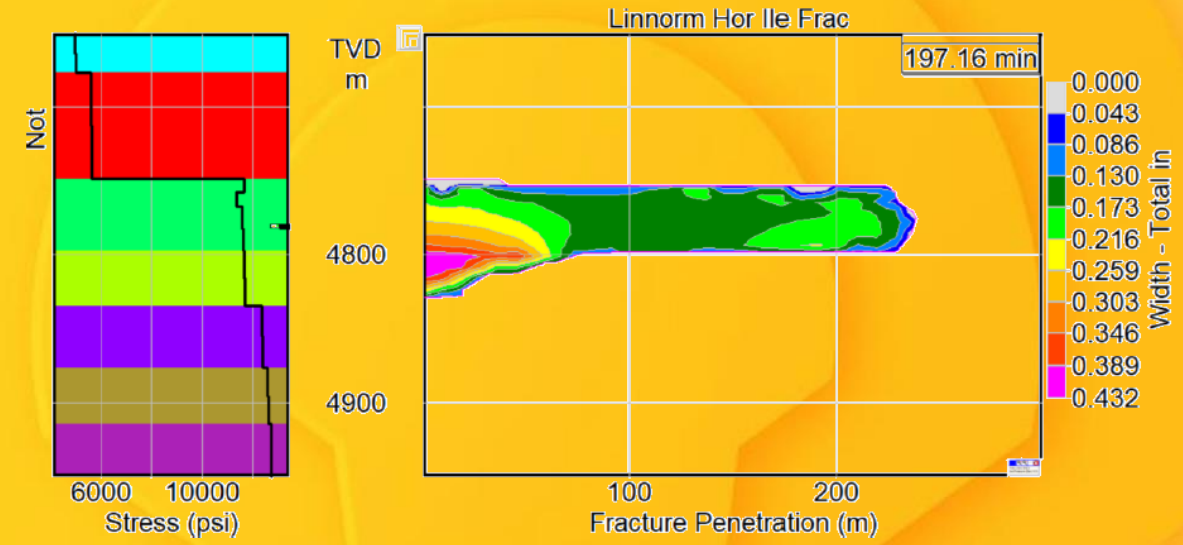
Linnorm – recovery evaluations from the tight reservoirs of the field

Force Seminar: Production from low perm reservoirs and hydraulic fracturing



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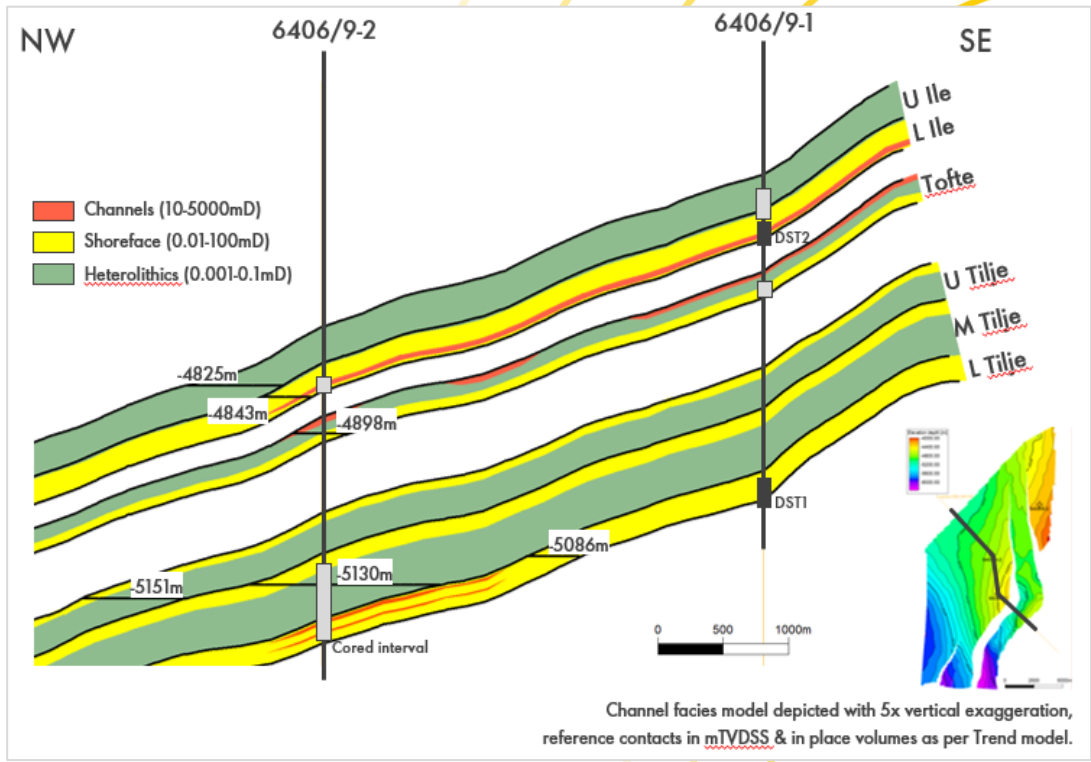
Introduction

