The role of shale anisotropy and heterogeneity in well log reservoir characterization

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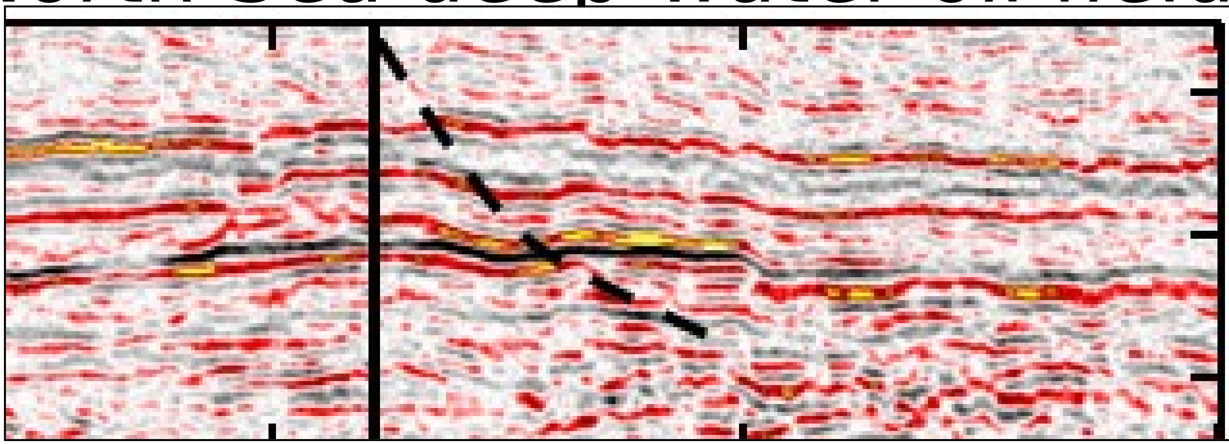
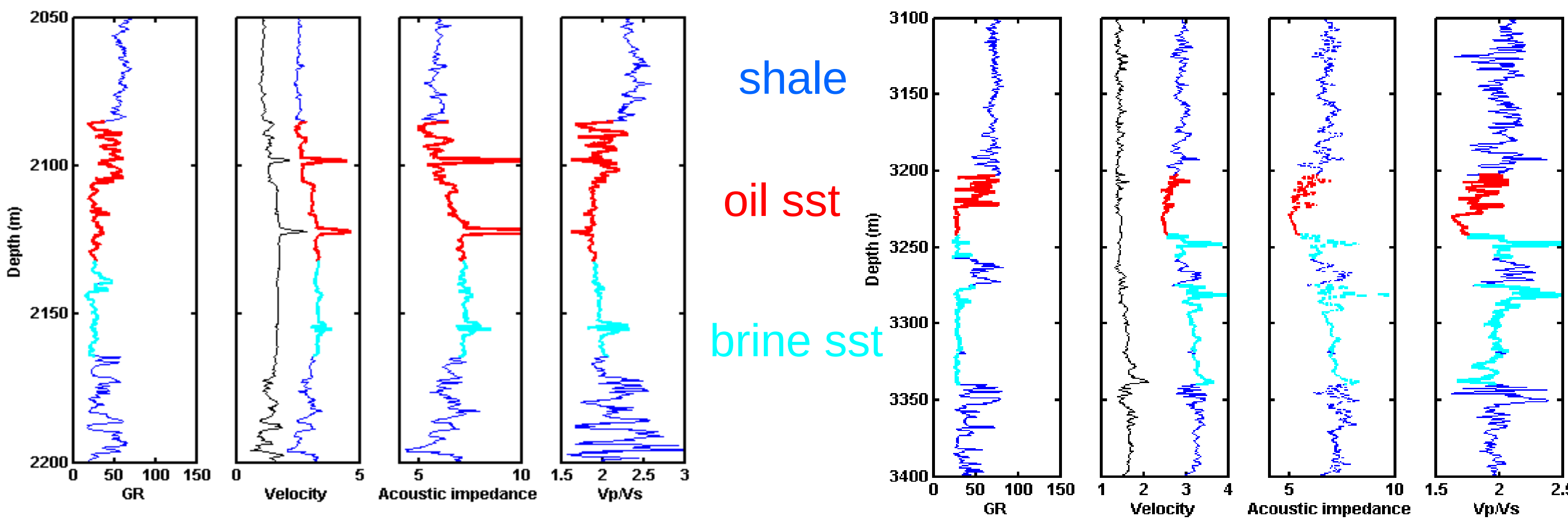
Vertical well and adjacent deviated well
(North Sea deep-water oil field)





