NEWFOUNDLAND AND LABRADOR OFFSHORE 2021 LICENCING ROUND TAIL OF THE BANK SEPTEMBER 2020

The area was last licensed for exploration in the late 1960s-early 1970s, but the seismic data quality at the time was poor and no wells were drilled outside of the Grand Banks shelf. The existing shelfal wells penetrated reservoir and source rocks and can be used for seismic ties to the modern seismic (Figure 1).

The Call for Bids area is a fragment of the North Atlantic Mesozoic rift network and includes the southern part of the Carson Basin, previously identified in academic publications as the Salar Basin. Close to the Jeanne d'Arc and Flemish Pass basins that both contain world-class oil fields, the area is considered highly prospective for hydrocarbons. Recently, exploration took place in the northern Carson Basin where modern 2D and 3D seismic were collected and a deepwater well is planned. Despite recent and historic 2D seismic coverage, the Sector area remains underexplored. The area was last licensed for exploration in the late 1960s-early 1970s, but the seismic data quality at the time was poor and no wells were drilled outside of the Grand Banks shelf. The existing shelfal wells penetrated reservoir and source rocks and can be used for seismic ties to the modern seismic (Figure 1).

OVERVIEW

Located on the east coast of Canada, the province of Newfoundland and Labrador (NL) is the country’s only offshore oil producing region. Since 1997, the province’s five producing fields – Hibernia, Terra Nova, White Rose, North Amethyst, and Hebron have produced in excess of 1.9 billion barrels of light oil (32-35° API). The NL offshore area now produces over 260,000 bopd and output is estimated to increase to approximately 400,000 bopd when the Hebron field reaches peak production.

With substantial undiscovered oil and gas resource estimates and 1.8 million km² of prospective acreage with less than 7% having been held under licence, the region holds great potential. This potential can be further realized in the 2021 Call for Bids Sector (Figure 1).

KEY ATTRIBUTES

• Sector totals 2,520,448 ha (22,704 km²) and will be divided into parcels.
• Water depths of 500 to 3,600 m.
• Competitive fiscal regime with low political risk.
• Modern and historic seismic coverage over the basin.
• Virtual Exploration Data Room available.
• Proximity to both North American and European markets.
• A successful bid is based solely on highest bid amount.
• For more information, visit www.cnlopb.ca
SOUTH EASTERN NEWFOUNDLAND AREA GEOLOGY

The Carson Basin can be divided into three distinct physiographic regions (Figures 3 & 4) based on tectonic and structural setting, position on the continental margin, and composition of sedimentary fill:

- **Shelf** – The shallow water, continental shelf region was historically known as the Carson-Bonnition Basin. Located on the easternmost part of the southern Grand Banks, the shelf region is separated from the Jeanne d’Arc Basin by a basement ridge trending approximately NE-SW and from the easterly slope part of the basin by a basement ridge capped in places by Late Triassic Argo salt. This ridge is mapped under the shelf break (Figure 3). Late Triassic to Quaternary successions were drilled on the shelf during the early 1970s and mid-1980s (Figure 3). While Late Jurassic Kimmeridgian and Tithonian shales of the Rankin Formation were drilled, no quality source rock was encountered at these locations. Late Jurassic source rocks are likely missing due to a local lack of restricted environment, non-deposition on basement highs, or erosion of source rock intervals due to the proximity to the Avalon Uplift.

- **Slope and Upper Rise** – The intermediate to deepwater, slope and upper rise region is historically known in academic publications as the Salar Basin. This region is separated from the shelf by a basement ridge trending approximately NE-SW (forming a hinge zone) and from the deepwater region by a tortuous fault zone and high ridge. Based on regional seismic markers, the region appears to contain the entire Mesozoic sedimentary section including Late Triassic salt and red beds strata (Figure 5). Mapping in the area reveals large and complex structures including those separated by deep penetrating faults. The basin continues to the south along the Tail of the Bank margin with Late Jurassic to Early Cretaceous strata accumulated in several mini basins and a Late Cretaceous and Tertiary sedimentary wedge including slope fans.

Northwards of the Carson Basin, the Mesozoic rift basin chain includes the shallow water Jeanne d’Arc Basin and the parallel Central and Eastern Ridges, before sloping into deeper water Flemish Pass and Orphan Basins. Two other major extensional stages have taken place in these basins during the Late Jurassic-Early Cretaceous and late Early Cretaceous and created conditions for viable petroleum systems and presence of numerous hydrocarbon traps. Thick coarse clastic intervals that preserve high porosities and permeabilities have been deposited during these stages. Further to the northwest, seaward of Labrador Peninsula, are the Hawke, Holton, Hopedale, Chidley, Sagle, and Henley extensional basins, formed during the Labrador-Greenland breakup in the Cretaceous.

