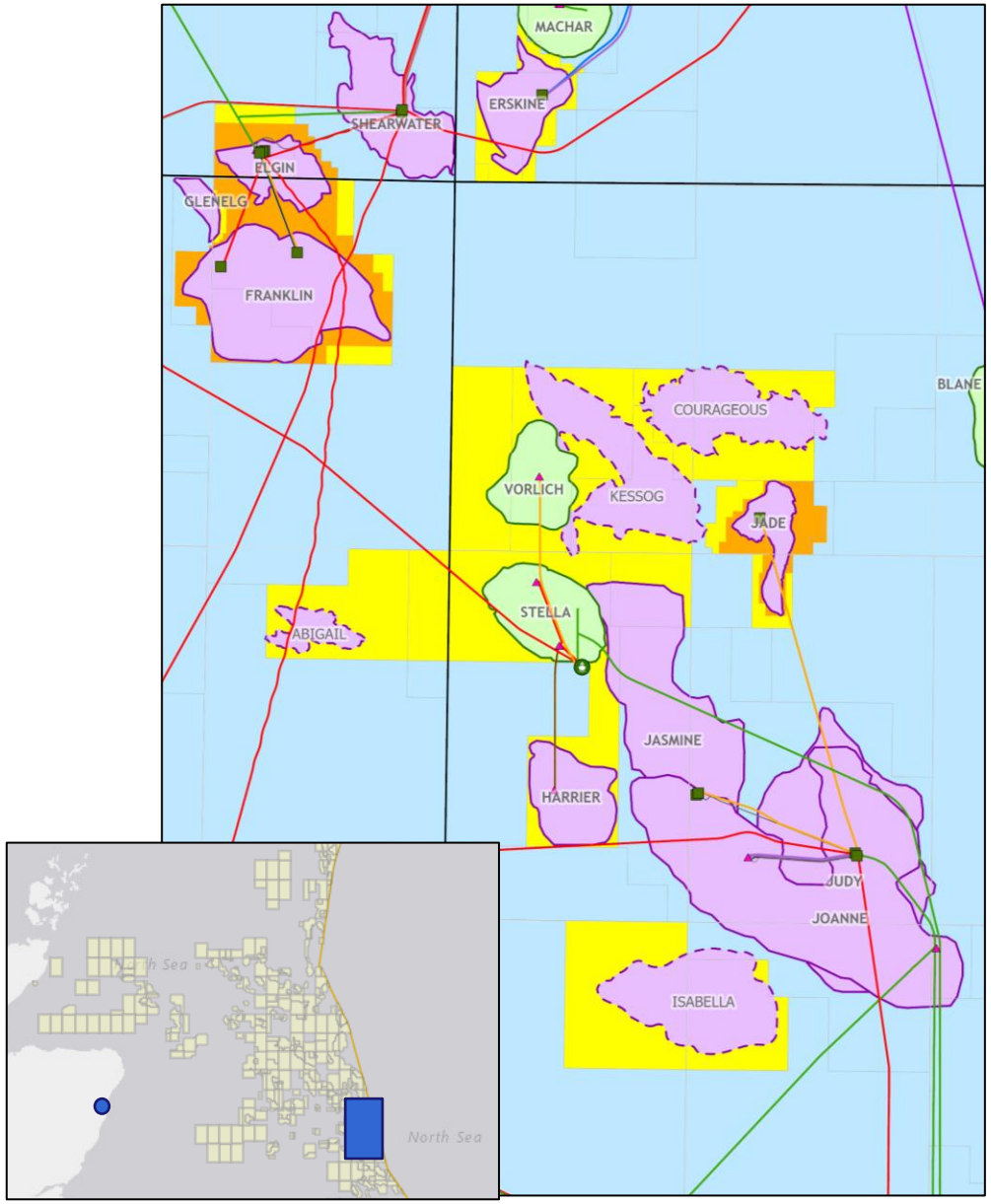
ITHACA ENERGY

Harrier Field: Development of a marginal low permeability chalk field

Jim Bramald

Location & Brief History

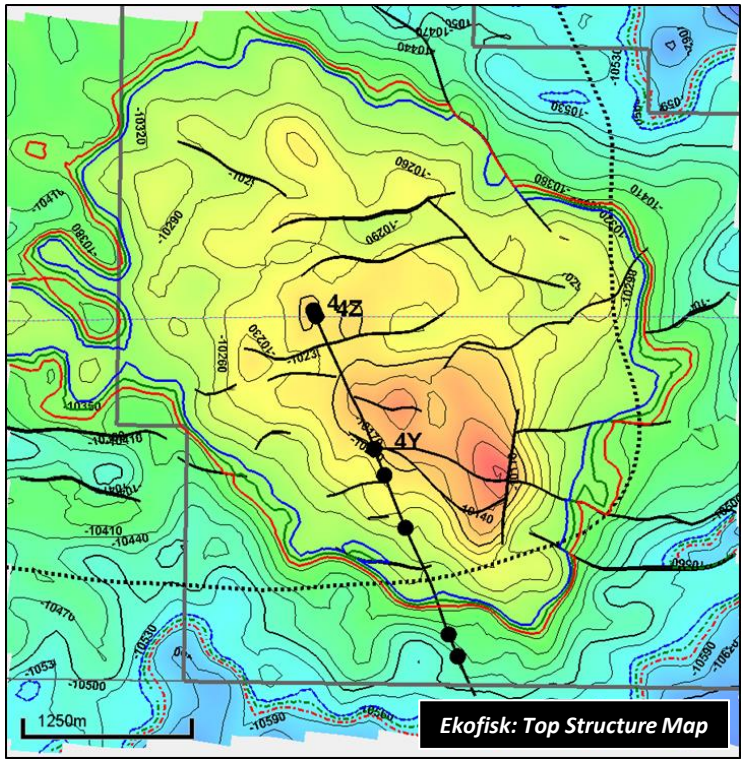


- **Located in 30/6a**
- **Discovered 2003**
  - Maersk 30/6-4, -4Z, -4Y, -4X
- **Development drilling 2017**
  - 30/6a-10, -10Z
- **Subsea single, two branch well exploiting lean gas condensate from the chalk**
  - Ekofisk Reservoir
  - Tor Reservoir
- **First gas August 2018**
  - Tie in to FPF-1

