Workshop on the Results of the first SCAN Well Amstelland-01

Utrecht, 04-03-2025

Ministerie van Klimaat en Groene Groei

Introduction

- Agenda
- Introduction to SCAN

Agenda

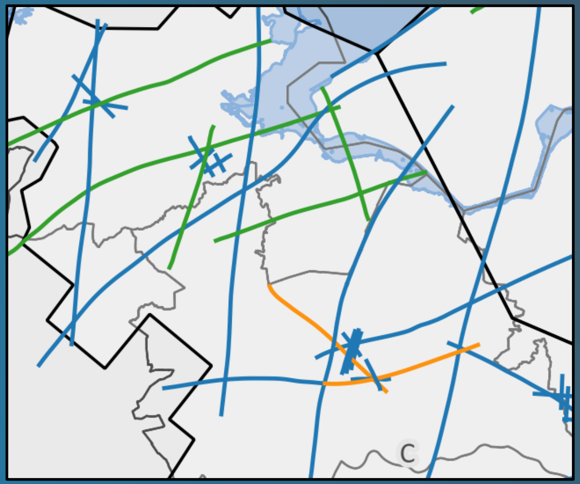
Introduction
Update on SCAN Well Campaign
Why Amstelland?
Amstelland-01 operational summary
Data Acquisition related to operational constraints (geomechanics)
Sedimentology: how was the reservoir deposited?
What happened to the reservoir after deposition?
How does the reservoir perform?
Temperature and water composition
Wrap-up & 3D survey Amstelland area

The SCAN Program: de-risking the Subsurface

Objective: gather data and knowledge of the subsurface in areas with data-scarcity in order to accelerate the development of geothermal heat in The Netherlands

SCAN 1&2

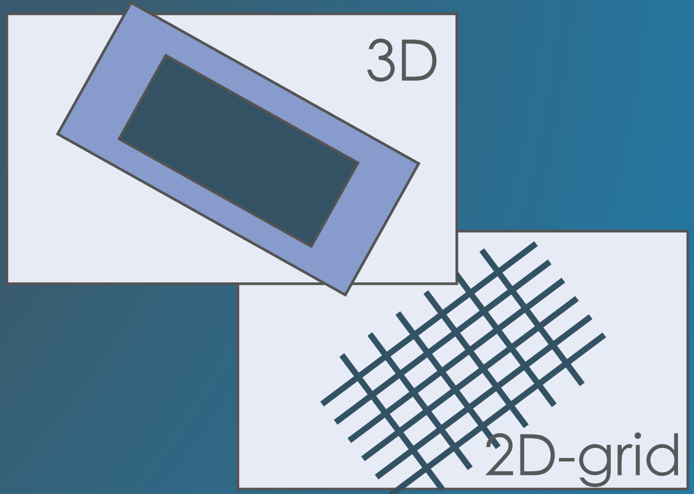
SCAN Regional 2D seismic surveys



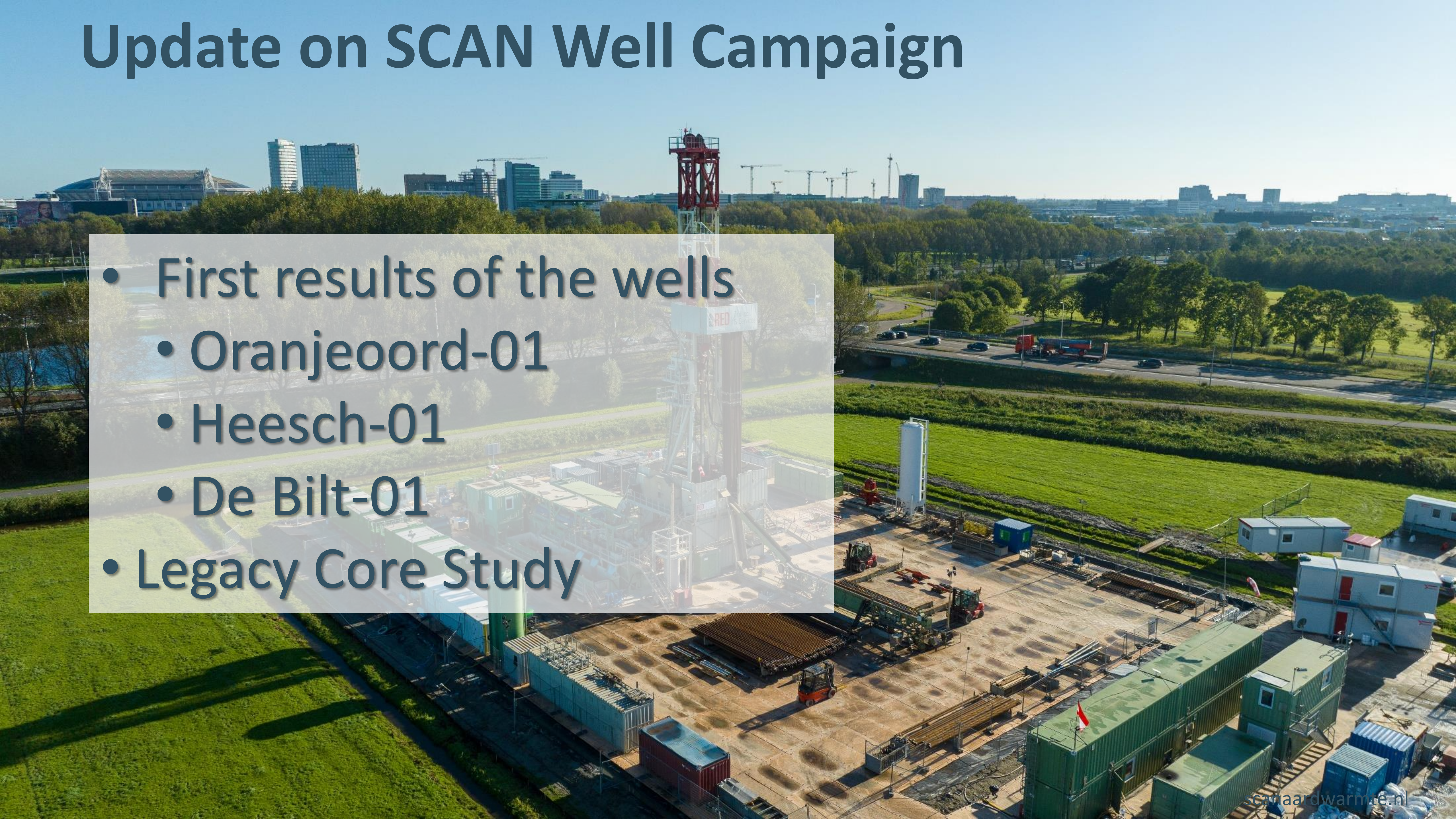
SCAN 3

SCAN Research & Exploration Drilling Campaign

SCAN detailed seismic surveys



Update on SCAN Well Campaign



- First results of the wells
  - Oranjeoord-01
  - Heesch-01
  - De Bilt-01
- Legacy Core Study

SCAN Drilling Operations

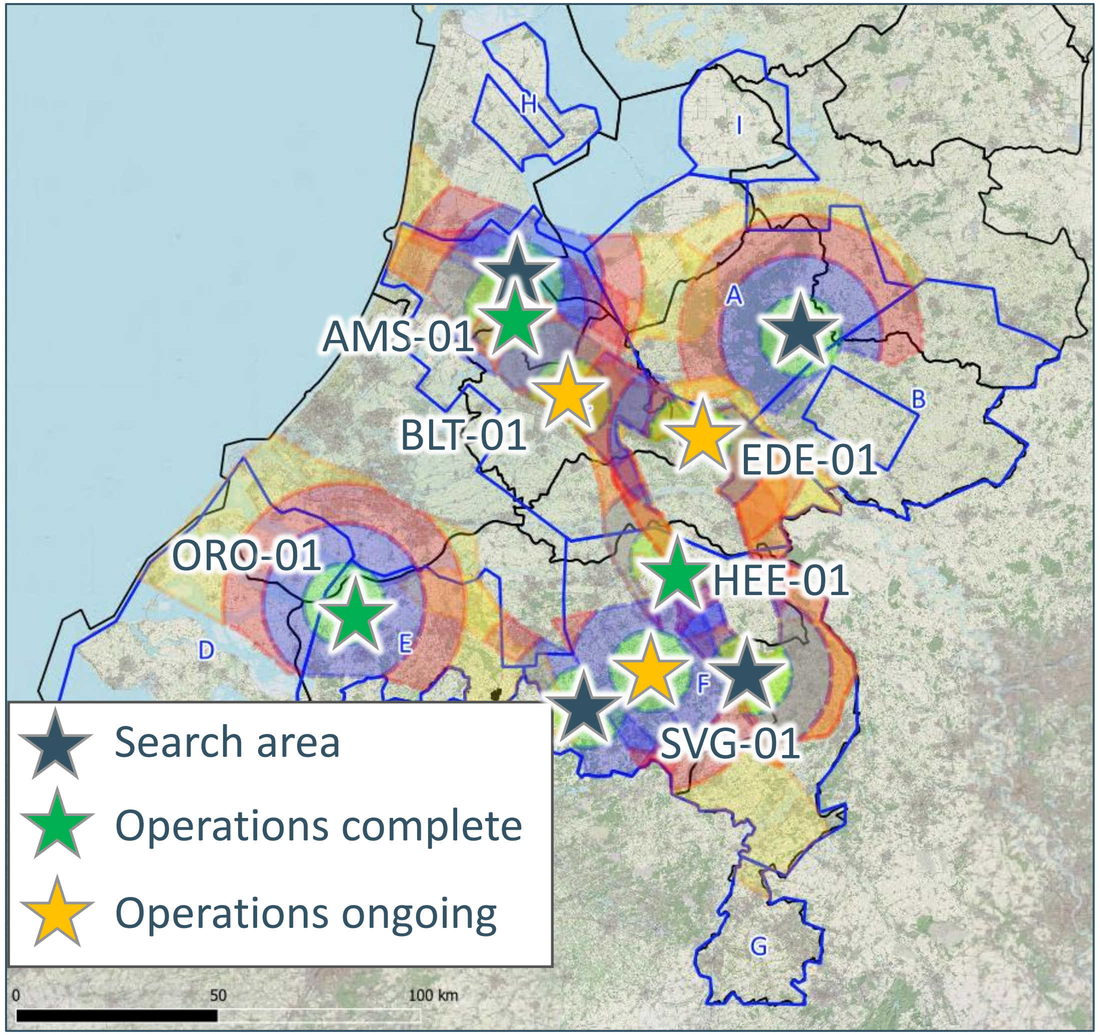
➔Operations for wells Amstelland, Oranjeoord& Heesch completed

➔Drilling Operations for De Bilt well complete, well test starts next week

➔Ede well currently being drilled

➔Conductor for SVG-01 (near Eindhoven) installed, start directly after Ede

Combined extent of play segments for SCAN search areas

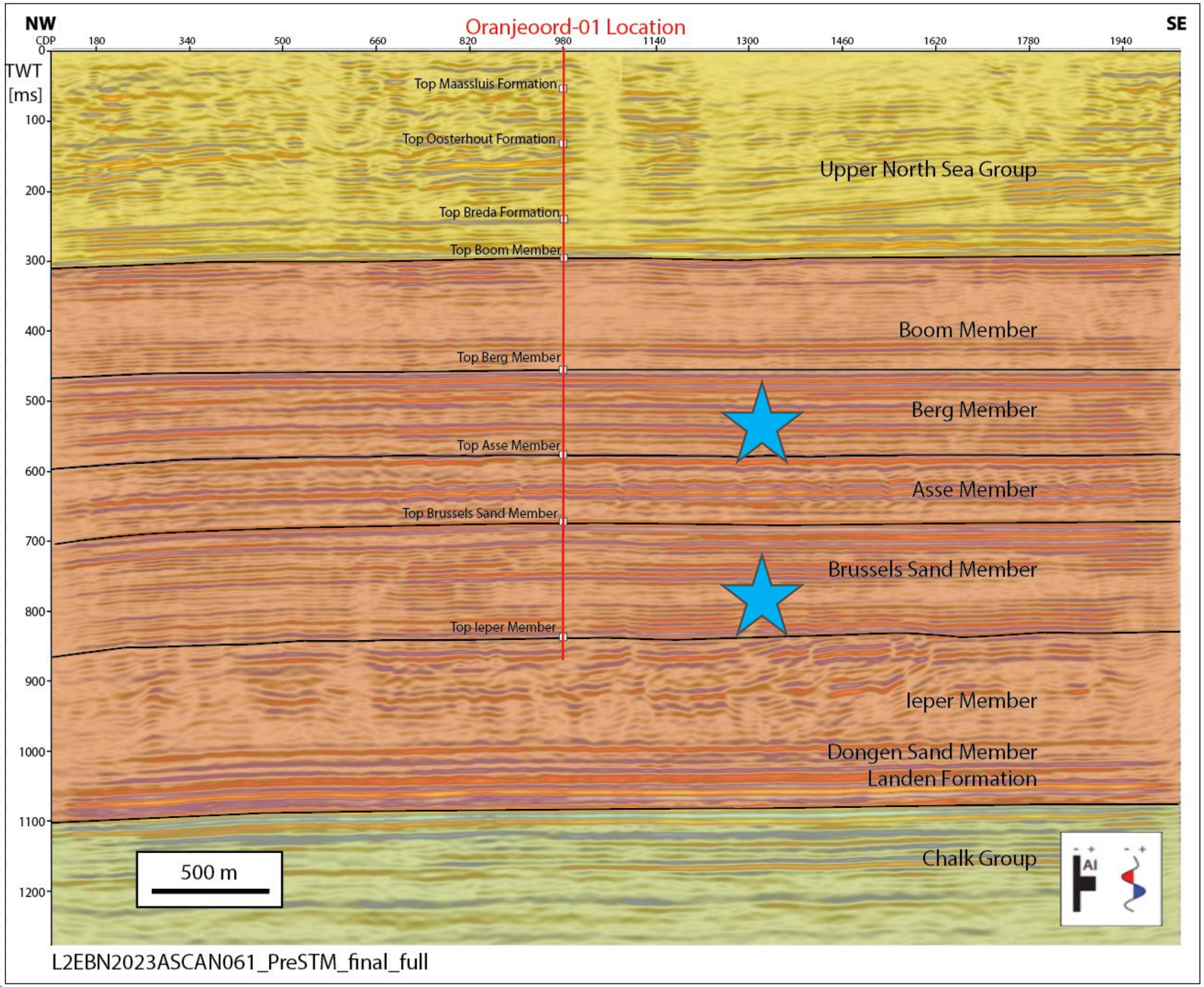


Note: currently, no well is expected near Apeldoorn

SCAN Well Oranjeoord-01 (ORO-01)

- ➜Second SCAN data-acquisition well
- ➜Location: Heijningen, Moerdijk
- ➜Total depth: 844 mMD
- ➜Geothermal targets:
  - ➜**Primary: Eocene Brussels Sand Member**
  - ➜Secondary: Oligocene Berg Member
  - ➜Each target includes the caprock above

Oranjeoord-01 well location

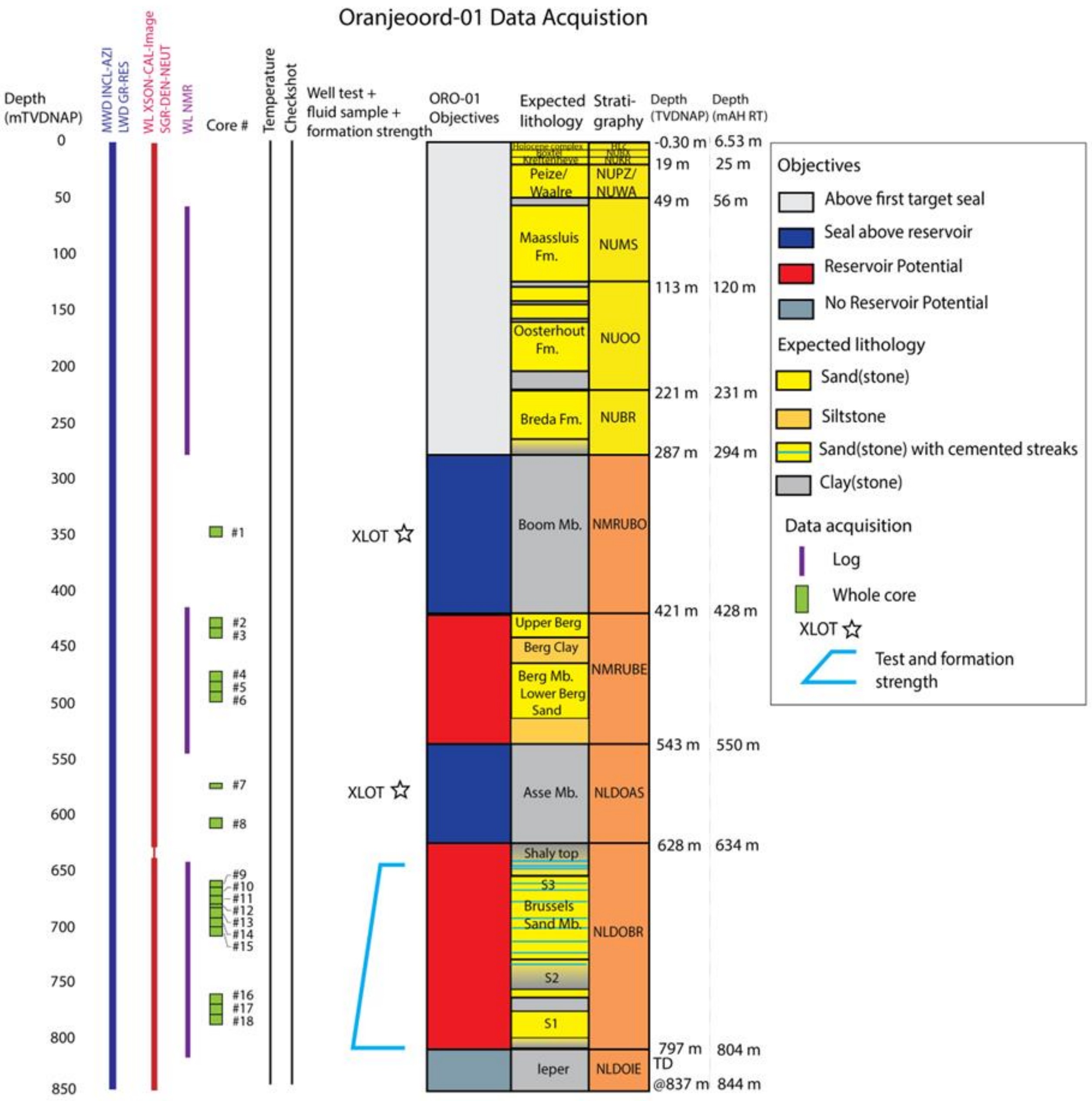


SCAN Well Oranjeoord-01 (ORO-01)

- All planned data-acquisition performed successfully:
  - All logging performed according to plan with good results.
  - 18 cores, total 133,8 m cored, recovered 122,9 m
  - Production-& injection test with 1000m^3 formation water
  - 2 Extended Leak-off Tests (XLOT) for in-situ stress conditions successfully concluded.
  - Checkshot survey performed
- Operations (including decommissioning) concluded on 20 May. Rig off location on 25 May.
- First data publicly available on NLOG.nl

ORO-01: Key results

- ➜Primary target Brussels Sand Member
  - ➜159 mAH thickness
  - ➜Average log porosity ~35%
  - ➜Core plug measurements
    - ➜ 300 – 3000 mD Gas permeabilities
    - ➜ 65 – 1140 mD Stressed Brine permeabilities
  - ➜Well Test:
    Transmissivity (K*H) ~ 22 Dm
  - ➜Formation temperature ~ 31°C
- ➜Secondary target Berg Member:
  - ➜119 mAH thickness
  - ➜Average log porosity ~33%
  - ➜Core plug measurements
    - ➜ 170– 1750 mD Gas permeabilities
    - ➜ 5 – 210 mD Stressed Brine permeabilities
- ➜<u>Numbers are preliminary and subject to change</u>



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SCAN Well Heesch-01 (HEE-01)

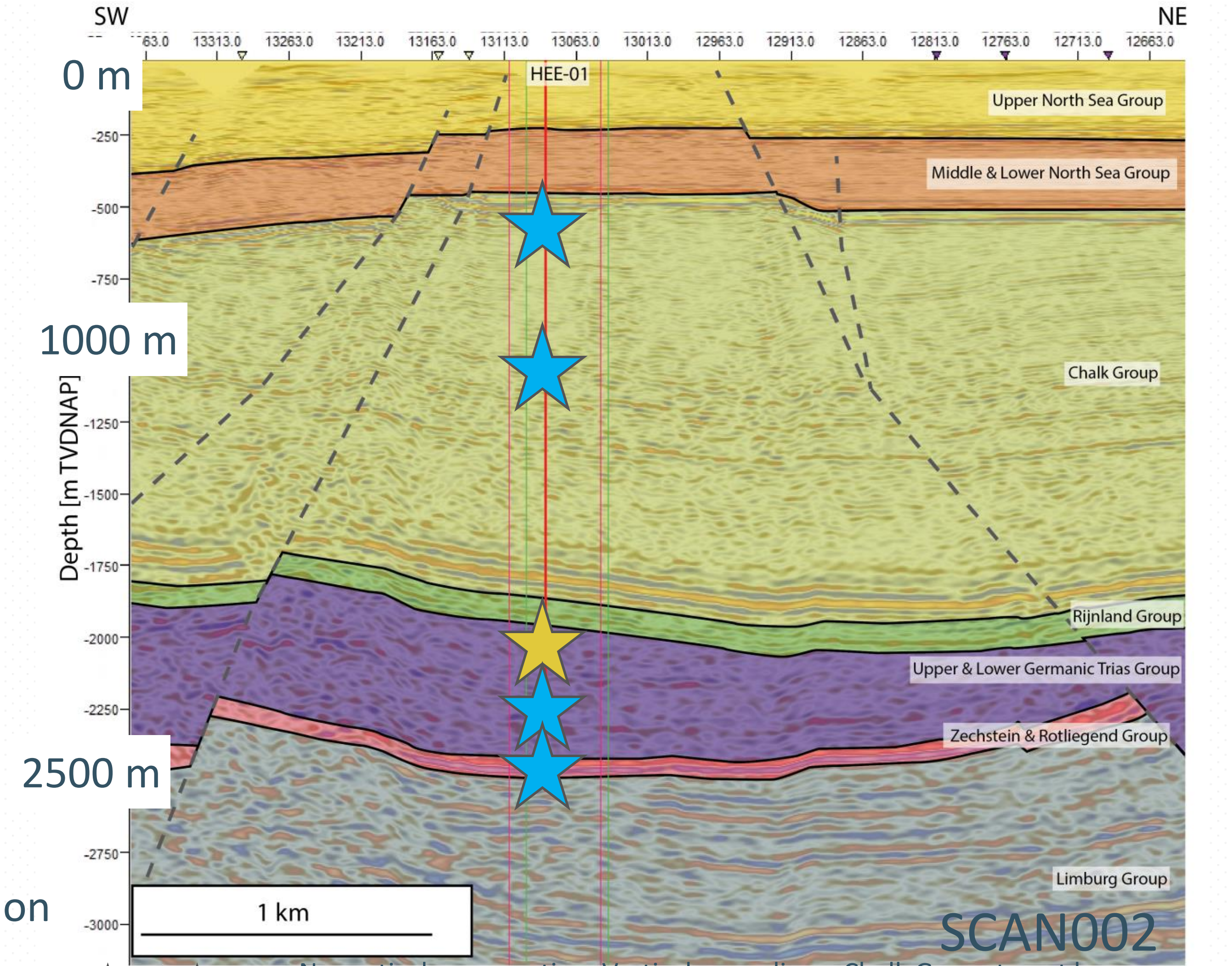
➔Third SCAN data-acquisition well

➔Location: Heesch, Gem. Bernheze

➔Total depth: 2525 mMD

➔Geothermal targets:

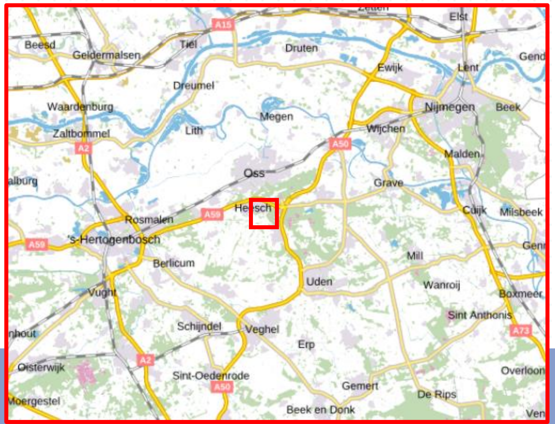
- ➔**Primary: Main Buntsandstein Subg. (RBM)**
- ➔Secondary: Chalk Group
  - ➔Maastricht & Gulpen Fm. (CKMA, CKGP)
  - ➔Vaals & Aken Fm. (CKVA, CKAK)
- ➔Secondary : Nederweert Sandstone Fm. (RBSN)
- ➔Secondary: Slochteren Formation (ROSL)
- ➔Each target includes the caprock above



No vertical exaggeration. Vertical green lines: Chalk Group target box

Primary / secondary target

Vertical pink lines: Triassic & Rotliegend tar



Heesch-01 location

HEE-01: Key results (preliminary)

➔Primary target Main Buntsandstein Subgroup

- ➔100 mAH Gross thickness, (64 m net)
- ➔Average porosity ~15% (total% net-reservoir)
- ➔Mid-reservoir temperature ~79°C

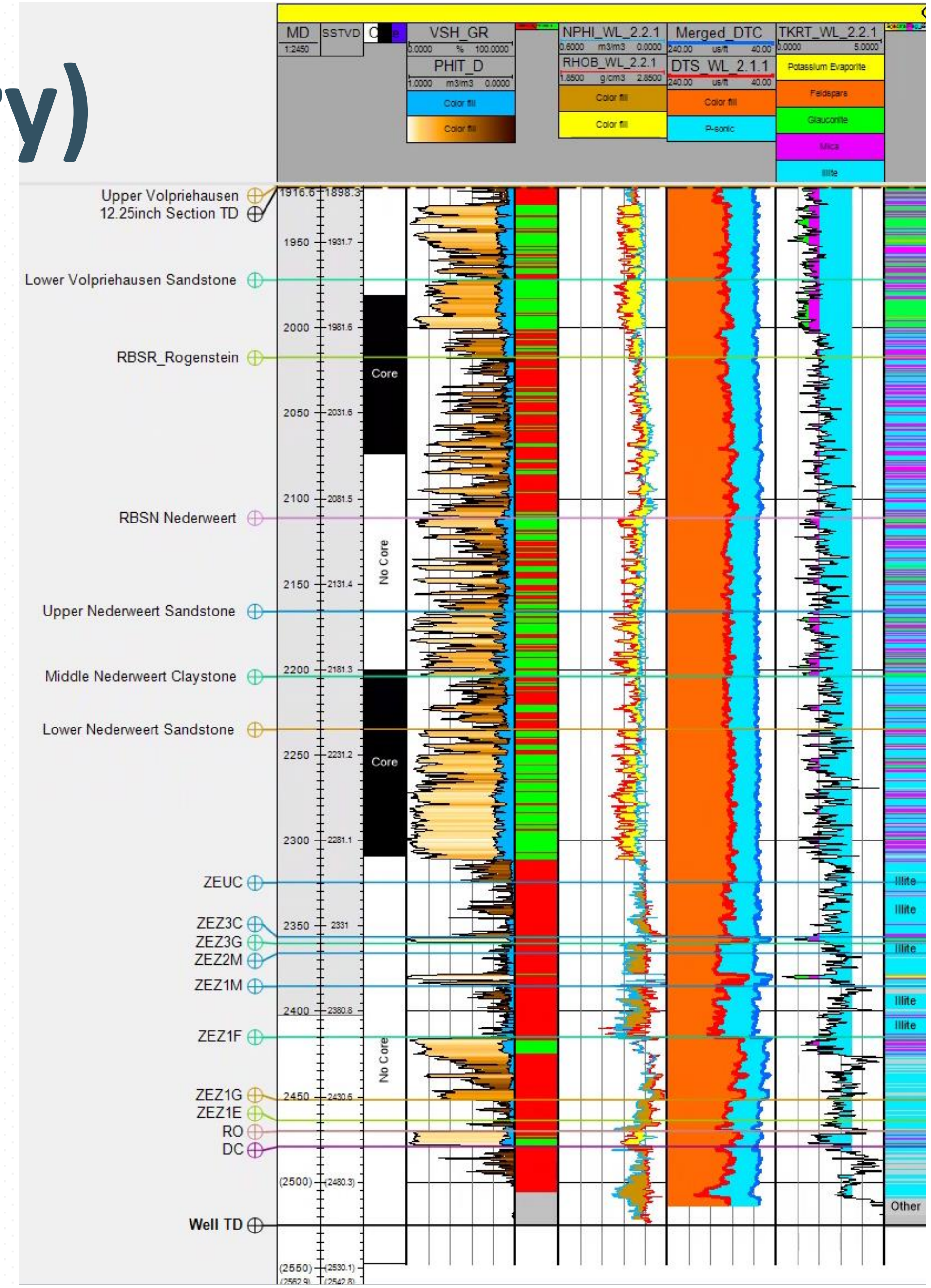
➔Secondary target Nederweert Sst. Fm.

- ➔213 mAH Gross, (123m net)
- ➔Average porosity ~16% (total% net-reservoir)
- ➔Mid-reservoir temperature ~ 87°C

Other Secondary targets:

- ➔No karst/fracturing in upper part Chalk Group
- ➔Vaals & Aken equivalent non reservoir-lithology
- ➔Slochteren Formation 8m thickness *(<10m $P_{aquifer}$ failure)*

<u>Numbers are preliminary and subject to change</u>

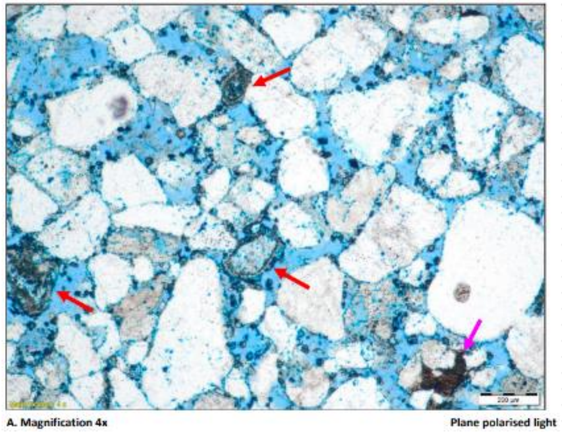


De Bilt-01 (BLT-01)

- ➔TD reached on 12 February at 2123 m MD in Limburg Group
- ➔Primary objective: Slochteren (130m)
- ➔Secondary objectives: Chalk Group (265m), Vlieland Sandstone, Main Buntsandstein (93m)
- ➔Extensive data acquisition, QC ongoing, first data published soon
- ➔Slochteren and Main Buntsandstein to be tested using coiled-tubing unit in March

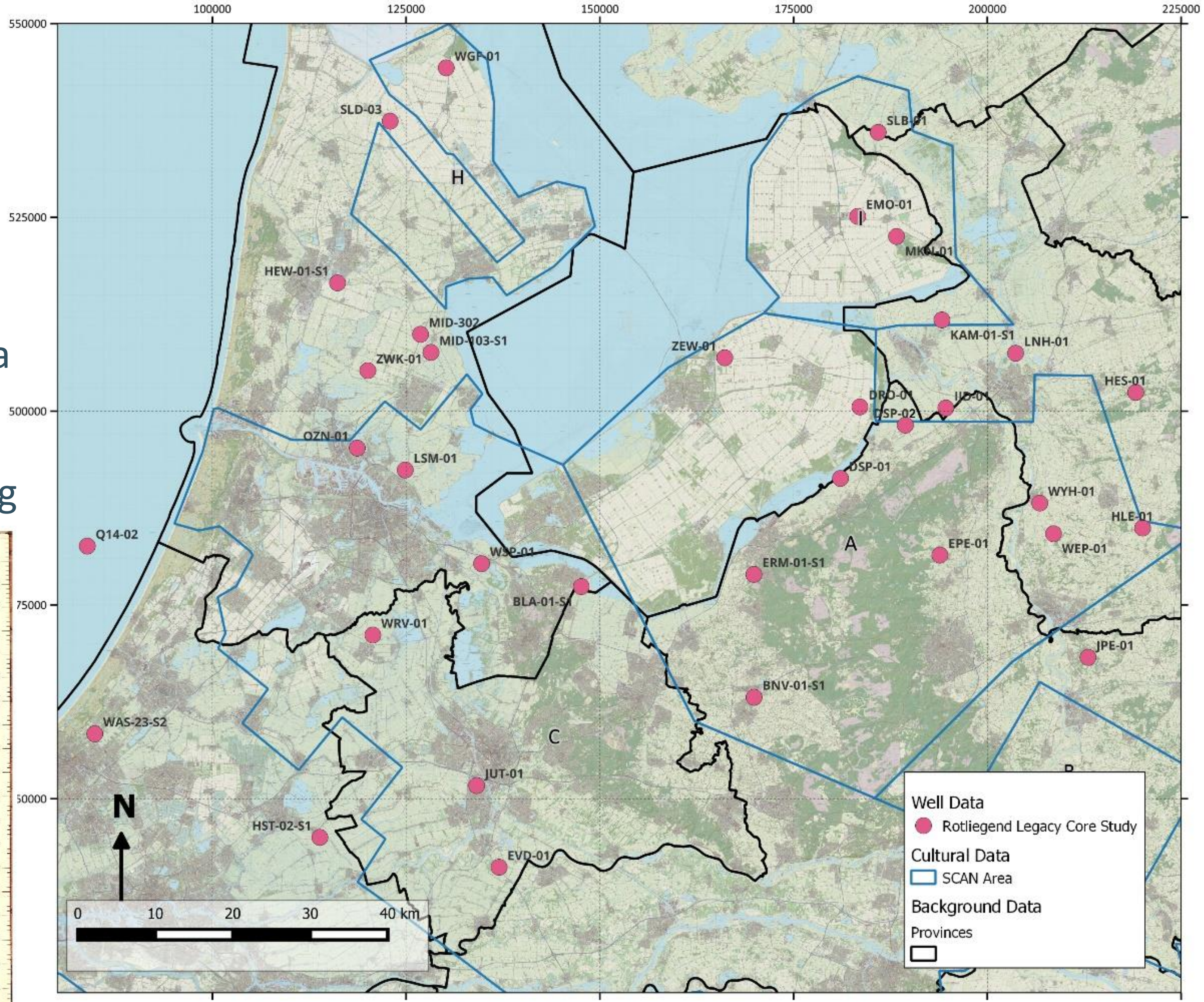
Legacy Core Study

- ➔Consistent description of legacy Rotliegend cores from central part of the Netherlands (drilled between 1950 -2012)
  - ➔34 wells with >900m core
- ➔New petrographic analysis
- ➔Integrated with existing Routine Core Analysis data
- ➔Executed by PanTerra Geoconsultants
- ➔All wells published on NLOG since 13 Feb, including summary report



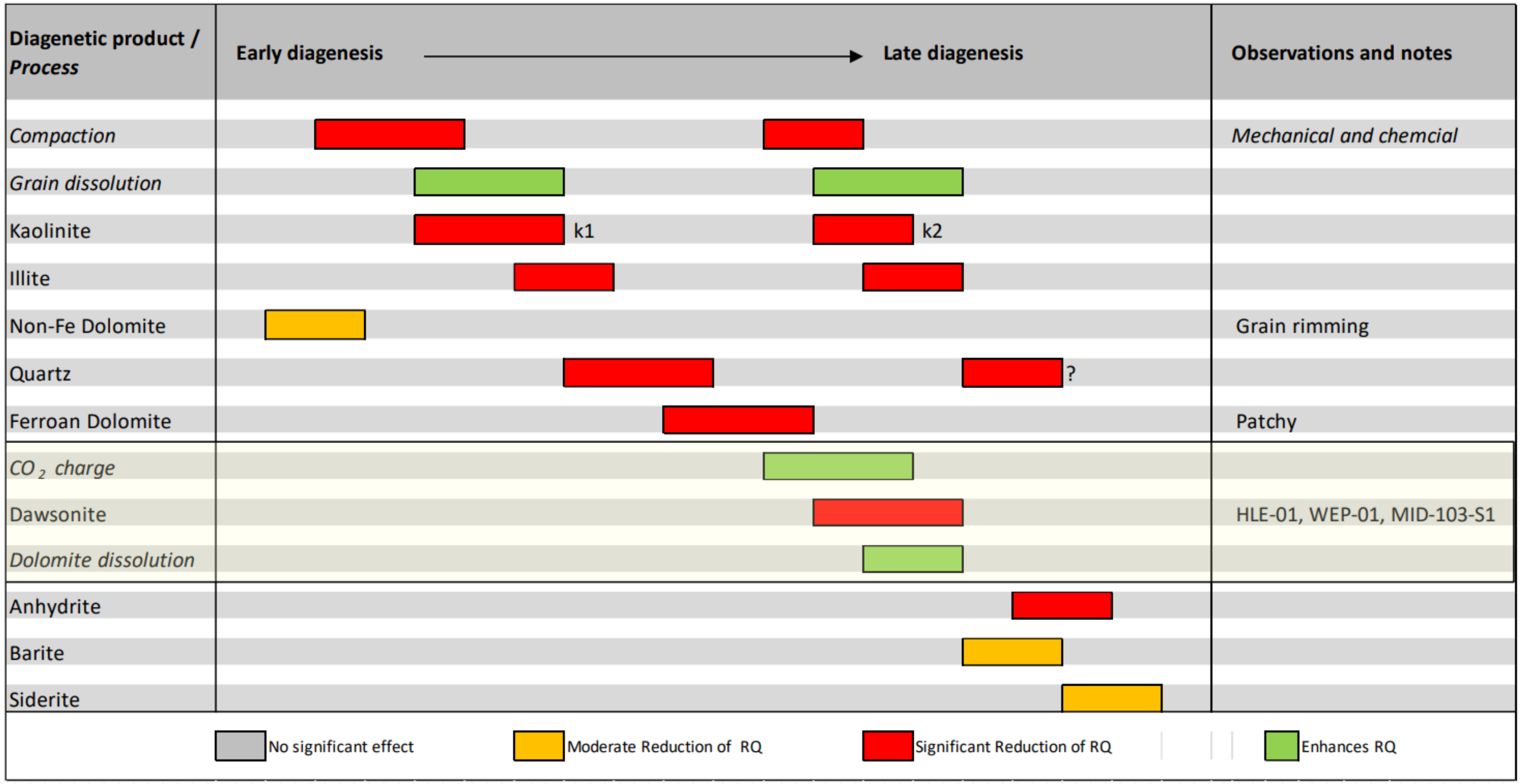
SLD-03


DSP-01 (Doornspijk)



Legacy core study (2)

- ➔Slochteren deposited predominantly in “dry” aeolian settings. Fluvial deposits are rare
- ➔Reservoir quality highly variable
- ➔Control of facies on reservoir quality limited
- ➔Compaction is the dominant porosity-reducing process
- ➔Diagenesis correlates well with structural element& burial history



Generalized paragenetic sequence. Not all phases/processes have occurred in each well

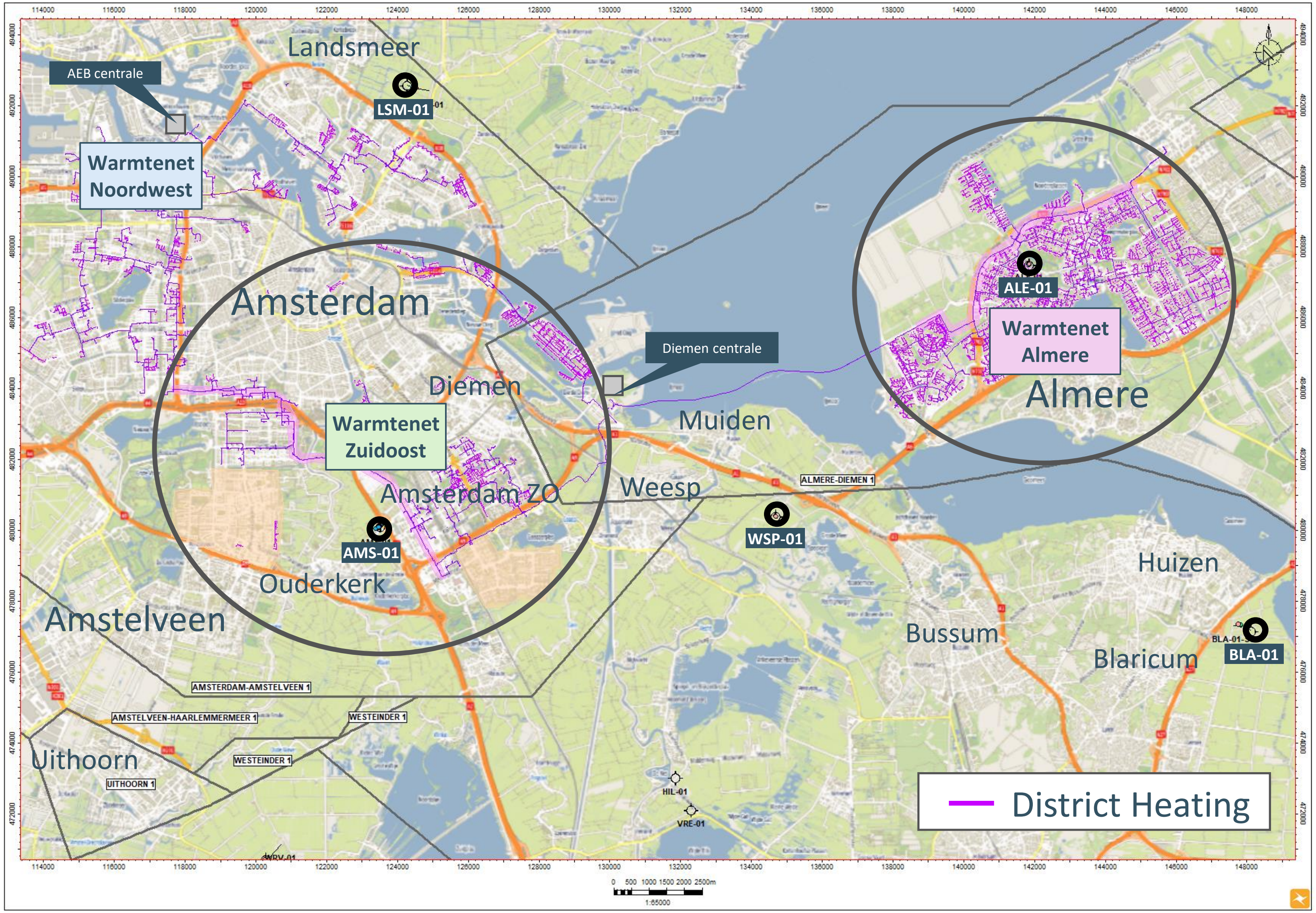
Why Amstelland?

