The Value of Well Testing and Pressure Monitoring in Injection Site Characterization

A. Shchipanov, L. Kollbotn, R. Berenblyum
International Research Institute of Stavanger (IRIS)
Contact: Anton.Shchipanov@iris.no

CO_2GeoNet Open Forum, 24-25 April 2018, San Servolo Island, Venice
Pre-Open Forum workshop organised by *ENOS*, 23 April 2018:
Experience-sharing focus groups: Advanced techniques for site characterisation

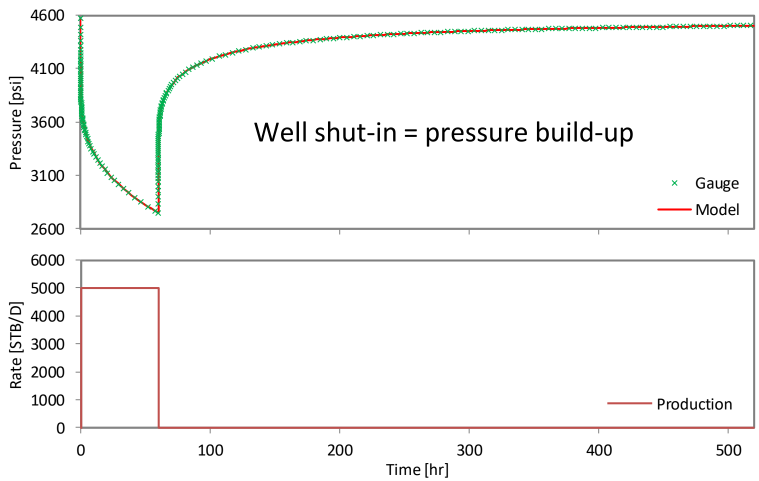
Outline

- Introduction
  - What is well testing and Pressure Transient Analysis (PTA)?
- Testing wells to characterize injection site
  - Well test designs
  - Radius of investigation
  - Interpretation of injection and fall-off responses
- An example of pressure monitoring helping in characterizing site boundaries
  - CO_2 injection at Tubåen formation of Snøhvit field
  - Time-lapse injection and fall-off pressure responses
  - Lessons learned from Snøhvit
- Acknowledgements

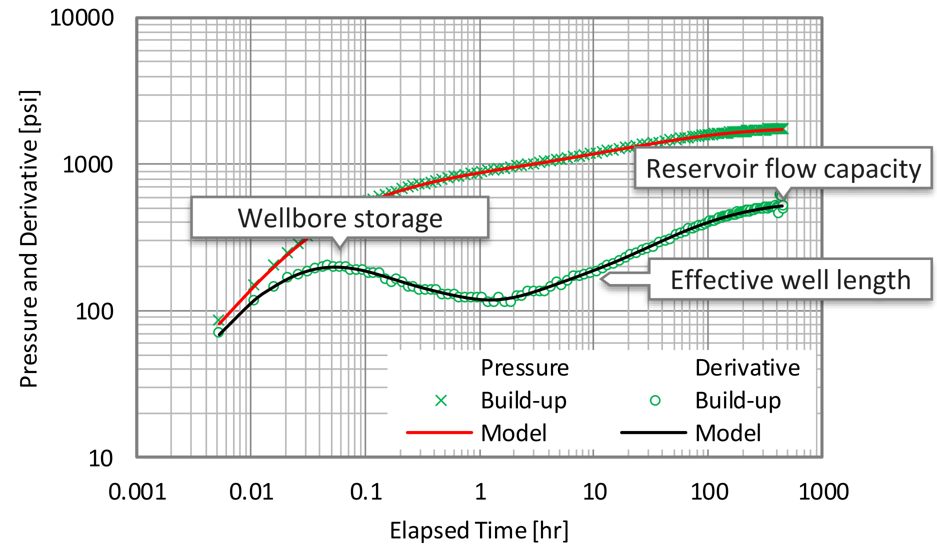
What is well testing and Pressure Transient Analysis (PTA)?

Pressure Transient Analysis (PTA)

PTA is ***history matching*** of well test including ***pressure derivative***



Typical well test (an example from Kappa Eng.):
Production and following pressure build-up



