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New Insights on the Slope and Deep Water Region of the Labrador Sea, Canada

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SUMMARY

Covering an area approximately ten percent larger than the U.S. Gulf of Mexico (over 600,000 km2) the Canadian Labrador Sea region remains largely unexplored. Dormant exploration activity has led to nearly a 30 year gap in acquiring data for exploratory purposes. In 2009, Nalcor Energy and Astrium engaged in a satellite survey of the Labrador Sea to map surficial, naturally occurring hydrocarbon slicks throughout the eastern margin of Newfoundland and Labrador. Results from that work led directly into extending a proposed Nalcor invested and partnered TGS-PGS multiclient 2D regional seismic survey into the deepwater extents of the Labrador Sea (Figure 1). As of 2012, this new regional long-offset seismic survey has now added over 22,000 line kilometres of high quality data to the area. Early interpretational results of that data have forced a revision of the regional model including preliminary definition of several new Mesozoic depocentres within the Labrador Basin Complex (LBC).

Introduction

Covering an area approximately ten percent larger than the U.S. Gulf of Mexico (over 600,000 km^2) the Canadian Labrador Sea region remains largely unexplored. Dormant exploration activity has led to nearly a 30 year gap in acquiring data for exploratory purposes. A partial update to shelf related 2D seismic was concluded nearly 5 years ago (Enachescu, 2006), however no regionally extensive seismic coverage existed in slope and deepwater regions. In 2009, Nalcor Energy and Astrium engaged in a satellite survey of the Labrador Sea to map surficial, naturally occurring hydrocarbon slicks throughout the eastern margin of Newfoundland and Labrador. Results from that work led directly into extending a proposed Nalcor invested and partnered TGS-PGS multiclient 2D regional seismic survey into the deepwater extents of the Labrador Sea (Figure 1). As of 2012, this new regional long-offset seismic survey has now added over 22,000 line kilometres of high quality data to the area. Early interpretational results of that data have forced a revision of the regional model including preliminary definition of several new Mesozoic depocentres within the Labrador Basin Complex (LBC).

Discussion

Rift basins associated with the opening of the Labrador Sea were previously concentrated dominantly on the shelf where both well control and sparse seismic data coverage constrained the limits. New insights obtained from the 2011 2D seismic acquisition over shelf and deep water regions have led to the identification of a significantly more complex margin than previously discussed. The evolution of the Labrador Sea is commonly described as involving an early rift phase (early Cretaceous through mid- to late Cretaceous) followed by a sea floor spreading drift phase through latest Cretaceous to earliest Paleocene (Balkwill and McMillan, 1990; Chalmers and Pulvertaft, 2001; Dickie et al., 2011). The tripartite megasequence division of Balkwill and MacMillan (1990) has been retained in this study, as it provides a logical separation between the rift, drift, and post drift phases of deposition. Major unconformities, that in part define the megasequence packages, can be regionally mapped. These include the base Cretaceous unconformity (k140 marker), the Cenomanian unconformity (k100), the base Tertiary unconformity (T65), and the middle Eocene unconformity (T45). Although these markers have been given semi-formalized names (Balkwill and McMillan, 1990; Enachescu, 2006), in order to facilitate correlation between basins on the eastern and western flanks of the Atlantic Margin, the convention applied by Dickie et al. (2009) using approximate age of the unconformable gap will be used in this study. Through regional scoping maps of these markers, combined with existing depth to basement maps, several Mesozoic syn-rift intervals were identified on the Labrador margin (Figure 1). This is similar to results on the southwestern Greenland slope where new data led to the mapping of the newly defined Mesozoic-aged Narsaq Basin (Knutsen et al., 2012). Although significant section and structuring has been identified within the Drift and Post-Drift megasequences throughout the study area, the focus of basin delineation centres on the Rift Megasequence.

