Intro: QI using AVO inversion and RPT analysis
- Defining rock physics attibutes optimal for seismic screening (CPEI and PEIL)
- Demonstration from Norwegian Sea
- Pit-falls

Seismic screening for hydrocarbon prospects using rock-physics attributes

PER AVSETH and TOR VEGGELAND, Tullow Oil
FREDERIK HORN, Qeye Labs

Abstract

Rock-physics templates (RPT), in combination with seismic AVO inversion data, can be used to screen for hydrocarbon prospects during exploration. With the improved quality and increased use of elastic seismic inversion, there has recently been a paradigm change in prospect mapping in the oil industry, and quantitative interpretation has become a widely used jargon. Rock-physics models are essential in that they help in converting elastic parameters from inversion data to reservoir parameters. In the screening phase of inversion data, rock-physics models also can reveal hydrocarbon-associated anomalies. Two new rock-physics attributes help in detecting hydrocarbons from seismic—the curved pseudo-elastic impedance and the trend angle. The first of these is similar to the extended elastic impedance or the fluid factor in that it represents a deviation from a wet-background trend in a rock-physics template. However, it honors the nonlinear nature of a compaction trend. The trend angle is a measure of slope angle between two adjacent data points in the AI-versus-V_P/V_S crossplot, and this attribute will highlight fluid trends in the data. Those two attributes can be used complementarily to detect and highlight hydrocarbon accumulations, as demonstrated on data from the Norwegian shelf.

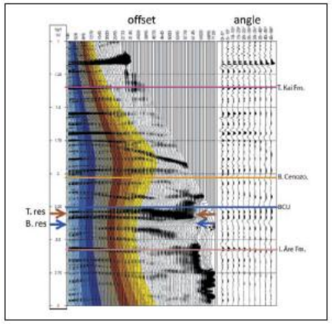


Figure 1. CDP gather and corresponding angle stacks at Well 1. The wiggle-trace amplitudes are European standard polarity, where the black peak represents soft and the white trough represents hard. Note the AVO anomaly right below the Base Cretaceous Unconformity (BCU) horizon, showing a weak negative becoming more negative at the top of the Middle Jurassic gas-filled reservoir.

Introduction — Rock-physics templates and quantitative interpretation

Rock physics represents the link between geologic properties and geophysical observables, and rock-physics templates are useful tools for quantitative interpretation of seismic-inversion data (Ødegaard and Avseth, 2004).

Figure 1 shows an angle gather in which we have highlighted a Class II–III AVO anomaly, representing a gas-condensate discovery in the Norwegian Sea. A simultaneous seismic AVO inversion was done on 3D angle-stack volumes generated from a set of offset gathers in an area surrounding this discovery.

Figure 2 shows the resulting estimates of acoustic impedance (AI) and V_P/V_S from those AVO data, along a selected cross section that intersects the discovery well (Well 1). Here, we see that the gas-condensate interval appears as an anomaly with low AI and corresponding low V_P/V_S. The

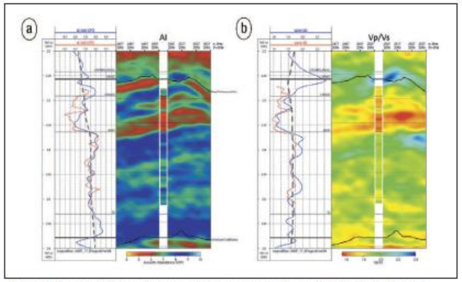


Figure 2. Seismic AVO inversion results along cross sections intersecting Well 1. (a) Acoustic impedance. (b) V_P/V_S. The blue curves in the log plots represent the final inversion results, whereas the red curves represent upscaled well-log data. The well was one of several wells used to constrain the low-frequency model (dashed gray curves) used in the seismic inversion, along with interval velocities. However, the gas zone was fluid-substituted to water before it was used for the low-frequency model. Hence, the low AI and V_P/V_S values in the interval representing the gas reservoir come from seismic data and not from the low-frequency model.

Avseth et al., The Leading Edge, March 2014

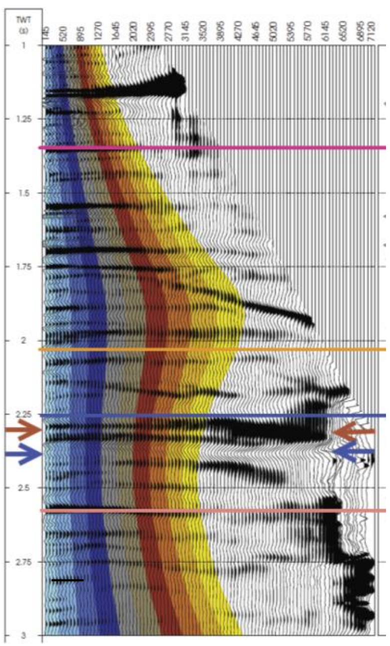
AVO is controlled by contrasts in AI and Vp/Vs (assuming isotropic, elastic media)

Verm and Hilterman approx:

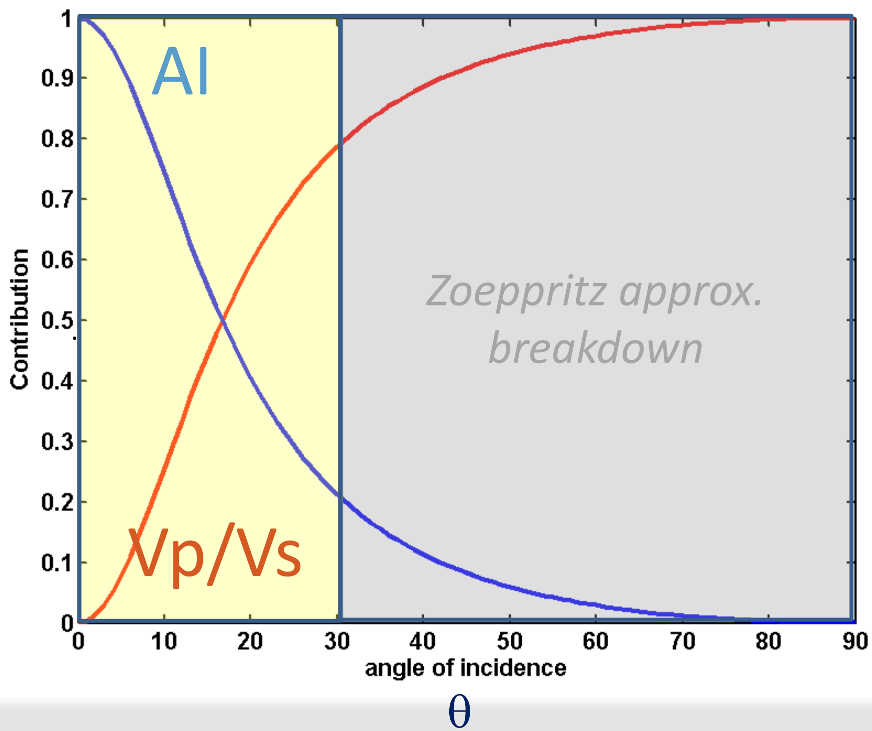
$$R(\theta) = NI\cos^2(\theta) + PR\sin^2(\theta)$$

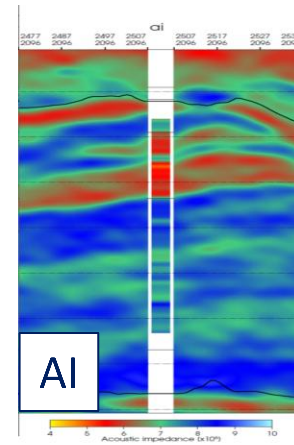
$f(\Delta AI / \overline{AI})$ $f(\Delta(Vp/Vs) / \overline{(Vp/Vs)})$

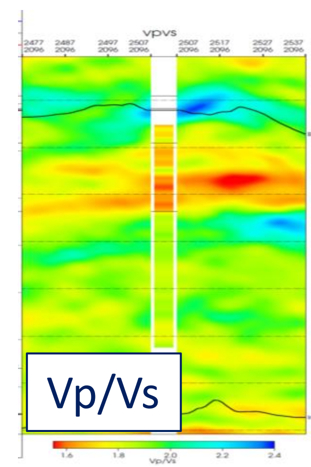
Offset gather



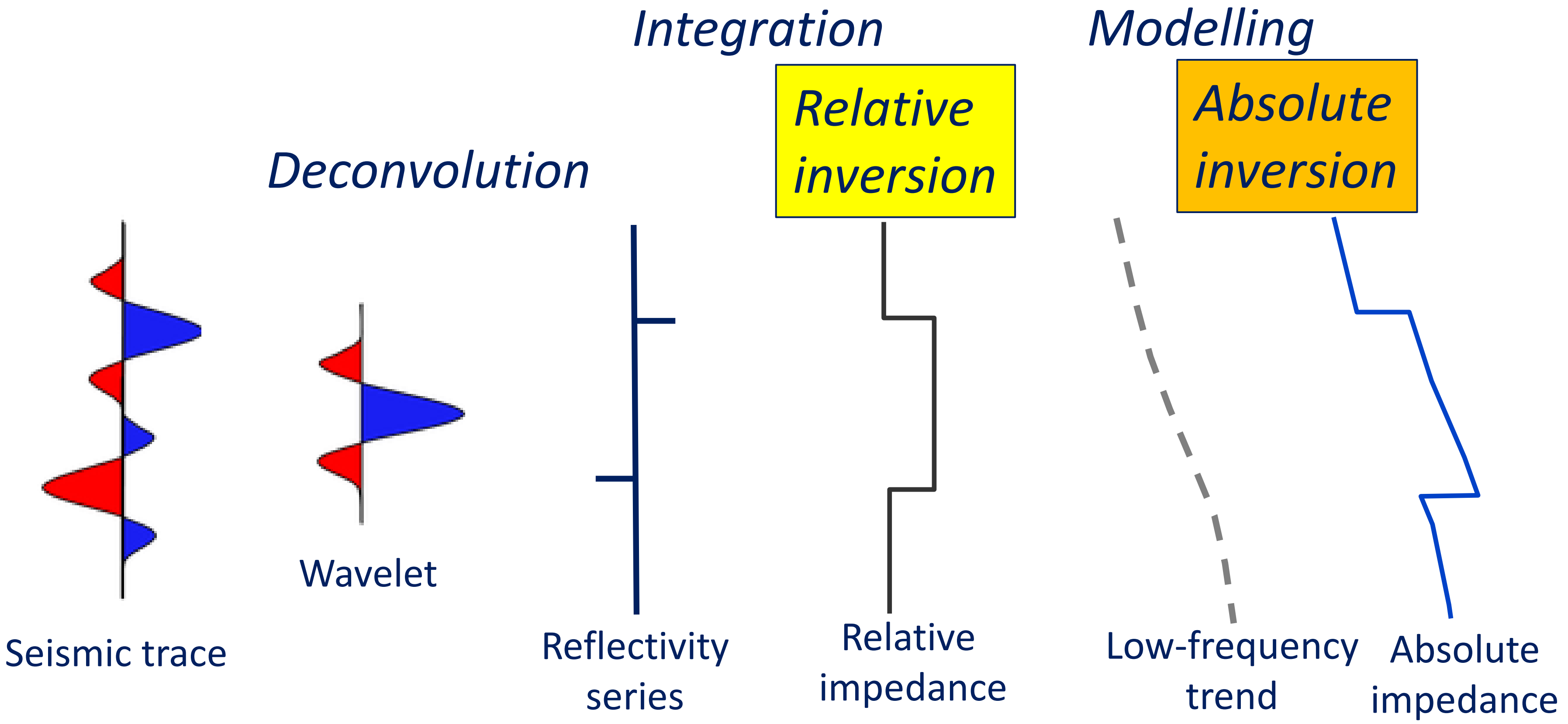
Valid







Seismic inversion in a nutshell:



Simultanous AVO inversion = Do the above procedure on angle stacks, simultaneously, with angle-dependent wavelet, to estimate AI and Vp/Vs (and density).

