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# Rock Physics of Organic Shale and Its Implication

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## Summary

Using Eagle Ford shale as the main focus, we show most significant rock physics issues relating to both petrophysical and seismic inversion interpretation in organic shales in general. Starting with newly developed petrophysical model that allows us to quantify TOC, total porosity, organic porosity and saturation we proceed to the rock physics model designed for highly anisotropic unconventional reservoirs. The model is based on the key variables controlling elastic wave velocities: Mineral matrix, porosity, pore geometry, and effective stress. The latter is handled via the stress-dependent crack density term. Main aspects of anisotropy are treated using both small scale core measurements and Backus modeling of end-member lithologies to demonstrate that velocity anisotropy is primarily affected by clay particle and kerogen preferred orientation parallel to bedding plane. Anisotropic geomechanical properties of organic shales are investigated using both core and log data and rock physics templates are used to quanify fracture gradient from simultaneous acoustic and shear impedance inversion of prestack seismic data.

## Introduction

Despite many recent publications, rock physics of organic shales with all their geographical perculiarities is still poorly developed. Here we utilize rock physics models published by Vernik and Kachanov (2010) and Vernik and Milovac (2011) with primary focus on vertical (bedding normal) velocities, allowing us to interpret standard logs in term of both petrophysical and geomechanical properties. The templates developed on log scale can then be utilized for quantitative analysis of prestack inversion of seismic data and, hence, for 3D model building of unconventional reservoirs.

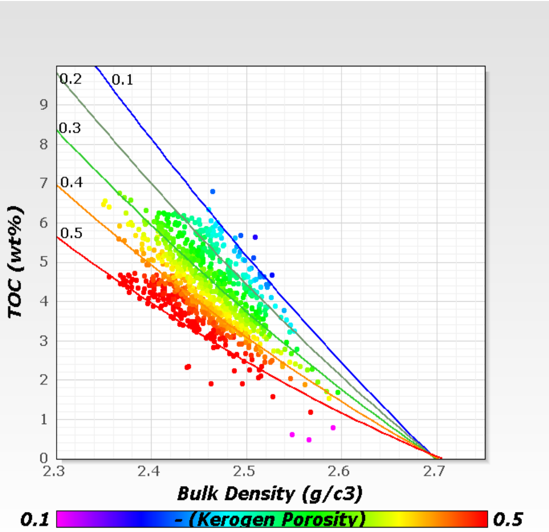


Figure 1: Log-derived TOC vs bulk density crossplot for Eagle Ford shale.