Pressure build-up and its derivative in log-log

Parameters estimated from PTA

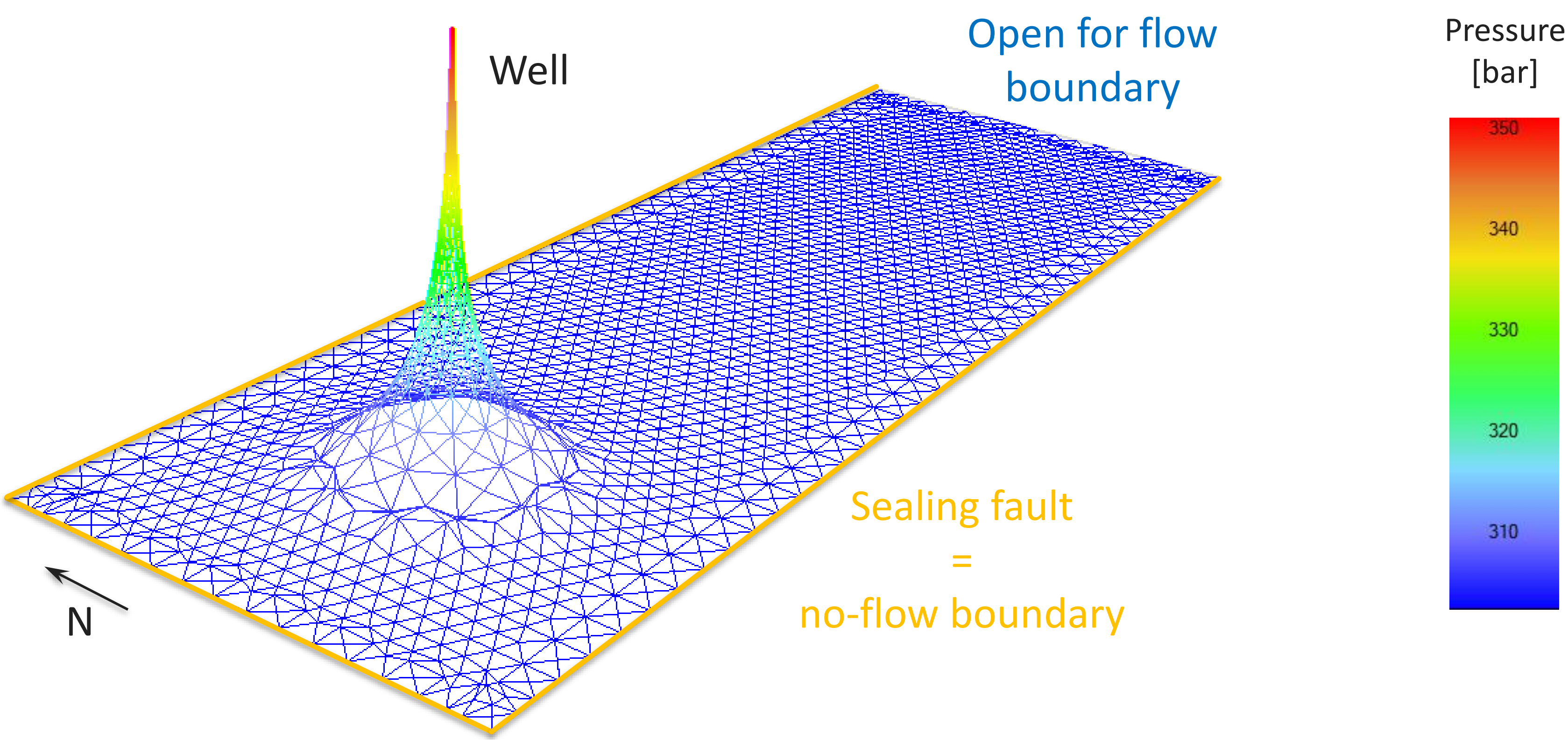
Well
- Storage
- Skin factor
- Induced fracture(s) properties
- Effective length (horizontal)

Reservoir
- Flow capacity / permeability (directional for horizontal well)
- Areal heterogeneity
- Dual porosity / permeability

Boundaries
- Faults
- Aquifer
- Well interference

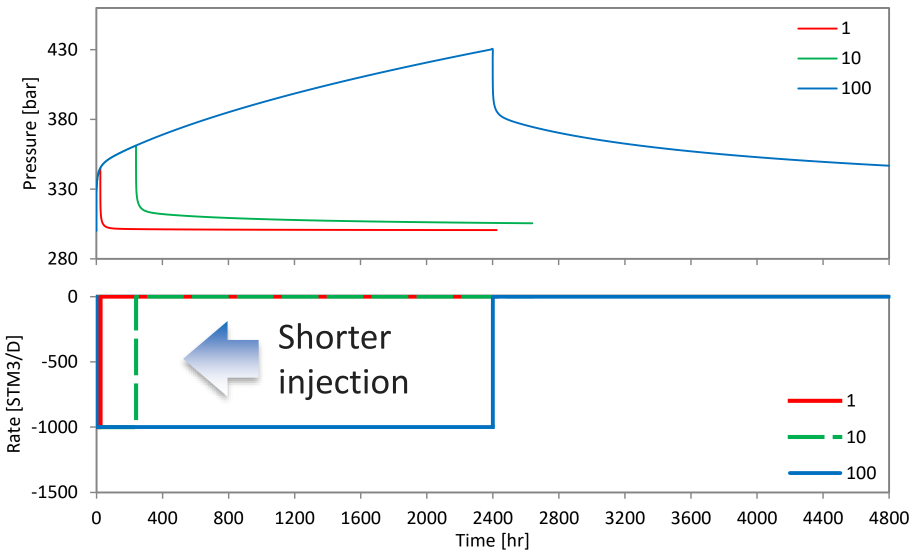
Testing wells to characterize injection site

