Hacking the source rock code in Nova Scotia's deep water

Natasha MacAdam[1*], Karyna Rodriguez[2], Neil Hodgson[2], Catie Donahue[3], Graham Spence[3] show how a modern WAZ 3D survey in the salt basin, combined with reservoir, trap and DHI studies, demonstrate significant, ready-to-drill prospects on the Nova Scotian slope.

Introduction

Exploration began on the Scotian Shelf in the 1960s, yielding a number of substantial discoveries linked to the gas prone type III – II Tithonian-aged source rock (e.g. Powel, 1982; Beicip et al., 2011; Fowler, 2020), Figure 1. As is often the case, early success focused activity on the shelf and the Tithonian play with a lack of exploration activity outboard. This margin, with its thick salt basin, abundant sand fairways and halokinesis-related traps has been left then, relatively unknow, and waiting for a new generation of explorers to unlock the source story on the slope and basin floor.

The explorers code for approaching an understanding of unexplored basins says that the three key risk factors for success are: source, source and source. Whilst this code may indeed be more of a guideline, as early as 2011 a NSDNRR Play Fairway Analysis study identified 'source rock' presence and effectiveness as a key exploration risk on the Nova Scotia slope and basin floor area (Beicip et al., 2021, 2023). Successful mitigation of this risk has been achieved by hunting for and recognising hydrocarbons both at and near the seafloor and deeper within the subsurface. Directly observing thermogenic hydrocarbons conclusively closes the debate on whether there is a working hydrocarbon system and focuses research on defining exactly which system is working.

Nova Scotia slope

The clearest evidence for a working hydrocarbon system in the subsurface of the Scotian slope comes from the discovery of oil in the recent Aspy-1 well, drilled in the east of the Tangier 3D area (Figures 1 and 2). Here oil-stained Cretaceous silts were encountered within the 4-way closure below a salt canopy. Additionally, thermally immature Middle Jurassic source rocks were encountered by the Cheshire-1 and Monterey Jack-1 exploration wells within the Shelbourne 3D area, which have subsequently been correlated into more deeply buried sections on seismic using their characteristic sweetness attribute and Type-IV AVO response (Hodgson et al., 2022, Rodriguez and Hodgson. 2023). Access to the state-of-the-art Wide Azimuth (WAZ) Tangier 3D (Figure 1), covering three of the blocks offered as part of the 2022-2023 Bid Round offshore Nova Scotia, allowed a detailed

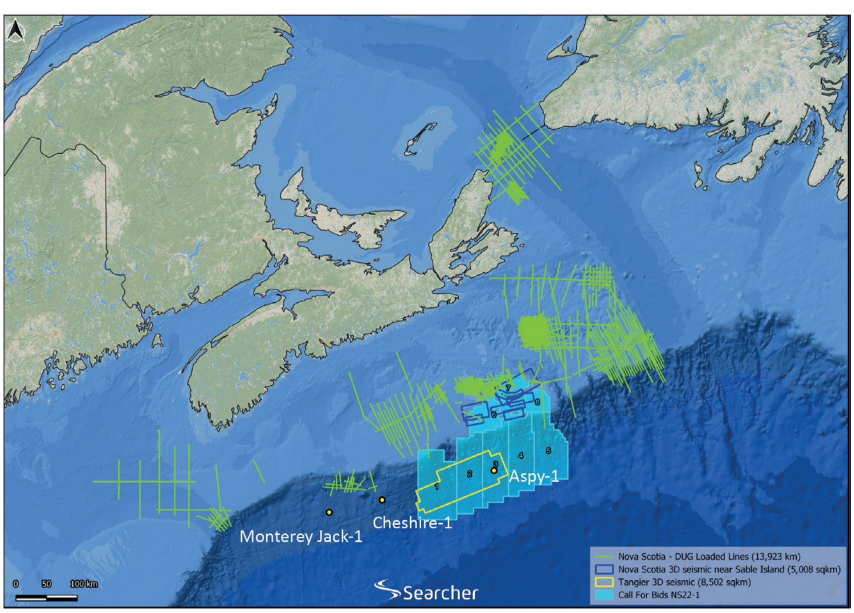

Figure 1 Open blocks in the ongoing 2022/23 call for bids, in addition to the Searcher legacy data 2D and 3D library on the Scotian Shelf, and the Tangier 3D seismic area on the Scotian Slope.