Vertical

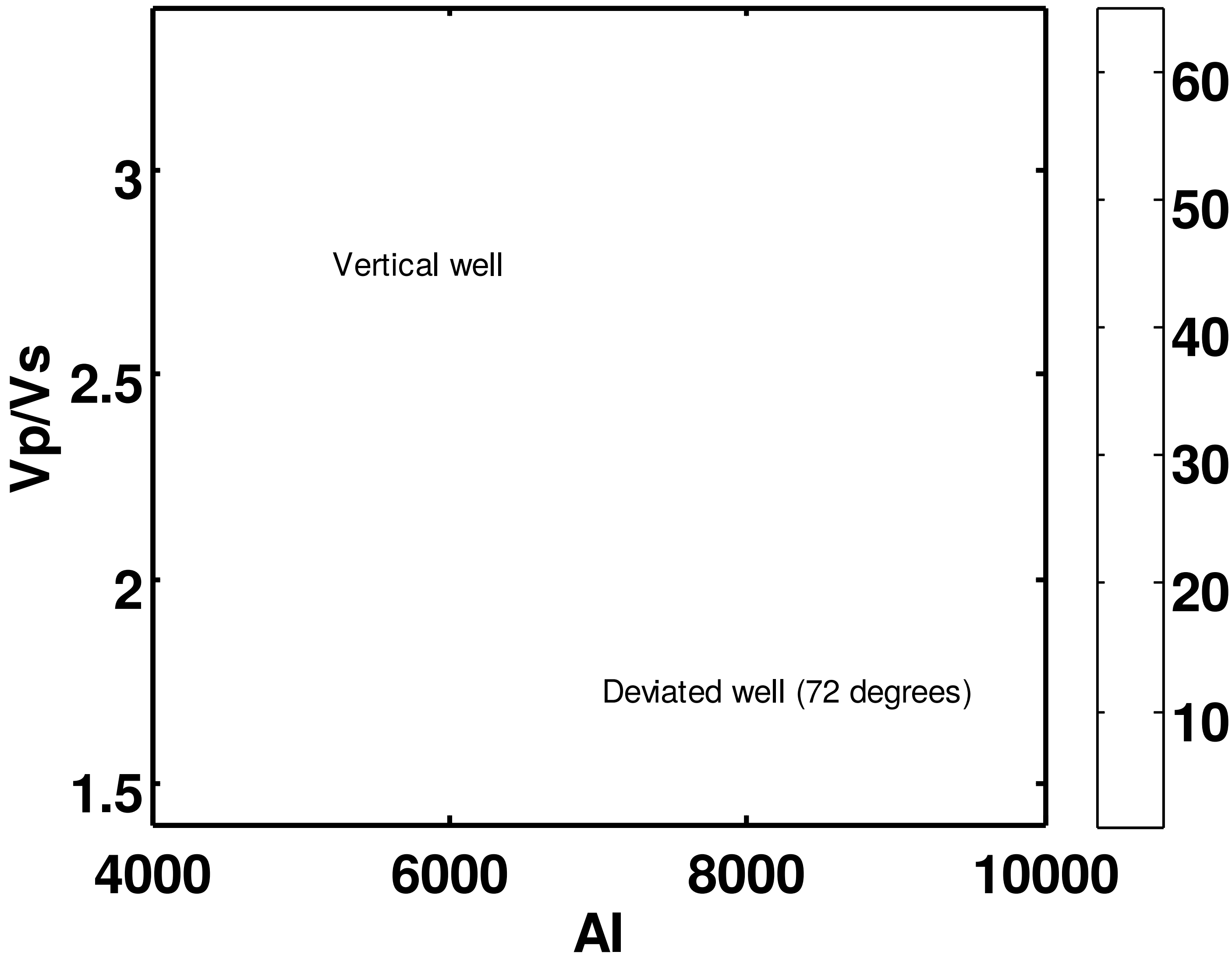
Deviated

Assuming cap-rock shale to be a TI medium:

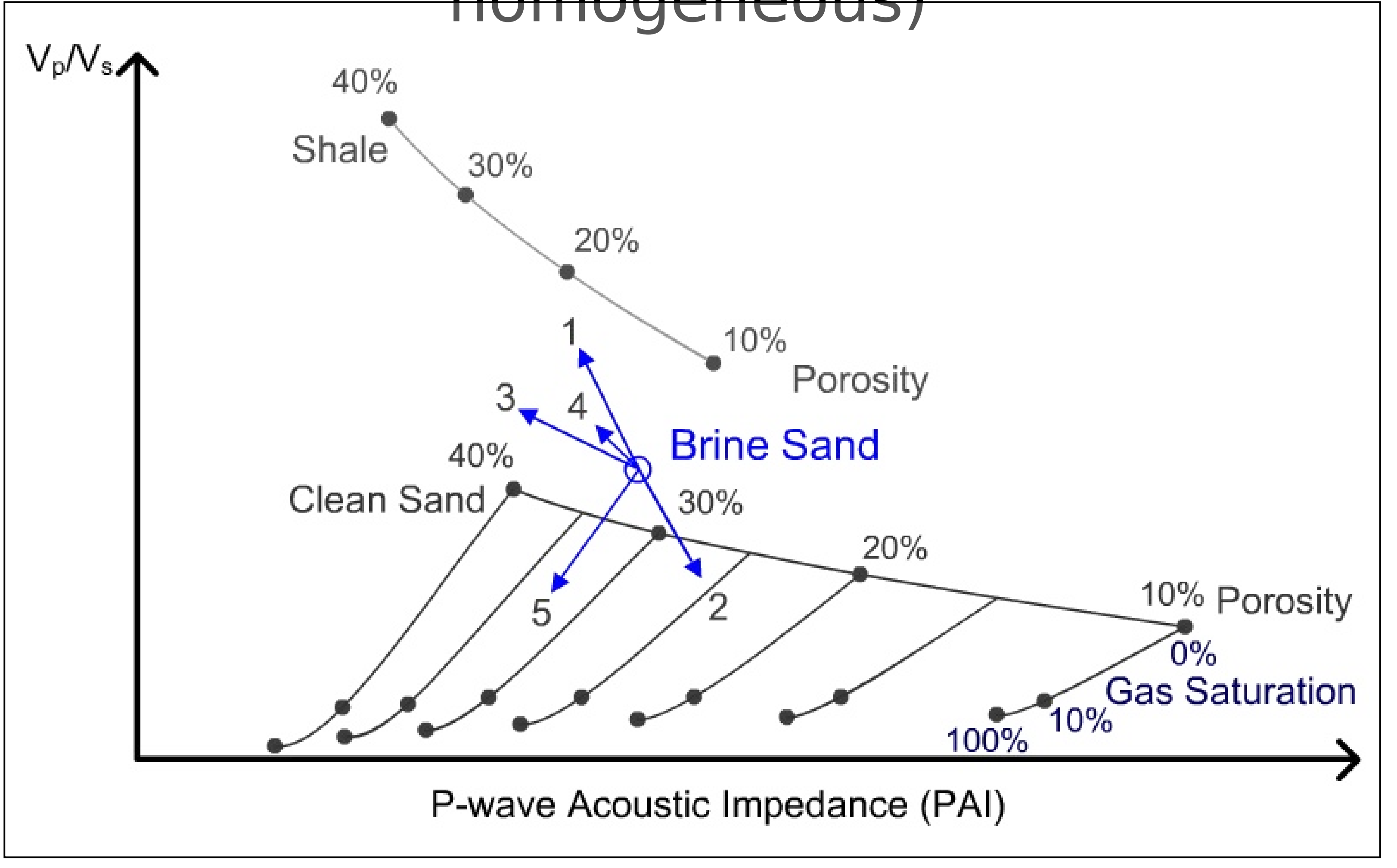
$$C_{ij} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & 0 & 0 & 0 \\ C_{12} & C_{11} & C_{13} & 0 & 0 & 0 \\ C_{13} & C_{13} & C_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{44} & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{66} \end{bmatrix}$$

