PL 890 – Licence status report

Summary

The prospectivity in PL890 has been re-evaluated based on PSDM seismic data that was specifically reprocessed for this licence. The high quality of the new data made it possible to continuously interpret the Garn Fm. from the Dvalin field into the Revfallet fault complex area, where it forms the Topaz prospect. However, the sealing element for this trap could not be identified doubtlessly on the new data and its interpretation is based on conceptual structural understanding of the Revfallet fault complex, including regional studies and comparisons to sandbox models.
Gas with similar properties to that of Dvalin is the expected hydrocarbon phase given discovery in Topaz. It is assumed that Topaz is part of the same high-pressure cell as Dvalin East. Porosity and permeability of the Garn Fm. are presumably higher than at Dvalin due to its much shallower burial depth. Furthermore, it is concluded that the reservoir thickness increases from Dvalin towards Topaz, as the Revfallet fault was most likely active during time of deposition. The dip of the reservoir beds in the Topaz prospect is with up to ~27° very high, and thus, an unusual high gas column needs to be trapped in this prospect to be of economic value.
Both, probability for migration and probability of finding a producible reservoir are very high, while the probability of an effective seal is very low for this presumably unprotected trap, leading to an overall low probability of success. The technical and economic valuation for Topaz resulted in a marginal positive expected net present value, but not valuable enough to justify a business case for a drill decision.

The licence applied successfully for a six-month extension period to evaluate the prospectivity within the Cretaceous sedimentary package. The New Hettakallen prospect in the Cretaceous Lysing Fm. was mapped based on a clear AVO anomaly updip of the meanwhile obsolete Hettakallen prospect (APA 2016). Further analysis and QC revealed that both the volume potential and the probability of success for the New Hettakallen prospect is lower than for the Jurassic prospect Topaz. In addition, the most likely hydrocarbon phase in New Hettakallen is a condensate rich gas, for which only limited capacity is available at Heidrun TLP within the coming 10 years.

An alternative interpretation model for the sealing mechanism of the Topaz prospect was suggested by one of the partners and its implication to the prospect evaluation and economic valuation were analysed comprehensively.
The Citra prospect –the main driver in the APA 2016 – was dropped as a prospect due to clear segmentation and too small volume potential in each of the segments. Other economic promising prospects were not identified within the licence boundary.

Finally, it was concluded that none of the evaluated prospects by themselves nor their aggregation can serve currently as a business driver for a drill decision. Hence, it was unanimously decided to surrender the licence.

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1 Licence history

Licence: PL 890

Awarded: 10.02.2017

License period: Expires 10.02.2024
Initial period: 7 years

License group:

Equinor Energy AS	40% (operator)
ConocoPhillips Skandinavia AS	20%
Spirit Energy AS	20%
Suncor Energy Norge AS	20%

License area: 94.846 km^2

Work programme: Acquire and/or reprocess 3D-seismic (fulfilled)

Meetings held:

19.04.2017	EC/MC startup meeting
13.11.2017	EC/MC meeting
19.06.2018	EC work meeting
27.09.2018	EC work meeting
19.11.2018	EC/MC meeting
07.03.2019	EC work meeting
19.06.2019	EC work meeting

Work performed:

2017: Licence startup; seismic reprocessing started

2018: Seismic reprocessing completed; geological/geophysical evaluation of prospectivity; technical and economic valuation of main prospect

2019: Further geological/geophysical evaluation of prospectivity; decision to surrender the licence

Reason for surrender:

Prospectivity was re-evaluated based on the licence focussed reprocessed MC3D-HVG2011STR17 survey. The Topaz prospect in the Middle Jurassic Garn Fm. was identified as of main economic potential. Conclusion after prospect analysis, QC and technical-economic valuation has been that the volume potential at the estimated risk is too marginal to justify a positive drill decision.

A similar conclusion was reached for the secondary prospect New Hettakallen in the Cretaceous Lysing Fm. Thorough prospect analysis, AVO study and QC revealed that both the volume potential and the probability of success for New Hettakallen is lower than for the Jurassic prospect Topaz. Neither Topaz, including its alternative interpretation model “Heep”, nor the aggregation of Topaz and New Hettakallen can serve currently as a business driver for a well and it was unanimously decided to surrender the licence.