[1] Nova Scotia Department Natural Resources and Renewables (NSDNRR) | [2] Searcher | [3] Geomark Research
[*] Corresponding author, E-mail: natasha.macadam@novascotia.ca
DOI: xxx

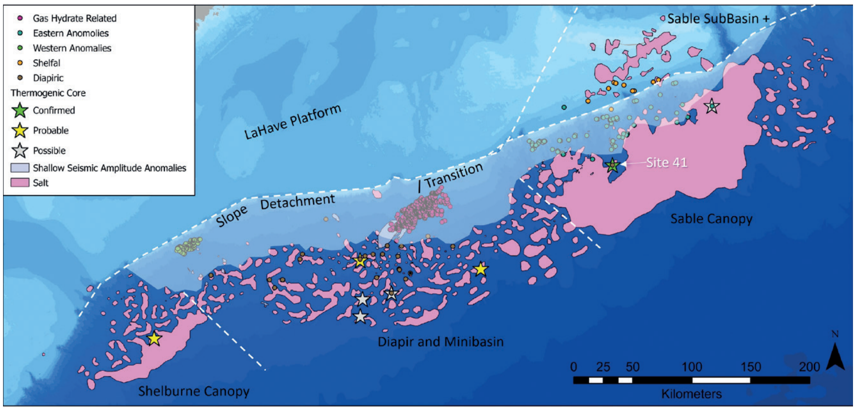

Figure 2 The Nova Scotian Margins salt basin halokenitic habitats and the distribution of the few wells drilled to date on this margin

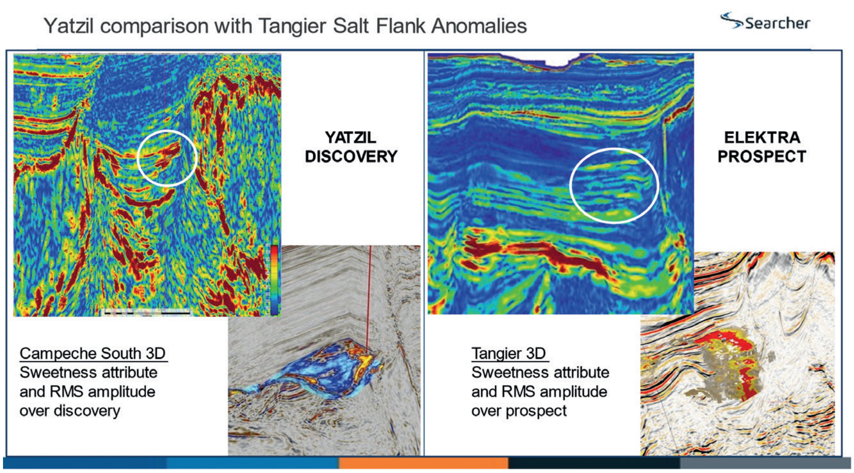

Figure 3 Comparison of seismic sweetness attributes for the recent Yatzil discovery in Mexico's Campeche salt basin, and the Electra prospect in the Tangier 3D of Nova Scotia's slope salt basin.

seismic based source rock evaluation which identified the Middle Jurassic (Callovian) Misaine Formation as a potential source rock, regionally present, associated with a high amplitude anomaly, a decrease in acoustic impedance and amplitude dimming in the far angle stack. The latter comprises an AVO Type IV anomaly, widely considered a reliable seismic indicator for the presence of organic-rich shales (Løseth et al., 2011, Davidson et al., 2018, Eastwell et al., 2016). Thermal maturity modelling using a BSR-derived geothermal gradient, indicated that the oil hydrocarbon window should start at around 5 km burial.

In western part of the Tangiers 3D, The Misaine Formation source lies below a number of well-defined diapir flank plays and prospects. The stunning salt flank Elektra prospect has five stacked reservoirs with depth-conformant AVO response with a conservative resource estimate of 2 BBO. This is compared to the recent Yatzil discovery in the Campeche Salt Basin offshore Mexico (200 MMBO) with compelling similarities. (Figure 3). Such prospects can now be mapped across all the deep-water blocks offered in the 2023 License round where they are associated with the major confined channels bringing coarse clastics off the shelf and down slope and offer significant resource potential low-risk traps with amplitude-dip conformity and AVO support.

Yet it is in the integration of these exciting subsurface seismic examples with cutting edge research on seabed samples that some of the biggest leaps in understanding the distribution of source rocks has been achieved. It is in the combination of a variety of techniques such as piston coring, geochemical analysis, microbial genomics on seafloor sediments, that when conflated with detailed seismic mapping and interpretive analysis that has unlocked the secret of the hydrocarbon system in the Nova Scotian slope.

