Investigating the role of crestal faulting on hydrocarbon trapping in rollover structures of the Sable Subbasin, Offshore Nova Scotia - Insights from the Migrant Structure.

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Introduction

Globally shelf margin deltas such as the Nile Delta (Sestini 1989; Beach & Trayner 1991), Amazon Delta (Cobbold & Szatmari 1991; Sydow et al. 2003), Niger Delta (Doust & Omatsola 1989), the ancient Sable Delta (Cummings & Arnott 2005), and the Gulf of Mexico (Nelson 1991; Cartwright et al. 1998) are well known for the formation of rollover anticlines in their sedimentary basins. These anticlines are syn-depositional features that develop in the downthrown side (hanging wall) of deltaic growth faults (listric normal) in sedimentary basins (Vendeville 1991; Cummings & Arnott 2005; Adam et al. 2006). Their formation is attributed to the interaction between gravity driven extension, syn sedimentary deposition and the movement of a mobile substrate (Vendeville 1991). These interactions are key for the formation and evolution of down to basin listric normal faults with associated structures. In sedimentary basins, these structure are known to contain a reservoir rock with some porosity and an impermeable seal rock capable of trapping hydrocarbons forming reservoir-seal pairs (Vendeville 1991; Adam et al. 2006)*.* Thus, they can form attractive hydrocarbon target.

As the extensional response of the anticline to a continuous displacement of the main listric fault (Vendeville 1991*),* the development of crestal faults on the structure from the folding and subsequent faulting of the folded strata have been reported to pose potential risk to hydrocarbon trapping in this type of structure (Richards et al. 2010). On the Scotian Shelf, the Sable Subbasin hosts hydrocarbon resources that are being explored by the energy industry. Exploration records show that stratigraphically and spatially similar geologic structures (i.e. plays) contain significant and commercial grade hydrocarbons (e.g. gas). Among the tested play types, rollover anticlines account for ~75% of the significant and commercial hydrocarbon discoveries made to date with about 95% of their reservoirs mainly Cretaceous aged sands (OERA 2011).

Recent work on historical hydrocarbon exploration drilling results from around the world highlights trap and seal failure as the reason half of the wells fail to encounter producible hydrocarbons (Rudolph & Goulding 2017). In addition, a well failure analysis table published by the Canada Nova Scotia Offshore Petroleum Board CNSOPB suggests that no fault seal is the primary reason most wells targeting rollover traps offshore Nova Scotia fail to find producible volumes of hydrocarbons even in the best quality sand reservoirs (CNSOPB 2013). Considering ongoing exploration offshore Nova Scotia, the results from this study will add to our understanding of why some rollover traps along the Scotian Margin contain commercial quantities of hydrocarbons and others do not.

Study Area and Stratigraphy

The Mesozoic Scotian Basin located offshore Nova Scotia and extends from the Yarmouth Arch in the southwest to the Grand Banks in the northeast, covering an area of ~ 300,000 km^2 (Wade & Maclean 1990; Hansen et al. 2004; Kidston et al., 2005; Figure 1). The history and evolution of the basin begins with continental extension, rifting, and opening of the North Atlantic Ocean. In the Sable Subbasin, the stratigraphy comprises mainly Mesozoic and Cenozoic sediments (Figure 2).

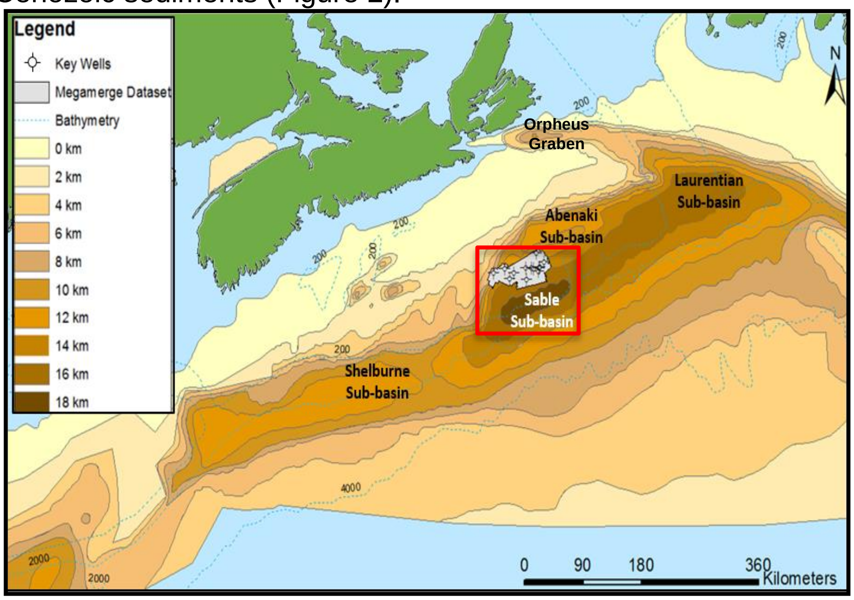

Figure 1. A sediment thickness map of the Scotian Basin (after Wade 2000). The Sable Sub-basin (Red Box) is one of the sub-basins in the Scotia Basin. The area shaded in grey represents the extent of the 3D Sable Megamerge seismic volume used for this study.

