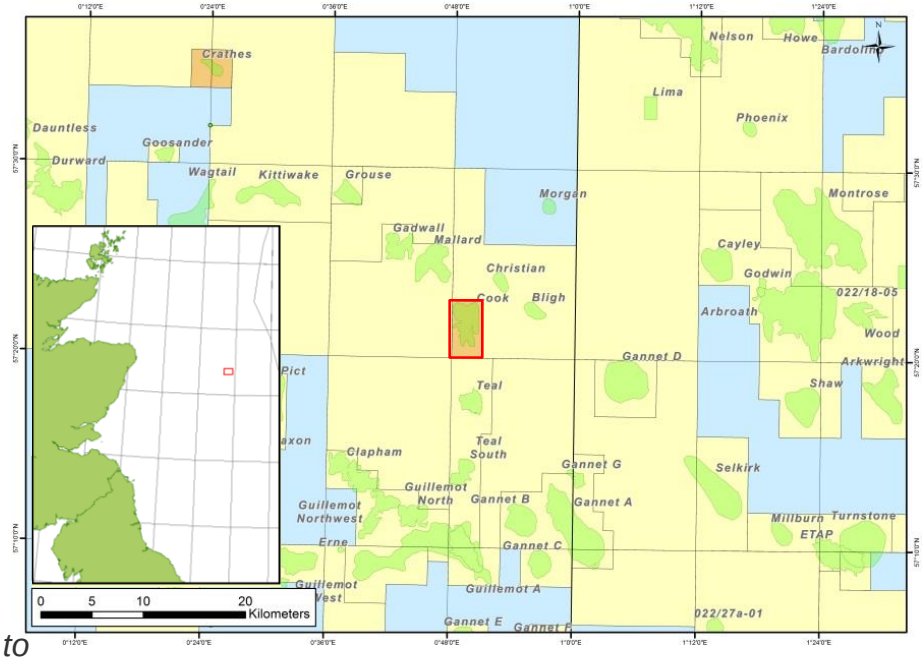
# Cook Field: Adding Water Injection to the Field That Keeps Giving

