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Evaluating Undrilled Structural Plays Imaged in New Data from the Labrador Sea Using Structural Forward Models

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Summary

Newly available fast track pre-stack depth migration (PSDM) data from the Labrador Sea reprocessed by TGS has clearly imaged abundant structural traps related to early Cretaceous rifting and a gravitationally-driven Tertiary fault system. This study applies interactive kinematic forward models of fault-related folding to assess possible plays with a higher degree of confidence than standard interpretation techniques alone. When combined with high quality data, structural models provide robust constraints on fault displacements, across-fault horizon correlations, growth strata geometries, and structural histories. This study shows that interactive structural modeling can provide significant insights into potential structural play locations, potential trap development, and fault seal at an early stage of the exploration process in a frontier basin. In the Labrador Basin Complex, these models reveal significant accumulations of known syn-rift source rocks within deep rift structures and show that structural trap formation within the Tertiary section was likely compatible with the timing of hydrocarbon expulsion.

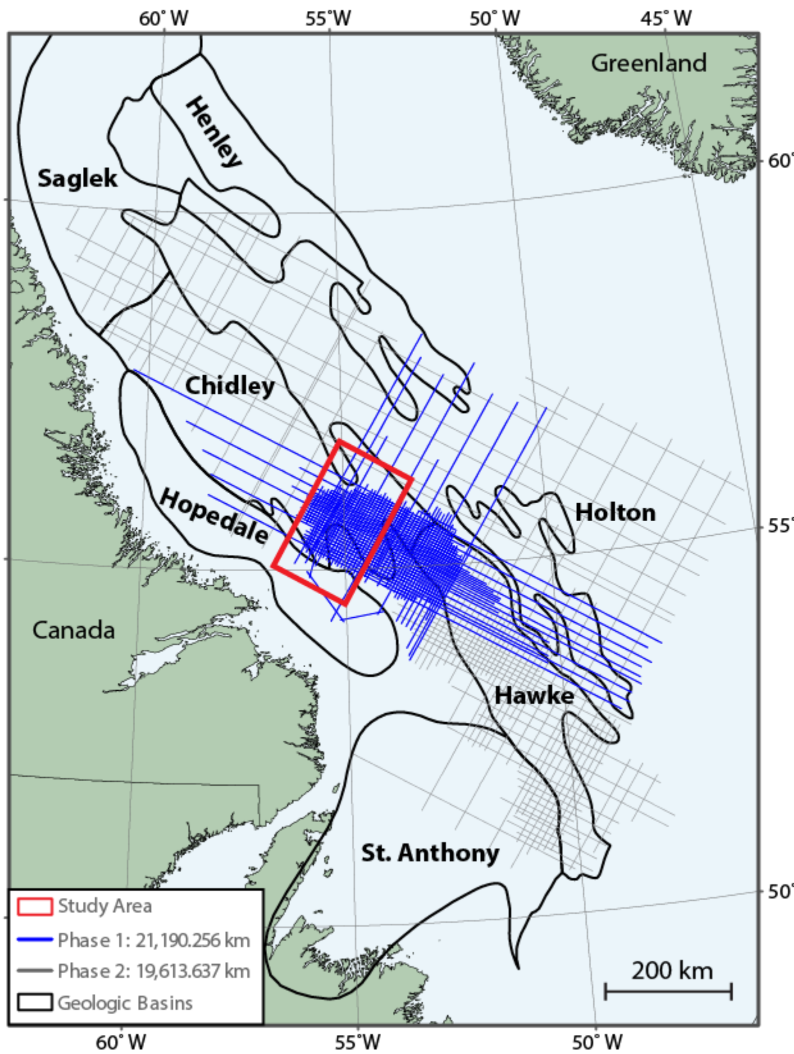

Figure 1: Map of the Labrador Sea showing the coverage of the TGS/PGS survey area, the sub-basins that comprise the Labrador Basin Complex, and the area covered by this study.