Most of the Grand Banks’ Mesozoic basins are confined, residing on continental crust. Several other basins are unconfined, located at attenuated continental margin, opposite their European conjugate basins in offshore Ireland (northeastern parts of Flemish Pass and Orphan basins) and Iberia (Carson Basin). Other Atlantic oblique and perpendicular rift branches, for instance the hydrocarbon-rich Aquitaine Basin and Viking Graben, also formed during the same series of extensional events.

REGIONAL GEOLOGY OF THE ATLANTIC MARGIN

The Late Triassic to Early Jurassic rifting of Pangea created a series of NE-SW oriented intra-cratonic basins extending from the Gulf of Mexico to the Barents Sea. In eastern Canada, the Mesozoic rift basin chain starts offshore Nova Scotia, stretches through the Scotian shelf and slope basins, including the Laurentian Basin, located between Cape Breton and Newfoundland (Figure 2). Further east along the southern Grand Banks are the shallow to deepwater South Whale and shallow water Whale and Horseshoe basins. On the easternmost part of the Grand Banks sits the shallow to deepwater Carson Basin comprised of several subbasins and ridges.

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**SOUTH EASTERN NEWFOUNDLAND AREA GEOLOGY (continued)**

- **Deepwater (slope and rise)** – The southern slopes and easternmost continental rise area where Mesozoic rocks overlie super-extended crust was referred to as the Salar Basin. This region is generally located east of a fault system, which divides the deepwater section into sub-regions. The area is structurally complex with thinner extensional stage sedimentary sequence above the densely faulted basement. Mapping reveals an assortment of tilted basement blocks, circular salt structures and transitional zone-like mounds (peridotite mounds?) intertwined with mini-basins containing deformed Mesozoic layers. Some of the blocks appear slightly inverted, probably due to transtension or isostatic rebound.

The 2021 Call for Bids Sector encompasses the southern part of the Carson Basin Mesozoic extensional area, which contains Jurassic to Early Cretaceous faulted fill overlain by a thick wedge of syndrift sequences including submarine fans. Several large structural and stratigraphic traps are mapped over stretched Lower Paleozoic and Precambrian basement and over transitional crust.

The Mesozoic-rifted Carson Basin represents the easternmost arm of the intracratonic network of rift basins developed on the Canadian margin during Late Triassic to Early Jurassic. During the Late Triassic to Early Cretaceous, the future Carson Basin area was an intra-continental rift valley, which was followed by an internal shallow and deepening sea stage interspersed with continental and marginal marine sedimentation. The Canadian margin underwent extension, transtension and subsidence and over time a widening, thickening depression developed between the Grand Banks of Newfoundland and the Iberia Peninsula.

After considerable thinning of continental crust and emplacement of transitional crust to the east, the final rift episode became oceanic during the late Early Cretaceous (Aptian-Albian), leading to separation and drift of the Grand Banks from Iberia. Hence, up to the late Early Cretaceous, the Carson Basin area shared a common tectonic and structural evolution with several other Grand Banks basins, including the oil proven Jeanne d’Arc and Flemish Pass Basins.

**Figure 3.** Location of Carson Basin in relation to other Grand Banks shelf and slope basins and subbasins (modified after Enachescu, 1988 & 1992). Subdivisions are marked as 1) On-shelf sector, 2) Slope and upper rise sector and 3) Deepwater sector. Exploration wells are: O = Osprey H-84, S = Skua E-41, G = St. George J-55 and B = Bonnition H-32, Green circles = ODP Leg 210 wells. Notations are: NTFZ = Newfoundland Transform Fault Zone (continent/ocean), NR = Newfoundland Ridge, TB = Tail of the Bank, SR = Salar Ridge, SJD = South Jeanne d’Arc Basin, JD = Jeanne d’Arc Basin, FP = Flemish Pass Basin, CR = Central Ridge, BP = Bonavista Platform, BK = Beothuk Knoll and FC = Flemish Cap. CC = continental crust, TC = transitional crust and OC = oceanic crust. F2 and F3 are major fault trends in the basin. Producing oil fields are: H = Hibernia, T = Terra Nova and W = White Rose. The black line shows the location of the generalized geological cross-section illustrated in Figure 4.
CARSON BASIN GEOLOGY

The Carson area is separated from the Jeanne d'Arc Basin by the Morgiana Anticlinorium, from the South Jeanne d'Arc Basin by a thin basement ridge, and from the Flemish Pass Basin by a series of NNE-SSW basement highs and narrow sedimentary troughs. A major fault marks the basin's northwestern boundary. Towards the south, the Carson Basin's sedimentary area is separated from the South Grand Banks basin by a basement high called Tail of the Bank (TB), which extends southward all the way to the Newfoundland Ridge (NR) (Figure 2).