A synthetic model of injection site (a fault block)



An aquifer fault-block (U-shape) confined by three faults (no-flow boundaries): West, North and South from the well

Well test designs: from best to more feasible



- ‘100’ (day): Long injection
  - 0.4% PV (of the model) injected, may be followed by fall-off, but not necessary
  - All boundaries* covered during injection
- ’10’ (day): Shorter injection – Long fall-off
  - 0.04% PV injected with long fall-off (100 day)
  - All boundaries may be captured during injection, fall-off serves for confirmation
- ‘1’ (day): Short injection – Long fall-off
  - 0.004% PV injected with long fall-off (100 day)
  - Very small volume injected short-term
  - No boundaries detected from injection, all boundaries covered by fall-off

*All boundaries = 3 boundaries in this U-shape example

Design ‘1’: Radius of investigation and flow regimes

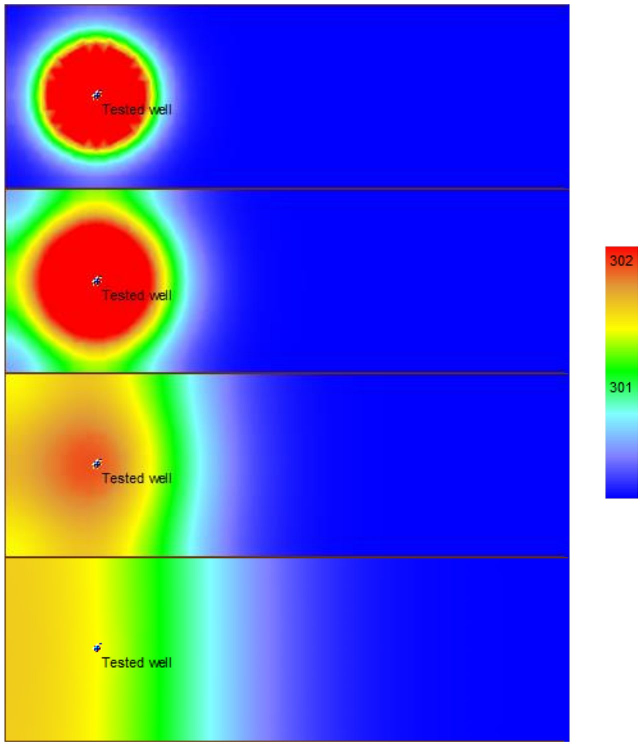
IRIS

1st day: end of injection

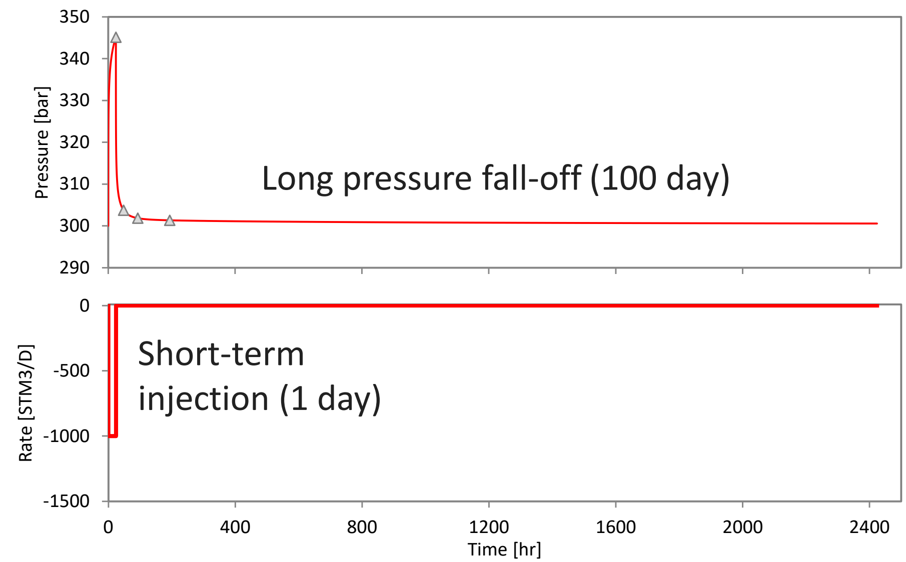
2nd day

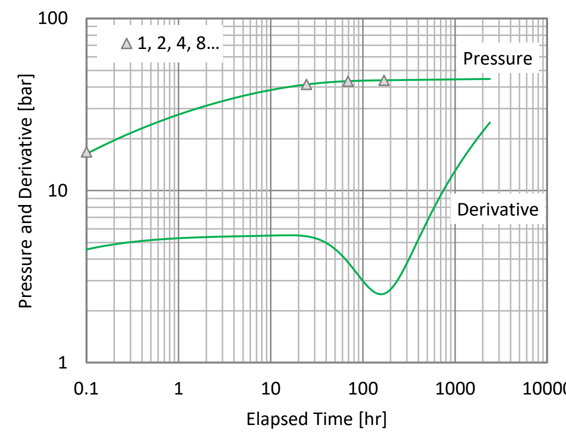
4th day

8th day: and similar picture afterwards



Pressure evolution in U-shape reservoir during well test. Pressure exceeding 302 bar is colored in red to highlight pressure evolution deeper into reservoir



