OFFSHORE OPPORTUNITY - 2021 LICENCE ROUND

LABRADOR SOUTH 2021 CALL FOR BIDS

EXECUTIVE SUMMARY

- On November 29, 2016, the Canada-Newfoundland & Labrador Offshore Petroleum Board (C-NLOPB) issued Call for Bids NL16-CFB03 in the Labrador South region. The Call was expected to close in 2017, however was delayed to allow for completion of the Labrador Strategic Environmental Assessment (SEA). The SEA Update, an initiative co-chaired by the C-NLOPB and the Nunatsiavut Government, is now on track to be completed in Summer 2021, enabling the Call for Bids to close 120 days after its completion. The C-NLOPB will announce the closing date when the SEA has concluded and is expected to close before year-end.
- The area is highly prospective with a proven petroleum system confirmed by wells drilled on the Labrador shelf where large gas fields were discovered in the 1970s and 1980s and a significant light oil show was obtained from Cretaceous sandstones. Despite the presence of a proven petroleum system and good seismic coverage, the area remains under-explored.
- Located on Canada's East Coast, the province of Newfoundland and Labrador (NL) has sustained significant levels of industry interest in its highly prospective offshore basins. Since first oil at Hibernia in 1997, the province's five producing fields - Hibernia, Terra Nova, White Rose, North Amethyst, and Hebron, have produced in excess of 2.1 billion barrels of predominantly light oil (32-35˚ API). Several large oil discoveries were also recently recorded in the Flemish Pass Basin. The NL offshore area now produces over 260,000 bopd and output is estimated to increase to 400,000 bopd when Hebron reaches peak production.
- Mesozoic sedimentary basins are found all along the east coast of NL, from the Laurentian Basin in the south, north through the Grand Banks basins and the deeper waters of the Flemish Pass and Orphan basins, and extending north-westwards to several Labrador basins.
- The C-NLOPB estimates the Hopedale Basin has 4.3 tcf of discovered gas resources. Undiscovered gas potential for the Canadian Labrador basins is estimated at 22 tcf (Bell and Campbell, 1990; Drummond, 1998). These estimates focused mostly on the shallow water where seismic data was available at the time. Numerous structural and stratigraphic traps remain undrilled, adding to the region's prospectivity especially on the slope and in the deepwater where new 2D and 3D seismic data sets are now available. Recent evaluations have considerably increased the potential of the Hopedale Basin's in-place hydrocarbon resources (e.g. Carey et al., 2019).

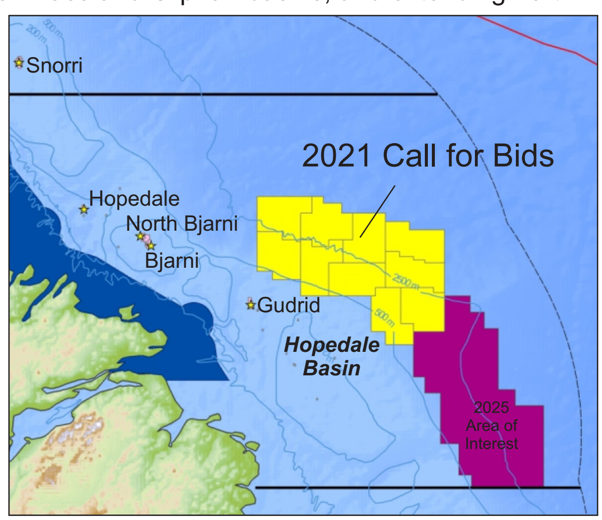


Figure 1. Labrador South region. Gas discoveries (stars).

KEY ATTRIBUTES

- Call for Bids totals 2,294,340 ha (5,669,437 acres).
- Closing date 120 days after SEA completion.
- Water depths from 450 m to 3,000 m.
- Competitive fiscal regime with very low political risk.
- Modern and historic seismic coverage and tie key wells.
- Virtual Exploration Data Room available.
- Proximity to both North American and European markets.
- Open and transparent land management and bid processing system.
- Winning bid based on the highest bid amount.
- For more information, visit www.cnlopb.ca

Newfoundland Labrador
CANADA

REGIONAL GEOLOGY OF THE ATLANTIC MARGIN

- The Hopedale and Saglek Basins in the Labrador Sea are Mesozoic extensional basins developed over hyper-stretched Precambrian and Paleozoic basement on the Canadian Atlantic Margin.
- Late Triassic to Late Jurassic rifting of Pangea created a chain of NE-SW oriented intracratonic basins extending from the Gulf of Mexico to the Barents Sea. Offshore Newfoundland basins are part of this Mesozoic rift system. Oblique and perpendicular rift branches (e.g. Bay of Fundy, Orpheus Graben, Aquitaine Basin, Viking Graben, Labrador Sea) also formed during the same series of extensional events.
- In Eastern Canada, the Mesozoic rift basin chain starts with George's Bank Basin offshore Nova Scotia, stretches through the Scotian shelf, slope basins and subbasins, and continues with the Laurentian Basin, located between Cape Breton Island and Newfoundland. To the north, the system continues with the shallow water Grand Banks basins that includes the Jeanne d'Arc Basin, before extending to the deepwater Flemish Pass and Orphan basins (Figure 2).
- During the Early Cretaceous, the Labrador basins, Hopedale and Saglek, formed as an arm of the main North Atlantic rifted zone.

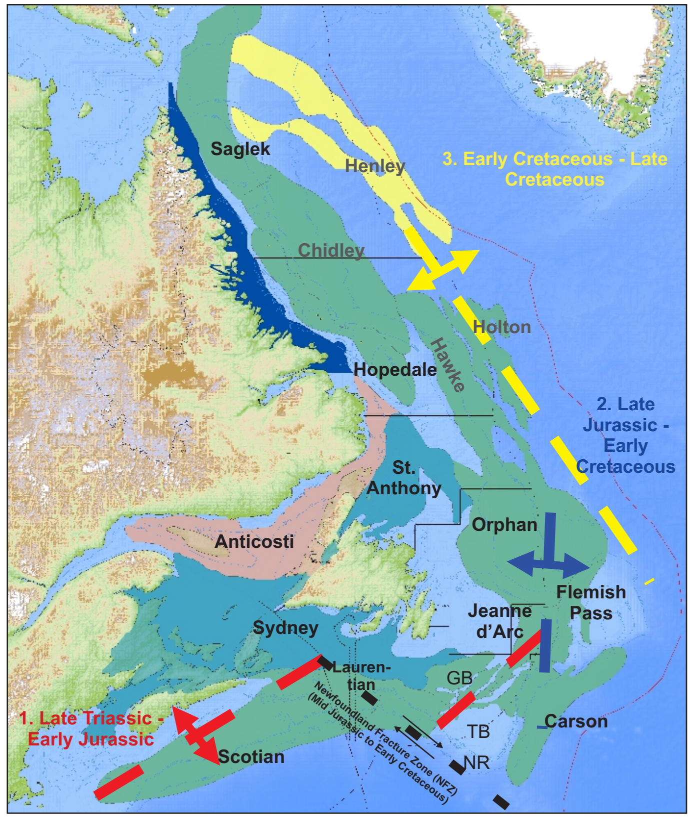


Figure 2. Regional geology of the Canadian Atlantic Margin showing main basins, sub-basins (grey text) and phases of extension. GB: Grand Banks, NR: Newfoundland Ridge, TB: Tail of the Bank. Modified after Enachescu (2020).

LABRADOR SEA GEOLOGY

- During its evolution, the Labrador continental margin was subjected to repeated orogenies, peneplaining, rifting, continental mantle exhumation, drifting, seafloor spreading between Labrador and Greenland, oceanic rift cessation, rift abandonment and significant thermal subsidence (Grant, 1972; McWhae et al., 1980; Bell (ed), 1989; Balkwill and McMillan,1990; Balkwill et al., 1990; Srivastava and Verhoef, 1992; Dehler and Keen, 1993; Keen et al.,1994; Srivastava and Keen, 1995; Chan et al., 1995; Srivastava and Roest, 1999; Roman, 1999; Chalmers and Pulversaft, 2001; Louden, 2002; Enachescu, 2005 and 2006; Enachescu et al., 2006 and 2007; Martin, 2007; Sibuet et al., 2007; Stead, 2008; Dickie et al., 2009 and 2011; Dafoe et al., 2017; Keen et al., 2018; Carey et al., 2019; Gillis et al., 2020).
- According to Geological Survey of Canada publications and earlier oil industry generated literature, the Canadian Labrador margin contains two large extensional basins: Saglek Basin in the north and Hopedale Basin in the south.
- Using a modern seismic grid covering the shelf and deepwater, OilCo. (previously Nalcor) has introduced a series of new names for the deeper parts of the basins. Thus, the deepwater Hopedale Basin appears in their more recent publications and presentations under the Chidley Basin name (e.g. Carter et al., 2013; Gillis et al., 2020). In this brochure we will continue to use the GSC formalized nomenclature for the Labrador basins, while locating on the maps the newly named subbasins and troughs (Figure 2).

