Goliat Discovery – A Knowledge-Based Approach, Persistence and the First Commercial Oil Development in the Norwegian Arctic*


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Abstract

The history of the first commercial oil discovery and development in the Barents Sea, made by Eni Norge, dates back to 1997 when the license acreage was awarded. The first well was drilled in September 2000 and discovered 43 m of oil column in the Upper Triassic part of the Realgrunnen Subgroup. The Goliat play is a four-way rollover down-faulted structure with fluvial deltaic Norian sandstones sourced by Upper Jurassic shales. The Goliat structure is located on the southern edge of the Hammerfest Basin and in the initial interpretations Goliat was considered to be too far away from the main kitchen area to the west of the Hammerfest Basin, especially in comparison with other larger structures closer to the basin axis. The Goliat discovery in 2000 came after 20 years of exploration drilling in the Barents Sea with just one commercial discovery, i.e. the greater Snøhvit gas field (brought on stream in 2007), over 54 exploration wells at that time. As a consequence, the discovery of Goliat came as a great surprise for the Norwegian oil industry and resulted in the widespread acceptance of Norsk Agip/Eni Norge’s innovative geological concept of “long-distance” migration and oil entrapment at the “basin margins/borders”. Of particular importance are the results of the third well in Goliat drilled in 2005. In addition to the discovered hydrocarbon column of 68 m in the Realgrunnen reservoir, the well penetrated an oil column of 80 m in the fluvial to deltaic sandstones of the Middle Triassic Kobbe Formation, which was the secondary well target but subsequently became the main oil pool in the Goliat Field. The oil in the Kobbe Formation is sourced from Lower and Middle Triassic shales. The results of the third well were a “game changer” for the Goliat discovery. The oil discovery in the Kobbe Formation opened a new play concept in the Hammerfest Basin and provided a solid basis for a viable development, the first oil development in the Norwegian Arctic. Today, the Goliat Field is operated by Eni Norge with a 65% interest, in partnership with Statoil 35%. Goliat is the first oil field to come on stream (March 2016) in the Norwegian part of the Barents Sea. Located at 71°30’ North, the field is also the world’s northernmost offshore development. Recoverable reserves are estimated to be 174 million BOE and according to the current development scheme the field will be produced through 22 wells all of which are tied back to the Goliat FPSO.
Goliat represents a valuable legacy for Eni Norge. The Goliat Field is the result of a challenging, long and successful exploration and appraisal campaign of Eni Norge in the Norwegian Arctic. The established and refined play model for Goliat has been applied to make the additional oil discoveries of Nucula in the eastern vicinity of Hammerfest Basin and Johan Castberg in the Bjørnøya Basin. Historically, top seal failure, leakage and oil biodegradation were the major risk parameters in shallow buried structures in the Barents Sea. With the build-up of deep geologic knowledge, Eni Norge is now able to tackle the additional risk elements, such as locally unpredictable reservoir facies distribution and complex migration pathways that have been somewhat underestimated in the initial play models. Over the years, the company has built an important database and a knowledge-based approach to the exploration of the Barents Sea. The use of the latest technologies, dedicated R&D projects, and the drilling of appraisal wells to confirm the hydrocarbon accumulations have allowed the company to grow its reserve base through exploration and, ultimately, to increase daily production substantially when the Goliat Field came on stream in March 2016.

References Cited


Goliat discovery:
A knowledge-based approach, persistence, and the first commercial oil development in the Norwegian Arctic

Tsikalas, F.\textsuperscript{1}, Uncini, G.\textsuperscript{1}, Mavilla, N.\textsuperscript{2}, Staine, I.\textsuperscript{1}, Casaglia, F.\textsuperscript{2}, Leutscher, J.\textsuperscript{1}, Gennaro, M.\textsuperscript{1}, Arrigoni, V.\textsuperscript{1}, Gustafsson, L-E.\textsuperscript{1}, Galimberti, R.\textsuperscript{2} and Daturi, C.\textsuperscript{2}

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Outline

- **Pre-conceived concepts; Norwegian Barents Sea: exploration retrospective**

- **Dare to drill; Goliat Jurassic oil discovery: a breakthrough**

- **Dare to persist; Goliat Triassic oil discovery: a game changer**

- **Dare to appraise; Reservoir development**

- **Goliat legacy**
Norwegian Continental Shelf: exploration retrospective

Opened since 1979

1965

1982
Barents Sea geological framework

Late Devonian (250 Ma)

Late Permian (220 Ma)

Late Triassic (200 Ma)

Late Jurassic (150 Ma)