2 Database overview

2.1 Seismic data

A subarea of the MC3D-HVG2011 survey was reprocessed purposively for PL890, with focus on (1) the Revfallet fault complex area for improvement of the structural understanding; and (2) the Cretaceous sedimentary package for amplitude preservation for AVO studies. The resulting survey, MC3D-HVG2011STR17 is covering the licence completely and stretches out to the adjacent fields Heidrun North and partly Heidrun in the southwest, Dvalin in the west and the southern part of Ærfugl in the north, see *Figure 1* (yellow polygon marks the outline of the reprocessed survey area).

2.2 Well data

The common well database is comprised of public available data for the wells annotated in Figure 1. The following analogue wells were analysed in detail with respect to reservoir potential in the Cretaceous and Jurassic strata: 6507/5-3 (Ærfugl), 6507/7-1, 6507/7-12, 6507/7-14 S (Dvalin East), and 6507/7-15 S (Dvalin West), 6507/7-5 (Heidrun), and 6507/8-6.

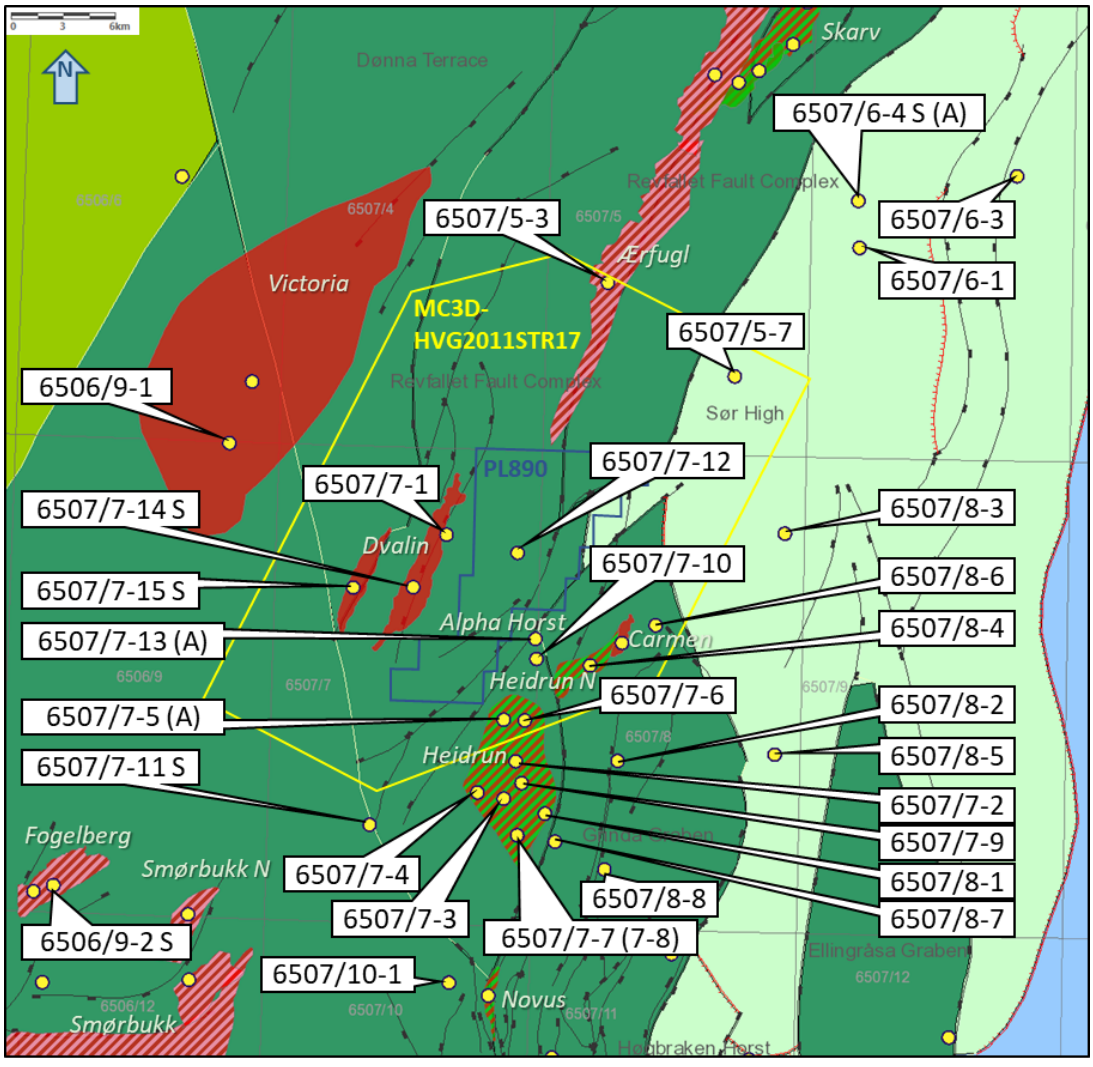

Figure 1: *Overview with location of the licence area (blue polygon), reprocessed survey area (yellow polygon), wells of the common data base (annotated), discoveries, fields, structural geologic elements, and blocks.*