Why drill a well here?

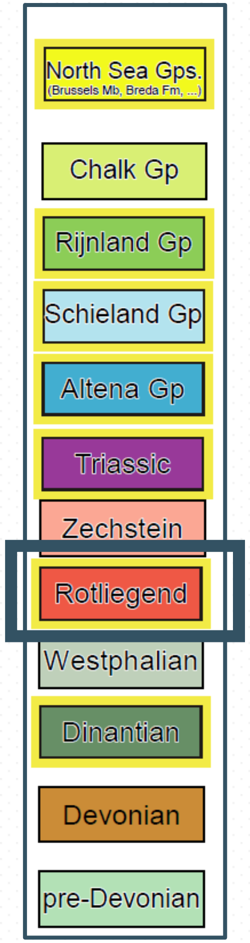
- Heat Demand
- Play analysis
- SCAN Regional Seismic
- Well Objectives

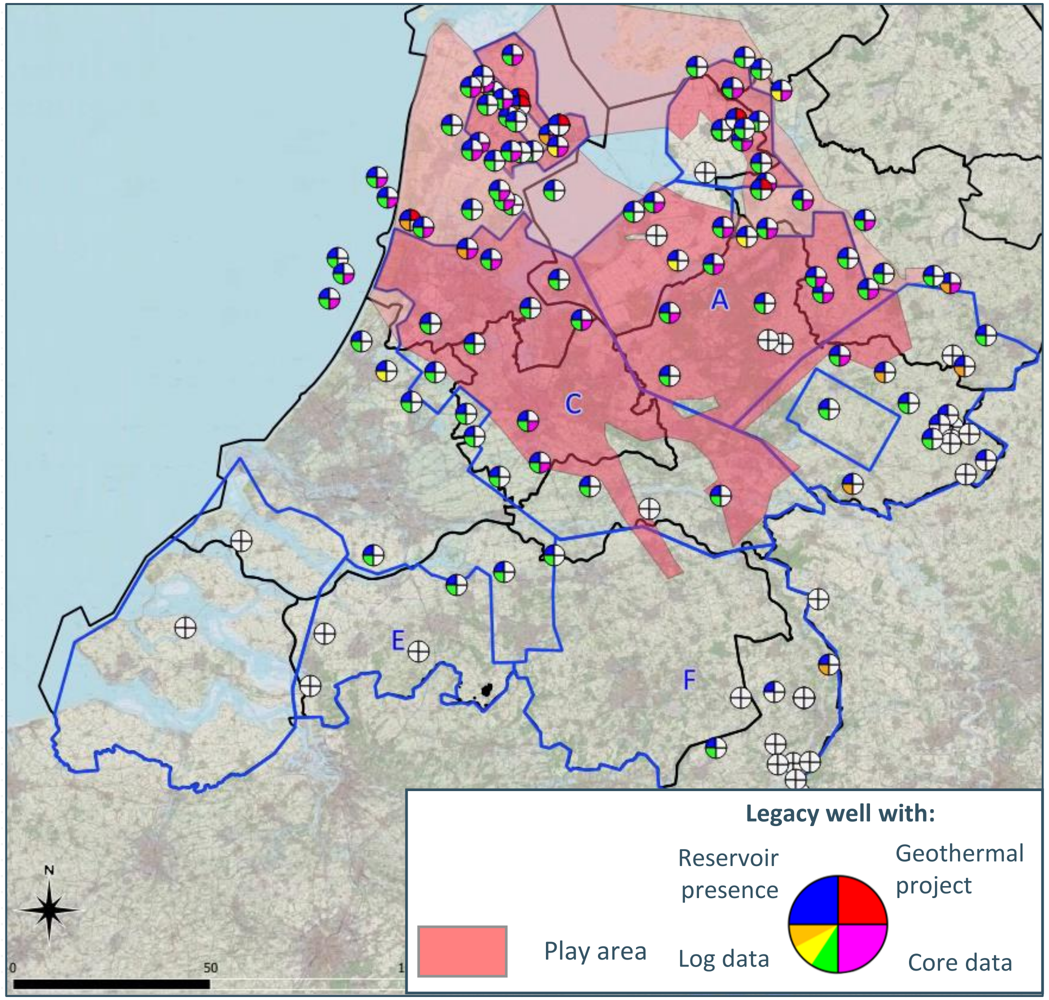
Heat Demand

- ➔Metropoolregio Amsterdam (MRA): large metropolitan area with major heat demand
- ➔Existing district heating networks, with substantial room for input of renewable energy



Play-Based Exploration for Geothermal



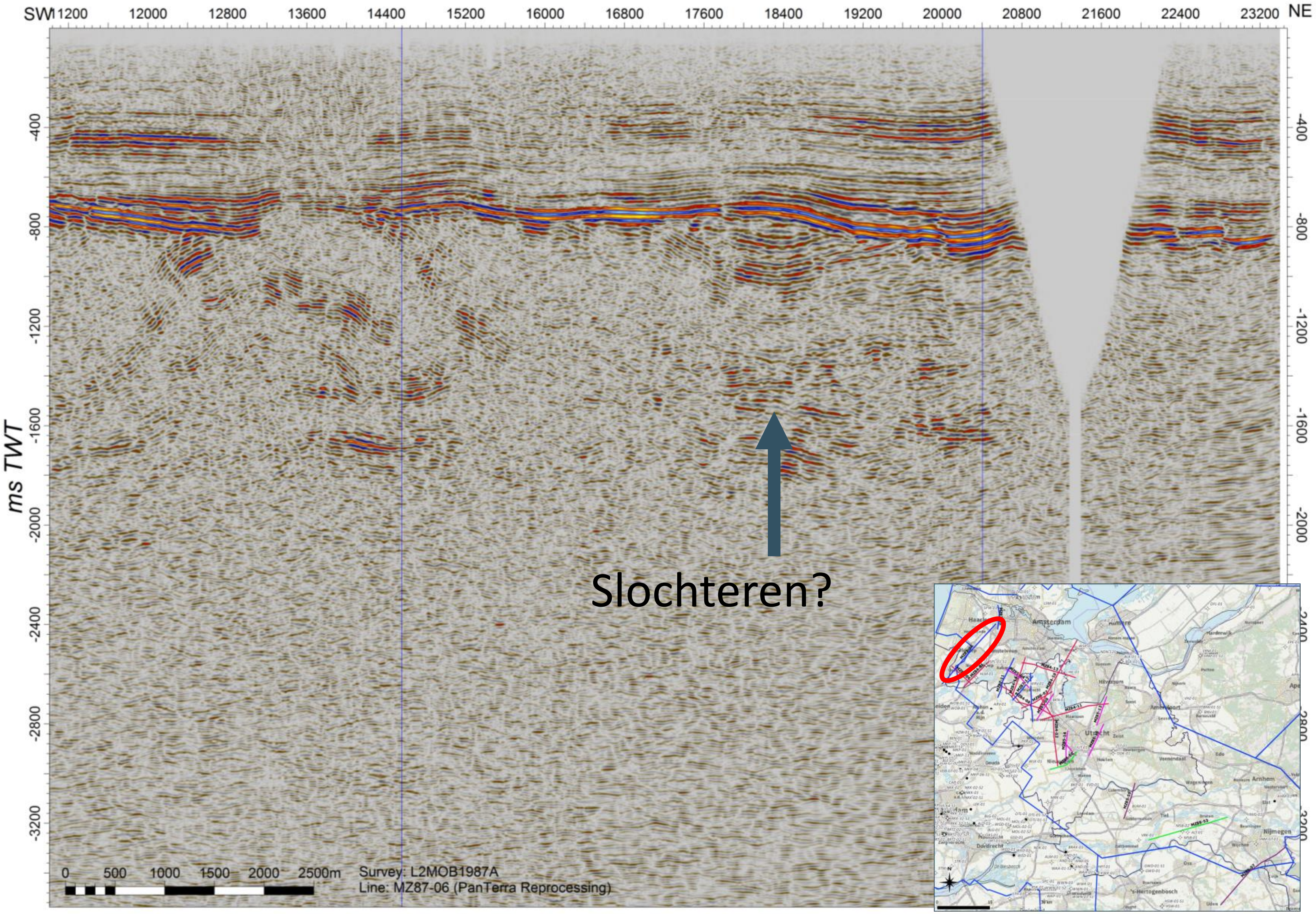


- ➔Play-Based Exploration forms the basis for SCAN
- ➔All plays were mapped and assessed based on existing data and regional knowledge
- ➔Conclusion for MRA region: Rotliegend Slochteren Fm primary target. Vlieland Sst is a secondary, more speculative target. Since we're here: log Chalk too.

Play Map of Rotliegend sandstone play , deposited in a predominantly aeolian setting

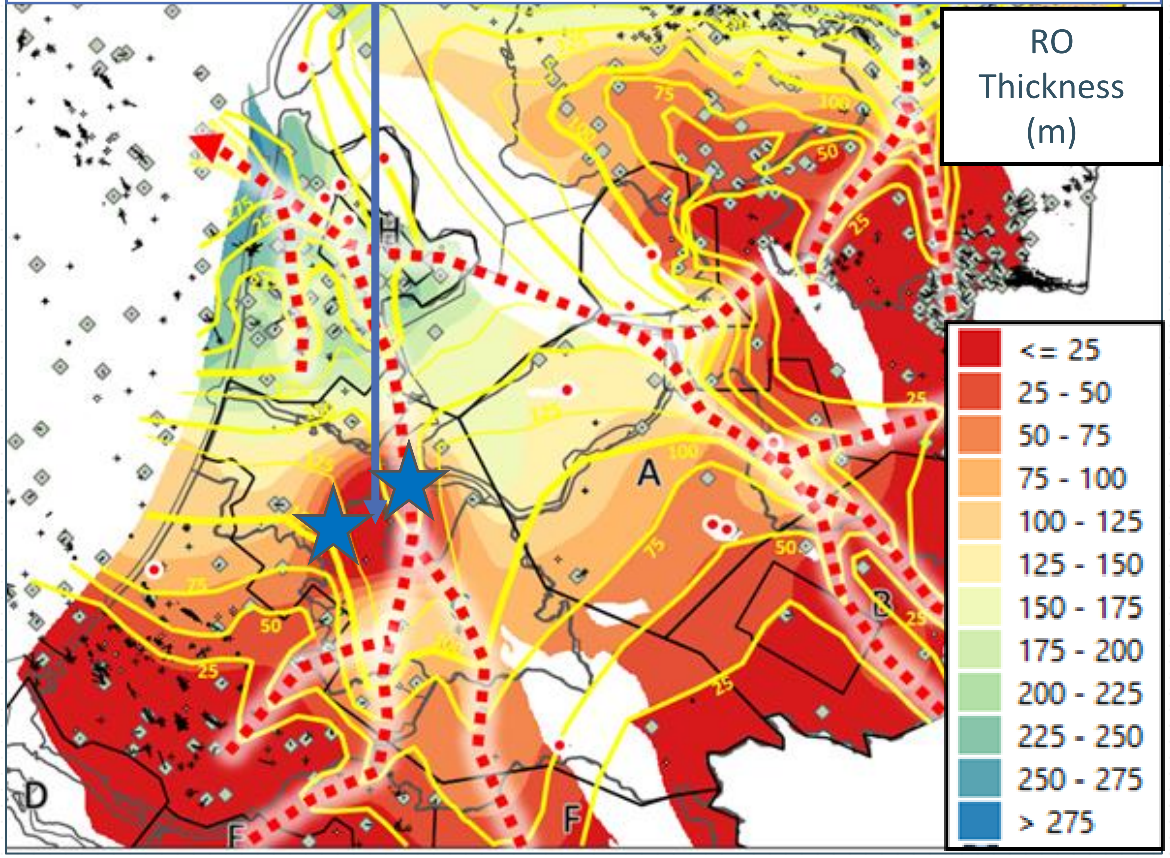
Example of seismic data quality in region prior to SCAN

- ➔Very poor continuity of reflections below Base North Sea Supergroup
- ➔Interpretation of Slochteren Fm on this data speculative at best



Thickness of the Slochteren reservoir

Old model: less than 25 m of Rotliegend



Yellow isopachs: SCAN thickness model
Colours in background: thickness in DGM-Diep v4

- ➔Thickness of the Slochteren Fm in MRA region was uncertain prior to SCAN: according to some models hardly any Rotliegend was present
- ➔These models were based on two vintage wells drilled in the 1970s
- ➔Our hypothesis: wells are anomalous. Actual Rotliegend thickness > 100 m.
- ➔Insufficient seismic data was present at the well locations, new seismic lines planned that tie these vintage wells
- ➔New Seismic Lines Acquired 2020/2021

MRA, Situation prior to SCAN Seismic Campaign

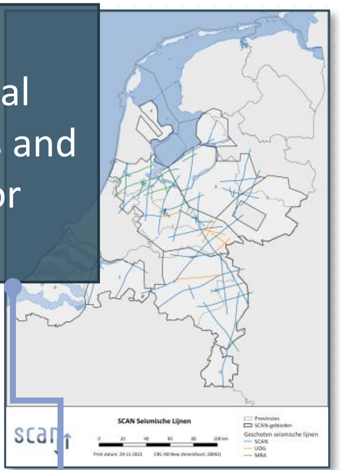
	Pessimistic Case Pre-SCAN	SCAN Hypothesis
Deposition	Study area was a high; Slochteren Formation very thin or absent	No high; thicknesses expected intermediate between areas north and south of the study area
Reservoir Quality	The small amounts of reservoir that are present may well be tight because of deep burial. Current moderate depths result from inversion; big burial anomaly	No big burial anomaly. Aeolian Slochteren Fm expected with possibly good reservoir quality
Seismic Imaging	This is a very challenging area to shoot seismic: urban area with thick peat-rich Holocene deposits. As a result, existing seismic data is of poor quality…	…we think we can do better!

SCAN project phases and activities

Project Proposal

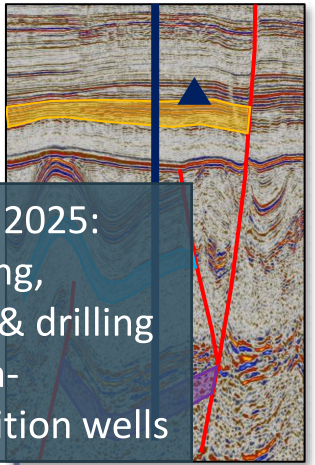
Seismic Funded

Seismic survey design complete. Long regional lines, connecting wells and infilling areas with poor seismic coverage.



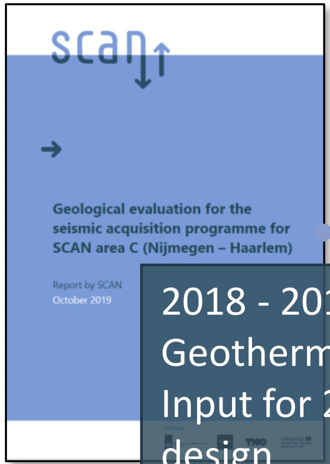
Wells Funded

2021 - 2025: Planning, design& drilling of data-acquisition wells



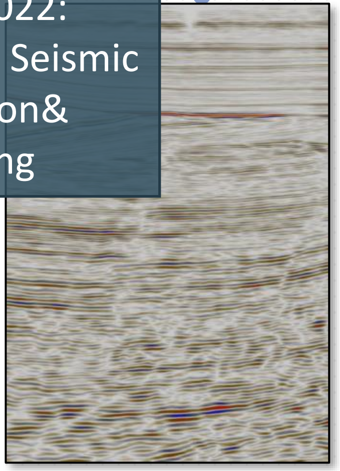
Additional 3D and 2D Seismic Acquisition Funded

2017 2018 2019 2020 2021 2022 2023 2024 2025 2026

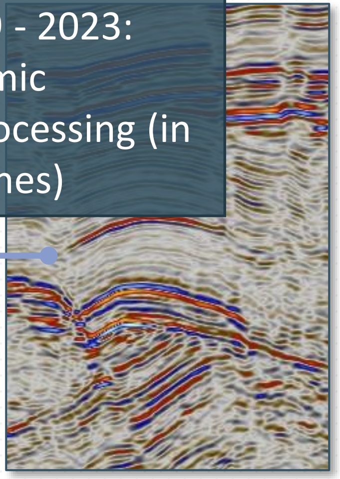


2018 - 2019: Geothermal play analysis. Input for 2D seismic survey design

2019 - 2022: Regional Seismic acquisition& processing



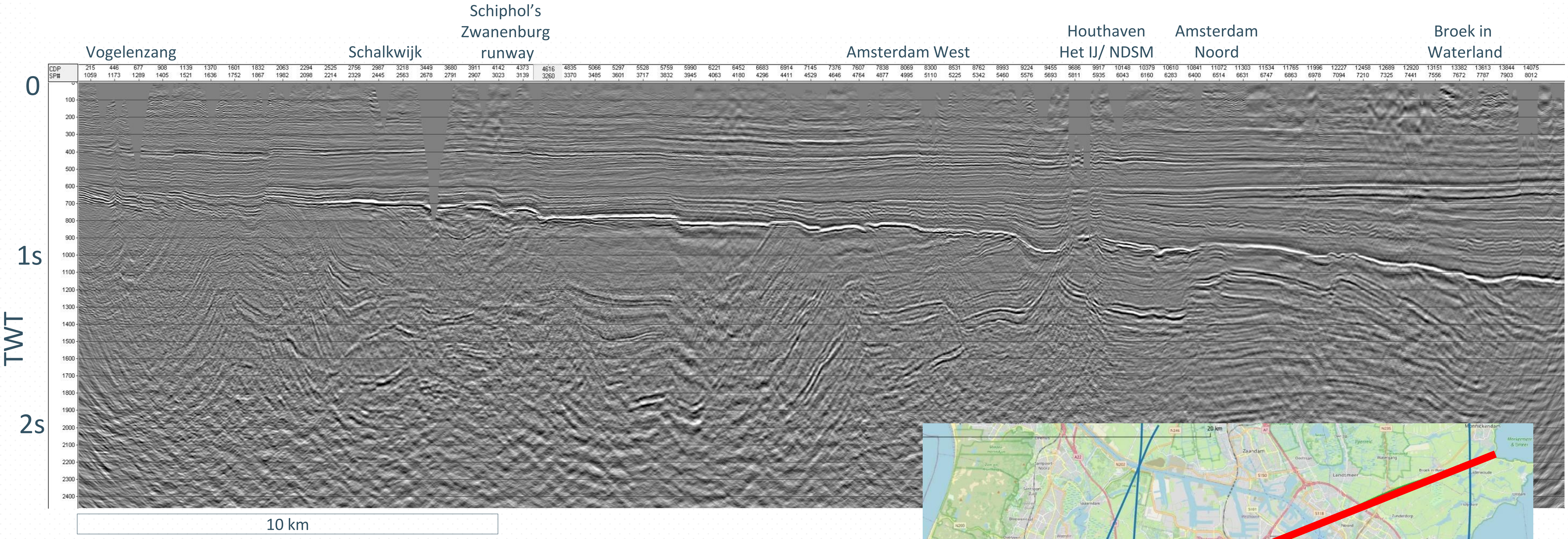
2019 - 2023: Seismic reprocessing (in batches)

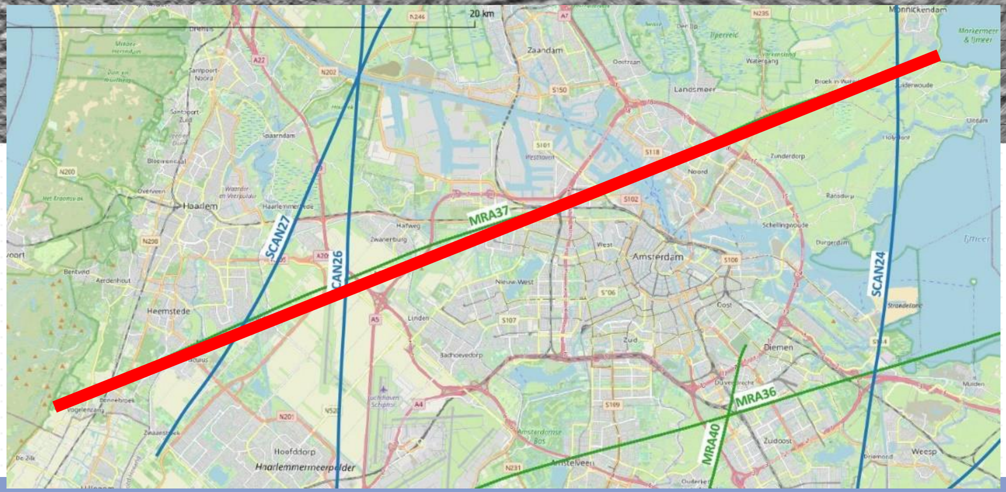


First well: Amstelland

Additional 3D and 2D Seismic Acquisition

SCAN 2D PreSTM processing – MRA037





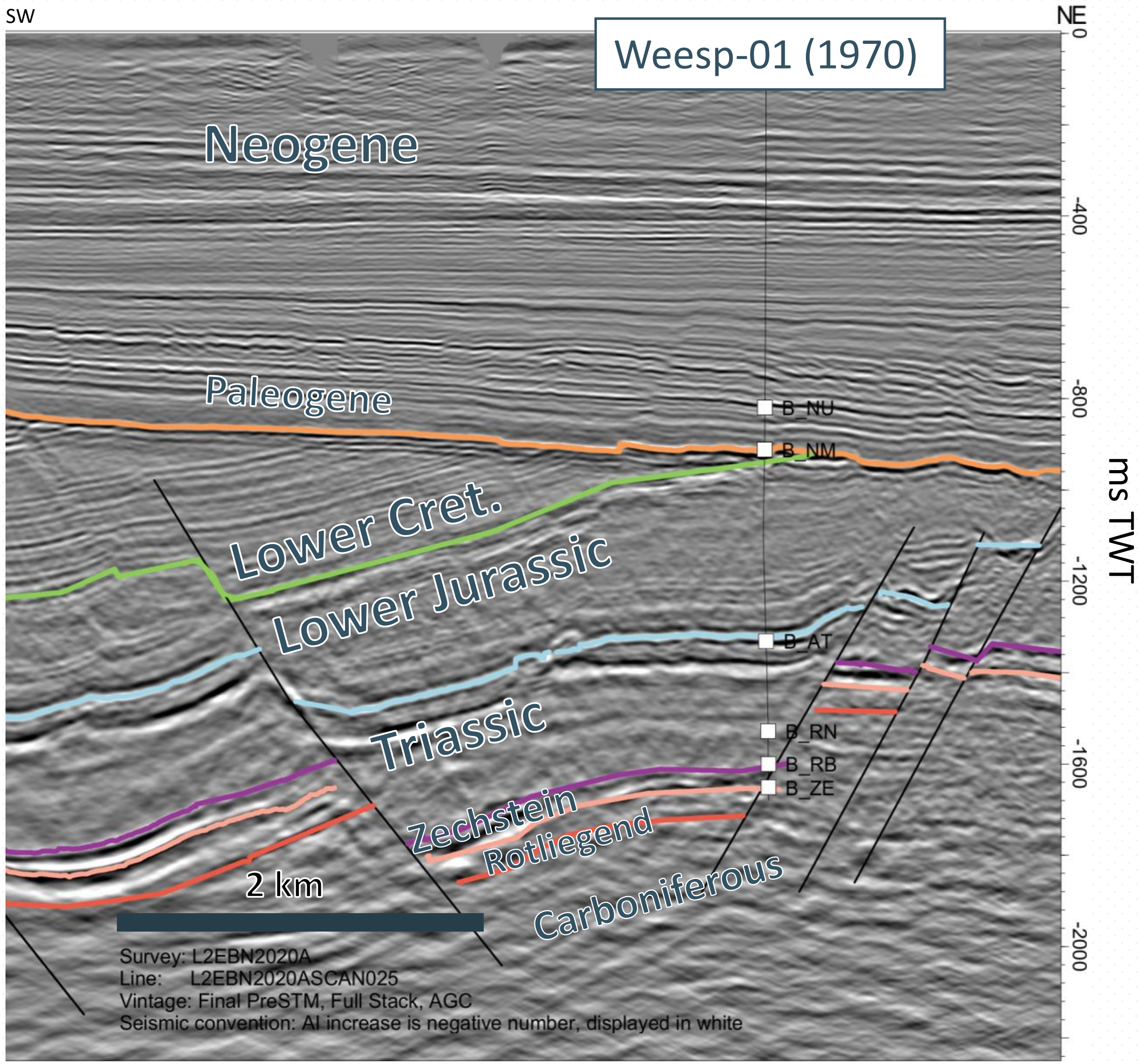
- With careful planning it was possible to acquire several 2D seismic lines through Amsterdam
- Excellent imaging below Base North Sea

Thickness Rotliegend Slochteren, after SCAN Seismic

➔New SCAN-seismic data shows that the Weesp well drilled the Rotliegend at a location where the reservoir is truncated by a fault. The well is therefore not representative for the region.

➔Reservoir thickness was now de-risked, which is good news for the geothermal potential of the region

➔Uncertainties on reservoir quality remained; a **new well** was needed to derisk this…

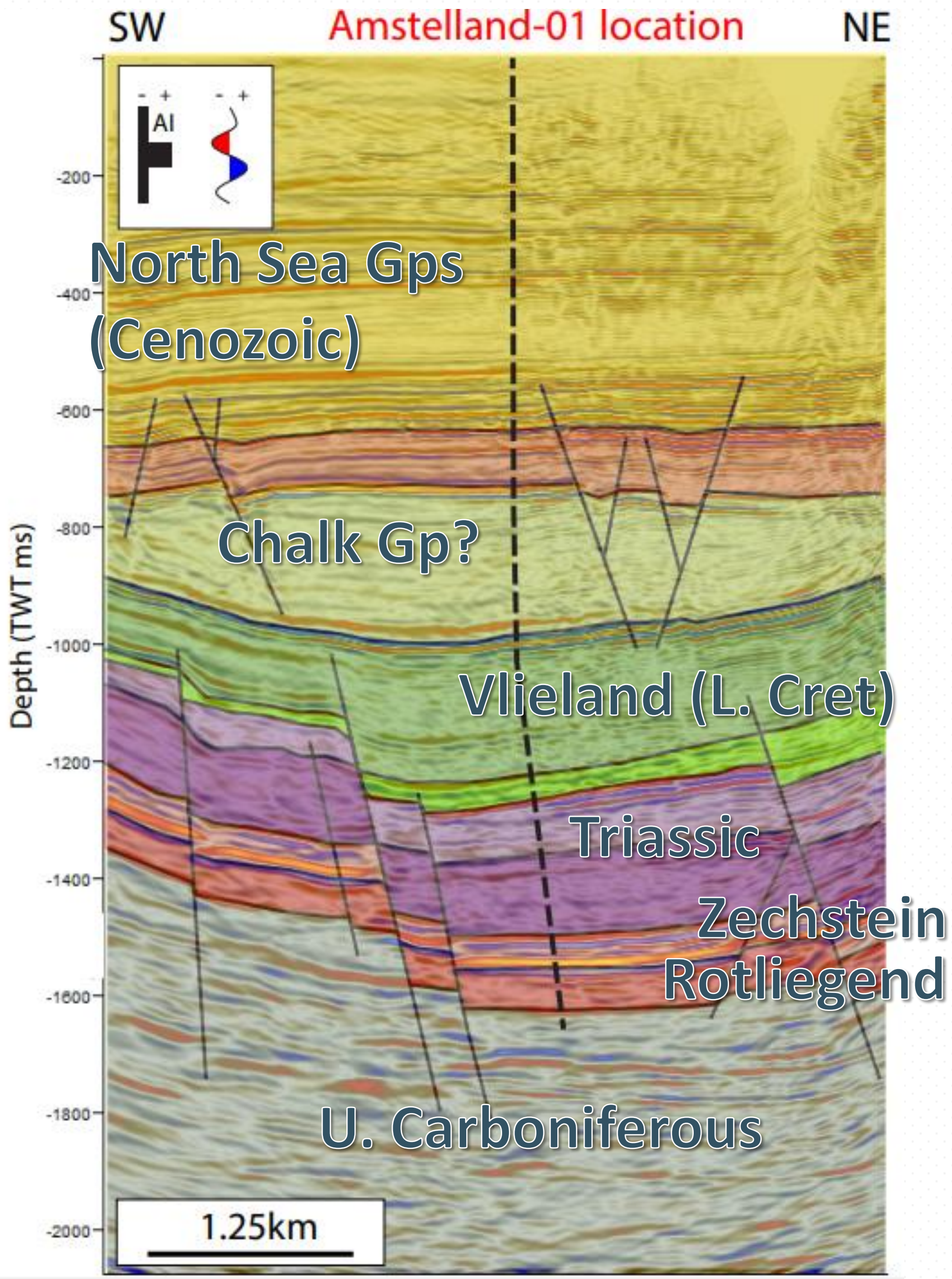


Objectives of the Amstelland well

- ➜Determine geothermal reservoir properties for three intervals:
  - ➜Primary: Permian Rotliegend sandstones
  - ➜Secondary: L. Cret. Vlieland Sandstone Fm
  - ➜Secondary: U. Cret. Chalk Gp (CK)
- ➜Determine geomechanical properties of the reservoirs, caprock and overburden
- ➜Determine formation fluid properties and temperature

Boring AMSTELLAND-01

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

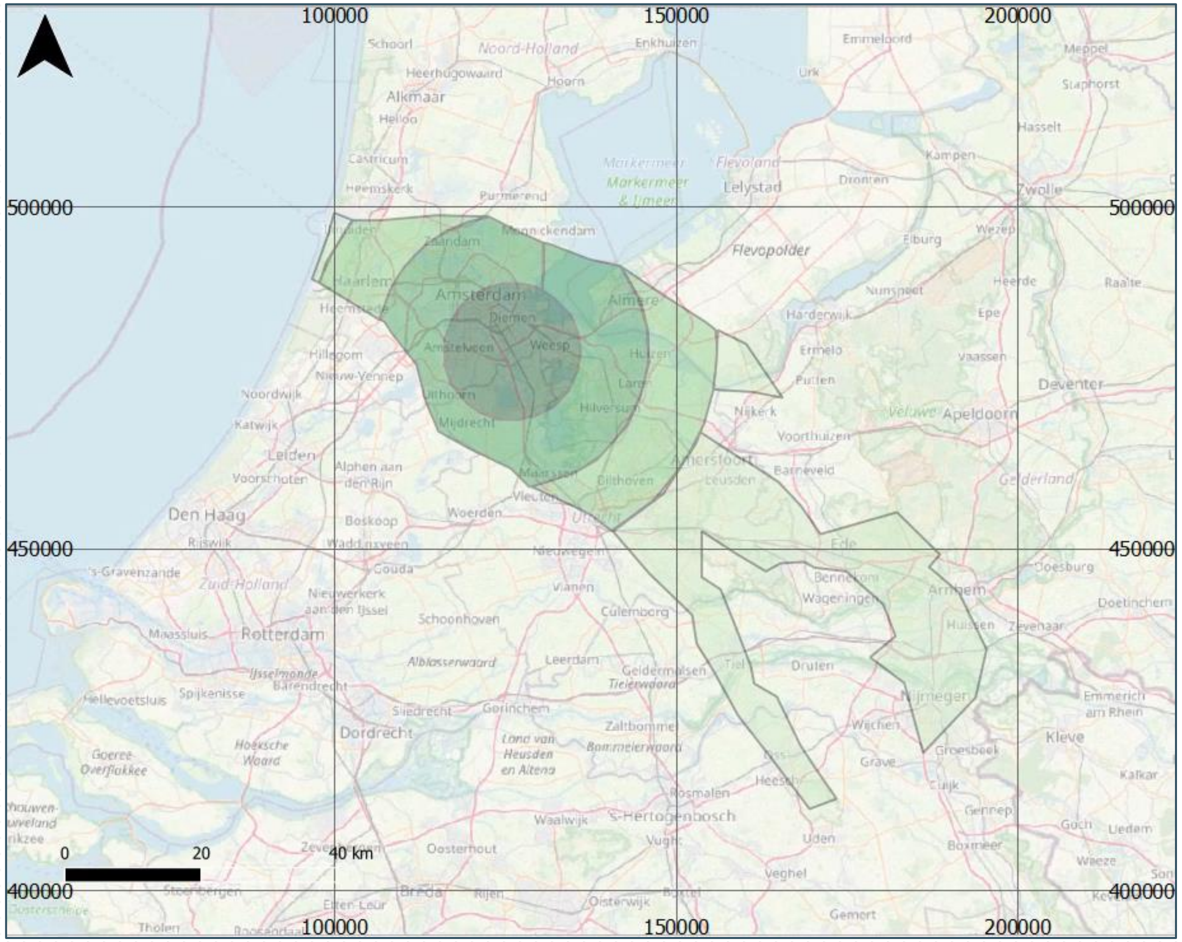


Pre-drill seismic interpretation

Area of influence

- ➔Amstelland search area and well location selected so that data collected is representative and relevant for a large area with high heat demand
- ➔Three geothermal “plays” of varying depth and temperature tested extensively

Play Segment map SCAN Amstelland well, Rotliegend target

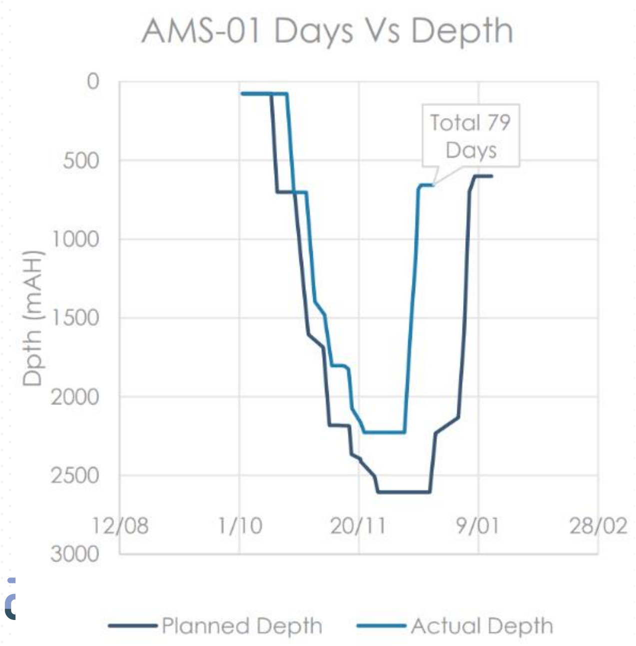


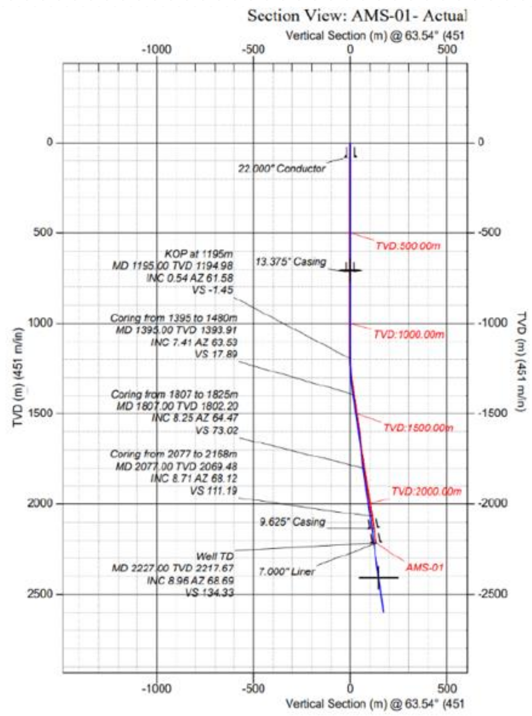
How was the well constructed?

