SCAN: Seismic data for geothermal energy

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KNGMG Symposium: Seismiek in de energietransitie

30.05.2024

EBN B.V.

Ministerie van Economische Zaken en Klimaat

ebn

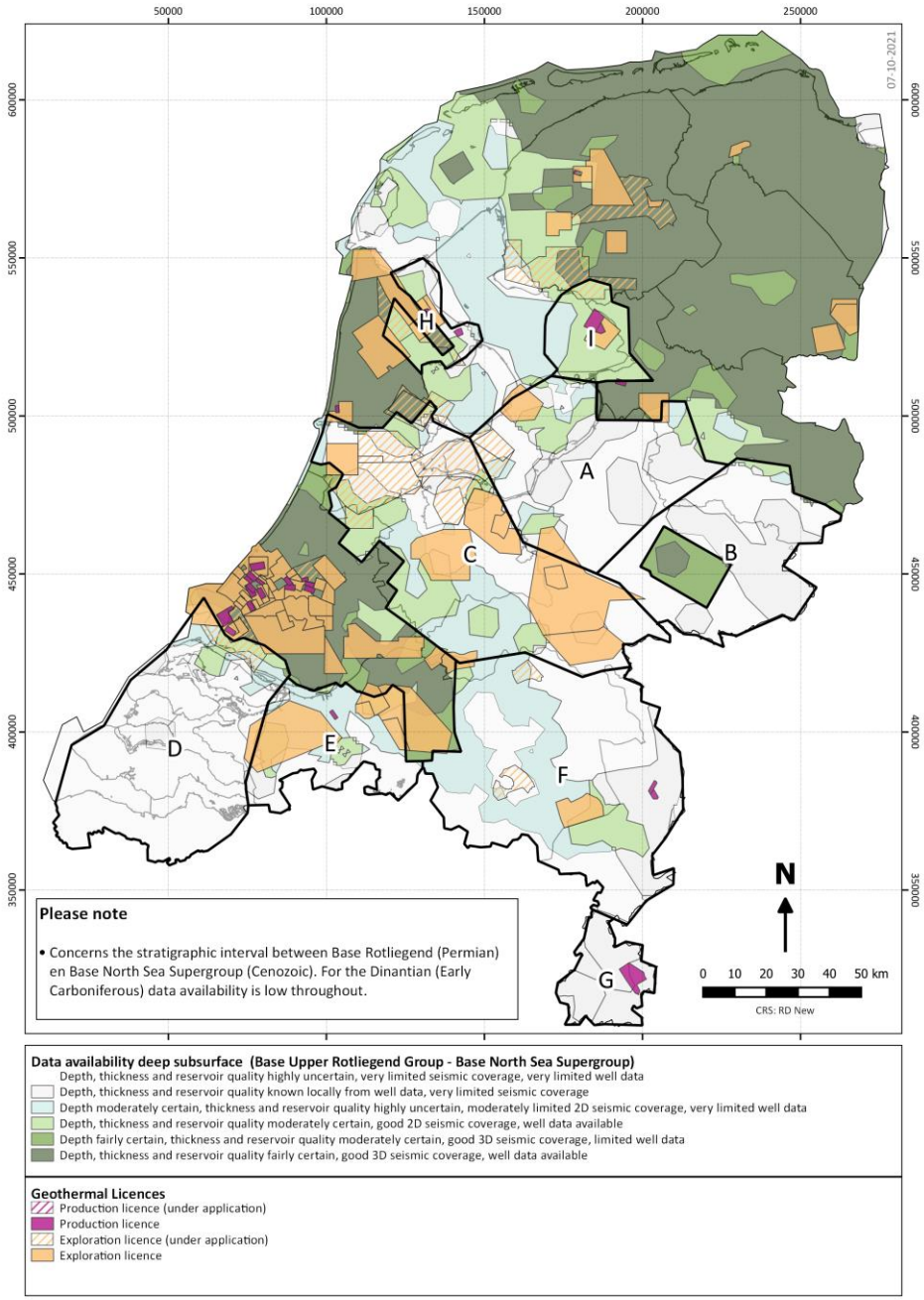
TNO

Agenda

- Introduction to the SCAN program
- Geothermal Plays
- 2D seismic acquisition & processing
- Seismic quality and ground water
- Wide lines and cross spreads
- Seismic inversion
- 2D seismic reprocessing
- Follow-up research
- Data acquisition wells
- SCAN data release

The SCAN program

- The SCAN program is implemented by EBN in collaboration with TNO and financed by the Dutch ministry of economic affairs and climate policy
- The aim of SCAN is to collect data in areas of the Dutch subsurface that have historically been left underexplored to accelerate the development of geothermal projects in the energy transition
- The SCAN data collection comprises:
  - Acquisition of new 2D seismic data (1950 km)
  - Reprocessing existing 2D seismic data (7500 km)
  - Drilling of several research wells
- All data SCAN collects is public and can be used by municipalities and project developers to better evaluate where opportunities lie for geothermal projects
- SCAN is a research program to collect subsurface data and will not develop geothermal projects

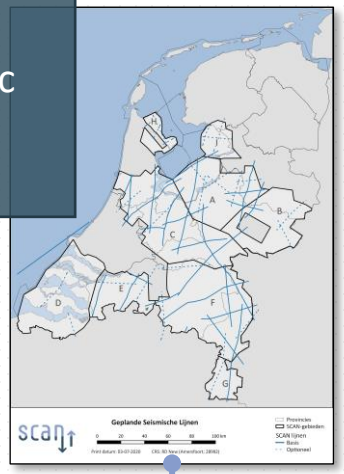


SCAN-project phases and activities

Project proposal

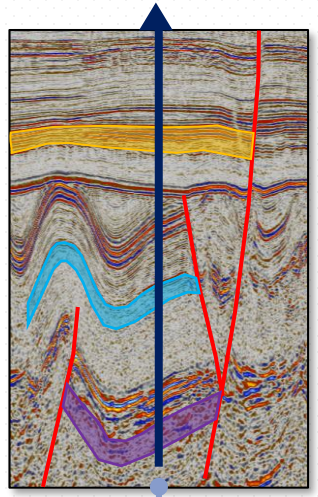
Subsidy Seismic

Design 2D seismic completed. Long seismic lines in areas with low seismic density



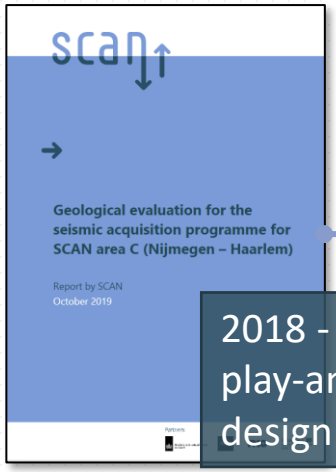
Subsidy wells

2021 - 2025: Planning, design and excecution of data acquisition wells



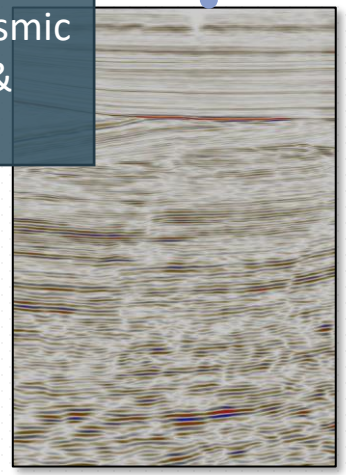
Subsidy follow-up research

2017 2018 2019 2020 2021 2022 2023 2024 2025

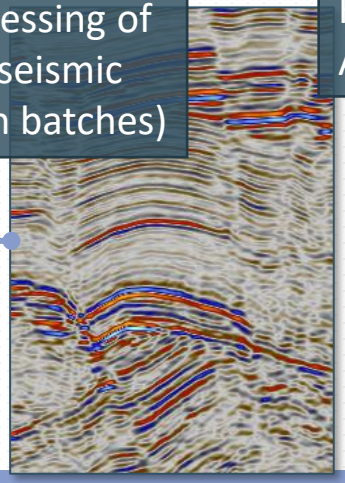


2018 - 2019: Geothermal play-analysis. Basis for design of 2D survey

2019 - 2022: Regional seismic acquisition & processing

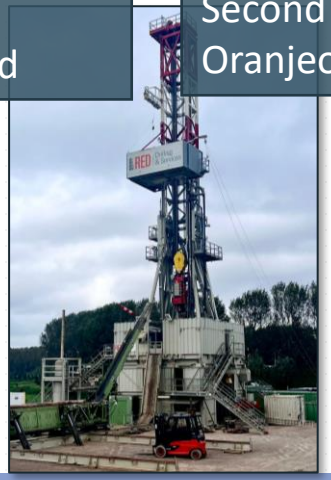


2019 - 2023: Reprocessing of legacy seismic data (in batches)



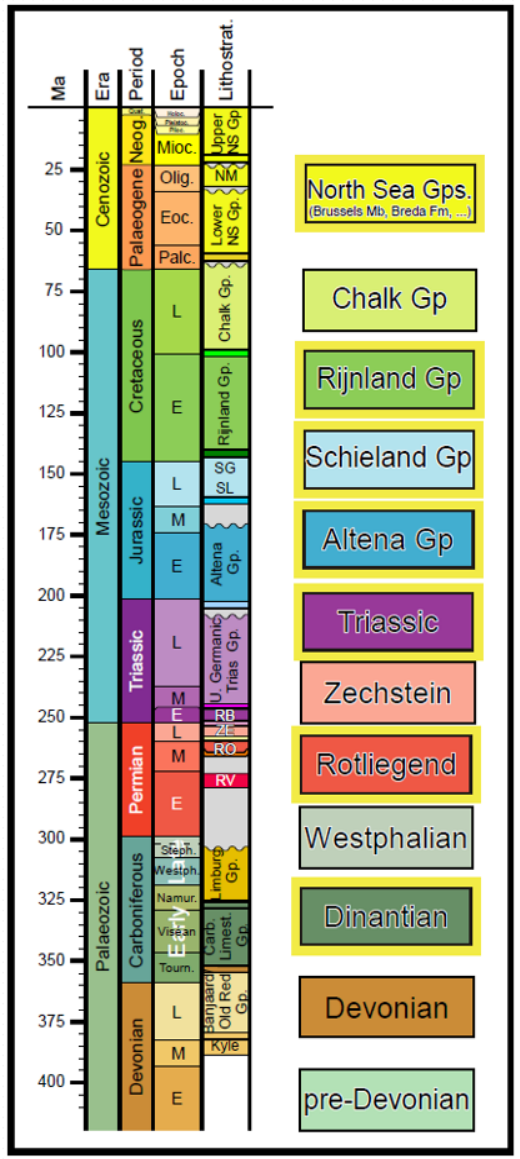
First well: Amstelland

Second well: Oranjeoord



SCAN: Geothermal plays

- SCAN looks at a wide range of geothermal plays
- **Focus on:**
  - Deep and Shallow geothermal (500 m – 4000 m)
  - Primary permeability
  - Secondary permeability (from karst or leaching)
- **<u>No</u> focus on:**
  - Ultra Deep Geothermal (UDG; >4000 m)
  - Fracture / fault permeability
  - Artificial/man made permeability systems (fracking, mine galleries, etc.)



✓ Primary play

• Secondary play

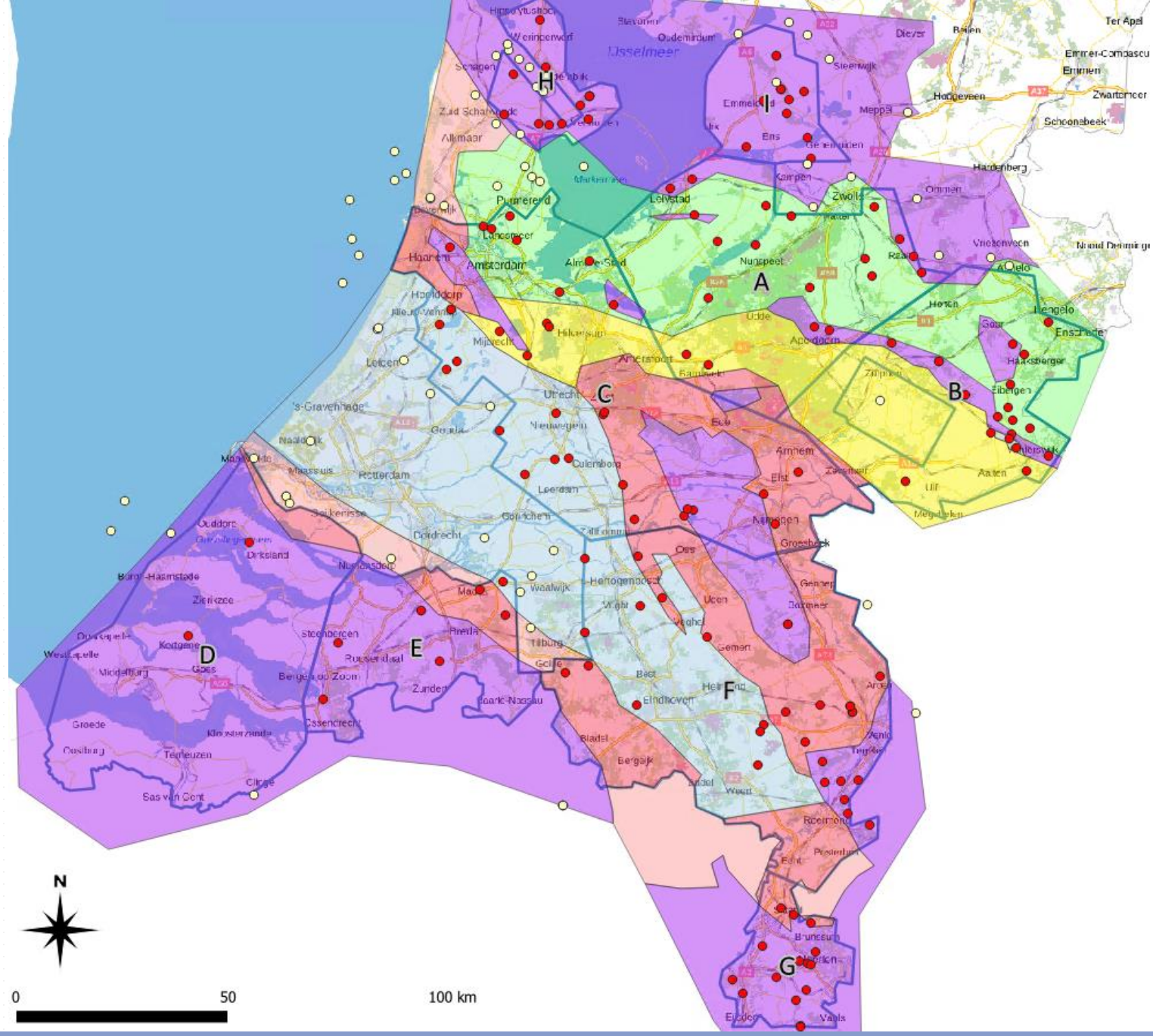
Playmap Triassic

➜As example: play map Triassic (Main Buntsandstein)

- Existing well, SCAN area
- Existing well, outside SCAN area

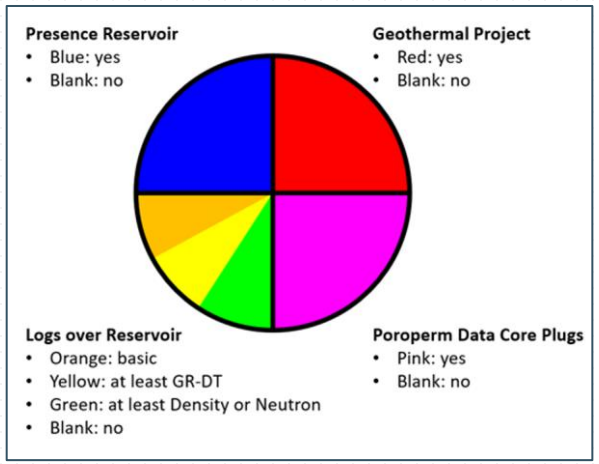
Triassic Play Map

- Reservoir eroded
- Reservoir shallower than 500m
- Reservoir isopach less than 20m
- Reservoir N/G ratio below 30%
- Permeability less than 10mD (P50) or 100mD (P10)
- Play Area SCAN
- Play Area non-SCAN



Well data Triassic

➜Well data availability and quality (Main Buntsandstein)



