Baffin Bay Elusive Plays: Geological Surprises of an Arctic Exploration Campaign*

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Abstract

Early regional evaluation of the frontier Baffin Bay acreage, offshore NW Greenland, identified a tilted fault block play in rifted Melville Bay and Kivioq basins, assuming reservoir-prone pre-rift lithology, charged by Cretaceous syn-rift source rocks. The exploration program started with a shallow coring of near-seabed inverted stratigraphy, aiming to reduce stratigraphic uncertainty and its impact on petroleum systems. The cores confirmed significant thickness of Cretaceous terrestrial and marine source rocks, but showed that pre-rift sequence is most likely of Precambrian age and devoid of reservoir rocks. The core changed the entire regional evaluation and proved the majority of the leads identified pre-bid were no longer viable. The focus shifted to the post-rift succession, above the basal Tertiary break-up unconformity. A newly acquired 3D seismic survey revealed a large Paleogene turbidite fan system sourced from the uplifted hinterland. The initial subtle traps were defined by lateral and updip stratigraphic pinchouts, aided by differential compaction. An inversion event, associated development of several regional unconformities, post-dates the deposition of presumed Paleogene reservoirs and indicates a switch to a compressional tectonic regime, which locally created new structural traps. Further seismic reprocessing suggested Mesozoic reservoirs may co-exist alongside the Proterozoic in the pre-rift structural closures. Nevertheless, the portfolio is dominated by sizeable, but risky Paleogene stratigraphic and combined traps. The lack of calibration, especially in the Tertiary section, made it essential to utilize loop-level seismic interpretation to de-risk reservoir interpretation, define/de-risk subtle traps, and improve volumetric definition. Due to large age uncertainty of the Tertiary stratigraphy, as wells as timing of the hydrocarbon expulsion and trap forming events, a scenario-approach was used to define the range of possible charge realizations. The basin modeling results, supported by local presence of shallow seismic hydrocarbon indicators, suggest the charge in the basin is likely, which, however, contrasts with the fact that AVO anomalies in the prospective intervals are sparse, and inconclusive. The Baffin Bay remains an intriguing exploration frontier, but further risk reduction will require a well to prove not only a working petroleum system, but also significant hydrocarbon volumes to justify a challenging development.

Baffin Bay elusive plays geological surprises of an Arctic exploration campaign

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Acknowledgements

JV Partners

Statoil

GDF SUEZ

NUNAOIL A/S

Additional members of shallow coring consortium

GEUS

Cairn

ConocoPhillips

INEOS DeNoS

MAERSK OIL

Definitions & cautionary note

Reserves: Our use of the term "reserves" in this presentation means SEC proved oil and gas reserves.
Resources: Our use of the term "resources" in this presentation includes quantities of oil and gas not yet classified as SEC proved oil and gas reserves. Resources are consistent with the Society of Petroleum Engineers (SPE) 2P + 2C definitions.
Discovered and prospective resources: Our use of the term "discovered and prospective resources" are consistent with SPE 2P + 2C + 2U definitions.
Organic: Our use of the term Organic includes SEC proved oil and gas reserves excluding changes resulting from acquisitions, divestments and year-average pricing impact.
Shales: Our use of the term 'shales' refers to tight, shale and coal bed methane oil and gas acreage.
Underlying operating cost is defined as operating cost less identified items. A reconciliation can be found in the quarterly results announcement.

The companies in which Royal Dutch Shell plc directly and indirectly owns investments are separate legal entities. In this presentation "Shell", "Shell group" and "Royal Dutch Shell" are sometimes used for convenience where references are made to Royal Dutch Shell plc and its subsidiaries in general. Likewise, the words "we", "us" and "our" are also used to refer to subsidiaries in general or to those who work for them. These expressions are also used where no useful purpose is served by identifying the particular company or companies. ''Subsidiaries'', "Shell subsidiaries" and "Shell companies" as used in this presentation refer to companies over which Royal Dutch Shell plc either directly or indirectly has control. Entities and unincorporated arrangements over which Shell has joint control are generally referred to as "joint ventures" and "joint operations" respectively. Entities over which Shell has significant influence but neither control nor joint control are referred to as "associates". The term "Shell interest" is used for convenience to indicate the direct and/ or indirect ownership interest held by Shell in a venture, partnership or company, after exclusion of all third-party interest.
This presentation contains forward-looking statements concerning the financial condition, results of operations and businesses of Royal Dutch Shell. All statements other than statements of historical fact are, or may be deemed to be, forward-looking statements. Forward-looking statements are statements of future expectations that are based on management's current expectations and assumptions and involve known and unknown risks and uncertainties that could cause actual results, performance or events to differ materially from those expressed or implied in these statements. Forward-looking statements include, among other things, statements concerning the potential exposure of Royal Dutch Shell to market risks and statements expressing management's expectations, beliefs, estimates, forecasts, projections and assumptions. These forward-looking statements are identified by their use of terms and phrases such as ''anticipate'', ''believe'', ''could'', ''estimate'', ''expect'', ''goals'', ''intend'', ''may'', ''objectives'', ''outlook'', ''plan'', ''probably'', ''project'', ''risks'', "schedule", ''seek'', ''should'', ''target'', ''will'' and similar terms and phrases. There are a number of factors that could affect the future operations of Royal Dutch Shell and could cause those results to differ materially from those expressed in the forward-looking statements included in this presentation, including (without limitation): (a) price fluctuations in crude oil and natural gas; (b) changes in demand for Shell's products; (c) currency fluctuations; (d) drilling and production results; (e) reserves estimates; (f) loss of market share and industry competition; (g) environmental and physical risks; (h) risks associated with the identification of suitable potential acquisition properties and targets, and successful negotiation and completion of such transactions; (i) the risk of doing business in developing countries and countries subject to international sanctions; (j) legislative, fiscal and regulatory developments including regulatory measures addressing climate change; (k) economic and financial market conditions in various countries and regions; (l) political risks, including the risks of expropriation and renegotiation of the terms of contracts with governmental entities, delays or advancements in the approval of projects and delays in the reimbursement for shared costs; and (m) changes in trading conditions. No assurance is provided that future dividend payments will match or exceed previous dividend payments. All forward-looking statements contained in this presentation are expressly qualified in their entirety by the cautionary statements contained or referred to in this section. Readers should not place undue reliance on forward-looking statements. Additional risk factors that may affect future results are contained in Royal Dutch Shell's Form 20-F for the year ended December 31, 2016 (available at www.shell.com/ investor and www.sec.gov). These risk factors also expressly qualify all forward-looking statements contained in this presentation and should be considered by the reader. Each forward-looking statement speaks only as of the date of this presentation. Neither Royal Dutch Shell plc nor any of its subsidiaries undertake any obligation to publicly update or revise any forward-looking statement as a result of new information, future events or other information. In light of these risks, results could differ materially from those stated, implied or inferred from the forward-looking statements contained in this presentation.
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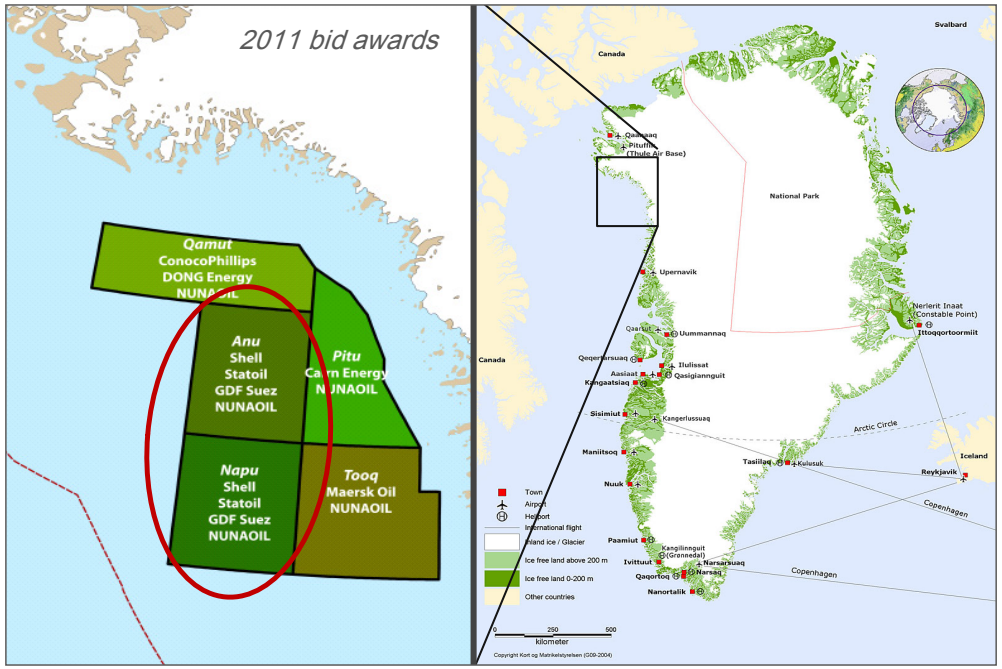
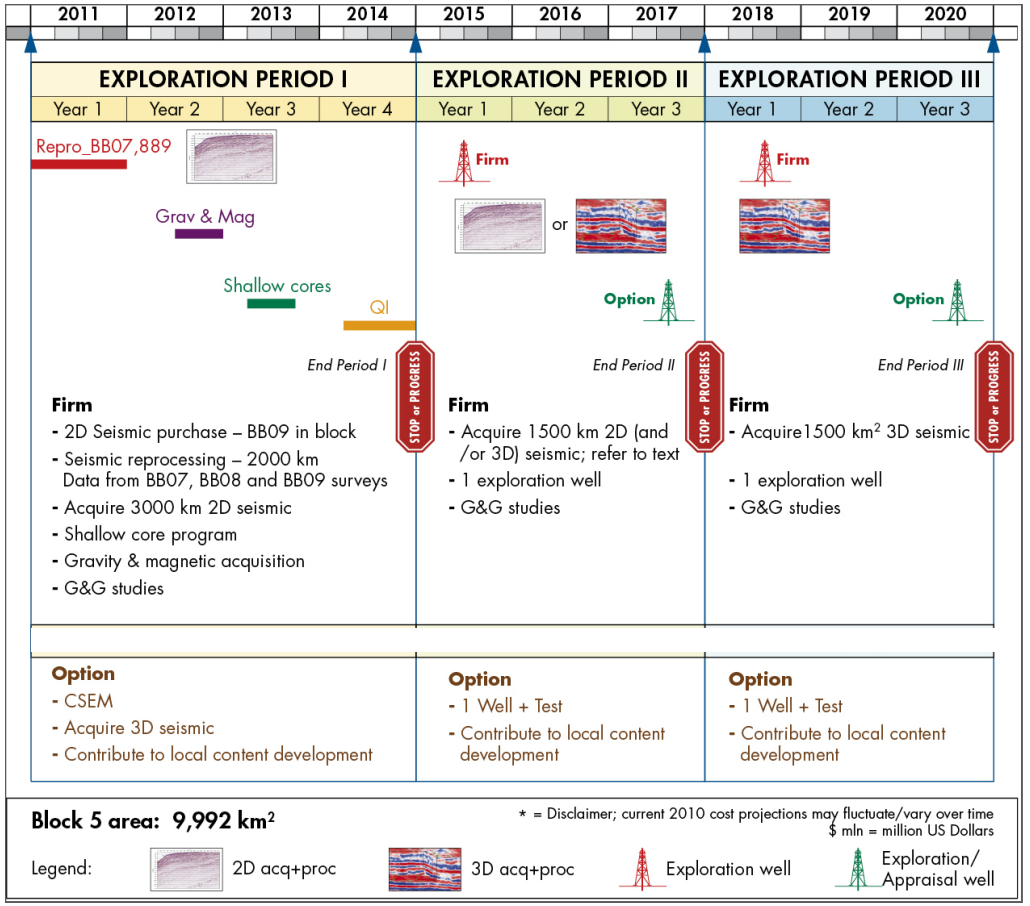
Outline

- Summary of the exploration campaign
- Prior regional knowledge: what motivated us to explore in Baffin Bay?
- Uncertainties of an uncalibrated basin analysis
- Surprises of shallow coring
- Play and trap re-definition by an early regional 3D seismic survey
- Petroleum systems modelling: range of possible outcomes
- Amplitude anomalies
- Next steps?