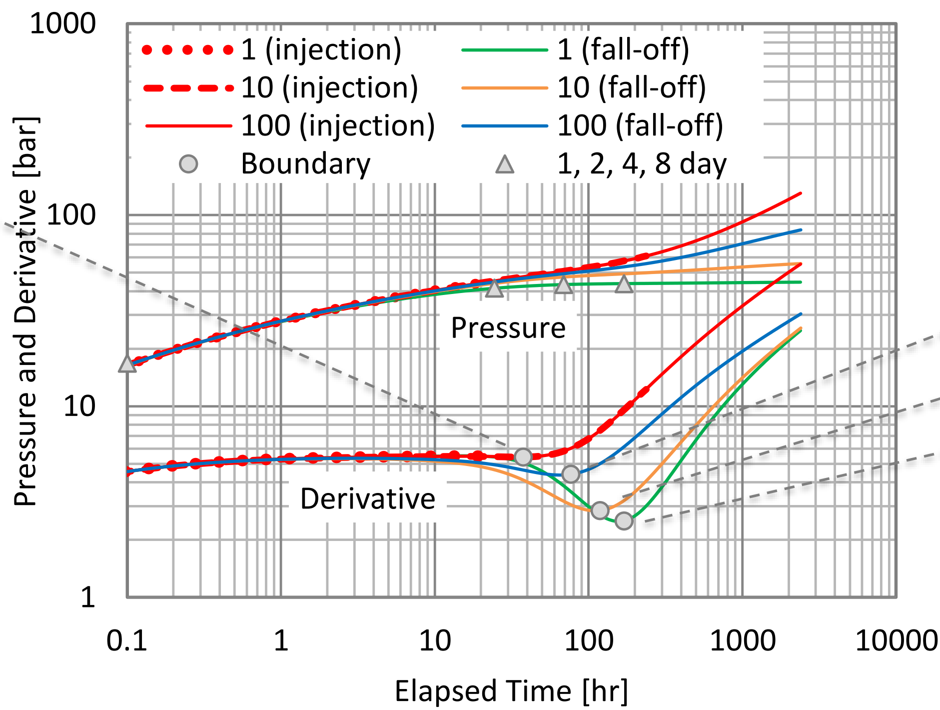


Fall-off response: Pressure and derivative

Interpretation of injection and fall-off responses

Injection

- Boundary dominated flow regime started after ~40 hr
- Reliable boundary indication after additional ~40 hr



Fall-off

- Beginning of boundary dominated regime depends on injection duration prior to fall-off
  - 100 day: after ~80 hr
  - 10: ~120 hr
  - 1: ~170 hr
- Reliable boundary indication after additional ~40 hr

- Flow barriers are most quickly captured from injection pressure interpretation (quick boundary indication = minimum test duration)
- If volume to be injected is limited, fall-off is an alternative (but longer test)

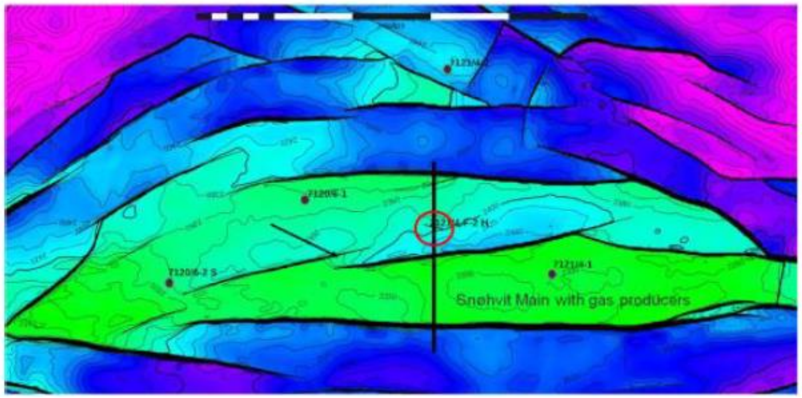
Testing wells to characterize injection site