Early Tertiary (60 Ma)

Blaich et al. (2017)

Torsvik et al. (2008); Dyvik, Tsikalas, Smelror (2010)

a. Concentration in Hammerfest & Tromsø basins: focus on siliciclastic reservoirs (mainly L-M Jurassic)

b. “Picky” expansion to other areas: focus on siliciclastic reservoir but also testing carbonate targets
The first season in the Hammerfest and Tromsø basins (1980’s)

Seismic mapping showed that the mission should be harvesting the same successful plays as those in Northern North Sea:

- Upper Jurassic and Lower Cretaceous sequences as source and seal
- Lower to Middle Jurassic sandstones as reservoir
- Structural unconformity traps - rotated fault-blocks and horsts blocks

Evans et al. (2003), Halland et al. (2014)
First season exploration campaign (1980’s): outcomes

**Outcomes**

- Successful gas discoveries (which become the “greater” Snøhvit Gas Field)
- Failure in economic oil discoveries, but almost all wells had oil staining and some structures had a thin oil leg
- Porosity in Lower to Middle Jurassic reservoirs on current 2.5 km burial could be compared with traps buried 4 km or more in Northern North Sea

In 1980’s the Hammerfest Basin was proven as a new hydrocarbon province on the shelf – but a **stranded gas province** *(Snøhvit: on stream since 2007)*

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**Spencer et al. (2008)**

**Hammerfest Basin**

**Original recoverable reserves:**
- 223 GSm³ (7.9 Tcf) Gas
- 25.8 MSm³ condensate
- 8.1 million tonnes NGL
Thick oil staining (paleo HC-column) (in several wells) & thin oil leg (below gas column) (in few wells)

Snøhvit - Well 7121/5-1

Snøhvit: 60-230 m gas column
14-17 m oil column

Paleo - Oil column 167 m

Paleo - Oil/Water contact 2535 m

Publicly released well courtesy to NPD
The second exploration season in the Hammerfest Basin (mid-late 1990’s): Pre-conceived concepts prior to Goliat Discovery

- **Shallow faults** will destroy an efficient seal

**Basin Center**

- Shallow empty structures due to poor seal capacity; if filled: risk of biodegradation

- **Uplift led to gas expansion and displacement of oil; “aqua fissante theory”**

**Basin Periphery**

- Uplift/erosion estimates

**Poor reservoir quality due to previous deeper burial**

**Uplift/erosion estimates**

**Plio-Pleistocene glaciations**

**Hammerfest Basin**

**Henriksen et al. (2011)**

**Knies et al. (2009)**

**Ohm et al. (2008)**

**Publicly released 2D line courtesy to NPD**
- Pre-conceived concepts; Norwegian Barents Sea: exploration retrospective

- **DARE TO DRILL;** Goliat Jurassic oil discovery: a breakthrough

- Dare to persist; Goliat Triassic oil discovery: a game changer

- Dare to appraise; Reservoir development

- Goliat legacy
PL229: awarded May 1997
(Barents Sea Project-1997)

Norsk Agip (25%) Operator
Phillips Petroleum (25%)
Statoil (20%)
Enterprise Oil (15%)
Neste Petroleum (15%)

Work commitment:
150 km² 3D seismic & 1 well into Permian

PL229/PL229B/229D (2017):
Eni Norge AS (65%) Op.
Statoil Petroleum AS (35%)

Publicly released 2D line courtesy to NPD
Goliat: Jurassic reservoir depth (2D data) (1996)
Goliat play models (1996)

Lower-Middle Jurassic Play Model

Compiled Mesozoic Play Concepts

Lower Triassic Play Model

Prospects & Leads
How did Eni Norge come to the perception to focus exploration on the basin margins?
Key issues: maturity & hydrocarbon migration distance

- **North Sea (paradigm):** very short HC migration distances, proximity to kitchen areas (few kilometres)

- **Hammerfest Basin:** Upper Jurassic SR (Hekkingen Fm.):
  - not mature within basin;
  - mature only at western part of Hammerfest Basin and at transition to Tromsø Basin

- **Long distance migration (tens of kilometres)**
Key issues: Goliat as a hydrocarbon migration/dis-migration focus area

- Paleo-oil column in Albatross/ "greater Snøhvit area" reveals fill-to-spill towards east & south: **Goliat is a hydrocarbon migration/dis-migration focus area**

- Late Cenozoic glacial uplift/erosion & related isostatic tilting

- Shows at several (almost all) stratigraphic levels
First exploration wells at Goliat (2000 & 2001): a breakthrough