Exploration campaign summary

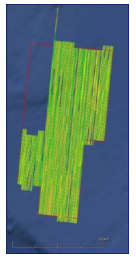
- Blocks awarded in 2011
- JV partners left in 2014
- Shell stayed for 2nd period

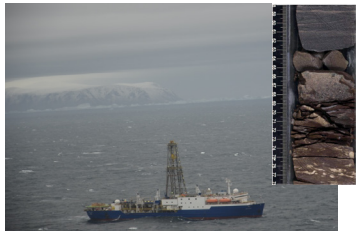




2011 Geohazard Site Survey Operations for Shallow coring Sites

2012 3D Sparse Seismic Acquisition (7,194 sq km area)

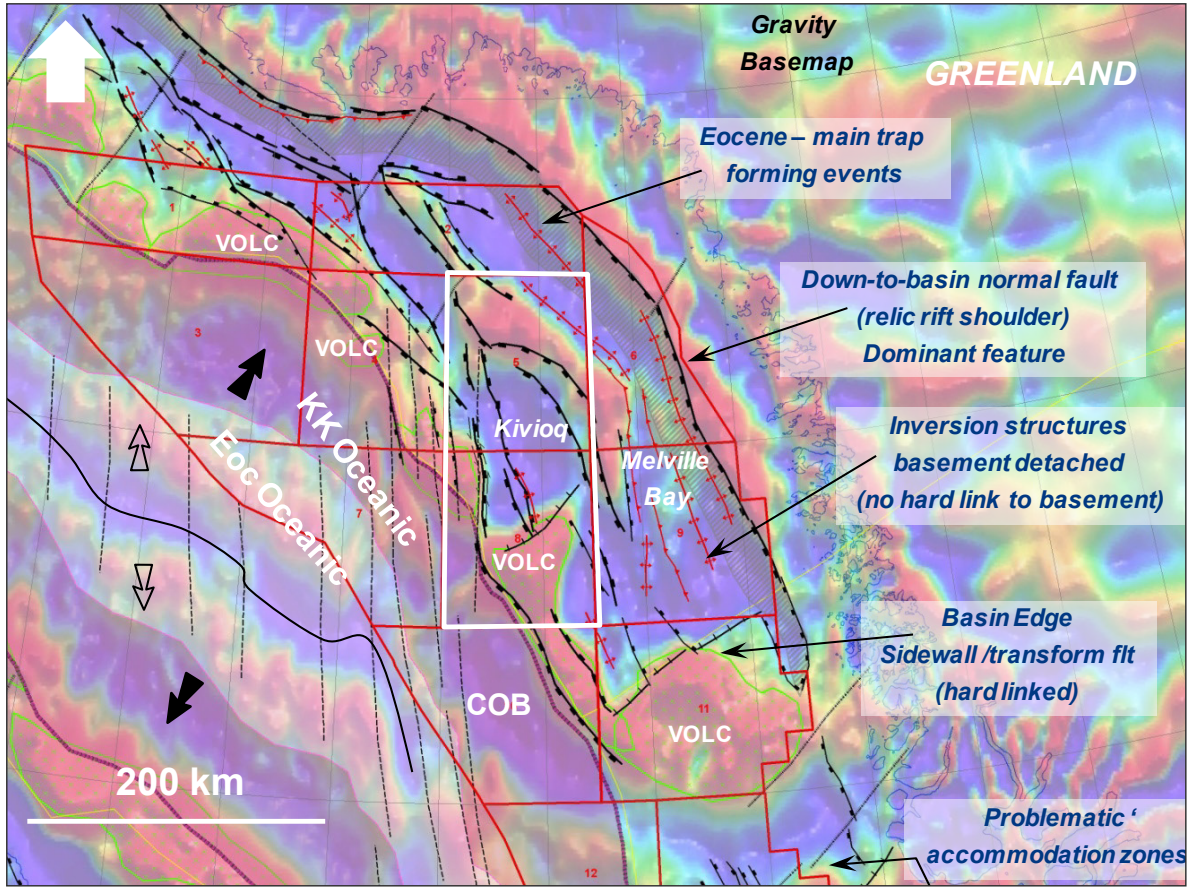




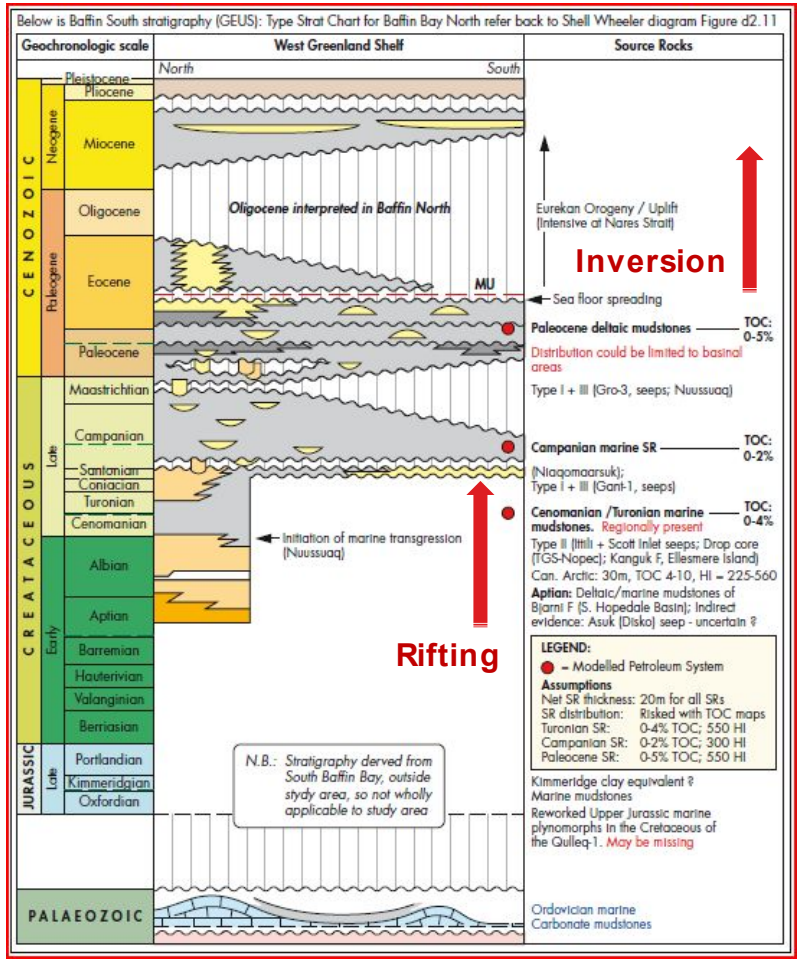
2012 Shallow coring (Leading 8 company consortium) 14 drill sites / 2 Km cored

Early promise: Rift basins and fault bounded highs

- Uncalibrated Cretaceous rift basins modified by Cenozoic transpressional re-activation of faults and localized uplift of basin highs
- Source rocks and reservoirs present in the region



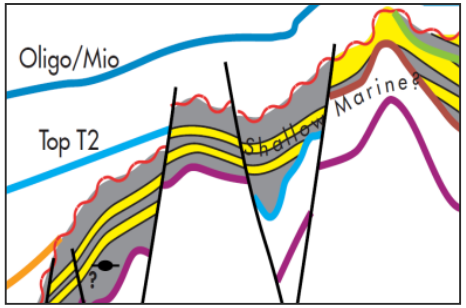
Bouguer gravity anomaly map



Potential trapping mechanisms

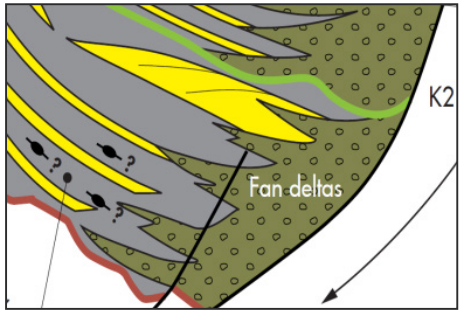
Different trap types formed during basin evolution
Identified initially on 2D seismic, verified by 3D

Pre-/ syn-rift tilted fault blocks



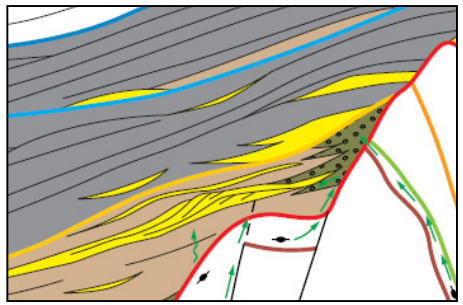
- Extensional rift fault-bound traps with pre-rift and syn-rift lithology
- Modified by uplift / erosion
- Above permeability floor (> 3.5 km dbml) only in the basinal highs

Syn-rift stratigraphic traps



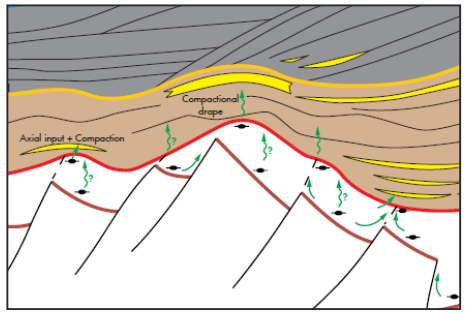
- Early syn-rift deltaic and later deep marine slope/ channel deposits limited to the axes of rift grabens
- Thinning (shaling out?) towards highs (any shorefaces?)
- Mostly deeply buried (> 4km dbml)

Post-rift stratigraphic traps



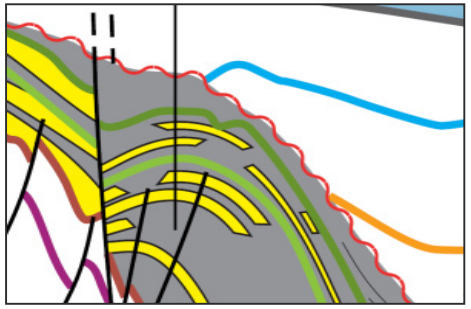
- Potential large Kivioq and Melville Bay turbidite system onlapping basin highs (seismic facies uncalibrated by coring)
- Coinciding with inversion