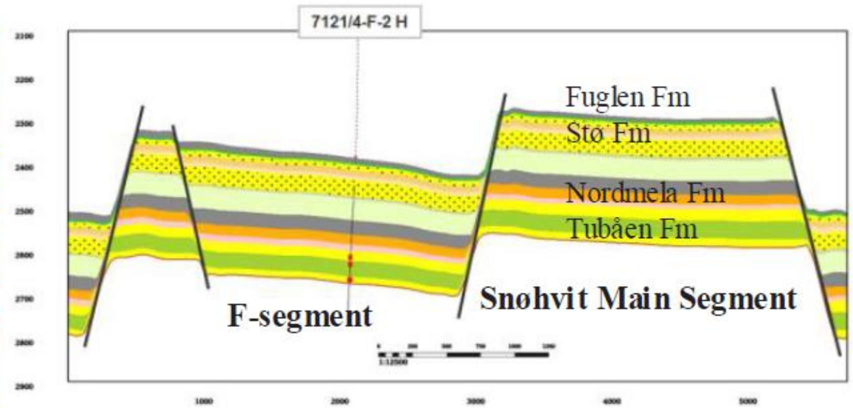
- Permanent Downhole Gauges (measuring P&T) must be installed
- A well test before the main injection phase may consist of a short water production or injection followed by long shut-in (to disclose distant flow barriers)
- Such a test gives information about critical geological features
  - Results may work as showstopper for the project!
- Using CO_2 for injection test leads to larger uncertainty with interpretation
- PTA of pressure dynamics during the main injection phase improves site characterization

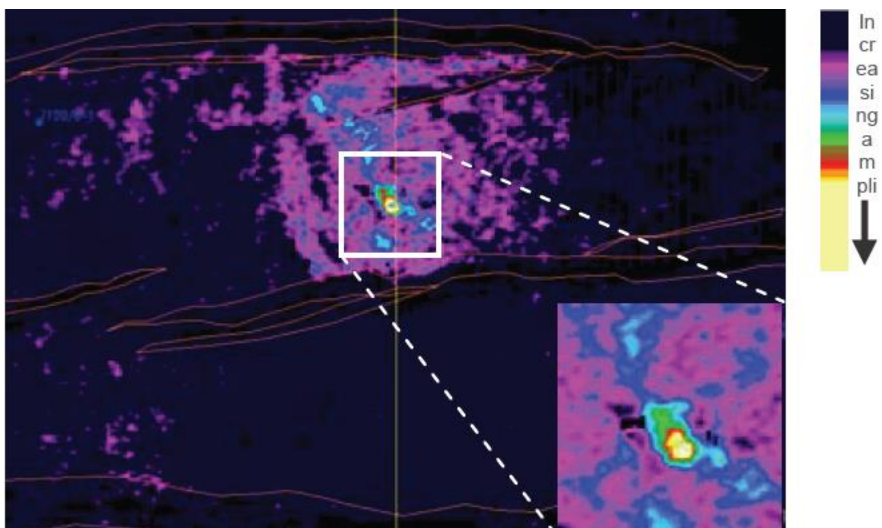
An example of pressure monitoring helping in characterizing site boundaries

CO_2 injection at Tubåen formation of Snøhvit field

Depth map of top Fuglen formation (left) and geological cross-section N-S through the reservoir sections at Snøhvit (right) [from Hansen et al., 2013]

