

Exploration in the Fylla Area, SW Greenland

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During an earlier phase of exploration, 5 wells were drilled offshore West Greenland in 1976-1977. They were in water depths ranging from 104m to 447m and had TD's ranging from 2,363m to 3,619m. All were P&A as dry holes, although one well had indications of gas and another possibly penetrated a hydrocarbon leg which was not tested. Between 1971 and 1983, a total of 31 wells were drilled on the Labrador Shelf, Baffin Island Shelf and Davis Strait areas of the Canadian margin. Two significant wet gas discoveries were made, and several other wells had shows of oil and gas. Due to the remote location, harsh climatic conditions and perceived gas prone hydrocarbon systems, oil company activity in the Labrador Sea area subsequently waned.

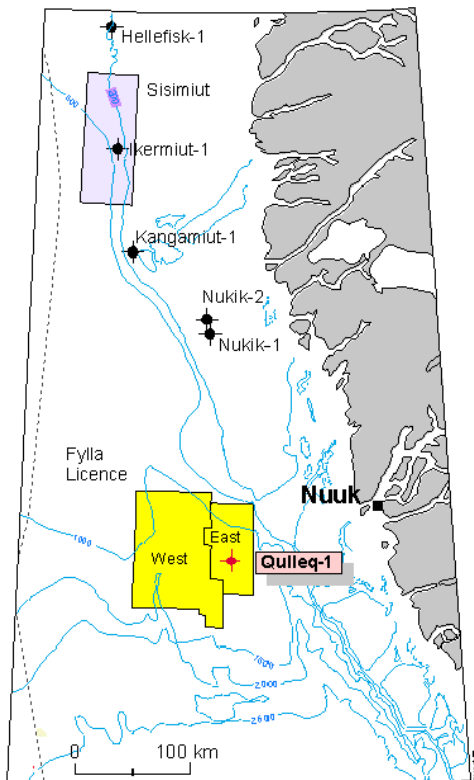


Figure 1. Location map. Fylla Licence & Qulleq-1 well.

Although oil company activity in the Labrador Sea area was low during the 1980's and early 1990's, geological and geophysical investigations by government agencies and academic institutions continued. On the West Greenland shelf much of this activity was carried out by the Geological Survey of Greenland (GGU), now part of the Geological Survey of Denmark and Greenland (GEUS). Seismic 'flat-spots' associated with thick sedimentary sequences and large tilt-block structures were first recognised in the Fylla Bank area on regional 2D seismic lines shot by the GGU in 1992. Their recognition as possible gas associated DHI's led to the acquisition of a semi-regional survey in 1994 by Nunaoil (the Greenland state oil company) . The NUNA 9401 survey consisted of some 1700 kms of 2D data on a rectilinear grid, varying from approximately 10 x 10 km to 10 x 20 km. This good quality data set confirmed the presence of locally thick sedimentary sequences, large tilt block structures and the widespread occurrence of the seismic 'flat-spot'. The latter appeared to be limited to a discrete interval and to be confined to structural closures. It occurred at different depths in different structures. All these observations strengthened the interpretation of the 'flat-spots' as possible gas fluid contacts (Bate et al, 1995).

Onshore investigations in the Disko and Nuussuaq areas of central West Greenland during the 1990's, also mainly carried out by GGU and GEUS, found widespread evidence of oil seepages and staining in the Paleocene volcanic lavas and hyaloclastites, which indicated the existence of working petroleum systems in the underlying Cretaceous and Paleocene fluvio-deltaic to marine sediments. Organic geochemical analyses revealed at least five distinct oil types, interpreted as originating from Early Tertiary and Cretaceous source rocks (Bojesen-Koefoed et al, 1999). The seismic 'flat-spots' in the Fylla Bank area, the documented onshore oil seeps and the earlier discovery of significant wet-gas accumulations in similar sedimentary basins on the Canadian margin were the basis for the Greenland Bureau of Minerals and Petroleum (BMP) in 1995 to designate the Fylla Bank area for petroleum exploration, and to invite bids for exploration licences from the international petroleum industry.

The Statoil (38,25%, operator), Phillips (38,25%), DONG (8,5%) and Nunaoil (15%) group were the successful bidders, and were granted exploration rights over the 9,487 km² Fylla Licence, offshore Southwest Greenland in 1996. In recognition of the deepwater and frontier nature of the acreage, the terms were favourable and the work commitment was moderate. The latter included 2,000 km of new 2D seismic data and the drilling of at least 1 firm well. Approximately 2,500 km of new 2D data were acquired in 1997 and 1998 and part of the pre-existing 2,400 km 2D data base was reprocessed. The firm commitment well, Qulleq-1, was drilled in the summer of 2000.

