Technische Presentatie en Q&A:
SCAN boring Amstelland-01

17 May 2024

Ministerie van Economische Zaken en Klimaat

ebn

TNO

Interreg North-West Europe DGE-ROLLOUT

Doel van deze sessie& Agenda

Doel van deze sessie: voorlopige resultaten uit SCAN-boring Amstelland delen en bespreken. Sterke technische focus.

Agenda:

1. Doelen van de Amstelland-boring
2. Verwachtingen
3. Operaties
4. Data-acquisitie
5. Bevindingen tot nu toe
6. Take home messages

Vragen? Stel ze via de chat.

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1: Doelen van de Amstelland boring

Objectives of the Amstelland well

1. **Late Permian Slochteren Fm (ROSL)**

   Prove **reservoir presence** and determine **reservoir properties** (e.g. porosity, permeability, transmissivity (kh)) by acquiring: 1. logs; 2. core; 3. well test

2. **Lower Cretaceous Vlieland Sandstone Fm (KNNS)**

   Prove **reservoir presence** and determine **reservoir properties** (e.g. porosity, permeability, transmissivity (kh)) by acquiring: 1. logs; 2. (if present) core; 3. (if sufficient transmissivity expected) well test

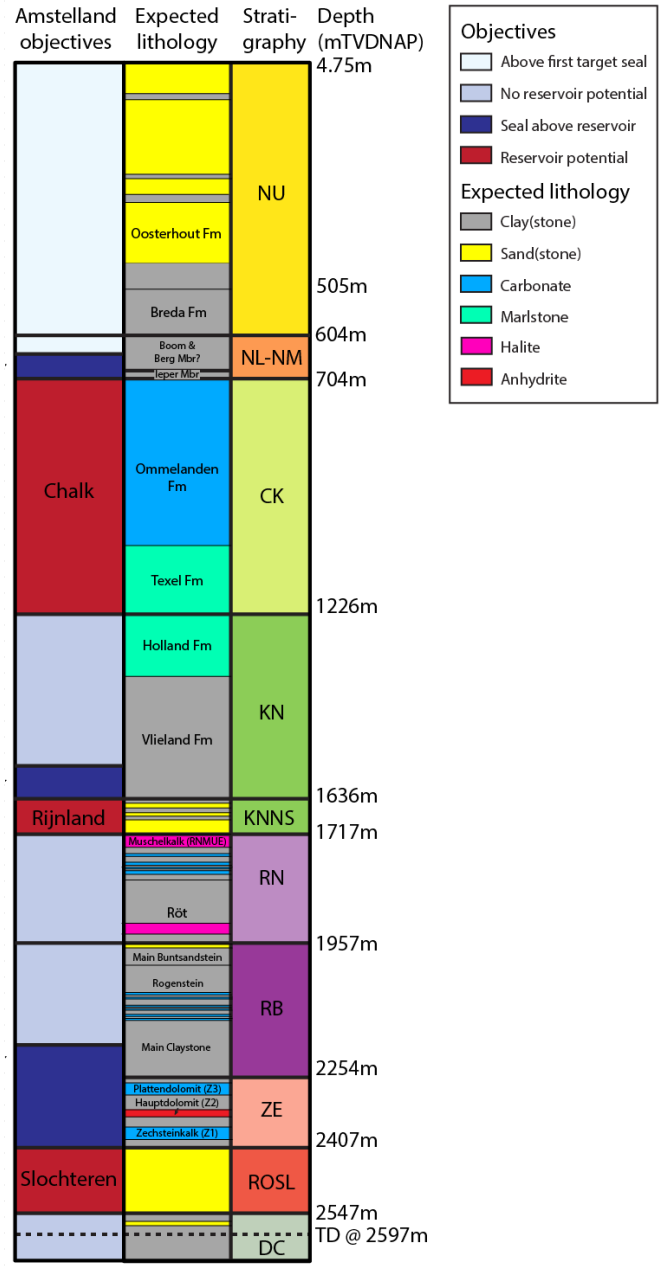
3. **Upper Cretaceous Chalk Gp (CK)**

   Prove **reservoir presence** and determine **reservoir properties** including primary and secondary permeability (i.e. fractures and/or karst) by acquiring: 1. logs;

4. Determine reservoir formation **fluid properties** and **temperature** for tested reservoirs (ROSL, KNNS) and the **temperature gradient** throughout the well

5. Determine **geomechanical properties** of the overburden for seismic-hazard quantification and operational constraints on injectivity

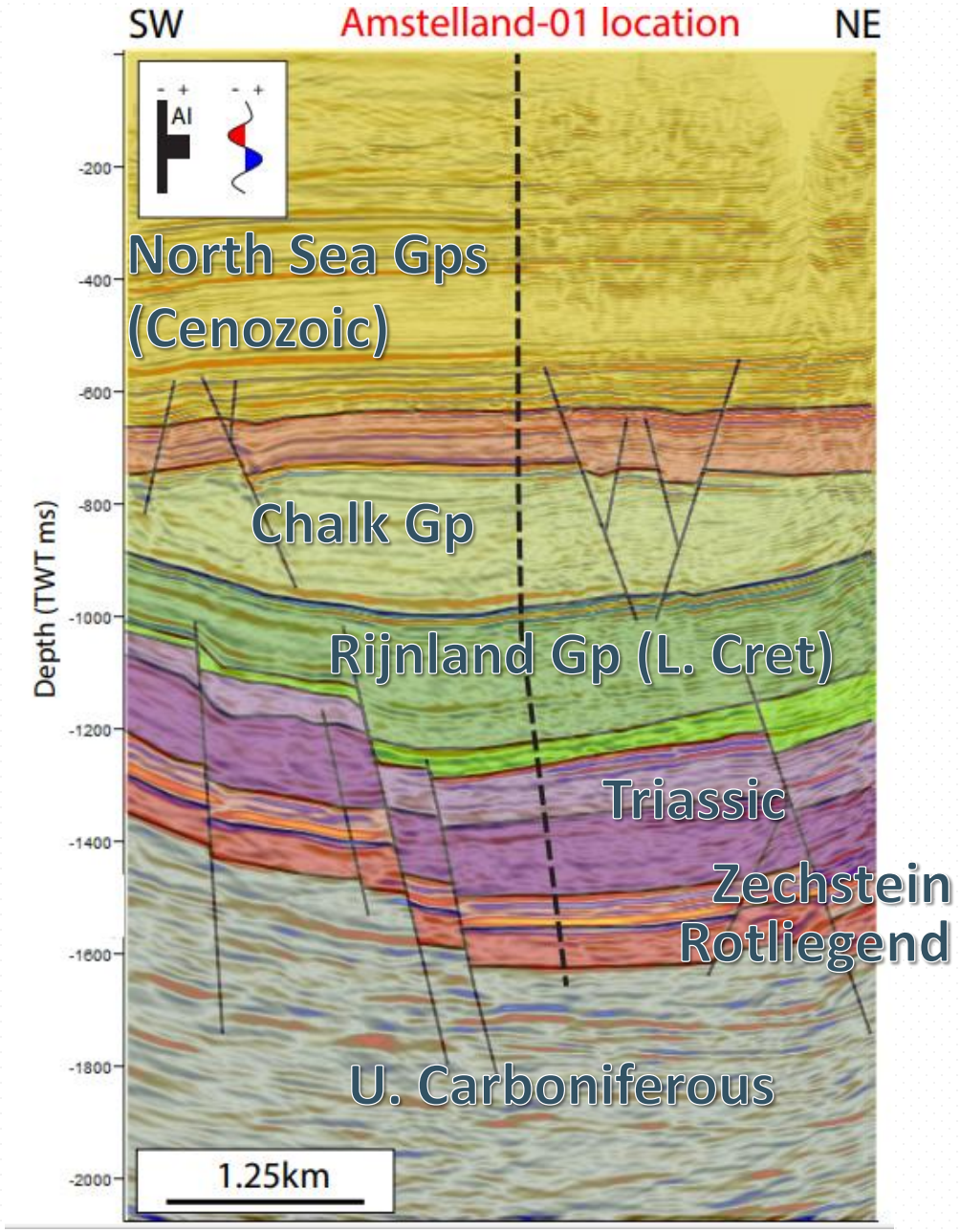
6. Establish **a confident tie** between the Amstelland well and SCAN 2D seismic data to allow extrapolation of well results



2: Verwachtingen

Pre-drill expectations

- ➜Geothermal targets:
  - ➜Primary: Permian Rotliegend (ROSL) sandstones (~87°C)
  - ➜Secondary: L. Cret. Vlieland Sandstone Fm (KNNS) (~62°C)
  - ➜Secondary: U. Cret. Chalk Gp (CK) (~39°C)
- ➜Geological probability of success (GPOS) for SCAN wells defined as: >10m net reservoir and >10mD average permeability
- ➜Main pre-drill uncertainty for ROSL: reservoir quality. Chance of presence of sufficiently permeable reservoir estimated at 65%
- ➜GPOS Vlieland Sandstone: 30%
- ➜GPOS Chalk: 40%



3: Operaties

Amstelland (AMS-01) Operations

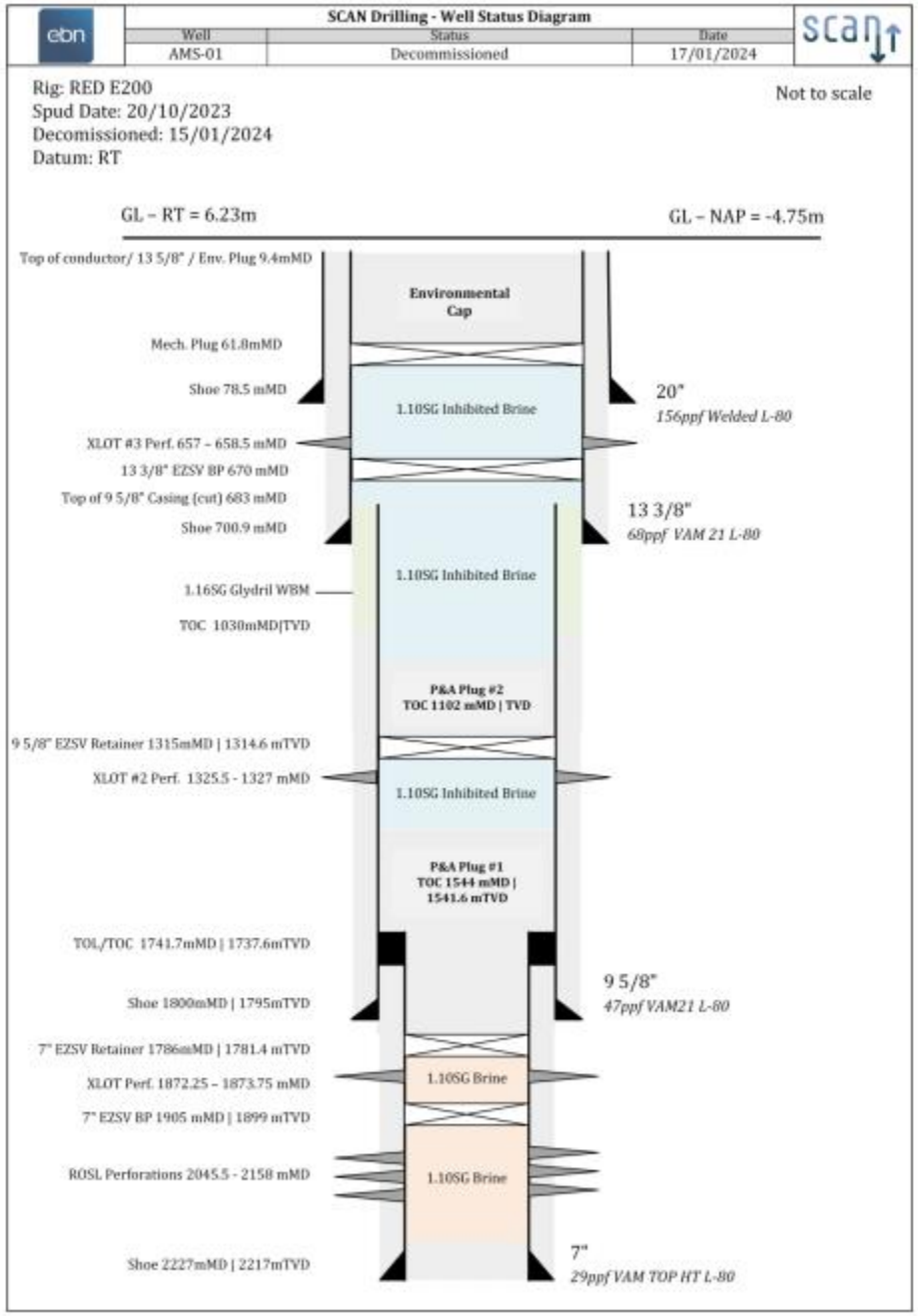
- ➜80 days of operations (including mob/ demob), less than the 104 days planned
- ➜No LTIs or major safety incidents
- ➜TD 2217.67m MD in Carboniferous Limburg Group
- ➜J-shaped trajectory, deviated towards northeast
- ➜8.96° from vertical at TD
- ➜Drilling fluids:

