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Ekofisk field
-A massive water shut off job-
An inspiring case story

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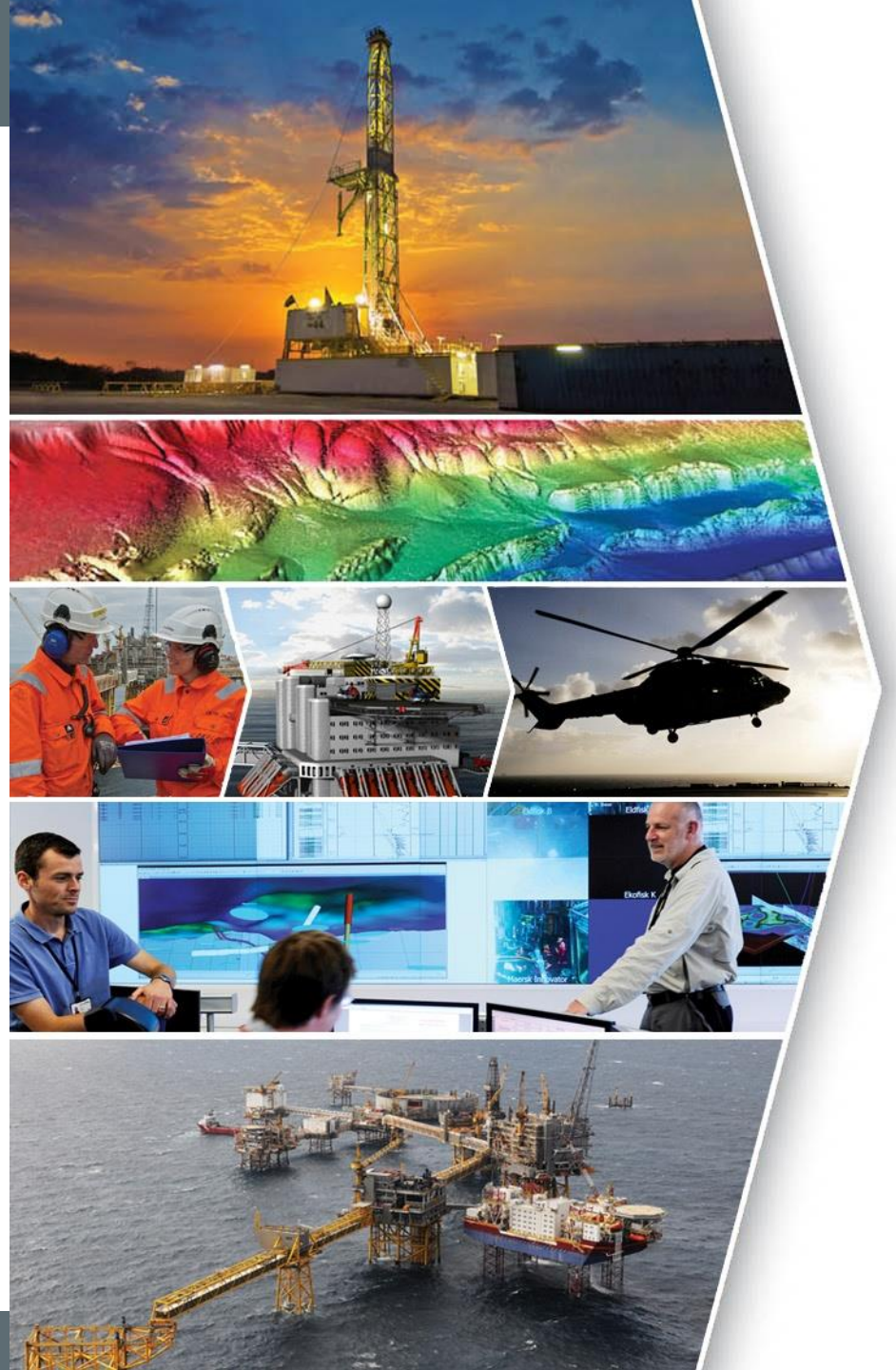

