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GEOLOGICAL SURVEY OF CANADA
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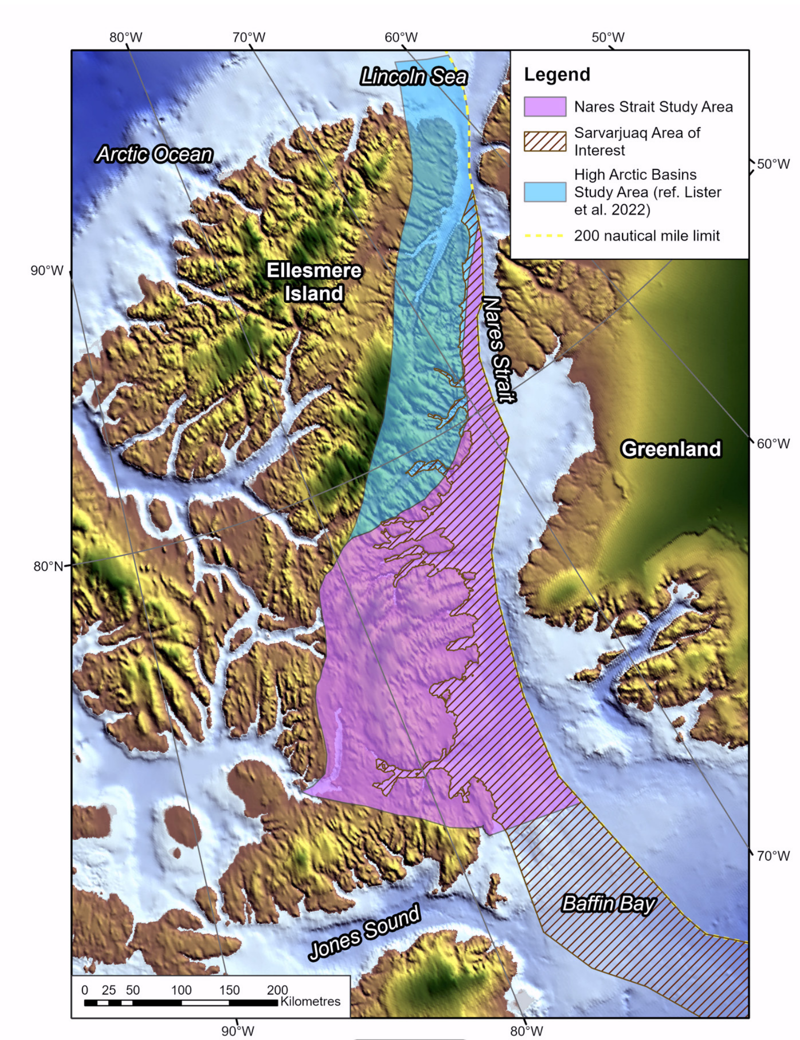
Hydrocarbon resource assessment of Nares Strait and central Ellesmere Island, Nunavut



A.M. Kalejaiye, K.E. Dewing, C.J. Lister, L.E. Kung, E.A. Atkinson, A. Krakowka, O. Khriashchevska, and C. Jiang

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Canada

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Cover Figure: Study Location map. (Showing the current study, part of previous High Arctic Basins MCT study and proposed Sarvarjuaq MPA)

EXECUTIVE SUMMARY

The Geological Survey of Canada carried out a qualitative assessment of the hydrocarbon resource potential of the Nares Strait and central Ellesmere Island. The assessment was requested by the Department of Fisheries and Oceans Canada and the Parks Canada Agency to help inform discussions about creating marine protected areas.

The study area is underpinned mainly by the Franklinian Basin which preserves Neoproterozoic–Devonian strata. Other smaller, Mesozoic–Cenozoic sedimentary basins exist within the study area under Nares Strait. Five potential plays were assessed with resulting qualitative hydrocarbon resource maps indicating that the study area has low hydrocarbon potential. Seal breach or absence is the most common risk associated with the plays in this area. This is premised on the age of the sediments and the effects of the Ellesmerian and Eurekan Orogenies which could have caused a migration or loss of previously generated hydrocarbon. There is also uncertainty over the presence of Triassic strata in the study area. Most publications do not support the extension of the Sverdrup Basin into the study area due to a lack of known outcrop.

In addition to the low hydrocarbon potential, there are no existing offshore oil and gas licenses, upcoming calls for bids, or proposed project activities in the study area. There is a very limited seismic data, no offshore wells have been drilled in the study area and there is a drilling moratorium in place. The operating conditions for oil and gas exploration in the study area are among the most extreme on the planet due to severe ice conditions, limited operating season, and geographic remoteness.

1. INTRODUCTION

The Nares Strait is a narrow water body that separates Ellesmere Island, Nunavut from northwest Greenland. It extends from the northern Baffin Bay area to the Lincoln Sea in the Arctic Ocean (Fig. 1). This area is ice covered for much of the year and present-day bathymetry is considered to be on the shelf with water depths of less than 200 m. The hydrocarbon resource assessment for this study area was embarked upon as part of the Canadian government's effort to achieve its commitment to carbon net zero by 2050. Fisheries and Oceans Canada commissioned the Geological Survey of Canada's (GSC) marine conservation targets (MCT) team to assess the hydrocarbon potential of the northern Baffin Bay area. This study area covers part of an area called Sarvarjuaq in Canadian Inuktitut; it is also known as the North Water Polynya, an area of year-round open water surrounded by sea-ice cover.

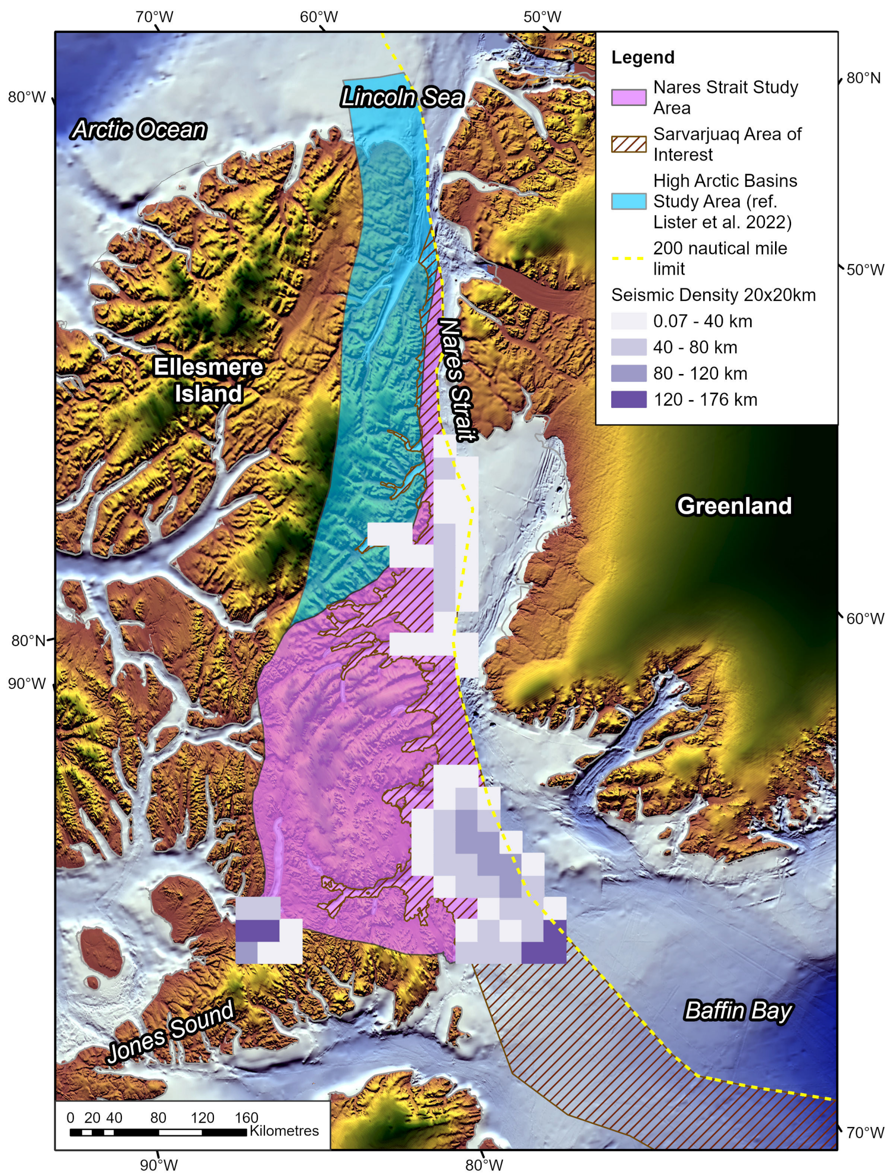


Figure 1: *Study Location map. (Showing the current study, part of previous High Arctic Basins MCT study, proposed Sarvarjuaq MPA and seismic lines in the study area)*

Assessment of the non-renewable resource endowment contributes to the decision-making process around conservation. This report provides a qualitative hydrocarbon resource potential map showing the likelihood of petroleum resources occurrence within the proposed Protected Area.

2. GEOLOGICAL SETTING

2.1 Tectonic History

Within the study area, the Canadian Shield consists of Paleoproterozoic basement gneisses, including granulite facies supracrustal rocks, unconformably overlain by a thin, Mesoproterozoic sedimentary succession with diabase dykes and sills (Smith Sound Group). The mid-Neoproterozoic breakup of Rodina lead to the establishment of the Arctic Platform, which is characterized by a thin, flat-lying, upper Neoproterozoic to lower Paleozoic, shallow water clastic to carbonate succession that unconformably overlies the Canadian shield (Evans et al., 2016, Ernst et al., 2016, Mayr et al., 2008). Clastic deposits are restricted to the Cambrian while carbonate deposits continued to accumulate until the Early Devonian (Dewing et al., 2019) Embry and Klovan (1976) suggested that most of the siliciclastic sediments deposited in the basin during the Silurian through Devonian were sourced from the Caledonian orogen in northeast Greenland but did not rule out minor derivation from a northern convergent margin. These sedimentary successions with thickness of up to 15km (Embry et al., 2019) were classified as the Franklinian succession in what is known as the Franklinian Basin (Fig. 2a).

