Understanding Trapping potential at the Exploration Time scale

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Assessing exploration risk requires an analysis of a range of issues including trap, seal, charge then considering reservoir issues. When risking 3-way structures across-fault juxtaposition and/or membrane seal are key issues. Trap preservation related to fault reactivation may also need be assessed.

Considerable work has been done by a number of workers (Vrolijk 2016) to calibrate membrane sealing. Most notably back calculating the pressure capacity of the Shale Gouge Ratio (SGR) algorithm, to allow forecasting of columns. Importantly, this back-fitting of SGR and seal capacity has been conducted on single “best” technical models with no direct modelling of uncertainty (Yielding 2002).

The methods we use considers across-fault leakage from potential hydrocarbon reservoirs, and consider lateral seals due to

- Juxtaposition
- Juxtaposition combined with impermeable/high capillary entry pressure fault rocks such as clay gouge or other fault related materials (membrane seal).

Monte Carlo simulation is used to model both geometrical and stratigraphic uncertainty. The Monte Carlo analysis produces multiple 3D Allan maps normal to fault plane models (Allan 1989) which are analysed for juxtaposition leak points and shale gouge ratio (SGR). To validate the proposed methods, multiple case studies of successful discoveries have been analysed using back testing - for these case studies the model outputs were compared with the independently observed hydrocarbon water contact (IHWC) obtained from drilling. Stochastic juxtaposition analysis with no contribution from fault rock seal or SGR gives the smallest error in estimation of the IHWC.

In general, the application of SGR methods in reservoirs with moderate Vshale artificially increases predicted column heights and enhances pre-drill chance of success. In well run risking processes these large columns are generally discounted through other geologic risk factors. When shorter columns are found, they are often “explained” by issues of charge or trap breach. It is well known that fault and stratigraphic uncertainties are significant and need to be explicitly included in the modelling of fault seal risk and inferred column heights.

Example Outcrop Mapping of Fault Rock

Whilst geologist commonly use cross sections to describe structures and traps it is vital in fault seal analysis to consider the strike variability of fault rock properties. When considering a strike outcrop in shallow to moderate dipping sediments it is reasonable to assume that over 10’s of meters, along strike, that the throw and stratigraphy are consistent.

Using a systematic approach to catalogue both how thick but also how thin the fault rocks are. As can be seen in Figure 1 a strike section of a fault that fault rock varies in thickness dramatically over the 10’s of centimetres scale.

A series of faults in Miri, Sarawak, have been mapped to measure the strike variability of fault rocks. This work greatly helps to understand the limitation of membrane seal algorithms (Sosio de Rosa 2018). This work shows that fault rocks become increasingly dissimilar at approximately 2 meters strike length.

The concept of a membrane fault rock seal requires a contiguous uninterrupted fault rock that provides a capillary barrier to movement of hydrocarbons into a neighbouring aquifer. Holes in fault rock, fractures and or sand gouge negate this concept. As can be seen in Figure 1 both fault rock holes and fractures are observed.