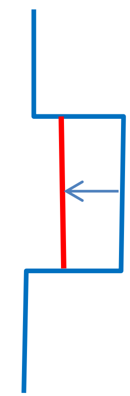
How do hydrocarbons affect AI and Vp/Vs? (Gassmann theory)

$\rho \downarrow$

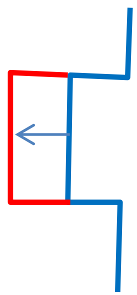
$$\sqrt{\frac{\downarrow K + 4/3\,\mu^{0}}{\rho \downarrow}} = Vp \downarrow$$

$$\sqrt{\frac{\mu^{0}}{\rho \downarrow}} = Vs \uparrow$$

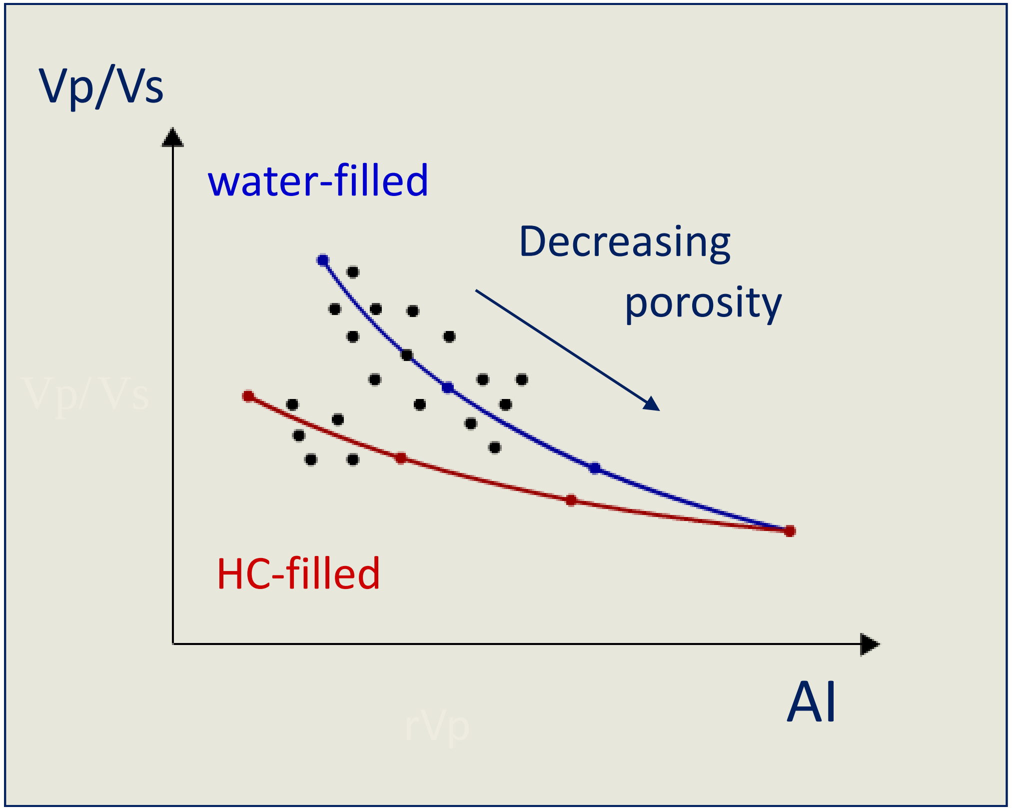
$\rho \downarrow,\ Vp \downarrow \rightarrow AI \downarrow$



$Vp \downarrow,\ Vs \uparrow \rightarrow Vp/Vs \downarrow$

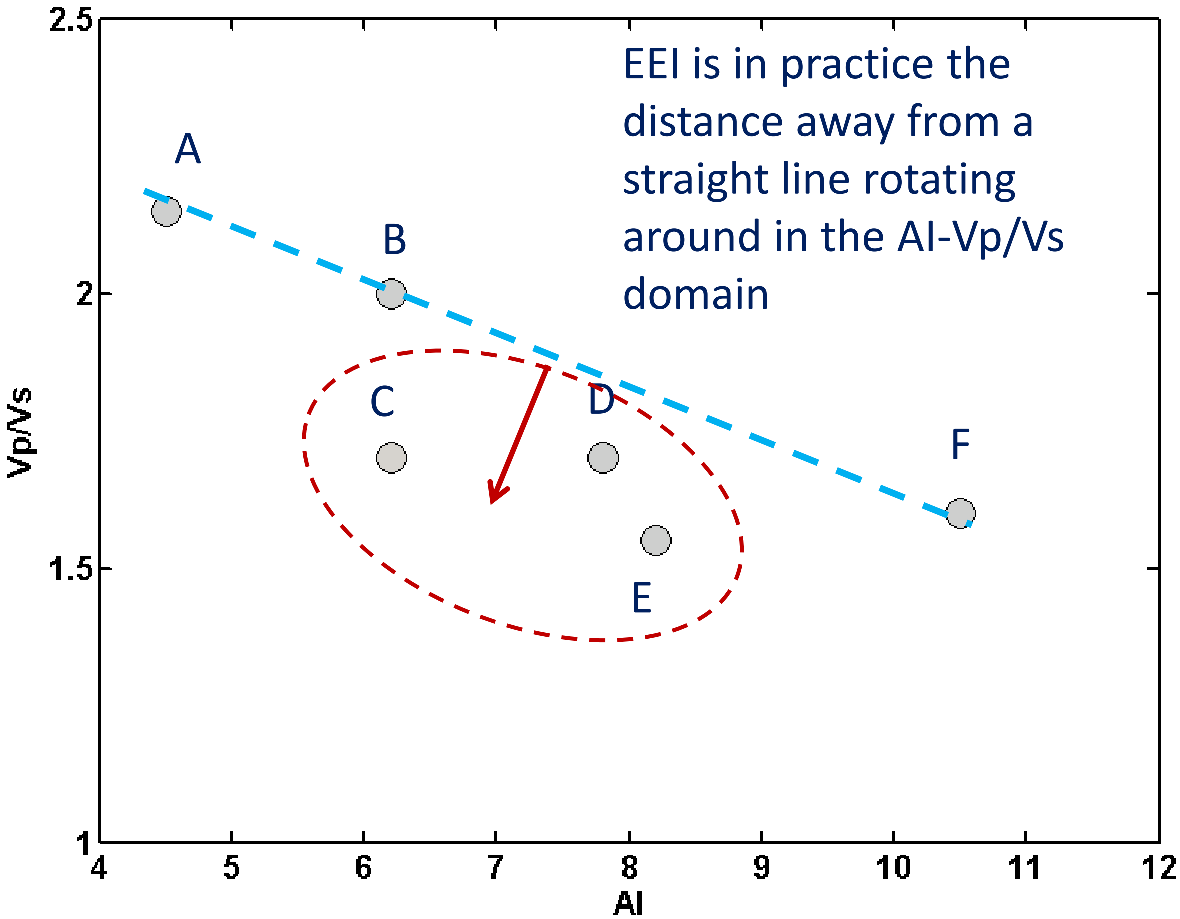


Rock Physics Template (RPT)



Projections of
rock physics models in
AI vs Vp/Vs space

Teaser: Can you detect the 3 discovery wells?

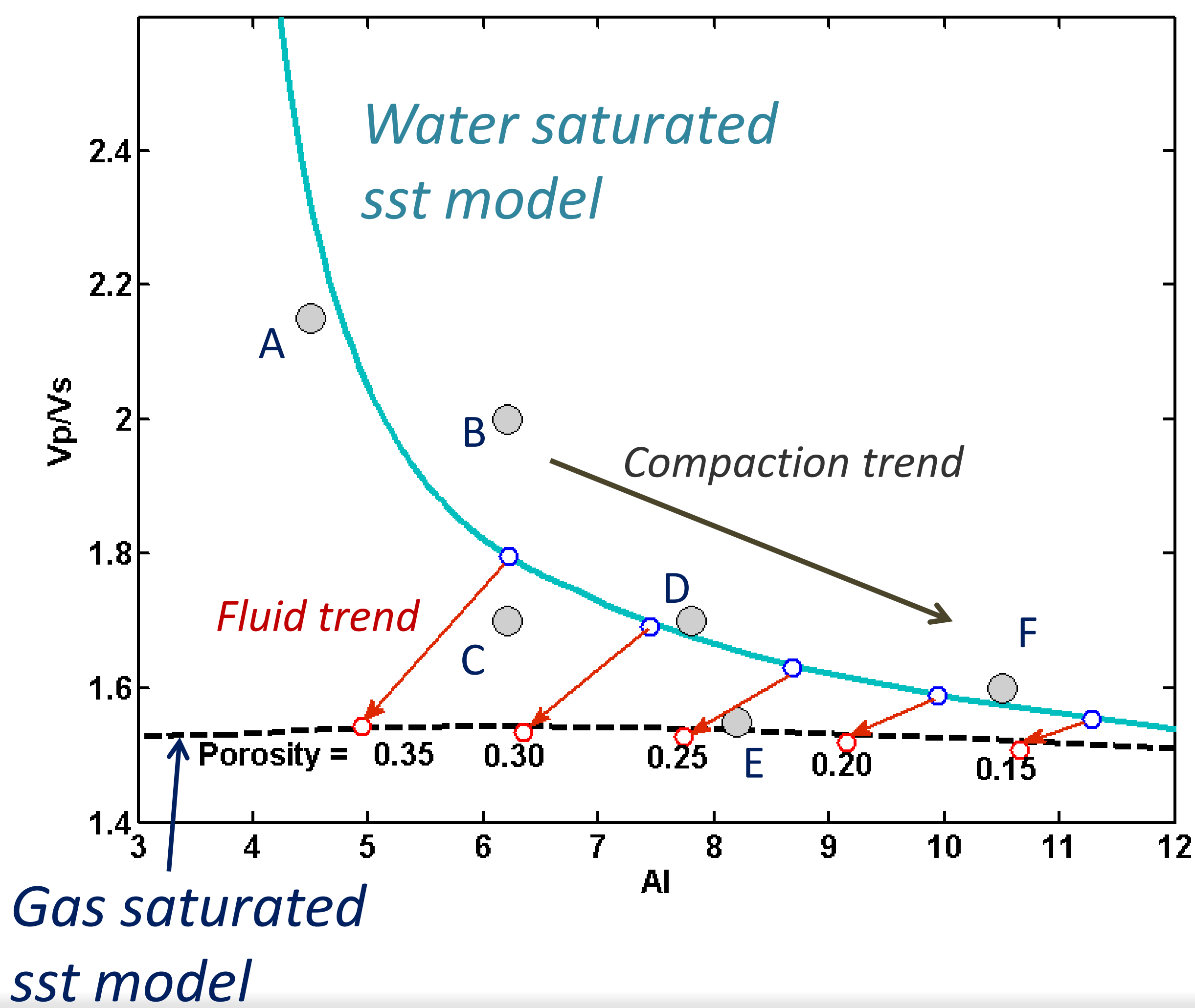


1) C, E and F

2) A, C and E

3) C, D and E

Rock physics template analysis of ”Teaser” data

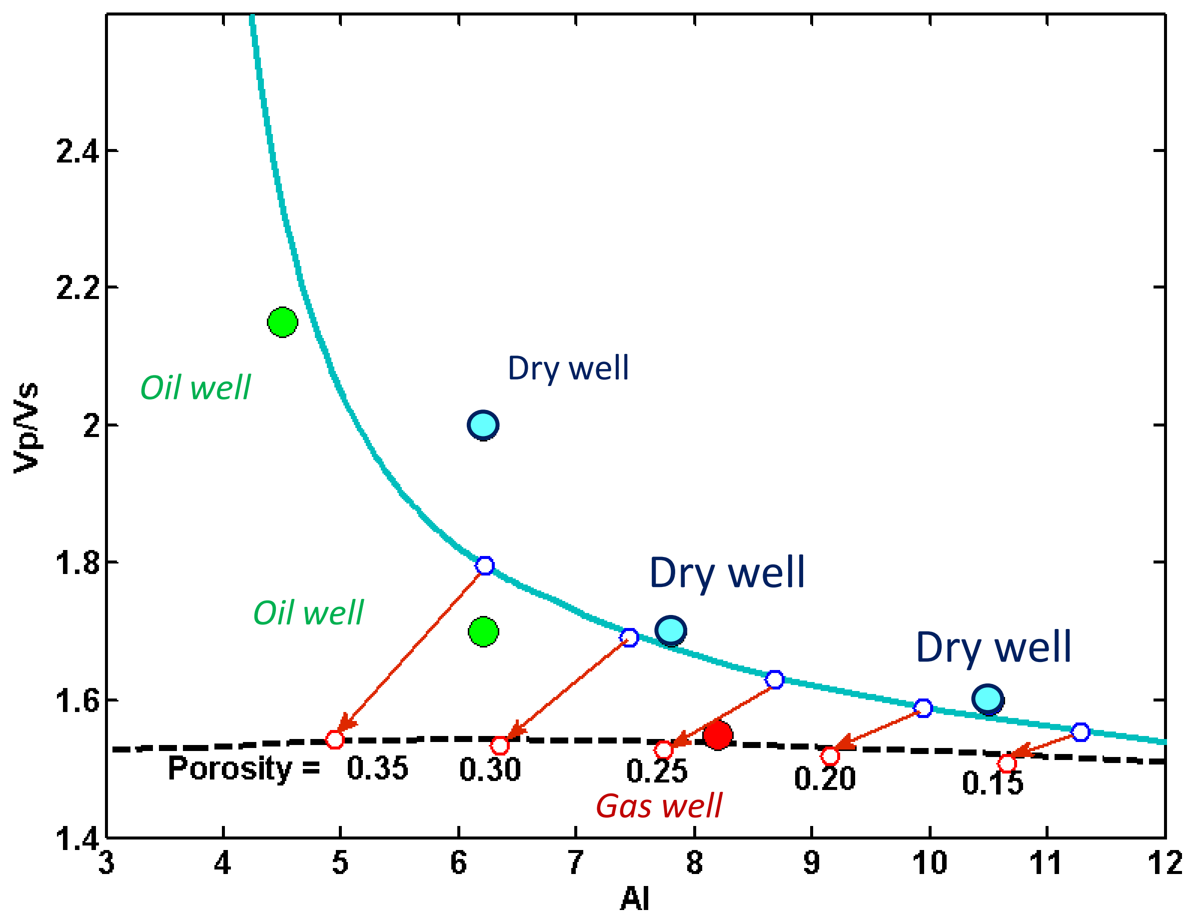


1) C, E and F

2) A, C and E

3) C, D and E

Rock physics template analysis of "Teaser" data (Average value in reservoir sand unit shown)

