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The role of seal integrity in the Vlaming Sub-basin (Perth Basin) for preservation of hydrocarbon accumulations

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SUMMARY

The offshore Vlaming Sub-basin, located in the southern part of the Perth Basin, is a Mesozoic depocentre estimated to contain over 12 km of sediments. It has several potential source rock intervals, good reservoir and seal pairs and an active petroleum system. The reasons for a lack of exploration success in this basin have been re-assessed by analysing fault reactivation and signs of hydrocarbon seepage. A recently completed study integrated structural mapping with analysis of fluid inclusion results. New data and interpretations show that a number of synrift faults with signs of reactivation in seismic data also have Fluid Inclusion Stratigraphy (FIS) anomalies above the regional seal. Many previously identified plays rely on the post-rift South Perth Shale for a seal. Our analysis suggests that many faults were reactivated after the deposition of the South Perth Shale, with some showing signs of present-day reactivation. Reactivated faults provided migration pathways for generated hydrocarbons; therefore, no accumulations were formed at these locations. The study provides insight into the location of leaky structures and areas with potentially valid plays in the Vlaming Sub-basin.

Key words: Vlaming sub-basin, seal integrity, hydrocarbons, petroleum prospectivity.

INTRODUCTION

As part of the National CO_2 Infrastructure Plan, in 2011–13 Geoscience Australia conducted a study assessing the prospectivity of the offshore Vlaming Sub-basin for CO_2 storage. The assessment focused on the post-breakup Gage Sandstone reservoir and the overlying South Perth Shale seal. The study showed that seal integrity is a critical preservation issue both for hydrocarbons and potential storage of CO_2 in the basin.

Seal integrity evaluation was based on the interpretation of seismic data, high-resolution bathymetric data and Fluid Inclusion Stratigraphy (FIS) results from eight wells. The analysis provided evidence of fault reactivation and seepage occurring on some faults throughout the post-rift history.

The Vlaming Sub-basin has been explored for hydrocarbons since the 1960s. Petroleum exploration in the sub-basin demonstrated the presence of an active petroleum system and potential prospectivity both for oil and gas. In the 1970s sub-economic oil accumulations were discovered at Gage Roads 1 and Gage Roads 2. In 1993 a small accumulation of dry gas was discovered in Marri 1. Additionally, in the 1990s, oil shows were detected in Tuart 1 and Araucaria 1.

At least three source rock intervals were identified in the basin with two of them in the oil or oil/gas generation window (Nicholson et al., 2008). It has been estimated that most of the hydrocarbon generation and expulsion occurred in the Valanginian, followed by smaller volumes of generation up to the Cenozoic, and in some parts of the basin hydrocarbons may continue to generate at present (Hall, 1989; Crostella and Backhouse; 2000, Neumann et al., 2007). The primary objective of the exploration wells was to intersect pre-breakup reservoirs located in fault blocks and sealed by the post-breakup South Perth Shale. Petroleum prospectivity assessments (Miyazaki et al., 1996; Crostella and Backhouse, 2000; Nicholson et al., 2008) attributed the lack of exploration success in the Vlaming Sub-basin primarily due to incomplete understanding of structure and insufficient resolution in mapping of the structural closures.

The results of this study show that seal integrity played a crucial role in the preservation of hydrocarbon accumulations in the offshore Vlaming Sub-basin. Therefore, fault reactivation needs to be considered when locating valid plays in this basin.

INTERPRETATIONS AND RESULTS

Fault reactivation

Fault reactivation and seepage signs were mapped using an extensive set of original and reprocessed 2D reflection seismic data and high-resolution bathymetry collected by Geoscience Australia in 2012. Across the sub-basin, the 2D data amounts to over 10 000 line kilometres and is of variable quality and spacing. Figure 1 shows a seismic example of several large synrift faults reactivated to the seabed. The offsets on individual faults are generally small (<20 m) and are just within the resolution of the regional 2D seismic data.

On the seismic line shown in Figure 1, two of the reactivated faults are partly masked by seismic anomalies that could be caused by a number of factors. Some of the most common causes are hydrocarbon seepage and carbonate hardgrounds (Causebrook et al., 2006). The Vlaming Sub-basin was shown to have an active petroleum system (Miyazaki et al., 1996; Crostella and Backhouse, 2000; Nicholson et al., 2008) and, therefore, the anomalies may correspond to gas chimneys. At the same time, the Rottnest Shelf overlying the offshore Vlaming Sub-basin is characterised by a large number of carbonate banks which could account for seismic imaging problems.