Within the Carson Basin, sedimentary fill includes Late Triassic to Mid Jurassic red beds, salt, limestones, and dolomites, followed by a Late Jurassic to mid-Cretaceous clastic sequence. A predominantly shaly sequence including several basin slope and floor sandstone intervals (fans?) characterize the Late Cretaceous to Quaternary cover.

The shelf area can be divided into a northern and a southern half graben, separated by a transfer zone. These two areas were historically called the Bonnition and Carson Basins, respectively. The northern shelf region contains thicker Mesozoic fill, while the southern area has suffered pronounced erosion during the mid-Late Cretaceous. Early Cretaceous sediments including sandstone reservoirs are generally preserved to the north and eroded towards the south. In the south, the Late Cretaceous and Tertiary strata form a thick clastic wedge.

The northern deepwater sedimentary depocenter includes Triassic salt and thick Jurassic to Cretaceous successions. Under the slope, the pre-rift section drops off significantly with rotated blocks and salt induced mini-basins. Large and complex Mesozoic structural and stratigraphic features are observed under the slope and upper rise, a number of which are salt cored. Salt features are missing in the southern part of the basin but above the red beds and basement, salt beds may exist intercalated with shale and other evaporites.

There are two exploration licences active in this part of the basin (Figure 1).

The less explored southern region of the basin, which is located in front of Tail of the Banks show a distinct structural setting. This are covered by the 2021 Call for Bids is characterized by basement rotated blocks with intervening mini-basins containing synrift deposits preserved under a thick postrift sedimentary cover that contains numerous possibilities of stratigraphic trapping up-slope and at the contact with the Newfoundland Ridge.

**Figure 4.** Schematic geological cross-section of the Carson Basin (modified after Enachescu, 1992). Location of cross-section is given in Figure 3. Abbreviations are: UB = unextended basement; BBF = basin bounding fault, WB = water bottom, EM = exhumed mantle, EB = extended basement; C = end of extensional stage unconformity (Avalon); SC = onshelf Carson Basin; all underlain by continental crust. TC = transitional crust region and includes highly extended continental crust intruded and overlain by lava flows. OC = old oceanic crust formed during the Tethys rifting stage. Small Mesozoic rift sedimentary and volcano sedimentary cuvettes are present in the transitional zone. East of J(Mo) magnetic anomaly and ridge, only Atlantic rift stage oceanic crust and syndrift sediments occur. From left to right, patterns indicate: continental basement, salt structures in the basin, intrusions, lava flows and extended old oceanic crust, and Atlantic stage oceanic crust.
**CARSON BASIN GEOLOGY (continued)**

Basin fill deformation is due to extension, salt movement (mostly in the northern basin) and detachment sliding. Inversion was a late-stage event and appears to be only a secondary mechanism for trap formation. Diapiric salt is more widespread on the slope and in the deepwater of the northern basin. In the southern part of the basin, diapiric salt is absent. Seismic reflection and potential field data show an en echelon fault system, ridges and minibasins trending approximately parallel to the shelf break mega fault.

Coarse-grained clastics sourced from Precambrian basement terrains surrounding the basin should be present within deltaic episodes deposited during the Late Jurassic to Early Cretaceous. Likewise, coarse clastics sourced from incised canyons on the Grand Banks are deposited on the faulted slope and upper rise in front of the Tail of the Bank forming an impressive passive margin sedimentary wedge.

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**Figure 5.** Stratigraphic chart for shelf and deepwater Carson Basin. Modified from Nalcor Energy (2018).
PETROLEUM GEOLOGY: OVERVIEW

The slope and deepwater portion of the Carson Basin included in the 2021 Call for Bids Sector is part of Newfoundland’s Mesozoic network of basins, which have preserved a significant Late Jurassic to Early Cretaceous sedimentary sequence. While the inner shelf was being eroded during the Avalon Uplift, the remainder of the basin started to subside and was blanketed by a thick Late Cretaceous-Tertiary cover that helped to preserve a potentially hydrocarbon-bearing synrift sequence. Due to proximity and similar tectonic evolution, it is anticipated that the Call for Bids area will contain similar oil prone petroleum systems (anchored by Kimmeridgian Egret Member or Tithonian source rocks) as those proven in the Jeanne d’Arc and Flemish Pass Basins. Additionally, Cretaceous source rock beds may have reached maturation within the thick sedimentary wedge shown by seismic data (Figure 11).

