

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

Blaich, O.A., F. Tsikalas, and J.I. Faleide, 2017, New Insights into the Tectono-Stratigraphic Evolution of the Southern Stappen High and its Transition to Bjørnøya Basin: *Marine and Petroleum Geology*, v. 85, p. 89-105.

Dypvik, H., F. Tsikalas, and M. Smelror (eds.), 2010, *The Mjølnir Impact Event and Its Consequences: Geology and Geophysics of a Late Jurassic/Early Cretaceous Marine Impact Event*: Springer Science and Business Media, 318 p.

Evans, D., C. Graham, A. Armour, and P. Bathurst, 2003, *The Millennium Atlas: Petroleum Geology of the Central and Northern North Sea*: Geological Society London, 390 p.

Halland, E.K., J. Mujezinovic, and F. Riis, 2014, *CO₂ Storage Atlas: Norwegian Continental Shelf*, Norwegian Petroleum Directorate, Norway, 163 p.

Henriksen, E., A.E. Ryseth, G.B. Larssen, T. Heide, K. Rønning, K. Sollid, and A.V. Stoupakova, 2011, Tectonostratigraphy of the Greater Barents Sea: Implications for Petroleum Systems, *in* A.M. Spencer, A.F. Embry, D.L. Gautier, A.V. Stoupakova, and K. Sørensen (eds.), *Arctic Petroleum Geology*, v. 35, Geological Society, London, *Memoirs*, p. 163-195.

Knies, J., J. Matthiessen, C. Vogt, J.S. Laberg, B.O. Hjelstuen, M. Smelror, E. Larsen, K. Andreassen, T. Eidvin, and T.O. Vorren, 2009, The Plio-Pleistocene Glaciation of the Barents Sea-Svalbard Region: A New Model based on Revised Chronostratigraphy: *Quaternary Science Review*, v. 28/9, p. 812-829.

Ohm, S.E., D.A. Karlsen, and T.J.F. Austin, 2008, Geochemically Driven Exploration Models in Uplifted Areas: Examples from the Norwegian Barents Sea: *American Association of Petroleum Geologists Bulletin*, v. 92, p. 1191-1223.

Spencer, A.M., P.I. Briskeby, L.D. Christensen, R. Foyen, M. Kjølleberg, E. Kvadsheim, I. Knight, M. Rye-Larsen, and J. Williams, 2008, *Petroleum Geoscience in Norden – Exploration, Production and Organization: Episodes*, v. 31, p. 115-124.

Torsvik, T.H., D. Carlos, J. Mosar, R.M. Cocks, and T.N. Malme, 2002, Global Reconstructions and North Atlantic Paleogeography 440 Ma to Recent, *in* E.A. Eide (ed.), Mid Norway Plate Reconstructions Atlas with Global and Atlantic Perspectives: Geological Survey of Norway, p. 18-39.

Torsvik, T.H., C. Gaina, and T.F. Redfield, 2008. Antarctica and Global Paleogeography: From Rodinia, through Gondwanaland and Pangea, to the Birth of the Southern Ocean and the Opening of Gateways, *in* A.K. Cooper, P.J. Barrett, H. Stagg, B. Storey, E. Stump, W. Wise, and the 10th ISAES editorial team (eds.), Antarctica: A Keystone in a Changing World: Proceedings of the 10th International Symposium on Antarctic Earth Sciences, Washington, DC, The National Academies Press, p. 125-140.

Torsvik, T.H., R.D. Müller, R. Van der Voo, B. Steinberger, and C. Gaina, 2008, Global Plate Motion Frames: Toward a Unified Model: Reviews Geophysics, v. 46/3, RG3004, 44 p.



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

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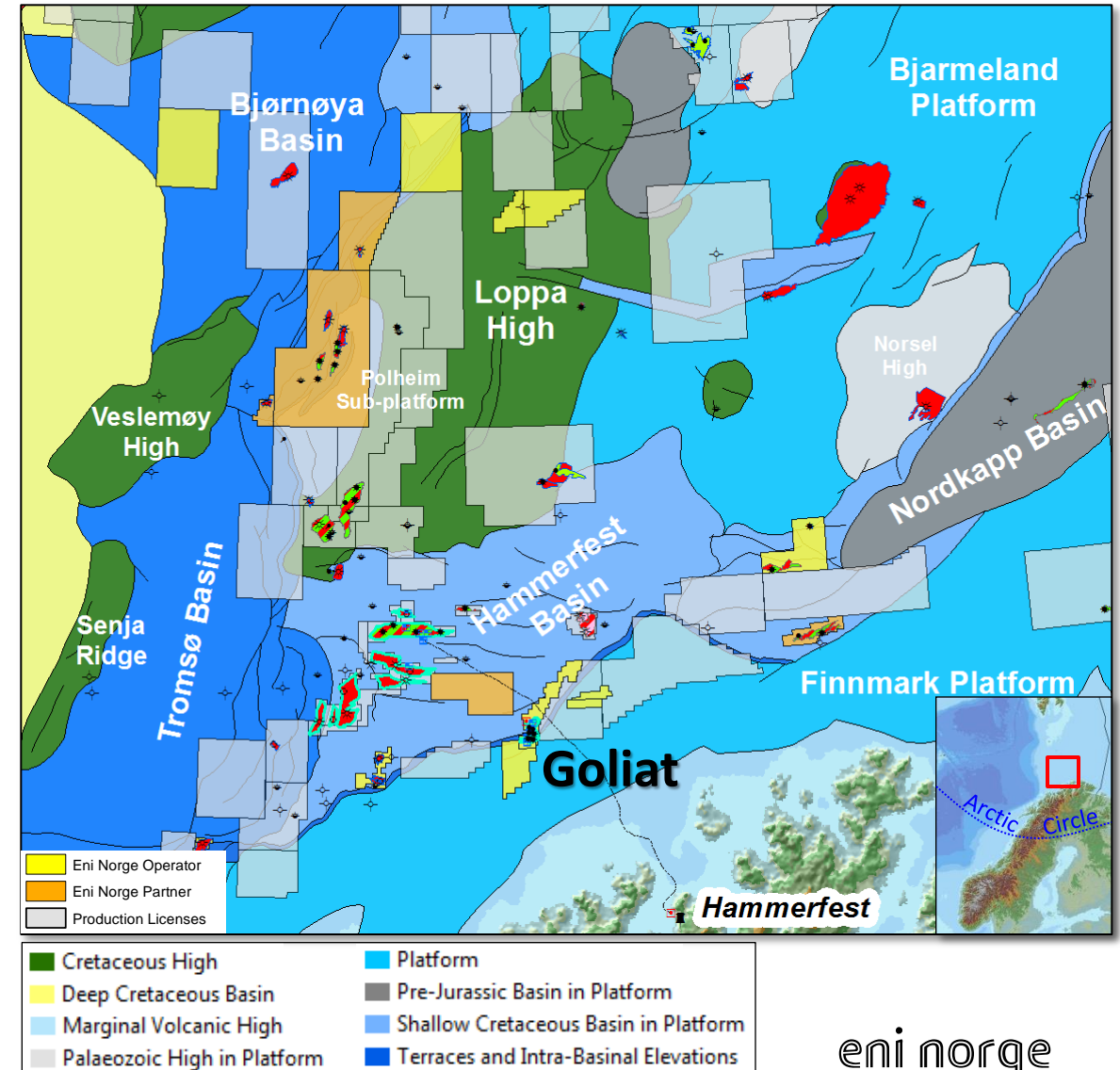
¹*Eni Norge, Stavanger, Norway*

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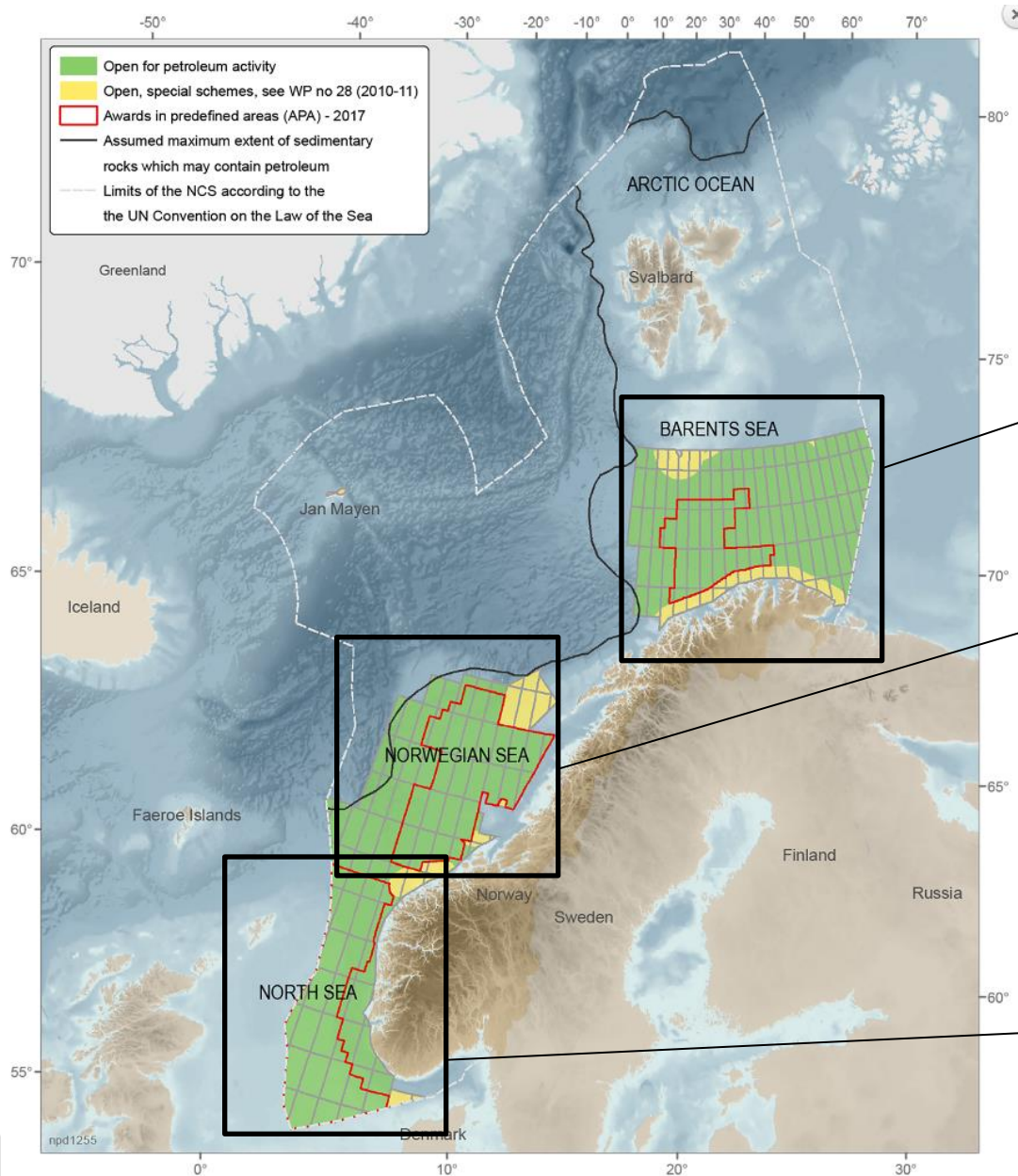
Outline



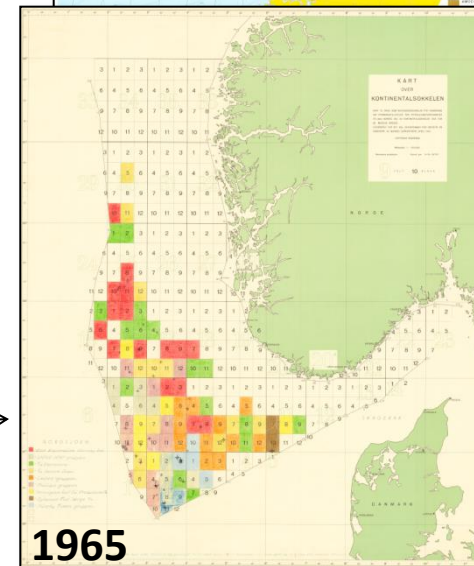
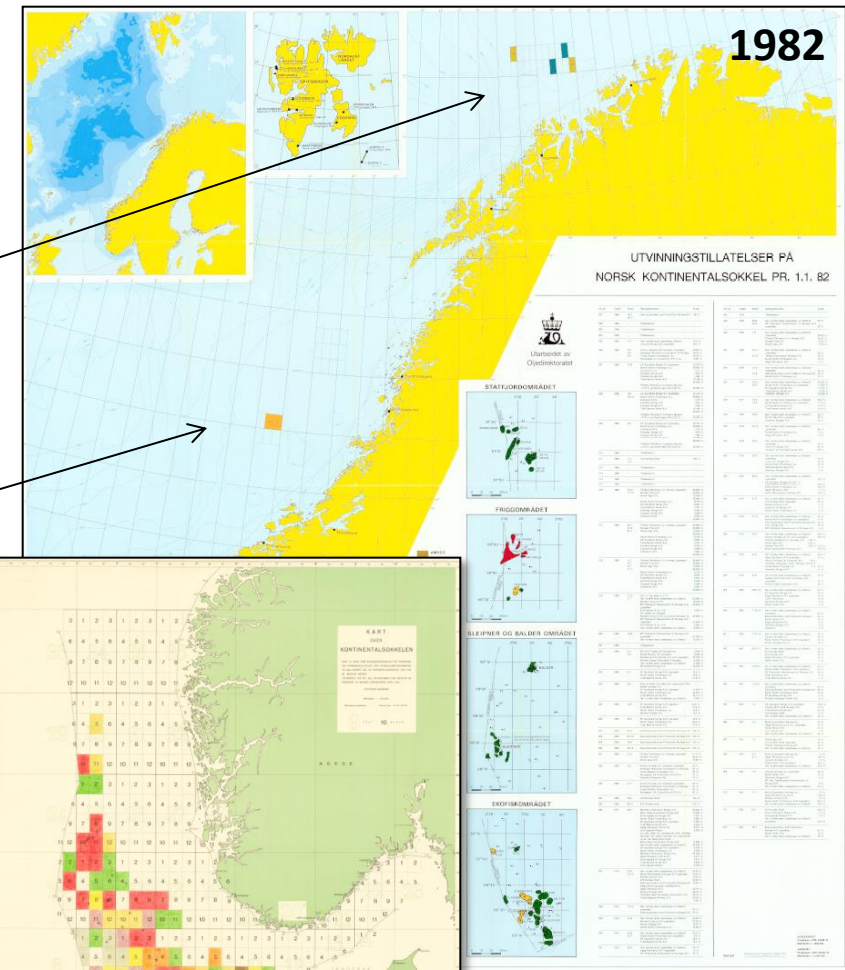
- *Pre-conceived concepts; Norwegian Barents Sea: exploration retrospective*
- *Dare to drill; Goliat Jurassic oil discovery: a breakthrough*
- *Dare to persist; Goliat Triassic oil discovery: a game changer*
- *Dare to appraise; Reservoir development*
- *Goliat legacy*