Existing well, SCAN area

Existing well, outside SCAN area

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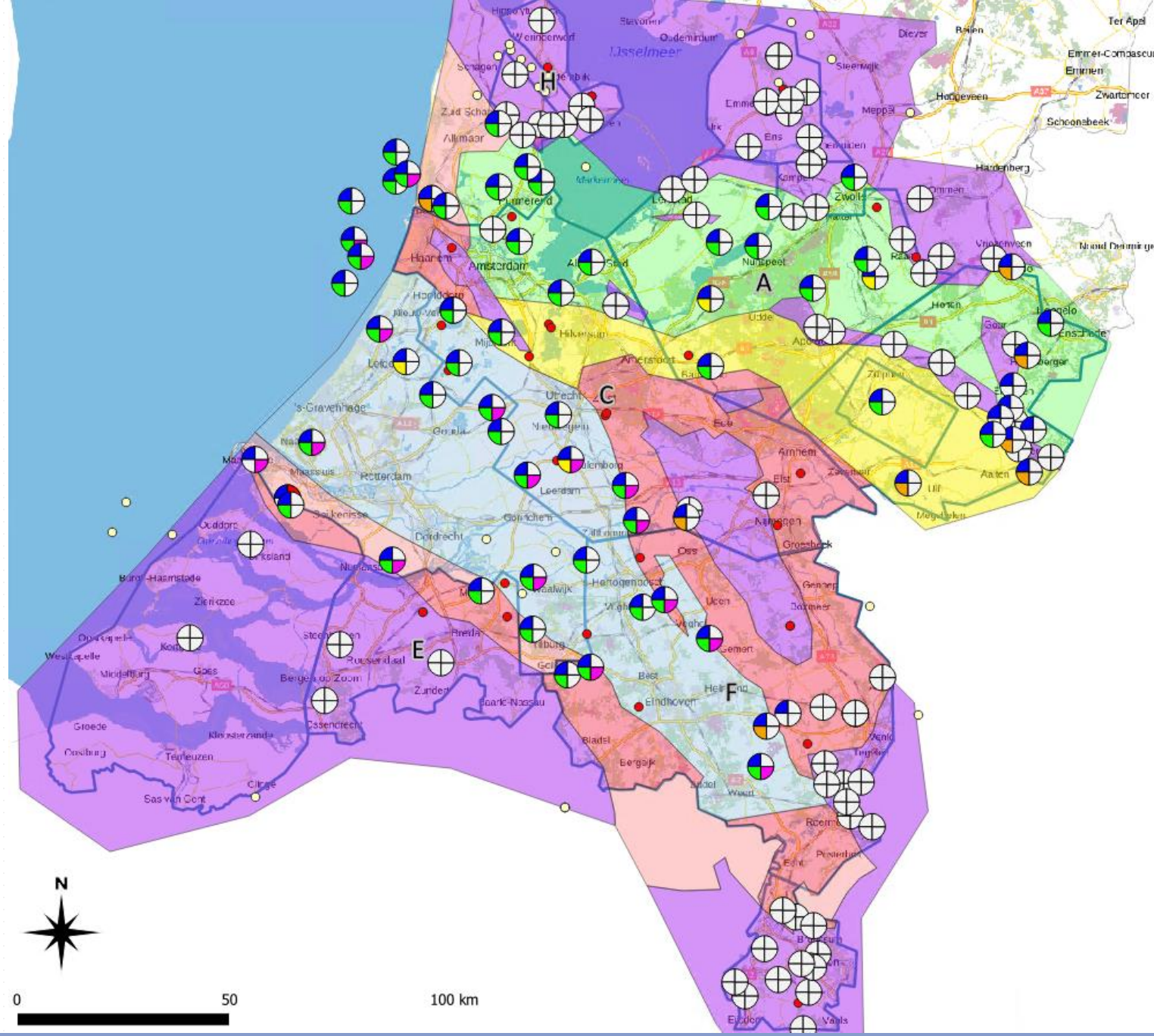
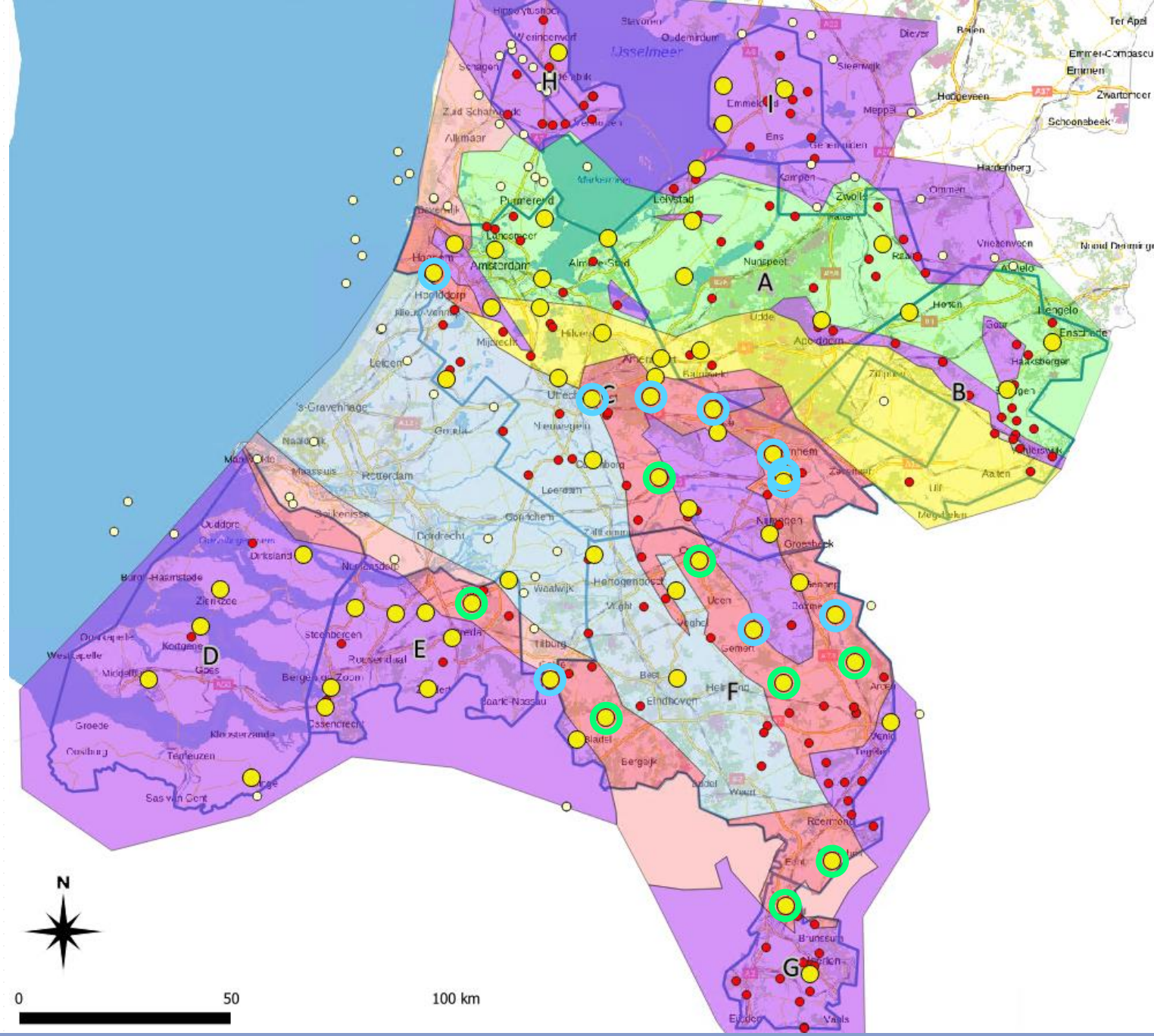


SCAN Leads

➜Preferred location where several plays can be tested in one well

- Existing well, SCAN area
- Existing well, outside SCAN area
- SCAN Lead
- SCAN Lead, with primary Triassic target
- SCAN Lead, with secondary Triassic target



SCAN 2D Acquisition

➜Acquired 2D seismic lines (black)

➜Note: Evaluations have been made for all geothermal plays

- Existing well, SCAN area
- Existing well, outside SCAN area
- SCAN Lead
- SCAN Lead, with primary Triassic target
- SCAN Lead, with secondary Triassic target

Triassic Play Map

- Reservoir eroded
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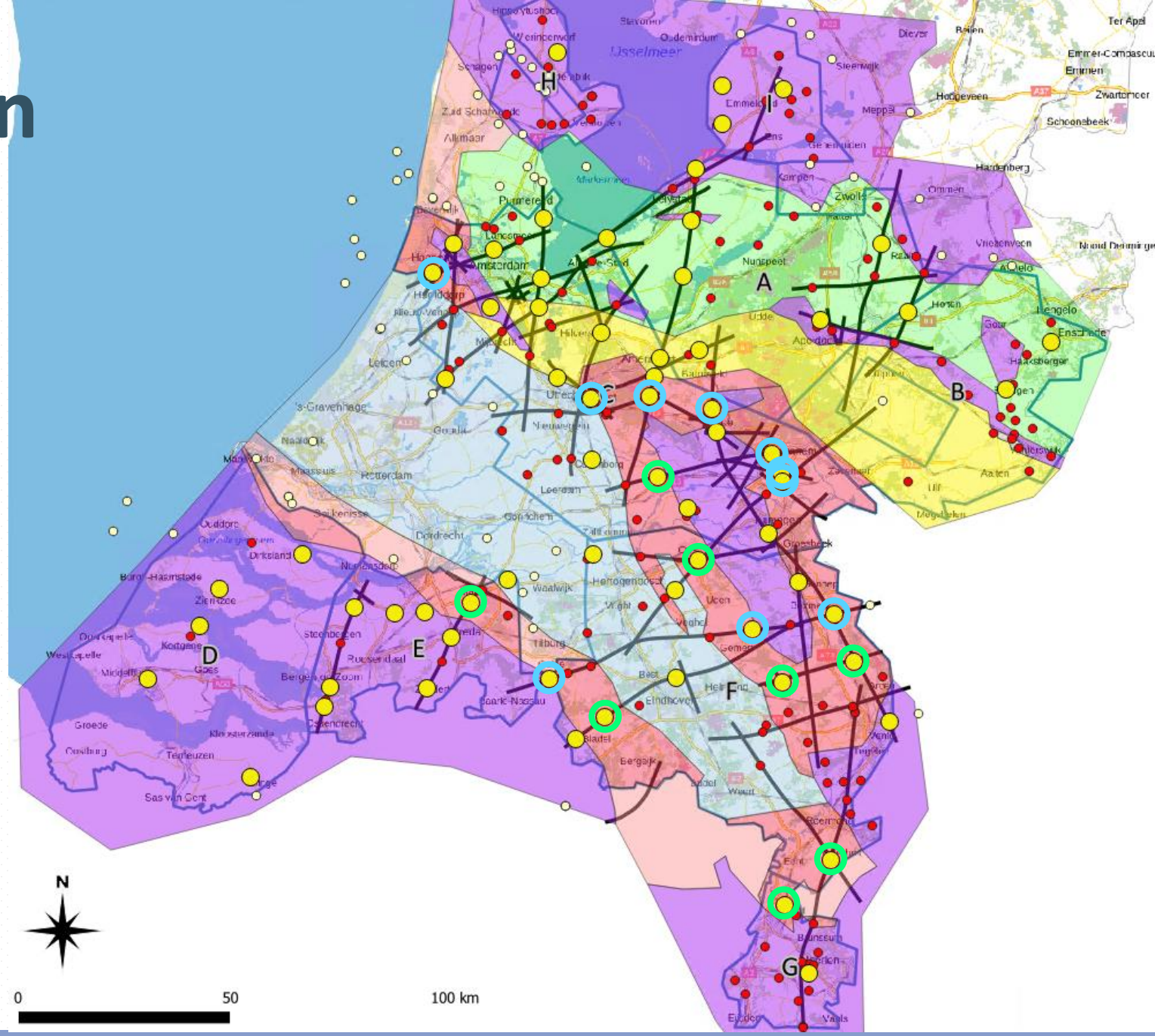


SCAN 2D seismic acquisition

- Acquired 1.837 line km of new regional 2D (46 lines) and 20 local lines (106 km) to support the SCAN well locations with zero LTIs
- Recorded 30.196 shots and 383.467 receivers planted
- SCAN acquisition was combined with local 2D seismic acquisition programs for UDG and MRA
- Visited 164 municipalities, distributed 135.000 letters into the neighbourhoods prior to acquisition
- Land access permissions from some 6.200 land users

SCAN 2D seismic acquisition

Key acquisition parameter:

- Shot spacing: 60 m
- Shot depth: Nominally 20 m
- Shot type: Seismic explosives
- Receiver spacing: 5 m
- Receiver type: Wireless nodes
- Spread type: Split-spread
- Maximum offset: 7 km
- Recording length: 10 seconds

Key SCAN HSE numbers (30.11.2023):

- Zero LTIs
- Manhours worked: 1.090.750
- Km's driven: 2.668.779

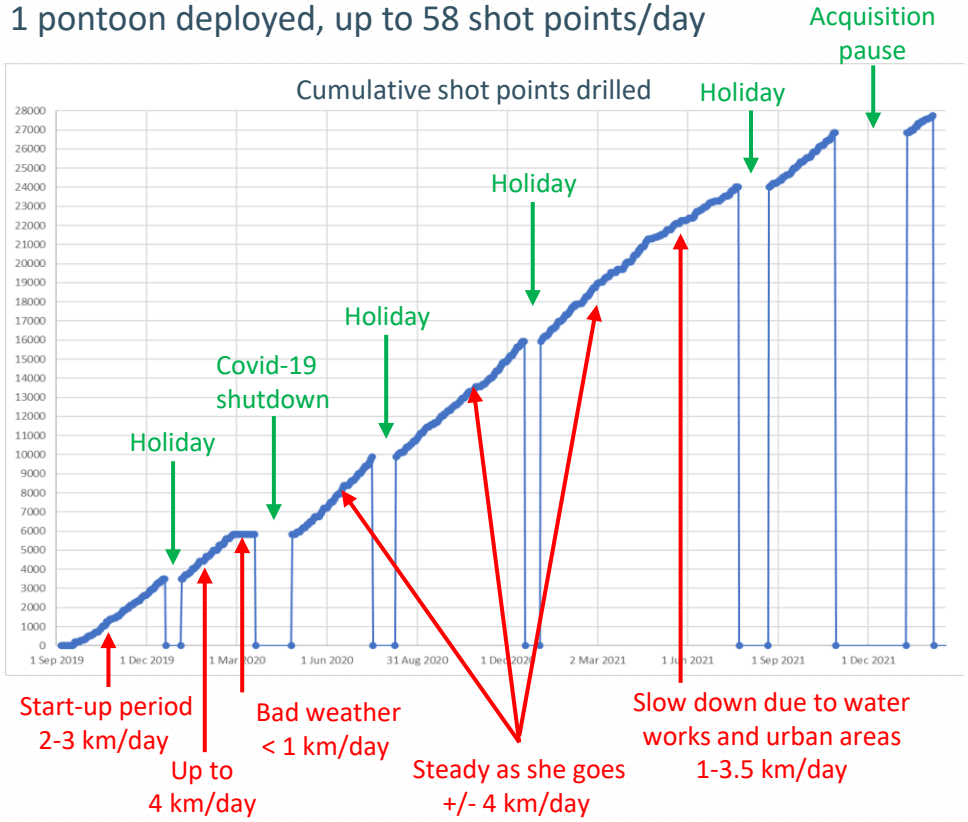
(Numbers include the EBN test line (SCAN001), and all local 2D seismic acquisition).