3 Results of geological and geophysical studies

The Jurassic Citra prospect (see *Figure 2a*) had been the main business driver in the APA 2016 for this licence. Evaluation of the reprocessed seismic data (MC3D-HVG2011STR17) made it apparent that this prospect is broken-up into several fault blocks of too small volume potential each. However, the high quality of the new data allowed to continuously interpret the Garn Fm. from the Dvalin field into the Revfallet fault complex area and the previously Topaz lead could be evaluated as the main prospect (see updated outlines in *Figure 2b)*. The Fangst Gp. is apparently increasing in thickness from Dvalin in the west towards the Revfallet fault complex in the east of the Dønna terrace. The inclination of the reservoir beds in the Topaz area is with ~27° very high. It is presumed that the over-steepening of the monocline in the hanging wall caused a landslide in Late Jurassic times, forming the Topaz trap below. The gravitational detachment surface of this landslide cannot be identified doubtlessly on the seismic data and its interpretation is based on conceptual structural understanding of the Revfallet fault complex. An alternative model for the trap concept was suggested by one of the partners, inferring a steep fault with a large throw juxtaposing the Fangst Gp. against Triassic Grey- and / or Redbeds. This alternative model, named Heep, interprets the prospect to be a classic down-faulted trap. The apex of the Heep model is ~130 m deeper than of the Topaz model, which implies differences in the prospect outlines (see *Figure 2*B). Based on the new seismic data, both models are plausible, and analogues are found in the same sandbox model (V*endeville et al. 1995, https://doi.org/10.1144/petgeo.1.2.179*, see *Figure 3*). The Heep model implies that the Revfallet fault complex has the character of a partially-decoupled fault-cover system over the entire prospect area, which contradicts the structural concept of the Revfallet fault complex that suggests a coupled fault-cover system in the central and northern part of the licence area (*Pascoe, et al., 1999, https://doi.org/10.1144/0050083*).