HOPEDALE BASIN GEOLOGY

- The Hopedale Basin, the focus of the Call for Bids, is the most southerly rift basin within the Labrador Sea and is located just north of the Orphan Basin. The Cretaceous and Tertiary sediments in several depocenters are approximately 10 km thick. The sedimentary column and the basement have been penetrated by 21 wells west and northwest of the Call for Bids with only 16 reaching their intended targets . In particular, the North Leif I-05 well, adjacent to the Call for Bids area, had an oil show of 33° API in the Cretaceous Bjarni sandstones.
- The on-shelf part of the basin is located in water depths of up to 450 m. The shelf was recently glaciated and contains several banks, plateaus and troughs (Bell et al., 1989). The continental slope is relatively gentle and less sculpted by canyons as compared to the Scotian Shelf or southern Grand Banks margins.
- Geologically, the Hopedale rift basin is bounded (Enachescu, 2006 and 2008):
  - to the west by the onlap of Mesozoic beds onto a prerift basement hinge zone or in places by a down-to-the sea basin-bounding fault;
  - to the south by the Cartwright Transfer Fault Zone separating it from the Cartwright Arch and Hawke Basin;
  - to the east by the lineament marking the Continent-Ocean Boundary, and
  - to the north by the Okak Arch and an implied transfer zone separating it from the Saglek Basin (Figure 3).

- On the western flank of the basin, cratonic basement is disrupted by a complex system of Cretaceous rift faults. This faulted area ranges in width from 40 km in the north to 120 km in the south (Balkwill, 1987; Bell et al., 1989).

HOPEDALE BASIN EXPLORATION HISTORY

- Two major Cretaceous-Tertiary basins, Hopedale and Saglek basins, comprise most of the Labrador continental margin. The southern Hopedale Basin was explored from the 1960s into the early 1980s. During this early exploration round, 120,000 km of 2D seismic data was recorded and 21 wells were drilled on the shelf. This exploration cycle, while successful for gas discoveries, was followed by two decades of inactivity, due to low gas prices and the remoteness of the area (Enachescu, 2007).
- Petroleum exploration of the Labrador Sea started with potential field surveys followed by acquisition of refraction and reflection data (Enachescu, 2007). Aeromagnetic surveys were completed by Tenneco (1966-1967), Geoterrex (1974), Eastcan Group (1976) and Petro-Canada (1980). Gravity surveys were completed by Eastcan (1973) and ESSO Resources (1974). The Geological Survey of Canada (GSC) integrated the various potential field surveys and produced regional maps. These maps indicated that a thick wedge of sediments existed on the shelf and several sedimentary basins occupy the continental margin off Labrador (Enachescu, 2007).
- Simultaneously, between 1965 and 1969 the Atlantic Geoscience Centre of GSC led seismic surveys across the Labrador continental margin. All of these surveys confirmed that above the tilted and stretched Paleozoic and Precambrian basement there is a wedge of sediments thickening away from the shoreline (Enachescu, 2007). Analyzing early refraction data, Mayhew et al. (1970) proposed that the Mesozoic and Tertiary sedimentary sequences were more than 7 km thick in places. The rough morphology of the Labrador margin and the thickness of sedimentary fill units were interpreted from reflection seismic by Grant (1972).
- Drilling started in 1971 with the spudding of the first Labrador well, Leif E-38. Other wells followed throughout the 1970s including Bjarni H-81 in 1973-4, Herjolf M-92 in 1976, Hopedale E-33 in 1978 and Tyrk P-100 in 1979. While oil was the intended target, only gas discoveries, some of large size, were made during this exploration cycle (Table 1).
- The first significant discovery well was Bjarni H-81, drilled in 1973 by Eastcan et al.. Drill stem tests produced 365,287 m^3/day (12.9 mmcf/d) from a Lower Cretaceous sandstone reservoir (C-NLOPB). Four other significant discoveries were recorded in the Hopedale Basin and one in the Saglek Basin. The largest, North Bjarni, is estimated to hold 2.2 tcf of recoverable resources. All of these discovery wells were abandoned and Significant Discovery Licences (SDLs) were issued.
- Several of the wells did not reach their petroleum targets and only 16 provide significant data in terms of basin analysis. The recorded success rate of 31% is very high for a frontier basin. During this early exploration cycle, several large and medium gas fields were discovered while exploring for oil. Within the Hopedale Basin, fields such as Bjarni/North Bjarni complex (3.1 tcf), Snorri (0.1 tcf), Hopedale (0.1 tcf) and Gudrid (0.9 tcf) were found (C-NLOPB). These wells tested between 8 and 20 mmcf/d. Excellent clastic reservoirs were drilled within the Early and Late Cretaceous, and Early Cenozoic and within Paleozoic carbonates, preserved in places within basement.

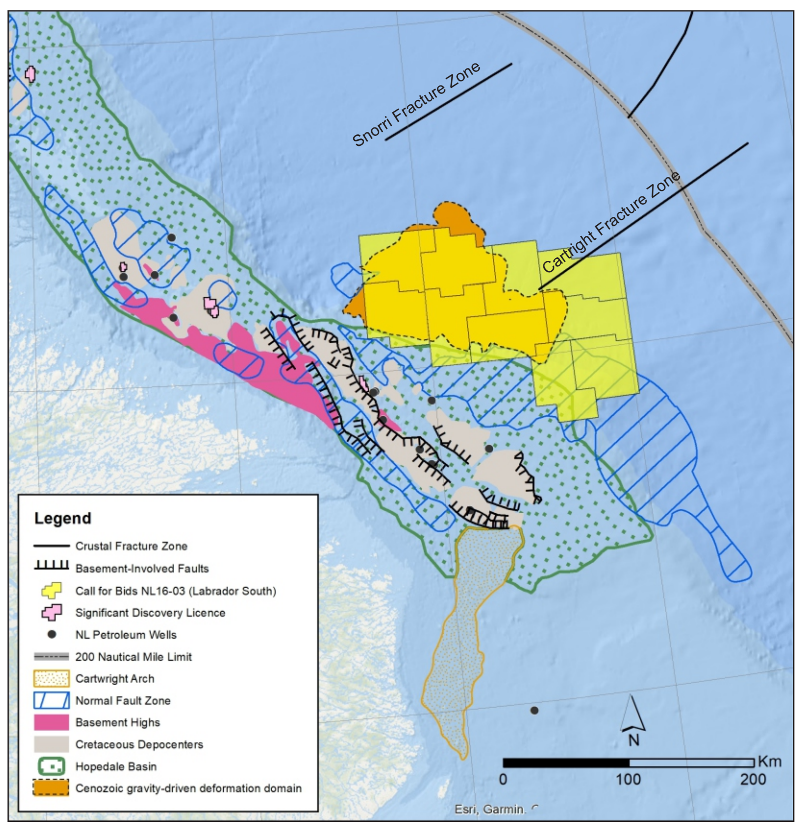


Figure 3. Labrador Sea geographic elements map relative to 2021 Call for Bids. Modified after Wardle et al. (1997), Funck et al. (2001), Nohr-Hansen et al. (2016), and Carey et al. (2020).

- As the exploration focus was centered on oil at that time, these gas fields were not developed. Their presence, however, proves the existence of a rich petroleum system (Enachescu, 2006). When compared to more southerly Grand Banks basins, the Hopedale Basin is relatively unexplored due to its northerly location and harsh physical environment. All drilling took place exclusively on the shelf in water depths between 100 and 350 m. Wells were usually drilled 2,500-3,500 m deep, targeting Cretaceous sandstones draped over basement highs. No drilling has occurred in the basin since 1983. The outer shelf, slope and deepwater regions remain completely untested.

PETROLEUM GEOLOGY

- The Hopedale Basin is floored by Proterozoic metamorphic rocks and in places by Paleozoic strata including reservoir quality Ordovician carbonates. The basement was significantly stretched during Early Cretaceous when volcanics and then continental clastics were deposited (Figures 2, 4 & 5). These synrift stage deposits contain the Bjarni Formation which includes both excellent, thick sandstone reservoir facies and quality petroleum source rocks.
- Following rifting, the continental mantle rocks which emerged to the bottom of the invading early Late Cretaceous sea, were modified by encroaching seawater and serpentinized. During this predrift stage, more clastics of the Markland Formation and Freydis Member including reservoir and source rocks were deposited in an enlarged and slightly subsiding basin.
- A drift stage followed when Labrador and Greenland separated and oceanic crust was emplaced between the two departing continental plates. For the duration of this stage, clastics of the Cartwright and Kenamu formations were deposited along the Labrador margin. Two other sandstone members, Gudrid and Leif, were deposited in coastal settings with the down-dip possibility of continuing in deepwater basin floor fans.
- A final postdrift stage followed. Throughout this stage, shelfal erosion and redeposition of sediments took place enlarging Labrador's continental margin and accommodating a great amount of subsidence in both the Hopedale and Saglek basins. The fine clastics of the Mokami Formation were followed by the coarse clastics of the Saglek Formation and by unnamed glacial beds (Figure 4).
- The Hopedale Basin discoveries made in the 1973-1983 exploration cycle have estimated resources of 4.3 tcf of natural gas and 123 million barrels of natural gas liquids of 50-60º API (C-NLOPB). One complex structure, formed by the adjacent Bjarni and North Bjarni fields, contains more gas than Nova Scotia's Sable Offshore Energy Project or the large White Rose field gas cap in the Jeanne d'Arc Basin (Figure 2). Therefore, a proven petroleum system exists in the Hopedale Basin and there are high expectations for further hydrocarbon discoveries in this basin.