Introduction

Within the last six years, over 47,000 km of 2D seismic data has been collected in the Labrador Sea through a joint venture between TGS and PGS. The survey area covers multiple basins within the Labrador Basin Complex with lines spanning shelf to deep-water settings (Figure 1). Newly available Fast Track pre-stack depth migration (PSDM) data from the area involved in the upcoming NL01-LS bid round has clearly imaged abundant possible structural traps related to early Cretaceous rifting and a Tertiary fault system where extensional faulting on the shelf is taken up by thrust faults on the lower continental slope, similar to the Niger Delta. In structural plays such as these, kinematic forward models of fault-related folding can be used to assess possible plays with a higher degree of confidence than standard interpretation techniques alone. When combined with high quality data, structural models provide robust constraints on fault displacements, across-fault horizon correlations, growth strata geometries, and structural histories. Quantitative animations of the models show the complete evolution of the structures over time. Within the Labrador Basin Complex, the structural models provide significant insights to the distribution of early Cretaceous synrift source rocks and the timing of potential structural trap development within the Tertiary section.

Methods

Initially, a regional grid of widely spaced 2D seismic lines were acquired in the Labrador Sea. As license rounds have been announced by the Canada Newfoundland and Labrador Offshore Petroleum Board, subsequent surveys have infilled the regional grid for appraisal of bid round areas. TGS is currently reprocessing approximately 20,000 km of the Labrador Sea data (Phase 1 in Figure 1) with final PSDM data available in June 2017.

As discussed above, the Labrador data images numerous structural features that were unrecognized until recently. Well control is only available on the continental shelf so correlating horizons across these structures and out toward the basin is greatly facilitated by kinematic forward models of fault related folding. The forward models presented here were developed using StructureSolver software, which allows the model parameters (such as fault shape, shear angle, displacement, and growth history) to be interactively modified until the model-predicted fold and fault geometry reproduces the structures imaged in the seismic data (Figure 2). In this paper, fault-bend-folds are modeled using inclined shear (Xiao and Suppe, 1992) and fault propagation folds are modeled with trishear (Erslev, 1991). These models quantitatively link horizon shape to fold geometry and displacement through basic kinematic assumptions such as conservation of area during deformation.

The model results constrain displacement, growth strata geometry, across-fault horizon correlations, fault trajectory at depth, and timing of fault slip. Once the model is complete, the entire structural history can be animated showing the development of the structures at any point in time. Quantitatively modeling fault geometry, associated horizon displacements, and history of fault slip provides a rigorous basis for confidently evaluating possible trap and fault seal potential in structural plays. Applying structural forward models to the high-quality data from the Labrador Sea allows confident interpretation of deep synrift sequences, fault locations, and constrains the relative timing of fault development within linked structural systems.

