Fault Seal Analysis: Constraining Fault Seal Risk Using Seismic Velocities*

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Abstract

Fault seal capacity is an important component in the conventional petroleum system. Assessing the capacity for a fault to seal or leak can be difficult to determine, particularly where well constraint is lacking. In the frontier basin, in a marine setting, seismic velocities may be the only data available. However, useful constraints on a faults sealing capacity can be extracted from this data alone. This study investigates the robustness of a number of empirical relations that can assist in extracting useful constraints from seismic velocities and amplitudes. Information on maximum and minimum stress magnitudes and pore pressures can be calculated and combined with basic fault architecture analysis, to place practical constraints on fault risk. A study area on the Rankin Trend, North West Shelf of Australia, found good correlation between well-based and seismic velocity-based pore pressures and stress magnitudes allowing a Coulomb Failure Function to be calculated. Faults separating the Rankin 1 well block from the Dockrell/Keast Field were shown to be within a stable stress regime. Well data for this area confirms a SHmax orientation of approximately 110° N +/− 10° indicating that steeply dipping faults striking within 20° of this direction may be at high risk of failure within the neotectonic setting, where stress magnitudes, pore pressures, and fault geometry predicate fault slip.

Selected References

Bowers, G.L., 1995, Pore Pressure Estimation From Velocity Data: Accounting for Overpressure Mechanism Besides Undercompaction: SPE Drilling and Completion, 27488, p. 89-95.

Keep, M., and S.J. Moss, 2000, Basement reactivation and control of Neogene structures in the Outer Browse Basin, North West Shelf: Exploration Geophysics, v. 31, p. 424-432.
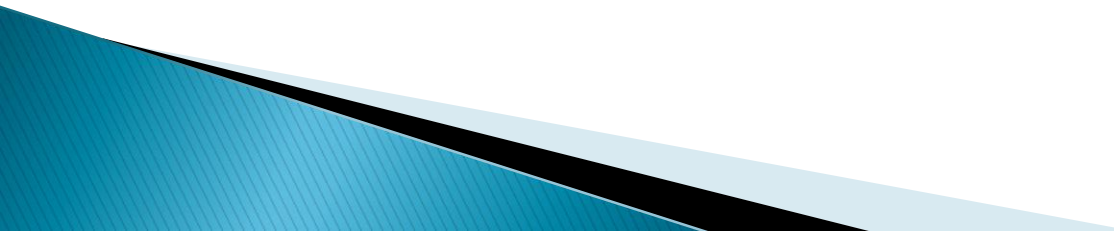
Fault Seal Analysis: Constraining fault seal risk using seismic velocities

Toby Colson

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Outline

- Motivation – The leaky fault
- Study area – Rankin Trend
- Fault architecture of study area
- Velocity profile
- Velocity based estimation of pore pressure and the Coulomb Failure Function
- Conclusions

Questions

- Fault seal capacity is a direct reflection of the permeability of the resulting fault gouge and dependent on several factors, including the seismicity of the fault and stress state conditions necessary for fault reactivation.

- The Coulomb Failure Function describes this critical condition useful in assessing fault risk.

- This study investigated of the robustness of using standard rock physics models to utilise seismic data for estimation of the Coulomb Failure Function.

West Dampier and Rankin Trend, North West Shelf Australia
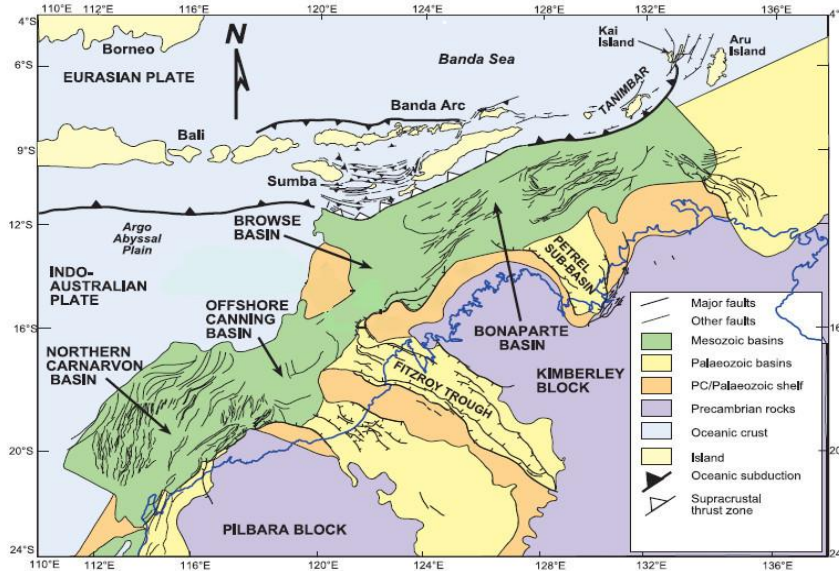
Modified from Keep, M. and Moss, S.J., 2000. Basement reactivation and control of Neogene structures in the Outer Browse Basin, North West Shelf. Exploration Geophysics, 31: 424–432.