- Linnorm field introduction
- Subsurface context
- Well concepts considered for Linnorm
- Evaluations and Results
- Conclusions
- Acknowledgement

Linnorm field introduction

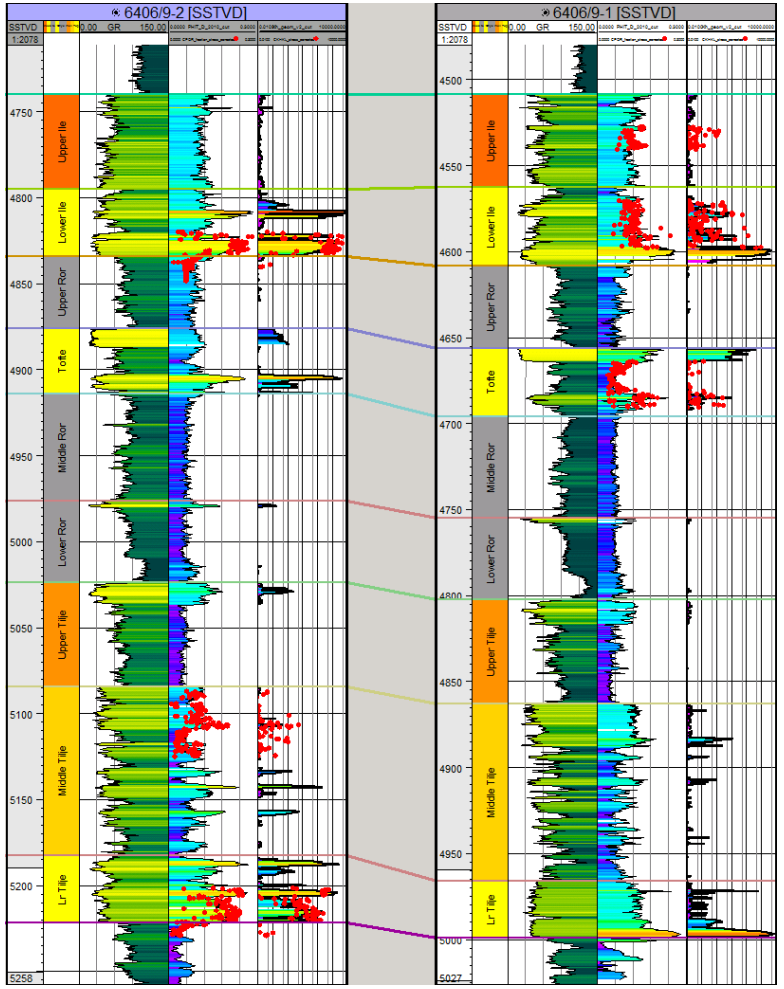
- PL255 License in the Norwegian sea
  - Shell (operator), Petoro, Total Energies, Equinor
- Discovered by well 6406/9-1 in 2005
- Down flank appraisal well 6406/9-2 in 2007 firmed up volumes
- Situated at 300m water depth
- Six separately stacked Jurassic reservoirs at about 4500-5000m TVDSS with varying reservoir quality (Ile, Tofte, Tilje)
- Porosity ~4–30 p.u./ Permeability ~0.01–5000 mD in L.Ile/Tofte/L.Tilje
  - Porosity ~0–20 p.u./ Permeability ~0.001–1 mD in U.Ile/M&U Tilje
- HPHT conditions: 840 bar, 180°C
- Two well tests in discovery well demonstrated good productivity of two reservoir zones (Lower Ile and Lower Tilje)
- Dry Gas PVT. CGR between 0 and 100 Sm^3/Mill Sm^3
- Appraisal well confirmed GIIP of ~100 BCM
  - about 50% of GIIP in tight reservoirs
- Contaminated by $C0_2$ (~7 mole%) and some H_2S (~30 ppm) and mercury.