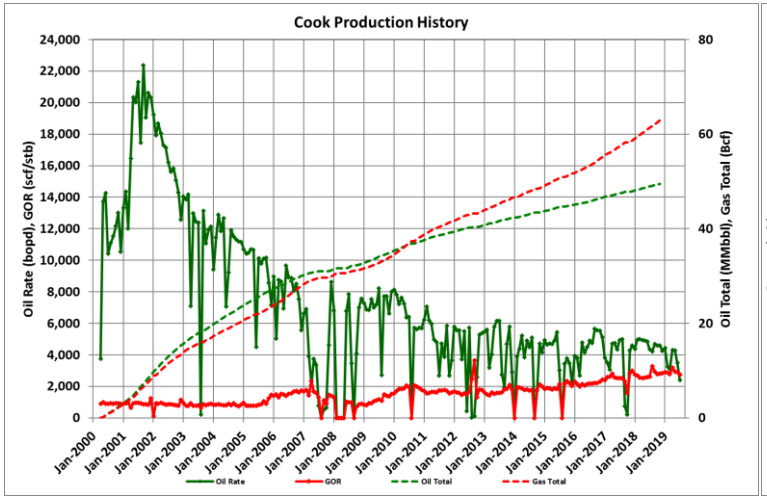
*DEVEX 23 September 2020*

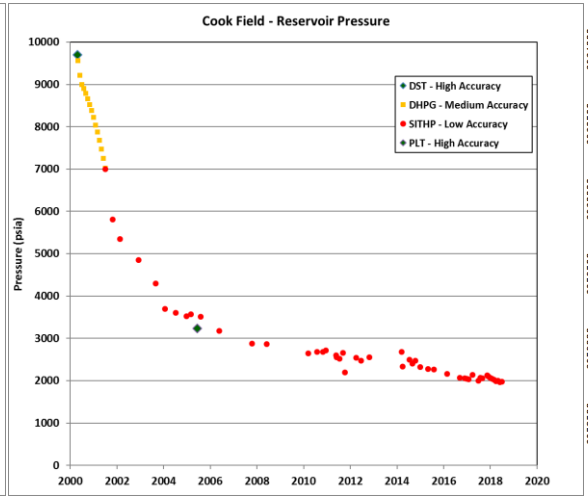
*Arvid de Groot*

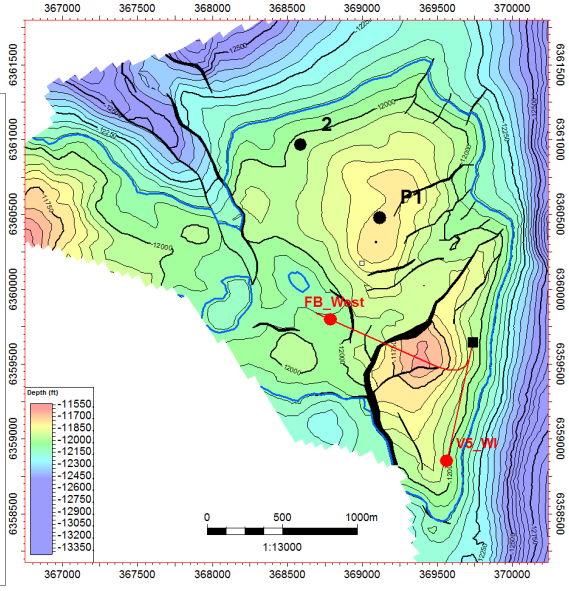
# Cook Field Overview

- **Cook field overview**
  - *Discovery: 1983 well 21/20a-2, First Oil: April 2000*
  - *Equity: Ithaca 61.3%, Ping 19.3%, Hibiscus 19.3%.*
  - *Reservoir: Upper Jurassic Fulmar*
  - *Reservoir Properties: Φ 12-25%, N/G 62%, K 30-1200md*
  - *Oil: API 38, Rsi 1000 scf/STB, Bubble point: 3425 psia*
- **Single production well (P1) has produced >50 Million stb**
  - *Zero water production to date*
  - *Reservoir is heavily depleted from initial pressure of 9700 psi to ~2000 psi*
- **Water injector(P2 / "V5_WI"), well drilled in 2019**
  - *To re-pressurise the field and arrest production decline*
  - *Targeting unswept oil to the South of the existing producer*
  - *Key uncertainty was pressure communication of primary target to production well, risk of drilling virgin pressure*