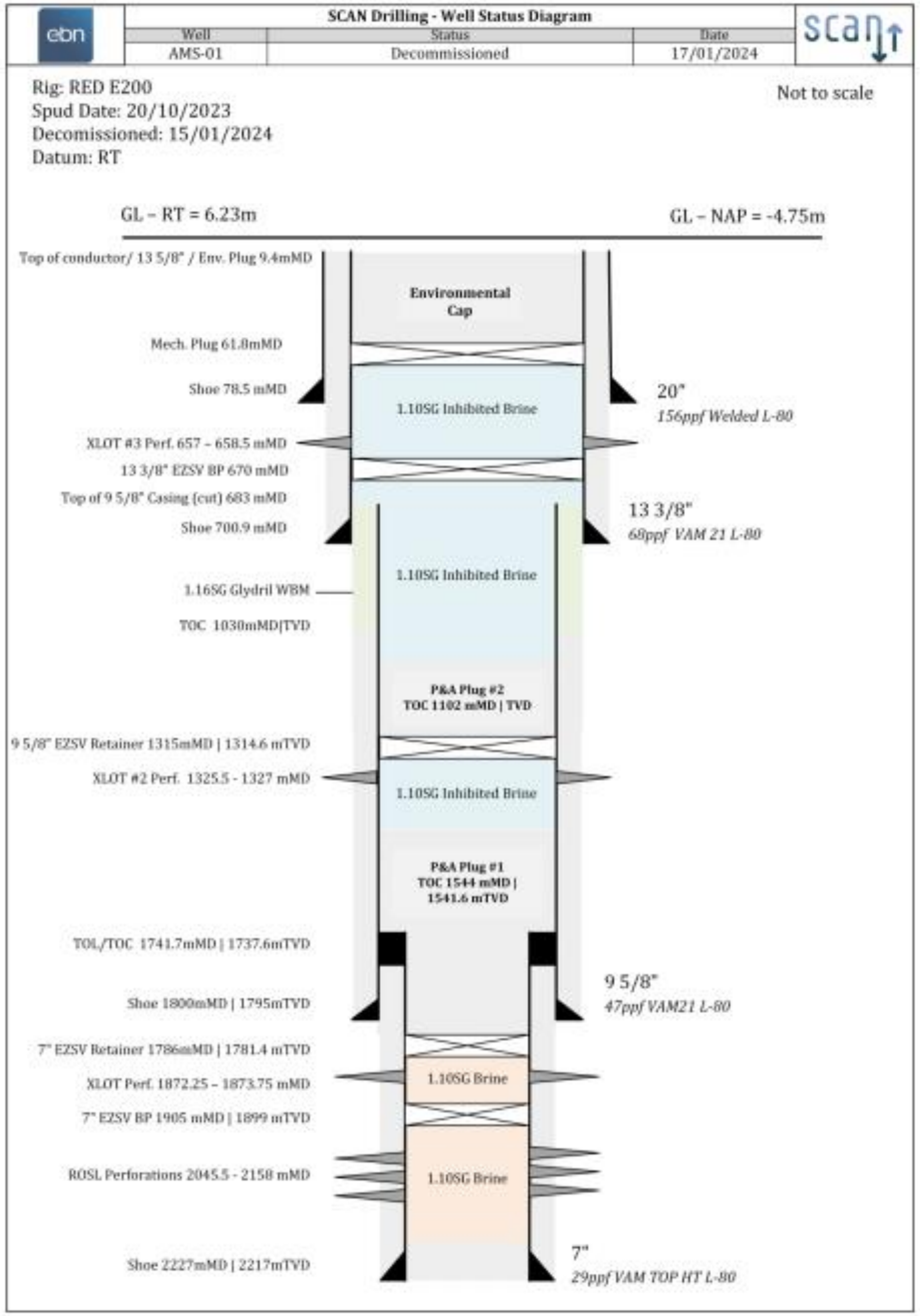
- Operations
- Data Analysis
- Key Results

Amstelland (AMS-01) Operations

- ➜ 79 days of operations (including mob/demob): less than 104 days planned
- ➜ No LTIs or major safety incidents
- ➜ TD 2227m MD in Carboniferous Limburg Group
- ➜ J-shaped trajectory, deviated towards northeast
- ➜ 8.96° from vertical at TD
- ➜ Extensive data acquisition performed throughout well, including over reservoirs, caprocks and overburden

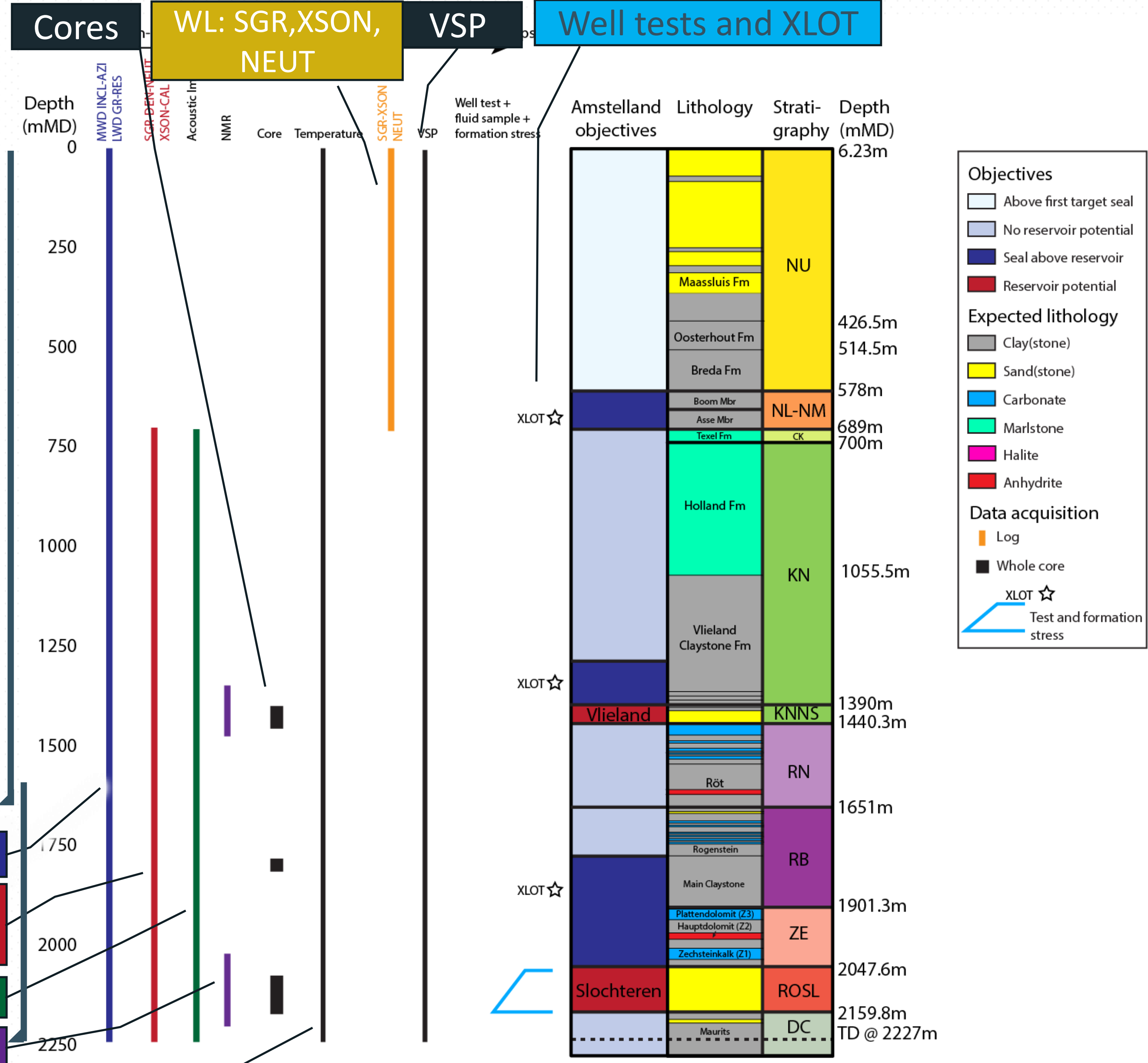






Data Acquired

- ➔Cuttings
- ➔LWD and (OH/CH) wireline log data
  - ➔(S)GR,RES,XSON,DEN,NEUT,IMAGE,NMR
  - ➔Temperature
- ➔VSP (geophone and fibre-optic)
- ➔Production/Injection test
  - ➔PLT
  - ➔Fluid samples
- ➔Core (193m)
  - ➔Screening analysis (CoreDNA)
  - ➔RCA, SCAL, core description
  - ➔Geomechanical tests
- ➔XLOT (3x)



Key Results

➔Primary target Slochteren Fm:

- ➔111 m true vertical thickness
- ➔High porosity and matrix permeability measured on cores in dominant eolian sandstones
- ➔Produced and injected 1000m^3
- ➔Formation temperature approx. 82°C

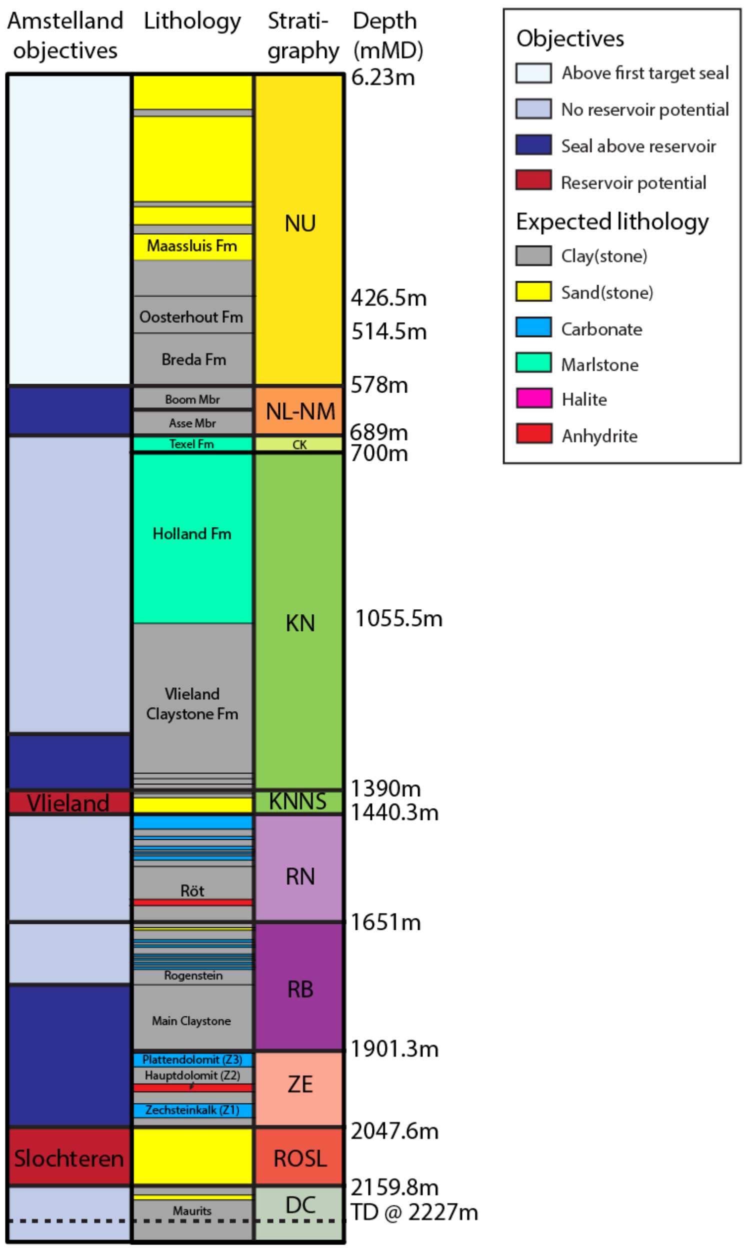
➔Secondary target Vlieland Sandstone Fm:

- ➔50 mAH encountered, insufficient porosity and permeability; no reservoir potential; not flow-tested

➔Secondary target Chalk Gp:

- ➔Only 11mAH Texel Marlstone present at the well location

Post-drill

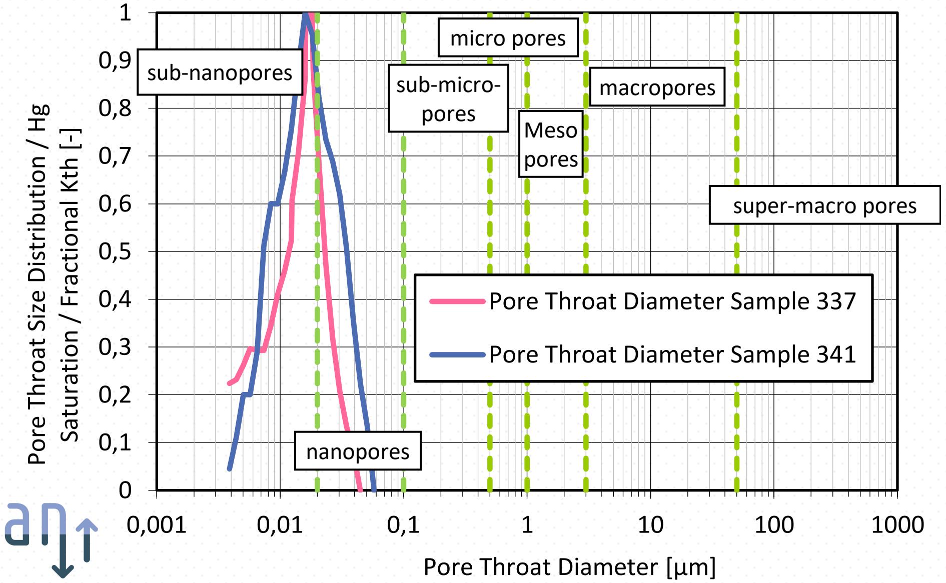


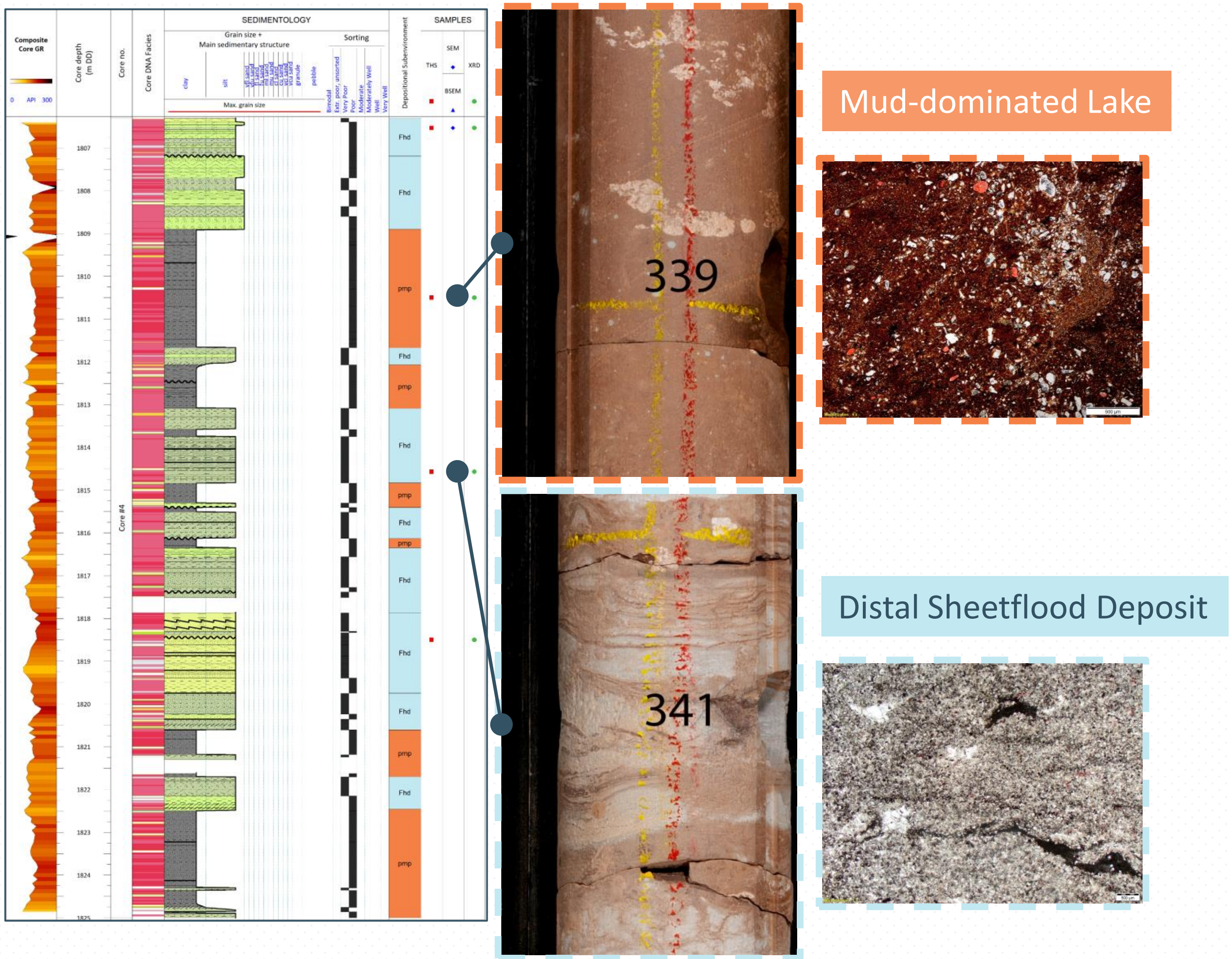
What geomechanical data did we acquire?

- Main Claystone Caprock Characterization
- Extended Leak-Off Tests (XLOTs)
- Additional Geomechanical Parameters

Main Claystone caprock

- ➔125m thick section overlying Zechstein Group and Slochteren reservoir
- ➔Alternating fine-grained silty claystones and siltstones
- ➔Small pore-throat diameters and low permeability => good capillary caprock
- ➔Collected various geomechanical data and XLOT to determine mechanical caprock characteristics





Core laboratory testing

➔Measurements on core of reservoirs and Main Claystone caprock

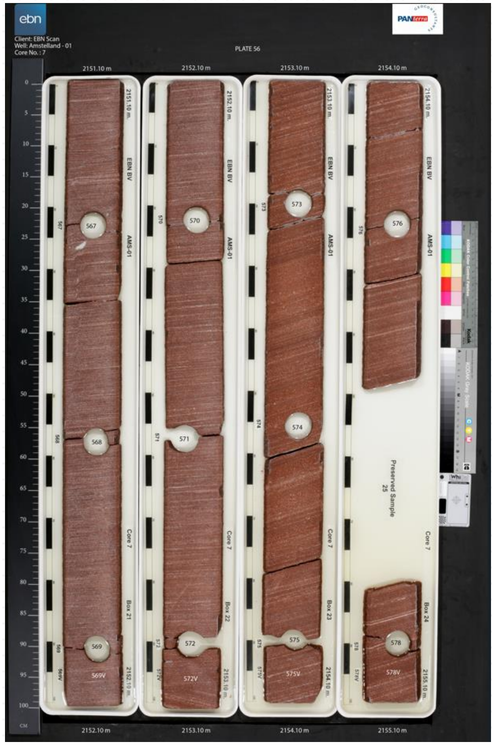
➔Scratch test to determine continuous record of the Unconfined Compressional Strength (UCS)

➔Strain-controlled tri-axial tests to determine elastic parameters, strength and post-failure slip

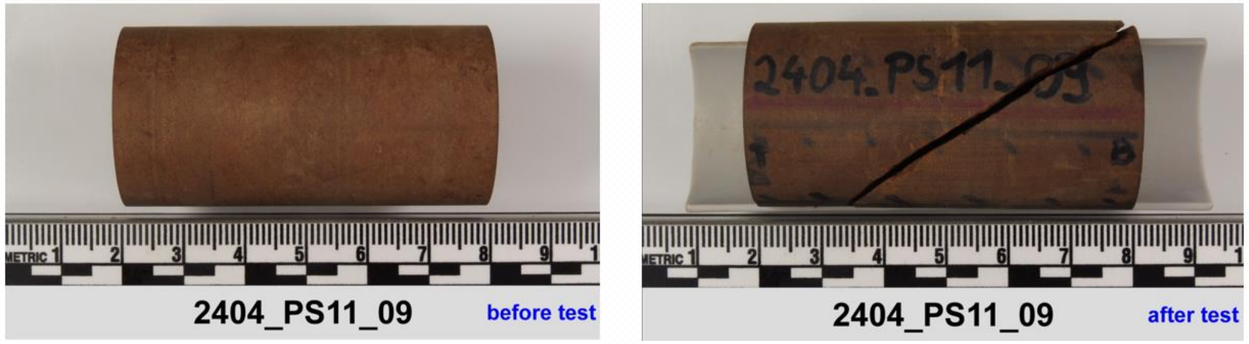
➔Linear thermal expansion coefficient and thermal conductivity measured

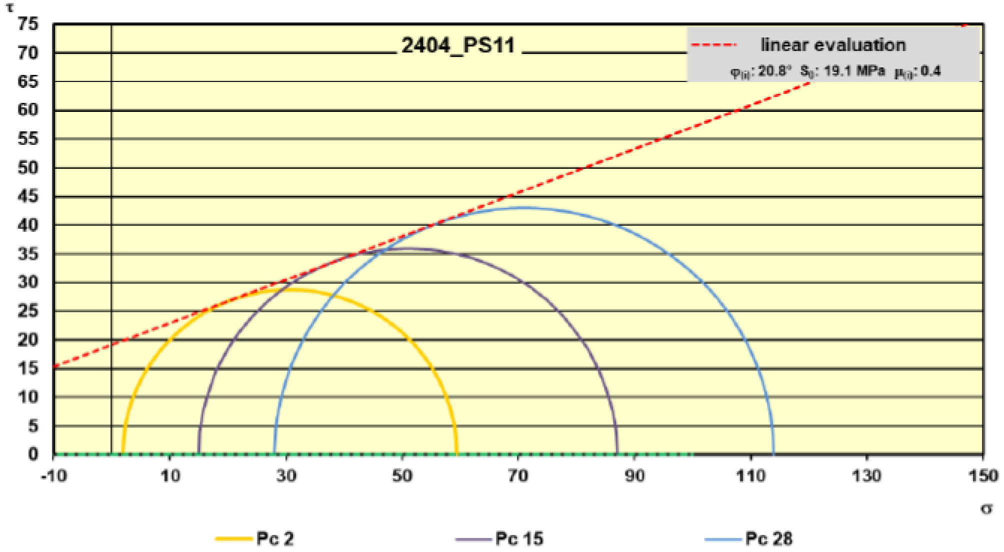
Main Claystone Fm - Caprock

Rotliegend Gp - Reservoir



Main Claystone Fm - Caprock





scan
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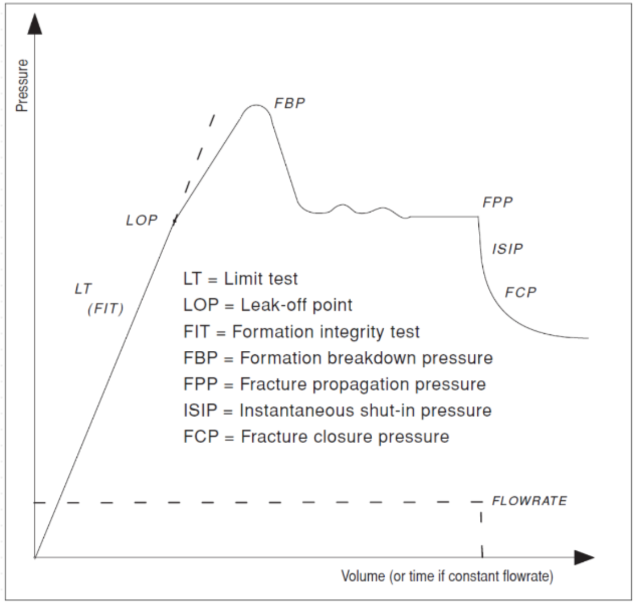
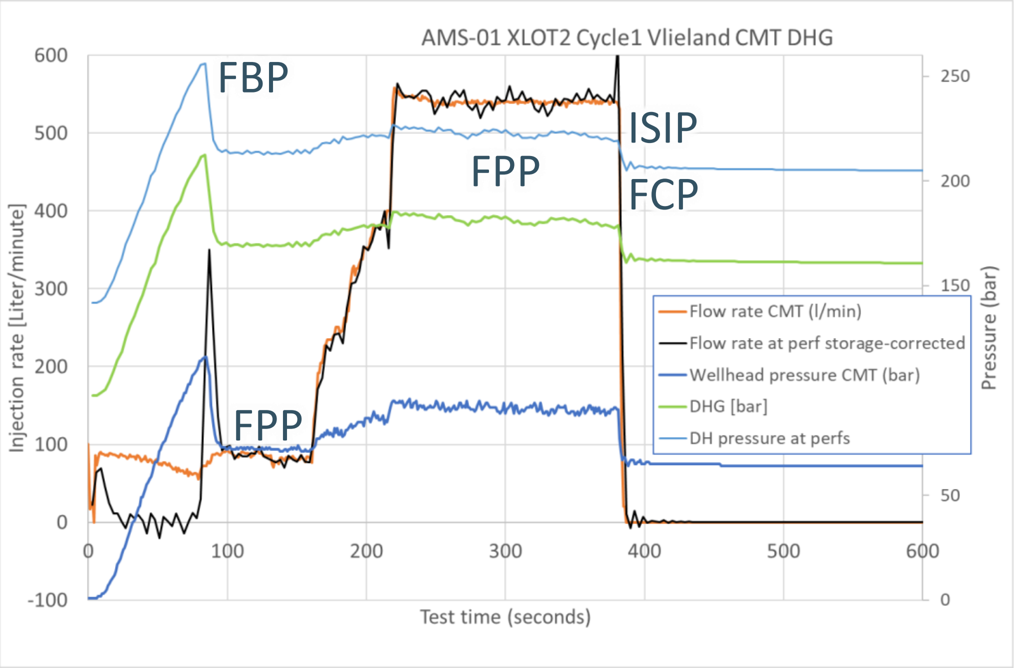
Extended Leak-Off Test (XLOT)

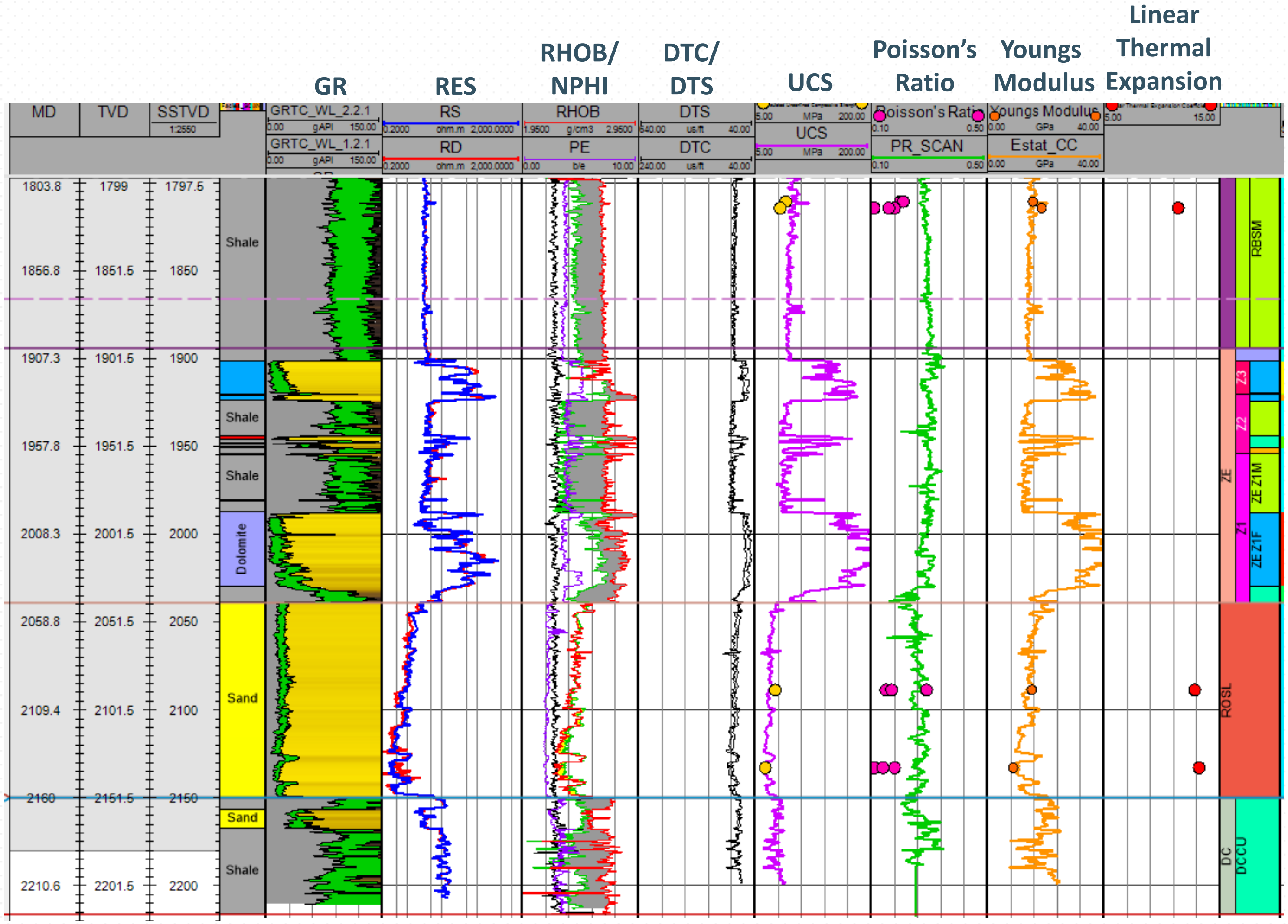
1. Determine magnitude **minimum horizontal stress**
2. SCAN performs XLOTs through a 1.5m perforated interval before well decommissioning
3. Three potential geothermal caprocks tested
4. For each interval determine:
   1. Formation breakdown pressure (FBP)
   2. Fracture propagation pressure (FPP)
   3. Instantaneous shut-in pressure (ISIP)
   4. Fracture closure pressure (FCP)
   5. Fracture re-opening pressure (FRP)
5. Can be used to calibrate geomechanical models based on X-dipole sonic, density and image logs

Gaarenstroom et al., 2003

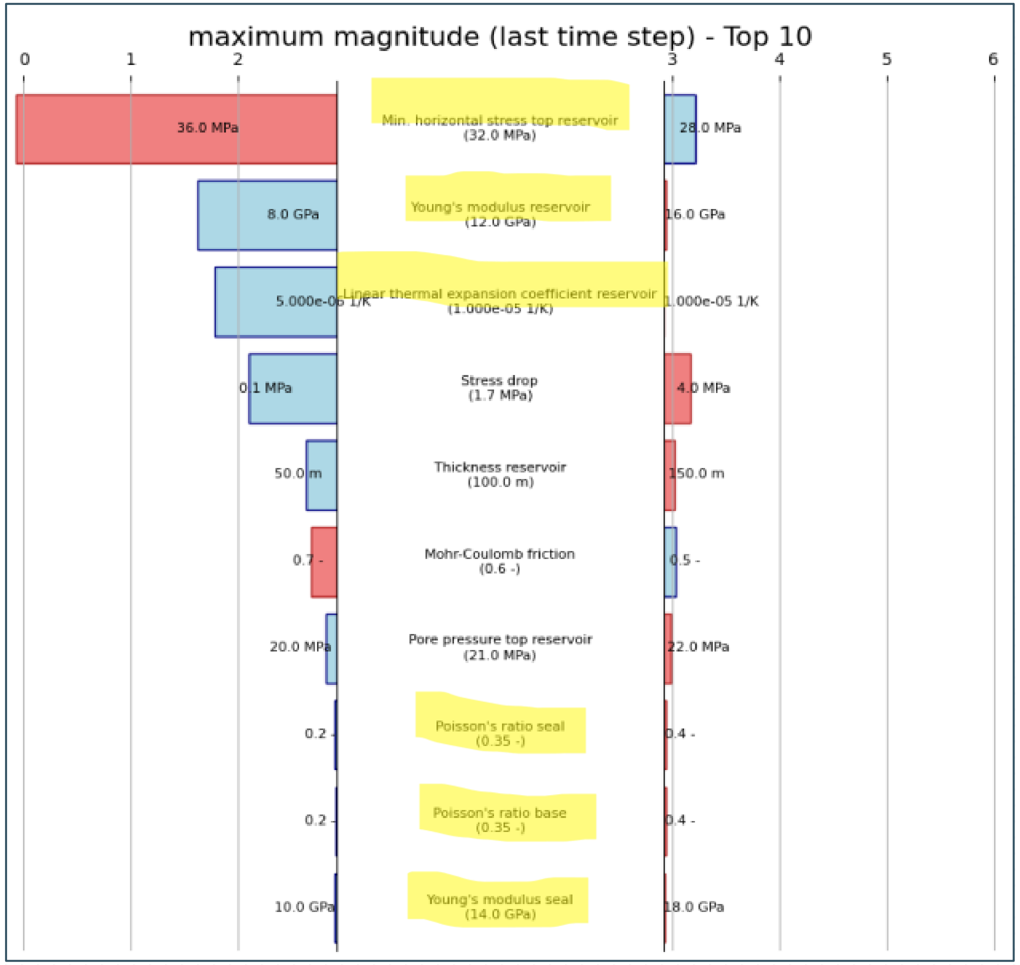




Additional Geomechanical Parameters

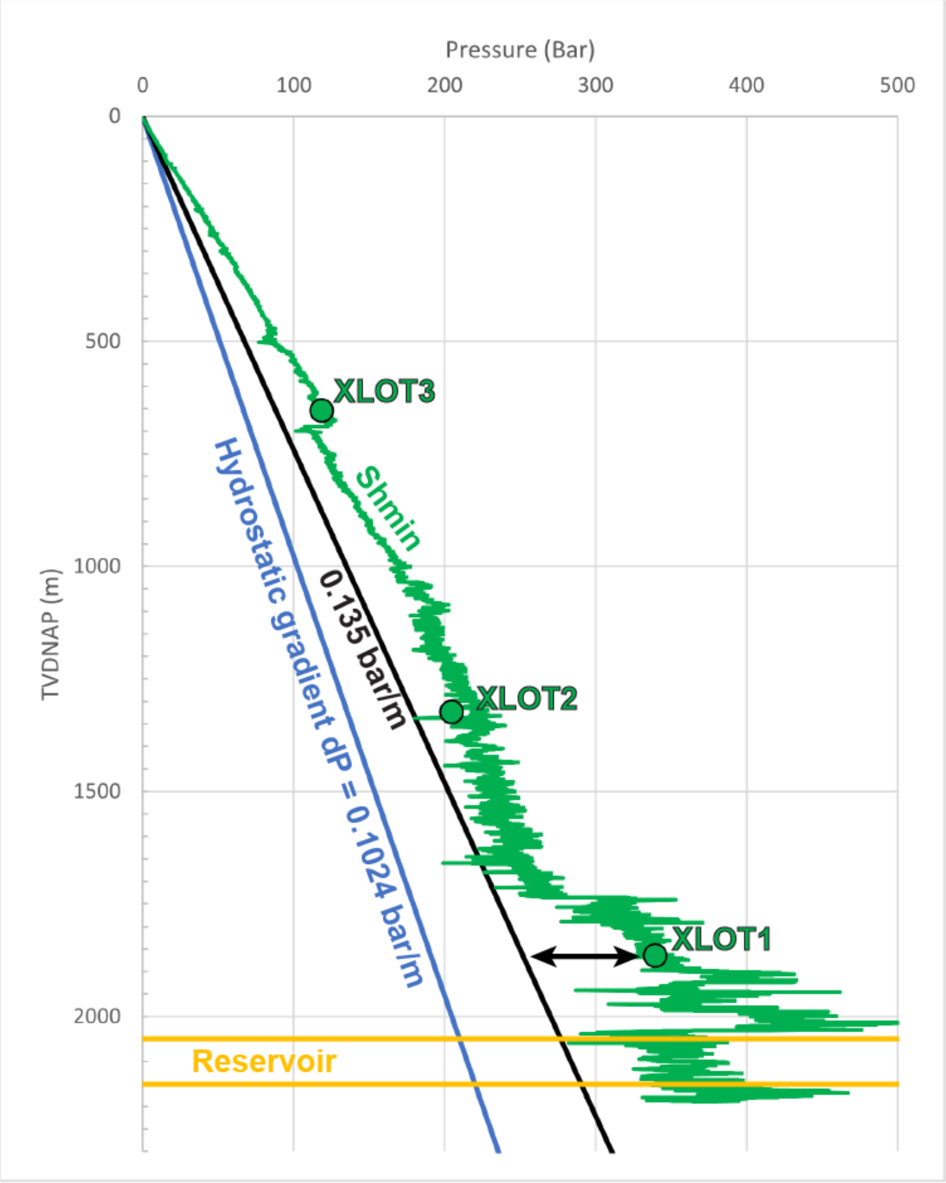


Example SRIMA output, Mijnlieff et al., 2023



Construction and Calibration of 1D geomechanical models

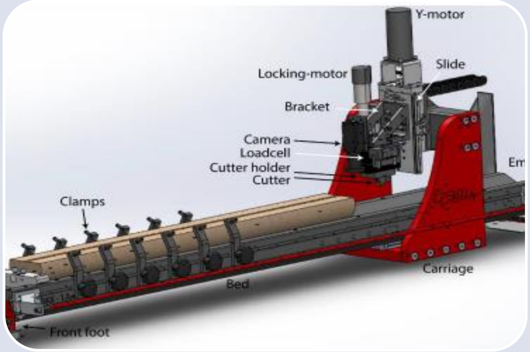
- ➔Amstelland dataset provides abundance of geomechanical parameters
- ➔Allows use of local parameters, rather than generic conservative estimates
- ➔Provides input to induced seismicity and caprock integrity workflows (SRIMA-TAS)

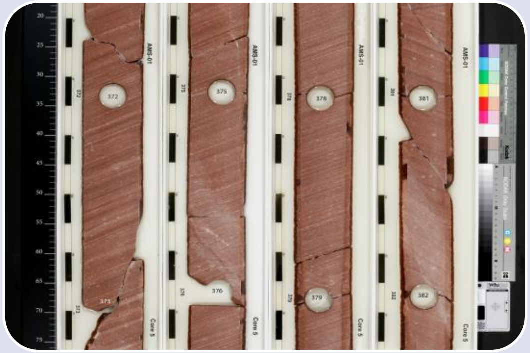


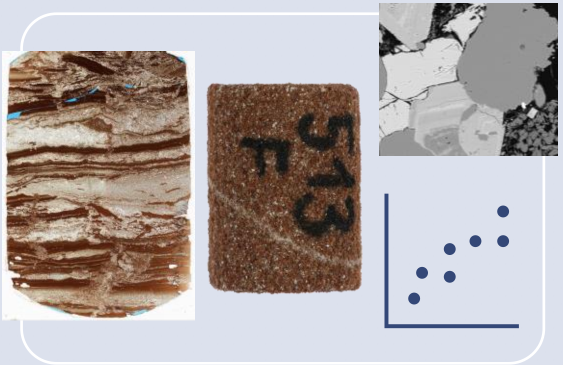
How was the Rotliegend reservoir deposited?