Despite being adjacent to the hydrocarbon prolific Jeanne d’Arc Basin, the Carson Basin remains underexplored, and untested on the slope and deepwater. In the early 1970s and mid-1980s, exploration wells drilled on the shelf were unsuccessful. This has been attributed to a lack of charge due to non-deposition and/or erosion of source rock at the well locations. However, a well is planned in the coming years on Exploration Licence 1136, just north of the Sector (Figure 1).

The Carson Basin’s oldest infill was deposited eastward of a major basin-bounding fault and consists of a structured synrift succession of coarse and fine-grained clastics (red beds), evaporites, and various carbonate lithologies ranging in age from Late Triassic to Middle Jurassic (Figure 5). These in turn are overlain by a Late Jurassic to late Early Cretaceous (Albian) succession deposited during two additional rifting stages and subsequently deformed by halokineti cs. Finally, the Late Cretaceous to Tertiary section contains a relatively thick succession of mainly fine clastics and thin carbonates, which appear mounded on the slope and parallel-bedded elsewhere. These were deposited during the thermal subsidence stage that started with transitional crust formation, followed by continued oceanic rifting and drifting accompanied by oceanic crust formation. The postrift sedimentary sequence contains numerous intervals that had positive AVO responses for the presence of hydrocarbons.

As no specific lithostratigraphic chart exists for the Carson Basin, a modified Jeanne d’Arc chart can be adopted (Figure 5) and used in conjunction with the bio- and lithostratigraphic well correlation diagram built along the four shelfal exploration wells (Figure 10). The early rift fill consists of a red bed sequence (Eurydice Formation) that may contain terrigenous (lacustrine?) source and reservoir rocks. This was followed by deposition of the Late Triassic-Early Jurassic Argo salt, coeval with salt deposited in other Grand Banks and Lusitania basins. The salt became mobile starting in the Jurassic, creating intrusions and salt-induced structures in the overlying sedimentary section of the northern basin. In tandem with salt deposition, it is possible that high total organic carbon (TOC) marine shales were also deposited either as intercalations or capping the halite. Only stratified salt section may exist in the southern part where the Call for Bids will be.

To date, the only producing petroleum system on the Grand Banks and environs that is feeding hydrocarbons into Late Jurassic to Tertiary sandstone reservoirs is sourced by the Late Jurassic marine shales known as the Egret Member of the Rankin Formation in the Jeanne d’Arc Basin or the Tithonian in the Flemish Pass Basin.

Although the eastern Grand Banks slope and deepwater regions have not been drilled, oil prone source rocks such as the Egret member shale, should be present in several Late Jurassic intervals identified on seismic reflection data. The Egret Member is primarily a thinly interbedded and finely laminated marlstone and calcareous shale possessing an organic-rich Type II marine-derived kerogen intermixed with a secondary, terrestrial Type III kerogen. The Egret Member has a 2-9% TOC range (average 4%) and a Hydrogen Index (HI) between 100 and 600 mg HC/g TOC. Geochemical studies indicate the Egret Member is generally mature when buried deeper than 2,800 – 3,000 m.

In the nearby Flemish Pass, a proven source rock is the Tithonian shale of the informally known Bodhran Formation. These Late Jurassic shales are world-class source rocks with high TOC and HI values. These source rocks are expected to be present in the intermediate and deepwater portions of the Carson Basin.

The potential for other source rocks is recognized in the Paleozoic, Early and mid-Jurassic, Early and Late Cretaceous, and Early Tertiary. High TOC Albian and Cenomanian-Turonian black shale intervals were cored during Ocean Drilling Program (ODP) Leg 210, Site 1276 (Figures 1 & 8), located south of the Flemish Cap and approximately 250-300 km east of the 2021 Call for Bids area. Also, the Integrated Ocean Drilling Program (IODP) hole 1407 of Expedition 342 (Figures 1 & 9) located approximately 100 km south of the Call for Bids Sector, on the Newfoundland Ridge, recovered Cenomanian-Turonian organic black shale.
PETROLEUM GEOLOGY: OVERVIEW (continued)

Reservoir rocks are present in all stages of basin development, although good quality clastic reservoirs are associated mostly with the Grand Banks synrift stages (Figure 5). Quality sandstone reservoirs were encountered on the shelf in several wells located near the NW boundary of the basin (Figures 3 & 10).