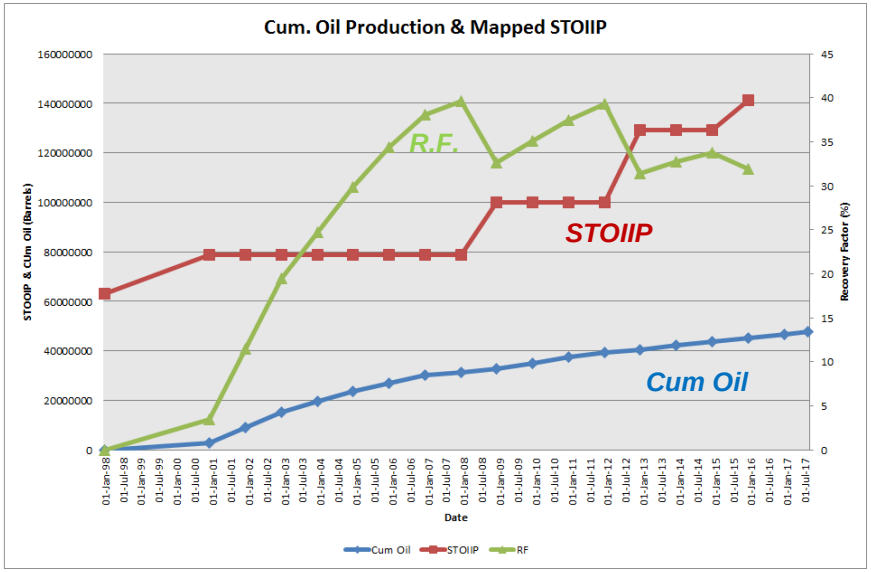


# The Cook Conundrum?

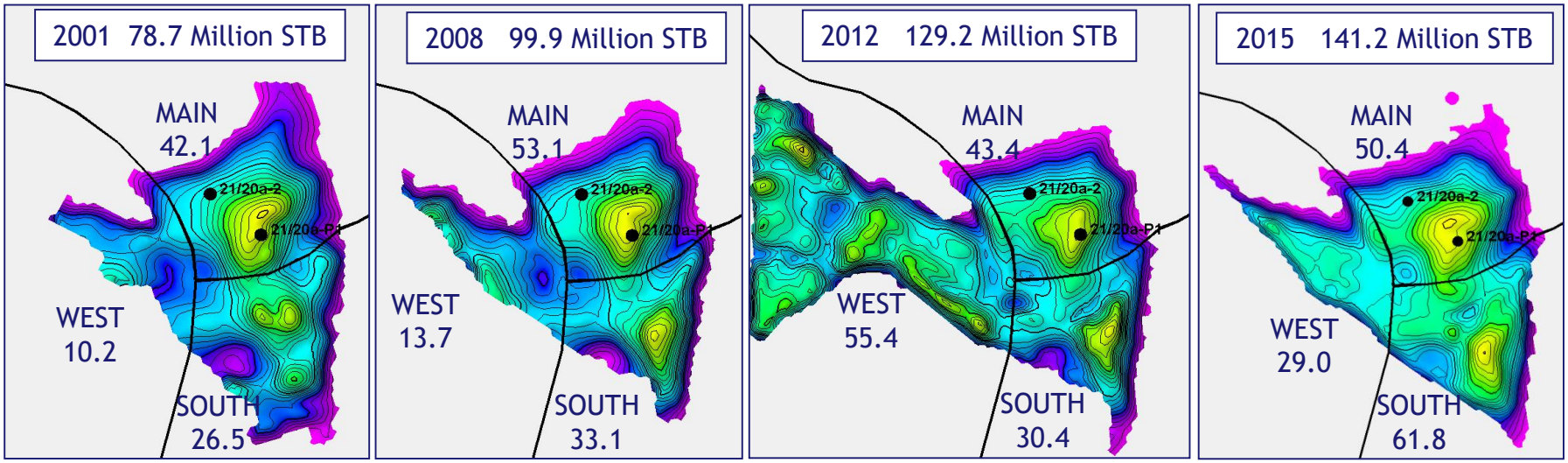



***STOIIP, Cum Oil & Recovery Factor over time***

**Material Balance indicates that the production well is accessing a larger volume than can be mapped.**

**Evolution of mapped STOIIP over time reflects different flavours of seismic and re-processing.**

**Spatial variation in volumetric distribution reflects reservoir presence uncertainty.**




***Static model volumes over time***

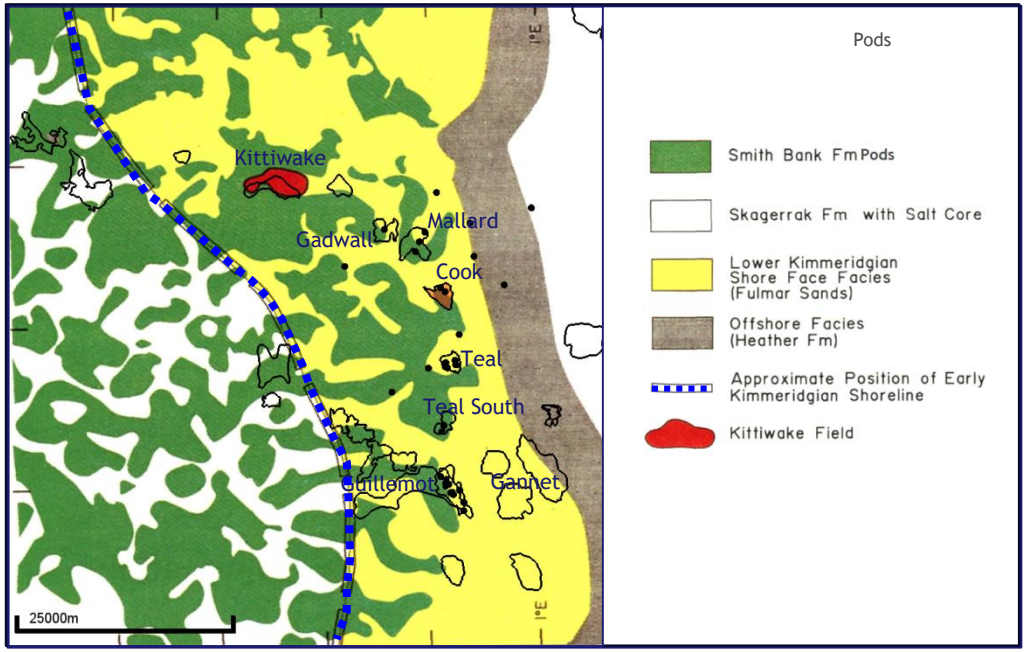
# Fulmar Regional Depositional Setting

**Fulmar shoreface sands were deposited in a series of paleo-valleys created by a combination of salt withdrawal inter-pods and or faulting**

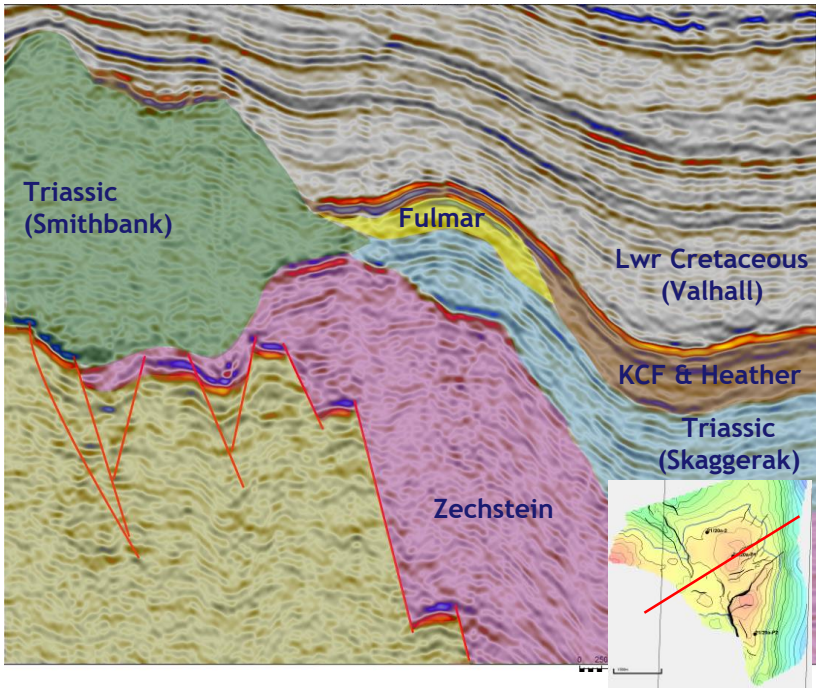
**Regionally there is no basin-ward shift in facies apart from the progradational sequence at the base of the Fulmar sands**

## Western Platform Fulmar Palaeogeography

(Modified from Wakefield et. Al. 1993)