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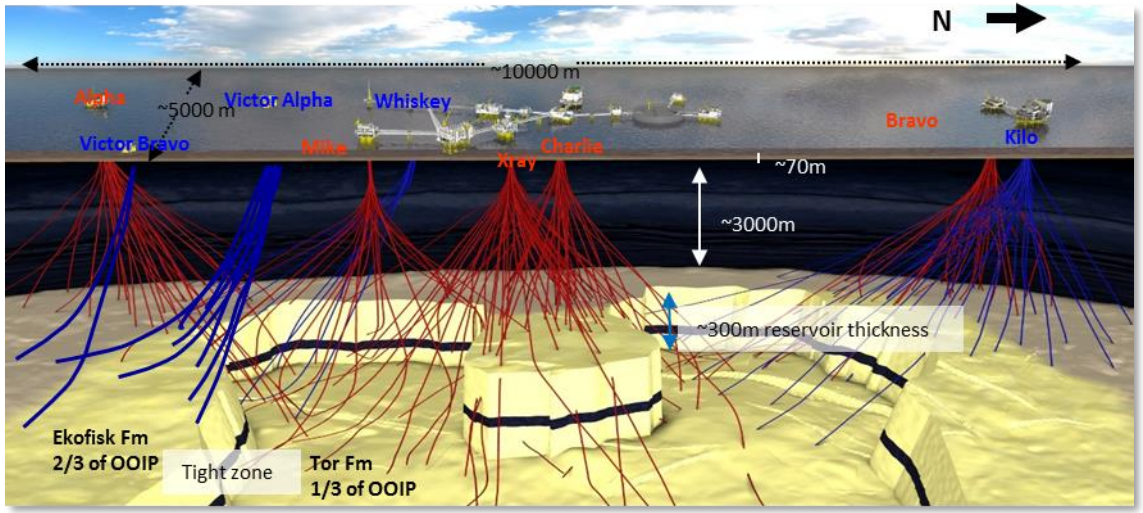
Presentation Outline

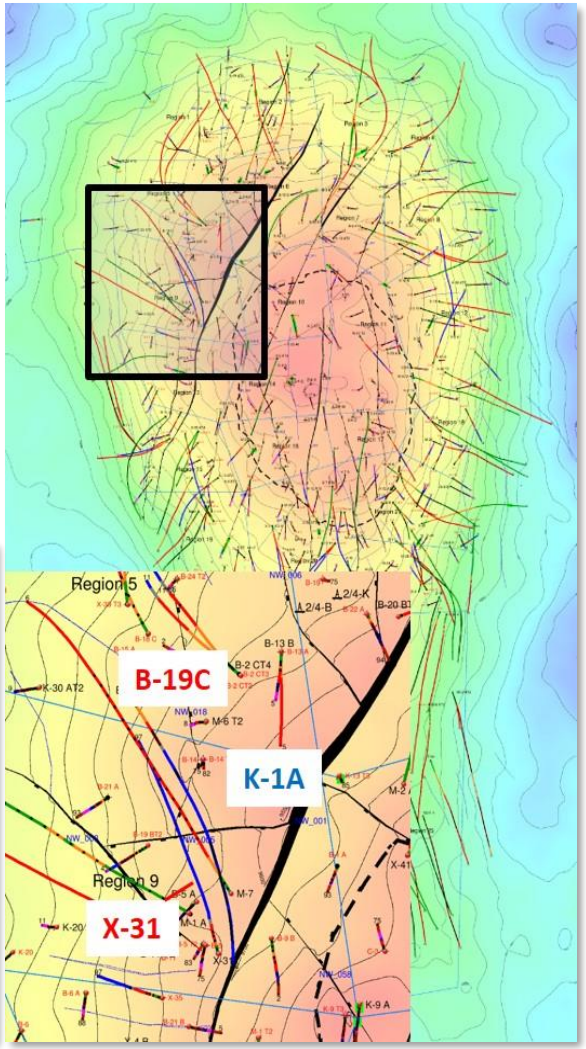
- Introduction
- Problem Identification
- Problem Understanding
- Solution Design
- Solution Execution
- Production Impact

Introduction

Ekofisk Field

- First production: 1971
- Initial Oil in Place: 6.9 BSTB
- Reservoir: Naturally Fractured Chalk
- Two main formations: Ekofisk, Tor
- Reservoir Properties:
  - Porosity: 25-45%
  - Permeability: 1-10 mD
- Waterflood process
  - First Injection: 1987
  - One dedicated injection platform
  - Two dedicated injection subsea templates





Problem Identification

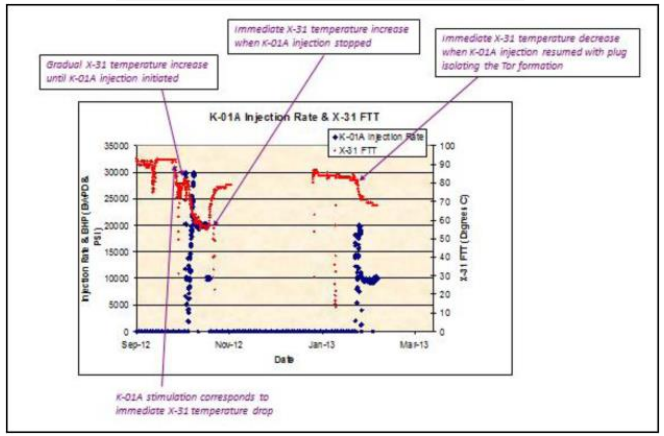
WBT Event: Initial indicators

- Injection and production performance trends
- Temperature response
- Water chemistry analysis