In the late Silurian, the central Ellesmere Island experienced a local uplift called Inglefield Uplift (Trettin, 1991). The Middle to Late Devonian succession represents a foreland basin developed along the advancing front of the Ellesmerian Orogeny; a major mountain building episode, culminating with folding and uplift during the Famennian (Late Devonian)–Visean (early Carboniferous) (Piepjohn et al. 2016). The resultant Ellesmerian structures form a classic fold-and-thrust belt characterized by large-scale folding with anticlines and synclines having amplitudes of several kilometers (Piepjohn and von Gosen, 2018). Thrust faults have detachment levels in the Neoproterozoic or Cambrian. Harrison (2008) estimated ~65 km of shortening on northern Ellesmere Island.

Following the Ellesmerian Orogeny, during the Early Carboniferous to Permian, the region experienced extension resulting in the formation of the Sverdrup Basin centered on the Canadian High Arctic islands, but the region did not receive significant clastic influx (Embry & Beauchamp, 2008). It is therefore assumed that the cratonic areas stayed close to surface levels and were neither significantly exhumed nor buried (Spiegel et al., 2023). In the Triassic, the region experienced a large influx of clastic sediments due to subsidence and widening of the Sverdrup Basin, which extended into the cratonic areas (Embry & Beauchamp, 2008; Embry et al., 2023). The Jurassic and earliest Cretaceous are described as a calm period with no major tectonic activity (Embry & Beauchamp, 2008; Embry et al., 2023). Sedimentary deposits from this period are missing in the study area (Harrison et al., 2015)

The Paleogene period of the region records the Eurekan Orogeny; an episode of deformation due to convergence between the Canadian Arctic and Greenland (Thorsteinsson and Tozer, 1960, 1970). The complexity of the region especially in the Nares Strait area, represented by the disputed magnitude of Cenozoic sinistral displacement along the proposed "Wegener Fault" (Wilson, 1965) between Ellesmere Island and Greenland, stems from the simultaneous evolution of multiple tectonic regimes, as well as overprinting of later tectonic activity (Gion et al., 2017)

Distinguishing between the Eurekan structures and Ellesmerian structures is difficult in most areas because the Eurekan structures are superimposed on the Late Paleozoic Ellesmerian Orogeny (Thorsteinsson and Tozer, 1960, 1970; Trettin, 1991). Many cases show that the Eurekan faults are offshoots of existing Ellesmerian faults with many Eurekan compression showing that Ellesmerian décollement was reactivated along large thrust faults (Piepjohn et al., 2007; Piepjohn et al., 2008)

However, in the study area (the Judge Daly Promontory/Nares Strait), a distinction between the two fault systems is only obvious where post-Ellesmerian strata are clearly deformed (Saalmann et al., 2005; Saalmann et al., 2008; von Gosen et al., 2008). The resultant Cenozoic Eurekan folds are broader, smaller, and less intense (Harrison et al., 2009).

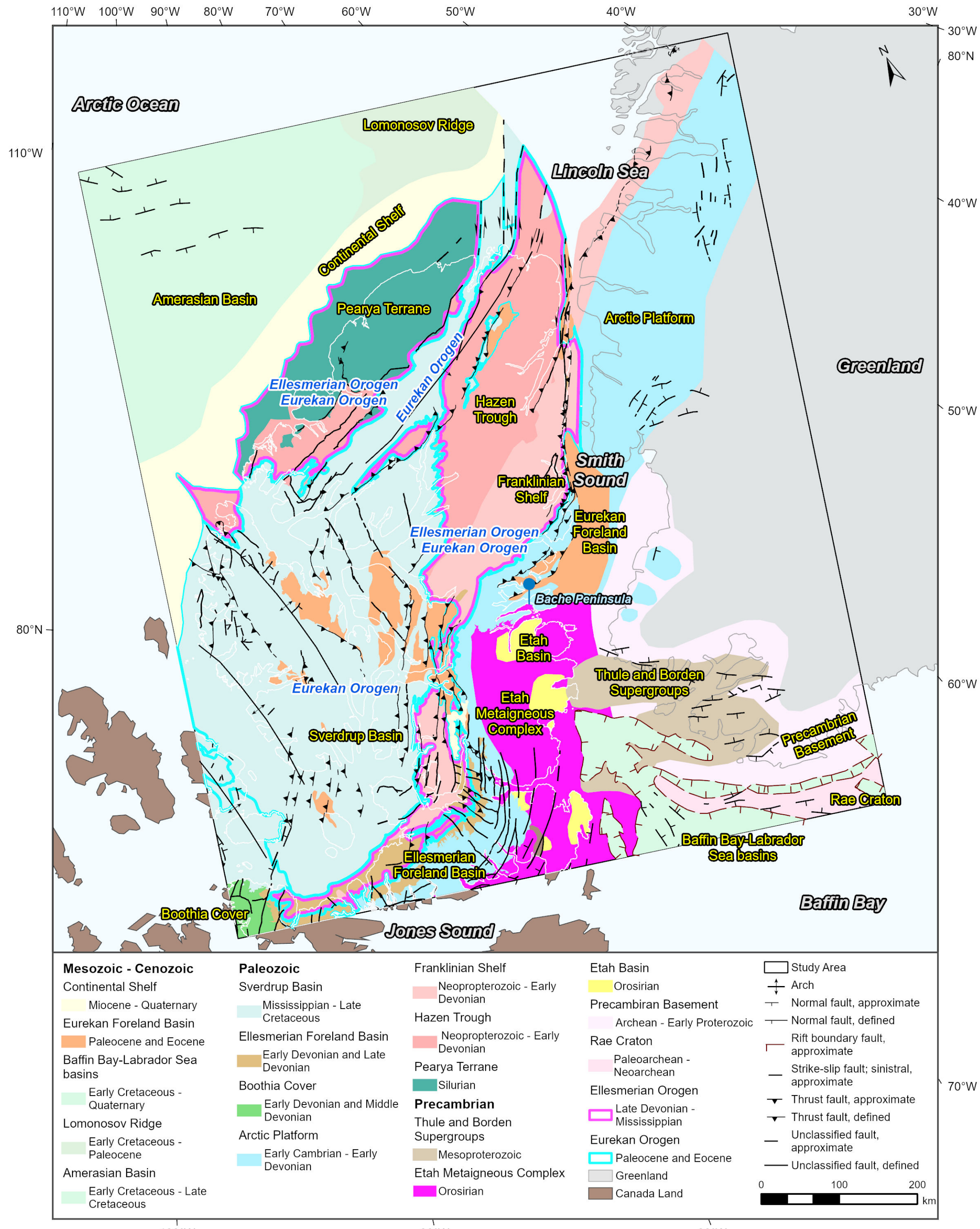


Figure 2a: *Regional Geologic map of the study area modified after St-Onge et al., (2015) (CGM187).*

2.2 Stratigraphy

2.2.1 Upper Neoproterozoic to Lower Devonian

The Franklinian Basin was filled by Neoproterozoic to Devonian sediments with thickness up to 15 km (Dewing and Hadlari, 2022). The Franklinian shelf succession is a northwesterly thickening wedge of Cambrian to Devonian strata deposited in inner to outer shelf environments, bound on the northwestern side by a major shelf-slope facies change which continued from the Early Cambrian to the Late Ordovician (Harrison et al., 2006). Basinal environments beyond the slope transitioned in the Silurian to foredeep flysch and foreland basin sediments. Preserved thickness of the sediment wedge ranges from less than 1000 m in the southeast to more than 13,000 m on central Ellesmere Island (Harrison et al., 2006). The Franklinian deposits of southeast Ellesmere Island and northwest Greenland are characterized by three distinct periods of clastic sedimentary deposition: i) Neoproterozoic to Cambrian, ii) lower Silurian to Lower Devonian and iii) Middle to Upper Devonian succession which is known as the Devonian clastic wedge (Embry and Klovan, 1976; Spiegel et al., 2023). On northeast Ellesmere Island, the exposed thick sedimentary sequence consists of Neoproterozoic shale and shallow-water carbonate; Lower Cambrian marine to deltaic siliciclastic deposits; Lower Cambrian to Upper Ordovician shallow-marine carbonate and evaporite deposits that formed a platform with distinct shelf-margin reefs; Upper Ordovician to Silurian shallow marine carbonate deposits that formed a platform with shelf-margin reefs and basinal, deep-water shale, chert and carbonate breccia (Dewing et al., 2008). A stratigraphic column modified after Dewing et al. (2008) is shown in Figure 2b.

2.2.2 Carboniferous to Cenozoic

The Sverdrup Basin located southwest outside of the study area has one of the most complete stratigraphic records representing the Carboniferous to Cenozoic timeframe and hosts a major petroleum province in Arctic Canada (Rayer, 1981). However, due to the Eurekan Orogeny with resultant fold belts and thrusts, only small outcroppings of the post-Ellesmerian and pre-Eurekan Sverdrup Basin are preserved in the northeast Ellesmere Island (Piepjohn et al., 2008). For instance, there are small outcrops of thin Lower to Upper Cretaceous strata in foreland areas of the Eurekan Orogeny, such as on Bache Peninsula (Lee et al., 2008). In southeastern Ellesmere Island, through the recent apatite fission track analyses of mainly Devonian clastic wedge samples from the area, Spiegel et al. (2023) inferred that Triassic deposits were once more widespread across most of Ellesmere Island and northwest Greenland and that the Sverdrup Basin as preserved today does not reflect its original extent. It is therefore uncertain if extended Triassic deposits are preserved anywhere in the study area as there are no mapped outcrops to support this, but some areas with Mesozoic strata (see Figure 3) are underwater.

Cretaceous - Lower Cenozoic basins (See Figure 3) related to the movement of North America away from Greenland are preserved along the coast of Nares Strait (Christie, 1964; Mayr and de Vries, 1982; Miall, 1982; Lee et al., 2008; Piepjohn et al., 2008). Cenozoic deposits on northeastern Ellesmere Island belong to the Eurekan Sound Group mainly of Paleocene to Eocene age (Thorsteinsson and Tozer, 1970; Miall, 1979; Miall, 1982; Sweet, 2008). The sedimentary package consists mainly of conglomerates, sandstones, siltstones and dark shales, deposited in non-marine to shallow marine environments (Saalmann et al., 2008). Subsequently as Greenland and northern Ellesmere collided resulting in the Eurekan Orogeny and the Central Ellesmere fold belt, Neoproterozoic and Paleozoic sequence were thrust over Cenozoic deposits.