Compactional drapes



- Turbidites draping Kivioq basin horsts, uplifted during inversion
- Medial to fringe fan position (?)
- Deeper burial depth (2.5 – 3.5km dbml)

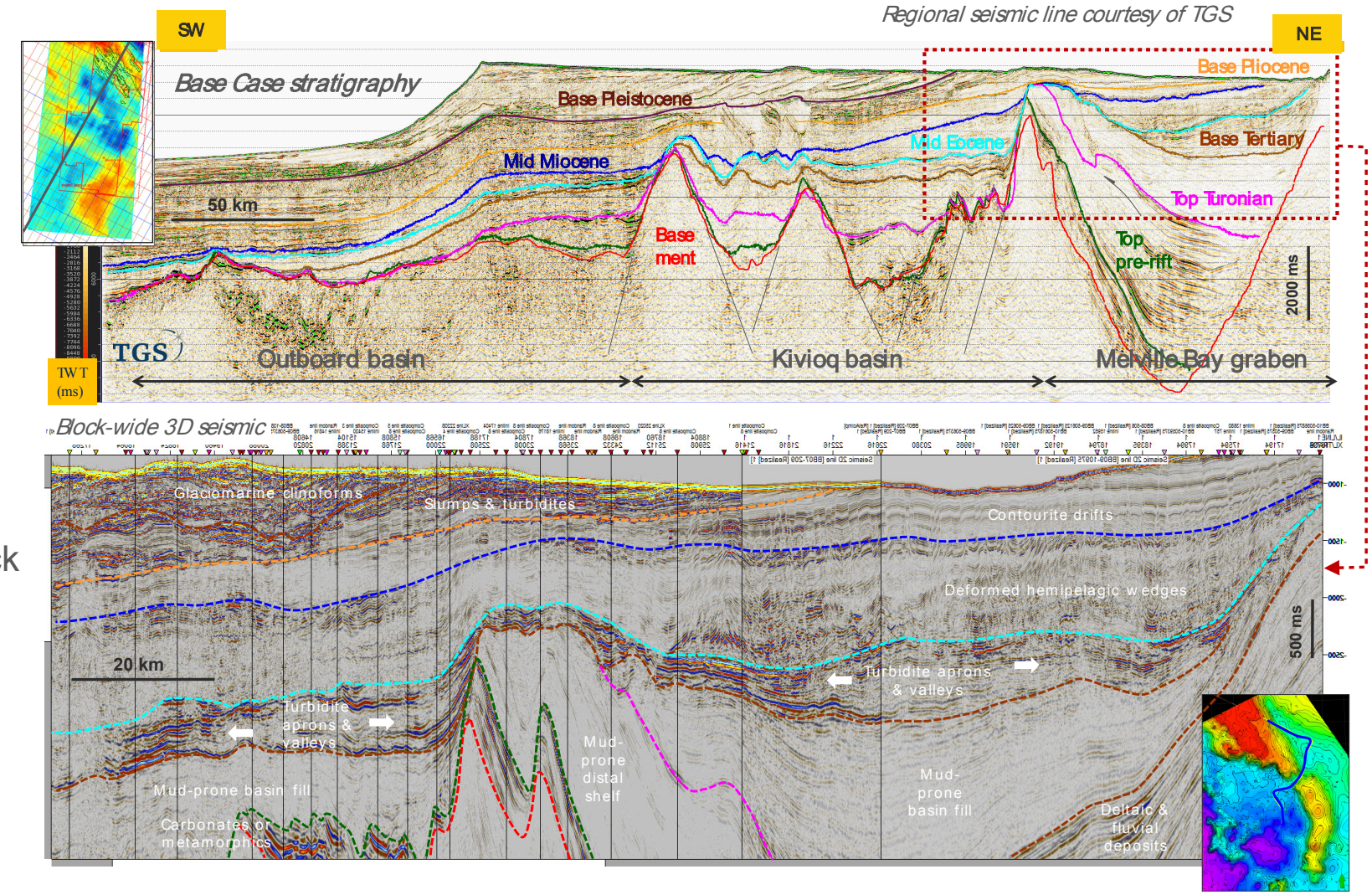
Inversion anticlines



- Thrust propagation (transpression / inversion) related folds on the flanks of the Melville Ridge
- Closures in both post-rift turbidites & syn-rift (Cretaceous) deposits

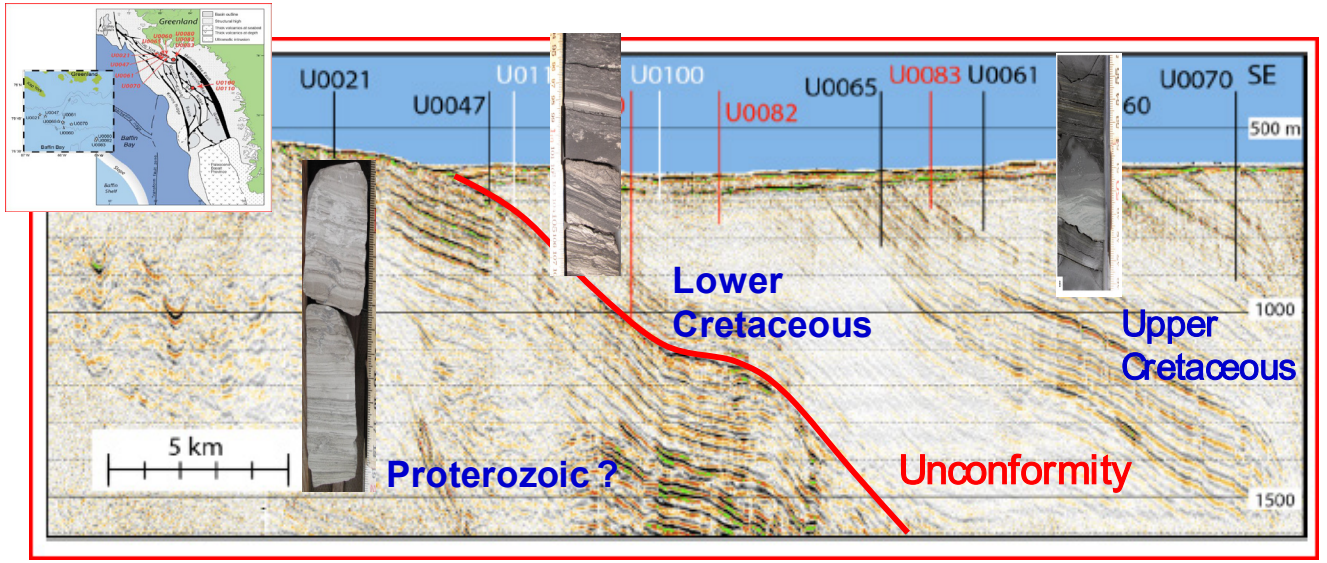
Uncertainties of basin evolution

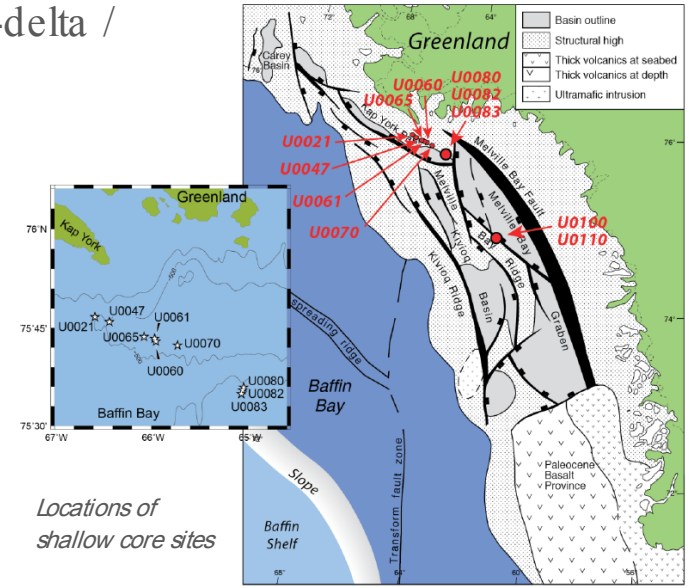
- Uncalibrated pre-rift forming bulk of basin highs
- Rifting in Early Cretaceous- continental deposits followed by shallow marine in Aptian/ Albian
- Erosion of faulted horsts?
- Deep-marine Cenomanian-Turonian – potential for SR deposition?
- Break -up, onset of volcanism & potential for turbidites in Paleocene
- Thermal subsidence produced a thick mud-prone (?) interval in Eocene
- Uplift related to the Eurekan Orogeny led to major uplift and erosion -
- Glaciation in Late Pliocene to Pleistocene times

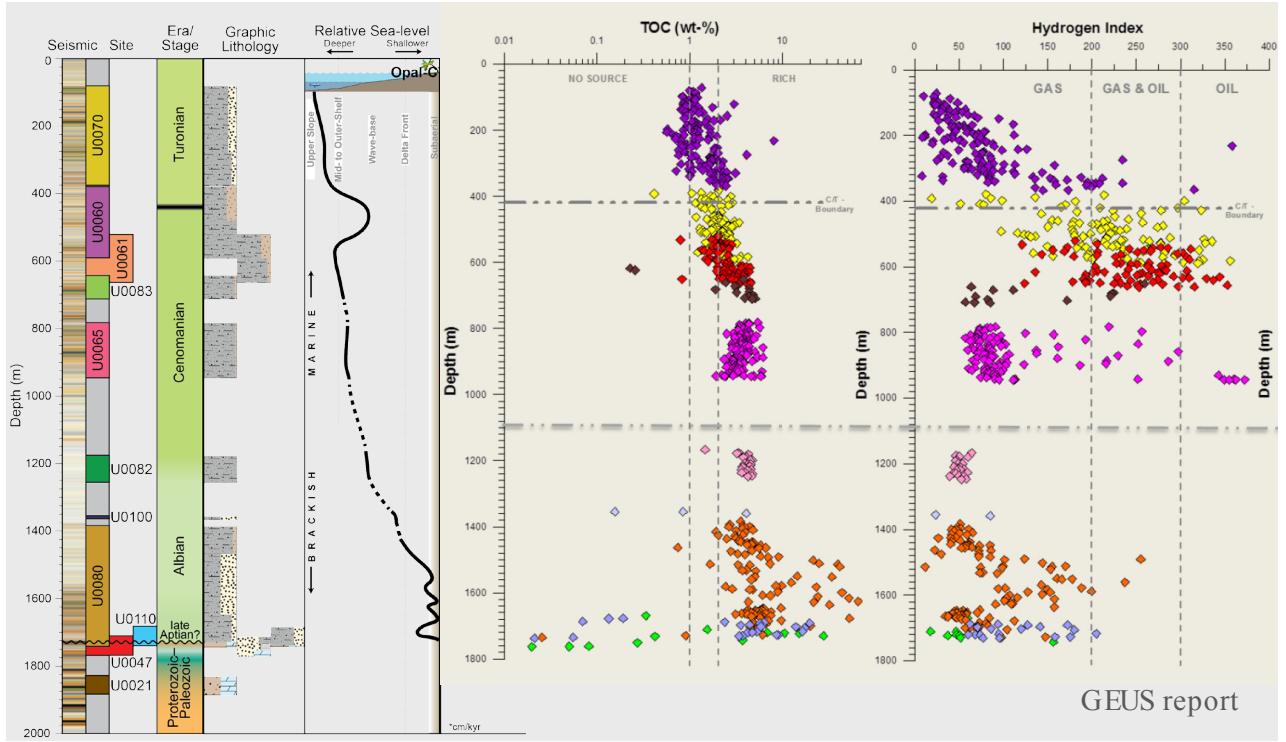


Shallow coring: pinning down stratigraphy

- Inverted stratigraphy close to sea-bed: opportunity to de-risk age of the sequences
- Joint industry consortium in 2011
- The pre-rift lithology making up most GRV in tilted fault blocks interpreted as tight Proterozoic
- Deltaic reservoir in Lower Cretaceous
- Mud-prone pro-delta / offshore above
- Mixed gas-oil prone source rocks in Cenomanian-Turonian (and Albian)