Seismic data quality was excellent and mapping and interpretation studies within the licence confirmed very large prospects, comprising tilted Cretaceous fault blocks draped unconformably by Tertiary sediments. The widespread presence of an anomalous flat lying seismic reflector was also confirmed. If the 'flat-spots' truly represented gas fluid contacts in porous sandstones, it was clear that potential gas volumes were extremely large. Economic screening studies indicated that dry gas alone would not be commercially attractive due to the remote location, Arctic conditions, great water depths (1000 to 1500m) and lack of infrastructure. It was however considered that

wet gas or a significant oil leg beneath the gas could possibly be commercialised. The exploration programme was therefore focussed on finding substantial volumes of liquid hydrocarbons. The possibility for this successful outcome was considered to be low, but the large upside potential justified the exploration risk.

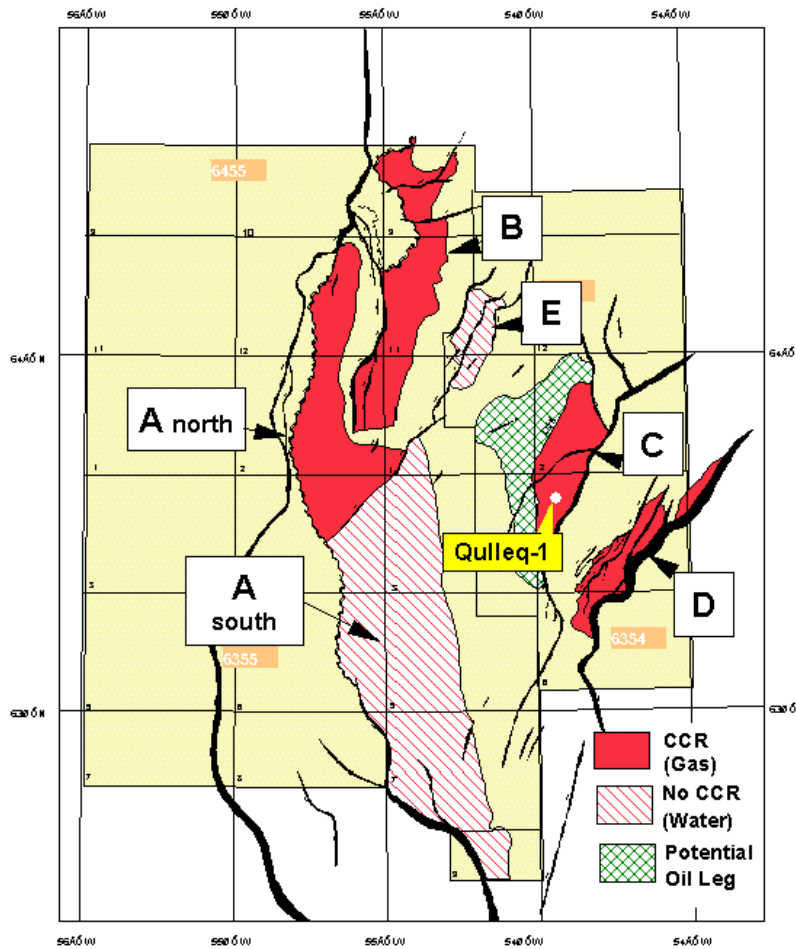


Figure 2. Pre-drill prospects.

Verification of the seismic 'flat spot' as a gas fluid contact (DHI) was prioritised in the exploration programme, as this was fundamental to the geological interpretation and to the technical and commercial risking. To term 'flat-spot' was considered to be too closely associated with gas fluid contact's, and within the licence group it was replaced by the more neutral term 'cross-cutting reflector' (CCR).

The following observations on the CCR were considered to be supportive of the interpretation that it was a gas associated DHI:

- The CCR was persistent on all seismic lines within limited areas and could be tied and mapped through the seismic grid.
- AVO studies on the CCR were interpreted as being consistent with a hydrocarbon charge in porous sands (Isaacson & Neff, 1999).

- RMS velocity studies indicated increased interval velocities at the CCR. It therefore appeared to be associated with a positive impedance event and modelling studies showed it's magnitude to be consistent with the effects of a gas charge over a fluid charge in porous sands.
- Locally a subparallel, deeper and weaker flat lying reflector was noted and interpreted as a possible OWC.
- The CCR was confined to a discrete stratigraphic interval - interpreted as a top and base sealed reservoir interval.
- Lateral changes in the strength of the CCR within the 'reservoir sequence' coincided with internal reflectivity (bedding) and were interpreted as variations in reservoir quality.