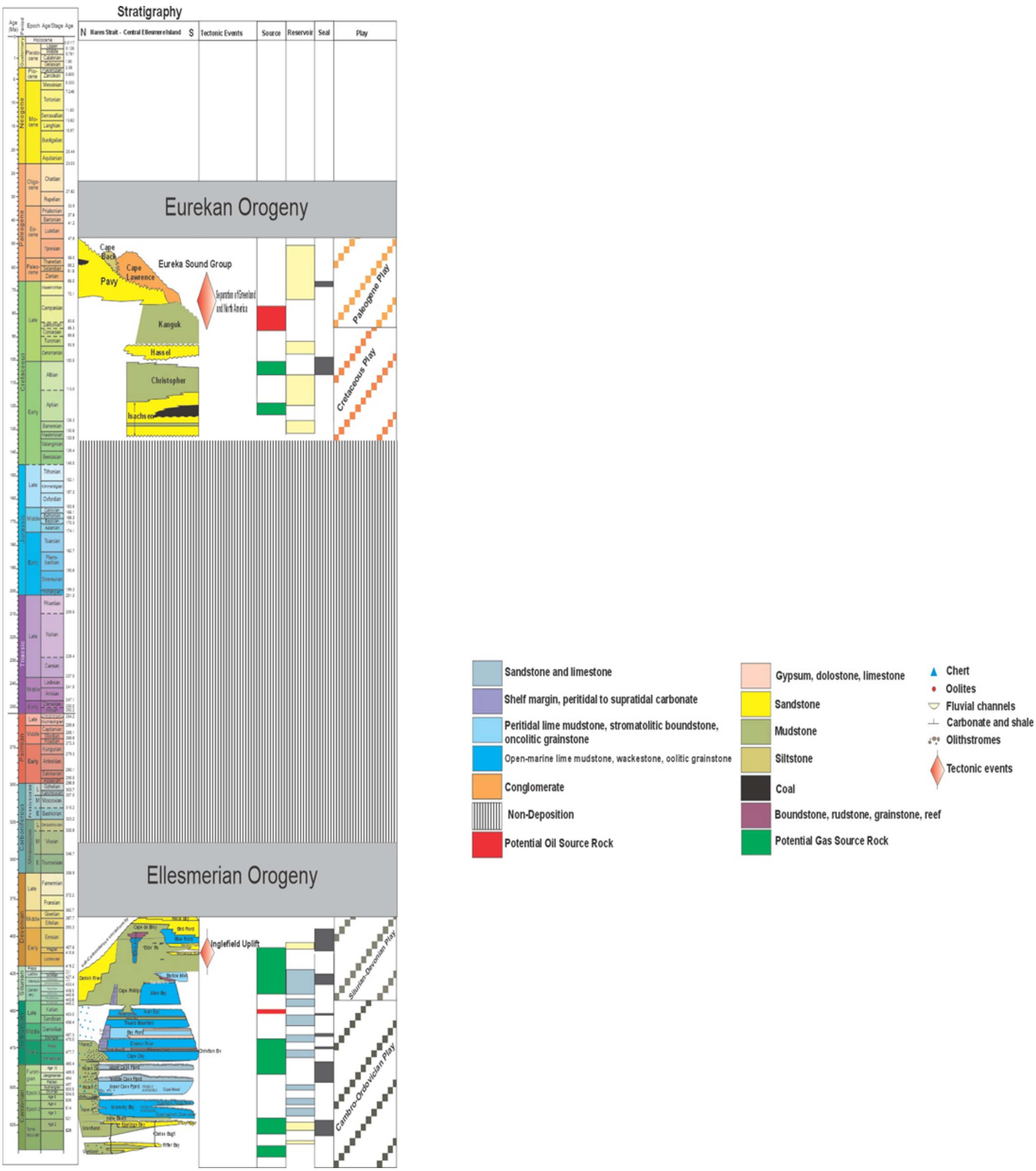


Figure 2b: *Stratigraphic column modified after Dewing et al. (2008) and Lee et al. (2008)*

3. EXPLORATION HISTORY AND DATA AVAILABILITY

There has been minimal hydrocarbon exploration in the study region due to its remoteness and harshness of the environment, in addition to sparse data availability. There are no wells drilled in Nares Strait; however, there are 11 shallow drill cores of depths up to 360 m on the nearby Melville Bay (north-east Baffin Bay), offshore West Greenland, funded by a consortium of eight petroleum companies (Nøhr-Hansen et al., 2021). These drill cores provide insights into the stratigraphic framework of the Lower Cretaceous – Cenozoic strata, in addition to the extensively and well documented studies of the outcrops located along the coast.

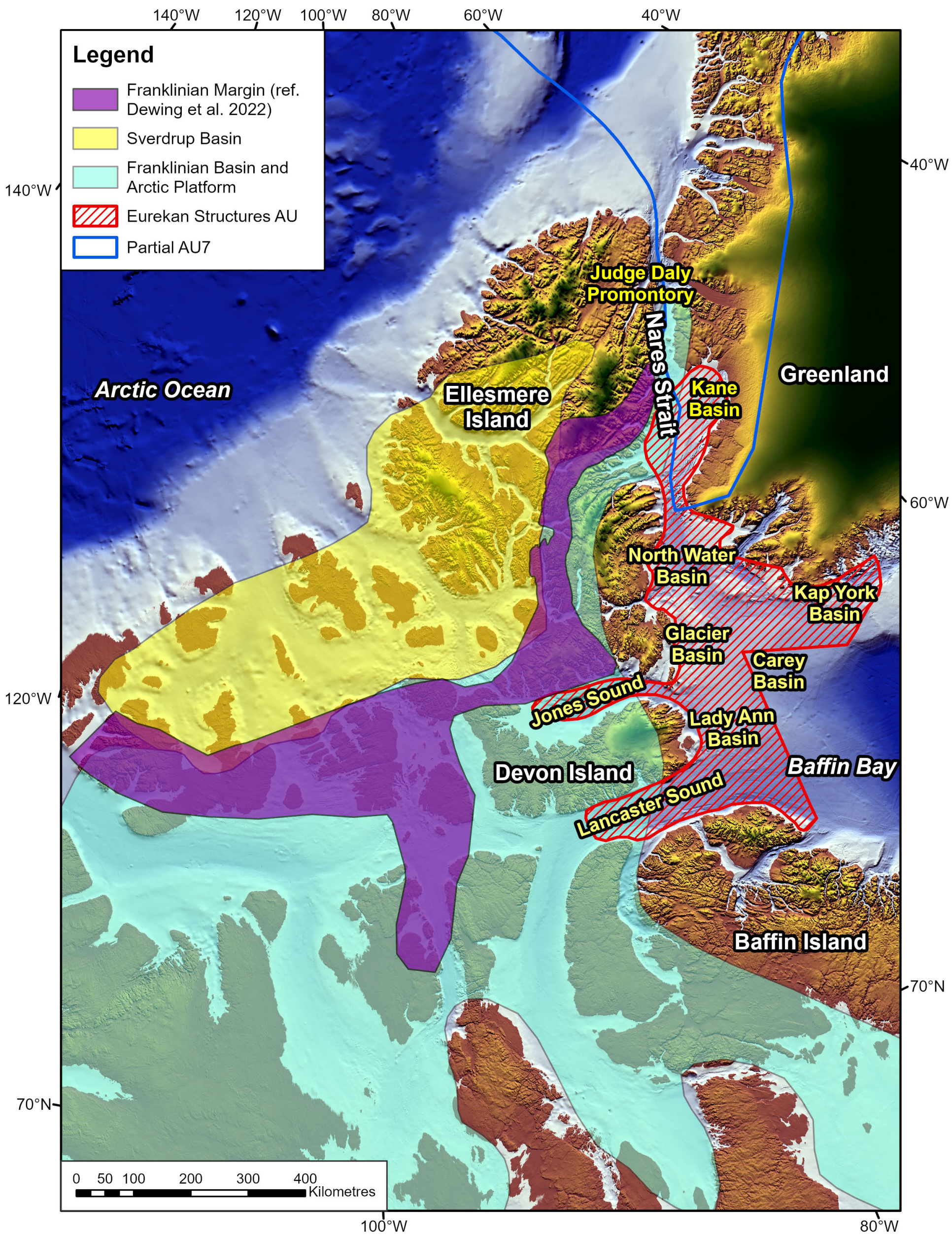
Harrison et al. (2008) conducted thermal maturity studies of Cambrian to Devonian rocks in North-east Ellesmere Island using the Conodont Colour Alteration Index (CAI) methodology. Dewing and Obermajer (2009; 2011) used Rock-Eval/TOC pyrolysis techniques to determine the amount, quality, and thermal maturity of kerogen of the Sverdrup Basin successions. The results of these analyses were used as analogues and contributed effectively to the identification of potential source rocks in the study area.

In 2001, German BGR (Bundesanstalt für Geowissenschaften und Rohstoffe) in conjunction with the GSC undertook a scientific expedition to the Nares Strait, with multi-fold marine seismic reflection data totaling 1201 km acquired as part of the expedition. The acquisition parameters were varied due to operations limitations from ice conditions in the high arctic. Data was sampled at 2–4 ms with record lengths of 6–10 ms. The resulting data were shallow and partly migrated and were not of major use in the present study due to its poor quality. Figure 1 shows Seismic data available in study area.

4. PREVIOUS RESOURCE ASSESSMENTS

Several resource assessments of varying scales have been carried out in the study area. Dewing et al. (2022) made a compilation of resource assessments of northern Canadian sedimentary basins from 1973 to 2022. The Franklinian margin outline of the report covers historical resource assessment of the study area. See Figure 3 for Franklinian margin outline where Lower Paleozoic strata of Neoproterozoic to Late Devonian are preserved. Sixty-eight boreholes intersect the lower Paleozoic succession; four wells had oil shows or discoveries, 3 had gas shows. One small oil field, at Bent Horn on Cameron Island, was discovered in a fractured Devonian reef (Dewing et al., 2022). The report concluded that petroleum systems elements that could result in hydrocarbon accumulations are Ordovician and Silurian oil-prone source rocks, carbonate reservoirs in Silurian and Devonian reef traps, and clastic reservoirs in large-scale folds. The timing of hydrocarbon generation was during Devonian over most of the area, but as young as Cretaceous near the northern contact of the Franklinian Margin with the overlying Sverdrup Basin.

In 2008, the U.S. Geological Survey (USGS) carried out an assessment of potential undiscovered conventional hydrocarbon resources of the West Greenland–East Canada Province as part of the USGS Circum-Arctic Resource Appraisal program. The study mainly assessed geological risks as technical



and economics risks were not assessed (Gautier, et al 2009). The assessed area spanned approximately 940 000 km^2 covering the offshore area between western Greenland and eastern Canada and included Baffin Bay, Davis Strait, Lancaster Sound, and Nares Strait west of, and including, part of Kane Basin. This USGS assessed area was divided into 5 Assessment units (AU) with the study area discussed in this report forming part of the Eurekan Structures AU (Fig. 3; Schenk, 2017).