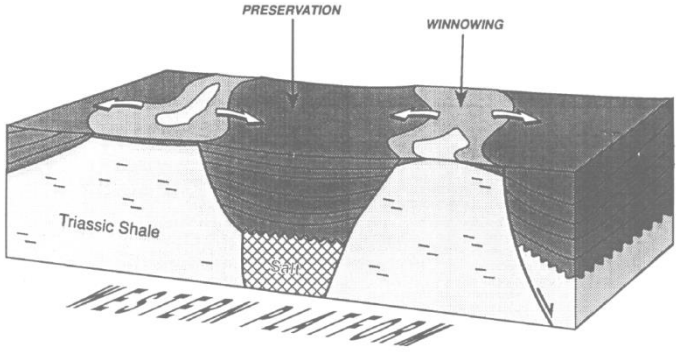



SW NE

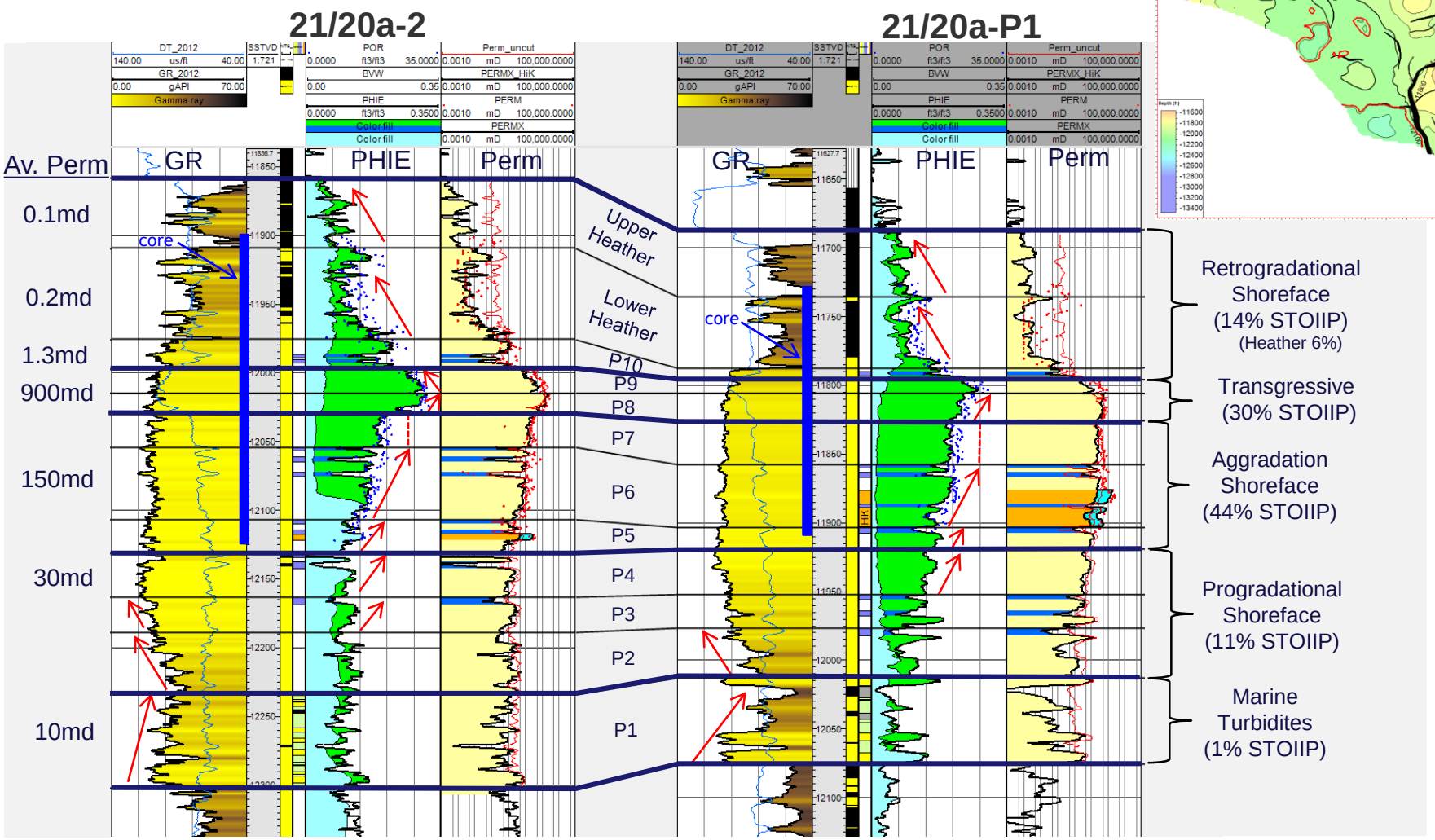


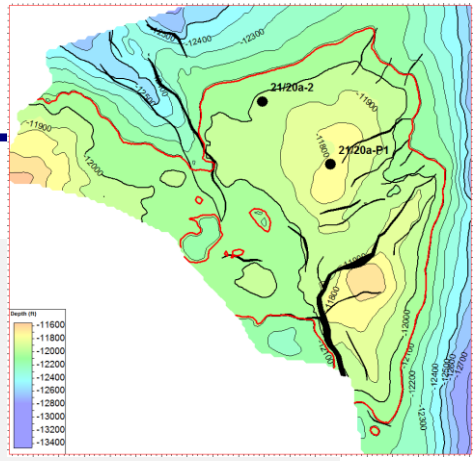

## Depositional Model for the Fulmar Formation

(from Wakefield et. Al. 1993)