A multitude of structural and combination hydrocarbon traps were formed in the basin during the repeated extensional and minor transtensional episodes. Prolonged salt halokinetics also produced a number of large traps in the northern part of the basin. Basement rotated blocks and silled minibasins are mapped in the Sector area. Stratigraphic traps are associated with slope formation, basin tilting, and fan development in front of the slope. These large stratigraphic traps have a significant presence on the slope and deepwater of the Sector area.

PETROLEUM GEOLOGY: SOURCE ROCKS

During the Late Jurassic, the area experienced in places, a restricted sea setting similar to the Jeanne d’Arc and Flemish Pass basins, leading potentially to the deposition of significant thicknesses of oil generating source rock. This Late Jurassic time interval is responsible for sourcing all the current oil fields in the Jeanne d’Arc Basin.

The most significant source rock offshore Newfoundland is the Egret Member of the Kimmeridgian Rankin Formation or its equivalent (Figure 5). In the Jeanne d’Arc Basin, the Egret Member is a Type II, oil prone source rock with up to 9% TOC, with a TOC average between 3.5 and 4.5%. It was deposited in a semi-silled, epeiric basin and represents the best marine source rock within the North American Atlantic rift system. At present, over 25 exploration wells on the Grand Banks have penetrated the Egret Member source, including wells within the Central Ridge – Flemish Pass area.

In the Central Ridge – southern Flemish Pass area, the Panther P-52 well (Figure 1) encountered more than 500 m of Tithonian and Kimmeridgian Rankin Formation marine source rock (Figures 6, 7, & Table 1). The 310 m thick Upper Kimmeridgian section averaged 2.4% TOC with a maximum value of 8.2%. HI values range up to 989 mg HC/g TOC (Geochem Labs, 1986). The rocks are deemed moderately mature and primarily oil prone with associated gas. For the 209 m thick Lower Kimmeridgian source interval, TOC values also average about 2.4% with HI values ranging up to 387 mg HC/g TOC (Geochem Labs, 1986).

At Golconda C-64, located approximately 25 km south of Panther, the well was drilled on a salt cored, anticlinal Jurassic structure which has been truncated by the Base Tertiary Unconformity (Table 1). The oil-prone Egret Member source is not present, but underlying Voyager (Oxfordian) shales do exhibit TOC values up to 3.5%.

![Figure 6](left). Panther P-52 modified van Krevelen graph. Data from Geological Survey of Canada (2012).

![Figure 7](right). Panther P-52 total organic content versus depth. Data from Geological Survey of Canada (2012).
PETROLEUM GEOLOGY: SOURCE ROCKS (continued)

Tithonian age (Jurassic) source rocks first identified at Baccalieu I-78, Panther P-52, and Lancaster G-70 wells in the Flemish Pass area and more recently in Mizzen and Bay du Nord wells in the Flemish Pass Basin are mostly shale having TOCs between 2 and 4%. Although unproven, there is potential for these source rocks to be present further south in the Call for Bids area.

Regionally, throughout the Central Ridge / Outer Ridge Complex – south Flemish Pass Basin, strong amplitude reflectors often associated with a Late Jurassic source rock appear mappable on seismic lines. Numerous regional seismic sections show that the Ridges, Flemish Pass Basin, and parts of Carson Basin were connected during the Late Jurassic to the oil prolific Jeanne d'Arc Basin and that the seismic signature of marine organic shales (“hot shale”) can be recognized in the half grabens and rotated blocks that contain synrift sedimentary sequences.

Late Jurassic shales that generated the giant Hibernia field on the Grand Banks of Newfoundland, are the main source rocks in other hydrocarbon prolific Atlantic Margin basins, including the Viking Graben, Aquitaine Basin and Norwegian Sea.

Seismic mapping in the Carson Basin and specifically in the Call for Bids area indicates that Egret Member source rock or other Late Jurassic organic shales are present and are widespread. Based on seismic interpretation and well correlation, a Late Jurassic section is indicated in the synrift section and especially within the minibasins created between the tilted basement blocks (Figures 14 &15).

The Mesozoic section in the Call for Bids area may be underlain by Carboniferous age, gas generating paludal and coaly source beds similar to those observed further west in the Maritimes Basin. Early Tertiary shales also show some intervals with high, however they are yet unproven as source rocks. They may become a hydrocarbon contributor when TOC adequately covered by thick drift stage sediments such is the case in the Sector area.