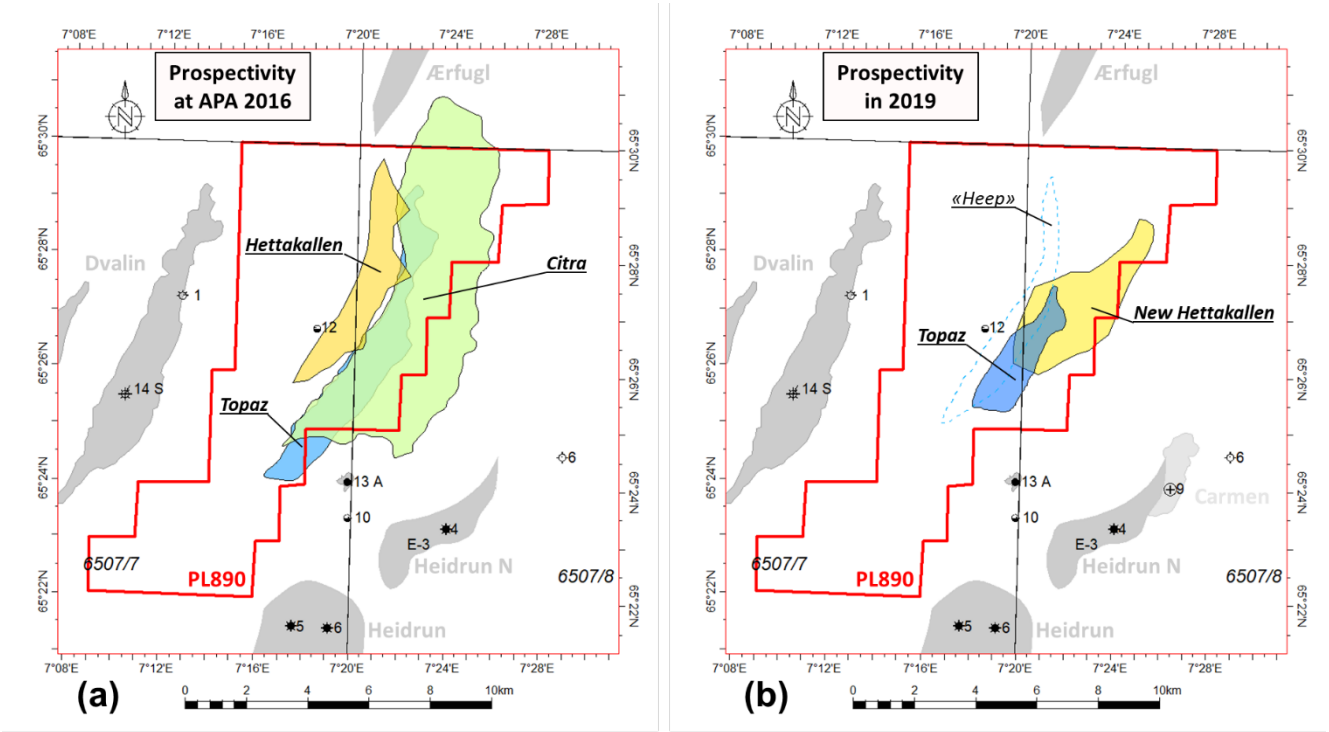

Figure 2: *Overview of prospectivity: (A) – at APA 2016 and (B) – in 2019. Hettakallen and New Hettakallen are Cretaceous prospects, while Citra and Topaz are Jurassic prospects. The Heep model is an alternative interpretation of Topaz with a different apex and outline.*

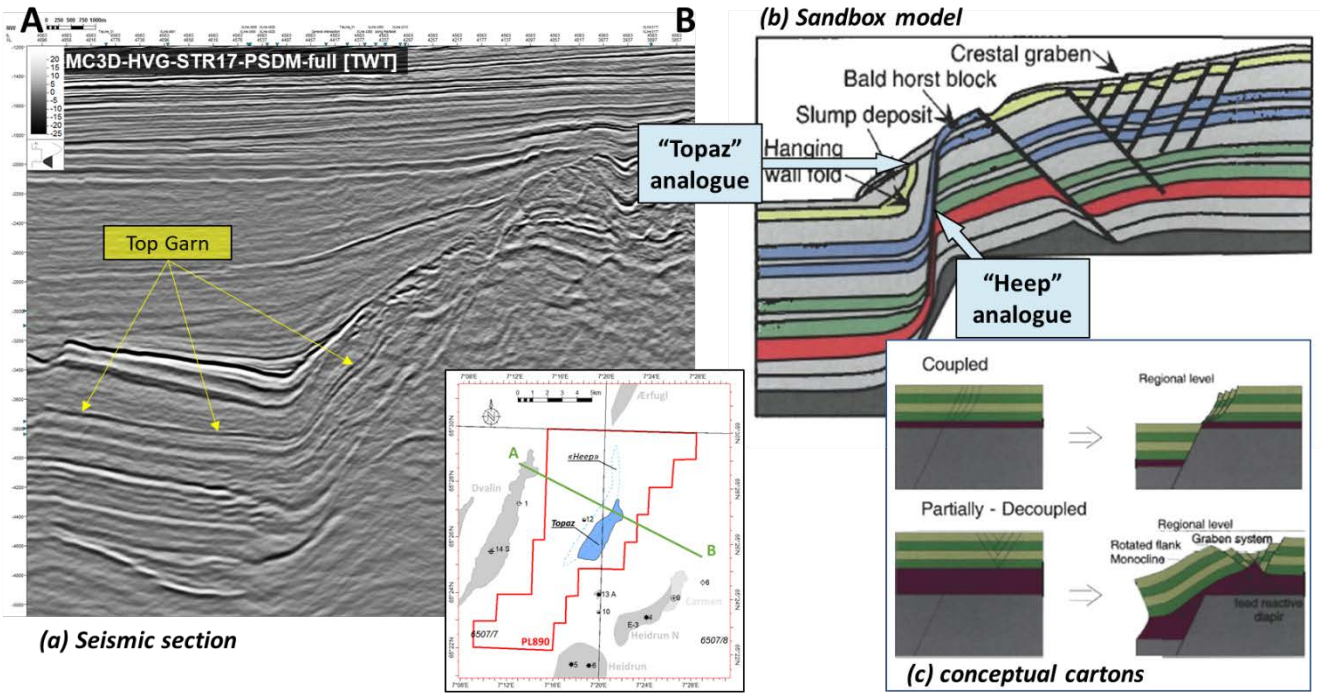

Figure 3: *(a) Seismic section through Topaz, location shown in inset; Top Garn reflection (marked with yellow arrows) can be followed from Dvalin East into the Topaz prospect area, critical seal is assumed to be the detachment surface of an overlaying slump zone; (b) sandbox model by Vendeville et al. 1995, coloured and annotated by Pascoe et al. 1999, giving analogues to both the model of a detachment surface (Topaz) and the alternative model of a large steep fault (Heep); (c) conceptual cartoons (Pascoe et al. 1999) illustrating the character of the Revfallet fault complex changing from partial-decoupled to coupled with increasing fault throw from the southern to the northern part of the licence area.*