# Reservoir Quality and Correlation




**Reservoir quality is very good, especially toward the upper half of the Fulmar sand**

**Reservoir has high degree of correlation**

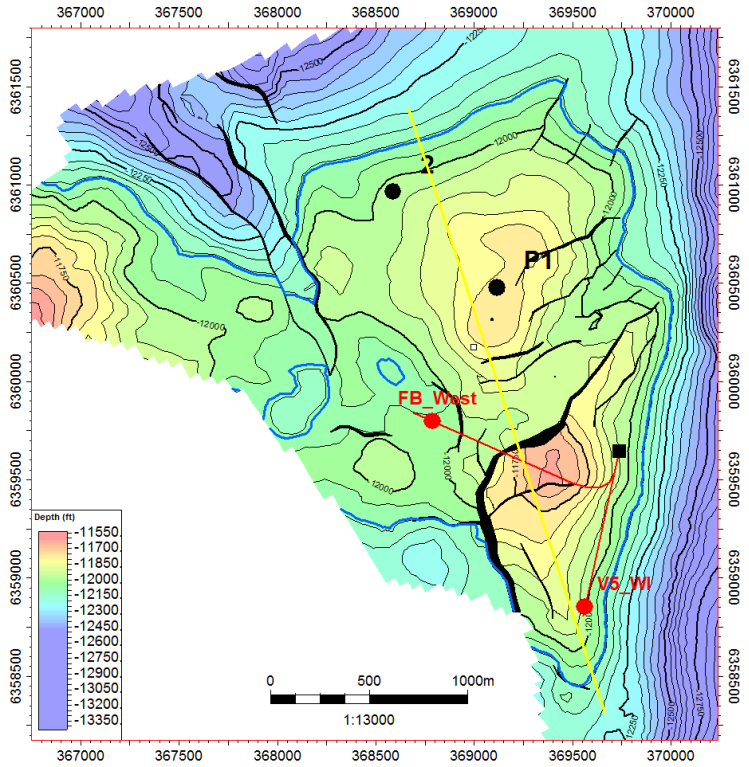
# Cook Water Injection Introduction

**P2 (“V5_WI”) planned as a water injector in the South of the field to give pressure support to the P1 producer in the main area**

**Seismic studies suggested continuation of the Fulmar reservoir to the South**

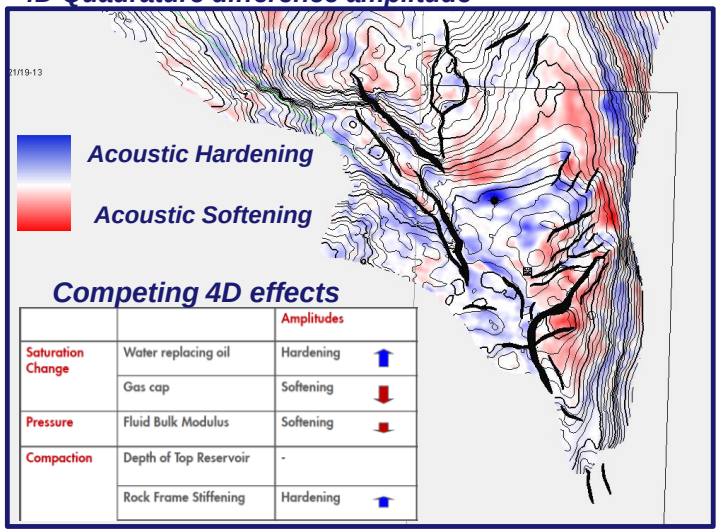
**Strong depletion in the South required for a successful well**

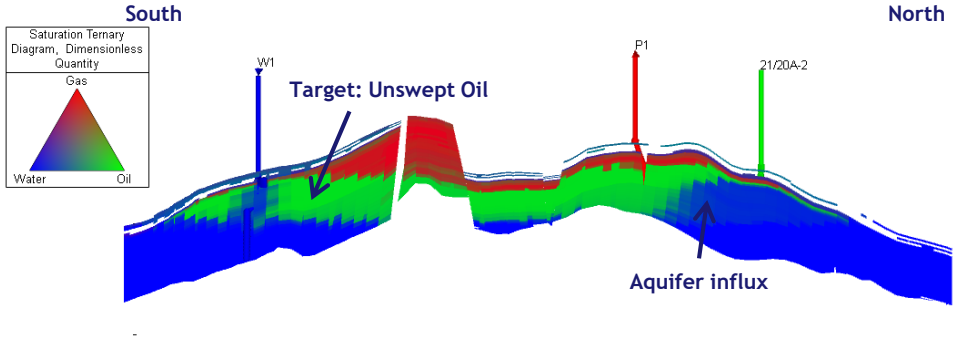
**If reservoir absent or virgin pressure then fall back location closer to P1 (“FB_West”) in the main field was planned**