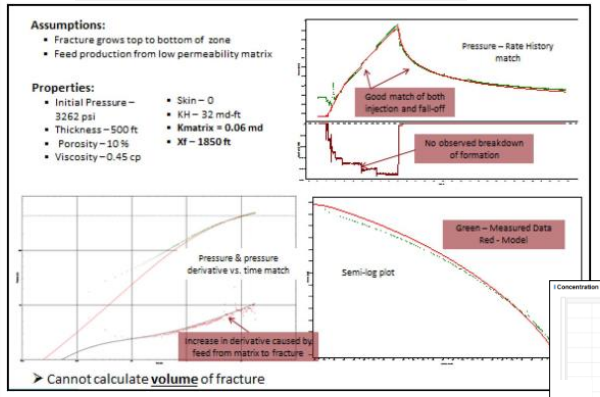
WBT Event: Diagnostics

- Injection profile and temperature log at different injection rates
- Pressure Transient Analysis, Step Rate Test
- Inter-well tracer: time to breakthrough and tracer concentration profile
- Interference test
- Geological and Geophysical interpretation

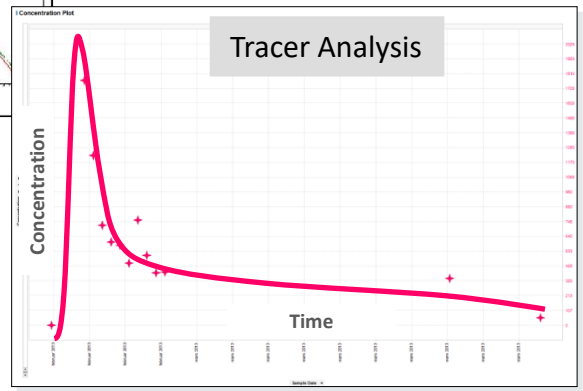
Monitor Temperature/Rate



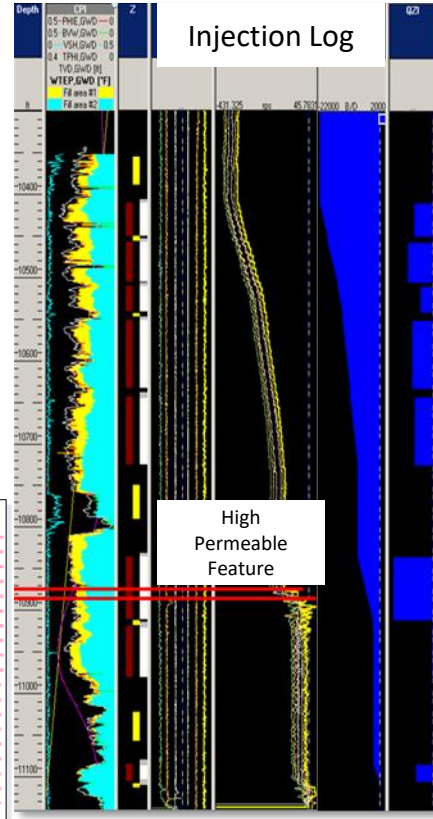
Pressure Transient Analysis



Tracer Analysis



Injection Log



Problem Understanding Summary

WBT X-31
Lost 2400 bopd

K-1A Open
Tracer Injection

B-19C First Prod.
Water zone isolated with packers

K-1A STIM/First Inj.
Pressure support for challenged regions (B-19)