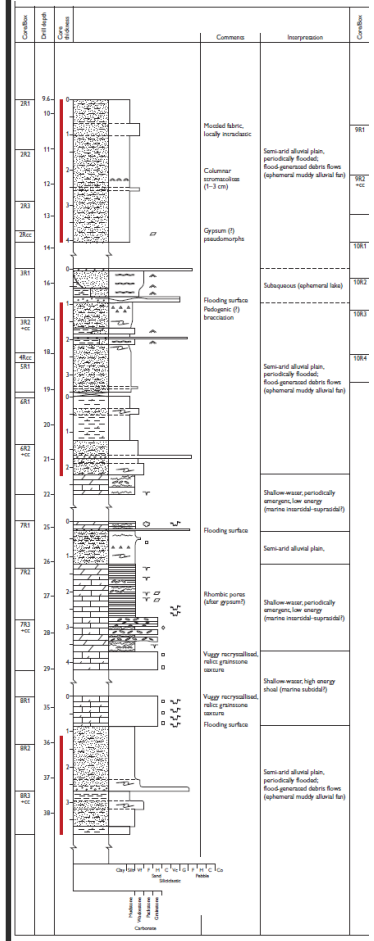




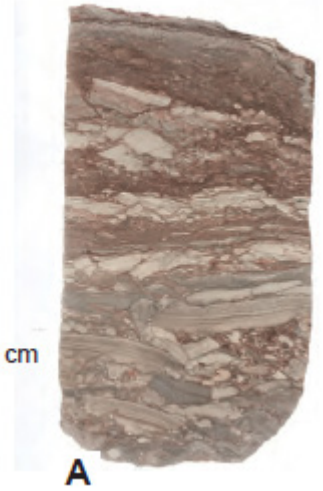


Alluvial, coastal & deep marine facies

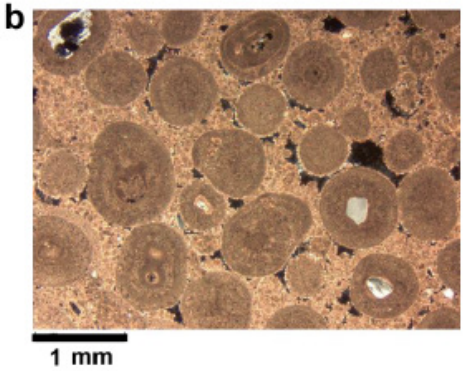
Pre-rift: PROTEROZOIC (Analogy with Thule Group)



Sedimentological log of U0021A (GEUS core report)

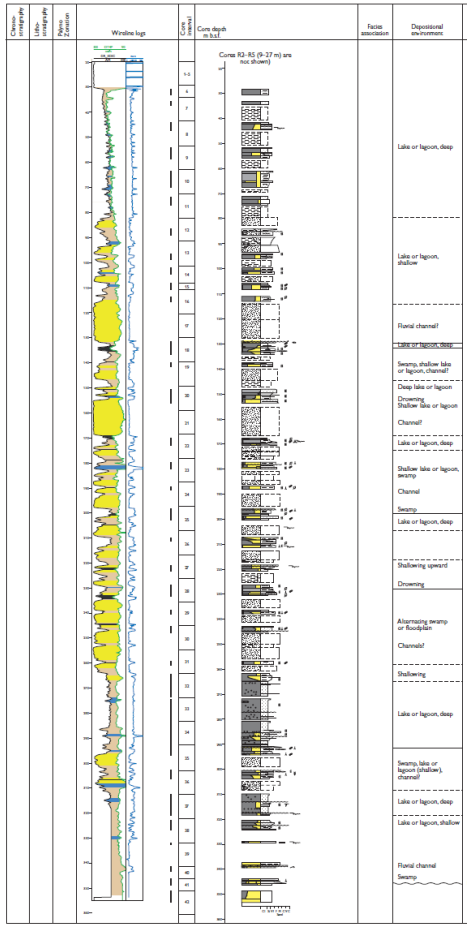


Semi-arid alluvial plain – boundary between carbonates and siliciclastic.



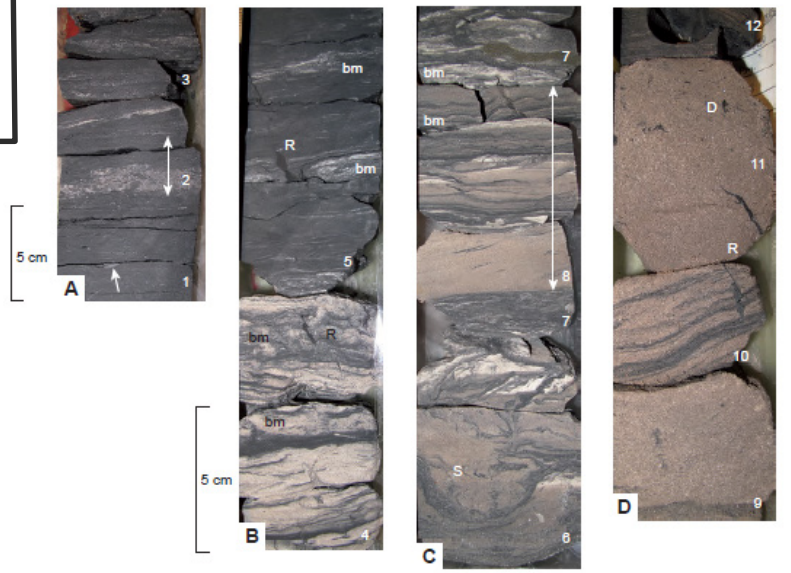
Thin section of oolitic texture (BBSCP report)

Syn-rift: CRETACEOUS



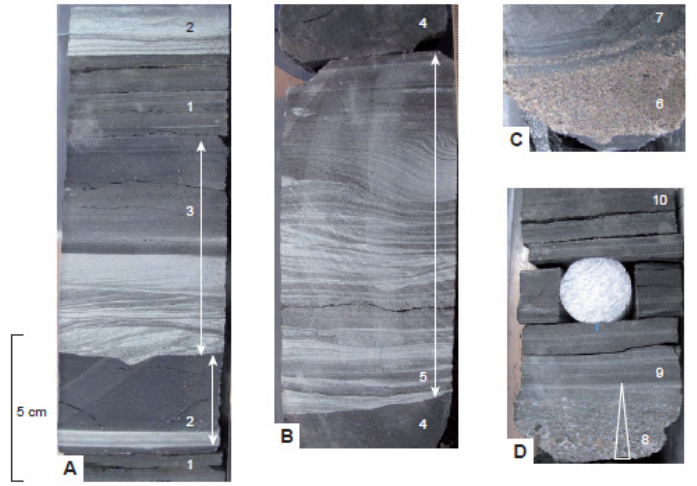
Sedimentological log of site U0080A. (GEUS core report)

Lower Cretaceous



Heterolithic succession with with coal, rootlets, current ripples / stratification & slumping.