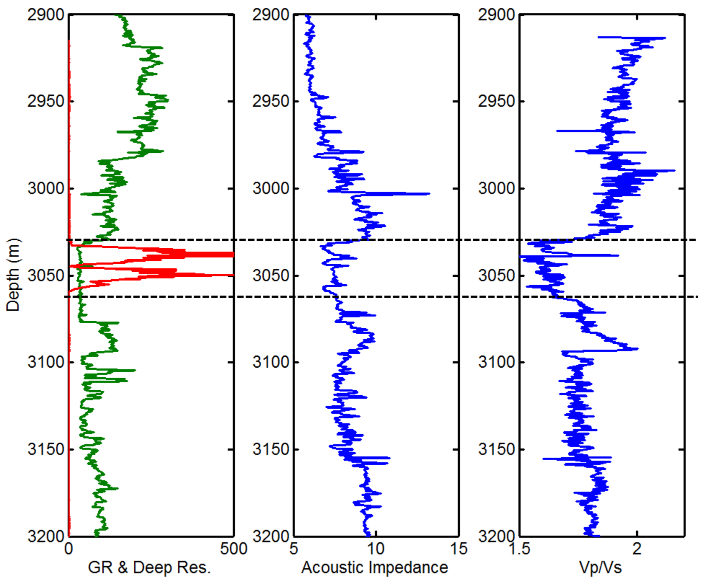


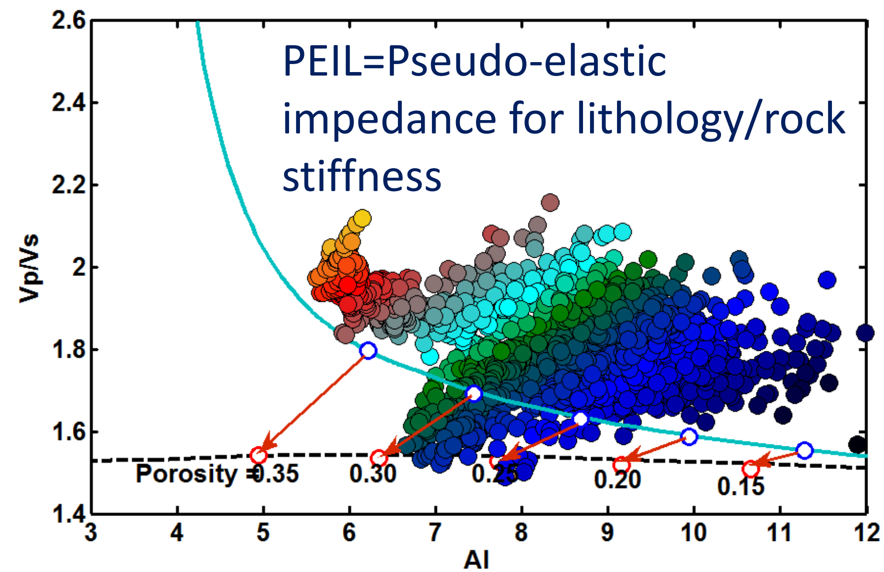
1) C, E and F

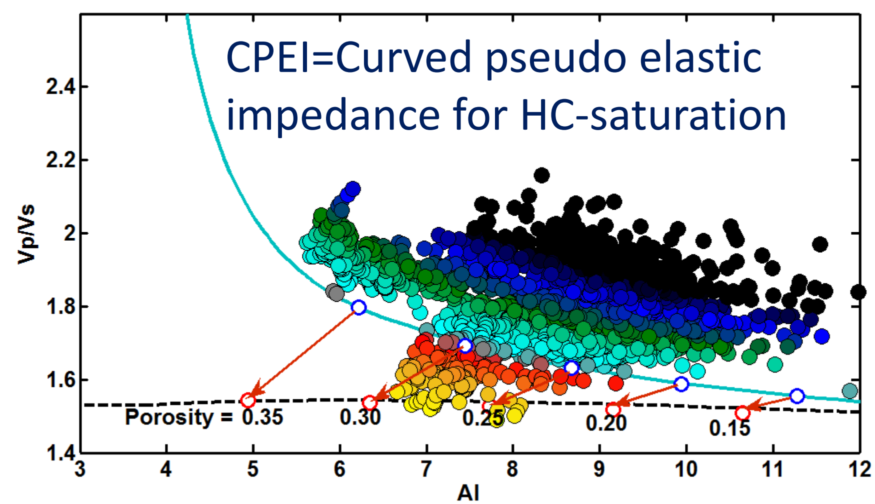
2) A, C and E

3) C, D and E

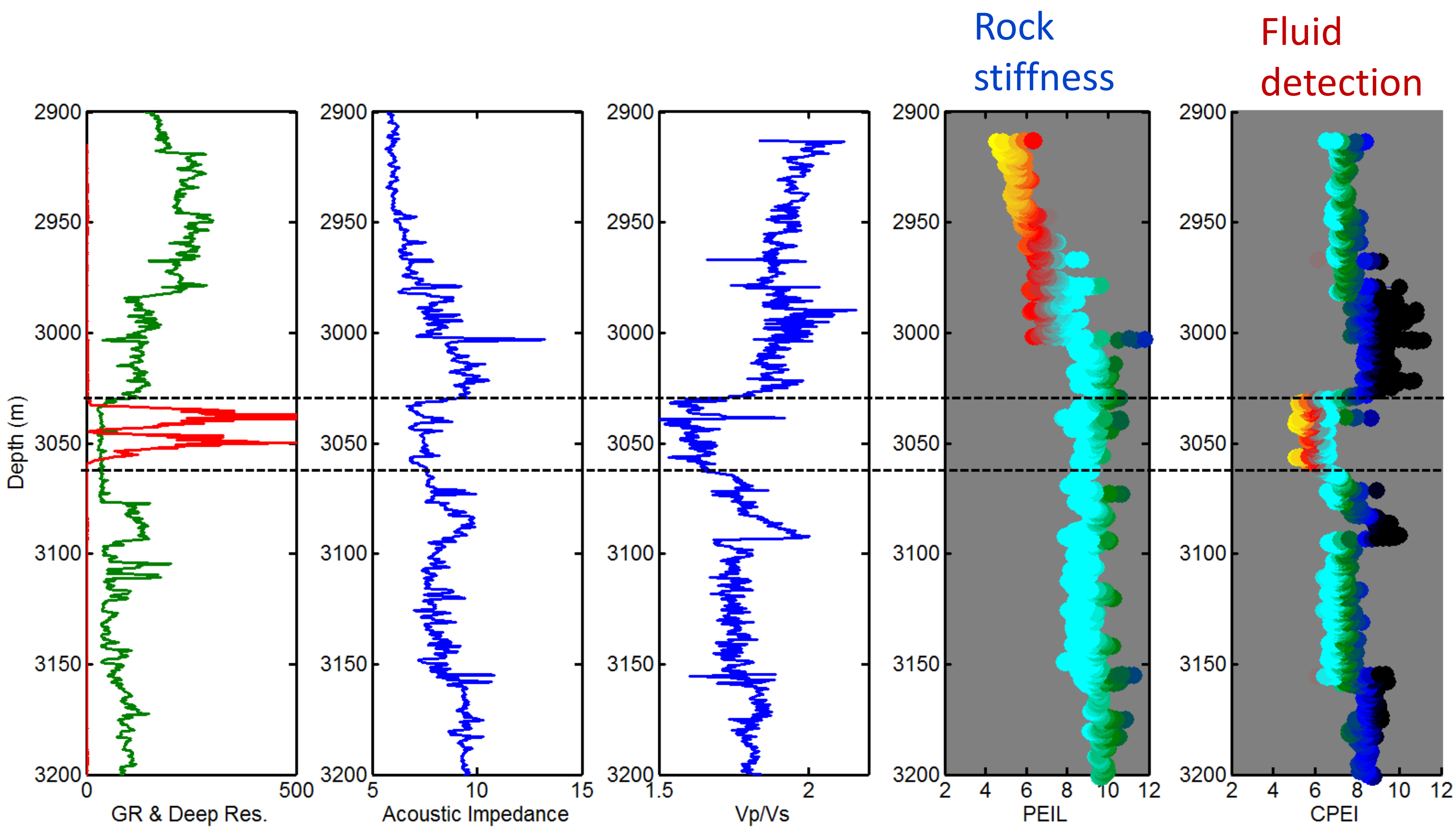
Rock physics template analysis of Well A
Extracting seismic fluid sensitivity and rock stiffness attributes



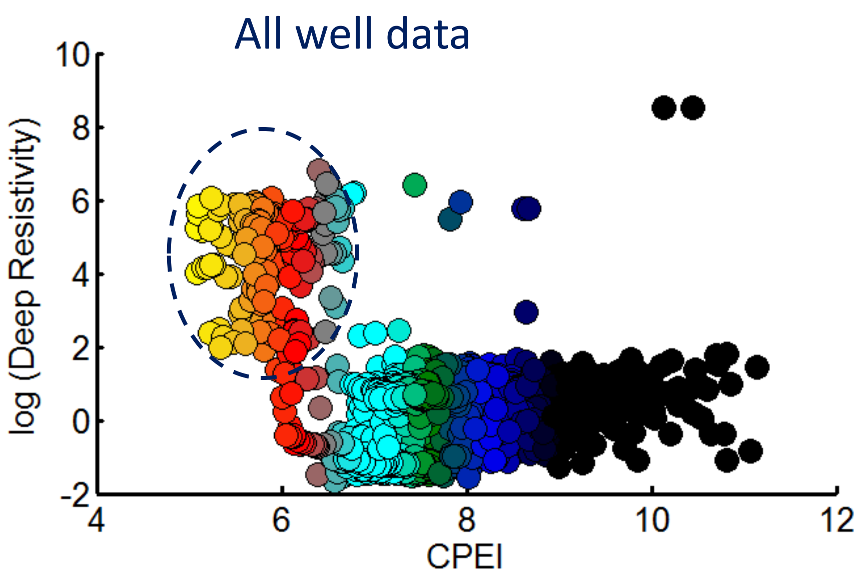


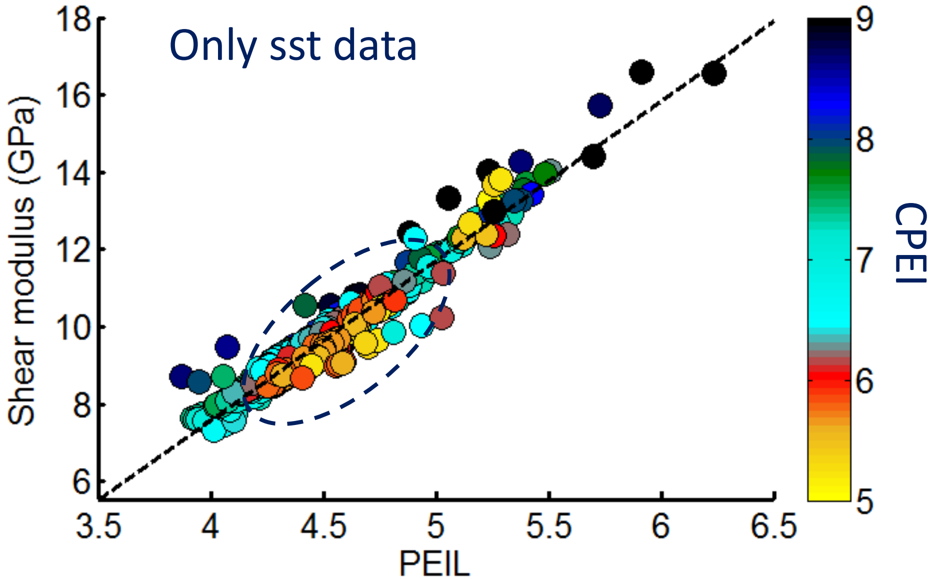


Well log data and estimated rock physics attributes, Well A



Demonstrating the connection between attributes and distinct physical properties (data from Well A)