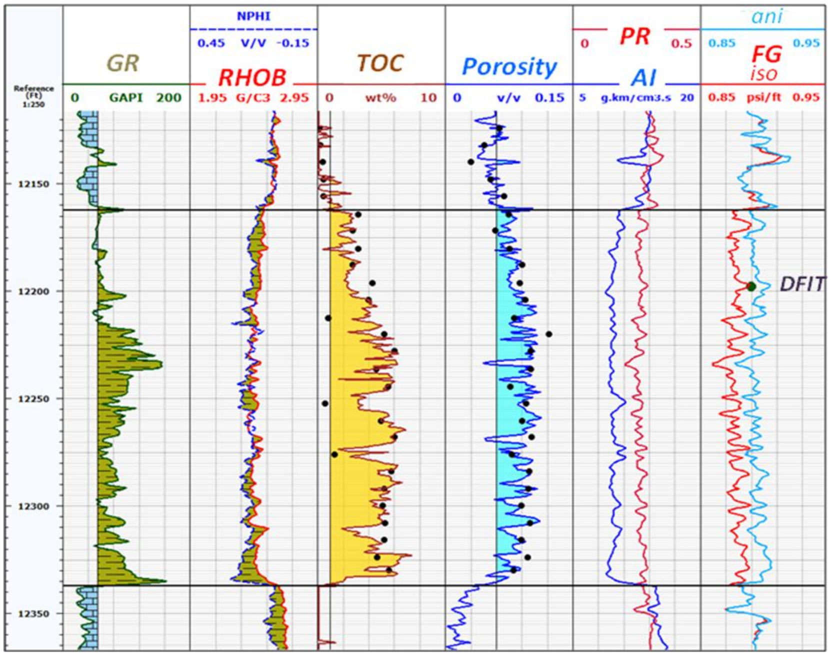


Figure 2: Petrophysical model display of Eagle Ford Shale

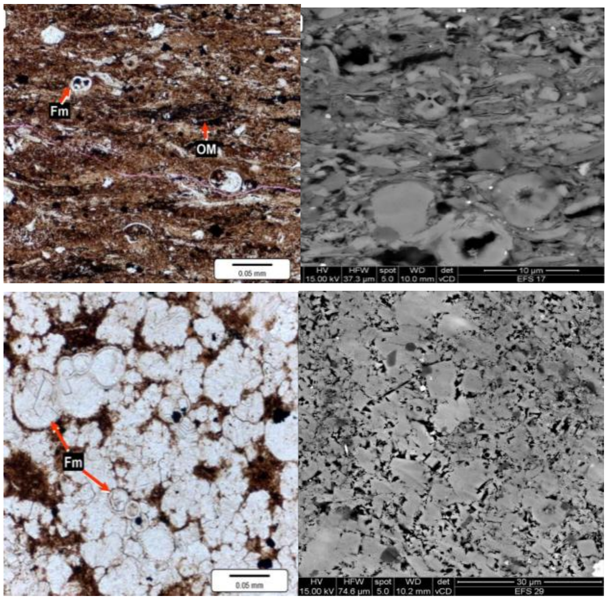


Figure 3: Main rock elements of Eagle Ford shale: Organic Marl (top, thin section and SEM) and Organic Limestone (bottom, thin section and SEM)

$$C_{33} = \frac{C_{33m}}{1 + p\phi + c\,\eta_o \exp(-d\sigma)}$$

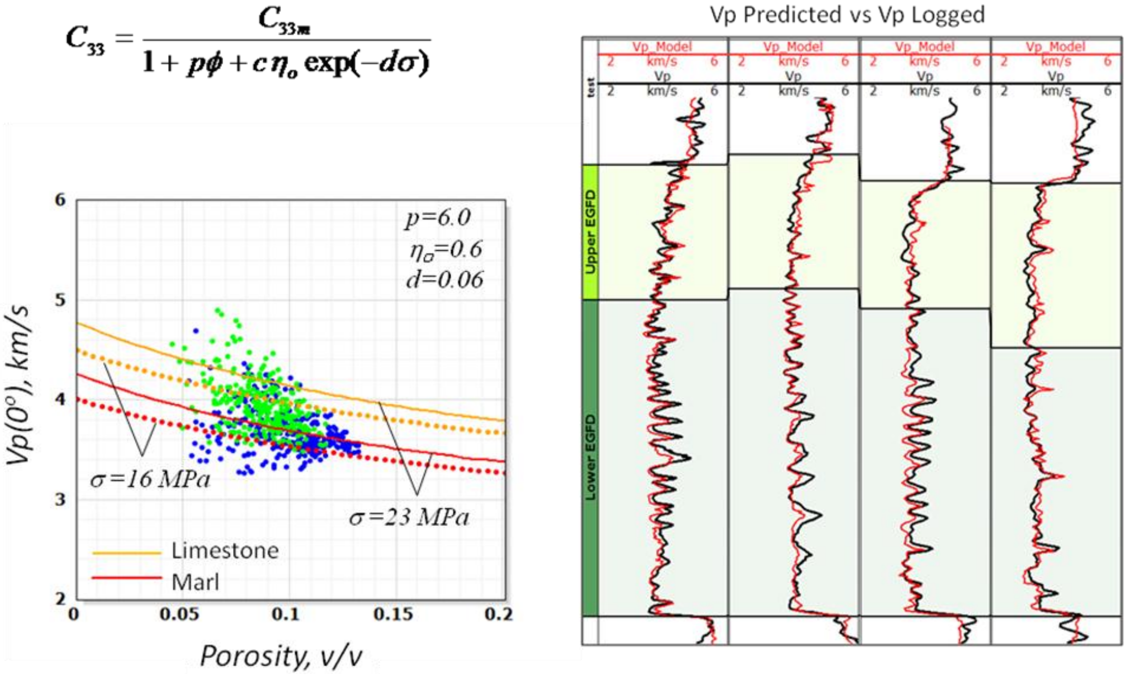


Figure 4: Rock physics model for bedding normal direction and its application to predict Vp in four Eagle Ford wells with sonic logs.

