The geothermal potential of the Rotliegend Slochteren Formation

New insights from SCAN wells Amstelland, De Bilt, Ede and Heesch & Legacy Core Study

DAP Symposium, Delft, 10-06-2025

Ministerie van Klimaat en Groene Groei

ebn

TNO

The SCAN Program: de-risking the Subsurface

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

SCAN 1&2

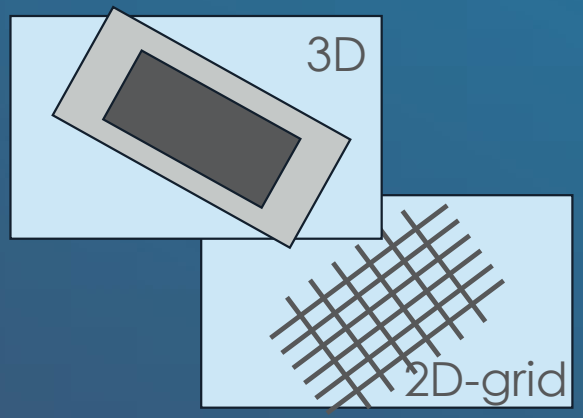
SCAN Regional 2D seismic surveys

SCAN 3

SCAN Research & Exploration Drilling Campaign

SCAN 4

SCAN detailed seismic surveys

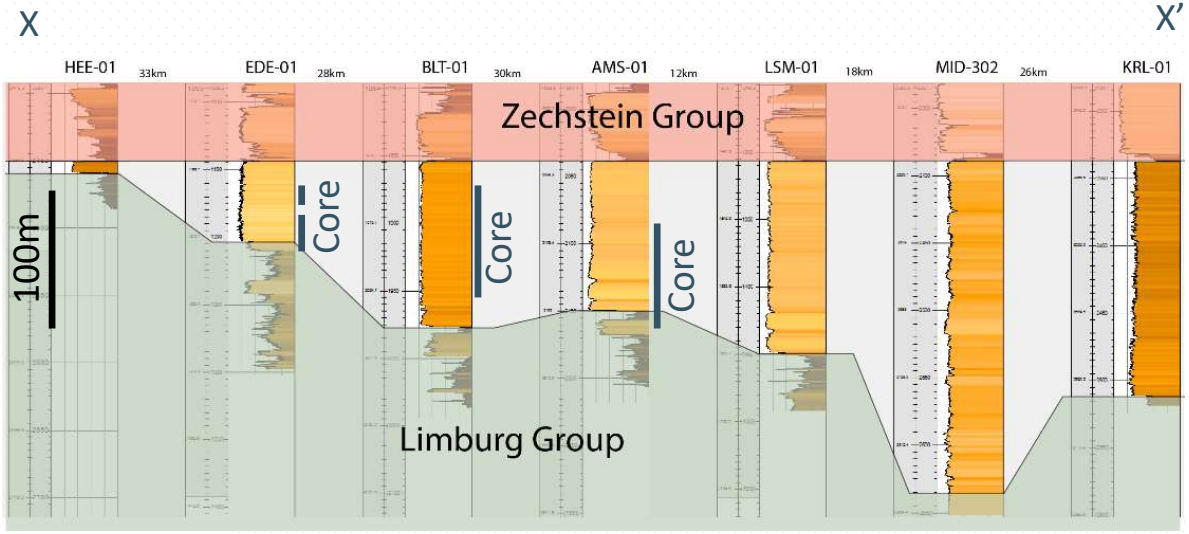


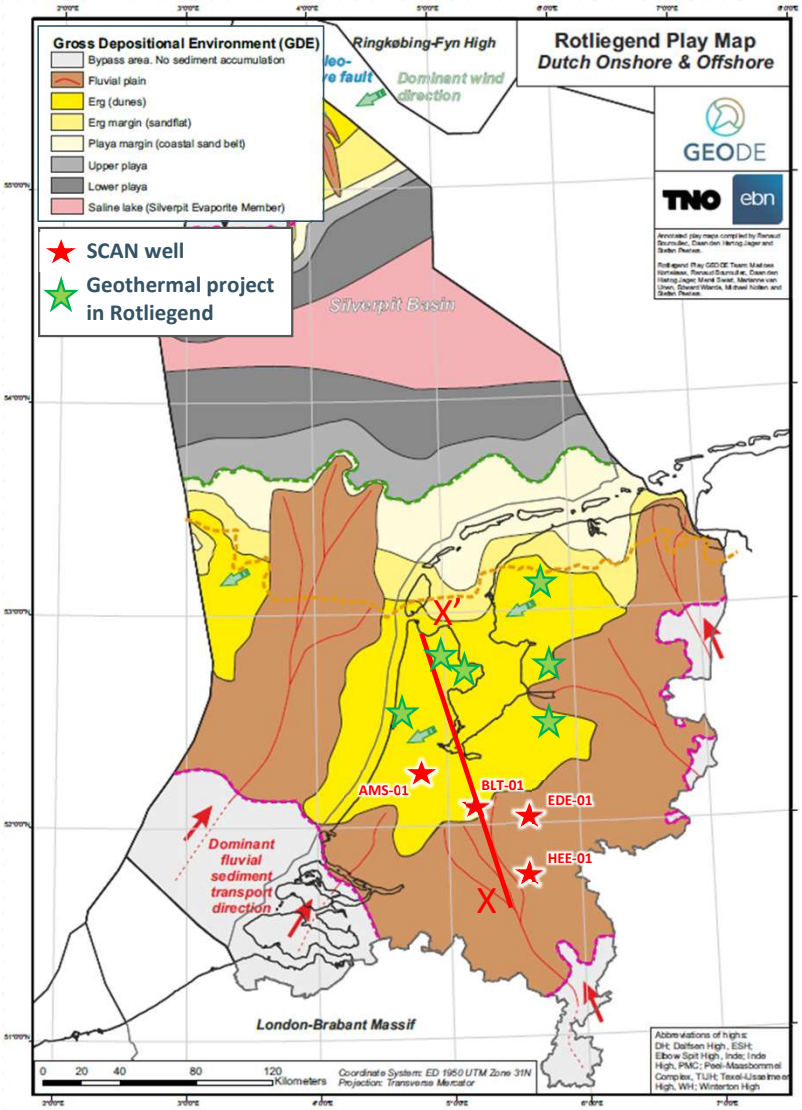
12:10 – Pieter Bruijnen – Well testing with downhole shut-in

15:45 – Ingrid Giebels – More detail on SCAN Project

Rotliegend Slochteren

- Permian epicontinental clastic deposits
- 50-250m thick, low clay content, little compositional variation
- In 2024 10 geothermal installations in Slochteren => all in northern half of NL
- Does the geothermal play extend further south?
- Tested by SCAN wells **Amstelland (AMS-01)**; Heesch (HEE-01); **De Bilt (BLT-01)** and **Ede (EDE-01)**

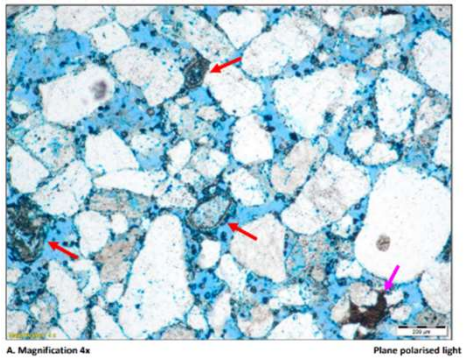




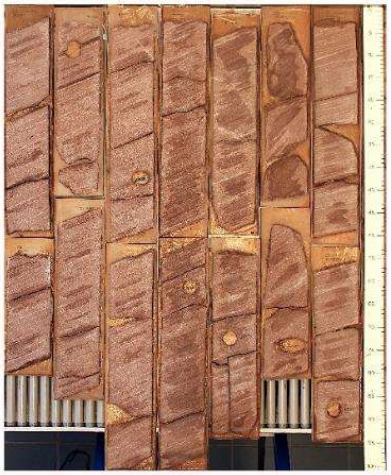
GEODE - Kortekaas et al., 2023 www.scanaardwarmte.nl