Boring AMSTELLAND-01

Identificatie: AMS-01
Locatie: 52.30751583, 4.92379283 (WGS84)
Aangeleverde locatie: 123395.295, 480050.996 (RD)

Section	Type	Start Depth (mMDRT)	End Depth (mMDRT)	Weight (SG)
17 ½" Tophole	FW Polymer	0	394	1.05 – 1.07
17 ½" Drilling	KCL Glydrill	394	703	1.16 – 1.24
12 ¼" Drilling	Versaclean OBM	706	1395	1.15 – 1.25
12 ¼" Coring	Versaclean OBM	1395	1480	1.25
12 ¼" Drilling	Versaclean OBM	1480	1803	1.25
8 ½" Drilling	Versaclean OBM	1806	2077	1.14-1.16
8 ½" Coring	Versaclean OBM	2077	2168	1.16
8 ½" Drilling	Versaclean OBM	2168	2227	1.16 – 1.19

- ➜Extensive data acquisition performed throughout well, including over reservoirs, caprocks and overburden



4. Data-acquisitie

Data on NLOG.nl

Well

1 of 1

Well AMSTELLAND-01

Identification: AMS-01
Location: 52.30751583, 4.92379283 (WGS84)
Delivered location: 123395.295, 480050.996 (RD)

Basic data | Deviation | Documents | Lithostratigraphy | Samples | Core analyses | Production figures | Logs LIS/LAS

Well AMSTELLAND-01

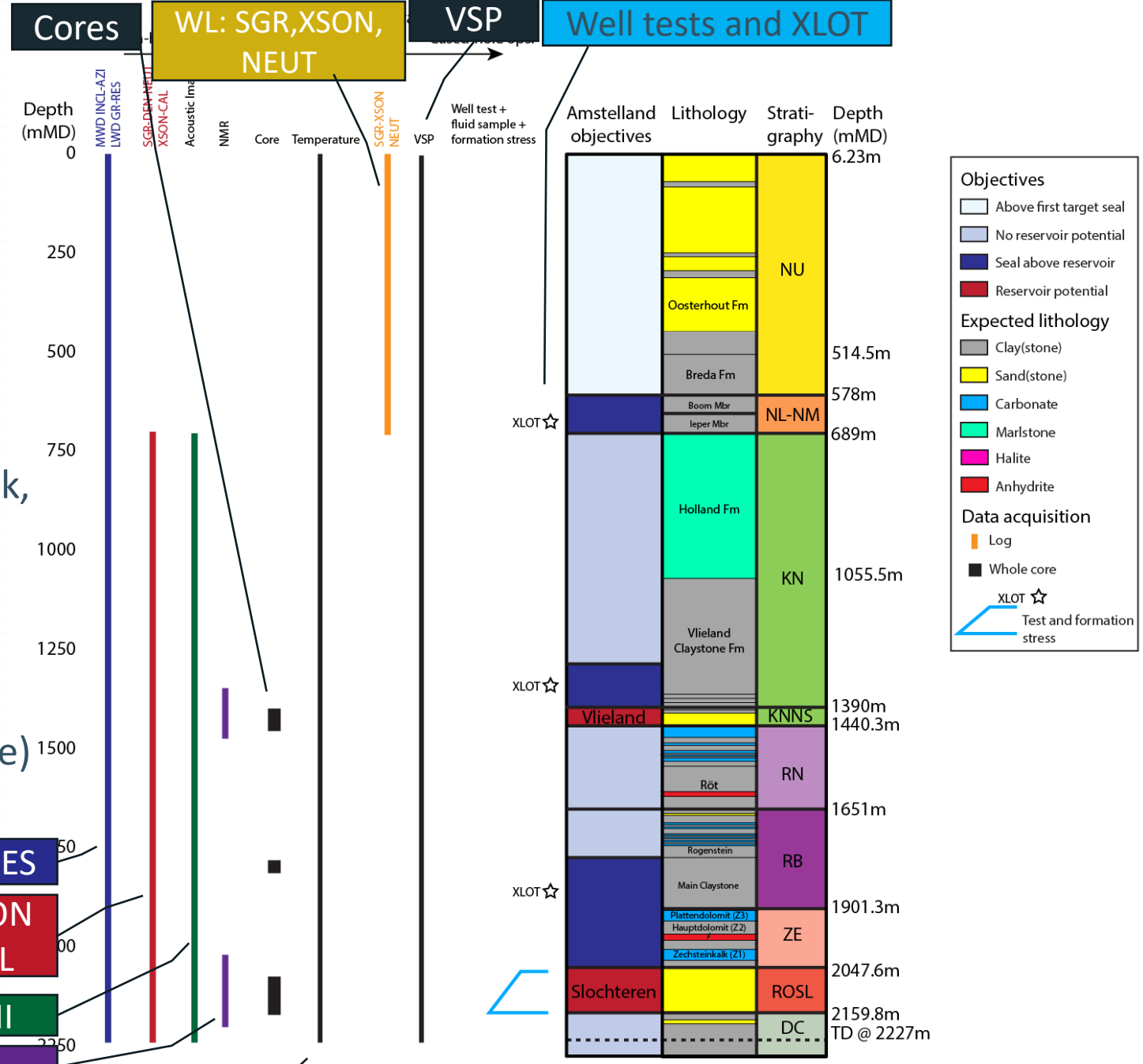
Category	Document
Borehole/Well - Final rapport	SODM EOWR(08 Feb 2024)
Documents containing borehole logs	12.25in_LWD_Run200_RM_MD(665-1395)(08 Nov 2023) 12.25in_LWD_Run300_RM_MD(1365-1803)(08 Nov 2023) 12.25in_Run1.1.1_AST_ANISOTROPY(700-1790)(14 Nov 2023) 12.25in_Run1.1.1_AST_SEMBLANCE(31-1790)(14 Nov 2023) 12.25in_Run1.2.1_CSNG(30-1798)(10 Nov 2023) 12.25in_Run1.2.1_DSN_SDLT(30-1803)(10 Nov 2023) 17.5in_LWD_Run100_RM_MD(25-690)(24 Oct 2023) 8.5in_LWD_Run400_RM_MD(1755-2077)(22 Nov 2023) 8.5in_LWD_Run500_RM_MD(2045-2227)(22 Nov 2023) 8.5in_Run2.1.1_AST_ANISOTROPY(1801-2212)(24 Nov 2023) 8.5in_Run2.1.1_AST_SEMBLANCE(1741-2210)(24 Nov 2023) 8.5in_Run2.1.1_CAST_Borehole_Shape(1801-2222)(24 Nov 2023) 8.5in_Run2.1.1_CAST_Manual Dip Analysis_Listing(15 Dec 2023) 8.5in_Run2.1.1_CAST_Manual Dip_Analysis(1801-2222)(24 Nov 2023) 8.5in_Run2.1.1_CAST_Static_Dynamic_Image(1801-2222)(24 Nov 2023)

Link to this page: https://www.nlog.nl/nlog-mapviewer/brh/3894840289?lang=en

Overview of status of deliverables at https://scanaardwarmte.nl/onderzoek-in-amstelland/

Amstelland Data Acquisition

- LWD and (OH/CH) wireline log data
  - (S)GR,RES,XSON,DEN,NEUT, IMAGE
  - *NMR (calibration with core in progress)*
  - Temperature
- VSP (geophone and fibre-optic)
- Core (193m: Vlieland Sandstone, Muschelkalk, Main Claystone, Slochteren and Limburg)
  - Screening analysis
  - *Routine core analysis, SCAL, core description*
  - *Geomechanical tests*
- Cuttings (*biostratigraphy*, vitrinite reflectance)
- Production/Injection test
  - PLT
  - Fluid samples
- XLOT (3x)



Log data

Logging-while-drilling (complete well)

- Gamma ray and resistivity

Wireline cased-hole data (17 ½" section)

