Thermal Modelling of the Central Scotian Slope, Offshore Nova Scotia: The Effects of Salt on Heat Flow and Implications for Hydrocarbon Maturation

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Summary

Seafloor heat flow measurements were acquired in the summer of 2008 across the central Scotian Slope along three existing deep MCS profiles (Fig. 1). In this area the Scotian Slope is cut by numerous highly thermally conductive salt bodies which significantly distort local geothermal gradients. Seafloor heat flow measurements were acquired both across salt structures and in regions not underlain by salt to measure the effects of salt on seafloor heat flow and to determine variations in regional heat flux across the margin respectively. Two phases of 2D petroleum systems models were developed to determine the hydrocarbon maturation potential of the region. Comparison of model seafloor heat flow predictions with the observed seafloor heat flow data indicate that early models can explain much of the variation across the salt structures, although some misfit suggests possible effects due to 3D variations in salt geometry or the presence of convective fluid flow through the overlying sediments. In addition, the regional heat flow values indicate much lower temperatures than previously suggested, which alters the predicted maturation of the expected deeply buried Jurassic and Early Cretaceous source rocks. New 3D petroleum systems models are being developed which include additional constraints of salt geometries from crossing seismic profiles and thermal constraints from seafloor heat flow measurements with regional basement heat flux histories calculated from standard lithospheric rift models. These 3D models will better predict the maturation potential of the margin than previous 2D models.

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) and has been the site of active hydrocarbon exploration since the 1960s. To date hydrocarbon exploration has been focused on the Scotian Shelf which has been pierced 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, 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). 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.

