Deep-Water Hydrocarbon Potential Beneath the Labrador Sea, Offshore Newfoundland and Labrador, Canada*

Kai Floistad[1], Ron Borsato[2], Jerry Witney[1], James Carter[3], Richard Wright[3], and Thomas Neugebauer[4]

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[1]PGS, Houston, USA (kai.floistad@pgs.com)
[2]PGS, Weybridge, UK
[3]Nalcor Energy, St. John's, Canada
[4]TGS, Houston, USA

Abstract

Exploration in the Hopedale and Saglek Basins (Figure 1) has a historical success rate of 25%, which is remarkable for frontier exploration. When we consider the size of the area and the very small number of wells, one per 4,000 km^2, it is clear that exploration to date has only scratched the surface. With exploration confined to the shelf and no test of the deep water potential conducted, leaving the remaining question of 'is there a potential in the deep waters of Labrador? Newly acquired 2D GeoStreamer data from the area is starting to help enlighten and de-risk this extensive under-explored area

Introduction

First oil was produced on the Grand Banks (Figure 2) in 1997 from the Hibernia field and since then the world-class oil producing fields Terra Nova, White Rose and North Amethyst in the Jeanne d 'Arc Basin have come on stream. It is estimated that recoverable reserves of 4.6 billion barrels of oil (BBO) and 18.8 trillion cubic feet (TCF) of natural gas exist in the Mesozoic basins of Grand Banks alone. The 2009 Mizzen oil discovery in the Flemish Pass Basin, estimated at 200 million barrels recoverable reserves, proved the extension of a working petroleum system, sourced by the prolific late Jurassic source rock into an area where it was previously only postulated to exist. The extent of the nascent Labrador Sea, in Late Jurassic-Early Cretaceous, northwest towards the Davis Strait was previously unknown and has now been partially delineated with the new 2D seismic data, which confirms the presence of a continuous Mesozoic rift section. The Mizzen discovery bordering the eastern perimeter of the East Orphan Basin fuels the idea that there could have been a seaway passage between Greenland and Canada comprised of early stage rift basins containing potential source rock. Insight from the new survey identifies rift section throughout the slope and deep-water regions of the Labrador Sea. Recent work along the western Greenland margin also confirms extensive Mesozoic rift basins, as well as Turonian-aged source rock in outcrop and in offshore exploration wells (Knutsen et al., 2012). These basins north and south of the Labrador Sea would have provided excellent conditions for deposition of source rock along the Labrador margin.

Exploration History and Petroleum Systems

The major period of exploration on the Labrador Shelf was in the 1970s and 1980s, when more than 200,000 km of 2D seismic were recorded and 30 wells were drilled (21 in the Hopedale Basin and nine in the Saglek Basin) with the last well drilled in 1983. In Hopedale Basin, five discoveries were made of which the Bjarni H-81 / North Bjarni F-06 complex is the largest, estimated to contain more than three TCF of natural gas. The discovery was made in the Bjarni Formation sandstone of Early Cretaceous age (Figure 3). The three other natural gas discoveries are Snorri J-90 within the Gudrid Member sandstone reservoir (Paleocene age), Hopedale E-33 in the Bjarni Formation sandstone reservoir and the Gudrid H-55 discovery which has an Ordovician carbonate reservoir. The only discovery in the Saglek Basin is the Hekja O-71 natural gas discovery, which is estimated to contain 2.3 Tcf in a Gudrid Member reservoir. It is important to note that all were drilled on the shelf, with no wells penetrating slope and deep water regions.

The Labrador Sea stretches from the Davis Strait in the northwest and includes the Hawke Basin in the southeast (Figure 1). The shelf is characterized by shallow banks separated by northeast trending channels and water depths of less than 200 m. The slope and rise are steep and the water depth in the northwestern survey area extends down to 3500 meters. Water depth generally increases to the southeast, reaching a maximum of 4,500 meters northeast of the Flemish Cap. There are three main sedimentary basins on the Labrador Shelf; the Hawke Basin in the south, the Hopedale Basin and the Saglek Basin in the north; the last two basins are separated by the Okak Arch. The Orphan Basin is located northeast of Newfoundland, and Flemish Pass Basin and Grand Banks are located almost directly east of Newfoundland.