Land drill tractor,
usually 5 tractors deployed,
up to 100 shot points/day

Shooting crew,
up to 160 shot points/day,
usually 1 crew deployed

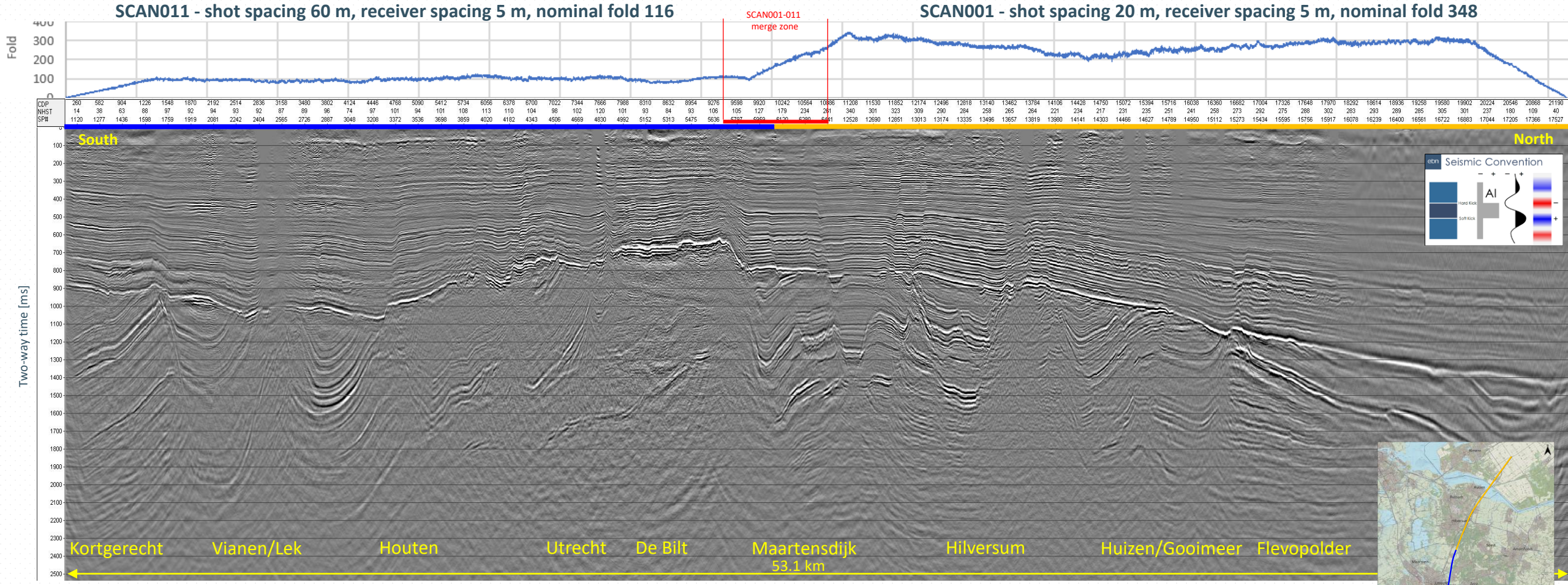
Geophones

Barge/pontoon mounted drill tractor, usually 3 barges and 1 pontoon deployed, up to 58 shot points/day



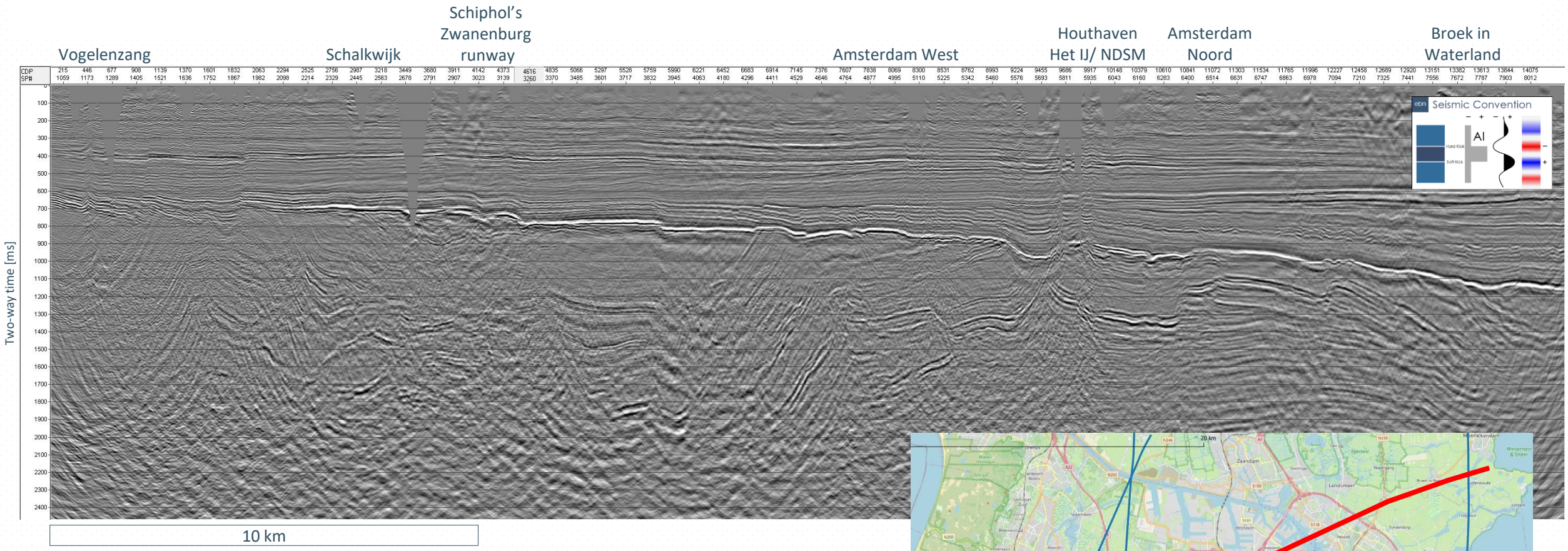
Average shot point drilling since acquisition start (477 days of shot point drilling) is 3.7 km/day.

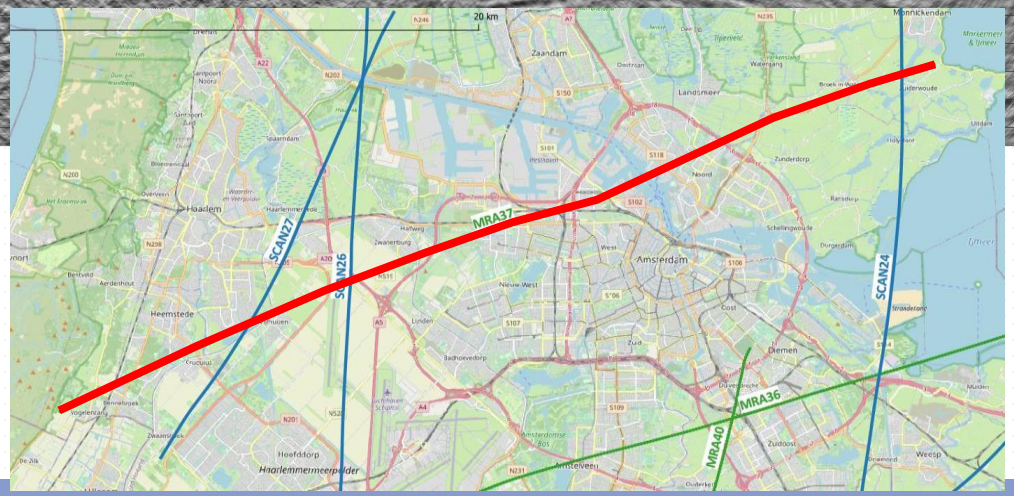
SCAN 2D PreSTM processing – SCAN011 & SCAN001



- Shot spacing of 60 m shot & 5 m receiver spacing provide adequate data quality for 2D regional seismic interpretation
- No significant data quality reduction compared to 2019 test line that would compromise seismic interpretability
- Test with PreSDM and RTM processing on line SCAN002 showed that PreSTM processing is sufficient for the objectives of the SCAN project

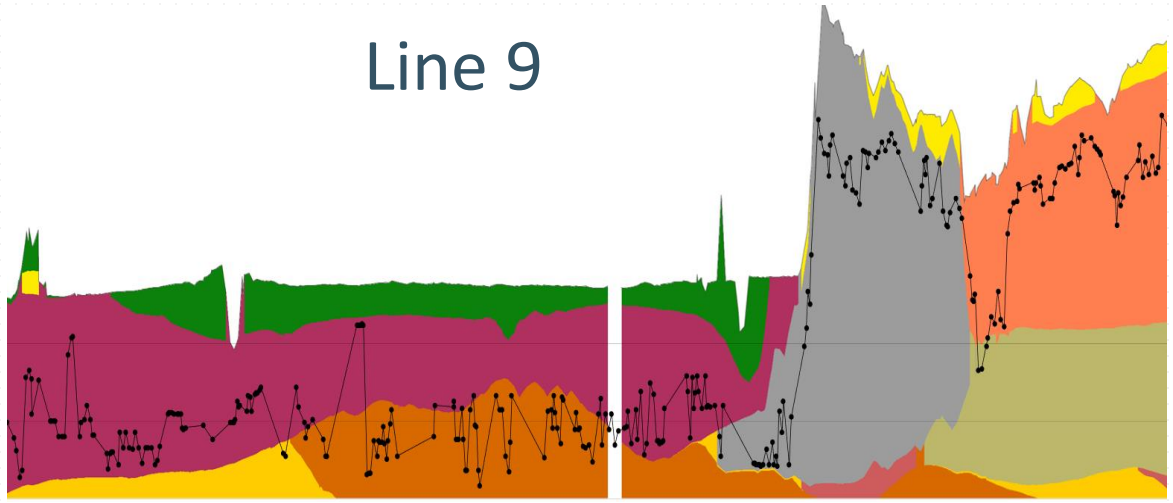
SCAN 2D PreSTM processing – MRA037

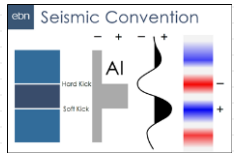


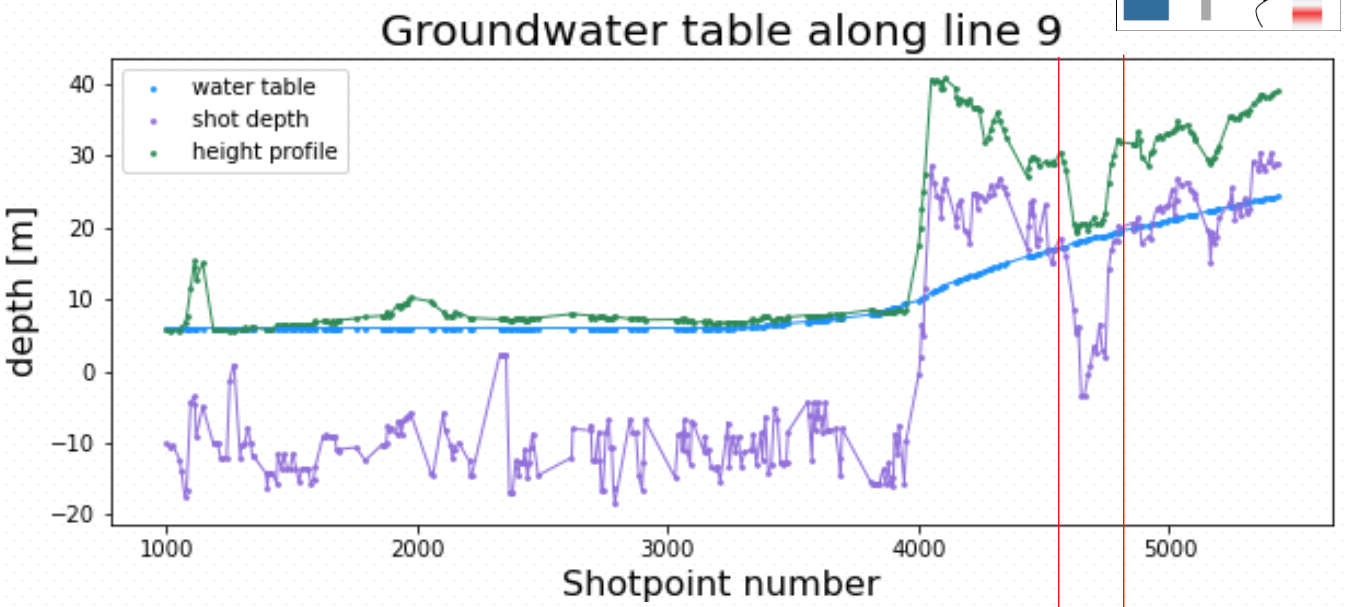


- With careful planning it was possible to acquired several 2D seismic lines in close proximity to Amsterdam.

Seismic quality and ground water table

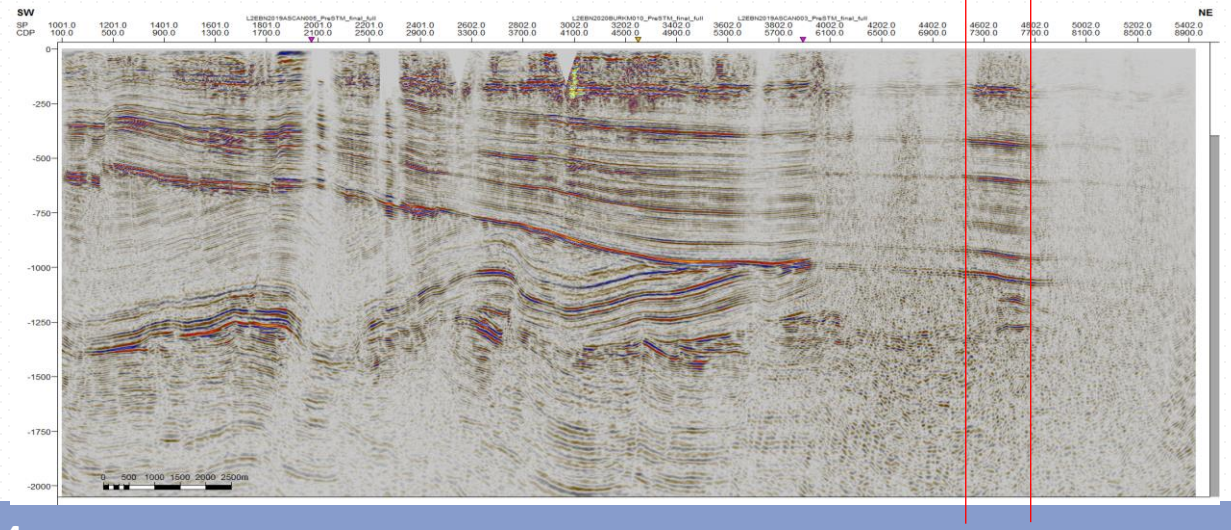




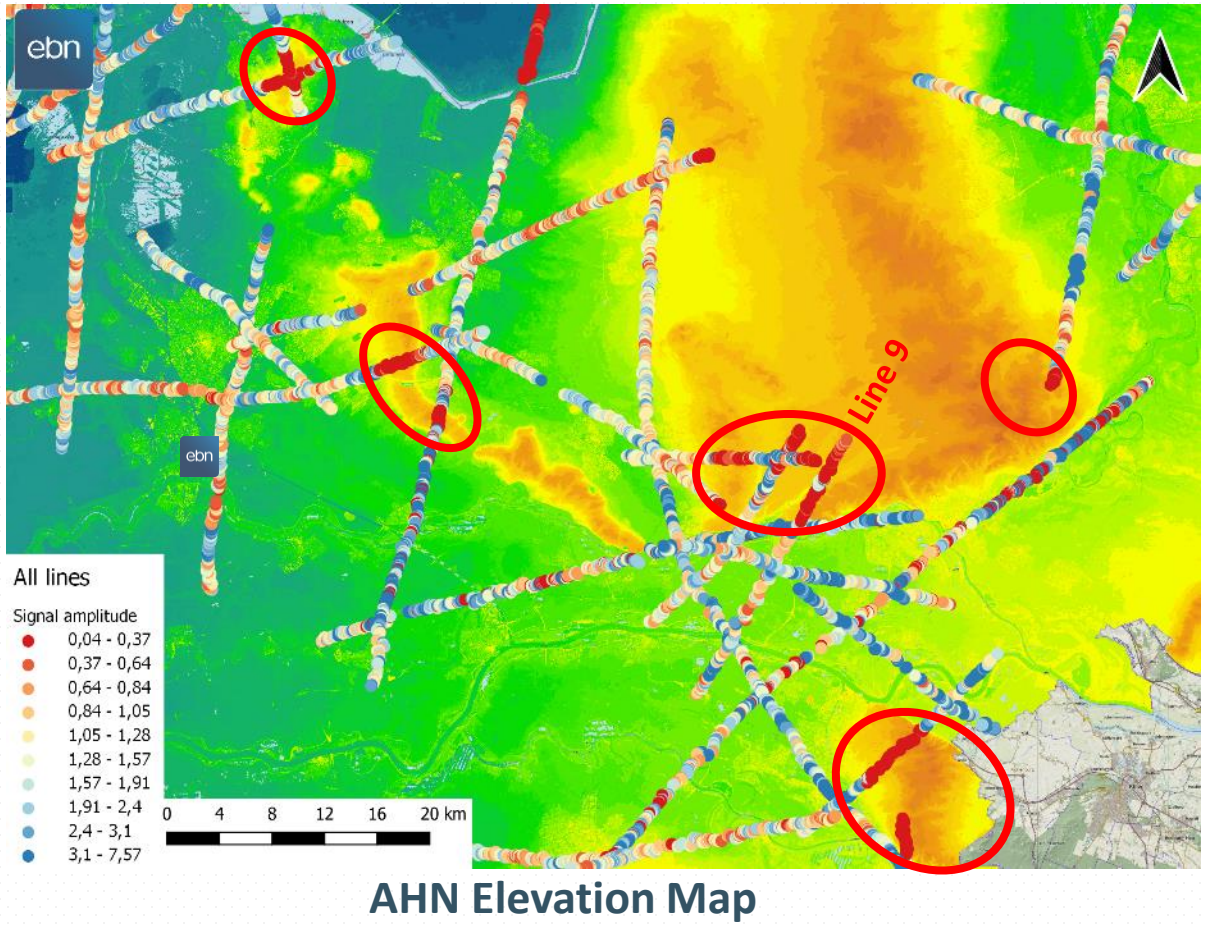


The quality of the seismic data is related to the depth of the ground water table