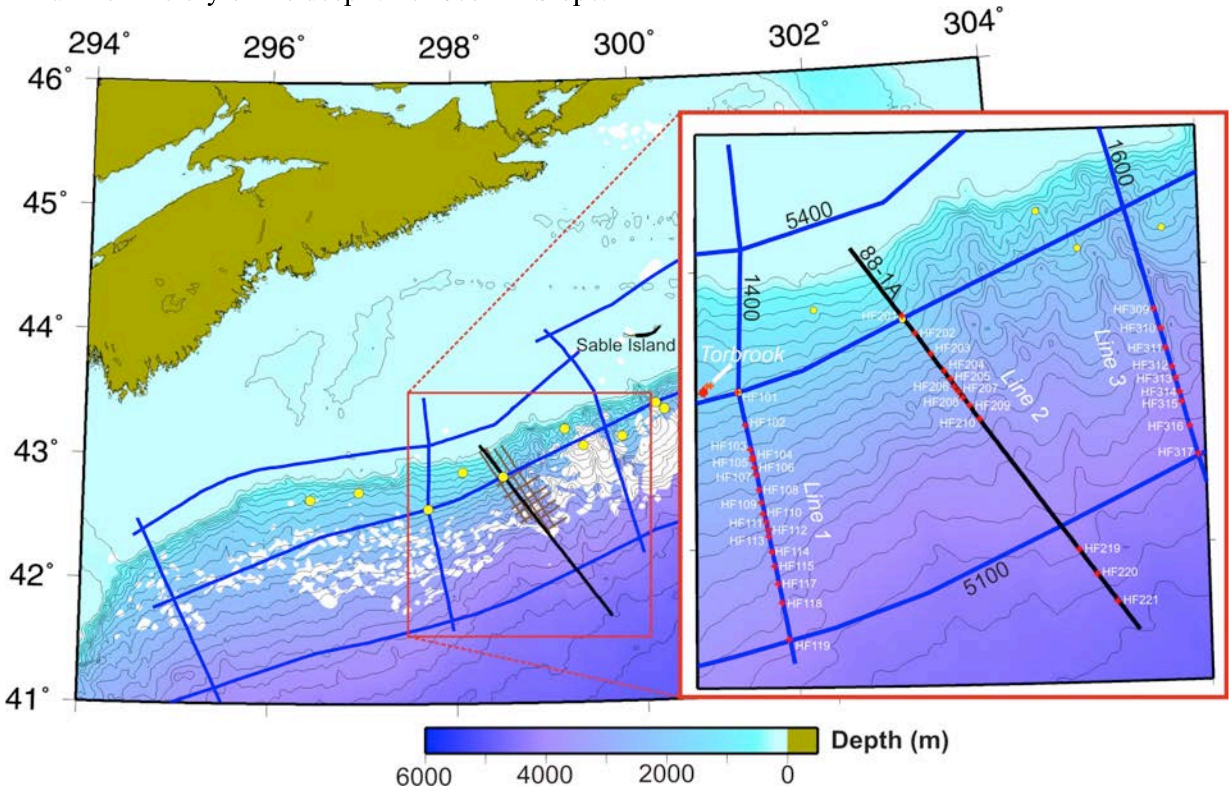

Figure 1: Location map of the central Scotian Slope study area showing NovaSPAN seismic profiles in blue, TGS-Nopec NS-100 seismic lines in brown, and Lithoprobe line 88-1a in black. Yellow circles represent Scotian Slope boreholes, white represents shallow salt after Shimeld (2004) and seafloor depth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

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 for deeper 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).

Initial petroleum systems models (2008) along the traces of seismic lines 1400 and 88-1a across the central Scotian Slope predict that all Jurassic and the lowest Early Cretaceous (Berriasian) strata occur within the dry gas window. The wet gas window rests within the Early Cretaceous (Top Berriasian to Top Barremian) strata while the oil window comprises the rest of the Early and Late Cretaceous sediments (Louden et al.2008). Thermal parameters for these models were lacking, as very limited vitrinite reflectance data from select wells was available. Therefore, the models predicted a higher seafloor heat flow than was measured in the ultra-deep zones (Fig. 2). The higher seafloor heat flow suggests these models may have over-predicted the degree of hydrocarbon maturation. A second phase of 2D petroleum systems models (2009), constrained by the new seafloor heat flow data, show slightly deeper oil and gas windows. The upper limit of the dry gas zone has been pushed down to the Top Jurassic boundary. The wet gas window now comprises the lowermost portion of the Early Cretaceous (Top Tithonian to Top Hauterivian), and the base of the oil window has been pushed from the Top Barremian to the Top Hauterivian strata (Louden et al., 2009).