PETROLEUM GEOLOGY: RESERVOIRS

- Up to now, gas and condensate accumulations and oil shows have been found in Bjarni and Gudrid sandstones and Ordovician carbonates.
- Younger sandstones with reservoir properties have been deposited in the basin during intermittent Neogene and Paleogene uplift of the basin flank (Labrador Peninsula), and related turbidites may have accumulated on the continental slope and in the deepwater.
- Turbidites and any other lowstand sand deposits are plays that are yet undrilled in the Hopedale Basin or anywhere on the Grand Banks and Labrador slope. The Tertiary sandstones encountered on the shelf have high porosity (up to 25%) and fair permeability.

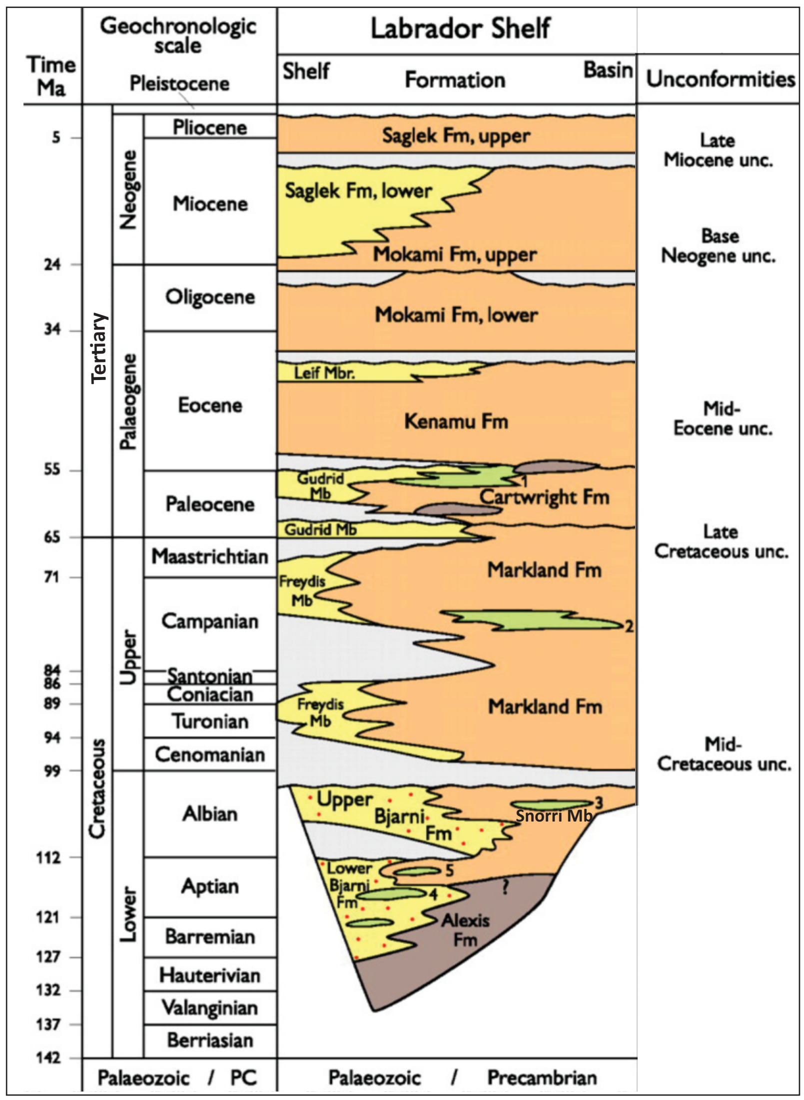


Figure 4. Labrador Sea stratigraphic chart. Modified from Sorensen (2006).

- Reservoir targets in the Call for Bids area are likely to be Tertiary Kenamu, Leif, and possibly Gudrid sandstones as depth becomes the restriction along the shelf slope.
- In the Eocene, the wide-spread transgression stopped abruptly in the Lutetian. This is indicated on seismic sections by an unconformity within the **Kenamu Formation**, which forms a shelf edge sometimes visible on seismic and by a thinned Lutetian section in the wells in the shelf wells. The rate of seafloor spreading identified by Roest and Srivastava (1989), could play a part in the abrupt stop and unconformity. Above the unconformity, during the apparent Lutetian lowstand, there may have been some sand-bearing sediments deposited seaward onto the slope. This was followed by transgression of the Lutetian shelf and highstand deposits consisting of upward-coarsening cycles that formed a series of gently dipping, prograding reflectors in the upper Kenamu. The upward-coarsening cycles commonly coarsen only to silt or very fine-grained sandstone, but in places develop into higher porosity sandstones of the Leif Member (Balkwill and McMillan, 1990). Distal wells in the southern Hopedale Basin show a transgression oversteps the unconformity at the top of the Kenamu. The unconformity at the top of the Kenamu has a distinct seismic signature over much of the inner shelf, perhaps the result of the slowdown in seafloor spreading rate. A triggering mechanism for the large slump features that occurred around the time of the top Kenamu unconformity can be seen on the shelf edge and slope (Dickie et al., 2011).
- In the Oligocene, global sea-level was dropping and a prominent seismic reflector appears to be an unconformity, which is widespread across the outer shelf of the Hopedale Basin and further afield. The strong reflector on the outer shelf has not been reliably dated, but the biostratigraphy of inner shelf wells places it in the Early Oligocene (Rupelian).
- Another period of major global climate cooling began in the mid-Miocene, associated with buildup of the Antarctica ice sheet (Zachos et al., 2001). The style of sedimentation on the Labrador margin changes in the Miocene, with more coarse-grained clastic deposition, culminating in a series of sandy prograding clinoforms of the **Saglek Formation** and a deeply channeled sequence over parts of the margin. A thick prograding package of reflectors forms the present-day, shelf edge. It has not been drilled but must be Late Miocene or younger; possibly Pliocene (Dickie et al., 2011). In the CFB area, the Saglek Formation (Neogene) is too shallow to be considered a potential reservoir target.
- The **Leif Member** of the Kenamu Formation (Late Eocene) is penetrated by several wells within the Hopedale Basin, including Gudrid H-55, Hopedale E-33 and Roberval C-02 that are closer to the Call for Bids. The Leif Member consists of a very fine to fine-grained sandstone with thin pyritic stringers, encased within mudstone. Biostratigraphy suggests it was deposited in a shallow marine setting (<200 m of water).
- The **Gudrid Member** of the Cartwright Formation (Paleocene) was intersected by several wells located on the inner continental shelf. The Gudrid Member was encountered in: North Leif I-05: 21 m of medium to coarse-grained sand, outer to inner neritic paleoenvironment (Dafoe and Williams, 2000); Gudrid H-55: fine to pebbly, subrounded feldspathic sandstone with kaolinite cementation throughout. Porosity is good (28%) with moderate permeability (33 mD). Biostratigraphy interprets a supralittoral to littoral, splash to nearshore environment; Roberval K-92: 335 m of fine to coarse-grained sandstone with good porosities of 20-22% deposited within a deeper water to open ocean setting (Williams, 1997).

  Seismically, it has an associated high amplitude marker but tracking it into the outer shelf and deepwater becomes difficult due to low seismic resolution (Figure 13) and lack of tie points. Gudrid sands may be present in the deepwater but are unproven by well data. The top of the sequence is an unconformity which may have allowed for Gudrid sands to be eroded and re-deposited into deeper water. The Gudrid sandstone tested gas at the Snorri J-90 well - the only well of the five significant discoveries in the basin to test gas from the Paleocene sandstone and had 18% porosity (C-NLOPB).

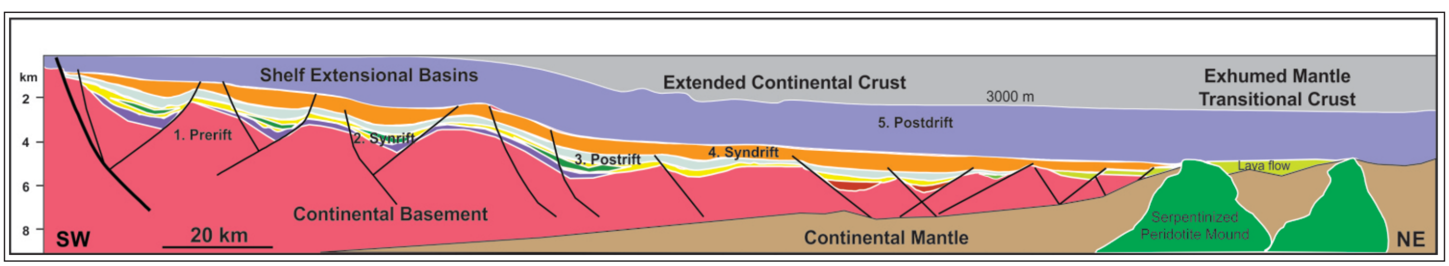


Figure 5. Regional schematic section of Canadian Labrador continental margin showing basement horst, graben, and rotated block lineaments. Modified from Enachescu (2007).

- **Bjarni sandstone.** During the initial intra-continental extension, elongated rift valleys and intervening ridges received a major pulse of coarse clastics that formed the predominantly sandy Bjarni Formation. The most widespread reservoir, the Bjarni sandstone, is thick in half grabens and thins on the ridges, showing syntectonic deposition. This Early Cretaceous synrift, non-marine arkosic sandstone, is the main reservoir in the Hopedale Basin. As some of the in-graben thickening is caused by the presence of Bjarni source rocks, this creates fortuitous source/reservoir juxtaposition. The top of the Bjarni Formation is a good quality marker that can be mapped with relative confidence on modern seismic data basinward of the Bjarni field and North Leif lineament and into the deepwater. However, as proven by the Roberval C-02 well, some of the high blocks are void of Bjarni sandstones due to non-deposition or postrift erosion.