Norwegian Continental Shelf: exploration retrospective

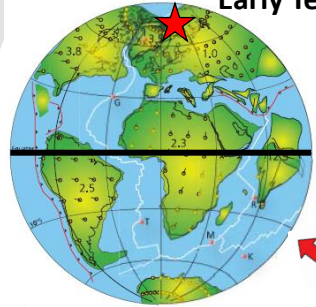


Opened since 1979








NPD-FactPages

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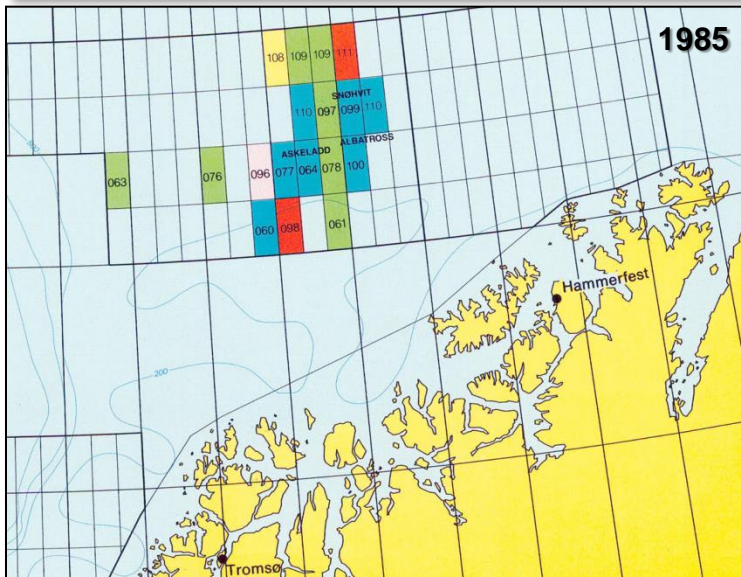
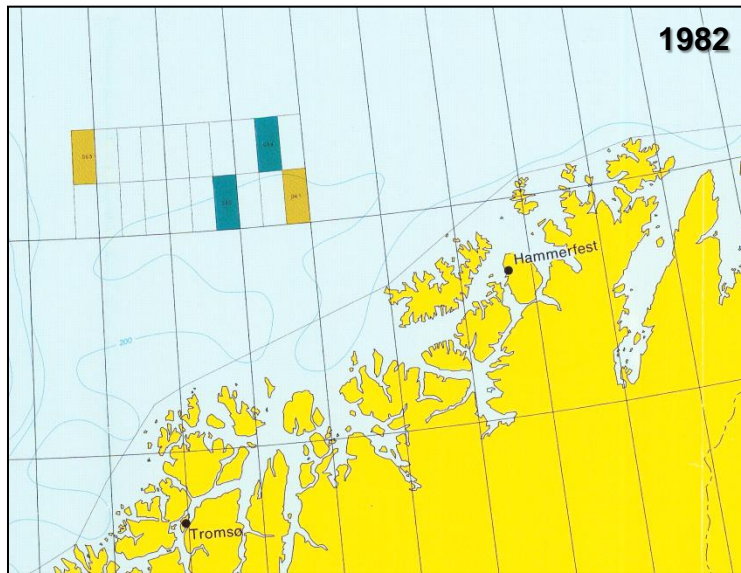


Torsvik et al. (2002)

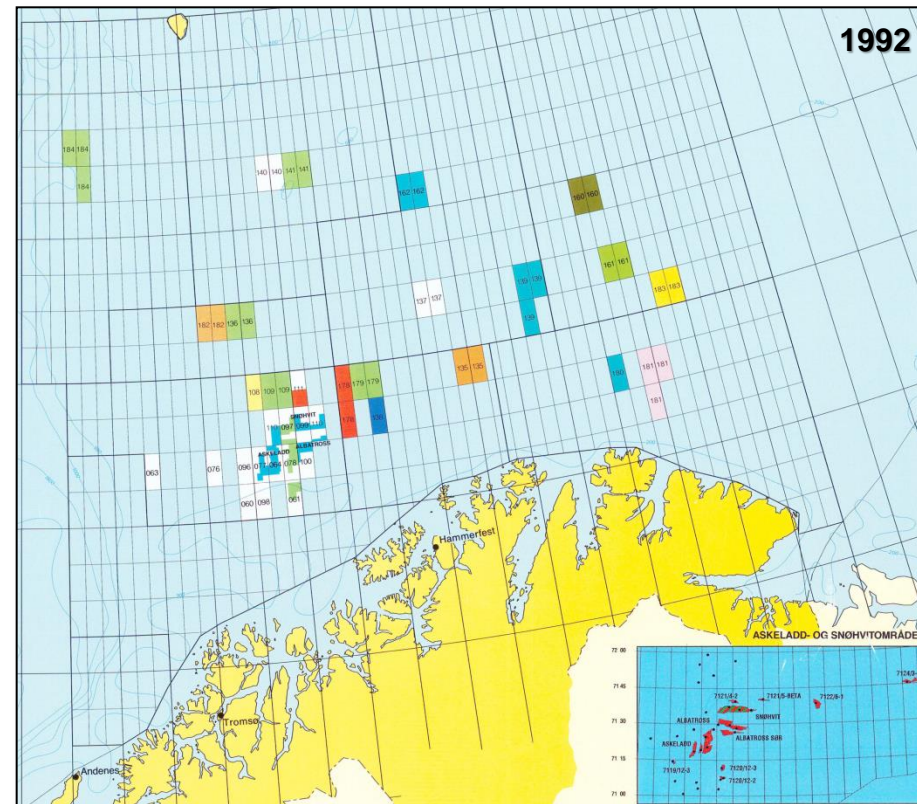


 Fluvial sandstones
  Marginal marine sandstones
  Shales
  Organic rich shales
 Sandy limestones
  Limestones
  Dolomites/Evaporites
  Spiculates
  Coal

Norwegian Barents Sea: 1st exploration campaign/season (1980-1992)



- 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

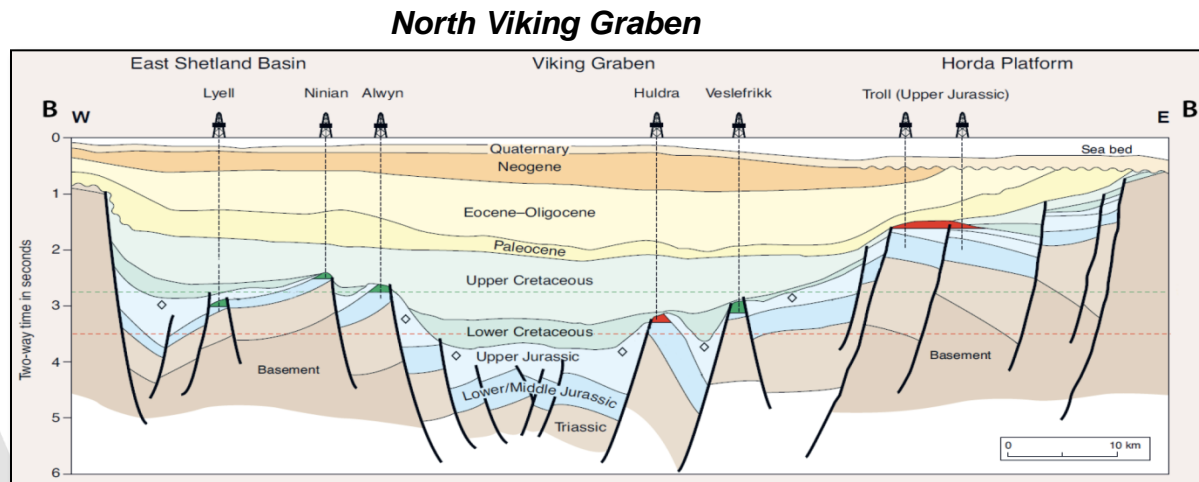


The first season in the Hammerfest and Tromsø basins (1980's)

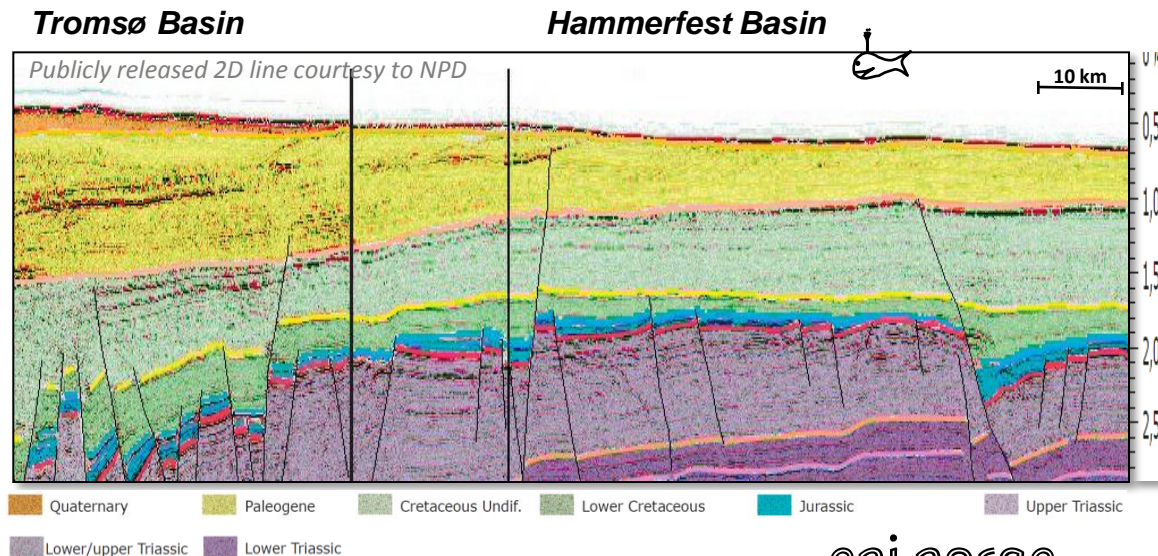


Seismic mapping showed that the mission should be harvesting the same successful plays as those in Northern North Sea:

- 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



Evans et al. (2003), Halland et al. (2014)

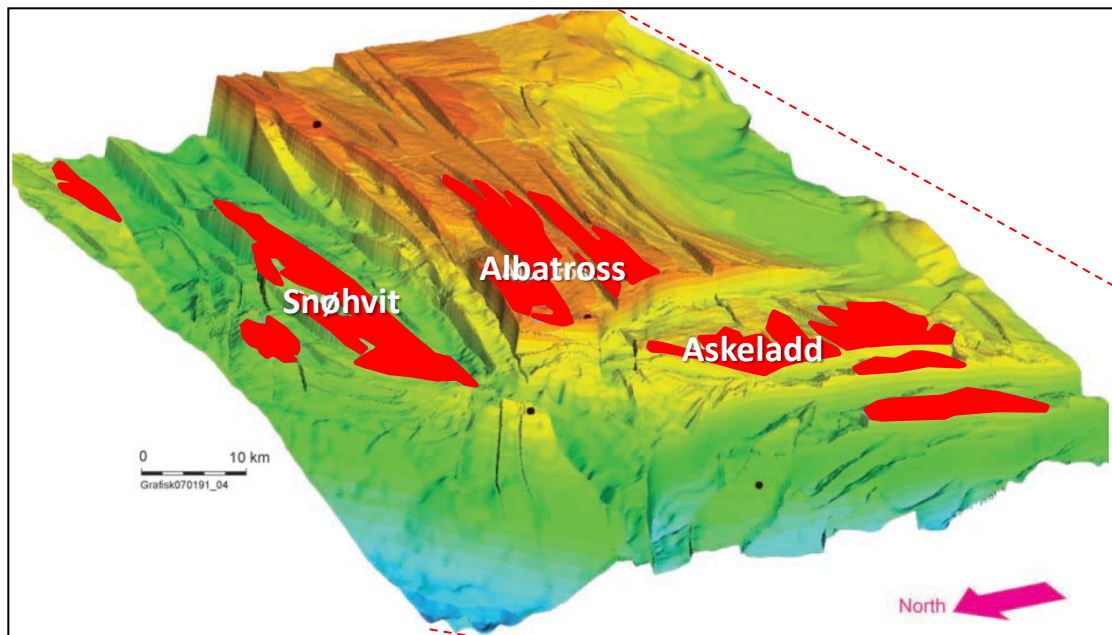


First season exploration campaign (1980's): outcomes



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

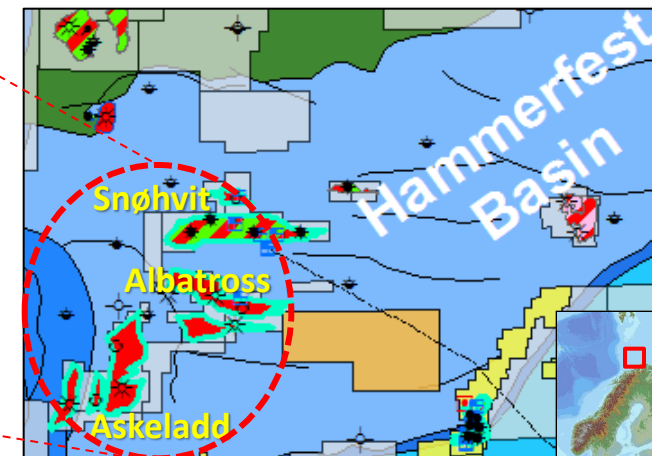


Spencer et al. (2008)

Original recoverable reserves:

223 GSm³ (7.9 Tcf) Gas
25.8 MSm³ condensate
8,1 million tonnes NGL

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)