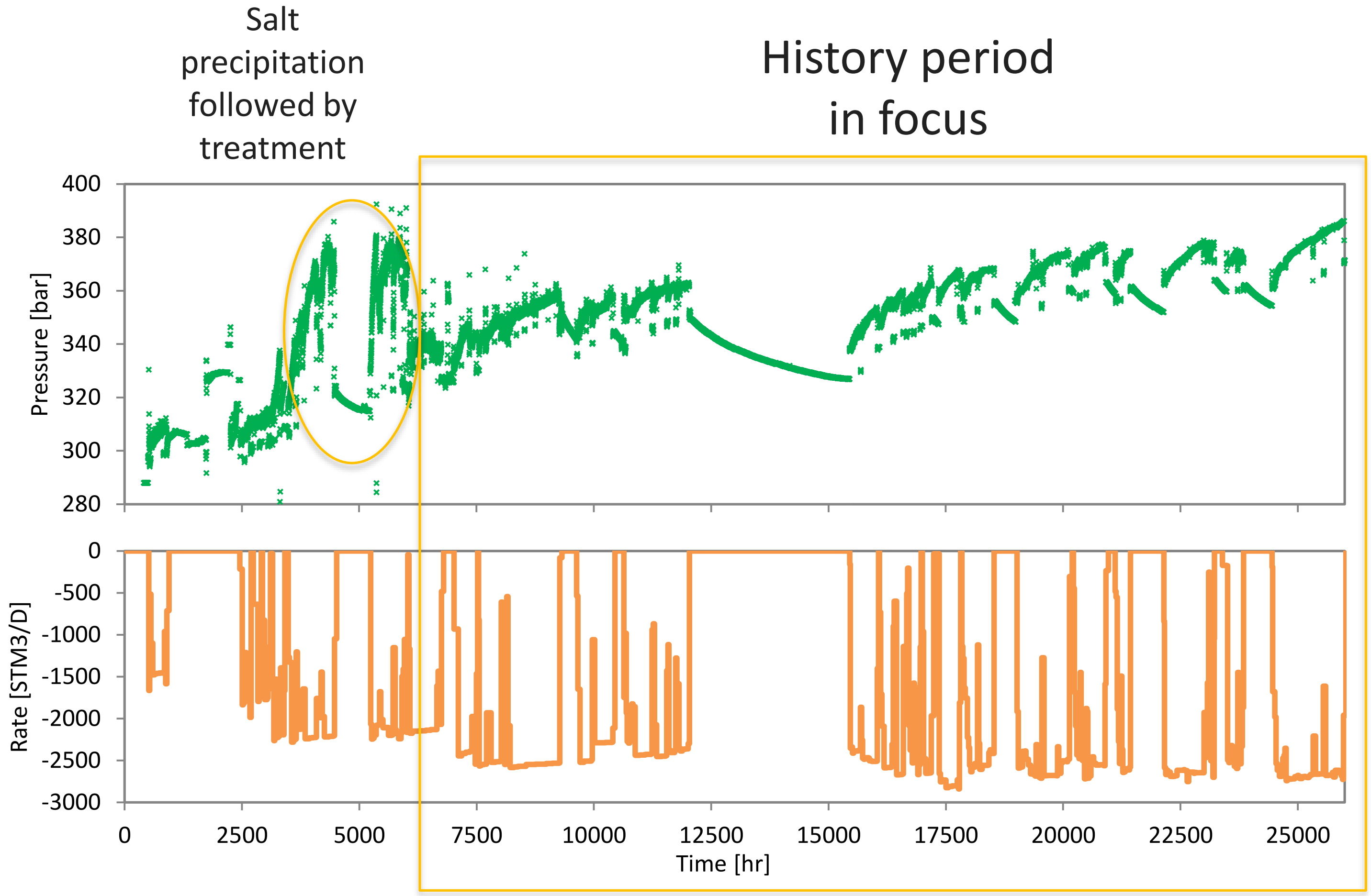




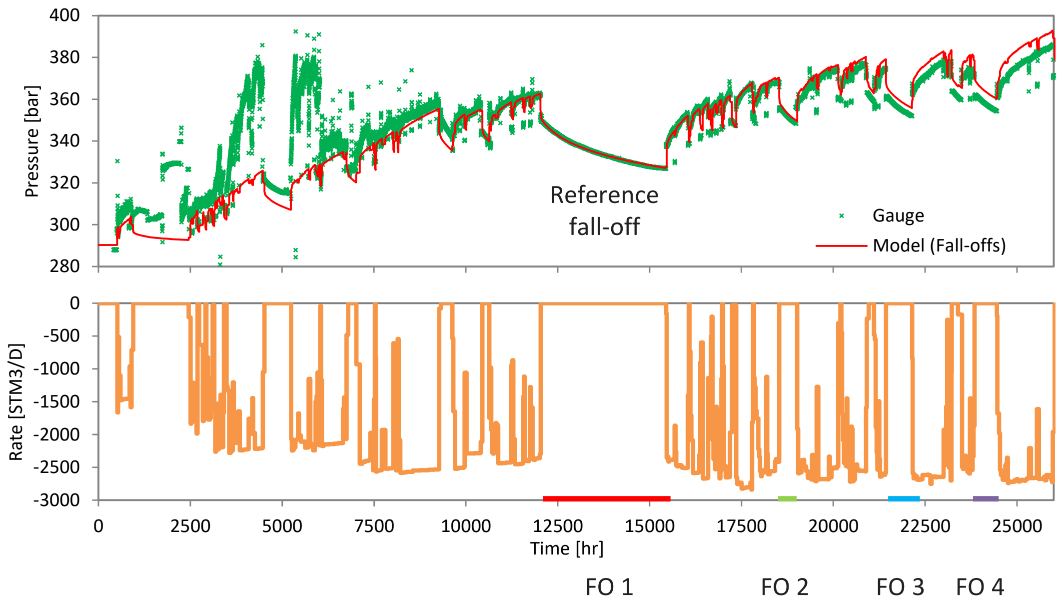


Difference amplitude map between baseline and monitor at base of the reservoir [from Hansen et al., 2011]

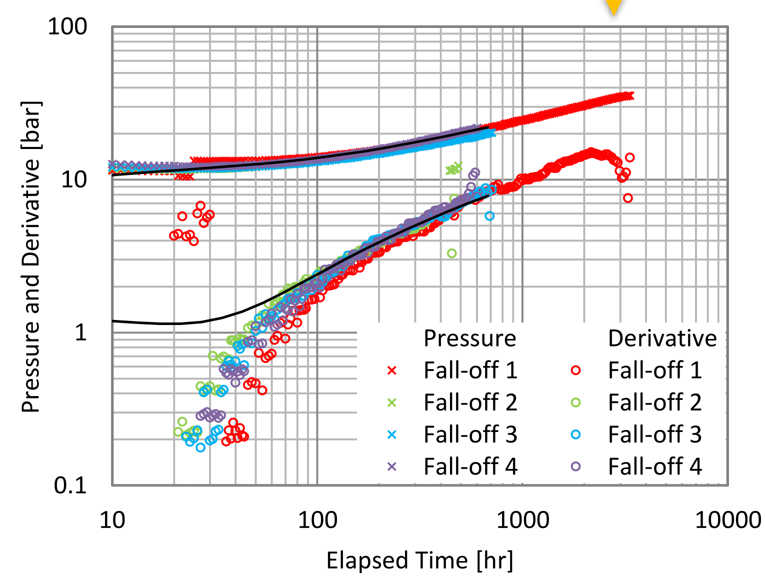
History of CO_2 injection at Tubåen formation