Publicly released 2D line courtesy to NPD
Southwestern Barents Sea: pressure regime

- **Bjarmeland Platform and Loppa High**: wells with hydrostatic pressure or even slight under-pressure.
- **Wells with 10 to 15 bar overpressure**
- **Wells with 10 to 20 bar under-pressure**
- **Rim zone with wells of slight overpressure to hydrostatic pressure**
- **Wells with 50-150 bar overpressure**
- **Deep basins**: wells with 150-250 bar overpressure
Current dynamic fluid-flow system
1. Neogene uplift
- PVT (pressure-volume-temperature) changes in traps
- changes in spill-points of the traps
- oil and gas leakage and dis-migration (areas with current hydrostatic- or under-pressure)

2. Dynamic fluid flow
Pressure gradient in the west:
- current dynamic fluid flow system
- new «fresh» gas and oil migration
- gas and oil leaks to sea floor or dis-migrates to a higher structure (migration will use previous oil saturated carrier fairways)

3. Migration shadows
Water-wet structures may occur due to migration shadows caused by new faulting and occurrence of “new established” low permeability zones.

Base Cretaceous Unconformity depth-grid

Gas has replaced oil accumulation
- Pre-conceived concepts; Norwegian Barents Sea: exploration retrospective

- Dare to drill; Goliat Jurassic oil discovery: a breakthrough

- **DARE TO PERSIST**; Goliat Triassic oil discovery: a game changer

- Dare to appraise; Reservoir development

- Goliat legacy
Key issues: Triassic source rock and potential Triassic play

- **Shallow drilling (Svalis Dome) & Svalbard onshore field studies:**
  - **Middle Triassic source rock potential**
    - present in several Arctic basins (Arctic Canada: Murray Harbour Fm., Alaska: Shublik Hoyle Bay Fm.)

- **Possibility for other (non-Upper Jurassic) petroleum systems:**
  - geochemistry results from initial wells in Barents Sea & shows at several (almost all) stratigraphic levels

While the Upper Jurassic source rock is regional extensive, the Lower-Middle Triassic source rocks seem to be linked to facies distribution, e.g. distal to prograding wedges.

Blanknuten Member (Anisian/Ladinian) is rich in Amorphous Organic Matter (75-90%) and shows very good - oil prone source properties.
Goliat Triassic oil pool discovery (2005): a game changer

7122/7-3 (2005): South compartment, 68 m HC-column in Realgrunnen, 80 m oil-column in Kobbe Fm., Snadd oil discovery. Oil discovery in Kobbe Fm. was a significant finding and opened a new play concept in Hammerfest Basin & Barents Sea. Now the project had a solid base of reserves to become a viable development, the first oil development in the Arctic.


<table>
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<tr>
<th>Exploration Wells</th>
<th>Drilling</th>
<th>Realgrunnen</th>
<th>Snadd</th>
<th>Kobbe</th>
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Appraisal well
7122/7-6 - Goliat M0 Appraisal Oct. 2012

May 15th 2007: PDO submission (license extension to 2042); PDO approval: 2009.
Goliat Field: on-stream since March 2016
Oil geochemistry in Goliat: 2 different oil families

- U. Jurassic Hekkingen oil prone source
- L.-M. Triassic oil prone source
- Realgrunnen & Snadd accumulations
- Kobbe & Klappmyss accumulations

Terpane chromatogram similarities:
- Botneheia Fm. (Svalbard)
- Shublik Hoyle Bay Fm. (Alaska)
Middle Triassic: petroleum system considerations & source rock features

**Petroleum systems modelling considerations:**
- Hammerfest Basin (Middle Triassic SR):
  - mature at NW corner of Hammefest Basin and at West (transition to Tromsø Basin)
- **Long-distance migration: a pre-requisite**

**Source rocks features in Goliat wells:**
- Kobbe source rock interval is not oil prone and not mature in the Goliat neighbourhood
- **Support of long-distance migration and fill-to-spill mechanism**
- Pre-conceived concepts; Norwegian Barents Sea: exploration retrospective

- Dare to drill; Goliat Jurassic oil discovery: a breakthrough

- Dare to persist; Goliat Triassic oil discovery: a game changer

- DARE TO APPRAISE; Reservoir development

- Goliat legacy
Realgrunnen Subgroup at Goliat

- upper part Realgrunnen Subgroup (Stø & Nordmela fms.): eroded
- lower part Realgrunnen Subgroup (Tubåen & Fruholmen fms.): upper reservoir level at Goliat

- Heterogeneous fluvial-nearshore deposits
- Good to excellent reservoir properties
- Thickness 70-120 m, thickens towards NW
  - Top Reservoir = “Top Realgrunnen”
  - Base Reservoir = Top Snadd
- Strongly compartmentalized by faults
  - 5 hydraulic compartments identified
Kobbe Fm. in Goliat: sedimentological concept & facies model

**Sedimentological concept**

**Regional delta front progradation towards NW**

- **UPPER KOBBE**: mouth bars and terminating fluvial channels of delta front superimposing tidal-influenced lobes of prodelta environment (HST)

- **LOWER KOBBE**: heterogeneous proximal facies (channels and crevasse sands) of LST-TST sequences bounded by a regional MFS at the top.