Nova Scotia Department of Natural Resources and Renewables (NSDNRR), in conjunction with many partners such as Genome Atlantic, have been researching prospective offshore hydrocarbon seeps along the Scotian Slope since 2015. This work undertaken has recovered evidence from seabed cores that prove the presence of thermogenic hydrocarbons on the Scotian Slope (e.g. Campbell et al., 2016, 2019). Seabed coring locations were selected using predominantly seismic mapping; first with 2D data then with high resolution 3D in later cruises, where seismic mapping identified potential Direct Hydrocarbon Indicators (DHIs) and shallow hydrocarbon migration pathways. These DHIs were then ranked based on features such as faults to seafloor, seafloor irregularities, fluid flow indicators, pockmarks and potential shallow hydrocarbon pools to determine coring locations (Figure 4).

Collected cores, based on identified DHIs, underwent geochemical analysis, including gas composition and isotopes of headspace gases, biomarker and GC/MS (Gas Chromatography/Mass Spectrometry) analysis of extracts, to distinguish between biogenic and thermogenic hydrocarbons. There were 11 sites that had potential indications of thermogenic hydrocarbons (Fowler and Webb, 2018). However, 2016 Site 41 showed the most promising evidence of liquid thermogenic hydrocarbons (Fowler et al.,

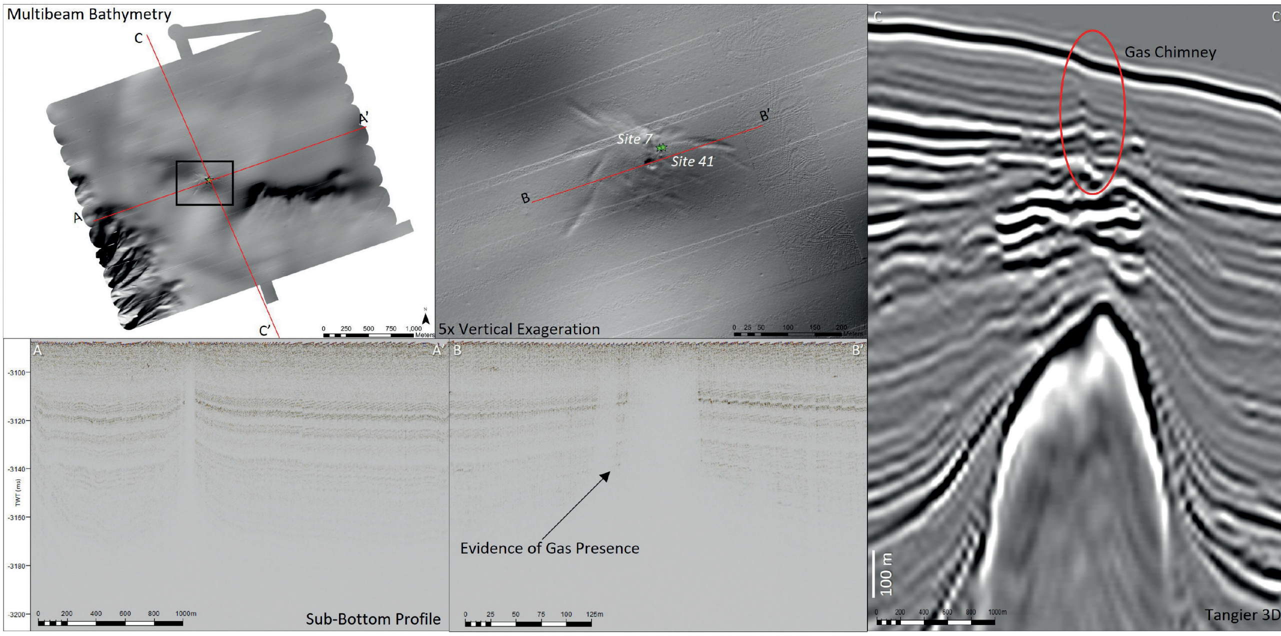

Figure 4 Seabed Multi-beam images and evidence for shallow fluid ponding or migration path ways are used to select seabed sample locations, recovering live oil seeps on the slope of Nova Scotias margin.

2016). This was confirmed by additional sampling in 2018where Site 7 proved oil seepage (Fowler et al. 2018).