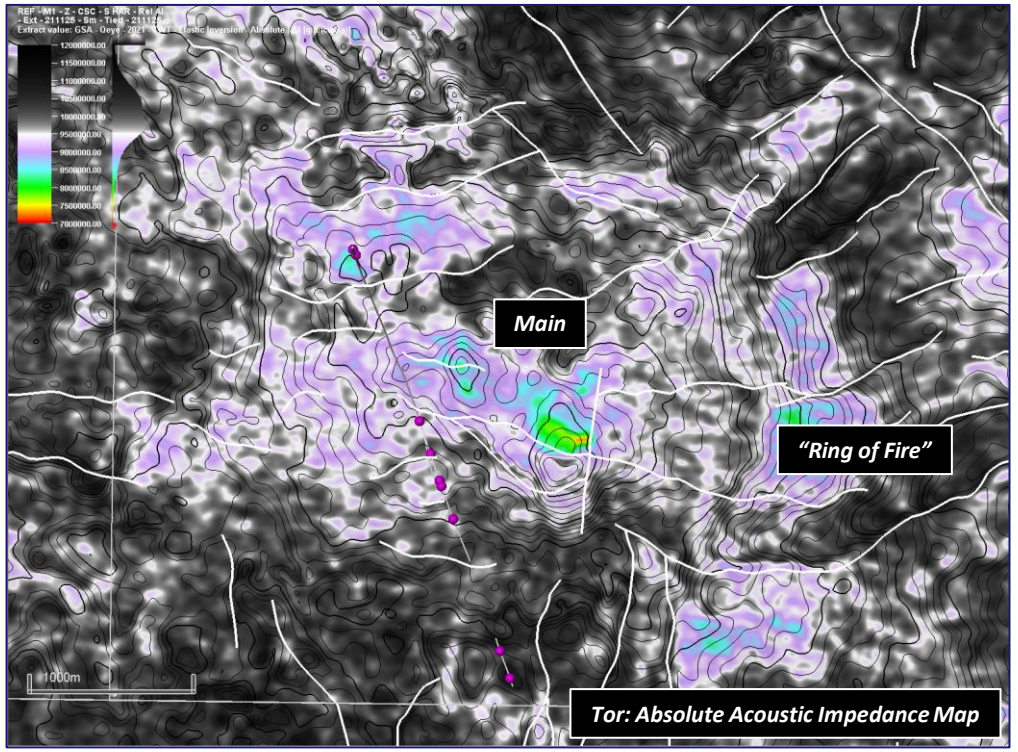
Harrier Field - Geology

- **Broad anticline**
  - 4 x 3 km, 300 ft loft
- **Cretaceous and Tertiary chalk**
  - Mudstone grain size
  - Few natural fractures

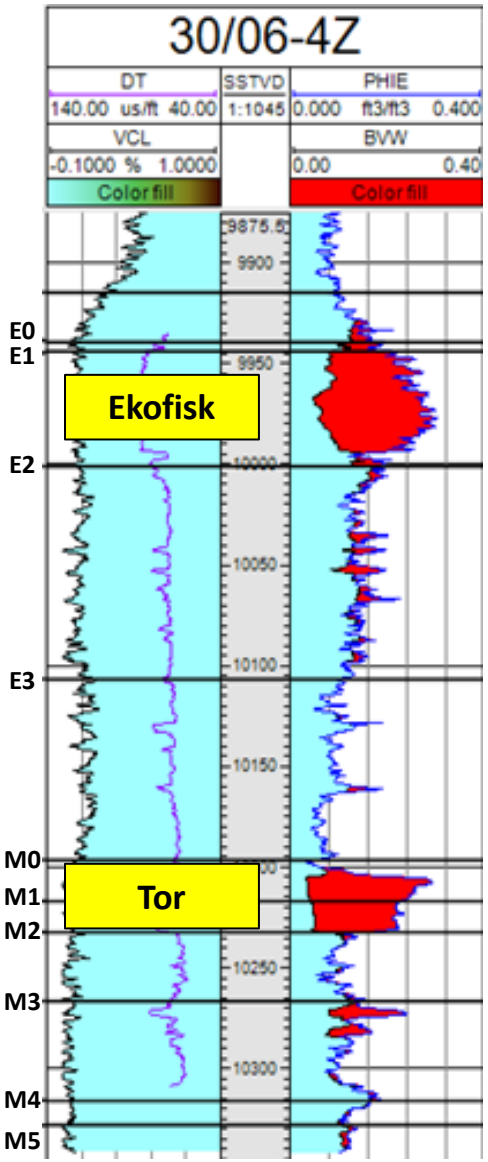
		TST ft TVD	Phie Fraction	NTG Fraction	Swi Fraction	k_{core} md	GIIP Bscf
Ekofisk	Main	60	29%	97%	18%	0.4	169
Tor	Main	30	30%	95%	11%	1.0	77
	Ring of Fire						62