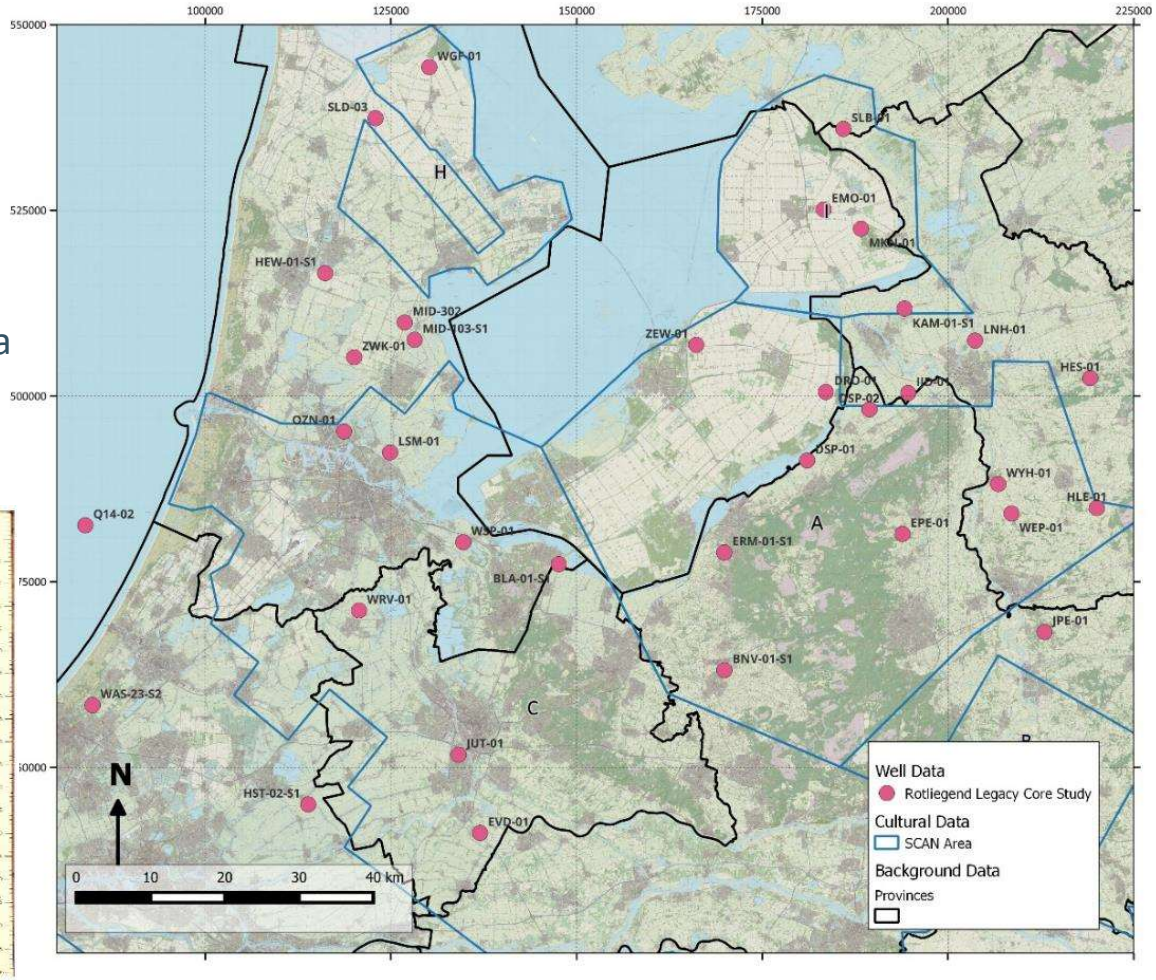
Legacy Core Study

- 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, including summary report



SLD-03



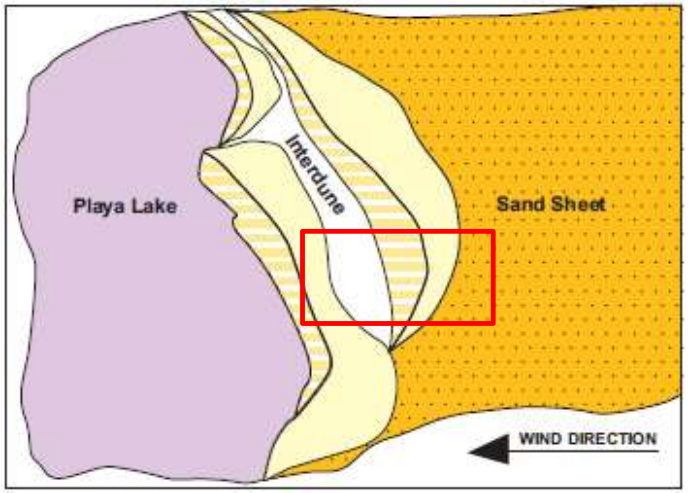


How was the Rotliegend reservoir deposited?

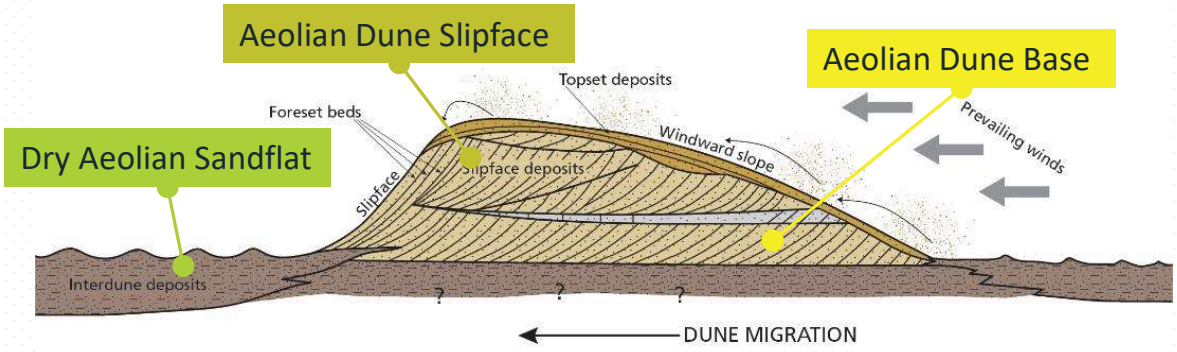
- Palaeogeography
- Depositional Environments
- Reservoir Quality Controls

Palaeogeography

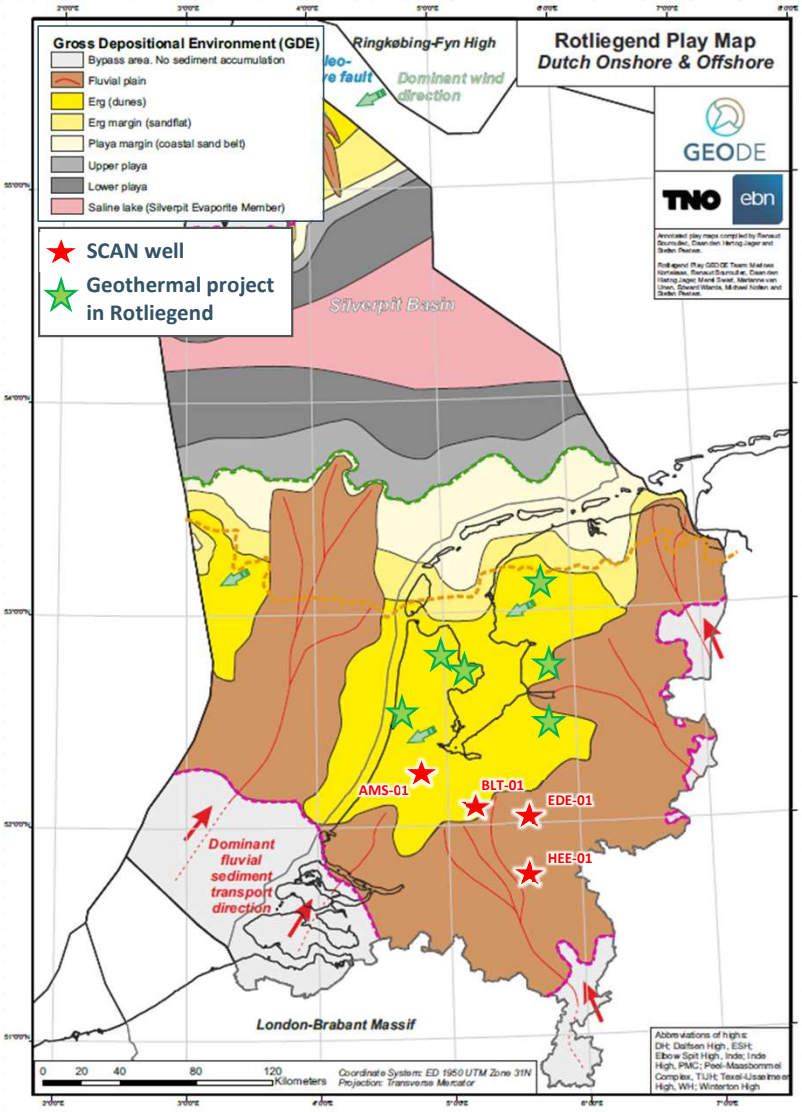
- Slochteren deposited predominantly in “dry” eolian settings. Fluvial deposits rare
- Migrating eolian dunes and interdune areas
- Constant uniform wind direction



