Borehole image for the understanding of heterogeneous geomechanical properties and cooling in a sandstone geothermal reservoir.

Everything Borehole Imaging
London 11-12-2025

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Presenter: Angela Pascarella

Agenda

- Introduction to Geo4all project and the Geothermal Energy in the Netherlands.
- Background information: The Middenmeer geothermie license and the Slochteren Formation.
- MDM-GT-11-S2: data interpretation and observations.
- Conclusions.

- 4 Years Dutch National innovation research program focused on advanced geothermal research and development in the Netherlands.

- Consortium of 23 partners varying from research institute to drilling company and service provider coordinated by TNO.

- Organized in 6 Work Packages (WP), covering different research topics. Details and results are available on the project website: Geo4all Innovation Program (https://innovatie.geothermie.nl/en).

- This work is part of WP4: ‘’Cold-front and Induced Seismicity’’ that applying monitoring, measurement, and modeling techniques aims reduce uncertainties in productivity lifetime and define operational bounds for injection parameters, seismic hazards, and caprock integrity.

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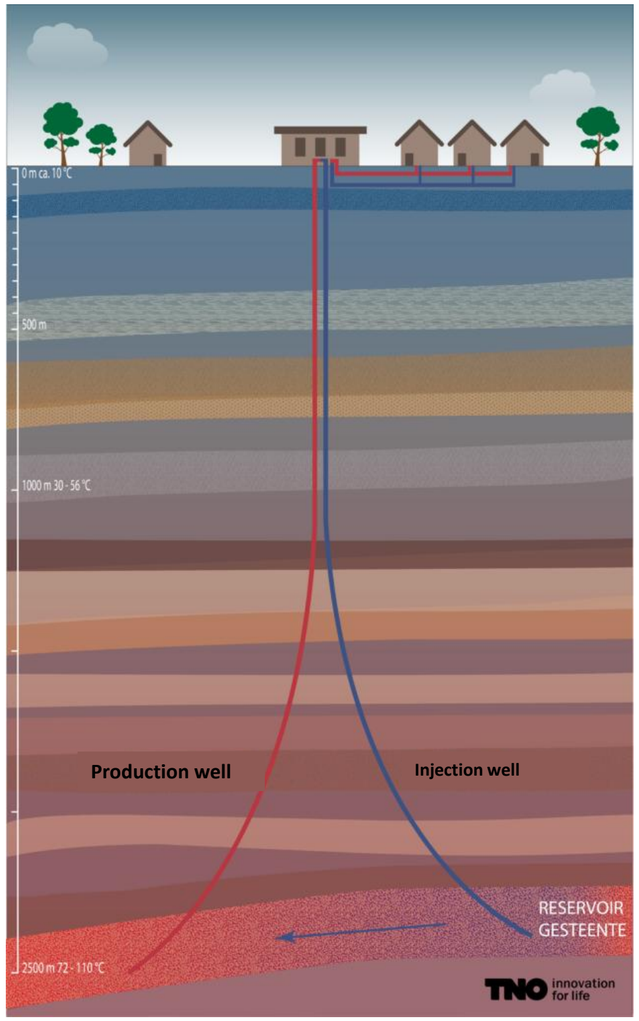
Geothermal energy in the Netherlands



[Geothermal energy - Geologische Dienst Nederland]

- The energy is recovered from highly permeable and porous aquifers with temperatures ranging from 45°C to 120°C from depths between 1,5-4 km.
- Well pairs (in Dutch: *doublets) are* drilled into the same aquifer, hot groundwater is pumped up through the Producer well, heat is extracted by heat exchangers and cooled-down water is re-injected into the aquifer through the Injector well.
- The extracted heat is used for heating purposes, primarily for horticulture but also for urban heating (Heat to Heat).
- First geothermal production in the Netherlands started in 2007, in 2024 23 operational installations collectively produced 7.49 PJ of geothermal energy.
- Understanding the cooling distribution and its effect on the reservoir properties is critical to correctly assess the potential risks of geothermal operation such fault reactivation and induced seismicity.

