Frontiers + Innovation
2009 CSPG CSEG CWLS CONVENTION • CALGARY, ALBERTA, CANADA

Thermal Models Across the Central Nova Scotia Slope Basin Constrained by New Marine Heat Flow Measurements

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Summary

New petroleum systems models are determined for profiles across the central Nova Scotia Slope Basin, in deep to ultra-deep water. Recent seismic data, including pre-stack depth migration and concurrent wide-angle velocity models, are used to improve constraints on sediment, salt and basement structure. Results suggest that petroleum maturation is predicted for suitable sources in the Late Jurassic and Early Cretaceous Verrill Canyon formation, although there is considerable variability between profiles in the potential for hydrocarbon accumulation. New measurements of heatflow along profile using shallow marine probes were made in July 2008 and are compared to model predictions in order to better constrain the basement heatflow and temperature variations caused by the presence of high conductivity salt structures. These thermal observations indicate that the regional basement heatflow is lower than previously thought, while thermal variations across salt structures are typically larger than expected. These results suggest that previous models might have over-predicted temperatures and hydrocarbon maturation adjacent to the salt structures while possibly under-predicting maturation above the shallower salt diapirs.

Introduction

Rifting on the Scotian margin occurred in the Late Triassic to Early Jurassic (~230-190 Ma), followed by three main post-rift periods of subsidence during the Jurassic, Cretaceous and Tertiary (e.g. Jansa and Wade, 1975) that resulted in the formation of various deep sedimentary sub-basins (Fig. 1). Most exploration has been undertaken in the Sable basin with the discovery of significant gas reserves. The sandstone reservoirs are located within shallow marine to deltaic sediments and are probably sourced from the Late Jurassic to Early Cretaceous prodelta to pelagic shales of the Verrill Canyon formation (Welsink et al., 1989; Wade and McLean, 1990). Maturation of the source rock was accomplished by increased post-rift subsidence during the Late Jurassic to Early Cretaceous. Other, more minor occurrences of both gas and oil are associated with Early Cretaceous clastic sequences (Missisauga and Logan Canyon) and are related to the edge of the Late Jurassic carbonate bank following the present shelf edge (Fig. 1).

Further offshore, large thicknesses of sediment also occur beneath the lower continental slope and rise of the Sable and Shelburne basins (Fig. 1). It was expected that reservoirs for these deepwater prospects might be associated with Cretaceous and Early Tertiary channels, turbidites and fan deposits, trapped by the steep walls of salt diapirs (Hogg, 2000) that extend along the margin within the Salt Diapiric Province southwest of seismic profile 89-1 (Fig. 1). However, the apparent lack of reservoir indicated by more recent wells on the upper slope, and especially those closest to the Sable gas fields (Fig. 1), suggests the need for wider investigations of the petroleum system in other areas of the margin (Enachescu and Wach, 2005). The purpose of this work is to examine petroleum systems models based on new interpretations of seismic data across the entire region of potential hydrocarbon generation and using additional constraints from new measurements of heat flow, beginning first with the central slope region.