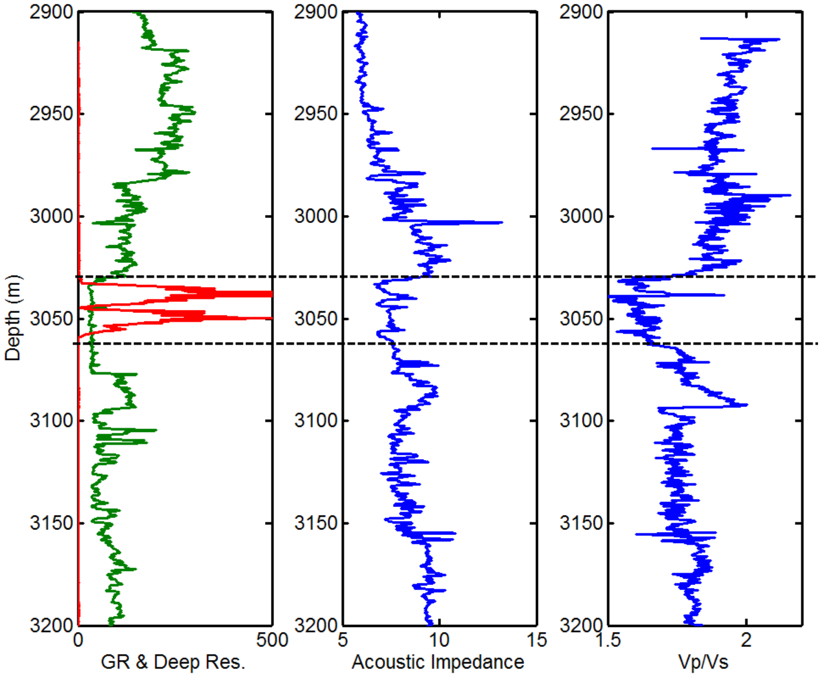


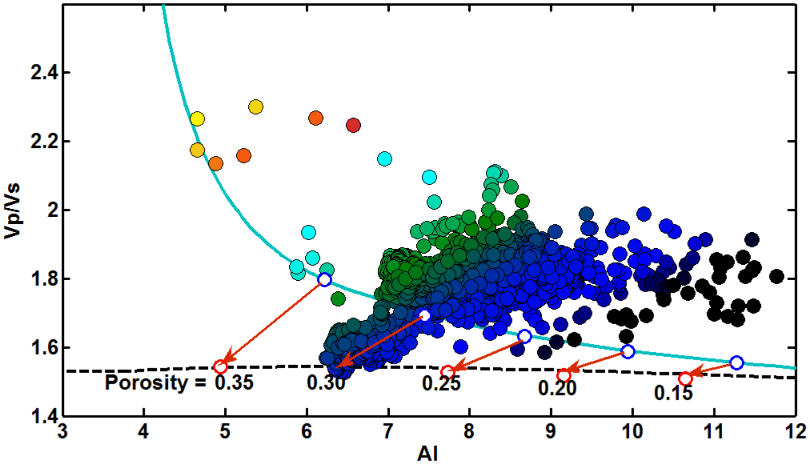


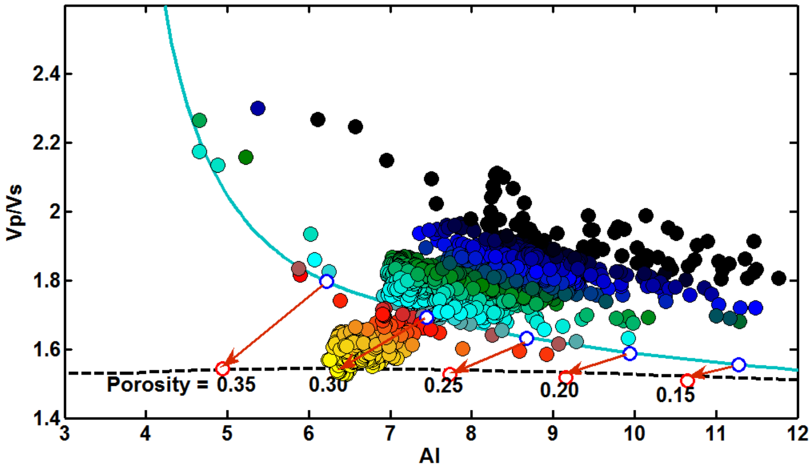
CPEI < 6.5 correlates with high resistivity = HC-filled reservoir

HC-filled sst plots on top of brine-filled sst → PEIL independent of fluid!

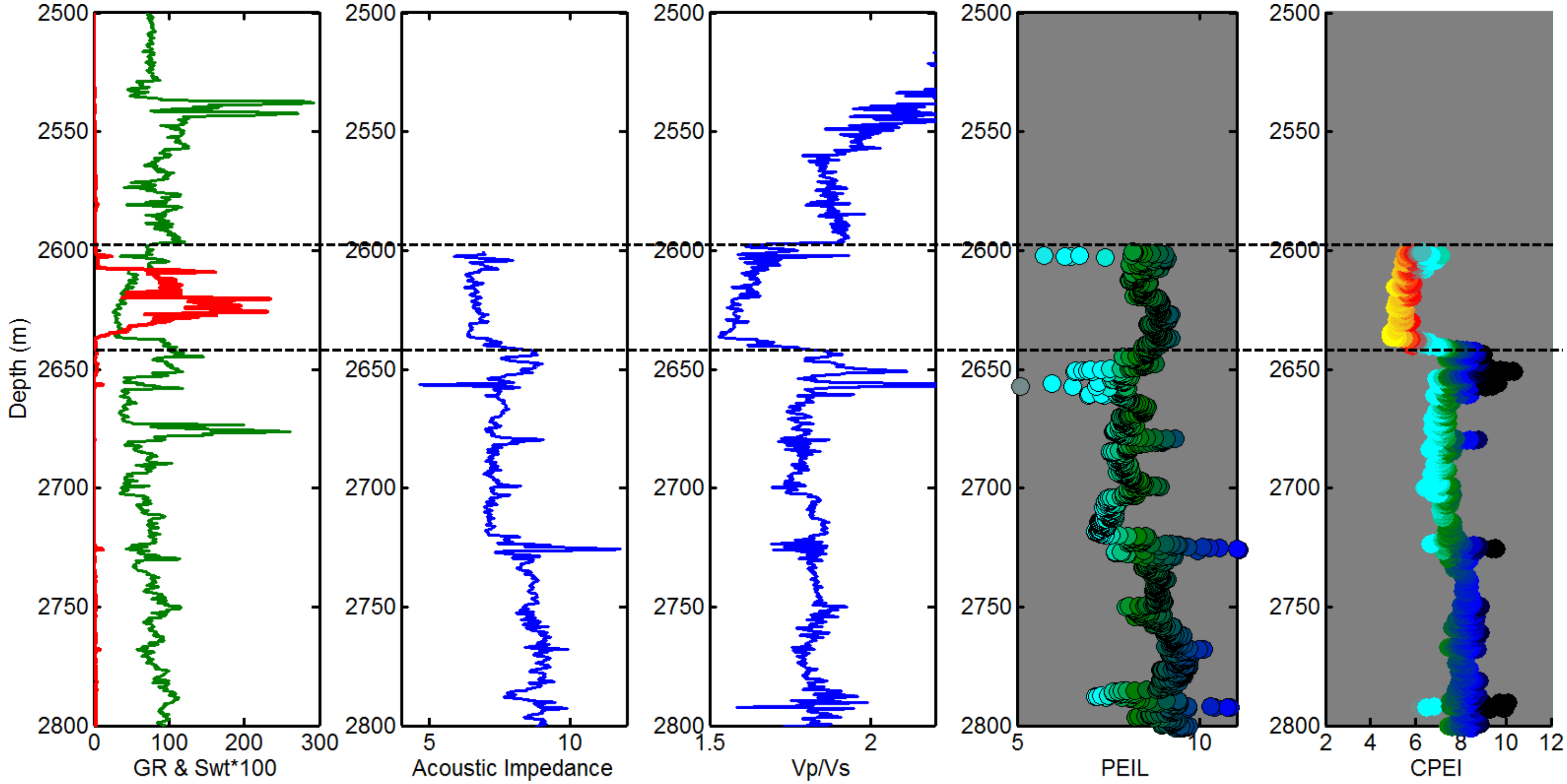
Rock physics template analysis of Well B (Jurassic reservoir in rotated faultblock)





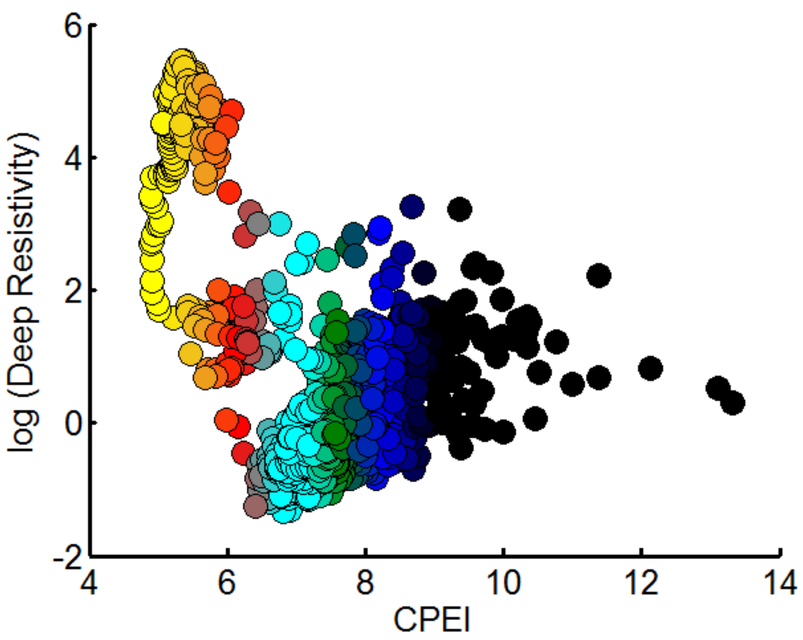


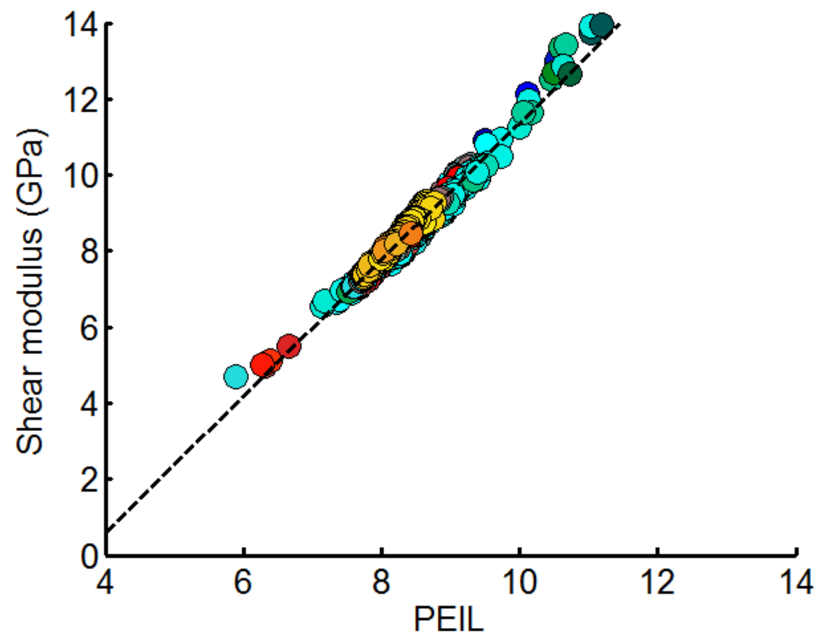
Estimated rock physics attributes in Well B



Controlling the physical relationships in Well B:

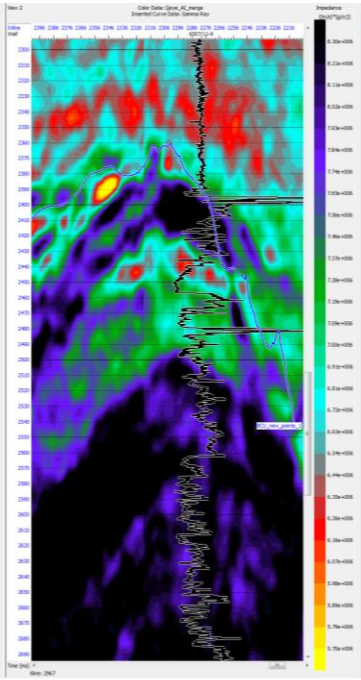
CPEI separates fluid saturation (i.e. resistivity); PEIL correlates perfectly with shear modulus.



