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Use of Oil Slicks to Unlock Reservoir Characterization of Broadband Seismic

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Summary

In offshore prospective areas, oil slicks at the sea surface are often seen as being the visible expression of a working petroleum system at depth. Synthetic Aperture Radar (SAR) has proven to be an effective tool for identifying these oil slicks by virtue of anomalously low backscatter values they produce. Linking surface oil slicks to features identified in the subsurface, such as vertical breaks in seismic, has been well documented as a successful step forwards in bringing additional value and confidence in both oil slick interpretation and subsurface data. Furthermore, recent progress in broadband seismic data processing and seismic reservoir characterization has opened the door to identifying and understanding subsurface features previously unseen, and has shown to significantly reduce the uncertainty of lithology prediction, especially by virtue of broadbands enhanced low frequency content. The following case study combines surface oil slicks, broadband 3D seismic, and well data to de-risk the petroleum potential of an area of offshore Malaysia. Our study not only provides a compelling example of oil slicks correlating with features observed in the seismic data, but it also demonstrates the significant value of pushing the workflow further, by linking surface slicks to modelled reservoir through seismic reservoir characterisation.

Introduction

In offshore prospective areas, oil slicks at the sea surface can be regarded as the visible expression of a working petroleum system at depth. Synthetic Aperture Radar (SAR) is a proven and effective tool for identifying these oil slicks by virtue of anomalously low backscatter values they produce. This results from dampened capillary waves on the ocean surface. It is recognised that this dampening effect can be due to various phenomena, such as natural organic film slicks, pollution slicks and slicks resulting from natural seepage from the seabed. Each of these slick types can be distinguished based on a number of constraints. These include size, morphology, flow direction, edge characteristics and repeatability (whether the slick forms on separate occasions).

The horizontal displacement of oil during its journey from the sea floor to the sea surface depends on the character of the water column, and the further translation due to surface currents. Indeed, surface slicks related to oil seepage from the seabed have been found within a circumference of up to five times the water depth as a result of these oceanic influences (Serié et al., 2016). As such, the uncertainty in linking slick to seabed increases significantly with water depth. In water depths of <100 m, horizontal displacement can be considered negligible.

Linking surface oil slicks to features identified in the subsurface, such as vertical breaks in seismic, has been well documented (e.g. Dembicki, 2014) as a successful step forwards in bringing additional value and confidence to oil slick interpretations and subsurface data. Correlating the two seems a natural step forward in the prospect de-risking process. Furthermore, recent progress in broadband seismic data processing and reservoir characterization has opened the door to identifying and understanding subsurface features previously unseen, and has shown to significantly reduce the uncertainty of lithology prediction, especially by virtue of broadband data’s enhanced low frequency content.

The following case study combines surface oil slicks, broadband 3D seismic, and well data to de-risk the petroleum potential of an area of offshore Malaysia, in a shallow water setting (35-70m water depth). The area in question has significant proven oil and gas reserves, and is defined by thick successions of inter-bedded sands and shales, separated by a major angular unconformity (the Shallow Regional Unconformity (SRU)). Our study not only provides a compelling example of oil slicks correlating with features observed in the seismic data, but it also demonstrates the significant value of pushing the workflow further, by linking surface slicks to modelled reservoir through seismic reservoir characterisation.

Oil slicks interpretation

A number of historical and recent weather-compliant SAR scenes were selected over the 3D seismic survey area and interpreted for natural oil slicks. Information such as slick morphology, sea current and weather conditions were used to (a) understand the probability of the slicks being related to hydrocarbon seepage from the seabed, (b) to define the surface emission point of each slick, and (c) understand the mobility/drift of each slick (see Figure 1). Ten individual oil slicks were observed carrying some of the characteristics associated with a single point origin, in this case potentially located on the seabed.

All the slicks are located within the northeast corner of the survey area, proximal to well-A. No obvious correlation can be drawn between the seafloor bathymetry (derived from the seismic data) and the location of slicks, due to the low resolution of the picked horizon.

