Thermal modelling of the central Scotian Slope, offshore Eastern Canada: Seafloor heat flow data, hydrocarbon maturation potential and the effects of salt on heat flow

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ABSTRACT

The Scotian Slope is an under-explored deepwater sedimentary basin, located offshore eastern Canada. As few wells sample the Scotian Slope the thermal structure and maturation of the inferred Verrill Canyon Formation source rocks remains unknown. Seafloor heat flow measurements were acquired in an attempt to better constrain the thermal structure of the central Scotian Slope. Local thermal anomalies associated with high thermal conductivity salt bodies are evident in the heat flow data. Seafloor heat flow data are coupled with simple crustal rift models, well data and 2D seismic data in constraining dynamic 3D thermal models of the study area to predict the maturation of varying source rock intervals. Early results suggest the Verrill Canyon shales occur within the late oil/wet gas producing zones.

1. Introduction

The passive continental Scotian margin located offshore Nova Scotia formed as the result of Late Triassic rifting of the North American and African plates. The associated Scotian Basin underlies both the shallow water Scotian Shelf (<200 m) and the adjacent deeper water Scotian Slope (200-4000 m) (Fig. 1). This basin comprises a series of deep sedimentary subbasins that resulted from syn-rift and three post-rift phases of subsidence (Jansa and Wade, 1975). The Scotian Basin has been the site of active hydrocarbon exploration since the 1960's. To date hydrocarbon exploration has been focused on the Scotian Shelf which has been sampled by over 150 boreholes. Despite continued exploration, production has so far been confined to the Sable Subbasin on the outer shelf in the region surrounding Sable Island (Fig. 1). The successful drilling on the Scotian Shelf has yet to be replicated in the deepwater as none of the 12 slope wells yielded commercially significant hydrocarbon shows. In the absence of wells, little temperature or vitrinite reflectance data are available for analysis of the thermal evolution and maturation history of Scotian Slope sediments (Mukhopadhyay et al., 2006). A Kimmeridgian source rock interval has been inferred as likely source rock for the Scotian basin following results from other eastern Canadian sedimentary basins (Enachescu et al. 2010). The goal of this study is to couple new seismic interpretations and heat flow measurements with simple rift models to better constrain the thermal structure and maturation history of the deep water Scotian Slope.

2. Thermal Modelling

Thermal and petroleum systems models are useful in predicting the hydrocarbon potential of a basin if sufficient data are available to constrain the models. Of particular importance in predicting the maturation potential of a basin is the use of vitrinite reflectance data (%Ro) in constraining the basin's thermal history. However, where vitrinite reflectance data are lacking, such as deep water frontier basins with limited drilling, other techniques must be applied. We apply constraints derived from surface heat flow measurements taken using a shallow marine probe along three deep MCS profiles across the central margin (Fig. 1).