Southern Labrador Sea Region

Commonly referenced in the literature but lacking clearly defined extents, the Hawke Basin (Figure 2) can now be defined as a Northwest-Southeast striking half graben feature formed during mid-Mesozoic rifting. To the South it connects with the northern limits of the Orphan Basin, while in the North the boundary is tentatively placed near the Cartwright Fracture Zone. The eastern extent at present consists of a series of basement highs that form a Northwest-Southeast set of lineaments that mark the transition into the western edge of the Holton Basin. Further interpretation of this region is necessary in order to discern whether the Holton is a separate basin, or rather an eastward continuation of the Hawke Basin. The western-edge of the Hawke is defined by a basin bounding listric fault that marks an abrupt end to the syn-rift section.

Central Labrador Sea Region

This region is represented by the Hopedale (shelf), Chidley (slope and deep water), and Henley (deep water) basins. The Hopedale Basin lies on the western extents of the study area and holds three significant gas discoveries as well as a single oil test. Previous authors (e.g. Balkwill and McMillan, 1990; Dickie et al., 2011) had defined the Hopdale as being a series of Northwest-Southeast striking rotated fault blocks holding syn-rift Cretaceous sediments. These blocks are bound by the Okak Arch to the North and the Cartwright Arch to the South, and to the West by the erosional edge of the syn-rift section. Definition of the eastern limits of the Hopedale Basin have historically been slightly more problematic, as the seismic coverage and quality from the distal shelf into deep water regions has been limited. Based on early interpretation of the newly acquired 2D data, the eastern limit of the Hopedale Basin may be interpreted as either extending from the shelf to the slope, or as constrained to the outer limits of the shelf. Under pinning the shelf-slope break, a long series of elevated basement blocks separate the early to middle syn-rift section of the Hopedale on the shelf from deposits of