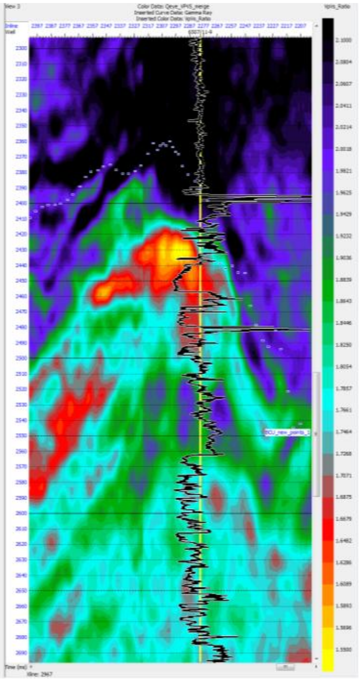


Using the same attributes on seismic inversion data. (At Well B fault block)

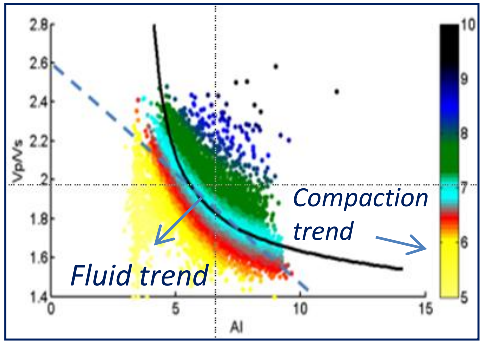
AI



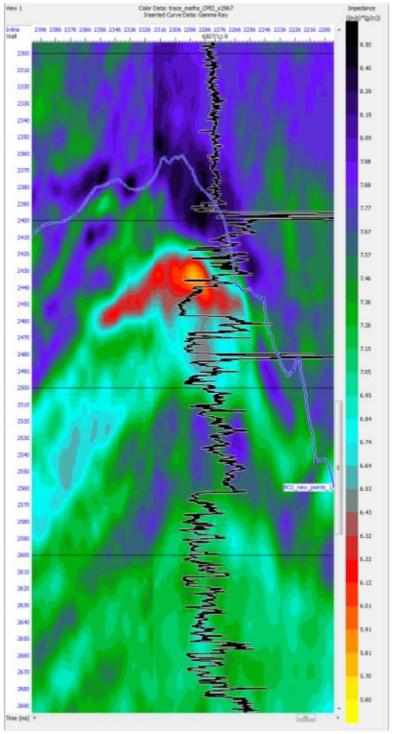
Vp/Vs



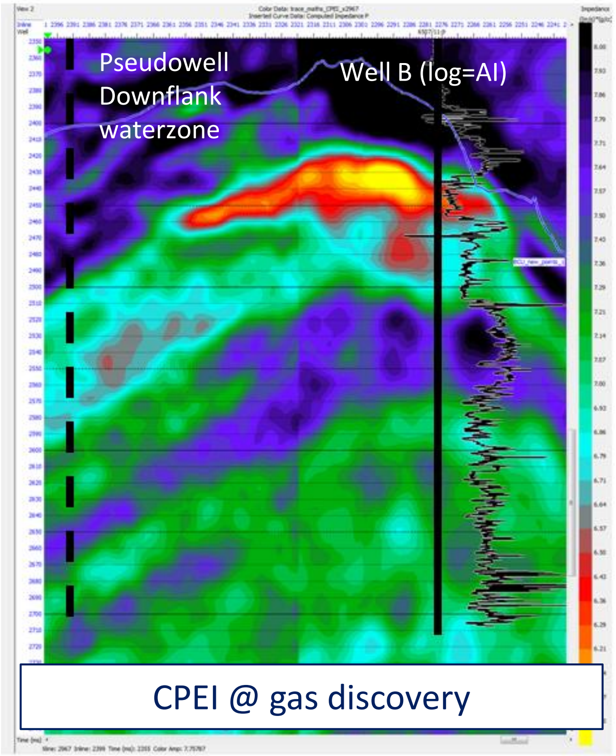
RPT

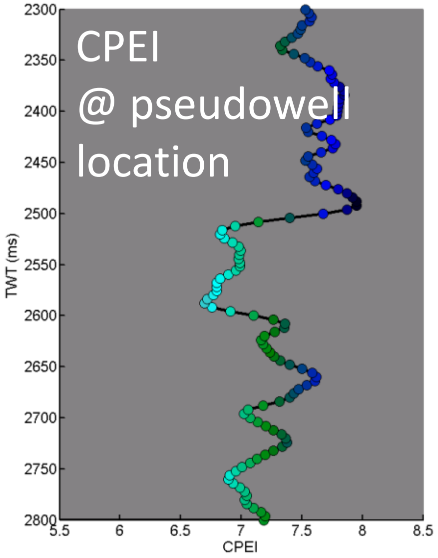


CPEI

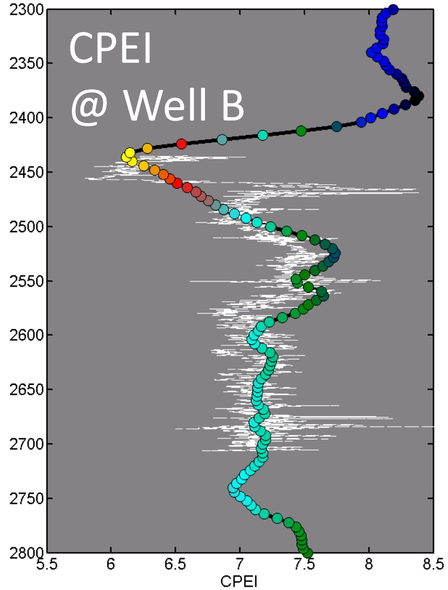


Investigating downflank water leg on same fault-block





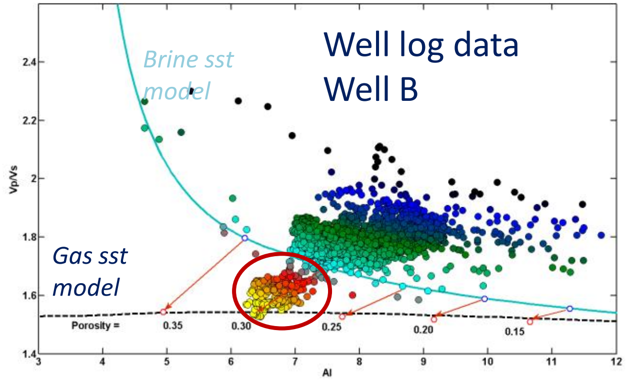
Water response

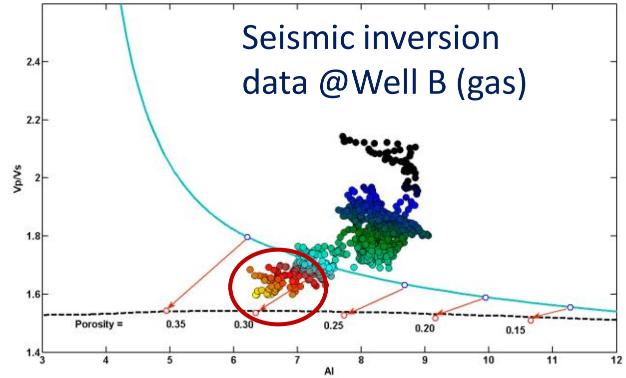


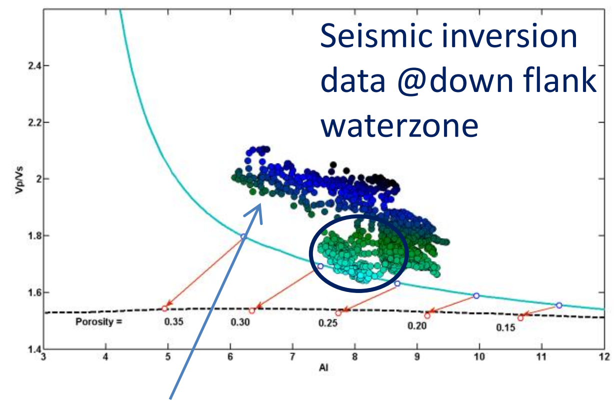
Gas response

Rock physics template analysis of well log and seismic inversion data @Well B

Colour = CPEI



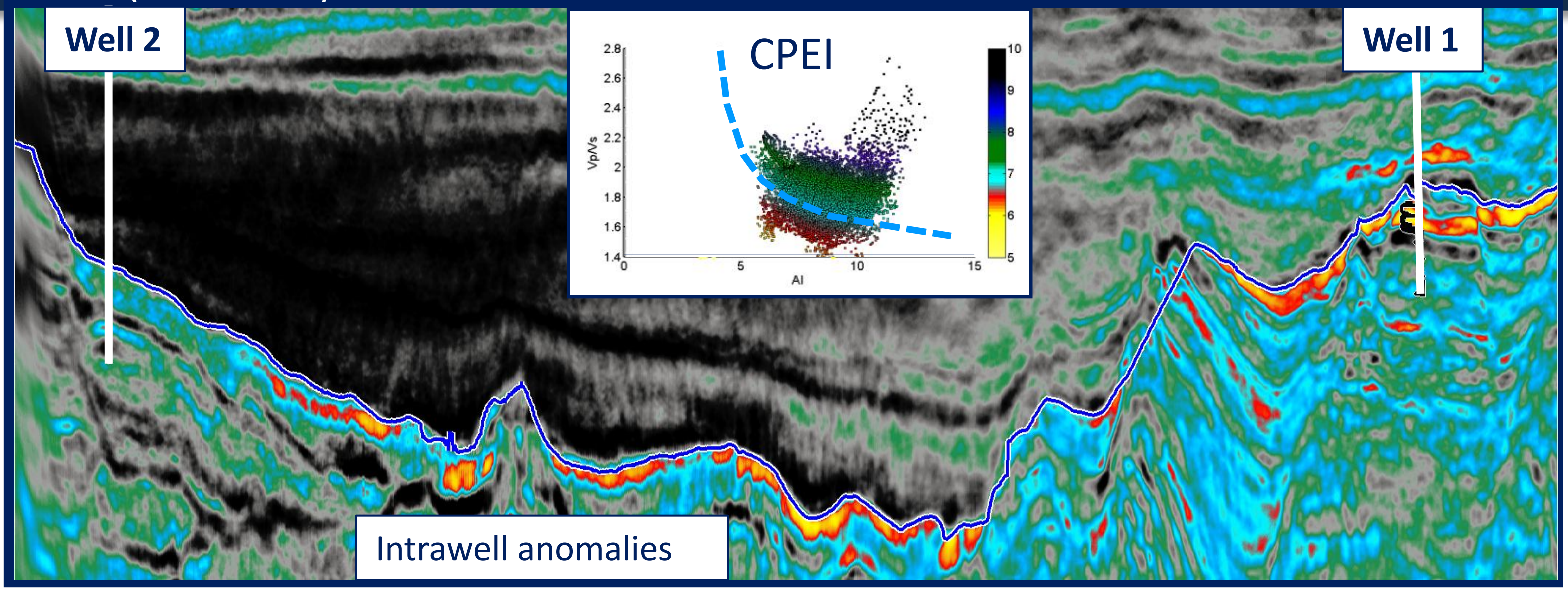




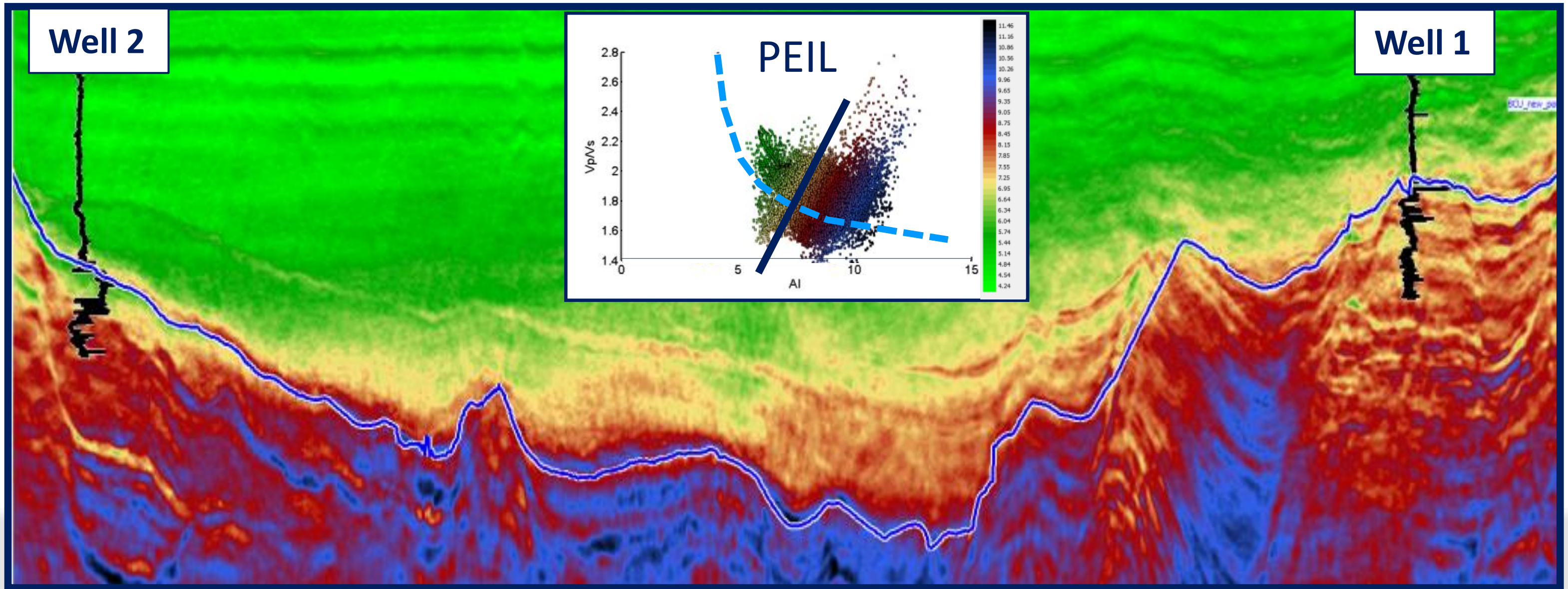
(Note that we are capturing more of overburden shale in downflank position for a given time interval.)