The Hettakallen prospect (*Figure 2a*) in the Cretaceous Lysing Fm. was defined on a seismic amplitude anomaly in the APA 2016, but AVO analysis and well modelling revealed that the most likely cause for this anomaly is an extensive carbonate cementation, as it is encountered in middle of the Lysing sandstones in 6507/7-12. In addition, the analysis showed that the lower part of the Lysing sandstones causes a distinct AVO anomaly updip of 6507/7-12, defining the "New Hettakallen" prospect (*Figure 2b*). Its class 2 – 3 AVO anomaly is in strength weaker than that of the Ærfugl field, indicating either a poorer and/or thinner gas filled reservoir, an oil filled reservoir of similar quality, or simply a good but mainly water filled reservoir.

The main characteristics of the New Hettakallen prospect are: (1) the Lysing Fm. dips with ~8° westwards in the prospect area; (2) the AVO anomaly reaches from 3310 m at its shallowest to 3800m at its deepest point; (3) no indication of a hydrocarbon-water contact is found in the seismic data; and (4) several faults offsetting the Lysing Fm. were identified and mapped, but none of them seals off the entire prospect, resulting in a stratigraphic pinch-out trap classification.

4 Prospect update report

4.1 Topaz prospect

Reservoir

The prognosed reservoir in Topaz is the Middle Jurassic Garn Fm., which was deposited in a predominantly tidally influenced deltaic setting and is laterally extensive and well developed over large areas of the shallow water Norwegian Sea. Offset wells that penetrate Garn Fm., such as the wells in the Dvalin area on the Dønna terrace, as well as those in the Heidrun area on the Sør High of the Nordland Ridge, encountered producible reservoirs. The quality of the reservoir is expected to range between that of the deeper buried Dvalin area and of the shallower situated Heidrun area. With the expected minimum reservoir values, it is assumed that the reservoir holds minimum connectivity and flowability to support detectable and sustained flow rates that are significant for production from one or more wells. Low productivity is expected if a reservoir is encountered in the very low end of the net-to-gross range.
The Fangst Gp. is mapped as an overall thickening package (based on coloured inversion and mapping top and base) from the Dvalin tie wells in the west/southwest into the prospect area within the Revfallet fault complex. In the base case it assumed that sandstones of the Ile Fm. shale out based on observation in the offset wells. This presumption is to be error-prone, as the well data are sparse towards the north of the prospect area. The volume potential of the Ile Fm. has not been accessed to the full extent, however it is regarded to be covered by the large GRV uncertainty range of the Garn reservoir - as the fault seal study for the mappable faults within the prospect has shown that communication between Garn and Ile sandstones is to be expected, if present.

Seal

The reservoir overlaying shales of the Melke Fm. and the underlaying shales of Not and Ror Fms. are proven top and base seals in the region. The critical sealing element is the gravitational detachment surface of the overlaying landslide zone. Very little is known about sealing potential of such detachment surfaces, especially in the hanging wall of a fault complex. Classical fault seal analysis principles cannot be applied to estimate the sealing capacity, as the evolution and dynamic processes of landslides are very different and faster than those of ordinary faults. Examples of detachment surfaces are found in fields with a footwall degradation, such as in the Brent, Ninian, Snorre, Statfjord and Strathspey fields. No example is found where hydrocarbons are trapped solely by a detachment surface, but differences in pressure and hydrocarbon-water contacts across these surfaces are indicating a seal potential of some degree.
The alternative interpretation model Heep is a classic 3-way down-faulted trap with a steep and large fault as critical seal, juxtaposing the prospect reservoir against the lower part of the Grey- and/or upper part of the Redbeds. Due to the large throw of that inferred fault (> 2 km) an excellent membrane seal is to be expected, but main risk for this model is the potential of sandstones dragged along the fault, acting as migration fairway into the Sør High of the Nordland Ridge.