- Core Analysis Program
- Palaeogeography
- Core Description
- Depositional Environments
- Reservoir Quality Controls

AMS-01 Core Analysis Program







Screening

- Core GR
- CoreDNA

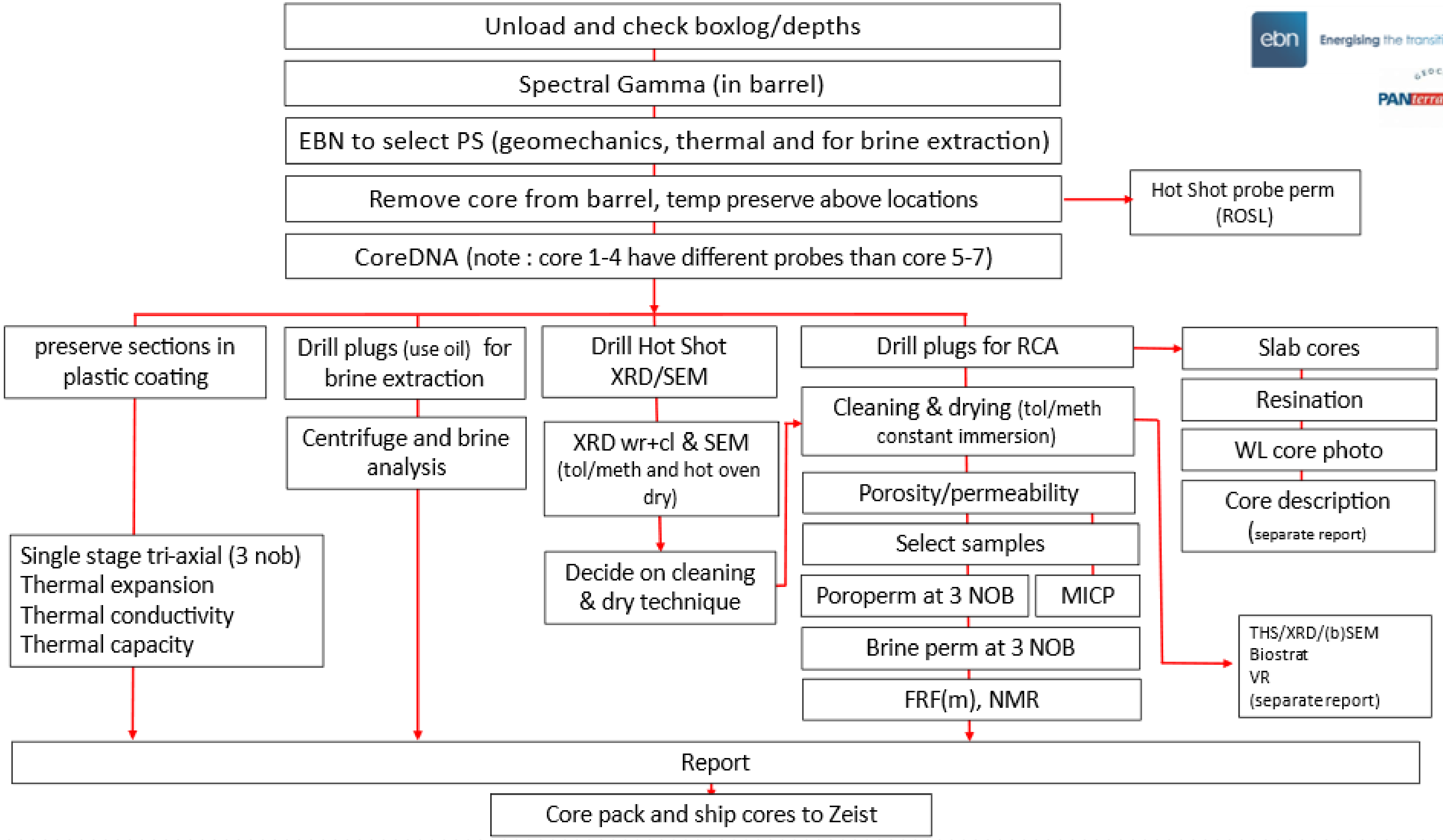
Core Description

- Digital recording in WellCAD
- Lithology, texture, contacts, fractures, …

Sample Analysis

- RCA (Ø, k_{air}, k_w)
- Petrography (THS, SEM, XRD)
- MICP
- SCAL (NMR, FRF,
- Geomechanics
- Thermal properties

Core Analysis – Scope of Work



Core Screening

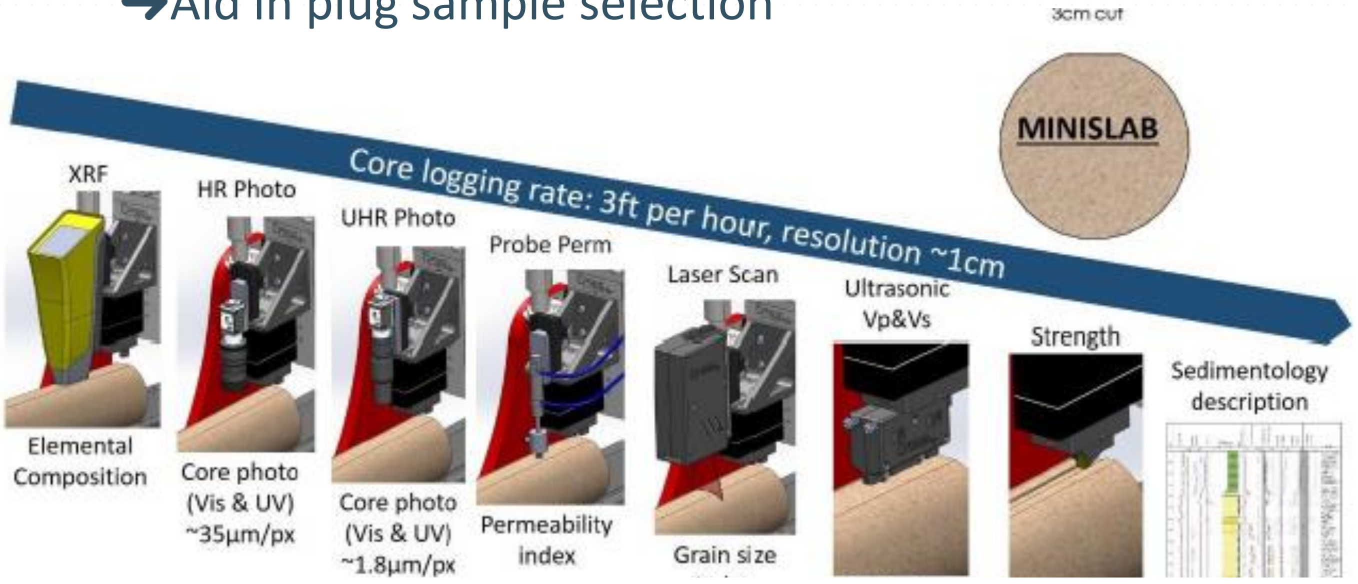
➔Screening along entire length of cores at cm scale:

- ➔Spectral core gamma ray
- ➔CoreDNA (multi-sensor)

➔Is useful for:

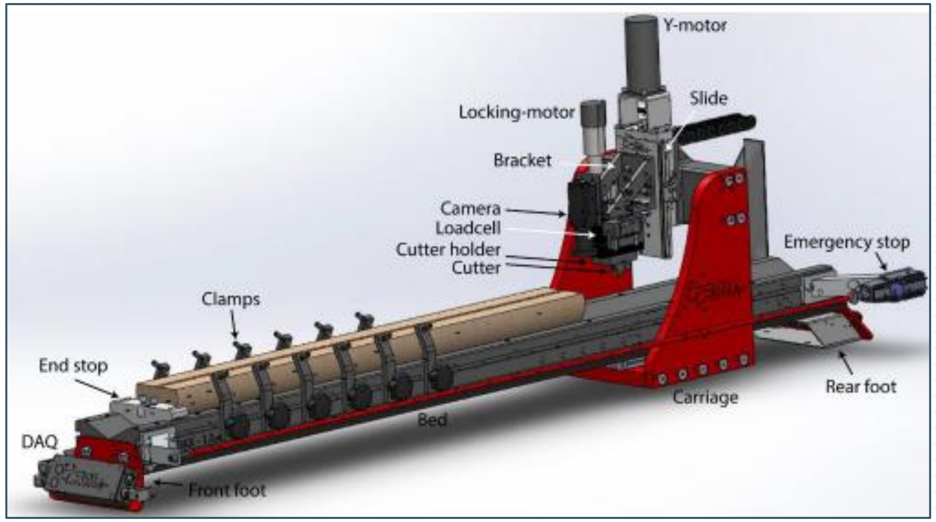
- ➔Core to log calibration
- ➔Indication of facies early in the program
- ➔Aid in plug sample selection


Gamma ray instrument



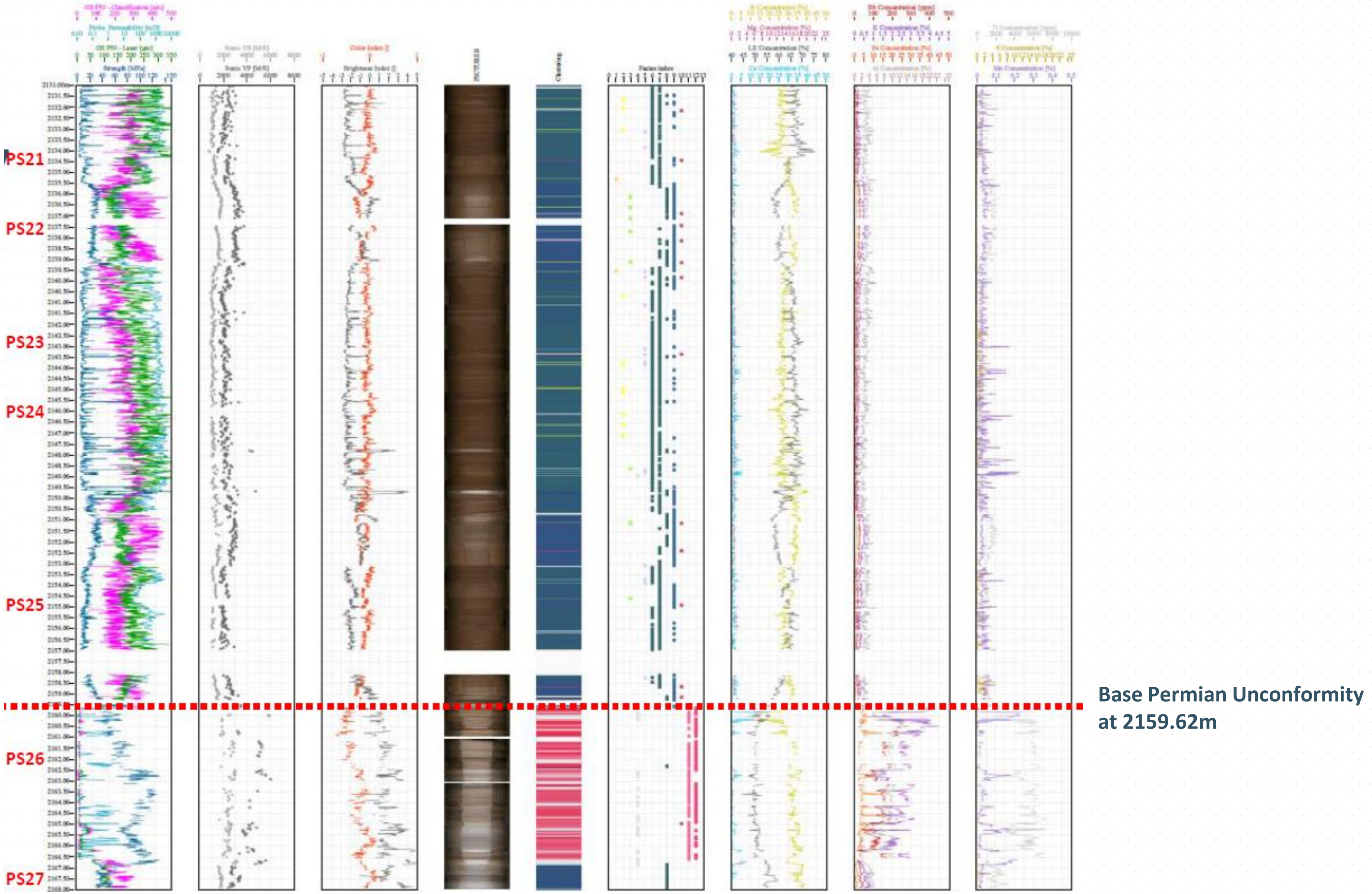
Probes selection AMS-01:

- Cores 1-4 – Vlieland, Main Claystone : UHR imaging, XRF, P&S wave & UCS strength
- Cores 5-7 – Slochteren, Maurits : Idem + laser grain size and permeability



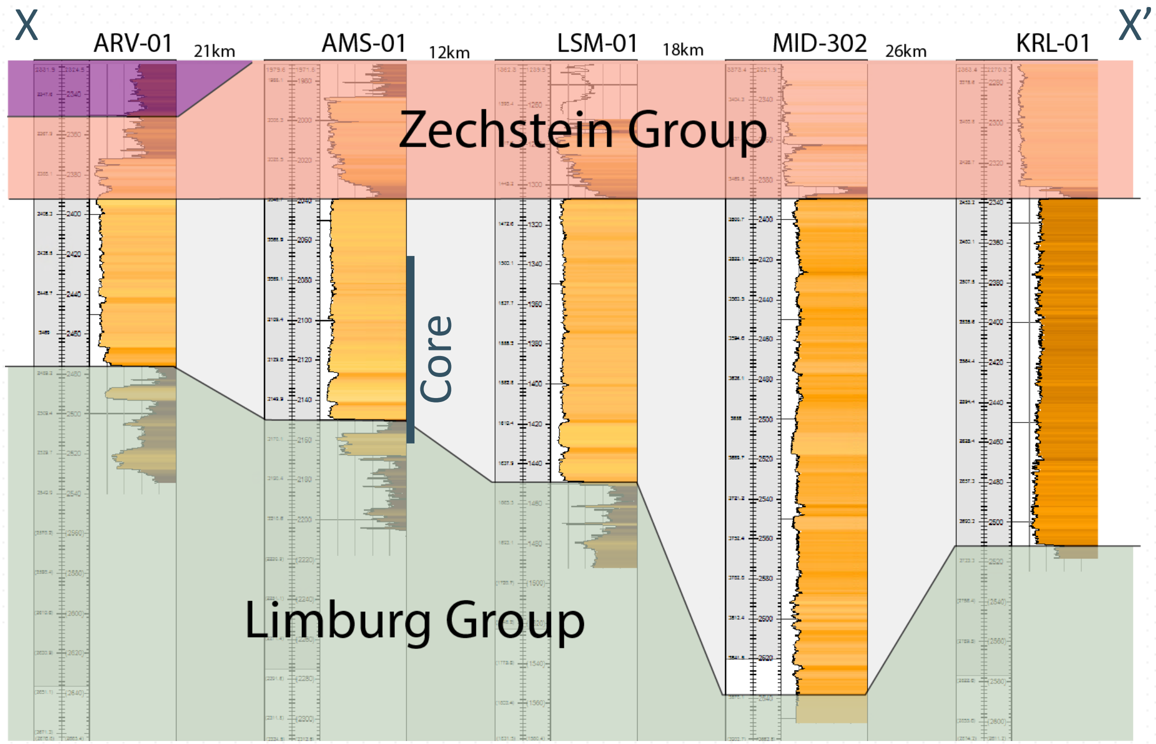
CoreDNA (from EPSLog)

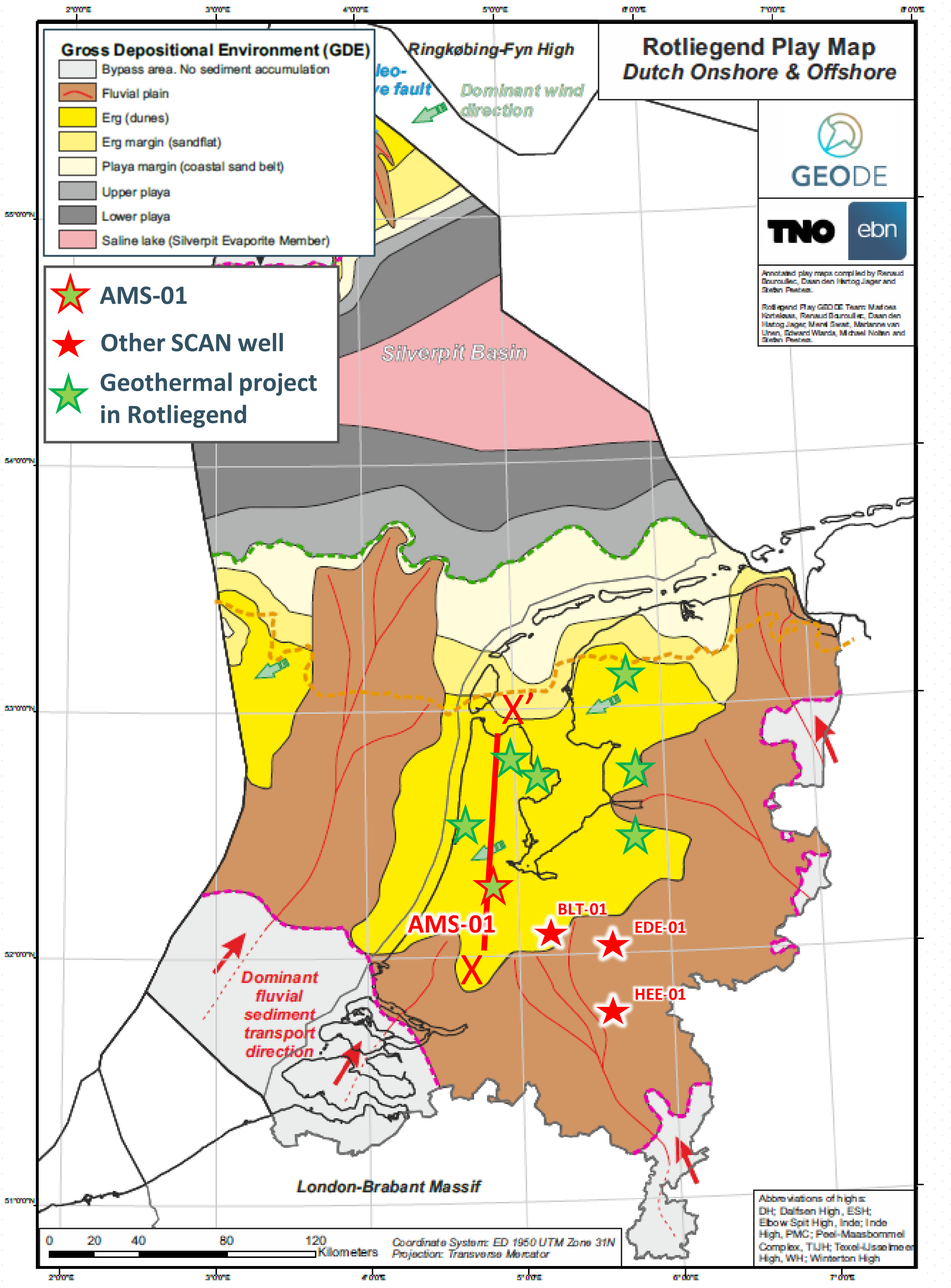
CoreDNA example



Rotliegend Slochteren

- Upper Rotliegend Group (Slochteren Formation)
- Permian epicontinental clastic deposits
- Eolian dunes (erg) with greatest flow potential
- 50-250m thick, low clay content, little compositional variation
- AMS-01: 111 meter True Vertical Thickness
- How to differentiate?
  - Grain size, sorting, bedding style...





GEODE - Kortekaas et al., 2023

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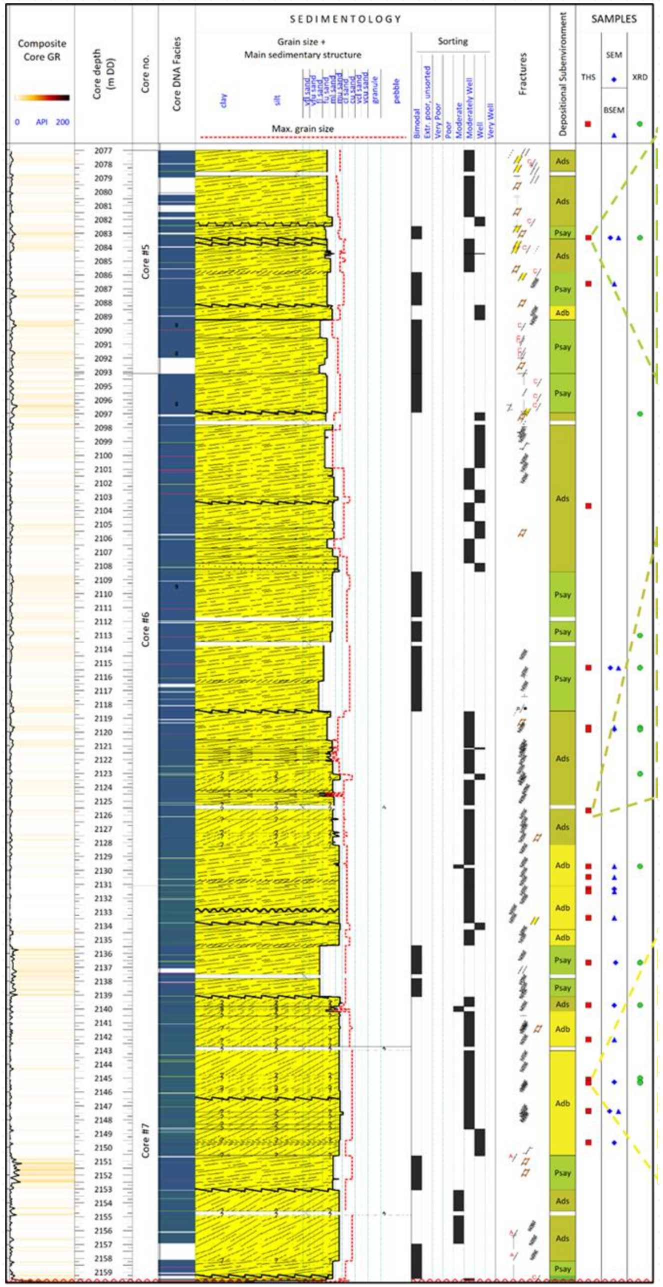
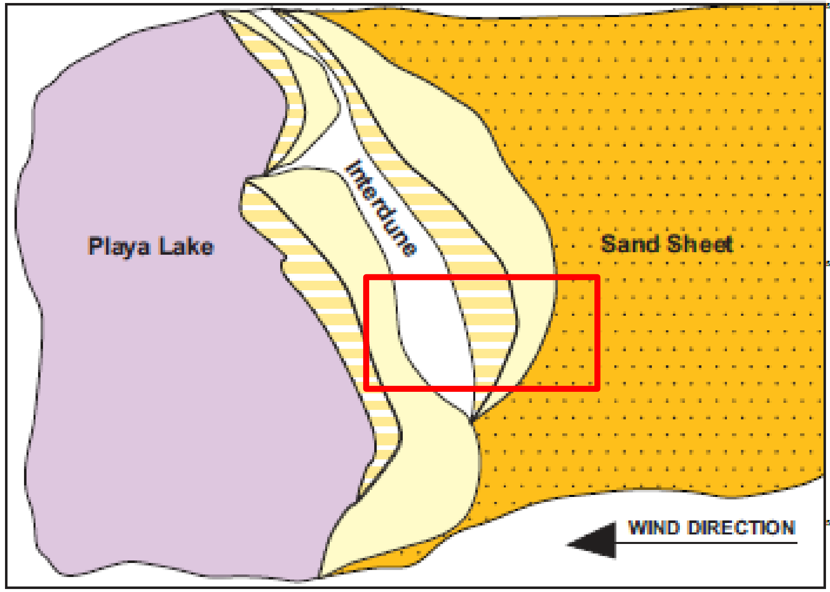
Composite core description

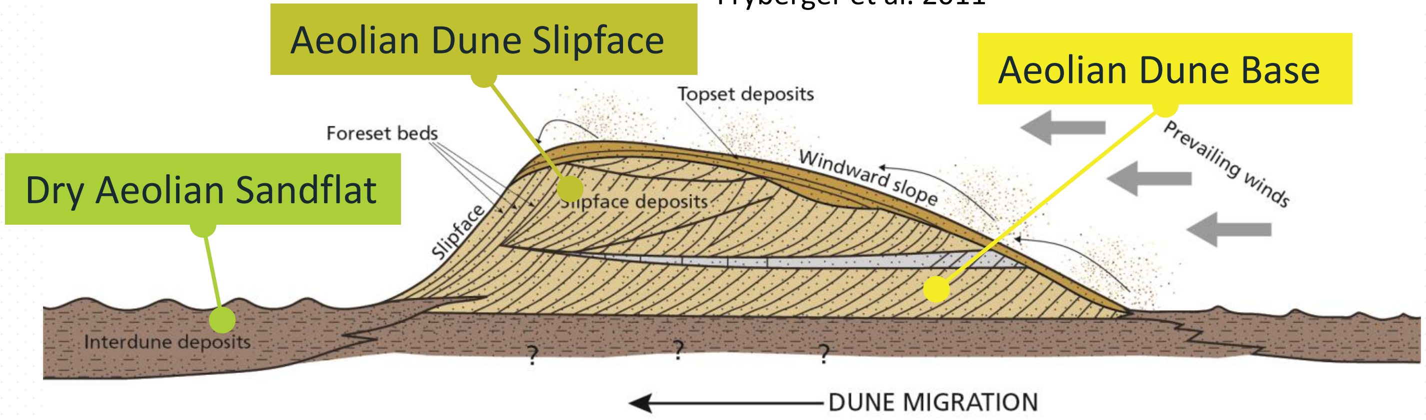


Palaeogeography

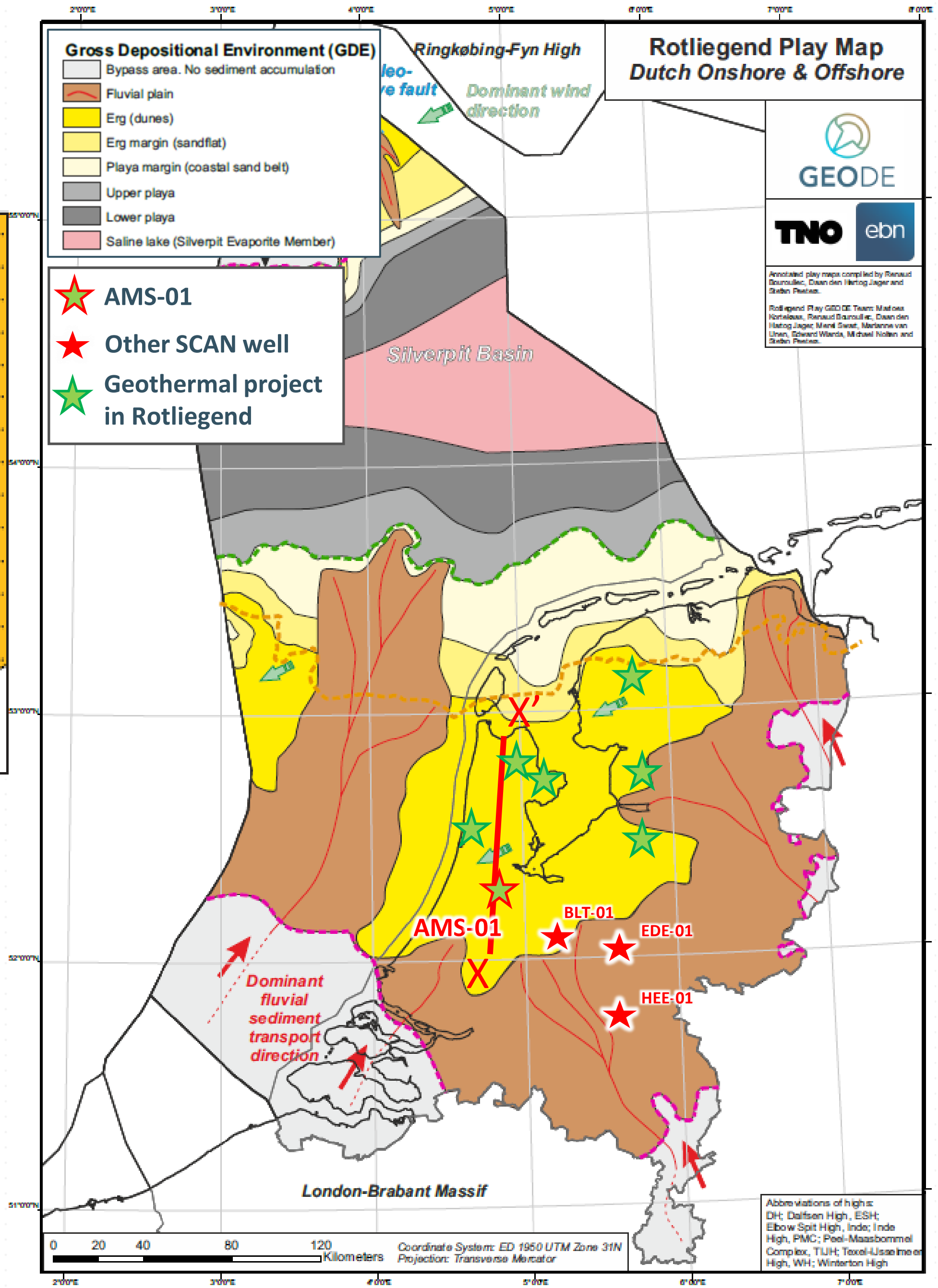
- ➜ Migrating aeolian dune forms and interdune areas
- ➜ Constant uniform wind direction
- ➜ Water table below sediment surface



Fryberger et al. 2011

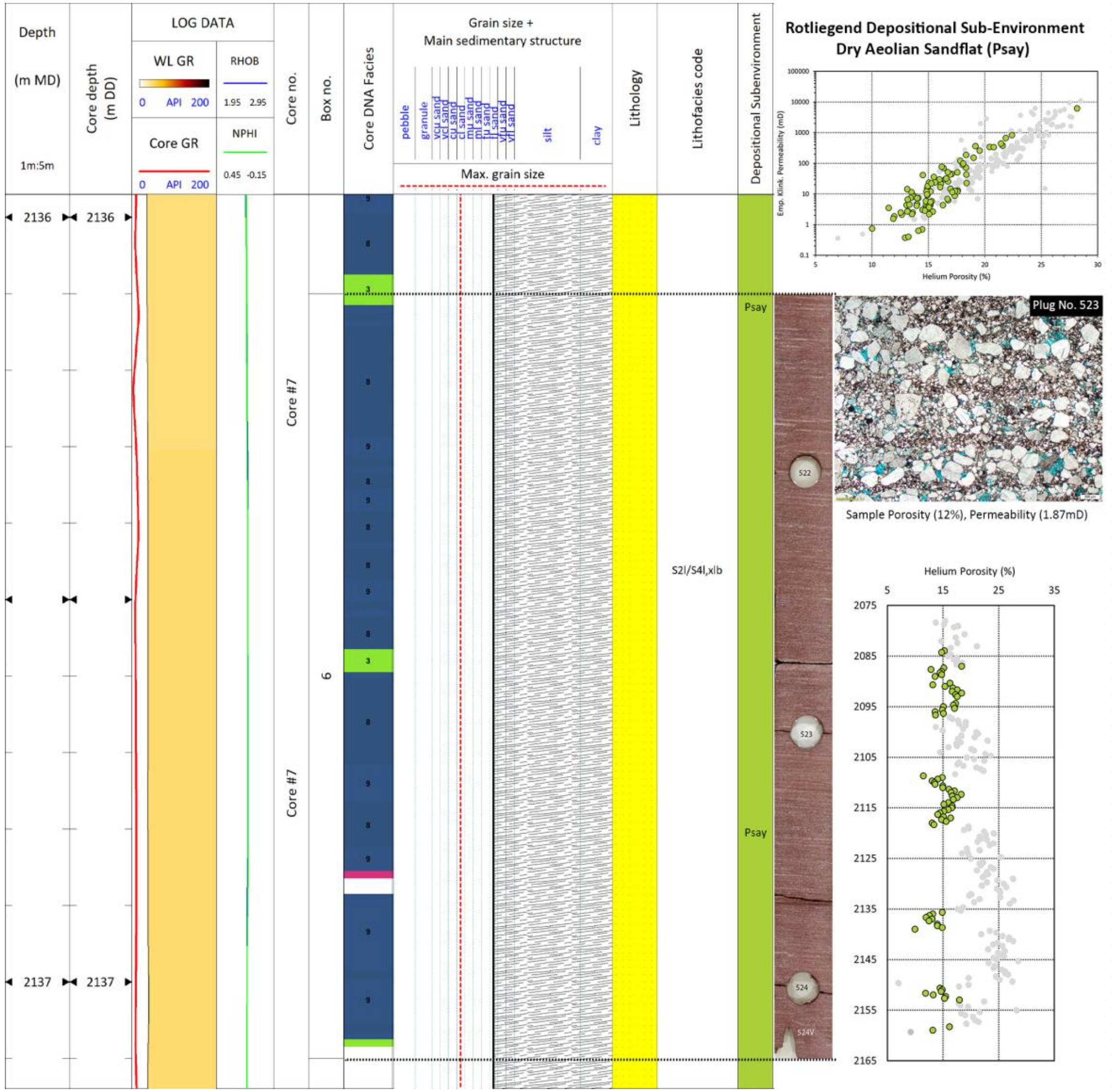


modified from Ahlbrandt and Fryberger (1982)



GEODE - Kortekaas et al., 2023

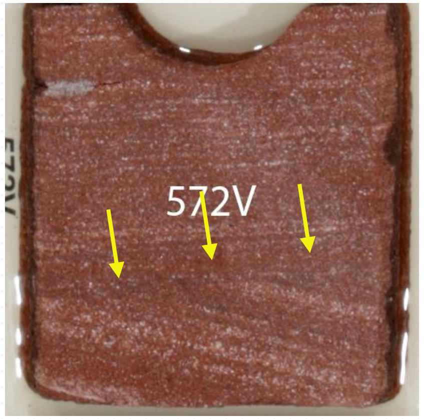
Dry Aeolian Sandflat sub-environment



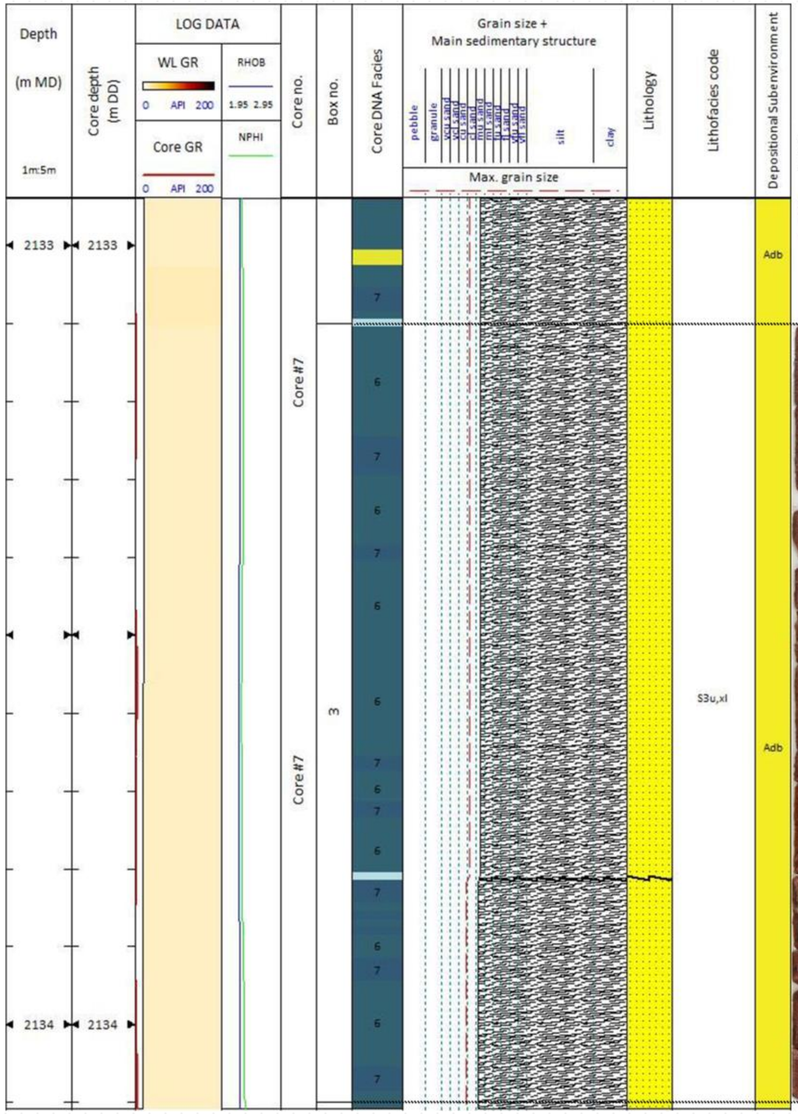
➜ bimodal sorting

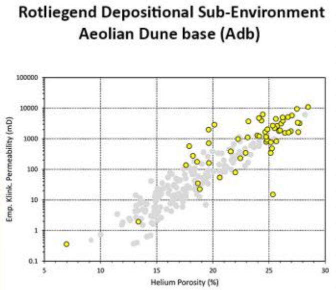
➜Fine sand laminae with medium to coarse sand (‘pin-stripe’)

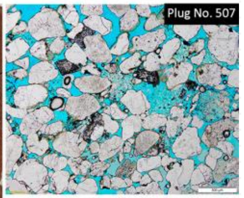
➜ Truncational at base



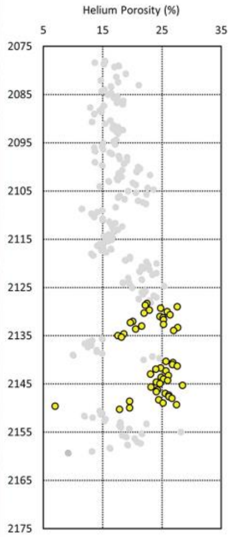
Aeolian Dune Base sub-environment





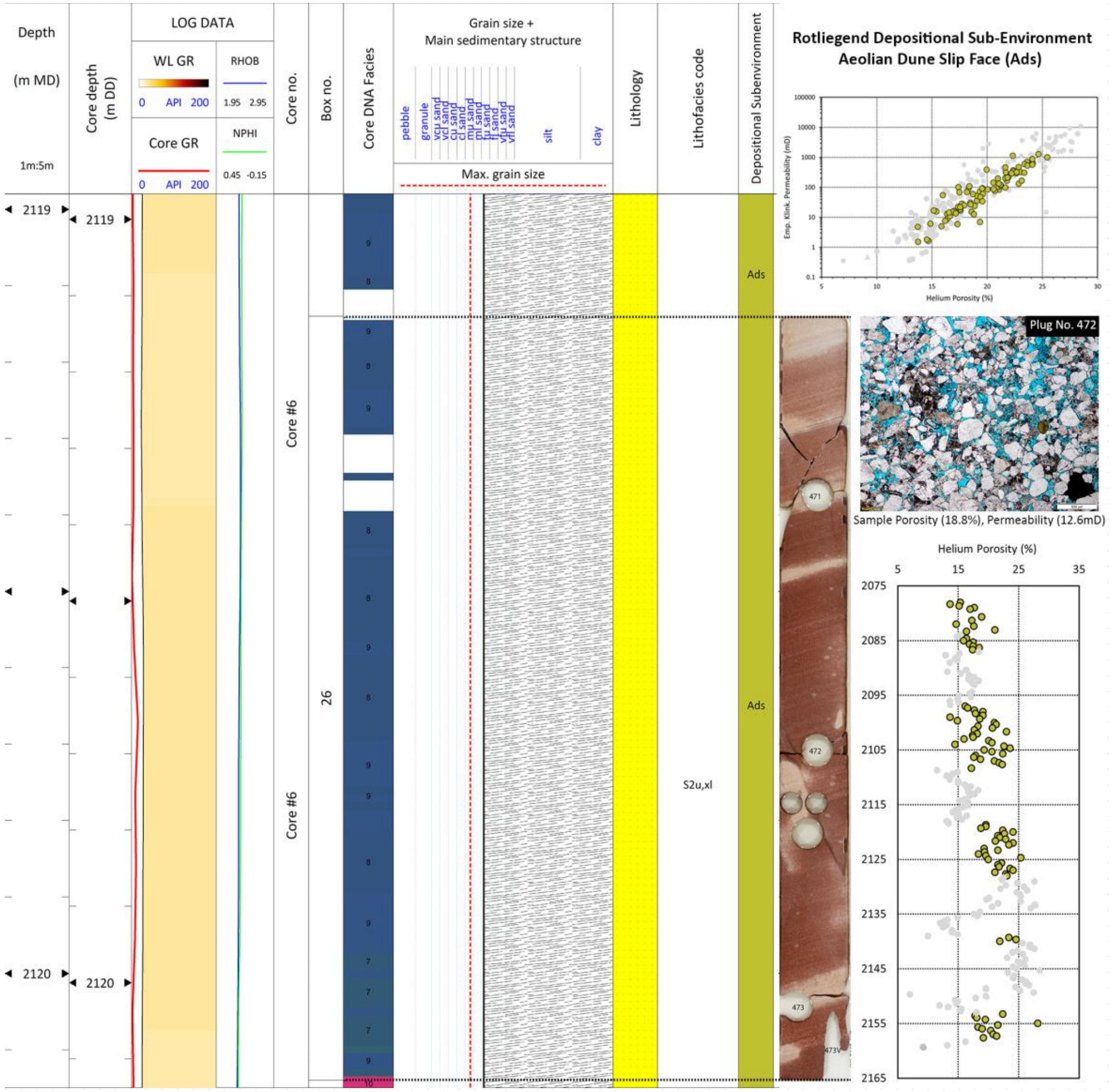


Sample Porosity (25.2%), Permeability (768mD)