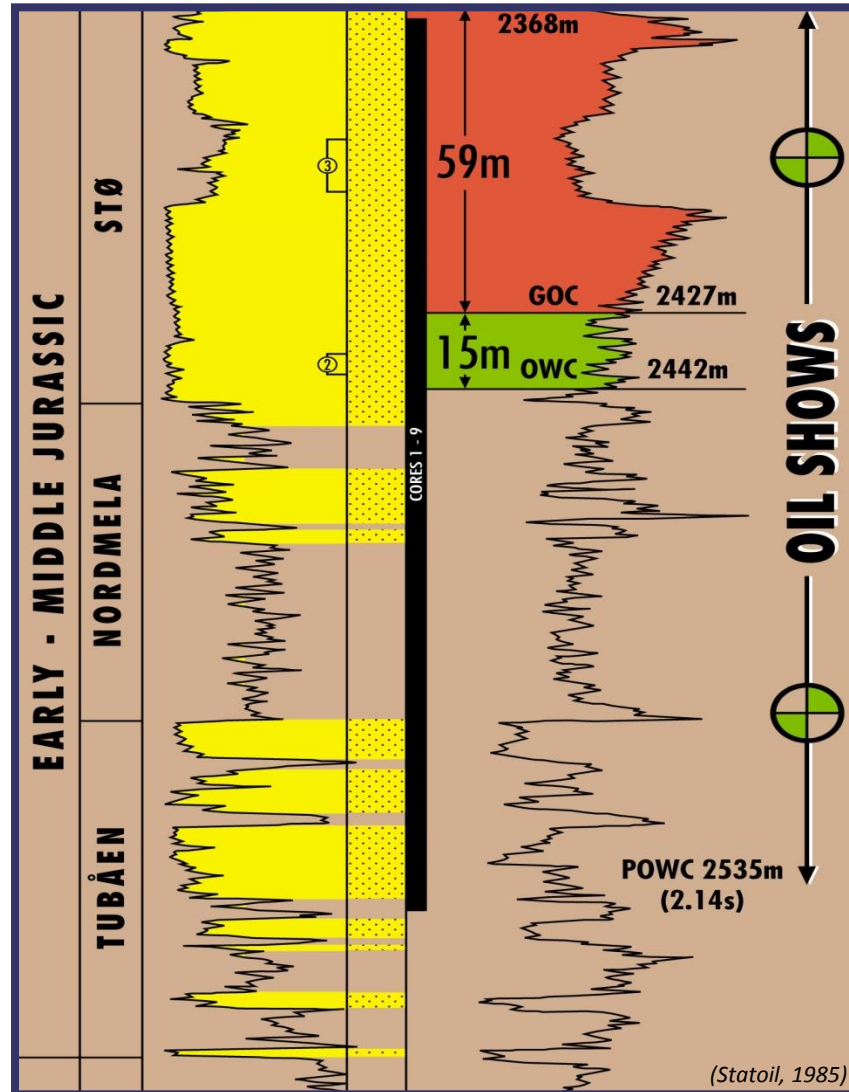


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Thick oil staining (paleo HC-column) (in several wells) & thin oil leg (below gas column) (in few wells)



Snøhvit - Well 7121/5-1

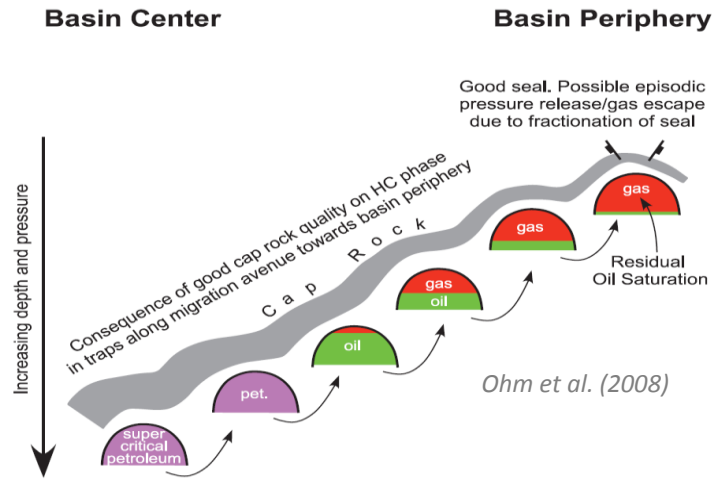


Snøhvit: 60-230 m gas column
14-17 m oil column

Paleo - Oil column
167 m

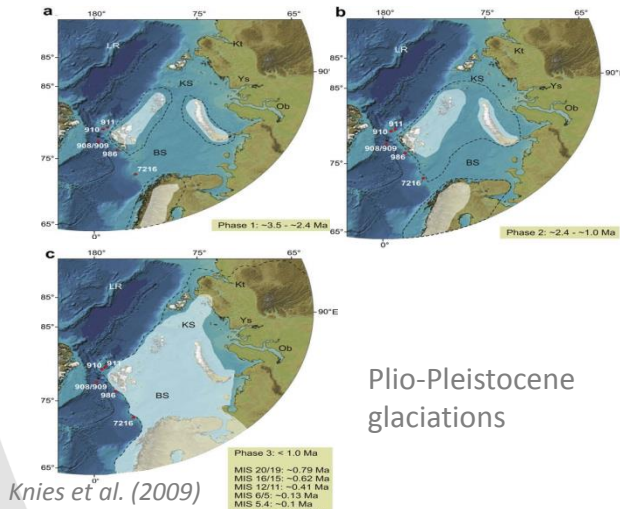
Paleo - Oil/Water contact
2535 m

The second exploration season in the Hammerfest Basin (mid-late 1990's): Pre-conceived concepts prior to Goliat Discovery

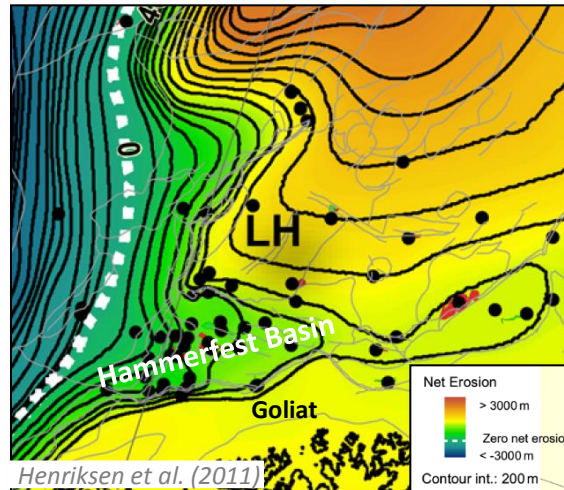


Uplift led to gas expansion and displacement of oil; “aqua fissante theory”

Uplift/erosion estimates

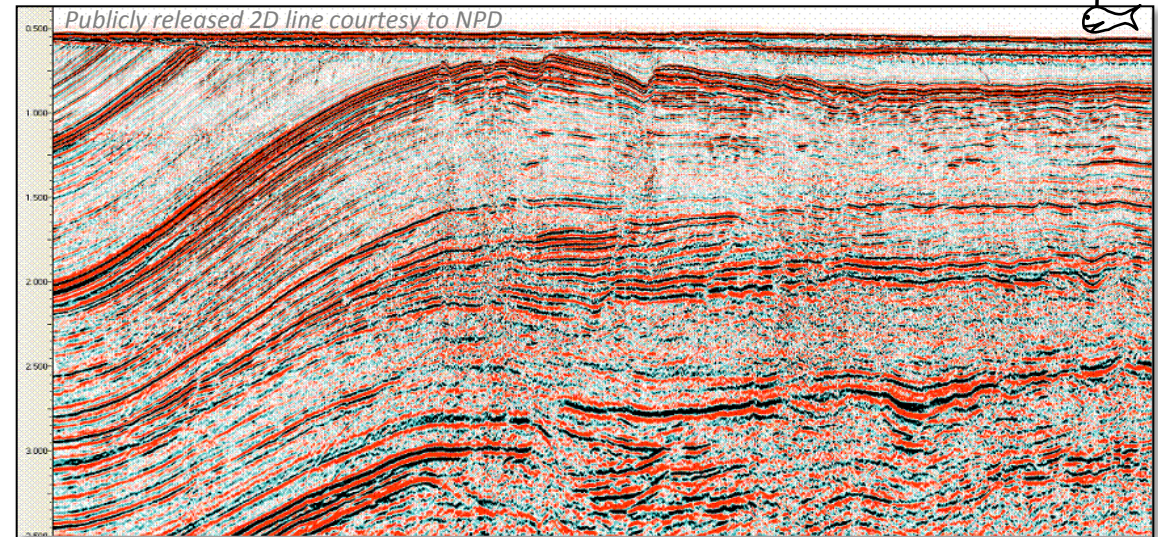
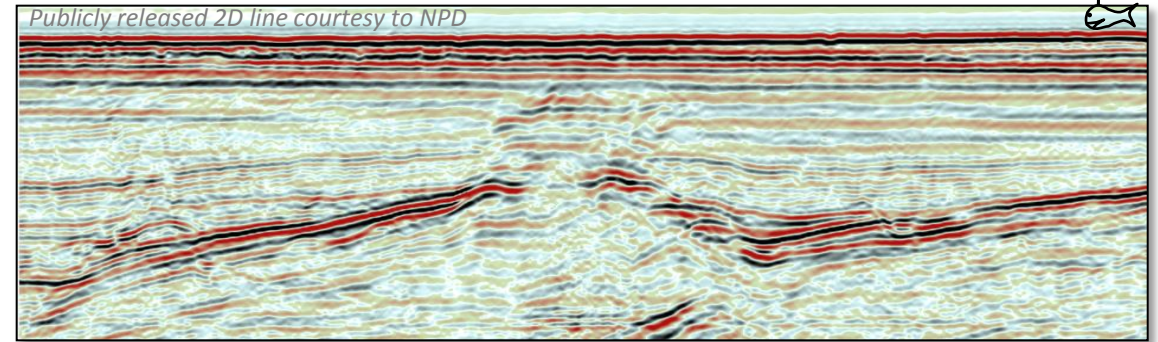


Plio-Pleistocene glaciations



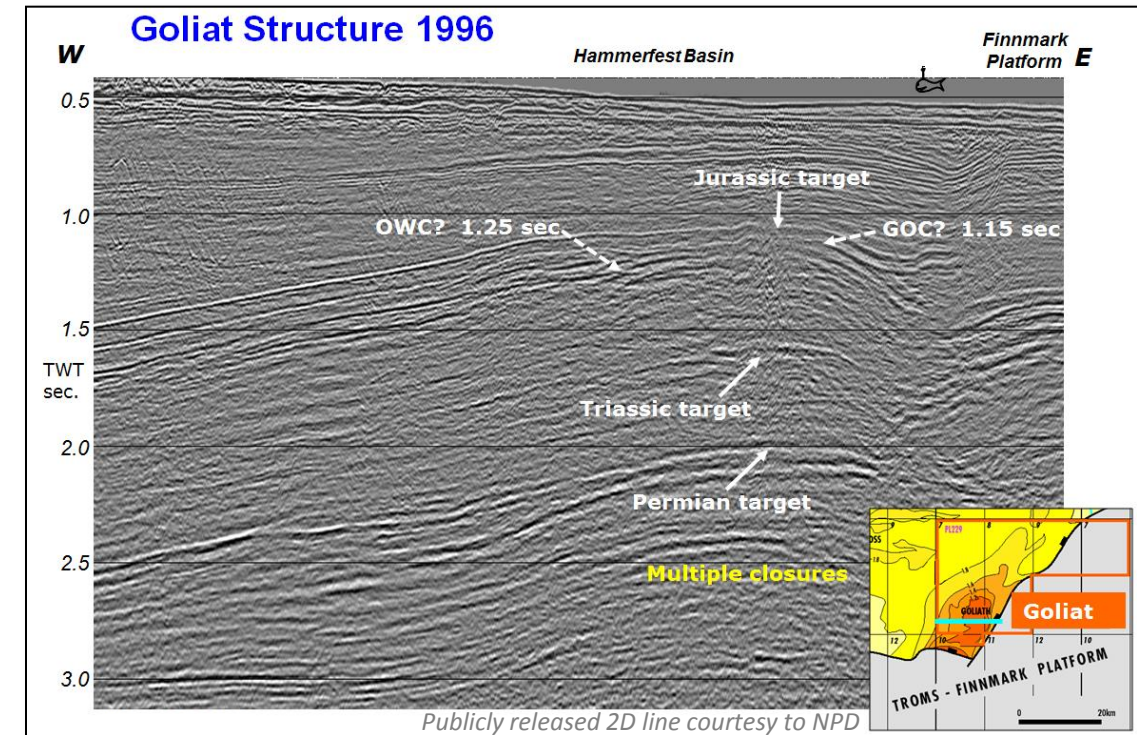
Poor reservoir quality due to **previous deeper burial**

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



Shallow faults will **destroy an efficient seal**

- *Pre-conceived concepts; Norwegian Barents Sea: exploration retrospective*
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PL229: Hammerfest Basin margin (1996/1997) & Goliat Structure 1996: 2D seismic profile



Finnmark
Platform E

PL229: awarded May 1997

(Barents Sea Project-1997)