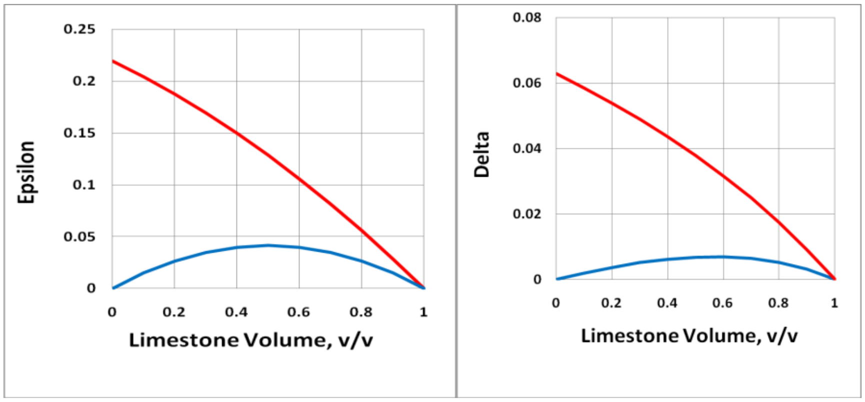


Figure 5: VTI anisotropy modeling using Backus equations. Locally anisotropic marls (ε=0.22, δ=0.06) are shown in red, while locally isotropic ones are in blue.

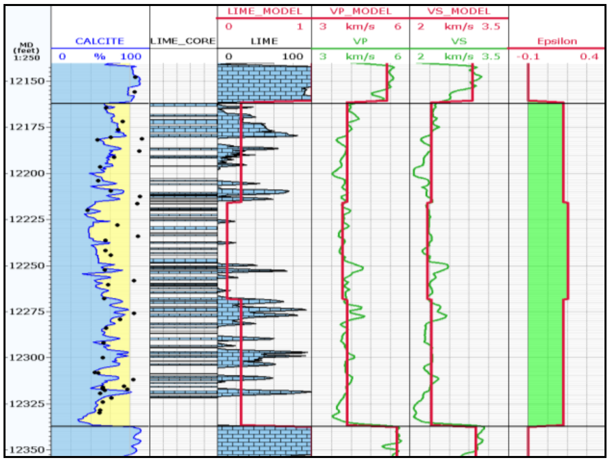


Figure 6: Upscaling seismic rock properties from log to member scale

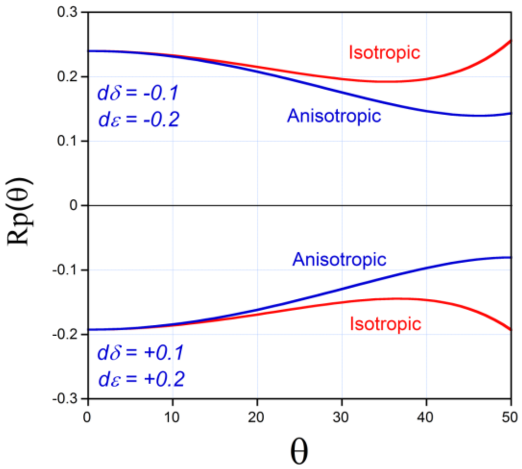


Figure 7: Half-space AVA models for top/base Eagle Ford shale – Class IV AVO response is expected.