K-1A SI
After 16 days of Injection

X-31 Tracers
90 minutes response time

B-19C Tracers
3 weeks response time

16 days

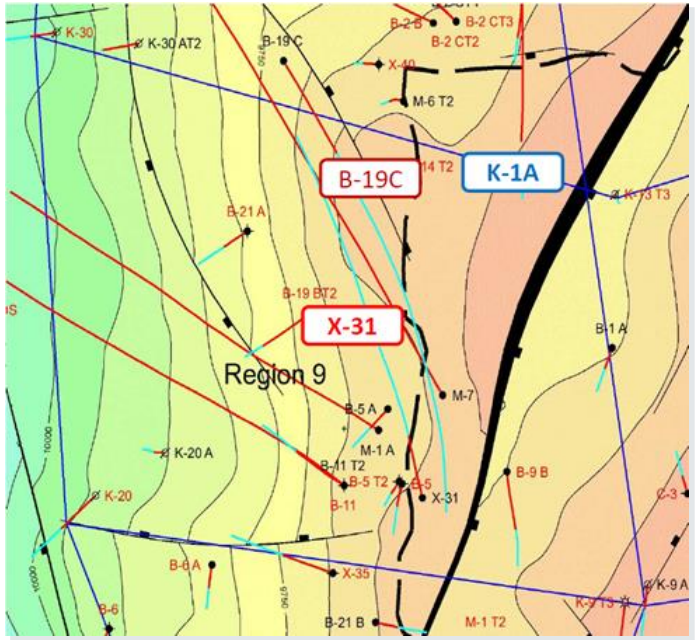
Aug 2012 | **Oct 2012** | **1Q 2013**

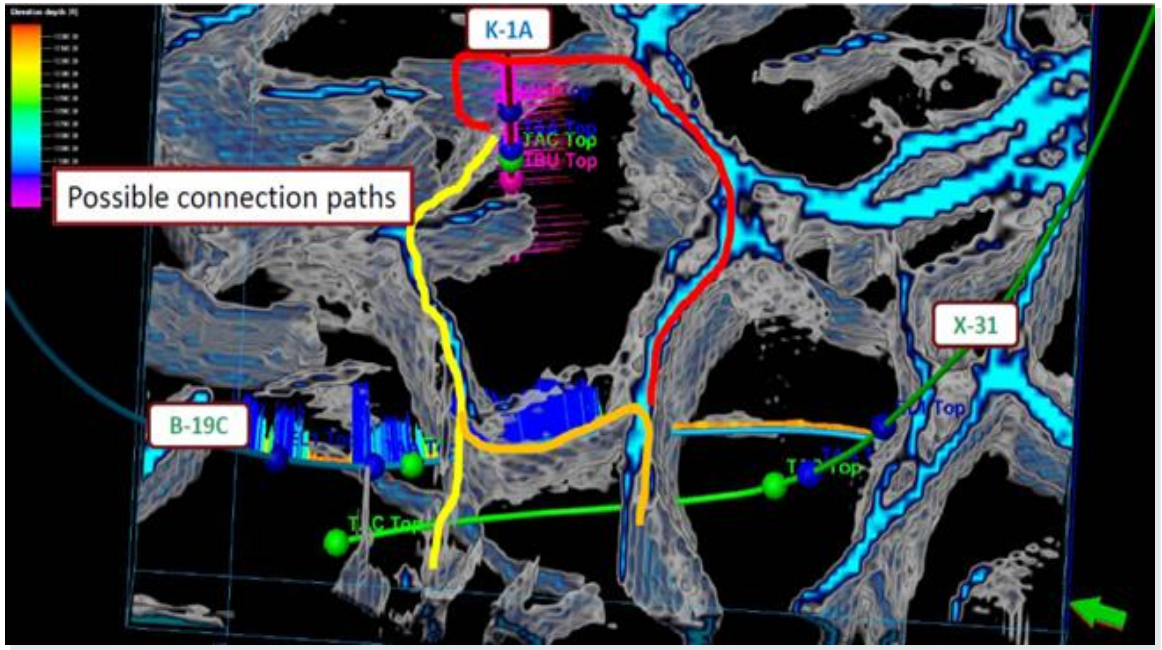
Water Breakthrough Event Consequences

1. Direct loss of 2000 bopd
2. Indirect oil production loss due to reduced pressure support for B-19C
3. K-1A SI, no value creation
4. Continued pressure challenge in the area.

Water Breakthorugh Event Findings

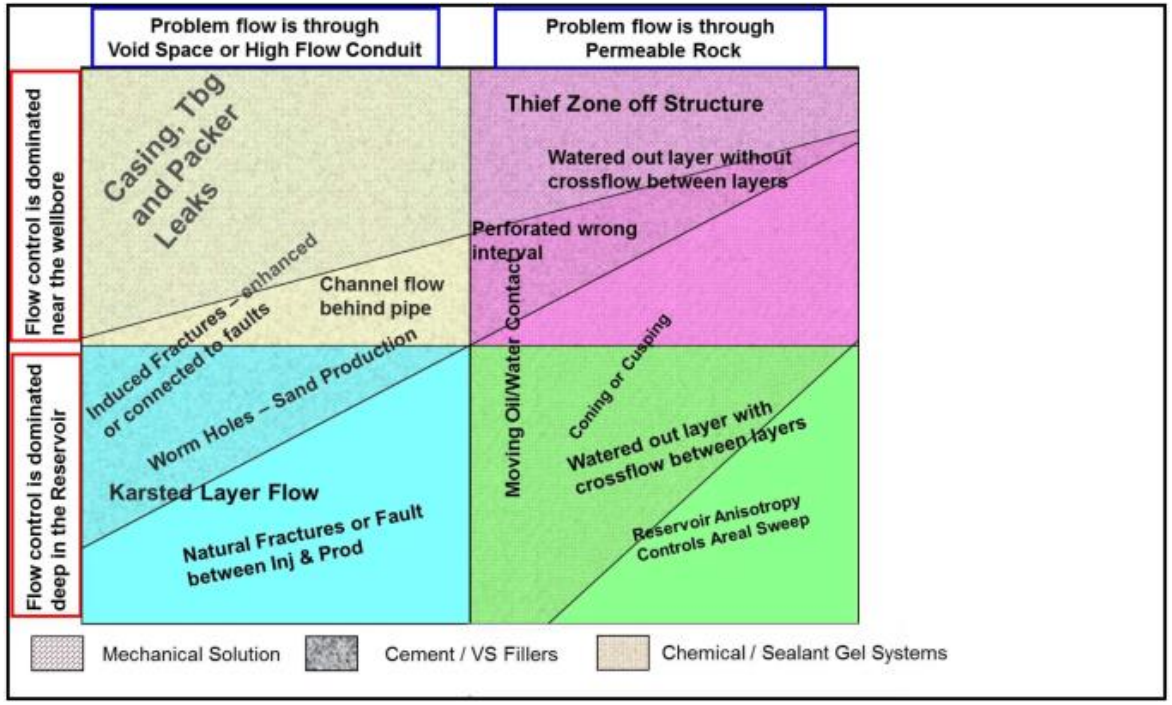
The fracture system is large, with direct communication to X-31.