- The five components of the stiffness tensor for a transversely isotropic material can be obtained from five velocity measurements: $V_P(0°)$, V_P (90°), V_P (45°), V_{SH} (90°), and $V_{SH}(0^0) = Vsv(0^0)$;
- One problem: We only observe Vp and Vs at zero and 72 degrees.

Shale anisotropy in AI versus Vp/Vs domain



Rock Physics Templates (isotropic and homogeneous)



1) Increasing shaliness
2) Increasing cement volume
3) Increasing porosity
4) Decreasing effective pressure
5) Increasing gas saturation

Ødegaard and Avseth (2004)

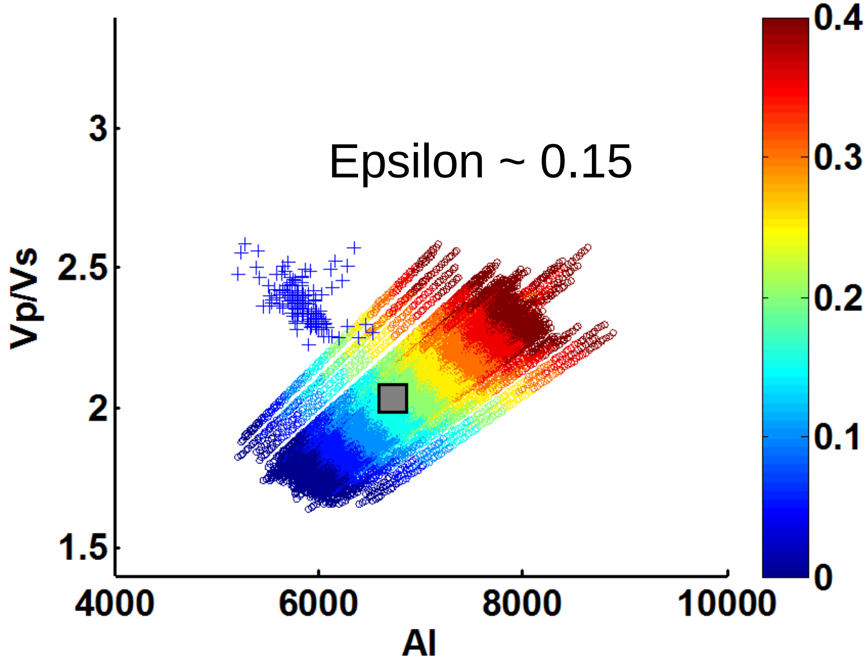
Scanning from vertical well to 72 degrees with varying epsilon and delta

$$V_P(\theta) \approx V_P(0^0)\cdot\left(1+\delta\sin^2\theta\cos^2\theta+\varepsilon\sin^4\theta\right)$$