Rifting in Labrador began during the Lower Cretaceous Berriasian and resulted in extensive peneplanation of the basement (Figure 4) with earliest syn-rift deposits encountered in shelf wells comprising the Alexis Formation volcanics and the fluvio-lacustrine Bjarni Formation. With expanding section observed on seismic in southern regions the possibility exists for preservation of older Mesozoic sediment over deep-water regions of the Labrador offshore. The Avalon unconformity (Cenomanian age) marks the transition into post-rift sediments, which consist principally of marine shales and their more proximal sand equivalent (the Freydis Member). Seafloor spreading commenced in the Late Maastrichtian or Early Paleocene and is marked by the Bylot unconformity (base Tertiary) these syn-rift sediments are mainly marine shales with some submarine fan and shallow marine sandstone deposits (Gudrid and Leif Members). Seafloor spreading ended in Late Eocene- Early Oligocene and is represented by the Baffin Bay unconformity with post-rift sediments comprising terrestrial and marine shales, siltstones, sandstones/siltstones and glacial beds.

The total organic carbon content of the Lower Cretaceous to Eocene shale deposits is considered sufficiently high to yield significant hydrocarbon source rock potential and in Labrador, they occur in the Cretaceous Markland Formation, the Paleocene Cartwright Formation and the Eocene Kenamu Formation. Turonian-Cenomanian marine shales of the Markland Formation are immature on the shelf, but are buried at greater depths in the slope and deep-water regions. The younger marine deposits are immature on the shelf and probably also in the slope and deep-water regions, these shales act as excellent regional seals. Reservoir rocks are present in the syn-rift Bjarni Formation, syn-drift Freydis Member, and syn-drift to post drift Gudrid and Leif Members (all sandstone). There is also a proven reservoir potential in Paleozoic dolomites/carbonates subcrop section (Figure 5).

On the shelf, the Bjarni Formation sandstone is the most widespread reservoir in both structural traps related to the rift topography and in combination structural/stratigraphic traps. The deep water Bjarni Sandstone onlaps rotated Paleozoic to Precambrian fault blocks and is draped directly over the fault blocks creating 4-way dip traps and the structural highs associated with fault blocks form 4-way dip closures in younger sediments. On the slope and rise the early syn-rift Bjarni is likely similar in depositional character, while the distal equivalents of the Freydis, Gudrid and Leif Member sands are expected to occur as basin fans with trapping mechanisms being stratigraphic and structural, as well as combination traps of both types.

Lower Paleozoic Ordovician rocks include carbonates and dolomites with preserved reservoir quality proven by wells in western Newfoundland and by the Hopedale E-33 well and the Gudrid H-55 well in Labrador. Carbonates with reservoir quality were also encountered in a few other wells in the Hopedale Basin, but have not been found in the Saglek Basin, as there are fewer wells and total depths terminating in younger section. However, Paleozoic sequences are present on Baffin Island and probably offshore West Greenland and may be present in the Saglek Basin.

Hydrocarbon Potential

Discoveries on the shelf have established one working petroleum system; there are three good source rock alternatives, it is uncertain which of them the primary contributor is and migration to the reservoir is believed to be short. Basin modeling of the Hekja discovery shows that the reservoir has barely reached the oil-window and the fact that the Gudrid sandstone reservoir was deposited directly on basalt implies that the gas in Hekja must have had a lengthy vertical and lateral migration route. This indicates the existence of a deeper source rock located outside the shelf and implies that there are at least two gas prone source rocks capable of charging large reservoirs. An oil-seep survey showed several active oil seeps in an area east of the Hekja discovery, and since gas is the only proven hydrocarbon in this area these slicks indicate another working petroleum system in the region. This is further supported by evidence of an Mid to Late Cretaceous oil prone source rock off of Western Greenland in the Disko Island region (Bojesen-Koefoed et al., 1999, 2004, Knutsen et al, 2012) and the northern tip of the Saglek basin trend. North Leif I-05 was the only shelf well to test oil (33o API waxy oil) on the Labrador margin, although other shelf wells had some limited oil stain noted in end of well reports. The North Leif well is considered a non-commercial discovery commonly thought to be sourced by terrestrial organic matter. A 2010 satellite oil slick mapping survey of the Labrador Sea revealed numerous satellite slicks in the deep-water regions. The satellite slicks identified in this survey were used to optimize positioning of the long-offset geostreamer seismic survey lines. Although early in the analysis of the new data, there are seismic amplitude anomalies in some of these frontier basins with AVO character consistent with hydrocarbon signatures in analogous basins of similar age. Could these amplitude anomalies represent HC and even better, could it be oil? A maturity study conducted in the Hopedale Basin indicate that a depth of 3300 meters is sufficient to reach the HC window, observed sediment thicknesses of 3.5 seconds (Figure 6) in the rift-basins close to the COB suggest sufficient burial of the potential Mesozoic (Late Jurassic and Turonian) source material to reach maturity. In some regions, long-range migration from these pools to the reservoir may be required, but we know this has happened in the Hekja well, decreasing the uncertainty of the play.