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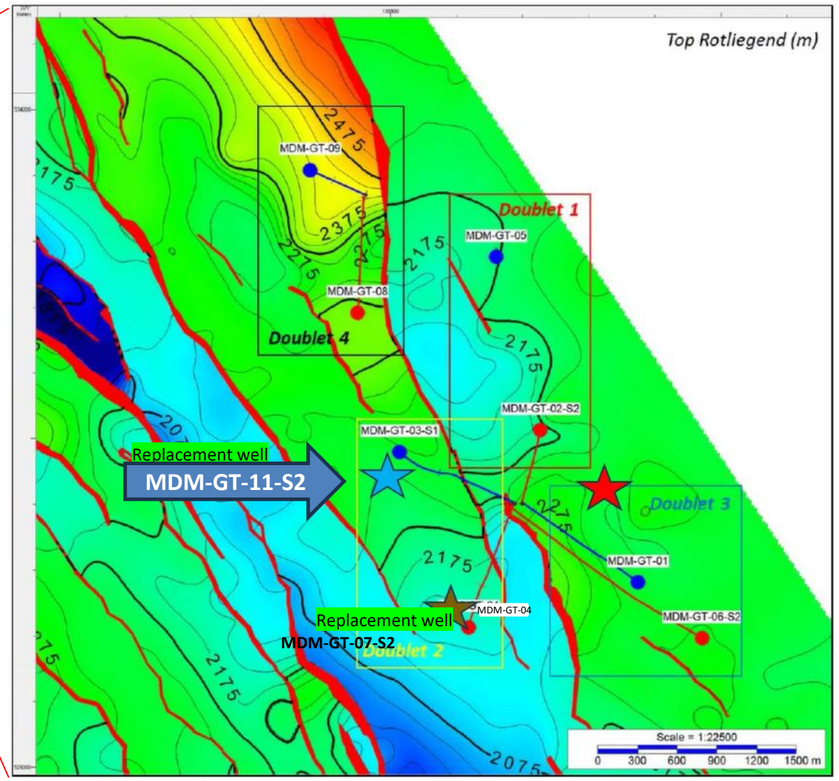
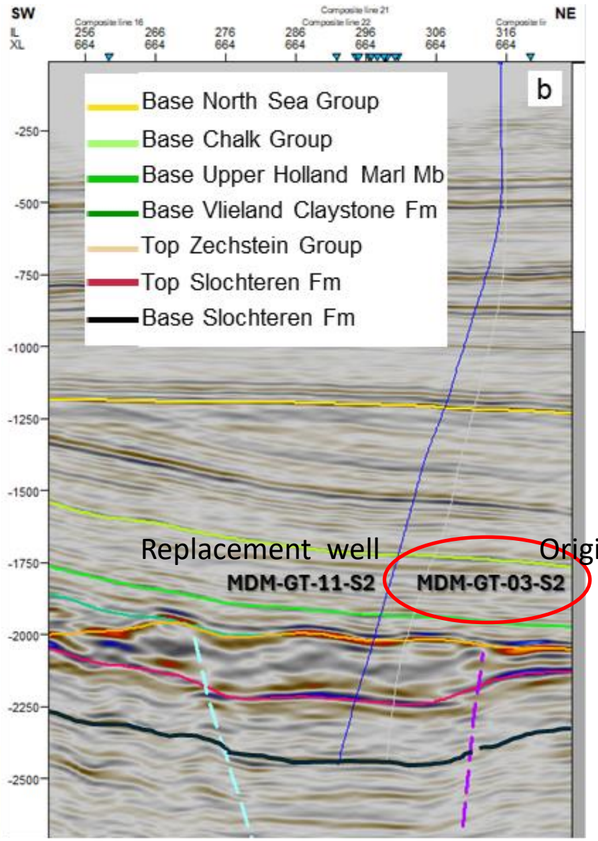
Middenmeer Geothermie license area and MDM-GT-11-S2