<table>
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<tr>
<th>Well</th>
<th>Drill Year</th>
<th>Well Status</th>
<th>Location</th>
<th>TD (m) below RKB</th>
<th>TD Formation</th>
<th>Reservoir Interval</th>
<th>Source Rock</th>
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<td>Abandoned</td>
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<td>Banquereau</td>
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Table 1. Exploration wells drilled near Call for Bids Sector in South Eastern Newfoundland land tenure region. Eq = Equivalent, Fm = formation, Mbr = member, OAE = Oceanic anoxic event, Sst = sandstone, TOC = total organic carbon. Data from C-NLOPB.
SCIENTIFIC WELLS: CRETACEOUS SOURCE ROCK POTENTIAL

In 2003, the ODP drilled two sites south of the Flemish Cap and 150 km east of the Carson Basin area. Sites 1276 and 1277 of Leg 210 terminated on transitional crust, and ultraslow emplaced ocean crust, respectively (Tucholke, B.E., Sibuet, J.C., & Klaus, A. (Eds.), 2007; doi:10.2973/odp.proc.sr.210.2007). These continuous cored drill holes (Figure 8) intersected a fine-grained succession including high TOC and HI Cretaceous black shales and thin, coarse-grained turbidite reservoirs (Marsaglia et al., 2004 & 2007; Hiscott, 2007; Hiscott et al., 2008; Enachescu, 2014).

In 2012, the IODP cored potential Cretaceous source rock on the Newfoundland Ridge, during Expedition 342, Site U1407 (Figures 1 & 9).

In ODP Leg 210, the Cretaceous Turonian to lower Albian-uppermost Aptian(?) shale succession (Unit 5) is greater than 700 m thick. It consists of gravity-flow deposits and non-calcareous hemipelagic mudstones interspersed with approximately 5% finely laminated, organic rich, black calcareous shales and marlstones. TOC is up to 10% in some of the organic rich shale beds, mostly due to the influx of terrestrial or mixed terrestrial/marine organic matter under somewhat reducing conditions. Exceptions to mainly terrestrial organics took place during Oceanic Anoxic Event (OAE) 2 (Unit 5A – Cenomanian-Turonian) and OAE 1b (Unit 5C – lower Albian) when thin, laminated black shales exhibiting TOCs between 3 and 7% and HI values ranging from 230 to 450 mg HC/g TOC were deposited. Geochemical data indicate a marine, algal origin (Type II) for this organic matter. Similar, although immature, finely laminated, organic rich black OAE 2 shales were also encountered at Site U1407 of IODP E-342. The OAE 2 shale beds observed at both deepwater locations are generally thin and immature. However, more mature and thicker OAE sediments may exist in the intervening 700 km between Site 1276 and Site U1407, possibly creating a source rock fairway. Traced back towards the slope/rise, the OAE 2 and OAE 1b shales, if present, may be thicker within restricted mini-basins, buried deeper or covered by a thicker sequence of Tertiary sediments than that observed in the ultra-deep environment.

The Cenomanian to Turonian aged organic shales encountered in ODP Leg 210 (Arnaboldi & Meyers, 2007; Mayers & Arnaboldi, 2011) are expected to also be found in the Carson Basin and may be mature in deeper depocenters. The Turonian-Albian black shale intervals are also possible source rock intervals (Arnaboldi & Meyers, 2007).

This fine-grained succession is stratigraphically equivalent to the Hatteras Formation described at multiple drill sites in the western North Atlantic and with the Nautilus Formation drilled in the Grand Banks' basins (Tucholke et al., 2004; Arnaboldi & Meyers, 2007). Five dark-colored intervals that contain up to 13% TOC of both marine and terrestrial provenance were identified in the Site 1276 sequence (Mayers & Arnaboldi, 2011). The portions of this interval that had high HI in places may be thicker and mature in the deeper sedimentary troughs of the Carson Basin such as those indicated in the Cretaceous maps made by Solvason (2006) and seen on seismic sections presented in this report (Figures 14 & 15).

Figure 8 (left). ODP Leg 210, Site 1276 core photo of Cenomanian-Turonian shales. From Tucholke et al. (2004).

Figure 9 (right). IODP Expedition 342, Site U1407 core photo of Cenomanian-Turonian shales. From Norris et al. (2014).
PETROLEUM GEOLOGY: RESERVOIR AND SEAL

Based on seismic interpretations, it appears the Jeanne d’Arc and Flemish Pass Basins were in communication with the Carson Basin area during the Late Jurassic to Late-Early Cretaceous. Therefore, the Call for Bids Sector area is also expected to contain high porosity, high permeability, quartz-rich sand intervals deposited in marine shoreface to deepwater settings similar to those observed in the northern Grand Banks basins.