  The Bjarni sandstone has good to high porosity (12% average) and good permeability (average 100 mD). In the North Bjarni F-06 well, the porosity was 19% while at Bjarni H-81 and Hopedale E-33 wells, Bjarni sandstone porosity was 20% and 11%, respectively (C-NLOPB). These excellent reservoir parameters make the Bjarni sandstone an ideal petroleum reservoir.

- **Lower Paleozoic Carbonate.** The Paleozoic prerift “basement” contains sedimentary rocks that cannot be written off as exploration targets in the Labrador region, as two large gas discoveries have been made in them. The Gudrid discovery (924 bcf recoverable) tested 20 mmcfd in Gudrid H-55 from an Ordovician dolomite with 10% porosity and the Hopedale discovery (105 bcf recoverable) tested 20 mmcfd in Hopedale E-33 from a Paleozoic (Ordovician) limestone with 8% porosity. These carbonate reservoirs were intersected in Gudrid H-55, Hopedale E-33, Roberval K-92, South Hopedale L-39, and Tyrk P-100 wells. The Paleozoic carbonate reservoirs (limestone and dolomite) seem to be present mostly in the southern part of the Hopedale Basin (Bingham-Koslowski, 2019). These carbonates were dated as Ordovician (e.g. Schwartz, 2008; C-NLOPB). The carbonate reservoirs below the acoustic basement are difficult to interpret on 2D seismic data. A combination of reflection data and high-resolution potential field data might help discriminate between metamorphic/intrusive and carbonate basement areas.

- **Other reservoirs.** The Freydis Member of the Markland Formation (Coniacian-Campanian) is a shallow-marine, shoreline sandstone that has an average porosity of 15% and permeabilities in the range of a few hundred millidarcies. It was encountered in the Freydis B-87, Gilbert F-53, Ogmund E-72 and Skolp E-07 wells, some located far from the Call for Bids area. Due to poor reflectivity contrast with encasing shales and the limited distribution, the Freydis Member cannot be regionally mapped with present seismic data density (Bell et al., 1989; Martin, 2007).

PETROLEUM GEOLOGY: SOURCE ROCKS

- Several Mesozoic intervals with medium to rich source rocks have been recognized from drilling and geochemical analyses (Powell, 1979; Rashid et al., 1980; McMillan, 1982; Balkwill, 1987; Bell et al., 1989; Balkwill et al., 1990; Fowler et al., 2005). Historically, the **Markland shales** have been considered the main source rock for the Labrador Sea gas accumulations (e.g., McWhae et al., 1980; Balkwill and McMillan, 1990; Bell et al., 1989). Fowler et al. (2005) documented that the **Bjarni shale** has high organic content, are mature and constitute the principal source rock for the area, including the Hopedale Basin. Graduate research work (sponsored by PRAC, NSERC and PPSC) at Memorial University of Newfoundland and Labrador based on geochemical parameters provided by GSC and available seismic data show increased source rock presence and adequate maturation on the outer shelf and slope (Enachescu 2006; Martin and Enachescu, 2007; Martin, 2007; Stead 2008; Dafoe et al., 2017; Keen et al., 2018; Carey et al., 2019; Gillis et al., 2020)

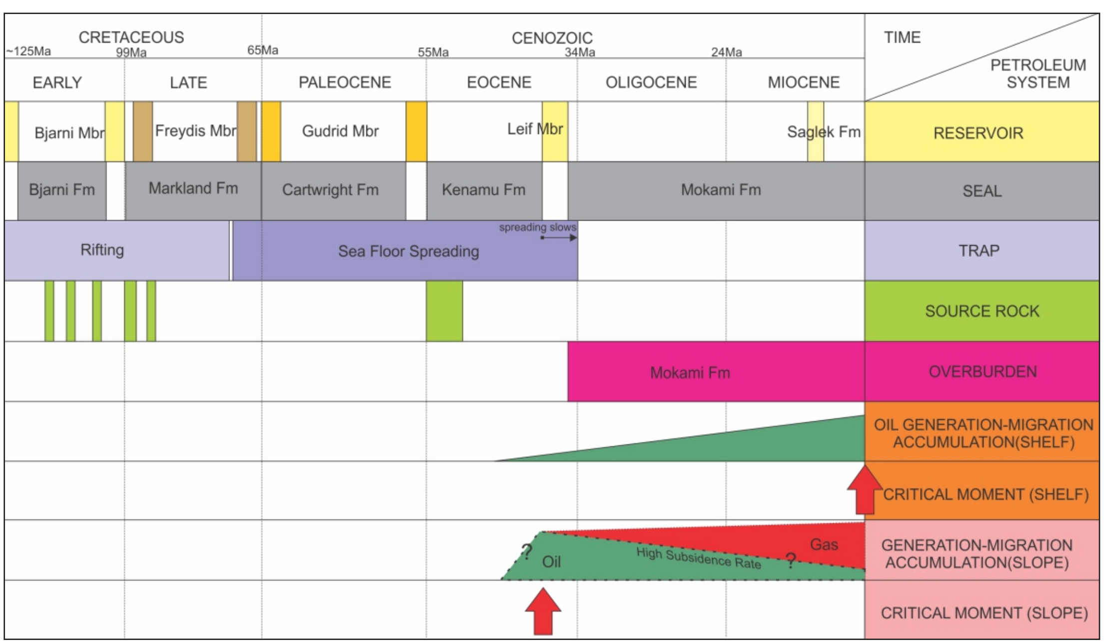
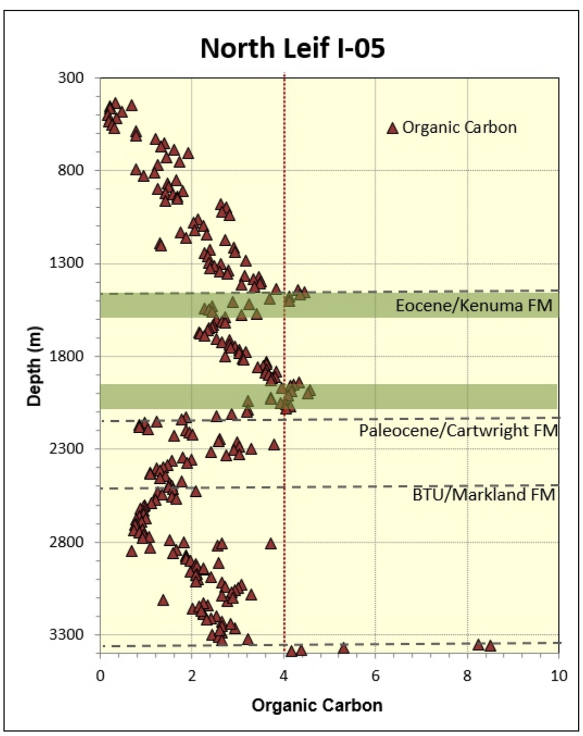


Figure 6. Petroleum system chart showing the timing of each petroleum system element for the Labrador region (Emberley, 2021).

- **Bjarni Formation shale**. Rock-Eval analysis of cuttings, geochemical analysis of organic-rich intervals and organic petrology show that the best source rock occurs in the Early Cretaceous Bjarni Formation and contains mostly Type III terrestrial organic content (Fowler et al., 2005) as shown in Figure 7. The source interval is quite thick (more than 500 m) at the Herjolf M-92 well, having a total organic content (TOC) of 5% and ranging between depths of 2.5-4.6 km. Additionally, coal seams are present in the Bjarni Formation that can generate gas. Bjarni shales are located mostly in the synrift depressions and show thickening in the numerous half-grabens in the outer shelf and on the slope. Generally, an average depth of 3,335 m is needed to attain vitrinite reflectance (Ro) greater than 0.7 (source maturity indicator) for burial of Bjarni shales in order to generate hydrocarbons, as computed by Martin (2007) . This average depth to maturation was used to produce a “kitchen” map for the Bjarni Formation, which showed an increased amount of possible Bjarni source rock on the eastern part of the shelf and in deepwater. The un-biodegraded, 32° API oil encountered at North Leif I-05 shows immaturity (Fowler et al., 2005) but more mature source rock and reservoired oil may exist in deeper parts of the basin. Vitrinite reflectance (Ro) at North Leif shows early maturity (Ro 0.6) starts at 2,300 m and by the bottom of the well, Ro approaches 1.0.
- **Markland Formation shale.** Until recently, the Cenomanian to Maastrichtian Markland Formation was considered the main source rock for the Labrador gas (GSC, 1989; De Silva, 2003; Maneley, 2003; Klassen, 2005; Enachescu & Fagan, 2005). According to these authors, the fine-grained Markland Formation includes high TOC shales (1-4%) and is a terrestrial-dominated source rock with some marine influence (Type II and III source rock). As noted previously, an average depth of 3,335 m to Ro>0.7 was computed by Martin (2007) from Hopedale Basin wells as the minimum depth of burial of Markland shales in order to generate hydrocarbons. Martin’s (2007) study agrees with the GSC Atlas (Bell et al., 1989) that the Markland Formation is mature in a very large area situated downdip from the wells drilled on the inner shelf. Time structure and isopach maps of the Markland Formation show that the gas discovery wells within the shelfal Hopedale Basin lie outside of the region where source rock maturity is predicted. However, their structures are open to updip hydrocarbon migration from the more easterly half-grabens where shales are mature. Unlike the intermittent presence of the Bjarni shale, the Markland Formation is a thick, regional shale that can provide a very large hydrocarbon kitchen. In the Call for Bids area, the Markland Formation is greater than 6 km TVDss and may have passed through the oil window, into the gas window.