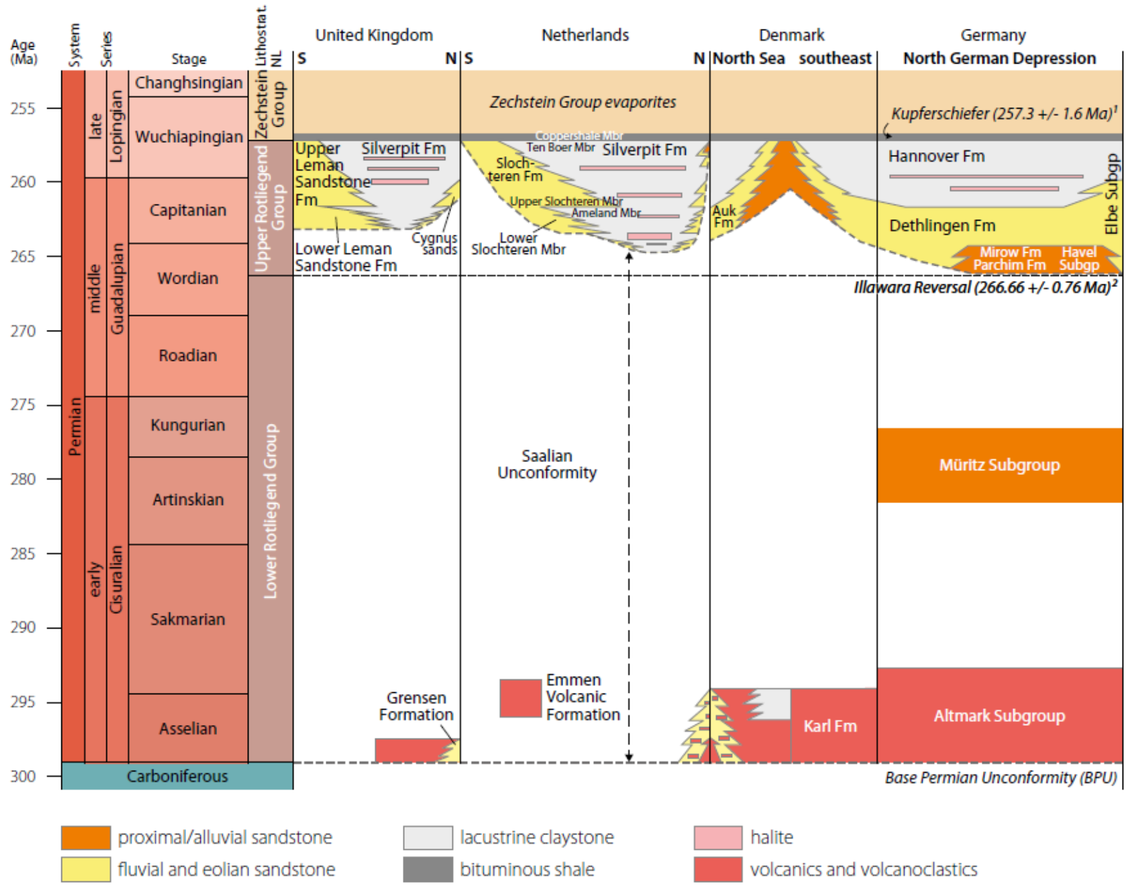




- Located in NW of the Netherlands.
- Operated by Ennatuurlijk Aardwarmte
- Hot water up to 94°C is circulated from the Permian Slochteren Formation (flow rates 150-350 m^3/hr)
- 4 Doublets drilled from 2013/4 to 2025
- 2 replacement wells drilled in 2024-5 (including MDM-GT-11-S2)
- MDM-GT-11-S2 is a replacement well adjacent (100m apart) to an injector well active for 10 years

Slochteren Formation

- Equivalent to Leman Sandstone Formation in the UK
- Permian in Age
- Part of Upper the Rotliegend Group
- Deposited in the Southern Permian Basin
- Consist of fluvial and Aeolian sands, and lacustrine claystone, interdune ponds and sabkas mudflats
- Good Reservoir properties in the Aeolian facies
- Main Gas Reservoir in the Netherlands



Tectonostratigraphic chart of the Permian of the UK, the Netherlands, Denmark and Germany. Modified from Gast et al. (2010). 1 = Re-Os isochron age for the Kupferschiefer (Brauns et al., 2003); 2 = age according to the geomagnetic polarity timescale for the Permian (Hounslow & Balabanov, 2016).

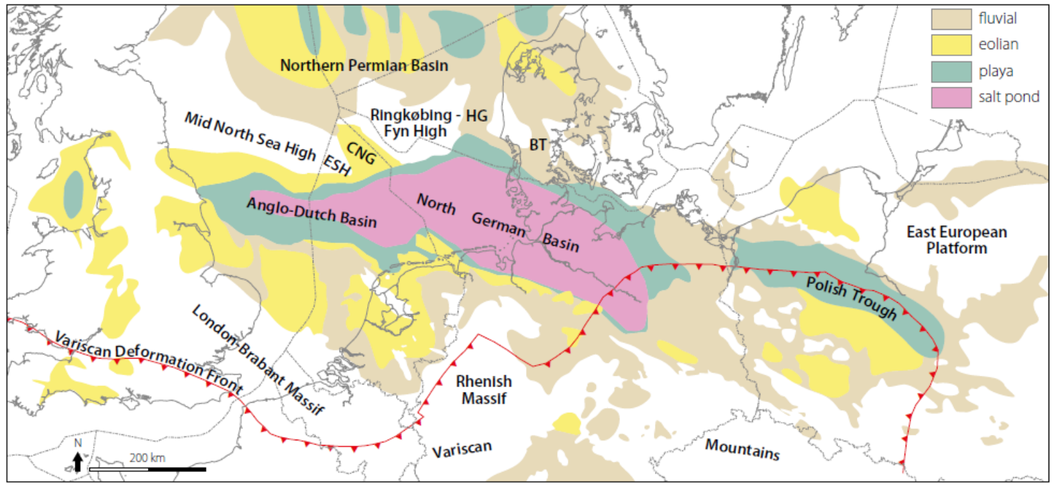


Figure 4.3. Present-day distribution and depositional environment of the Upper Rotliegend Group (late middle to early late Permian) in the Southern Permian Basin. BT = Bramble Trough; CNG = Central North Sea Graben; ESH = Elbow Spit High; HG = Horn Graben. (Modified from Geluk, 2005, 2007; De Bruin et al., 2015).