- ➔Dominant medium sand
- ➔Low-angle or high-angle cross-bedded
- ➔Moderately well sorted
- ➔Cm- to dm-thick structureless beds with mm-thick fine sand laminae

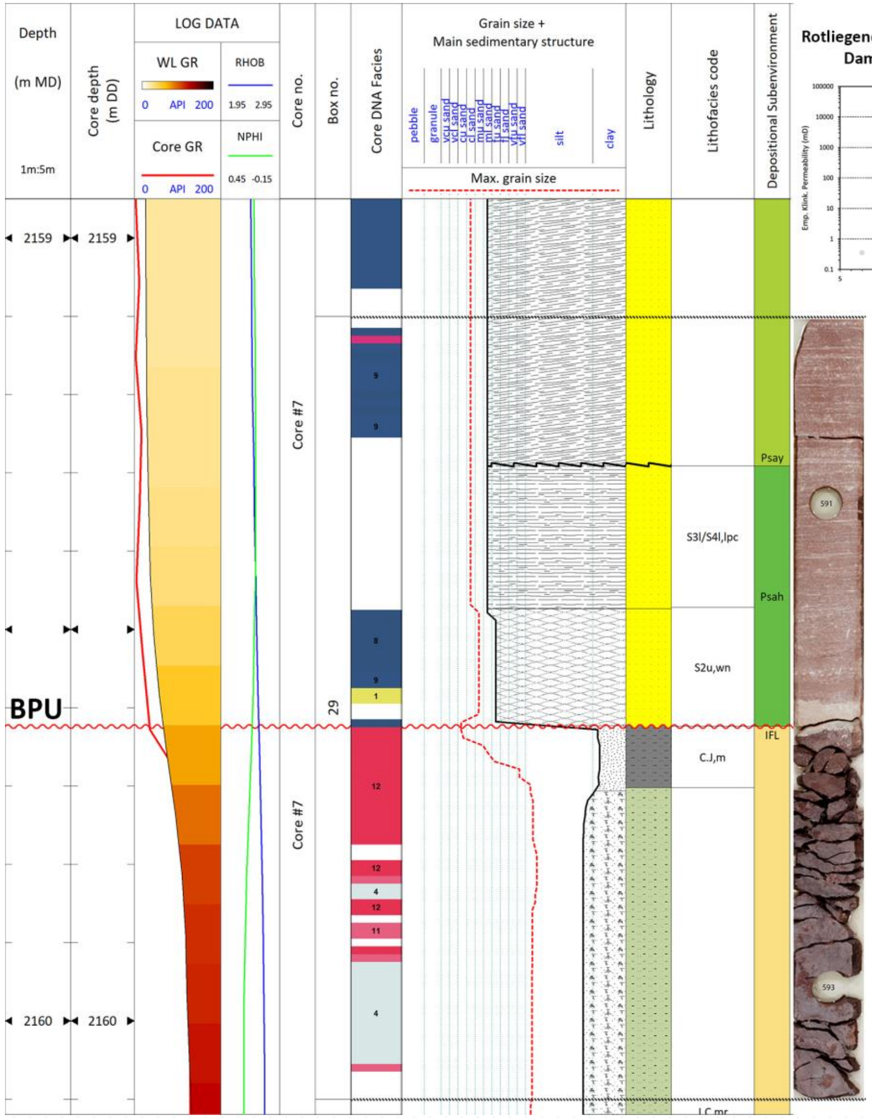
Aeolian Dune Slipface sub-environment

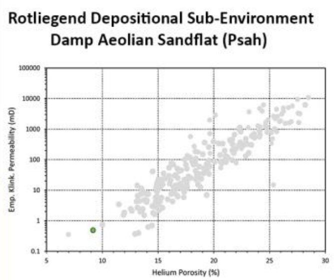


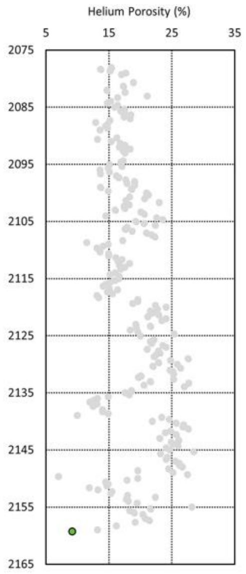
- ➜Fine to medium sand (upward fining trend within units)
- ➜Moderately well sorted
- ➜Mm- to cm-thick low-to high-angle cross-beds
- ➜Occasional subtly normal- or reverse-graded beds
- ➜Medium sand beds often tapered

scan

Damp Aeolian Sandflat sub-environment



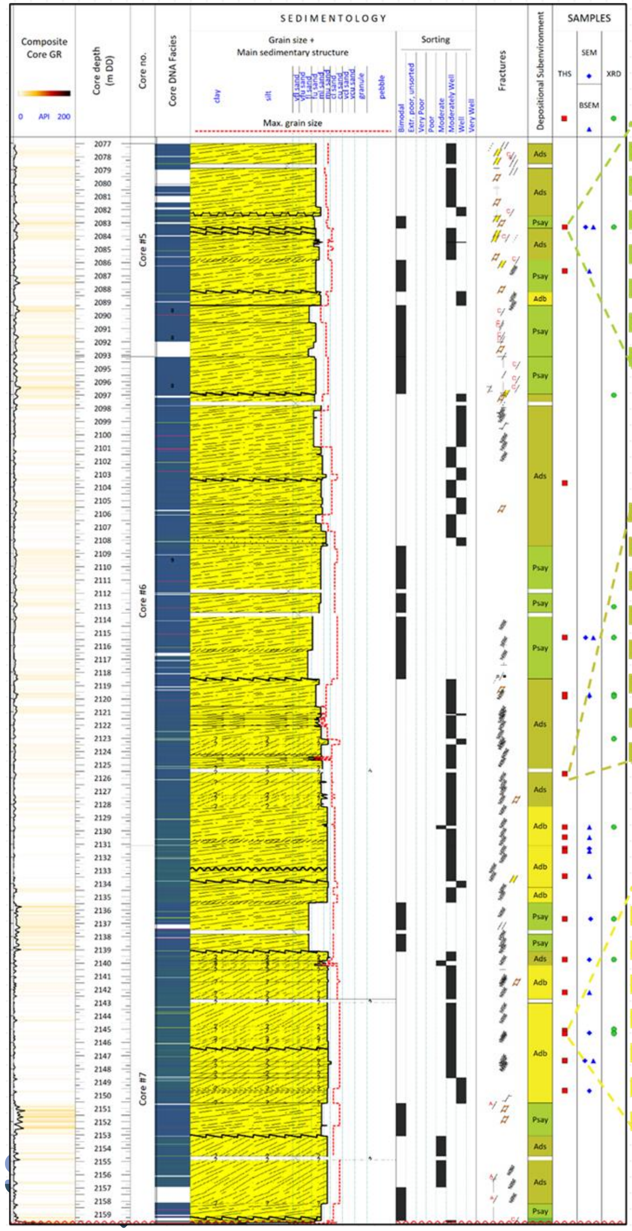


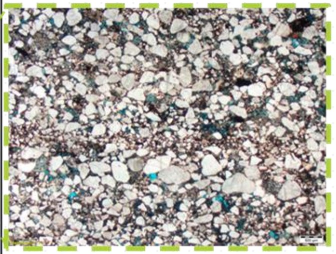


10cm

- ➔Fine sand grading upwards to medium sand
- ➔Horizontally wavy laminated (adhesion ripples)
- ➔Common anhydrite
- ➔Extraclasts at base Base Permian Unconformity (BPU)

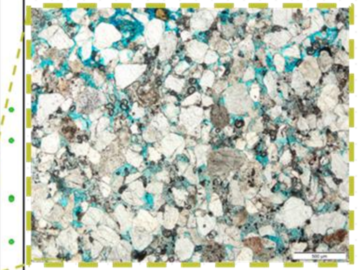
Sedimentological controls on reservoir quality





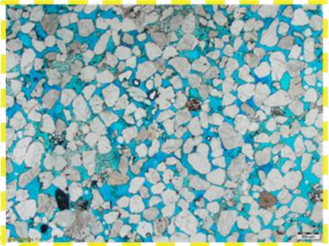
Plug 366 (2083.31m): Dry Aeolian Sandflat

Low-angle cross-stratified sandstone, bimodally sorted with fine- (upper) and coarse- (lower) grained laminae.



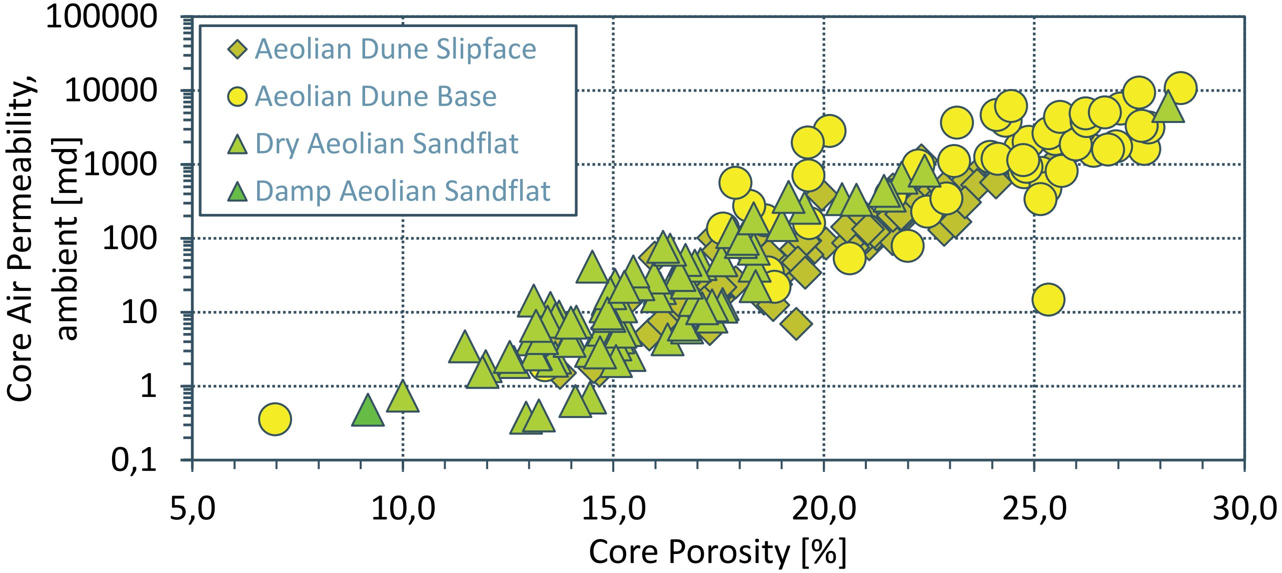
Plug 424 (2103.67m): Aeolian Dune Slipface

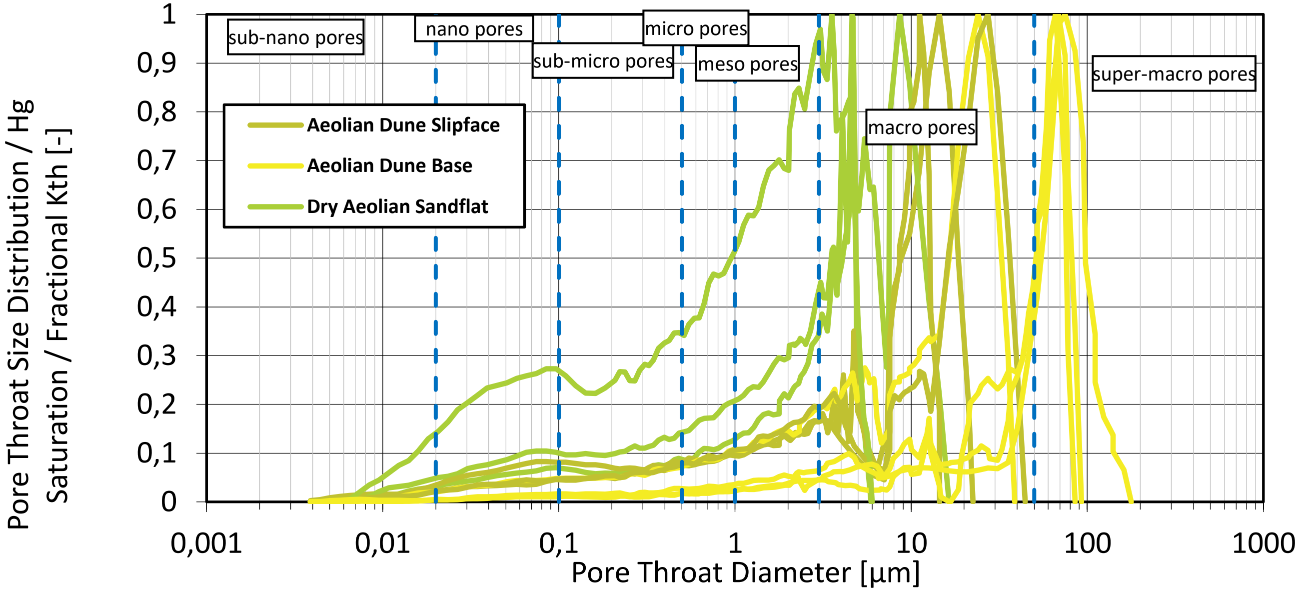
Low-angle cross-stratified sandstone, moderately well sorted with medium (lower) sand grain size



Plug 549 (2145.33m): Aeolian Dune Base

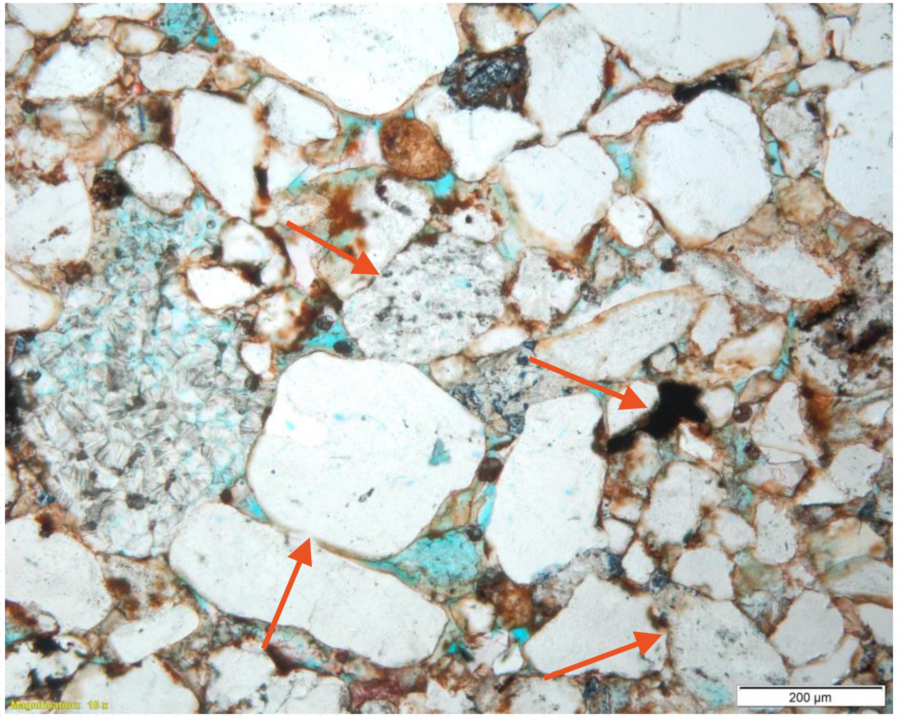
High-angle cross-stratified sandstone, moderately well sorted with medium (upper) sand grain size

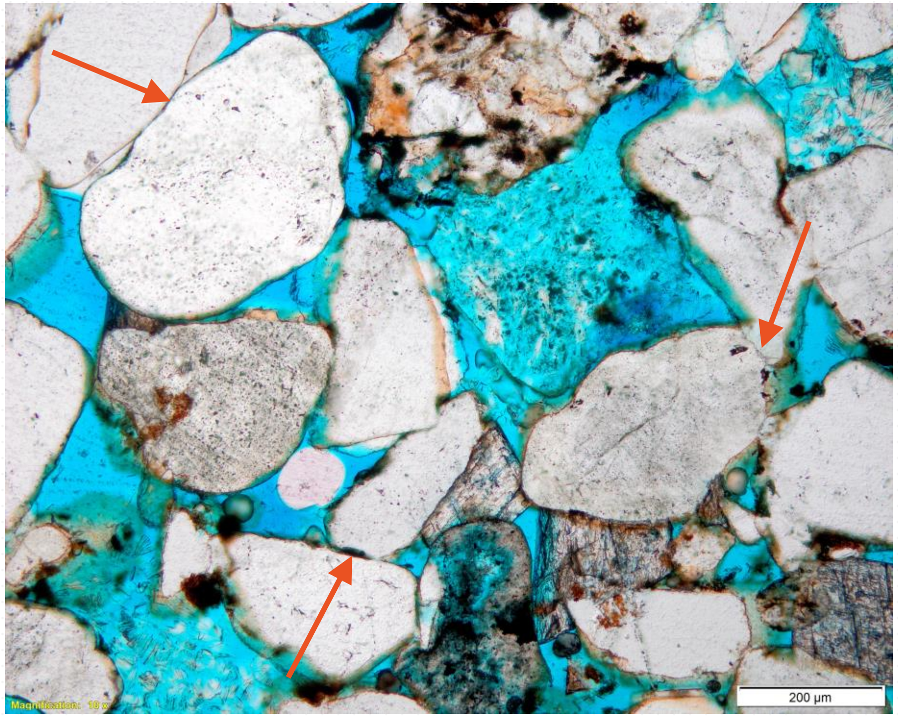




Composition and Compaction

Grain contacts!





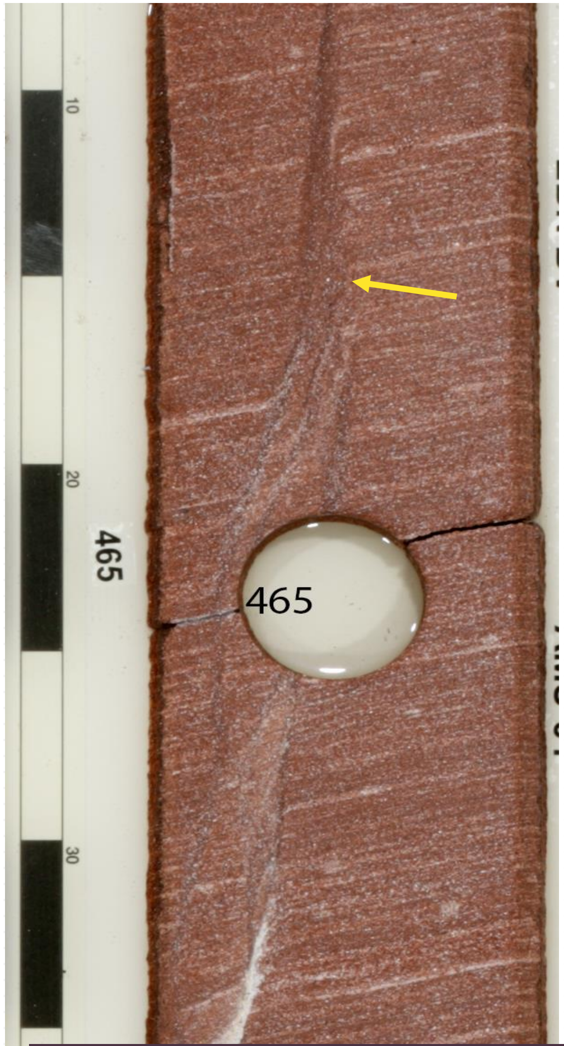
- Sample 459, Dry Aeolian Sandflat
- Interlaminated fine sand and coarse sand
- 8% infiltrated clay, IGV = 25.7% vol.
- 16% Helium porosity, 5% visible, 29.6 mD

- Sample 507, Aeolian Dune Base
- Medium sand
- Traces of detrital clay, IGV = 27.3% vol.
- 25.2% Helium porosity, 20% visible, 786 mD

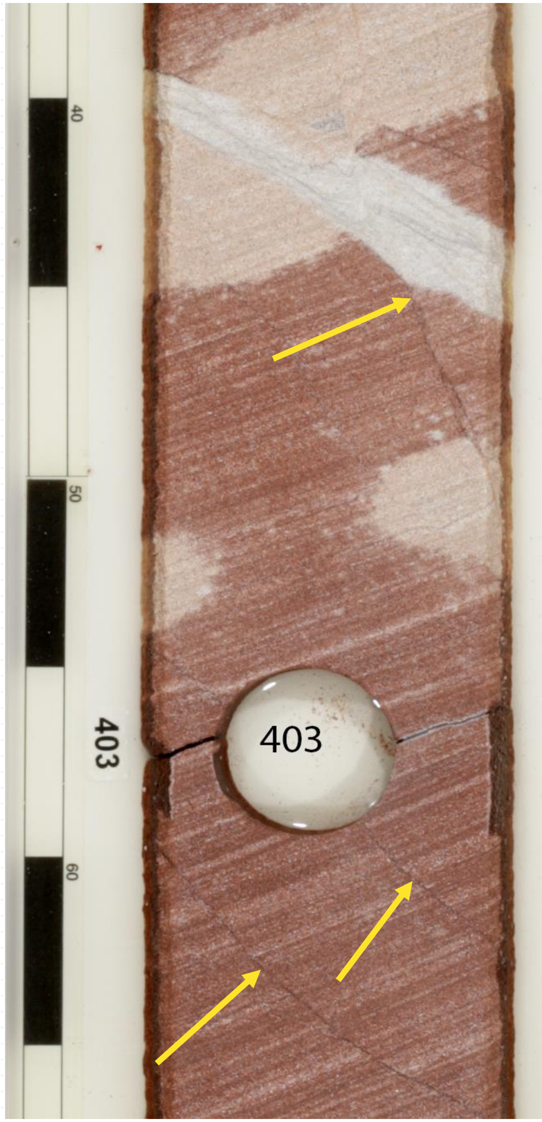
What happened after deposition?

- Faults, Fractures& Deformation Bands
- Diagenetic Cements

Small-scale Faults

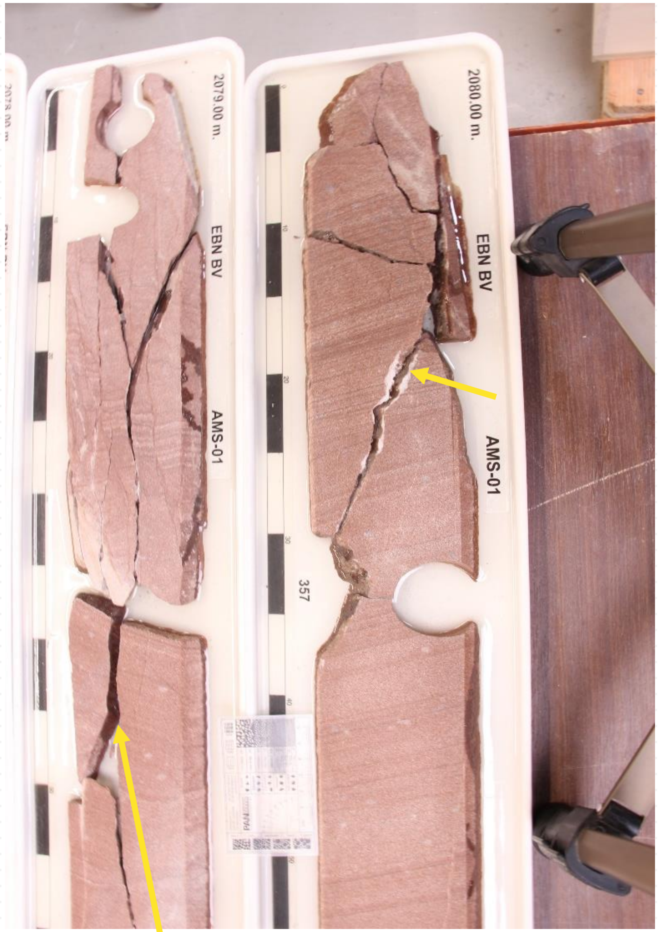


Steep angle fracture in thinly-bedded sands, large displacement, with fault drag



- ➔High-angle fractures and sets, appearing to be clay-lined
- ➔Mostly mm-scale, but can have multiple cm of displacement
- ➔Rare fault drag
- ➔Predominantly normal fractures, locally appearing to be reverse, though probably dip effect

(Partly) Cemented Fractures

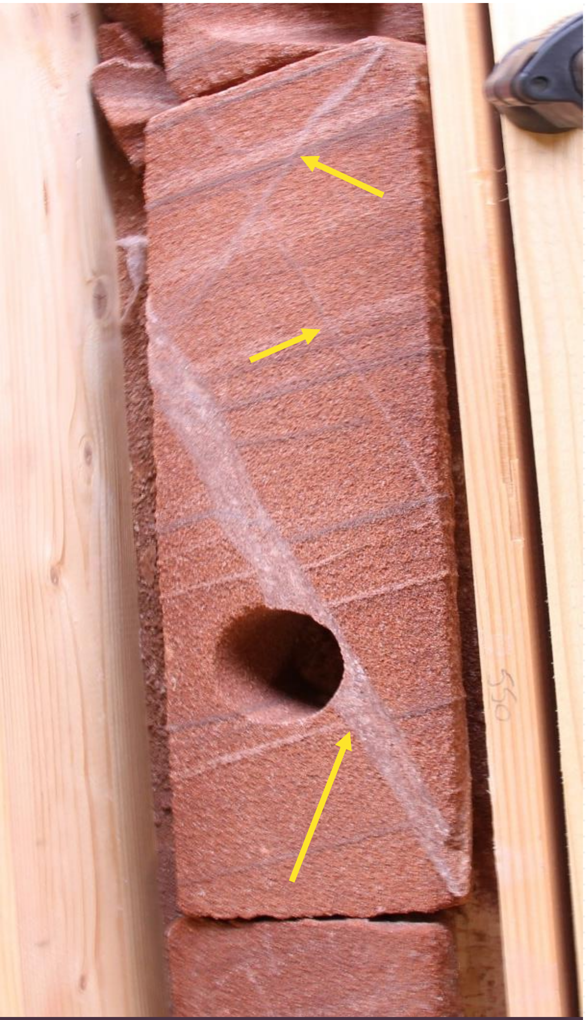


open fracture?

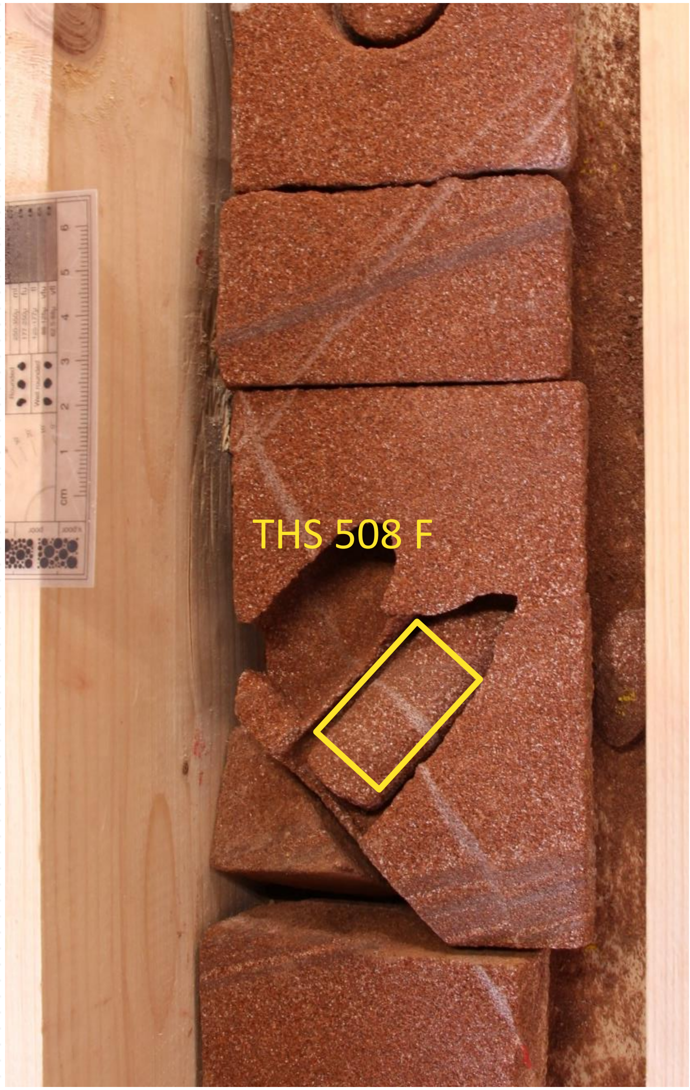
➔High angle to near-vertical fractures, partly or completely cemented by anhydrite

➔Virtually no displacement to rarely mm-scale displacement

Deformation Bands



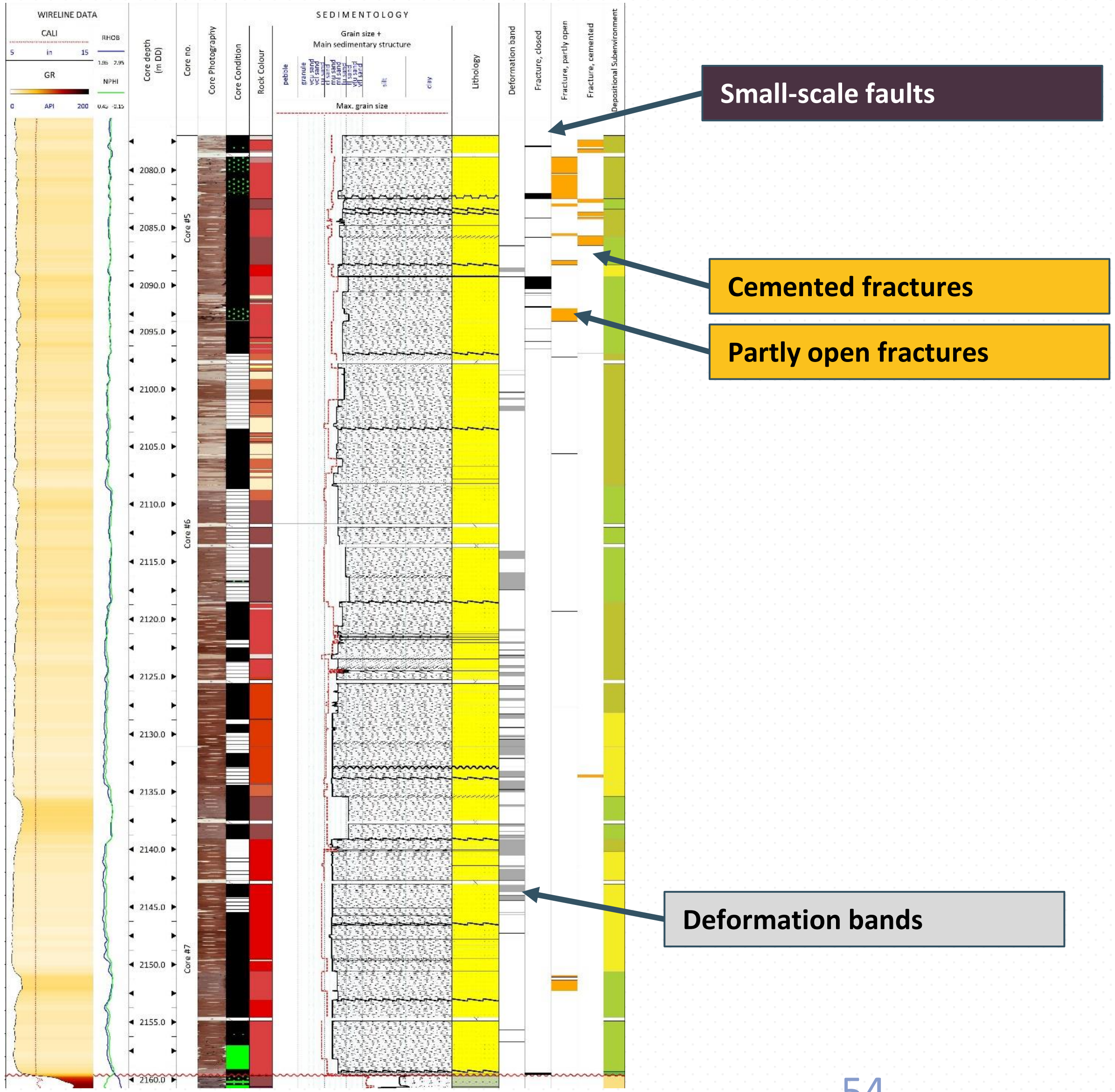
Thick 'swarm' of deformation bands and conjugate set



➔Single discontinuities to swarms of quartz-cemented bands, often conjugate sets

➔Up to mm-scale displacement

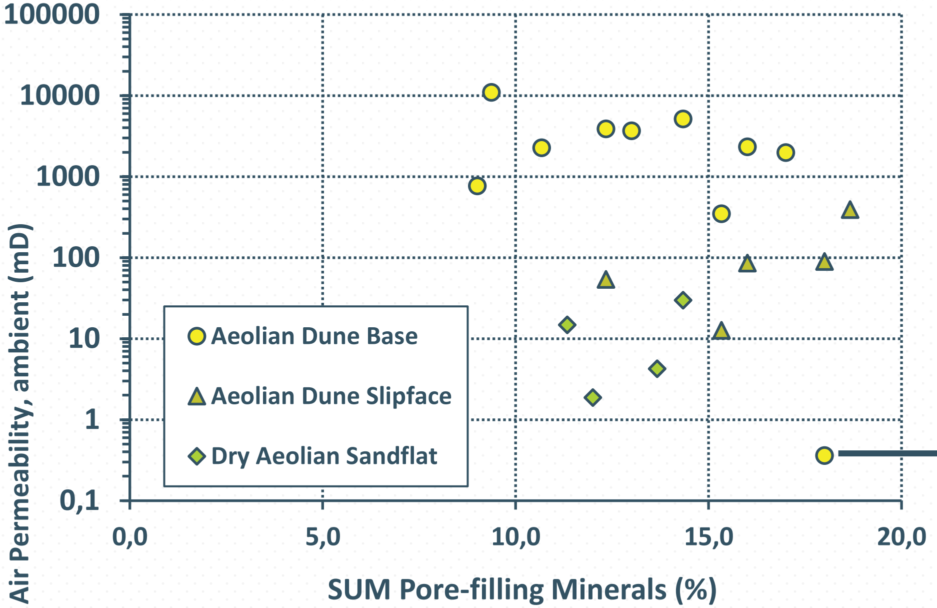
Fracture Distribution

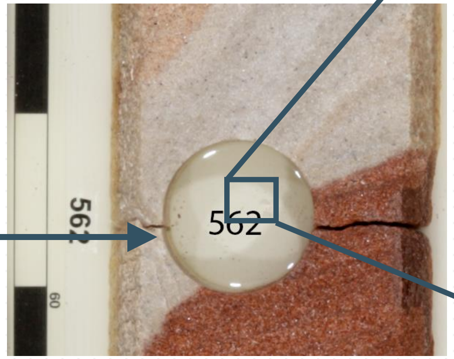


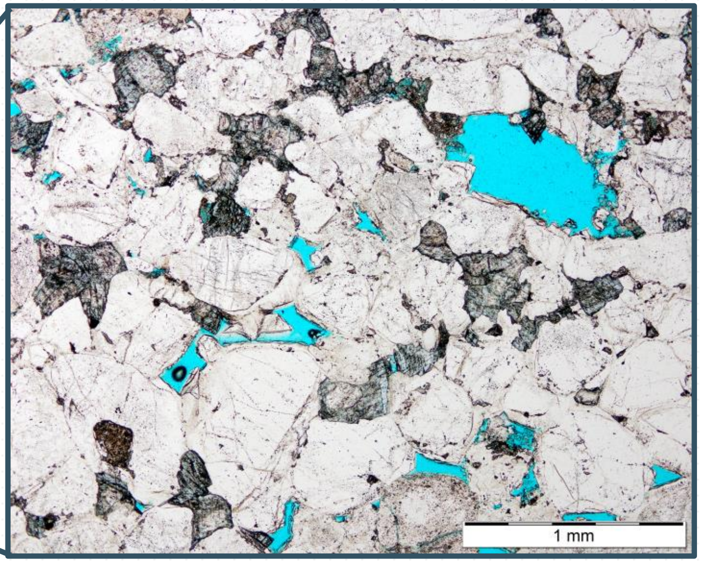
- Deformation Bands associated with most porous intervals
- Small scale faults and (partly) open fractures constrained to top part
- Cemented fractures rare

Diagenetic cements

Role of diagenetic cements minor, despite local effects (e.g. quartz-cemented zones)

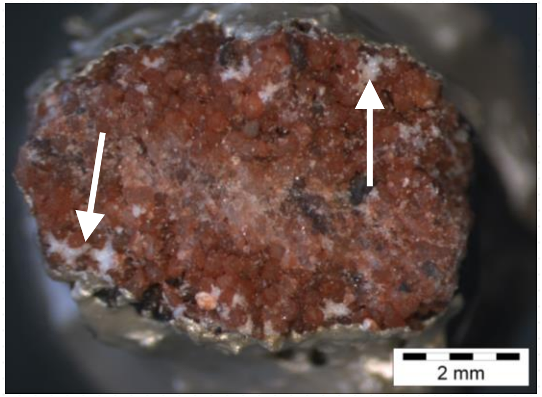




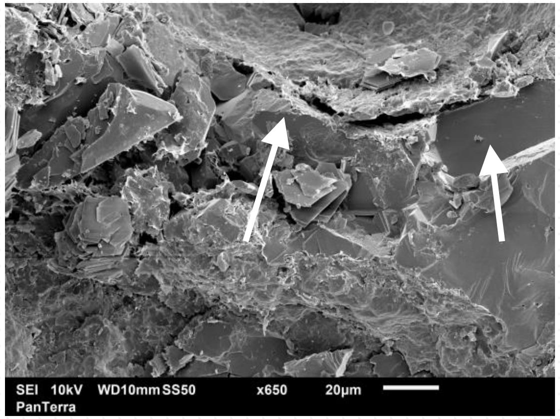


Quartz-cemented zone

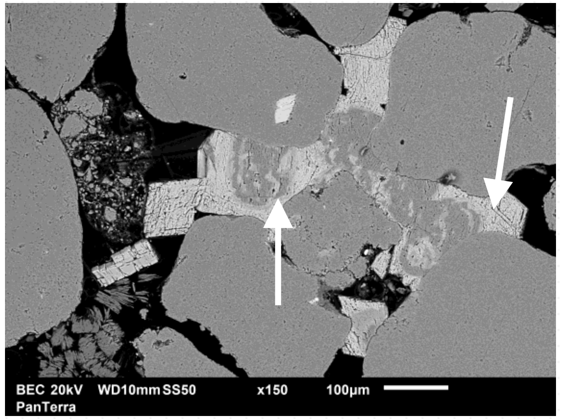
Kaolinite



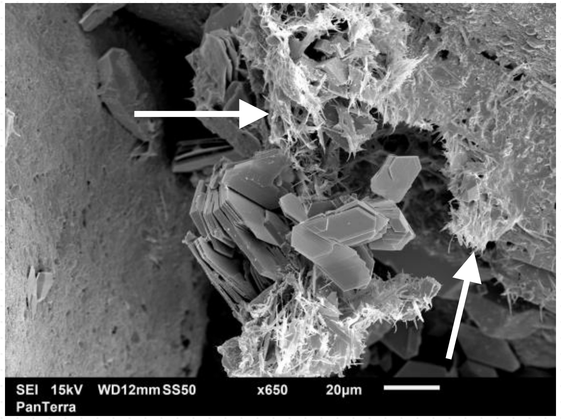
Quartz



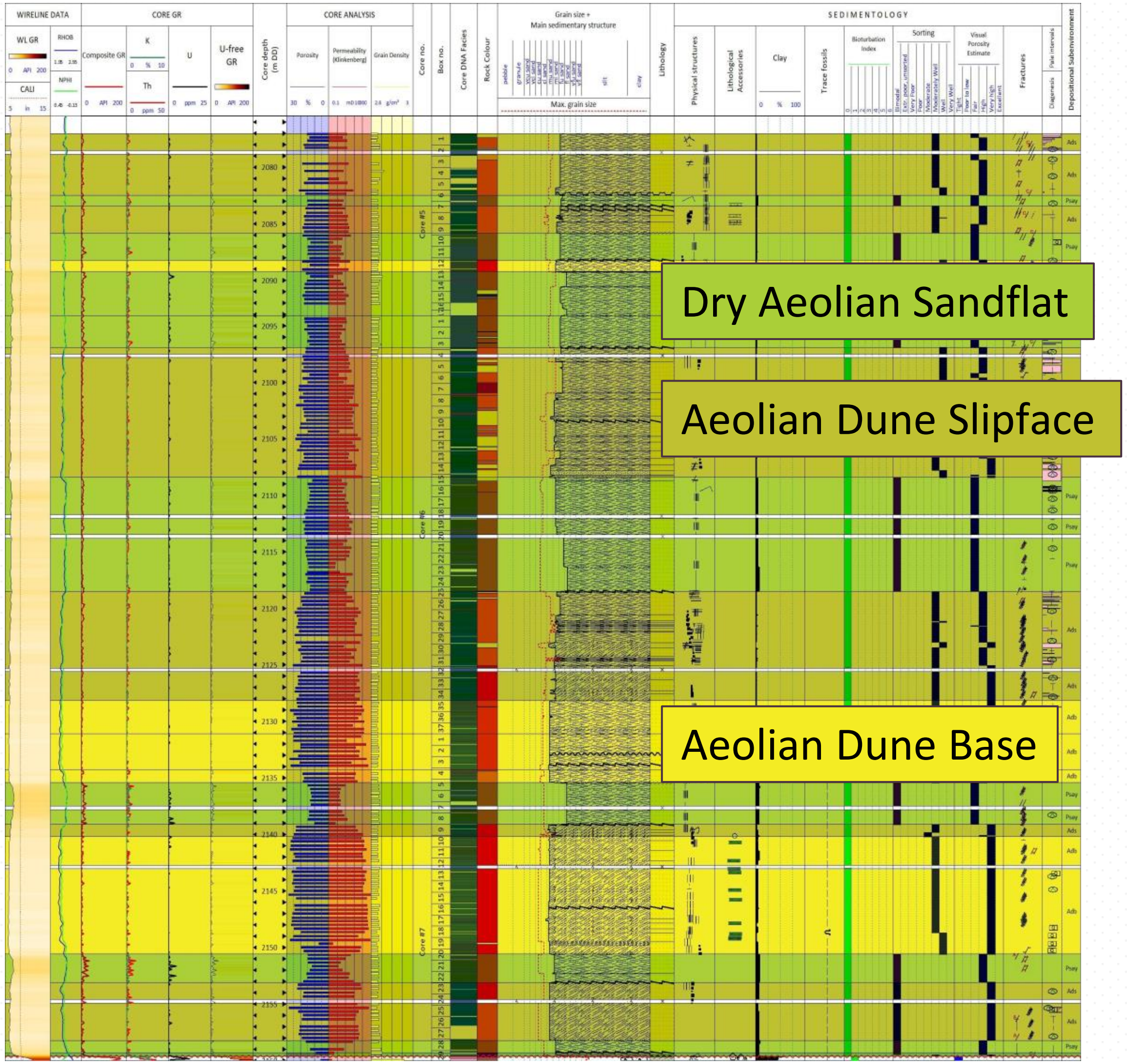
Dolomite



Illite



Summary



- Aeolian Rotliegend Slochteren Formation, with differentiation into Dry Aeolian Sandflat, Aeolian Dune Base and Aeolian Dune Slipface sub-environments
- Reservoir matrix properties linked to depositional facies
- Role of diagenetic cements minor, despite local effects (e.g. quartz-cemented zones)
- Best flow intervals in Aeolian Dune Base sandstones
  - Medium sand
  - Moderate impact of compaction and low to moderate cementation
- This applies to plug scale; lateral connectivity on km-scale uncertain
- Additional heterogeneity by fractures, particularly deformation bands

How does the Rotliegend reservoir perform?