Geoscience Australia 2012: AUSTRALIA 2012 Offshore Petroleum Exploration Acreage Release
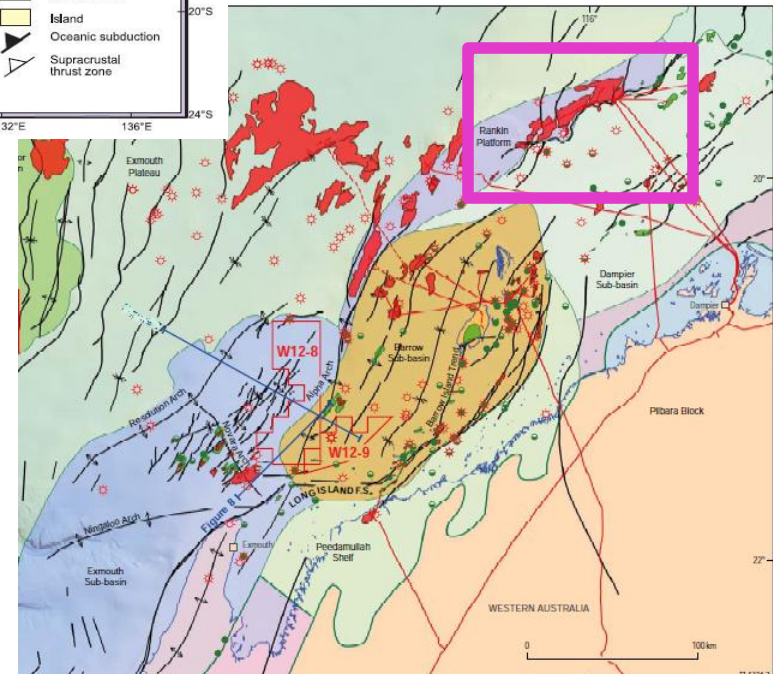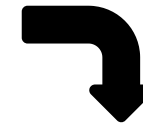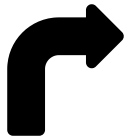
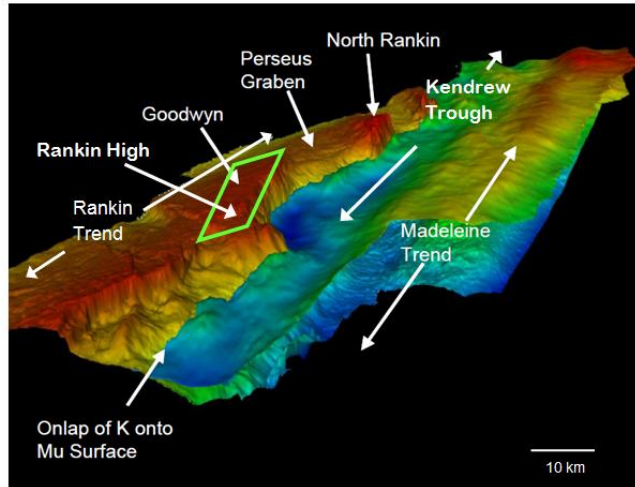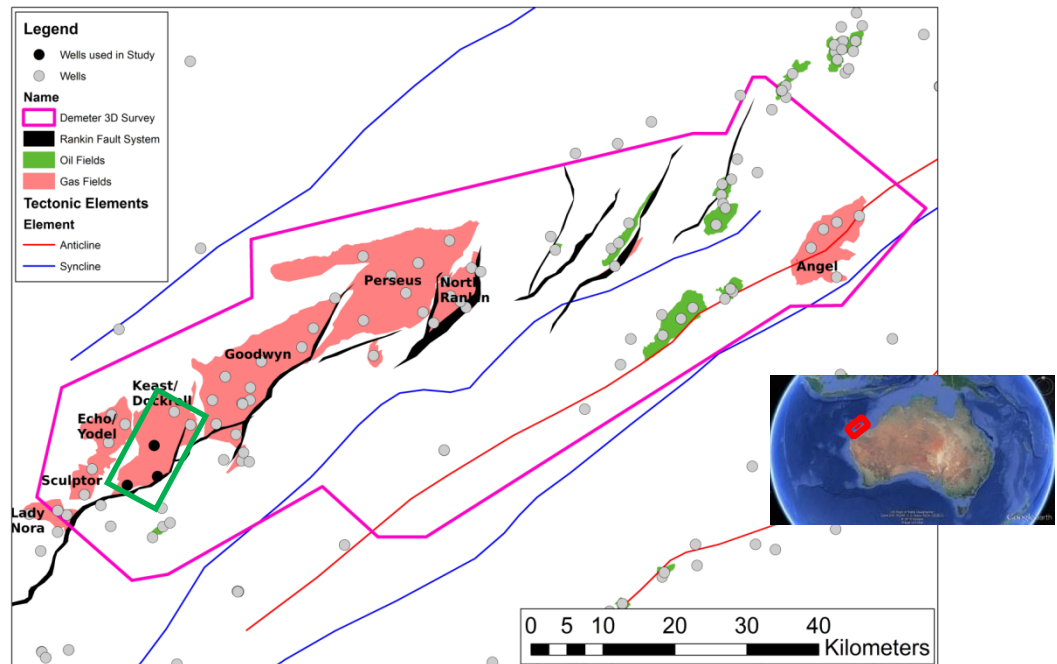# Demeter 3D MSS and the study area over the Rankin Block

