Snorre In-depth water diversion

Snorre Silicat Field Pilot

FORCE-seminar

6. November 2013

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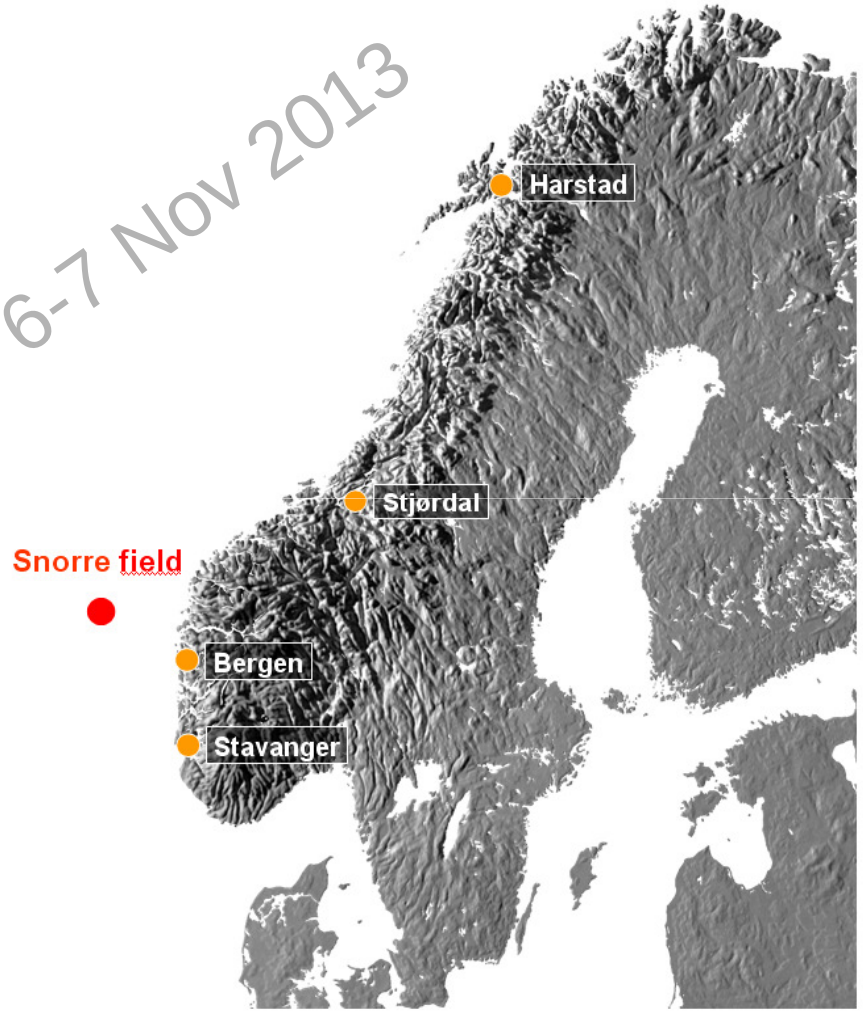
Outline

- Introduction
  - Snorre field introduction
  - Water based IOR - How we work
  - Elements important for progression
- Large scale In-depth water diversion pilot

Snorre field summary

- Fluvial sand deposits
- Permeability: 0.1 – 4 D
- Initial Reservoir Pressure: 383 bar
- Reservoir Temperature: 90-95 °degC
- Production start: 1992 with water injection
- WAG injection from 1996 in parts of the field



Snorre IOR Workshop 05.12.2007

- Water based IOR
  - Reduce residual oil saturation (Lowsal)
    - Lab study – 2008 (0,1 m scale)
    - Single well field pilot (10 m scale) – November 2008
    - Conclusion – Insignificant potential *(SPE 143836)*
  - Improve large scale sweep (In-depth water diversion using sodium silicate)
    - Lab study 2008-2009 (0,3 m and 2 m scale)
      - Conclusion: Promising result *(SPE 143836 and EAGE April 2011)*
    - Single well field pilot (50 m scale) – July 2011
      - Conclusion: Successful pilot *(SPE-154004)*
    - Large scale field pilot (2 km well spacing) – 2013

Elements important for progression (NB! Case dependent)

- Technology development driven by the license
  - Good support from central organisation.
- Close cooperation with Research institute and Contractors.
- Partner involvement
  - Partner involvement from the start - Keep the partners informed
  - Involvement gives ownership and enthusiasm.
- Up-scaling
  - Focus on large field pilot from the start
- Operation: Minor interference with operations on the Platform (Snorre A)
- Sanctioning process:
  - Positive NPV for the pilot
  - Agreement and support from all the partners.

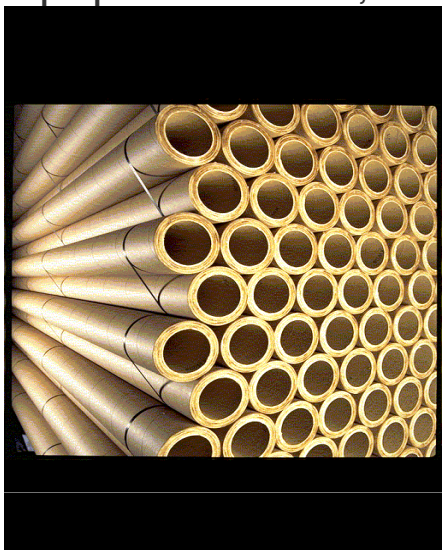
Outline

Snorre in-depth water diversion from Sodium Silicate

- Snorre field description
- Background
  - Laboratory work
  - Single well field test
- Two well Sodium silicate pilot
  - Operational concept
  - Sub surface
  - Main risks
  - Success criteria
  - Current status