Conclusion

Exploration in Labrador has been somewhat dormant for well over two decades, with no deep-water tests. The new seismic dataset acquired over slope and deep-water regions will help de-risk future exploration models and provide a much better understanding of the petroleum system. Early indications from the newly acquired dataset suggest a Mesozoic rift basin fairway that stretches from the Orphan basin in the south through to the Saglek basin in the north, with syn-rift sediments reaching burial depths far in access of those encountered on the shelf. Could there have been an early seaway passage between Greenland and Canada providing the correct environment for deposition of high quality marine source rocks in restricted rift basins in Late Jurassic and similarly in the Late Cretaceous? The question is still unanswered, but by covering the failed rift-arm, this dataset provides a unique opportunity to search for these rift basins close to the COB in the hunt for a potential Jurassic and Turonian-Cenomanian source rock. Despite a limited number of deep water wells in the Orphan basin, the extension of the Mesozoic rift section throughout the survey area has led to the identification of genuine opportunities on the slope and rise offshore Labrador. The syn-rift Bjarni Formation and Freydis sandstone reservoirs fill the half grabens of the transitional crust while syn-drift proximal Gudrid and Leif Member intervals on the shelf continue into deep water as distal equivalent basin fans.

Trapping mechanisms could be structural, stratigraphic or a combination of both. Further acquisition will continue to test the potential of the region, with positive insights suggestive that now may be opportune time to re-engage exploring for hydrocarbons in the deep waters of the Labrador Sea.

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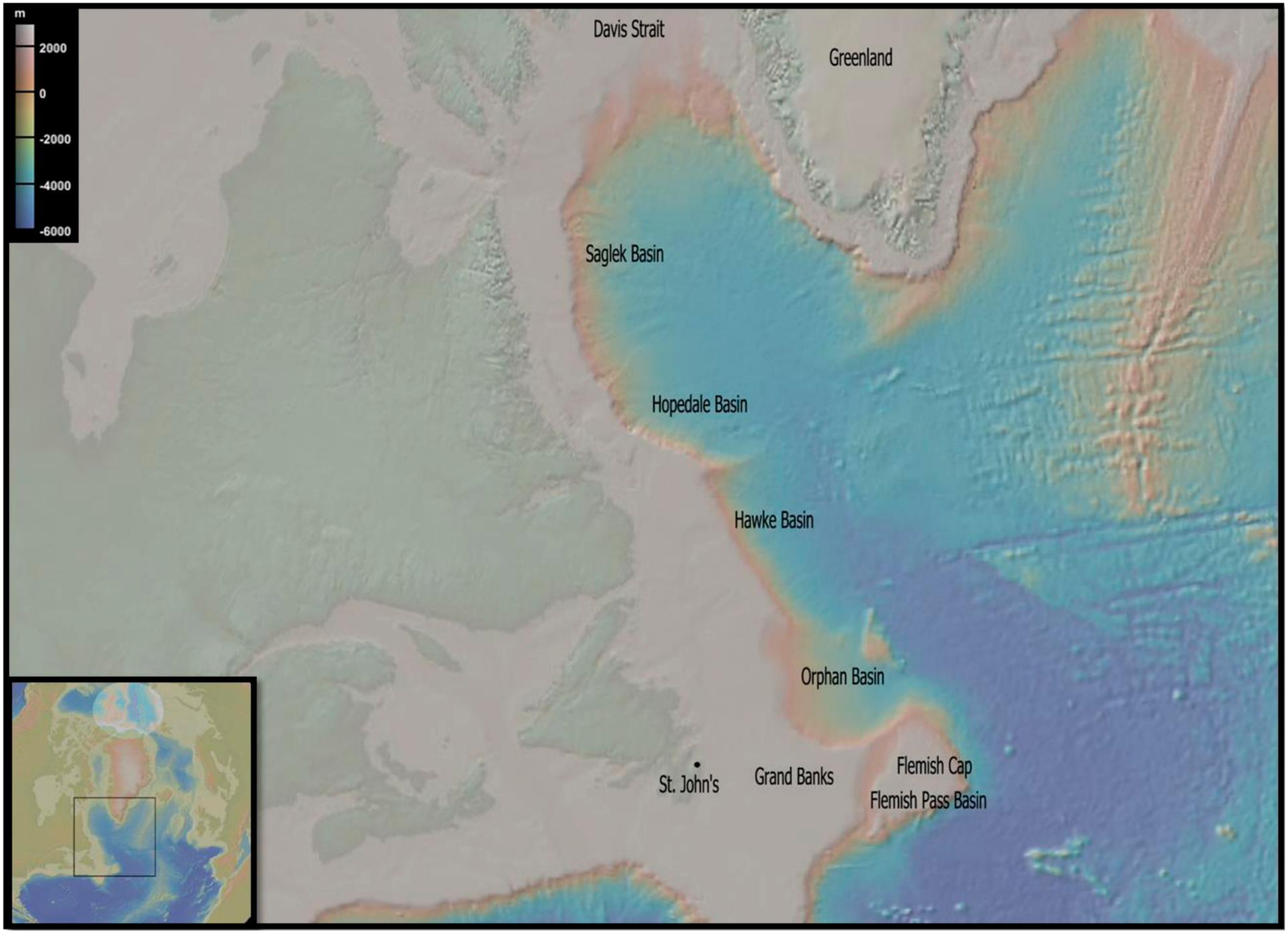