Image modified from Bennett, K., 2005. Demeter 3D Seismic Interpretation Report, Northwest Shelf Venture Area, Carnarvon Basin, Australia., Woodside Petroleum Ltd.

Survey	Inlines	Crosslines	Depth Range (ms)	Bin Size	Area (km^2)
Demeter 3D - subset	**1800**	**1400**	**0 - 6000**	**6.25 x 25**	**394**
HDVA Vels	**900**	**1400**	**32 sampling interval**	**12.5 x 25**	**394**

Velocity profile accross the base Norian Horizon
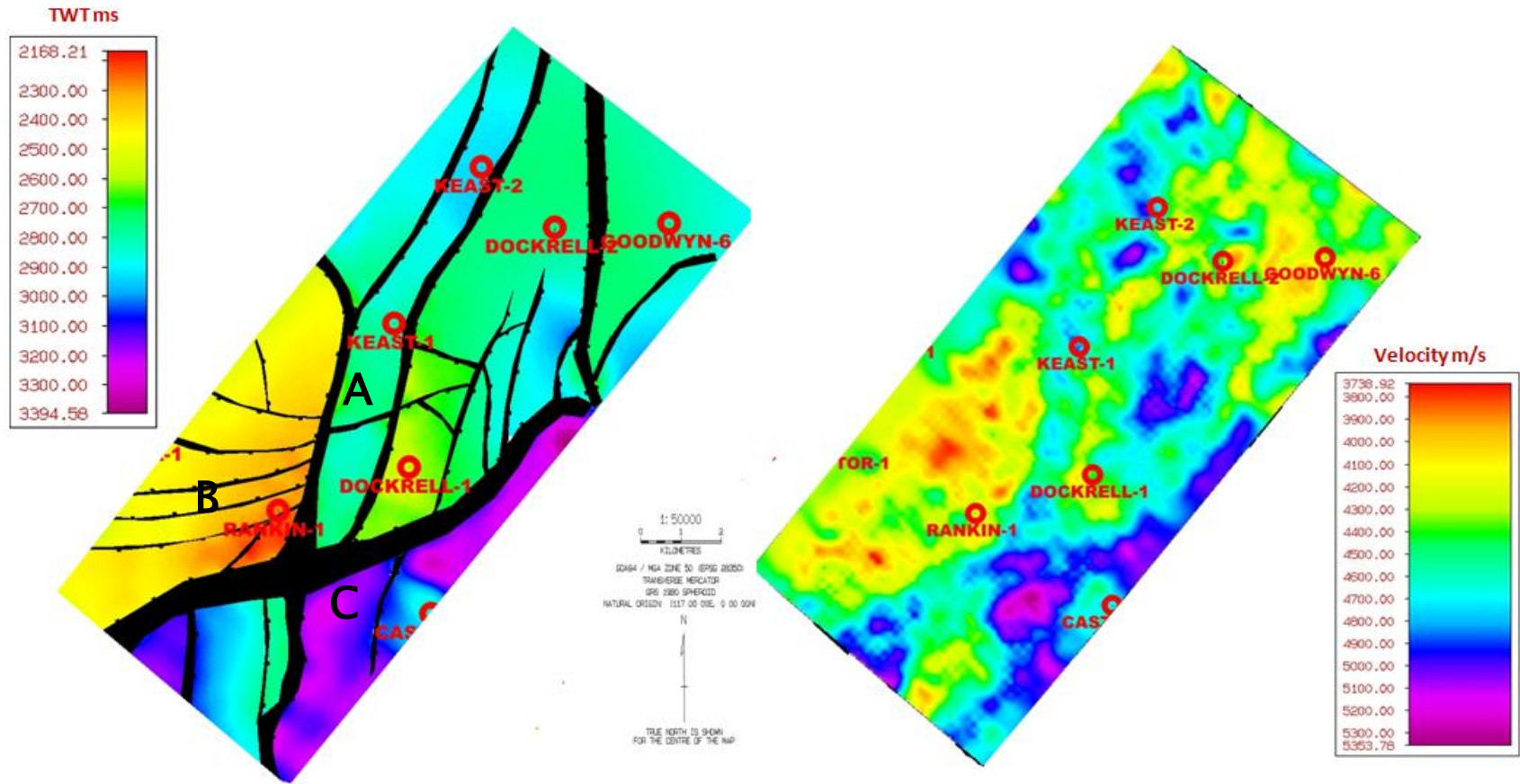