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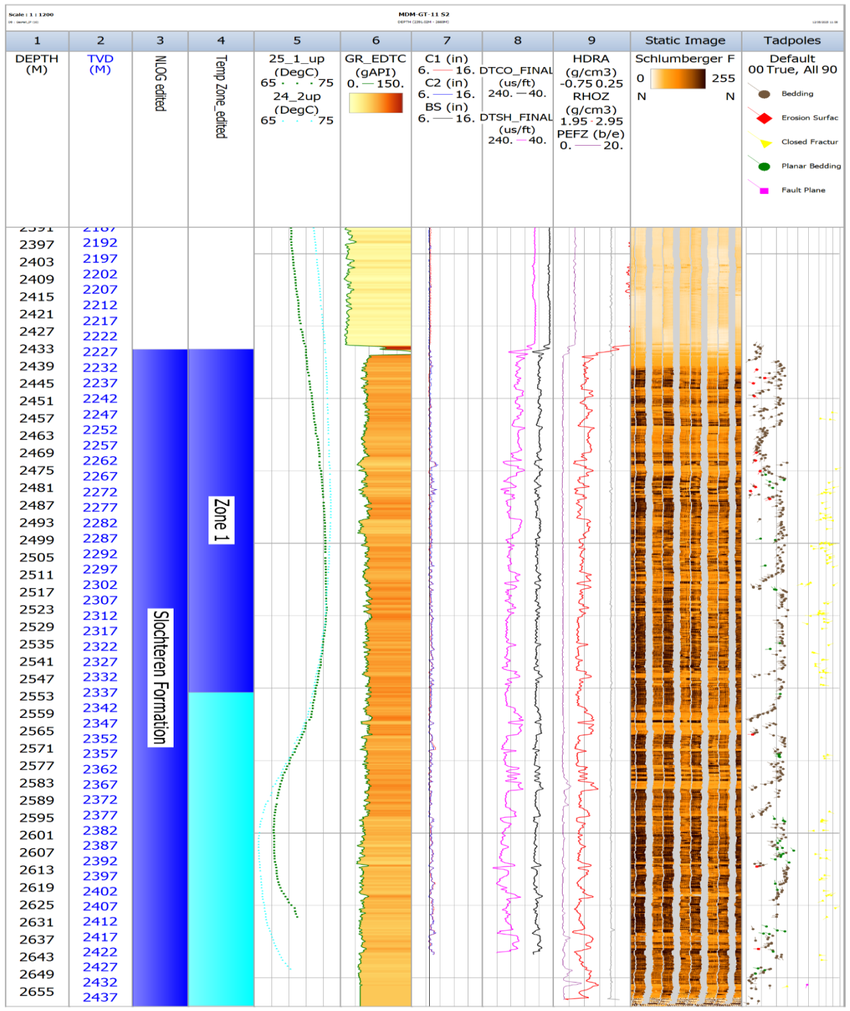
MDM-GT-11-S2 log data overview



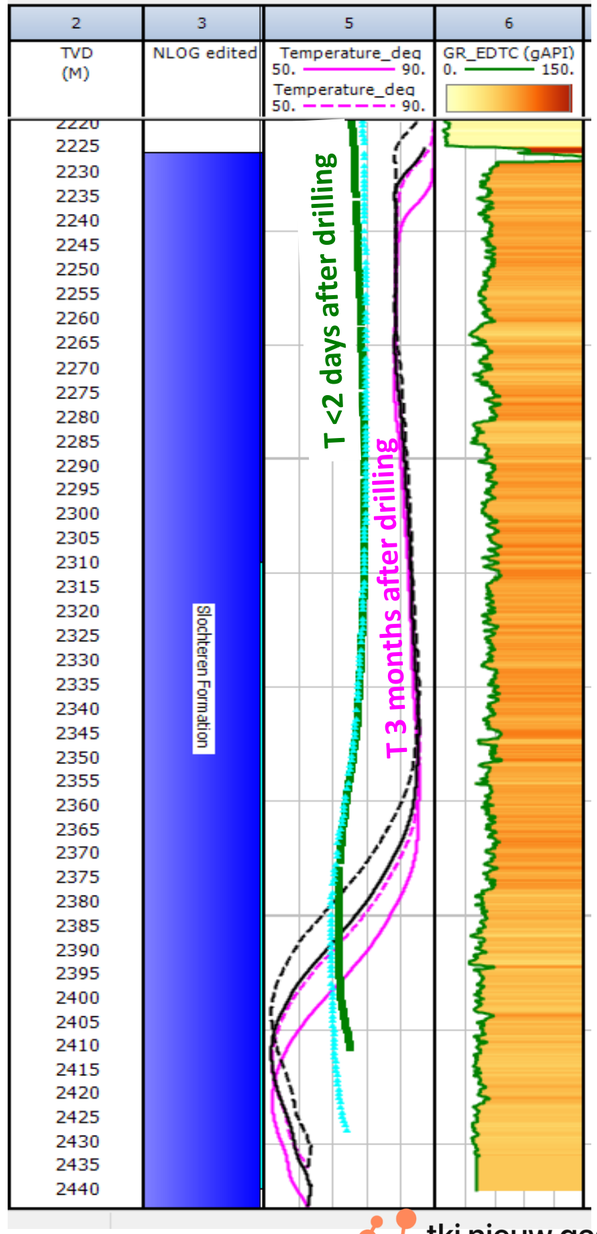
- **Objective of data acquisition:**
- Understanding the effect of 10 years of injection on a reservoir
- Selection of stress test (leak-off tests) location