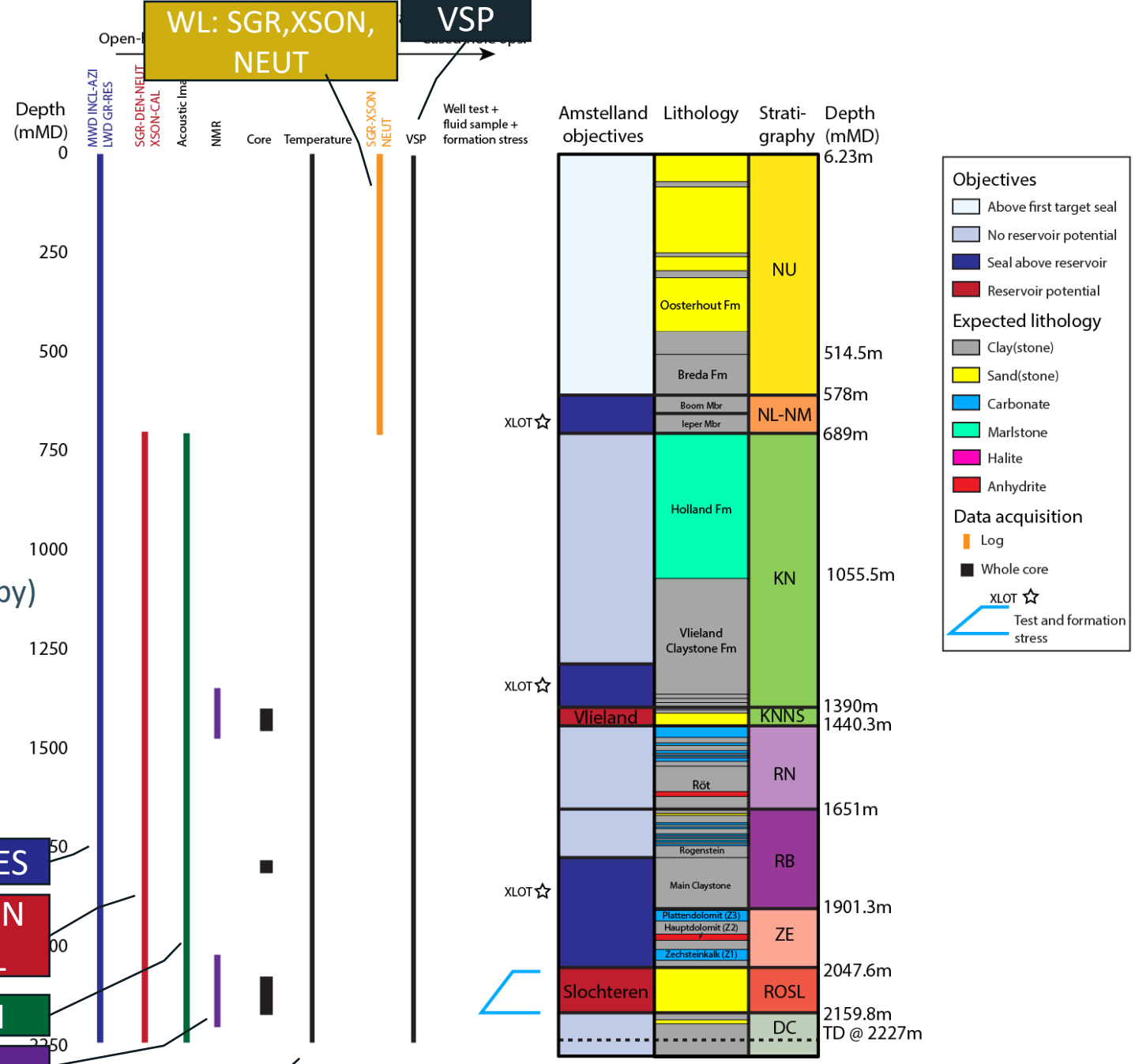
- X-dipole sonic (compressional)
- Spectral gamma ray
- Neutron

Wireline open-hole data (12 ¼" and 8 ½" section)

- X-dipole sonic (compressional, shear, Stonely, S-anisotropy)
- Acoustic image logs
- Spectral gamma ray
- Density (and photoelectric effect)
- Neutron
- NMR (potential reservoir intervals)

Wireline cased-hole data (complete well)

- Temperature and VSP



Core data

Take note of shifts between LWD, WL and core data!

- 193 meter cored
  - Vlieland Sandstone Fm (reservoir – 44m – 5 ¼”)
  - Muschelkalk Fm (base – 40m – 5 ¼”)
  - Main Claystone Fm (seal – 18m – 4”)
  - Slochteren Fm (reservoir – 83m – 4”)
  - Limburg Gp (base – 8m – 4”)
- 100% recovery/efficiency
- Preserved sections selected for future analysis
- Core Analysis
  - RCA: Ambient helium poro-perm (H and V); Klinkenberg poro-perm @ overburden stress
  - SCA: FRF and “m”, brine permeability, HPMI, NMR
  - Geomechanics: single-stage tri-axial tests, thermal expansion coefficients
  - Sedimentology, petrography, SEM, BSEM
- All core material to be stored at TNO after analysis finalised

Vlieland Sandstone Fm

Main Claystone Fm

Production/injection tests

blue: *primary* goals

Production test:

1.	N_2 lift via coiled tubing (23 hours)	clean out + P.I.
2.	Buildup with surface shutin (12 hours)	skin + kh
3.	Downhole water sample	reservoir fluid
4.	Temperature logs	reservoir T

Injection test:

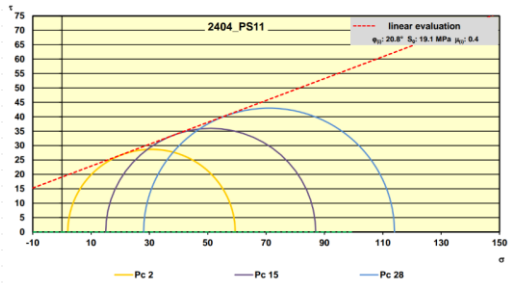
3.	Injection #1 @ 25 m3/h (3 hours)	I.I.
4.	Fall-off #1, surface shutin (20 hours)	skin + kh
5.	Injection #2, multirate (20 hours) + PLT	I.I. + flow profile
6.	Fall-off #2, surface shutin (30 hours)	skin + kh

Note: productivity index (P.I.) is identical to the injectivity index (I.I.), provided that there are no viscosity effects or hydraulic/thermal fraccing effects

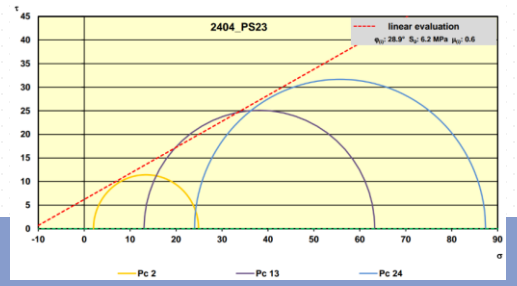
Geomechanical data

- ➜Log data
  - ➜Vertical stress from density log
  - ➜Elastic parameters from X-dipole sonic
- ➜Acoustic image logs to determine orientation stress field
- ➜3 XLOTs to determine magnitude minimum horizontal stress
- ➜Geomechanical tests on cores of seals and reservoirs including thermal properties

Main Claystone Fm



Slochteren Fm



Upcoming work

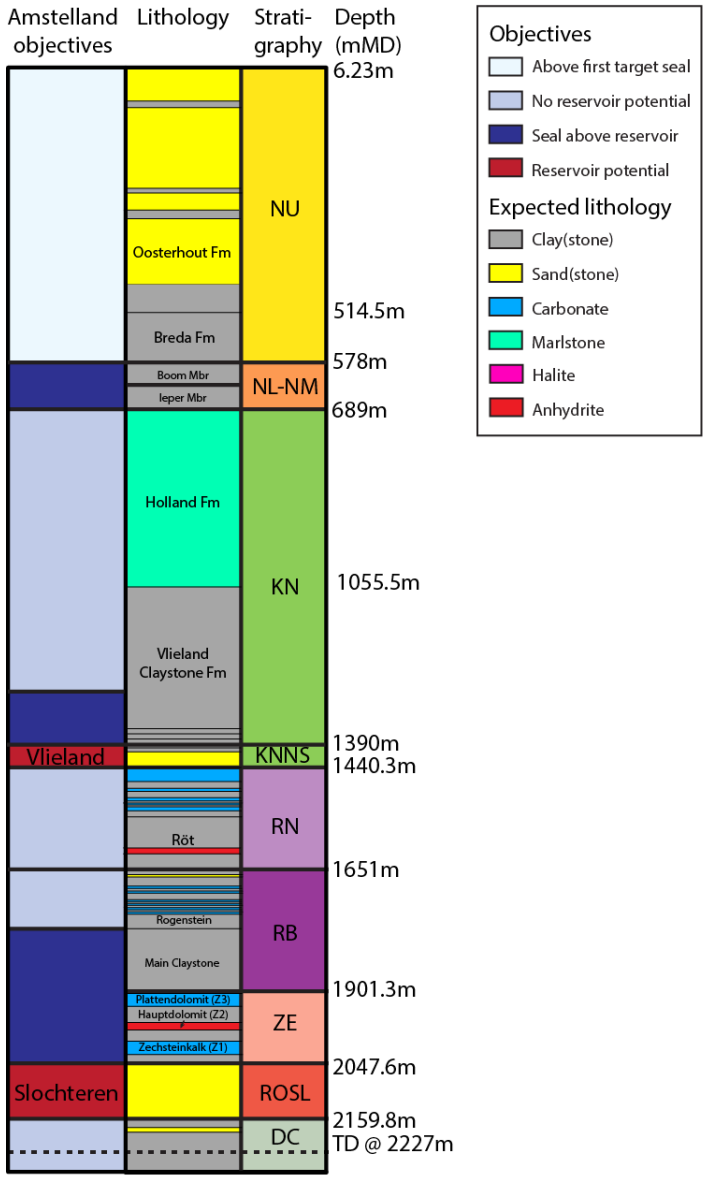
- ➜Finalise and report Routine Core Analysis
- ➜Finalise and report Special Core Analysis
- ➜NMR log calibration with core data
- ➜Core thin sections and petrography
- ➜Sedimentological description cores
- ➜Biostratigraphy Cretaceous and Carboniferous
- ➜Formation damage study
- ➜Integration of all data to explain Slochteren reservoir performance
- ➜Data-acquisition report with description of all collected data