Time-lapse fall-off pressure transients



2-year history of CO_2 injection at Snøhvit may be reproduced with analytical models matched by PTA

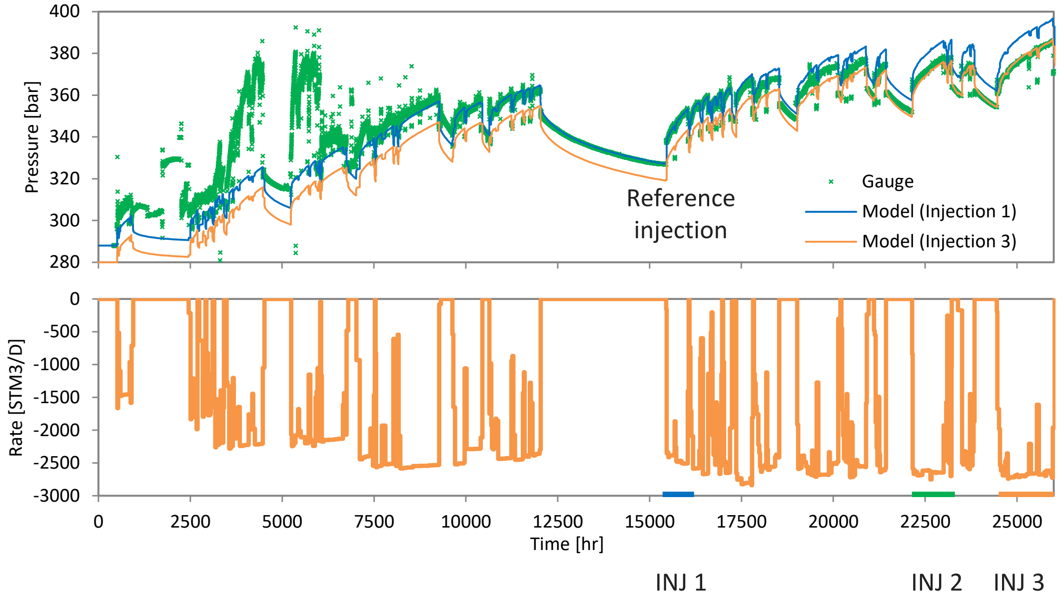


Four pressure fall-off responses caused by well shut-ins
All fall-offs indicate U-shape reservoir

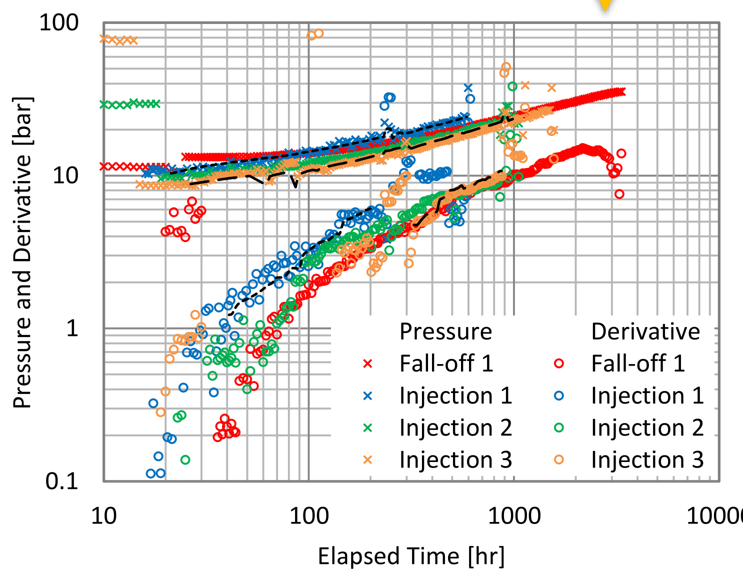
Fall-off responses / derivatives

- All faults may be captured by the shortest fall-off (10 days fall-off is already enough)
- Follow exactly the same trend indicating no changes in sealing capacity of the faults

Time-lapse injection pressure transients



The overall pressure build-up may be predicted with ~10% error based on the models matched to noisy injection data



Three injection pressure responses and longest fall-off response

Injection responses / derivatives

- Rate fluctuations cause noisy pressure transients
- Spread of transients is observed even after smoothing, but they approach the same trend as fall-offs

Lessons learned from Snøhvit

- **PTA** of real-time pressure measurements (PDG) or continuous ‘well test’ is **the most efficient tool** to characterize and monitor site boundary conditions