CPEI and PEIL attributes along random line;
from Well 1 (gas), via prospect, Well 2 (gas), via deeper graben, and
Well 2 (hot shale)

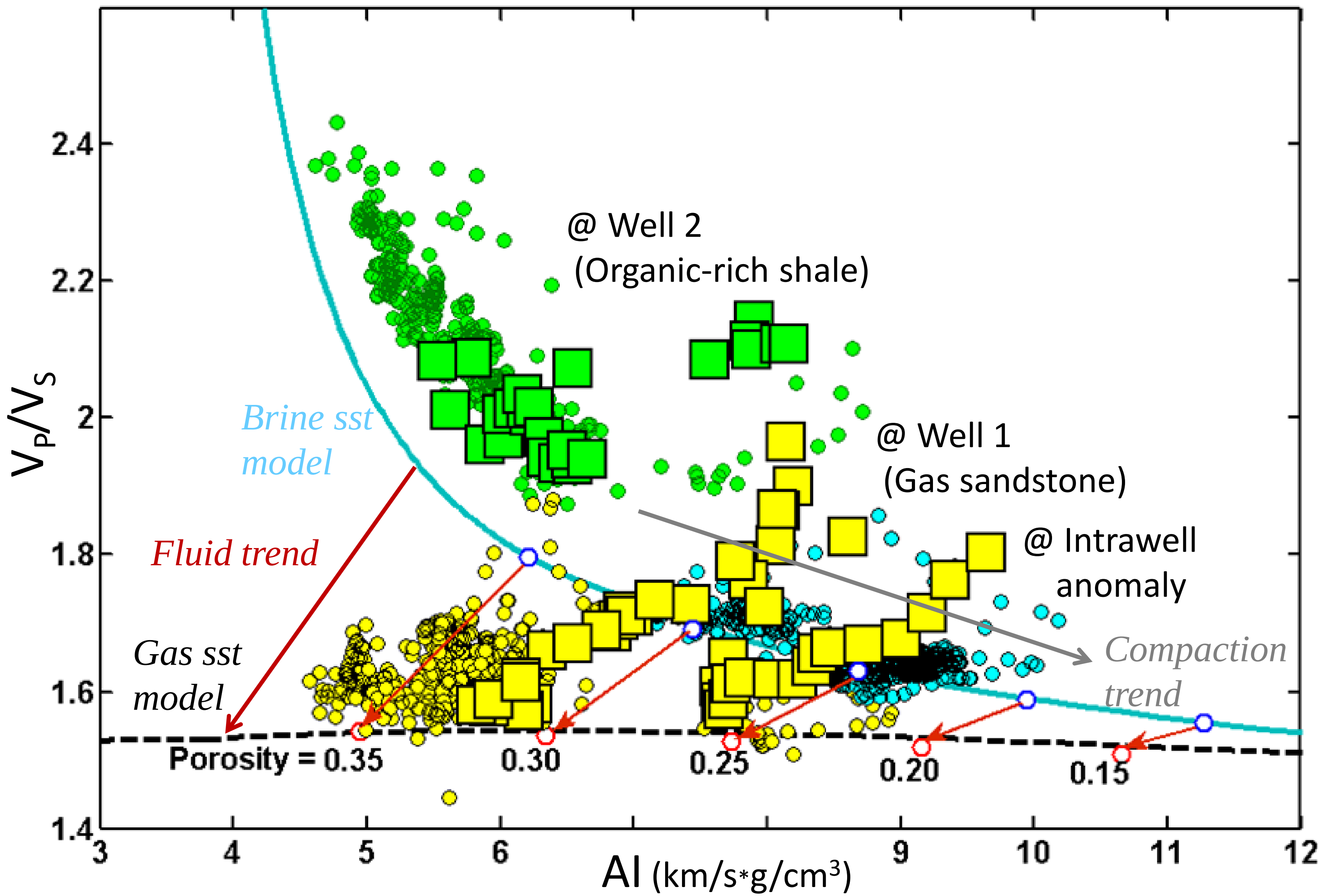
a)



b)



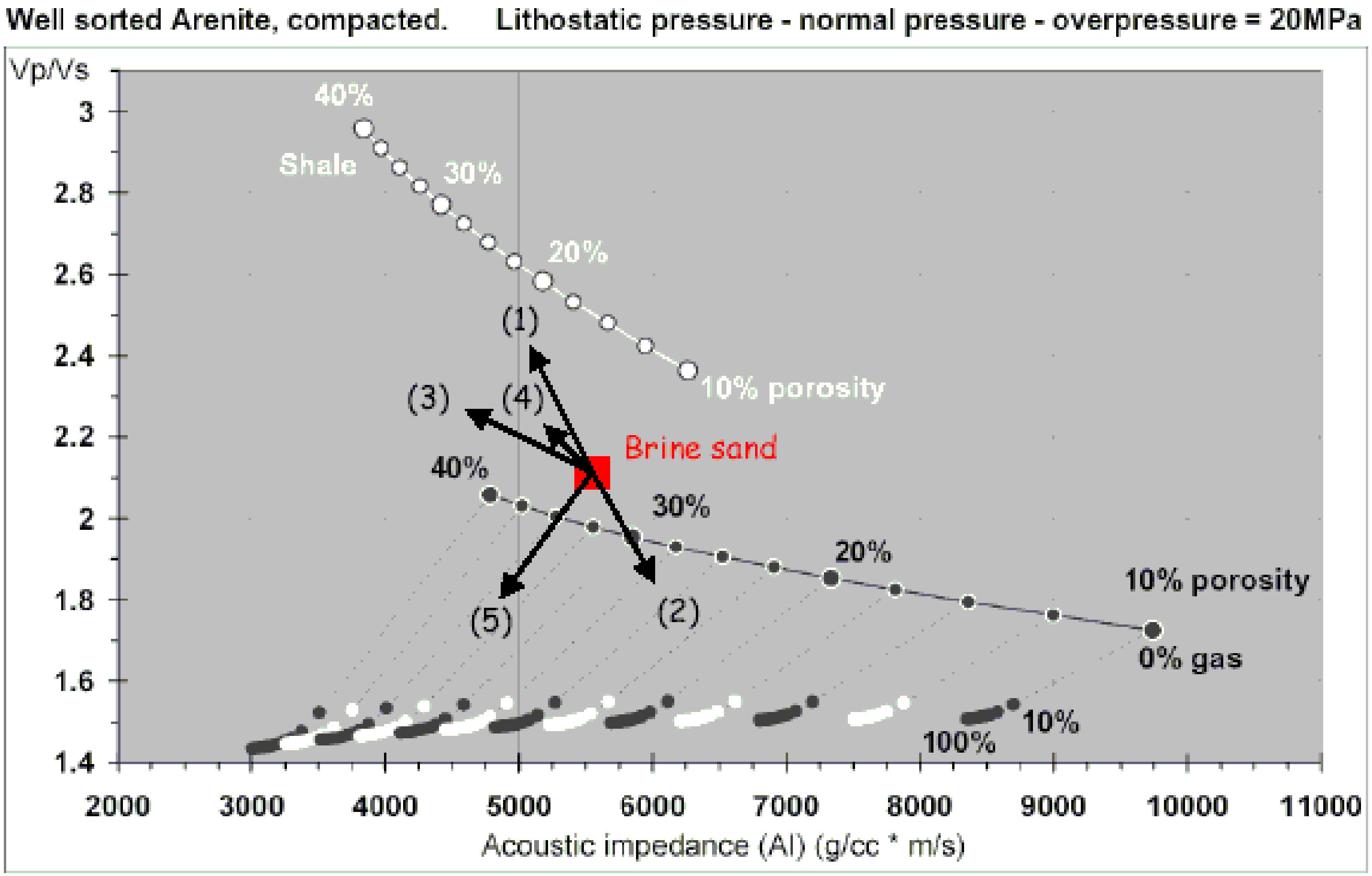
Rock physics template analysis of well log data versus seismic inversion data, corresponding to random line 2



Pit-falls and uncertainties

- Data quality (noise, multiples, imaging issues, processing artifacts)
- Overburden effects
- Offset to angle estimations
- Gather alignement
- **Poor well ties and wavelet estimation uncertainties**
- **Anisotropy**
- Attenuation
- Refractions
- Tuning and thin-bed effects
- **Low-frequency model uncertainties**
- Inversion non-uniqueness
- **Wrong choise of rock physics model and model parameter uncertainties**
- Fluid properties
- **Low gas-saturation** (*same AI and Vp/Vs as commercial saturation*).
- Poor fluid sensitivities versus geologic variability (overlaps between HC and water classes)
- Poor geologic control (unknown or surprising geologic scenarios away from existing wells)

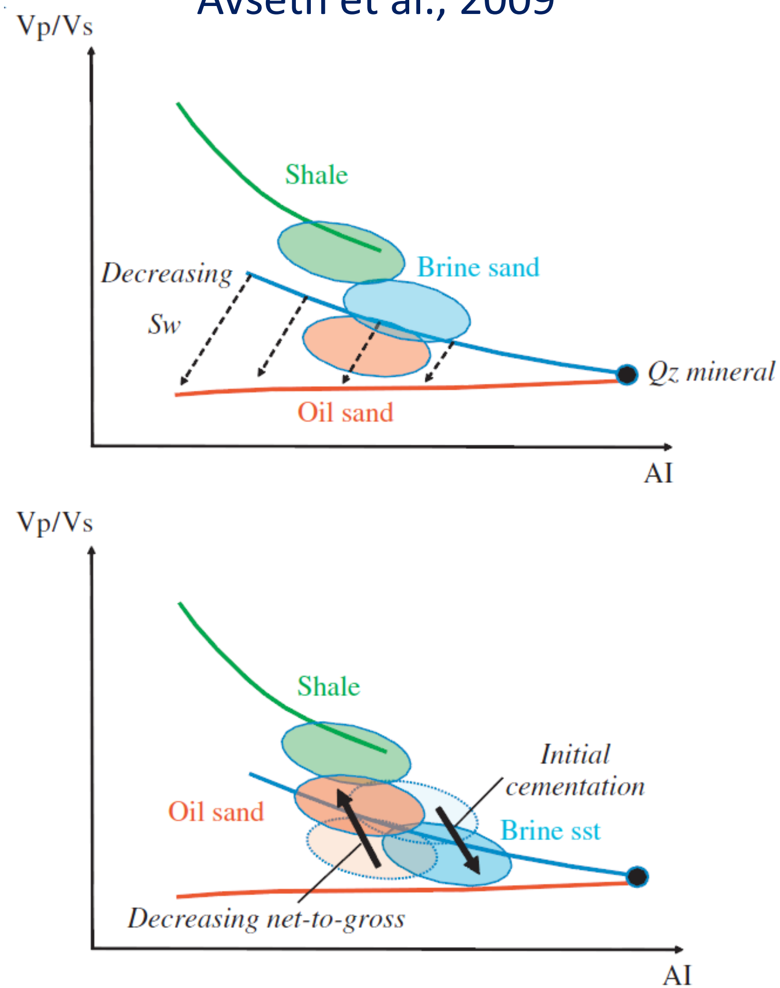
Geologic variability and rock physics uncertainties – → More unknowns than observables!