  As mentioned, the Labrador Basin Atlas (Bell et al., 1989) indicates that when Ro for Markland shales are greater than 0.7%, shales are buried deep enough to generate hydrocarbons. Issler and Beaumont (1987) suggest that Ro values of 0.6 are sufficient for source maturation; other authors conclude that hydrocarbon sources start generating gas even at lesser values of 0.4-0.6 Ro.
- **Other source rocks.** Some of the younger formations (Cartwright, Kenamu and Mokami) are predominantly shaly and may contain source rock intervals. If this is the case, they will be mature only on areas near the shelf break, on the slope and in some deepwater troughs. The Kenamu Formation is laterally extensive predominantly shaly interval with its top at ~1500m tvd. From Figure 7, the high organic content in the North Leif I-05, illustrates the Kenamu has two likely organic rich shale intervals. Although this samples are immature on the shelf, when placed in the CFB area, the formation is ~ 5.5 km deep. There is a strong indication, that the Kenamu Formation on the shelf break and slope would currently places them in the oil window. The questions remains of the timing of subsidence in this area and the rate at which the Kenamu organic-rich shales arrived in the oil window to start producing oil to migrate in to possible traps in the area.



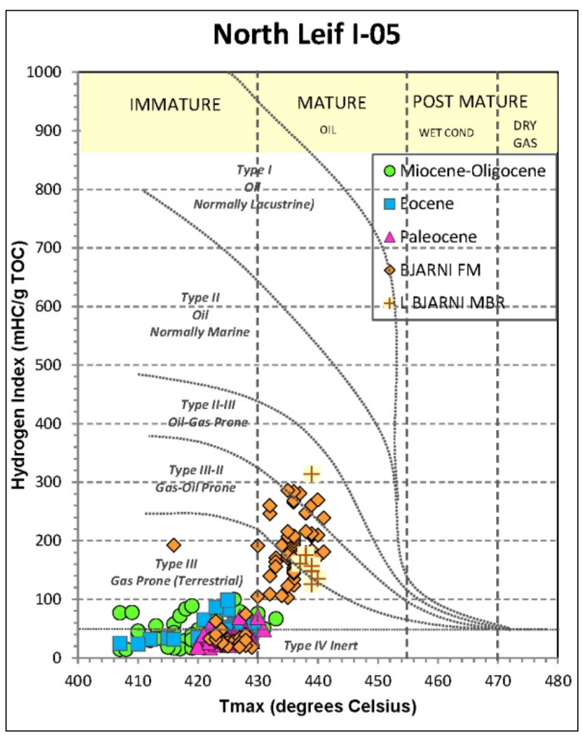


Figure 7. Left: North Leif I-05 total organic content versus depth illustrating higher TOC content (>4%) in the organic-rich Kenamu Formation shales. Data from Geological Survey of Canada (2019); **Figure 8.** Right: North Leif I-05 modified van Krevelen graph. Data from Geological Survey of Canada (2019).

- Several indications that Kimmeridgian source rocks may extend into the Labrador Sea from the oil proven Grand Banks and SW Ireland offshore basins have been presented (e.g. Bojesen-Koefoed et al., 1999 & 2004; Sønderholm et al., 2003; Enachescu et al., 2008). A series of small and deep sub-basins (Figure 2) are observed from new seismic data in the outer shelf and slope area. These smaller sub-basins may have started extending earlier (in Late Jurassic), or the epicontinental Late Jurassic Sea present on the Grand Banks and offshore Ireland may have sent arms between Labrador and Greenland, depositing organic rich shales. Increased exploration activity has taken place across the sea on Greenland's continental margin where indications of older sequences, including Late Jurassic source rocks, have been observed in outcrop and on seismic data. The Late Jurassic shales are high TOC, high HI, Type I source rocks that have generated the prolific Jeanne d'Arc Basin oil and gas fields. However, this hypothesis is unproven by direct geologic results as no wells have been drilled in areas suspected to contain older than Cretaceous rocks on either margin of the Labrador Sea.
- The organically-rich Paleozoic sedimentary rocks are overmature and are unlikely to have generated hydrocarbons in the Labrador Sea basins.

PETROLEUM GEOLOGY: MATURATION AND MIGRATION

- Gas discoveries in the Hopedale Basin prove that source rocks in the basin are mature and migration of hydrocarbons to trapped reservoirs has occurred. It is largely accepted that the Hopedale Basin had a high geothermal gradient of 2.7ºC/ 100 m and that source rocks started expelling wet gas after reaching burial depths of approximately 2,500 m probably in Late Oligocene - Early Miocene time (GSC, 1987; De Silva, 2003). While we agree with these authors that source rocks should start expelling hydrocarbons at about 2,500 m depth, adequate source maturation for both Bjarni and Markland shales should occur at depths of about 3,335 meters (corresponding to Ro>0.7). These subsea depths for source rocks occur just east of the Gudrid-Bjarni-Snorri wells lineament and suggest a very large kitchen exists on the outer shelf slope and rise (Enachescu, 2006; Martin, 2007). The gas accumulations in horst blocks and drape anticlines have benefited from lateral migration of hydrocarbons from the eastern deeper troughs where Cretaceous source rocks should be mature (Powell, 1979; Enachescu and Martin, 2007; Martin 2007). According to Fowler et al. (2005), the oil window should be deeper at 3,000-3,500 m. The North Leif I-05 well contained waxy crude which was believed to be generated from terrestrial Type II and III kerogens found within the partially mature Bjarni Formation (Issler and Beaumont, 1987). Recent work also suggests the thermal gradient in the deepwater area could be lower than that observed on the shelf (Gillis et al., 2020).
- Numerous seismic amplitude anomalies and other Direct Hydrocarbon Indicators (flat spots, gas chimneys, frequency attenuation, bright spots along faults, etc.) are present in the basin, therefore indicating hydrocarbon migration and accumulation (Enachescu, 2006).There is no doubt that a prolific petroleum system(s) exists in the shelfal Hopedale Basin and should extend eastward into the outer shelf and slope of the Labrador Sea.
- The current depth of the organic-rich source rocks in the **Bjarni Formation** on the shelf slope would place it currently in the gas window at depths greater than 7 km. Understanding the rate of subsidence in the area is key to determine when these source rocks passed through the oil window. Dickie et al. (2011) studied the extent of the total subsidence of basement (including the sediment load, corrected for eustatic sea-level and paleowater-depth variations as well as compaction effects). This study shows in the Hopedale Basin there is a significant increase in the rate of subsidence starting around 63-70 Ma (Late Cretaceous-Early Cenozoic) with the onset of seafloor spreading. The most easterly well of those evaluated is Corte Real P-95 in the Hopedale Basin, which exhibited a higher rate of subsidence greater than those to the west on the shelf. If the rate of subsidence is higher as you progress to the slope, then the oil window for the source rocks in the CFB area would be shorter before passing through into the gas window, as seen in the petroleum systems graph (Figure 6). The length of time for the oil window in this region is not yet fully understood and is illustrated as questionable (Figure 6).
- Seismic mapping in the CFB area, show a quick deepening of the Cretaceous and Tertiary formations from west to east. While the **Bjarni Formation** organic-rich source rocks may currently be in the oil window on the shelf (Figure 6), this formation now sits beneath the oil window on the shelf slope and basin floor over 7 km TVDss. The **Kenamu Formation** organic-rich source rocks, while in the immature window on the shelf at less than 2 km TVDss, sit at ~4-5 km TVDss on the shelf slope and deeper placing it in the active mature oil window currently (Figure 6). The question remains, how fast was the rate of subsidence on the shelf slope when the seafloor started spreading over the ~ 35Ma period before it ceased in the Oligocene (Figure 6). How long were the Bjarni organic-rich shales in the oil window before passing into the gas window? Based on work by Roest and Srivastava (1989), they noted the rate of subsidence increased substantially in the most eastern well of the study, Corte Real P-95. In the CFB area, the Kenamu organic-rich beds (note the high TOC in the Figure 7 in North Leif I-05 situated on the shelf to the west of the CFB area) are ~5 km deep and has the potential to still be in the oil window, supporting migration of oil into the possible lowstand plays and any shale-encased reservoir targets in the Eocene on the slope.

PETROLEUM GEOLOGY: TRAPS

- Numerous types of structural, stratigraphic and combination traps are identified on seismic data in the Hopedale Basin. Early successful drilling of the Bjarni sandstone on structural highs made this the favourite hydrocarbon play in the basin and focused on the shelf. A large number of horst and fault blocks are seen on seismic data, forming impressive exploration leads with targets being anticlinal features over basement ridges, drape, onlap and lateral pinchouts of the

Cretaceous sandstones. Cretaceous and Tertiary sandstone reservoirs are widespread on the Labrador shelf and are derived from both rift shoulders and intra-basinal ridges.

- On the outer shelf and slope, extensional anticlines modified by compression (Enachescu and Hogg, 2006) and listric faults and associated rollovers could be exploration targets. Paleozoic limestones and dolomites found on the tops or sides of higher basement blocks often have reservoir properties (Figure 13).
- On the shelf breaks and in the deepwater, traps include anticlines, rotated blocks, rollovers due to gravity-induced, detachment faulting, listric faulting and compressional anticlines over basement or transitional crust (Enachescu, 2006 and 2008, Enachescu and Hogg, 2006; Martin, 2007; Carey et al., 2019, Figure 13). More stratigraphic traps likely exist along the slope and in deepwater and may consist of lenses of sandstones (turbidites) of the Freydis, Gudrid or Leif sandstones' deepwater equivalents encased within thick shales.