Channel facies model depicted with 5x vertical exaggeration, reference contacts in mTVDSS & in place volumes as per Trend model.

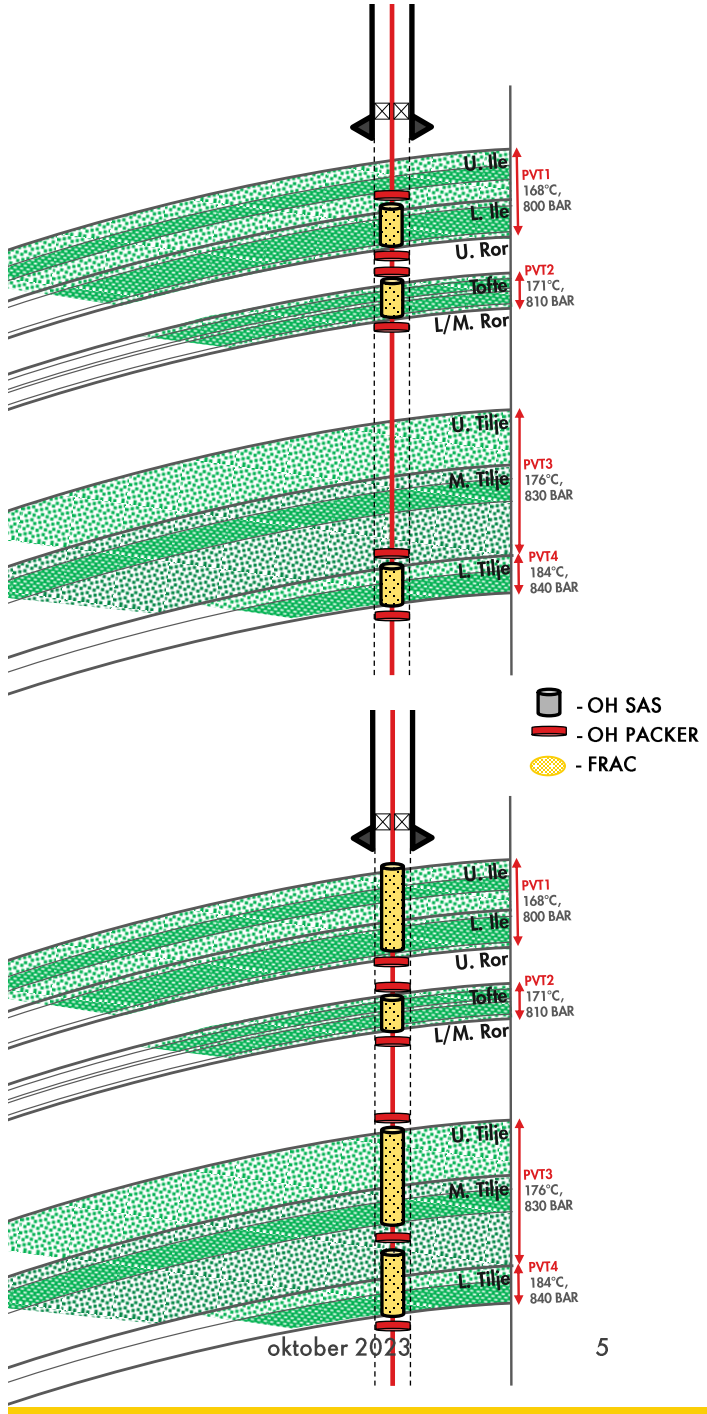
Context

- The GIIP in the secondary target reservoir sands (Upper Ile, Upper Tilje and Lower Tilje) represents approximately 50% of the total Linnorm GIIP.
- Evaluating whether this gas can be produced economically has had focus in the project and License.
- In the Assess phase of the rejuvenated project (2018/2019), both internal expertise -from Houston- and external expertise -from OPECS and Ridge- were involved in the project to assess what could be done to enhance recovery and particularly to look at what could be achievable in Linnorm around hydraulic stimulation of the secondary reservoirs.
- Fishbones technology was also evaluated.
- Several well designs were thought of and tested to best cover the whole possible range of recovery methods from the three secondary target reservoir sands, including vertical, deviated, horizontal and multi-lateral wells, with and without hydraulic fracturing.