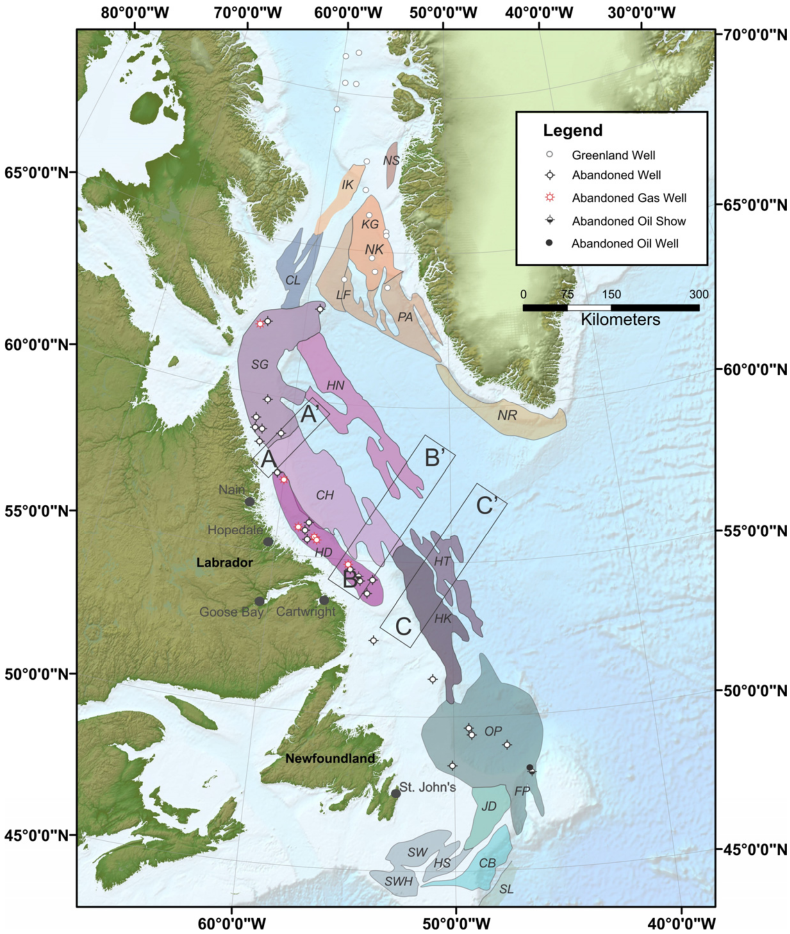

Figure 1 *New Mesozoic basin configuration of the Labrador Basin Complex. CH – Chidley Basin; HK – Hawke Basin; HN – Henley Basin; HT – Holton Basin; HP – Hopedale Basin; SG – Saglek Basin. Mesozoic basins of the Grand Banks (CB – Carson-Bonnition; FP – Flemish Pass; HS – Horseshoe; JD – Jeanne d'Arc; OP – Orphan; SL – Salar; WH – Whale; SWH – South Whale) and Davis Strait/Western Greenland (CL – Cumberland; IK – Ikermiut; NS – Nagssugtoq; KG - Kangamiut; LF – Lady Franklin; NR – Narsaq; NK – Nuuk; PA – Paamiut). West Greenland basins modified from Knutsen et al. (2012). Lines of section are illustrated in following figures.*

similar age in the slope and deep water. Alternatively, some preservation of the latest syn-rift deposits continues over these highs and can be correlated into the deep water section. Preliminary work on sediment thickness along the slope and deep water shows a continuous, thick syn-rift section that extends from the Saglek Basin in the North to the Hawke Basin in the South. The Okak and Cartwright arches, while important for the definition of the Hopedale Basin, do not appear to separate this continuous package to the East of the basement ridge (Eastern Ridge Complex). Given that, the eastern extents of the syn-rift section in the Hopedale are taken to end at the basement ridge