PETROLEUM GEOLOGY: SEALS

- Seal should not be a problem in the Labrador Sea. Numerous tight intervals exist in all postrift sequences (predrift, syndrift and postdrift sequences). The Hopedale Basin has a high percentage of fine clastics facies in all marine successions following the synrift main sandy pulse. Both the Markland and Kenamu formations are excellent regional seals. On the inner shelf, faults are usually restricted to the synrift and predrift sequences and die out in the predominately shaly Mokami and Kenamu formations.
- On the shelf slope and deep basin, the seismic shows the presence of highly rotated Tertiary fault blocks, creating potentially prospective traps. With these defined traps, the cross fault juxtaposition becomes a factor when determining fault seal risk. More in-depth consideration to understand this cross fault stratigraphic relationship should be evaluated.

PETROLEUM POTENTIAL OF 2021 CALL FOR BIDS PARCELS

- Exploration in the Labrador Sea is recommencing after more than 30 years with the announcement of the CFBs in the deepwater area of the Hopedale Basin and the acquisition of new geoscientific data. Although early exploration in the region was targeting oil fields, the wells drilled in the Hopedale Basin found natural gas, confirming a working petroleum system in the region, and had a 30% success rate. With new geoscientific surveys acquired, modern mapping will lower the geological risk for finding hydrocarbons in the high risk, high reward frontier Hopedale Basin.
- The significant size of each CFB parcel, exceeding the typical Gulf of Mexico outer continental shelf tract by 100 times, allows for each parcel to hold several large structural and stratigraphic features capable of containing significant discoveries. New discoveries in addition to the existing gas reserves will lower the economic risk and create the required resource threshold for a Labrador Sea gas development. The recognized risks in regard to harsh climate conditions and remoteness of the basin are mitigated by the presence of very large undrilled features, high quality reservoirs and widespread, mature source rocks.
- Geologically, the parcels fall within an area with a thick post rift sedimentary fill overlying basinward thinning of synrift sedimentary successions. The Late Cretaceous to Cenozoic sedimentary cover that blankets the extended basement thickens from 2 km in the west on the shelf to about 8 km in the east (Figures 5 & 12).
- With abundant terrestrial and probable marine interludes of source rock deposition and numerous structural and stratigraphic trapping possibilities, the Hopedale Basin has significant undrilled petroleum potential on the shelf and deepwater. Only 16 wells have reached planned targets resulting in five gas discoveries. Despite these discoveries, these resources remain stranded and await additional gas resources to reach an economic threshold for development.
- All major petroleum system elements (reservoir, trap, seal and source rock) were in place before the migration and accumulation of oil and gas (Figure 6). Over the CFB area, the slope is a different system than on the shelf where the wells are. The subsidence rate plays a big factor in the timing of the hydrocarbon generation and migration. There is also the risk of updip fault seal to the west of the highly rotated fault blocks in the Paleogene gravity-driven detachment feature (Figure 13).

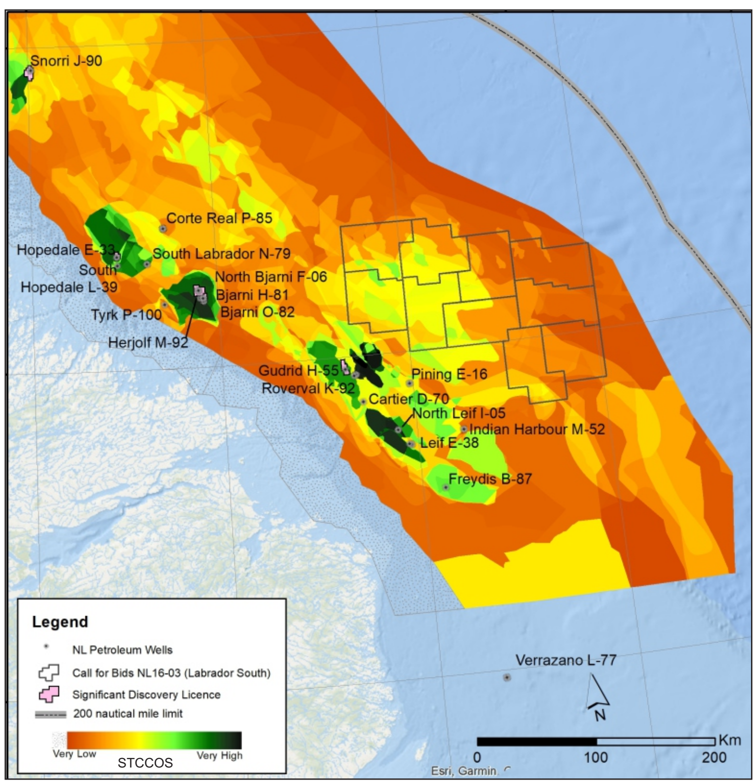


Figure 9. Total Combined Chance of Success (STCCOS) across all formations for the Labrador Margin. Call for Bids parcels in yellow polygons, sector in purple polygon. Modified from Carey et al. (2020).

- The GSC conducted a qualitative assessment of petroleum potential offshore Labrador and found the total combined chance of success across all formations in the CFB to be greatest in the western parcels (up to 0.6) (Figure 9; Carey et al., 2020).
- The area's proven resource of non-associated gas is substantial and the potential resource is enormous. Challenges to exploration and production in Hopedale Basin remain great, but the demand for cleaner energy, increased commodity prices, improved government regulations, large size of the prize, technological advancements and relative proximity to the largest world markets will make the basin an attractive petroleum exploration area in the coming years. The CFB parcels are well positioned to host additional gas reserves and present a significant opportunity to advance the proven resources of the basin to an economic threshold for development.

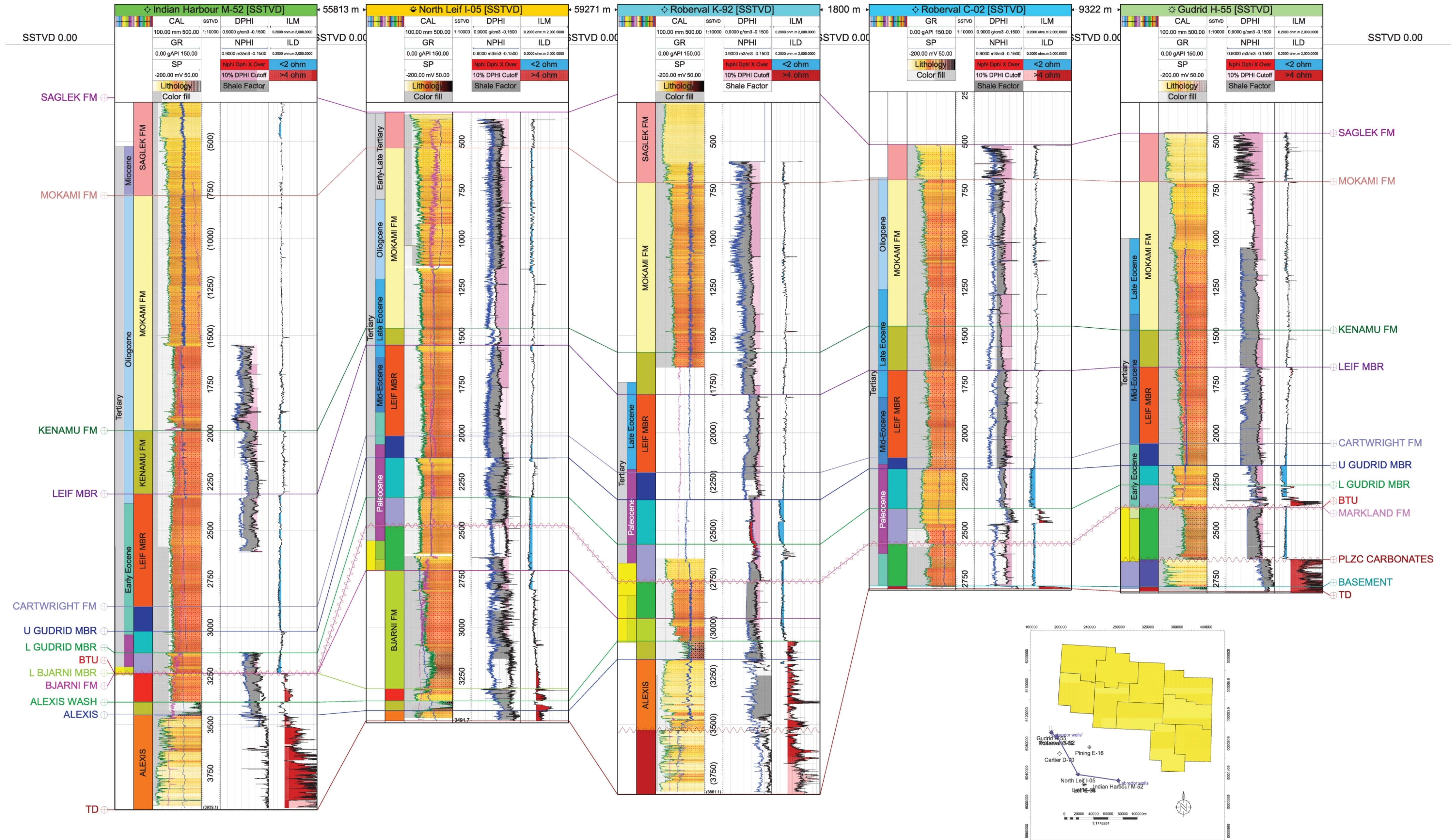
WELL DATA

- Between the 1970s and 1980s, 21 wells were drilled on the Labrador shelf. All wells were abandoned, some with good oil and gas shows (Table 1) that lead to the issuance of Significant Discovery Licences (Figure 1).
- Key wells drilled to the west of the Call for Bids include Gudrid H-55, Roberval C-02, Roberval K-92, and North Leif I-05. These wells encountered Early Cretaceous reservoir and source rocks. Biostratigraphic data for these wells suggest the Call for Bids area's thickest sediments are post-rift Tertiary age with thinner sedimentary interval are syn-rift Cretaceous age on top of the continental and transitional crust.
- Well results point toward exploring in deeper basinal areas such as those offered in the Calls for Bids where younger source rocks may be mature.
- These well results are in the public domain. Well reports and paper copies of logs are available from C-NLOPB. Digital logs can be obtained for a fee from vendors or viewed in Industry, Energy & Technology's (IET) Virtual Exploration Data Room.