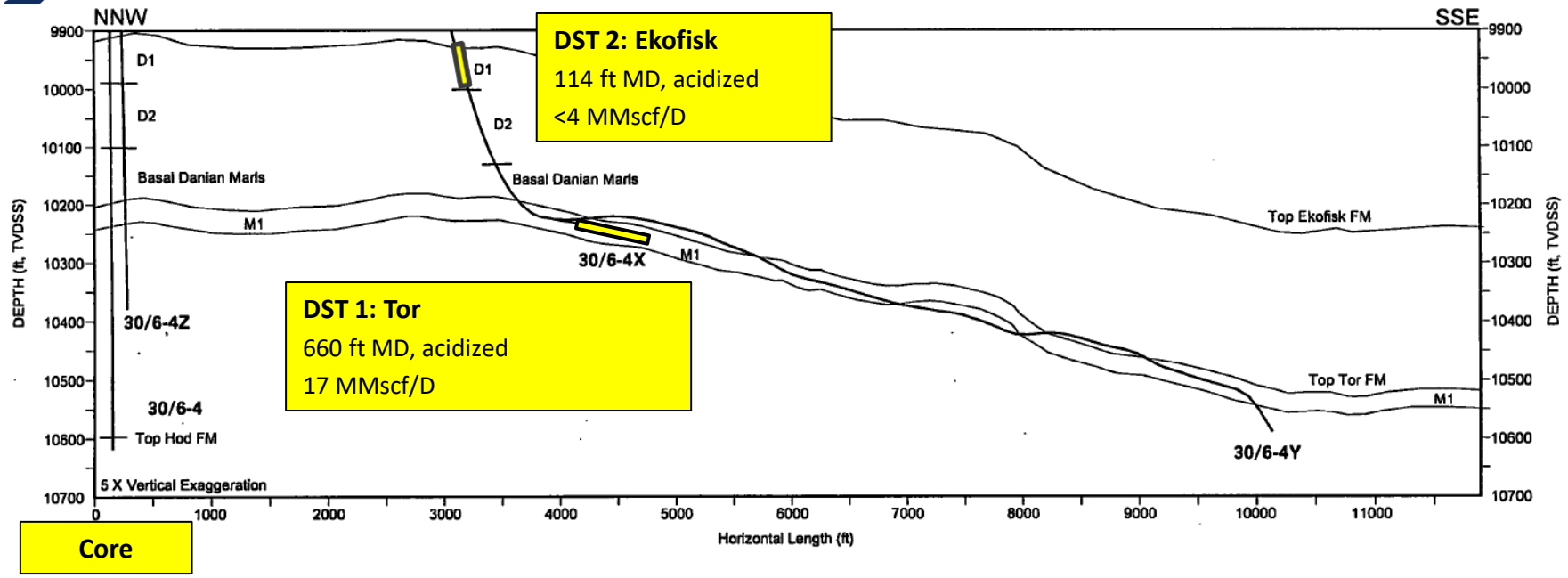
Ekofisk: Top Structure Map

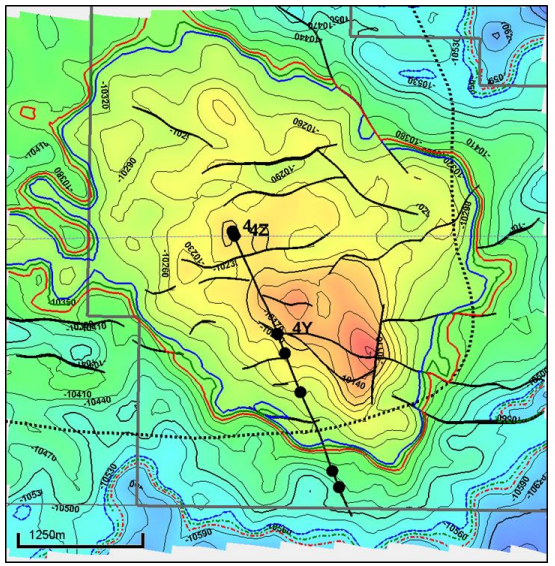


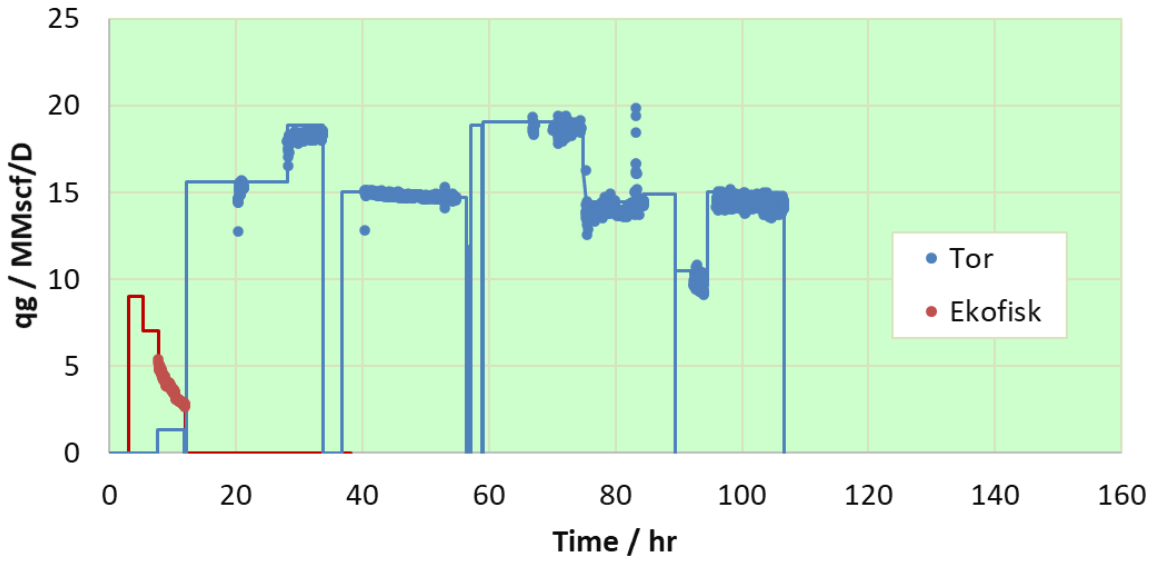
Tor: Absolute Acoustic Impedance Map

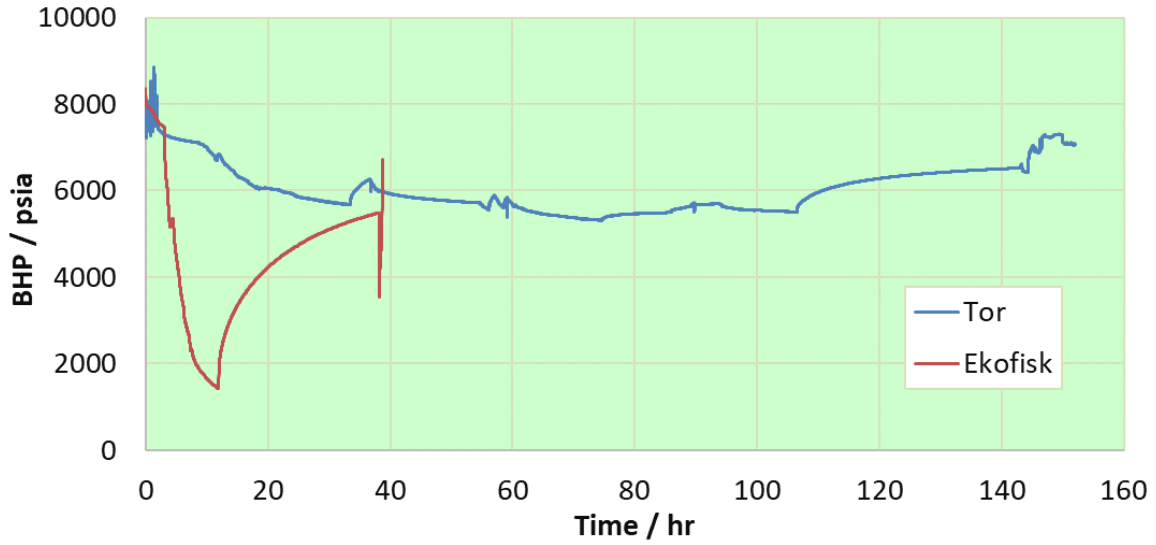


Reservoir Productivity – 30/6-4X DSTs



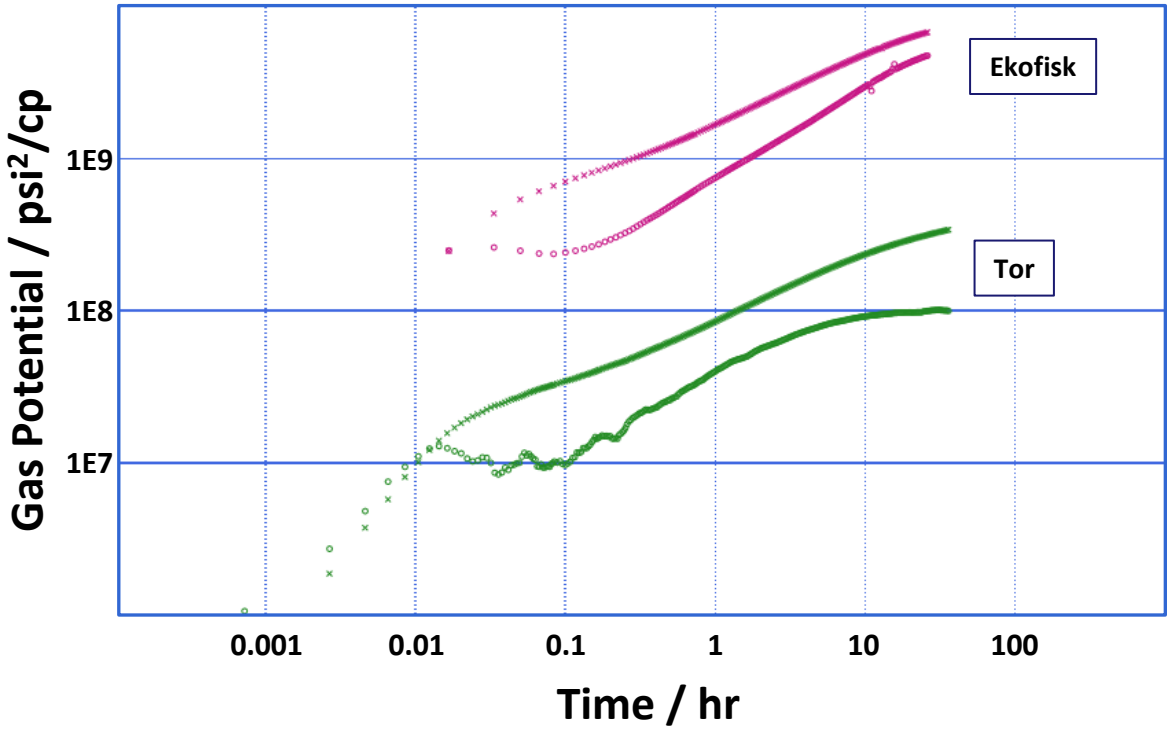






Reservoir Productivity – 30/6-4X DSTs

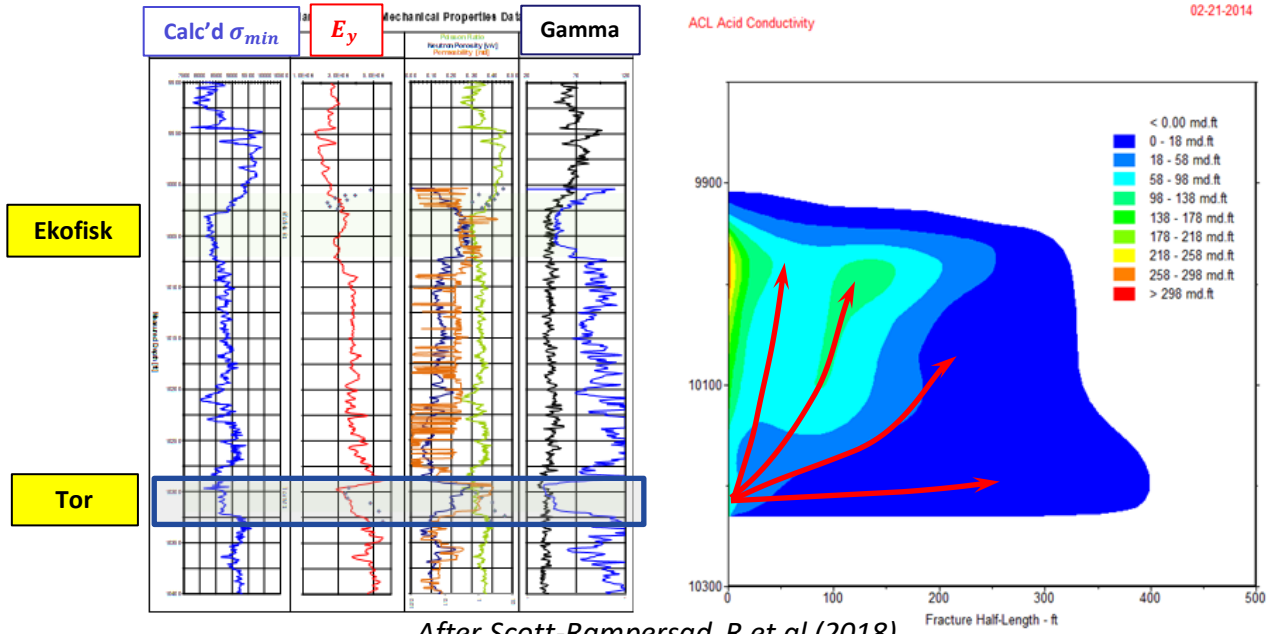
- **Pressure Build up response of Ekofisk and Tor DSTs**
  - Tor productivity superior to Ekofisk