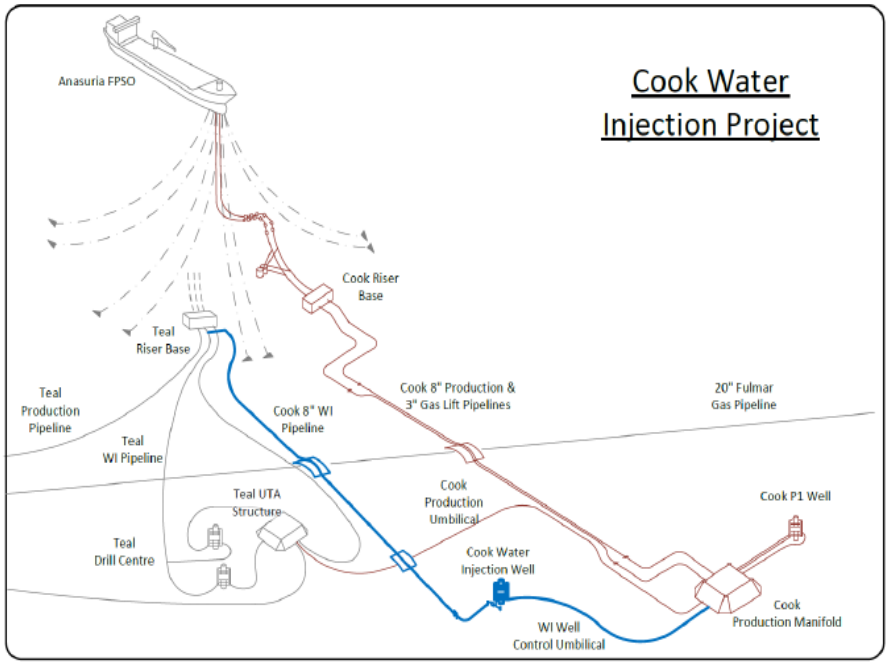

***Top Fulmar Time Structure***

***4D Quadrature difference amplitude***

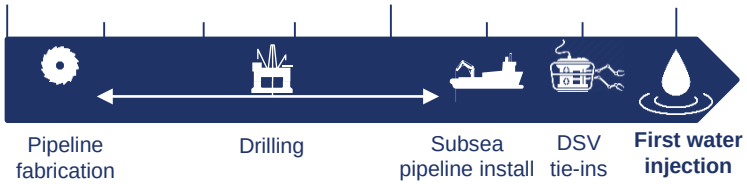


# Cook Water Injection Project




**Schedule**




ODFJELL

DeepSea Bergen

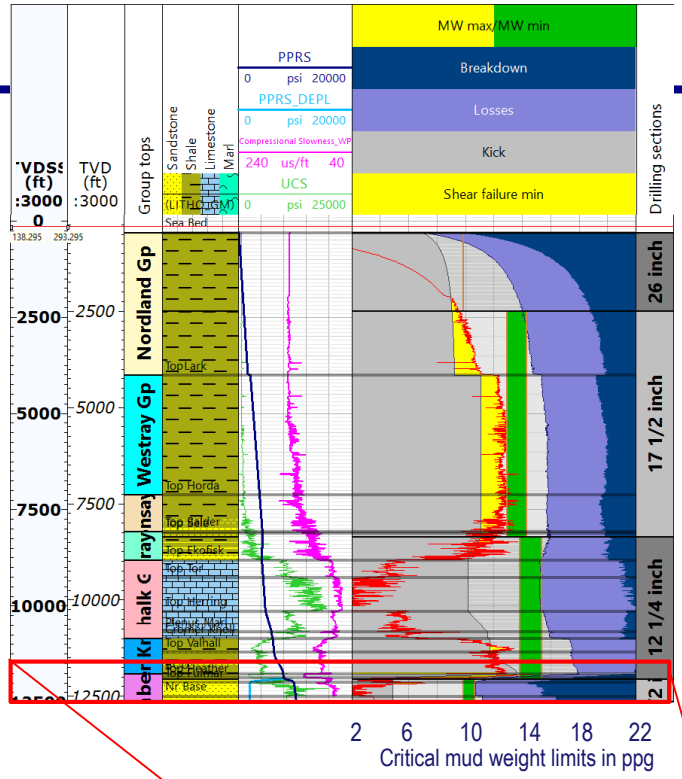

- **Drilling scope**
  - *Drill deviated well without incidents and accidents*
  - *Complete the well*
  - *Perform Water Injectivity test*