Figure 2 shows mapped reactivated faults and seismic anomalies. The majority of reactivated faults are on the eastern flank of the depocentre in the Badaminna Fault Zone. The predominant orientation of reactivated faults is NNE–SSW and the secondary orientation is NNW–SSE.

Regional mapping of the seismic anomalies (Figure 2) shows that they are not always associated with reactivated faults, but roughly follow the shelf break. High-resolution swath bathymetry (2 m) acquired during the Geoscience Australia marine survey GA334 in 2012 (Figure 2) highlights the complex geomorphology of carbonate banks, some of which were interpreted as cemented palaeo-coastal dunes formed during a lower sea level (Nicholas et al., 2013). Diagenetic changes associated with cementation of these features possibly contributed to creation of carbonate hardgrounds causing seismic anomalies.

Fluid Inclusion Stratigraphy

To investigate whether seepage occurred or is occurring along the reactivated faults, eight wells were analysed using the Fluid Inclusion Stratigraphy (FIS) method. FIS is a technique developed for the oil industry to map the presence of very small quantities of hydrocarbons in the borehole. FIS involves rapid and complete analysis of trapped organic and inorganic volatiles in fluid inclusions from cuttings, core, or outcrop samples using quadrupole mass analysers attached to an automated high-vacuum sample introduction system (http://fittulsa.com/fis.php). Fluid inclusion gas geochemistry provides information on when (if at all) oil or gas may have moved through the sedimentary succession (Parnell et al., 2001). Distribution of gaseous species and species ratios in the borehole may also provide information on the presence/absence of seals and present-day microseepage of formation fluids.

The anomalous FIS responses recorded in the Vlaming Sub-basin wells were analysed in relation to stratigraphic position of the samples, lithological characteristics of the seal, proximity to reactivated synrift faults and possible migration pathways. Most of the analysed wells recorded wet or dry gas anomalies at least in one of the formations with the strongest responses in the pre-breakup reservoir intervals. Significant dry gas anomalies in the reservoir units often indicate an active petroleum system and may correspond to the palaeo- or present-day charge. Significant gas responses in the Vlaming Sub-basin reservoirs are consistent with petroleum systems modelling predictions (Neumann et al., 2007) and past hydrocarbon discoveries.

Seals can be identified from a sudden lack of FIS response, suggesting that gases and fluids cannot migrate through the interval. FIS anomalies recorded above the seal may indicate seal breach or lateral migration. In six out of eight wells, FIS anomalies were recorded within or above the South Perth Shale seal. This is an indication of containment problems.

Figure 2 shows that Bouvard 1 and Parmelia 1, which have significant dry gas anomalies above the South Perth Shale, are not covered by good quality seal ("effective seal" of Southby et al., this volume). Lithological descriptions of the South Perth Shale in these wells confirm predominantly sandy lithologies with poor sealing properties. The presence of dry gas anomalies may indicate current hydrocarbon seepage due to poor seal quality.

In Peel 1 the basal part of the South Perth Shale comprises claystone and shale, which should provide a good seal (Figure 2). However, FIS recorded high values of dry gas above the seal, as well as bacterial sulphur. Bacterial alteration resulting in release of sulphurous volatiles often occurs at the seepage sites (Parnell et al., 2001). Peel 1 is located on a structural high close to a reactivated fault, which could be causing seal breach and hydrocarbon seepage.

In contrast to the wells described above, a lack of FIS anomalies in and above the seal in Gage Roads 1 and Marri 1 (Figure 2) suggests effective sealing of the reservoir units. This is in agreement with the presence of a small oil accumulation in Gage Roads 1 and a gas show in Marri 1. At both locations the South Perth Shale displays predominantly claystone lithologies and there are no reactivated faults.

In Warnbro 1 (Figure 2) there are no significant FIS anomalies in the pre-rift section, but there were visible fluid inclusions and wet and dry gas anomalies in the post-rift section. Warnbro 1 is located on a structural closure underpinned by a large fault block with a large reactivated fault going through the well (Figure 2). It appears that the well intersected most of the synrift succession in the footwall, while the post-rift succession is intersected in the hanging wall. The presence of significant FIS anomalies in the post-rift section suggests that the fault may have provided migration pathways for hydrocarbons generated from deeper parts of the hanging wall block (not intersected by the well). The presence of hydrocarbons in the synrift part of the hanging wall block is supported by an oil show at Araucaria 1 drilled on the same structure 3.2 km to the NE.