Sodium Silicate

- paper industrie, adhesive/lamination



- binding material for foundry

- soil remediation/soil solidification

- Coatings

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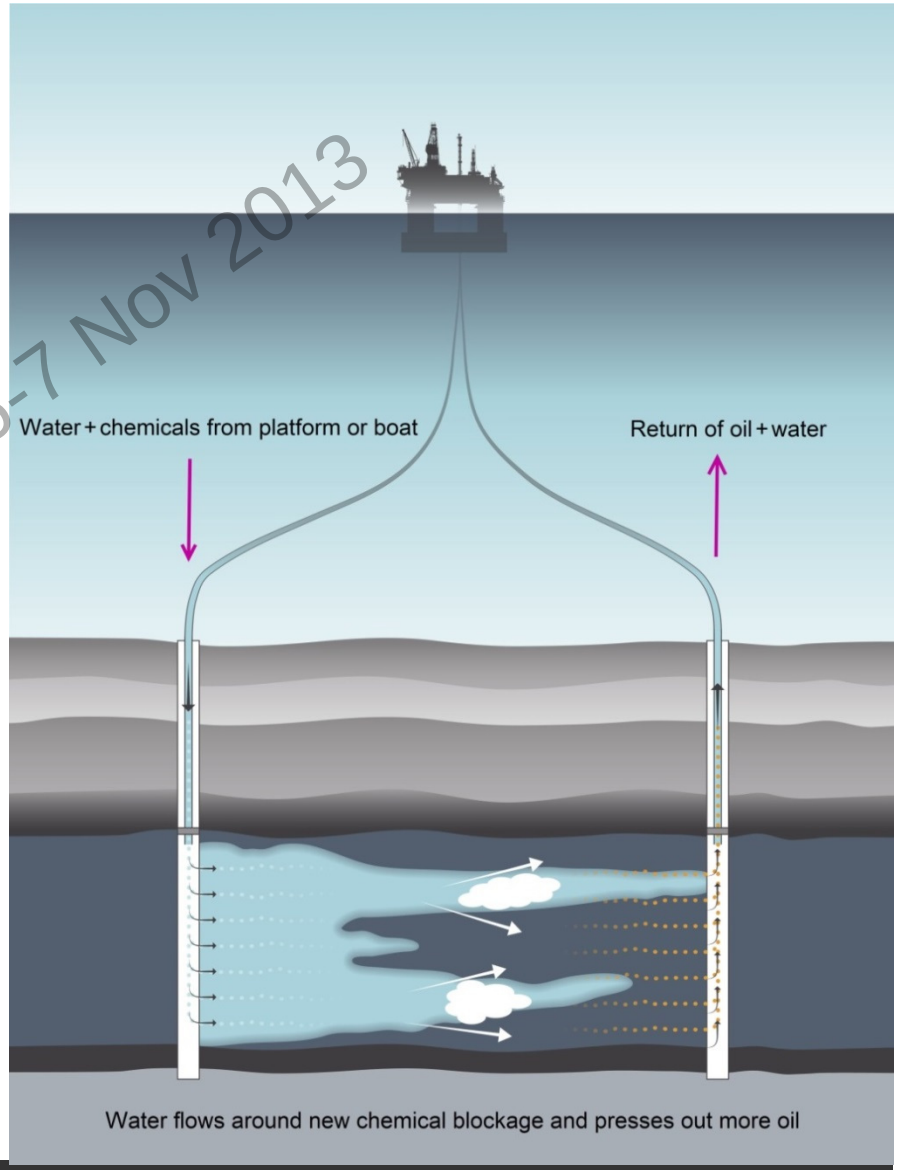
In-depth water diversion – Sodium silicate
(SPE 143836 and SPE 154004)

Goal: Establish flow restrictions in flooded areas to improve lateral and vertical reservoir sweep

•Precipitation of Mg(OH)2 from mixing with seawater

•Gelling:

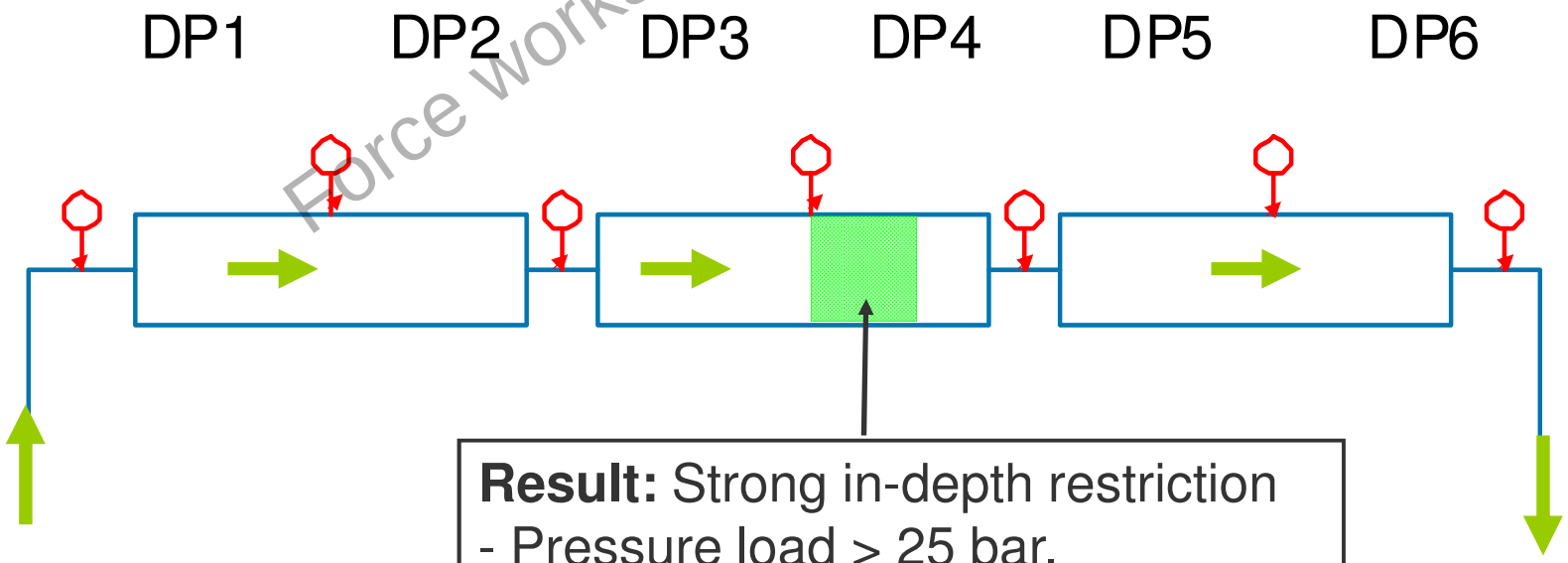
- Static gelling
- Dynamic gelling:
  - Lab: > 25 bar
  - Single well test: > 80 bar



Dynamic sand pack flooding experiments (EAGE April 2011)

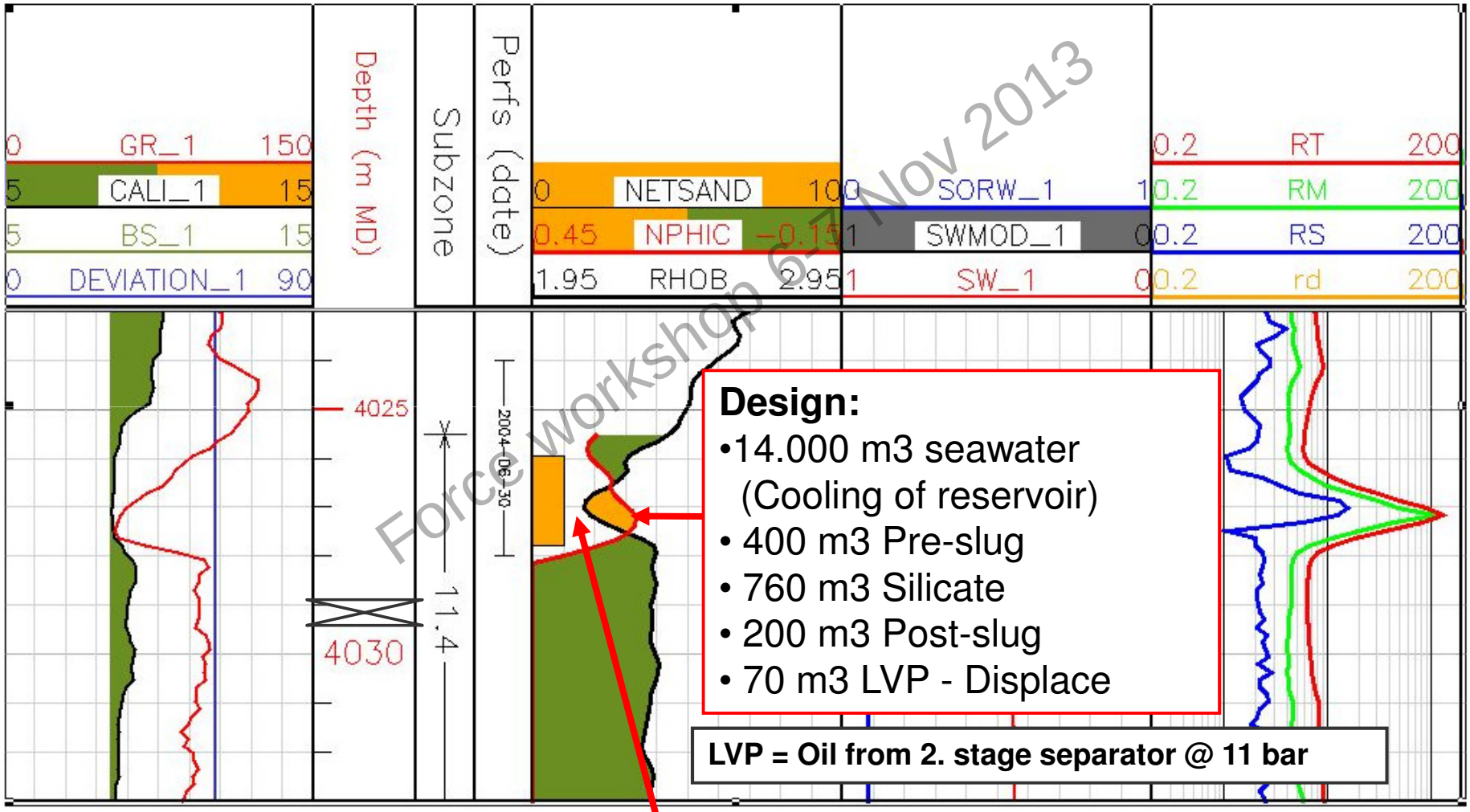
Sodium Silicate Gelling time:
- pH
- Temperature
- Concentration
- Salinity