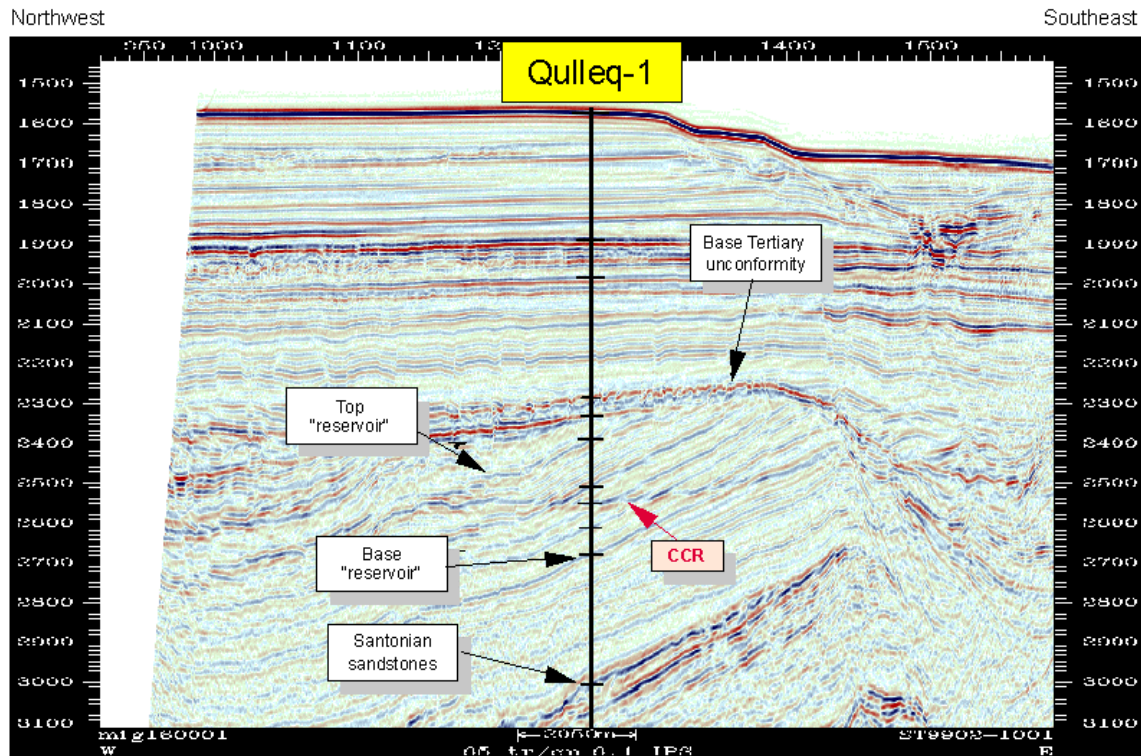


Figure 3. 2D seismic line through Qulleq-1 well location.

- In two large tilt block structures (A_{north} and B) the flat event was found to be at the same level, and coincident with mapped structural closure - suggesting that they were full to spill and in communication.
- A third, very large closure (A_{south}) was interpreted as being crestally breached. Within this structure the CCR was only weakly present on a few lines and absent on the remainder. This suggested that the 'reservoir' had been depleted.
- In a fourth tilt block structure (C) the flat event was some 150 to 200m higher than its common spillpoint with structure B - this allowed for the possibility of the C structure being underfilled with gas, leaving room for a significant oil leg.
- Two discrete, subcircular diapiric structures, extending upwards to mid-way through the Tertiary cover, were mapped close to the spill point of structure B. These were interpreted as fault associated, active, gas charged, mud volcano's.

- Detailed studies of the Tertiary sequence concluded that there was shallow gas leakage, associated with crestal fracturing, over several of the tilt block structures. Indicating an active hydrocarbon system at depth.

Despite this body of evidence, there were however other observations which cast doubts on the interpretation of the CCR as a gas associated DHI. These included the following:

- Mapping of the CCR showed that it was not flat. Within each of the three large tilt block structures where it was strongly developed (A_{north}, B and C) the CCR was tilted, being shallowest beneath the crests and deepest downflank. Locally the tilt could be 'modelled flat' by assuming reasonable lateral interval velocity variations in the overburden and within the 'gas' zone. In other instances the velocity assumptions required to flatten the CCR were unreasonable.
- Locally the CCR appeared to extend laterally into the sequences either above or below the 'reservoir' sequence, casting doubt on the topseal and base-seal interpretation.
- The CCR appeared to be locally offset by small faults, which was inconsistent with a thick and porous reservoir sequence.
- A change in polarity where the CCR intersected the topseal was predicted from modelling studies, but not observed in the data.
- The predicted AVO response at the top 'reservoir' surface was not as predicted from the model of shales overlying gas filled sands.

In pre-drill studies the following eight alternatives to account for the observed CCR were considered.