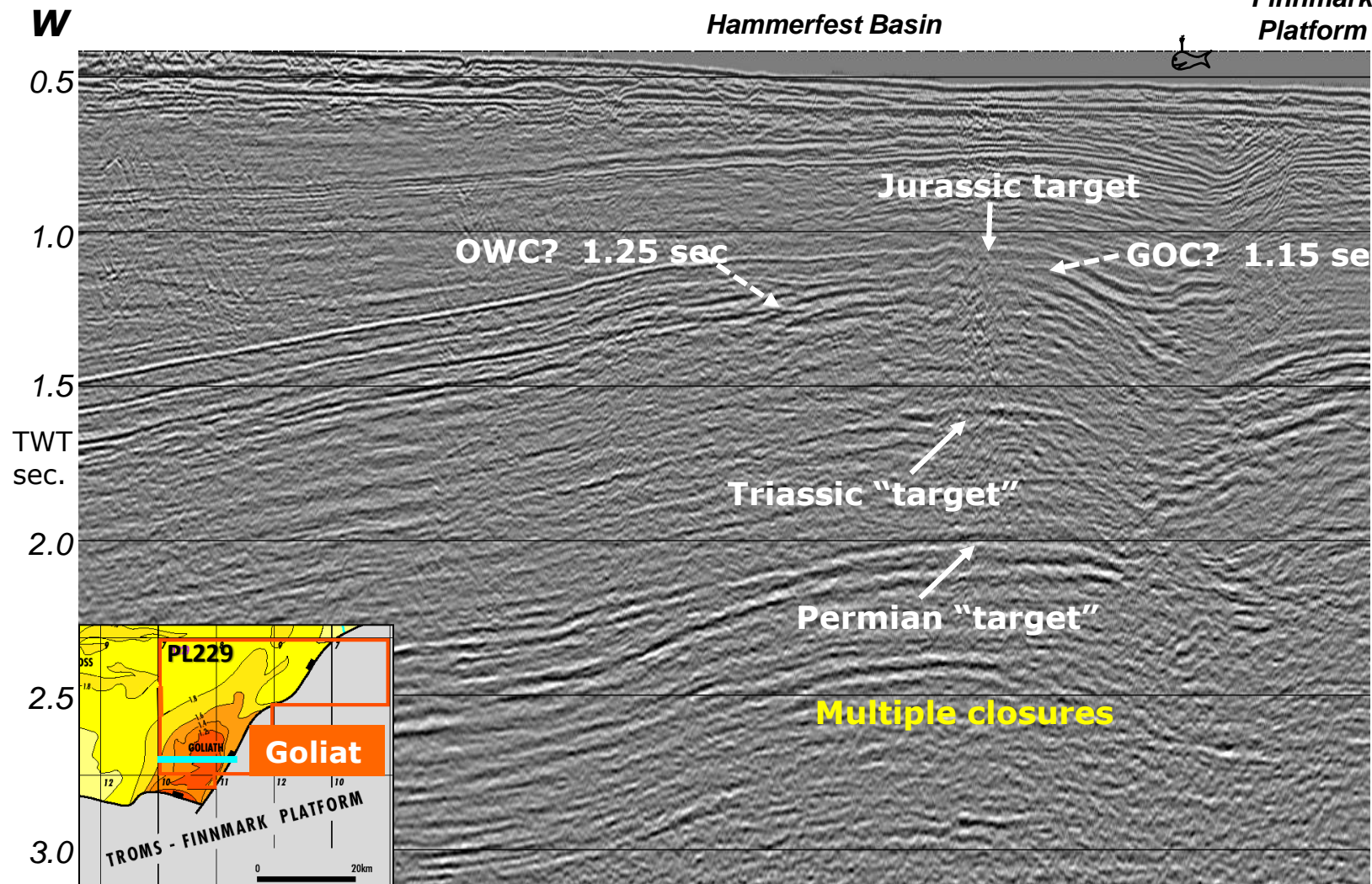
Norsk Agip	(25%)	Operator
Phillips Petroleum	(25%)	
Statoil	(20%)	
Enterprise Oil	(15%)	
Neste Petroleum	(15%)	

Work commitment:

150 km² 3D seismic & 1 well into Permian

PL229/PL229B/229D (2017):

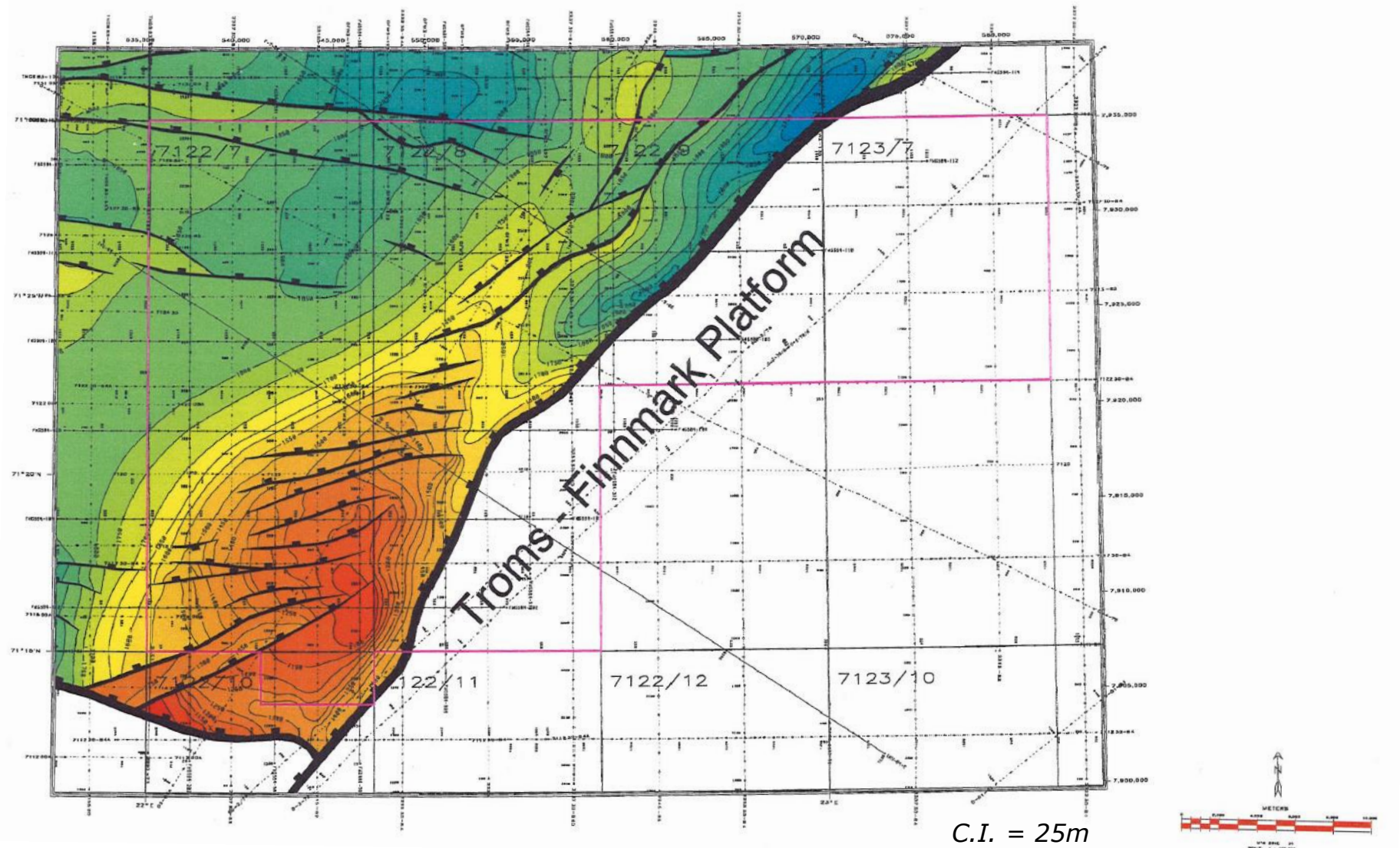
Eni Norge AS	(65%)	Op.
Statoil Petroleum AS	(35%)	



Publicly released 2D line courtesy to NPD

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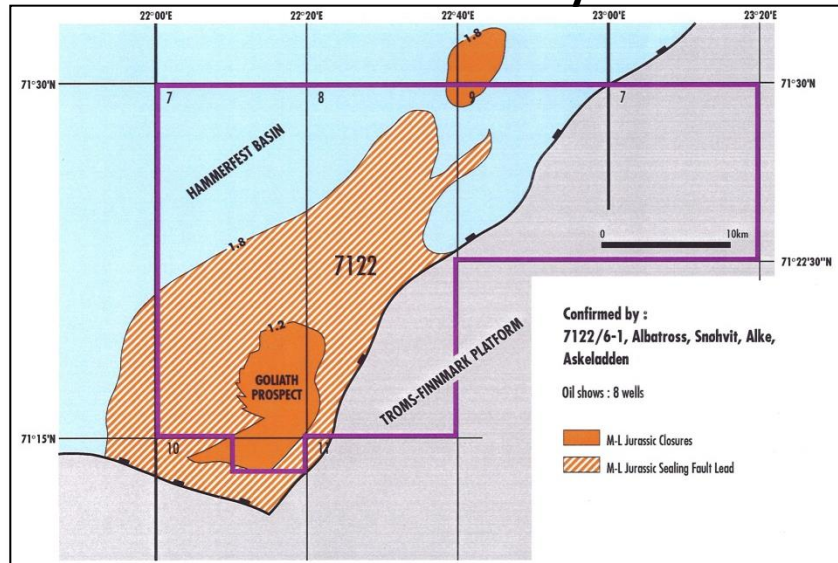
Goliat: Jurassic reservoir depth (2D data) (1996)



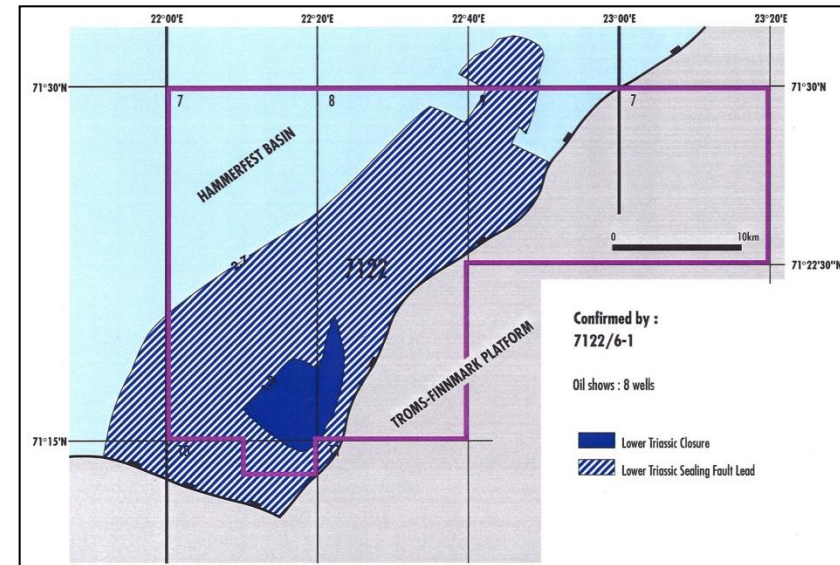
Goliath play models (1996)



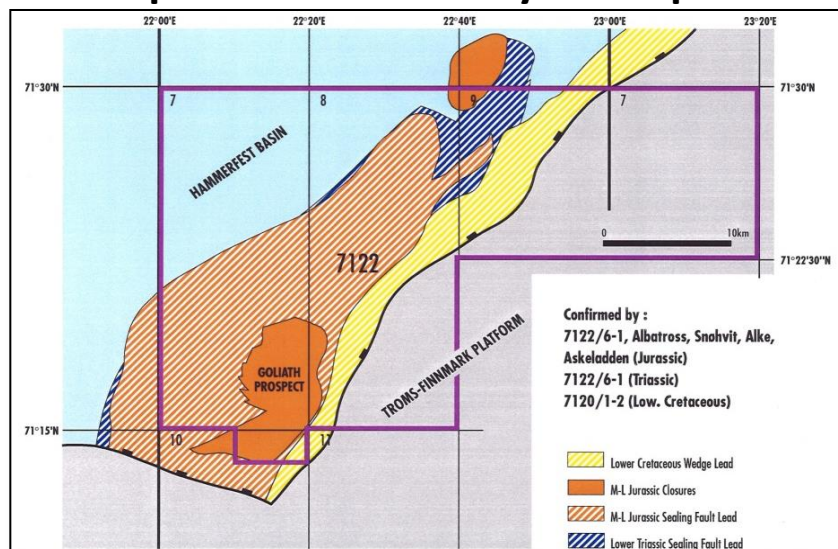
Lower-Middle Jurassic Play Model



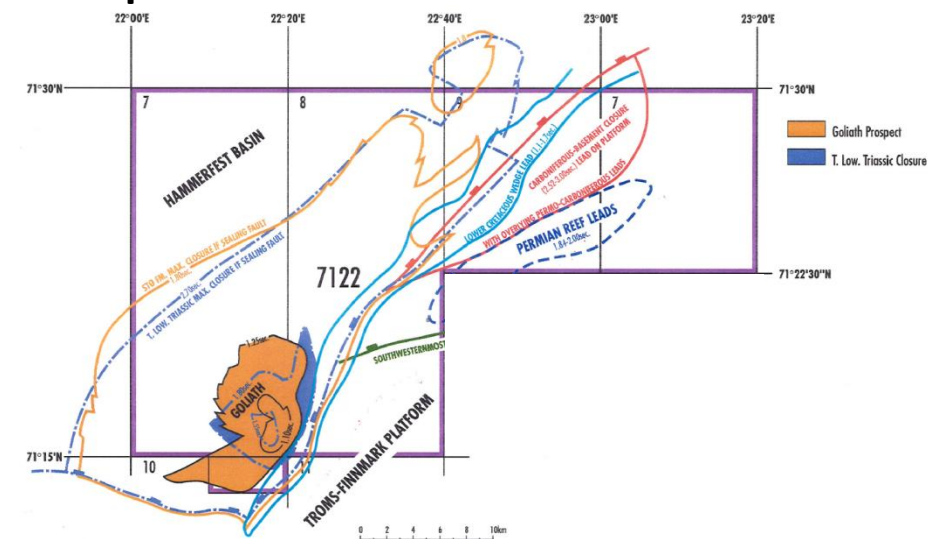
Lower Triassic Play Model



Compiled Mesozoic Play Concepts



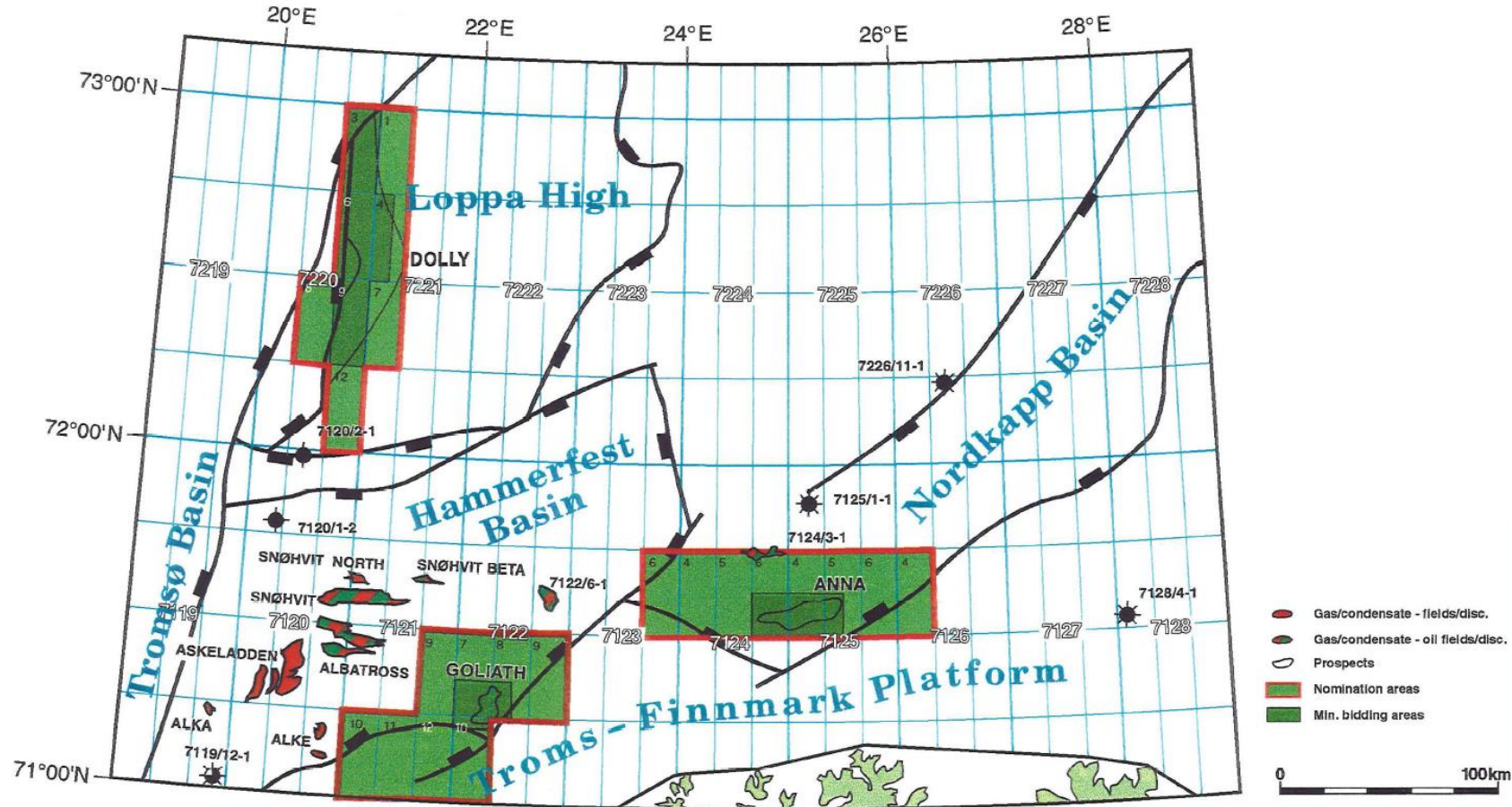
Prospects & Leads



Nominated areas (1996) → Driver: basin margin boundaries



AEN-Group (Norsk Agip/Enterprise/Neste)