5. Bevindingen tot nu toe

Key results

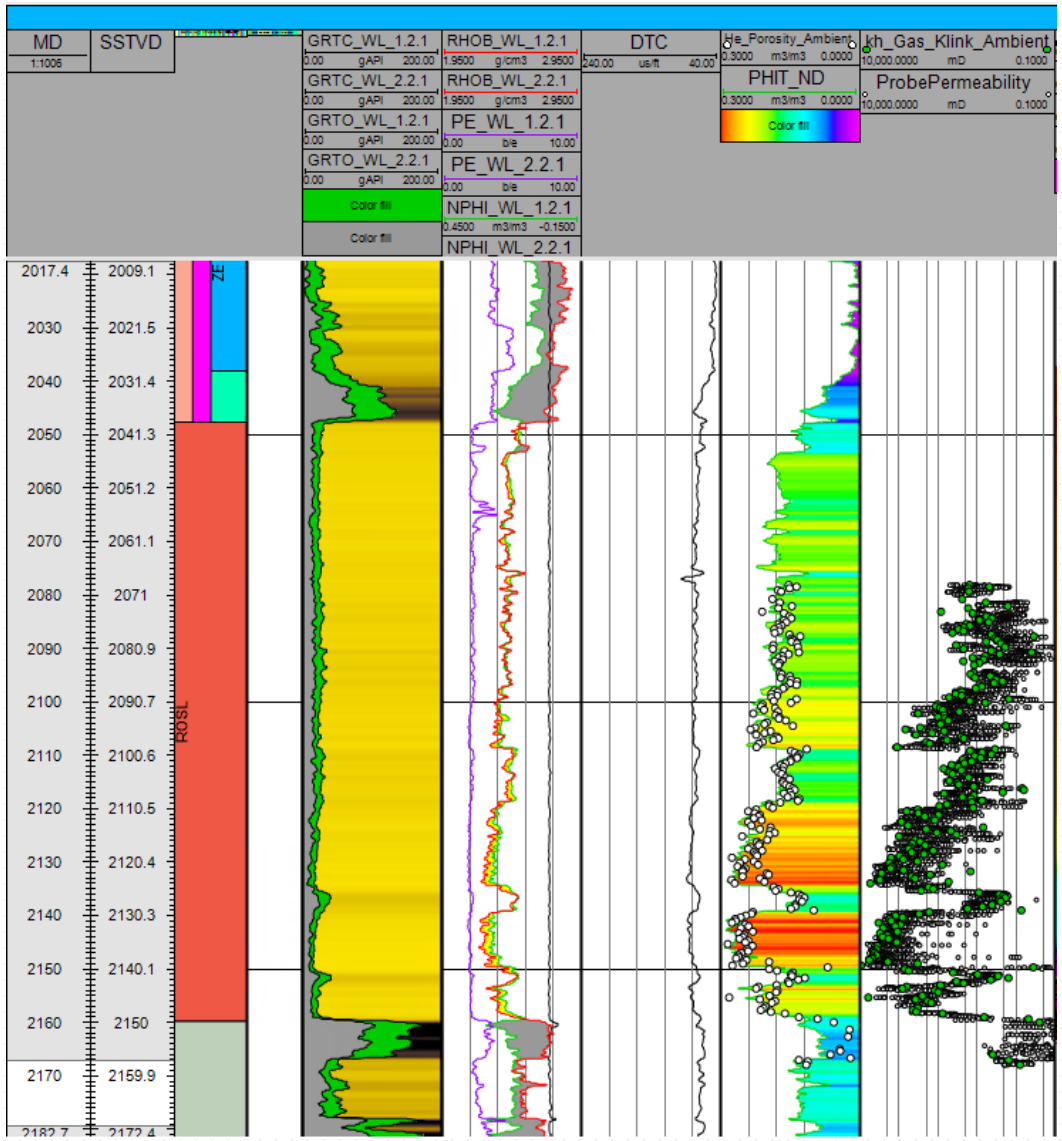
- ➔Primary target Slochteren Fm:
  - ➔112 mAH thickness
  - ➔Average porosity 18%, up to 26%
  - ➔High permeabilities measured on cores
  - ➔Produced and injected 1000m^3
  - ➔Formation temperature approx. 82°C
- ➔Secondary target Vlieland Sandstone Fm:
  - ➔50 mAH encountered, insufficient porosity and permeability; not flow-tested
- ➔Secondary target Chalk Gp:
  - ➔Not present; eroded at the well location

Post-drill

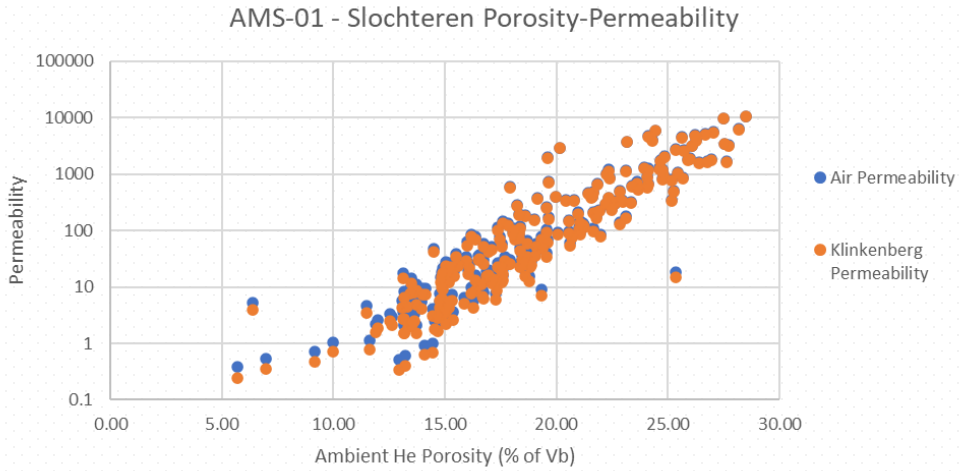


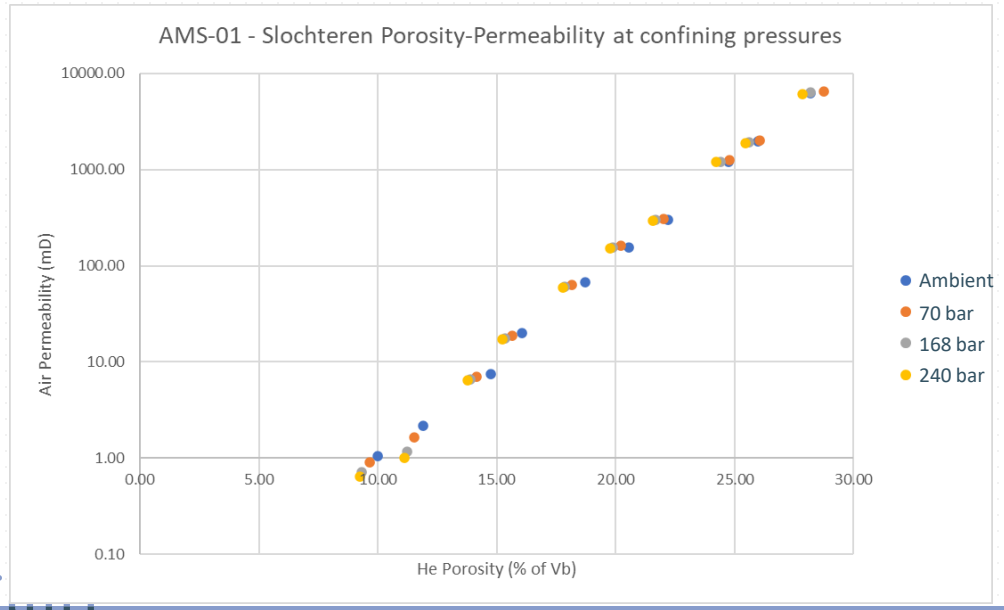
Amstelland Slochteren Reservoir Quality

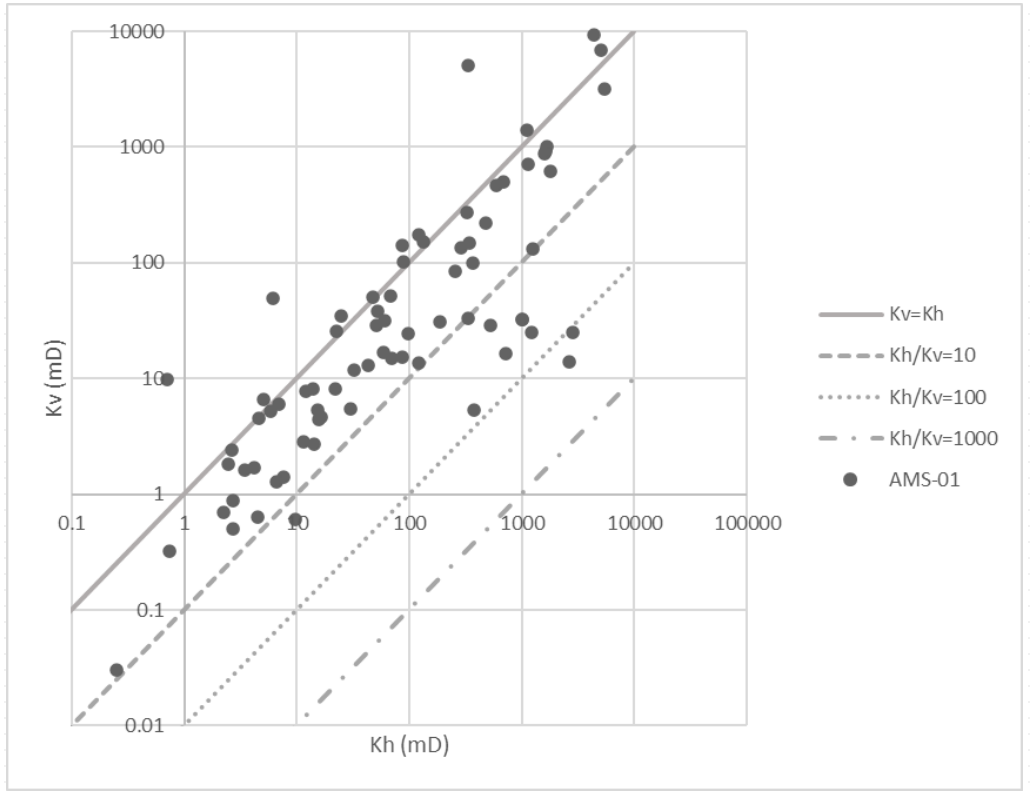
- ➜Clean (eolian?) sandstone
- ➜Thickness: 112 mAH
- ➜Average porosity: 18%; up to 26%
- ➜High permeabilities (probe, helium and HPMI) in core: up to 9.5 Darcy
- ➜No evidence for illite (in XRD, tbc with thin sections)