  - Tor IARF flow regime identifiable
  - Ekofisk remains in linear (?) flow
- **Large discrepancy between core and DST permeability for Ekofisk**
  - True reflection of reservoir deliverability or could completion be improved?
- **Remaining dilemma:**
  - Ekofisk has high gas in place, but very low permeability
  - Tor has acceptable permeability but low gas in place



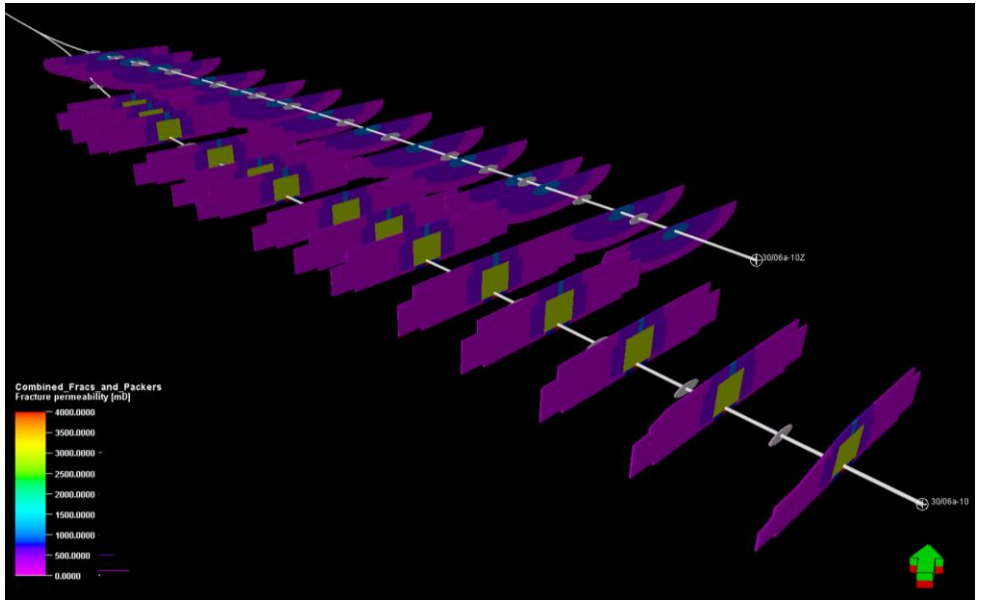
		TST ft TVD	h ft AH	k_{core} md	k_{DST} md
DST 2	Ekofisk	63	114	0.4	0.005
DST 1	Tor	29	660	1.0	0.9