The Bonnition H-32 and St. George J-35 wells that were drilled on the shelf encountered a number of Jurassic to Early Cretaceous sand intervals exhibiting fair to excellent porosity (Table 1 & Figure 10). These sand intervals are time equivalents to the Jeanne d’Arc, Hibernia, Avalon, Ben Nevis, and South Mara reservoir sands and were deposited as valley fill, deltaic, and shoreline sequences. Further seaward beyond the shelf edge, turbiditic sands, slope channel sands, and basin floor fans are expected.

In addition, the Late Cretaceous - Early Tertiary sequence has a real and effectively untested potential for large oil and gas pools, especially in the deepwater area. Secondary migration would be required to fill these postrift turbidite, channel, and basin floor fan sands.

From an exploration perspective, reservoir sands can be envisioned in a number of stratigraphic and structural settings. In the Sector area, seal risk should be minimal due to the abundance of fine clastics, tight sandstones, and tight, fine-grained deepwater limestones, all deposited at various times during synrift and postrift extensional and thermal subsidence events. On the shelf, formations such as Downing, Rankin, Fortune Bay, Whiterose, and Nautilus should provide an adequate seal for trapped hydrocarbons. Postrift Petrel and Wyandot Limestone as well as syndrift Banquereau formation fine clastics also form basin-wide seals.

Figure 10. Chronostratigraphy of wells drilled to date (all shelfal) in the Carson Basin using biostratigraphic data (Hogg & Enachescu, 2020).
Numerous possible stratigraphic traps are present on the slope. Trap styles include but are not limited to paleo-valleys, sub-unconformity truncations, pinchouts, and basin margin to basin slope / floor fans and associated feeder channels. It is worth mentioning that this play has never been targeted by exploration on Newfoundland continental margin in an unconfined basin setting.

There is also some risk of finding lower API oils present in shallower reservoirs. This is a situation encountered in the Jeanne d'Arc and Flemish Pass Basins where several accumulations were found to contain biodegraded oil or where heavier oils were generated by a marginally mature source rock. However, excellent quality oils (low sulfur, 30-35° API) have been found in the majority of offshore Newfoundland’s large discoveries.

Based on seismic interpretations, structural traps are plentiful in the Sector. Their formation can be attributed to multi-stage rifting and breakup along the North Atlantic margin, leading to extensional and gravity faulting, block rotation, compartmentalization, minor transtension, inversion, differential subsidence, and regional tilting. Trap styles include but are not limited to rotated / tilted fault blocks, rollover anticlines related to extensional faulting, compression modified extensional anticlines, elongated horst and graben structures involving basement or restricted to synrift sequences, and drape features over basement highs / rotated fault blocks. Significant structural complexity is created by both down-to-basin and down-to-margin normal fault systems affecting the basement, creating traps such as tilted blocks, horsts, and elongated ridges. Several oblique normal faults and transfer faults have also been mapped further creating structural traps. Closer to the magmatic Newfoundland Ridge, other structural and combination traps are created by various intrusions formed during thinning of the crust and Cretaceous breakup.

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The main hydrocarbon play expected to be successful in the southern Carson Basin will likely be:

- Anchored by a Late Jurassic source rock such as the Egret Member or equivalent; Tithonian, Callovian or Oxfordian organic shales, or a blend of these sources,
- Reservoired most likely in synrift Late Jurassic sandstones or Early Cretaceous sandstones, and
- Trapped in extensional/salt related faulted anticlines with faults providing kitchen source migration conduits.

This structural play has provided giant oil accumulations in the Jeanne d'Arc Basin and recently proved significant discoveries at Mizzen, Harpoon, and Bay du Nord in the Flemish Pass Basin.

The main risk in the basin remains source rock quality. On basin margins and high ridges, the risk is source presence and maturity. Profound erosion at the Avalon, Cenomanian, and Base Tertiary Unconformities may unseal the deeper synrift reservoir or reduce the amount of sedimentary cover necessary for maturation.

There is also some risk of finding lower API oils present in shallower reservoirs. This is a situation encountered in the Jeanne d'Arc and Flemish Pass Basins where several accumulations were found to contain biodegraded oil or where heavier oils were generated by a marginally mature source rock. However, excellent quality oils (low sulfur, 30-35° API) have been found in the majority of offshore Newfoundland’s large discoveries.