Amstelland Slochteren Core Analysis



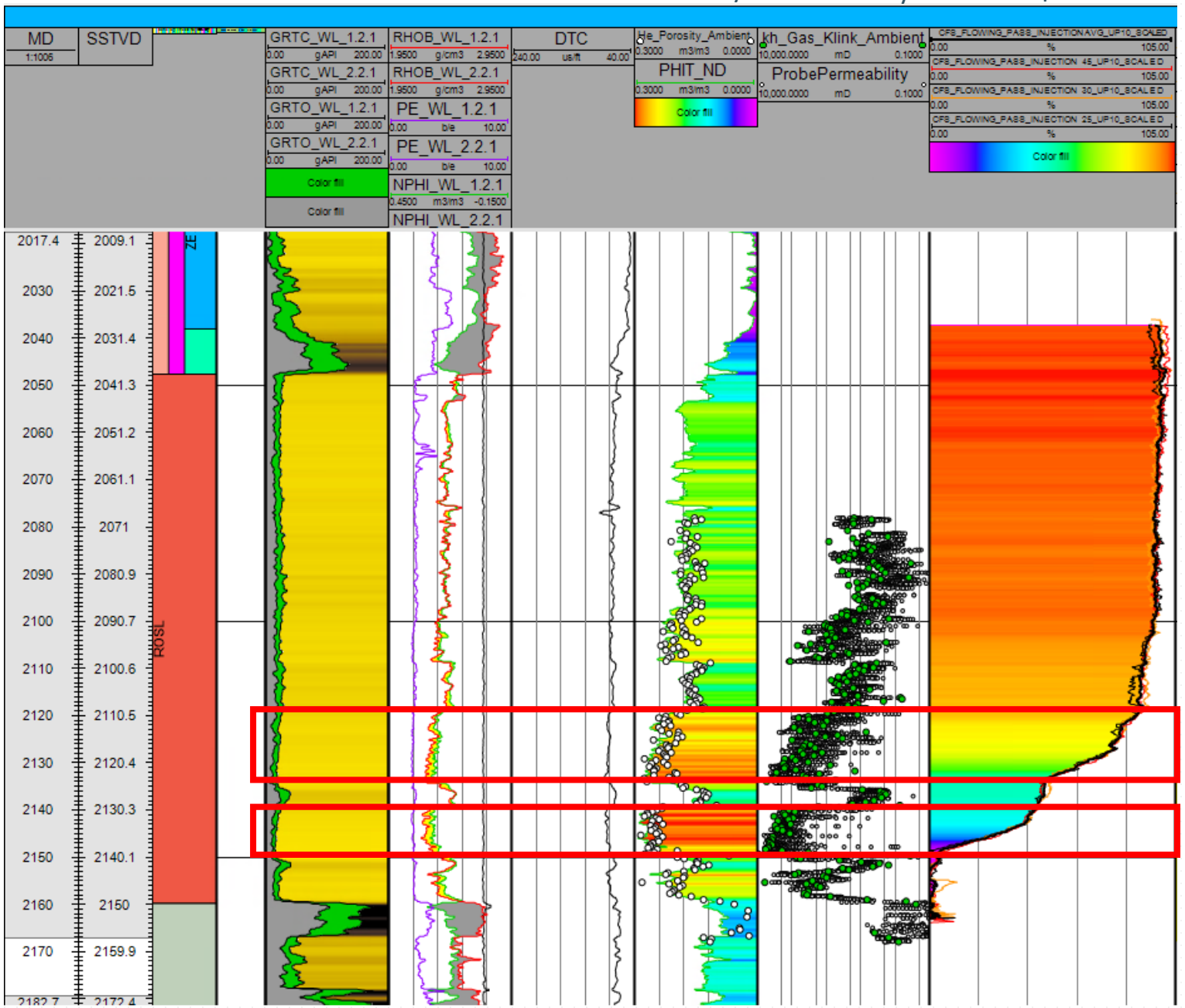




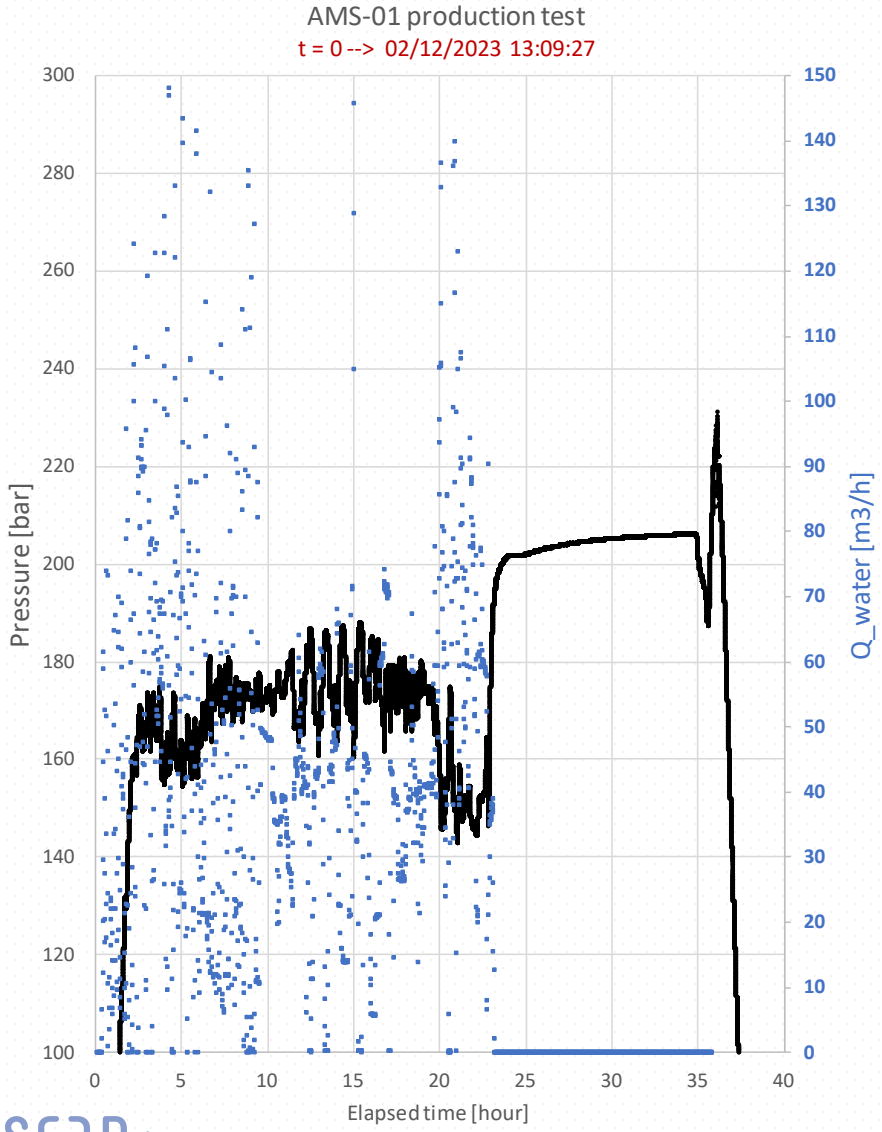
- >300 hot-oven dried 1.5” core plugs => total porosity
- Permeability corrected for Klinkenberg-effects and overburden
- Horizontal and vertical plug permeabilities
- Brine permeability measurement in progress

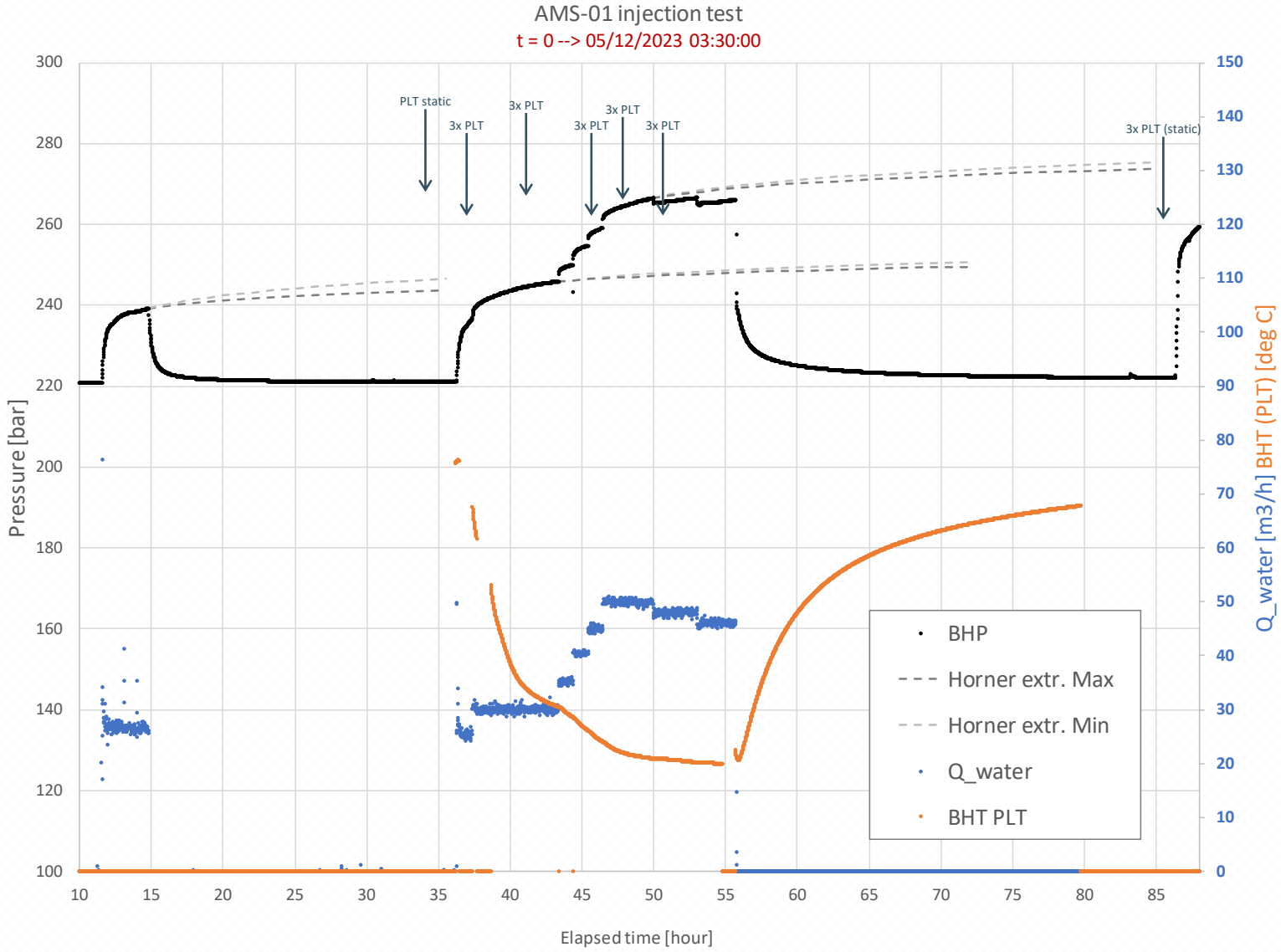
PLT results

- ➜90% of injected water into two flow units with highest measured porosity and permeability
- ➜75% of reservoir thickness hardly contributes to flow
- ➜Using a poro-perm transform and averaging this using arithmetic and geometric means, these two units <u>each</u> have up to several 10's Dm transmissivity