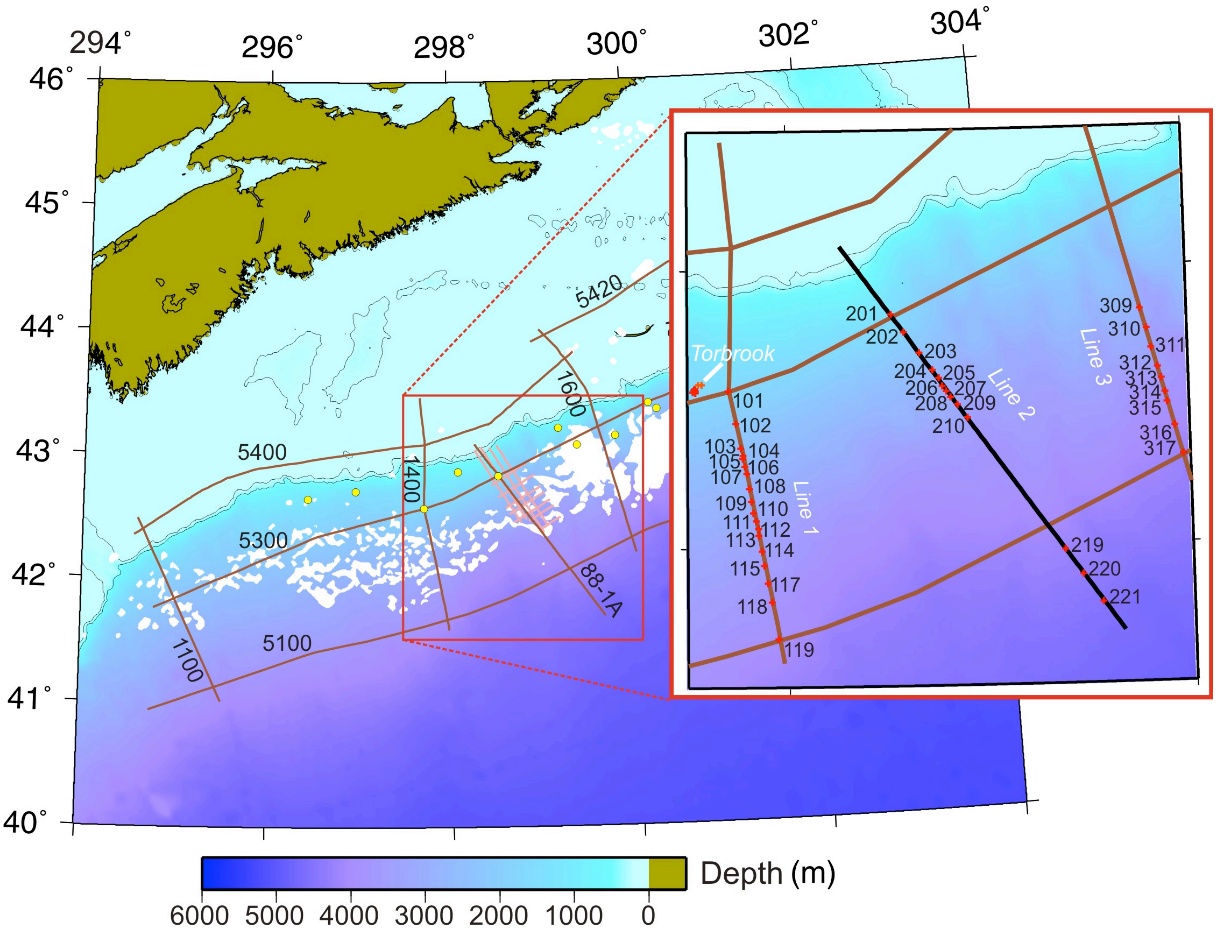

Figure 1: Location map of the central Scotian Slope study area showing NovaSPAN seismic profiles in brown, TGS-Nopec NS-100 seismic lines in pink, and Lithoprobe line 88-1a in black. Yellow circles represent Scotian Slope boreholes, white represents shallow salt after Shimeld (2004) and 200 m and 400 m seafloor depth contour intervals are shown as fine black lines. Zoom section shows locations of seafloor heat flow stations as red crosses at the Torbrook gas hydrates mound (Torbrook) and along the traces of seismic reflection profiles 1400 (Line 1), 88-1a (Line 2) and 1600 (Line 3).

Thermal models, constrained by available well data from the Scotian Slope, seafloor heat flow data, available 2D seismic data (Fig.1), and simple crustal rift models are used to constrain structure and stratigraphy. The pure shear uniform stretching model of McKenzie (1978) was employed to predict the basal heat flux history of the study area. Crustal stretching factors across the central Scotian Slope were defined after velocity modelling of seismic refraction profile SMART Line 2 (Wu et al. 2006). To constrain other parameters in the model that are important for predicting the history of basal temperatures (e.g. lithospheric thickness and asthenospheric temperature), we compared predicted crustal heat flux with our observed seafloor heat flow data, after correction for the effects of salt and sedimentation. An initial lithospheric thickness of 100 km and athenospheric temperature of 1350 °C yielded the best fit to our corrected seafloor heat flow data.

Two dynamic 3D models (Model 1 and 2) were run using PetroMod 11 basin modelling software. This bottom up modelling package is used to model the thermal evolution and structure of the central Scotian Slope since Late Triassic rifting. The two models run both contain the same geologic structure and boundary conditions with the exception of the basal heat flux history curves. Model 1 was constrained using the basal heat flux derived from the uniform stretching model with a 100 km thick lithosphere, while Model 2 was constrained using a 125 km thick lithospheric heat flux. The second model was run in an attempt to lower the predicted present day seafloor heat flow, as Model 1, when compared to our measured data, over predicted seafloor heat flow in the seaward limits of the study area. The predicted seafloor heat flow values are plotted against our measured seafloor heat flow data in Figure 2. In regions unaffected by salt we see good agreement between our modelled and measured seafloor heat flow data (the most landward two seafloor heat flow measurements record anomalously low geothermal gradients and may be ignored). The seaward measured heat flow data fits the Model 2 predictions best, while the landward data better matches Model 1 predictions. The increase in measured heat flow in the landward direction may be the result of increased radiogenic heat production in the thickening continental crust not accounted for in our 3D models. While there is relatively good agreement between measured and modelled seafloor heat flow in regions unaffected by salt, modelled values above salt bodies do not always fit our measured data. Local increases above salt, as expected, are predicted by the models; however, large variability in measured heat flow above single diapirs suggest additional process to conductive heat transfer may be affecting the seafloor heat flow which are not accounted for in our dynamic 3D models.