The oil samples collected offer additional insights into the geologic framework of the region. The North Atlantic and its European conjugate exhibit a multitude of oil families, indicating numerous source rock development opportunities along this passive margin. However, in the context of the Scotian Shelf, the collected oil samples specifically reveal the presence of both terrestrial and marine source rocks within the Jurassic to Cretaceous section (Figure 5)

Microbiological testing proves very effective in improving understanding of hydrocarbon seepage on this margin. Research at the University of Calgary has examined bacterial communities in sediment samples using 16S rRNA gene sequencing. Li et al. (2022) highlights Caldatribacteriota and Campilobacterota OTUs to distinguish thermogenic vs biogenic hydrocarbons. Thermophilic spore forming bacteria observed in seabed samples, are genetically similar to bacteria that live in deep hot oil reservoirs and are believed to be transported to the surface with thermogenic hydrocarbons during seepage. Thermospore DNA signals in sediment recovered from Sites 41 and Site 7 cluster show clear thermogenic hydrocarbon signals (Gittens et al 2022).

The results of these geochemical and microbial analyses imply the presence of at least one source rock with a wide areal extent across the area, capable of generating heavier liquid hydrocarbon. Following this positive evidence, an autonomous underwater vehicle (Ocean Infinity, 2020) was used to further pinpoint seafloor features. Features indicative of seepage sites were sampled with a remotely operated underwater vehicle in 2021 to visualise seepage in real time (Bennet and Desiage, 2022).

To have seeps at seabed, there must be migration pathways present. Ten 3D seismic surveys along the Scotian Slope were studied to identify possible migration pathways. This included mapping features such as shallow pipes or gas chimneys, shallow DHIs, and other amplitude anomalies. From this mapping, it is evident that salt and halokinesis plays a large role in hydrocarbon migration along the margin. There is a significant lack of anomalies above the salt canopy, indicating it is likely to be acting as a seal for deeper hydrocarbon sources. Fluid-flow ‘pipes’ or ‘chimneys’ that reach, or come close to, the seafloor occur predominantly over salt diapirs. The majority of these occur near bottom simulating reflector (BSR) anomalies above the salt diapirs. BSRs are typically much thinner over diapirs where high heat flow rising through the thermally conductive salt diapir acts like a candle, thinning the overlying gas hydrate layer. In 3D, this heatflow creates subsurface 4-way closure at the BSR base, where oil is trapped in shallow clastics. Faults associated with dynamically active, reactive-rise salt diapirism periodically leak hydrocarbons to the sea floor where they can be sampled

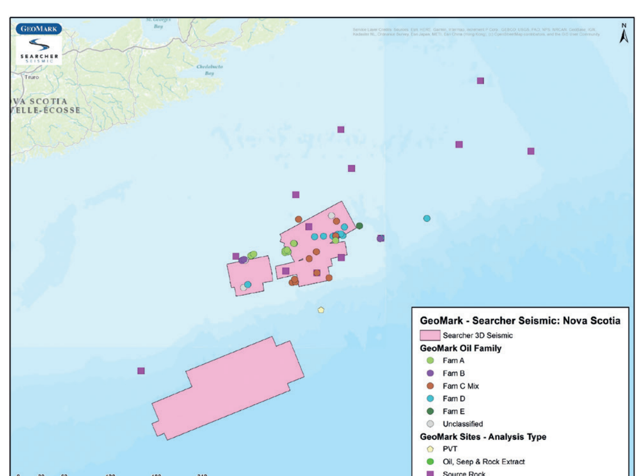

Figure 5 Geomark Oil families Nova Scotia indicating a number of different source rocks are present on the shelf and upper slope.

by seabed cores. Such seabed seeps are presented in pockmarks, where chemosynthetic communities can often be observed on multibeam data (Figure 4).

Potential hydrocarbon pathways to the base hydrate closures are likely to involve migration up flanking sediments to the diapirs, where these have not created sealing structures such as the Electra style prospects (Figure 3).

Source Code Hacked

Combining the evidence for a working hydrocarbon system on the Nova Scotia slope from well data, seabed coring and seismic, it is beyond question that there is a working hydrocarbon system active on this margin. It is likely that the Middle Jurassic is the principal source although where deeply buried, and close to the thermal high heatflow around salt diapirs the Palaeocene could in-part be also an effective source.

The perceived riskiness of those three key factors for success in the slope of Nova Scotia appears to have been significantly reduced by the sterling work and investment of the NSDNRR and her partners over the last decade, focused to prove, by direct sampling that a working hydrocarbon system is present on the slope. The source rock code is hacked and the explorer's code is cracked on the Scotian slope. Modern WAZ 3D in the salt basin allows the combination of this analysis with reservoir, trap and DHI studies that demonstrate a number of really significantly sized, ready-to-drill prospects sit on the Nova Scotian slope, drawing the attention and excitement of the new generation of exploration buccaneers.