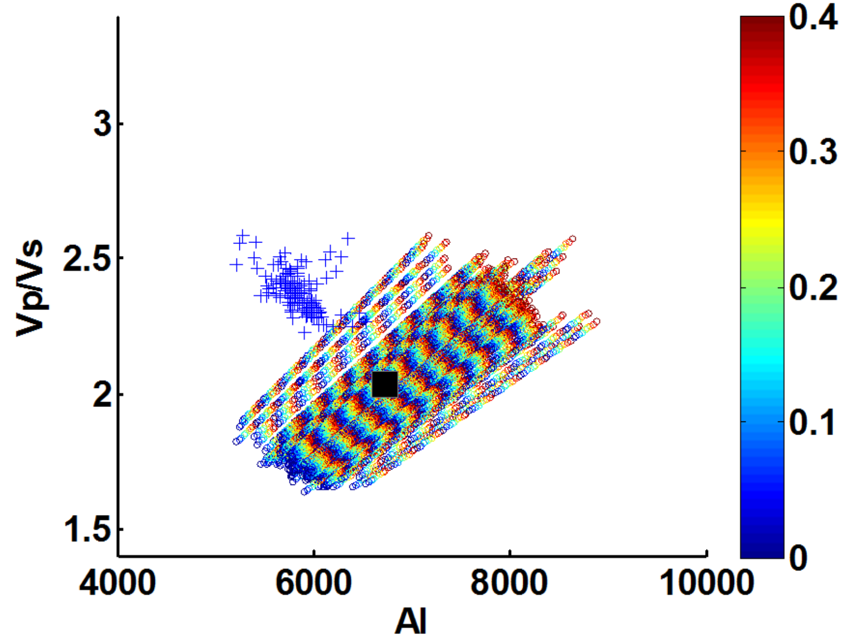
$$V_{SV}(\theta) \approx V_{SV}(0^0)\cdot\left(1+\frac{V_P{}^2(0^0)}{V_{SV}{}^2(0^0)}(\varepsilon-\delta)\sin^2\theta\cos^2\theta\right)$$