Source presence and maturity

An Upper Jurassic Spekk Fm. source rock is considered the most likely candidate for charging Topaz, as it is the main contributor of hydrocarbons to numerous fields and discoveries in the greater Nordland-Halten area. Additionally, the Upper Jurassic Melke Fm., which is also proven, could contribute hydrocarbons. Other source rocks could include Aptian to Albian aged marine source rock as well as the predominantly terrestrial Åre Fm. The Spekk and Melke Fms. source rocks are in the gas-expulsion temperature window to the west of Dvalin over a large area. The Spekk Fm. source rock is modelled as being in the oil window along the flank of the Revfallet fault zone.

Hydrocarbon migration

The Topaz trap is expected to have been in place by Late Jurassic / Early Cretaceous while hydrocarbon migration is modelled to have taken place during the Cenozoic. The most likely migration route into Topaz is spill from Dvalin, which

is expected to focus hydrocarbons from a large catchment to the west. Migration from farther south, where fluids with lower condensate-gas ratios are encountered (Smørbukk Nord) is considered possible but less likely.
Up-dip, to the south and east of Topaz, oil is proven in the Alpha Horst and in Heidrun, although migration into these structures may have been along a different route and not through the prospect area.

Hydrocarbon phase

Gas is the most likely hydrocarbon phase given discovery in Topaz, the chance for finding oil is estimated to be below 10% and not considered in the economic valuation.

Pressure and Temperature

Pressure in the Topaz reservoir is estimated to be 575 – 600 bar, at same overpressure (~202 bar) as encountered in Dvalin East. Reservoir temperature is modelled to be 120 – 140°C, based on depth of the reservoir and the well-known regional temperature gradient.

Direct fluid indication (DFI)

No direct fluid indication has been observed in the seismic data. Due to the depth of target (reservoir below 3300 m) and the steep dip of reservoir beds (~27°), there may be an issue with all far angle information being recorded with the 7 km long receiver cables. In addition, the likelihood of increased structuration and deformation in the prospect area is high, which may also impact any DFI assessment. Hence, no DFI modification has been applied to the risk estimation.

Volumes and probabilities

The spill point is more than 1000 m deeper than the apex, but it is estimated that gas columns above 500 m would lead to fracturing pressure conditions near the apex. The minimum gas column needs to be around 200 m for finding recoverable volumes of economic value. Thus, the in-place volume potential is estimated to be 4 – 9 GSm^3 of gas (P90 – P10), with a mean of 6 GSm^3. Risks for migration and producible reservoir are low, while the risk for the seal to hold the minimum gas column is very high, leading to an overall geological probability of success of 16.2%.

4.2 New Hettakallen prospect

Reservoir

Prognosed reservoir are sandstones of the Upper Cretaceous Lysing Fm., with deposition of turbidity sediment flow into a ponded mid-slope setting. Sandstones of the Lysing Fm. are encountered in all nearby wells drilled on the Dønna terrace (6507/5-3, 7-1, 7-12, 7-14 S, 7-15 S), with varying thickness and reservoir quality. The nearest well (6507/7-12) directly down-dip of the prospect has the lowest thickness (38 m) and contains a ~10 m tight interval with massive calcite cementation and no flow potential. In the prospect area, it is expected that this cemented layer is on top of a sandstone layer with producible reservoir properties that increases in thickness from the 6507/7-12 well.

Seal

Top and base seals are the over- and underlaying Cretaceous shales. Critical seal elements are in parts faults and cementation, but near the apex a stratigraphic pinch-out or sub-seismic faults must be assumed to be effective.

Source presence and maturity

Main source rocks are Spekk and Melke Fms. Secondary source rocks are Aptian/Albian and coals of the Åre Fms. Spekk and Melke Fms. are west of Dvalin in the gas-expulsion temperature window, while they are modelled to be currently in the oil-expulsion temperature window in the local area basin down-dip of New Hettakallen.

Hydrocarbon migration

Expected hydrocarbon migration is by spill fill from Ærfugl. No oil shows in Lysing Fm. in 6507/-12 directly down-dip of New Hettakallen. Oil migration into the prospect close to the apex is possible, but not regarded as very likely.

Hydrocarbon phase

Main expected phase is gas with likelihood of 90%, but oil cannot be ruled out.

Pressure and Temperature

Expected pressures are 310 – 360 bar, which corresponds to an overpressure of 77 bar, as found in the lower part of the Lysin Fm. in 6507/7-12 (~10 bar lower than at Ærfugl). Temperature is assumed to range from 70 – 100°C, based on the depth estimation and the well-known regional temperature gradient.