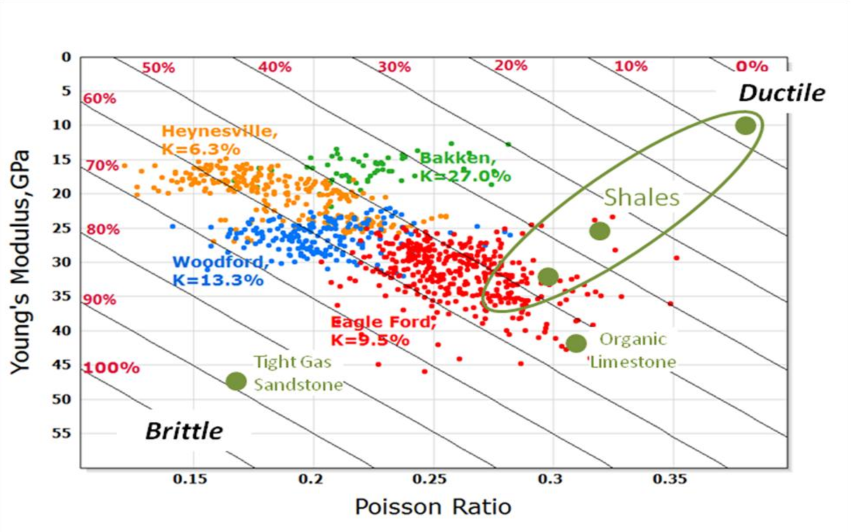
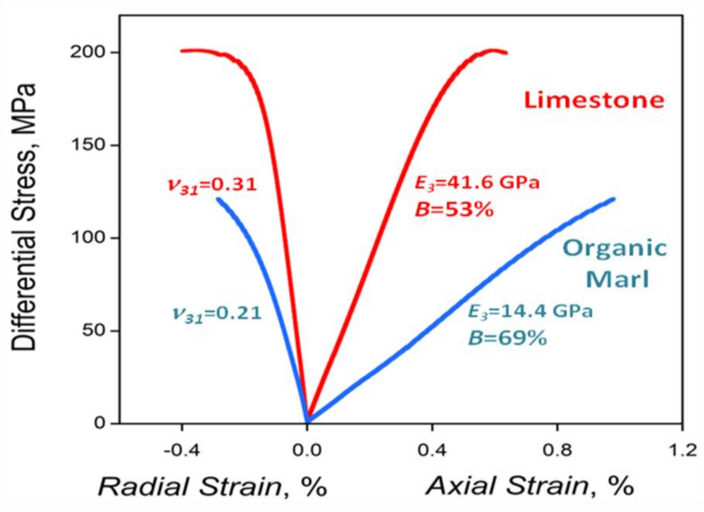


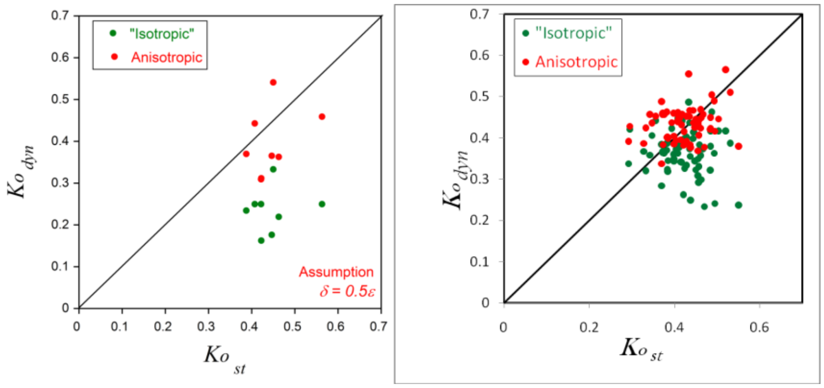
Figure 8: Half-space AVA models for top/base Eagle Ford shale – Class IV AVO response is expected.



'Brittleness'

$$B = \frac{\varepsilon_y}{\varepsilon_f}$$

Figure 9: Triaxial testing of major Eagle Ford lithologies.



$$FP = K_o(Sv - \alpha Pp) + \alpha Pp$$

$$K_o = \frac{C_{13}}{C_{33}} = \frac{\nu_{13}}{1 - \nu_{12}}$$

$$\nu_{31} \neq \nu_{13} \neq \nu_{12}$$

Figure 10: Stress coupling factor: Static vs. Dynamic. Left – $E_1/E_3$>1.5, right – $E_1/E_3$<1.5.

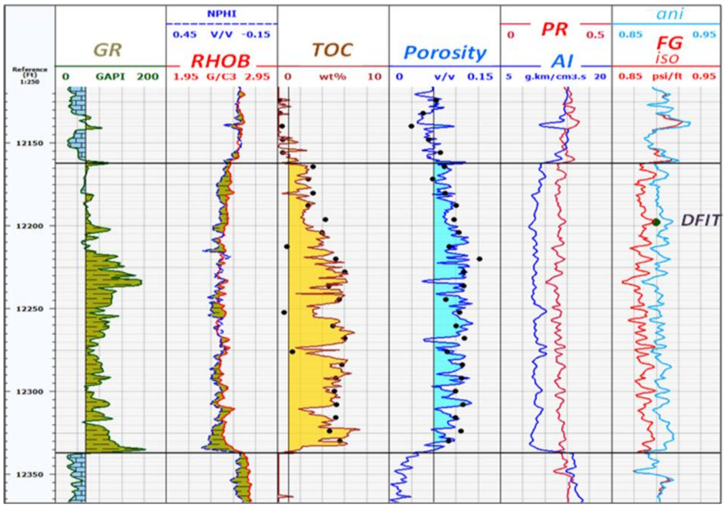


Figure 10: Log-based fracture gradient vs DFIT test result.