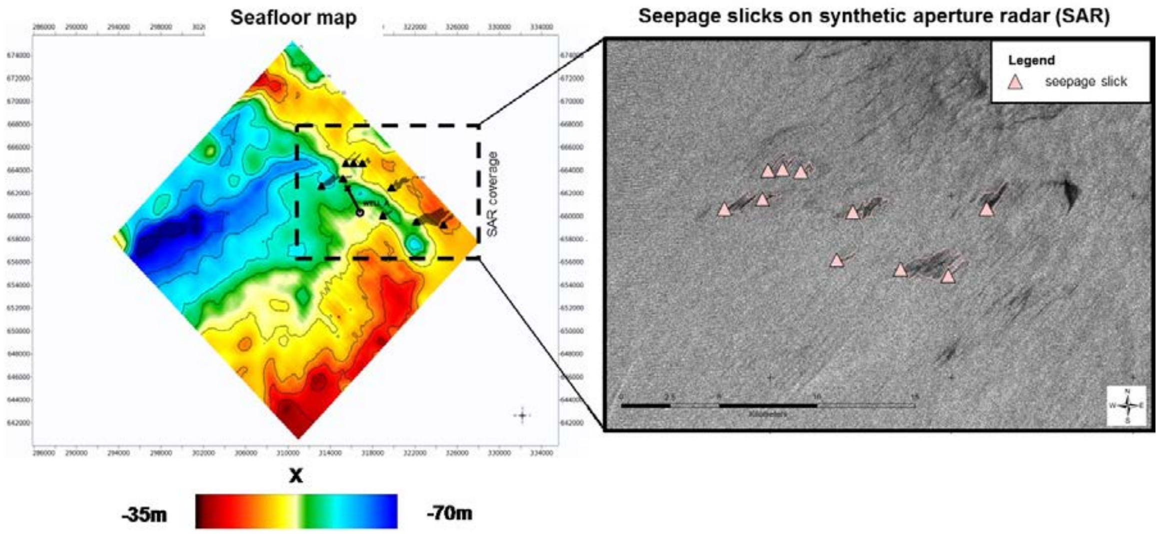


Figure 1 *Seafloor map (left), picked on 3D seismic data overlaid with location of well A, seepage slicks emission point (black triangle) and slick polygons (grey). Seepages slicks on synthetic aperture radar (SAR), (right).*

Shallow gas leakage on broadband seismic

A conventional 3D seismic dataset was reprocessed using broadband de-ghosting techniques through Pre-Stack Depth Migration (PSDM) to enhance the low frequencies. The result of the reprocessing significantly improved the imaging and thus, the understanding of the subsurface in the study area.

Notably, shallow leakage features between the seafloor and the SRU were observed and related to gas displacement within the sediment. Shallow sediments, above the SRU, are considered unconsolidated due to the low pressure regime, allowing gas to migrate vertically as seen on Figure 2 (dash red line highlighted boxes).

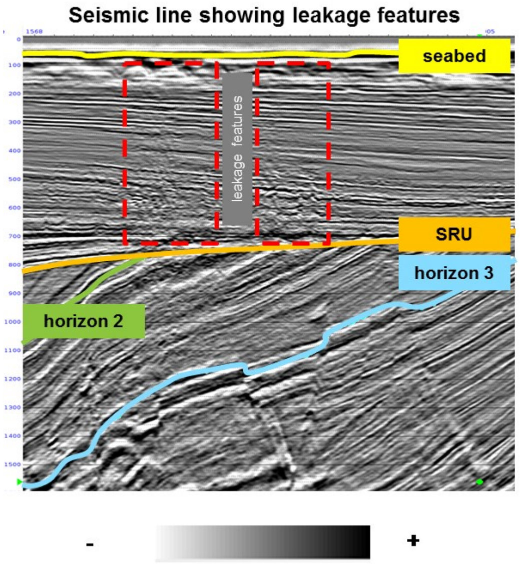


Figure 2 *Leakage features above the SRU seen on the reprocessed seismic (2016).*