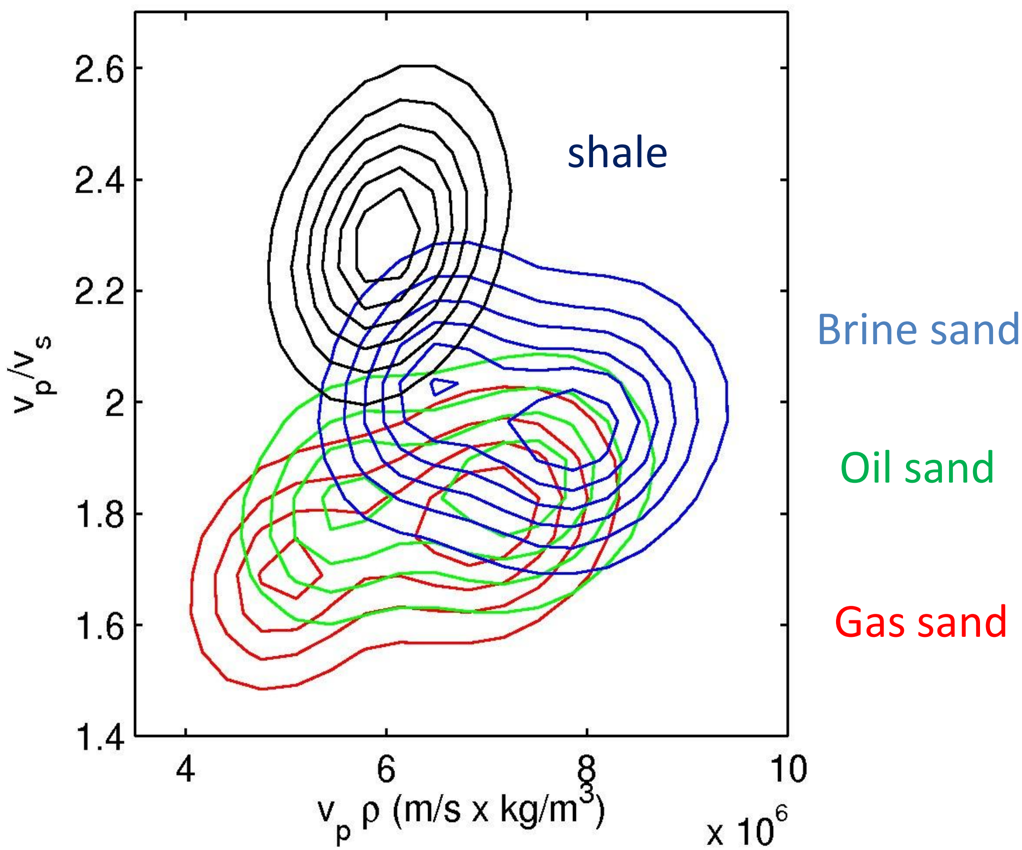
1) Increasing clay volume; 2) Increasing cement volume; 3) Increasing porosity; 4) Increasing pore pressure; 5) Increasing HC-saturation

Rock physics uncertainties (ctd.)

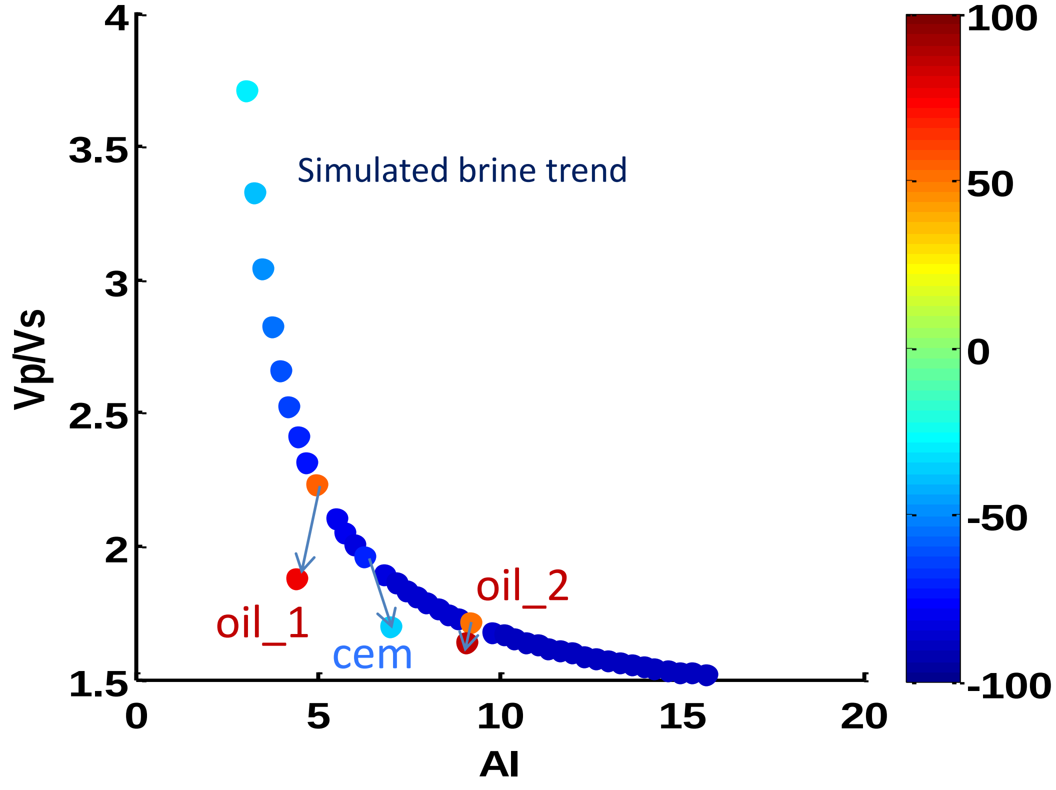
Avseth et al., 2009

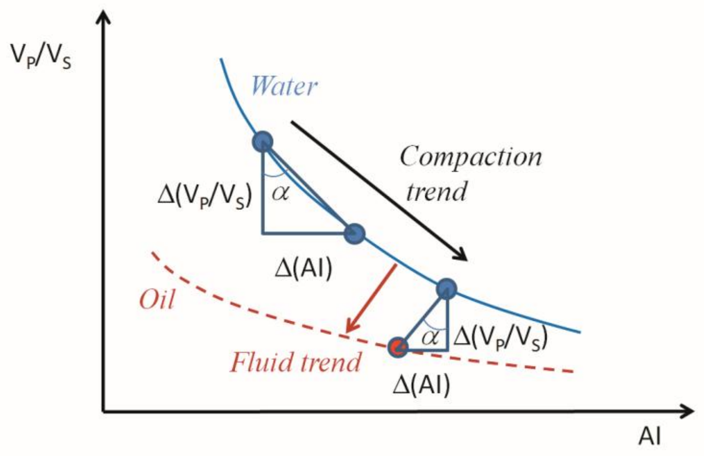


Rimstad et al., 2012



Trend analysis; investigating a way to separate oil trend from cement trend in RPT plot



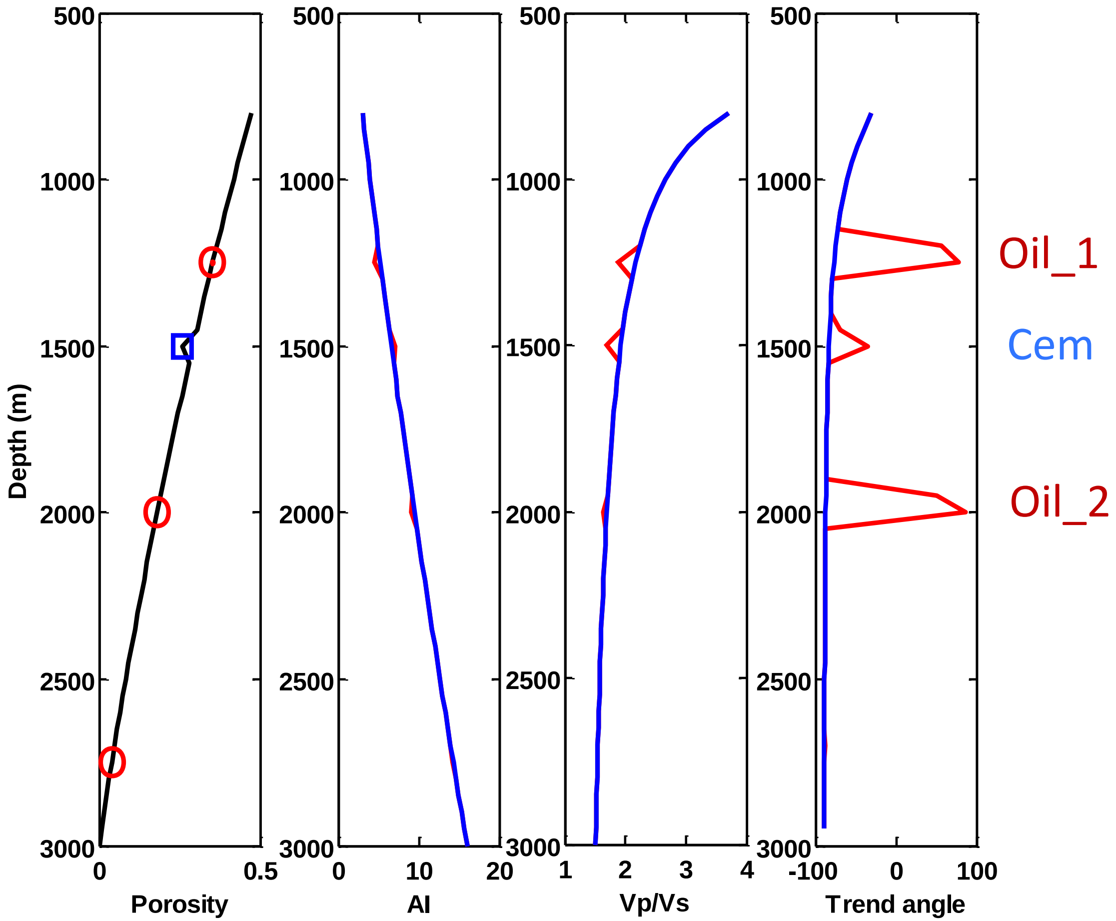


Trend=arctan(dAI/dPS)

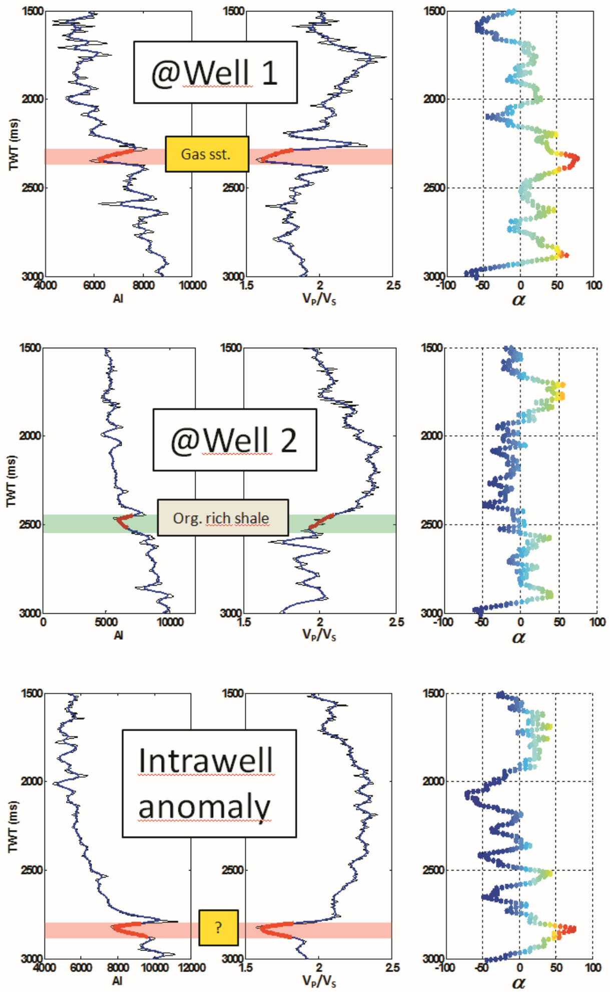
Por, AI, Vp/Vs and Trend angle versus depth (simulated data)

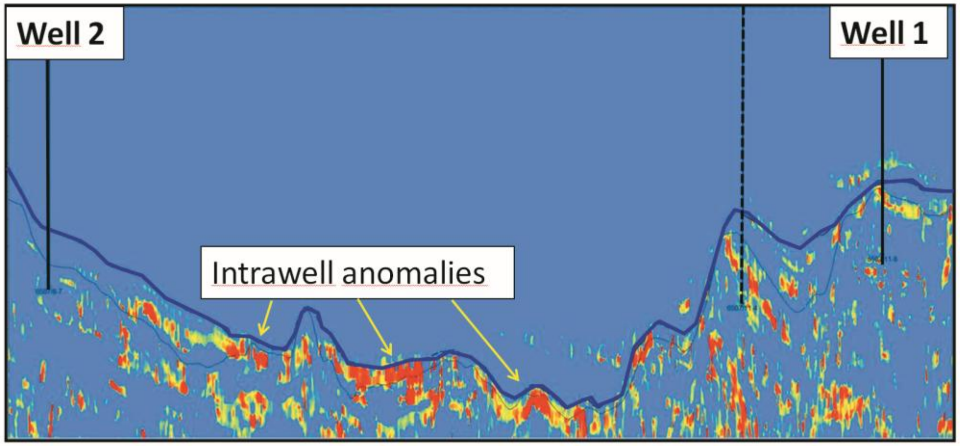
Note how the trend angle attribute detects both oil sands, even if the second has much lower fluid sensitivity.

Also the trend angle discriminates the cemented event.