Figure 1. Location map of Newfoundland and Labrador.

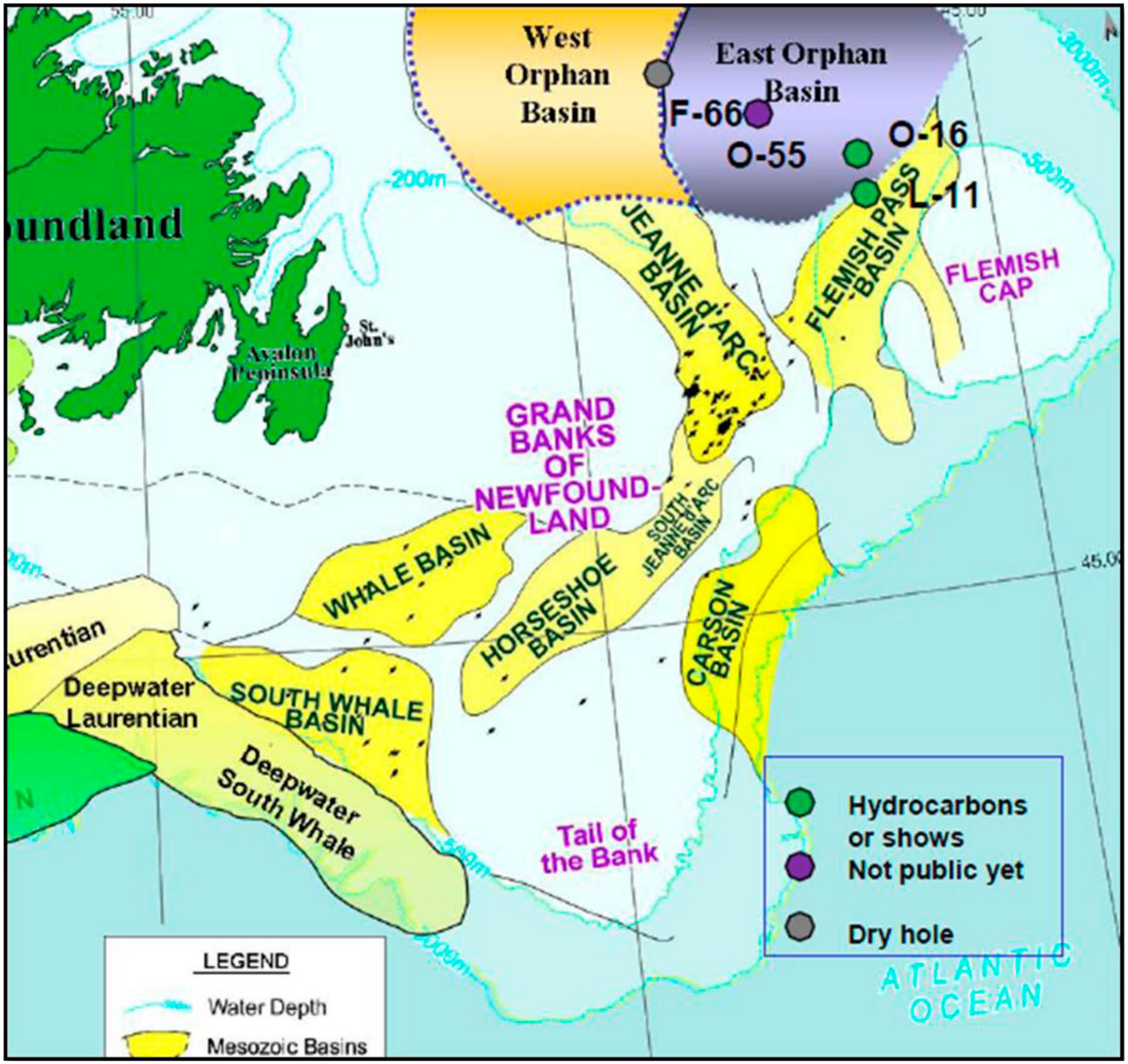

Figure 2. Distribution of Mesozoic basins on Grand Banks offshore Newfoundland (Enachescu, 2010).