Fryberger et al. 2011



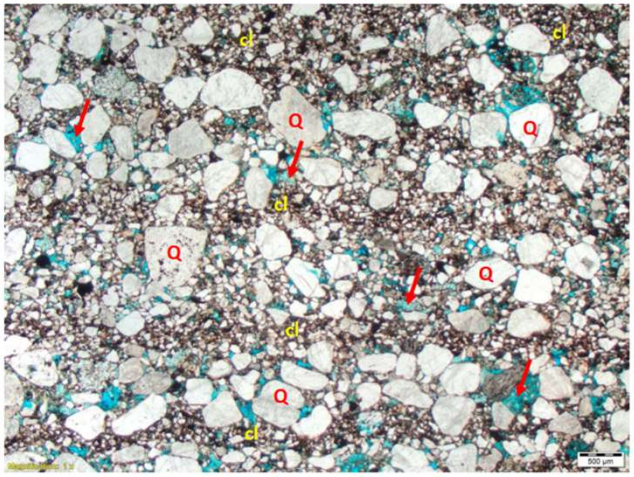
modified from Ahlbrandt and Fryberger (1982)



GEODE - Kortekaas et al., 2023

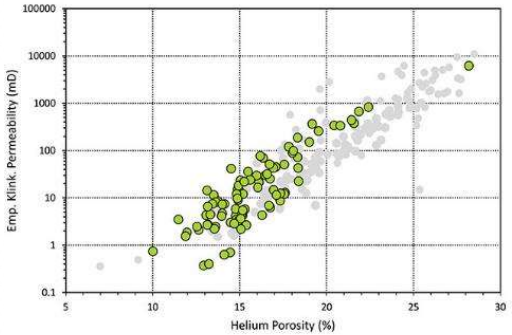
Dry Aeolian Sandflat sub-environment

WELL: AMS-01 SAMPLE NUMBER: 523 DEPTH (m): 2135.67



A. Plane polarised light

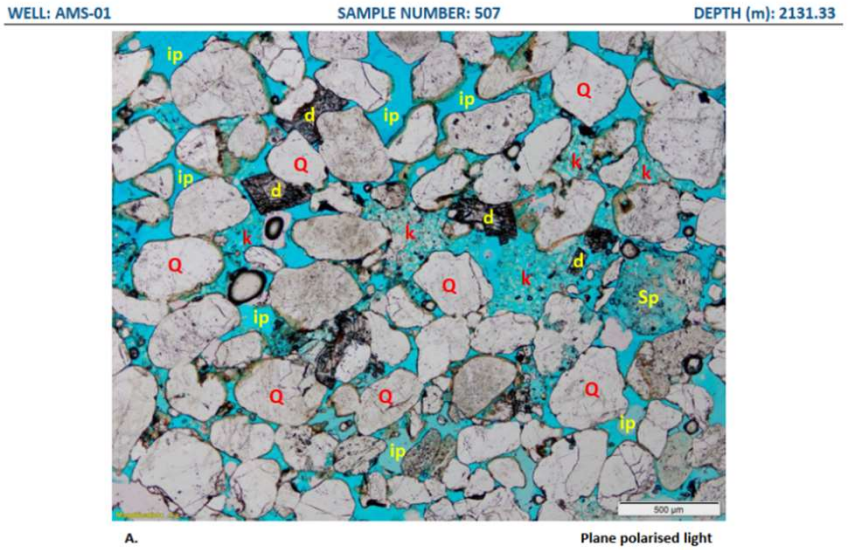
Rotliegend Depositional Sub-Environment
Dry Aeolian Sandflat (Psay)



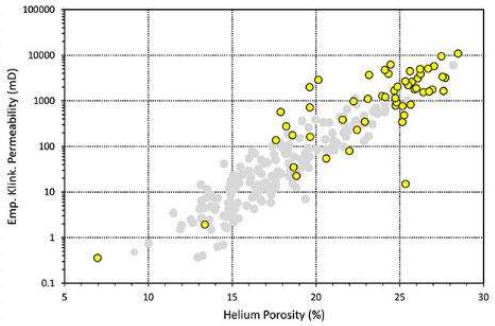
10cm

- ➜ Bimodal sorting
- ➜Fine sand laminae with medium to coarse sand (‘pin-stripe’)
- ➜ Relatively low porosity and permeability

Aeolian Dune Base sub-environment

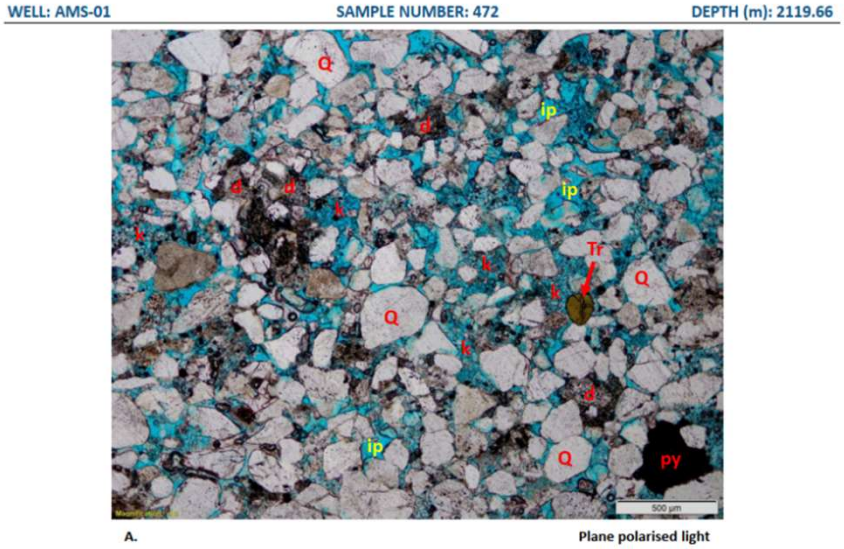


Rotliegend Depositional Sub-Environment
Aeolian Dune base (Adb)

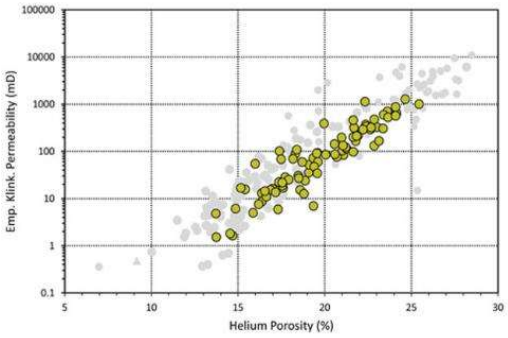


- ➜Low-angle or high-angle cross-bedded
- ➜Dominant medium sand
- ➜Moderately well sorted
- ➜Cm- to dm-thick structureless beds with mm-thick fine sand laminae
- ➜Relatively high porosity and permeability