Fault Architecture of the study area
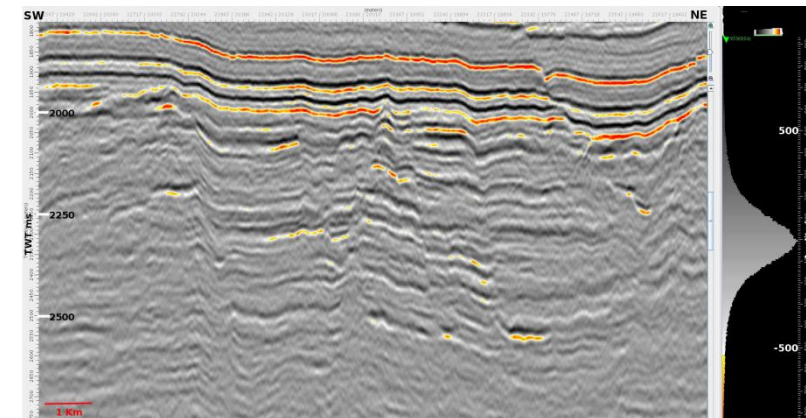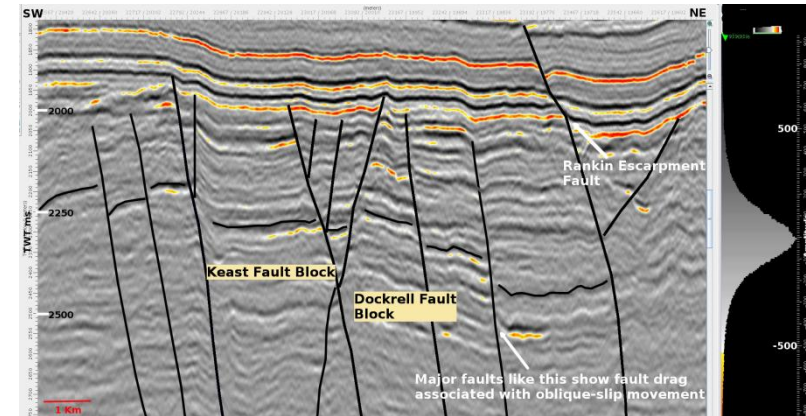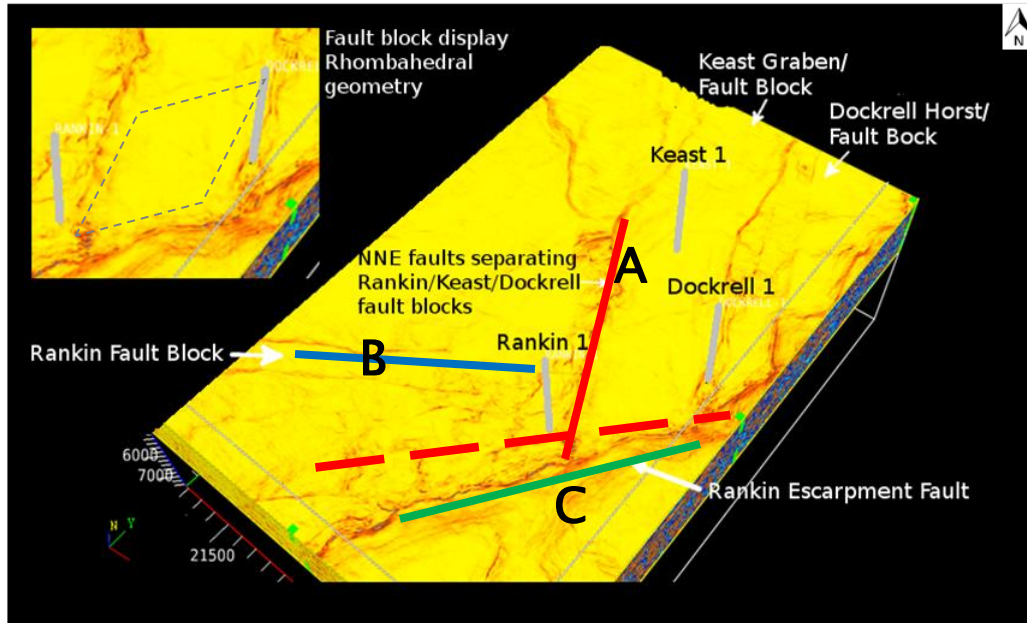
Stress tensors and the Coulomb Failure Function

The Coulomb Failure Function

$$CFF = \sigma_s - \mu_s(\sigma_n - Pp)$$

▸ The Overburden

$$S_v = \rho_w g z_w + \int_{sb}^{z} \rho(z) g \, dz$$

ρ density
g gravity
z depth

Density Relationships for Rankin 1

Bulk density (g/mm3)

1.5	1.7	1.9	2.1	2.3	2.5	2.7	2.9

Depth (mTVDSS)