Direct fluid indication (DFI)

The prospect is defined by mid to far offset amplitude brightening, best to be seen at an AVO-fluid cube, see *Figure 4*. The lack of depth consistency and the lower amplitude strength compared to the Ærfugl discovery is making a low saturation gas and a pure reservoir response the most likely scenario. A significant change of the AVO anomaly strength that could indicate a hydrocarbon-water contact could not be identified. Hence, a negative DFI modification was applied to the risk estimation.

Volumes and probabilities

With a large minimum hydrocarbon column of 200 m, the in-place volume potential is estimated to be 3 – 9 MSm^3 of oil equivalent (P90 – P10), with a mean of 6 MSm^3. Risks for migration and producible reservoir are low, while the risk for the seal to hold the minimum hydrocarbon column is very high, leading to an overall geological probability of success of 10% after DFI modification.

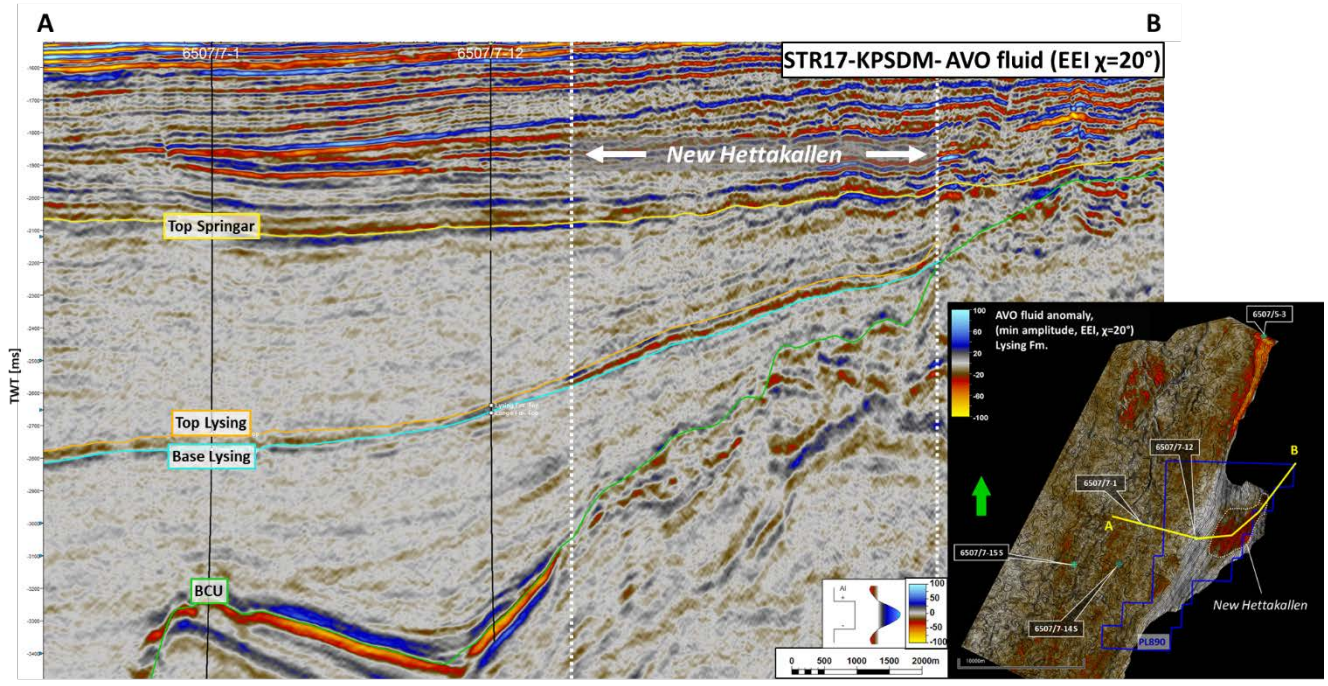

Figure 4: *New Hettakallen prospect defined by AVO-fluid anomaly (extended elastic impedance (EEI), with χ=20°)*

5 Technical evaluation

The technical and economic valuation for the Topaz prospect contained a development solution with a single gas producer from a single-slot template with a subsea tie-back to the Dvalin gas train at the Heidrun TLP. The expected net present value after tax related to this development solution resulted marginal positive at ~11 MUSD in November 2018. The internal rate of return was 15.8% and break-even Brent blend price ended at 53 USD/bbl (Table 1). This valuation included an exploration discovery well cost of 301 MNOK, no appraisal wells, investment costs of 2539 MNOK, and a yearly average OPEX cost of 8.3 MNOK. A certain production holdback in 2026 and 2027 had been considered in the valuation (see Figure 5), due to the expected plateau production of Dvalin until 2027.
The suggested development solution is very lean, but it includes adjustments to condensate pump and metering system at the Dvalin gas train to allow for production of a slightly more condensate rich gas. These adjustments might not be possible, if gas at Topaz is close to dew point containing a high amount of condensate.