$$V_{SH}(\theta) \approx V_{SH}(0^0)\cdot\left(1+\gamma\sin^2\theta\right)$$

~ 0.4

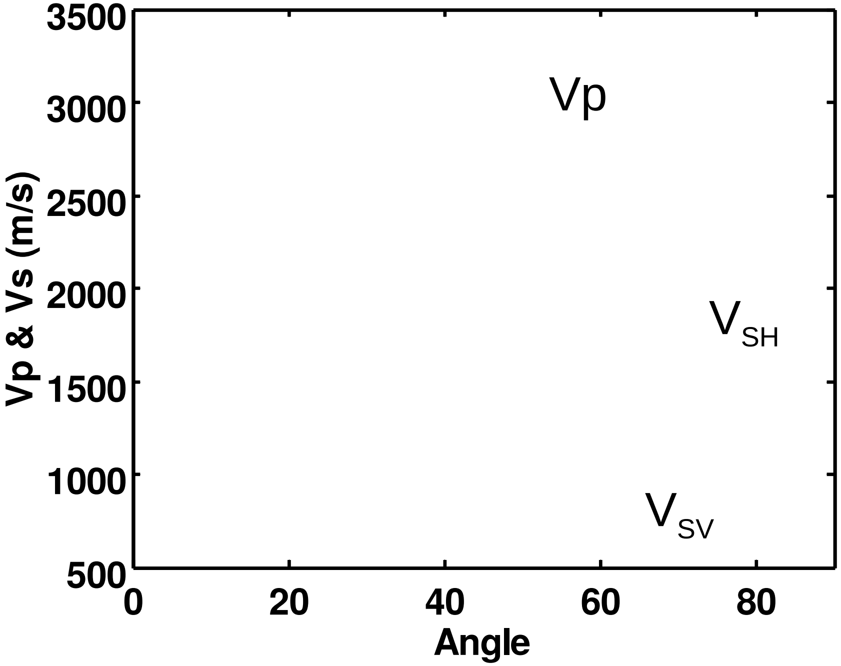


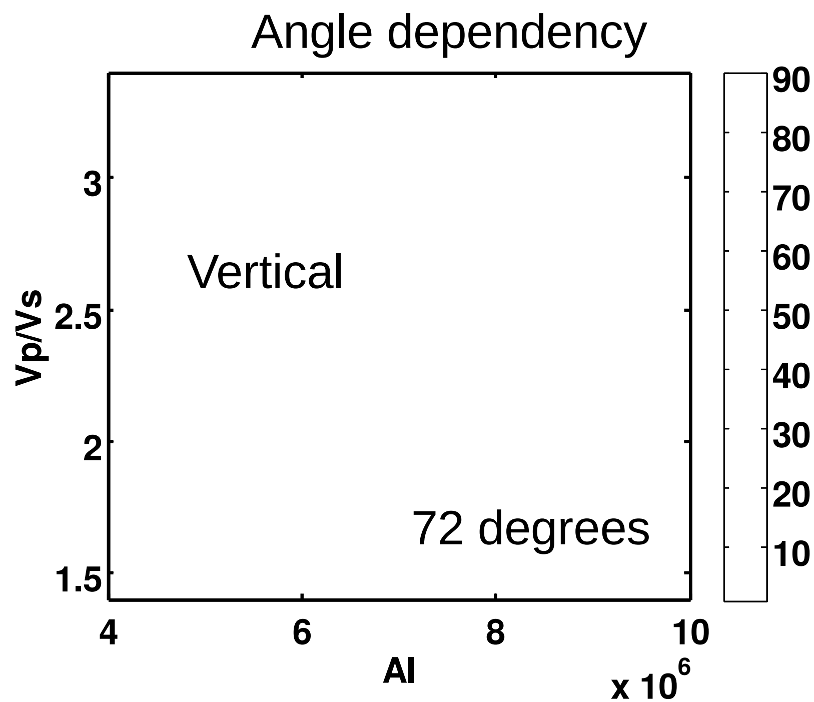
Scanning epsilon



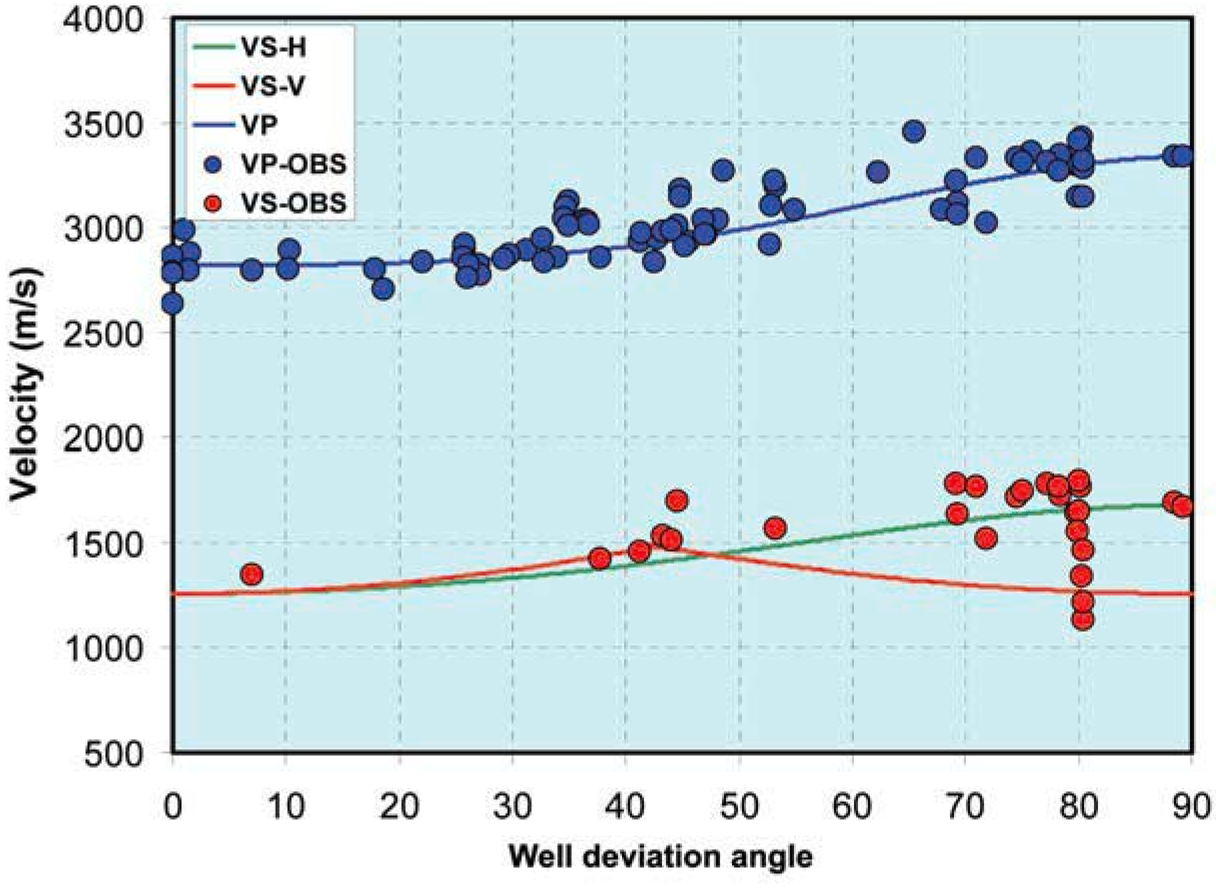
Scanning delta

Quantifying anisotropic phase velocities as a function of inclination (weak and exact solutions)

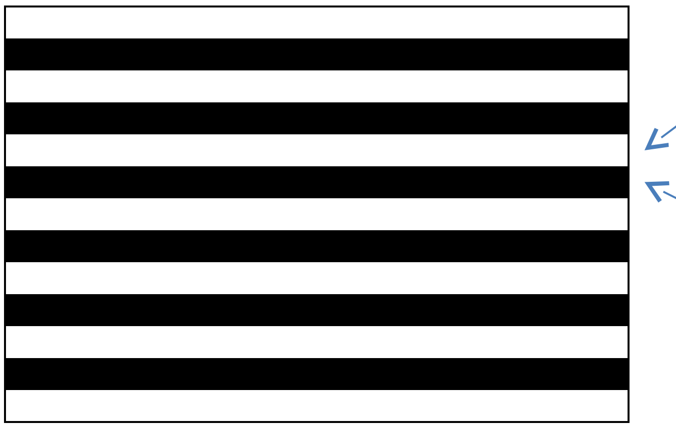




Brevik et al (2008)



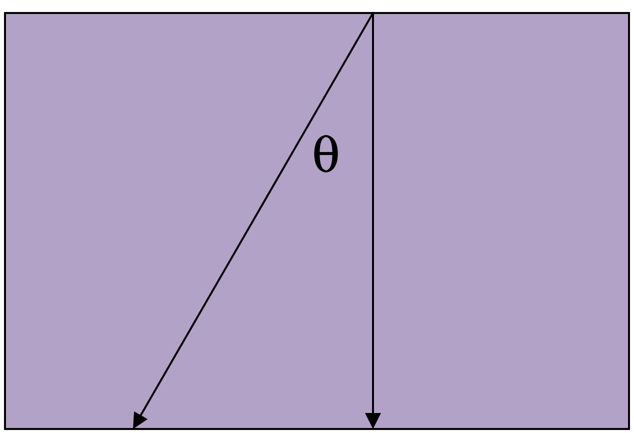
Rock physics modeling of heterogeneous reservoir