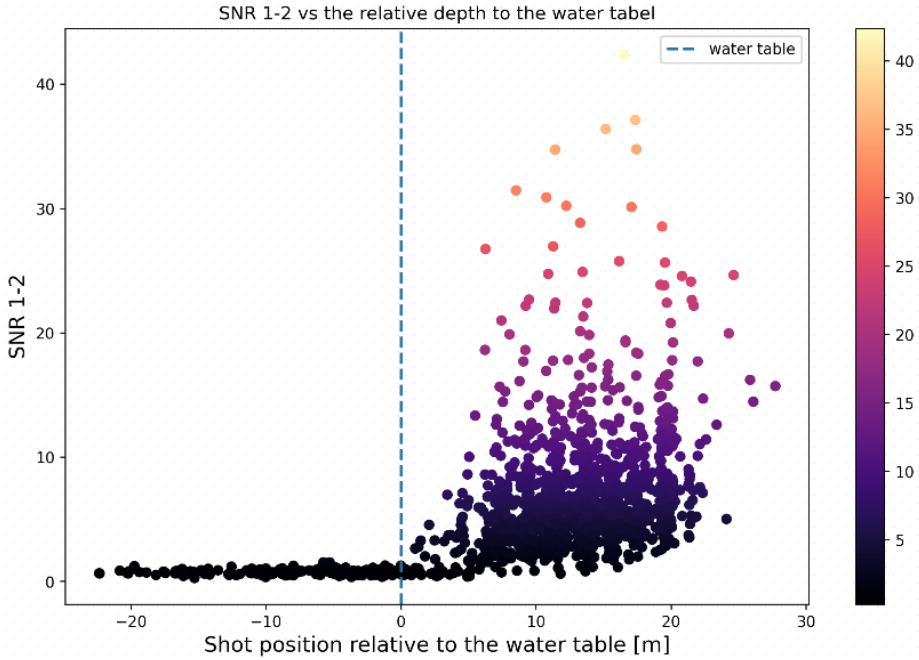
- Most shots are below the water table and give good results
- Shots above the water table result in low signal to noise ratio due to poor coupling



Quality dependance on water table



AHN Elevation Map

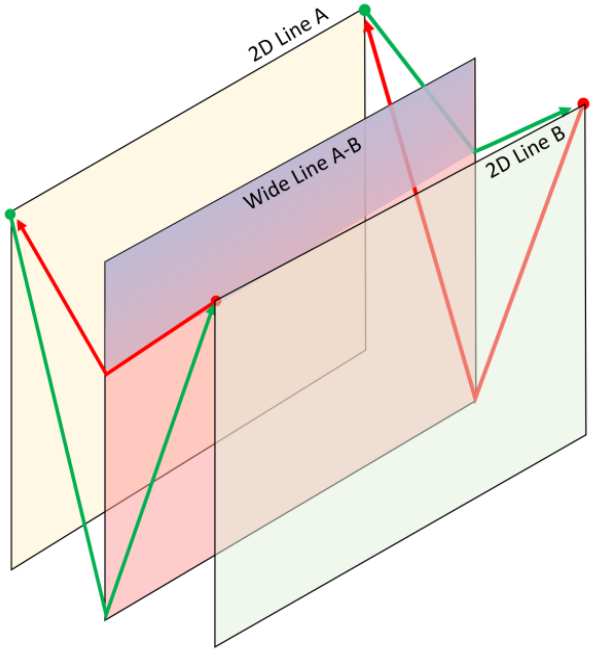


Shots above the water table are always poor due to low coupling

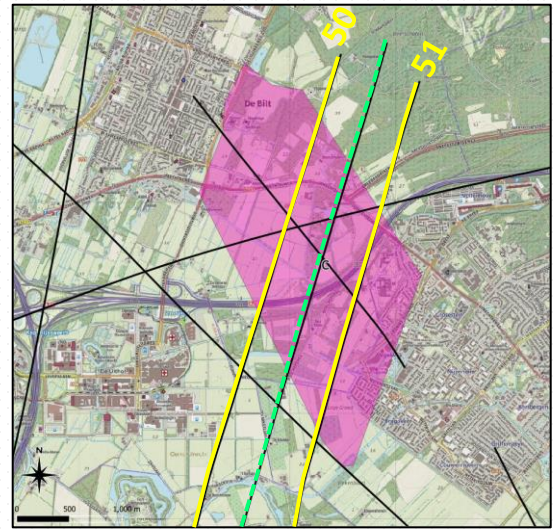
On ice-pushed ridges (stuwwallen) the water table is typically well below ground level. Boulders may also have a scattering effect

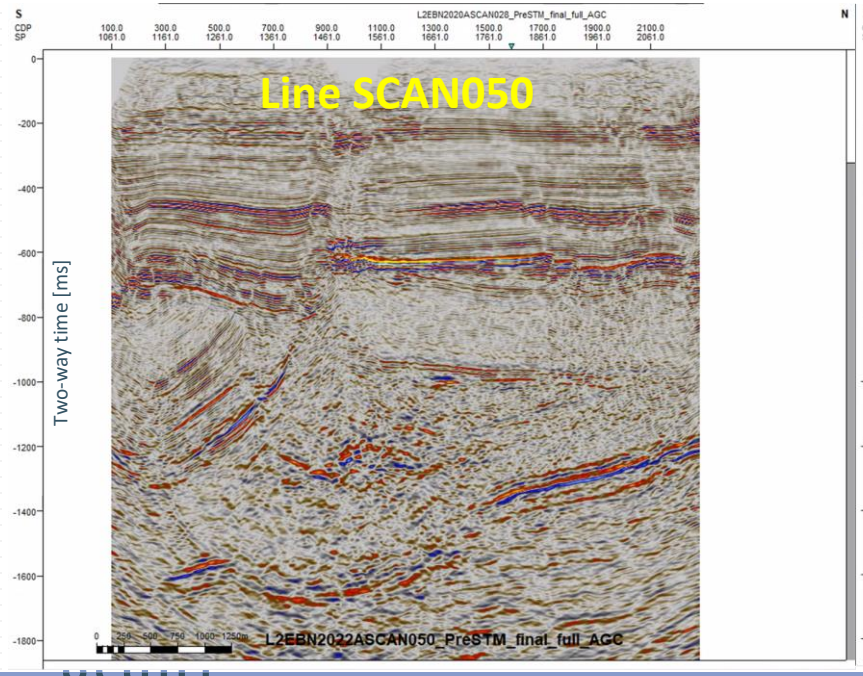
Wide lines

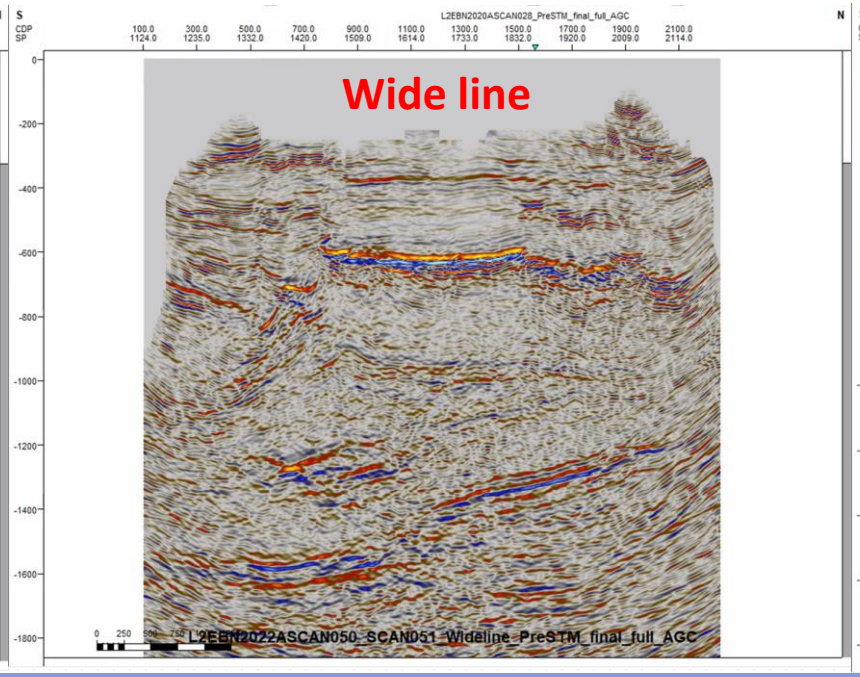
- A 2D wide line can be acquired when two 2D lines are shot parallel at close distance (~ 1 km)
- Shots from one line are also recorded into the geophones of the second line and vice versa
- The shallow part of the wide line cannot be acquired due to missing short offsets