0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000

◇ Density log data
● Castagna's 1993 relationship
▲ Gardner's 1974 relationship
✕ Castagna's 1993 relationship using stacking velocities
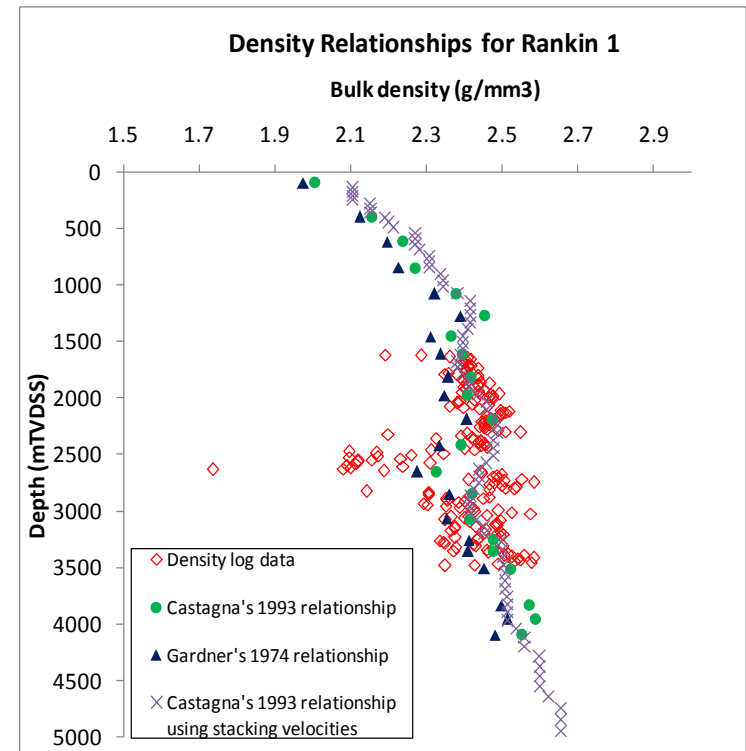
▸ What about horizontal stress (Shmin and Shmax)– Constraining the magnitude?

Minimum horizontal stress

Comparison of Shmin empirical methods to Sh_{min} from LOT

Legend:
- Shmin from empirical Poisson
- Shmin from Porosity relation
- Shmin from Hubbert & Willis (1957)
- Shmin from Zoback & Healy (1984)
- Shmin from LOT trend
- Eaton (1969)
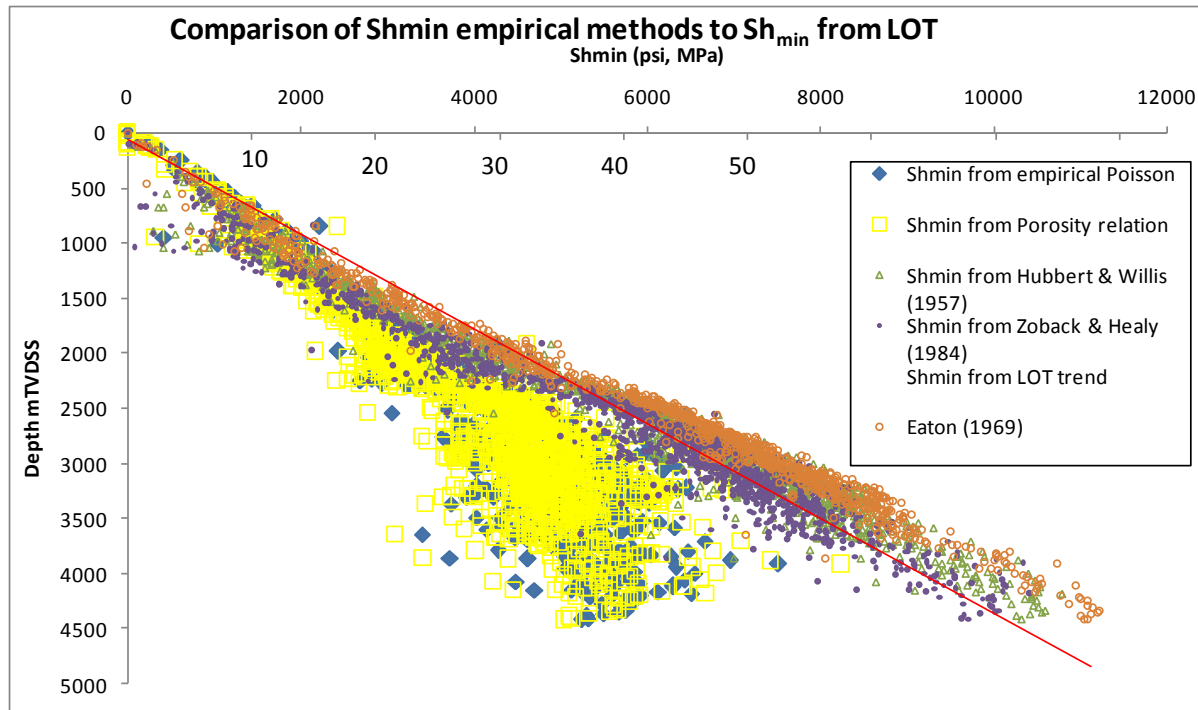
$$\nu = \left(\frac{V_p^2 - 2V_s^2}{2(V_p^2 - V_s^2)} \right) \implies S_{Hmin} = \left(\frac{S_v}{(1/\nu) - 1} \right) \quad ✗$$