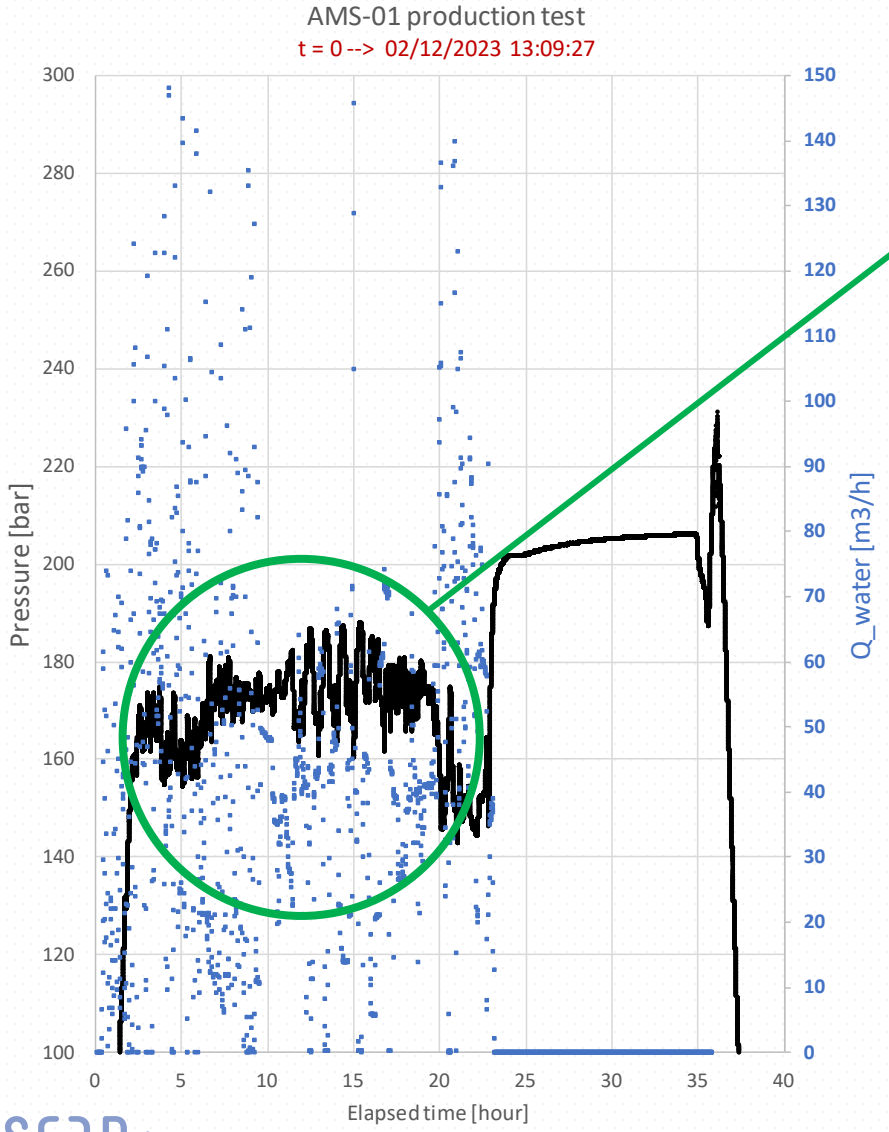
Well test - overview

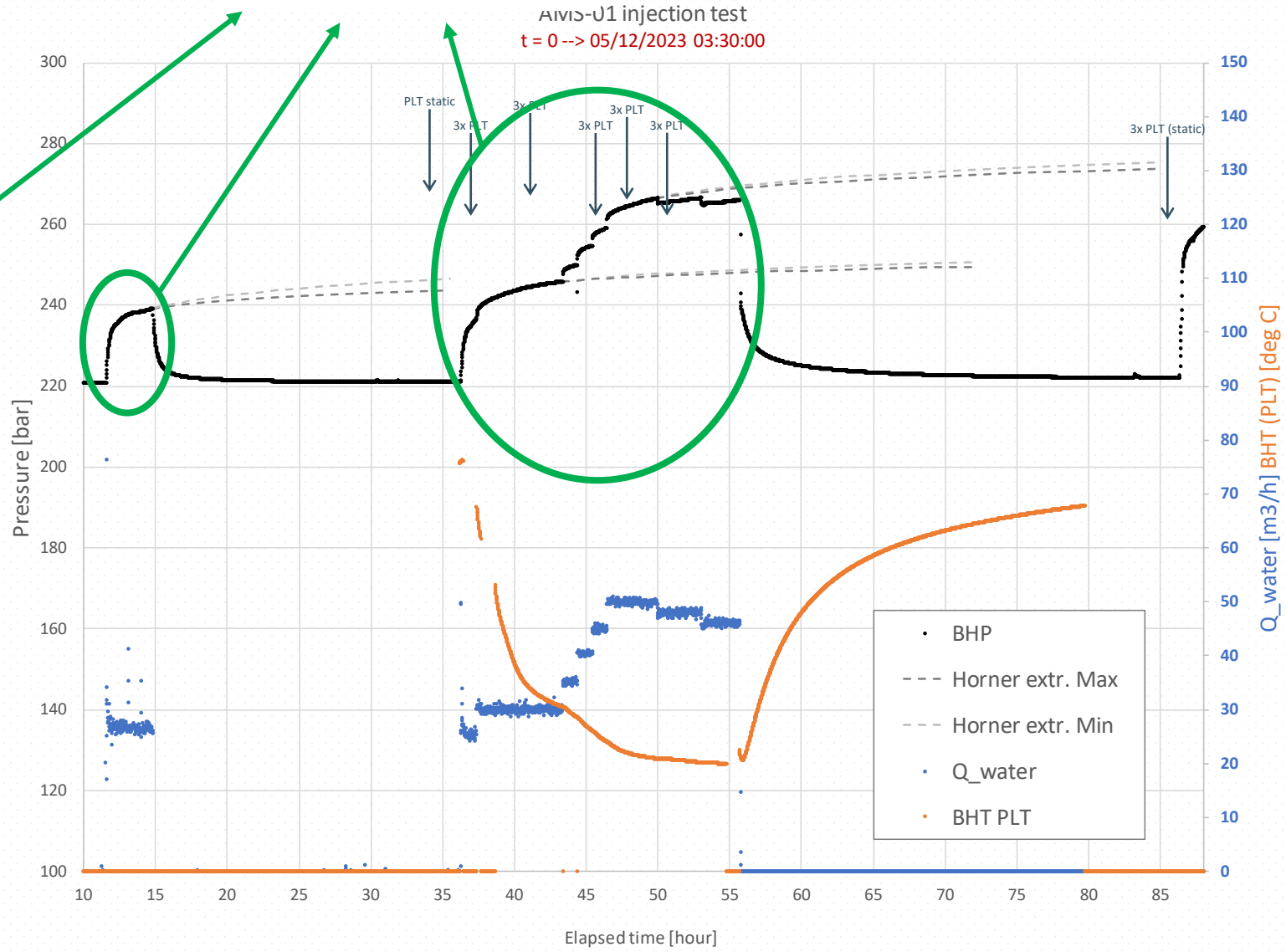




Well test - overview

Determination of P.I. and I.I. → **Objectives met; successful**

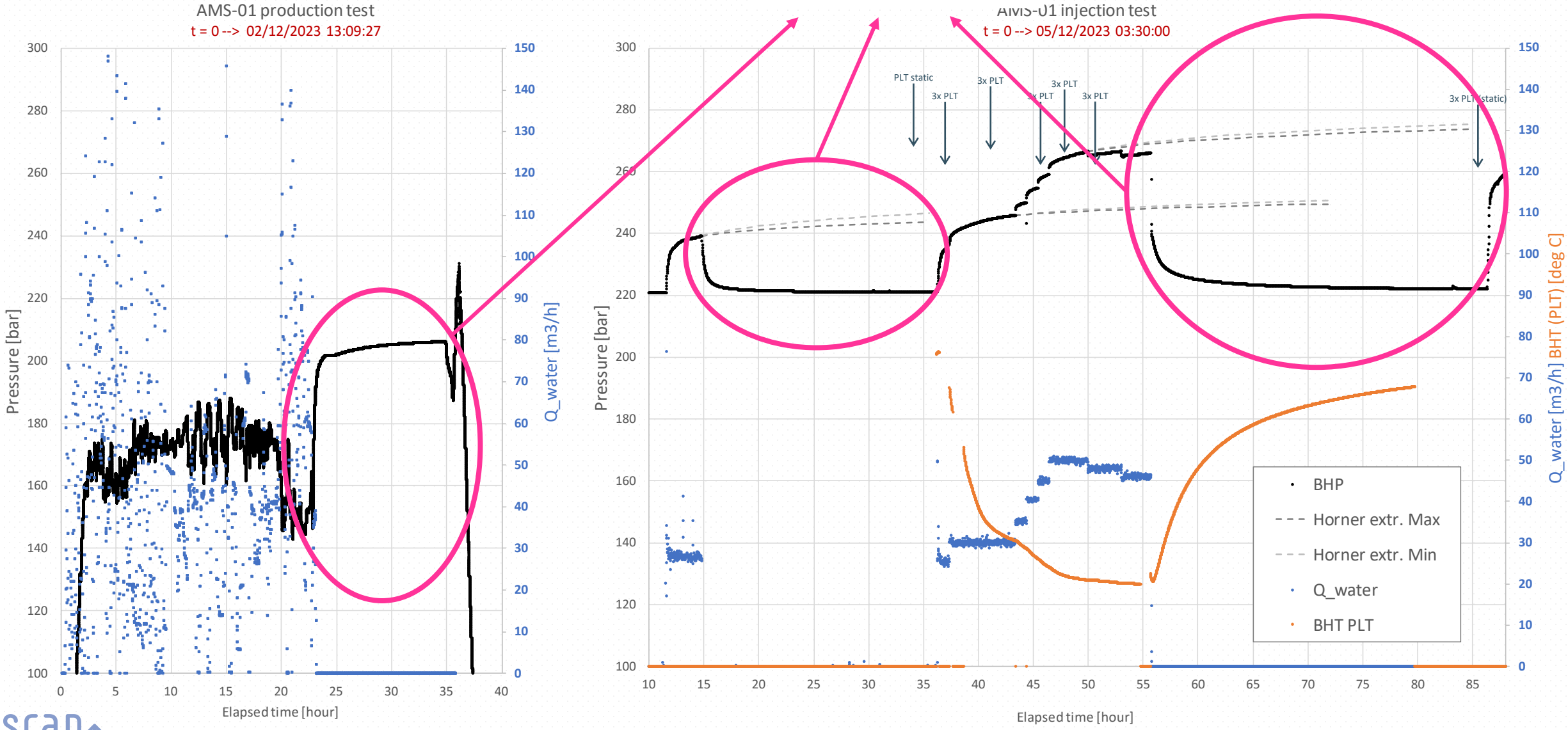




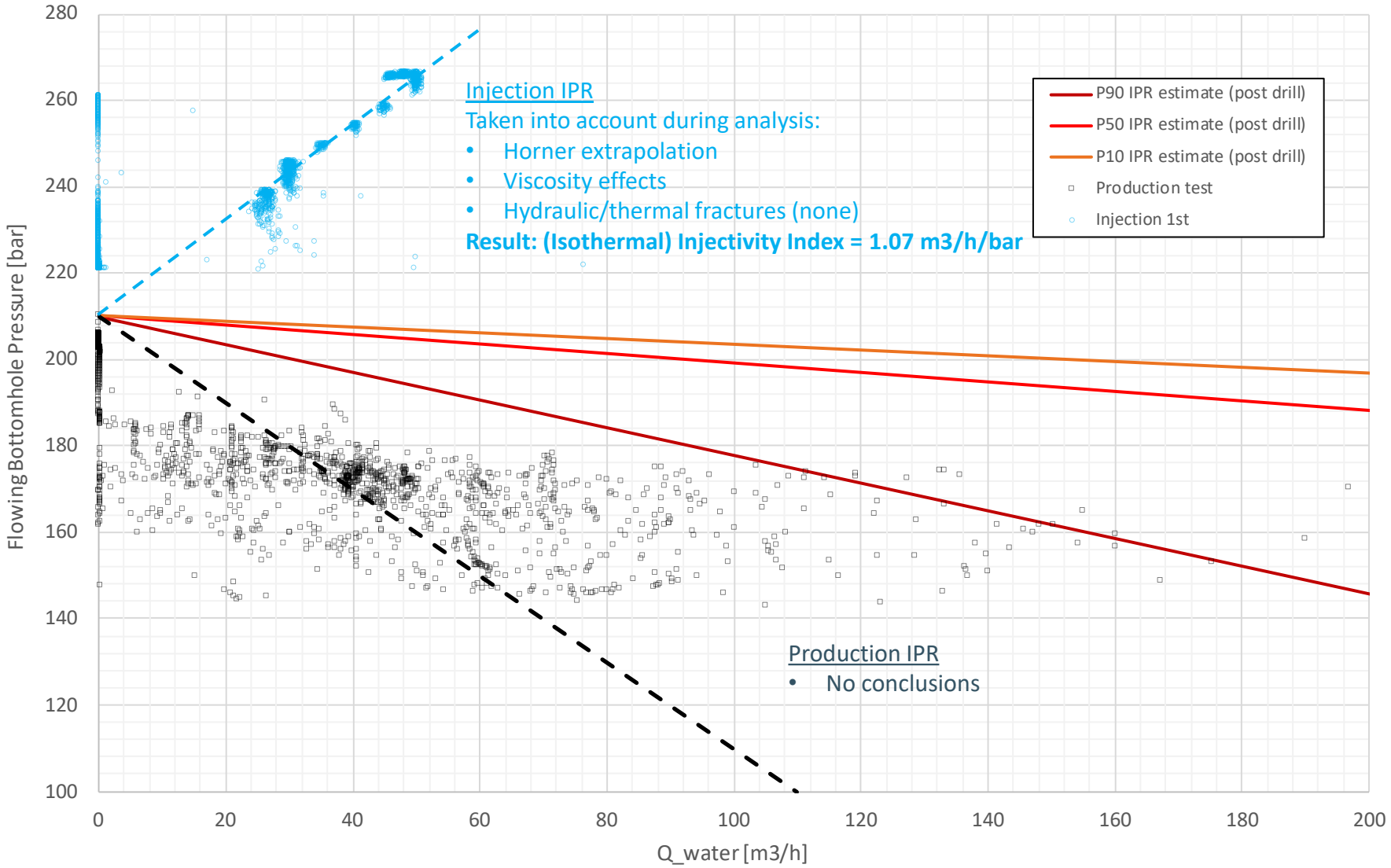
Well test - overview

Determination of skin and kh

Objectives *not* met; *not* successful



Productivity Index / Injectivity Index



Analysis:

- P.I. = I.I. = slope of straight line on this plot
- P.I. can *not* be derived due to unstable production. However:
- I.I. can be derived (taking transient and temperature effects into account)

Result:

- P.I. = I.I. = **1.07 m3/h/bar**
- High level of confidence

Conflict with geological results:

- Why is the P.I. (or I.I.) so much lower than the post-drill P90 expectation?
- Option 1: skin much higher than expected?
- Option 2: kh much lower than what the logs + cores tell us?

Summary of AMS-01 welltests

- ➜ P.I. (I.I.) can be calculated with large confidence
- ➜ Extremely risky to calculate the skin and kh using Pressure Transient Analysis