Development of the Solution Plan in K-01A – Basic principles

- Solution Identified Void Space Filler (VSF)
  - VSC is swept and has little or no value
  - Fill as much of VSC as possible – product needs to stay in VSC
  - Do not damage matrix or tight fractures in process
  - Problem character requires strength and volume
    - Cement is strongest but volume is difficult and expensive
    - Volume selected as maximum operational limit
  - Other concerns (Protection of offset wells)
    - B-19C (Currently straddle isolated – VSF in annulus should add value)
    - Direct conduit to X-31 is small (Tracer breakthrough data)
      - X-31 will require protection due fish – Solids Less Kill Pill (SLKP) to be used
- Solution Design
- Solution Execution
  - Complex and complete risk assessment analysis
  - Execution challenges recognized and addressed
  - Regular communication allowed questions to be addressed
  - Assistance from cementing expert



Solution Design

Gel-cement emulation job on K-1A

- Objective: test the volume of high permeable feature (prove that the volume of cement can be pumped without problems); simulate anticipated pressure response;
- Product: GUAR gel

Protection of key offset well X-31

Objective: prevent cement entry/plugging of wellbore

Product: Solid-less Kill Pill (SLKP)

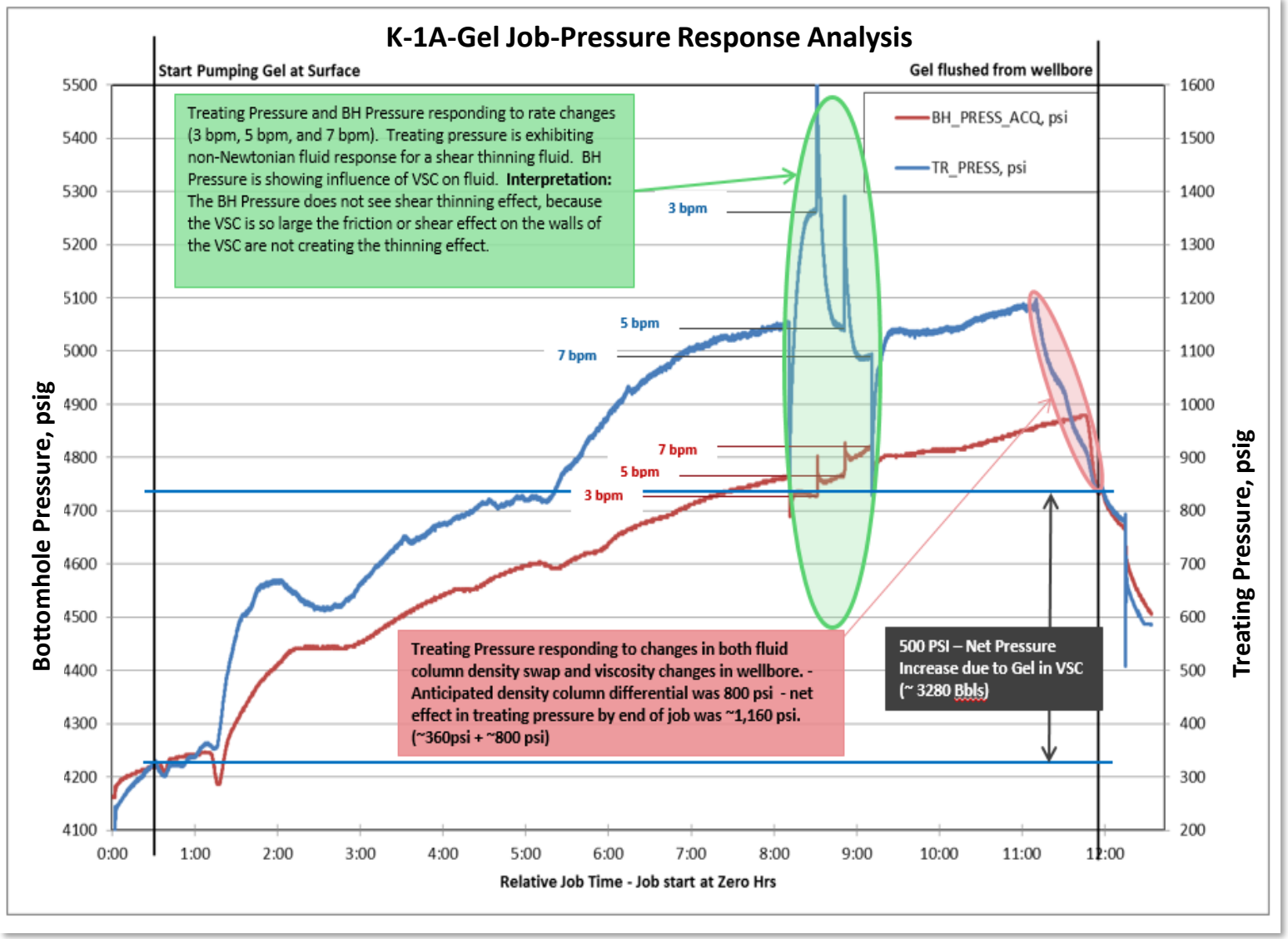
Monitoring pressure response in offset wells