Data acquired

- Temperature log
- GR
- Caliper
- Sonic
- Density PEF
- Image log (FMI HD) including dip picking from SLB

Wells in the license area with good datasets:

- MDM-GT-09 (drilled in 2022)
- MDM-GT-05 (drilled in 2022)



The temperature log shows thermal cooling concentrated within approximately one-third of the reservoir thickness.

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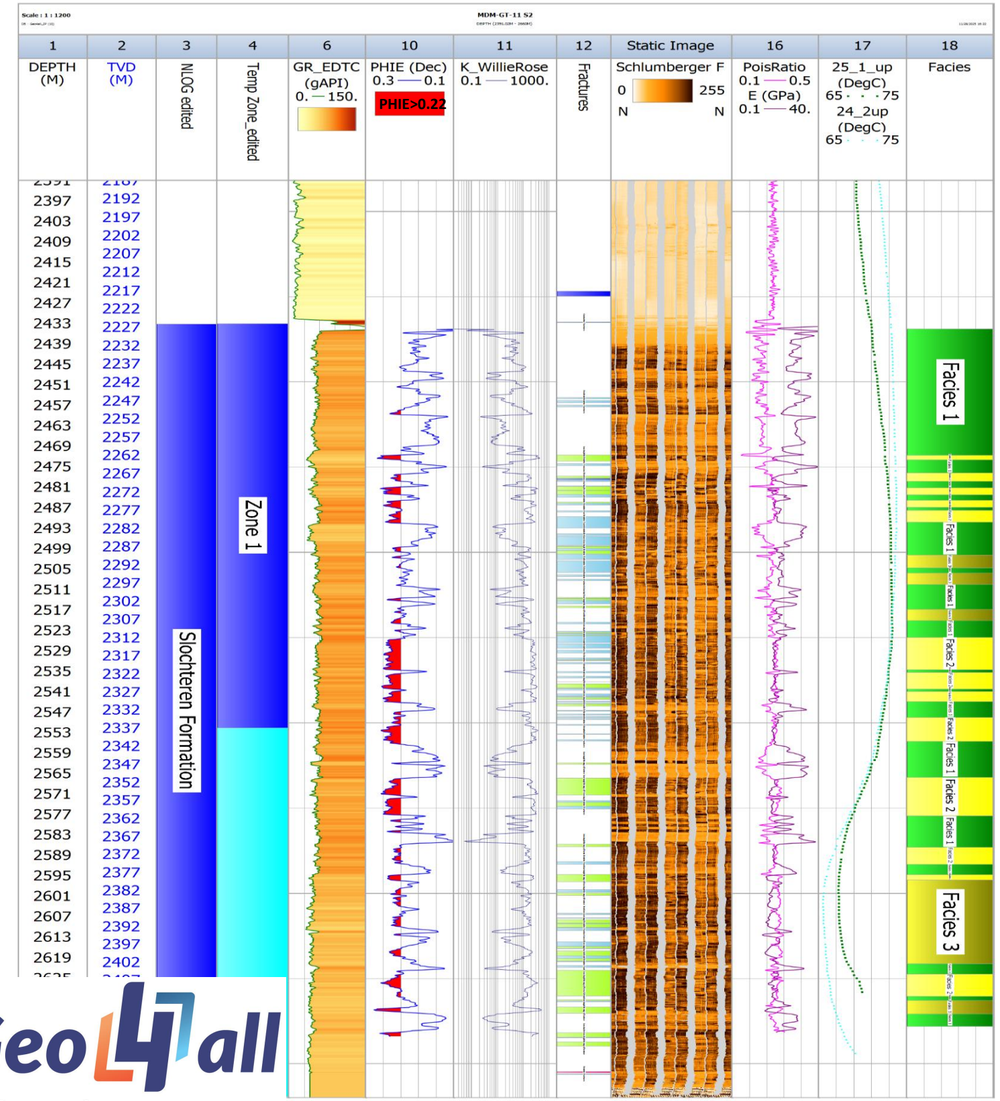
MDM-GT-11-S2 log data processing

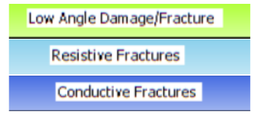


Volume of shale (Vsh) from GR.

Porosity (PORO) from Density (using GD 2,66g/cm3).

Permeabilities from: Wyllie and Rose equation (as in MDM-GT-05) and with poro-perm transform based on **AMS-01**.