Pre-Development Studies

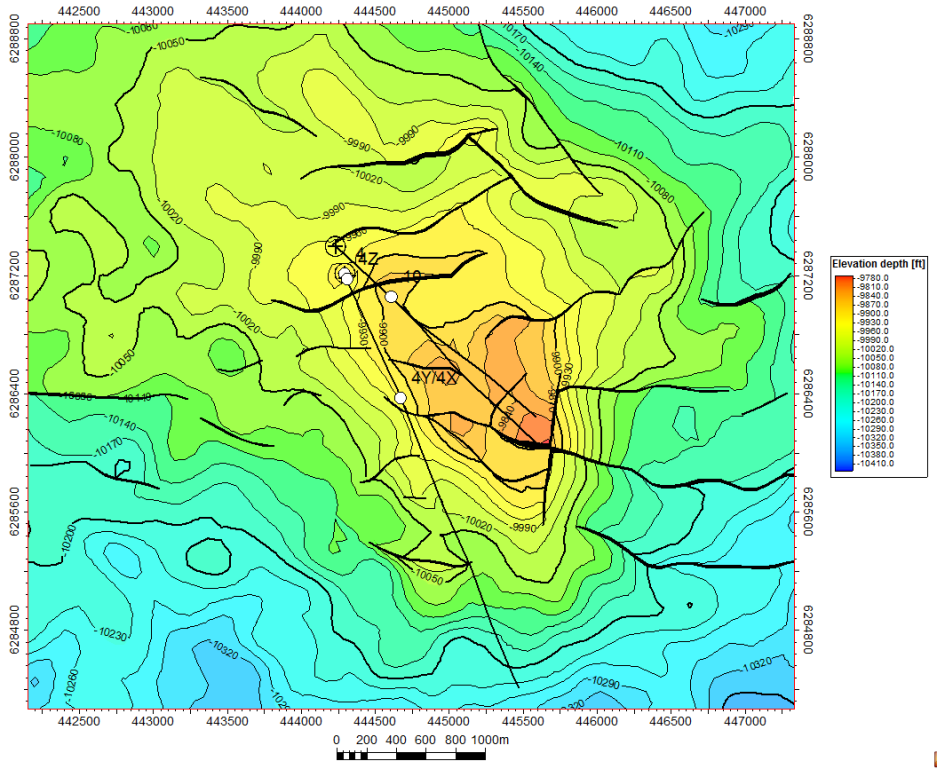
- **Maximise well deliverability using staged acid fractures**
  - Cross linking gels to develop etched fracture surfaces
- **Rock mechanics model based on 4Z petrophysics and calibrated with core**
- **Incorporate into simulation model explicitly with LGRs**

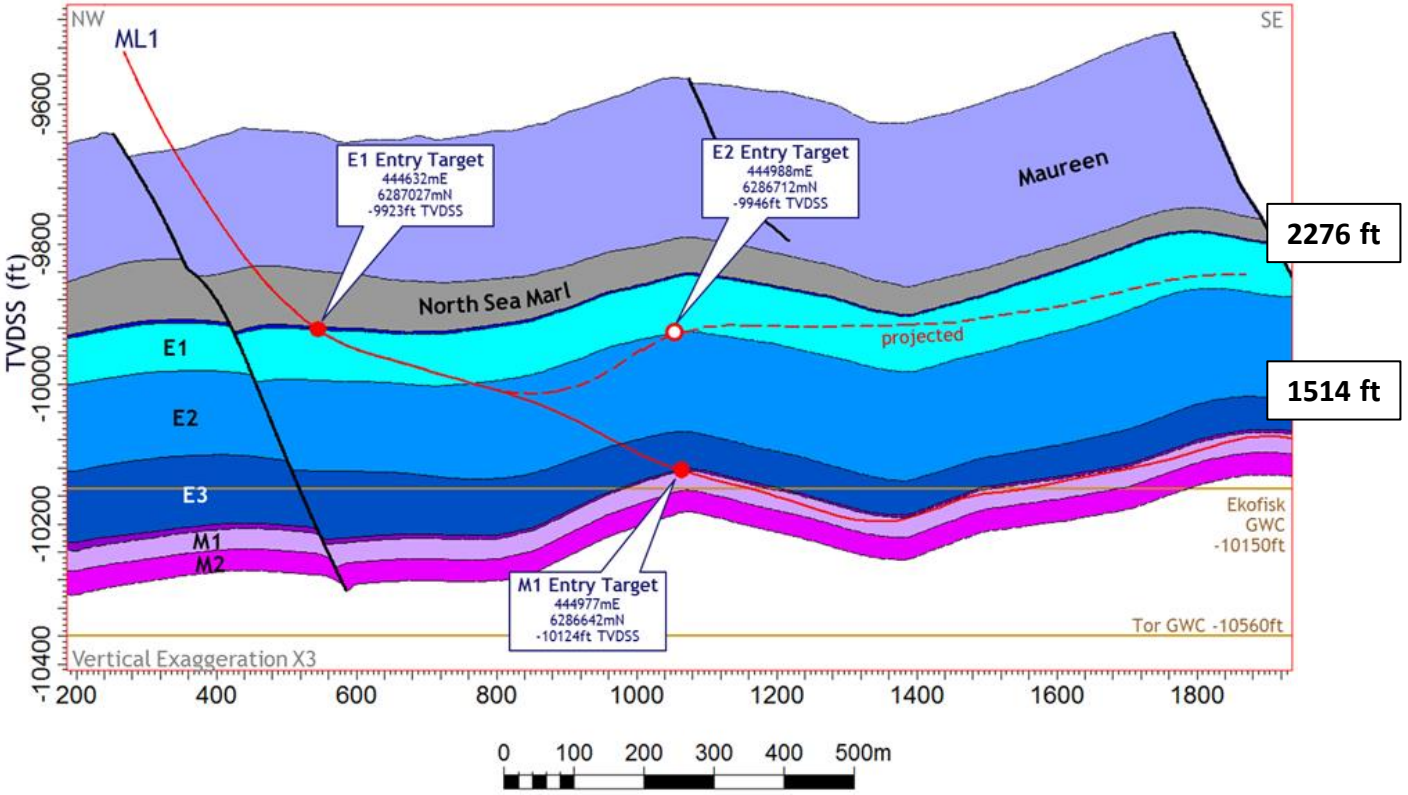


After Scott-Rampersad, R et al (2018)