Experiment:
- Temp = 55 degC
- Diameter 5.36 cm
- Length: 3x75 cm
- Perm.: 7-10 Darcy



Result: Strong in-depth restriction
- Pressure load > 25 bar.

Snorre well: Up-scaled lab experiment
In-depth restriction 30-50 m from the wellbore



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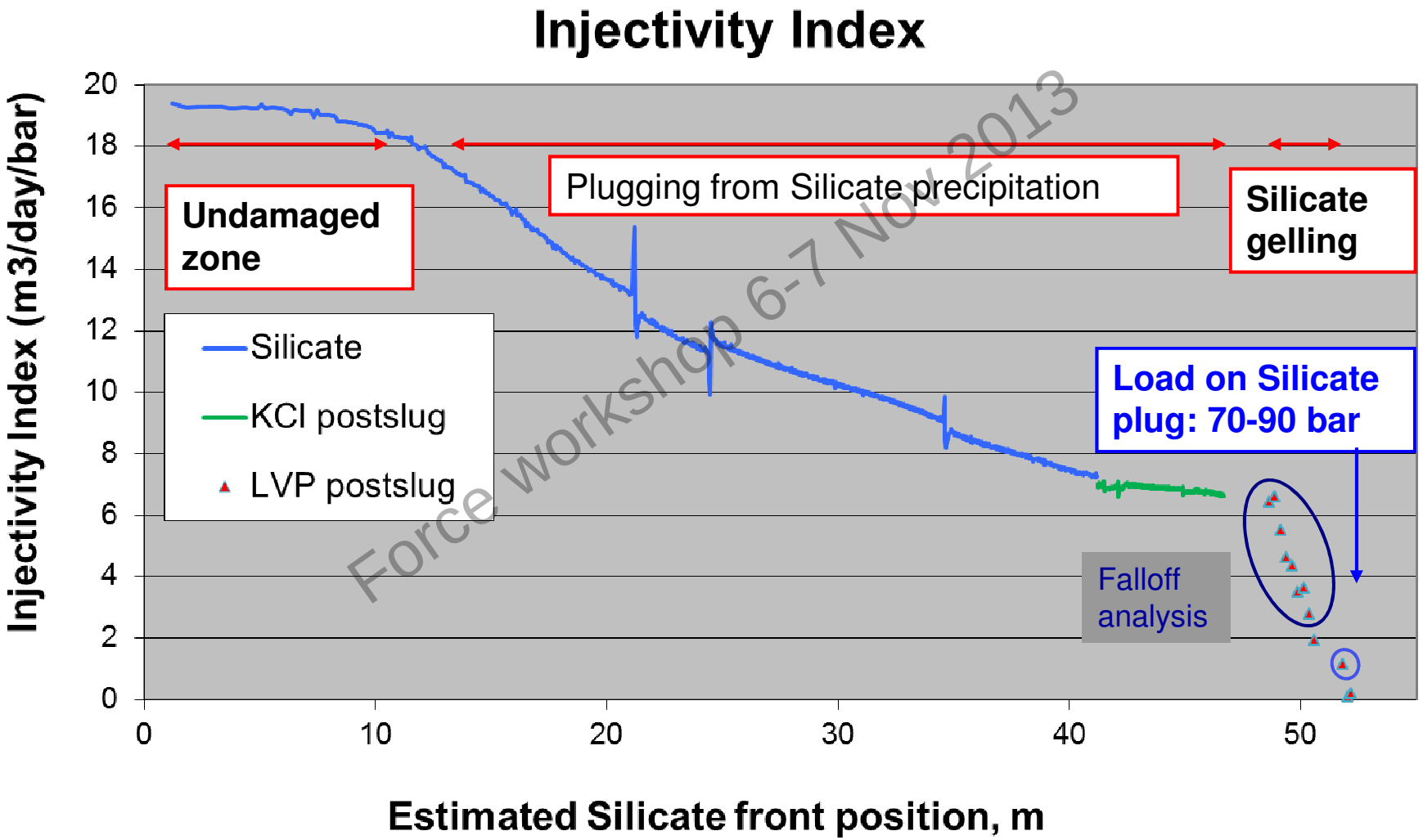
Result - Injectivity vs. theoretical depth (SPE 154004)