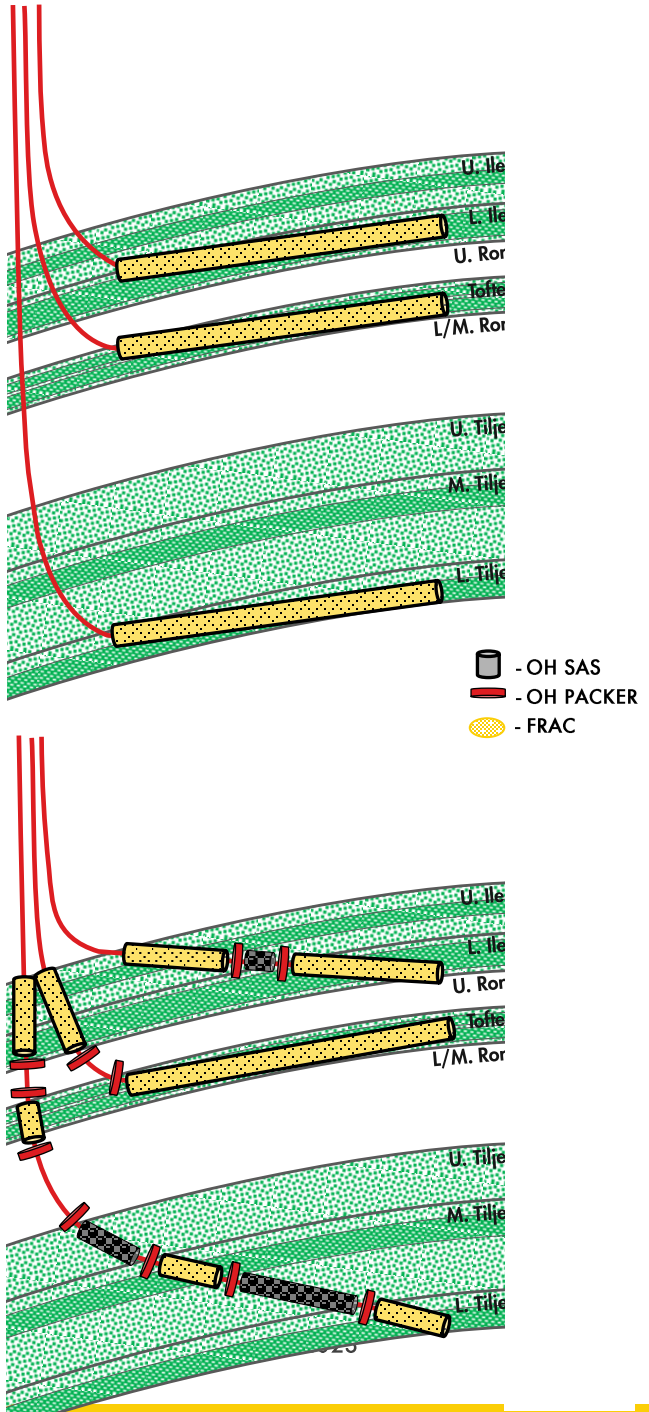
Well concepts considered for Linnorm (I)

- Conventional development well
  - Vertical wells with completions in conventional reservoirs /+ tight reservoirs