Figure 3: *Previous hydrocarbon assessments outlines with surrounding basins. Eurekan Structures AU; Schenk (2017) AU7; Dam et al., (2023) Franklinian Margin Historical assessment compilation; Dewing et al., (2022).*

The Eurekan structures AU, situated mainly in Nares Strait and central Ellesmere Island, primarily covers the region characterized by enhanced compression and inversion as a result of the Eureka Orogeny in the Paleogene. The total area of the Eurekan Structures AU is about 146,000 km², and includes most of Kane Basin, Kap York Basin, Glacier Basin, North Water Basin, Lady Ann Basin, Lancaster Sound Basin, and others (Harrison, 2005). Figure 3 shows the Eurekan structures AU and associated Cretaceous – Lower Cenozoic basins located in study area.

The result of the USGS resource assessment indicated an estimated mean volume of undiscovered recoverable resources of 10.7 billion barrels of oil, 75 trillion cubic feet of gas, and 1.7 billion barrels of natural gas liquids for the West Greenland–East Canada Province (Schenk, 2017). The portion of the total assessment volume contributed by the Eurekan Structures AU is 1.1 billion barrels of oil and 8.6 trillion cubic feet of gas, which was mainly estimated using the *Structural Setting-Compressional Analog Set* of the U. S. Geological Survey analog database (Charpentier et al., 2008). This analog database is useful for assessment of undiscovered hydrocarbon resources in frontier areas. The volume is shown in Table 1. It is worth noting that these volumes are representative of the entire assessed Eurekan Structures AU area, without any reference to the Canadian-Greenland international boundary.

Table 1. *Assessment results – Eurekan Structures AU: Mesozoic–Cenozoic composite total petroleum system, modified after Schenk (2017).*

Assessment unit	AU Prob-ability	Field type	Largest ex-pected oil field size	Total undiscovered resources											
				Oil (MMBO)				Gas (BCFG)				NGL (million BNGL)			
				F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean
Eurekan Structures AU	0.25	Oil	1,086	0	0	6,626	1,133	0	0	10,490	1,784	0	0	285	48
		Gas	6,485	n/a	n/a	n/a	n/a	0	0	39,428	6,806	0	0	1,055	181

MMBO is million barrels of oil; BCFG is billion cubic feet of gas; BNGL is barrels of natural gas liquids. Undiscovered gas resources are the sum of non-associated and associated gas. F95 denotes a 95% chance of at least the volume stated in the table; other percentiles are defined similarly. AU probability describes the likelihood of at least one accumulation of minimum size within the AU.

In 2023, NUNAOIL in collaboration with the Geological Survey of Denmark and Greenland (GEUS) and the Government of Greenland published a Greenland Resource Assessment with the aim of providing an estimate of a quantitative, play-based yet-to-find potential of conventional hydrocarbons on the Greenland continental shelf. The assessment was based on pre-existing data collected by the industry, GEUS, NUNAOIL and the Greenland Government. These data were interpreted by GEUS, and other academic institutions and the results reflect the state of geologic knowledge of the offshore and onshore areas of Greenland at the time of study (Dam et al., 2023). The entire Greenland margin was divided into seven assessment units (AU), with the AU7 area (Figure 3) being most relevant to the present study. This area covers the onshore Neoproterozoic to earliest Devonian Franklinian Basin and the offshore Carboniferous to Palaeogene Lincoln Sea Basin. The study was limited to the Greenland side of the margin and the assessment concluded that there is limited exploration potential in the Franklinian Basin due to the general lack of structuring in areas with mature source rocks and wide-ranging shallow burial depths, with large parts of the succession being exposed (Dam et al., 2023). As a result, no hydrocarbon volume calculations were made in that study. A similar conclusion was reached by the USGS in their analysis of the Franklinian Shelf Province AU (Tennyson and Pitman, 2020).

5. PETROLEUM RESOURCE ESTIMATION

5.1 Qualitative resource potential methodology

The GSC methodology for qualitative petroleum potential maps is based on analyzing each of the plays that could reasonably exist in a study area (Lister et al., 2018). A petroleum exploration 'play' is a conceptual model of prospects and fields in a region that have the same petroleum system elements namely: hydrocarbon source, timing of generation, migration, reservoir development, trap configuration, and seal. The extent of four petroleum system elements for each play and the chance of success (COS) for each element is estimated.

- Source (includes source rock presence and quality; hydrocarbon generation; migration; timing relative to trap formation)
- Reservoir (presence and quality)
- Trap (presence, extent, geometry)
- Seal (includes preservation)

When determining the COS for each petroleum system element, data quality/calibre, data density, and confirmation of physical data was considered. COS maps reflect both the amount of available information and confidence in that information (Lister et al., 2018). These petroleum system elements are then combined by multiplication into a COS map for a chosen play over the whole study area. Finally, the plays are weighted by an estimated global scale factor to rank their volumetric significance and global competitiveness for offshore exploration. The weighted plays are summed, to create a regional petroleum potential map (Fig. 4).

To establish the plays present, this study began with an extensive literature review of previous studies in the area and across the West Greenland margin.

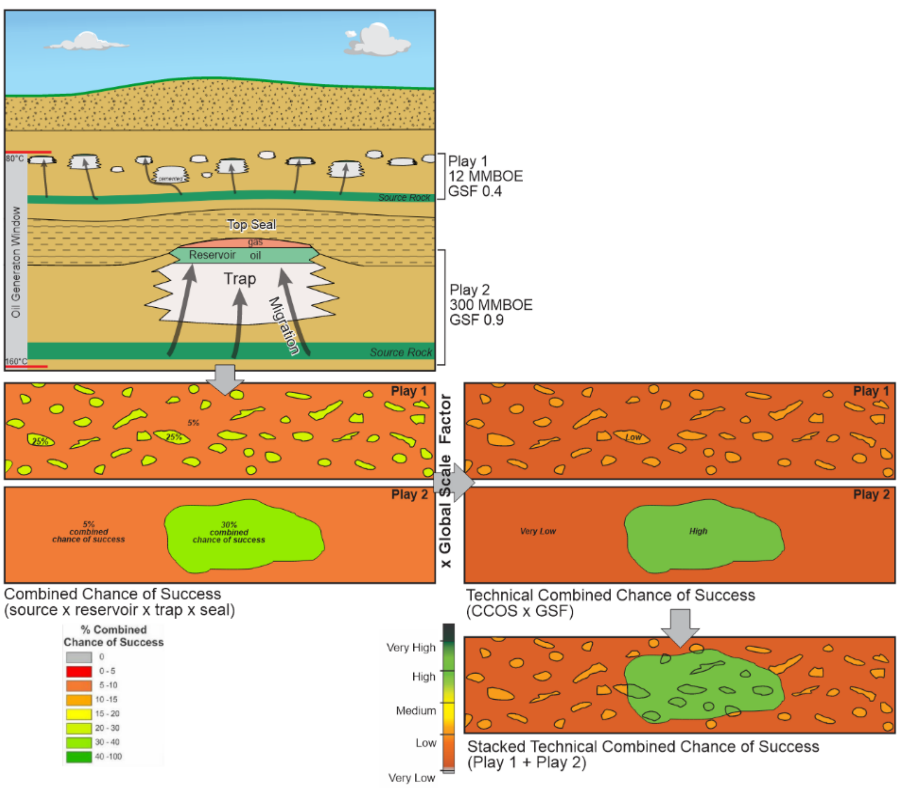


Figure 4: ***Combining plays in qualitative mapping***. *Play 1 is inherently smaller so has a lower Global Scale Factor (GSF) than Play 2. The combined chance of success for each play is multiplied by that play's GSF to produce a technical combined chance of success. Plays are then added to get a final stacked technical combined chance of success that shows the hydrocarbon potential of the area (figure from Dewing et al., 2023)*

The Canadian Geoscience Map 187 (CGM187) by St-Onge et al., (2015) shown in Figure 2a, in addition to field samples analysis reports, were used as a basis for defining the presence and extent of the petroleum elements that make up plays in the study area. The Nares Strait and central Ellesmere Island region is sparsely explored with very few, inadequate quality refraction and reflection seismic data, but geological data from extensively mapped outcrops along with interpretations of gravity and magnetic potential field from previous studies were synthesized to generate the petroleum potential maps.

5.2 Global Scale Factor calibration

A global scale factor (GSF) was applied in order to compare the plays in the study area globally. The Global Scale Factor was defined by Lister et al (2018) as 1.0 where a play has a P50 (median) chance of producing one 500 MMBOE recoverable field, and three 300 MMBOE fields. The lower end GSF of 0.1 is for plays where the largest field is less than 3 MMBOE recoverable and the sum of the four largest fields is less than 9 MMBOE recoverable; GSF of 0.2 has a largest field size of 3–6 MMBOE etc. Table 2 shows the GSF bins currently being used in GSC studies.

Table 2. *Global Scale Factor bins*.