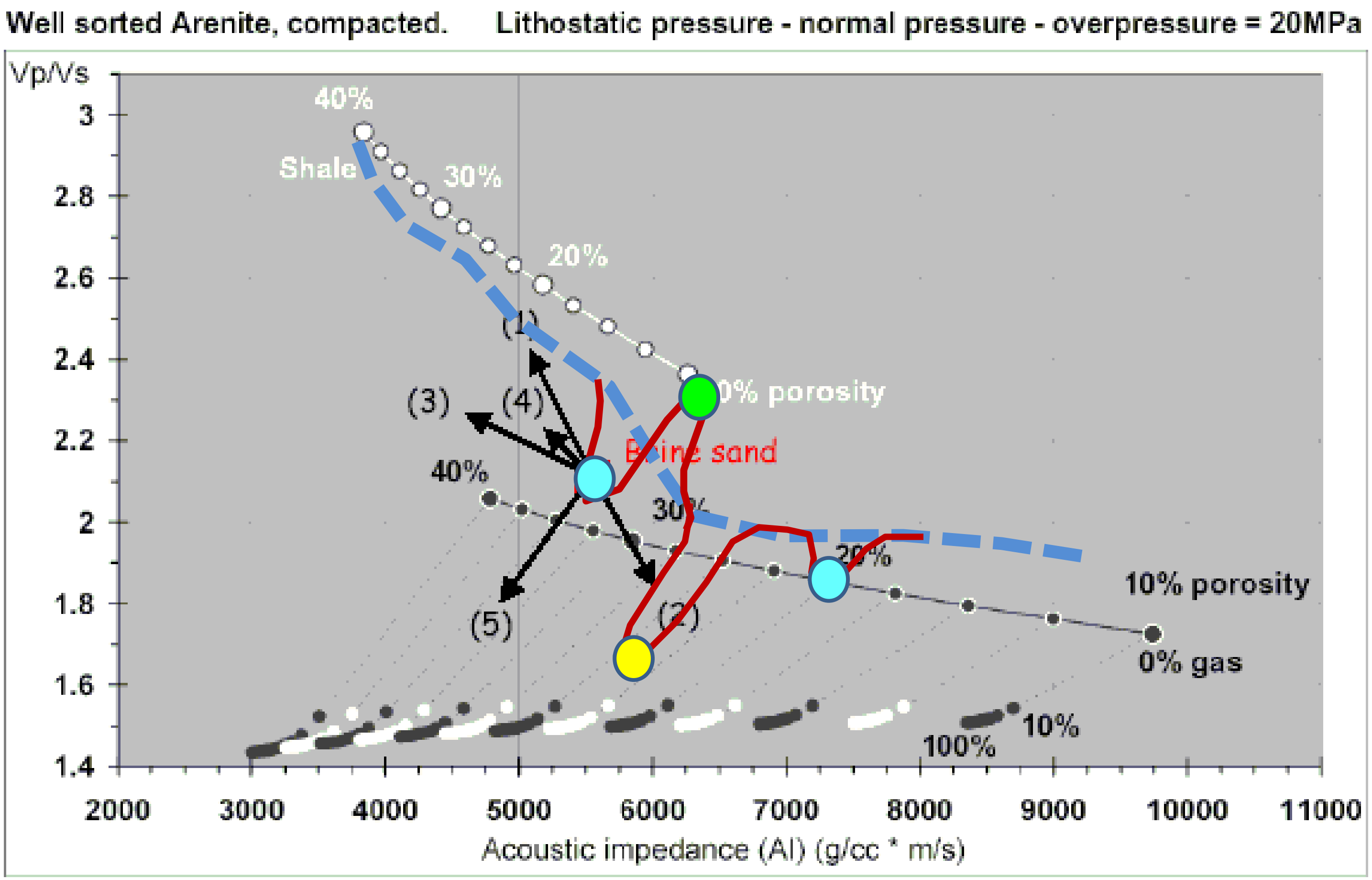


Trend angle analysis along random line 2

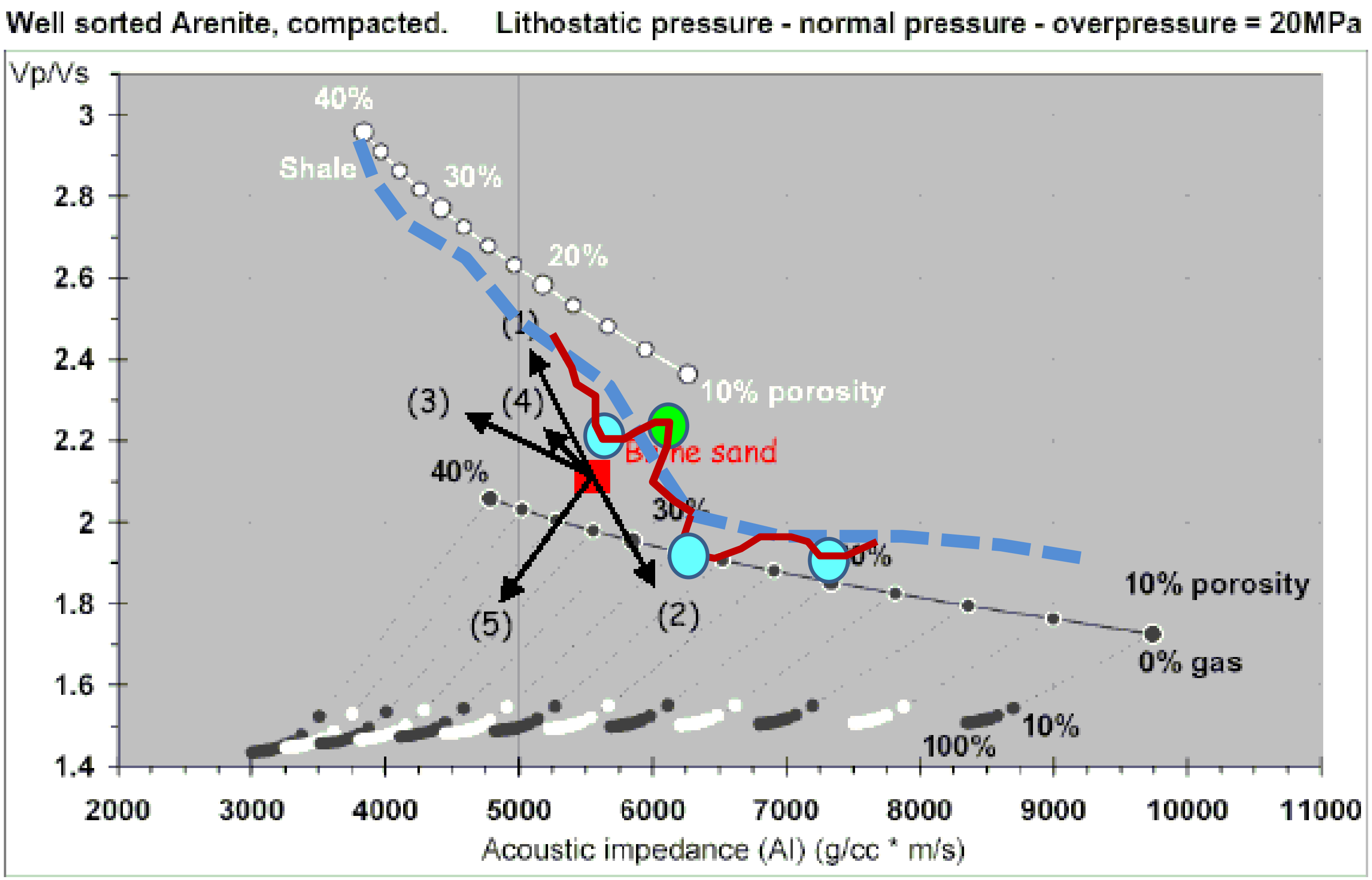




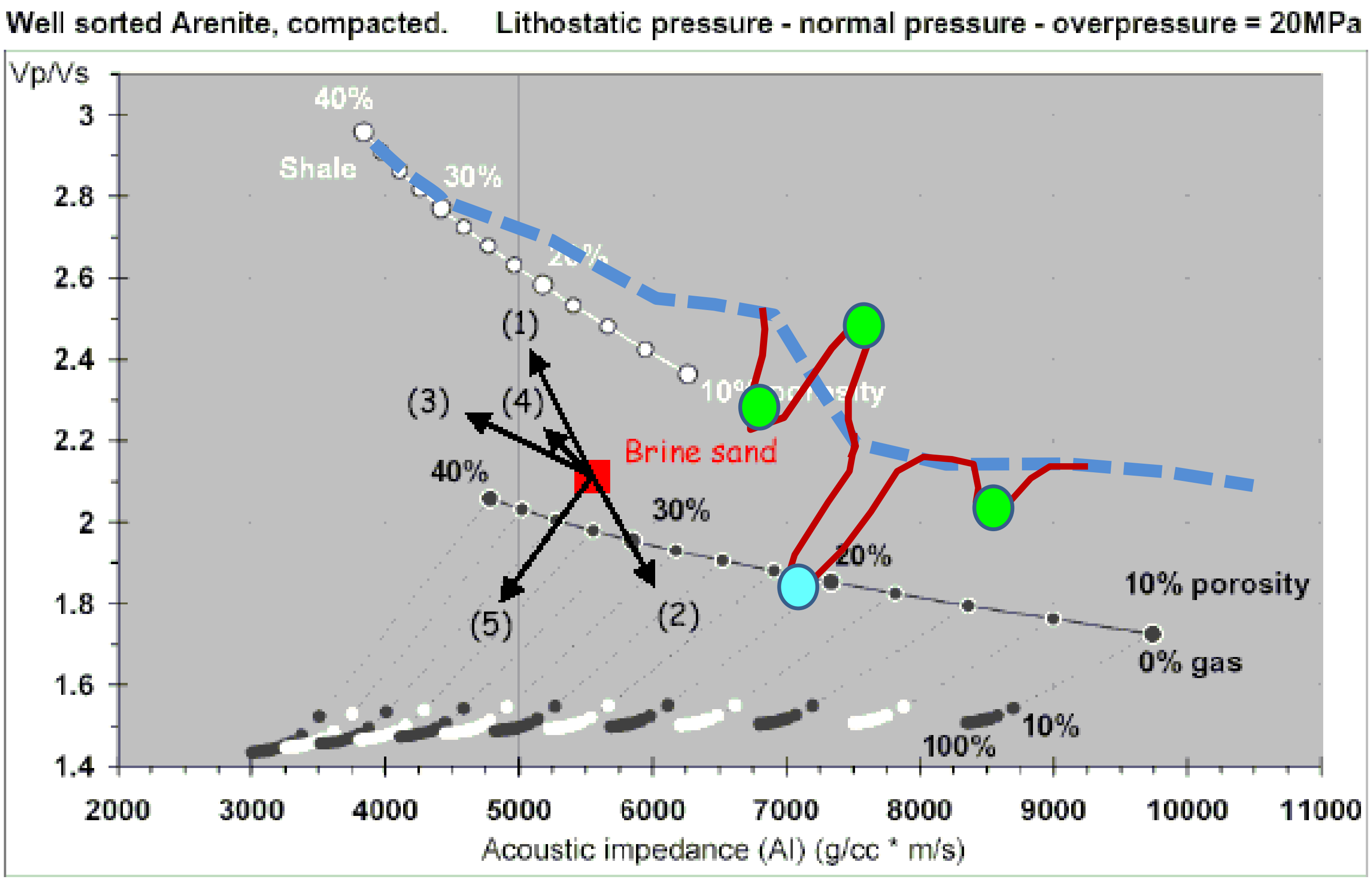
Good low-f model and optimal wavelet



Representative low-f model, but poor wavelet



Bad low-f model, but optimal wavelet



Conclusions

- Based on rock physics models, we have defined some useful attributes for screening of fluid saturation and rock stiffness from seismic AVO inversion data.

- The defined attributes are similar to the extended elastic impedance approach. However, the CPEI attribute honors the non-linear behavior of the water-saturated background trend in the AI-Vp/Vs crossplot domain.

- The attributes (CPEI and PEIL) have been validated on well log data and applied to seismic inversion data from the Norwegian Sea. Proven discoveries are nicely identified with our seismic screening methodologies.

- The trend angle attribute can discriminate diagenetic events from hydrocarbon saturated reservoirs in a rock physics template, as both tend to have low Vp/Vs. The attribute can work even for well consolidated rocks where fluid sensitivities are relatively low.

- The main pit-falls in this work includes low gas saturation, anisotropy effects, and errors in the low-frequency model and/or wavelet estimation.

Quantitative seismic interpretation = Paradigm Change!

Seismic inversion should be used like a lamp post - to light the way, not to lean upon.

– John Clearbout, 1985

Seismic inversion, integrated with rock physics and geology, can be used like a lamp post – to light the way and to lean upon.

– Tullow Oil Norge, 2015

Technology leap and improved integration!

Thanks to Tor Veggeland and other colleagues at Tullow Oil Norge for great teamwork, and to Q-eye Labs for AVO inversion data.