Well	Year Spud	Water Depth (m)	Status	Potential	TD (m)	TD in	Reservoir	Source Rock
Cartier D-70	1975	310	Plugged & Abnd	Noted gas shows in Gudrid sst,	1927	Bsmt	Leif, Gudrid sst	Immature; poor to fair oil to possible wet gas in Tertiary -U.Cret
Gudrid H-55	1974	299	Plugged & Abnd	Significant Discovery - Gas	2839	Bsmt	Leif, Gudrid sst	No geochem data available
Indian Harbour M-52	1975	198	Plugged & Abnd	no significant gas detector response; no shows	3958	Alexis	Leif, Gudrid sst	Immature to moderately immature oil; poor biogenic and thermal gas source
Leif M-48	1973	165	Plugged & Abnd	no significant gas detector response; no shows	1879	Alexis	Leif sst	immature gas prone with one exception in the Gudrid Mbr to have good potential for source rock
North Leif I-05	1980	144	Plugged & Abnd	Oil to surface, gas shows in Bjarni	3513	Alexis	Leif, Gudrid, Bjarni sst	Oil-prone/ immature Tertiary and Cret; Heavily oil-stained E Cret Bjarni/Snorri Mbr
Roberval C-02	1980	276	Plugged & Abnd	gas shows and oil staining in Bjarni	2823	PLZC carbonates	Gudrid, Bjarni sst	one fair gas source rock sample in the lower Leif Mbr
Roberval K-92	1978	269	Plugged & Abnd	no significant gas detector response; no shows	3874	PLZC carbonates	Leif, Gudrid, thick Bjarni sst	minor Tertiary, fair TOCs and low HI in Eocene
North Bjarni F-06	1980	150	Plugged & Abnd	gas condensate discovery	2813	Bjarni Fm	thick Bjarni sst	poor data quality

Table 1. Labrador South well summary table. All wells have been plugged and abandoned, Bsmt: Basement, Cret: Cretaceous, Fm: Formation, Mbr: Member, PLZC: Paleozoic, sst: sandstone.

Figure 10. Well cross-section through shelf wells located to the west of the 2021 Call for Bids. Ages are provided where biostratigraphic information is available. Disclaimer: Formula used to create density porosity logs (Emberley, 2021). Data from C-NLOPB.



SEISMIC DATA

- Historically, seismic data acquisition focused on the shelf however, modern seismic data coverage focused over the slope and deepwater area. Seismic coverage over the Calls for Bids is excellent with ties to shelf wells and includes a dense 5x5 km grid of 2D data and over 6,000 km^2 of 3D for purchase from seismic vendors (Figure 11).
- A large amount of vintage (pre-1980) 2D seismic lines were acquired in the area and may be available from data vendors or petroleum companies with a seismic library in the area (Figure 11). Most of this data was recorded with short streamer lengths (2.6 to 3.5 km) that preclude deep penetration, adequate multiple suppression and proper migration of the deeper events.
- The modern seismic data quality is good to excellent for all parcels and recorded long offsets (8-10 km). Some water-bottom multiples, while greatly diminished, are still visible in areas with shallow basement or at the shelf break (Figure 13). This is due to the presence of a hard water bottom in the area.
- Seismic quality varies from good to very good in the Tertiary-Cretaceous sequence where reservoirs are present. Data deteriorates on the shelf break due to gas migration, and in the volcanics and Basement interval. Pre-rift basement is mappable in places (Figures 12 & 13).
- Key seismic horizons can be interpreted within the Hopedale Basin. These regional markers can be tracked with varying degrees of confidence from the shelf into the deepwater area (Figure 12). The markers match regional unconformities and geologic formation tops (Figure 4). Some sandstone members have a seismic signature close to the basin edge, however their deepwater equivalents are harder to track (Figure 13).
- Several strong amplitude reflectors are observed on the seismic, away from existing wells, within the Saglek and Kenamu formations. These could correlate to sandstones, siltstones or intra-formation unconformities.
- Seismic ties from the shelf wells Gudrid H-55 and North Leif I-05 through the Call for Bids show a thickening of the Cenozoic sediment package and a thinning of the older formations (Figure 13). Two possible interpretations for the thick sediment package within the Call for Bids are a delta (Gillis et al., 2019, Carey et al., 2019) or a slope detachment complex and thin-skin deformation (Enachescu 2006 and 2008; Martin 2007; Le Guerroue et al., 2018; Pichot et al., 2018; Carey et al., 2019). The feature is approximately 17,500 km^2, up to 8 km thick and is interpreted to be Eocene to Miocene (Gillis et al, 2020).

Within the feature, Kenamu (Leif), Mokami, and Saglek equivalent sandstones have been seismically identified using a calibrated 3D forward stratigraphic modelling approach (Pichot et al., 2018) and appear as strong amplitude reflectors. AVO studies suggest the potential for two phases of hydrocarbons (Montevecchi et al., 2019; Gillis et al., 2020).

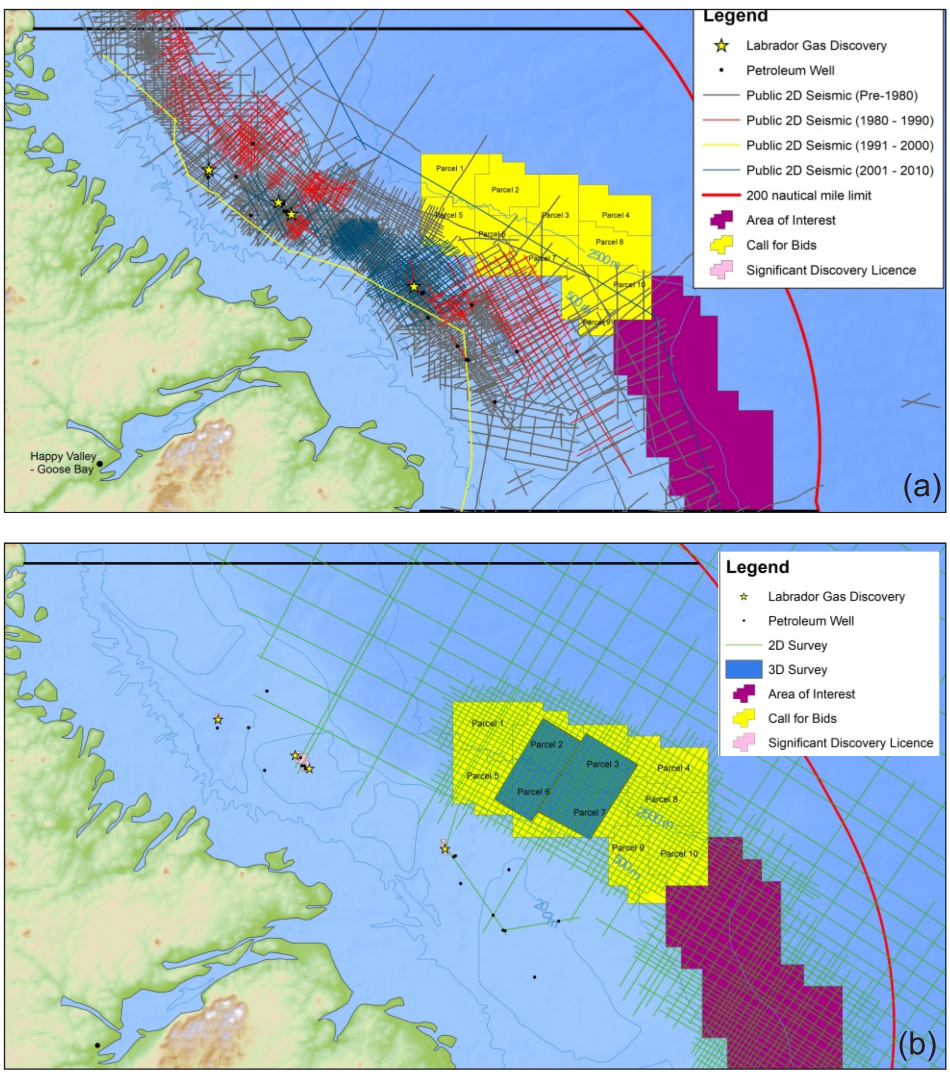


Figure 11. Labrador South seismic data coverage. (a) Public-domain seismic. Map can be accessed at Department of Industry, Energy & Technology (IET) (www.gov.nl.ca/iet/energy/maps/). Pre-1980 data (in grey) may only be available from seismic vendors or data owners. Post-1980 data may be available from the C-NLOPB and available to view in IET's Virtual Exploration Data Room. Data from C-NLOPB. (b) TGS/PGS/OilCo. modern seismic data coverage. Data courtesy OilCo. (https://oilandgas.nalcorenergy.com/ness/overview/).