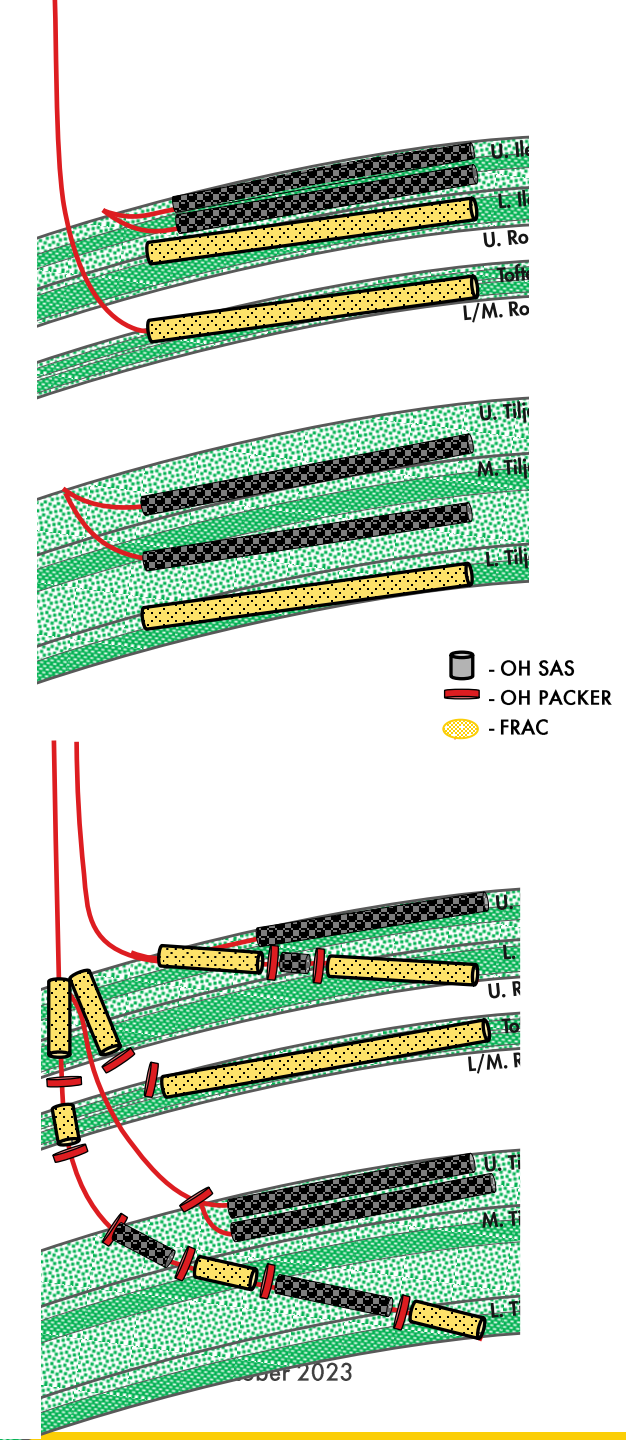
Well concepts considered for Linnorm (II)

- Conventional development well
  - Vertical wells with completions in conventional reservoirs /+ tight reservoirs
- Horizontal wells
  - Completions in conventional reservoirs /+ tight reservoirs



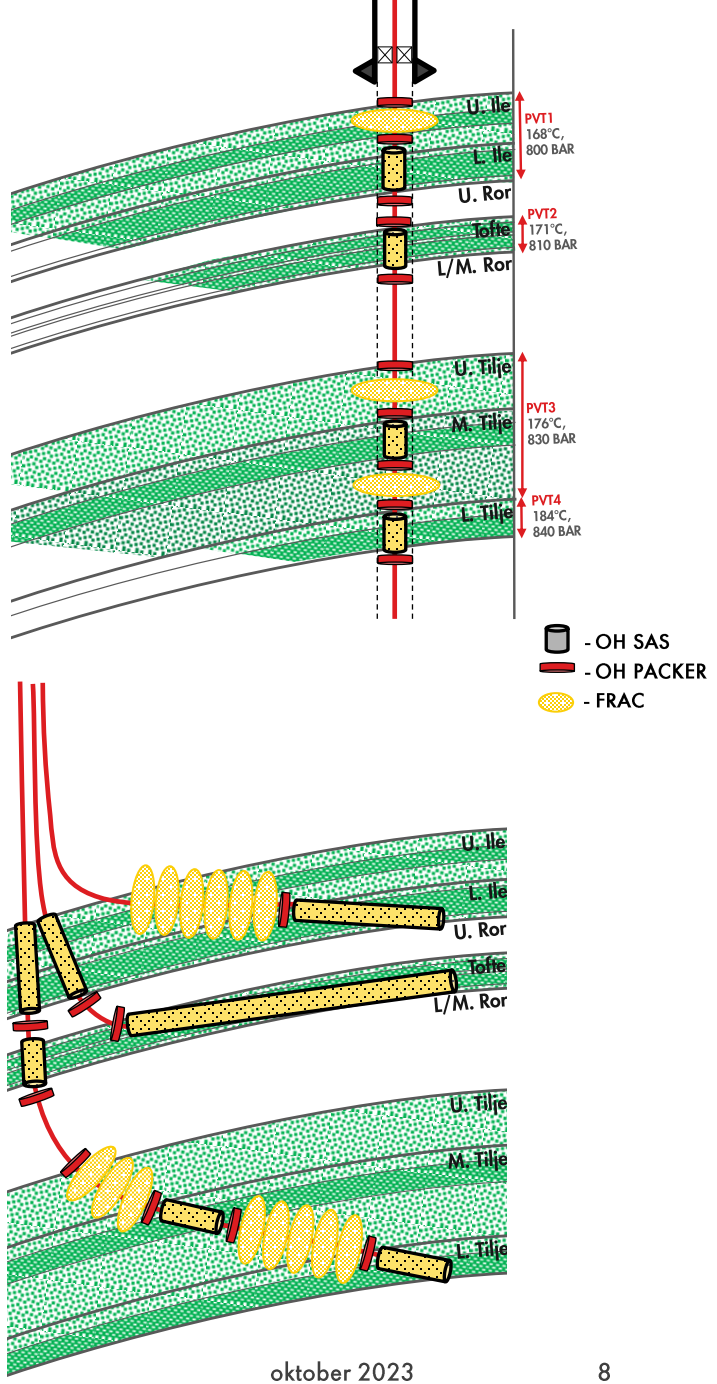
Well concepts considered for Linnorm (III)