- Live gas/water or gas/oil contact (GWC or GOC)
- Live oil/water contact (OWC)
- Tar mat (fossil OWC)
- Seismic artifact (multiple etc)
- Cementation zone (fossil hard-ground, paleo water table, etc)
- Opal A to Opal CT transition
- Base of a wet gas hydrate stability zone (HSZ)
- Fossil bottom simulating reflector (BSR)

A Statoil internal multidisciplinary study, commissioned by the Fylla Licence group, examined and ranked all these possibilities. The study concluded that a gas water contact was the most probable explanation of the CCR in the the Fylla C prospect. This explanation was found to be consistent with the available geophysical data and avoided most of the geological problems associated with several of the alternatives. A GOC, OWC, base of a wet gas hydrate zone, a thin raft of gas hydrates or an opal A to opal CT transition were all considered to be plausible, but less likely explanations. Carbonate cemented zones, silcretes, cementation at paleo-hydrocarbon contacts or seismic artifacts were all considered to be very unlikely causes of the CCR.

The Qulleq-1 well was drilled during summer 2000 at a downflank location on prospect C (Qulleq Prospect). It was drilled by the West Navion drillship in 1152m of water. The location was chosen to optimally evaluate the lower part of the anticipated gas column in an area where the CCR was well developed and flat. It was also in an area where there was a suitable Cretaceous casing seat above the predicted 'Top reservoir', and where there was sufficient 'reservoir' beneath the CCR to fully evaluate the potential oil leg.

The well penetrated a Tertiary marine sequence, mainly Mio-Pliocene in age, and crossed an unconformity into Cretaceous rocks around 1900m, some 36m high to prognosis. The Cretaceous sediments were marine mudstones of Campanian age, more or less as anticipated. The logging program run prior to setting casing at 1920 mRT included a 'look ahead' VSP which confirmed the expected reflector sequence, including the Top Reservoir, Intra-Reservoir and Base Reservoir horizons. All were predicted to come in some 40 to 50m above original prognosis. However no sandstones were encountered in the predicted reservoir sequence and instead the well penetrated a monotonous sequence of marine mudstones with thin silty dolomitic stringers. Towards the base thin siltstone stringers were encountered. At the level of the CCR no significant changes in lithology occurred, no significant deviations were seen on the MWD logs and no hydrocarbon shows were recorded on the mudlog.

Below the 'reservoir sequence' the well continued in marine silty mudstones with thin silty sandstone stringers, more or less as prognosed, to around 2650m where it crossed into sandstones. Interbedded sandstones, siltstones and mudstones were drilled to TD at 2973 mRT. The uppermost 100m of sandstones had good reservoir quality. They consisted of stacked channel sands with an average porosity of around 23%. The sands were drilled within mapped closure but several hundred metres downflank from the structural crest. No hydrocarbon shows were recorded while drilling, and no traces of migrated hydrocarbons were found in subsequent analyses. The sandstones flowed water on wireline test. The sandstones are interpreted as marine base of slope deposits. At the base of the well, sediments are interpreted as being no older than Upper Santonian. Seismic evidence suggests that the sandy interval is widespread in the Fylla area and unconformably overlies a deeper, presumably Lower Cretaceous, sedimentary sequence which is locally more than 2 km thick.

Post-well X-Ray Diffraction analyses and studies carried out on side-wall core material show that there is a transition from opal CT to microquartz within the Campanian mudstones which corresponds to the position of the CCR. The XRD data show that above the CCR the sediments contain an average of 15% (by weight) of opal CT and an average of 32% of microquartz, whereas below the CCR opal CT is absent but the sediments contain an average of 47% microquartz. These data clearly document an opal CT to microquartz transformation. Other evidence from the well indicates that this transformation has probably occurred at a temperature of 40⁰C or less, considerably lower than the transformation temperature of around 80⁰C which had been previously assumed. A slight density increase was recorded at the level of the CCR but otherwise log responses were surprisingly weak. Textural changes were however noted at the level of the CCR, with the mudstones becoming more brittle. This led to caving and washouts in the lower part of the 'reservoir' zone. The textural changes are probably associated with elasticity changes in the rock which will have contributed to its seismic response.

It is therefore concluded that the CCR in the Fylla Bank area is the result of an opal CT to microquartz transition within a silica rich interval of Campanian mudstones. Late Santonian base of slope sandstones were progressively buried by slope mudstones through the Campanian. The upper slope sediments are interpreted as having been enriched with organic silica due to marine upwelling and enhanced organic activity. Later progradation of outer shelf sediments probably switched off the upwelling and the organic silica enrichment. The organic silica enriched upper slope mudstones therefore form a discrete stratigraphic unit with a thickness in the order of 300m. They extend across the Fylla Licence in a broad, NW-SE trending zone, reflecting the

position of the Campanian shelf-edge. The CCR is confined to this silica enriched zone, and its lateral terminations within dipping sequences are now interpreted as being due to the depositional absence of significant amounts of organic silica in the underlying and overlying sediments.

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