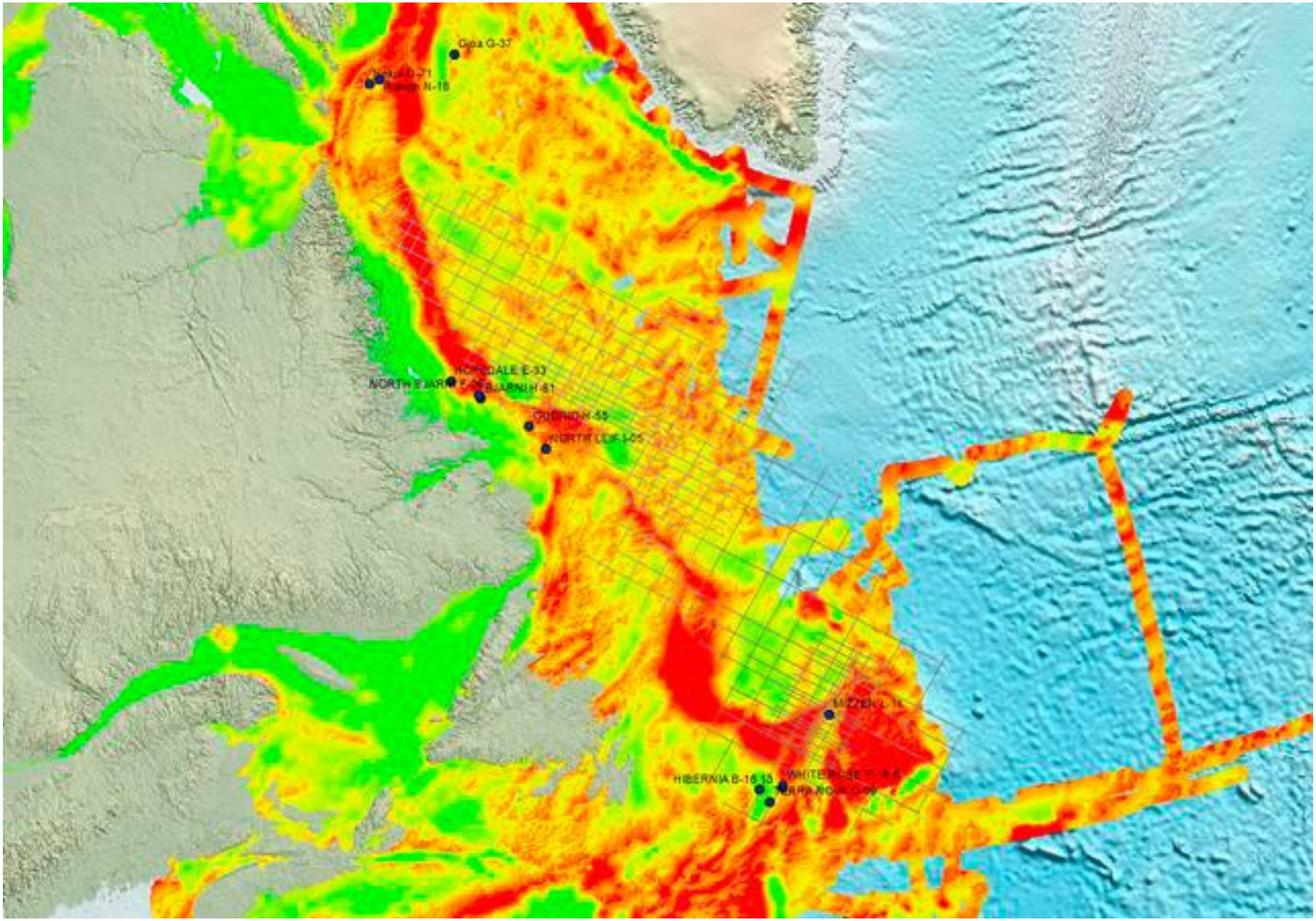

Figure 3. Key wells, GeoStreamer survey and free air gravity (Green denotes gravity low that equates to thicker sediments).