Aeolian Dune Slipface sub-environment

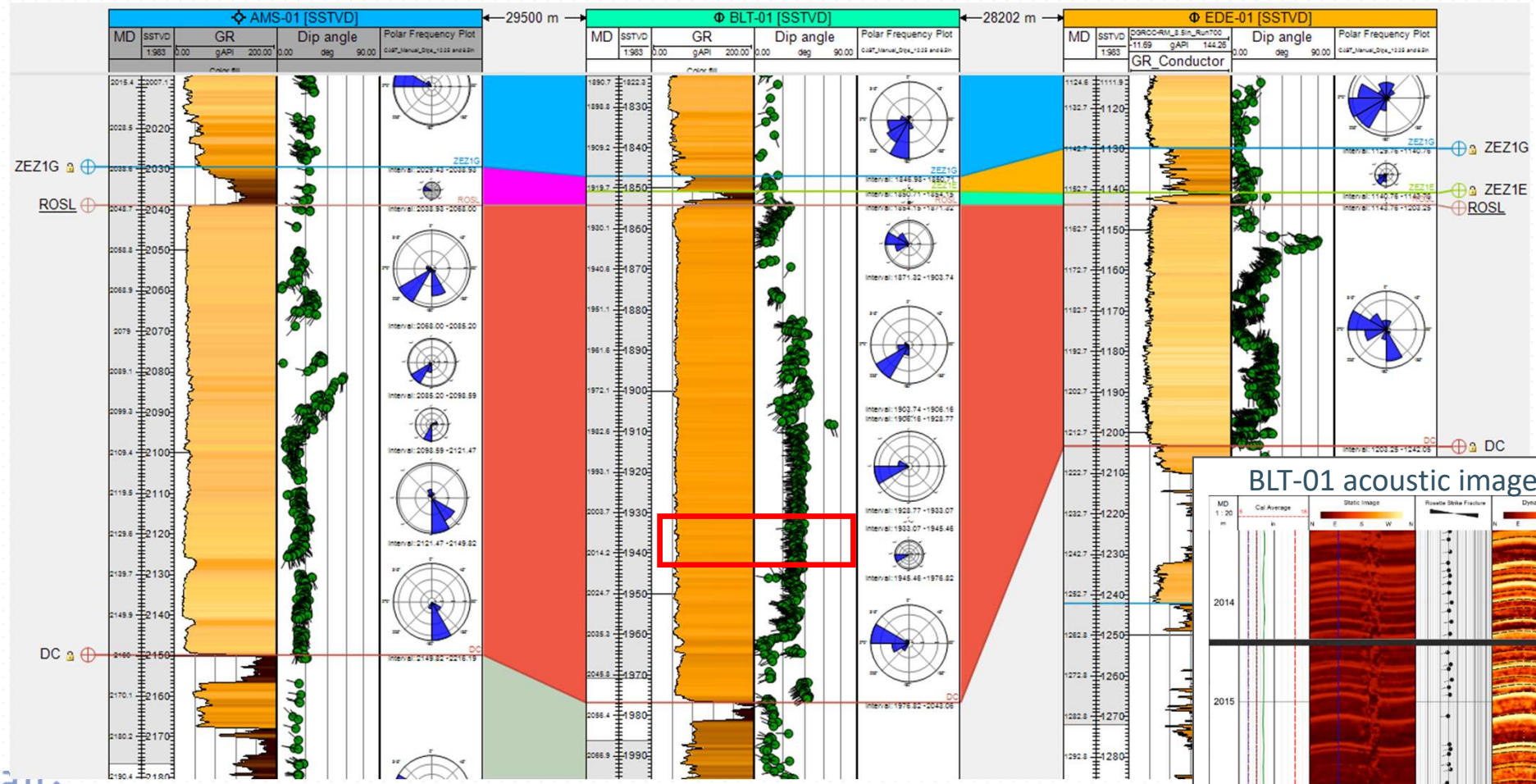


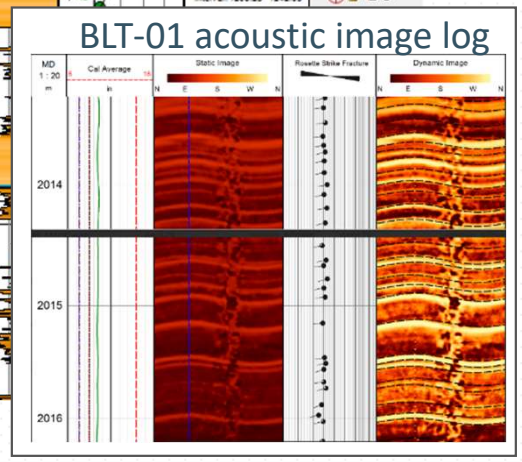
Rotliegend Depositional Sub-Environment
Aeolian Dune Slip Face (Ads)



- ➜Mm- to cm-thick low-to high-angle cross-beds
- ➜Fine to medium sand (upward fining trend within units)
- ➜Medium sand beds often tapered
- ➜Medium porosity and permeability

Image log data

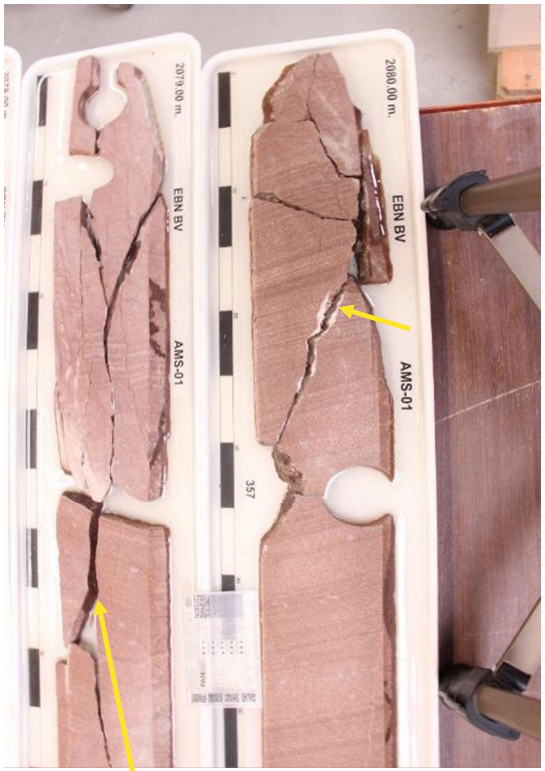




What happened after deposition?

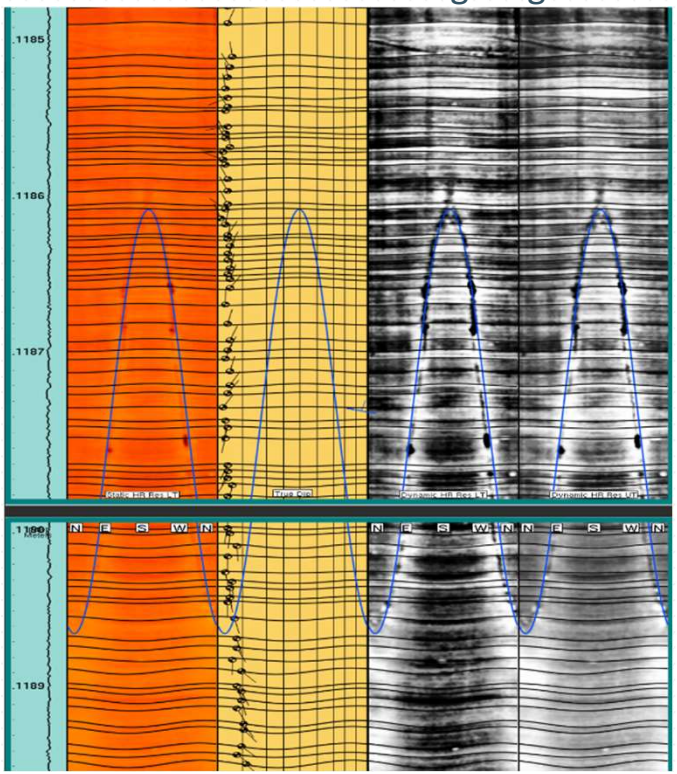
- Fractures& Deformation Bands
- Diagenetic Cements

(Partly) Cemented Fractures



open fracture?

EDE-01 acoustic image log

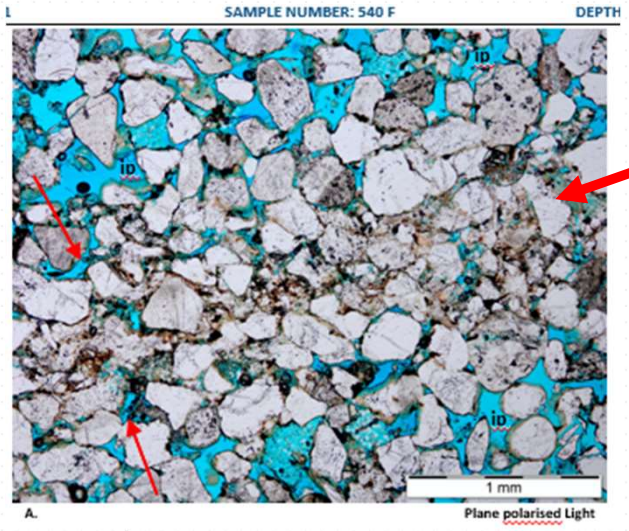


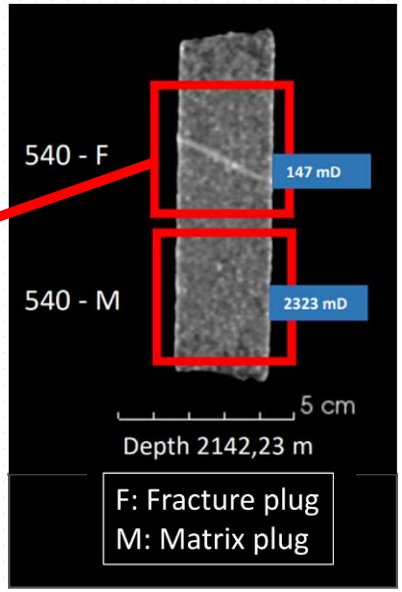
➜High angle to near-vertical fractures, partly or completely cemented.