  - ➜ Buildup, Fall-off and Injection periods cannot be used, due to wellbore storage effects and/or temperature effects. Neither of them can be modelled in known analytical software.
  - ➜ Based on the welltest, no conclusions can be drawn regarding the skin and kh
  - ➜ Welltest cannot explain the mismatch between the disappointing well performance and observed logs/cores

Possible explanation for discrepancy between well performance and geological logs/cores:

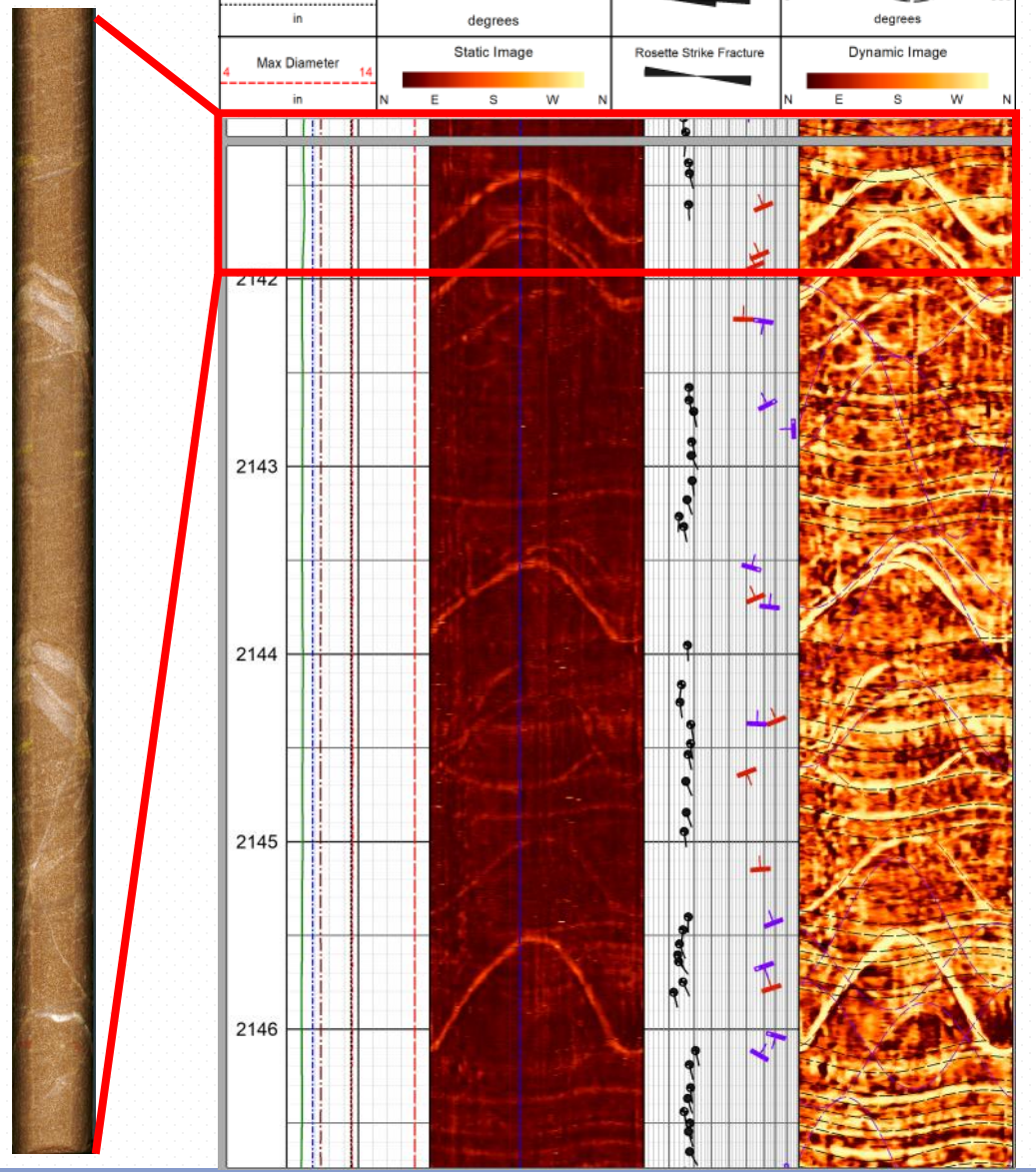
- ➜ Cemented fractures restrict flow of fluids
- ➜ Significant difference between air and brine permeability
- ➜ Large skin caused by mud cake
- ➜ Large skin caused by OBM (relative permeability effects)

Additional studies and numerical modelling ongoing

Fractures/deformation bands

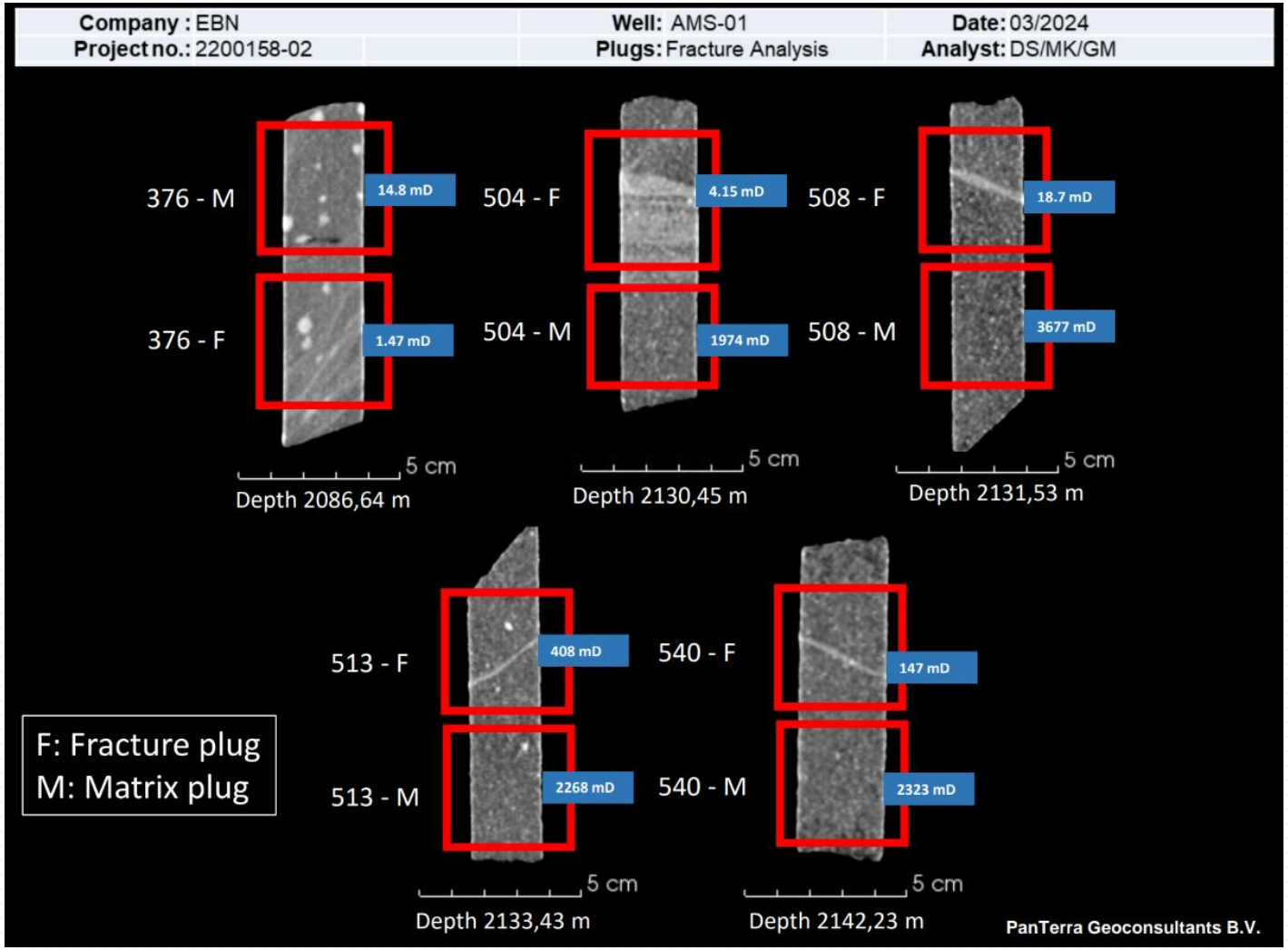
- ➜High number of fractures observed in acoustic image logs
- ➜EW to NE-SW striking conjugate set
- ➜Highest density in highest permeability units (up to 3 fractures/meter)
- ➜Majority of these appear to be high or mixed amplitude
- ➜Quartz cemented based on XRF