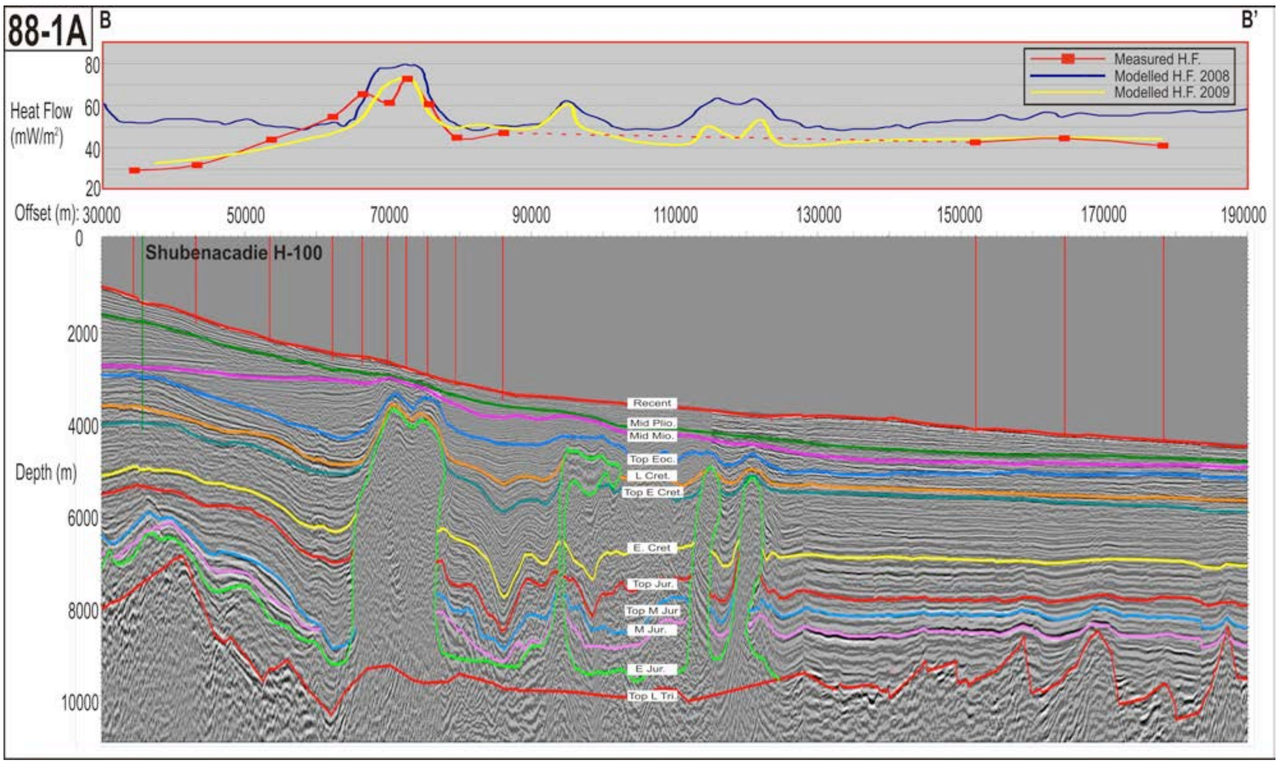

Figure 2: Seismic interpretation of Lithoprobe Line 88-1a. Basement is outlined in red, and salt in green. Vertical red lines represent locations of seafloor heat flow stations and the vertical green line represents the location of the Shubenacadie H-100 well. Plotted above the seismic interpretation are both measured (red) and modelled (blue and yellow) seafloor heat flow values. Modelled values from 2008 (blue) are constrained by available vitrinite reflectance data while 2009 modelled values are constrained by both vitrinite reflectance and measured seafloor heat flow data.

While there is relatively good agreement between measured and predicted heat flow from 2D petroleum systems models in regions unaffected by salt, measurements above salt are not exactly as expected. The measured values are not replicated in static, purely conductive 2D models which suggests that there may be out of plain 3D effects of salt affecting measured heat flow. In order to account for potential 3D effects of salt on heat flow we are in the process of running 3D thermal and petroleum systems models of the region surrounding the central heat flow transect, Line 2. Salt distribution in these models is constrained by interpretations of available 2D seismic lines surrounding Lithoprobe line 88-1A. The seismic data form a grid with line spacing of ~8 km (Fig. 1). Once the distribution and structure of salt bodies has been determined 3D models can be run to determine if the measured heat flow variations above salt bodies can be explained by out of plain variations in salt geometry or if other processes such as bottom water currents or convective fluid flow are affecting the measured values. In addition to seafloor heat flow and limited vitrinite reflectance data, simple crustal rift models (e.g. McKenzie 1978, Royden and Keen 1980) are employed to better constrain the thermal parameters of the 3D models. Crustal stretching factors (β) after Wu (2007) will be used to predict the basement heat flux history for the region.

Conclusions

In petroleum systems models, basement heat flux is primarily constrained by temperature and vitrinite reflection data from boreholes. In the Scotian Slope frontier basin, which has a limited number of wells, we have investigated the use of shallow marine heat flow measurements coupled with crustal rift models to help constrain thermal models of the basin. In the presence of salt, purely conductive 2D thermal models are often insufficient in predicting seafloor heat flow as demonstrated by recent seafloor heat flow measurements. Out-of-plain variations in salt geometry, only accountable for in 3D models with well-constrained salt geometries, may affect measured temperature gradients and seafloor heat flow. 3D petroleum systems models constrained by seismic interpretations of sediment and crustal structure, the margins rift and subsidence history and measured seafloor heat flow values are self-consistent and can be used to predict the maturation potential of a basin through time.

Acknowledgements

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