➜Virtually no displacement to rarely mm-scale displacement

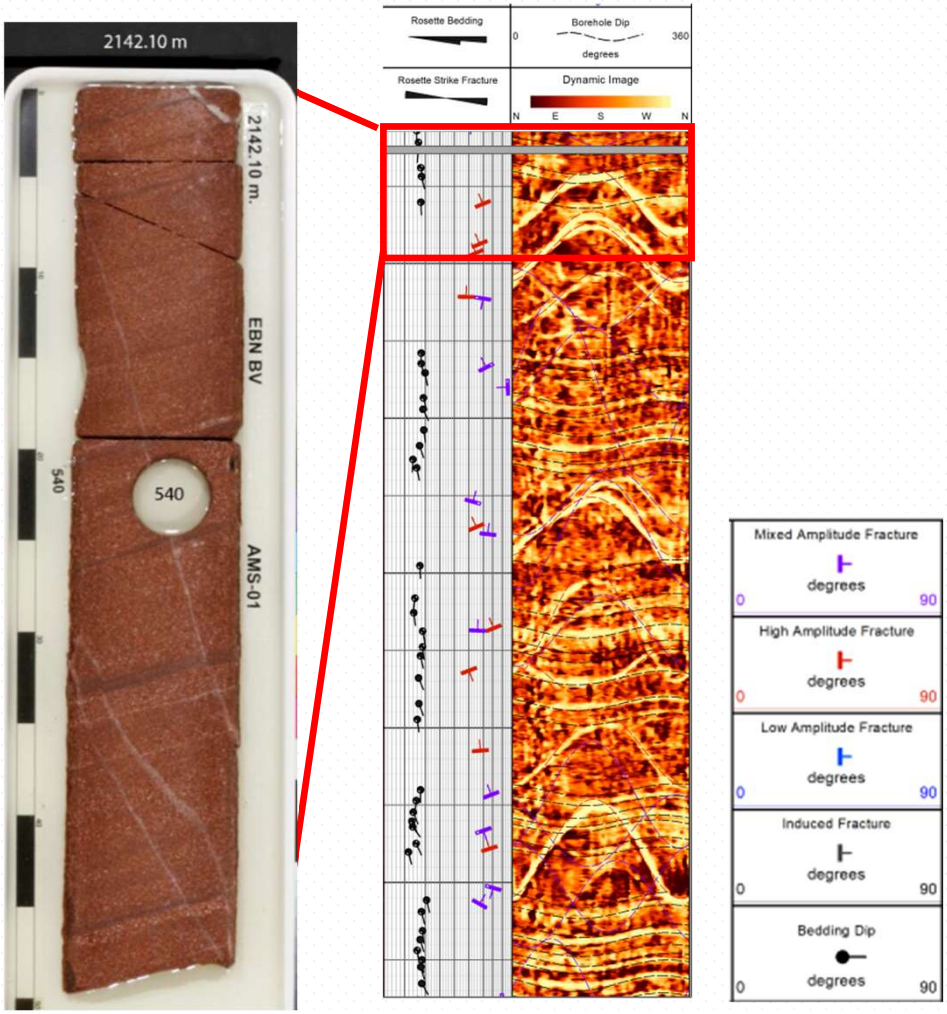
Deformation bands

➜High-angle features in AMS-01 acoustic image log and core
➜Single discontinuities to swarms of quartz-cemented bands, often conjugate sets
➜Up to mm-scale displacement
➜Bands significantly less permeable than matrix (~25x)



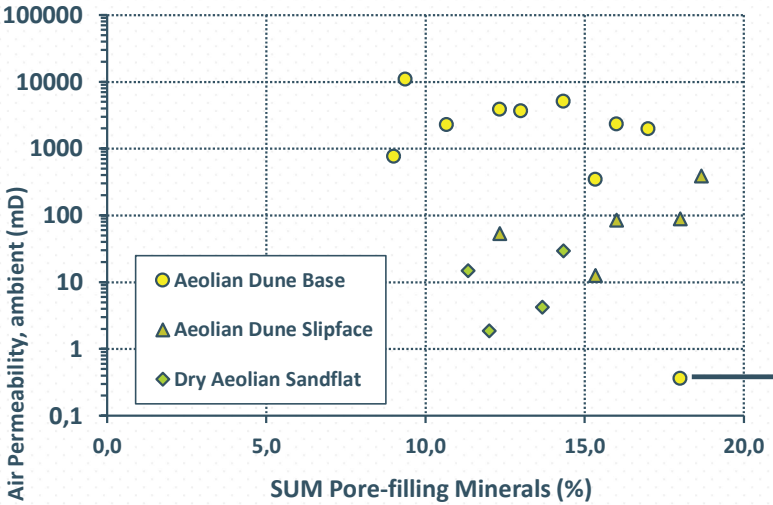


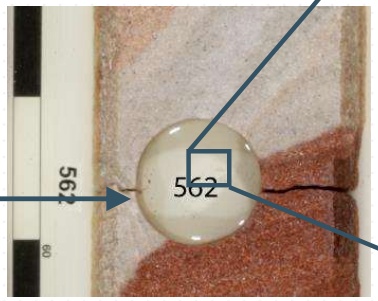
Dynamic acoustic image:
Light means high velocity = low porosity

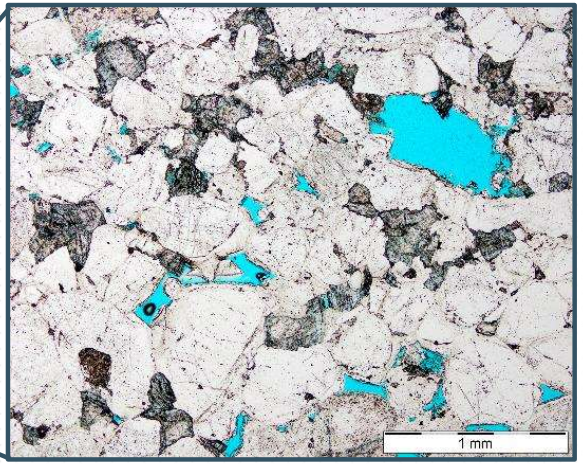


Diagenetic cements

Role of diagenetic cements minor in AMS-01, despite local effects (e.g. quartz-cemented zones)
To be evaluated in BLT-01 and EDE-01