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)*

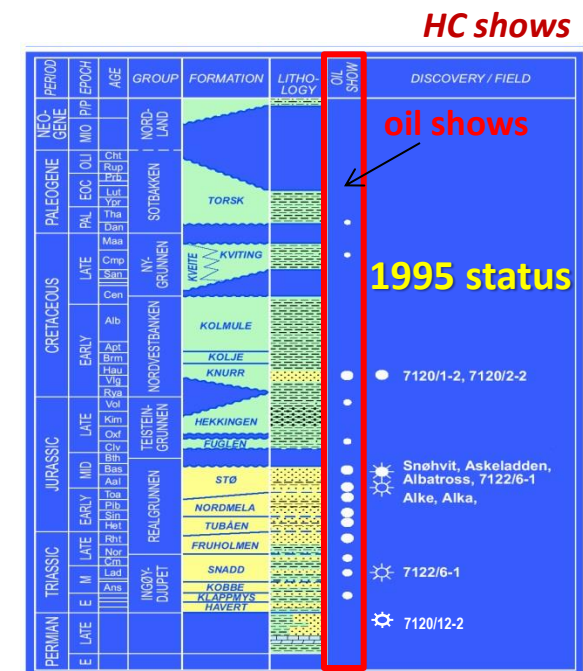
- Hammerfest Basin: Upper Jurassic SR (Hekkingen Fm.):
 - not mature within basin;
 - mature only at western part of Hammerfest Basin and at transition to Tromsø Basin

- **Long distance migration (tens of kilometres)**

Key issues: Goliat as a hydrocarbon migration/dis-migration focus area



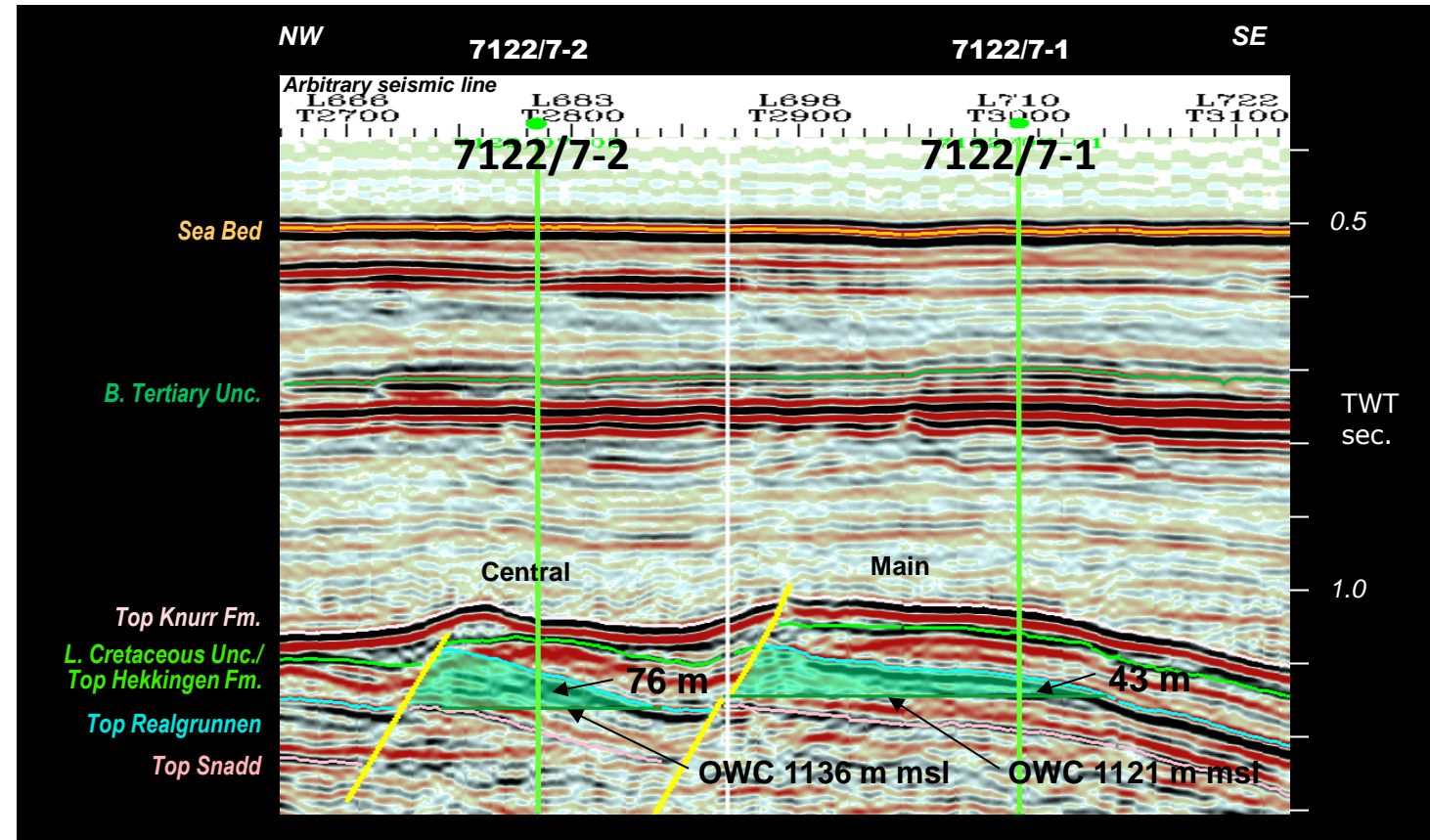
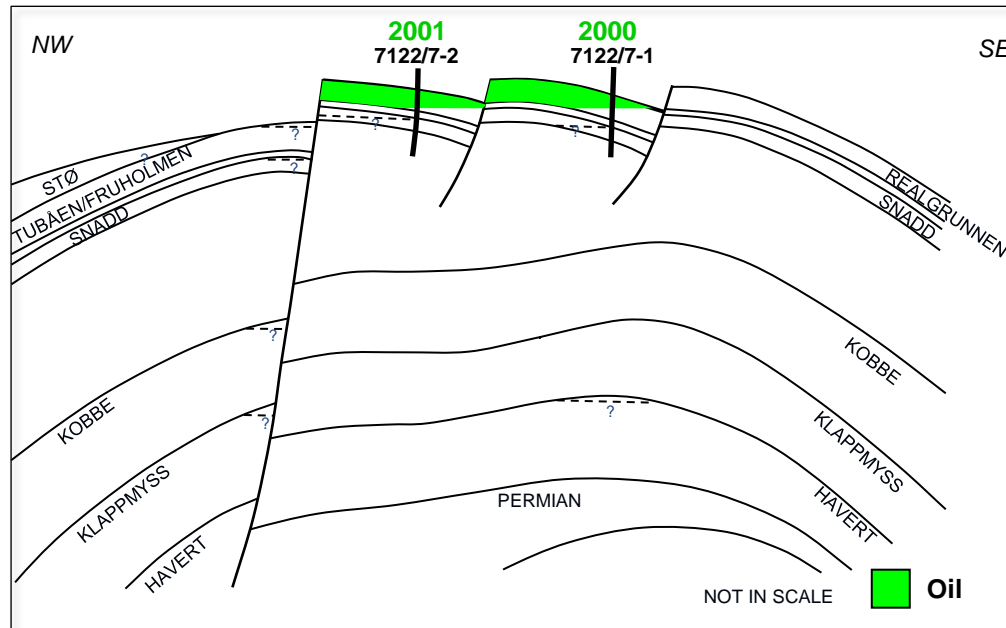
- Paleo-oil column in Albatross/ "greater Snøhvit area" reveals fill-to-spill towards east & south:
Goliat is a hydrocarbon migration/dis-migration focus area
- Late Cenozoic glacial uplift/erosion & related isostatic tilting
- Shows at several (almost all) stratigraphic levels



First exploration wells at Goliat (2000 & 2001): a breakthrough

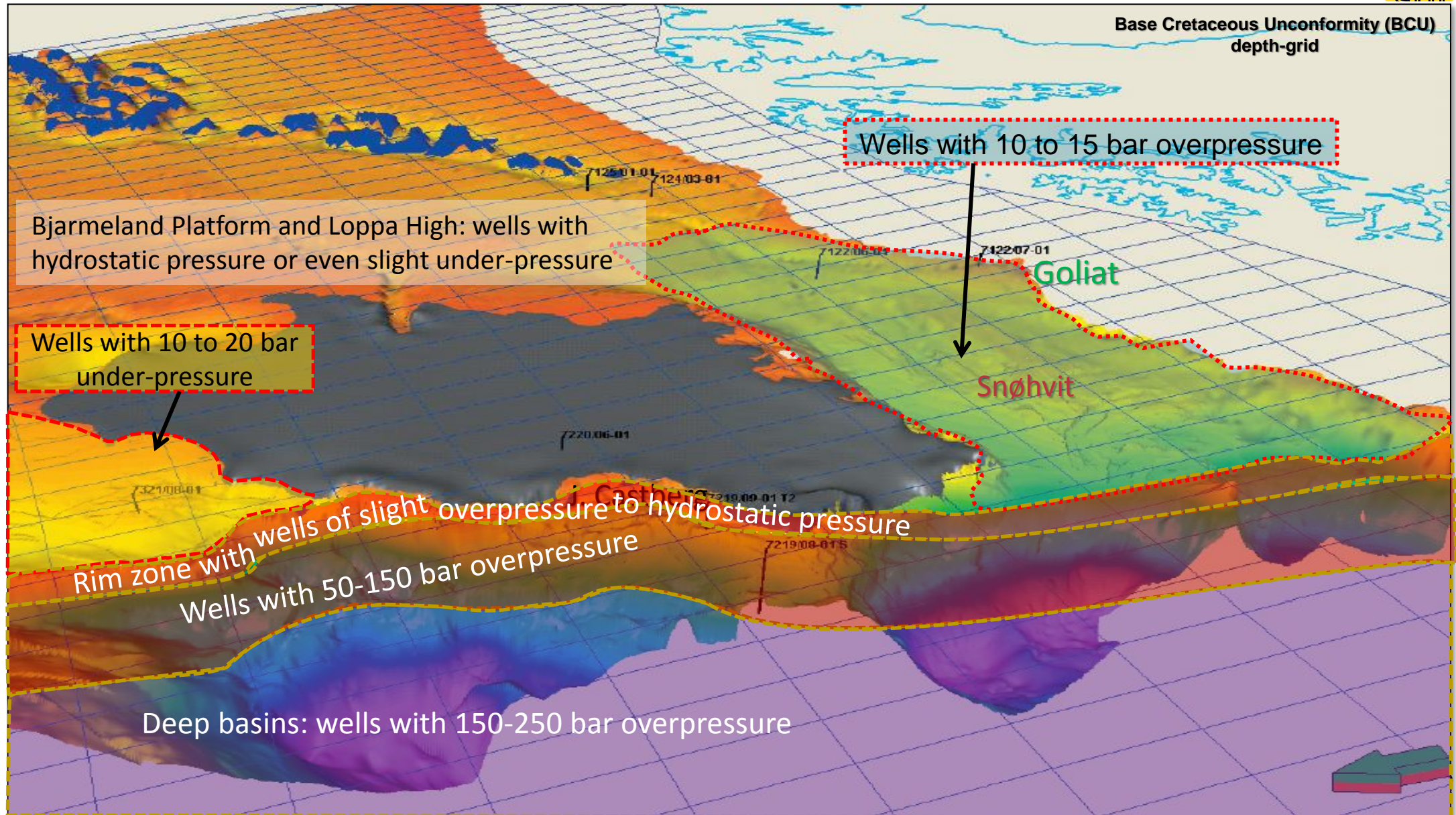


Goliat (2000-2001) well results: long distance migration & fill-to-spill: PROVED!!