References

Bennett, R, and Desiage, P. [2022]. *Expedition report 21CONDOR: Scotian Slope*, August 14-29, 2021. Geological Survey of Canada, Open File 8889.

Campbell, D.C. [2019]. *CCGS Hudson expedition 2016-011, phase 2. Cold seep investigations on the scotian slope, offshore Nova Scotia*, June 15-July 6, 2016. Geological Survey of Canada, Open File 8525, 88.

Campbell, D.C. and MacDonald, A.W.A. [2016]. *CCGS Hudson expedition 2015-018-geological investigation of potential seabed seeps along the Scotian Slope*. Geological Survey Canada Open File 8116.

Campbell, D.C. and Normandeau, A. *CCGS Hudson Expedition 2018-041. High-resolution investigation of deep-water seabed seeps and landslides along the Scotian Slope*, May 26 – June 15 2018.

Davison, I., Rodriguez, K.and Eastwell, D. [2018]. Seismic Detection of Source Rocks. *GeoExpro*, **6**.

Eastwell, D., Hodgson, N. and Rodriguez, K. [2016]. source rock characterization from seismic in frontier basins a global approach *First Break* Vol 36 2016.

Fowler, M. [2020]. *Geochemical Evidence for Multiple Source Rocks on the Scotian Shelf*. APT Canada report, APT20-6124. Report submitted to The Offshore Energy Research Association (OERA).

Fowler, M. and Webb, J. [2015]. *Report on Geochemical Analysis of Piston Cored Samples, Offshore, Nova Scotia*. Report submitted to The Offshore Energy Research Association (OERA).

Fowler, M. and Webb, J. [2018]. *Summary of Geochemical Investigations on Offshore Nova Scotia DoE 2015-2017 Piston Coring Samples. Microbial Genomics for De-Risking Offshore Oil and Gas Exploration in Nova Scotia Workshop*. Calgary, January, 2018.

Fowler, M., Webb, J., Olsen, H., Ashraf, F. and Gulbrandsen, S. [2016]. *Geochemistry Data Report for 2016 Scotian Slope Piston Coring Program* [online]. Available from https://documents-oera-ca.s3.ca-central-1.amazonaws.com/files/2019-06/Geochemistry%20Data%20 Report%20for%202016%20 Scotian%20Slope%20Piston%20Coring%20Program.pdf.

Fowler, M., Webb, J., Gulbrandsen, S., Austnes, L-K. and Ashraf, F. [2018]. *Geochemistry Data Report for 2018 Scotian Slope Coring Program* [online]. Available from https://oera.ca/sites/default/files/2019-05/Geochemistry%20Data%20Report%20for%202018%20Scotian%20Slope%20Coring%20Program.pdf

Genome Atlantic. [2020]. *Looking good: initial results published on research to de-risk offshore oil and gas exploration*. [online]. Available from https://genomeatlantic.ca/looking-good-initial-results-published-on-research-to-de-risk-offshore-oil-and-gas-exploration/.

Gittins, D.A., Desiage, P.A., Morrison, N., Rattray, J.E., Bhatnagar, S., Chakraborty, A., Zorz, J., Li, C., Horanszky, O., Cramm, M.A., Bisiach, F., Bennett, R., Webb, J., MacDonald, A., Fowler, M., Campbell, D.C. and Hubert, C.R.J. [2022]. Geological processes mediate a microbial dispersal loop in the deep biosphere. *Sci Adv*. Aug 26;8(34).

Hodgson, N., Rodriguez, K., Hoiles, P., Davies, J., and Kovacic, G. [2022]. New Arcadia: seismic acceleration of the Nova-Scotian margin. *GeoExpro*, November 2022.

Løseth, H., Wensaas, L., Gading, M., Duffaut, K. and Springer, M. [2011]. Can hydrocarbon source rocks be identified on seismic data? *Geology* 2011, **39** (12), 1167-1170. doi: https://doi.org/10.1130/G32328.1.

Ocean Infinity. [2020]. *Pacific Constructor – OERA Final Report*. Report submitted to The Offshore Energy Research Association (OERA).

Rodriguez, K., and Hodgson, N. [2023]. Sands and Source rock delivered by the Tangier WAZ3D in the current Nova Scotia License Round. GeoExpro May 2023.