Upper Cretaceous

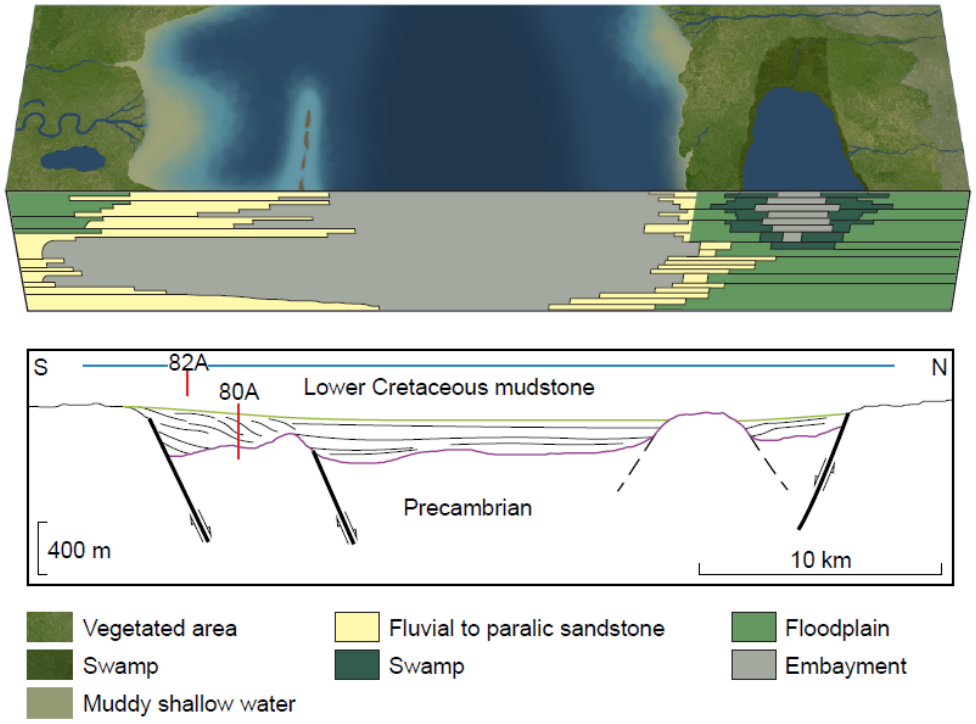


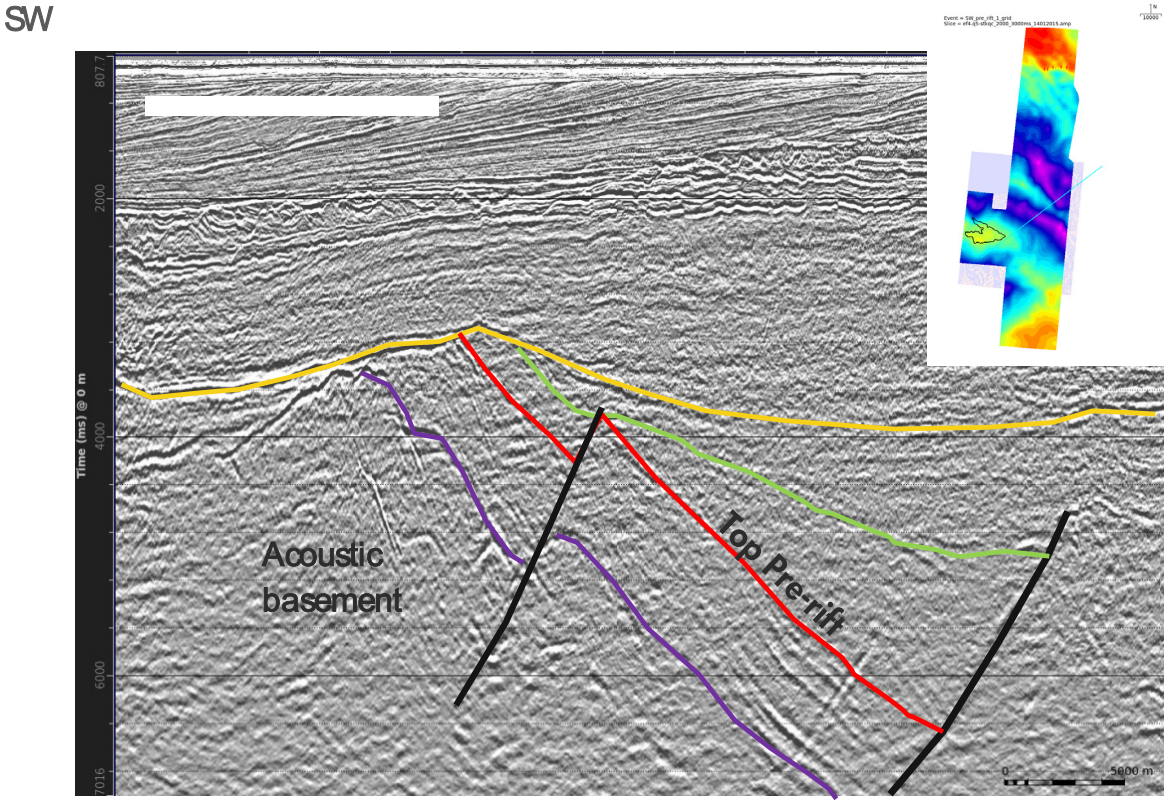
Laminated mudstones and graded sandstones (interpreted as a turbidite), mudclasts, conglomerates

Calibrated: Syn-rift Cretaceous play

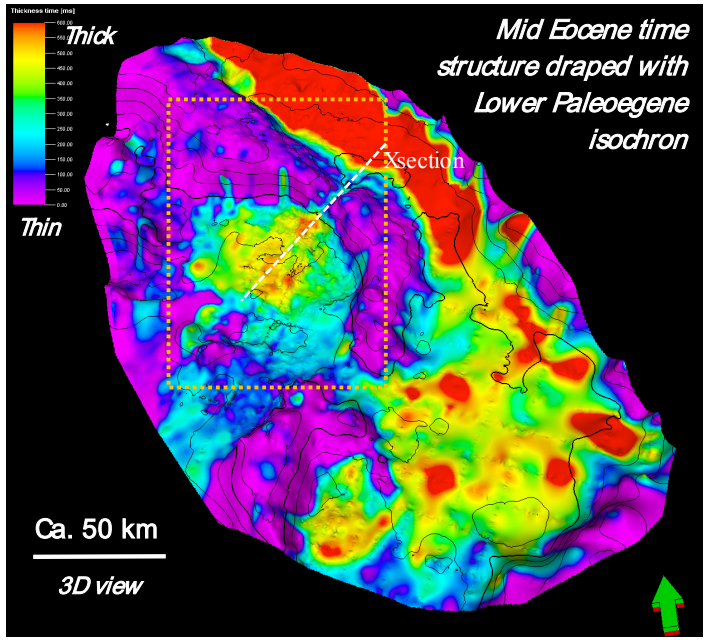
- Fluvial to deltaic reservoirs may be present, although hard to detect (shallow core seismic calibration)
- Requires low relief during Cretaceous to deposit sand and an uplift during the Cenozoic (Cretaceous sediments in closure)
- Likely seal of Paleocene age (mud-prone seismic facies)

Paleo-environment as suggested by GEUS following shallow core results

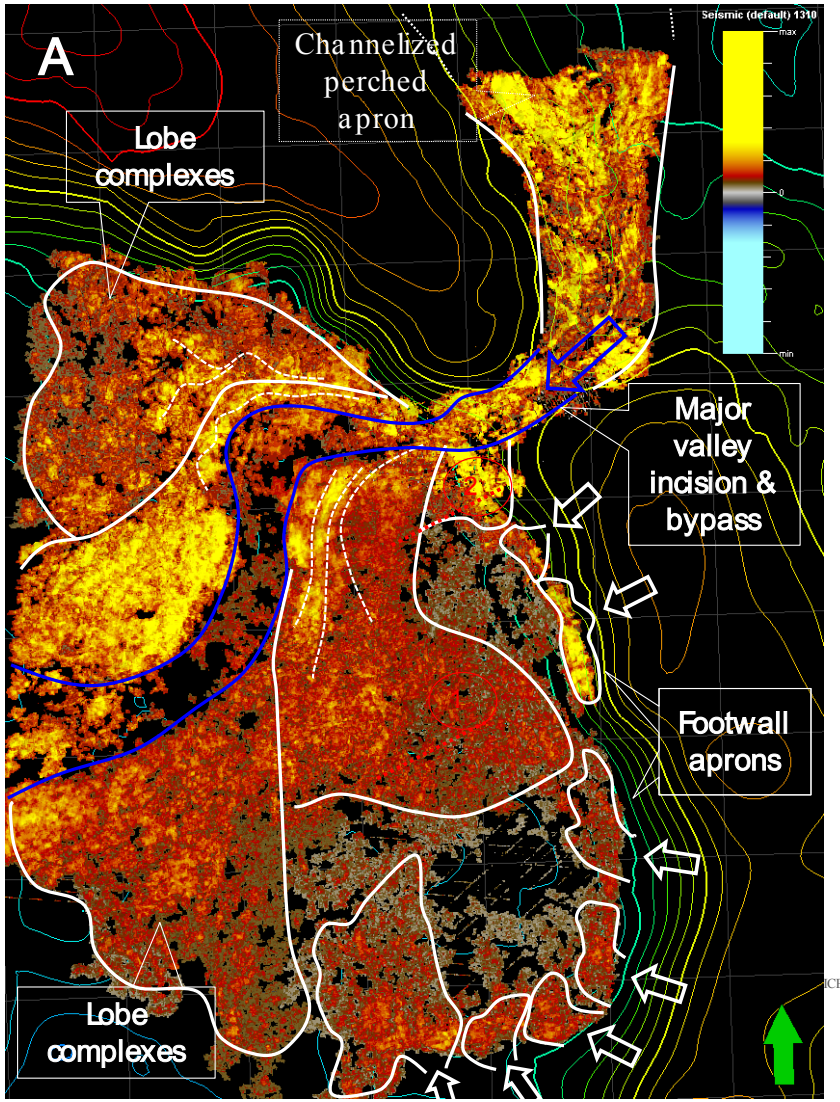


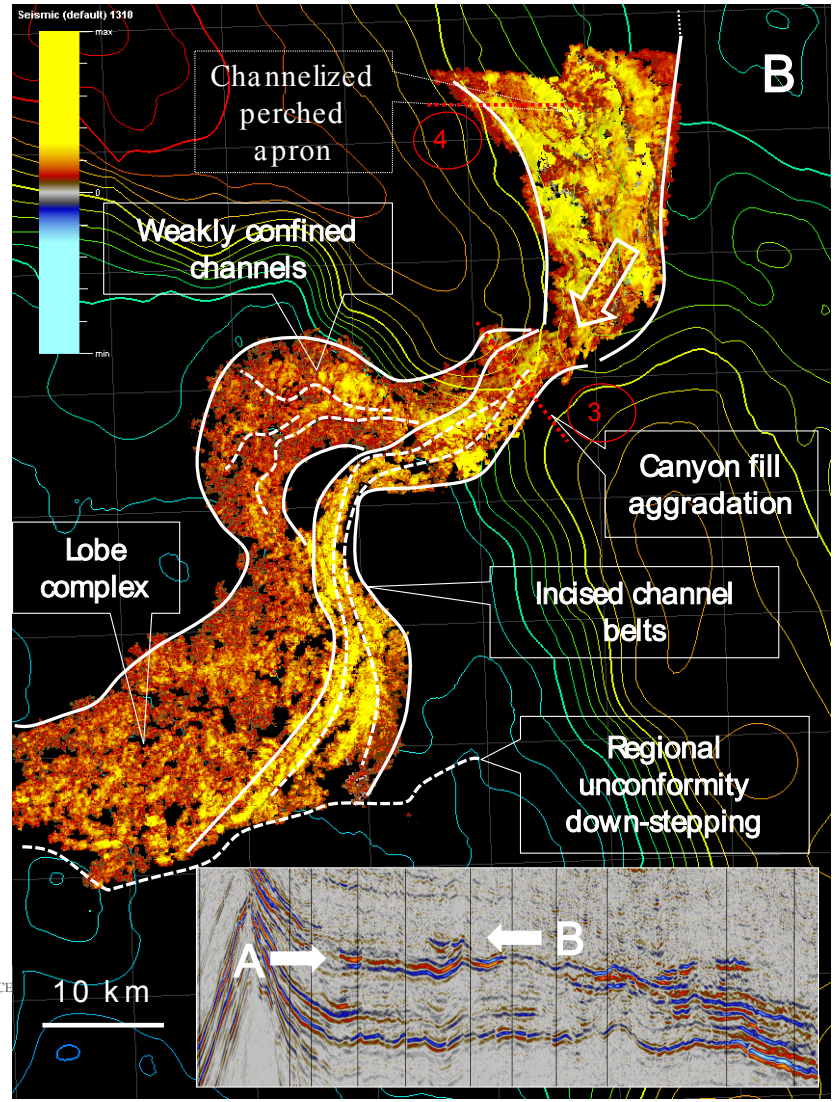


Uncalibrated: Post-rift turbidites



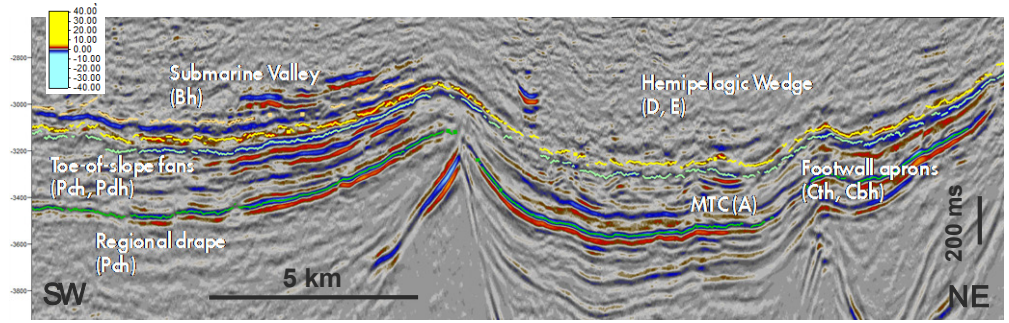
- Not cored – a seismic based concept
- Unknown grain size but channel & lobe architecture identified
- A canyon in Melville ridge feeding Kivioq basin turbidite fan?