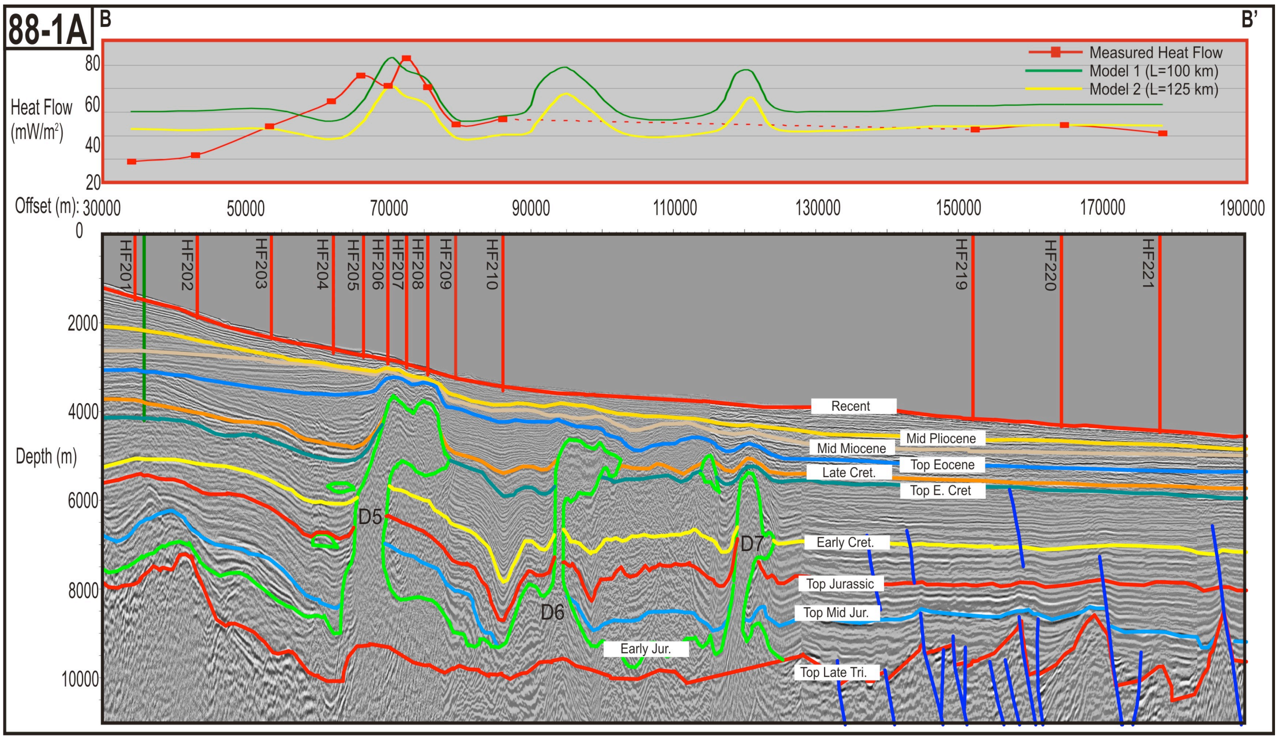

Figure 2: Seismic interpretation of Lithoprobe Line 88-1a. Basement is outlined in red, and salt in green. Vertical red lines represent locations of seafloor heat flow stations, vertical green line represents the location of the Shubenacadie H-100 well and inclined blue lines are faults. Three salt

diapirs are labeled D5-7. Plotted above the seismic interpretation are both measured (red) and modelled (green and yellow) seafloor heat flow.

In addition to predicting the seafloor heat flow of the central Scotian Slope the models also predict the maturation of inferred source rock intervals. According to Model 1 the Kimeridgian Verrill Canyon source rocks occur within the wet gas window, while model 2 places these same source rocks in the late oil producing zone. This shows that variations in the basal heat flux history can have significant effects on the maturation in hydrocarbons. While the method derived above combining seafloor heat flow data, seismic data and simple crustal models is useful as a first approximation to the hydrocarbon maturation potential of a deepwater frontier basin, in order to truly constrain the maturation of Scotian Slope source rocks deep drilling is required.

Acknowledgements

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