In the Sable Subbasin, the Migrant rollover anticline (Figure 2) is a four-way dip structure that formed above the low side of a listric fault with an active petroleum system. The structure was drilled and operated by Mobil (now ExxonMobil) in 1977 to test for hydrocarbons trapped in Early Cretaceous Missisauga and Late Jurassic MicMac sands in the structure. Located 12 km off Sable Island, the Migrant N-20 exploration well reached a total depth of 4669 m in the MicMac Formation and flowed gas to the surface from a reservoir zone between 4333 - 4361.7 m (CNSOPB 2009). Despite its close proximity and similar trapping style to the downdip Thebaud gas field (i.e. a commercial discovery), the hydrocarbons discovered in the structure were not of commercial quantities. This project will focus on the Early Cretaceous Missisauga Formation and Late Jurassic Mic Mac Formation. Both of these stratigraphic intervals comprise deltaic sand reservoirs that were targeted by the Migrant N-20 well.

The Tithonian to Aptian Missisauga Formation comprises fluvial-deltaic siliciclastics that form a thickening seaward wedge that thins in the Sable Subbasin (Weston et al. 2012; Figure 2). The formation reaches a maximum thickness of approximately 3.5 km below the modern shelf edge (Wade & MacLean 1990). In the central parts of the Sable Subbasin, the formation overlies deltaic deposits of the Mic Mac Formation, and is overlain by offshore mudstones of the Naskapi Member of the Logan Canyon Formation. Further, the Missisauga Formation downlaps Jurassic carbonates of the Abenaki Formation at the western edge of the Sable Subbasin. The Missisauga Formation is divided into three members; a lower member, a middle member and an upper member (Wade & MacLean 1990).

The Oxfordian-Tithonian Mic Mac Formation records the first phase of delta progradation into the Sable Subbasin and is represented by cyclic interfingering of distributary channels and delta front fluvial sands with pro-deltaic and shelf marine shales of the Verrill Canyon Formation (Weston et al. 2012; Figure 2).

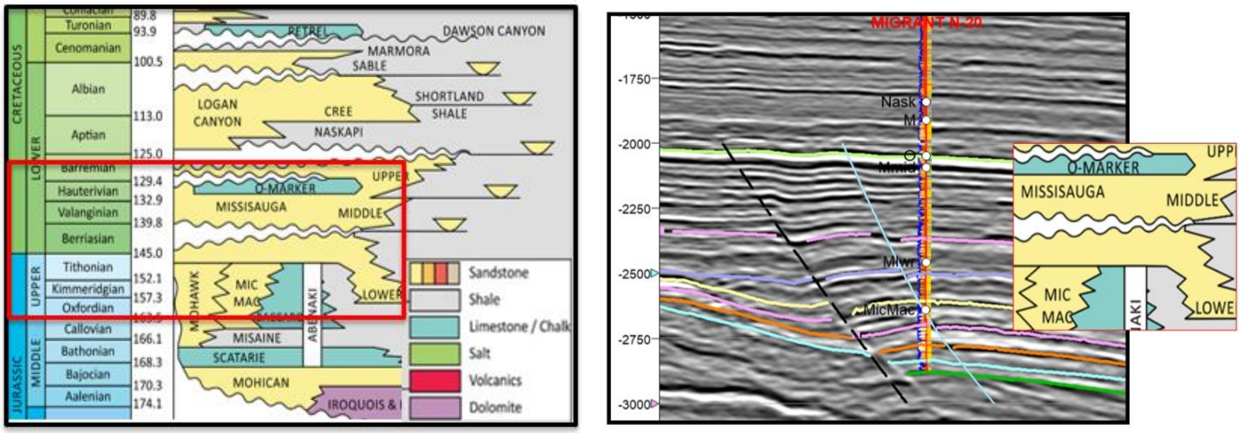

Figure 2. (Left) Lithostratigraphic chart of the Scotian Basin showing the interval of interest outlined in red (Weston et al. 2012). (Right) A seismic profile showing the Migrant rollover with the N-20 well penetrating the structure with interpreted horizons.

Data and Method

For this study, literature review, well data (including pressure and core data), and 3D seismic is used to demonstrate the fault sealing mechanism in the Migrant Structure. New results and interpretations from this work combined with predictive models add to new insights and understanding of hydrocarbon spill/leakage scenarios and fault sealing in rollover structures offshore Nova Scotia.