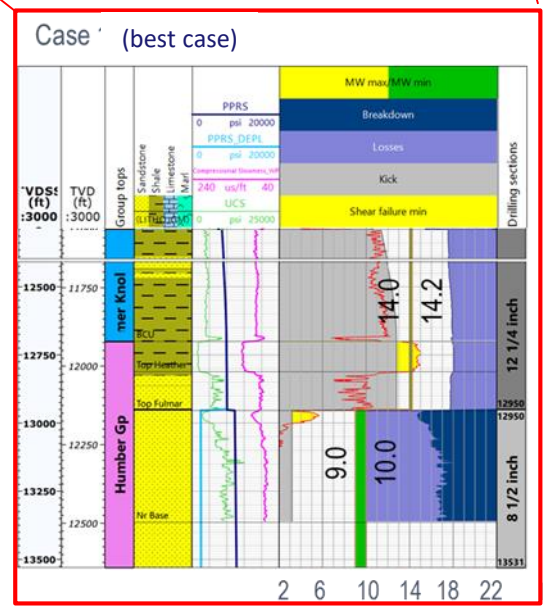
- **Subsea scope**
  - *New 11km 8" pipeline; 1km umbilical; new well tie-ins(x1); tie-ins to existing Teal riser base, topsides control mods*
  - *Pipeline trenching & installation*
  - *Post installation surveys & metrology*
  - *Rock dumping & final DSV tie ins*

# Drilling Challenges - Well Design

- **Uncertainty in connectivity of the South to the North**
  - *Reservoir pressure could be virgin ~9700 psi*
  - *Reservoir pressure could be ~2000 psi if good connectivity with North*
  - *Reservoir pressure could be somewhere in between…*
- **Sidetrack water injector if not sufficiently connected to the North to alternative location to support P1 production**
  - *Cook Primary: Max deviation 30°, Azimuth 153°*
  - *Cook Fallback: Max deviation 45°, Azimuth 300°*
    - *Drilling the fallback will be much more challenging due to the hole angle*
- **Geo-mechanical model/hole stability**
  - *Reduced reservoir fracture gradient expected in reservoir depletion case*
  - *Uncertainty of integrity/location of top seal*
    - *Case 1 depletion starts at top Fulmar Fm*
    - *Case 2 depletion starts at top Heather Fm*
    - *Case 3 depletion starts above top Heather (BCU)*
  - *Significant potential for losses with the possibility of virgin pressure*
- **Mitigations**
  - *Set 12 ¼ " casing section within the Heather Fm. The Kimmeridge Clay Fm is expected to be over pressured with a risk of breakouts*
    - *If the Heather Fm is depleted, there is a risk of breakdown*
  - *Setting an additional casing point above the KC Fm reduces risk of losses in Chalk and Palaeocene sands*
  - *Design a good bridging package to limit losses in the depleted reservoir section, geomechanical core testing undertaken*