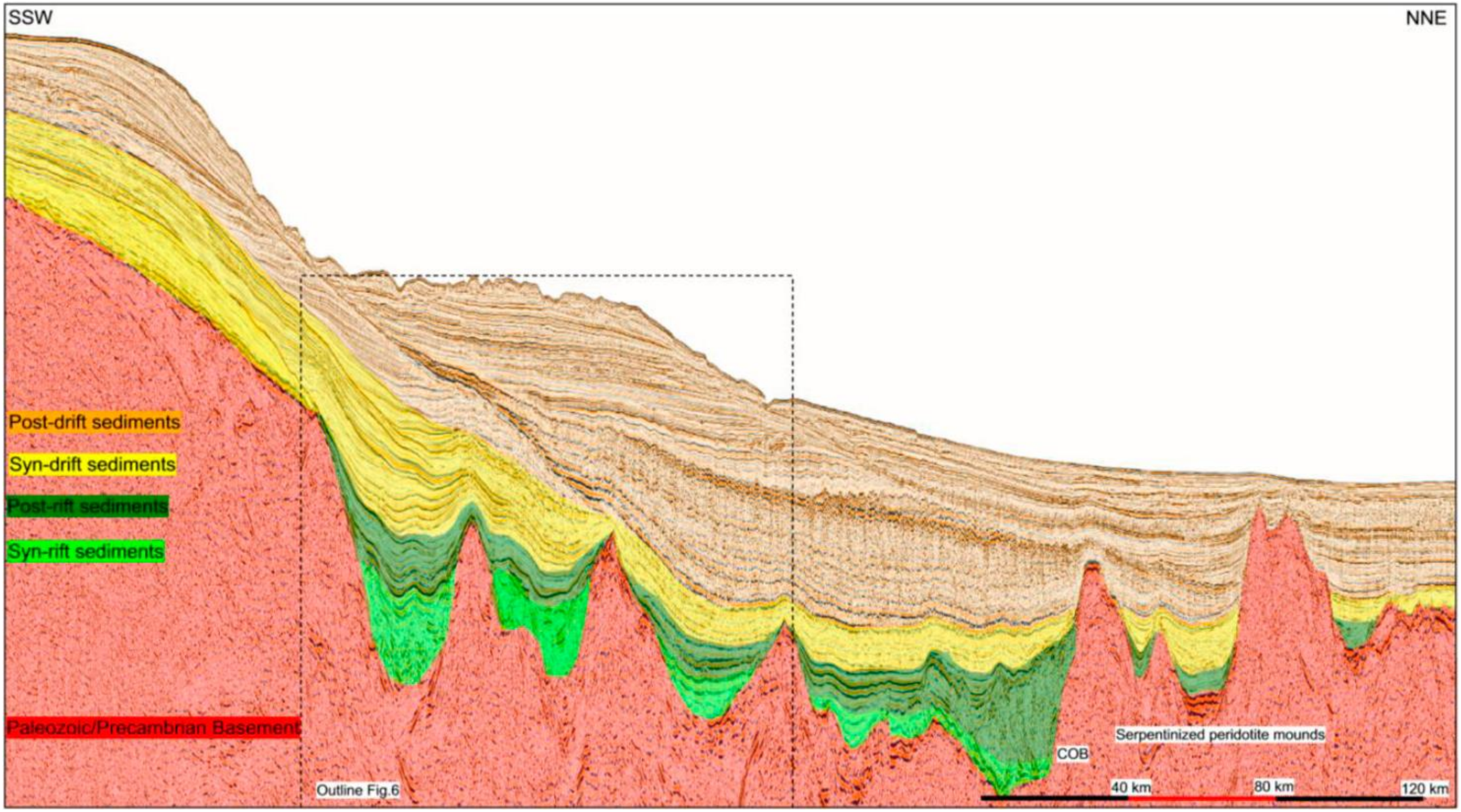

Figure 4. Dip line from shelf to across the continent-oceanic plate boundary (COB). There are several distinct unconformities on the shelf and upper slope related to paleo-shoreline adjustments. The rift basin landward of the basement highs/serpentinized peridotite mounds could contain Late