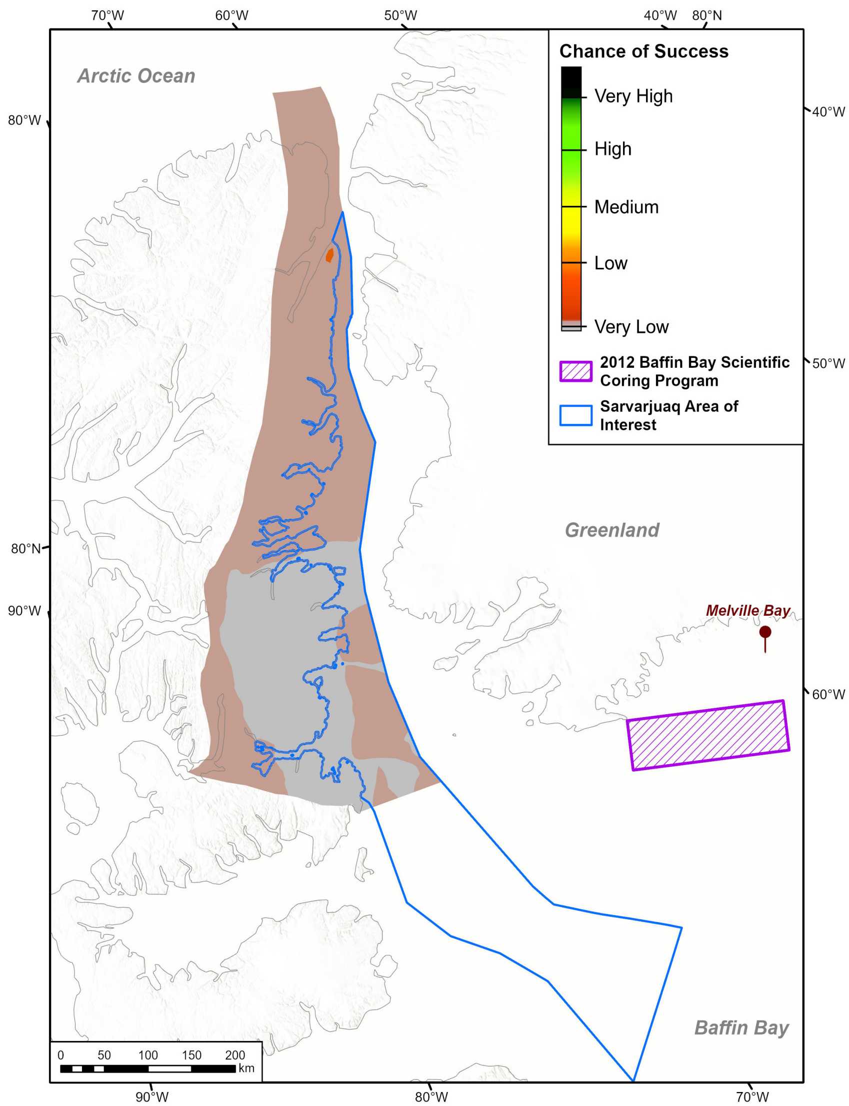
Global Scale Factor	Largest Field greater than (recoverable MMBOE)	Second to fourth largest fields average (recoverable MMBOE)	Minimum Total recoverable MMBOE in four largest fields
1.0	500	300	1400
0.9	325	175	850
0.8	200	100	500
0.7	100	50	250
0.6	50	30	140
0.5	25	15	70
0.4	12	8	36
0.3	6	4	18
0.2	3	2	9

For example, GSF of 0.2 is assigned where the largest field is 3-6 recoverable MMBOE in addition to three additional fields averaging 2 MMBOE (Dewing et al., 2023).
MMBOE - Million Barrels of Oil Equivalent

5.3 Plays / Petroleum Systems

Five plays were considered in the study area, they are the Proterozoic, Cambro-Ordovician, Silurian–Devonian, Cretaceous and Paleogene in age. Some of these plays are conceptual while the others have been tested in the region and discoveries were made.

5.3.1 Proterozoic Play



The Proterozoic Play is the oldest play in the study area. Nøhr-Hansen et al., (2021) reported that stratigraphic sections of inferred Neoproterozoic age were recovered at four out of eleven sites of the 2012 Baffin Bay Scientific Coring Program in Melville Bay northwest Greenland (See Figure 5). Analysis of cores show thick succession of cyclic hetherolithic siliciclastic redbeds and pale carbonates/dolomites deposited in low supra- to sub-tidal sabkha-like environment which was interpreted to belong to the Narssârssuk Group of Upper Thule Supergroup. In addition, very limited organic material were observed in this interval. Mean porosities range from 12% in siltstone and 9% in vuggy dolomite (Acton et al., 2012). The Thule Supergroup of Meso – Neoproterozoic age was deposited in continental to shallow-marine environments, in a rifted continental margin (Dawes, 1997).

Figure 5: *The Qualitative hydrocarbon resource map of the Proterozoic play shows very low hydrocarbon potential due to the factors described above. Grey area is the outcropped Precambrian basement rock.*

The main risk associated with this play is source as no source rock has been mapped for this play and any potential source rocks have a high chance of being overmature due to the age of the rocks.
Potential reservoirs are sandstones of the Lower Thule Supergroup. The hetherolithic silisiclastic redbeds and dolomites of the Narssarssuk Group which have extremely low porosity as reported above

by Acton et al., (2012) due to heavy cementation observed in the cores, are resrticted to the Melville Bay in the south eastern margin (Dawes, 1997). Seals are the shale and basaltic volcanic rocks of the lower Thule Supergroup while traps are mainly the fault bounded blocks associated with the rift.

5.3.2 Cambro-Ordovician Play

The second oldest play is the Cambro-Ordovician Play that is expected to be widespread across the study area as Ordovician rocks have been observed from Ellesmere Island to Melville Bay in northwest Greenland (Gregersen et al., 2019). The main risks associated with this play is the timing of structural trap formation and seals. The Ellesmerian Orogeny, the main trap forming event, occurred at a much later time, likely after hydrocarbon migration had occurred. In addition, seals may have been breached potentially during the uplifts associated with the Ellesmerian Orogeny. This could cause remigration of already trapped hydrocarbons.

Source Rock: One of the potential source rocks for this play is the Hazen Formation, which is the basinal equivalent of many platform carbonates on the shelf. It is a thick succession of silisiclastic sediments that were deposited through the Cambrian and Ordovician. The black shales of the Hazen Formation in areas where they have been exposed as outcrops is described to be organic poor both due to its older age and deposition in a deep basin (Dewing et al., 2008).

The other potential source rock for this play is kukersite source beds which have been described from the Ordovician Thumb Mountain Formation regionally, though these source beds have not been observed in any outcrops in the study area.

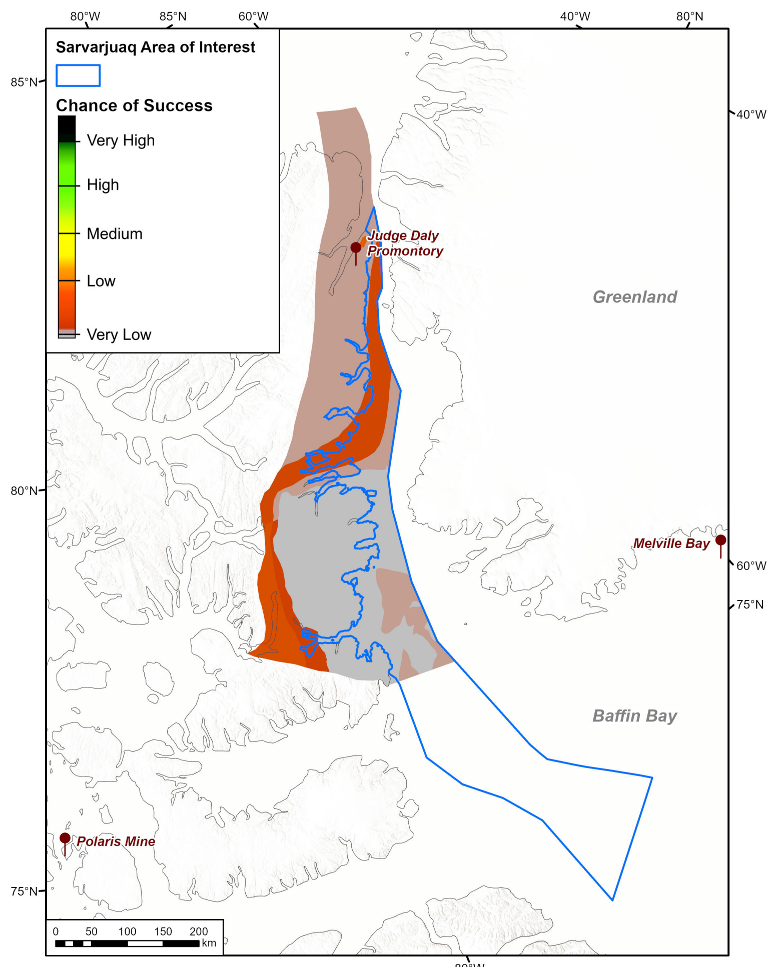


Figure 6: *The Qualitative hydrocarbon resource map of the Cambro-Ordovician play shows very low hydrocarbon potential due to the factors described above. Grey area is the outcropped Precambrian basement rock.*

Kukersites with Type I kerogen, TOC content as high as 17.7% and HI of 717 mg HC/g, indicative of an excellent, early matured type I source rock is described from middle Cambrian strata (Pre- Cass

Fiord unit) on southern Ellesmere Island (Mayr et al., 1994). These source beds are known to be relatively thin and prolific, often generating a huge volume of hydrocarbon compared to its thickness. A typical example of this type of source rock is a 1–3 m thick organic-rich bed in the Thumb Mountain Formation at Polaris Mine with TOC that varies between 2 and 10 wt% and HI of 590 to 825 mg HC/g TOC (Obermajer et al., 2007; Reid et al., 2013a). See Figure 6 for Polaris Mine location.

Reservoirs: There is an abundance of potential reservoirs represented in this play. They are mainly the platform margin carbonates of the Cass Fjord, Cape Clay, Eleanor River, Bay Fiord and Thumb Mountain formations. These formations are widespread across Ellesmere Island. 10-15% vuggy porosity was recorded in Cape Clay formation (Dewing et al., 2008). This porosity might be sufficient for gas production but low for oil production.

Traps / Seals: Anhydrite layers of Baumann Fiord with thickness ranging from 80 m to 335 m in northeast Ellesmere Island and Bay Fiord formations with thickness ranging from 180 m – 230 m have been identified as potential seals for this play. However, these formations thin or disappear towards the northern part of the study area on Judge Daly Promontory (Dewing et al., 2008)

Other potential seals are the intraformational shales and tight carbonates of the potential reservoirs mentioned above.

Traps are expected to be mainly small offset faults and structural folds formed during the Ellesmerian Orogeny. There is also potential for stratigraphic traps such as pinch-out traps in areas where shallow marine facies such as Thumb Mountain, Cass Fjord, Bay Fiord units change into basinal facies of Hazen Formation (Dewing et al., 2008). The Cenozoic Eurekan Orogeny may have impacted earlier formed traps while creating new ones thus causing a loss of hydrocarbons trapped in earlier traps.

5.3.3 Silurian-Devonian Play

Evidence of a working petroleum system was observed in mid-Devonian carbonates (Blue Fiord Formation) in the Bent Horn Field on Cameron Island in the western Arctic, see Figure 7. The field was discovered in 1974, and the West Bent Horn A-02 well sustained commercial production, with total production between 1985 and 1993 reaching 2.02 million barrels. The hydrocarbon resources are believed to have been sourced by the Cape Phillips Formation (Obermajer et al., 2010). In addition, spectacular exposures of major Silurian carbonate build ups and patch reefs, some now containing migrated hydrocarbons, have been observed on islands in Nares Strait and in western Washington Land, Greenland (Higgins et al., 1991).