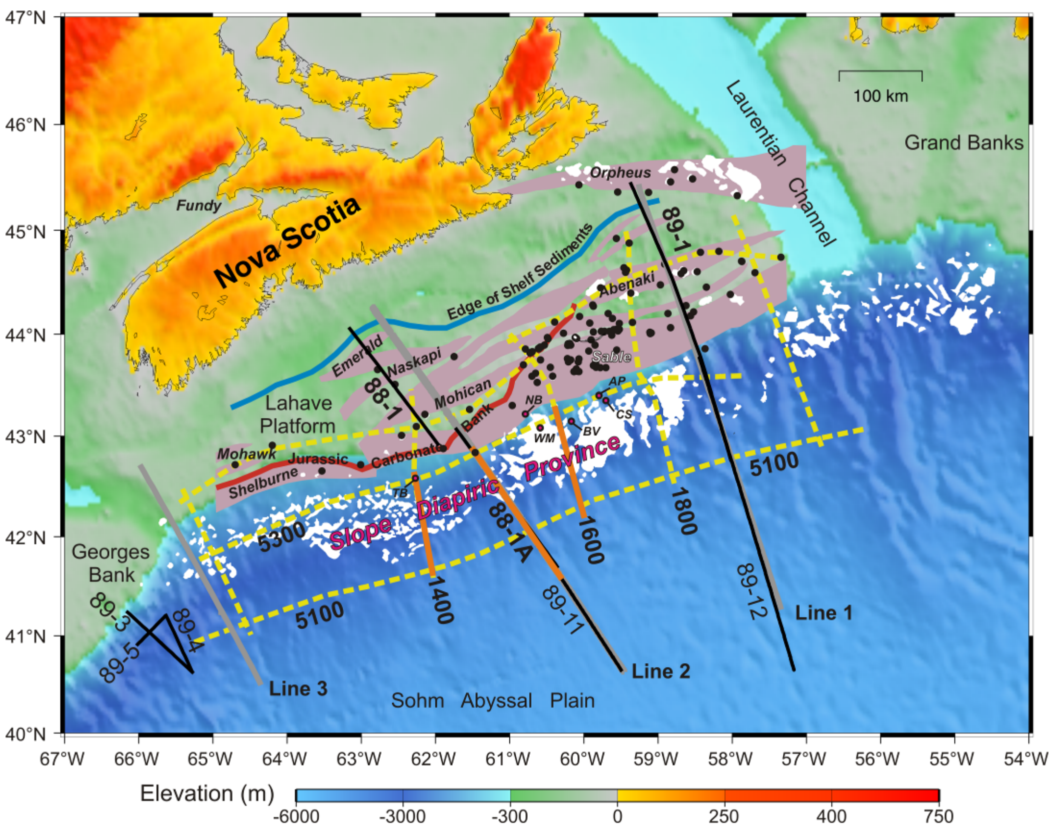

Figure 1: Location map of seismic profiles and sediment structures across the Nova Scotian margin. Seismic profiles include GXT Nova-Span MCS profiles (broken lines), Litho-probe and BGR MCS profiles (solid black) and SMART wide angle profiles (solid gray). Sediment structures include shallow-water basins (pink fill) and boundaries of shelf sediment and Jurassic carbonate bank (blue and red lines) from Enachescu and Hogg (2005), and major salt bodies (white fill) from Shimeld (2004). Also shown are exploration wells (filled circles, with selected deeper water wells identified) and shaded seafloor topography (colour scale). Location of 2008 marine heat-flow measurements shown in orange.

Thermal Models and Heat Flow Measurements

Petroleum systems models, following on previous work by Mukhopadhyay (2006), have been determined along profiles LE88-1A and GXT 1400 for various potential source rocks and reservoirs (e.g. Fig. 2). Imaging of deeper structures in depth section is improved, using pre-stack depth migration (NovaSpan 1400) or pre-stack time migration and wide-angle velocity models (Lithoprobe 88-1A; Wu, 2007). Stratigraphic and lithologic interpretation of the profiles are based on neighboring wells and previous interpretations (e.g. Kidston et al., 2002; Young, 2005). Along both profiles, assumed salt flank and salt crest Late Jurassic and Early Cretaceous reservoirs form the primary exploration targets. On line GXT

NovaSpan 1400, assuming a medium basement heatflow, the Early Jurassic source rocks occur within the dry gas zone while both the Jurassic and Cretaceous Verrill Canyon source rocks remain within the oil window (0.5% to 1.35% Ro) and will have contributed major volumes of liquid hydrocarbons within various reservoirs. The Early Cretaceous reservoirs lie within a moderate pore pressure regime with a temperature <100 ^{o}C, while the Late Jurassic reservoirs would remain within the overpressure regime with a temperature >100 ^{o}C.