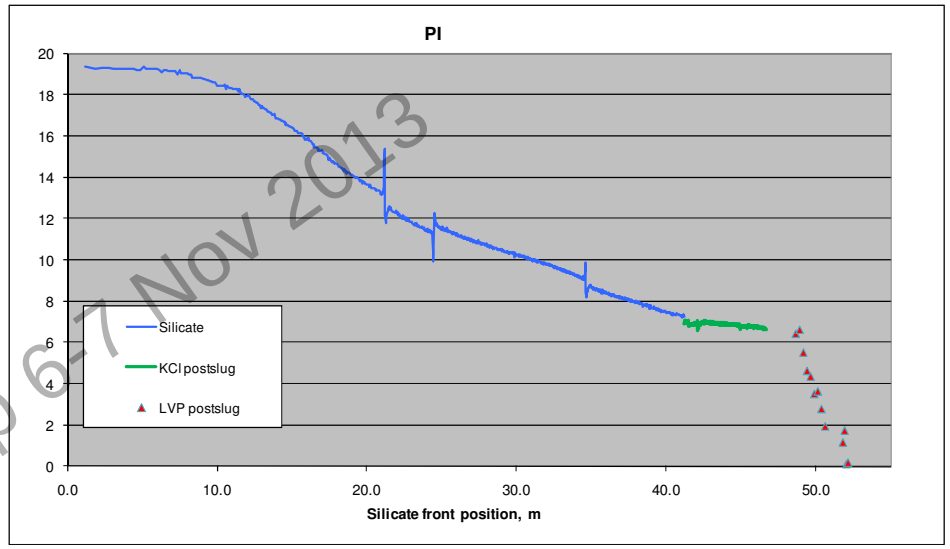
Summary

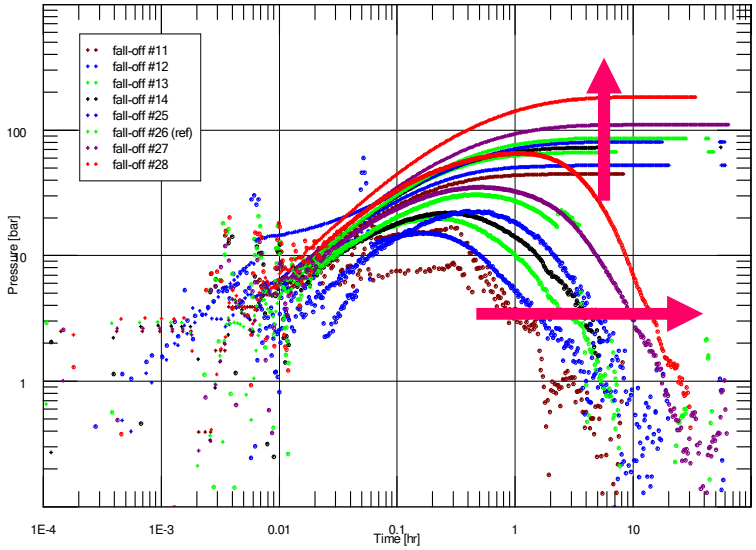
Success criteria

- Operational: Transportation, mixing and pumping silicate into the reservoir. **Confirmed**
- Sub surface:"In-depth" flow restriction approximately 50 m from the wellbore. **Confirmed**
  - RRF>100 in the flow restriction area. **Confirmed: RRF>>100**

Response measurement

- Reduced injectivity **Confirmed**
- Restriction verified from Pressure falloff analysis. **Confirmed**





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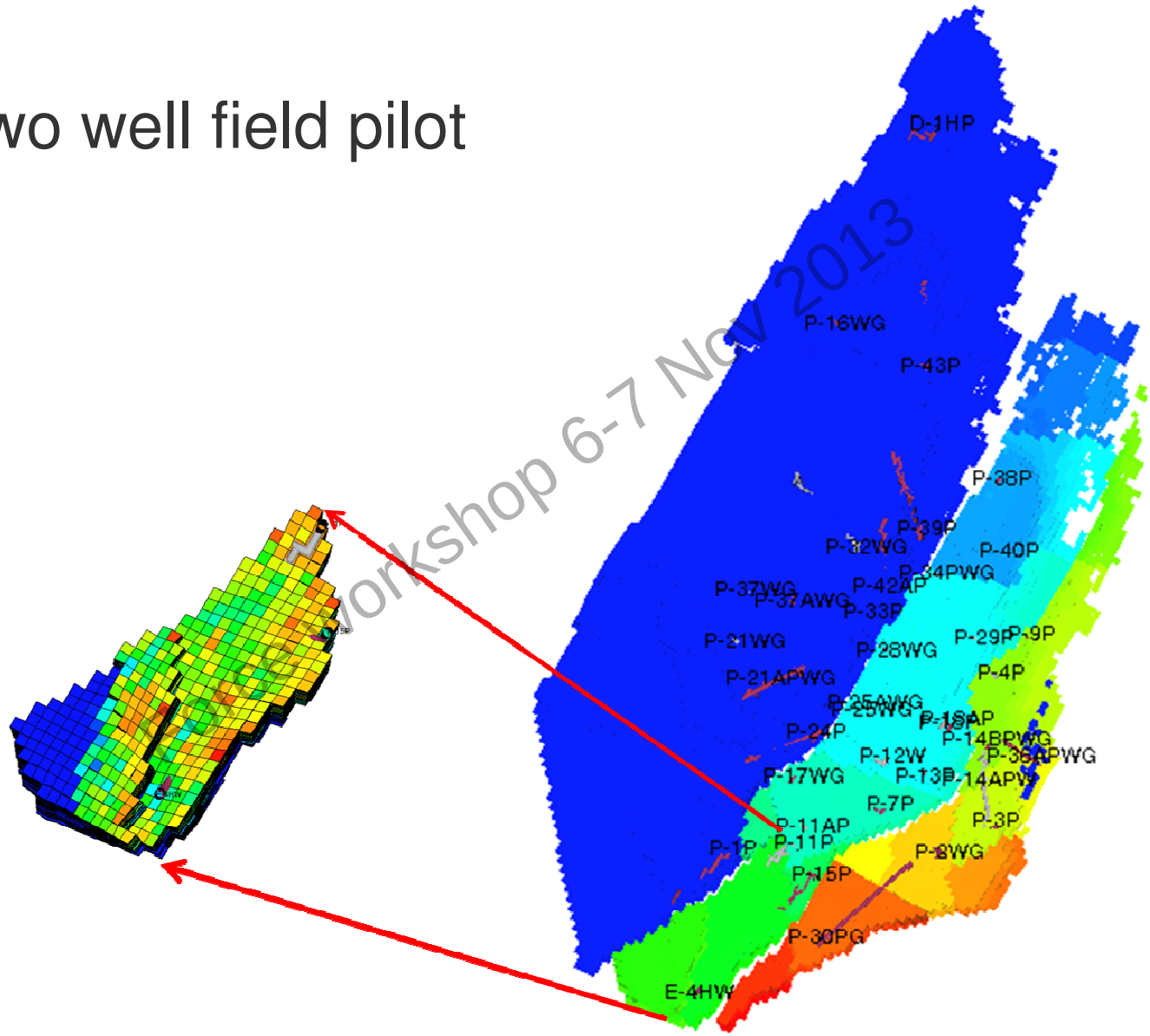
Summary

- Gelling time in agreement with the predictions derived from laboratory experiments
- The size of the spacer slug applied should have been larger.
- P-7 pilot did not aim to demonstrate IOR-potential
- IOR-potential must be verified by a two well field pilot