Zone-by-zone monitoring of B-19C

Nitrified/foamed cement on K-1A

Objective: fill as much volume as possible of the high permeability feature

Product: Grading strength of foamed cement (highest near wellbore)

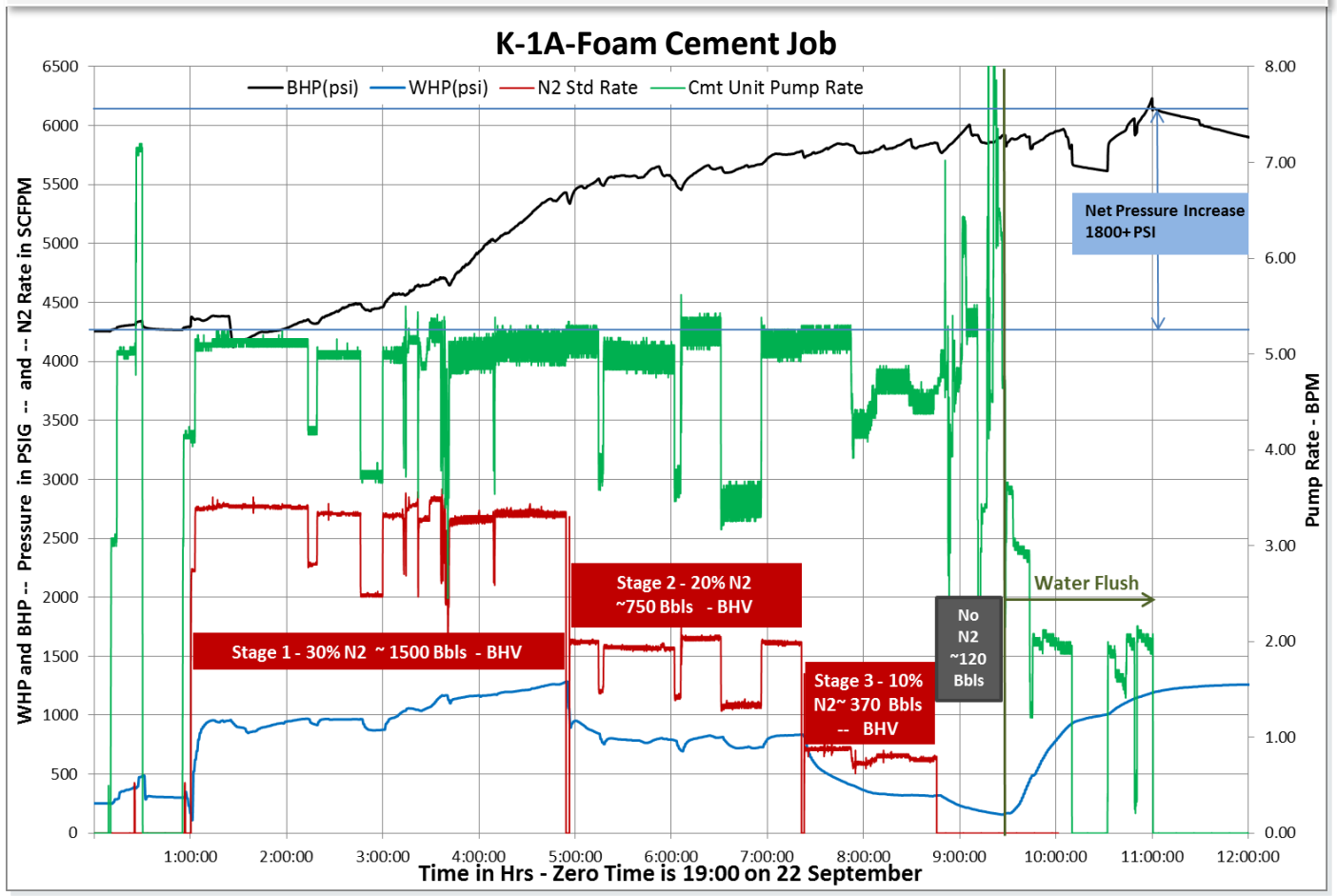


Solution Execution: Foam Cement Operation

K-1A Foam Cement Job

Largest single foam cement job done in the oil industry, onshore and offshore

Great Operational execution and treatment success

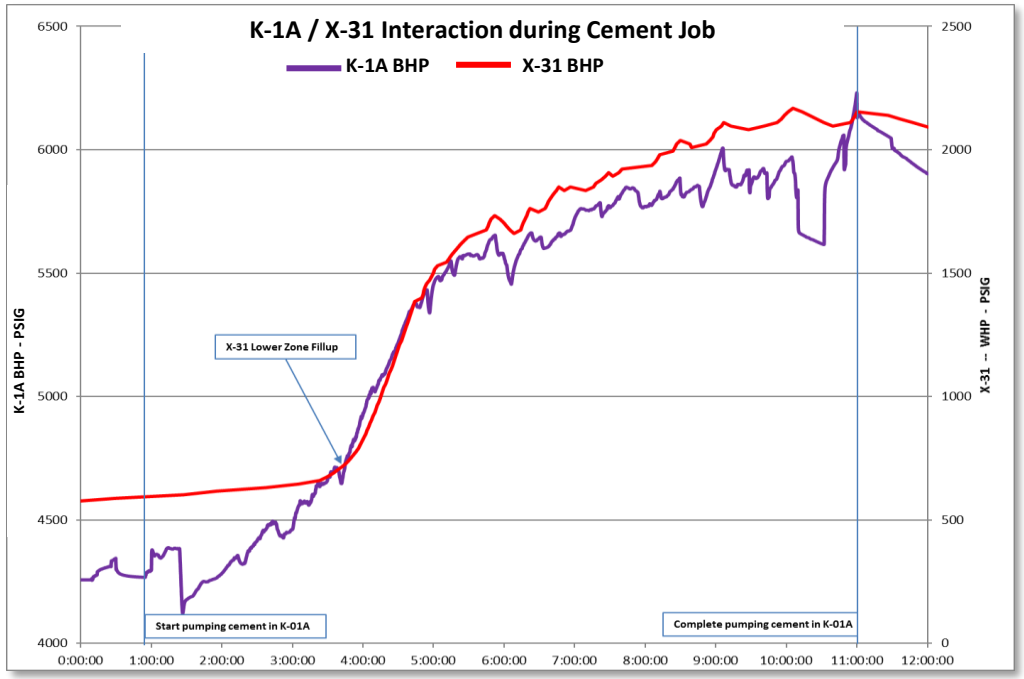


X-31 Response Summary

Early response limited due to high permeability feature and X-31 wellbore fill-up below high permeable feature intersection

Post fill-up response indicates connection between wells is close to full.