Mullaloo 1 and Charlotte 1 are located in the central part of the northern depocentre and both have a thick seal (150–300 m) for which recovered lithologies indicate a reasonably good seal. Smaller dry and wet gas anomalies are recorded in both wells in and above the South Perth Shale. Synrift strata are highly faulted in this part of the basin, but signs of fault reactivation cannot be readily identified in the seismic due to the presence of a very large seismic anomaly. Fault reactivation may be responsible for FIS anomalies at these locations, but cannot be confirmed at this stage.

FIS results showed that hydrocarbons were generated at most locations. There is a good correlation between the presence of FIS anomalies above the seal, seal lithologies and proximity to reactivated faults. Analysis of FIS results confirms that reactivated faults provided fluid migration pathways for hydrocarbons in the geological past and at some locations seepage may be taking place today.

CONCLUSIONS

Seal integrity assessment of the South Perth Shale in the central Vlaming Sub-basin showed that reactivated synrift faults provided migration pathways for hydrocarbons generated after the deposition of the South Perth Shale regional seal. Our study demonstrates that the lack of hydrocarbon discoveries in the Vlaming Sub-basin is, at least partly, due to seal breach and seepage. Future prospectivity assessments of this basin should focus on seal quality and integrity in defining a valid prospect. The distribution of mapped reactivated faults indicates that areas in the western part of the main depocentre are less affected by reactivation and therefore are more likely to host valid plays.

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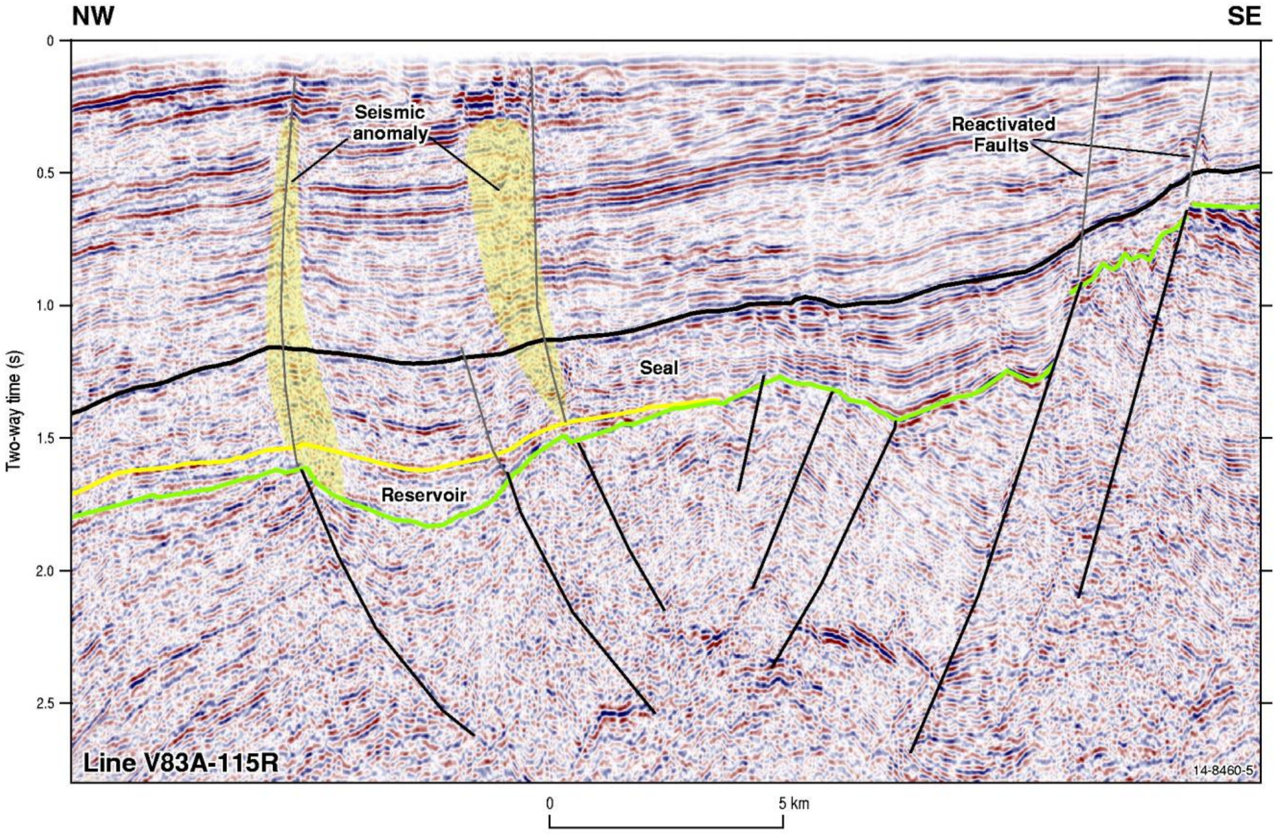

Figure 1. Sesimic line showing examples of reactivated faults and seismic anomalies in the southern Vlaming Sub-basin. The location of the line is shown in Figure 2.