Successful pilot test in 2011

Vessel on way to Snorre for the injection pilot

Snorre two well field pilot



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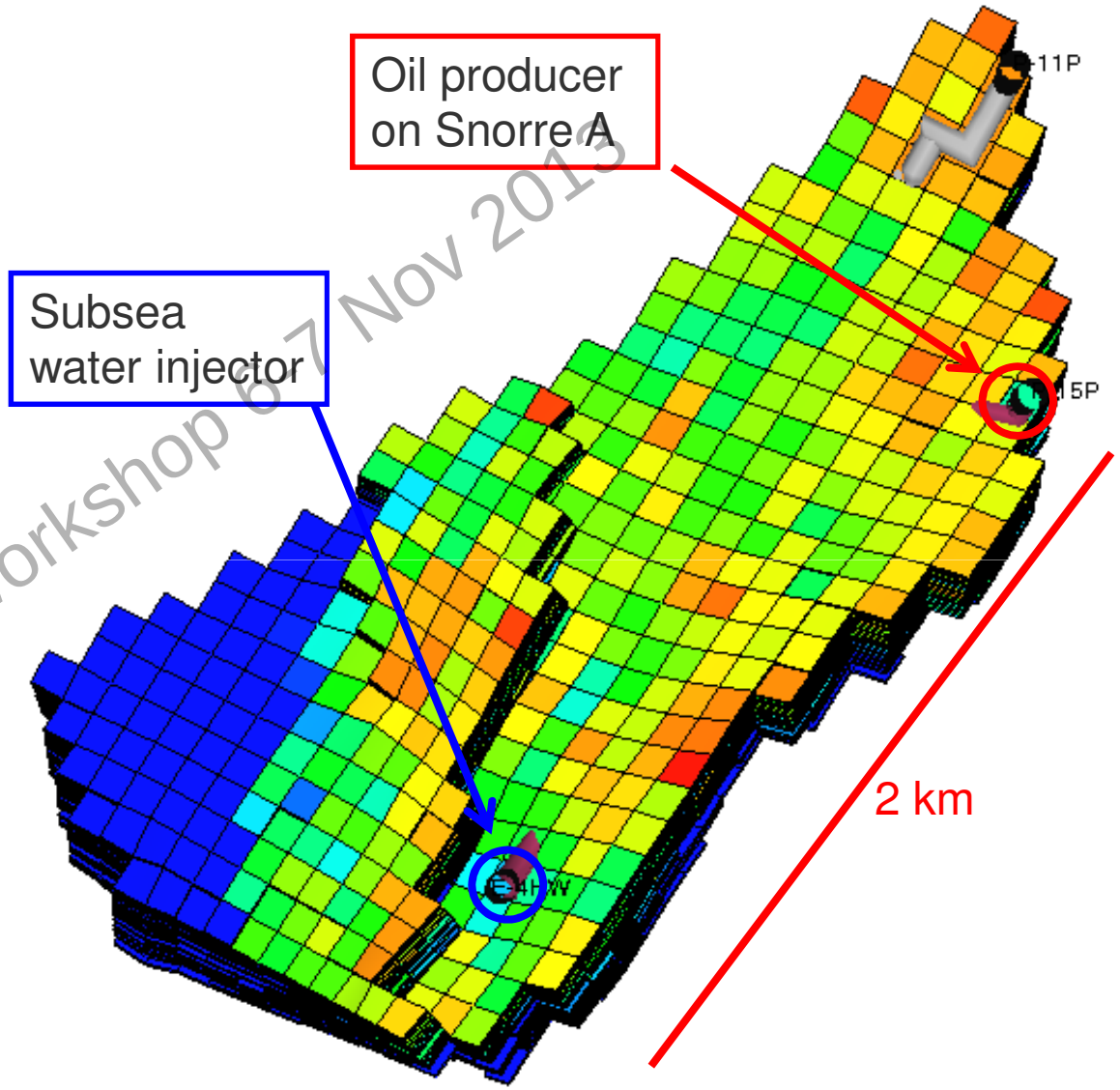
Pilot area

Thief zone challenge

Initial injection water front speed: approx. 6 m/d (2002-2003)

Water tracer injection (2008)
Tracer front speed: 9-11 m/d



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Silicate injection program

- 1 months Pre-flush: 120 000 m3
  - Concentrated KCl
  - Diluted with desalinated water
- 2 months Silicate injection: 240 000 m3
  - Concentrated Silicate
  - Diluted with desalinated water
  - pH adjustment with HCl (diluted from concentrated acid)
- 0,5 month Post-flush: 40 000 m3
  - Concentrated KCl
  - Diluted with desalinated water

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Vessel modifications

Accomodation
Life boat
Helicopter deck

Mezzanine deck
Fresh water plant – Generators
Acid storage
Mixing equipment
HP-pumps – Control cabin
Silicate refill

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Tank Configuration

Initial Loadout

Slops	6 P/S	5 P/S	4 P/S	3 P/S	2 P/S	1 P/S
Diesel 1000 m3 890 MT	Brine Mix/Day 0 MT (*FW 800 mt)	Silicate Conc 3291 m3 4444 MT	FW 3291 m3 3291 MT	Silicate Mix/day	Brine Conc 2000 m3 2208 MT	Silicate Conc 3222 m3 4350 MT
Diesel 1000 m3 890 MT	Silicate Conc 572 m3 772 MT	Silicate Conc 3291 m3 4444 MT	FW 3191 m3 3191 MT	Silicate Mix/Day	Brine Conc 2000 m3 2208 MT	Silicate Conc 3222 m3 4350 MT

Mothership capacity is 50% of the Sodium Silicate
One offshore vessel-to-vessel re-supply of Sodium Silicate

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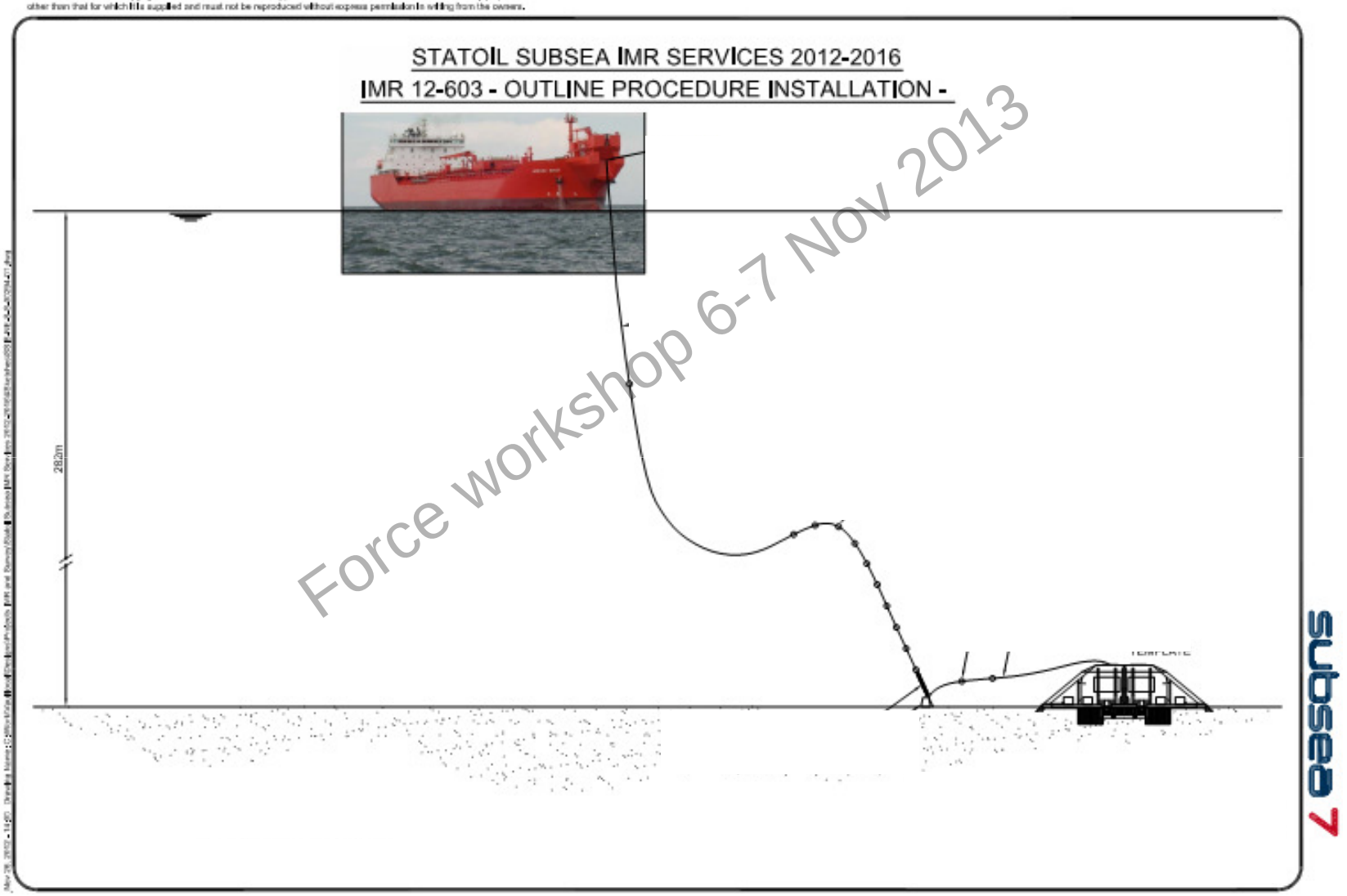
Subsea water injection well – Modified vessel