Fractures Log: from dip picking.



Elastic Moduli:

Poisson Ratio from Sonic Compressional and Shear defines the deformations perpendicular to the applied force (compression and pulling).

Young Modulus (E) from Density, Sonic Compressional and shear describes the resistance of a material (stiffness) to elastic deformation in the same direction of the stress.

Facies Log: from image log calibrate to AMS-01 core data

Dry aeolian sand flat
Aeolian dune slipface
Aeolian dune base

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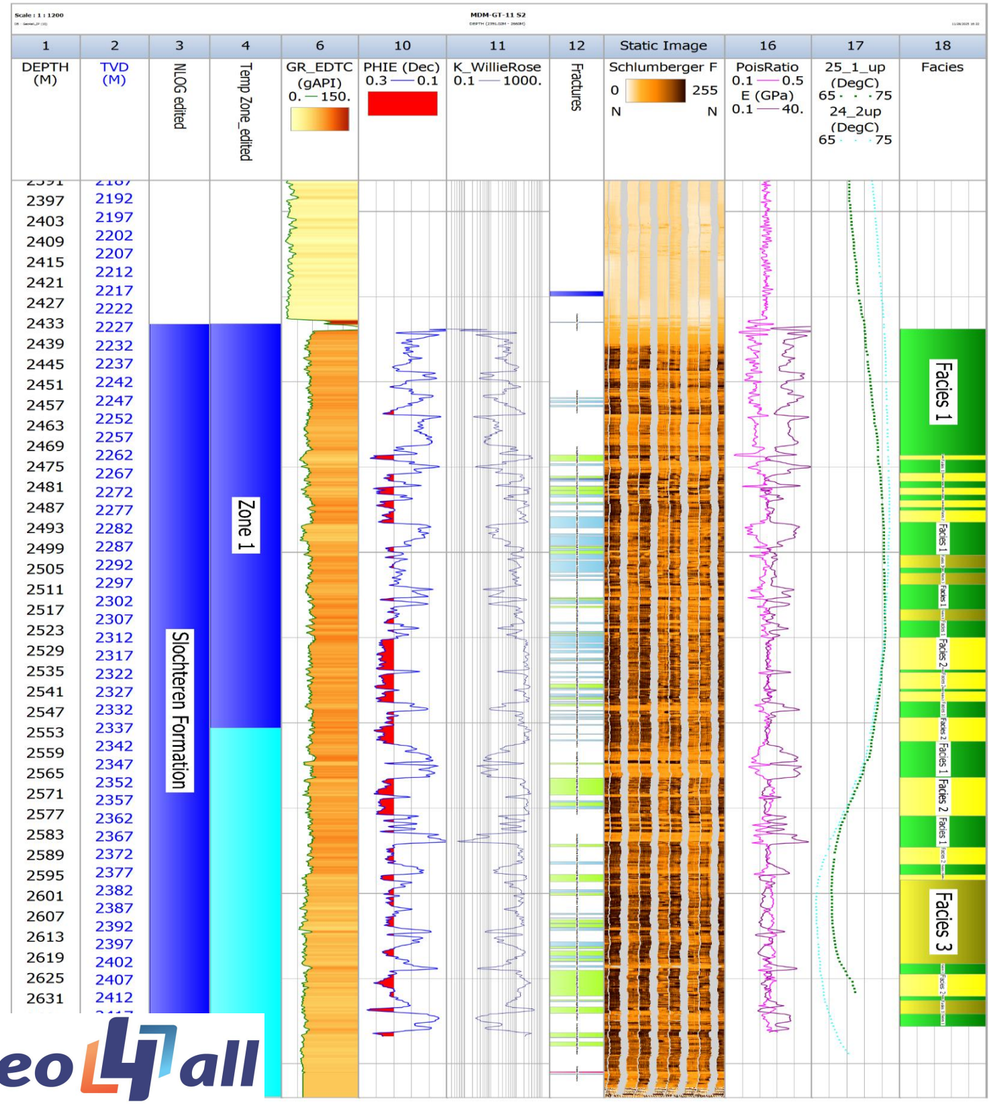
MDM-GT-11-S2 Image log analysis: Facies



Facies 1:

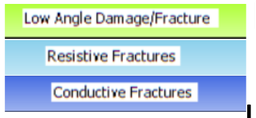
Lowest porosity *PHIE* <0.15/
Highest Young's modulus and the lowest Poisson's ratio anticorrelated response
Very resistive on the image
In the core from AMS-01 interpreted as dry aeolian sand flat deposits

Facies 2:

Highest porosity within the interval of interest,
High angle cross bedding
Intermediate Poisson's ratio and Young modulus
In the core from AMS-01 interpreted as Aeolian Dune base facies

Facies 3

Intermediate porosity
Cross over between the Young's modulus and Poisson's ratio
Lowest Young's modulus highest Poisson's ratio
In the core from AMS-01 interpreted as Aeolian dune slipfacies.