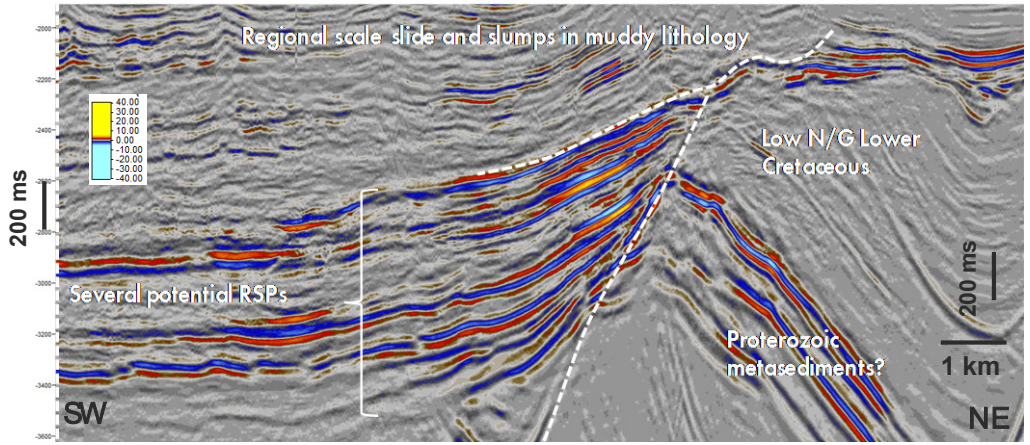


Post-rift trapping style

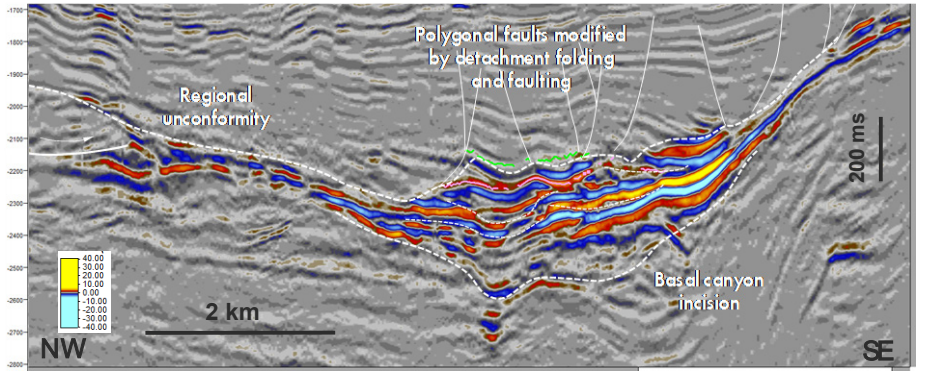
1. Compactional drapes / inverted traps (Ummimak)



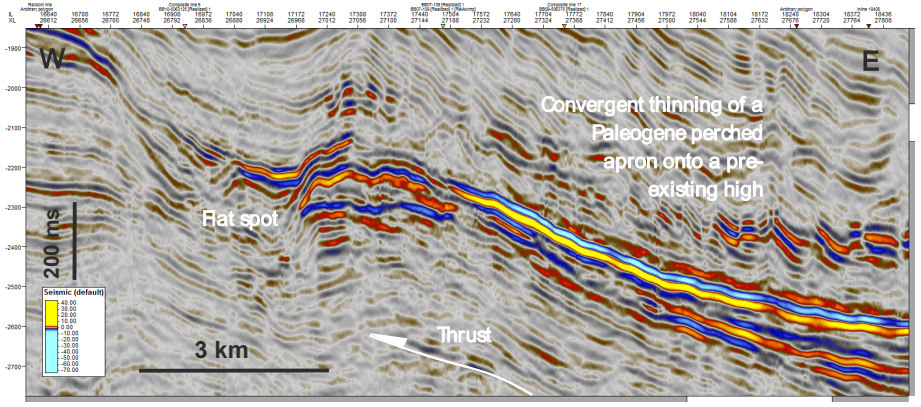
2. Updip & lateral fan pinchout (Ummimak Onlap)



3. Combined structural / lateral valley pinchout (Bowtie)



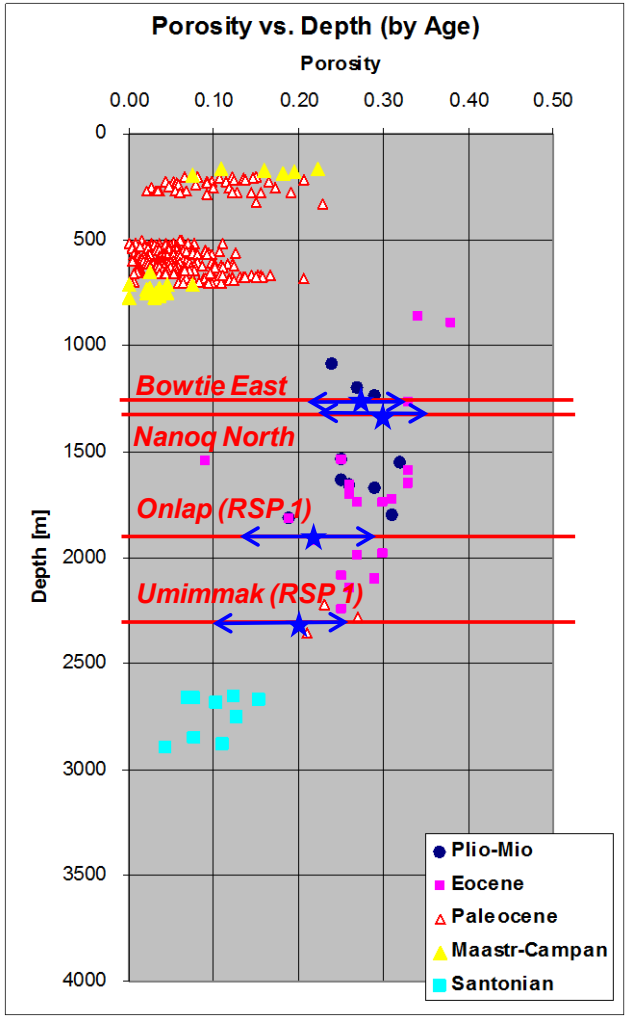
4. Inversion anticline (Nanoq North)



- Stratigraphic traps rely on a top unconformity and/ or lateral pinchout
- Combined and structural traps may have increased reservoir risk due to syn-deformational deposition

Paleogene analogues

Offshore & onshore wells, outcrops



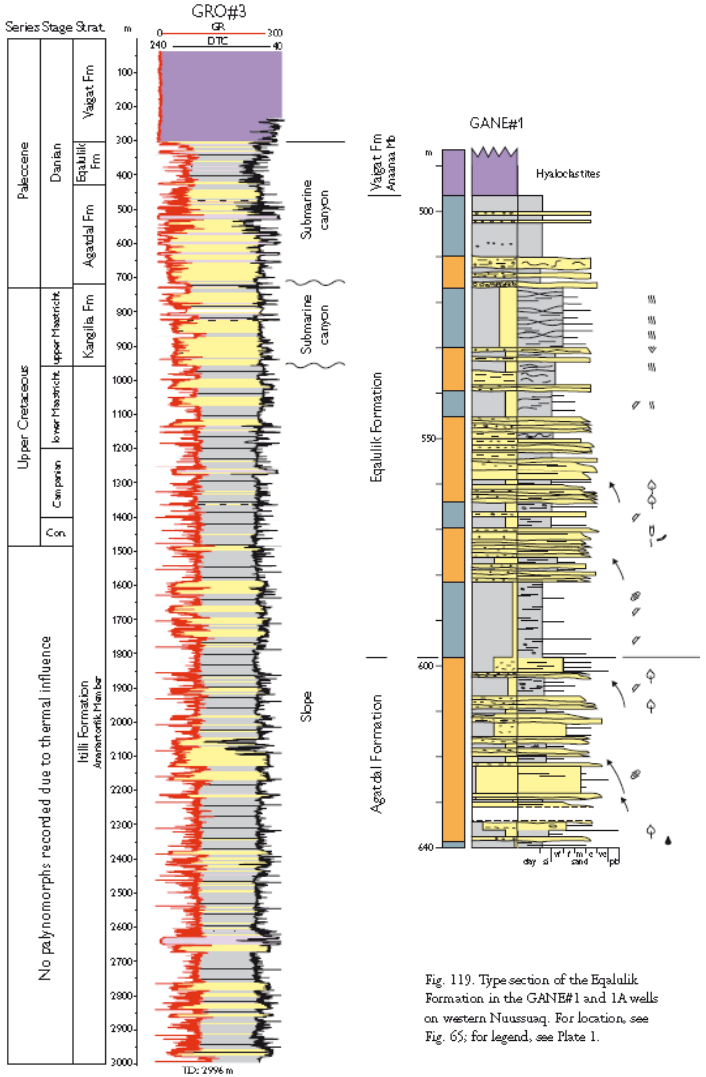


Fig. 119. Type section of the Eqalulik Formation in the GANE#1 and 1A wells on western Nuussuaq. For location, see Fig. 65; for legend, see Plate 1.

- Sand in submarine canyons and aprons
- 20 - 200m+ gross thickness, variable N/G

GEUS report

Fig. 114. Type locality of the Agatdal Formation in Turritellakløft (Rosenkrantz 1970; for location, see Fig. 113). The section is approximately 80 m high. In the present paper, the Agatdal Formation is not subdivided, but the formally abandoned 'Turritellakløft Member' and 'Andreas Member' are shown to provide a link to Rosenkrantz (1970). The Agatdal Formation is overlain by a thin development of the Abraham Member which is part of the Eqalulik Formation. For measured section, see Plate 3 (section 1).