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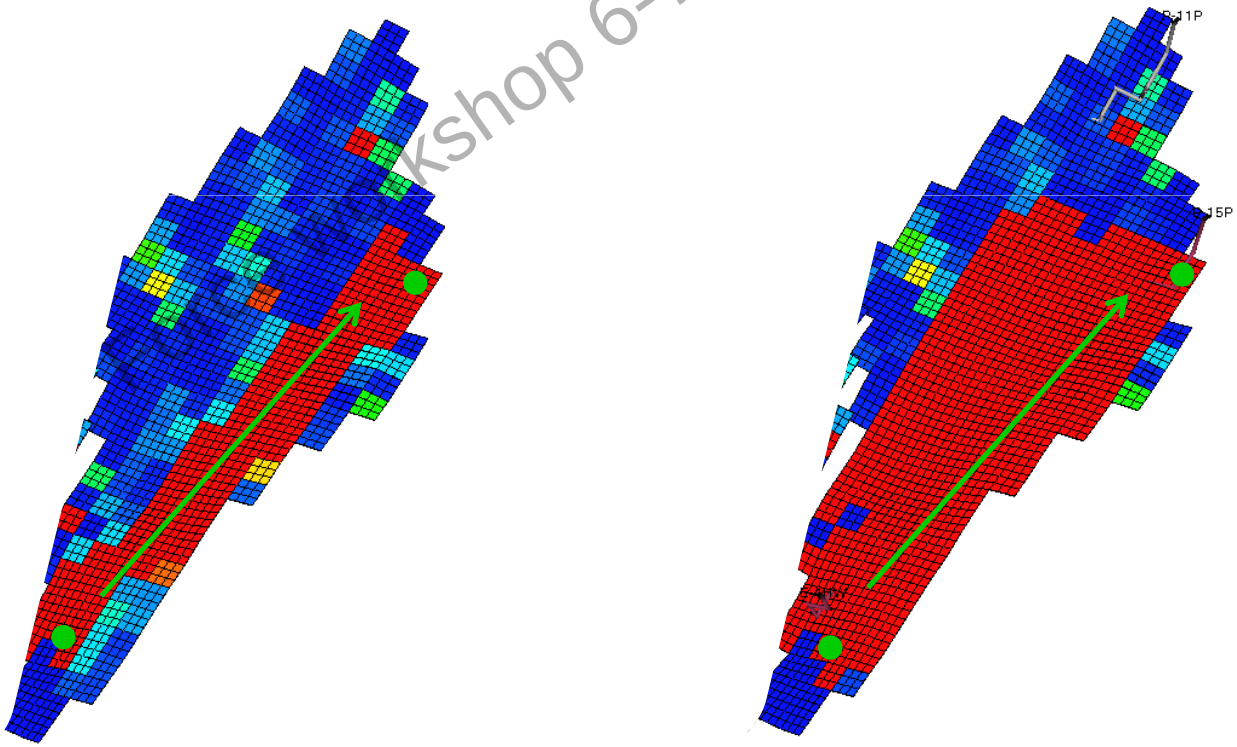
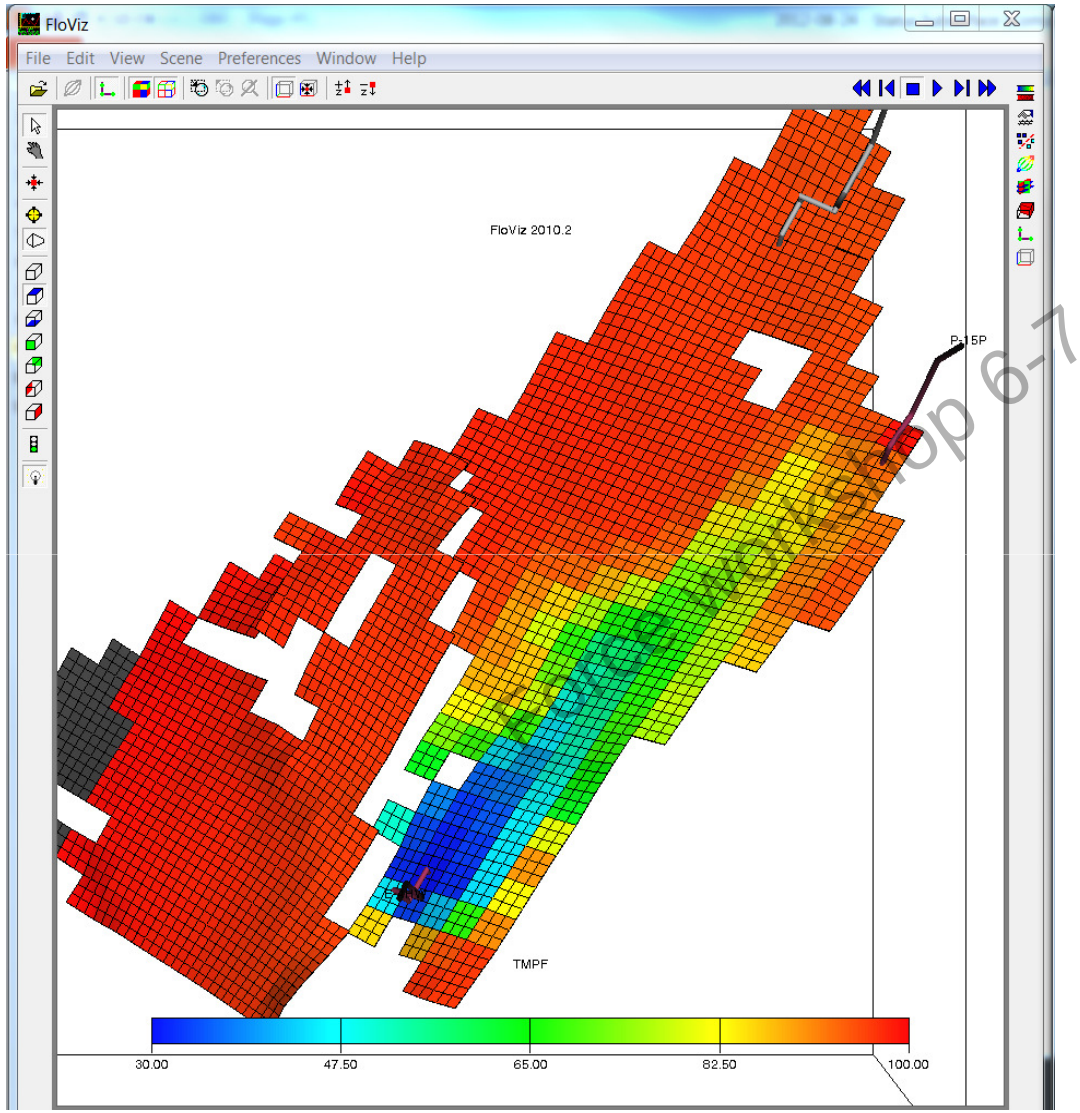
High permeable thief zone