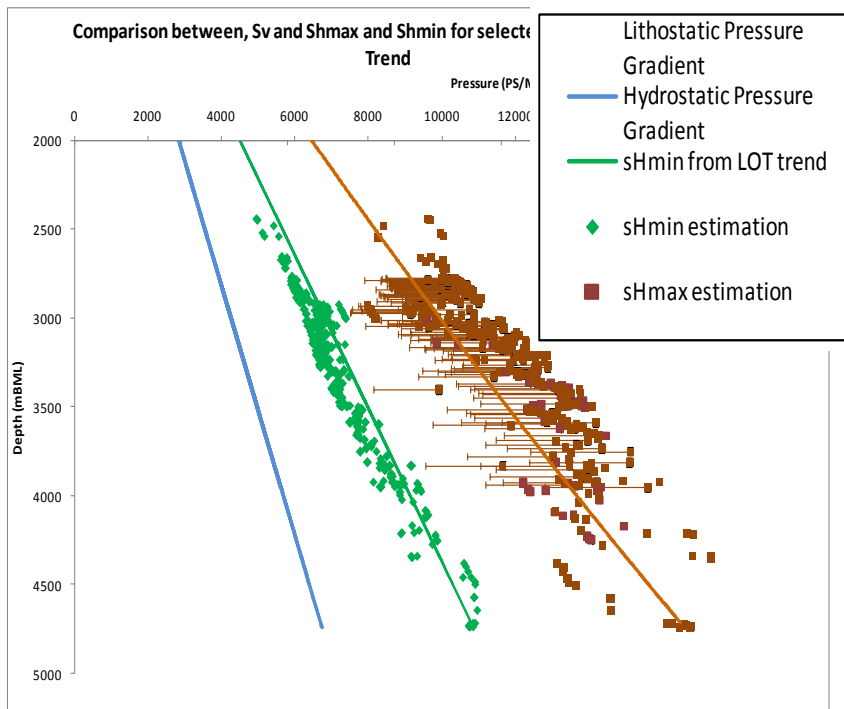$$\boldsymbol{S_{Hmin} = (S_v - P_p)/FF + P_p} \quad ✓$$

ν: poisons ratio,   *Sv: overburden, Pp pore pressure,*

Maximum horizontal stress and the stress regime

Comparison between, Sv and Shmax and Shmin for selected Trend

Lithostatic Pressure Gradient

Hydrostatic Pressure Gradient

sHmin from LOT trend

sHmin estimation

sHmax estimation

Stress Polygon for Rankin 1 at 3149 mTVDSS

TF

SS

NF

Shmax = 9267 $\pm$ 2094 psi / 63.89 $\pm$ 14.44 MPa

Shmin = 7173 psi / 49.46 MPa
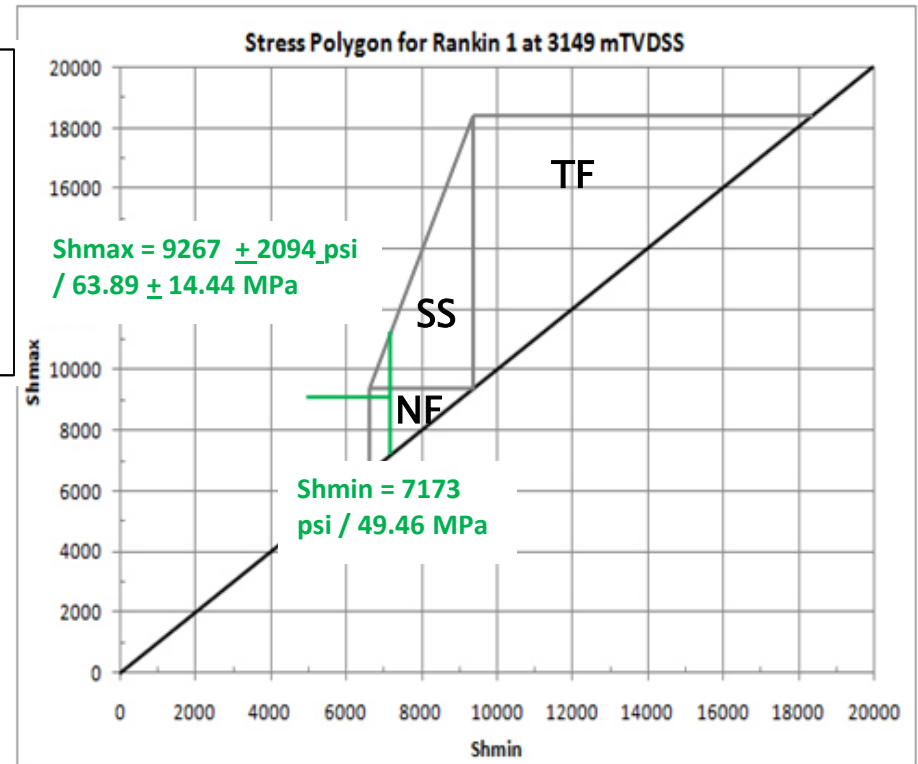
Calculating Pore Pressure from the Velocity