Jurassic-Early Cretaceous source material. There is no distinction made between clastic and volcanic rocks in the syn-rift sediment package, the extension of these sediments all the way to the COB is however uncertain.

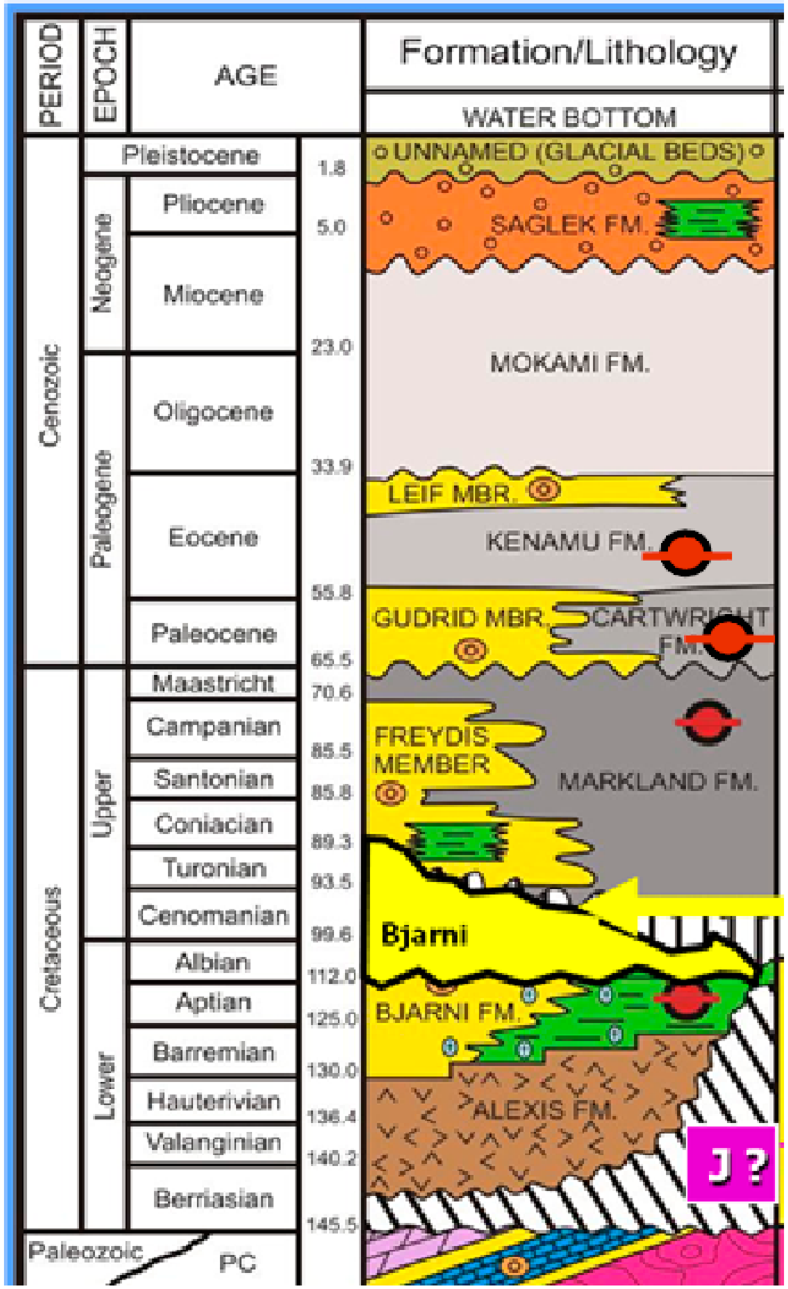

Figure 5. Canadian Labrador basins stratigraphic column (after Enachescu, 2011).