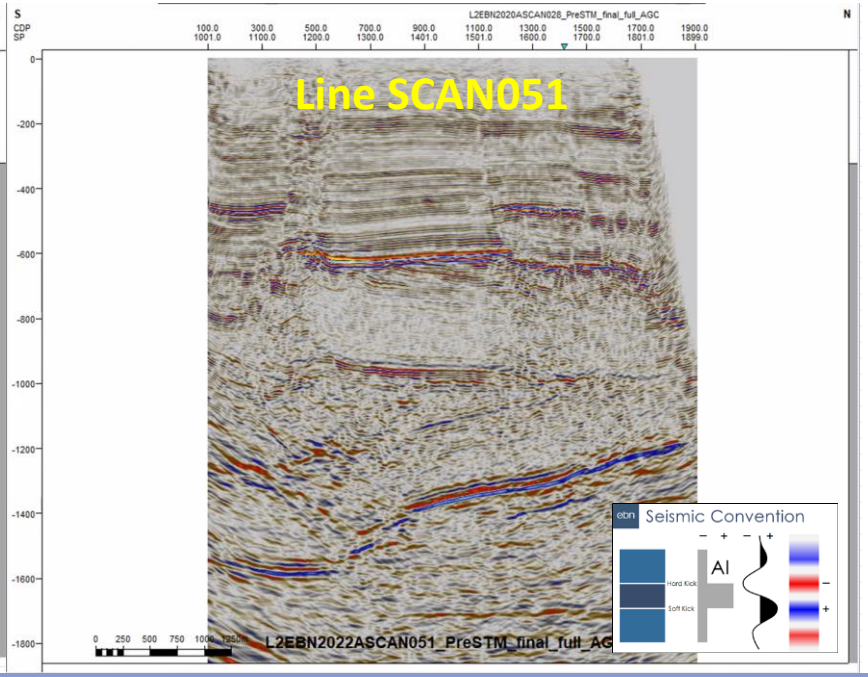


Yellow: input wide lines
Green dashed: wide line



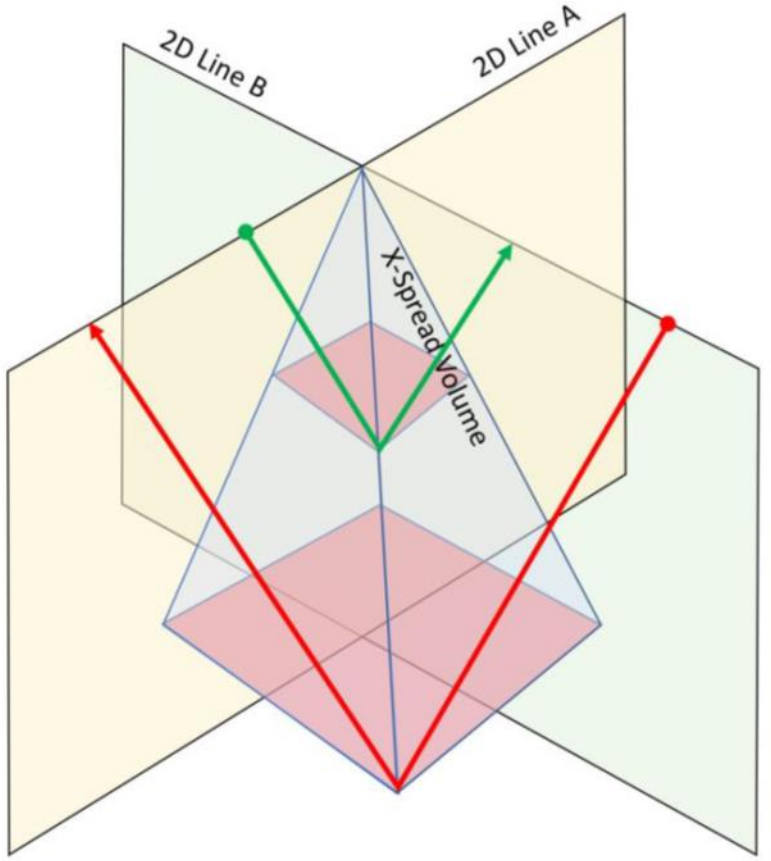






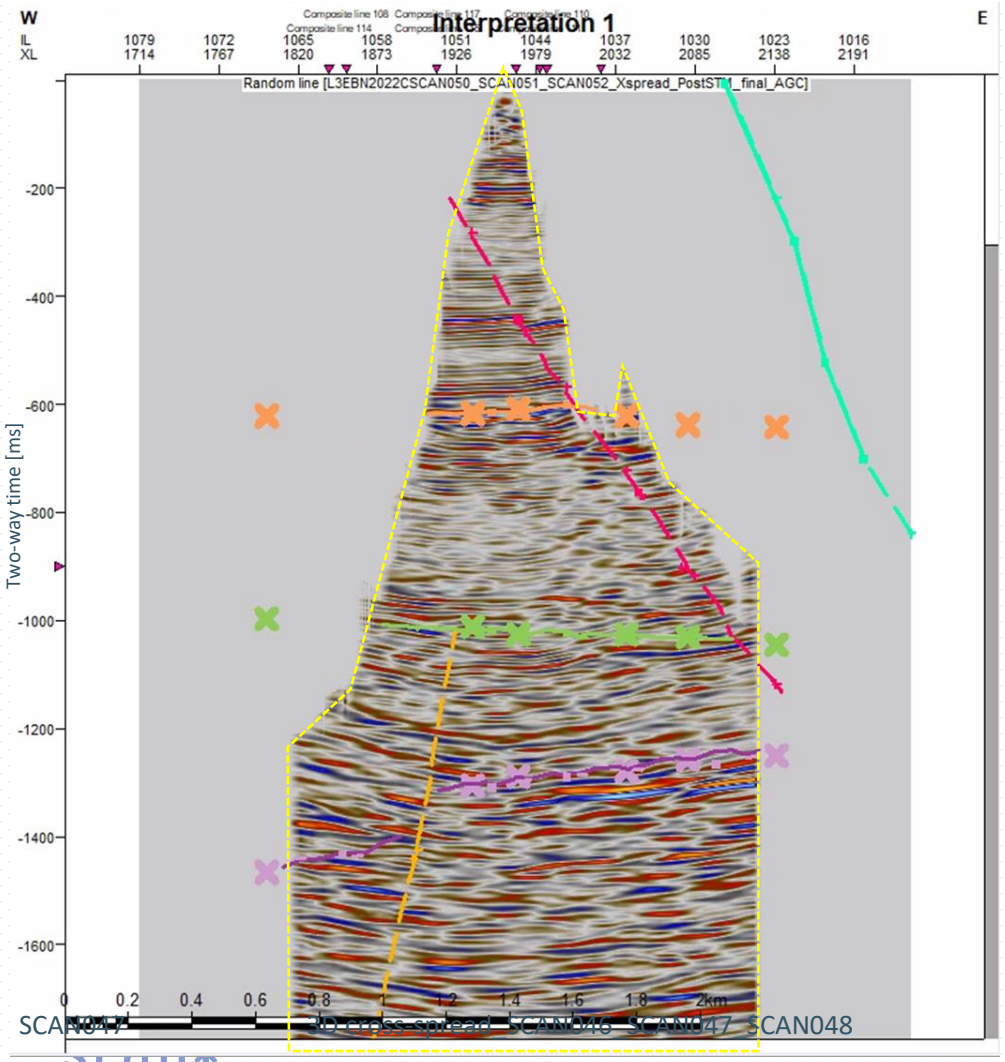
Cross-spread

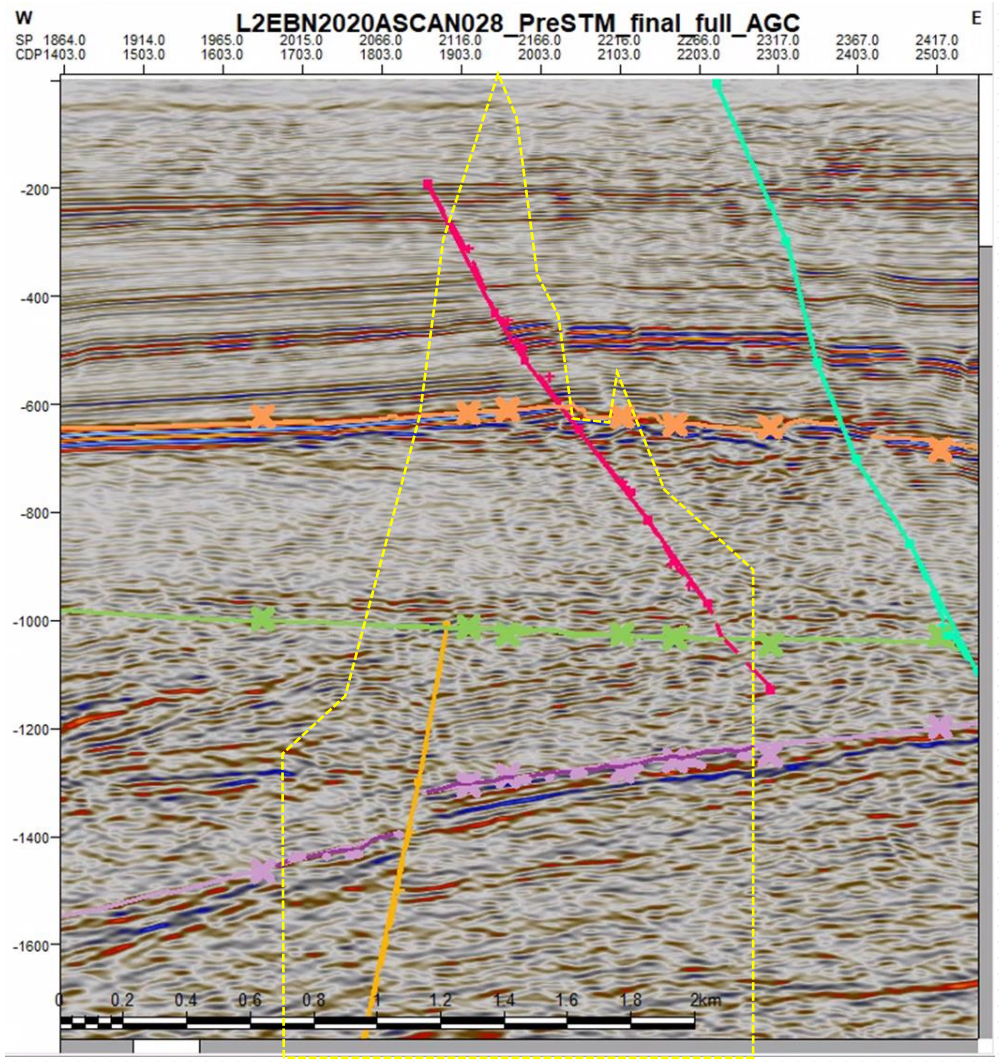
- A 3D cross-spread can be acquired when two (or more) 2D lines are crossing each other
- Shots from one line are also recorded into the geophones of the second line and vice versa
- A cone shaped 3D volume can be acquired, with an apex at the intersection point of the two lines
- If sufficient geophones are available to lay out ALL lines at ONCE, then the seismic recording of a 3D cross-spread or 2D wide line is almost “for free”
- Extra effort is only required during data downloading and to compile the cross-spread or wide line shots, and for processing. Some efficiency may be lost due to a more staggered acquisition (lay-out, shooting and pick-up)
- Note: It does require a seismic source strong enough to record the wide crossline offsets
- EBN considers the 3D cross-spread or 2D wide line acquisition a very useful data supplement to any local 2D acquisition

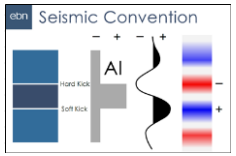


SCAN 3D cross-spread acquisition (De Bilt-Zeist example)

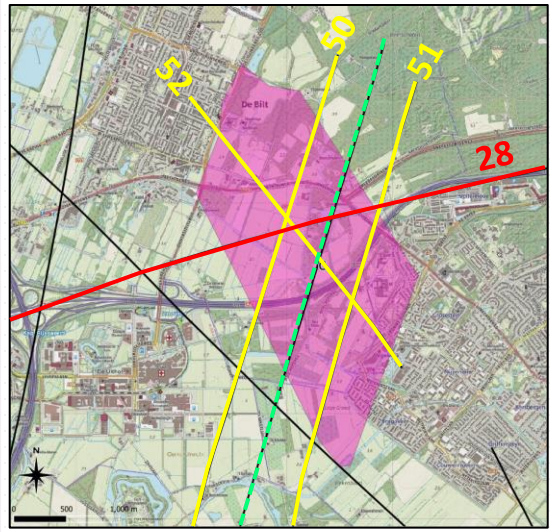
Comparison of random line trough 3D cross-spread parallel to SCAN line 28 (not used as input)





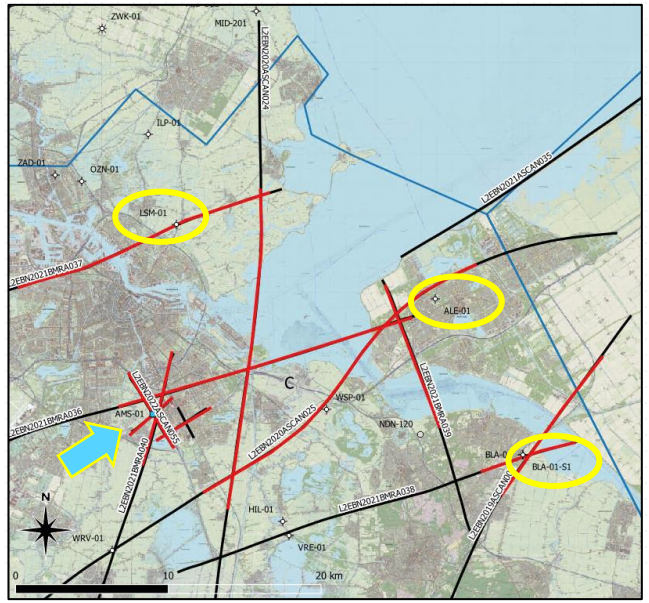


Yellow: input lines X-spread
Green dashed: wide line
Red: SCAN line 028 (pre-existing)
Polygon: Cross-spread area



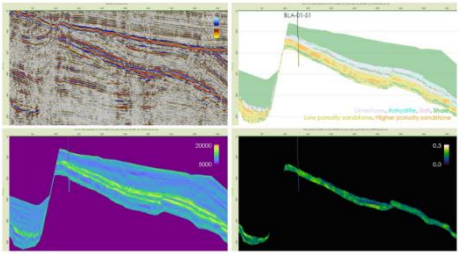
Seismic inversion

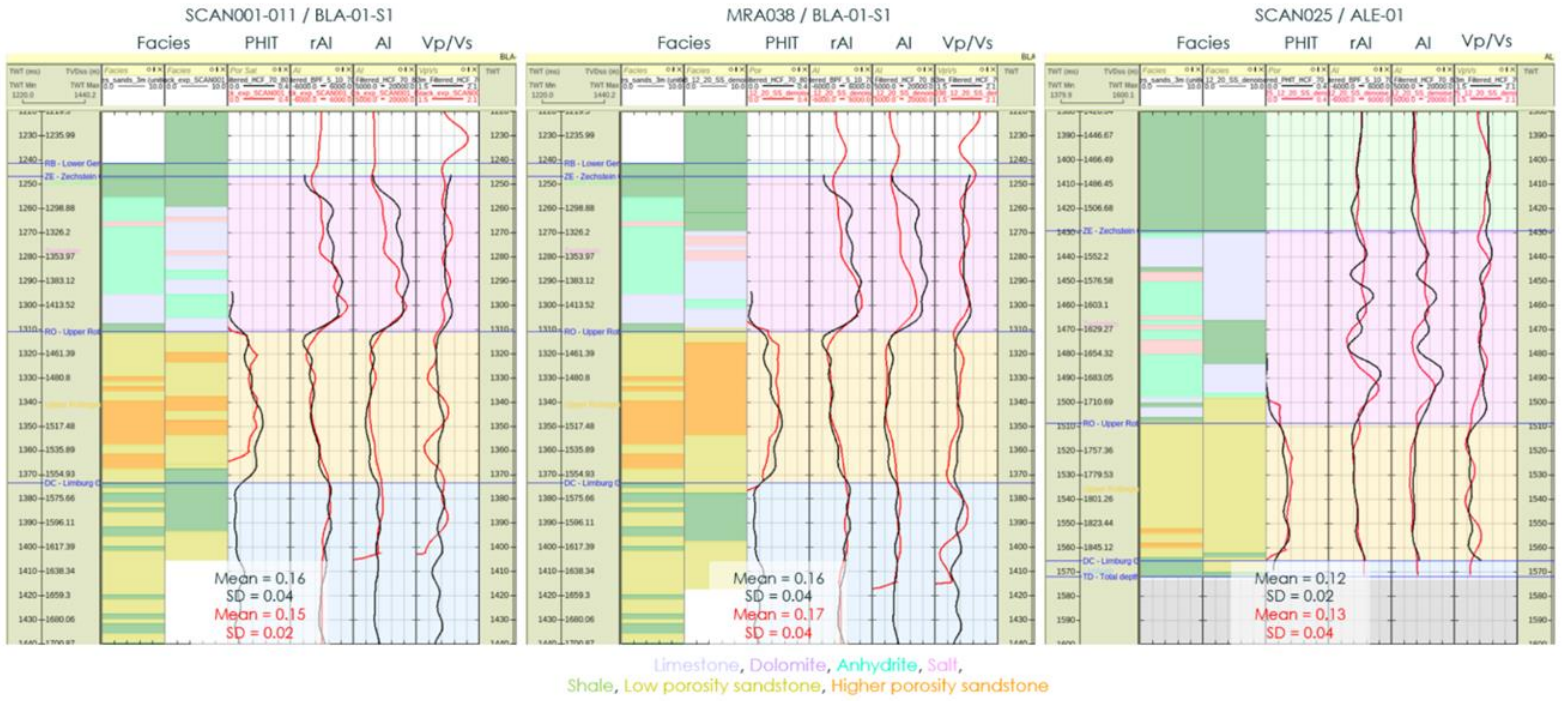
- Reservoir quality is one of the most important factors for a geothermal project
- Ikon Science performed early 2023 a seismic inversion study on SCAN 2D lines near Amsterdam
- The inversion was calibrated with wells BLA-01-S1, ALE-01 and LSM-01
- Resulted in facies and porosity sections including the then undrilled Amstelland structure



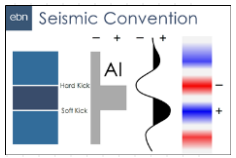
SCAN Seismic Inversion: Study Report

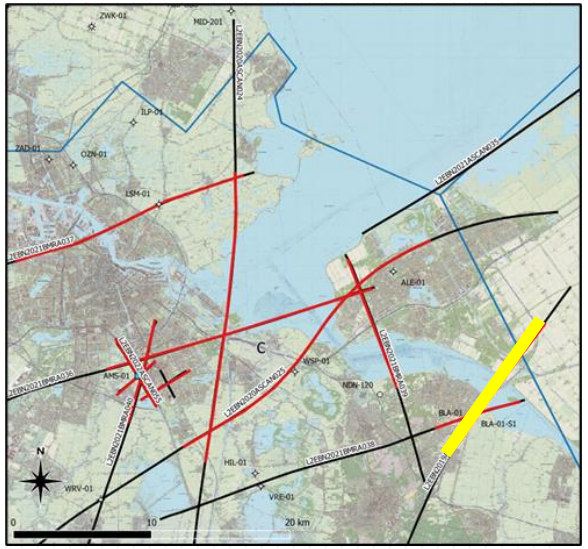
Report for EBN (Energie Beheer Nederland), Contract: GTO-22-C112
Ikon Science (Reference: OPP-0004843)
Contributors: Simon S. Payne, Jeremy Neep & Iestyn Russell-Hughes
07/06/2023