Source Rocks: Two major organic-rich source rocks were identified in this Lower Paleozoic succession from the study area. They are the Cape Phillips and lower Eids formations, of Silurian and Mid-Devonian age respectively (Mayr et al., 1994). The Cape Phillips Formation is 100 m of black shale while the lower Eids Formation is 90–125 m of black shale and siltstone, deposited in an oxygen-poor setting (Dewing et al., 2008). TOC of samples obtained from Blue Fiord E-46 and Eids M-66 wells (See Figure 7) drilled on southern Bjorne Peninsula range between 1.42 wt.% to a maximum of 7.75 wt.%. The source rocks are described to be of Type II kerogen and in the mid-mature to early postmature stages of oil generation (Mayr et al., 1994)., Conodont Alteration index (CAI) values are between three and four for the Cape Phillips Formation samples obtained onshore of the study area while that of the only location of Eids Formation within the study area sampled is five. These results indicate that the two source rocks are within the thermally overmature geological domain to the west and north of the study area but have the potential to be within the mature window in the offshore area as shown in the trend of thermal maturity by Harrison et al. (2008) using CAI data (see Appendix). The age equivalent of the Cape Phillips Formation in northwest Greenland is the Wulff Land Formation of late Llandovery age (Dewing et al., 2008). A large, exhumed bitumen-impregnated Silurian reef in Greenland indicates that this petroleum system was successful (Stemmerik et al., 1997).

Reservoirs: The main reservoirs for this play are Allen Bay, Blue Fiord, Danish River, and Bird Fiord Formations. These reservoirs are bioherms (Allen Bay and Blue Fiord formations) which are expected to be sizable for this play (Rayer, 1981), and flysch deposits (Danish River, Bird Fiord formations) in Nares Strait (Harrison et al., 2006). These flysch deposits were transported into the basin as a result of the northeast Greenland Caledonian Orogeny.

Traps / Seals: Identified seals for this play include the widespread shales of Eids and Cape de Bray formations. Traps are mainly folds formed during the Late Devonian Ellesmerian orogeny. The timing of hydrocarbon generation was during Devonian over most of the area (Dewing et al., 2022) therefore timing of trap formation poses a major risk for this play. The timing of trap formation versus hydrocarbon generation and migration plays a key role in hydrocarbon retention. If generation and migration predate trap formation, then a significant proportion of hydrocarbons generated will be lost.

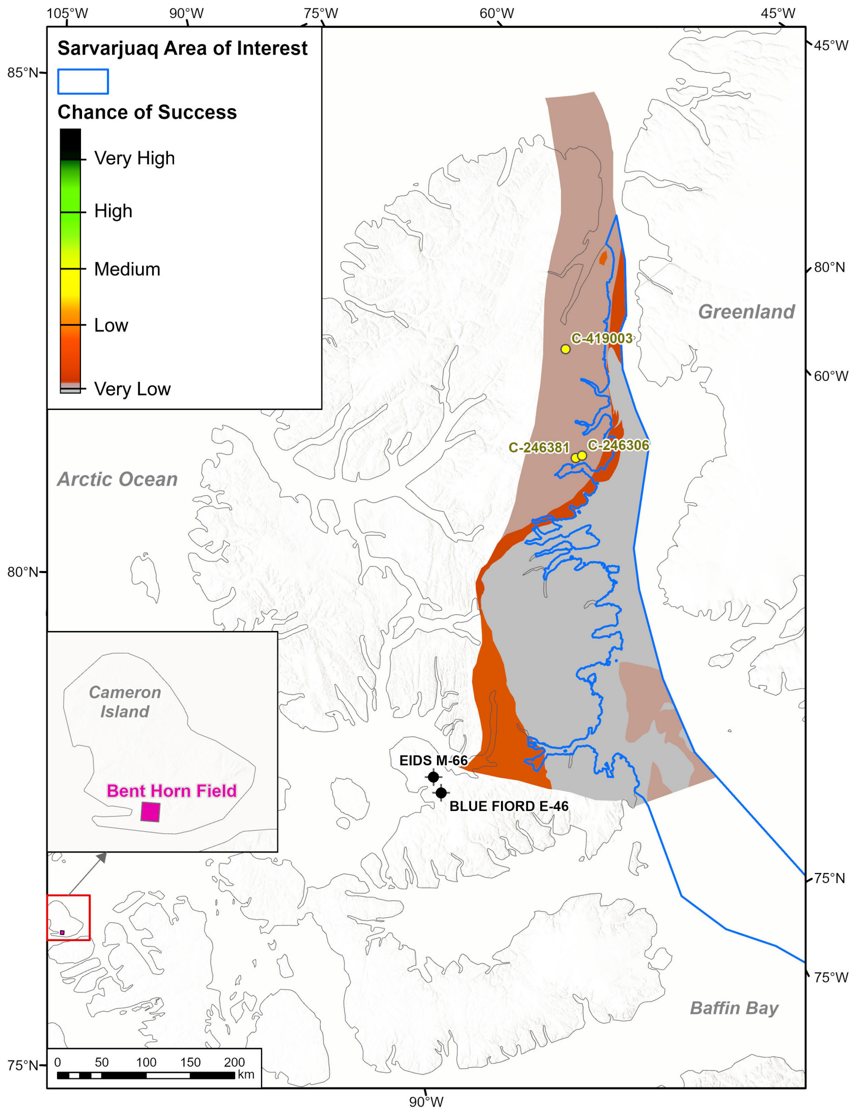
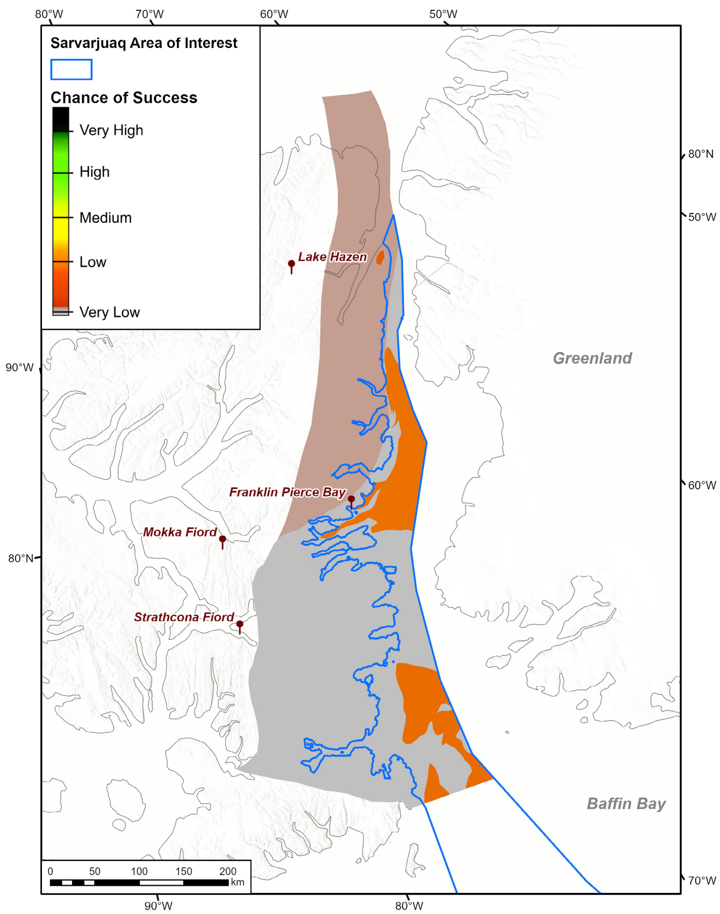


Figure 7: *The Qualitative hydrocarbon resource map of the Silurian-Devonian play shows very low hydrocarbon potential due to the factors described above. Grey area is the outcropped Precambrian basement rock.*

Seal breach is another major risk for this play, this is because of the play's proximity to the late Devonian Ellesmere Orogeny, making faults in the region active and acting as conduits for hydrocarbon migration thus affecting their sealing capabilities and hydrocarbon retention.

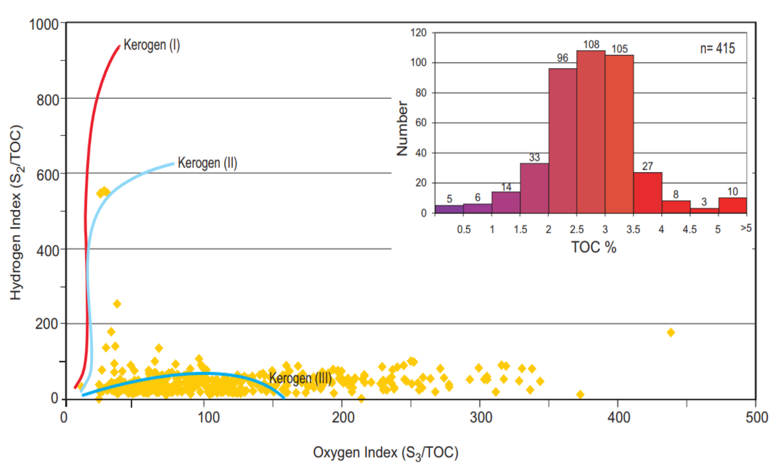
5.3.5 Cretaceous Play

Cretaceous and younger sediments are preserved in small outliers and observed in few locations of the study area (Lee et al., 2008) See Figure 8 for outcrop locations. The major risk associated with this play is hydrocarbon charge, based on Cretaceous source rock maturity.



Source Rocks: The main source rock for this play is the Christopher Formation. In the study area, only one exposure in Franklin Pierce Bay was observed, the thickness is unknown but was estimated to not exceed few tens of metres (Lee et al., 2008). Rockeval analysis carried out on this source rock indicates a type III kerogen, with TOC 2.5-3.0 wt% and very low Hydrogen Index (HI), see Figure 9. Other potential source rocks are the coal of the Isachsen Formation. There are at least two exposures of this formation in the study area. The Isachsen is made up of sandstone and coals, with the coals making up to 50% of visible rock in most areas (Lee et al., 2008). Rock eval analysis by Obermajer et al., (2007) indicates a type III kerogen with TOC of 2-3.0 wt% and average HI of 100

Figure 8: *The Qualitative hydrocarbon resource map of the Cretaceous play shows low hydrocarbon potential due to the factors described above. Grey area is the outcropped Precambrian basement rock.*



Thermal maturity is likely low over much of the study area, due to a lack of subsequent burial, although there is potential for biogenic gas from organic-rich units in low maturity areas.

Reservoirs: This play is supported by sandstones with good reservoir qualities, in particular the Lower Cretaceous Isachsen and Hassel formations. These units host hydrocarbons in the main part of the Sverdrup Basin.