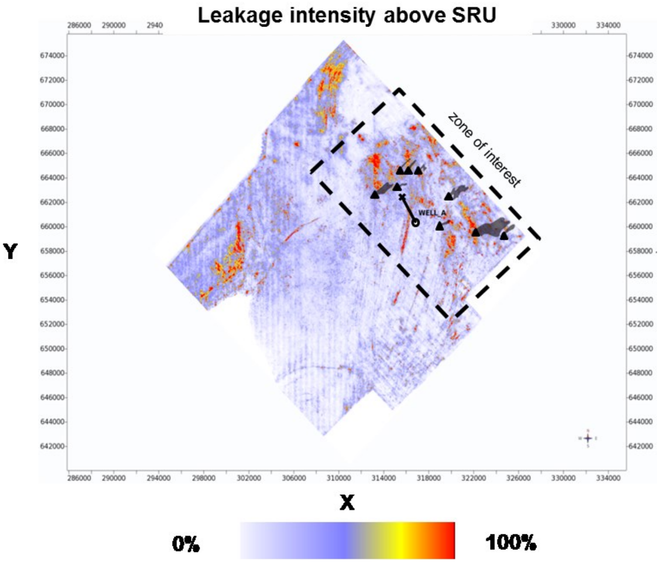


Figure 3 *Leakage intensity map above the SRU overlaid with location of well A, slick emission points (black triangle) and slick polygons (grey).*

The leakage features were captured throughout the 3D volume, and then mapped and overlaid with the oil slicks interpreted from the SAR scenes. As seen on the Figure 3, a good correlation is observed between the occurrence of oil slicks and the leakage features observed on the 3D seismic data, both being located in the northeast corner of the survey area.

The correlation observed in Figure 3 suggests that a fraction of oil is also likely leaking through the upper sediment pile, in the area where gas leakages were observed.

Sand prediction using acoustic seismic inversion

Acoustic seismic inversion was applied to the sediment pile below the SRU to predict for P-Impedance. Well-A, located in the vicinity of the oil slicks, shows relatively good well ties (at around 70%) with the full stack (0-35 degrees). Due to the enhancement of the low frequency from the broadband reprocessing, the PSDM seismic velocity was used for low frequency model building, and did not require any further kriging or interpolation as seen on Figure 4.

The inverted results were then used for Sand/Shale prediction below the SRU, using a bayesian statistic approach, defining a density probability function for each lithology (Coulon et al., 2006). Crossplots of P-Impedance vs Vp/Vs indicated a good separation between the sands and the shale using P-Impedance only. The results of the prediction are displayed in Figure 5, along the inline passing through the head of Well-A.

Good prediction of sand was achieved from the seismic acoustic inversion and was used for mapping the sand distribution below the SRU.

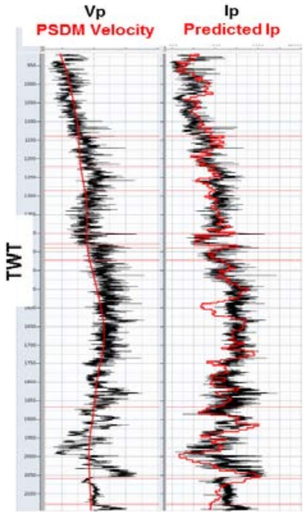
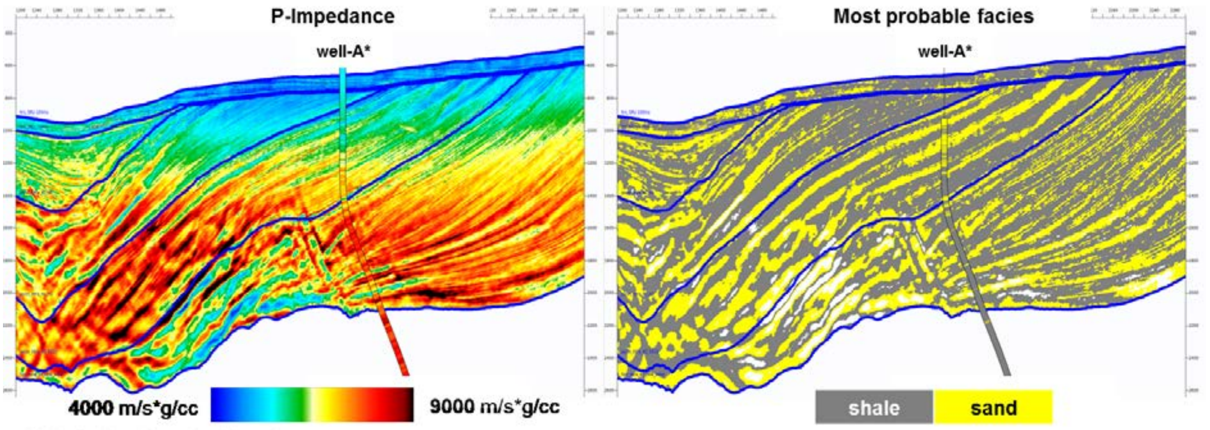