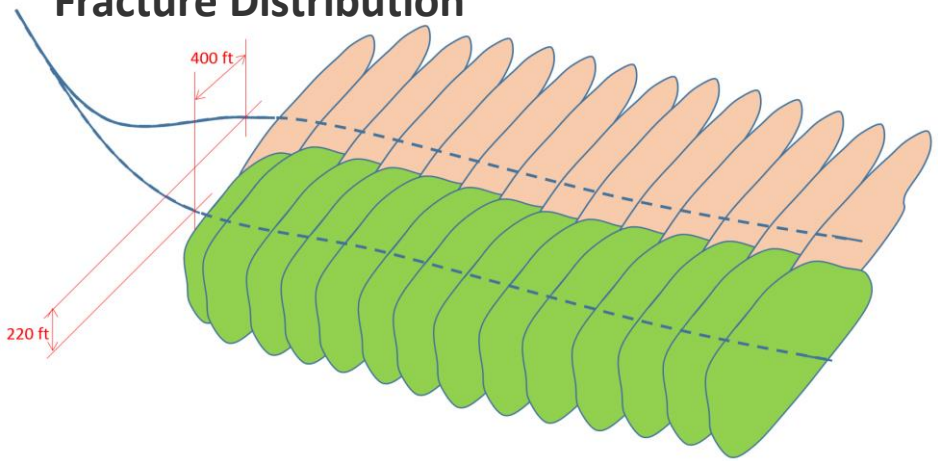


Development Well





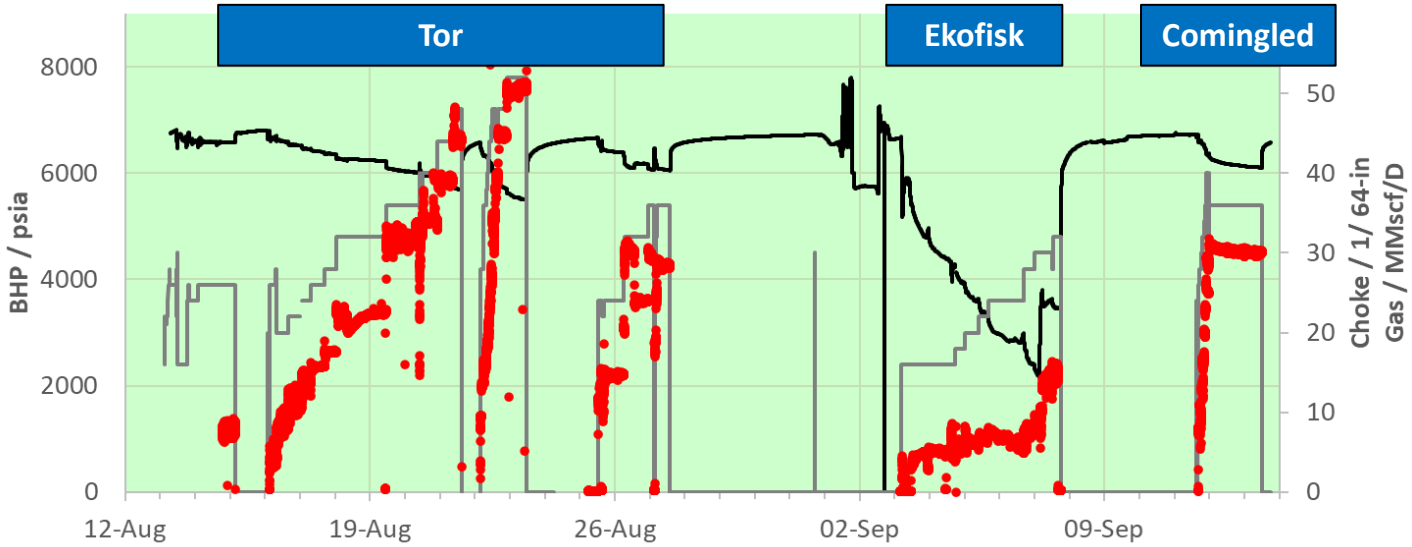
Fracture Distribution

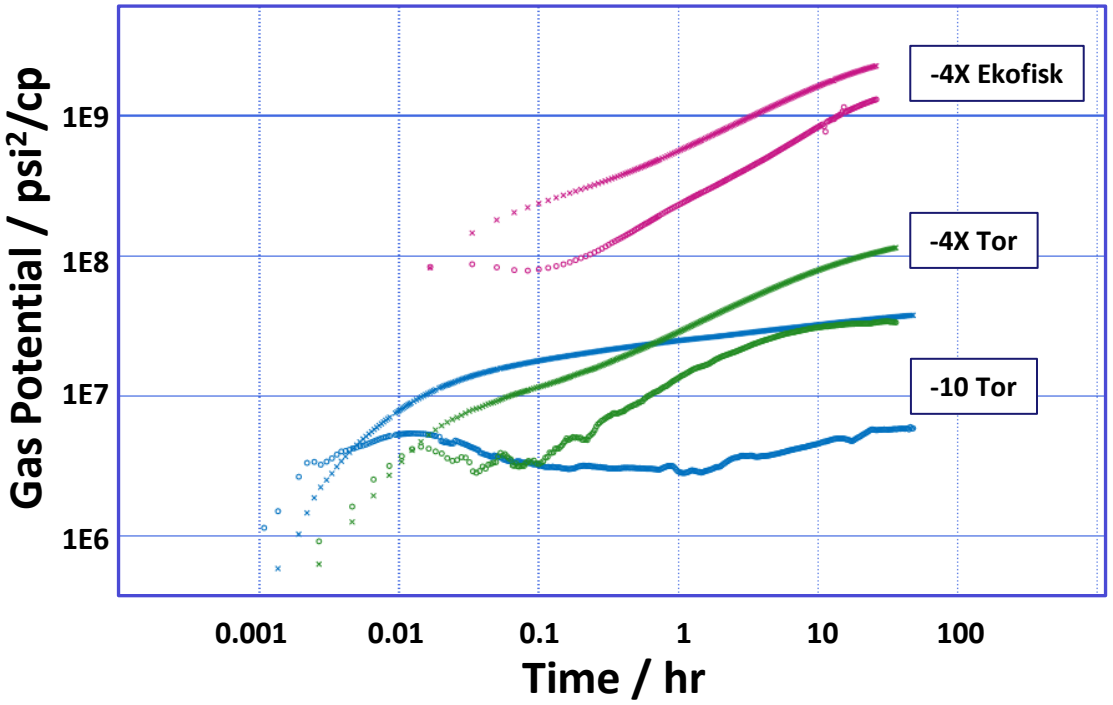


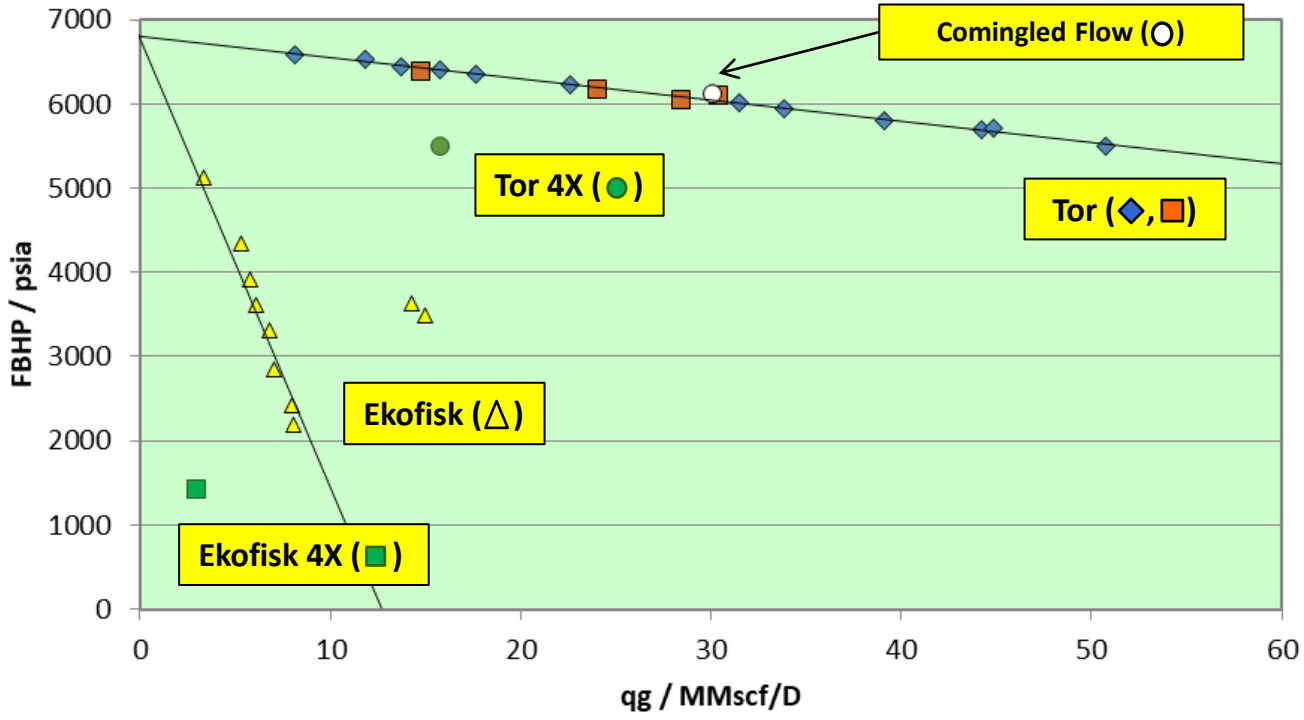
- **Two branch well**
  - Multi-stage acid fracture stimulation (14 stages in each lateral)
  - Tuning fork geometry, Level 2 junction
  - Extensive clean up to rig

Development Well Clean Up

- **Clean up flow to rig**
  - Flow each branch separately, then comingle