- Conventional development well
  - Vertical wells with completions in conventional reservoirs /+ tight reservoirs
- Horizontal wells
  - Completions in conventional reservoirs /+ tight reservoirs
- Multilateral wells
  - Main bore into conventional reservoirs with MLT legs into tight gas zones



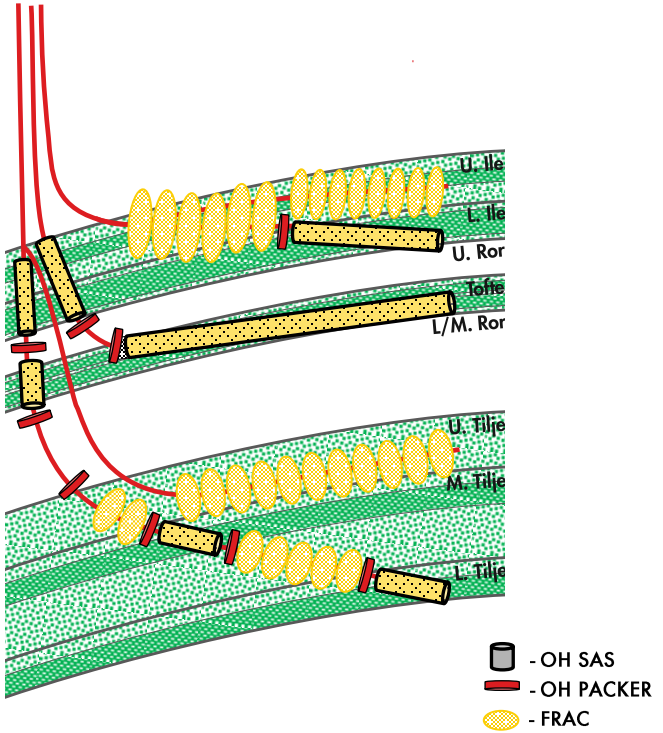
Well concepts considered for Linnorm (IV)

- Conventional development well
  - Vertical wells with completions in conventional reservoirs /+ tight reservoirs
- Horizontal wells
  - Completions in conventional reservoirs /+ tight reservoirs
- Multilateral wells
  - Main bore into conventional reservoirs with MLT legs into tight gas zones
- Conventional + fracture zones
  - Open hole Stand Alone Screens in conventional reservoirs with fracture in tight zone(s)