**Predicted safe mud weights for Primary well – Top hole**



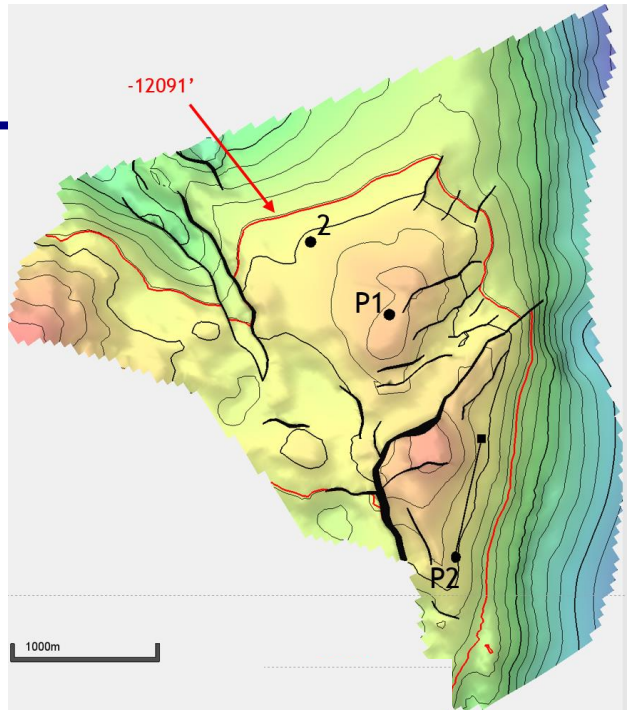



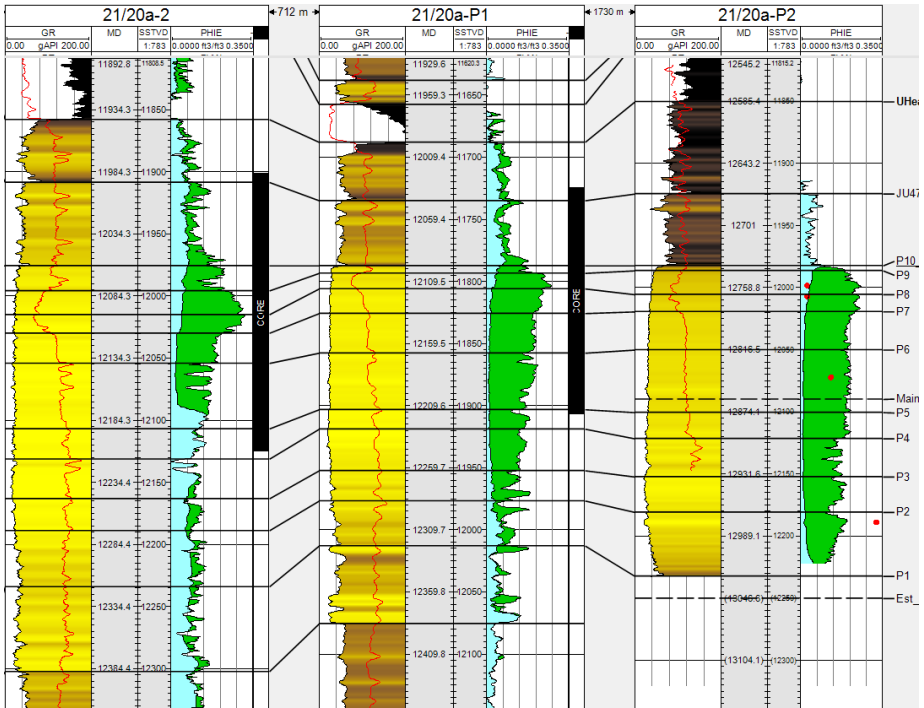
# Drilling results

- **12 1/4” section drilled into the middle Heather without losses and casing set**
  - *Apprehensive to drill into the Fulmar and experience significant well bore stability and potentially losing the whole 12 ¼” section.*

- **8 1/2” section drilling results**
  - *Drilled out of the 9 5/8” shoe into the Lower part of the Heather with 13.5 ppg mud weight. No losses were observed*
  - *Upon drilling the Fulmar pressure points were taken, giving Formation pressures between 2028 psi and 2078 psi (equivalent mud weight of 3.2 ppg)*
  - *This indicated the reservoir was depleted from the virgin 9700 psi and well connected to the North. No signs of losses were observed with such a large overbalance*
  - *Base intentionally not penetrated – fear of over-pressured basal shale*

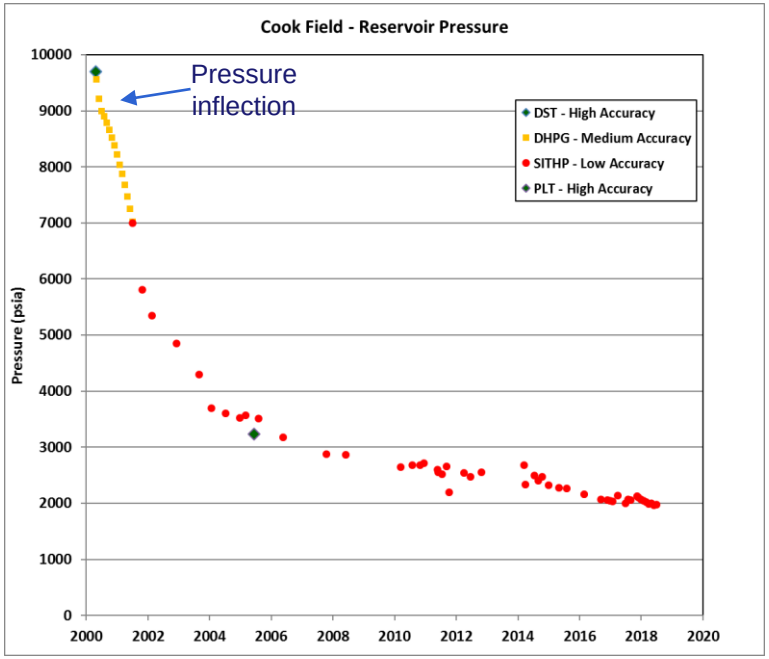
- **Top Fulmar 1 ft shallow, full oil column: 250 ft gross with average N:G 0.95 and porosity of 18.4%**
- **Light oil gradient observed from the pressure points**
- **No OWC penetrated in the well, plan was to intersect the known contact from the North**
  - *Estimated OWC in South significantly deeper than OWC in the North*
  - *Fault separating the North from the South inferred as pre-production barrier*
- **Successful Injectivity test**
  - *Injected up to maximum rates*



# Conclusion

- **Drilled a heavily depleted reservoir without losses**
  - *Key to this success has been the bridging package design*




- **Reservoir depleted – well connected to production well**
- **Discovered deeper contact, found more Oil**
- **This combined result is somewhat counterintuitive**
  - *Pre-production fault sealing mechanism can explain this and is believed to be due to Cataclasis*
    - *Salt induced movement of the structure together with complex diagenetic processes have likely resulted in the sealing of this fault*
    - *Fault seal appears to have broken down at ~500 psi differential pressure, this seems to corroborate with other North Sea examples of fault seal breakdown*

- **Additional hydrocarbons discovered resolves the Cook Conundrum of 'missing' oil, which explains the excellent historic production behaviour**
- **Water injection well delivers pressure support to the production well**
- **Previously unswept oil in the South adds significant reserves and life extension to the field**

**Good things happen when you drill wells (sometimes)**

# Acknowledgements & Questions

**Discipline integration is the key to understanding the production performance of Cook and optimising the remaining recoverable volumes**

**Acknowledgements**

**Thanks to the Ithaca team involved in the Cook project and our partners Hibiscus Petroleum, Ping Petroleum, Anasuria Operating Companying & Ithaca Energy management for permission to publish this work.**