Static-Dynamic acoustic image:
Light means high velocity = low porosity



Faults/deformation bands

- (Empirically Klinkenberg Corrected) Permeability measured on dedicated core plugs
- Fractures are significantly less permeable than the reservoir itself



Formation damage

- OBM filtrate invasion observed in Slochteren cores
- OBM filtrate invasion suggested by petrophysical evaluation of resistivity logs
- Modelling of depth of invasion of solids and mud filtrate into reservoir ongoing
- Modelling of perforation depth ongoing: did we perforate beyond invaded zone (probably not)?
- If not, what were the relative permeability effects of an OBM in a water reservoir?
- Formation damage study on cores planned

PS-21
RUN #2

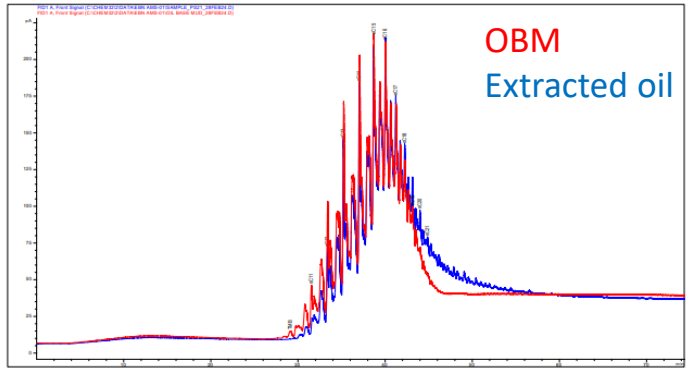
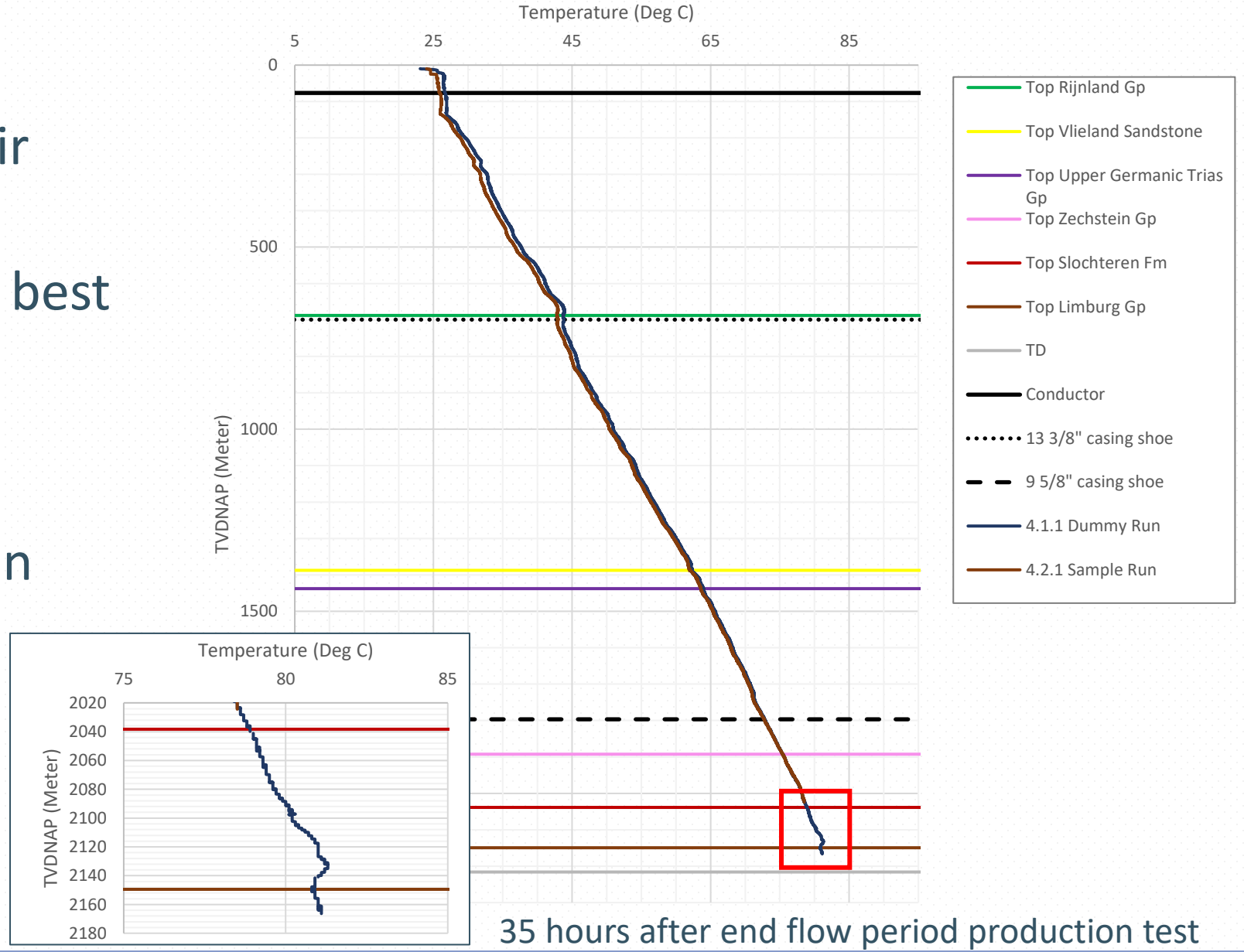


Figure 13 - Chromatogram of Oils Extracted from Brine Sample PS 21 and Respectively Filtered from OBM overlapped in the Area of Interest

Invasion of drilling fluid into the core

Temperature

- ➜82°C Slochteren reservoir temperature
- ➜5°C higher than pre-drill best estimate at this depth
- ➜Obtained gradient will provide improved temperature-prediction in the area



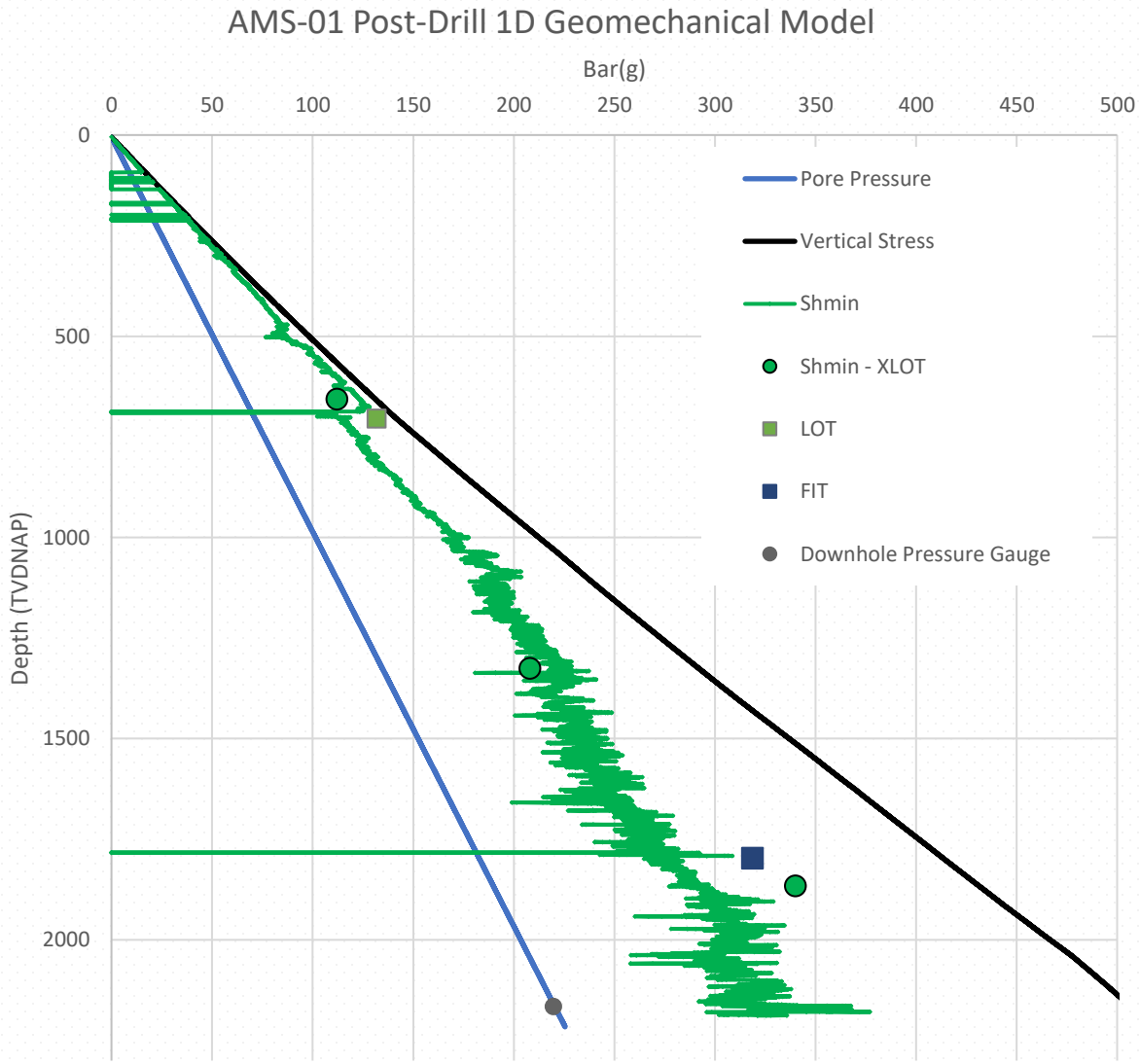
35 hours after end flow period production test

Fluid properties

- ➜Downhole and surface fluid samples analysed
- ➜Bubble point @81°C: 88 bar
- ➜TDS: 190.000 mg/l, salinity 176.600mg/l
- ➜Dissolved gas:
  - ➜GWR: 0,442 sm^3/m^3 at surface conditions
  - ➜70% weight% methane, 9% weight% CO_2
- ➜Lithium: 23 mg/l

Geomechanical Properties

- Three Extended Leak of Tests (XLOTs)
  - Ieper Mbr
  - Vlieland Claystone Fm
  - Main Claystone Fm
- One conventional Leak of Test and one FIT
- 1D-geomechanical model built based on:
  - Vertical stress from density log
  - Elastic properties X-dipole sonic log
  - Pore pressure from
- Good match with XLOTs in North Sea and Vlieland Claystone
- High minimum horizontal stress magnitude and low permeability (from MICP data) of Main Claystone suggests it's a good geothermal caprock
- Main Claystone higher XLOT-derived minimum horizontal stress than "predicted" by model which might be explained by tectonic stresses?



6. Take Home Messages

Take home messages

- ➜Successfully drilled first well of the SCAN project: no LTI's or major safety incidents
- ➜All data acquisition carried out as planned
- ➜Large amount of data gathered to reduce uncertainties in the geothermal potential and "consequences of geothermal heat harvesting"
- ➜Amstelland well proved the presence of 112 m of Slochteren sandstone reservoir with good porosity and permeability
- ➜At the well location, reservoir temperature is approximately 82°C
- ➜Productivity/ injectivity lower than could be expected based on logs and core; investigation ongoing (geology/formation damage/excessive skin)

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Ministerie van Economische Zaken en Klimaat

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