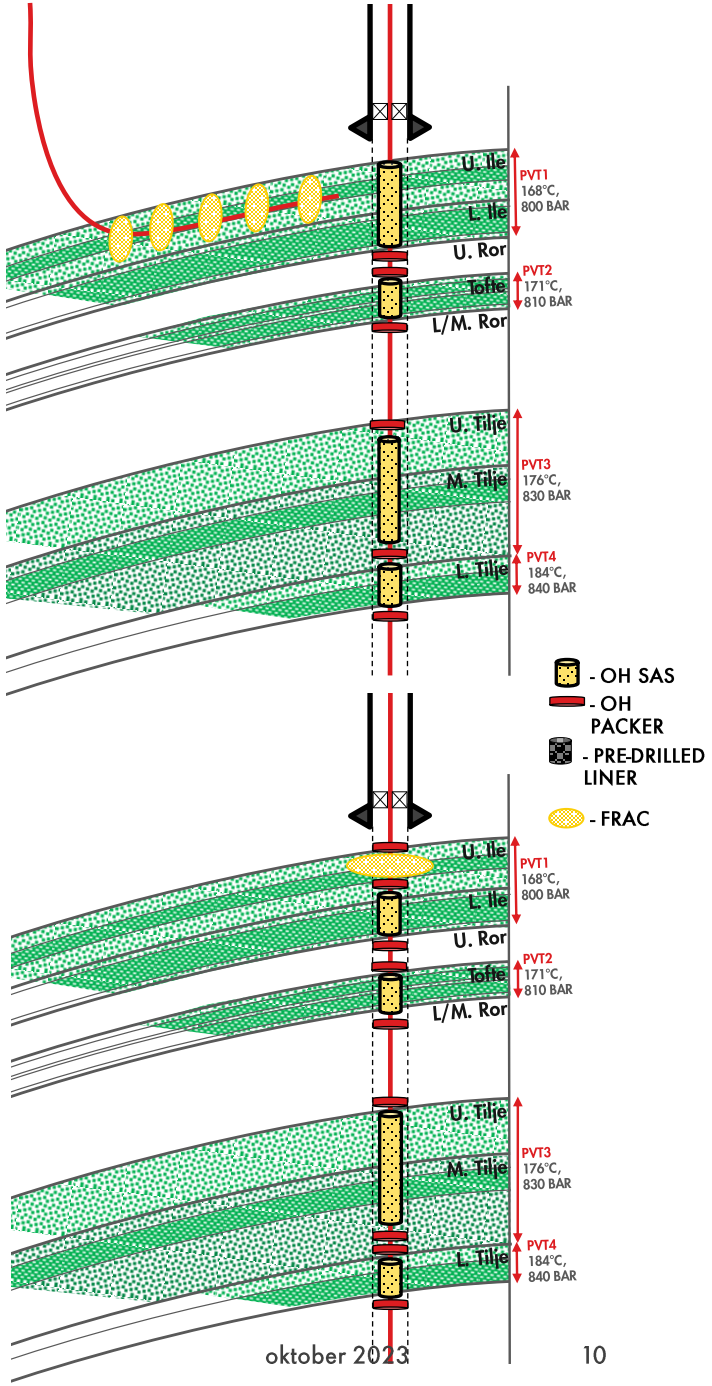
Well concepts considered for Linnorm (V)

- Conventional development well
  - Vertical wells with completions in conventional reservoirs /+ tight reservoirs
- Horizontal wells
  - Completions in conventional reservoirs /+ tight reservoirs
- Multilateral wells
  - Main bore into conventional reservoirs with MLT legs into tight gas zones
- Conventional + fracture zones
  - Open hole Stand Alone Screens in conventional reservoirs with fracture in tight zone(s)
- Multilateral wells
  - Open hole Stand Alone Screens with fractures in tight gas zones



Well concepts considered for Linnorm (VI)

- Conventional development well
  - Vertical wells with completions in conventional reservoirs /+ tight reservoirs
- Horizontal wells
  - Completions in conventional reservoirs /+ tight reservoirs
- Multilateral wells
  - Main bore into conventional reservoirs with MLT legs into tight gas zones
- Conventional + fracture zones
  - Open hole Stand Alone Screens in conventional reservoirs with fracture in tight zone(s)
- Multilateral wells
  - Open hole Stand Alone Screens with fractures in tight gas zones
- Conventional development + dedicated frac well in upper Ile
- Conventional wells with single fracture in Upper Ile