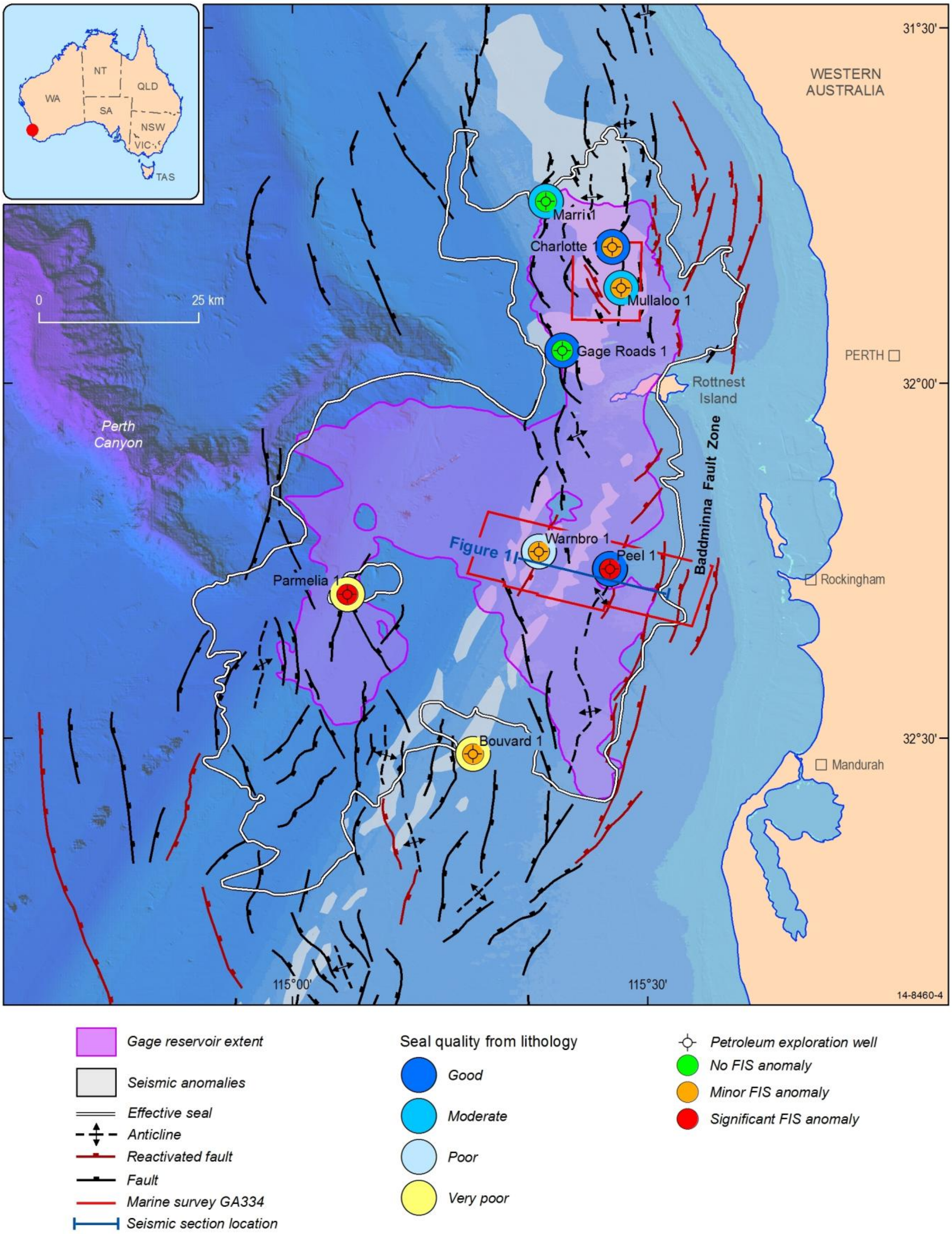

Figure 2. Summary of FIS results in relation to seal lithology and potentially leaky faults.