Figure 4 *Comparison between P-Sonic and PSDM velocity used as low frequency model (left). Comparison between predicted P-Impedance from seismic inversion and P-Impedance from the well (right).*



*Seismic plane through well head

Figure 5 *P-Impedance and most probable facies from lithology prediction along the seismic line passing through the well-A head. Well-A log P-Impedance and lithology flag are respectively displayed on the section.*

Interpretation of results

The stratigraphic isochrones shown in Figure 6 demonstrate some level of correlation with the leakage features seen above the SRU, with a preferred NNE-SSW strike. Interestingly, the northern and southern parts of the horizon 2 sequence boundary have been affected by some significant leakage – confirmed by the presence of oil slicks towards the northern end of the boundary. However, the apparent absence of leakage in the middle portion of the boundary is notable, and could be reflecting the integrity/extent of the seal in that particular area.

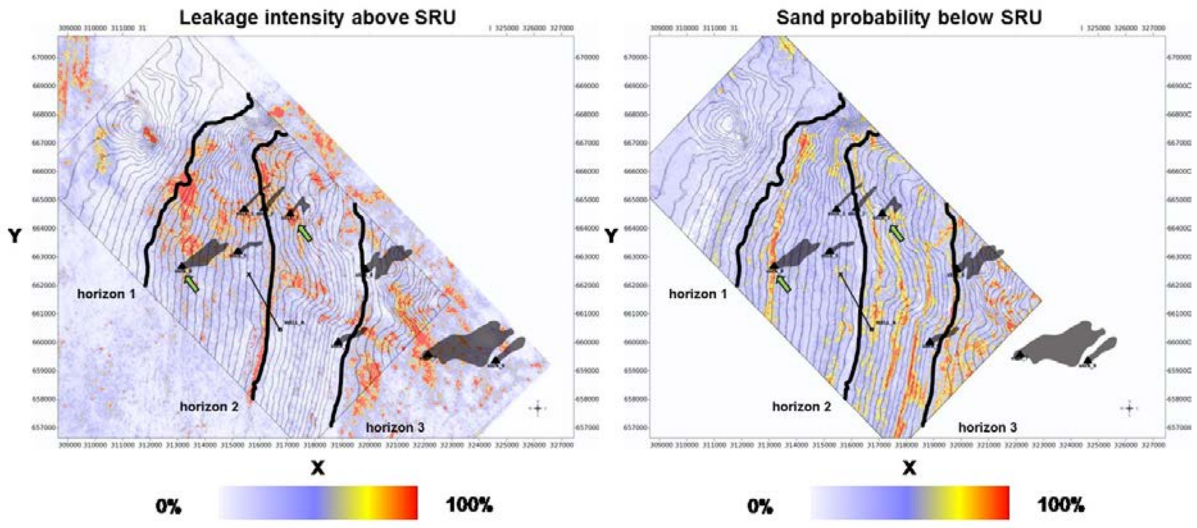


Figure 6 *Leak intensity map above the SRU (left) and sand probability from seismic inversion below the SRU (right). Stratigraphic isochrones below the SRU were generated, and depict younging of sediments towards the northwest. Major sequence boundaries (Horizon 1, Horizon 2 and Horizon 3) are shown as bold black lines.*

When the sand probability distribution below the SRU is considered, we see a compelling picture that provides further insight to the on-going leakage processes, and arguably, insight to seal integrity. Indeed, oil slicks located above areas of high probability sand estimation, strongly suggest these sands are the likely source of the leakage seen above the SRU. We have highlighted a number of slicks, (green arrows, Figure 6) that coincide with both leakage features above the SRU and high sand probabilities below it, suggesting those particular slicks likely record seepage from the seabed, and originating from the sands predicted by the seismic inversion below the SRU.

Conclusion

The methodology presented here illustrates the value of oil slicks as part of a comprehensive and integrated workflow that utilises 3D broadband seismic and well data. Not only does this integration provide additional confidence in each independent dataset, but it has the ability to aid our understanding of third-order migration pathways in regional, block or sub-block scale petroleum studies.

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