- PTA of PDG data (analytical models)
  - Uses gauge data available for the most of modern wells
  - Fast and cheap: minimum time, computations and data input
  - Efficient in characterizing large geological domains: pressure diffuses mainly in low-compressible saline aquifer, even after CO_2 plume appearance

- Site monitoring
  - The above advantages makes time-lapse PTA of PDG data a perfect tool for site monitoring, e.g. CO_2 reservoir containment

Acknowledgements

A part of this presentation was prepared and presented at 2015 Annual EAGE conference (paper published at EarthDoc*)

The authors acknowledge Statoil Petroleum AS and the Snøhvit license partners for providing access to the Snøhvit data presented at the EAGE conference

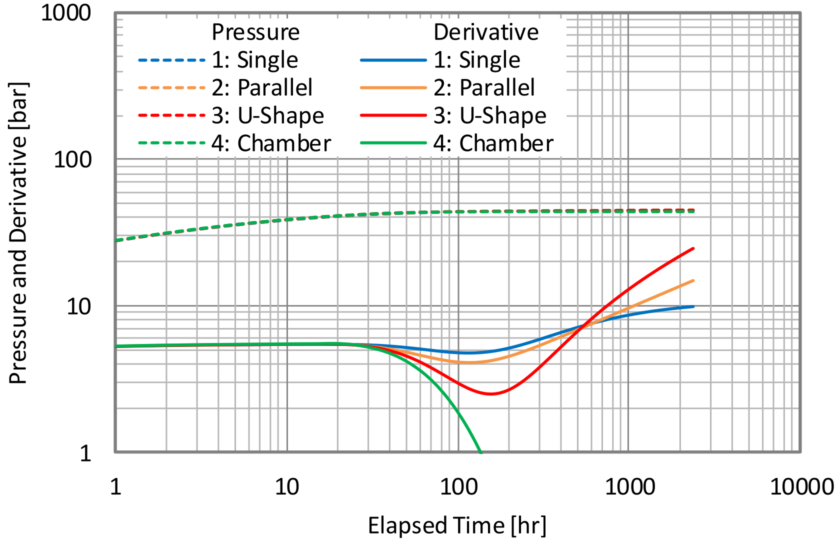
*Shchipanov A., Kollbotn L., Berenblyum R. Pressure Transient Analysis in CO_2 Storage Projects - From Reservoir Characterization to Injection Performance Forecast // 77th EAGE Conference & Exhibition. IFEMA Madrid, Spain, 1-4 June 2015

Thank you for your attention!

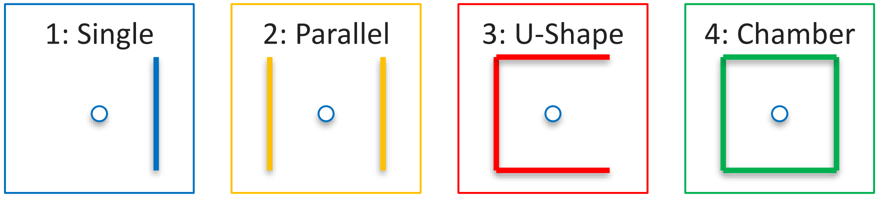
IRIS

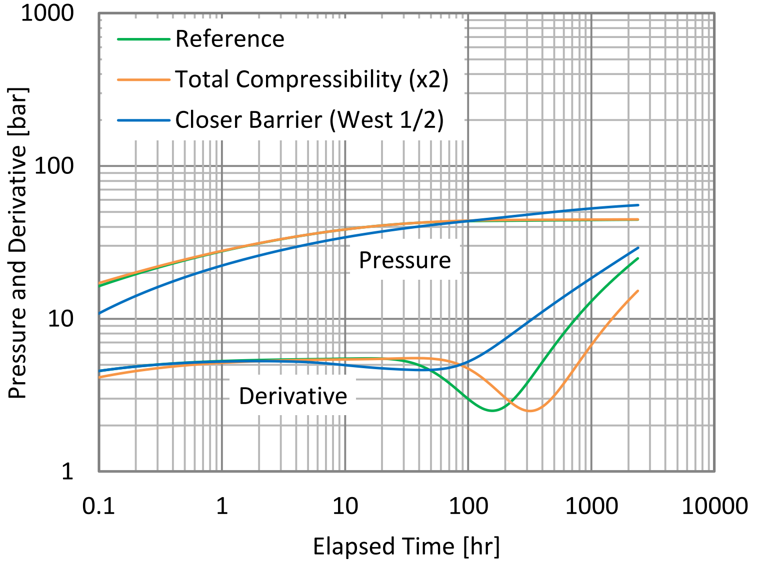
Contact: Anton.Shchipanov@iris.no

Sensitivity to flow barriers and compressibility



Sensitivity of fall-off response to number of sealing faults (no-flow boundaries)





Sensitivity to distance to West fault and total compressibility (U-Shape case)