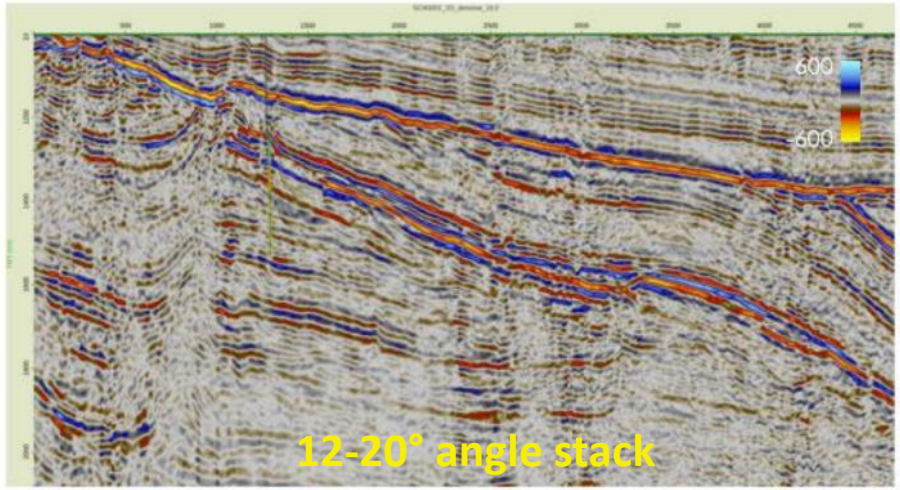


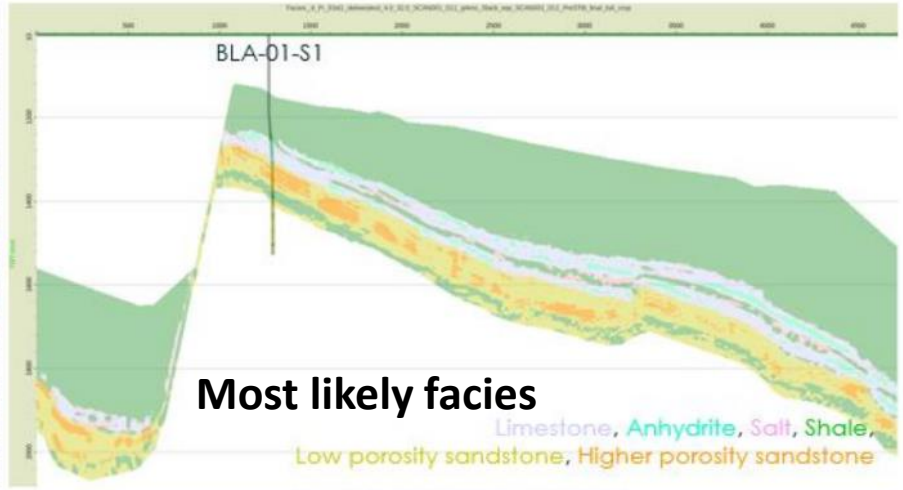


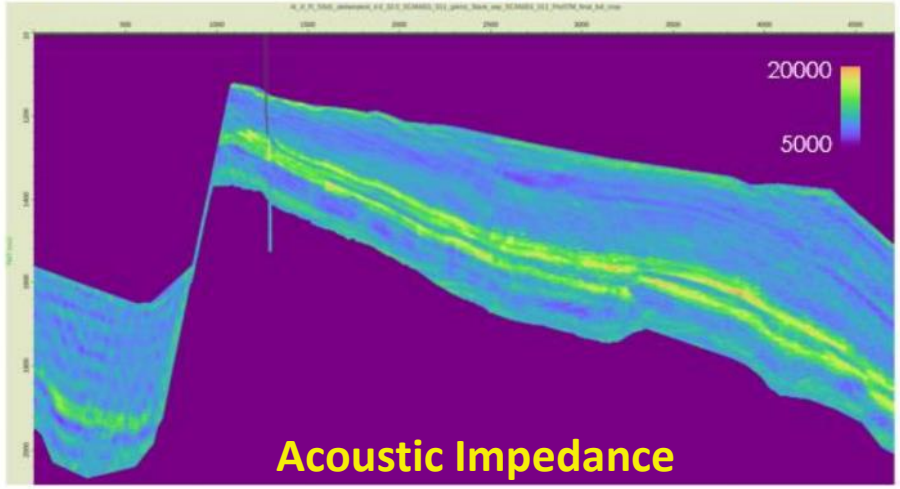
Seismic inversion BLA-01-S1











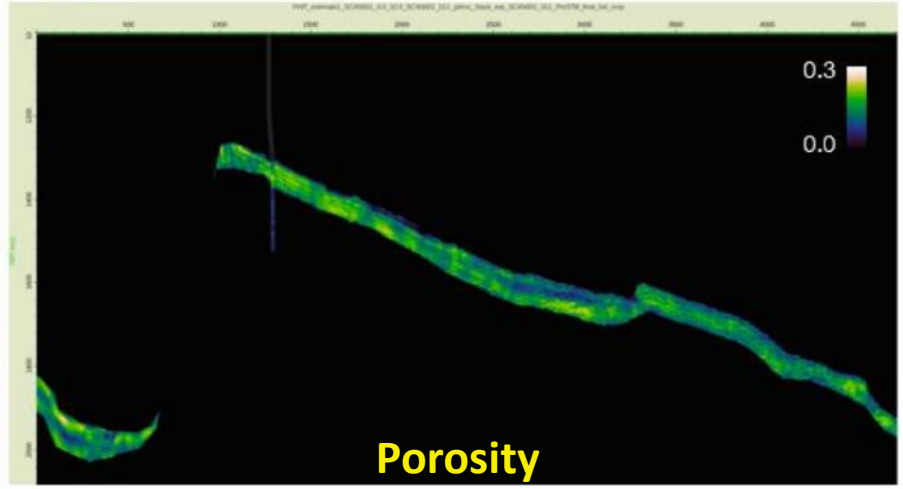
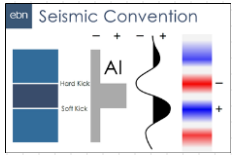
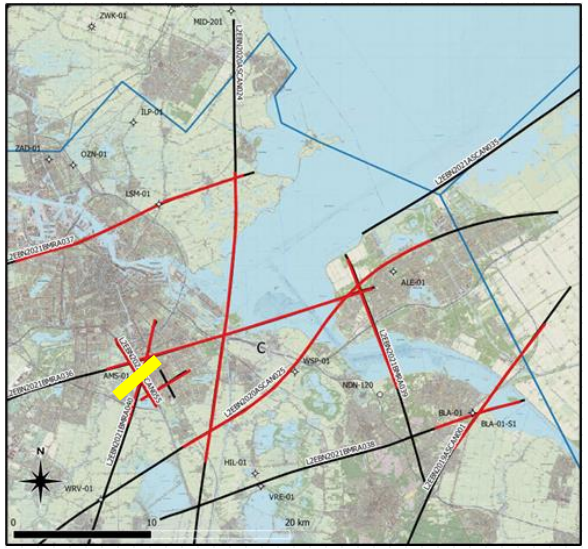


Figure 56: Seismic inversion results for the SCAN001-011 line: conditioned 12-20° angle stack, most-likely facies, AI and porosity.

Seismic inversion near AMS prospect





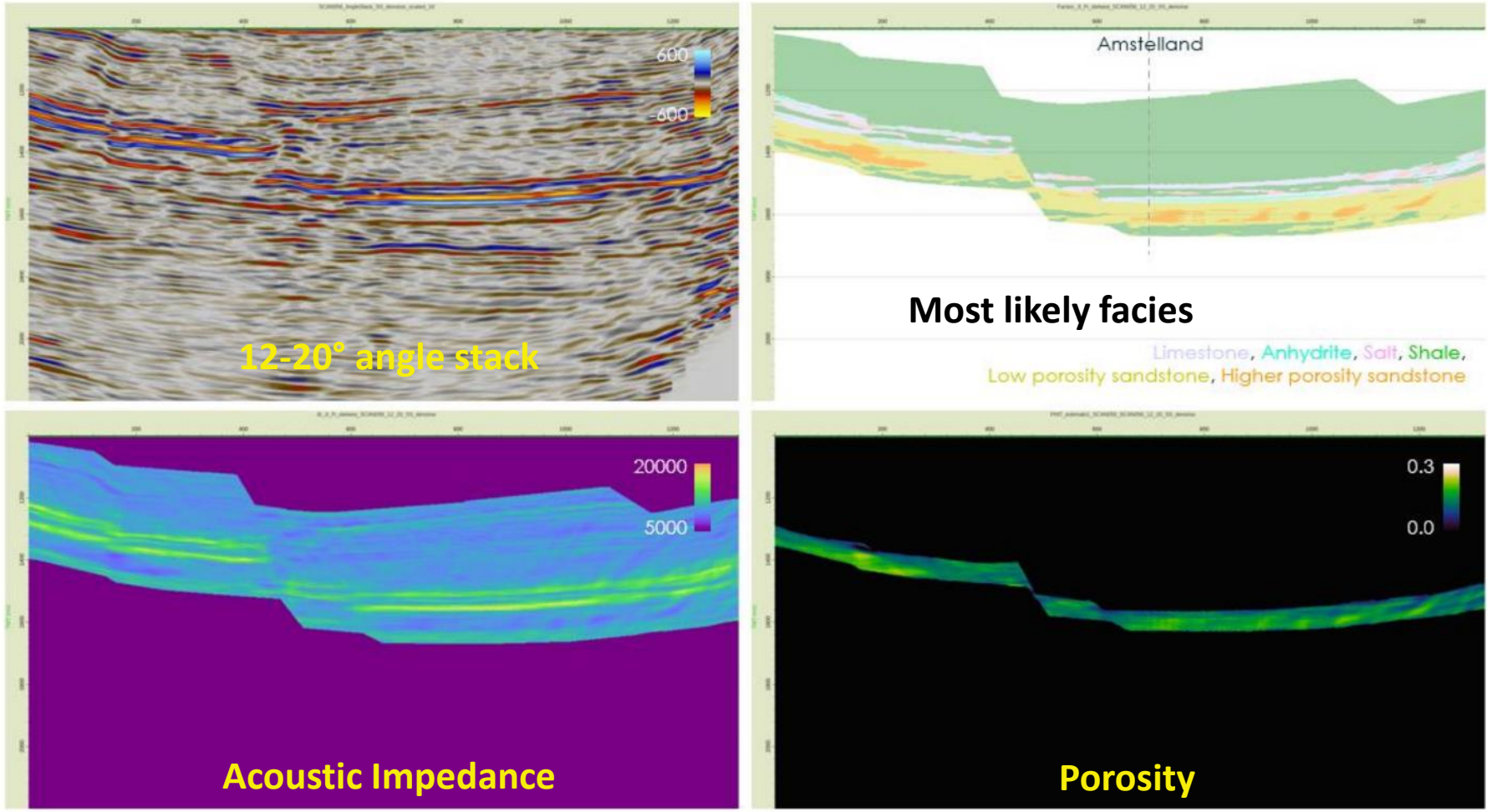
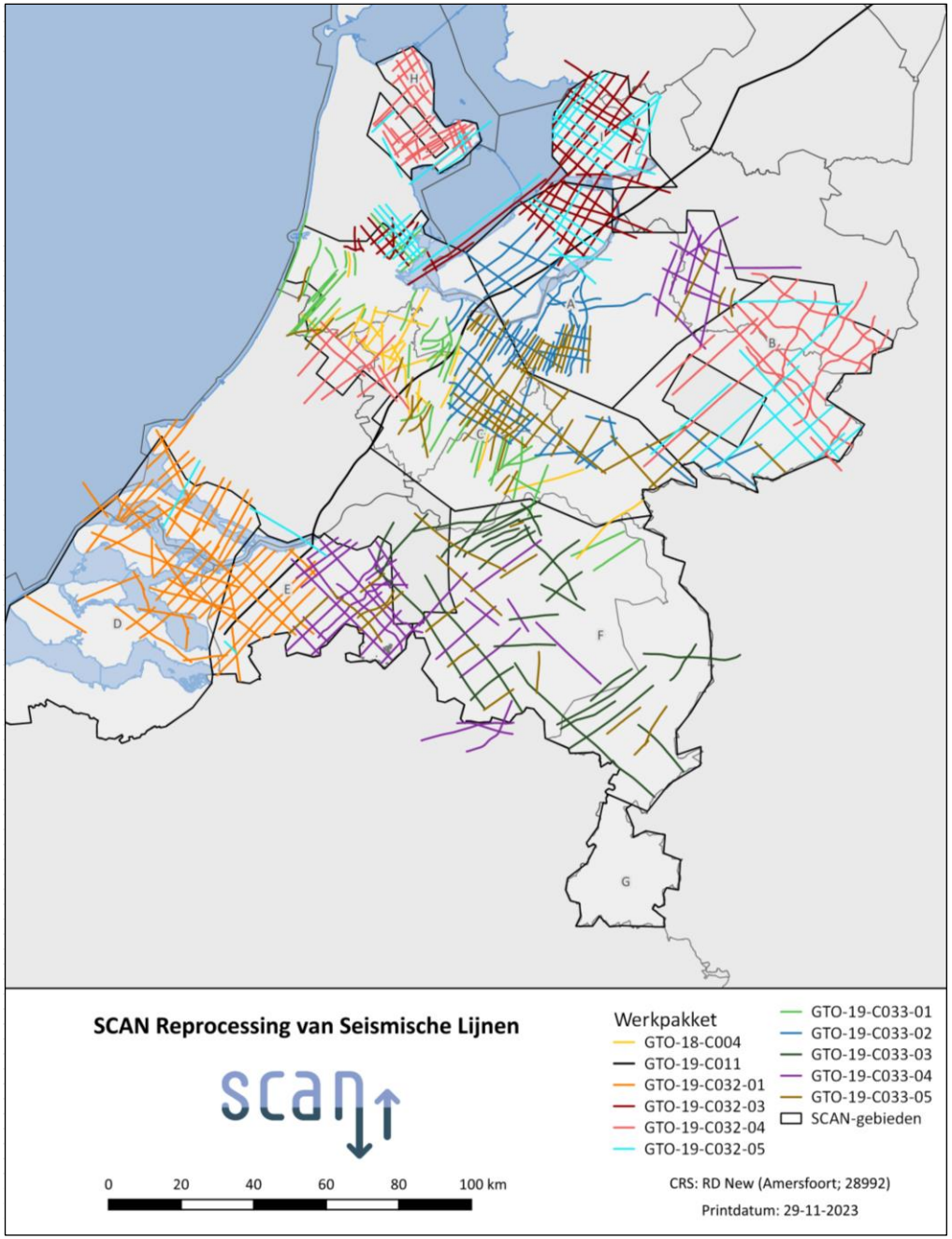


Figure 60: Seismic inversion results for the SCAN056 line: conditioned 12-20° angle stack, most-likely facies, AI and porosity.

SCAN 2D reprocessing summary

- 2D seismic data, acquired mainly from the early 70s to early 90s, is reprocessed through a broad-band Pre-Stack Time Migration sequence
- Retrieval and QC of vintage data performed by TNO and EBN took more than 6.500 hrs (> 3.5 FTE years)
  - Completeness check of raw field shots, observer logs and navigation data
  - Readability check of raw field shots (SEGY format)
  - If need be, reconstruction of navigation data
  - If need be, reconstruction of elevation data
- A total of 11 reprocessing projects have been released to NLOG, which amounts to 7.504 line km (451 lines)
- Time spend by EBN on QA/QC of seismic processing contractors was more than 5.100 hrs



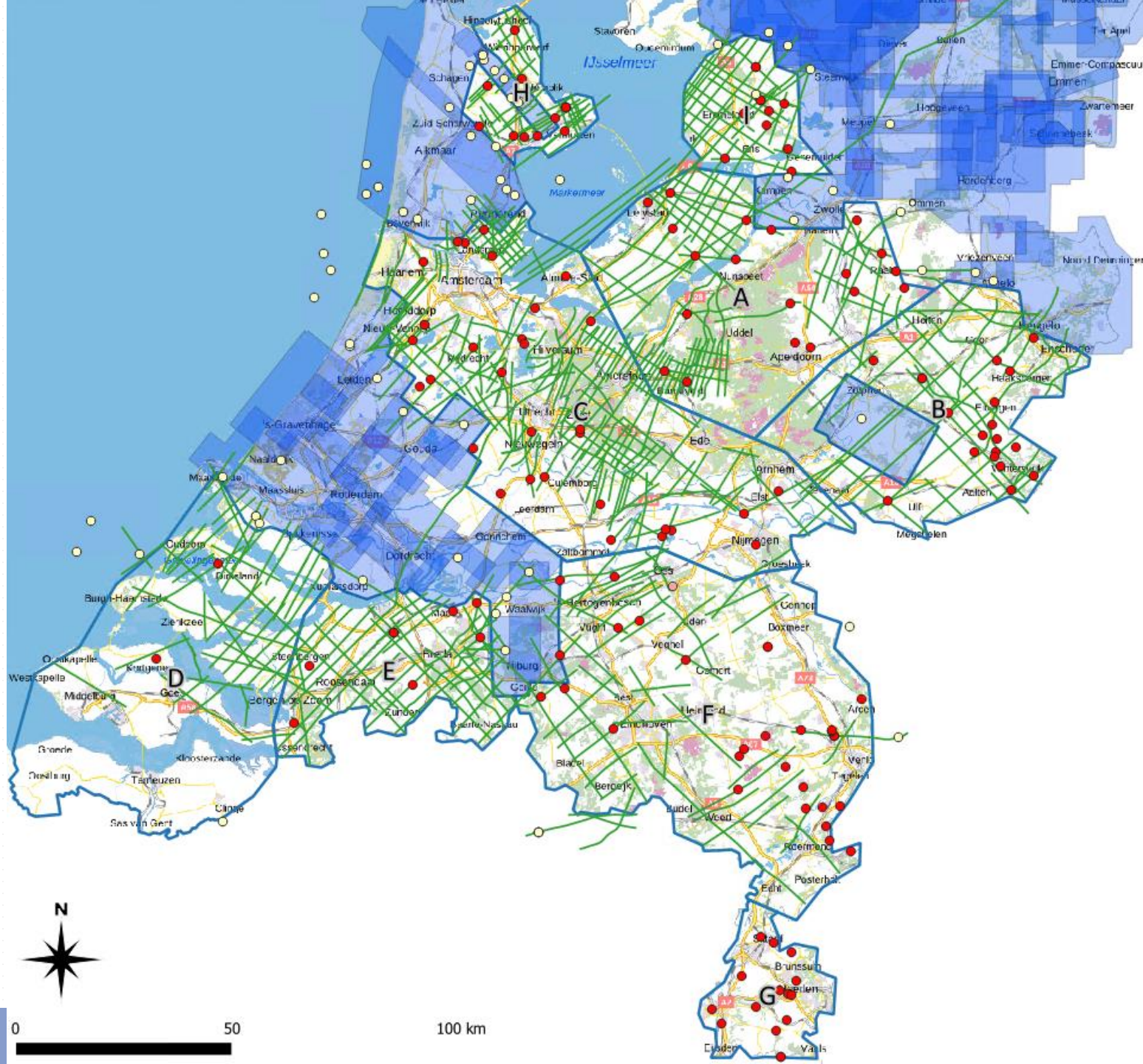
Reprocessing

➜Selected lines:

- ➜ Long regional lines, preferable with relative modern high-fold acquisition parameters
- ➜ Areas with significant heat demand
- ➜ Areas close to potential SCAN drilling locations
- ➜ Lines with well ties
- ➜ General preference was given to dip lines rather than strike lines
- ➜ Lines where currently no migrated data was available
- ➜ Lines that intersect with SCAN lines, other reprocessing lines or which connect with a 3D survey
- ➜ Lines running through urban areas, where the acquisition of new data would be rather difficult

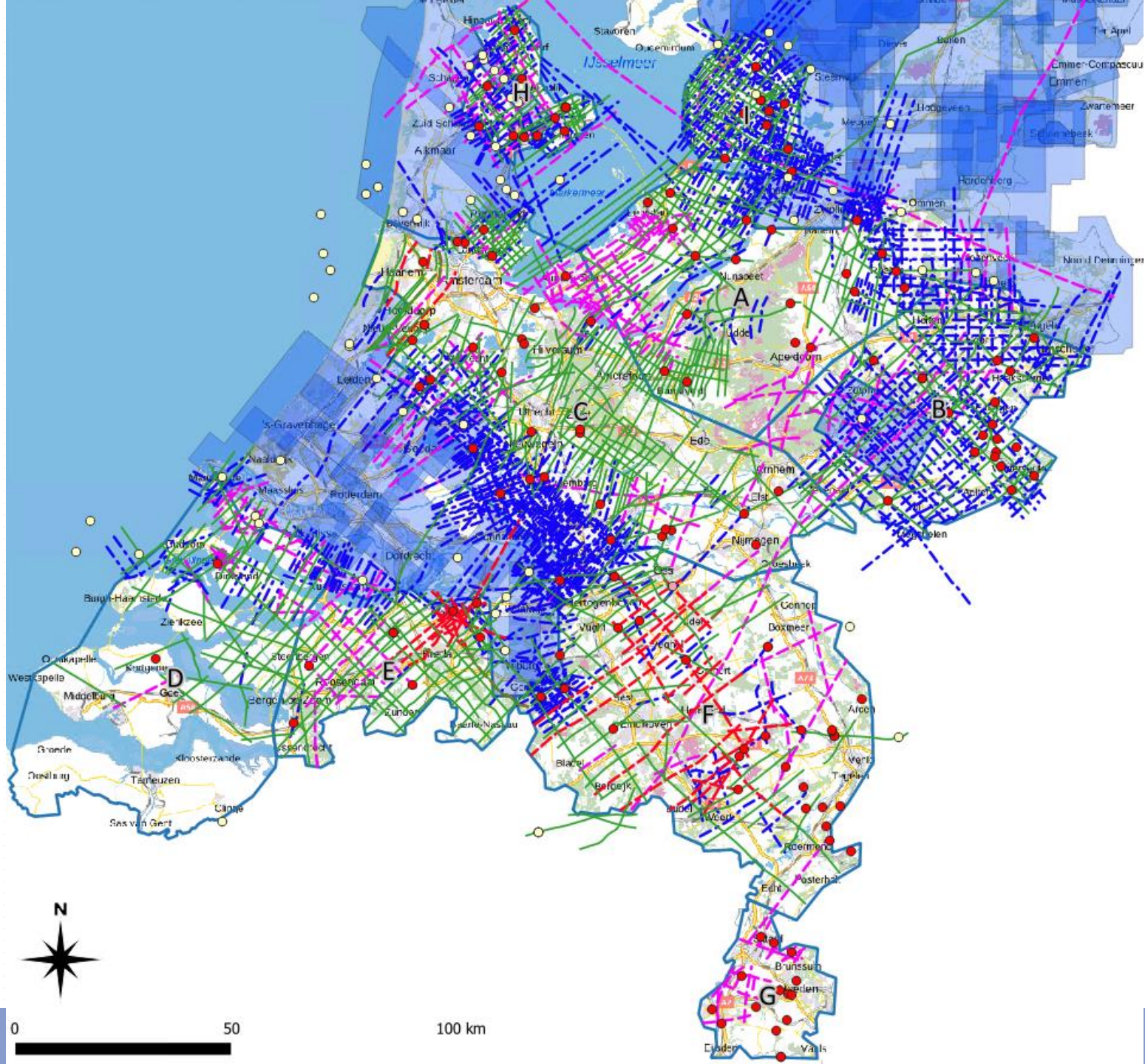
➜Deselected lines:

- ➜ Recently reprocessed by other companies
- ➜ Closely overlapping with the newly acquired SCAN lines
- ➜ Rather short lines
- ➜ Lines running mainly outside of the SCAN areas

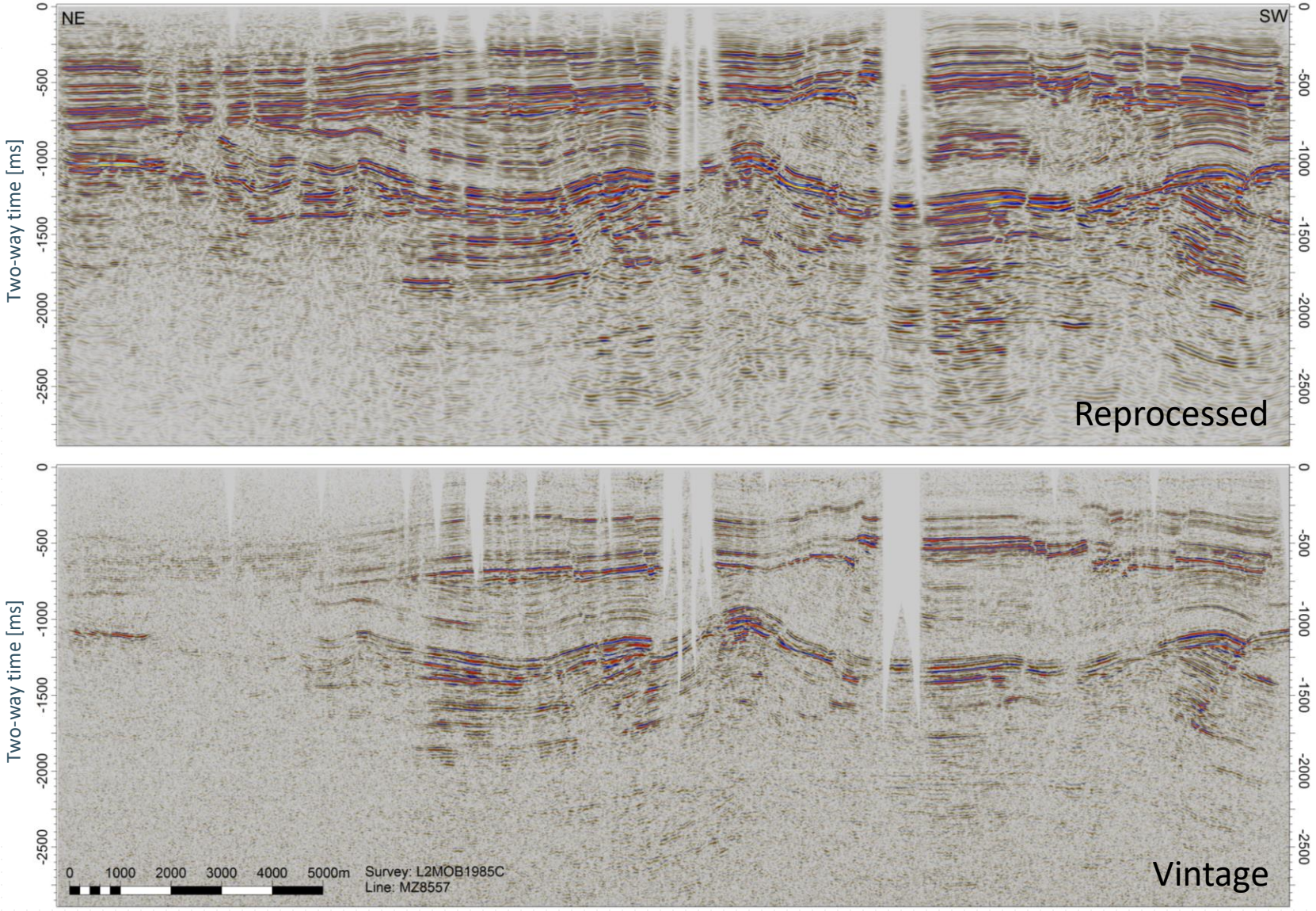


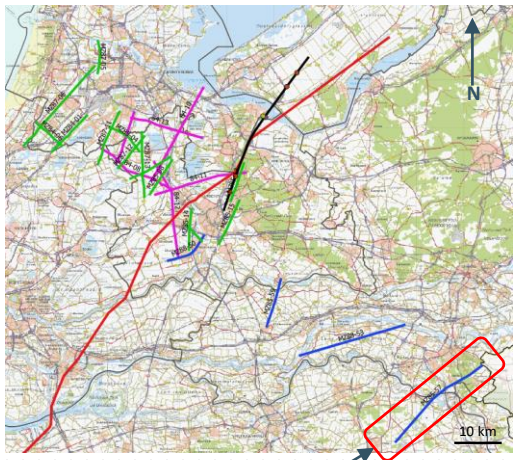
Not reprocessed

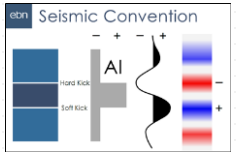
- ➜Pink lines: no field data available
  - ➜No records exist
    - ➜Amoco
    - ➜Delft Geophysical
    - ➜NEOM
    - ➜RGD
  - ➜Corrupted lines
  - ➜Individual lost lines
- ➜Blue lines: lines not selected
- ➜Red lines: recently reprocessed



SCAN 2D reprocessing – Old digital vs. new digital

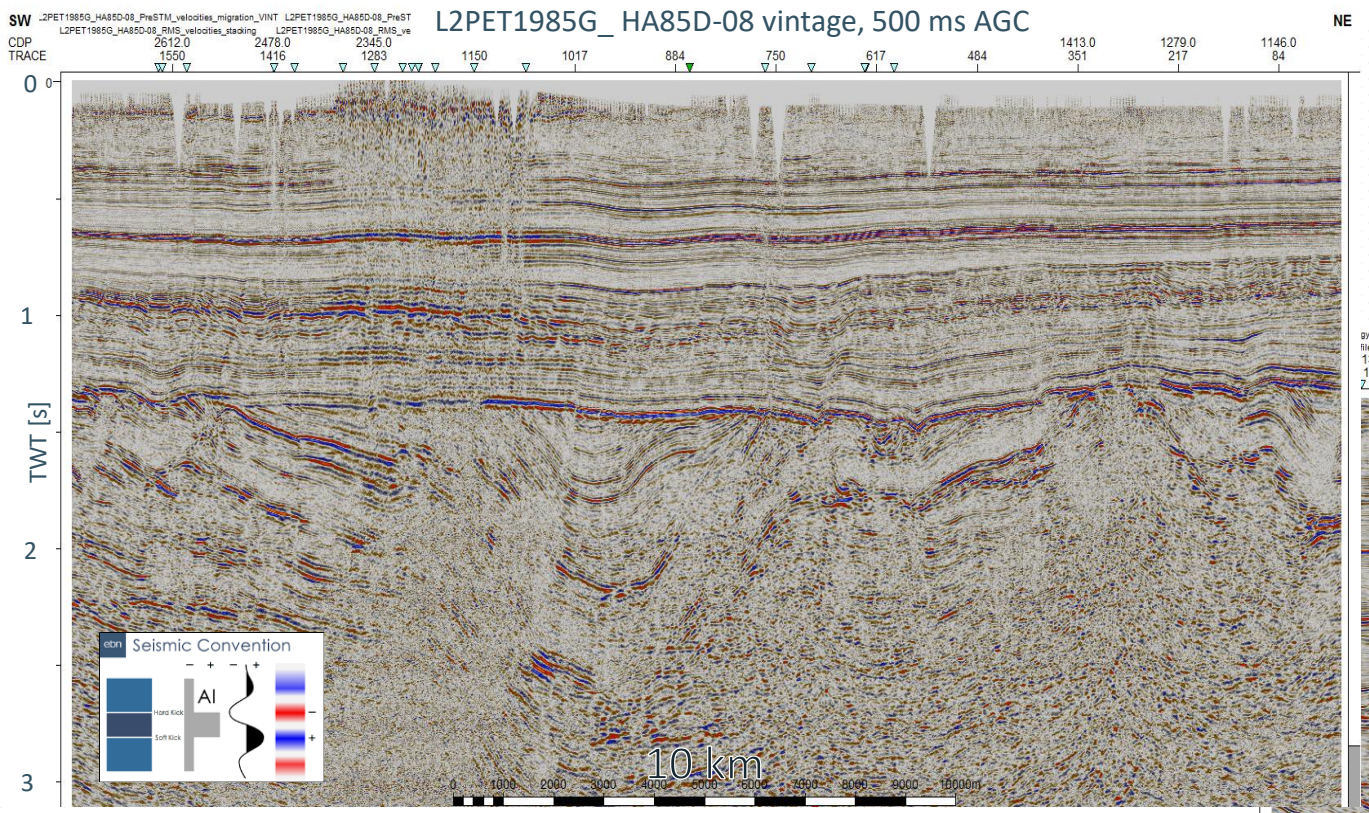




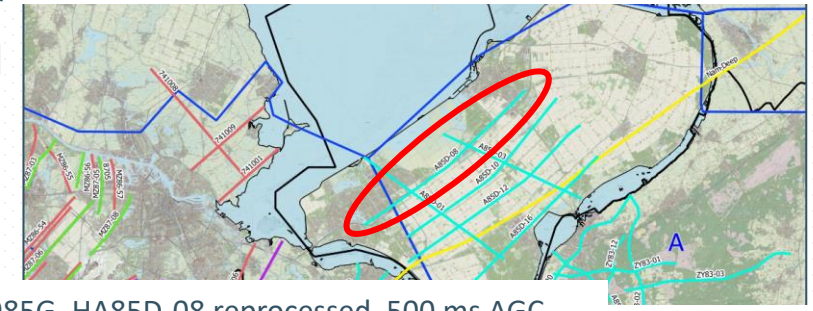


- Reprocessing usually improves Signal-to-Noise, event continuity as well as fault imaging

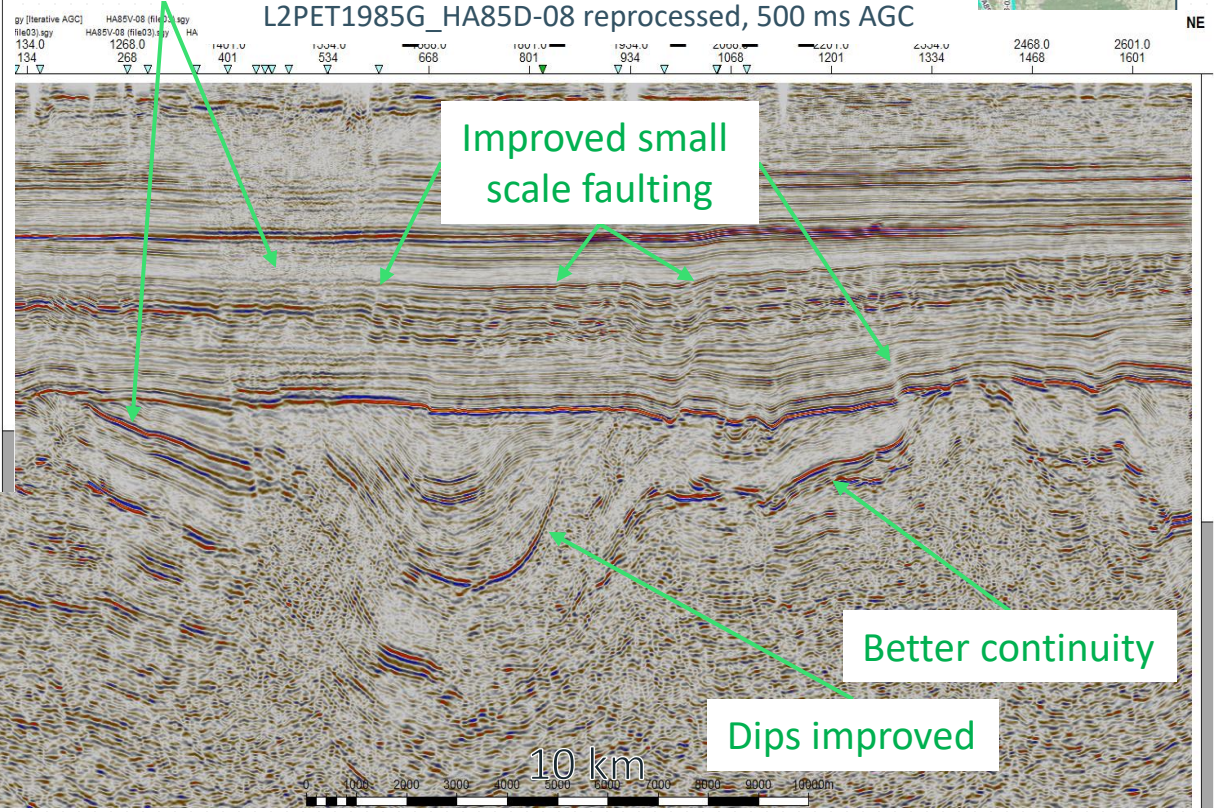
SCAN 2D reprocessing – Old digital vs. new digital line