- Petrophysics
- Well Test Interpretation
- Impact of Deformation Bands
- Formation Damage
- Integration

Permeability Measurements

Permeability is the key geothermal reservoir property!

➜ CoreDNA probe permeability

- ➜ Every 3cm, interpolated to 1 cm, performed on uncleaned core

➜ Routine air permeability

- ➜ Every 33cm, 240 horizontal & 80 vertical plugs

➜ Klinkenberg air and brine permeability at reservoir conditions

- ➜ 10 horizontal plugs for each

➜ Mercury-Injection Capillary Pressure (MICP/HPMI)

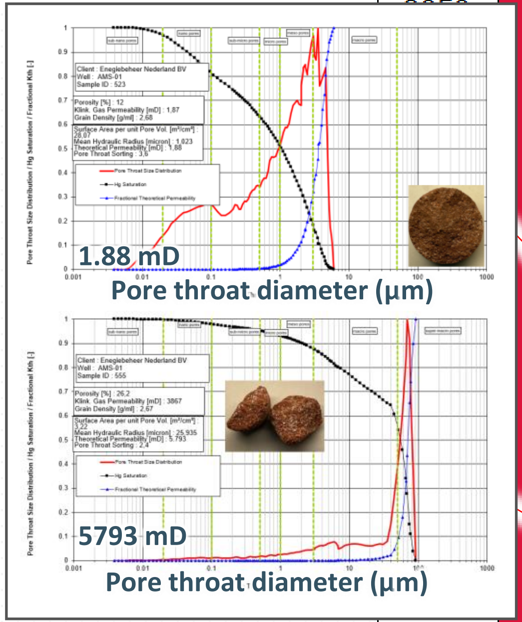
- ➜ Pore-throat diameter => Theoretical permeability

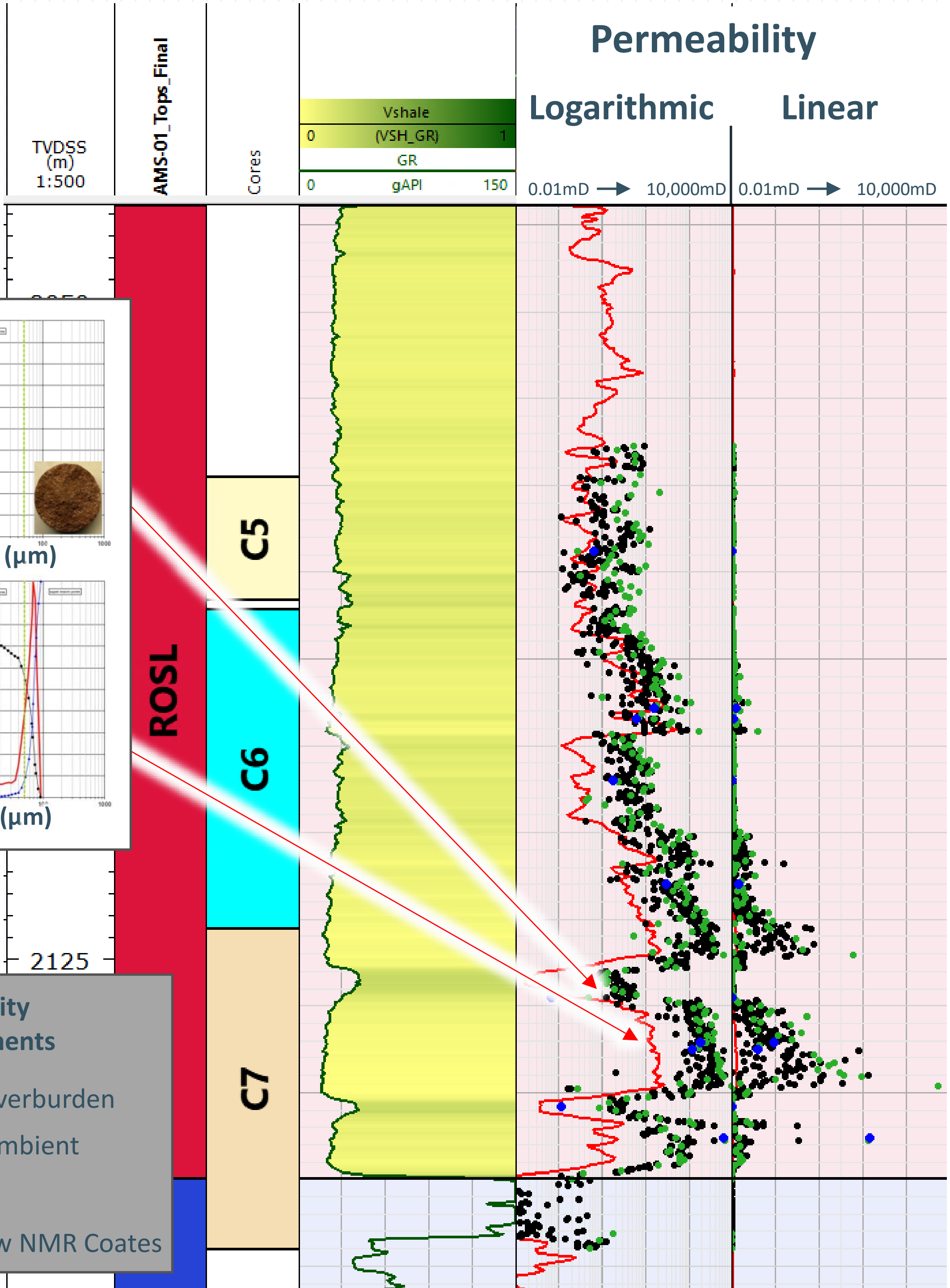
➜ NMR logs

- ➜ Timur-Coates model yields permeability

➜ Well test

- ➜ Transmissivity (permeability * reservoir height)





Core-to-log integration – Why?

Log domain

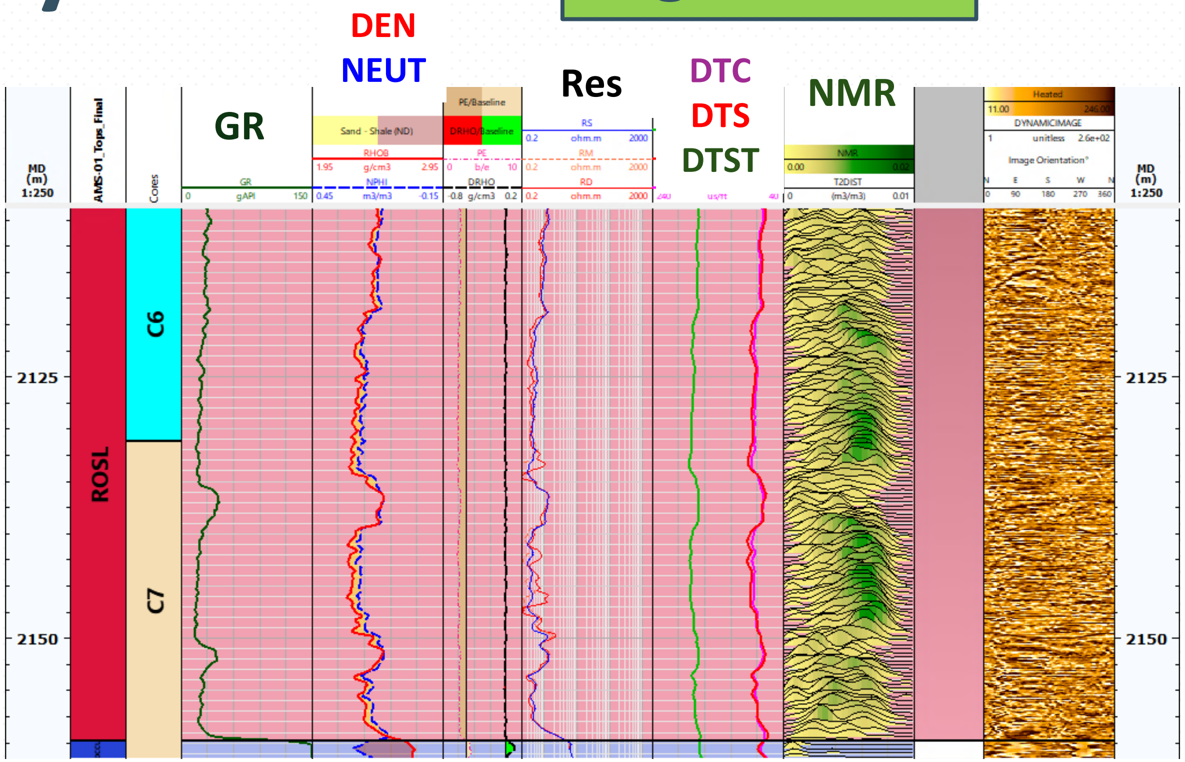
➜ Logs are acquired under reservoir conditions

➜~82 °C & ~168 bar isostatic stress

➜ Most core data under ambient conditions

➜Correct (ambient) core data (as good as can be done) to reservoir conditions

➜ Use core data corrected to reservoir conditions to calibrate & constrain the log derived petrophysical interpretation



Core domain

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Correct (ambient) core data to reservoir conditions

Core domain

- Routine core analysis (RCA):
  - Ambient conditions
  - **240 horizontal plugs**
  - Helium porosity and gas/air permeability

Core porosity

Stressed core porosity

Stress correction for core porosity

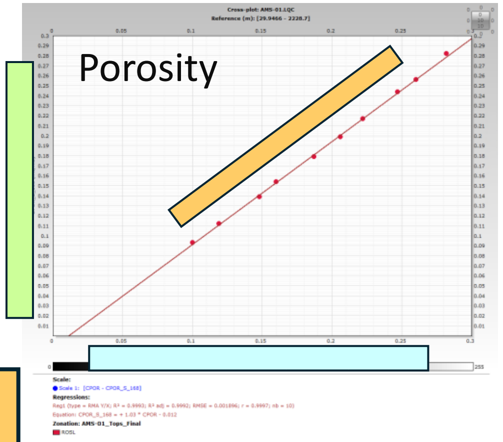
Stress & brine corrected poro-perm relationship

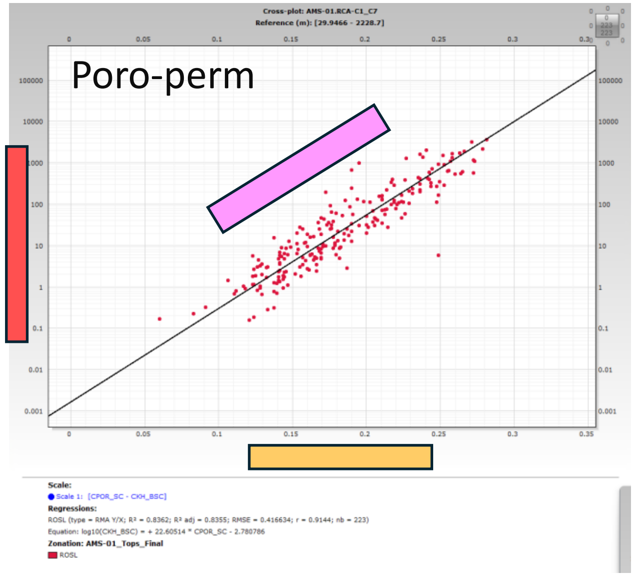
Core gas/air permeability

Stressed core brine perm

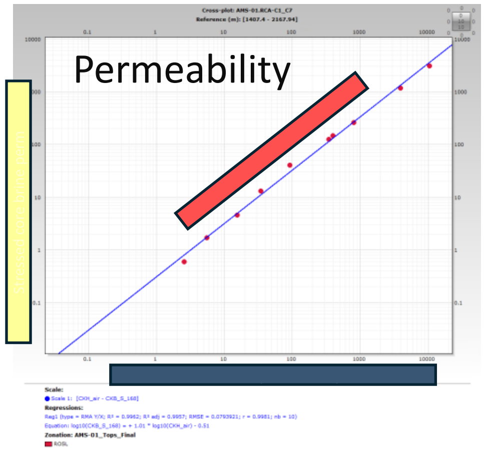
Stress & brine correction for core air permeability

$$k_{SB} = \mathbf{0.31} * k_{air}^{1.01}$$





$$PERM = 10^{22.6*POR-2.781}$$



- SCAL:
  - 10 plugs: stressed core porosity (168 bar)
  - 10 plugs: stressed core brine permeability (168 bar)

Log domain

Calibrate logs to corrected core data

Stress & brine corrected core permeability

Stress corrected core porosity

Calibrate

Log derived total density porosity

Permeability is logarithmic in nature. Add lognormal noise to better capture the spread in values

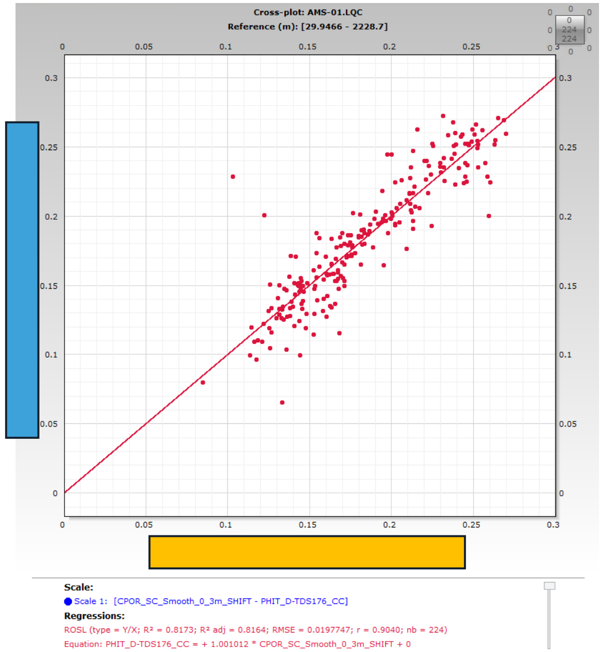
Intermediate log permeability

Stress & brine corrected final log permeability

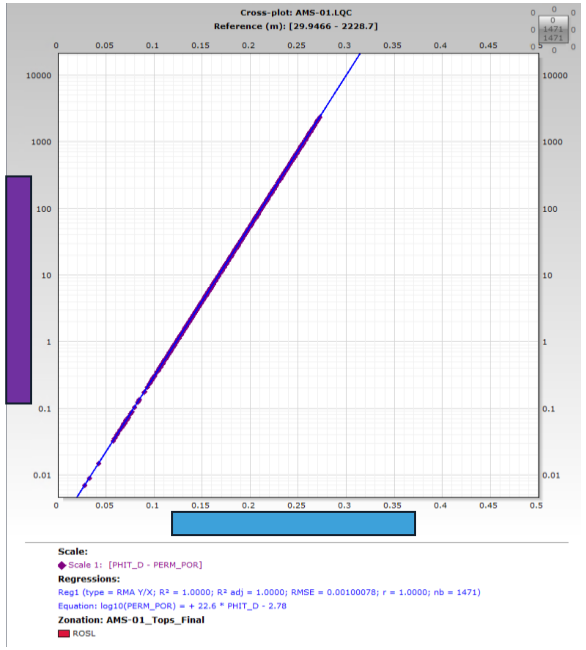
Apply to log derived porosity

Stress & brine corrected poro-perm relationship

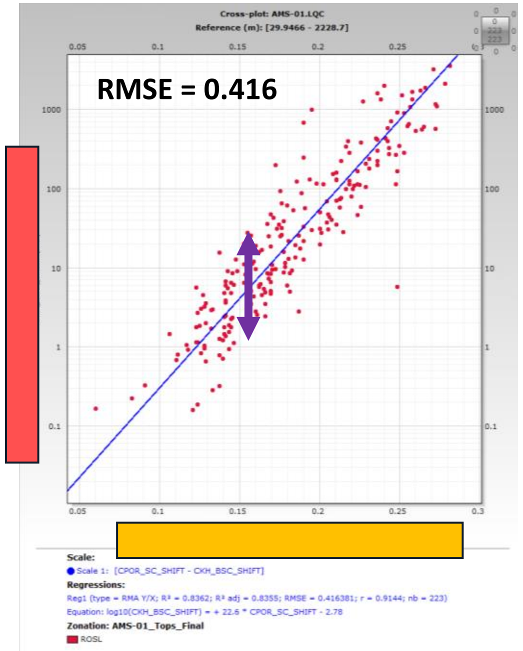
Log Por vs core Por



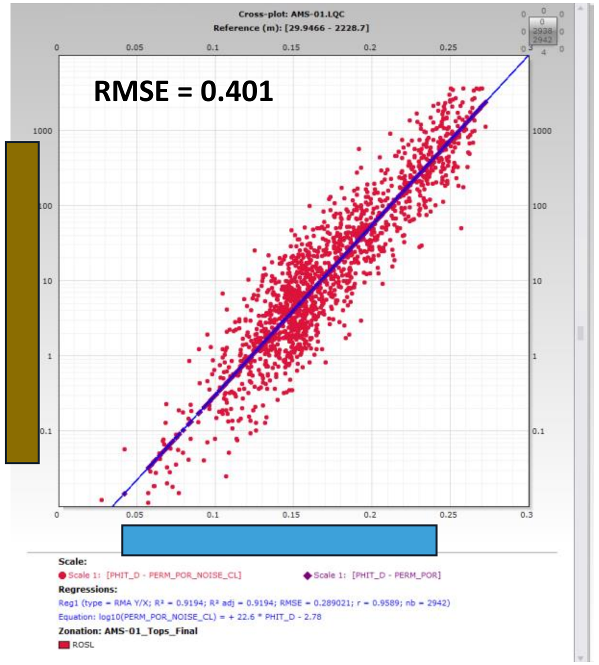
Log poro-perm



Core poro-perm



Log poro-perm



NMR log and calibration

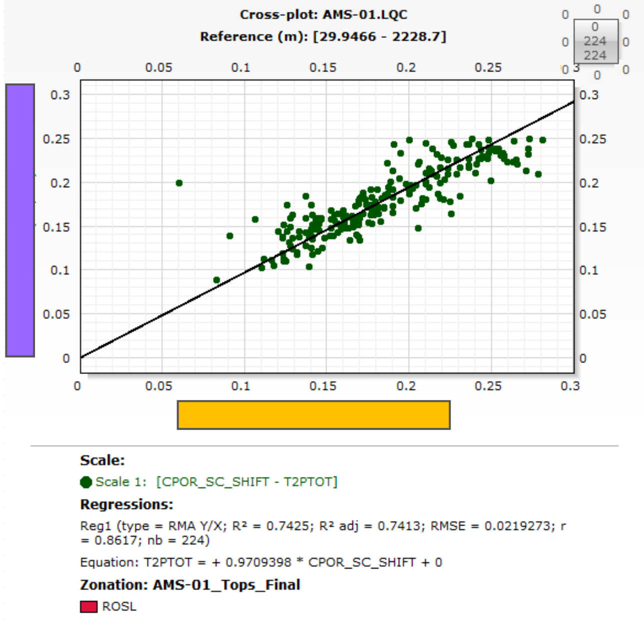
- ➜ Measures T2 distribution
- ➜Bound Volume & Free Fluid Volume calibrated to core data
  - ➜Clay bound water/CBW cutoff: **2ms**
  - ➜Capillary bound water/BVI cutoff: **7ms**
- ➜ Gives independent porosity and permeability measurements

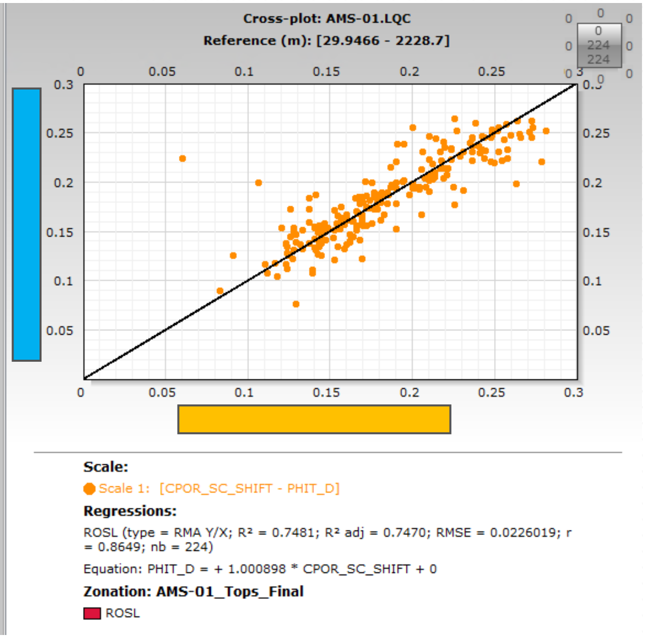
- ➜ NMR total porosity and Log derived total porosity in agreement.

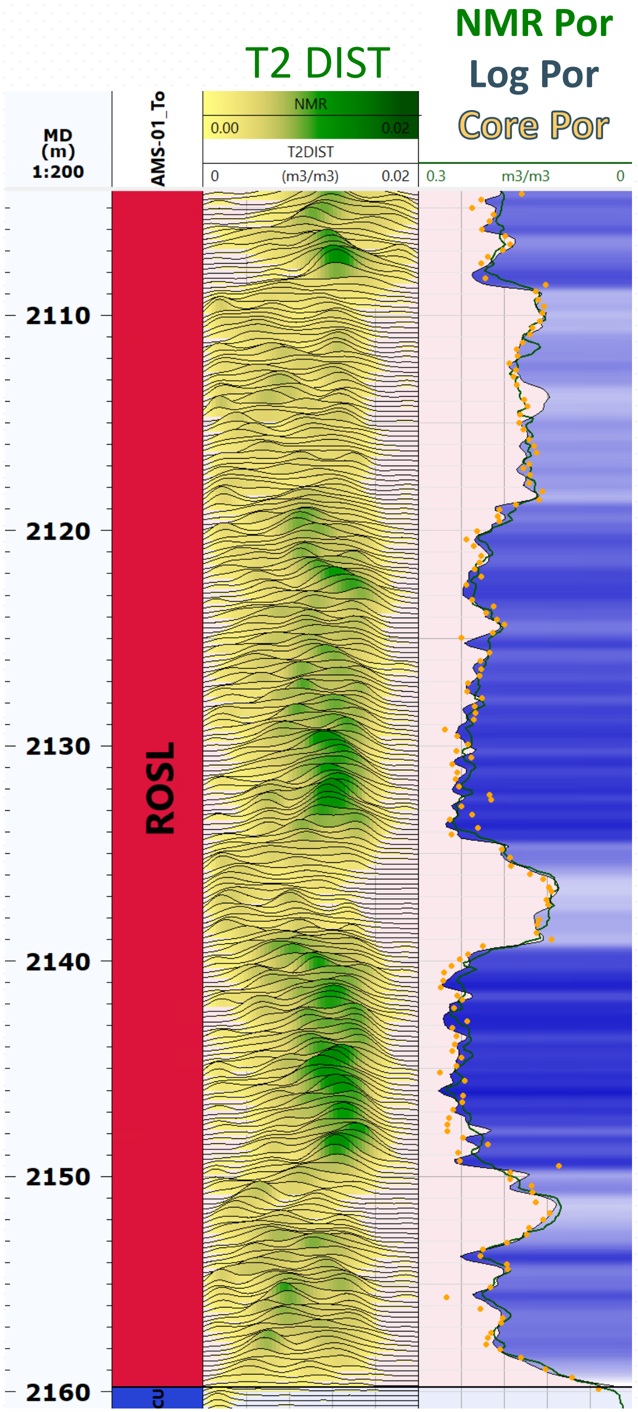
Core calibrated total density porosity

Stress corrected core porosity

Total NMR porosity

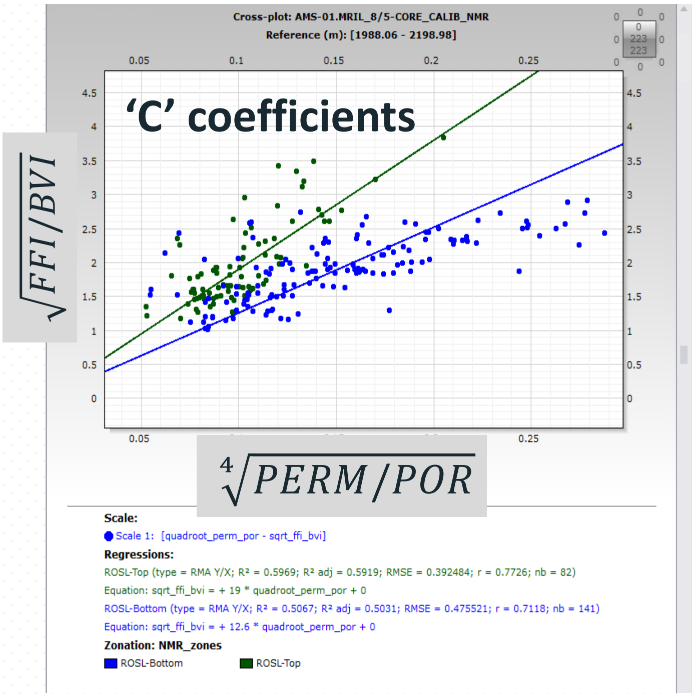


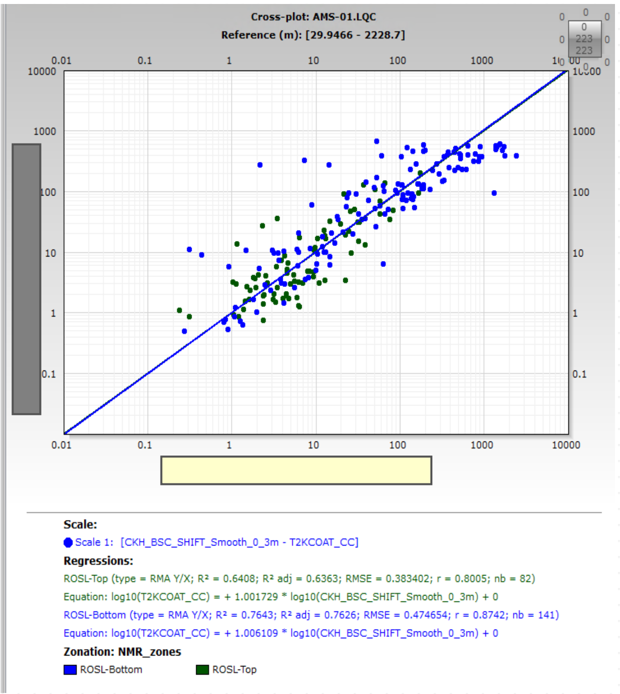




NMR log calibration

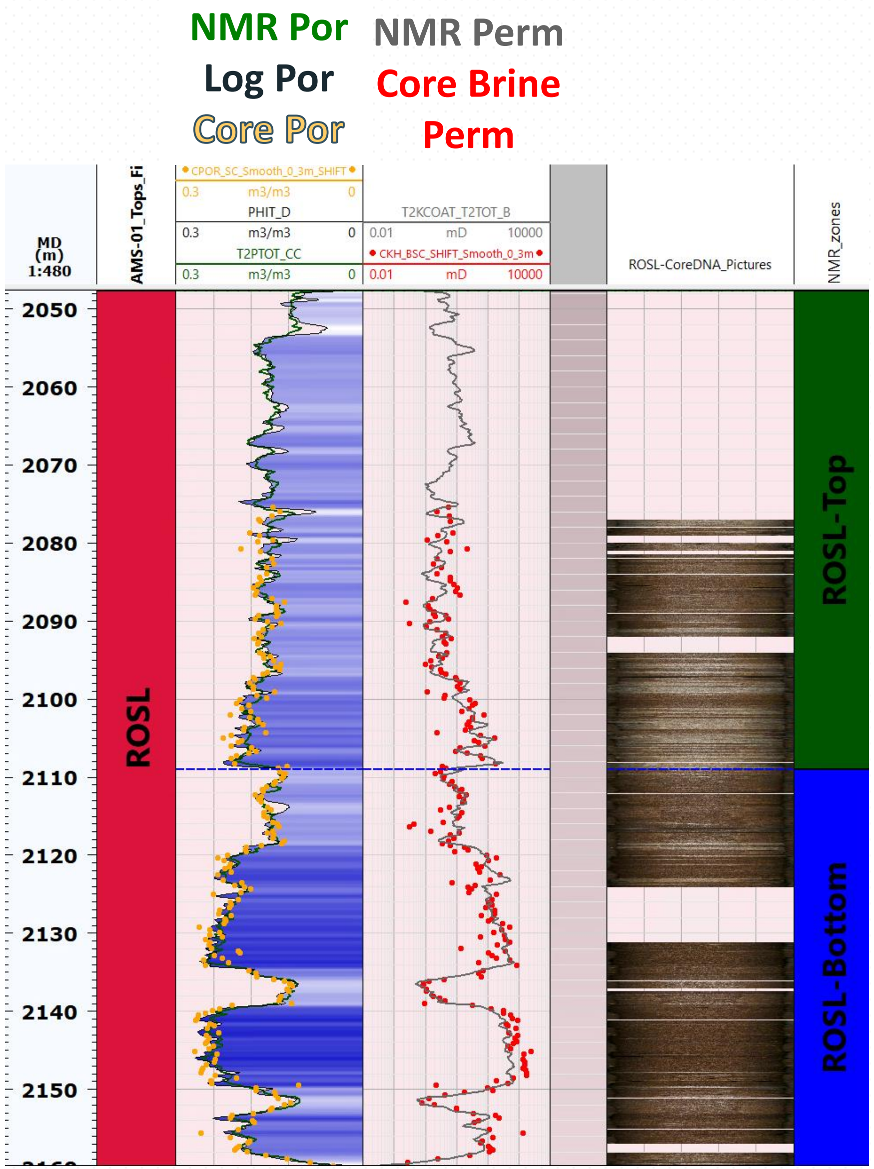
- ➜ Use Timur Coates equation to calculate NMR Perm.
  - ➜ $PERM_{TC} = \left(\frac{FFI}{BVI}\right)^2 * \left(\frac{POR}{C}\right)^4$
- ➜ Calibrate to brine permeability by modifying 'C' parameter.
  - ➜ $\sqrt{\left(\frac{FFI}{BVI}\right)} = C * \frac{\sqrt[4]{PERM}}{POR}$ ➜ Using calibrated NMR log & reservoir conditions core data
- ➜ ROSL is divided into 2 zones (Top & Bottom) for 'C' calibration.
  - ➜ Color & Fe?





Brine calibrated NMR perm

Stressed corrected core brine perm



	ROSL-Top	ROSL-Bottom
C	19	12,6

Core-to-log integration - Results

➔ Average stress corrected porosity: **17%**

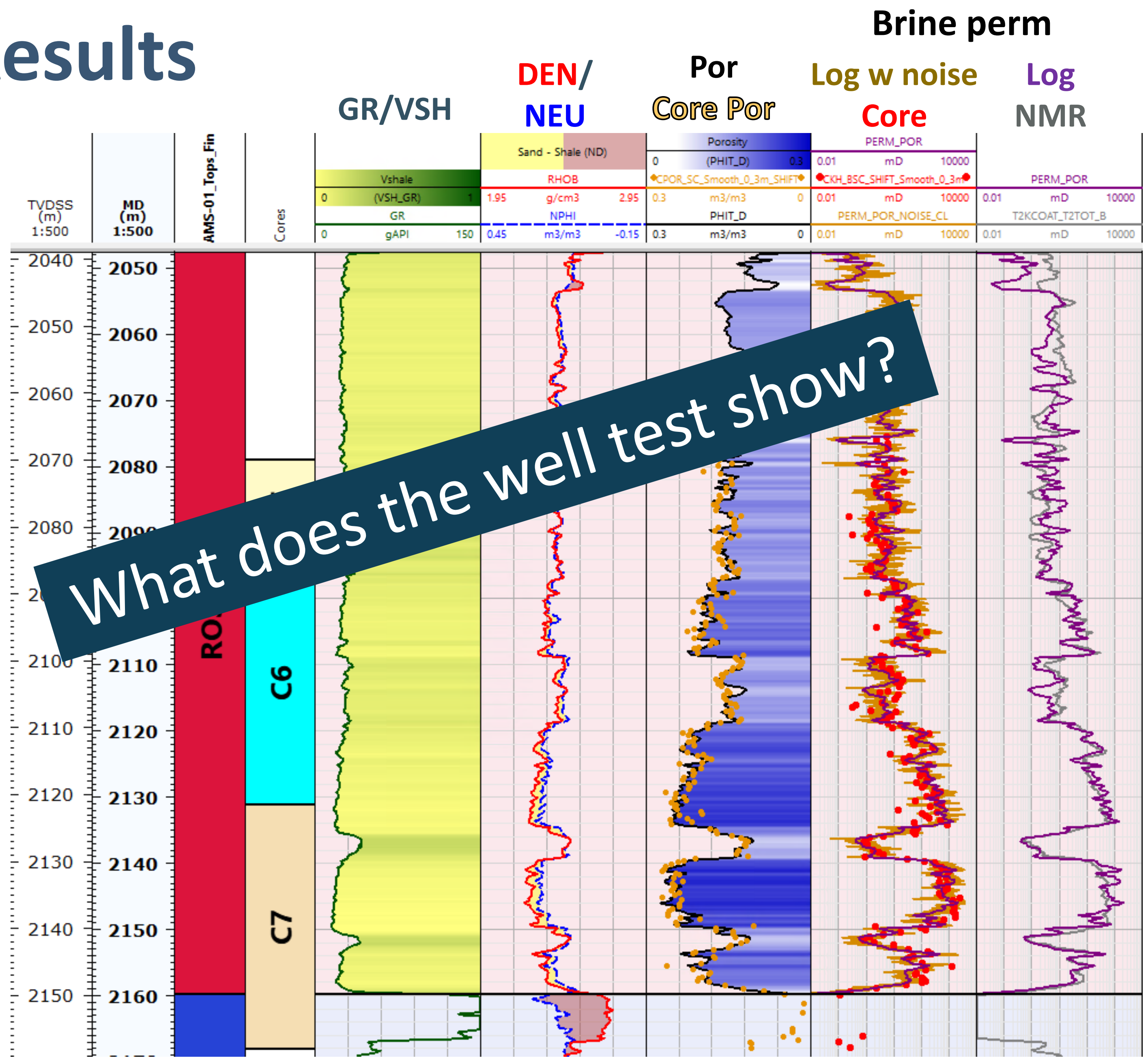
➔ Applied core derived stressed brine poro-perm relationship to log domain.

➔ Introduction of lognormal noise also introduces spread in final averaged log permeability.

➔This variability is also observed in probe permeability measurements.