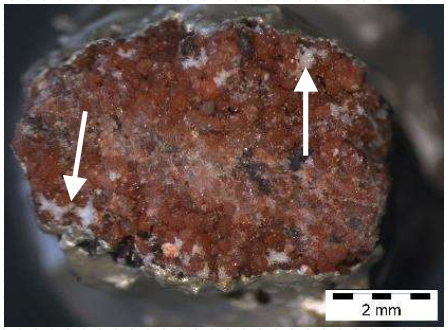




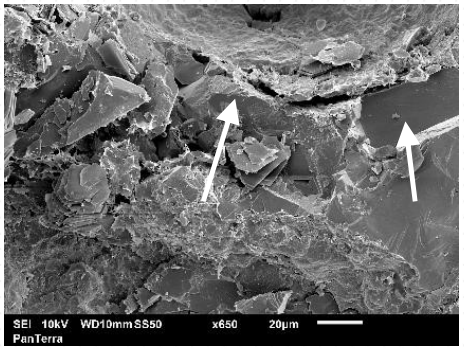


Quartz-cemented zone

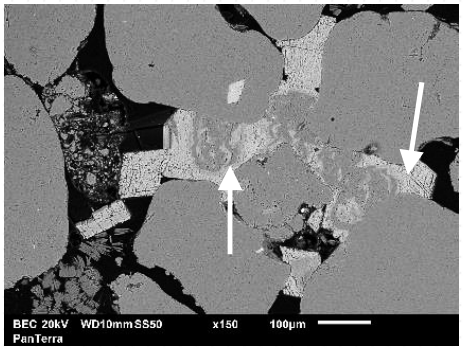
Kaolinite



Quartz



Dolomite



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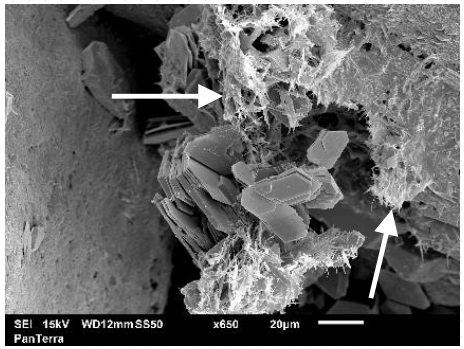
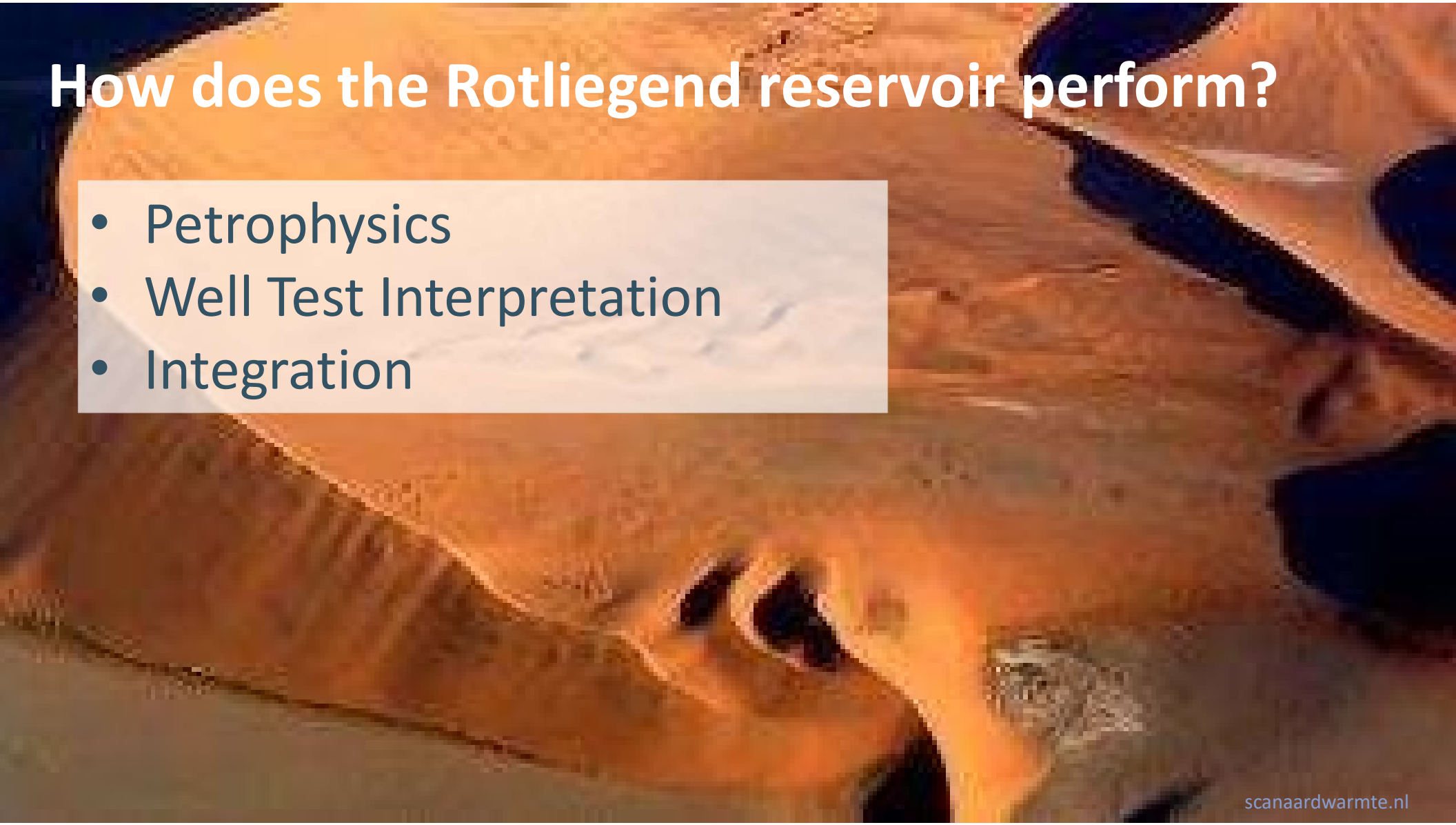


How does the Rotliegend reservoir perform?

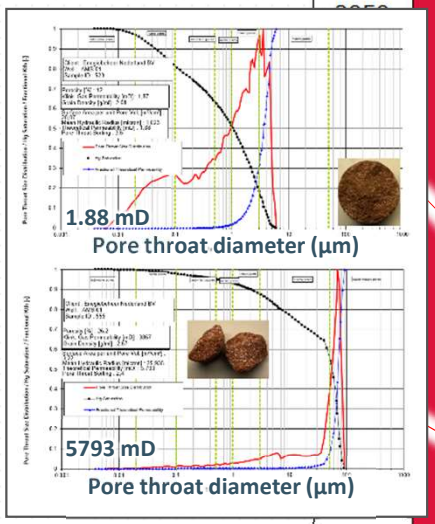
- Petrophysics
- Well Test Interpretation
- Integration