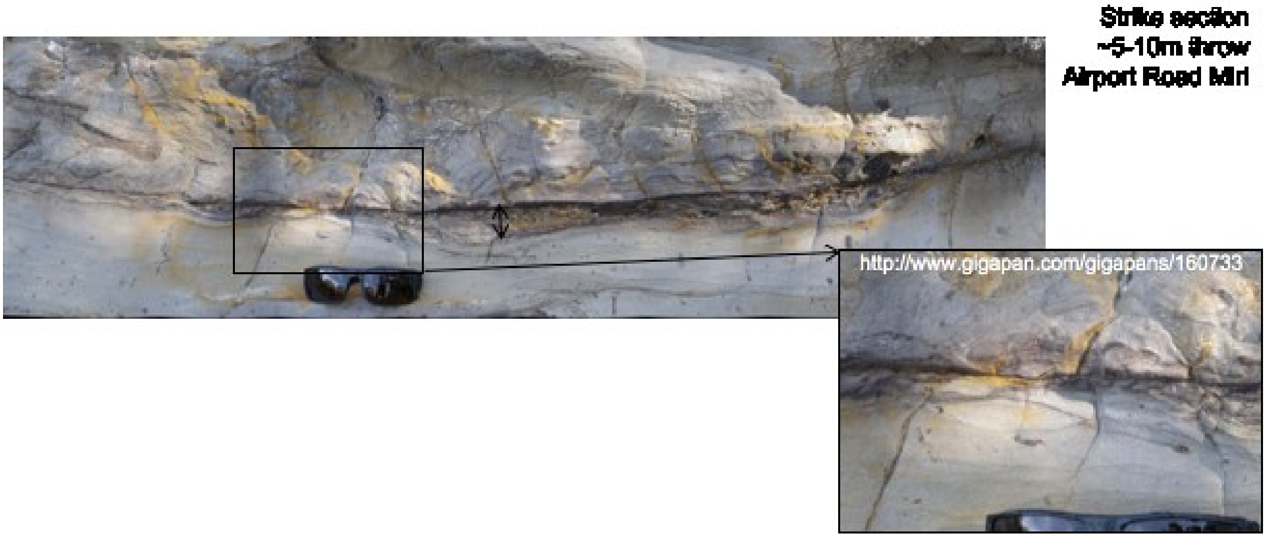

Figure 1 *Strike outcrop view of faults at Airport Road Miri, Miri, Sarwak, Malaysia. It shows significant lateral variations in fault rock over the decimetre scale. A high resolution example of this image can be seen at http://www.gigapan.com/gigapans/160733*

Example Corallina Field – Timor Sea North West Australia

The Corallina field is close to the Timor- Australian territorial boarder North West Australia. When Woodside drilled the Corallina 1 well they found that the Initial Hydrocarbon Water Contact (IHWC) was found to be substantially shallower than expected. In the Woodside Energy 1996 discovery report (Geoscience Australia https://nopims.dmp.wa.gov.au) it was postulated that one of the bounding faults could be leaking. Corallina is amongst a series of under filled fields and dry wells where paleo hydrocarbon columns have been reported and it was suggested that the shallower IHWC is due to a range of fault reactivation phenomena (Castillo et al 2000, de Ruig et al 2000).

Whilst extensive geomechanics and process are proposed no Allan maps are presented. As it was suggested that the fault throw was less than the thickness of the top seal and that no thief zones have been reported (Langhi et al 2010, de Ruig et al., 2000). In de Ruig 2000 a fault reactivation leak point 56m deeper that the IHWC was identified.

The map (from the Corallina-2 well completion report) has 20 m contours, and shows two faults, one on the north side, and one on the south side (Figure 2). The oil water contact, IHWC, based on pressure testing was initially thought and petrophysics was identified at -3219 m. The fill to spill level or lowest closing contour (SSP) is approximately -3330 m, as observed from the map.

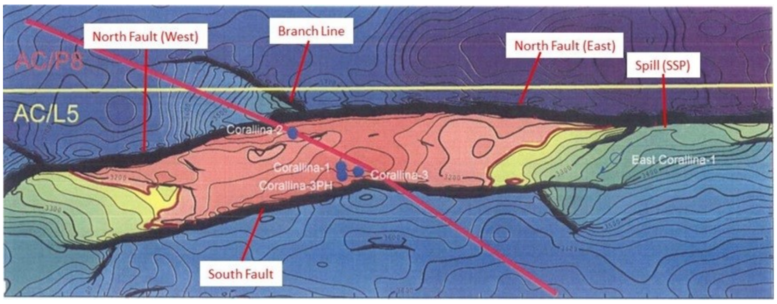

Figure 2 Depth structure contour map of the top Laminaria Formation for the Corallina Field (from the Corallina-2 well completion report).