1. Gassmann fluid substitution (isotropic) in sandy layers for different porosities (0.25 and 0.35).

2. Shale layers are assumed anisotropic with same elastic properties as cap-rock shale. Assumed fully brine saturated

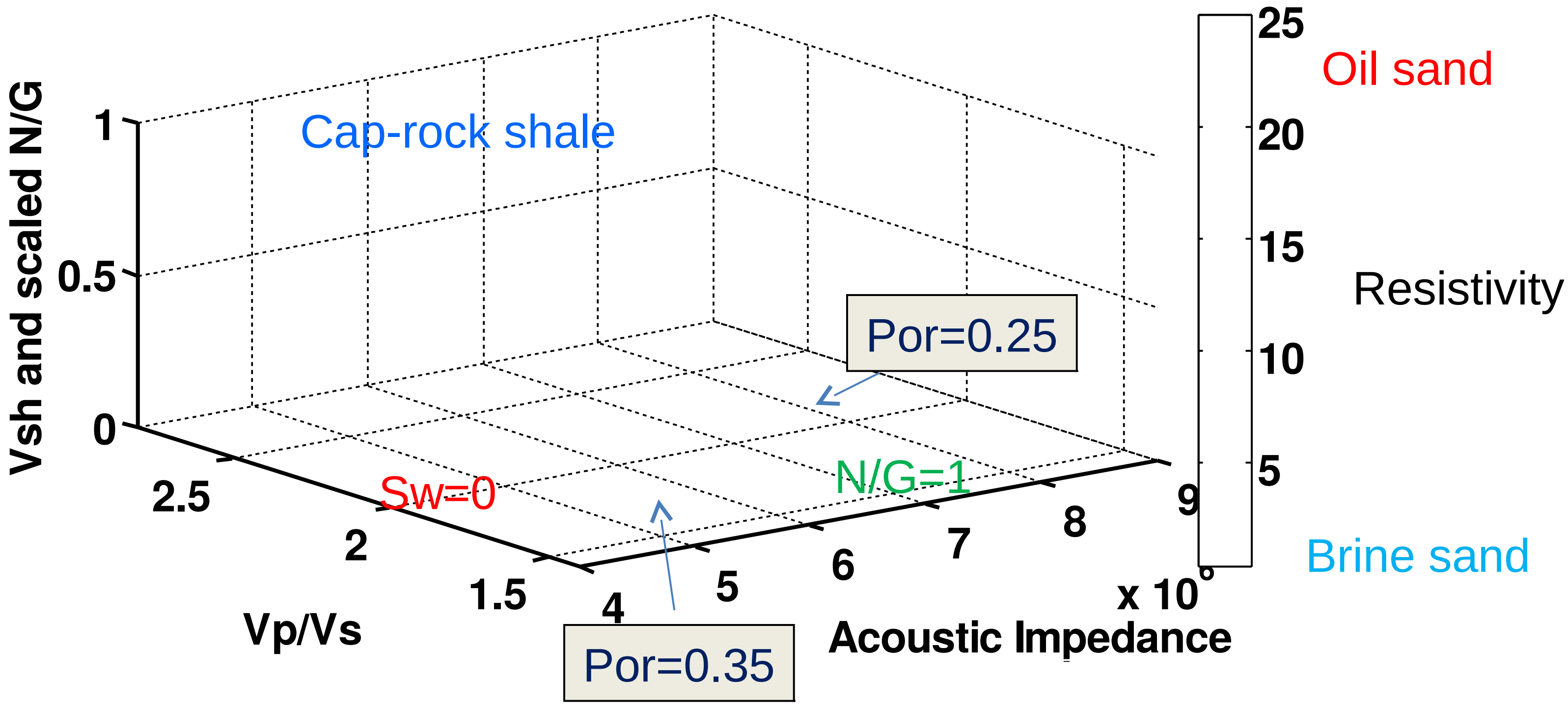
Effective rock