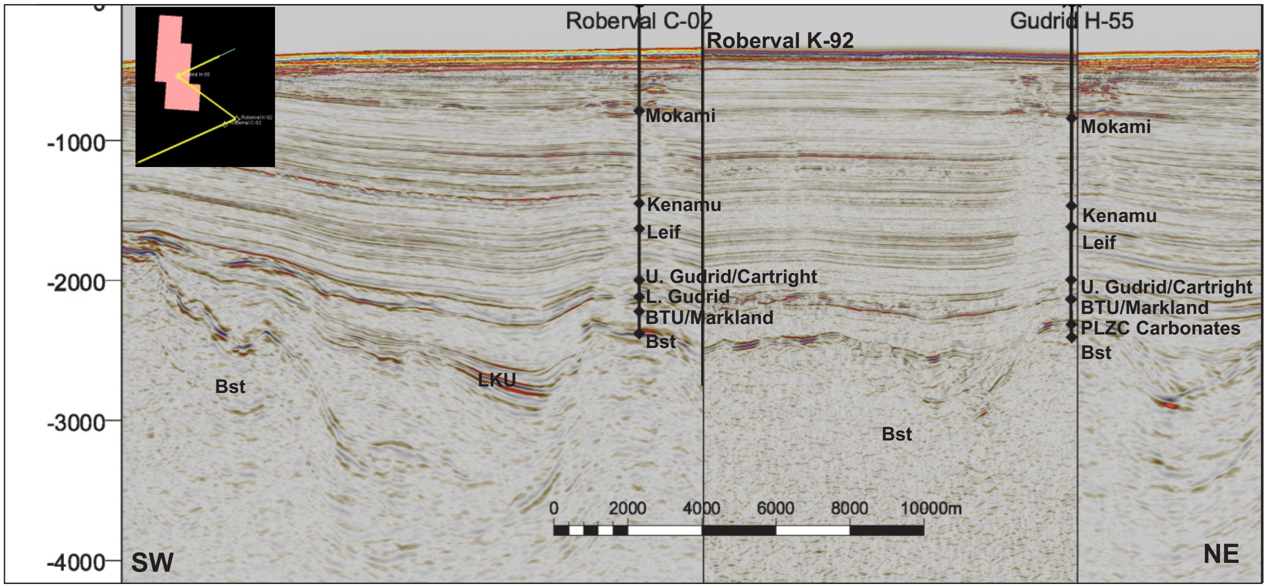
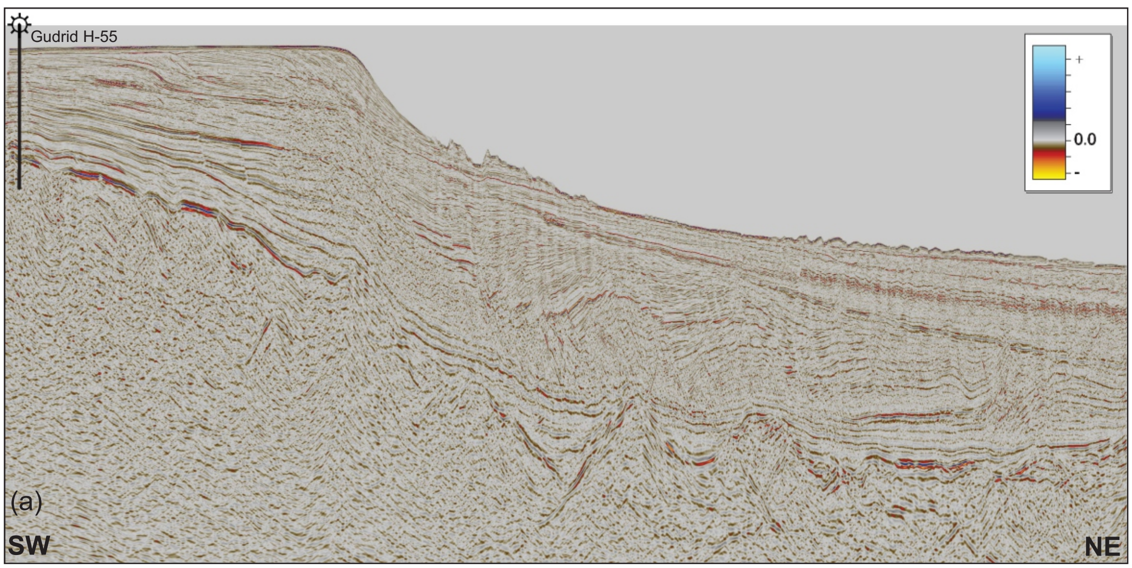
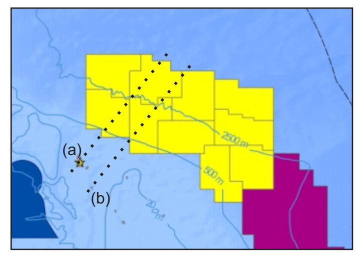


Figure 12. Public-domain seismic line through shelf wells located to the west of Call for Bids. Seismic is normal polarity (peaks are red, troughs are blue). Data from C-NLOPB. Available upon request to C-NLOPB or subscription to IET's Virtual Exploration Data Room. **Bst:** Basement; **BTU:** Base Tertiary Unconformity; **LKU:** Late Cretaceous Unconformity.





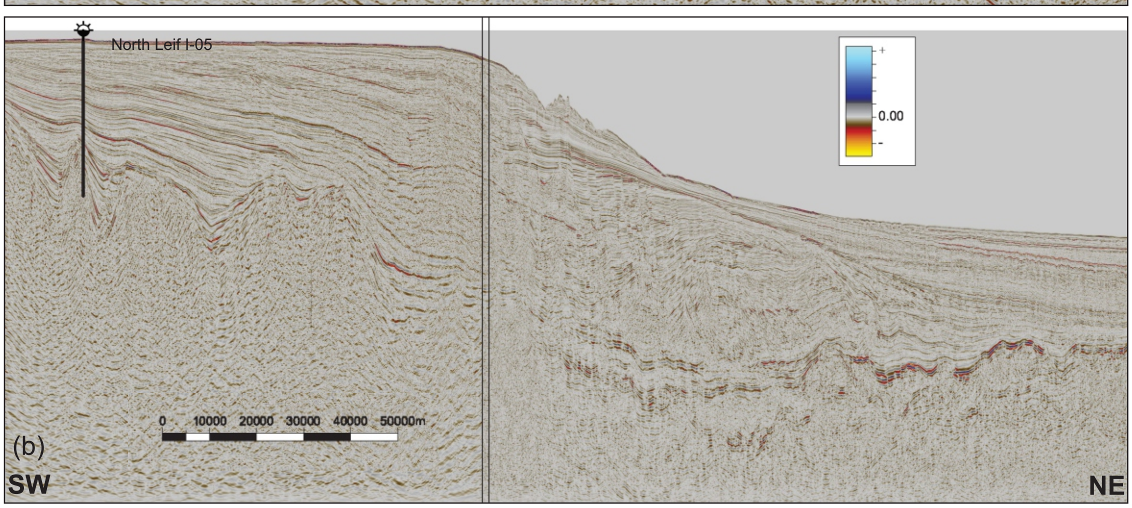


Figure 13. Privileged seismic lines from key shelf wells through Call for Bids. Note locations of lines are approximate. Data courtesy OilCo.

ADDITIONAL INFORMATION AND CONTACTS

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MANDATE AND ROLES

The **Canada-Newfoundland & Labrador Offshore Petroleum Board (C-NLOPB**) is mandated to interpret and apply the provisions of the Atlantic Accord and the Atlantic Accord Implementation Acts to all petroleum-related activities of operators in the Canada-Newfoundland and Labrador Offshore Area and to oversee operator compliance with those statutory provisions.

Their role is to facilitate exploration for and development of petroleum resources, including health and safety of workers, environmental protection, effective management of land tenure, maximize hydrocarbon recovery and value, and Canada/Newfoundland and Labrador benefits.

As Offshore Regulator and Administrator for Call for Bids, the C-NLOPB are the primary contact for participation in this resource opportunity. They operate a registry to record exploration, significant discovery and production licences and information related to these interests for public review. They are also the curators of all geoscientific data pertaining to the Newfoundland and Labrador Offshore Area. The C-NLOPB has no active role in promotion of the Province's hydrocarbon resources.

The **Government of Newfoundland and Labrador, Department of Industry, Energy & Technology** is responsible for providing marketing and promotional services to foster the exploration, development and production of the Province's hydrocarbon resources internationally as well as promoting the maximization of fiscal and industrial benefits through the negotiation, development, administration and monitoring of petroleum project agreements and legislation.

Compiled by A. Krakowka and N. Emberley of Department of Industry, Energy & Technology from previously published studies, papers, and Department of Industry, Energy & Technology work. Several publications were used to generate text and illustrations (e.g. Enachescu, 2006 and 2008; Carey et al., 2019). Reviewed by M. Enachescu and J. Hogg.

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