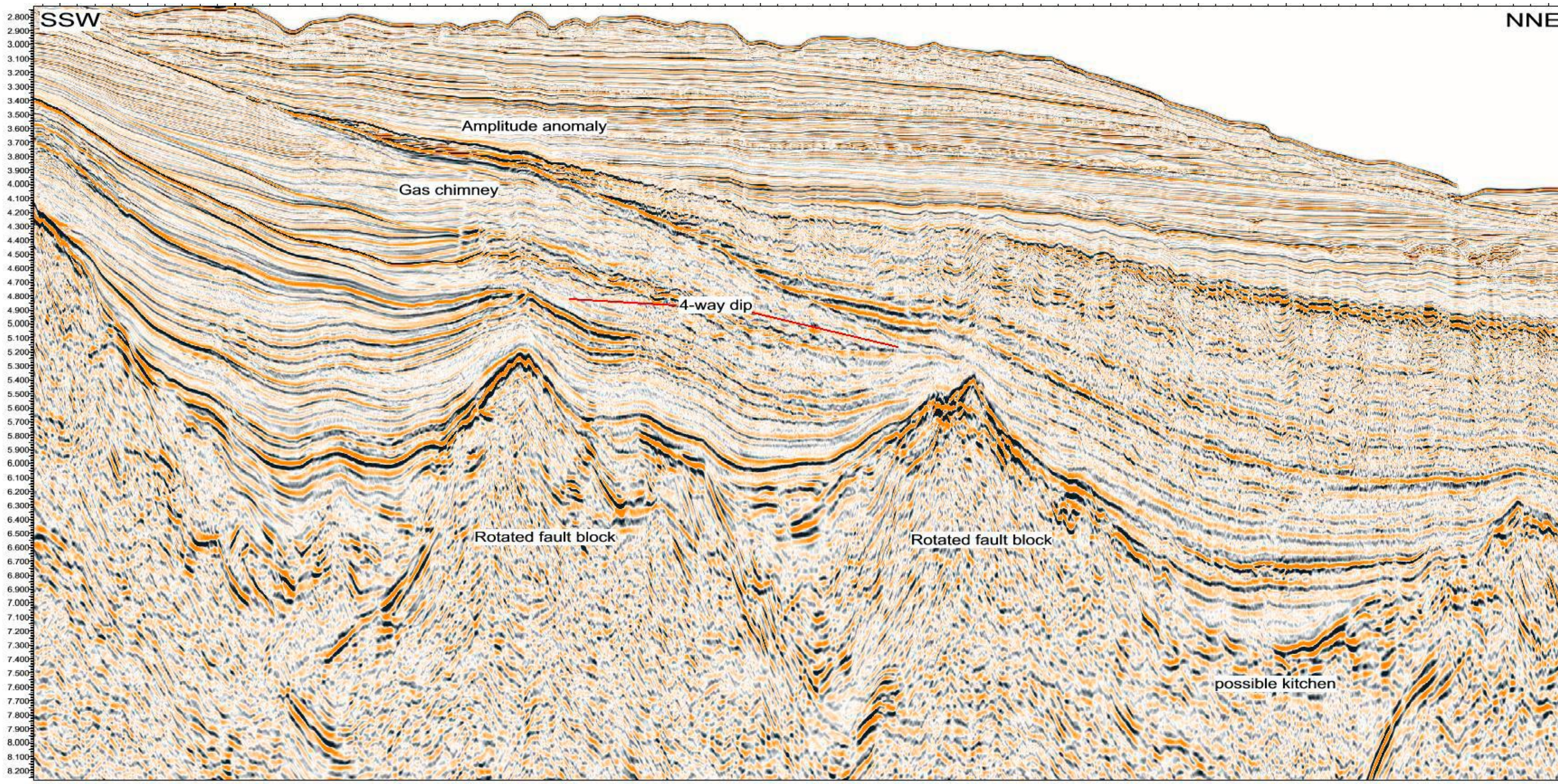

Figure 6. Large rotated fault block, consisting of Mesozoic rift section and possible Paleozoic carbonate reservoirs with potential 4-way dip closures above the fault blocks. There are several gas chimneys seen over the top of the fault blocks. A wedge of reflections with anomalously high amplitudes is seen pinching out towards the shelf.