➔Monte Carlo approach for permeability averaging (1000 runs)

➔Average horizontal brine permeability of matrix at reservoir conditions: **~150mD (~1/3rd of air perm)**



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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

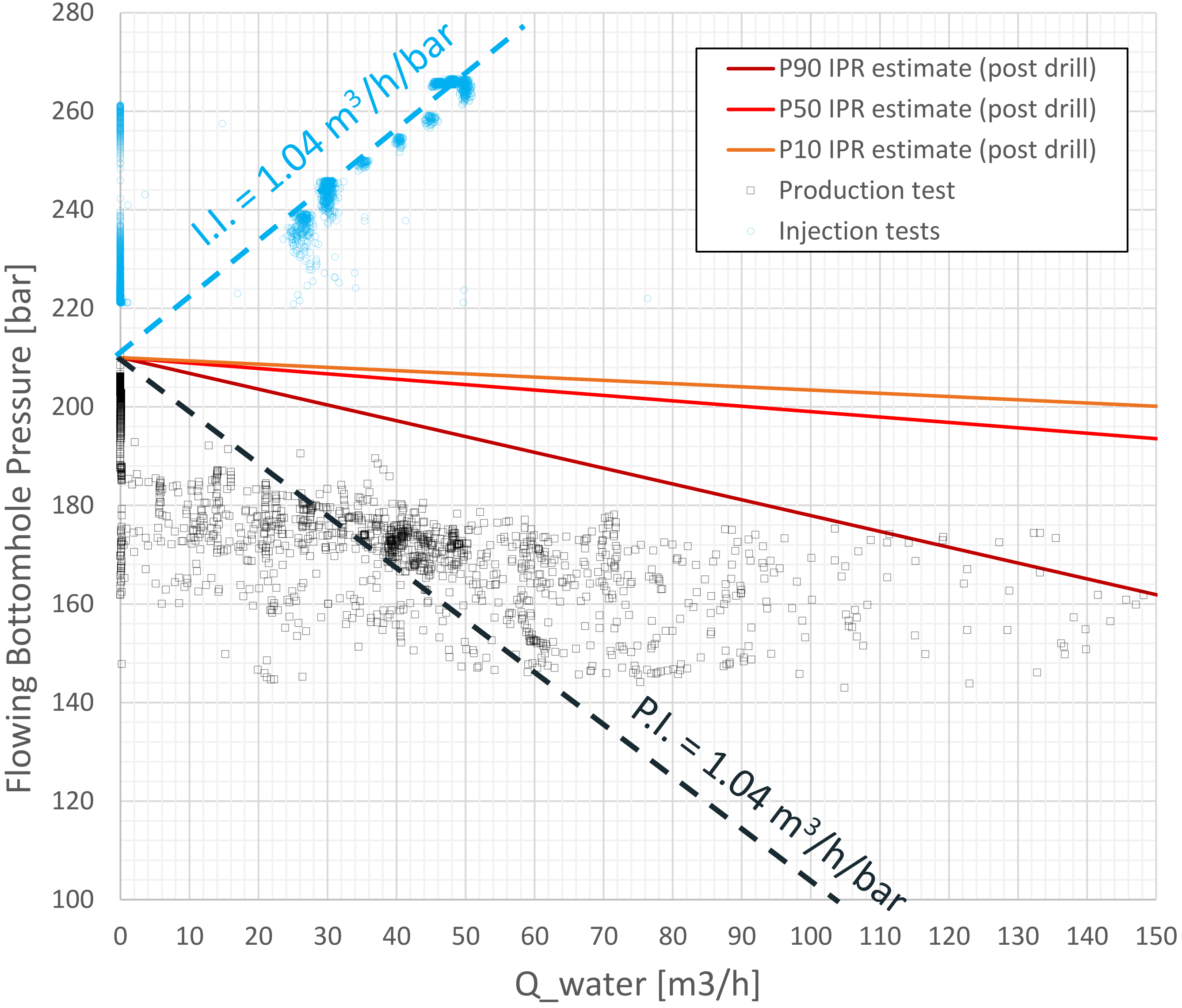
Injection test:

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

AMS-01 test results

- Where the objectives met?
  - Determination of P.I. / I.I. → **yes!**
  - Determination of skin and kh → **no…**

- Rather disappointing flowrates during the test. Why?
  1. Very low (matrix) permeability?
  2. Very low height?
  3. Non-matrix permeability?
  4. Very high skin?



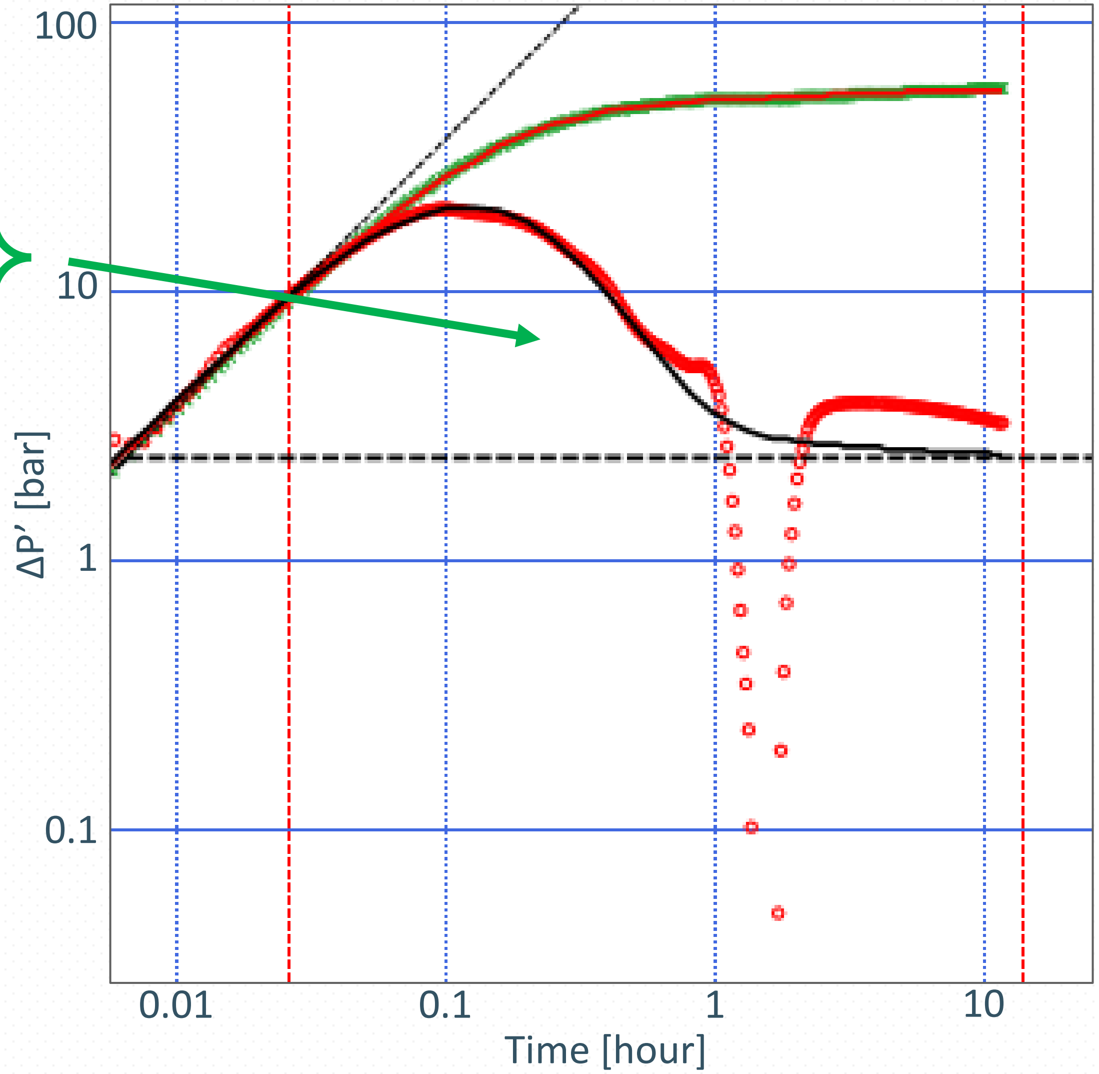
Pressure Transient Analysis (PTA)

1. PTA production test: *not possible* due to fluctuating flowrates.
2. PTA buildup test: *highly uncertain* because of severe wellbore storage effects (due to absence of downhole shutin). kh = 3.1 Dm and Skin = 7.7 (but uncertain!!)
3. PTA injection test: *highly uncertain* due to viscosity effects caused by injection of cold water → propagating cold front. kh >> 1.7 Dm but most likely significantly higher.
4. PTA fall-off tests: *not possible* due to severe wellbore storage effects due to absence of downhole shutin (vacuum, condensation, vaporisation, etc), further complicated by viscosity effects in reservoir.

Recommendation for future wells:

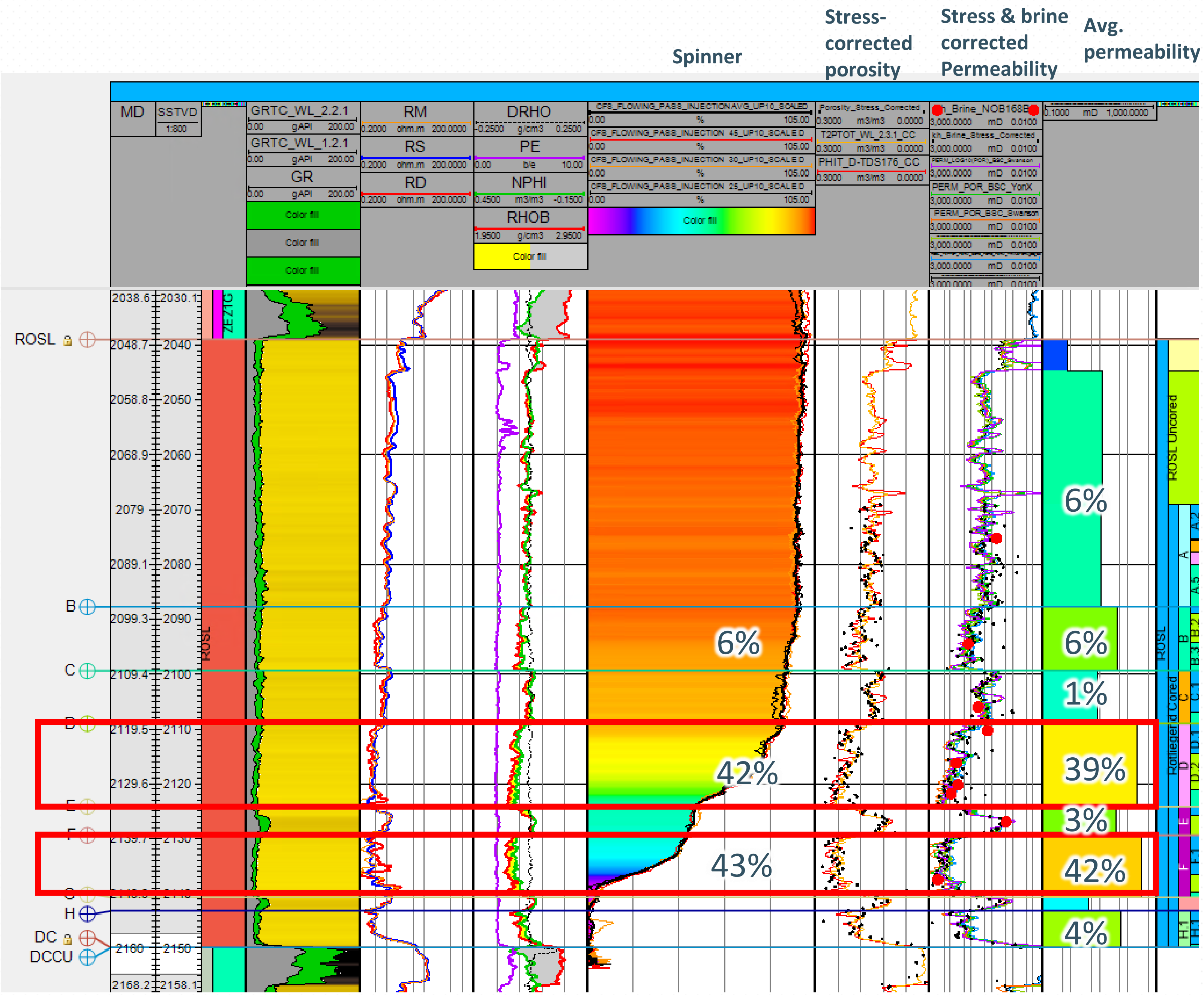
- Downhole shutin → implemented on all SCAN wells after AMS-01
- Focus on production / buildup test (to eliminate T distortions)

Buildup AMS-01



Transmissivity Distribution

- ➔Spinner run during injection test
- ➔85% of injected water into two flow units with highest measured porosity and permeability
- ➔Relative flow contribution consistent with calculated relative transmissivity (kh) for each unit



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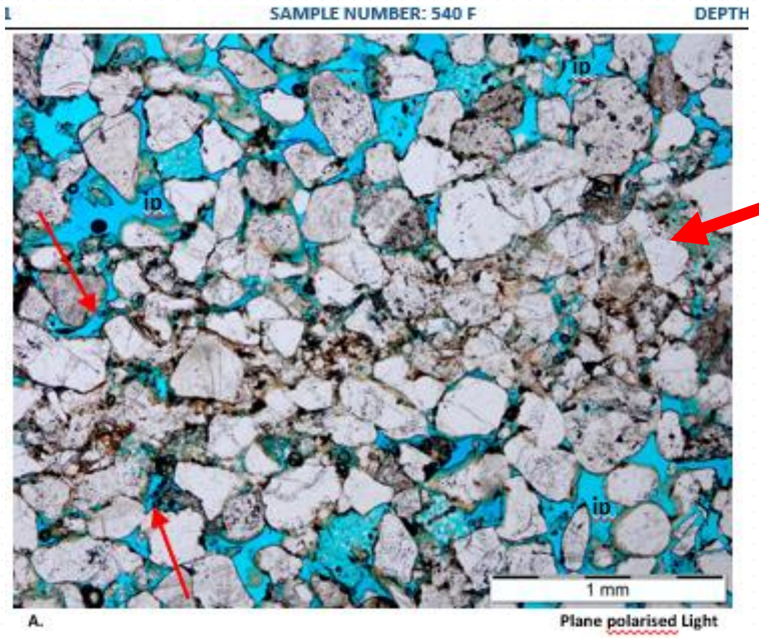
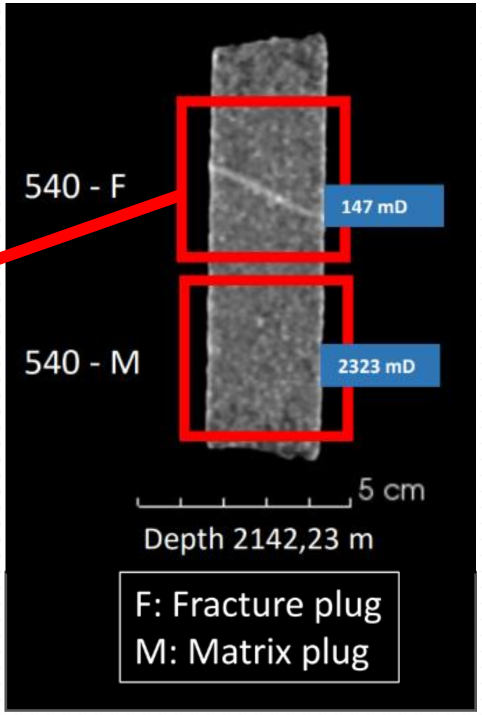
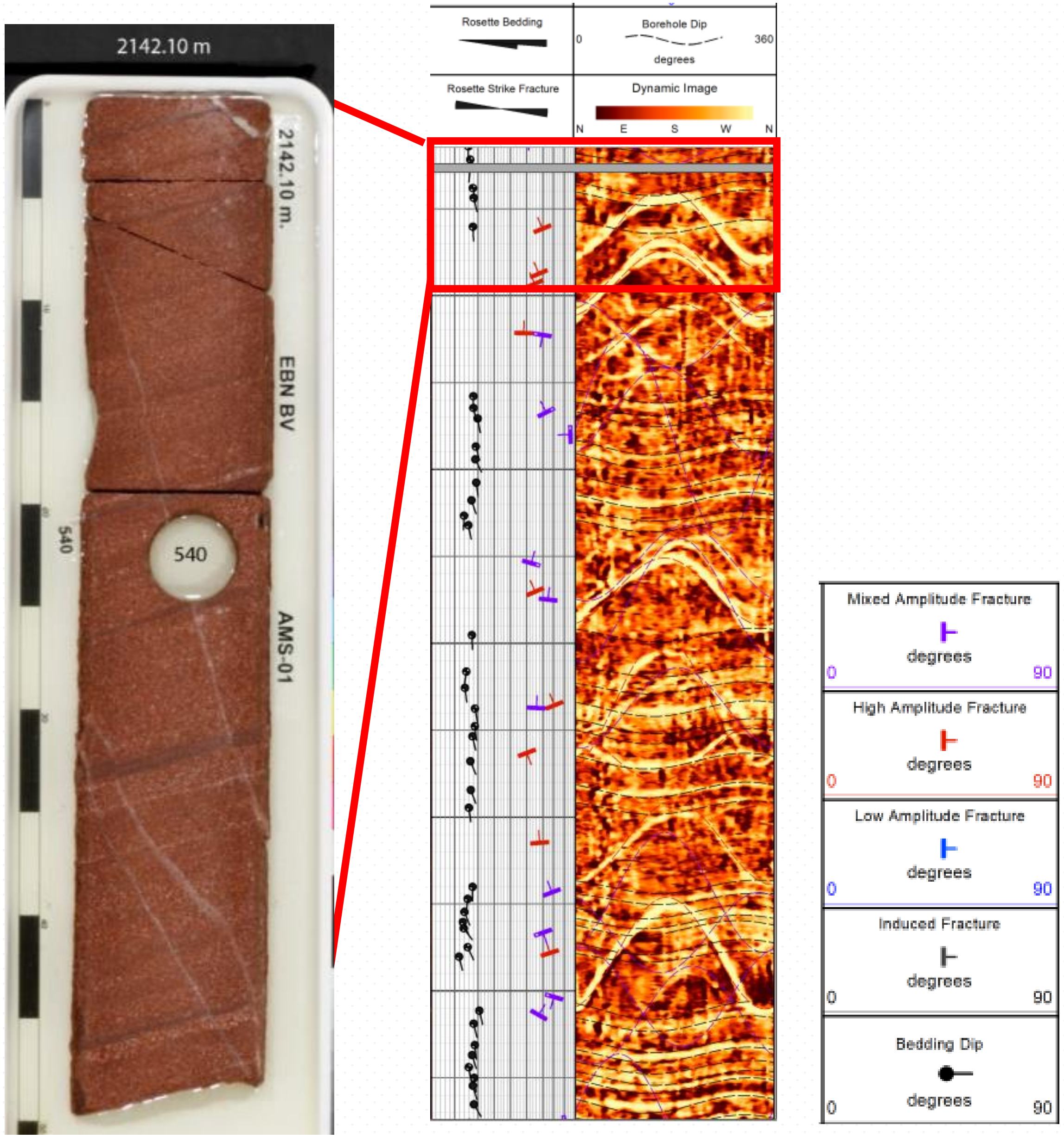
Deformation bands

- ➔Large number of high-angle features in acoustic image log and core
- ➔EW to NE-SW trending conjugate set
- ➔Highest density in highest permeability units (up to 3 bands/meter)
- ➔Deformation bands are significantly less permeable than matrix (~ 25x). But what is the net effect on productivity?

Dynamic acoustic image:
Light means high velocity = low porosity

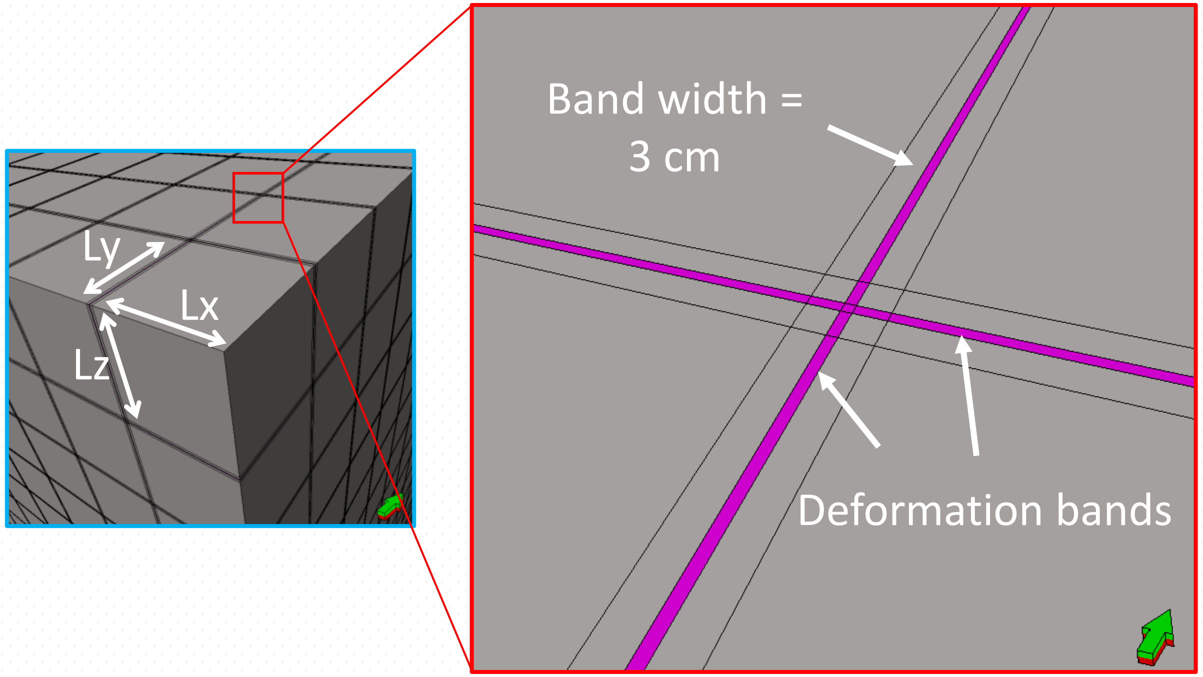


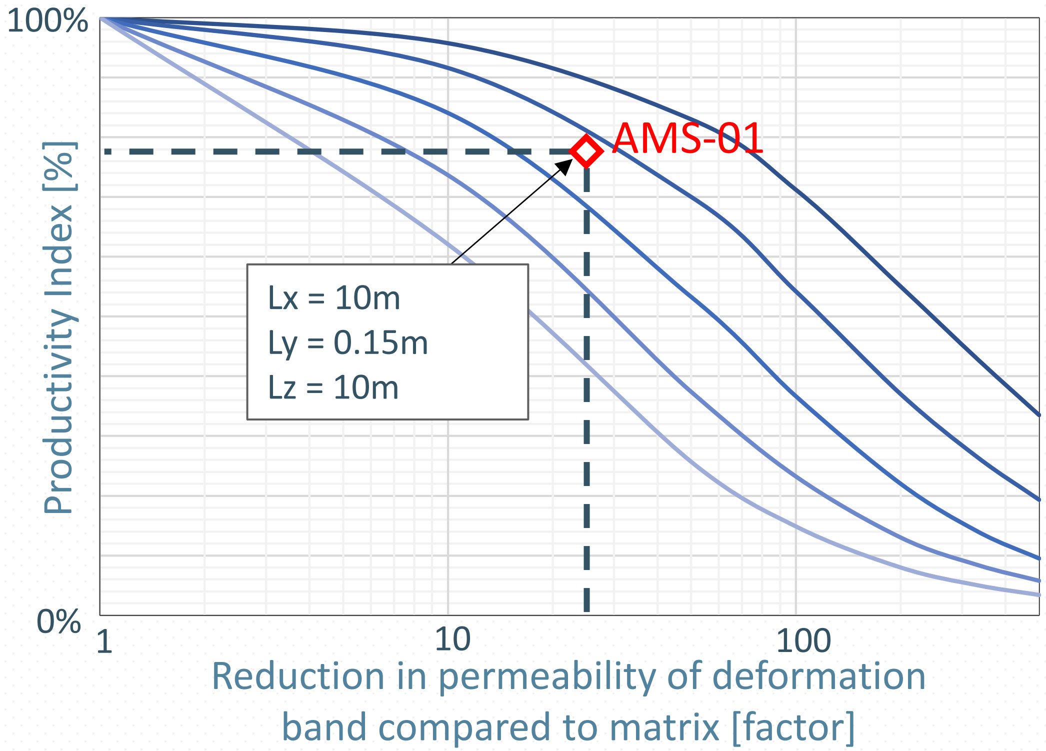




Deformation bands

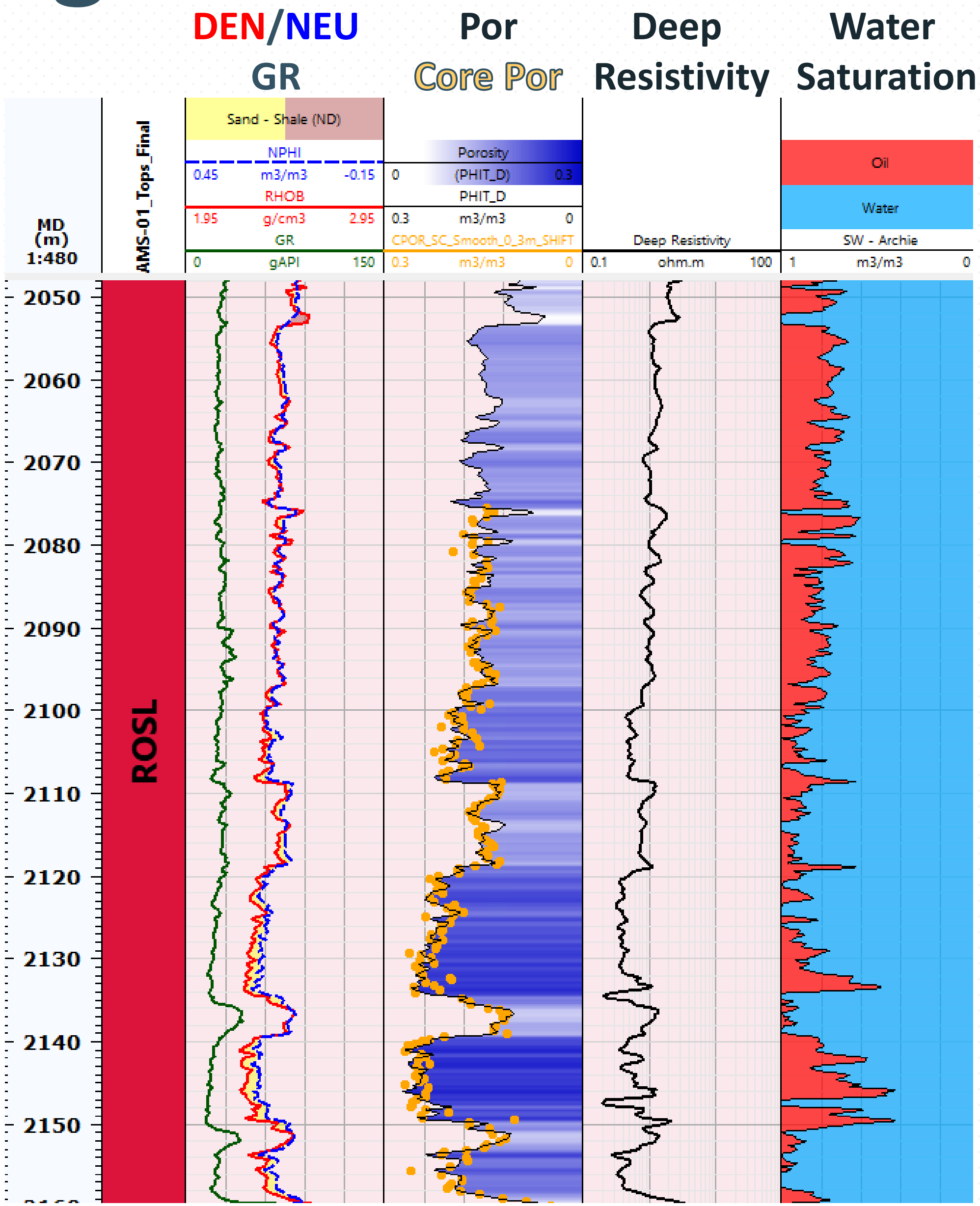
- Numerical model in Eclipse: impact of deformation bands on reservoir performance
- Result: If perm in deformation bands is reduced by a factor 25, and Lx = 10, Ly = 0.15 and Lz = 10m, and band width = 3 cm, then **the reduction in P.I.> is 22%**.
- Overall ('composite') permeability after taking into consideration deformation bands = 150 mD x (78%) = ~ **120 mD => 13 Dm transmissivity**





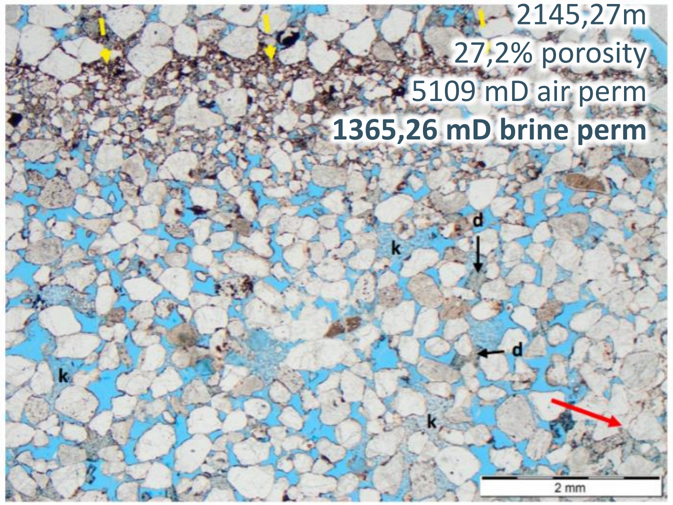
Formation damage

- **OBM seen in core**
- **3.5m3 OBM unaccounted for; seepage losses into reservoir**
- **Logs indicate presence of HC:**
  - Depth Of Investigation of deep resistivity: **~0.5m**
- **Water Saturation calculated using Archie equation**
  - Average Oil Saturation: 20%
  - In high perm zones: 50-60%
- **Perforations probably did not reach beyond invaded zone:**
  - Modelled 38-47cm perf. depth
- **Various formation damage studies performed:**
  - Special Core Analysis (relative permeability
  - OBM saturations,
  - OBM filtrate invasion

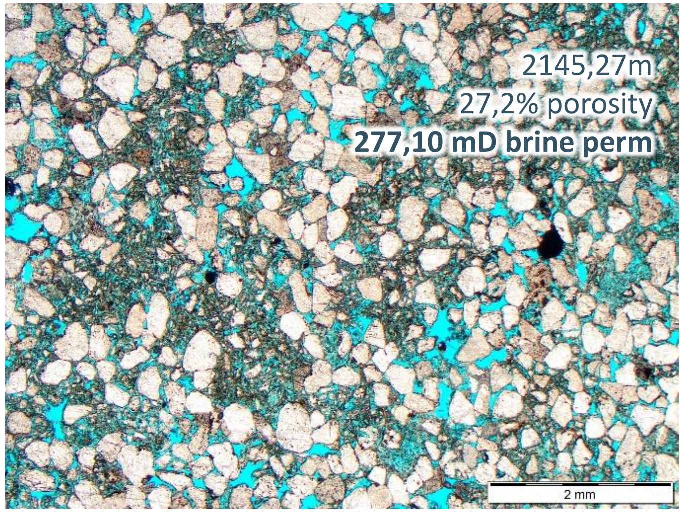


OBM filtrate invasion study

Initial sample

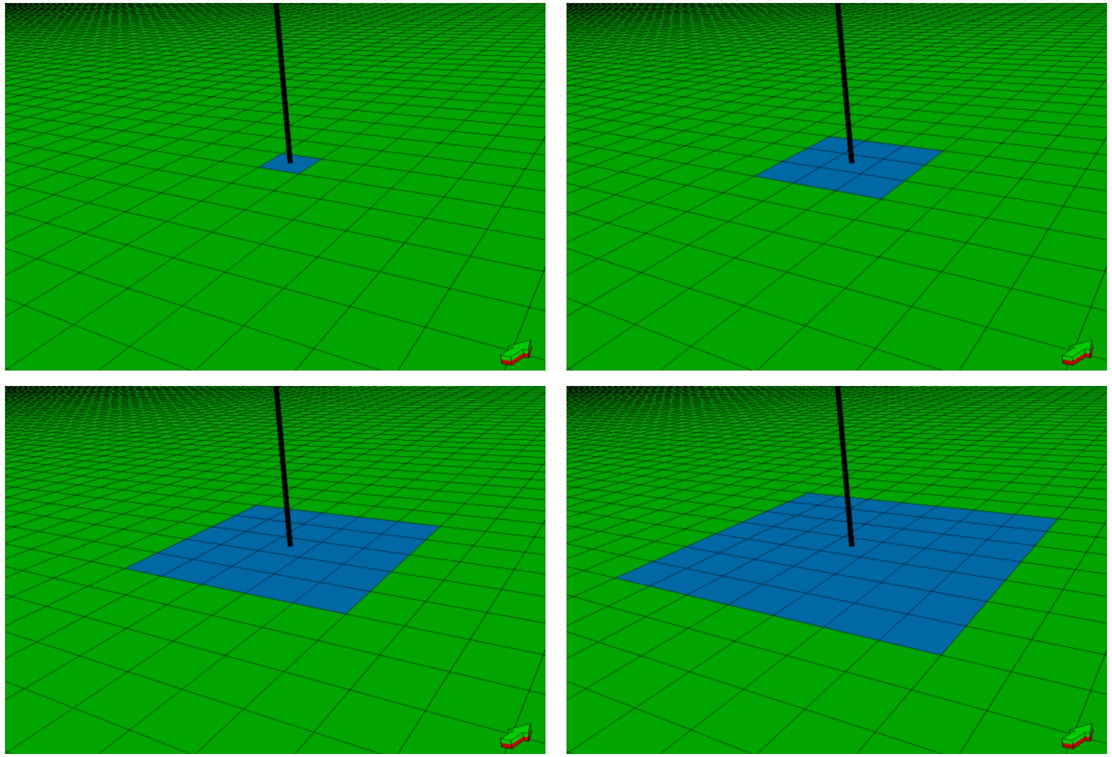


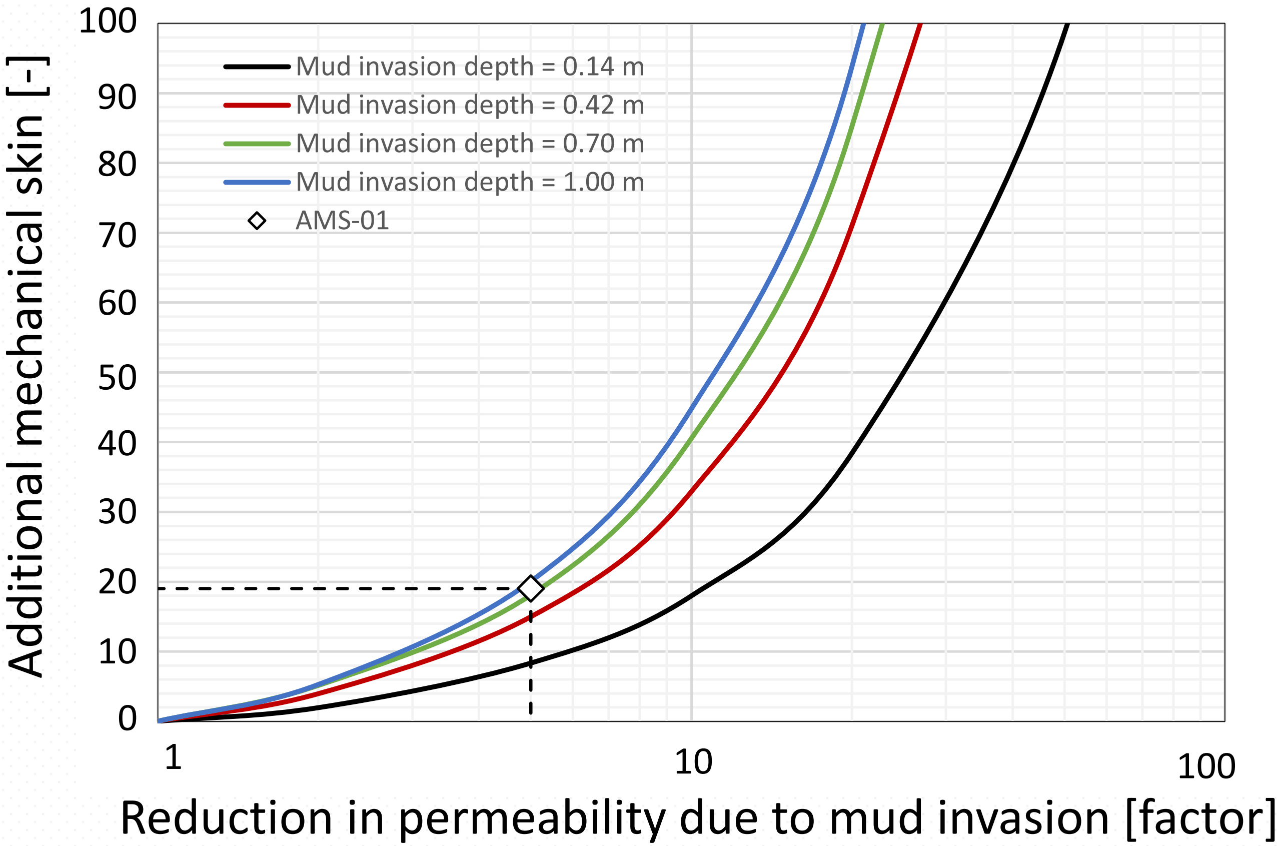
After formation damage study



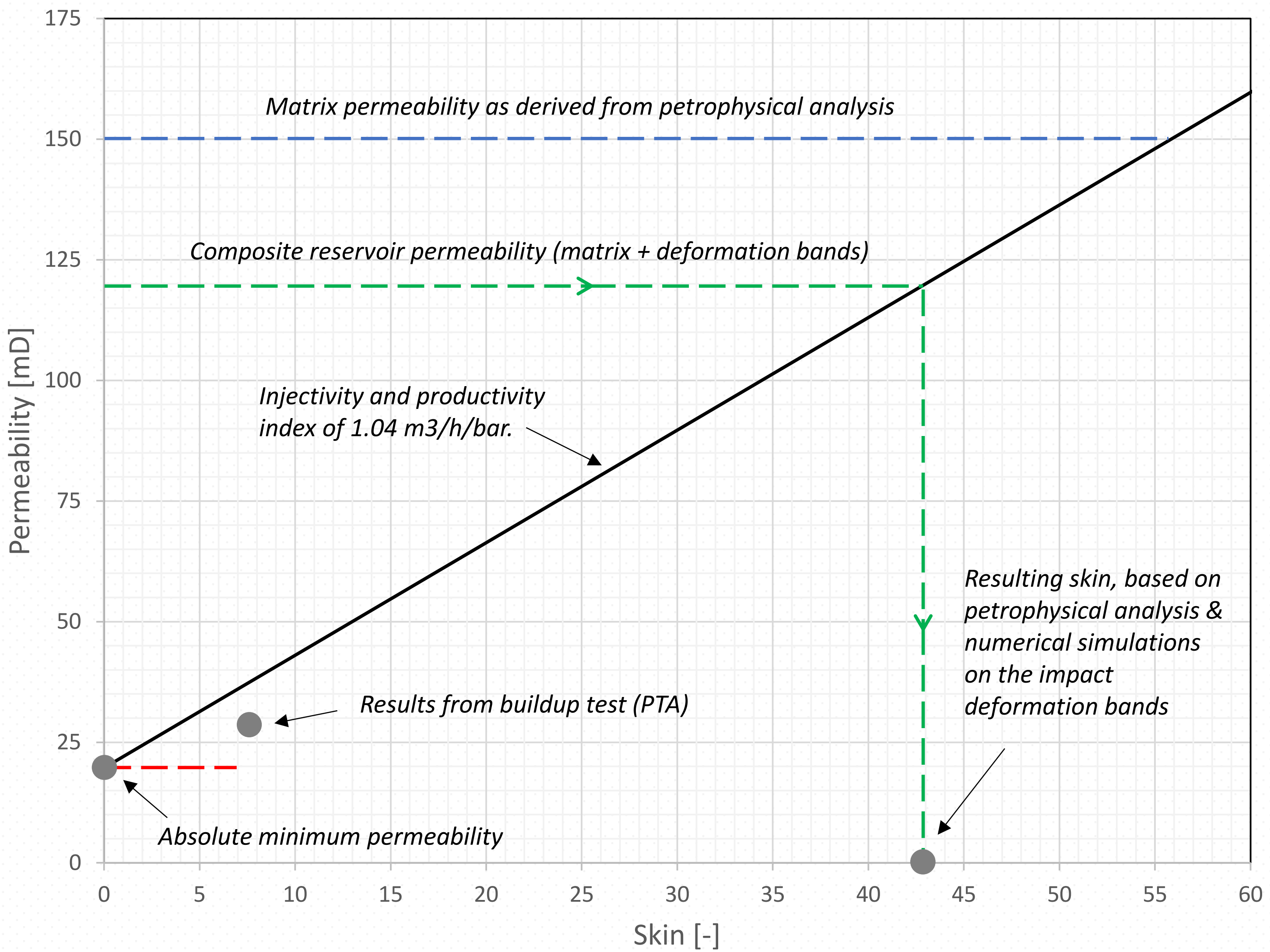
Formation damage

- Effect quantified in these studies: 20% of brine permeability remains (reduction in permeability is factor 5)
- Numerical modelling in Eclipse: impact of near wellbore reduction on skin
- Result: if reduction in permeability is factor 5 and mud invasion depth = 0.7 m, then *additional* skin = 20