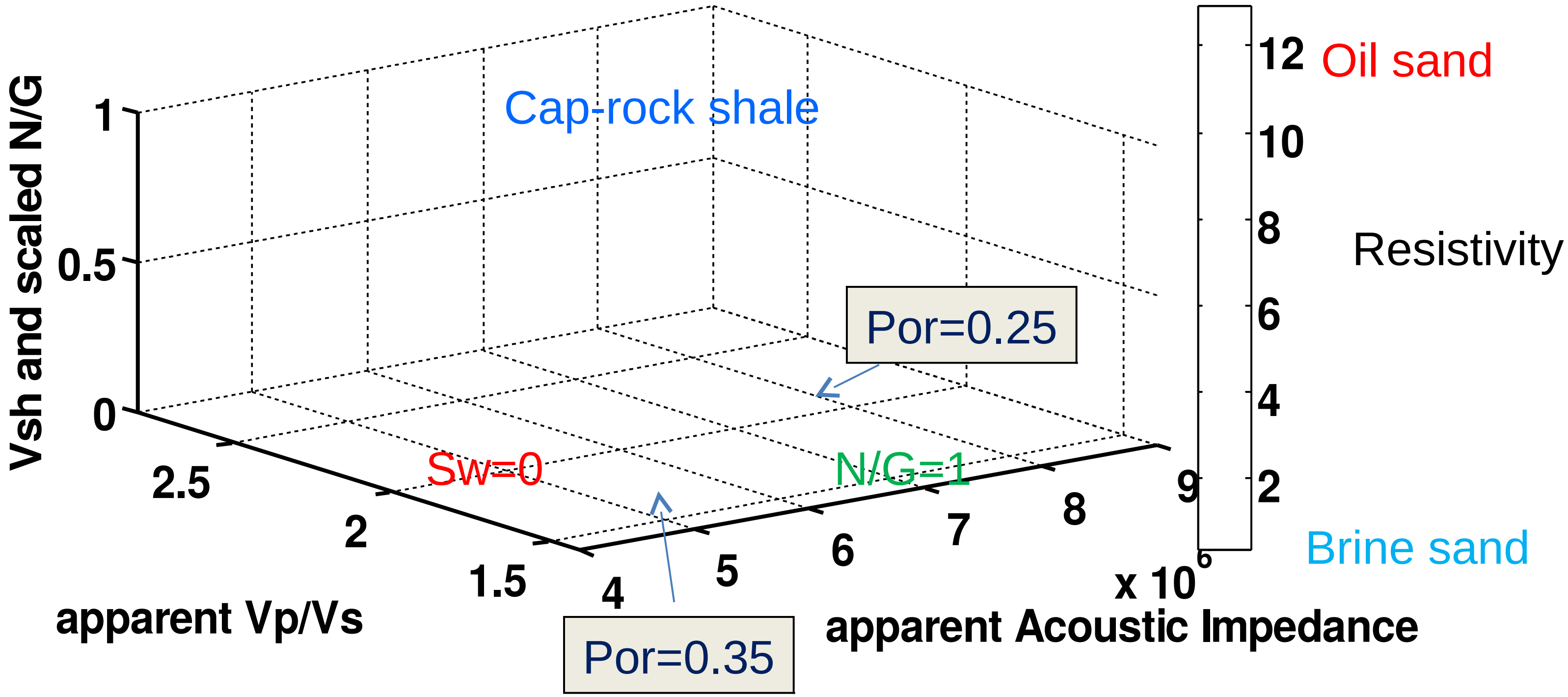
3. Backup average and upscaling to effectively anisotropic medium, for varying net-to-gross (0 to 1).

$$V(\theta) = f(C_{11}, C_{13}, C_{33}, C_{44}, C_{66}, \rho)$$

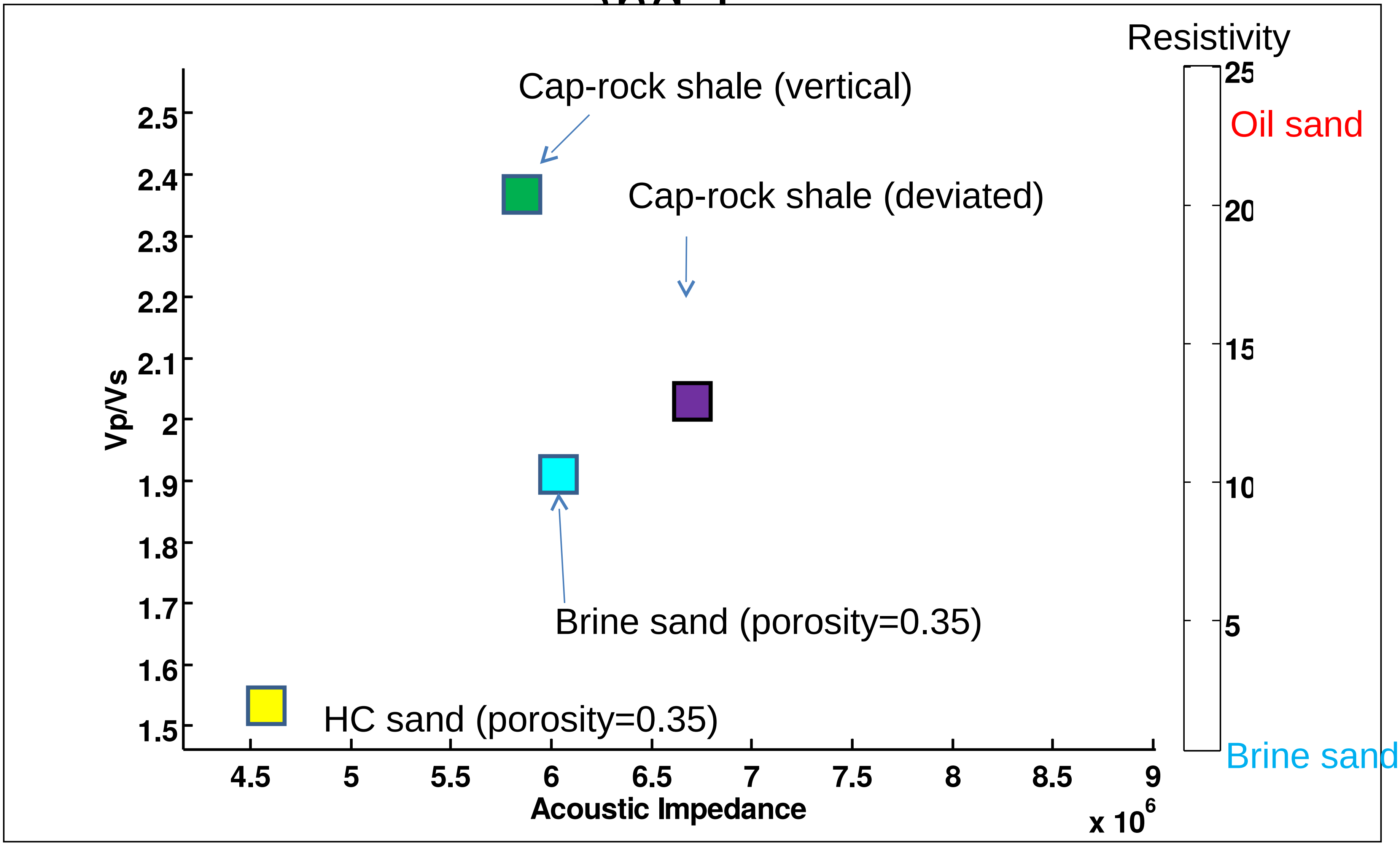
Modeling results and data observations (vertical well)