Pore pressure comparison between RFT and velocity measurements on Rankin 1
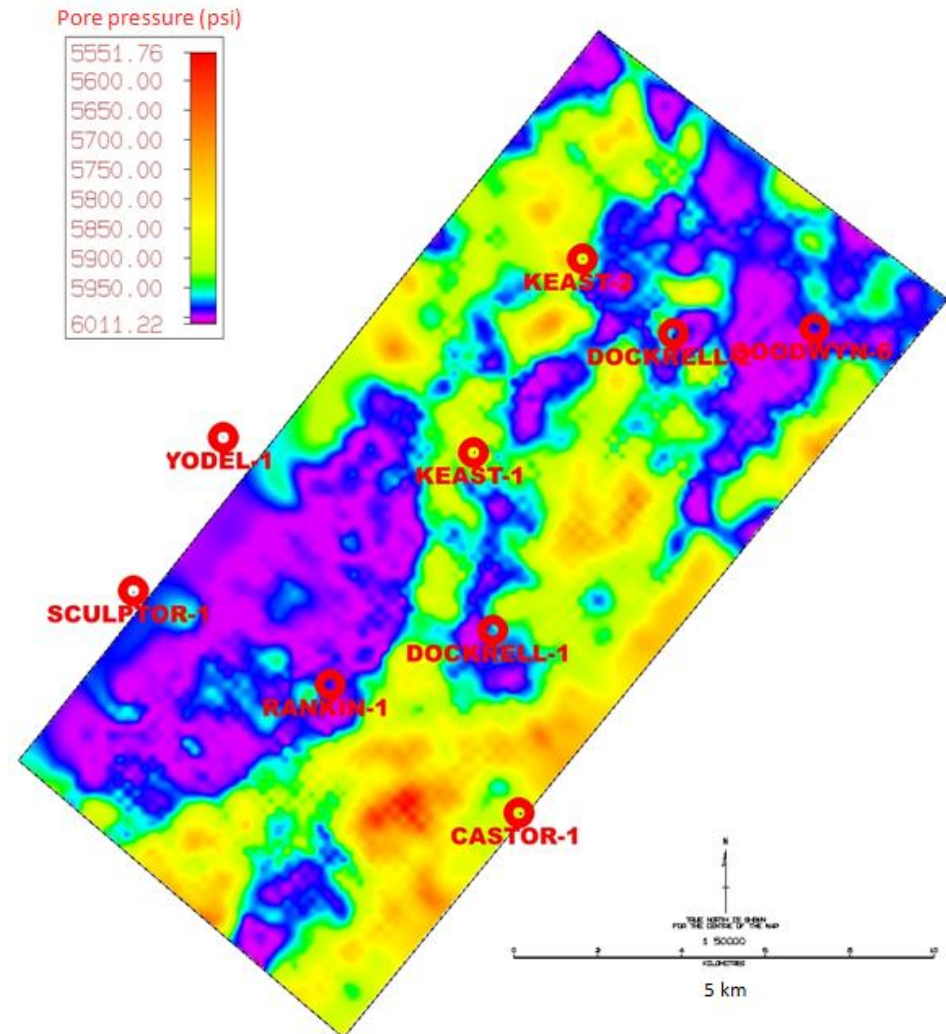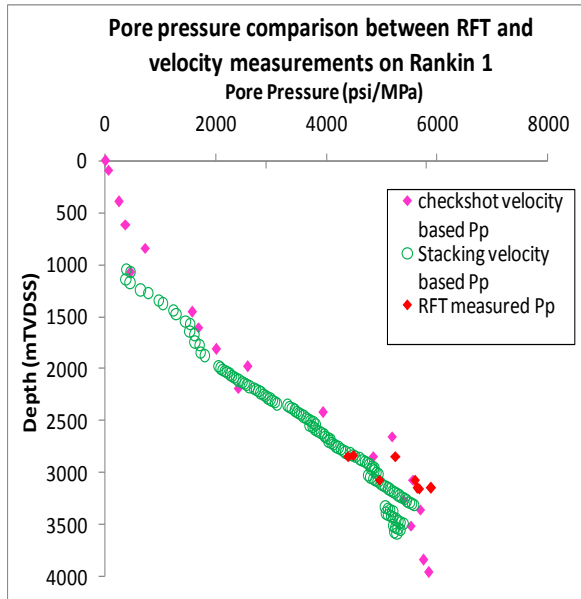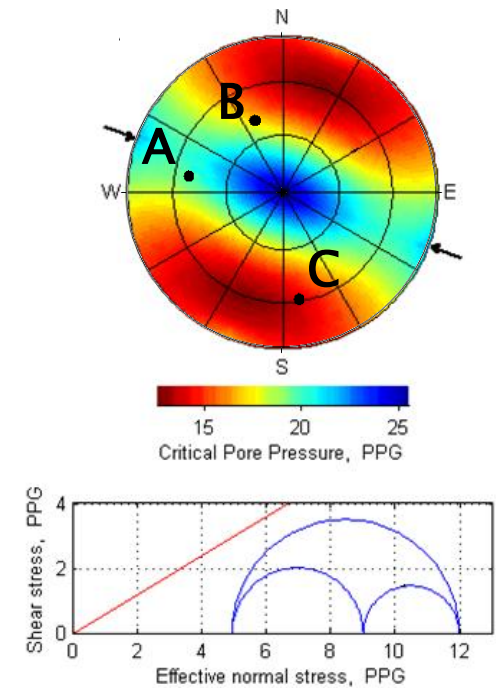