**Facies model**

- 9 stratigraphic zones: K9 to K1 with progressively lower reservoir quality
- Upper Kobbe (K9-K8): delta front-prodelta HST facies (gross thickness: 32-57 m)
- Lower Kobbe (K7-K1): fluvial facies LST-TST (gross thickness: 173-215 m)
- “Object-based” geostatistical modeling in each zone
- Pre-conceived concepts; Norwegian Barents Sea: exploration retrospective

- Dare to drill; Goliat Jurassic oil discovery: a breakthrough

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- Dare to appraise; Reservoir development

- Goliat legacy
Continuous model refinements & geological knowledge are needed

**Barents Sea Exploration**

**Initial major risks:**
- top seal failure
- leakage
- oil biodegradation
- experienced deeper burial (reservoir efficiency)

**Additional risks:**
- unpredictable reservoir facies distribution
- complex migration pathways

Several dry (or non-economic disc.) wells at basin margins: Alke_Lunde, Zapfe, Heilo, Ensis, Salina, Goliat Eye ...
Eni’s contribution in boosting the ROS\textsubscript{NFW} in Barents Sea exploration: “best in class”

**Exploration activity focus 1991-2017: Barents Sea**

- **Best in class** in rate of exploration success (ROS\textsubscript{NFW}).

- Since its entrance in 1991, Eni Norge is the only one of the «Majors» that did NOT abandon the exploration in Barents Sea.

- Eni Norge success elements (organic growth through exploration: Goliat major contribution):
  - build-up an important database and knowledge-based approach to Barents Sea exploration
  - use of latest technologies available and tailor dedicated R&D projects
  - drilling of appraisal wells to confirm hydrocarbon accumulations

### Production licenses

**Barents Sea**

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**1st Expl. phase 1980-1992**

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**2nd Expl. phase 1993-2017**

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*O: Eni Norge Operator; P: Eni Norge partner by Oct. 2017*
Conclusions (I)

- Goliat discovery in 2000 came after 20 years of exploration drilling in Barents Sea with just one commercial discovery (greater Snøhvit gas field), over 54 exploration wells at that time.

- Prior to Goliat, Barents Sea was largely considered a gas-prone province. Pre-conceived concepts (deriving from intensive 1980’s exploration campaign) included:
  • late Cenozoic glacial-related uplift and erosion (~1-1.5 km) leading to gas expansion and displacement of oil
  • poor reservoir efficiency due to previous deeper burial and then uplift at shallower levels
  • top seal integrity and breaching, leaking shallow faults, possible biodegradation at shallow accumulations

- Integration of available geochemistry, PSM, pressure data and well considerations led Eni Norge to envisage and realise, earlier than others:
  • possible long-distance migration through fill-to-spill mechanisms
  • a current dynamic fluid-flow system in western Barents Sea, with current active HC migration/re-migration from west toward east against the basin margins.
Conclusions (II)

- **Goliat Jurassic oil discovery (2000-2001) (uppermost Triassic reservoir): a breakthrough**
  - innovative geological concept of “long-distance” migration (tens of kilometres distances through a fill-to-spill mechanisms) and oil entrapment at “basin margins/borders”

- **Goliat Triassic oil discovery (2005) (Middle Triassic reservoir): a game changer**
  - oil discovery in Middle Triassic Kobbe Fm. opened a new play concept, Middle Triassic play, against the Jurassic dominant siliciclastic play in Barents Sea until that time
  - provided a solid base of reserves (main oil pool at Goliat)

- **Goliat paradigm (knowledge-based approach & persistence) take-away messages:**
  - Dare to drill
  - Dare to persist
  - Dare to appraise

  paid off at Goliat turning an initially pre-conceived high-risk prospect into a valuable discovery and providing a solid basis for a viable development, the first oil development in Norwegian Arctic
Acknowledgements

- **PL229 partner:**
  - Statoil Petroleum AS

- **Session Chairs & particularly Jonathan Craig**