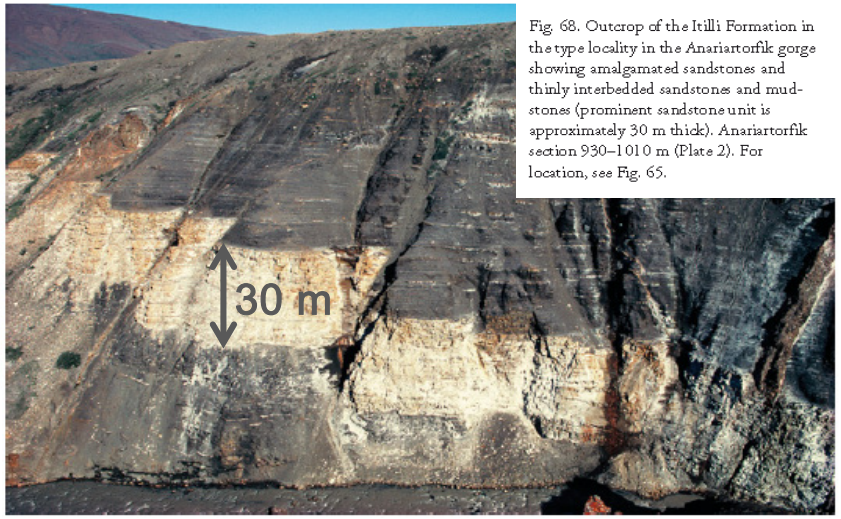
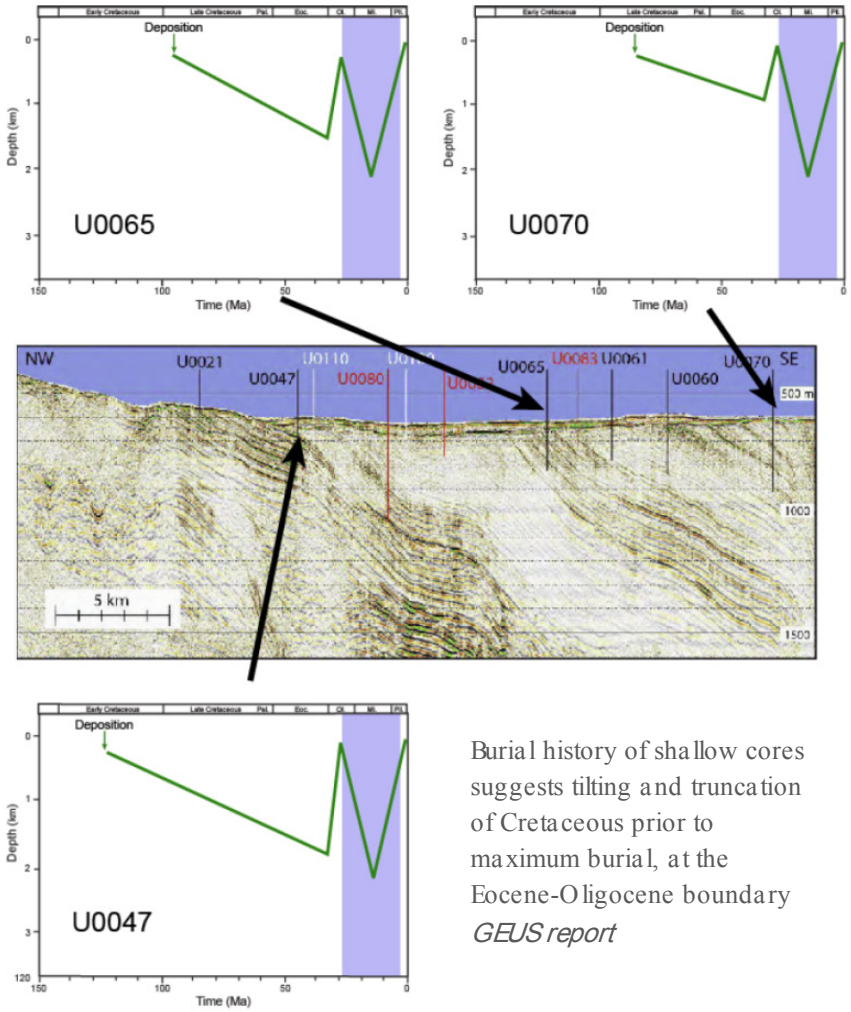


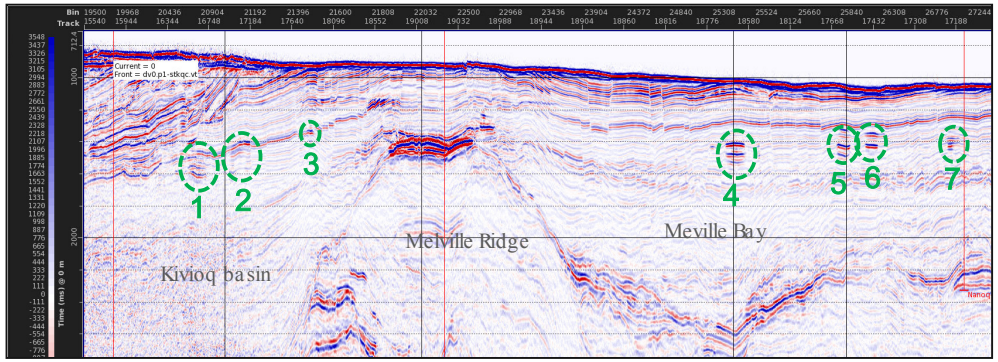
Fig. 68. Outcrop of the Itilli Formation in the type locality in the Anariartorfik gorge showing amalgamated sandstones and thinly interbedded sandstones and mudstones (prominent sandstone unit is approximately 30 m thick). Anariartorfik section 930–1010 m (Plate 2). For location, see Fig. 65.

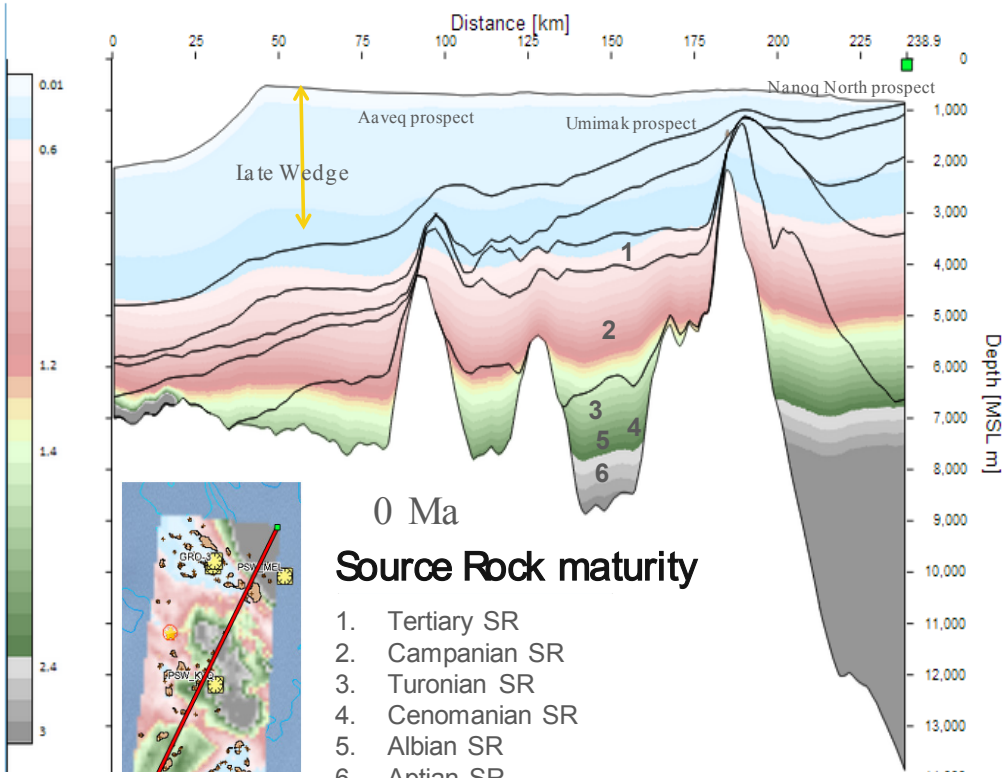
Petroleum system uncertainties

- Complex uplift & burial history
- Shallow gas flags indicate HC generation
- Likelihood of gas vs oil is equivocal
- Timing assumed favourable in Kivioq Basin, but may precede trap formation in Melville Bay
- Retention is an issue due to late inversion

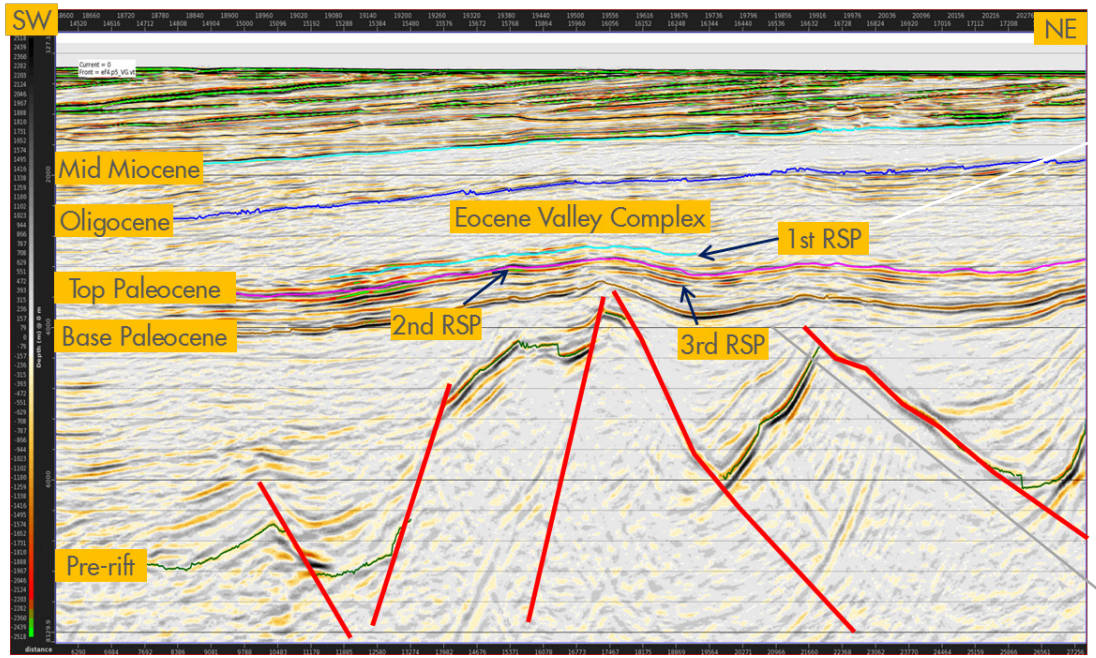


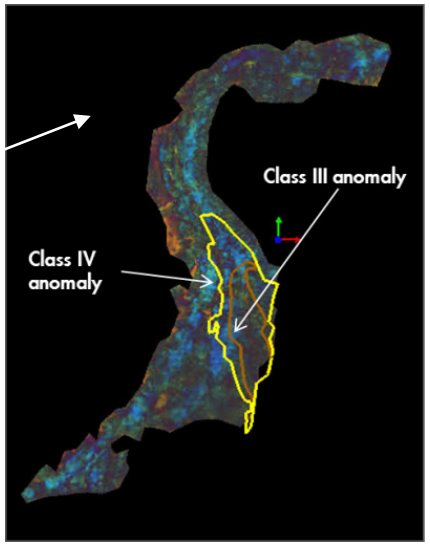
Burial history of shallow cores suggests tilting and truncation of Cretaceous prior to maximum burial, at the Eocene-Oligocene boundary *GEUS report*