As the Sector area can be considered a true exploration frontier, we cannot underestimate the possible occurrence of other undrilled type of plays, such as slope fans fed by Cretaceous or early Tertiary source rocks, that have been successful on other Atlantic margins.
PETROLEUM GEOLOGY SUMMARY

The Carson Basin area represents a high risk, high reward petroleum play on the Newfoundland Atlantic Margin. The offered Sector is located in an underexplored, undrilled area but in the proximity to proven prolific hydrocarbon basins where the giant oil accumulations of the Jeanne d’Arc Basin are producing and the significant discoveries in the Flemish Pass Basin at Bay du Nord, Harpoon, and Baccalieu are slated for future development.

Multiple trap types are conceptualized in the Sector area: large structural fault-bounded closures and minibasins with synrift beds, Cretaceous fans, Tertiary lowstand submarine fans, and channel complexes. Some of the exploration locations mapped contain multiple stacked targets. The trap will likely be sourced by a world-class Late Jurassic source rock with little or no contribution from other possible source beds.

Conventional plays that are expected to be successful in the Carson Basin, with analogues to the adjacent Jeanne d’Arc Basin, will likely contain Late Jurassic Jeanne d’Arc equivalent sandstones, Early Cretaceous Hibernia equivalent sandstones, and late Early Cretaceous Avalon and Ben Nevis equivalent sandstones.

Late Cretaceous and Early Tertiary lowstand clastics are expected to have significant play potential on the basin’s slope and upper rise. The main play risk is considered to be charge, notably source rock presence and maturity.

SEISMIC DATA

Good to excellent 2D seismic grids, both modern and historic, are available for the area (Figures 12 & 13). Excellent modern seismic coverage exists (Figure 13) over several extensional structures located on the slope including a 3D survey planned for the 2020 acquisition season.

Seismic data quality is good to excellent in most of the area but deteriorates at the shelf break due to the presence of multiples in steep slope areas and at the level of the faulted and fragmented basement.

Seismic mapping (Figure 11) is possible using high quality regional seismic markers such as carbonate intervals within clastics, sandstone within shales, and several widespread unconformities. Good local markers and detachment surfaces within the postrift sedimentary wedge can also be easily mapped. Main and secondary faults are readily traceable.

Seismic ties to shelf wells and to the nearest oil discoveries (Hibernia, Terra Nova, Hebron and White Rose) are possible using the long regional lines covering the shelf and deepwater.

Figure 11. Time structure maps based on non-privileged 2D seismic data that show the (a) Water bottom to base Mesozoic sediment time thickness and (b) Base Mesozoic time structure. Contour interval is 500 ms. Green line mark approximate 1,000 (left) and 3,000 m water depths (right). Purple boxes mark the 2021 Call for Bids Sector.
Figure 12. Non-privileged seismic data coverage in Carson Basin area over 2021 Call for Bids Sector. CP: Cumulative parcels. Data courtesy of C-NLOPB. Data also available in Natural Resources’ virtual Exploration Data Room.

Figure 13. Privileged seismic data available for purchase in Carson Basin area over 2021 Call for Bids Sector. CP: Cumulative parcels. Data courtesy of Nalcor Energy.
Figure 14. Non-privileged seismic lines through the 2021 Call for Bids Sector. Purple boxes mark the Sector boundary. Bst - Basement, BTU - Base Tertiary Unconformity, EK - Early Cretaceous, LK - Late Cretaceous, J - Jurassic, OC - oceanic crust, v - volcanics. Data from the C-NLOPB. Inset map data courtesy Nalcor Energy.
Figure 15. Non-privileged seismic lines through the 2021 Call for Bids Sector. Purple boxes mark the Sector boundary. Bst - Basement, BTU - Base Tertiary Unconformity, EK - Early Cretaceous, LK - Late Cretaceous, J - Jurassic, NR - Newfoundland Ridge, OC - oceanic crust, v - volcanics. Data from the C-NLOPB and available on a subscription-basis in the Department of Natural Resources’ Exploration Data Room at www.hydrocarbonassets.com. Inset map data courtesy of Nalcor Energy, Oil and Gas.
**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 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 the exploration for and development of petroleum resources, including health and safety of workers, environmental protection, effective management of land tenure, maximum hydrocarbon recovery and value, and Canada/Newfoundland and Labrador benefits.

As Offshore Regulator and Administrator for the Areas of Interest, 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 Natural Resources 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** Department of Natural Resources from previously published studies, papers, and Department of Natural Resources work. Edited and reviewed by M. Enachescu.

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