  - Gradual clean up to protect fractures
  - Significant difference in layer deliverability

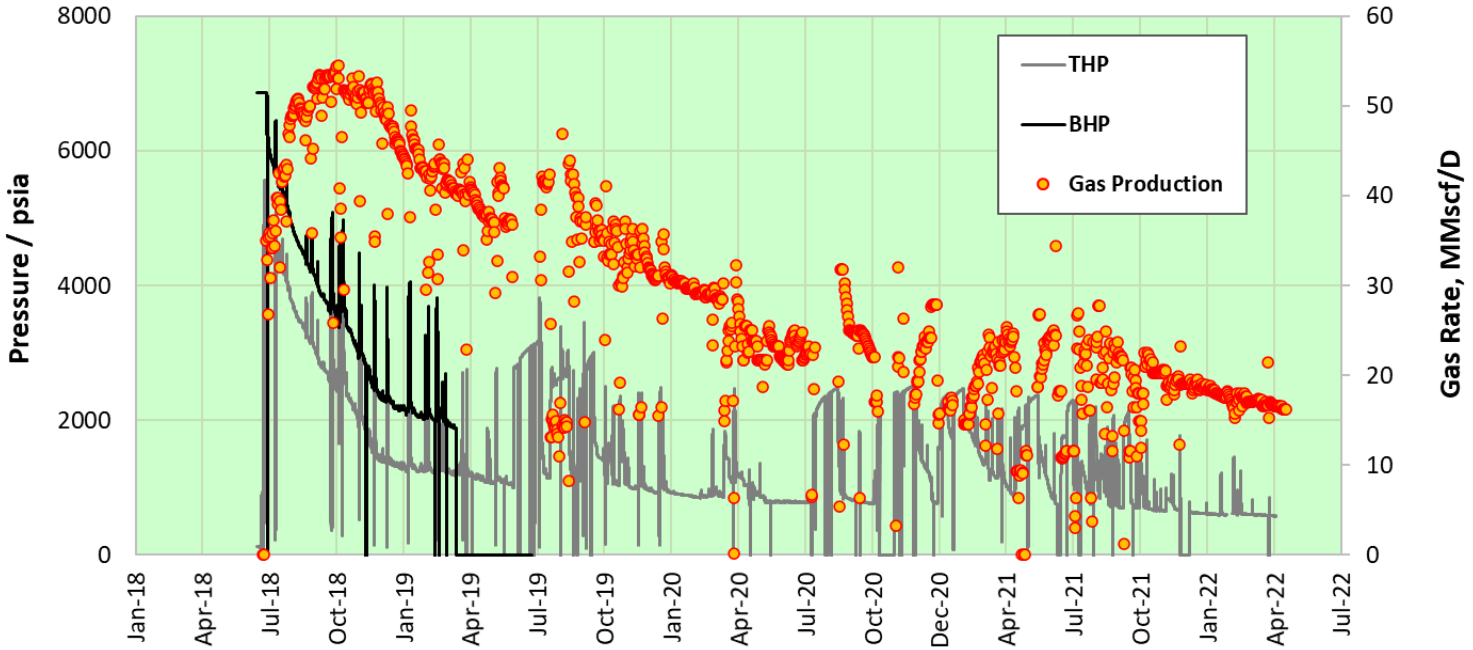






Production Performance

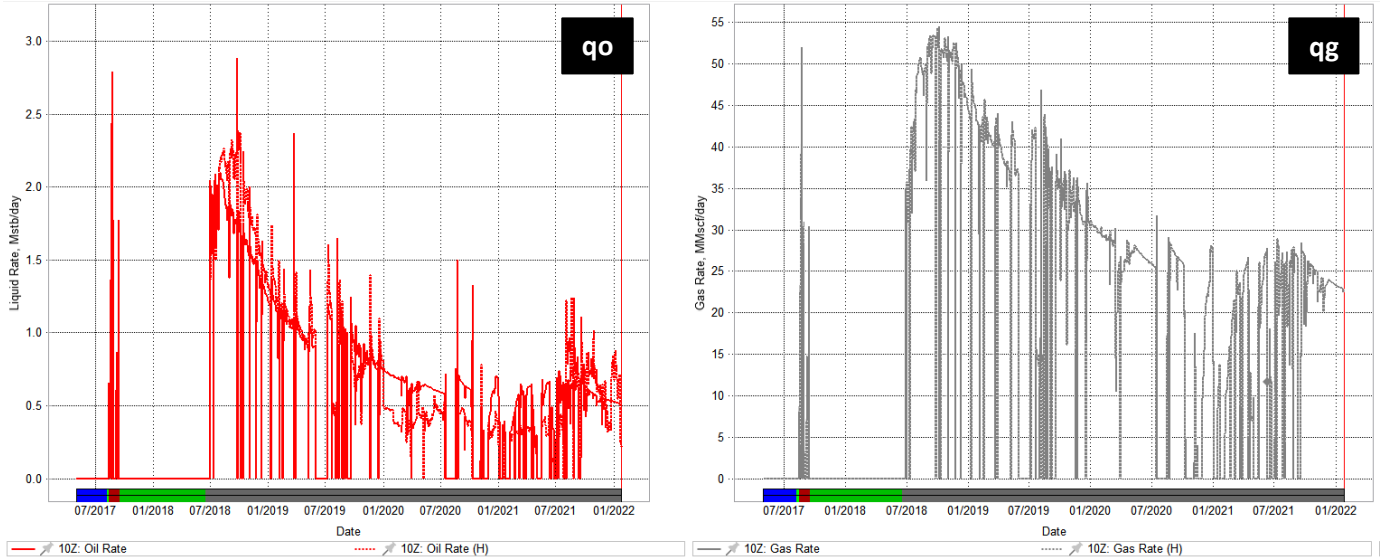
- **Peak rate 50 MMscf/D**
  - Measurement from subsea MPFM
  - Little water production
- **Failed DHG**
  - Rely on extrapolating surface pressure
- **History Matching suggests Ekofisk feeding in slowly as dP_{DD} increases, but at modest rates**