- Uncertainty in geometry
  - Narrow channel
  - Wider sheet sand



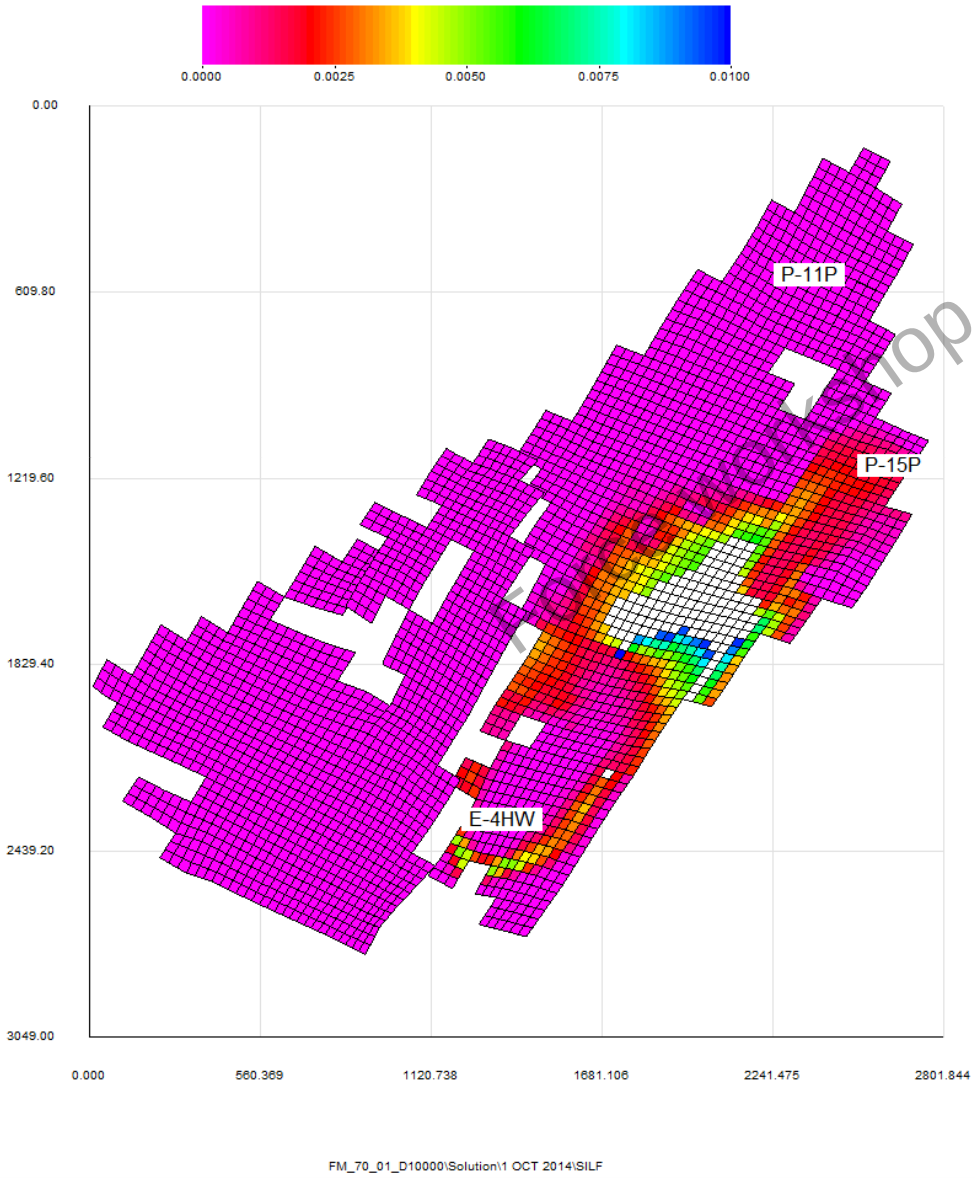
Simulated reservoir cooling



Simplified modelling of Silicate gel plugging:

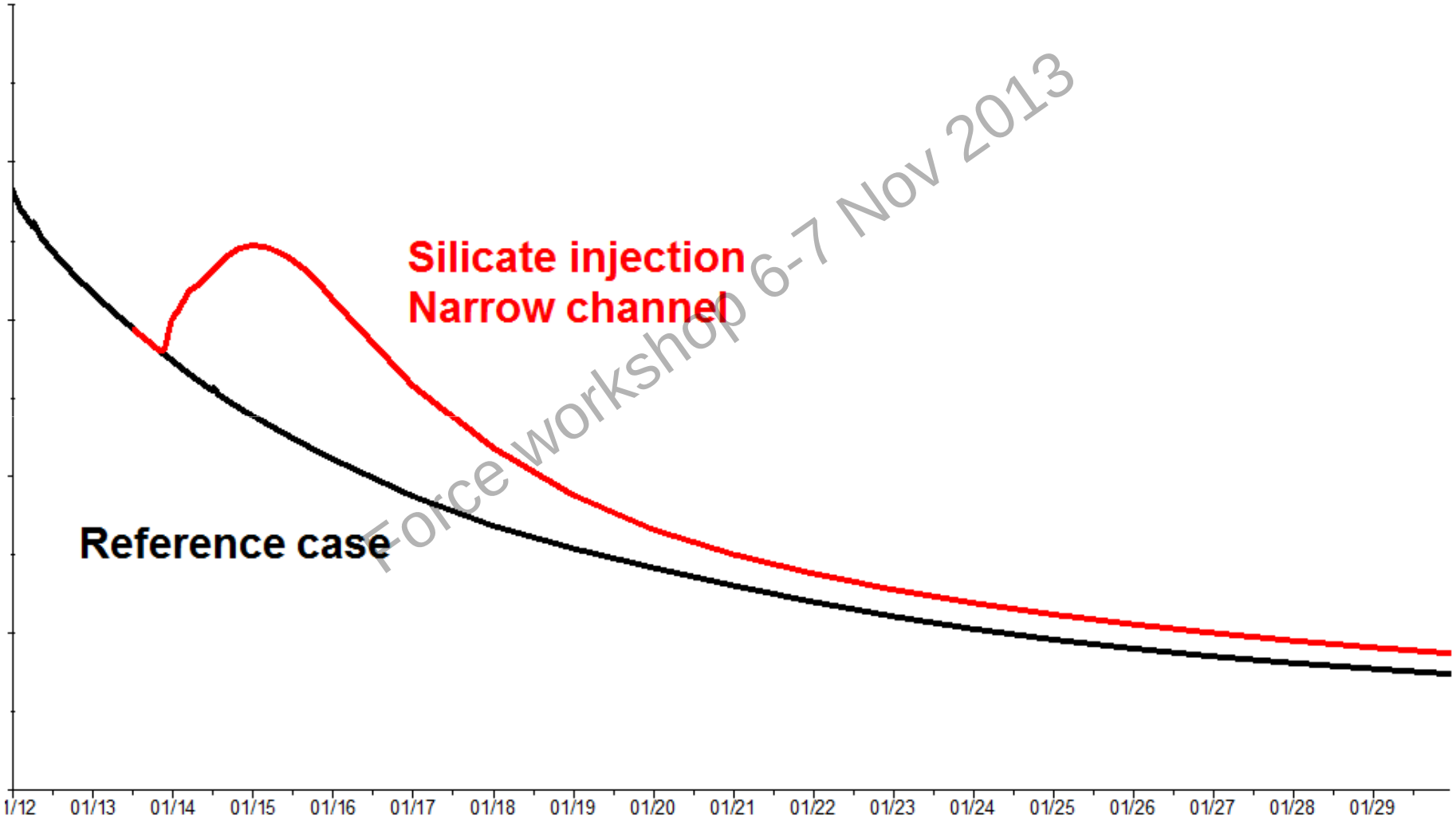
* Temp > 70 degC
* Silicate cons. > 1%

Silicate concentration



White area sil. conc. > 1%

Oil production rate



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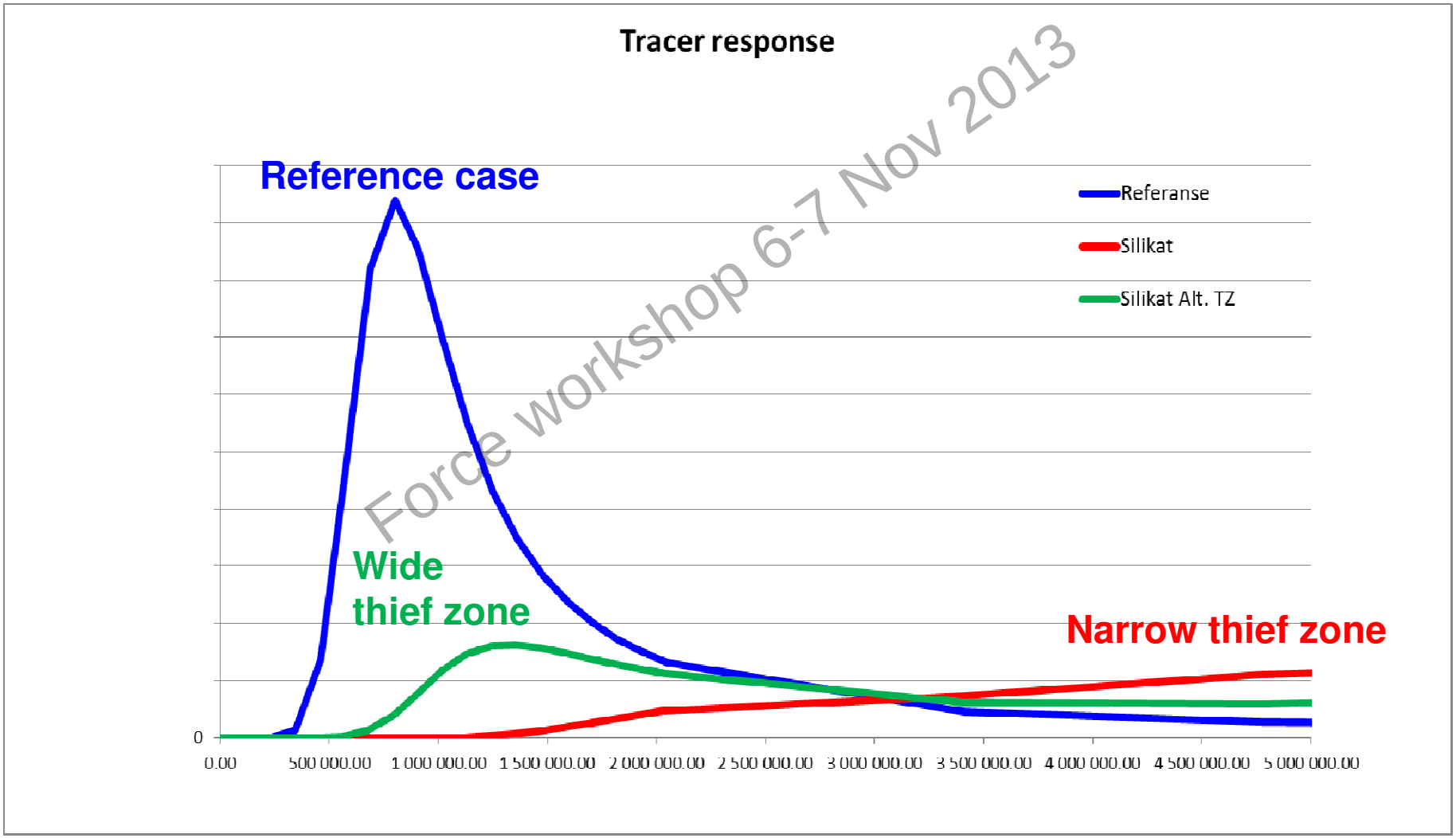
Tracer response



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Main sub surface risks

- Damage of injection well or production well.
- IOR response below detection limit.

Snorre interwell field pilot - Success criteria

- **Objective:**
  - **Provide conclusive input to the DG1 for the IOR-project " Snorre in-depth water diversion" regarding Sodium Silicate as in-depth water diversion measure from a response measurement period of 12-18 months after the pilot injection .**
- **Technical success criteria:**
  - **Operational successful large scale transportation, mixing and pumping of silicate into the reservoir.**
  - **Proved ability of creating an "in-depth" flow restriction (in the range of 0,5-1,5 km) from the well with minor near wellbore damage.**
  - **Proved significant change in flow pattern from in-depth water diversion.**
  - Delayed tracer response.
  - Seawater fraction in produced water.
  - Separator-testing/Decline analysis
  - Injectivity/Productivity
  - Buildup/Falloff-analysis and interference-test
- **Economical success criteria:**
  - **Conclusive IOR-response from in-depth water diversion (reduced water cut).**
  - Separator tests/Decline analysis/Tracer response

Overall injection status and plan

- 113.500 m3 KCl preflush injected (02.06.13-15.07.13)
- 240.000 m3 Sodium Silicate injected (16.07.13-13.10.13)
- 40.000 m3 KCl postflush – Ongoing
  - Status 23/10: 38.400 m3 injected

- Estimated date for end of injection operation: 27.10.13
- Hose removal with IMR vessel from 03.11.2013

Main conclusions from the operation

- The new concept with injection from a shuttle tanker directly into a subsea well has worked well and shown to be robust
- Silicate logistics has worked good
  - Product has been kept clean – (5 micron absolute filter on Siri Knutsen)
  - Re-supply of silicate to Siri Knutsen while injecting
- No damage of injection well
- Pumping operation period and costs increased due to:
  1. Extended commissioning time (HMHB and RO-system)
  2. RO-system for fresh water generation (main reason)
  3. Regularity of HP-pumps
  4. Weather conditions

Plans for future data acquisition

- Regular monitoring
  - Separator testing of production well
    - Oil rate, water cut, ion analysis, tracer analysis, downhole temperature
  - Injectivity in the injection well
- Transient testing and tracer injection

Response measurement time

The production response the coming 1-3 years will reveal if the pilot is a success.

- Change in oil rate/water cut: ~1 year
- Delay in tracer response: ~2-3 years

Acknowledgements

- Statoil colleges
- Snorre Partnership
  - Statoil ASA
  - ExxonMobil E&P Norway AS
  - Core Energy AS
  - Idemitsu Petroleum Norge AS
  - Petoro AS
  - RWE Dea Norge AS
- Contractors
  - IRIS
  - Knutsen NYK Offshore Tankers
  - Halliburton
  - BASF
  - SS7