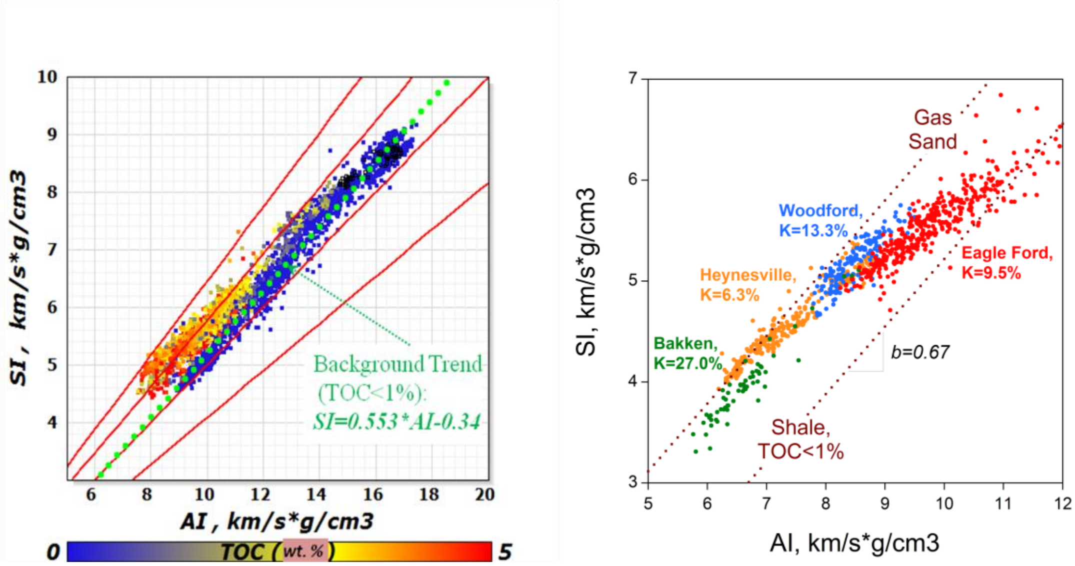
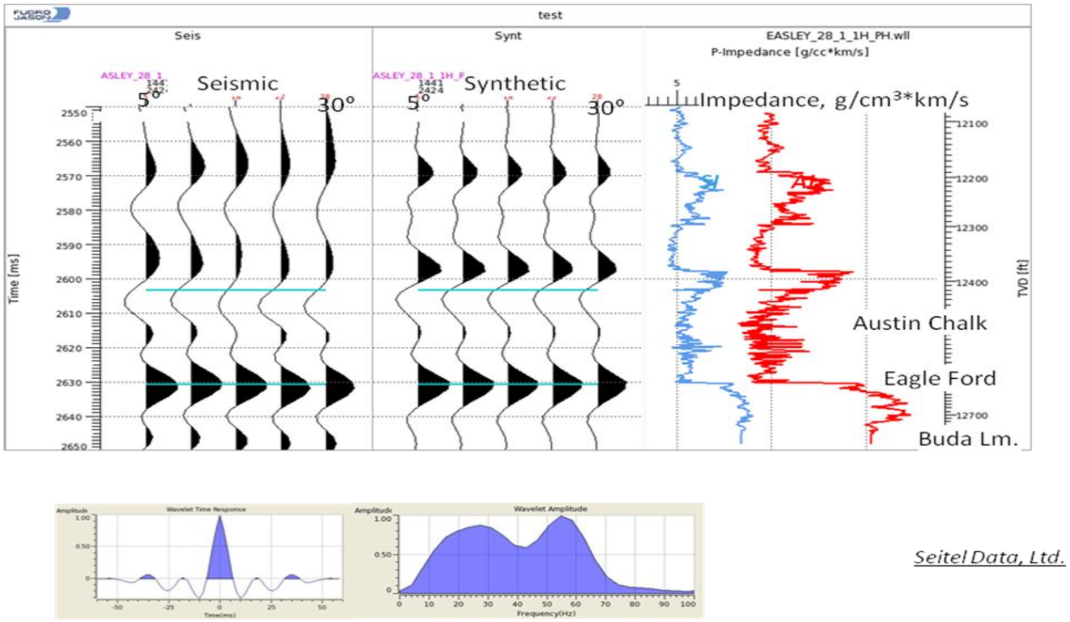


Figure 11: AI-SI template for unconventional shales (red linear lines on left are fracture gradients from 0.8 to 0.95 psi/ft)



*Seitel Data, Ltd.*

Figure 12: Seismic vs synthetic well tie showing predicted Class IV AVO response on top/base.