Pore pressure (psi)

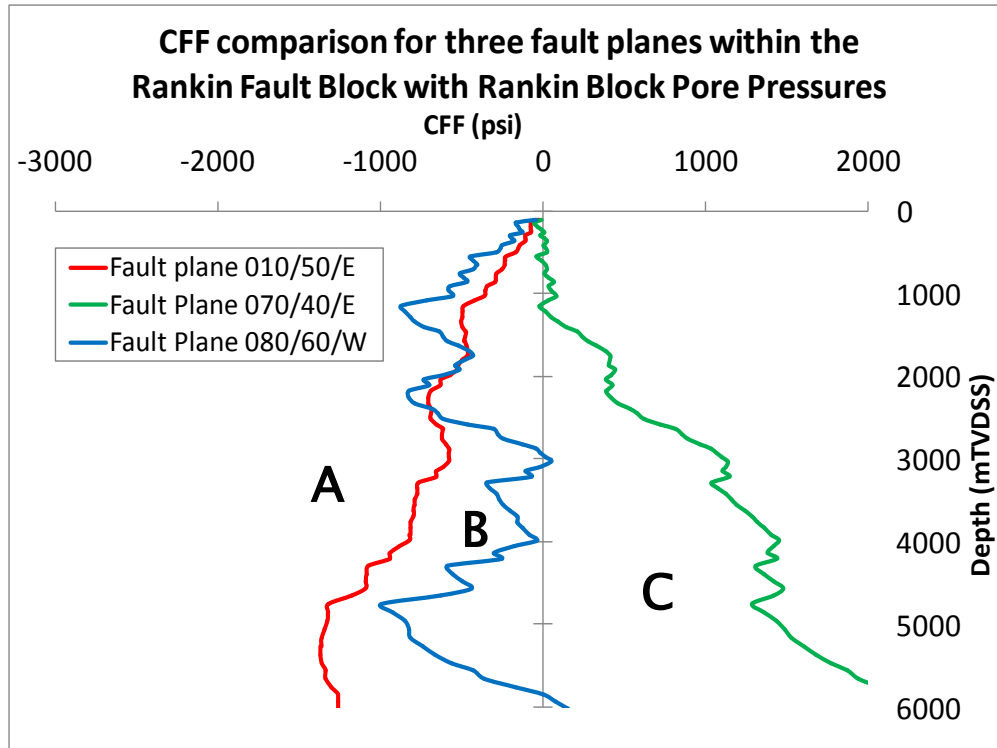## Bowers' Formula

$$P_p = (3.46 * z) - \left(\frac{V_{int} - 1530}{16.5}\right)^{1/0.6}$$

Vint: Interval velocity, Pp pore pressure,

Bowers, G.L., 1995. Pore Pressure Estimation From Velocity Data: Accounting for Overpressure Mechanism Besides Undercompaction. SPE Drilling and Completion. 27488: 89–95.

Which faults might reactivate?

Critically orientated faults show potential for slip in the overpressure 'zone'.

Conclusions

▸ This study has shown that useful constraints on pore pressures and stress tensors can be estimated from seismic velocities.

▸ When combined with a basic fault architecture assessment (dip, strike, sense of offset, and evidence of reactivation), and an understanding of the implications of this architecture in terms of kinematics, an assessment of fault seismicity can be made.

▸ A case study of the Rankin and Dockrell/Keast fault blocks shows that there is correlation between measured data and empirically derived values using standard rock physics models. They show that the main faults separating the Rankin and Dockrell and Keast fault blocks are in a stress regime suggesting further fault reactivation is unlikely.

▸ High vertical sampling and forward modelling of velocities required to achieve the practical degree of confidence recommended for pressure and lithology measurements.

Questions?