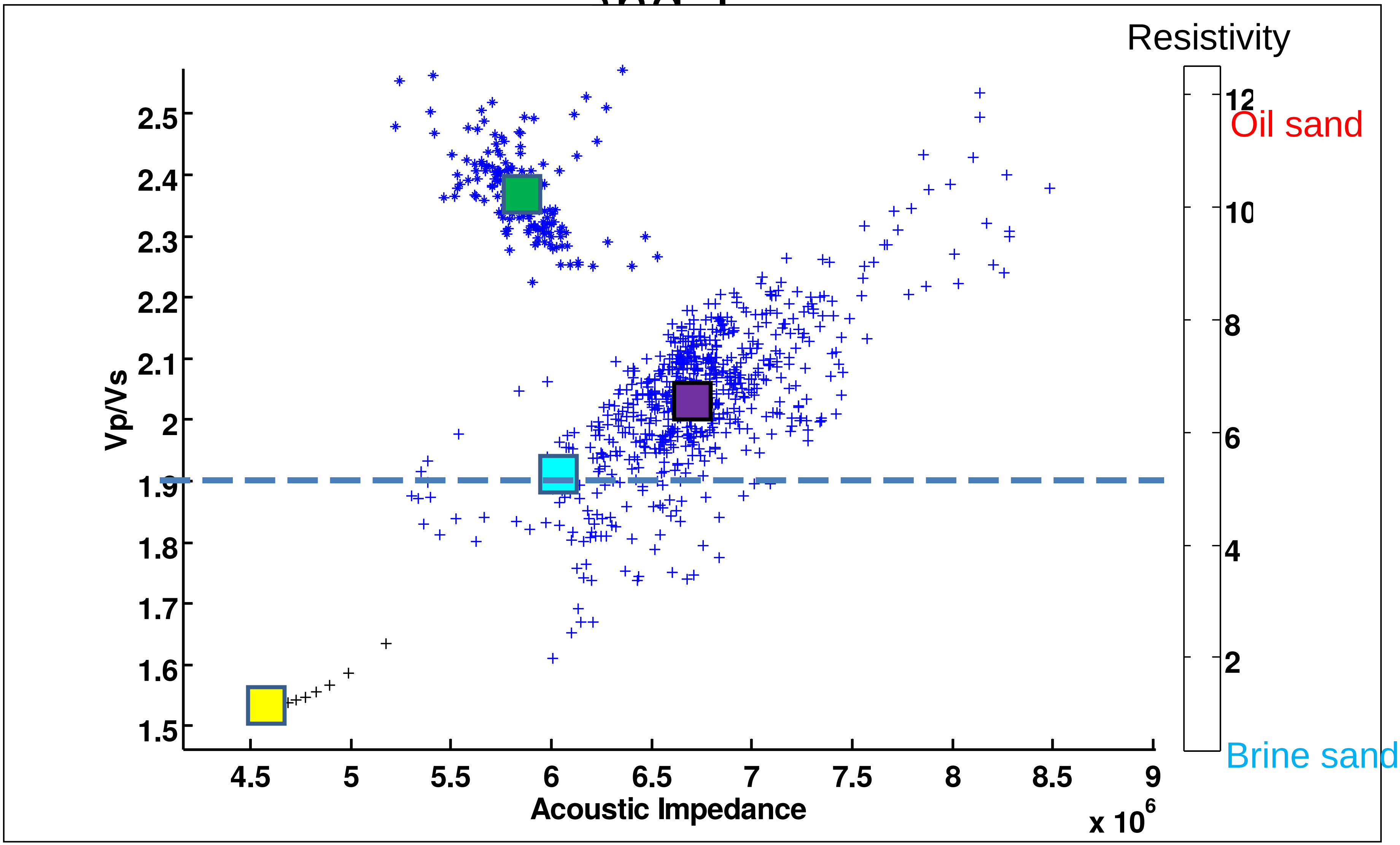
Modeling results and data observations (deviated well)



Vertical well
Porosity=0.35, N/G and Sw vary between 0 and 1



Deviated well
Porosity=0.35, N/G and Sw vary between 0 and 1



Conclusions and further work

- We are able to quantify shale anisotropy in North Sea shales from one vertical and one highly deviated well, by a forward scanning procedure of Thomsen parameters.
- We apply the estimated shale anisotropy in modeling and interpretation of underlying heterolithic reservoir sandstones, and obtain a good match between model and observations.
- Hydrocarbon filled zones with low N/G can be more easily discriminated from brine sands using Vp/Vs measurements in highly deviated wells, than in vertical wells.
- Future work will study the effect of shale anisotropy and associated uncertainties on seismic detectability of heterogeneous reservoirs.

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