Integration welltests + simulations



$$P.I.(or\ I.I.) = \frac{q}{P - P_{wf}} = \frac{2\pi \boxed{kh}}{\mu B_w \left[ln\left(\frac{R}{R_w}\right) + \boxed{S} \right]}$$

- Deformation bands as stand-alone hypotheses cannot explain the poor well performance.
- Numerical simulations: *additional* skin of 20 is likely (on top of ‘normal’ skin) → total skin of 20-30 (?)
- Additional skin of 20 to 40 (given all uncertainties w.r.t. fluid- and solid invasion) is not unrealistic

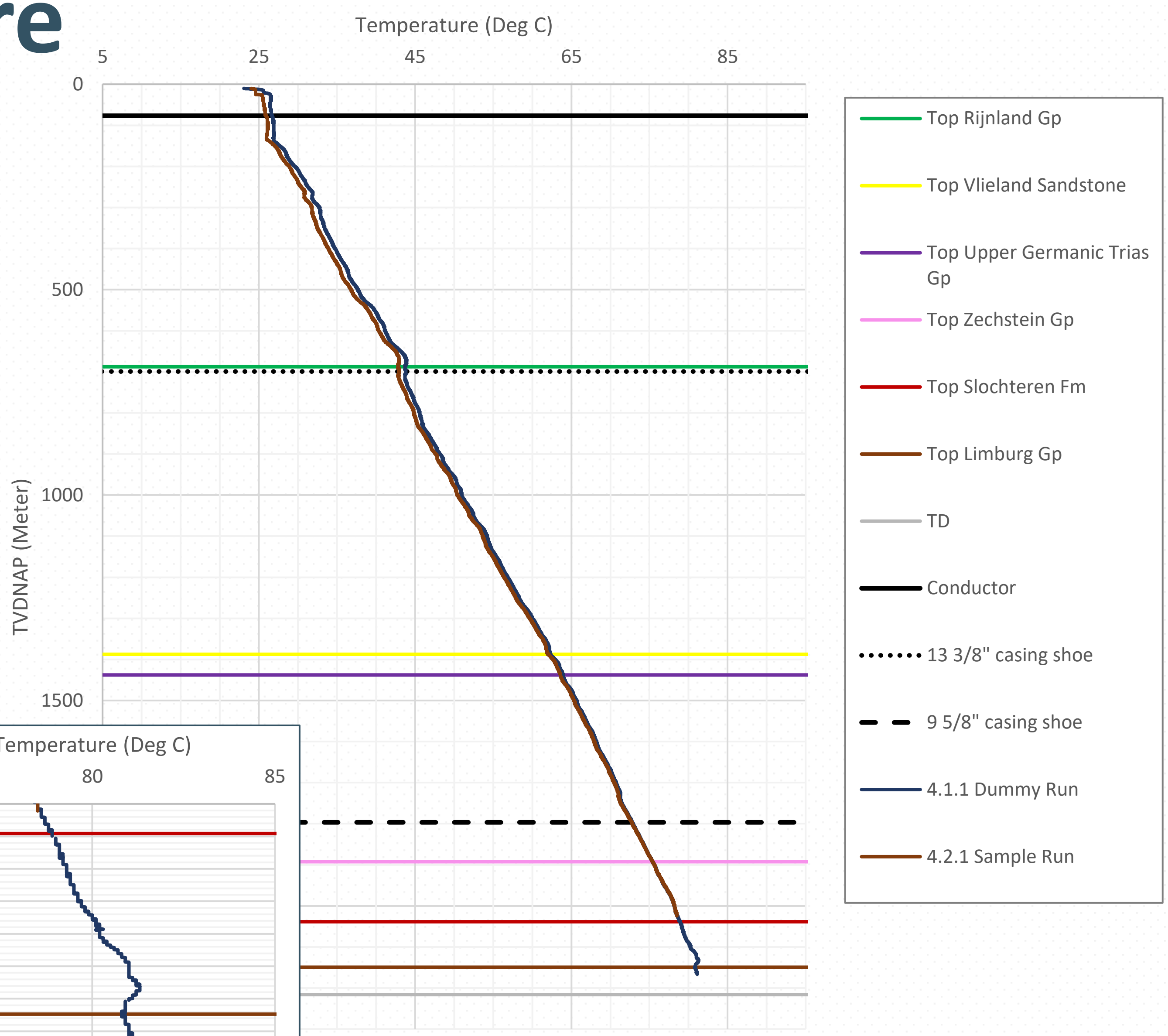
→ Mud invasion resulting in high skin is the strongest theory for disappointing flow rates

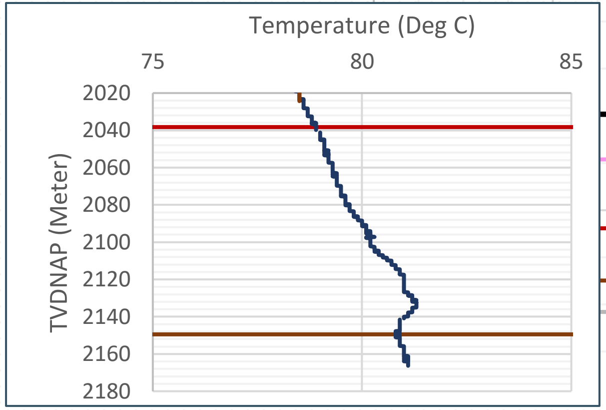
scan

What is the temperature and composition of the water in the Rotliegend aquifer?

Slochteren Temperature

- ➔Large amount of different temperature data acquired
- ➔82°C Slochteren reservoir temperature
- ➔Gradient of 33.7 °C assuming 10°C at surface
- ➔5°C higher than prediction using Bonté et al (2012) gradient
- ➔Thermal conductivity measured on core





12 hours after shut in

scan

Slochteren Fluid Composition

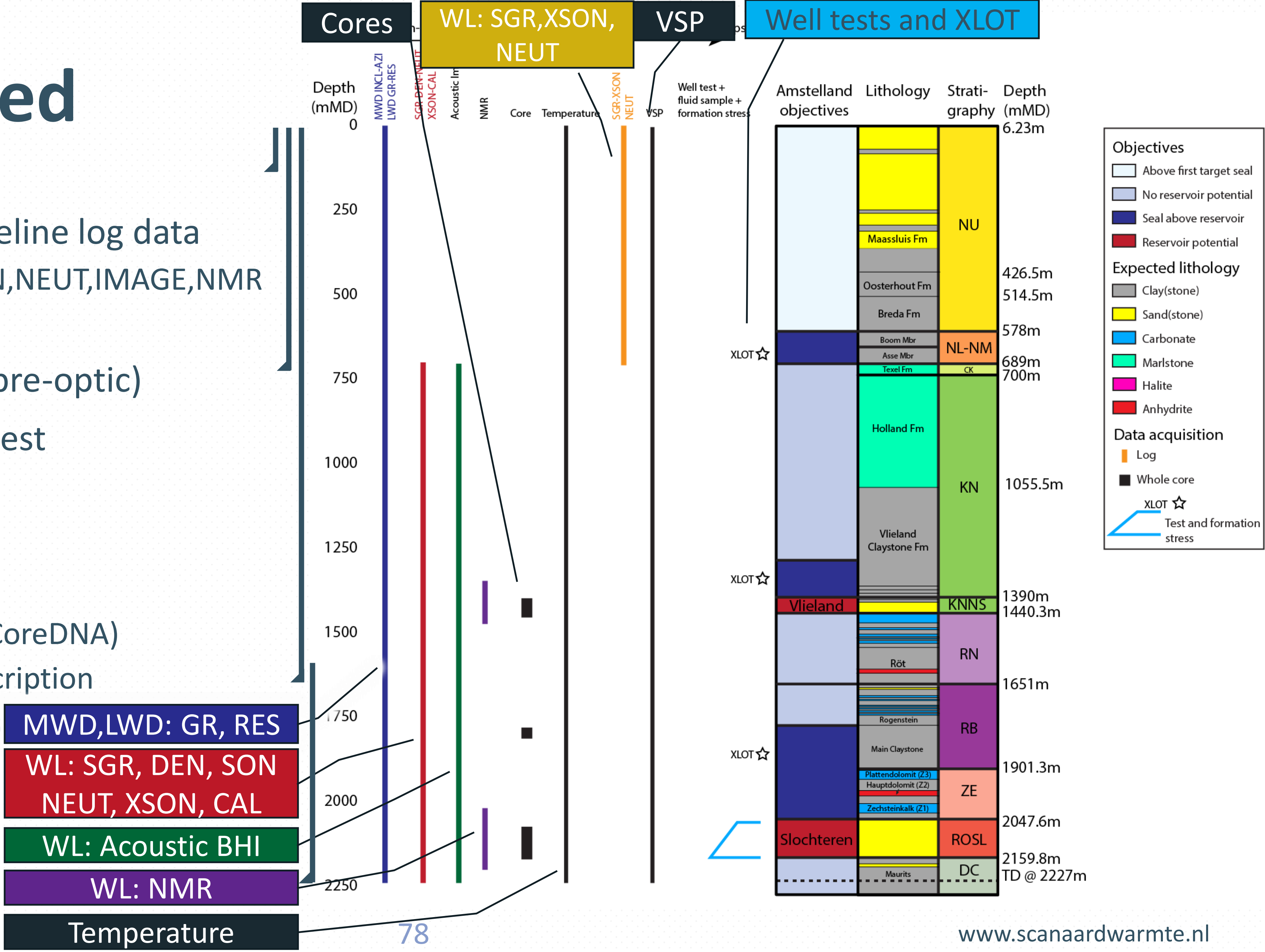
- ➔Formation water sampled downhole, at surface and extracted from core
- ➔Full compositional analysis
  - ➔TDS: 190 g/l
  - ➔Lithium: 23 mg/l
- ➔0.442 sm^3/m^3 dissolved gas
  - ➔Bubble point 88 bar
  - ➔Predominantly methane, some CO_2 and N_2, no H_2S

Wrap-Up & Special Announcement

- Wrap-up
- Special Announcement

Data Acquired

- ✓ →Cuttings
- ✓ →LWD and (OH/CH) wireline log data
  - ✓ →(S)GR,RES,XSON,DEN,NEUT,IMAGE,NMR
  - ✓ →Temperature
- ✓ →VSP (geophone and fibre-optic)
- ! →Production/Injection test
  - ✓ →PLT
  - ✓ →Fluid samples
- ✓ →Core (193m)
  - ✓ →Screening analysis (CoreDNA)
  - ✓ →RCA, SCAL, core description
  - ✓ →Geomechanical tests
- ✓ →XLOT (3x)

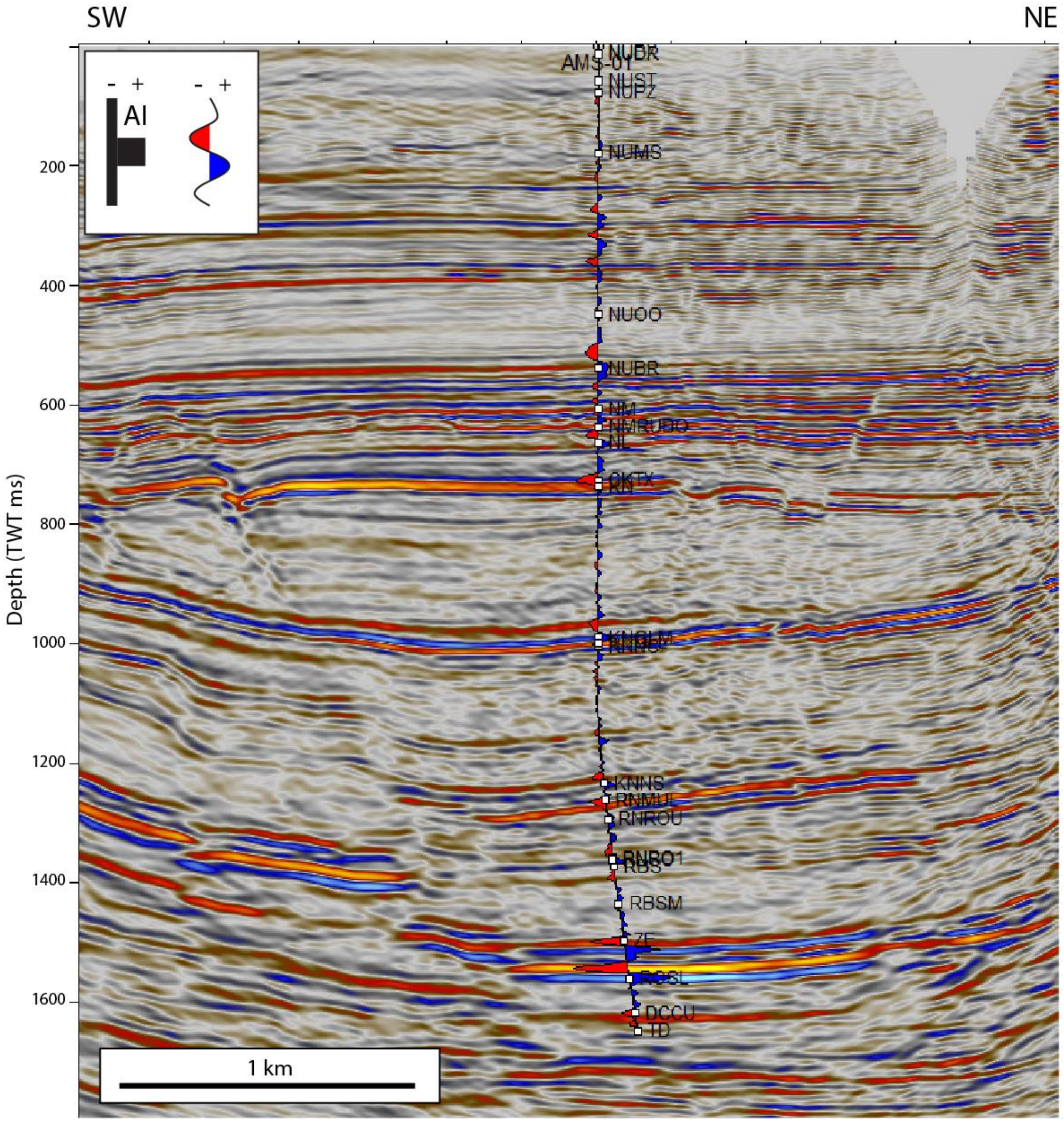


scan

Summary

- ➜ All data acquisition carried out as per plan
- ➜ 111m thick sand-dominated eolian Slochteren reservoir encountered
- ➜ Reservoir matrix properties controlled by depositional sub-environments, grain-size and composition, low control by diagenetic cements
- ➜ Average matrix brine permeability of ~150 mD
- ➜ Fluid flow somewhat affected by fractures, particularly deformation bands
- ➜ Overall "composite" transmissivity (permeability matrix - deformation bands * reservoir height) of approximately 13 Dm
- ➜ Well test without downhole shutin impossible to interpret with certainty
- ➜ Significant formation damage resulted in relatively low productivity during well test
- ➜ All data published on NLOG to evaluate regional geothermal potential

Seismic-to-well tie AMS-01 on 2D seismic line SCAN 056



scan

3D survey Amstelland area

Ministerie van Klimaat en Groene Groei

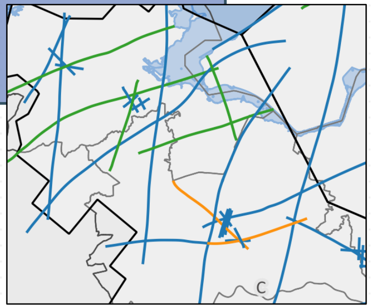
ebn

TNO

Exploration Order: 2D, drilling a well, 3D

Regional Exploration

- Regional 2D-seismic
- 2D-seismic to plan a well

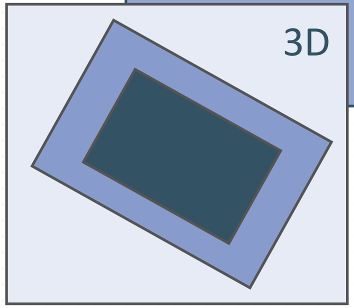


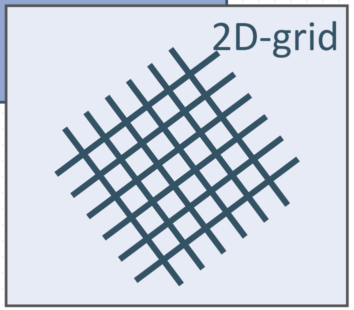
Drilling an exploration well

- Research-/
- Exploration well

Project development

- 3D-seismic or a sufficiently dense grid of 2D-seismic (depending on the structural complexity)





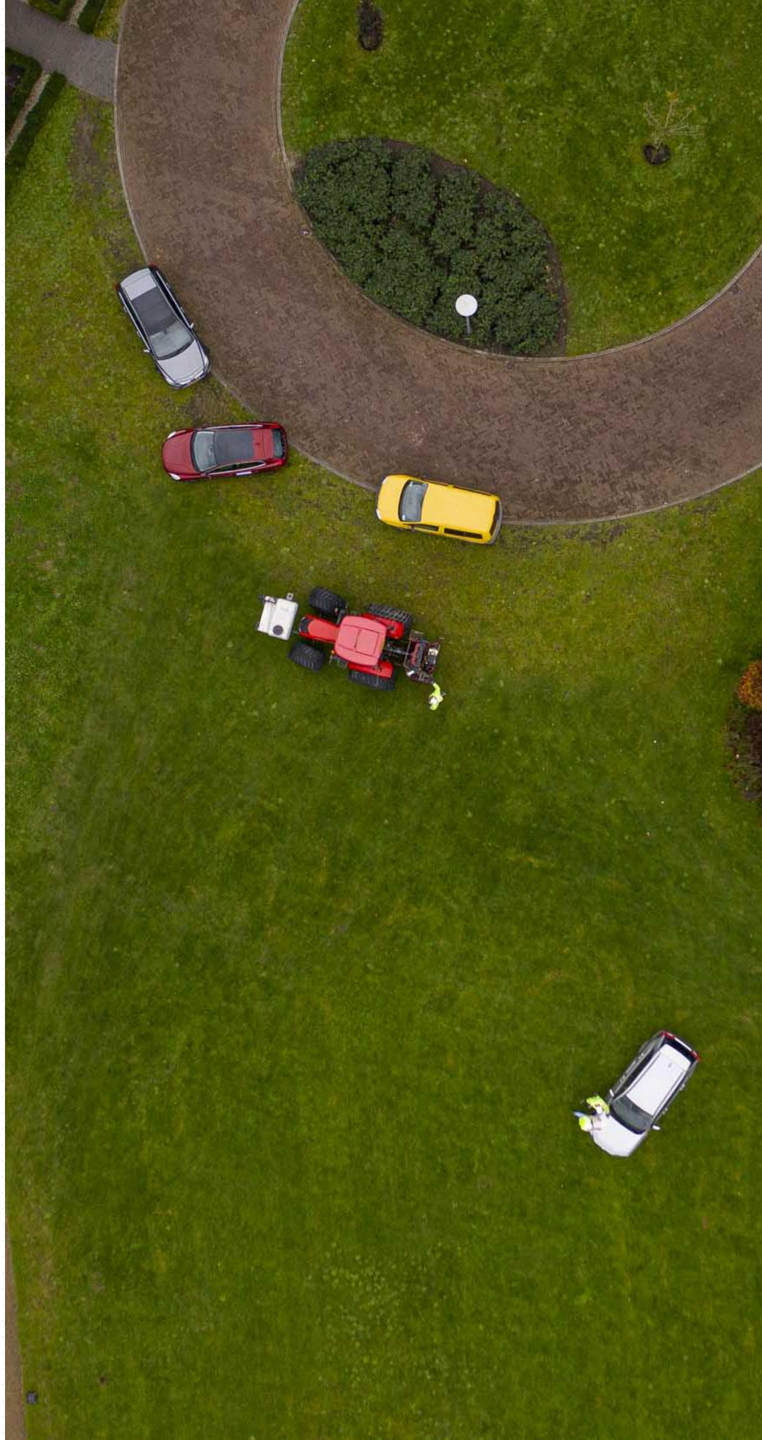
3D acquisition almost always comes after drilling and exploration well

SCAN 4 seismic acquisition

Aim: decrease geologic uncertainty in areas that are promising but where data is sparse, in order to accelerate and optimise the development of safe geothermal projects.

Selection criteria for seismic surveys are (a.o.):

- Sufficient heat offtake, preferable in an existing heat network;
- Promising but uncertain subsurface;
- Significant repeat potential in the geothermal play;
- Accelerates development of projects;
- The new seismic is required to develop projects;
- Good fit with plans of municipalities and provinces;
- No spatial limitations that exclude development of future projects.



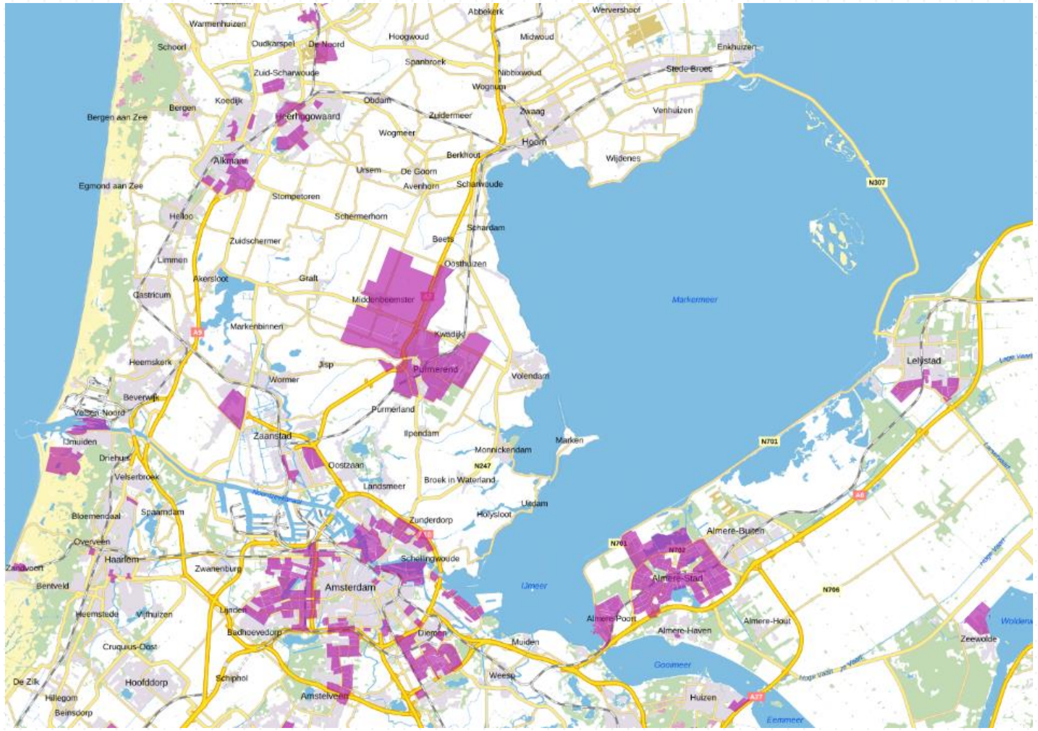
SCAN 4: Focus on existing large district heating networks

SCAN 4 focuses on accelerating a sustainable solution for our heat demand through the development of geothermal energy.

To achieve results on the short/ medium term means focus on;

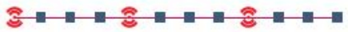
- Existing networks, because the development of new district heating networks is currently progressing slowly
- Large networks, because small district heating networks have a high risk of underutilization
- Executing 3D surveys for only one or two doublets is relatively expensive, given the required migration edges of a 3D survey

Conclusion; develop an exploration program that focusses on the long term and includes both drilling and seismic acquisition.



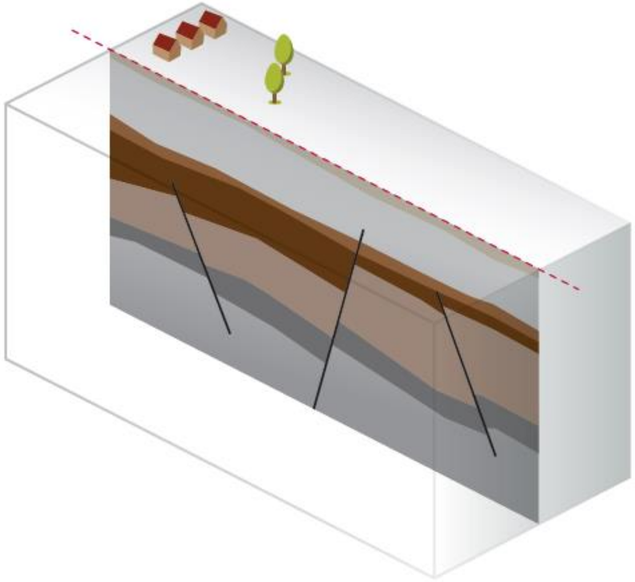
Overview of district heating in the Amsterdam Metropolitan Area

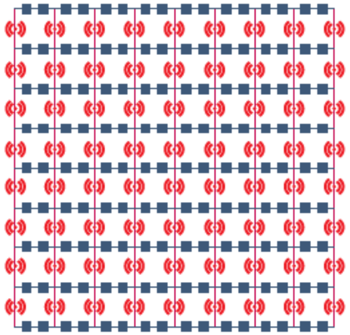
2D and 3D seismic acquisition explained



Source
Receiver

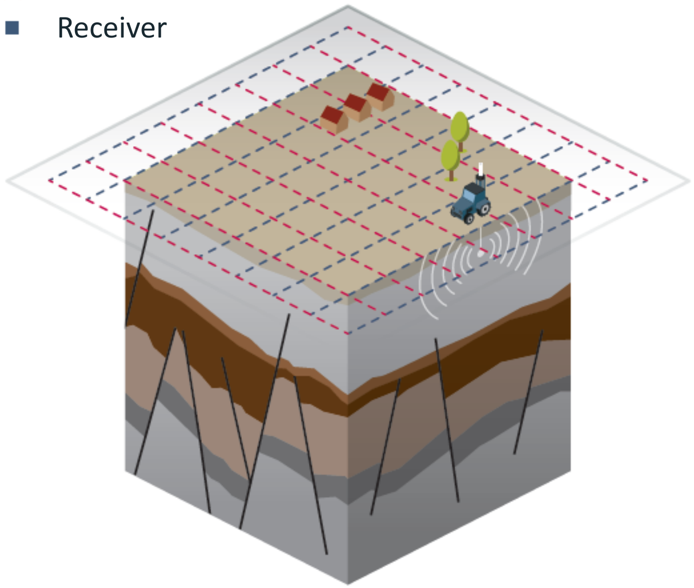
2D seismic





3D seismic

Source
Receiver



Simple structure → Some complexity → Complex structure

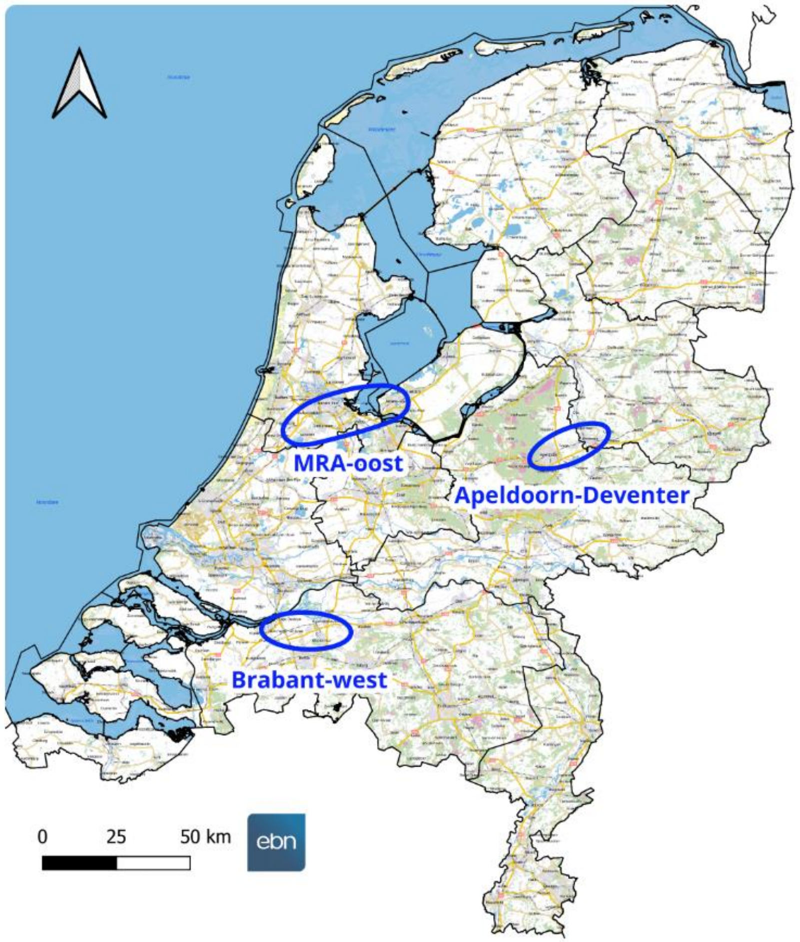
Some 2D-lines → More 2D-Lines → 3D-seismic → Geothermal energy not possible

scan

SCAN 4 – areas of interest

SCAN website, November 1, 2024

SCAN verkent drie regio's voor nieuw seismisch onderzoek



November 2024, we announced that we are investigating the possibilities for additional seismic acquisition in three areas;

- Amsterdam Metropolitan Area- East side
- Brabant-West
- Apeldoorn-Deventer

Additional areas will be announced this year.

Match Amstelland Area with SCAN 4 aims

Aim: decrease geologic uncertainty in areas that are promising but where data is sparse, in order to accelerate and optimise the development of safe geothermal projects.

Selection criteria for seismic surveys are (a.o.):

- Sufficient heat offtake, preferable in an existing heat network;
- Promising but uncertain subsurface;
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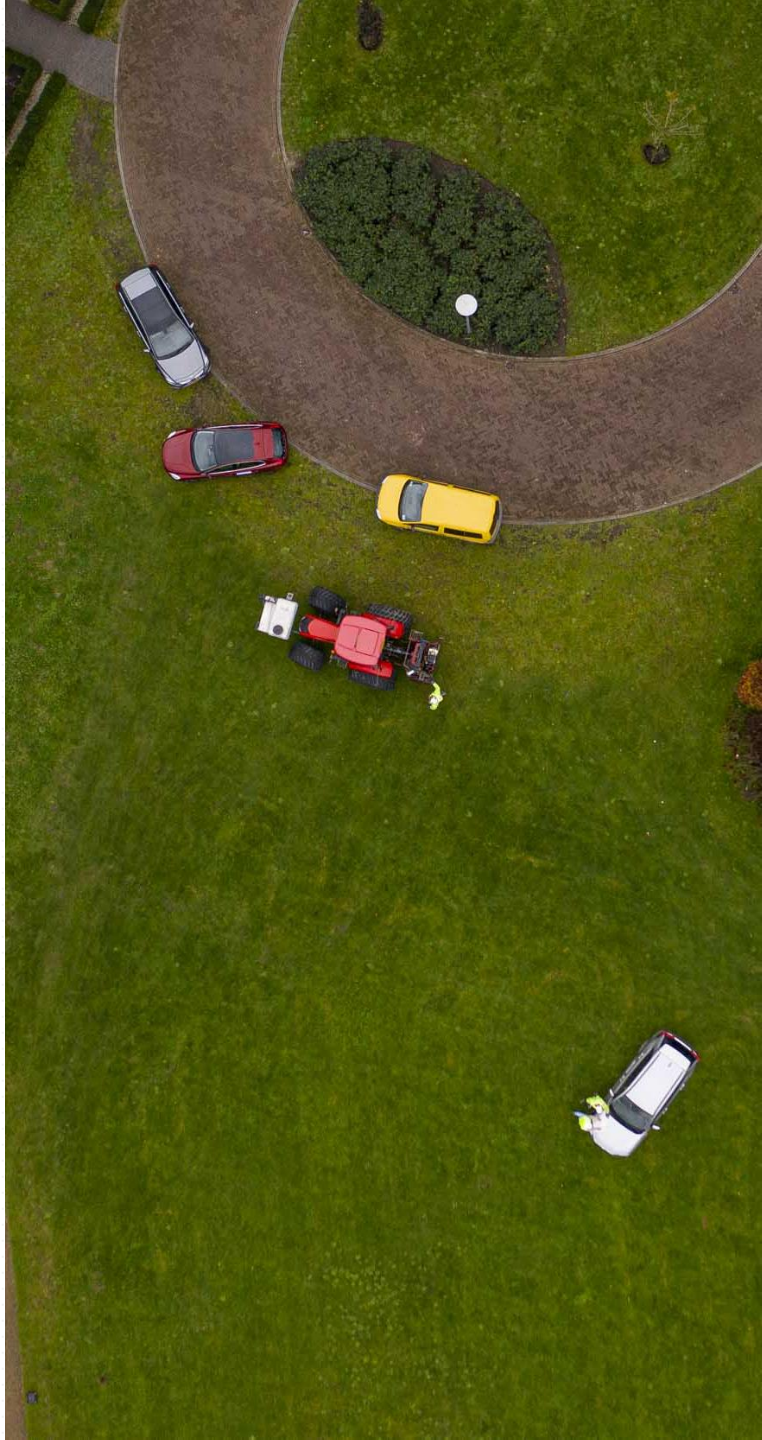
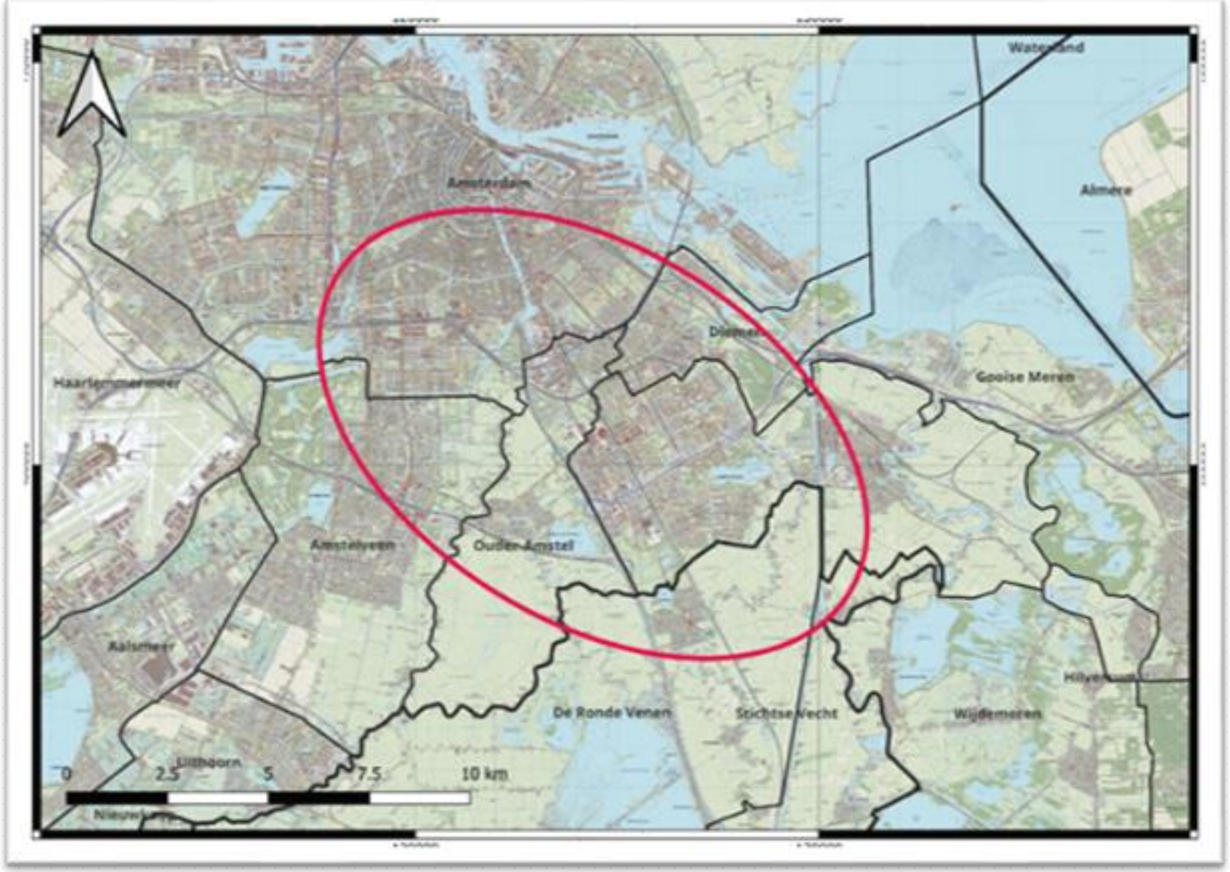


scan

Large-scale seismic survey of the Amsterdam Metropolitan Area

- First 3D survey in the SCAN 4 program
- With co-funding from the license holders *Search area Amsterdam-Amstelveen 1**
- Execution expected end Q3/ early Q4 2025
- Preparations are in full swing
- Final outlines of the survey are being determined
- Seismic contractor Smart Seismic Solutions has executed 3D seismic surveys in cities like Geneve and Marseille



Follow the latest news on Uitvoering seismisch onderzoek - SCAN aardwarmte

* *Funding from Gemeente Amsterdam, Vattenfall Power Generation Netherlands BV, EBN Aardwarmte BV*

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Ministerie van Klimaat en Groene Groei