Resistive fracture dominant in the top - middle part of the reservoir

Low angle fractures dominant in the lower part of the reservoir roughly corresponding to the cooled interval

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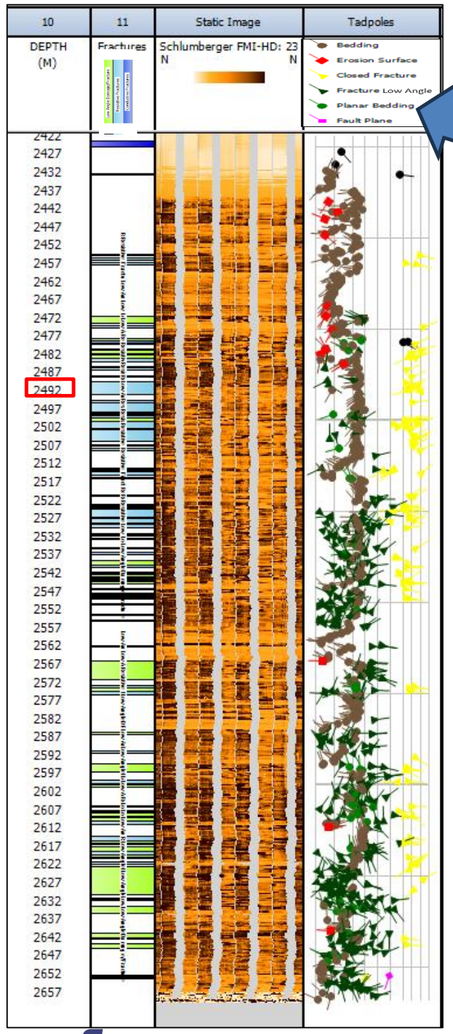
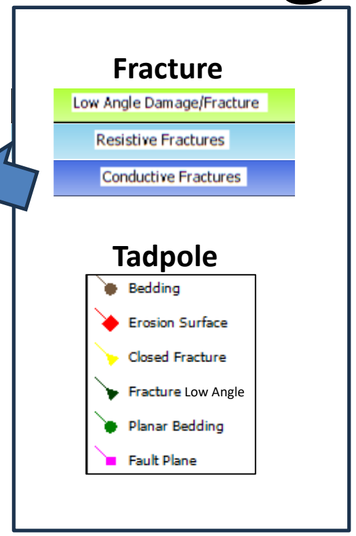
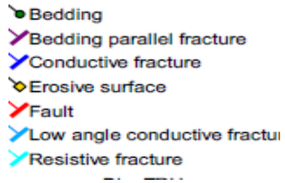
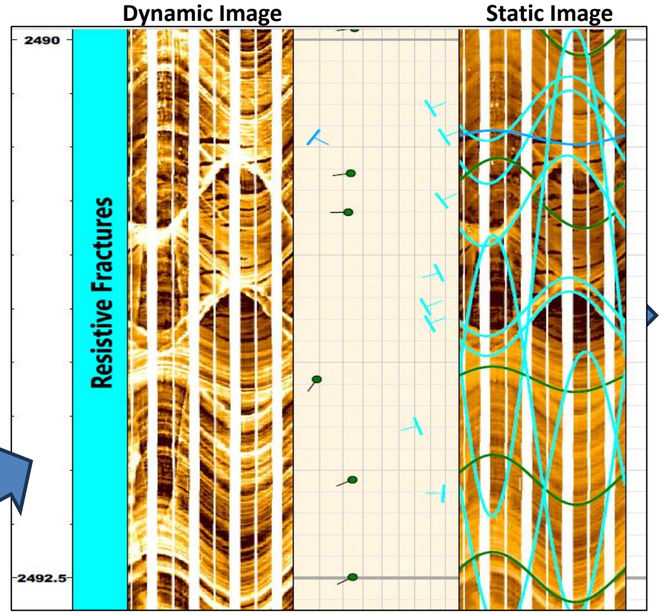
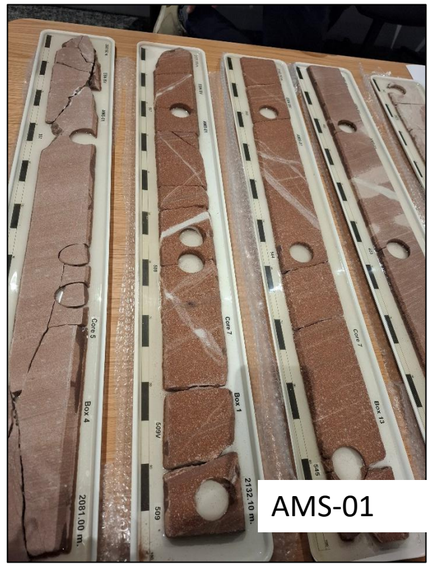
MDM-GT-11-S2 Image log analysis: Fractures











Dip picking is from Rush Interpretation performed by Schlumberger

- The Resistive fracture are Deformation Bands (zones of localised compaction, shear and/or dilation in deformed porous rocks).
- They tend to have a negative impact on permeability.
- Resistive fracture dominant in the top - middle part of the reservoir where cooling did not occur.