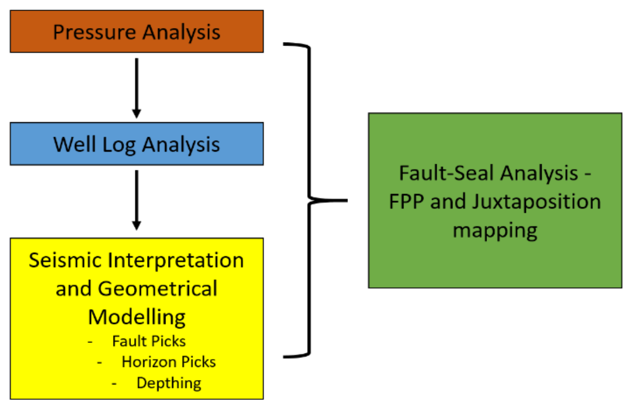

Figure 3. Simplified workflow used for this study.

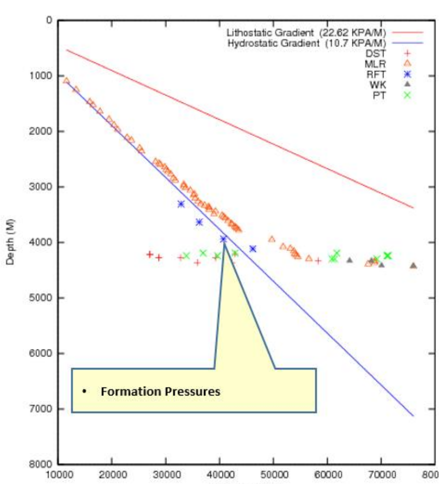

Figure 4. Pressure elevation plot of the Migrant Structure (NRCAN BASIN Database 2018).

Result

Petrophysical analysis: In the Migrant Structure, most of the shallower reservoirs are within a high net to gross section. The reservoirs near the base of the well are tight with low effective porosity. In some of the reservoirs (including those reported to contain water from the DST report), residual gas saturation is as high as 40%.

Pressure analysis: In Figure 4, the mud weight appeared to mimic the hydrostatic curve. At ~4000 m depth, a rightward shift to higher pressures hints at a likely onset of overpressure.

Of three DST intervals in the Migrant Structure, one at the base of the well (at depths where reservoir quality is poor due to fluid related diagenesis) flowed gas at a rate of 10 million standard cubic feet per day to the surface. Although there was pressure decline over the duration of the test.

Fault-Seal analysis: In the Migrant Structure, the shallow reservoirs are within a high net to gross succession. At shallower depths, increased fault throw led to the establishment of juxtaposed leak points in the structure (Allan 1989; Figure 5). At the intermediate to deeper sections, the fault throw decreases progressively into lower net to gross intervals that occur deep in the structure. This is the commercial sweet spot in the structure given that the best traps begin to form as the fault offset diminishes into the core of the structures (Richards et al. 2008; 2010). At greater depths, the reservoirs are tighter and more discontinuous.

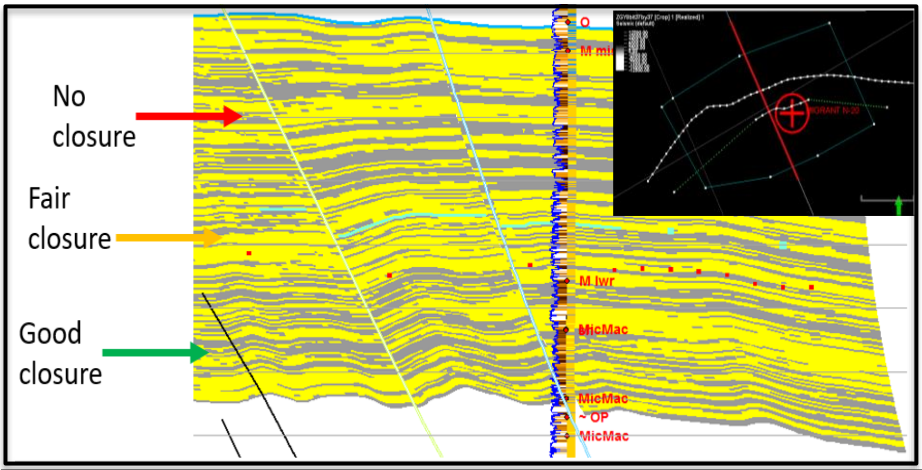

Figure 5. A modelled cross section of the migrant structure populated with sand and shale properties from shale volume calculation. The figure shows the magnitude of crestal faulting through the offset of sand-shales.

Conclusion

In the Sable Subbasin, the issue of hydrocarbon leakage associated with small extensional faults on the crest of lowside rollover structures have been reported (CNSOPB 2013). The tight reservoirs tested around the lower section of the Migrant Structure have low effective porosity, which may have resulted in localized trapping. Rapidly depleting test rates from well report supports the idea of distally trapped hydrocarbons in a diagenetically isolated reservoir. Additionally, it appears that the increased levels of hydrocarbon saturation in intermediate to shallow reservoirs in the structure are a result of cross-fault hydrocarbon migration, up-section, to levels not within structural closure. This forms the underlying reason why the Migrant structure is wet.

Acknowledgements

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