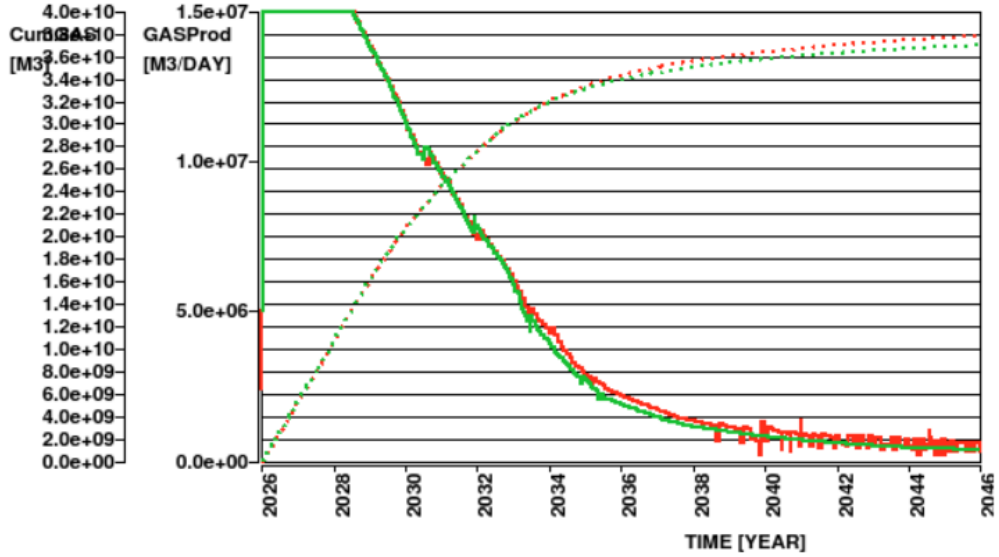


Evaluations and Results

- Shell in-house reservoir simulator (MoReS) was used to evaluate the production profiles/ UR from all well concepts.
- In addition, elements like HSSE and Risk, well robustness, maturity and economics were considered in a scoring matrix for all the concepts.
- While running the exercise it became clear that tight gas development in Upper Ile had most potential.
- Study run with Ridge to evaluate achievable fracture size in Upper Ile. Results from this study were included in the final results.
- Resulting UR by including a fracture in the upper Ile was up to 1 Bcm.
- Adding a dedicated frac well in Upper Ile results in up to 4 Bcm. incremental recovery, but this case need to be compared to running an additional conventional well which then reduces the ultimate gain to a conversation about risk and cost.

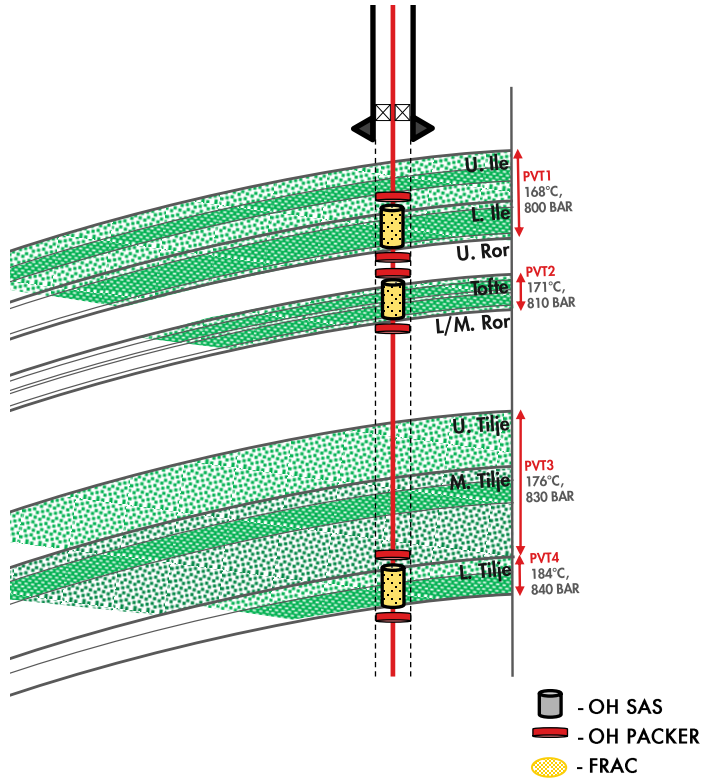
Parameter	Coarse Screening	Final Screening
Frac half length	40 meters	200 meters
Fracture height	30 – 40 meters	30 – 40 meters
Fracture Width	0.1 meter	0.01 meter
Fracture Permeability	3 Darcy	3 Darcy
Theta	45 degrees	45 degrees

Typical delta between conventaional wells and vertical frac in Upper Ile



Conclusions

- Hydraulic stimulations for Linnorm poses big challenges in terms of operational risks, lack of good analogues (HPHT, Offshore), failure rate deemed high and potential negative impact on drainage of conventional reservoirs
- Studies show that parts of the tight reservoirs can be drained if the frac is carried by a well also targeting the conventional reservoirs
- The production/ UR benefit vs cost/ risk is not attractive
- Dedicated fractured well(s) can potentially be carried as a future infill opportunity
- Based on this work (and other studies), the Linnorm development case is based on comingled producers through all reservoirs with stand-alone screens in the conventional reservoirs.



Acknowledgements

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Q&A