SD Response indicates K-1A is isolated and X-31's pressure is supported by N2 expansion.



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High Level Results – 1

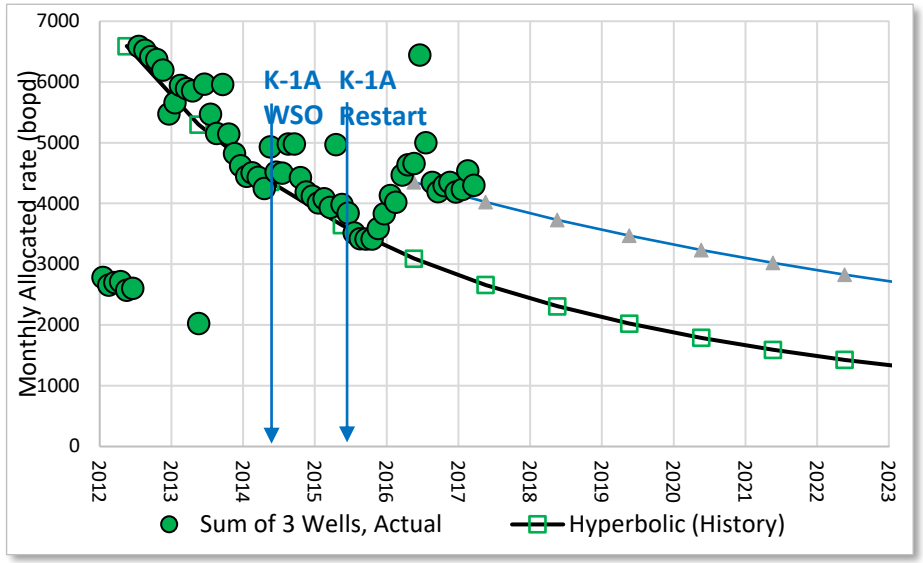
Predefined Success Criteria's – Post Job Evaluation	
No HSE Incidents	
Successfully place 3000 bbl of foam cement into the high permeable feature connected to K-1A	2740 Bbl*
Effectively shut off the direct water communication between K-1A & X-31	Yes
Continued injection in K-1A to provide pressure support in the area without increased risk of WBT in B-19C and mitigate the need for K-1A replacement drilling	See Post Solution Performance
No cement breakthrough in currently active wells (except X-31)	
Knowledge gathering to enable effective WSO in future wells	Performed in other well