Figure 9: *Rock-Eval analysis of Lower Cretaceous Christopher succession (Obermajer et al., 2007).*

Traps/Seals: Seals are expected to be the overlying Kanguk Formation and intraformational shales within the reservoirs, although seal poses a risk in this play due to the expected patchy presence of the Cretaceous aged formations (Lee et al., 2008). The hydrocarbon of this play is expected to be trapped in mainly small offset faults, and folds.

5.3.6 Paleogene Play

This is the youngest conceptual play in the study area, but there are no discoveries yet along the northeastern Canadian margin. The Cenozoic strata are preserved in seven outliers along the coast of northeastern Ellesmere Island, see Figure 10 for locations. In the study area, the Eureka Sound Group of the Cenozoic strata comprises of mainly the sandy units of Pavy, Cape Lawrence and Cape Back formations. (Lee et al., 2008) The major risk associated with this play is seal due to the amount of sand present in the play.

Source Rocks: The major source rock associated with this play is the Kanguk Formation, a well known and widespread, Late Cretaceous type II kerogen black shale in Sverdrup Basin with only two known exposures in the study area: Allman Bay as described by Lee at al., (2008), and Cape Lawrence (de Freitas and Sweet, 1998). See Figure 11 for Rockeval analysis. The main risk associated with this source rock in the study area is thermal maturity as it may not have been sufficiently buried to generate hydrocarbon. Paleogene reservoirs could possibly be charged by older source rocks they are in contact with, as in the case of Pavy Formation which uncorformably overlie the Mid Devonian Eids Formation source rock.

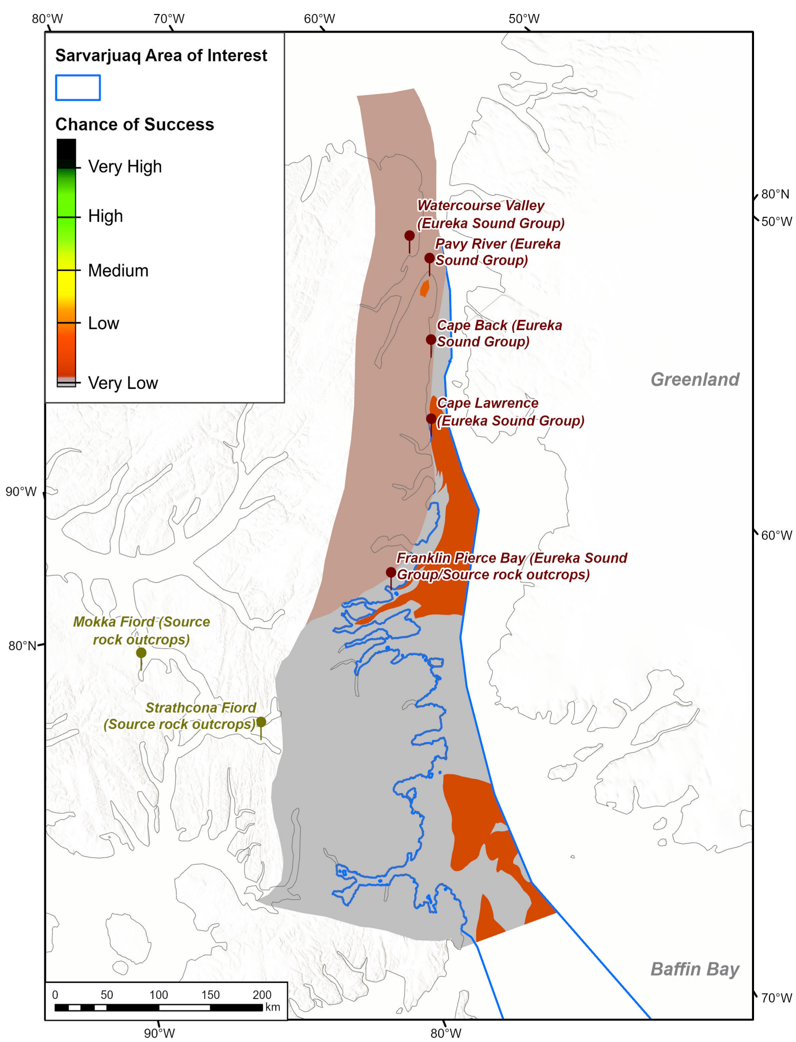


Figure 10: *The Qualitative hydrocarbon resource map of the Paleogene play shows very low hydrocarbon potential due to the factors described above. Grey area is the outcropped Precambrian basement rock.*

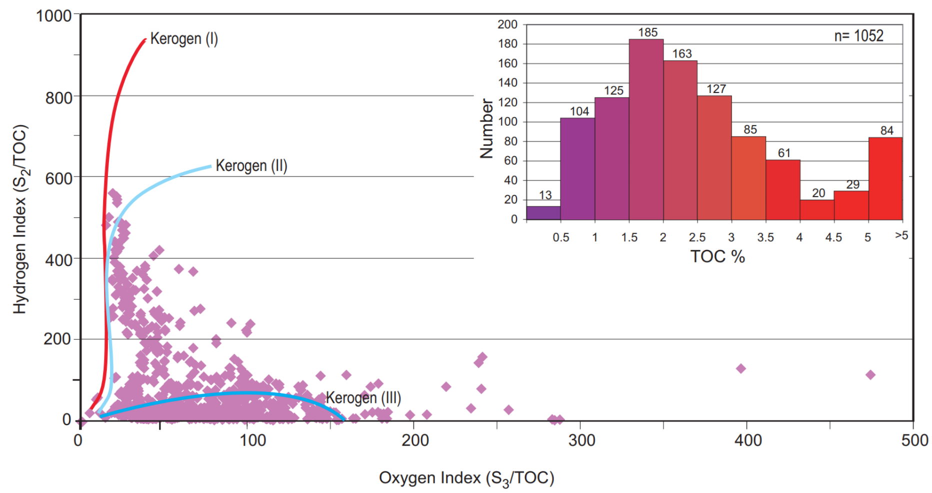


Figure 11: *Rock-Eval analysis of Early Cretaceous Kanguk succession (Obermajer et al., 2007).*

Reservoirs: As mentioned, there is an abundance of potential reservoirs in this play due to the Eurekan Sound Group being mainly sandy. Lee et al., (2008) described the Pavy Formation with thickness more than 700 m as the most widespread in the study area. It consists mainly of sandstone with interbeds of siltstone and mudrock, all interpreted to be of fluvial origin. The Cape Back Formation with thickness more than 1300 m was divided into two members and described as a lower member of siltstone, mudstone and minor coals while the upper member consists of calcareous sandstone and minor conglomerate. The third unit named Cape Lawrence Formation with thickness up to 1000 m was described by Lee at al., (2008) as consisting of mainly conglomerates deposited as alluvial fans.

Traps/Seals: Seals poses a major risk for this play as there is no mapped regional top seal and the play would have to rely on intraformational shales of the Eurekan Sound Group to preserve hydrocarbons. Mainly structural traps formed during the Eurekan Orogeny are expected to be present in this play.

5.4 Qualitative resource potential map

Chance of Success (COS) was defined for each element of the petroleum system (See Table in Appendix) based on all the available data as described in the methodology section and rolled up into a technical combined chance of success (TCCOS) at play level. Table 3 shows the resulting qualitative hydrocarbon potential. All qualitative hydrocarbon resource potential maps shown in this report display part of the High Arctic basins petroleum potential resource assessment carried out by Lister et al., (2022). This portion is shown in Figure 1.

The TCCOS range for all the plays in the study area are mainly in the “unlikely” spectrum of GSC Chance of Success (COS) Scale (See Figure 12).

Figure 13 shows the stacked technical combined chance of success (STCCOS) of all the six plays described in this report.

Table 3. *Chance of success (COS) per play.*

Play	**Hydrocarbon Potential**
Paleogene	Very low
Cretaceous	Low
Silurian – Devonian	Very low
Cambrian- Ordovician	Very low
Proterozoic	Very low