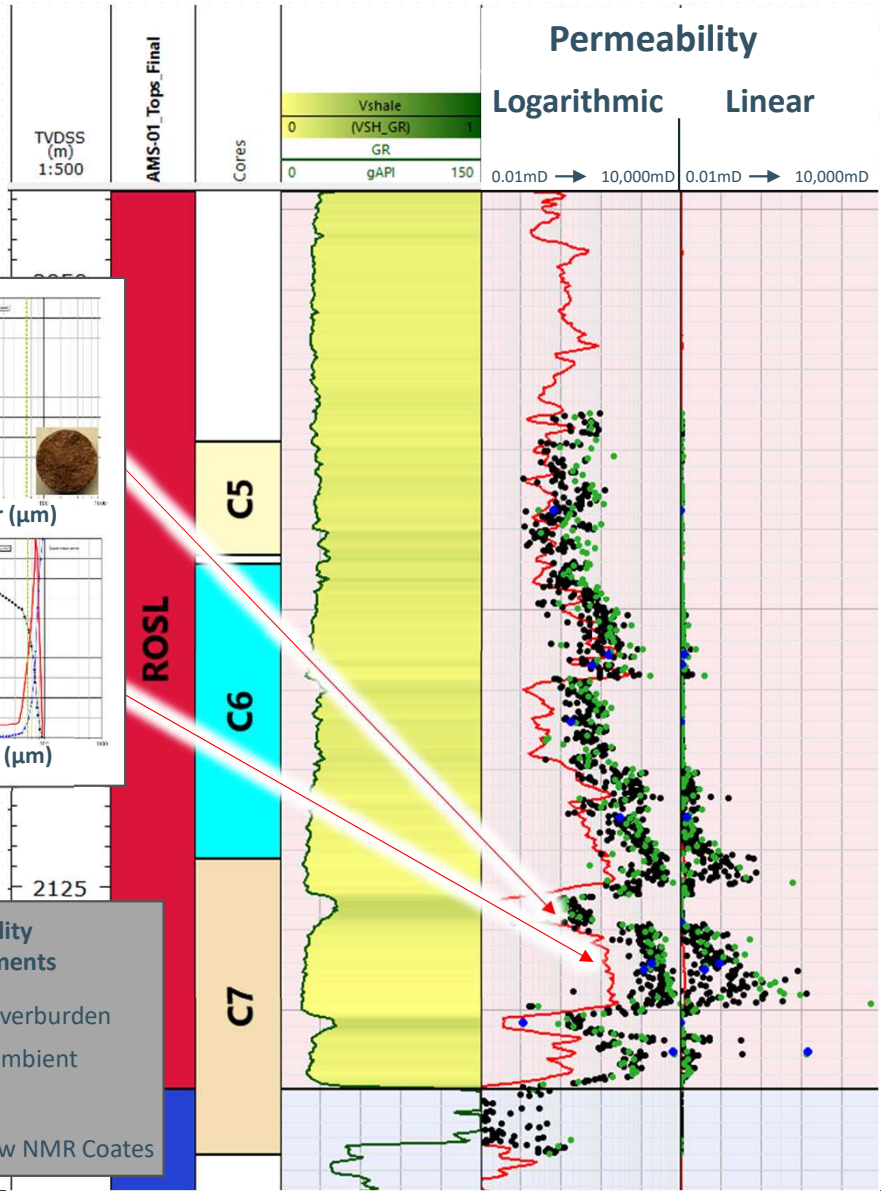


Permeability Measurements

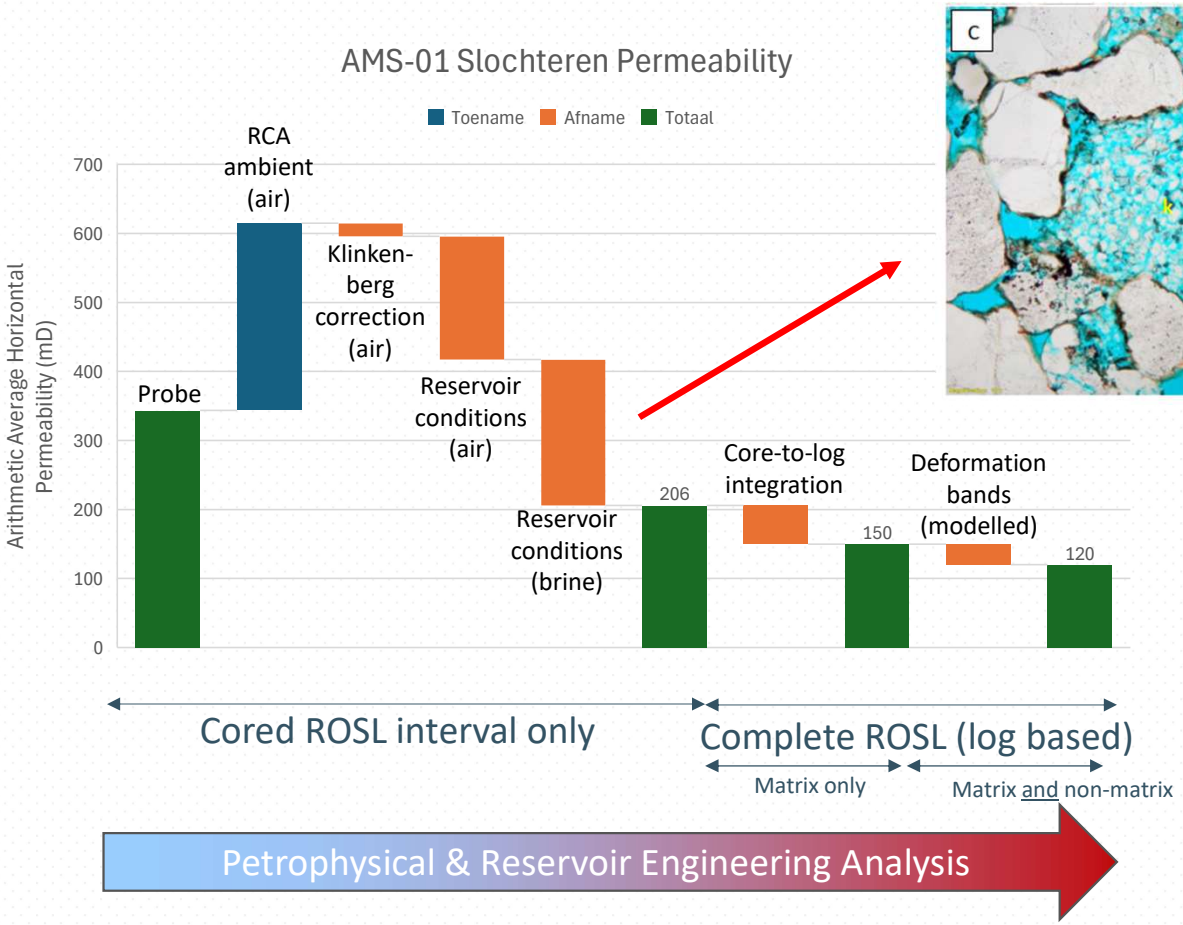
Permeability is the key geothermal reservoir property!

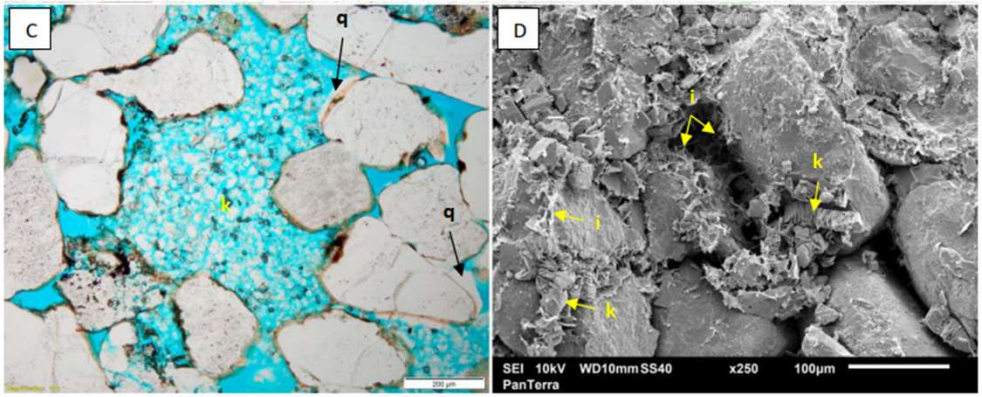
- ➜ Probe permeability
  - ➜ Every 3cm, performed on uncleaned core
- ➜ Routine air permeability
  - ➜ Every 33cm horizontal, every 100cm vertical
- ➜ Klinkenberg air and brine permeability at reservoir conditions
  - ➜ 10 horizontal plugs for each
- ➜ Mercury-Injection Capillary Pressure (MICP/HPMI)
  - ➜ Pore-throat diameter => Theoretical permeability
- ➜ NMR logs
  - ➜ Timur-Coates model yields permeability
- ➜ Well test
  - ➜ Transmissivity (permeability * reservoir height)