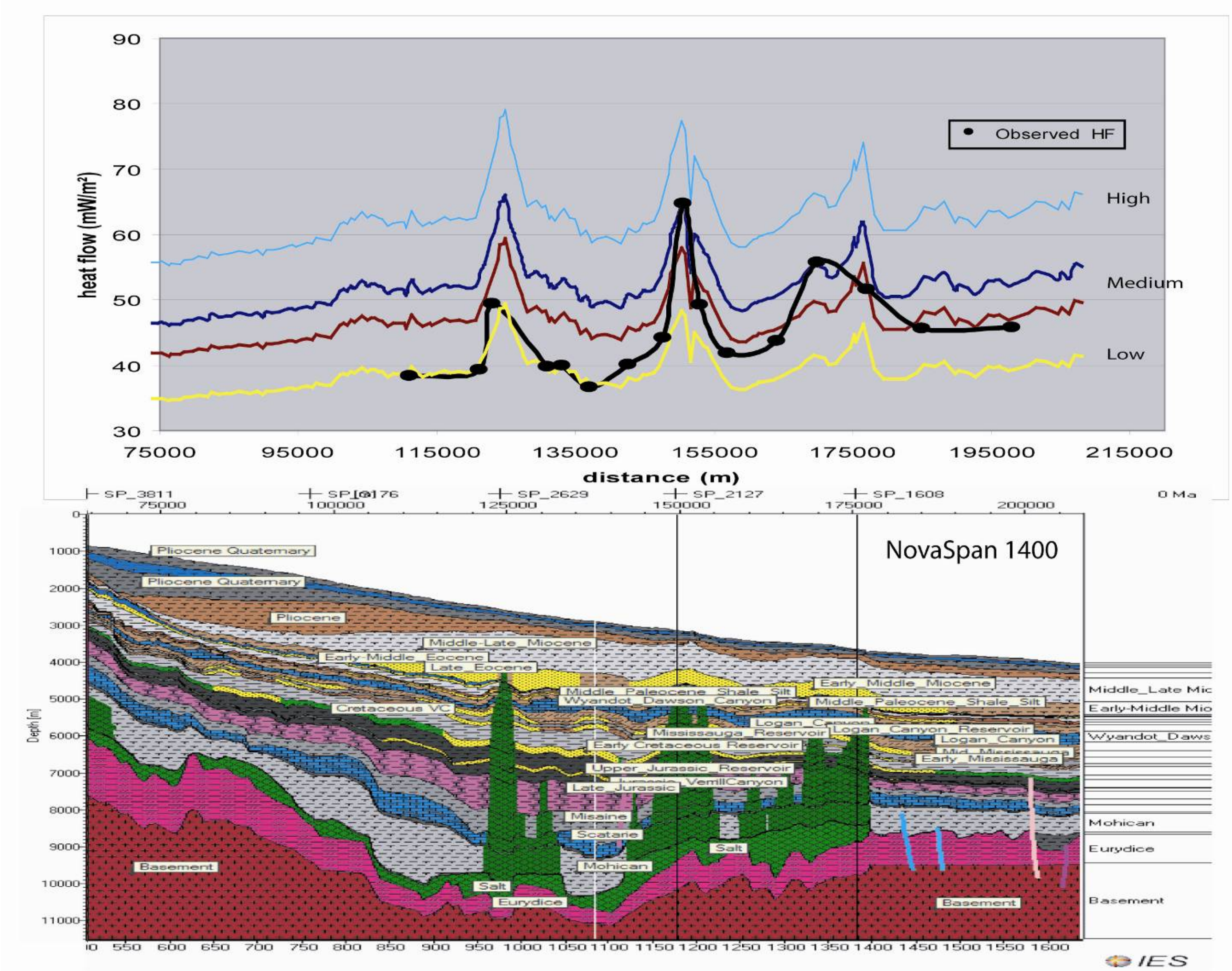

Figure 2: (upper) Heatflow values predicted along GXT line NovaSpan 1400 (coloured lines as indicated for low, medium and high basement heat-flow) compared to observed heatflow (filled circles connected by thick black line).

(lower) Lithologic and stratigraphic units interpreted along profile. Yellow dotted areas are conceptual target sandstone reservoirs and dark and medium gray units are potential source rocks, as identified.

To help constrain the model predictions, heatflow measurements were conducted along the profiles in July 2008 using the Dalhousie marine heatflow probe with 32 sensors over a 6-m length. Successful measurements of both temperature gradient and conductivity were taken at approximately 50 stations along three profiles (Fig. 1). Results for lines 1400, 88-1A and 1600 indicate a lower than expected regional basement heatflow, suggesting that previous models might have over-predicted temperatures and hydrocarbon maturation. Measurements of elevated heatflow above salt structures compared with model predictions indicates some values which are considerably higher than expected (e.g. Fig. 2 at distances of

150 and 170 km). Further modeling will be conducted to determine the implications to maturation calculations.

Conclusions

Predictions of maturation from petroleum systems models are dependent on values of basement heatflow, which are typically constrained by observations of vitrinite reflectance from drill sites. For deep-water frontier basins, such as the Scotia slope basin, such data do not typically exist. We demonstrate, however, that observations of surface heatflow along seismic profiles can be used to give alternative constraints. We also show that closely-spaced heatflow data can help to constrain the shape and depth extent of high conductivity structures such as salt diapirs and canopies that can significantly alter the temperature field. Our ultimate goal is to develop self-consistent regional thermal maturation models that are constrained by sediment and crustal structures, rifting history, subsidence and heatflow.

Acknowledgements

This work has been funded by the Nova Scotia Offshore Energy Technical Research Association (OETR) and by NSERC. The NovaSpan MCS profiles were provided by ION/GXT. E. Negulic is supported by a Penrose scholarship from the Nova Scotia Department of Energy.

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