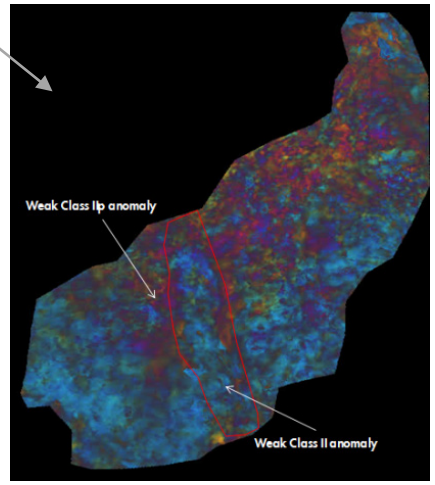


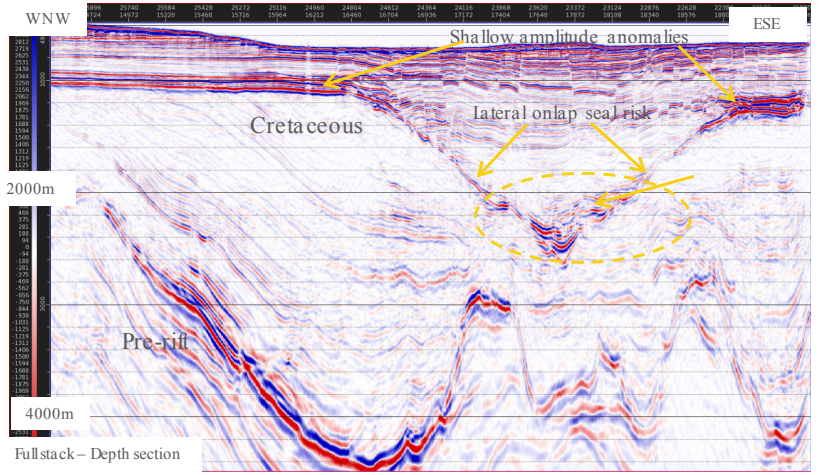


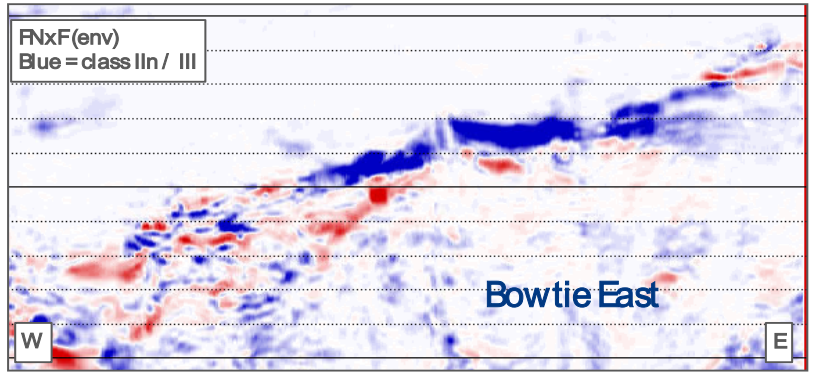
Seismic hydrocarbon indicators

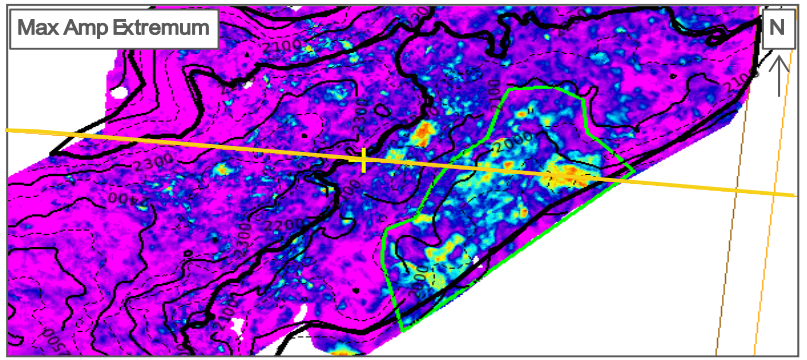








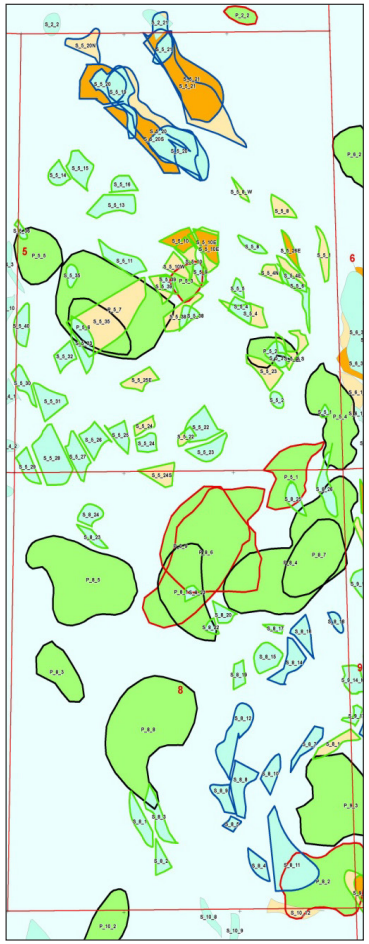




- Several leads with weak to moderate indications of HCs
- Uncalibrated environment – reliance on global RP trends
- Anomalies consistent with the proposed geological models, but lack a convincing fit to structure

New data = changed portfolio

Pre-bid combined prospect portfolio (2010)



- Improved trap definition by 3D seismic

Legend

Coast (IHSE)

Baffin_Bay_Blocks

Leads_Shell_03March2010

Trap_type

Stratigraphic

Structural drape

inversion structure

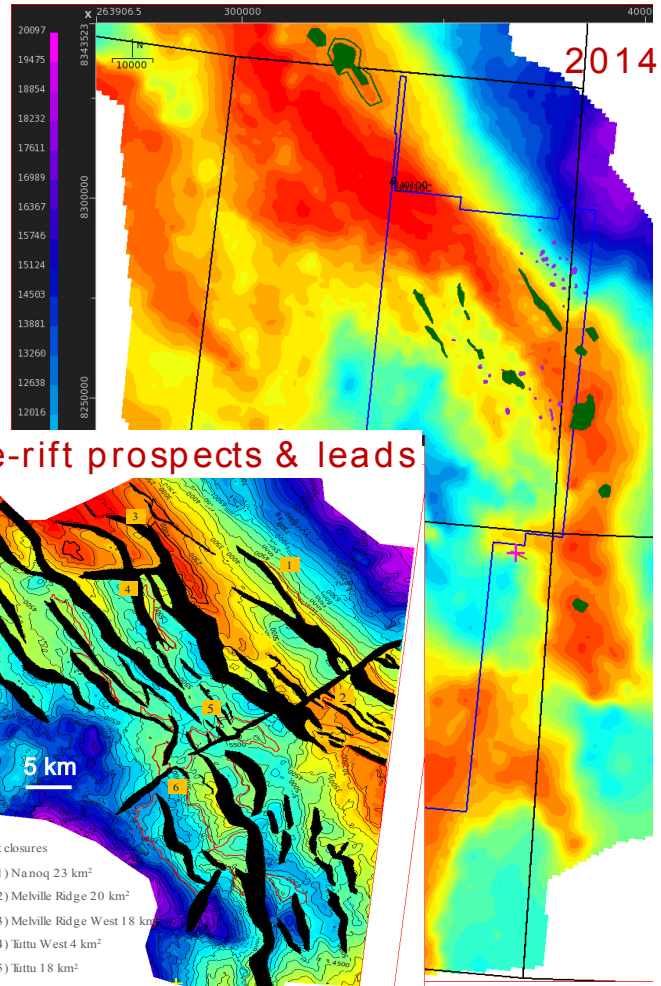
tilted fault block

Leads_Shell_03March2010

LEV

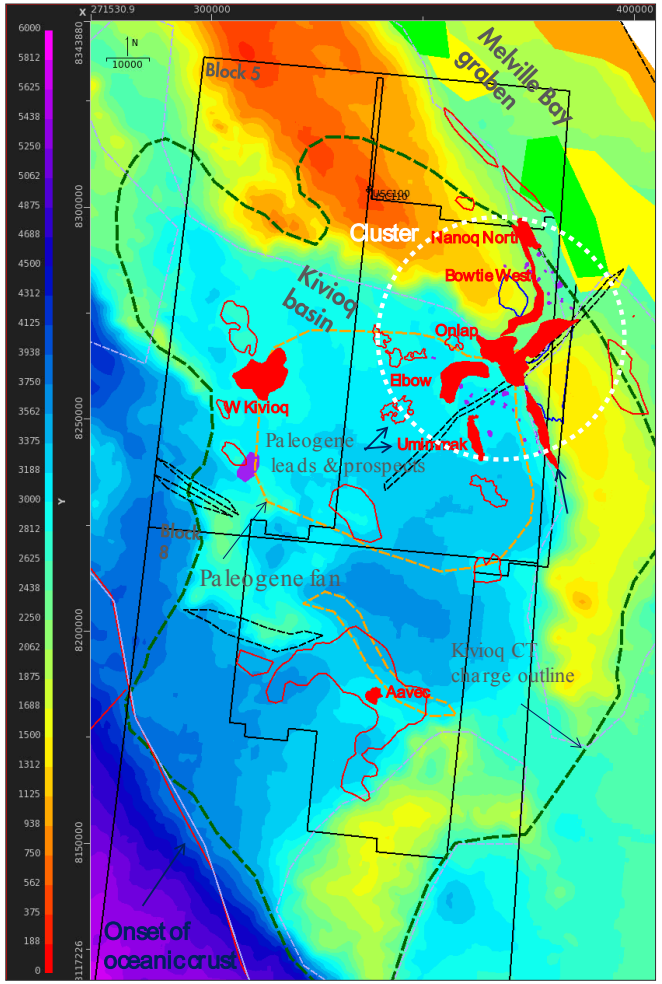
- Stratigraphic calibration by shallow core

Syn-rift play prospects & leads



Pre-rift prospects & leads

Post-rift play prospects & leads



Conclusions

- Baffin Bay licenses covered large area in uncalibrated hydrocarbon province, 100s of km from nearest wells
- Early acquisition of a regional 3D seismic survey and shallow coring campaign significantly changed our understanding of the basin evolution & fill
- Exploration re-focused from a pre- and syn-rift structural play to a post-rift, stratigraphic trap dominated play
- Pre-rift lithology appears to be very old and lacking reservoir – but is it true everywhere?
- Tertiary turbidite play is likely but remains un-calibrated
- Cenomanian - Turonian source rock has been proven, but its distribution and maturity is uncertain
- Amplitude anomalies in the prospective intervals are sparse, and inconclusive for fluid fill
- Detailed re-assessment of the prospectivity resulted in a smaller clustered prospect portfolio with large expectation volumes but significant remaining risks (<20% POS)
- Further risk reduction will require a well to prove not only a working petroleum system, but also significant hydrocarbon volumes to justify a challenging development.
- An alternative: sponsorship of academic research (IODP to test the Tertiary stratigraphy?)