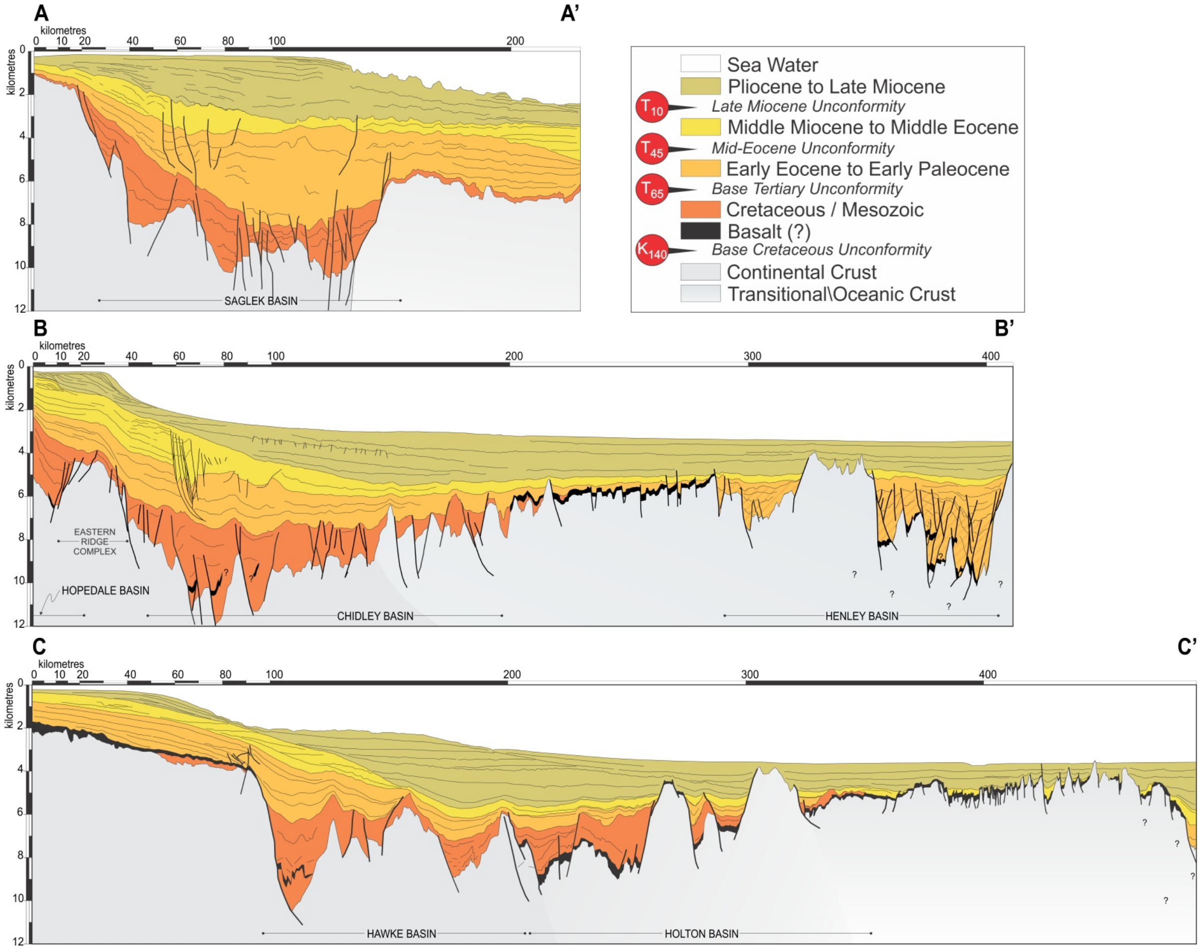

Figure 2 *Lines of Section illustrating Mesozoic section through slope and deep water regions of the Labrador Basin Complex.*

lineament. Syn-rift deposits East of that lineament mark the onset of the Chidley Basin. Much like the Hawke to the South, the Chidley basin consists of a series of connected rotated fault blocks with preserved Mesozoic section that underly the slope to deep water region of the Labrador Sea. Bound to the South by the Cartwright Fracture Zone where it intersects with the Hawke and to the North where it connects with the Saglek, the Chidley Basin is a large half graben structure that has 3 to 4 kilometres of Mesozoic section in the West to gradual pinch out in the East. The Henley Basin lies in the centre of the Labrador Sea and consists of over 8 kilometres of section from water bottom to basement. Interpretation of stratigraphic intervals in this basin has proven to be somewhat problematic. Although several markers have similar character to the base Tertiary marker, implying Mesozoic fill, seismic tie lines from the Saglek are inconclusive. Recent work by Dickie et al. (2011) define the central Labrador Sea region where the Henley Basin lies as characterized by the dormant spreading ridge related to the end of the opening of the Labrador Sea. Basin fill would likely be Late Eocene and younger in that scenario.

Northern Labrador Sea Region

The southern extents of the Saglek and northern extents of the Henley Basin overlap in the northern region of the study area. The Saglek Mesozoic section is continuous with equivalent section in the Chidley Basin. The western extent, where covered by seismic, is bound by a down to the East listric fault that places syn-rift sediments against granitic basement. To the East, several West dipping faults place Mesozoic section abruptly against transitional and/or oceanic crust. This is in contrast to the Chidley Basin where the Mesozoic section thins and merges with the base Tertiary marker. The Henley Basin appears to merge with the Saglek in the northern-most extents of the study area, however further interpretation is required to determine where the Mesozoic limits are in the eastern-most basin.

Conclusions

New acquisition techniques have greatly improved the imaging of seismic markers within the rifted Labrador margin allowing for strong ties from shelf to deep water. Acquisition over the previously un-imaged slope and deep water regions has extended the margins of Mesozoic syn-rift deposition into four expanded basin areas throughout the Labrador Sea region. Mesozoic section within these depocentres ranges from 3 to 4 kilometres thick on average. Implications of the syn-rift section is dominantly two-fold. Firstly, additional reservoir potential within rotated fault blocks exists throughout the Atlantic margin slope and deep water vastly increasing the exploration potential of the region. Secondly, the liquid hydrocarbon potential is drastically increased as Cenomanian through Maastrichtian source rock has a high preservation potential within these basins, is moderately faulted, and has reached significant burial depths in some regions increasing the chance of the shales entering the oil window. Cenomanian source rocks have been described in West Greenland both on land, and in an immature state in the offshore (Bojesen-Koefoed et al., 2004). Further indication of an active petroleum system within these newly defined regions is supported by satellite slick mapping over the Labrador Basin Complex that highlights naturally occurring surficial oil sheen that occur overtop these Mesozoic basins. Where these slicks occur near a seismic line, hydrocarbon anomalies (cloud, chimneys) are observed. This is analogous to observations made over several discovery regions within the Jeanne d'Arc Basin to the South. Early stage AVO (amplitude variation with offset) work using the recently acquired long offset Labrador Sea seismic data provides additional evidence supporting the presence of active petroleum systems in these newly delineated basins. .

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