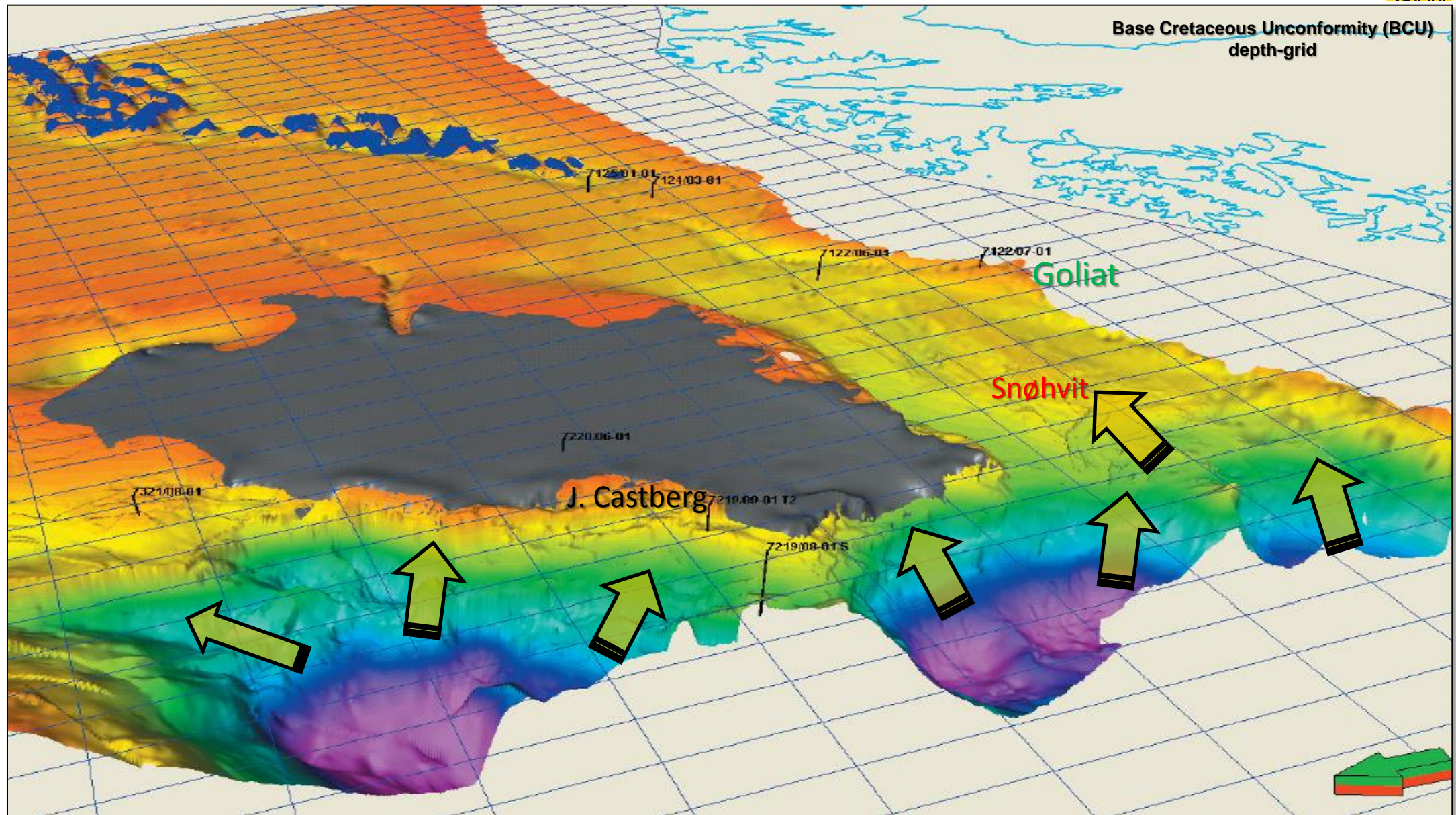


Publicly released 2D line courtesy to NPD

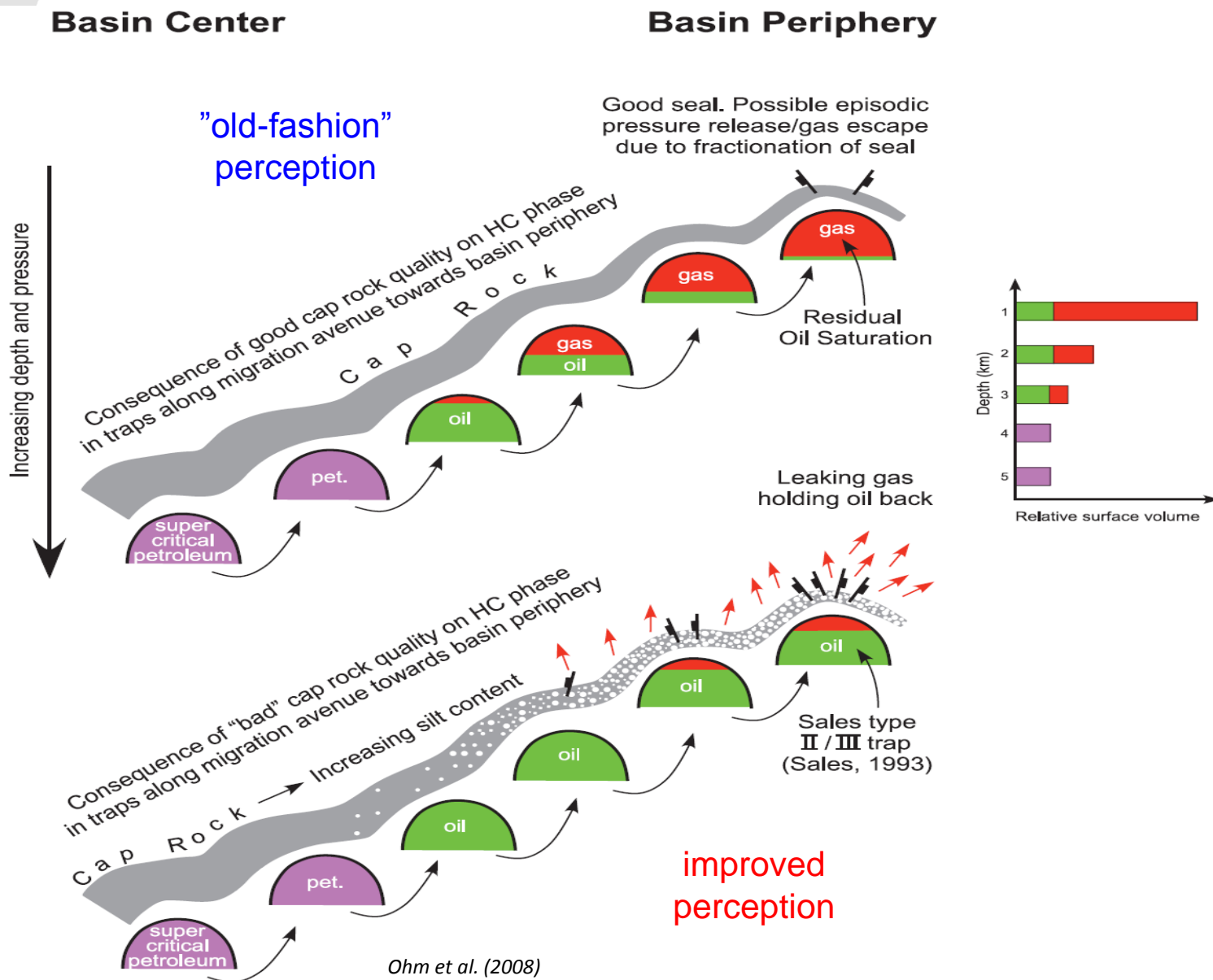
Southwestern Barents Sea: pressure regime



Current dynamic fluid-flow system



Uplift, pressure & fluid model in SW Barents Sea: elaboration of possible scenarios: Eni perceptions



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

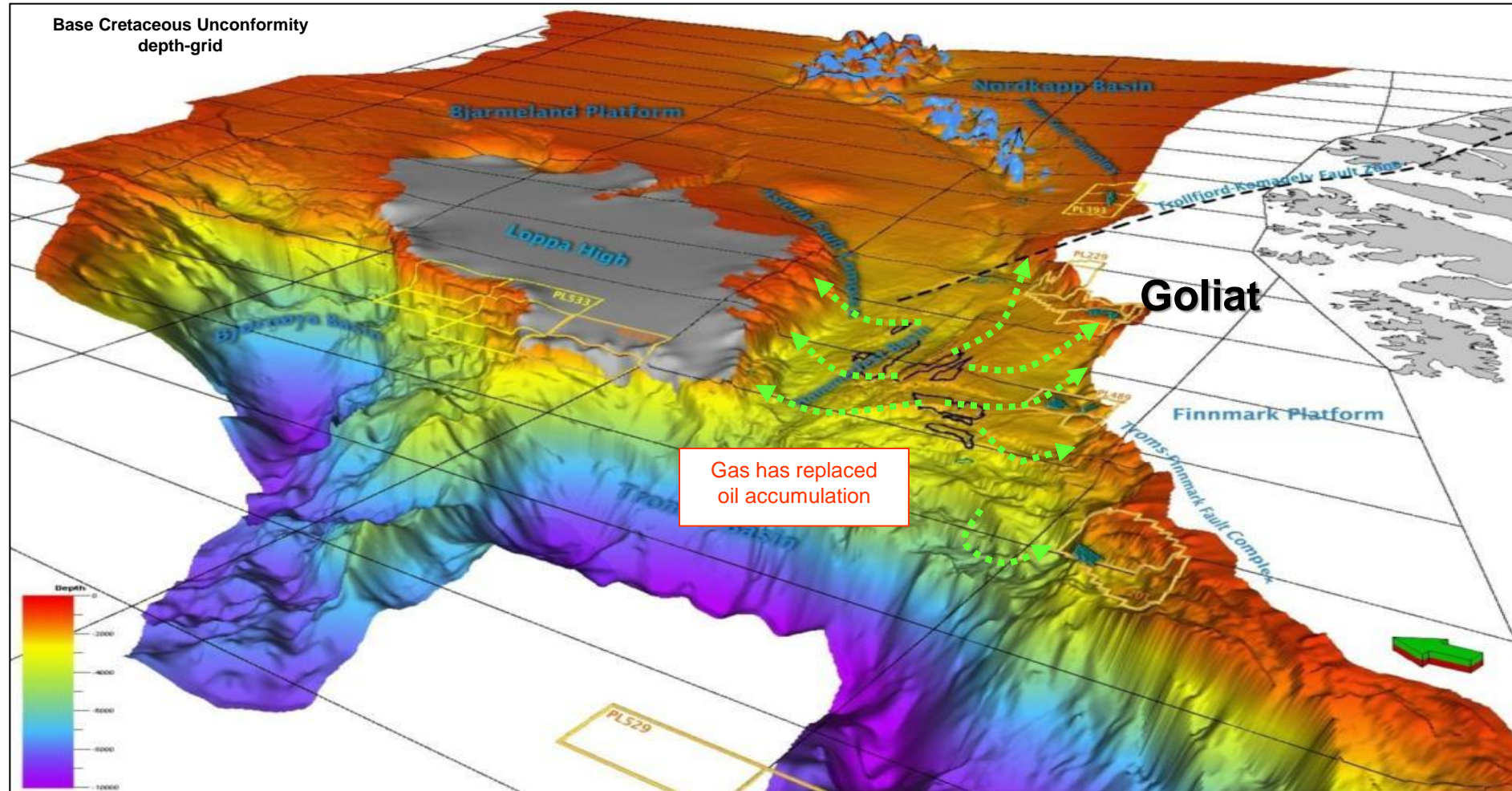
Pressure gradient in the west:

- 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)

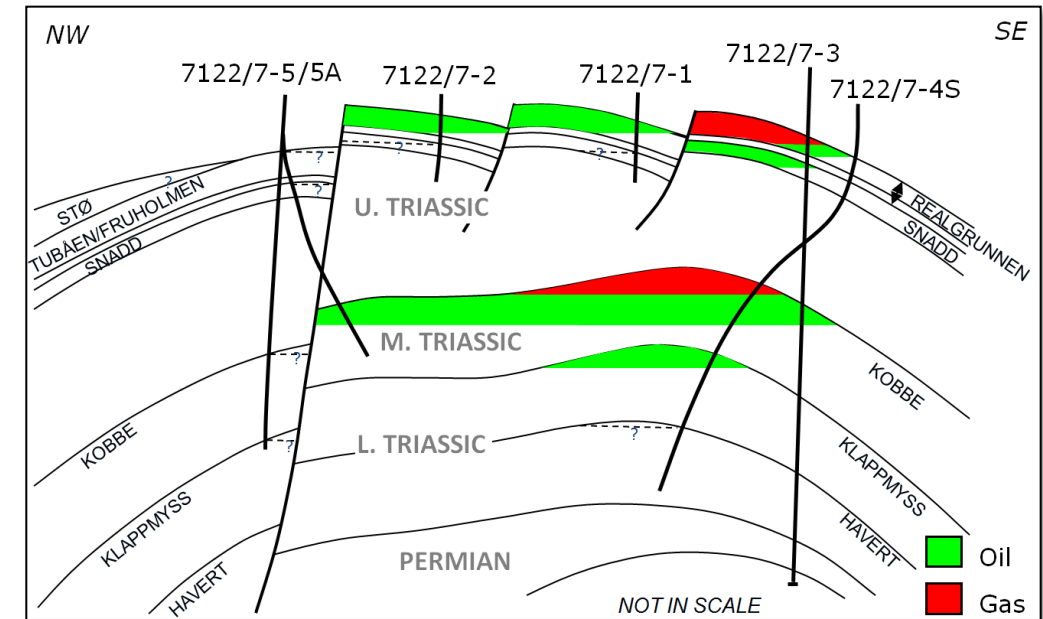
3. Migration shadows

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

Goliat Realgrunnen oil pool discovery (2000 & 2001): a breakthrough



- *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*



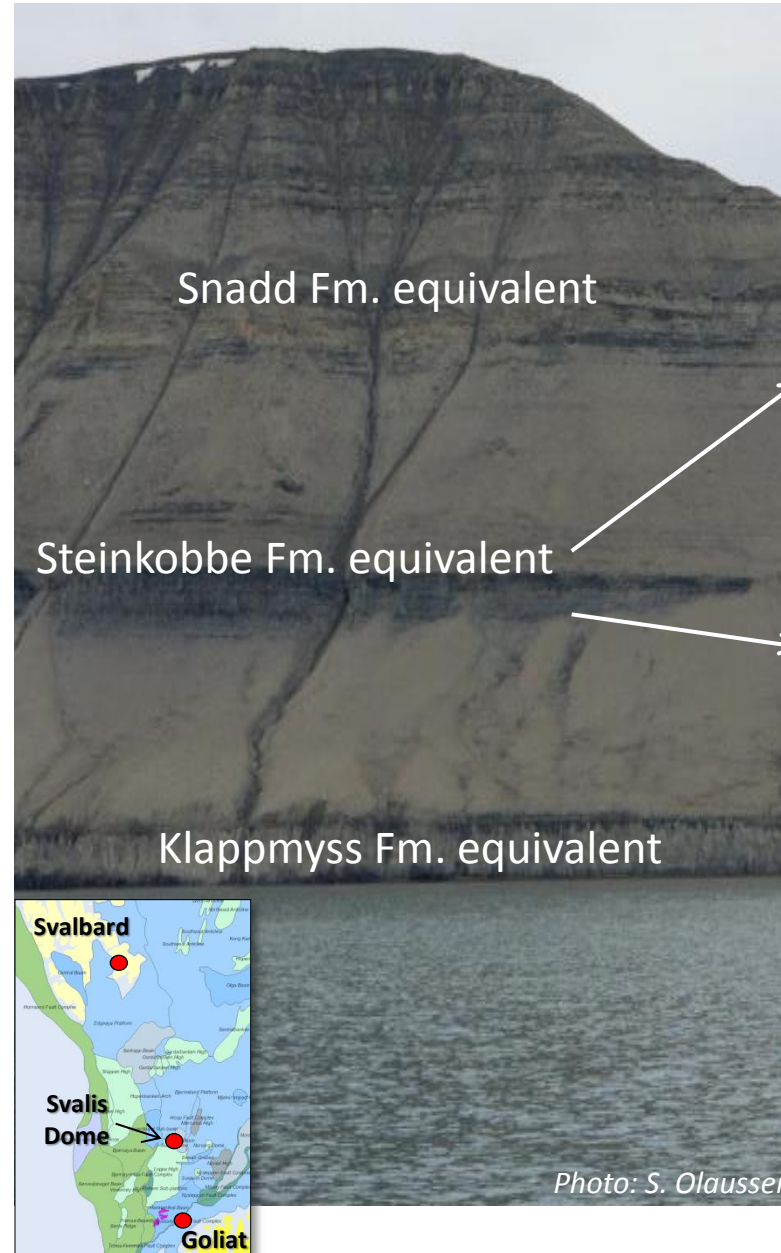
Key issues: Triassic source rock and potential Triassic play