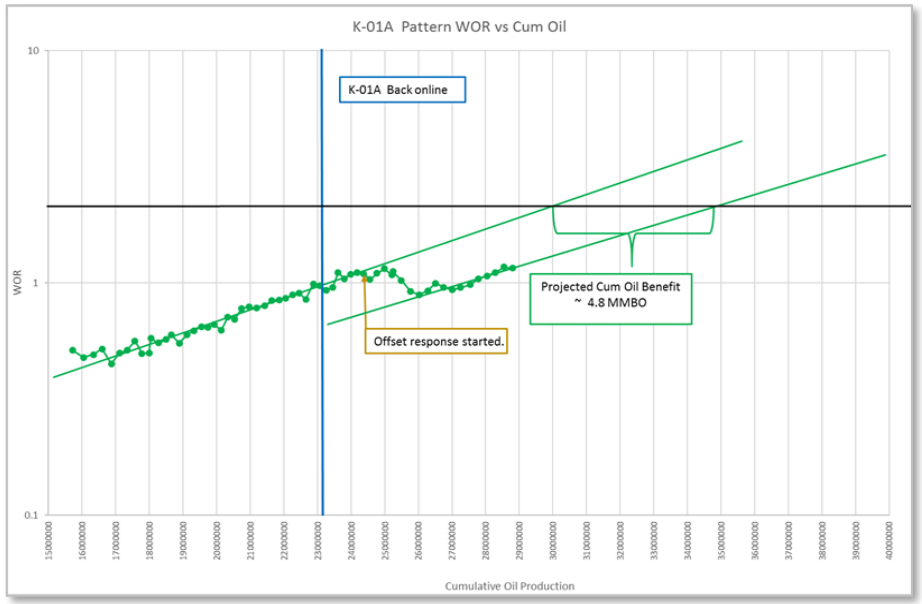
* Largest single job volume of nitrified cement ever pumped in the oil industry.

High Level Results – 2

Additional Key Results & Learnings
Net pressure gain during K-1A foam cement job was 1800+ psi, indicating good fill-up and probable control of the high permeable feature.
All SI producers and injectors (except X-31) have been successfully brought back to online.
Key to success – problem understanding, comprehensive planning, detailed job design and focused execution.
GUAR cement emulation job did not accurately represent the pressure behavior for the foam cement job but provided confidence in the ability to place 3000 Bbls of foam cement.

Production Impact

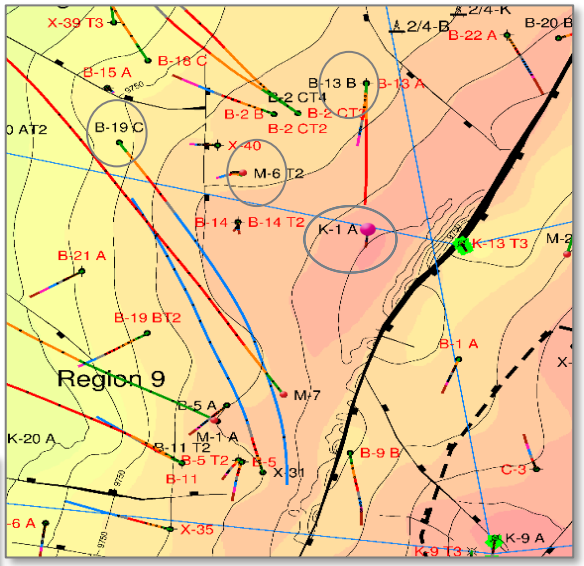


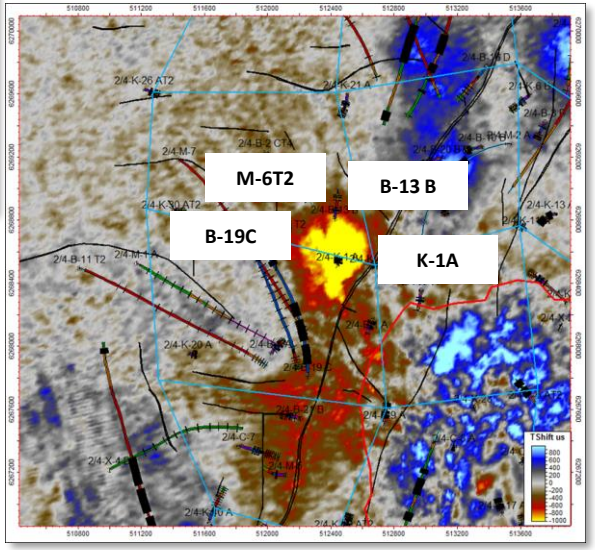


Peak Incremental Oil Rate: ~4000 STB/D

Reduction in Water Cut 12%

Estimated Increase Recoverable Oil in the pattern: 4.8 MMSTB





Overburden response due to pressure increase in the reservoir

Acknowledgements

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