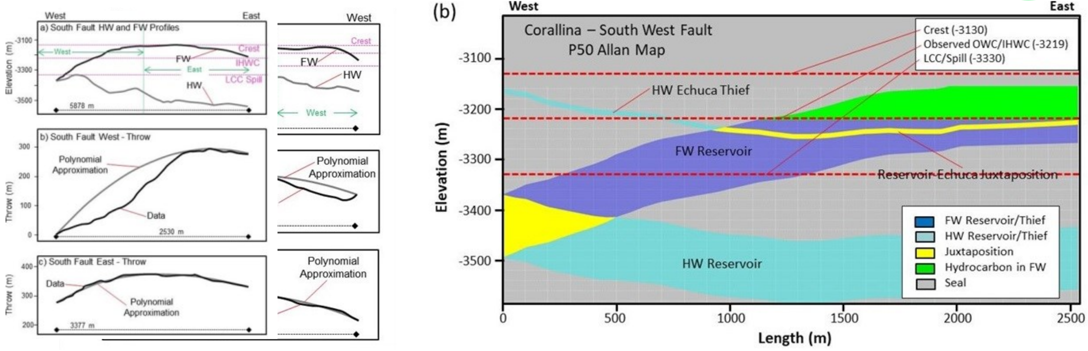

Figure 3 Fault profiles for the North and South Fauls, Corallina. (a) Hanging and foot wall profiles - these are the elevations of the intersections between the South Fault and the Top Laminaria Formation surface. Both faults were reasonably divided into two segments and the throw for the segments is shown in parts (b) and (c)

The map (Figure 2) was used to digitize the top Laminaria Formation intersections with the North and South Faults.

The North Fault was divided into two sections because there is a distinct and clear branch line. To the west of this branch line the north fault has a throw of 300-350 m, and to the east of the branch line, the throw is 560-620 m. The North Fault throw profiles are shown in Figure 6. The South Fault was divided into two sections, based on the throw profile (Figure 3). We used two sections (which are likely the same fault) because we can then achieve a very good match between the observed throw profiles and the polynomial approximation (Figure 3).

Composite logs from Corallina-1 to develop a basic stratigraphy (Figure 4). A key point of our analysis was to use the observed gas logs and completion reports. In these data we found that prominent gas kick started in the Echuca Shoals Formation and/or the Darwin Formation. Although the Echuca Shoals Formation has a high Gamma Ray response, it is a source rock (Palu et al 2017). The observed prolific mud gases show that the unit is transmissive, thus we inferred that this unit could act as a thief zone for the purposes of exploration time scale fault seal analysis.

Stratigraphy	Type	Thicknes			Vshale		
		Min	Mean	Max	Min	Mean	Max
Prion TO	Seal	400	500	600	5%	15%	30%
Hibernia TE	Seal	300	400	500	5%	15%	30%
Bathurst T	Seal	85	115	140	10%	35%	50%
Jamieson KC	Seal	75	85	95	10%	40%	70%
Darwin NKA	Seal	8	10	12	10%	40%	70%
Echuka KA	Thief	20	25	35	20%	40%	60%
Flamingo-Frigate	Seal	190	215	220	50%	70%	90%
Laminaria JO	Reservoir	110	130	150	10%	20%	30%

Figure 4 Probabilistic Stratigraphy

All four fault segments are potentially important in the analysis and were run using the Monte Carlo analysis techniques (Murray 2019). The results suggest that the main juxtapositions of importance are the reservoir when juxtaposed against the Echuca Shoals thief zone, particularly along the central part of the South Fault

Figure 5. Allan Map

In 98% of the realizations have shallowest juxtapositions on the west segment of the South Fault, and 2% on the east segment of the South Fault. SGR seal analysis, 100 % of the realizations fill to spill.

- Juxtaposition mean error 21.7 m with a standard deviation of 12.0 m.
- SGR mean error 111.0 m with a standard deviation of 8.2 m.
- Fault reactivation leak point approximately 57 m (de Ruig et al 2000).

juxtaposition seal provides more accurate OWC error compared with SGR.

This result is consistent with more than one hundred other cases as illustrated in Murray et al 2019.

Conclusions

Our analyses clearly suggest that the addition of SGR and thus any other membrane fault seal mechanisms to juxtaposition analyses can erroneously increase predicted hydrocarbon column height.

Systematic outcrop analysis illustrates that there is no relationship between fault throw, stratigraphy and fault rock type /thickness. Thus drawing serious doubt on the capacity of fault rocks to form a contiguous uninterrupted membrane to provide a capillary seal.

As Primary juxtaposition seal analysis provides a significantly smaller error than secondary juxtaposition augmented with an SGR/membrane seal, we suggest that there is little to no reason to use membrane seal analyses in exploration, unless there is sound validation from nearby fields and dry wells.

We also conclude that a stochastic or probabilistic analysis is essential for a successful hydrocarbon column forecasting because of the number of input parameters, their interrelationships, and the large uncertainties that are inherent in the da

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