- **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**

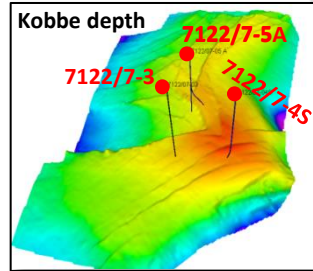
Blanknuten Member (Anisian/Ladinian) is rich in Amorphous Organic Matter (75-90%) and shows **very good - oil prone source properties**

Goliat Triassic oil pool discovery (2005): a game changer

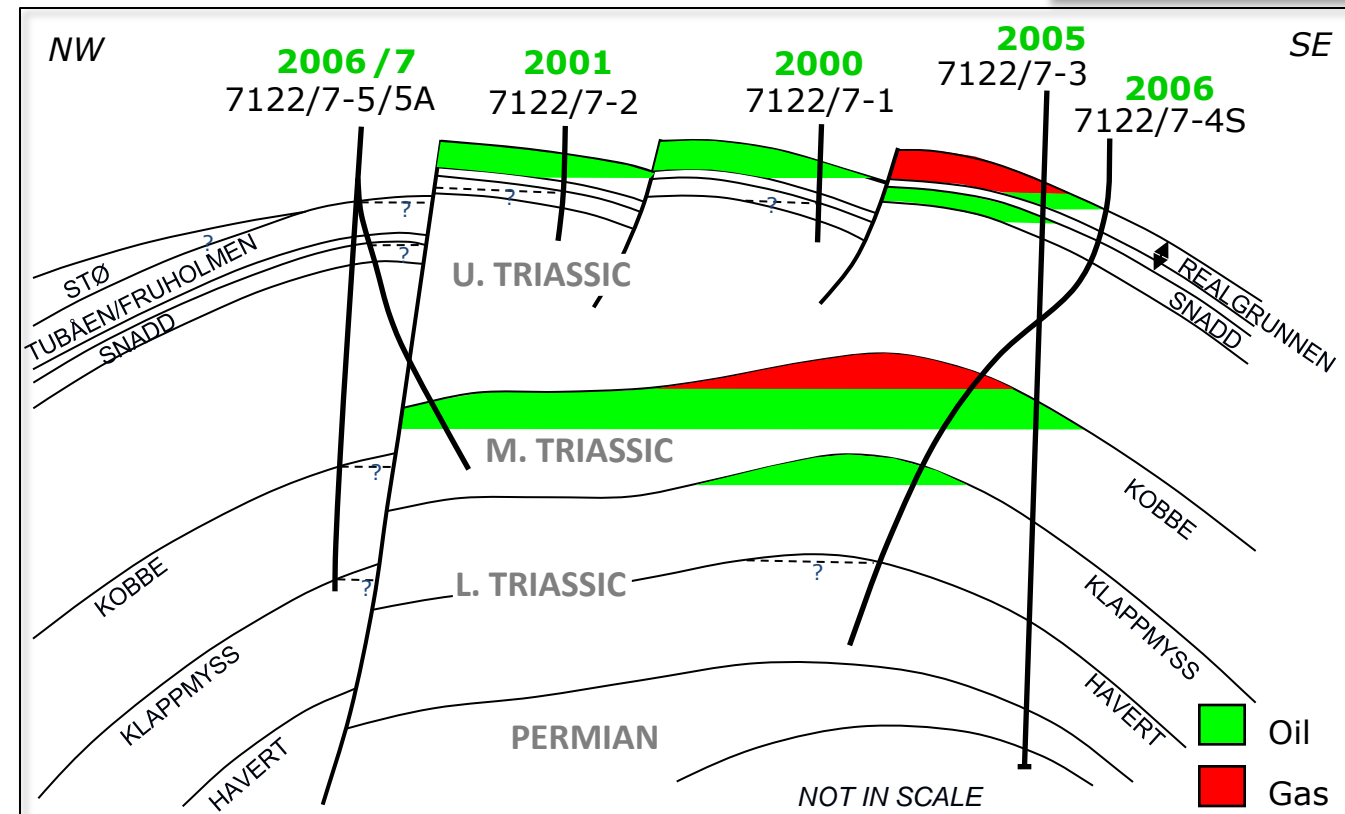


7122/7-3 (2005): South compartment, 68 m HC-column in Realgrunnen, 80 m oil-column in Kobbe Fm., Snadd oil discovery. Oil discovery in Kobbe Fm. was a significant finding and opened a new play concept in Hammerfest Basin & Barents Sea. Now the project had a solid base of reserves to become a viable development,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

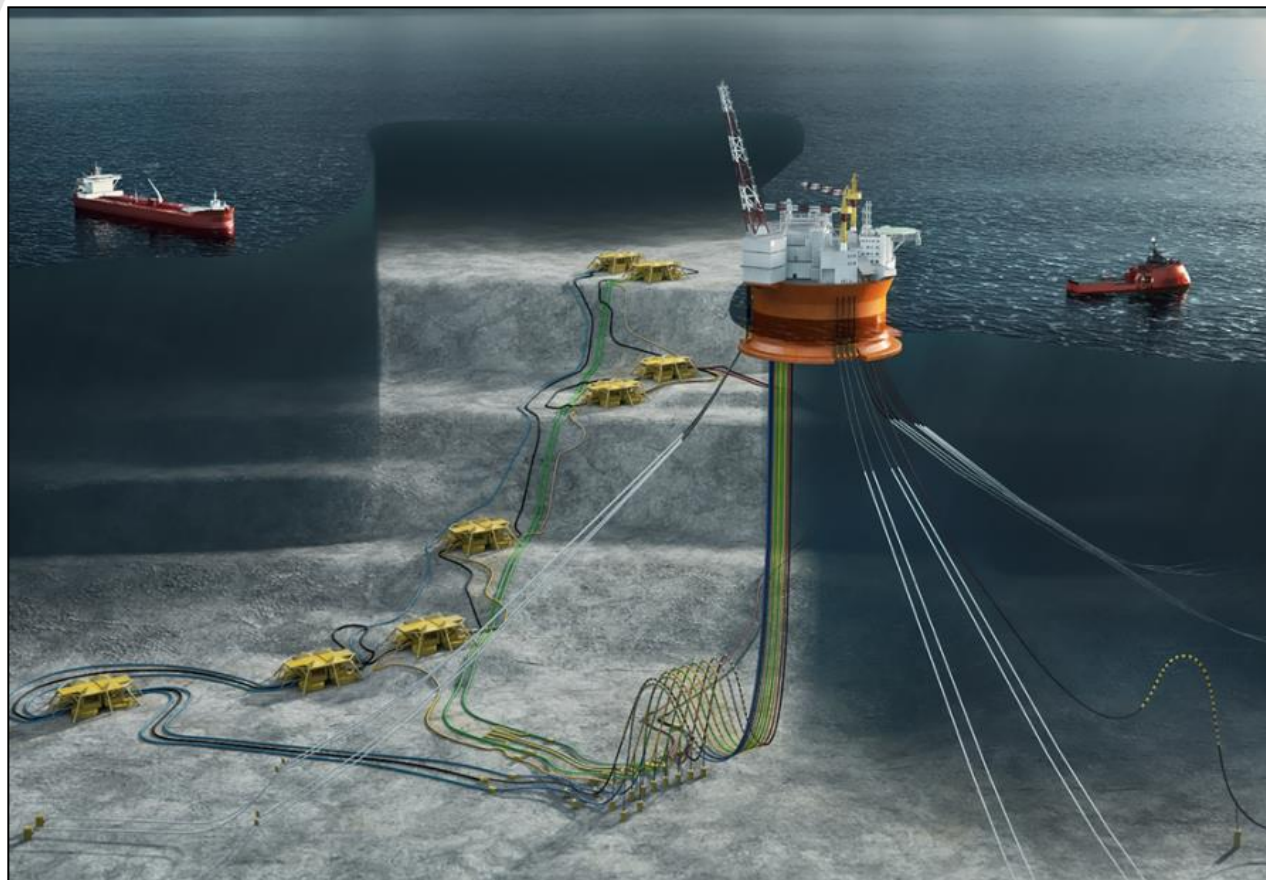
7122/7-4S, 7-5, 7-5A (2006-2007): Exploration/Appraisal wells to better define the complex setting of the structure. May 15th 2007: PDO submission (license extension to 2042); PDO approval: 2009.



Exploration Wells	Drilling	Realgrunnen	Snadd	Kobbe	Klappmyss
7122/7-1	Sept. 2000	●			
7122/7-2	Sept. 2001	●			
7122/7-3	Oct. 2005	●	●	●	
7122/7-4S	Sept. 2006			●	●
7122/7-5	Nov. 2006			●	
7122/7-5A	Jan. 2007			●	
Appraisal well					
7122/7-6 - Goliat M0 Appraisal	Oct. 2012	●		●	

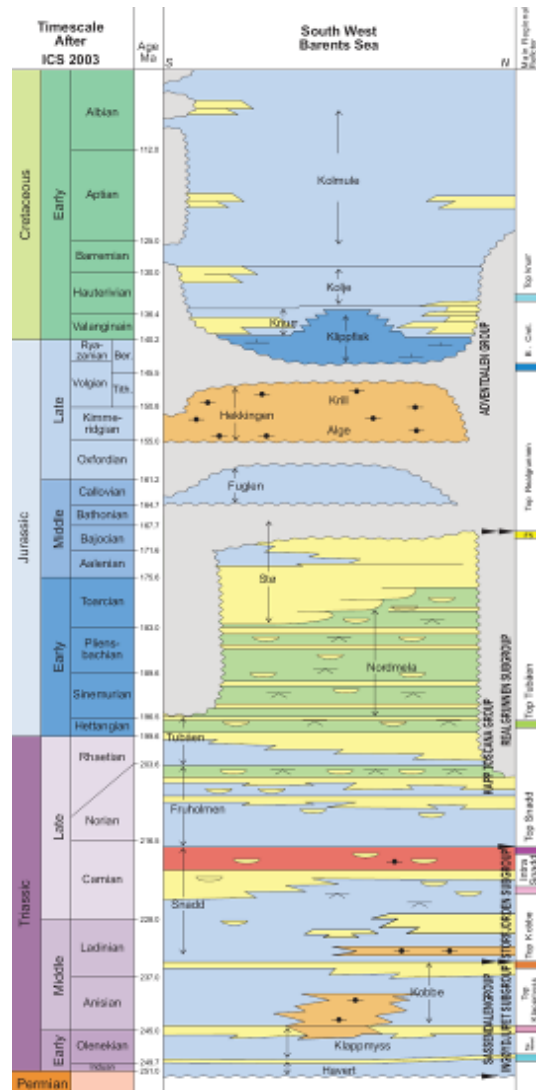


Goliat Field: on-stream since March 2016



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Oil geochemistry in Goliat: 2 different oil families



*U. Jurassic Hekkingen
oil prone source*

*Realgrunnen & Snadd
accumulations*

*L.-M. Triassic
oil prone source*

*Kobbe & Klappmyss
accumulations*

Terpane chromatogram similarities:

- Botneheia Fm. (Svalbard)
- Shublik Hoyle Bay Fm. (Alaska)

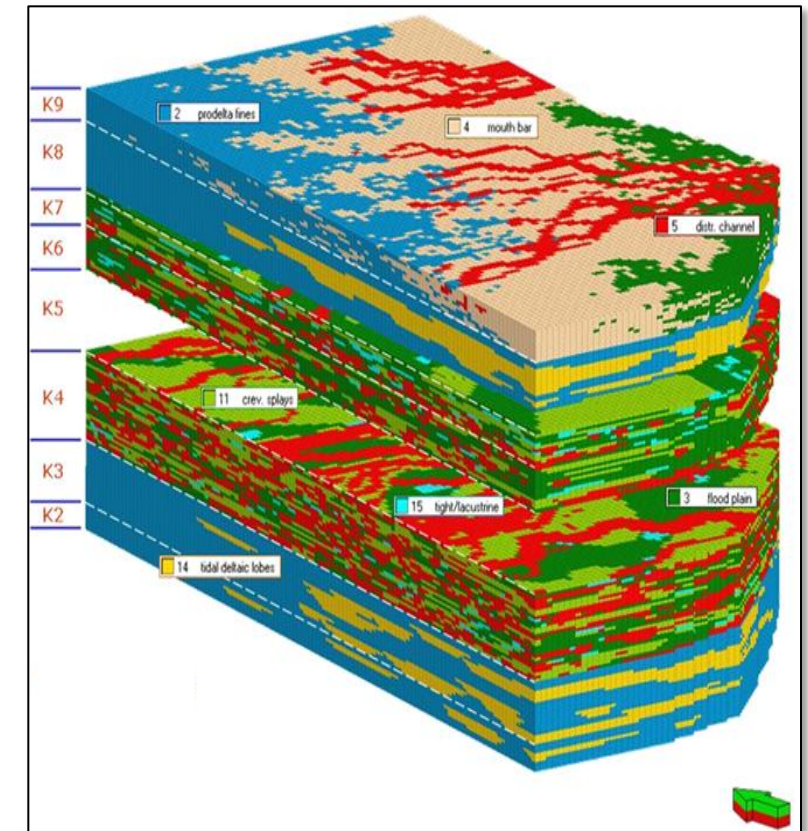
Petroleum systems modelling considerations:

- Hammerfest Basin (Middle Triassic SR):
 - mature at NW corner of Hammerfest 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**

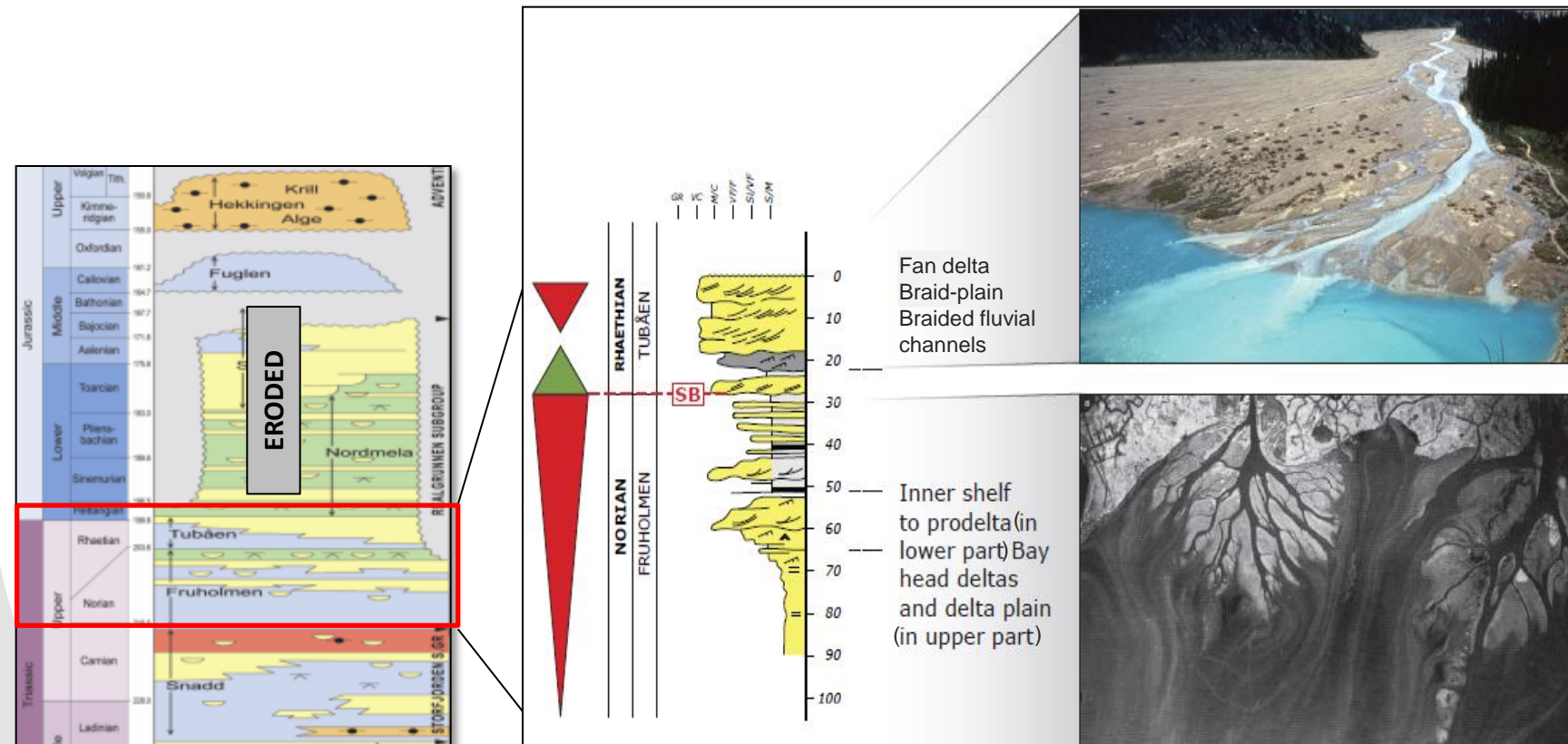
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- *Goliat legacy*



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



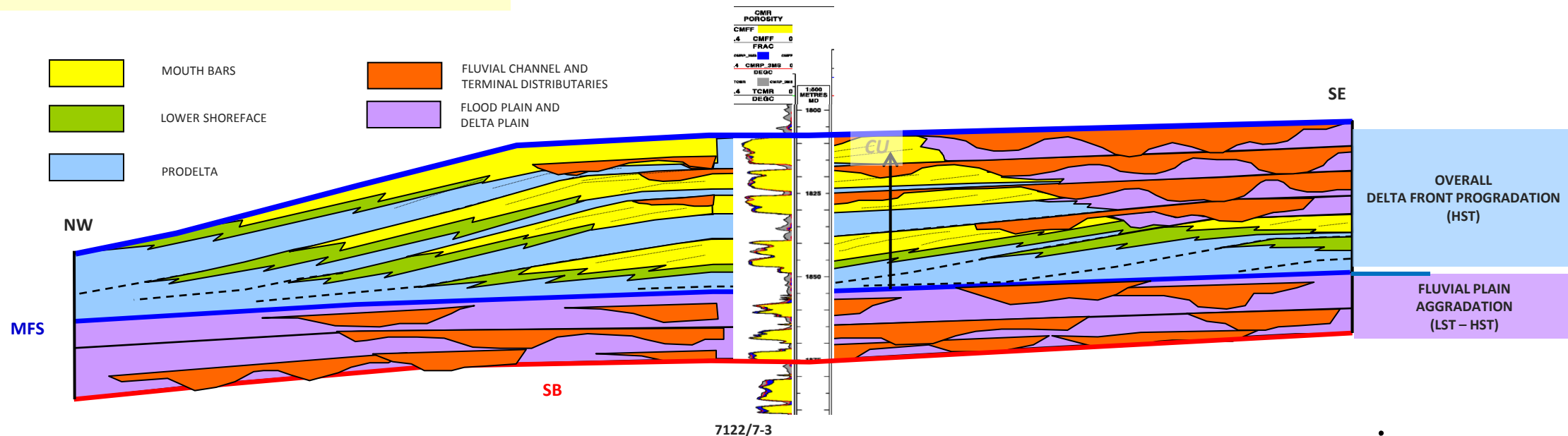
Sedimentological concept

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.

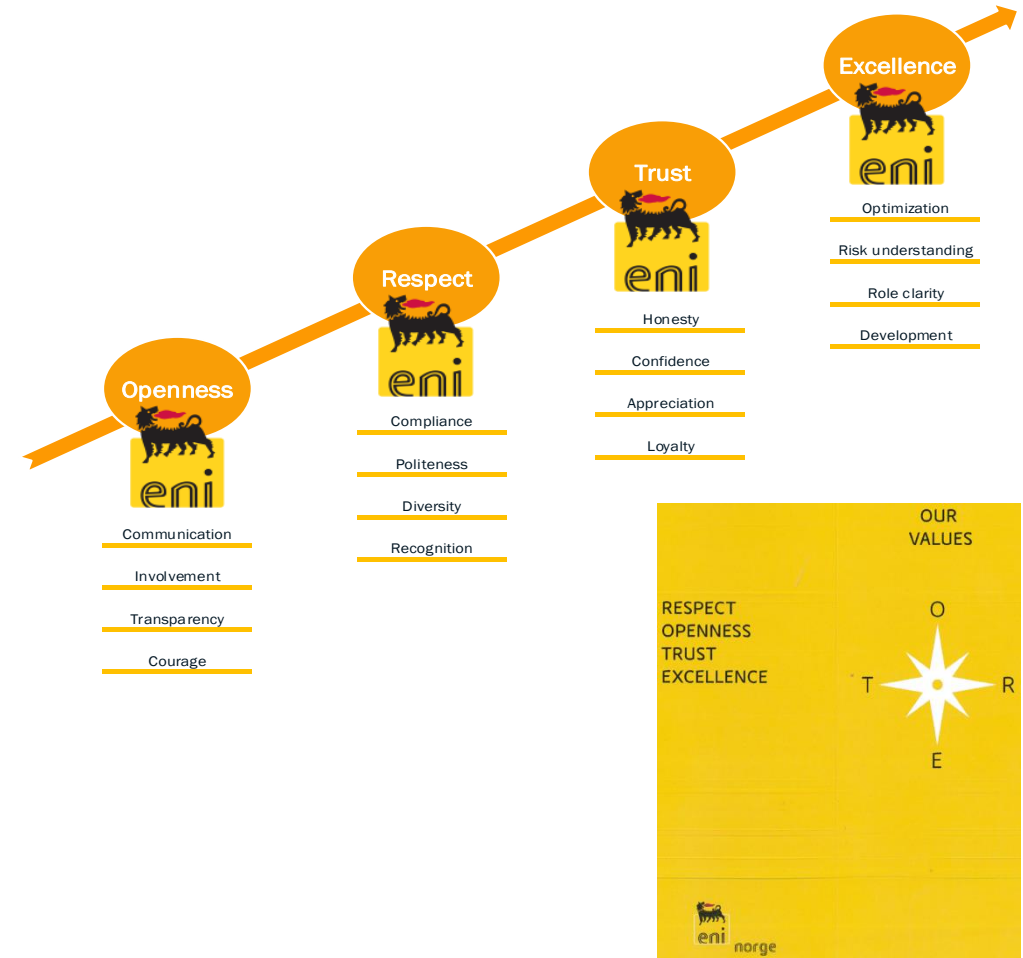
Facies model

- 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*
- *Dare to persist; Goliat Triassic oil discovery: a game changer*
- *Dare to appraise; Reservoir development*
- ***Goliat legacy***



Continuous model refinements & geological knowledge are needed



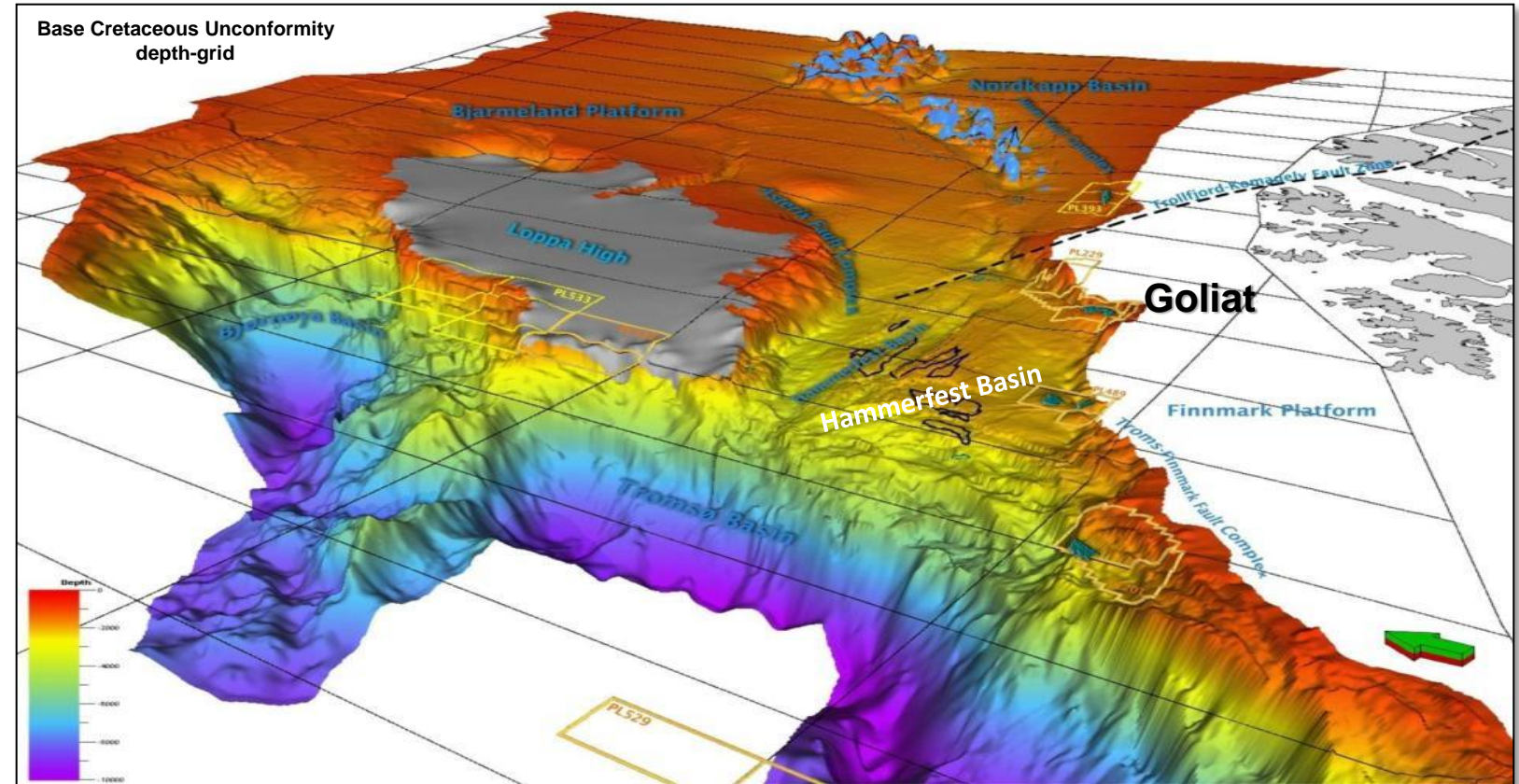
Barents Sea Exploration

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_{NFW} in Barents Sea exploration: “best in class”



Exploration activity focus 1991-2017: Barents Sea

- **Best in class** in rate of exploration success (ROS_{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

Oct. 2017	Barents Sea
Operated	9
Partners	5
Total	14

Exploration Wells	1 st Expl. phase 1980-1992			2 nd Expl. phase 1993-2017			Total Barents Sea
	All	Without ENI	ENI Total	All	Without ENI	ENI Total	
Wildcat	50	50	-	68	44	24 (11O + 13P)	118
Appraisal	7	7	-	22	17	5 (3O + 2P)	29
Grand Total	57	57	-	90	61	29 (14O + 15P)	147
Discovery	17	17	-	39	22	17	56
ROS (%)	34%	34%	-	57%	50%	71%	47%

O: Eni Norge Operator; P: Eni Norge partner

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.*

- 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



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- *Session Chairs & particularly Jonathan Craig*