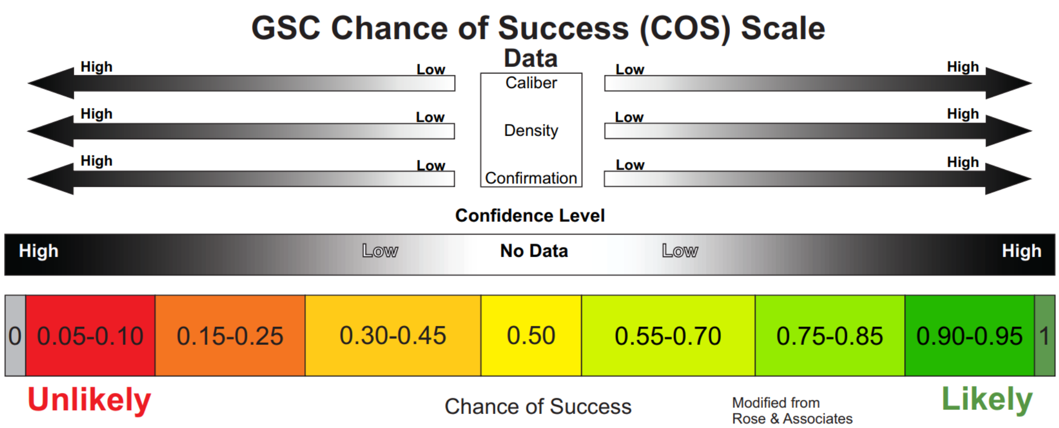


Figure 12: *GSC Chance of Success (COS) Scale*

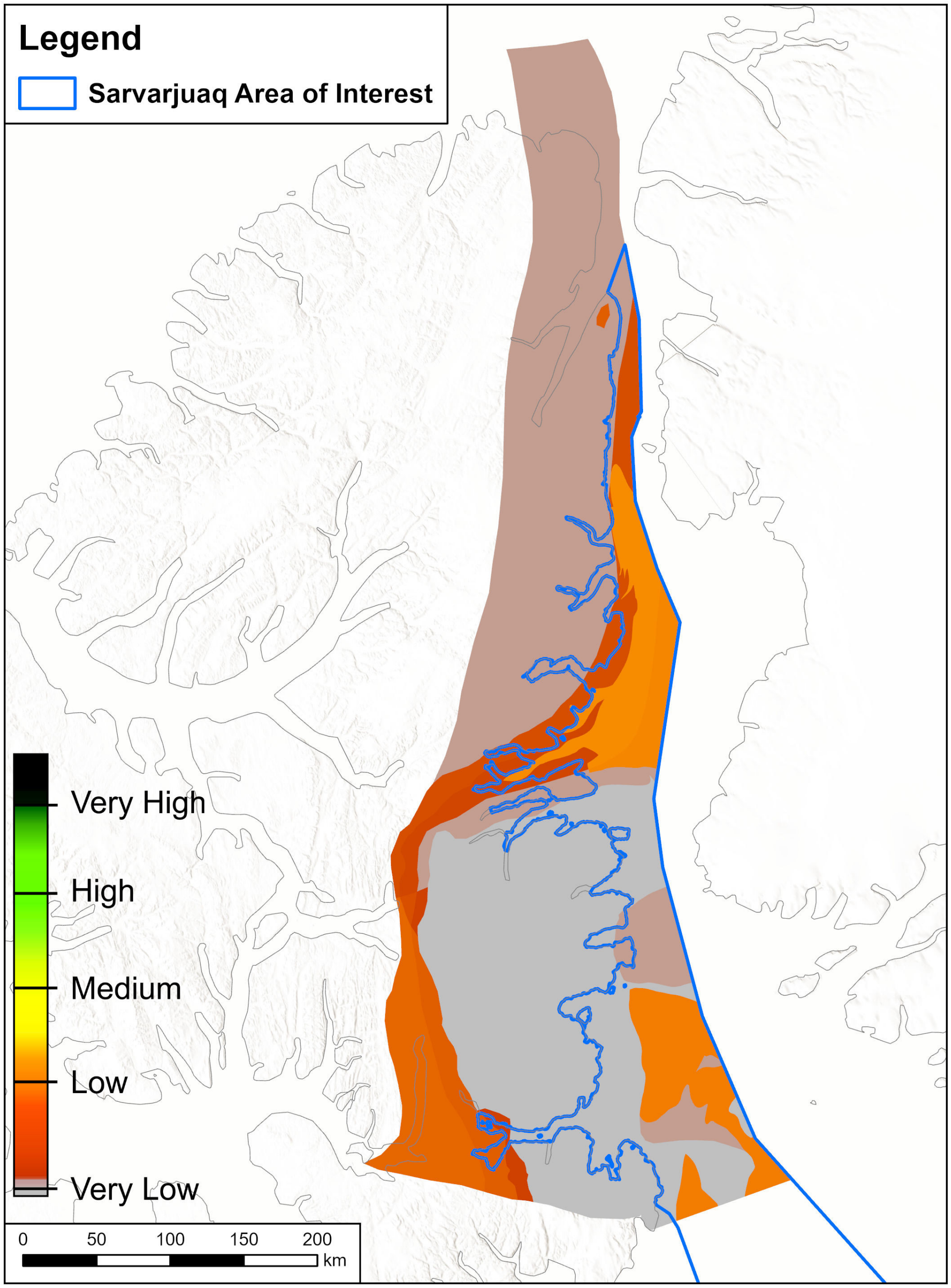


Figure 13: *Qualitative hydrocarbon potential map.*
Map showing stacked technical combined chance of success (STCCOS) of all five potential plays in study area. Grey area is the outcropped Precambrian basement rock.

6. CONCLUSIONS

The assessment of the study area produced qualitative hydrocarbon potential maps which indicate that the area has low hydrocarbon potential. Five potential plays were identified but the Cretaceous Play has the highest technical chance of success, though it is not widespread in the study area as it is only preserved in outliers of mapped outcrops. Source rock quality and maturity in addition to seal are other uncertainties associated with this play. The lower Paleozoic plays are potentially overmature while the younger Paleogene play is potentially immature. The Proterozoic Play have the lowest technical chance of success due to the age.

The results published in this report were obtained by synthesizing all the available data at the time of the study, thus the low hydrocarbon potential conclusion may improve if more data becomes available for the study area which is currently underexplored.

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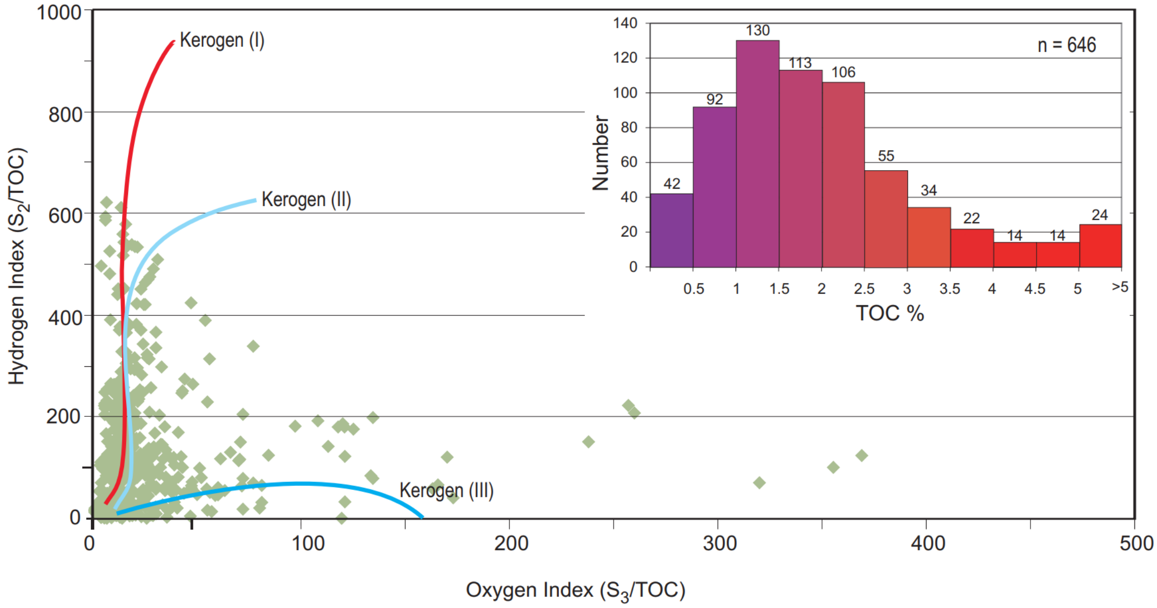
APPENDICES

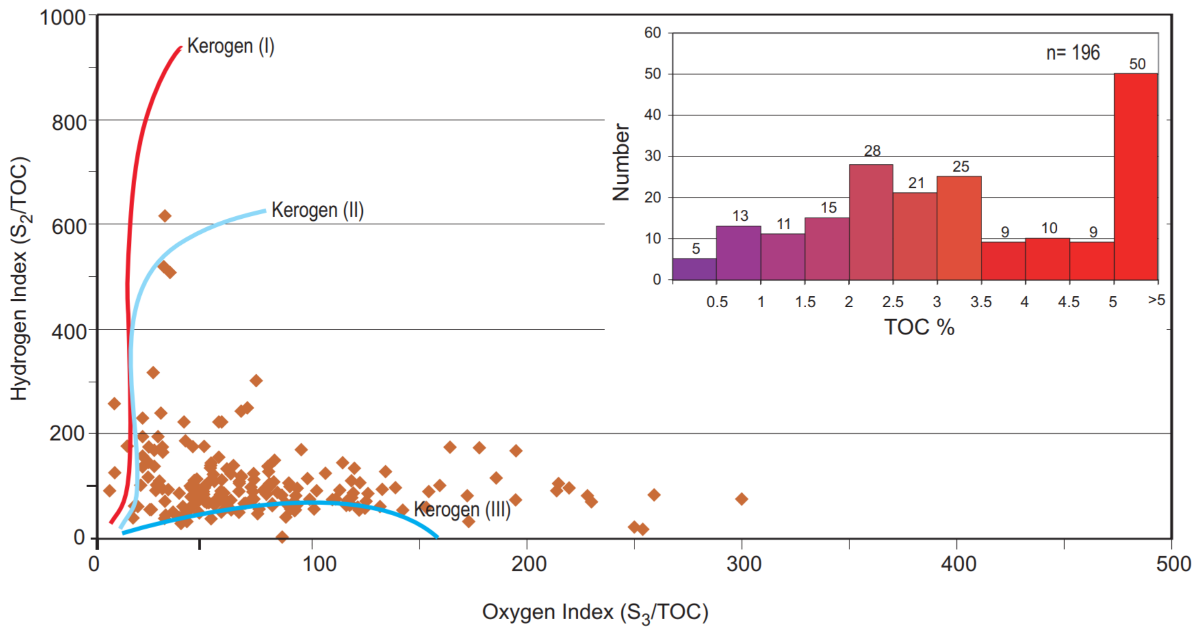
Table: Nares Strait/Central Ellesmere study area petroleum potential chance of success summary

Nares Strait/Central Ellesmere study area petroleum potential chance of success summary							
Age (Ma)	**Play**	**Source**	**Reservoir**	**Trap**	**Seal**	**Highest uncertainty**	**Global Scale factor (0-1)**
61	Paleogene	Christopher, Kanguk	Clastics (Eurekan sound group)	Stratigraphic / small offset faults, folds	Intraformational Shales of Pavy Fm, Cape Back	Seal	0.50
120	Cretaceous	Christopher, Coals of Isachsen	Isachsen, Hassel	Structural (small offset faults, folds)	Shale (Christopher, Kanguk)	Source quality	0.50
435	Silurian - Devonian?	Cape Phillips, Eids, Ibbet Bay?	Carbonates, Clastics (Allen Bay, Danish River, Barrow inlet, Blue Fiords)	Stratigraphic / Structural small offset faults, folds	Shales (Eids, Cape de Bray	Timing of trap formation / Seal	0.40
458	Cambro-Ordovician	Hazen, Kukersite	Carbonates (Cass Fjord, Cape clay, Eleanor River and Thumb Mountain	Stratigraphic / Structural folds	Tight Carbonates, Shales, salt (Baumann Fiord Formation, Bay Fiord, Irene Bay Formation, Cape Phillips	Timing of trap formation	0.40
999	Proterozoic structural	Smith Sound, Nares Strait groups	Clastics of Smith Sound, Nares Strait and Baffin Bay groups	Fault bounded blocks	Shales and basaltic volcanic rocks of the lower Thule Supergroup	Source / Preservation	0.50
Presence and Quality		High	Med	Low			

Rock-Eval analysis of Silurian Basinal succession (Obermajer et al., 2007)



Rock-Eval analysis of Early Cretaceous Isachsen succession (Obermajer et al., 2007)



Conodont Alteration Index (CAI) data showing thermal maturity trend of Northeastern Ellesmere Island (Harrison et al., 2008)