Prospect	Mean recoverable gas volume (GSm^3)	Pg	**Expected Net Present Value (MUSD)**	**Expected break even (USD/bbl)**	Expected IRR
Topaz	4.03	16.2%	**11**	**53**	15.8%

Table 1: *Results of technical and economic valuation of Topaz*

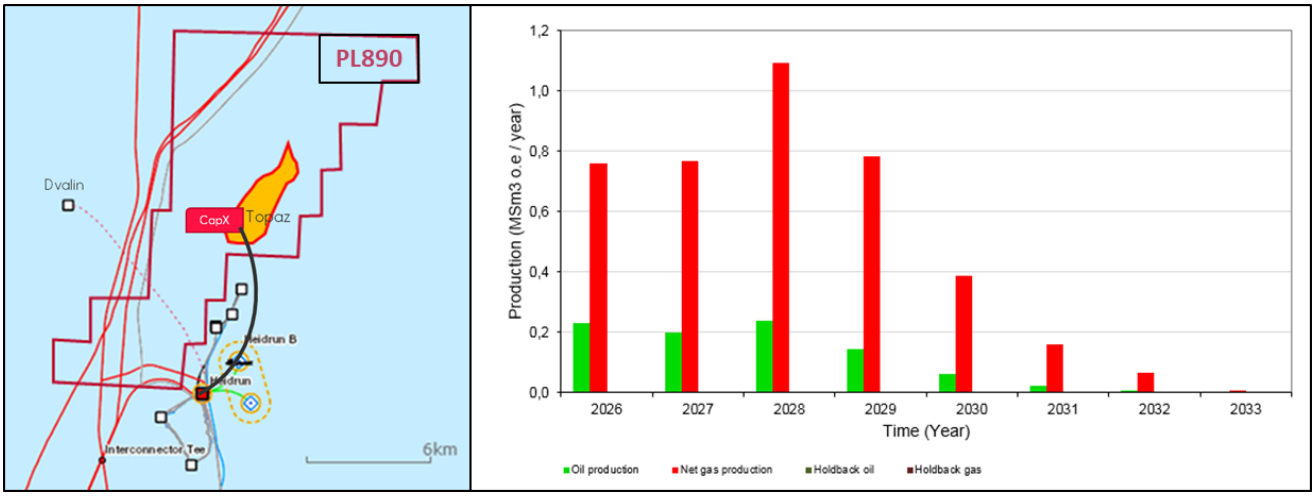

Figure 5: *Facility locations (left) and production profile for Topaz (right). Lean development solution with single slot template and a 9 km long flow line to Heidrun TLP. Minor modification for condensate handling at Dvalin gas train needed. Production holdback in the first two years due to expected plateau production at Dvalin until 2027.*

A direct implication of the alternative interpretation model (Heep) to the economic valuation of Topaz would be, on one hand, that in case of discovery a side track is needed to verify the interpretation. On the other hand, a multi-scenario case combining Topaz and Heep would lead to a slightly higher probability of success. These two aspects have effect on the expected net present value of the valuation, but larger and decisive changes to the results are not be expected.

A technical and economic valuation for the New Hettakallen prospect has not been carried out. A common production of New Hettakallen and Topaz from a shared template seems not feasible due to their locations and the expected differences in gas-condensate ratios.

6 Conclusion

The licence purposive reprocessed seismic data resulted in a great uplift of the deeper situated Mid-Jurassic strata within the Revfallet fault complex below a collapsed monocline structure (slump zone of a gravitational landslide), while only minor changes to the structural imaging of the collapse zone itself were observed. Thus, the main prospect (Citra) of the APA 2016 could not be pursued further and had to be dropped, while the previously Topaz lead could be matured as the main prospect.

Beside its low probability of success, the technical and economic valuation for Topaz resulted in a positive expected net present value, but it was too low to be a business driver for a drill decision. Neither the alternative interpretation model of Topaz, nor the secondary Cretaceous target New Hettakallen could lift the economic value decisively. Hence, the conclusion to surrender the licence was reached unanimously between the licence partners.