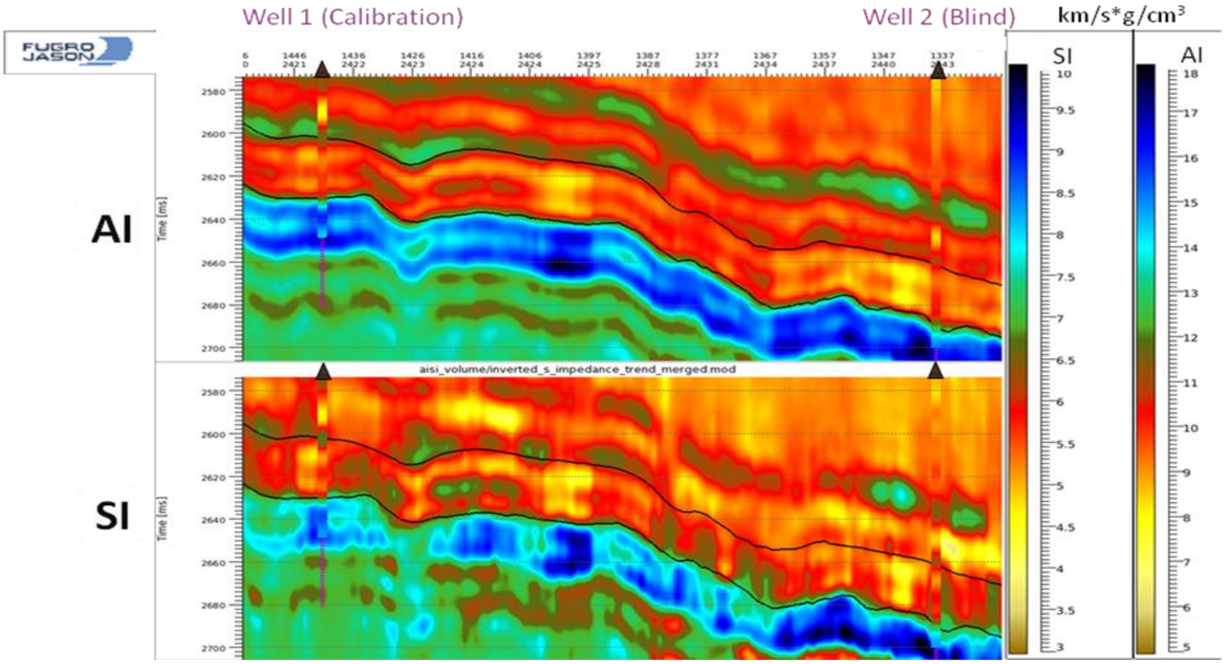


Figure 13: Simultaneous AI-SI prestack inversion of seismic data with well control.

## Conclusions

- ☐ Sonic velocity and porosity of organic mudstones can be predicted using a combination of the material balance model (Alfred and Vernik, 2012) and rock physics model (Vernik and Kachanov, 2010)

- ☐ Elastic anisotropy of organic mudstones makes them distinct among other sedimentary rocks; this property remains significant in upscaled models and must be account for in inversion

- “Brittleness Index” computed using elastic properties is unlikely to reflect real brittleness of organic mudstones – more elaborate triaxial tests will need to conducted to address the problem

- Fracture gradient (i.e., fracability) of organic mudstones is inversely related to TOC; the effect of anisotropy can be negligible even in moderately anisotropic rocks

- AI-SI crossplot reveals interesting trends related to organic richness as well as other mineralogicalpeculiarities of organic mudstones

- Simultaneous AI-SI inversion of prestack seismic data using Jason’s RockTrace software yields fairly accurate characterization of Eagle Ford reservoir

## Acknowledgements

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### References

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