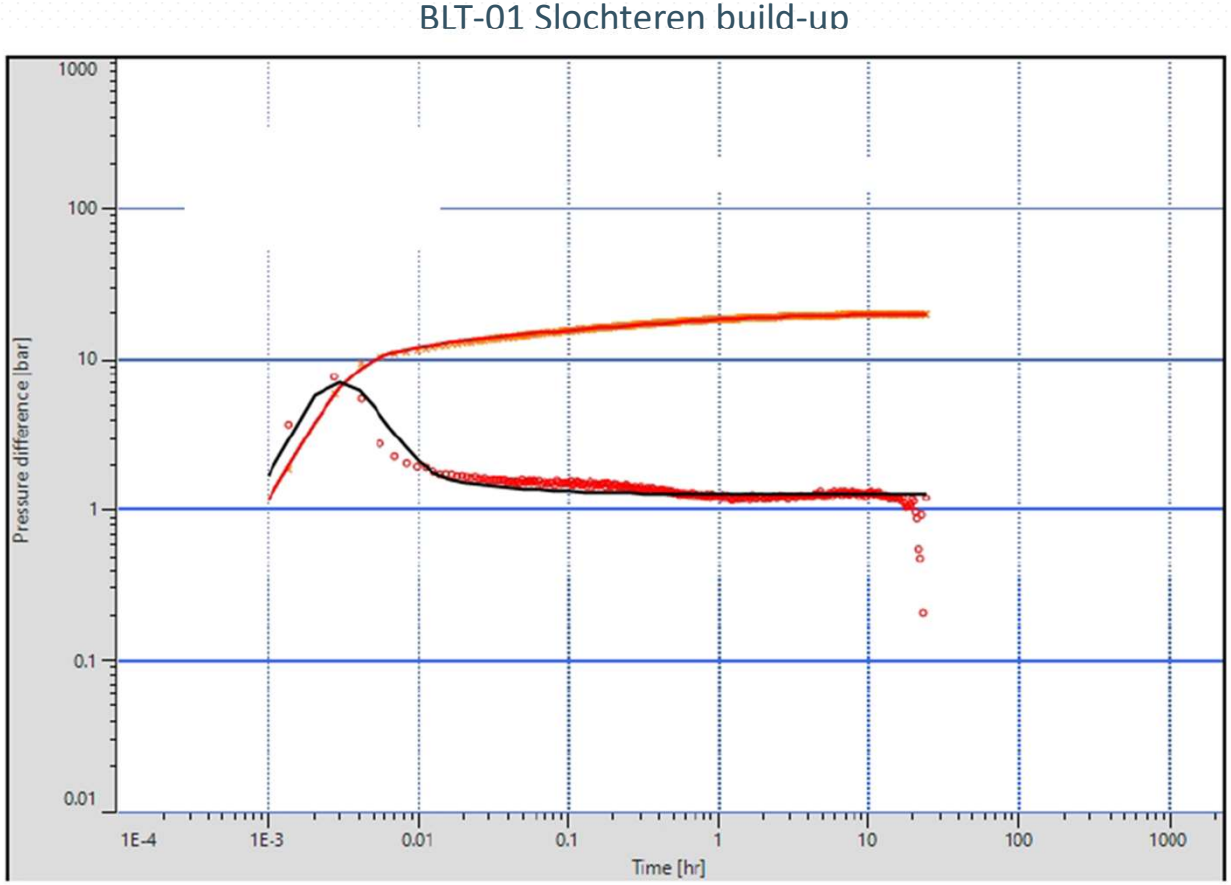
Permeability Measurements





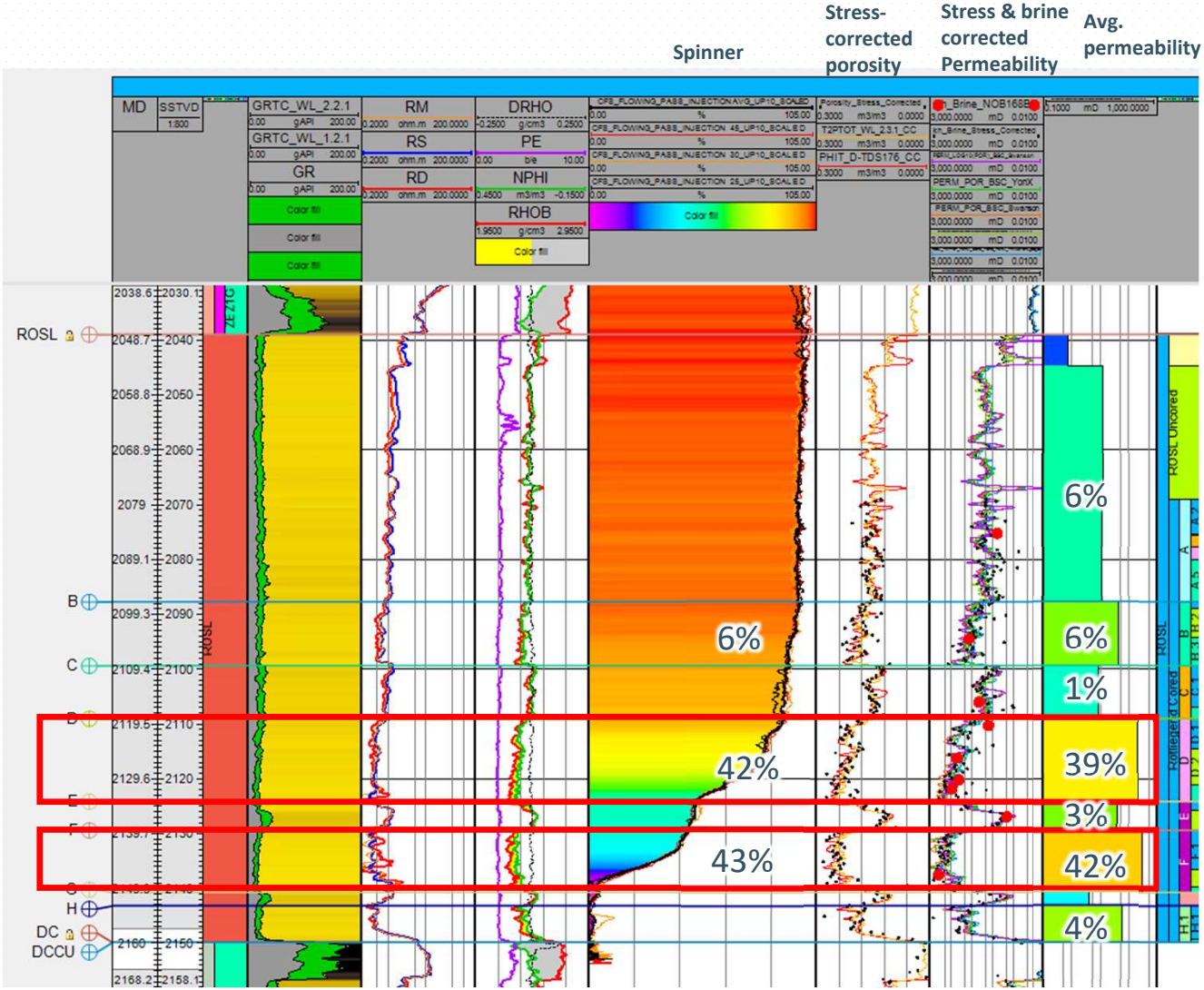
Integration Production and Injection Tests

- ➜Slochteren in AMS-01 and BLT-01 production- and injection-tested; EDE-01 to be tested in early July 2025
- ➜Pressure Transient Analysis on build-up data gives transmissivity (and skin)
- ➜Preliminary analysis of the Slochteren test in BLT-01 shows a transmissivity of approximately 6 Dm (average permeability of 50md)

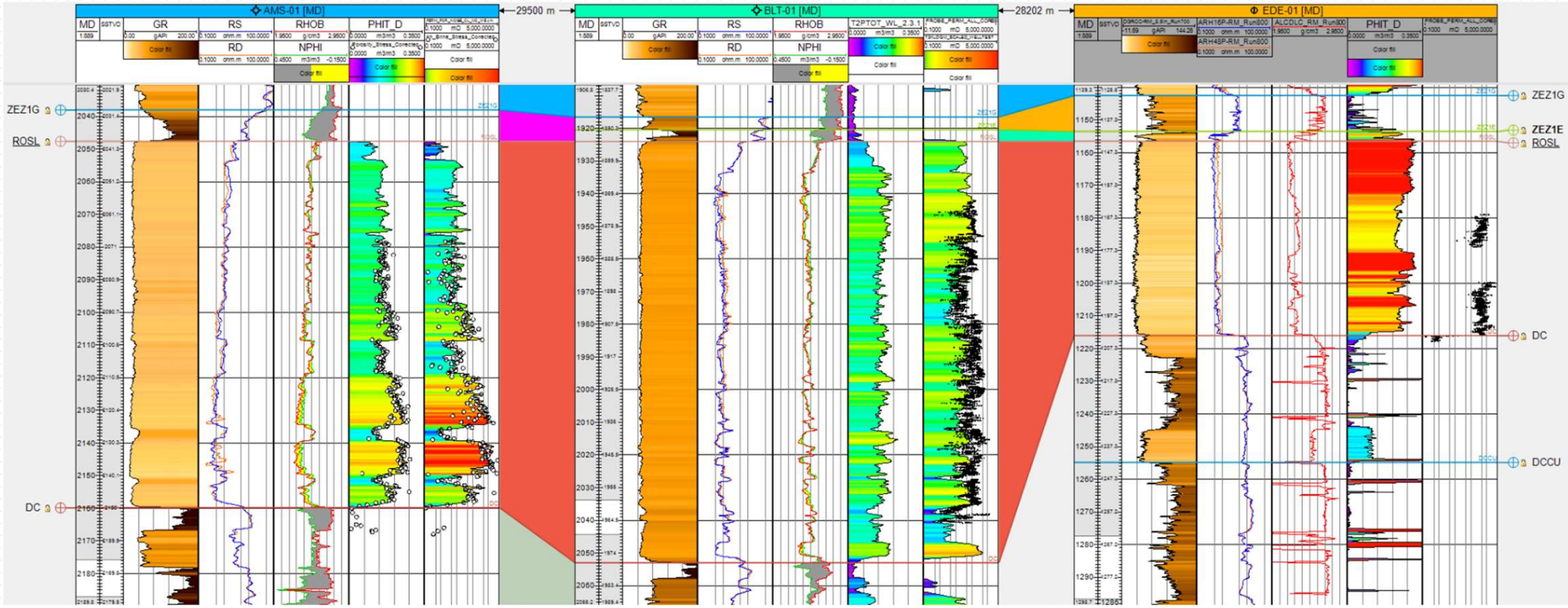


Transmissivity Distribution

- ➔Spinner run during injection test
- ➔In AMS-01 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



SCAN Slochteren Reservoir Quality Summary



Total Porosity: 17%
Average permeability: 120 mD
Transmissivity: 13 Dm

Total Porosity: 15% (NMR)
Average permeability: 50 mD (test)
Transmissivity: 6 Dm (test)

Total Porosity: ~24% (SON-DEN)
Average permeability: TBD
Transmissivity: TBD

Summary and what is next?

- ➜Sand-dominated eolian Slochteren reservoir encountered in four SCAN wells
- ➜Moderate to excellent matrix reservoir quality
- ➜Reservoir matrix properties predominantly controlled by depositional sub-environment
- ➜Fluid flow somewhat affected by non-matrix fractures (deformation bands and fractures)
- ➜EDE-01 well test early July 2025
- ➜Core analysis BLT-01 and EDE-01 ongoing
- ➜All AMS-01 data published on NLOG to evaluate regional geothermal potential, BLT-01 and EDE-01 data publication ongoing
- ➜SCAN Amsterdam well (ASD-01) with Slochteren target: spud expected in August 2025 on Strandeiland IJburg between Amsterdam and Almere

Well test set-up at BLT-01

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