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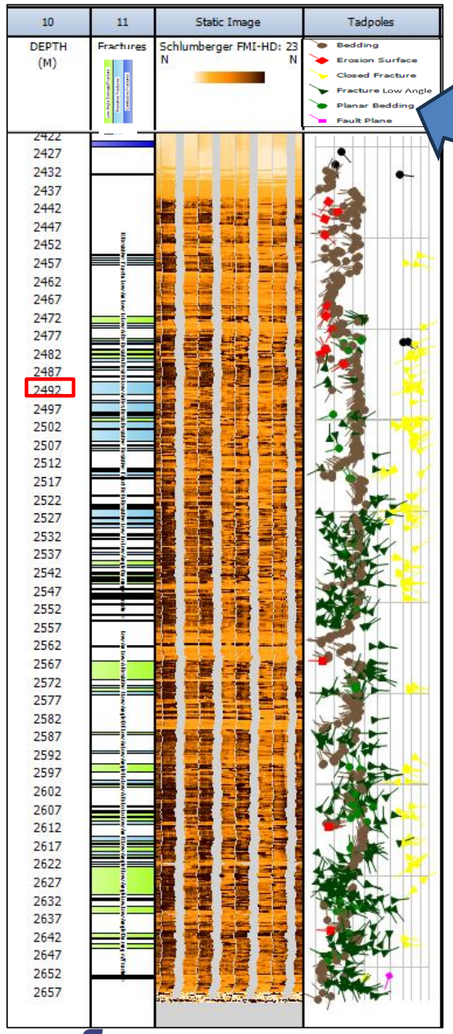
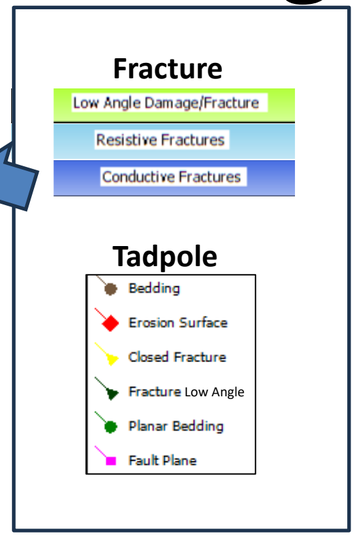
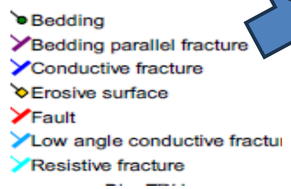
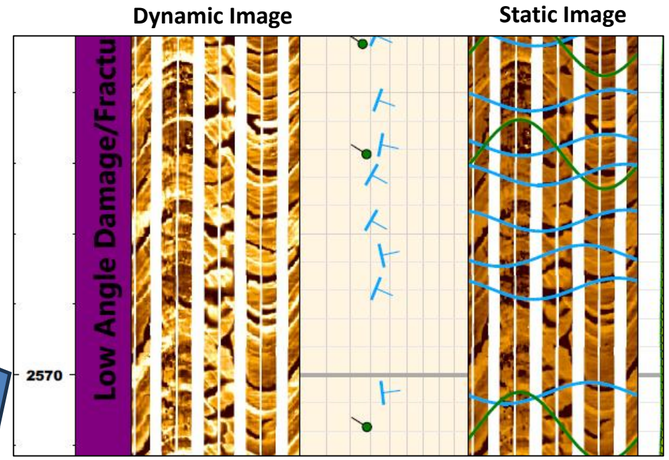
MDM-GT-11-S2 Image log analysis: Fractures









Dip picking is from Rush Interpretation performed by Schlumberger

- Low Angle conductive features, without preferred orientation interpreted as artefacts caused by stress unbalance during drilling (SLB report)
- They are bed bounded features enhancing existing sedimentary surfaces
- Intervals with high density of such features show a reduction of the Young modulus compared to the interval with less fractures in the same well.
- They are not typical of the Slochteren Formation
- They are abundant in the cooled interval therefore they could be related to the cooling.

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Conclusions

Heterogeneities of the geomechancal properties in MDM-GT-11-S2 are strongly related to depositional facies.
Each depositional facies in the well is characterized by distinctive geomechanical properties.

The heterogeneities in the cooling seems to be related to a combination of depositional facies and tectonic features (deformation bands).

The low angle conductive fractures interpreted as drilling artefacts, are observed mostly in the cooled part of the reservoir and could be related to the cooling.

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Thank You! Questions?

Drilling rig at Middenmeer Geothermie license area

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