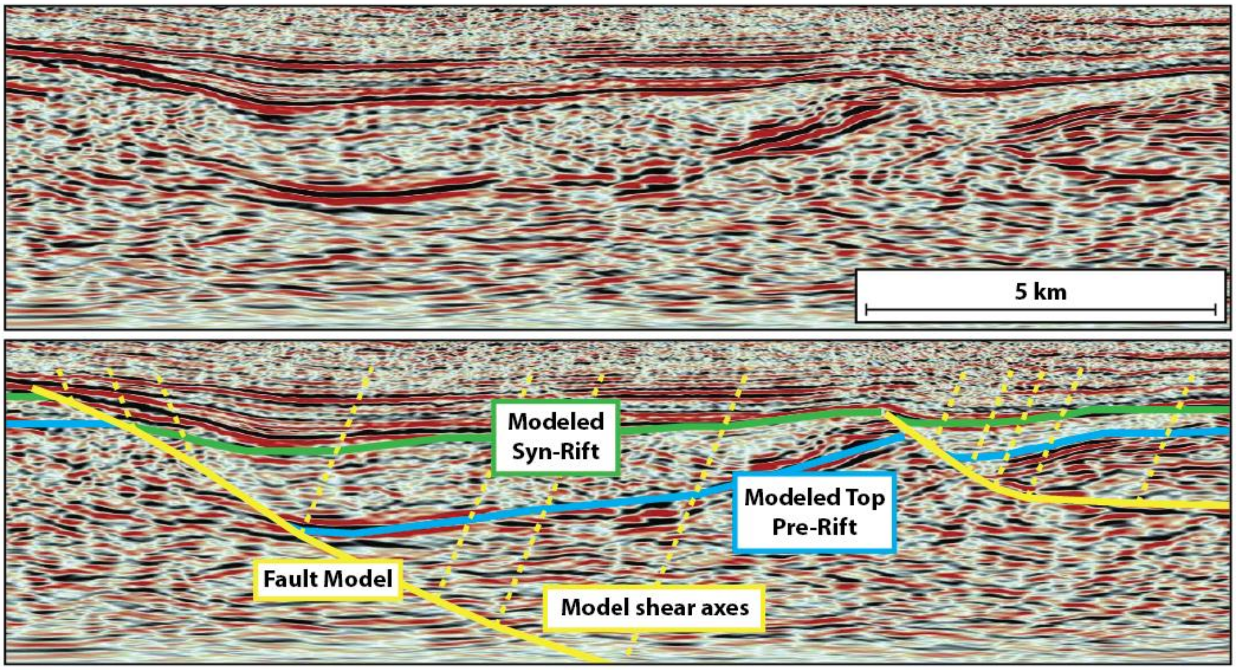

*Figure 2: Seismic section showing the deep Cretaceous rift structure imaged within the study area shown in Figure 1. **Top:** uninterpreted seismic section **Bottom:** Example of two structural forward models of the rift structures imaged above. The fault shape (yellow), footwall location, and fault displacement were interactively adjusted until the computed horizon geometry (blue, green) matches the horizon geometry observed in the seismic image. Horizon geometries are computed based on fault bends using shear across axes that emanate from bends in the controlling fault (shear axes, yellow dashed lines). The model shown here suggests likely across-fault correlations within the rift graben as well as fault displacement and shape at depth. The models indicate that significant syn-rift strata thicknesses, likely the Bjarni and Markland formations, are present within some of the deep rift structures*

Discussion and Examples

Applying kinematic structural models to the new Labrador Basin Complex data reveals key insights into possible plays along the continental slope. The new data successfully images half-grabens at the mid and lower slope related to the early Cretaceous rifting (Figure 2). Structural models based on these fault plane reflections indicate significant thicknesses of Cretaceous synrift sediments are localized within these grabens. This is of particular note given that the Cretaceous Bjarni formation is a proven source rock for the region. The modeled syn-rift growth strata indicate that the grabens were actively extending during deposition of the Cretaceous Bjarni and Markland Formations but had ceased by deposition of the Paleogene Cartwright formation.

In the overlying Tertiary section, structural models for normal faults on the upper slope and thrust faults on the lower slope significantly refine the stratigraphic and structural framework, linking well control on the shelf to the lower slope. While the data shows numerous normal faults, the models show that the majority of extension is mainly accommodated on 2-3 faults and burial of potential sand intervals increases significantly across these structures. Within the distal thrust belt on the lower slope, modeling of the thrust faults indicates a “break backward” sequence deformation, with faulting propagating backward toward the shelf rather than forward toward the basin. Models for both the extensional and contractional fault systems indicate that both regimes detach in the Eocene Cartwright formation. The sequence of deformation indicated by the models suggests both faults systems were concurrently active during deposition of the intra-lower Mokami formation in the Oligocene. The fact that both systems share a detachment and were active concurrently is consistent with a gravitationally driven deformational system. Basin and thermal models indicate that the Markland and Cartwright formations underlying the linked extensional-contractional fault system on the slope are within the oil window and suggest expulsion during the late Eocene to Oligocene (Tibocha et al., 2016). The structural models developed in this study imply that traps related to these structures would have been in place at the time of expulsion.

Conclusions

In early stages of the exploration process in frontier basins, interactive structural modeling based on high quality seismic data can be applied at initial stages of the exploration process to provide key insights into structural plays. In the Labrador Basin Complex, new data spanning the continental shelf and slope shows numerous potential structural plays including half-grabens related to Cretaceous rifting and a Tertiary fault system driven by gravity tectonics. Structural forward models provide robust correlations of horizons across faults, locate changes in fault trajectory with depth, and determine the relative timing of their development. Quantitative animations show the complete development of these structures over time. Models of the Cretaceous rift structures show how and where deposition of Bjarni syn-rift source rocks was localized during extension. Models for the Tertiary fault system show that potential structural traps associated with the lower slope toe-thrust would have been in place at the time of hydrocarbon expulsion from the Markland and Cartwright formations.

Acknowledgments

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References

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