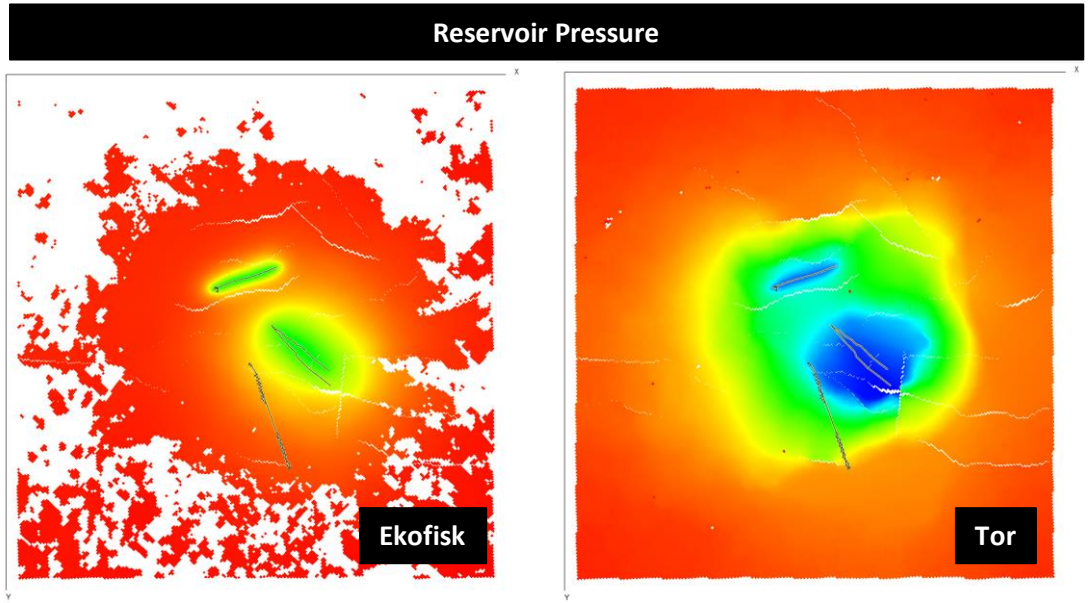


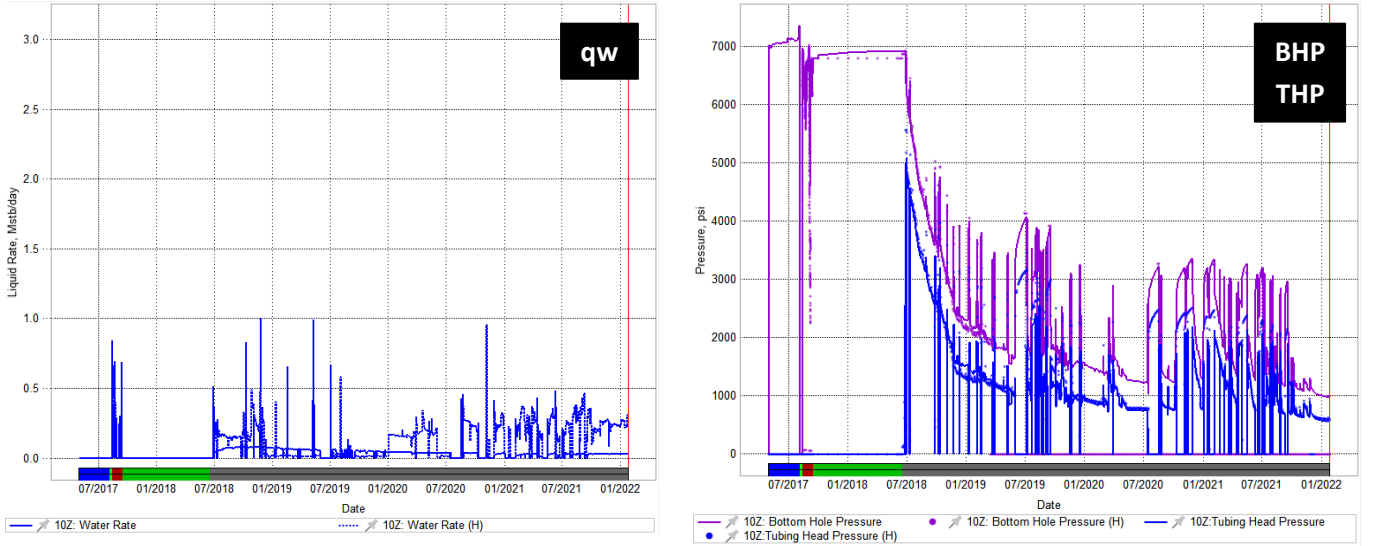
Future Opportunities

- **Possible infill well**
  - Main Field or “Ring of Fire”?
  - Tor and Ekofisk, or Tor only?

- **Reservoir studies to help understand**
  - Long term performance of Ekofisk
  - Ekofisk vs. Tor in place
  - Connectivity to “Ring of Fire”







Key Experiences / Learnings

- **In this area of North Sea, Ekofisk reservoir quality is marginal**
- **Drilled and Completed a Complex Multilateral well, with both branches acid-fracture stimulated**
  - Success – could be deployed elsewhere
  - Both branches in Tor reservoir?
- **Vendors and Supply Chain**
  - Good relationships with Oil Field Service Companies
    - Finance, Drilling and Completion engineering, Access to stimulation vessel
- **Industry Links**
  - Spoke to several other operators, in UK and Denmark
- **Some interesting references:**

Oberhofer, R *et al* (2018) "Completion and Stimulation Design of the First Offshore Acid Fractured Multistage Dual Lateral Well" **SPE-191390-18IHFT-M**

Scott-Rampersad, R *et al* (2018) "Harrier Development: Successful Implementation of the World's First Offshore Multilateral Installation with Staged Acid Fracturing Performed on Both Laterals" **SPE-190820-MS**

Bocaneala, B *et al* (2019) "Multilateral Multistage Hydraulic Fractured Offshore Wells; A New Trend in Completion Design and Optimization for More Effective Field Development" **SPE-195774-MS**