Flevopolder
Almere-Lelystad

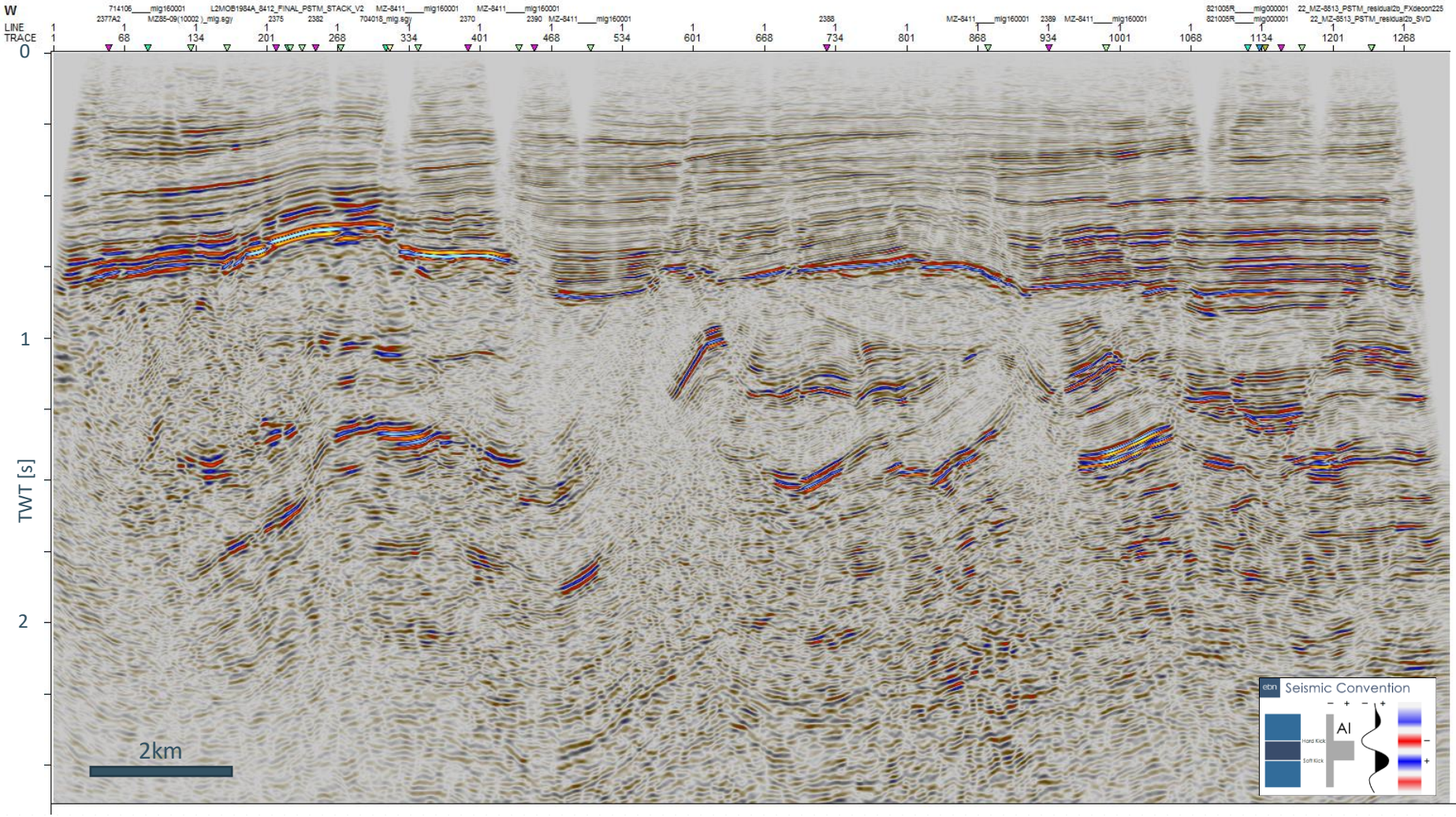


Better S/N



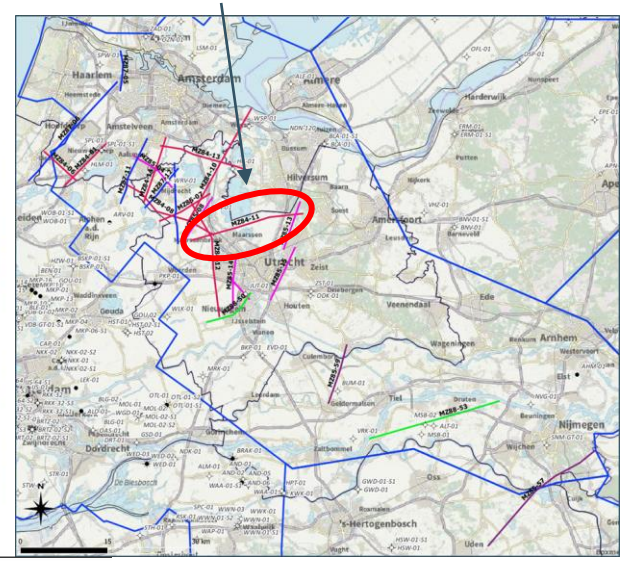
- Reprocessing usually improves Signal-to-Noise, event continuity as well as fault & dip imaging

SCAN 2D reprocessing – “New” digital vintage line

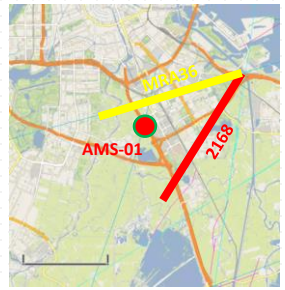


- No digital or paper section present in TNO archive for this line.
- Used vintage field data to create a “new” line

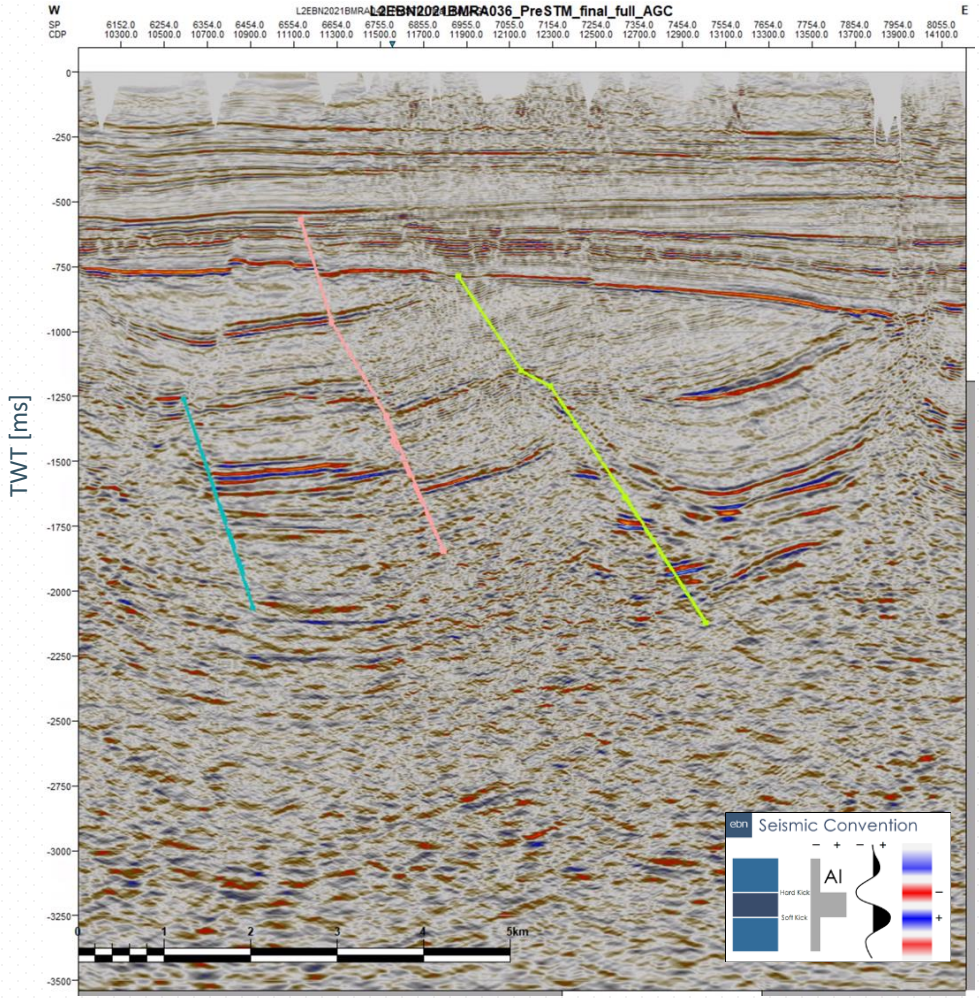
Line MZ84-11 north of Utrecht

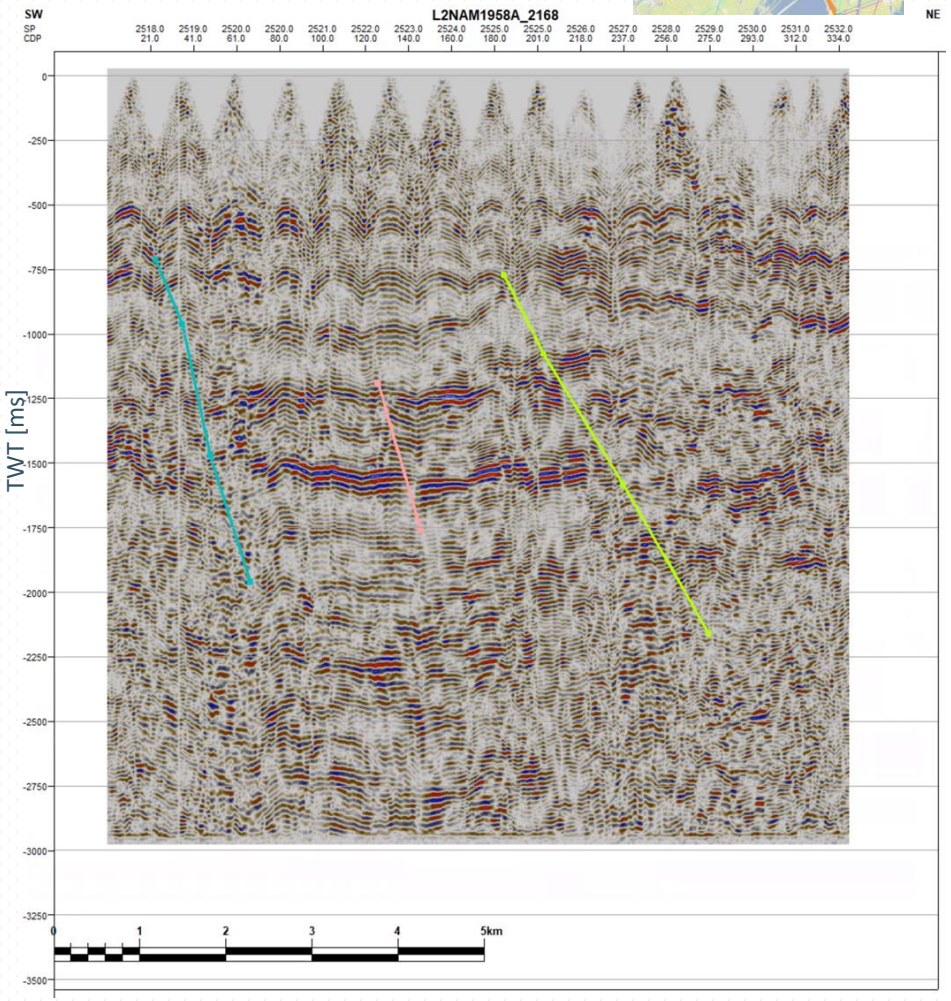


The joy of a really old seismic line (1958)



- Not all seismic data could be reprocessed
- There is more seismic data available from NLOG if you ask for it (note: there is a cost charge)
- Even very old data can help you to refine your geological model
- Example Amstelland fault block on single-fold unmigrated seismic from 1958





SCAN follow-up research

- Necessity for follow-up research in some areas became clear
  - Site specific
  - Focussed on accelerating project-development
- Subsidy from the Ministry was granted late 2023
- Process of setting up the required organization and selection criteria has started
- Most likely for additional 2D or 3D seismic

SCAN-search area data acquisition wells

	SCAN-search area	Primary target	Secondary targets
A	Amstelland	Rotliegend	Chalk, Rijnland
B	Utrecht	Rotliegend	Triassic, Rijnland, Chalk Gp.
C	Ede-Veenendaal	Rotliegend	Rijnland
D	Apeldoorn-Deventer	Rotliegend	Noordzee (Paleogene), Tubbergen Fm.
E	Oss	Trias	Rijnland, Rotliegend, Chalk Gp (Vaals Fm.)
F	Kempen	Trias	U. Carboniferous
G	Deurne	Trias	Chalk Gp (Vaals Fm.)
H	Eindhoven	Noordzee (Neogene& Paleogene)	None
I	West-Brabant Noord	Noordzee (Paleogene)	None

★ Search area

➜9 Search areas

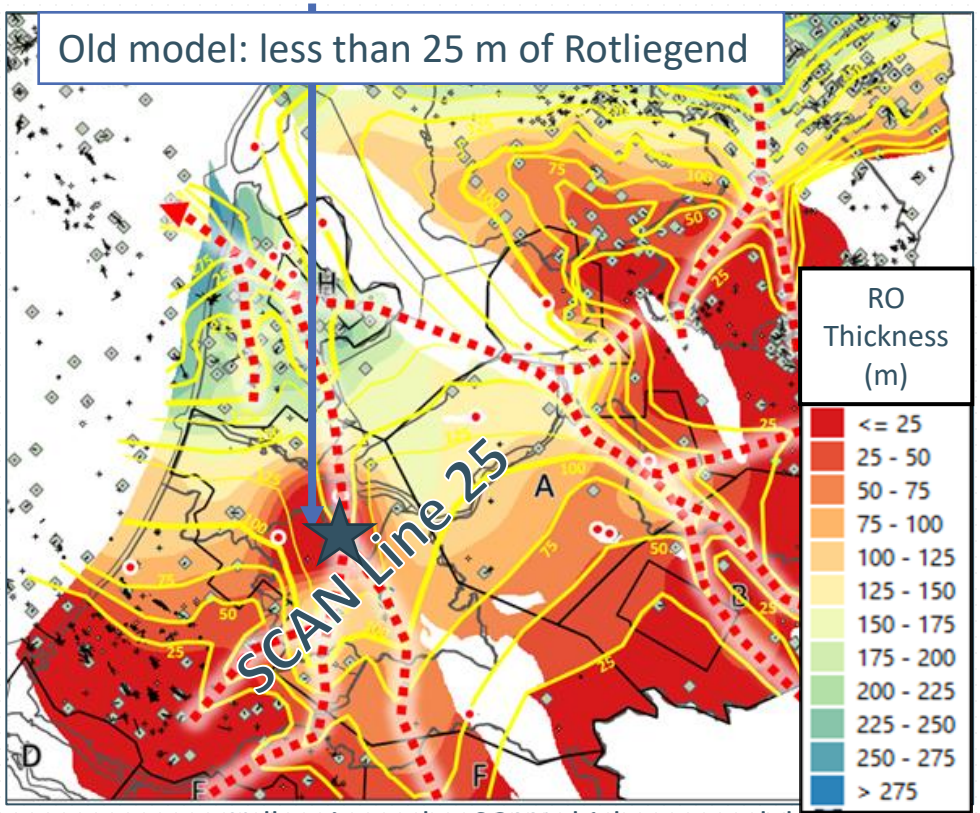
➜Budget for around 7 wells

➜List sorted on primary target; no drilling sequence implied

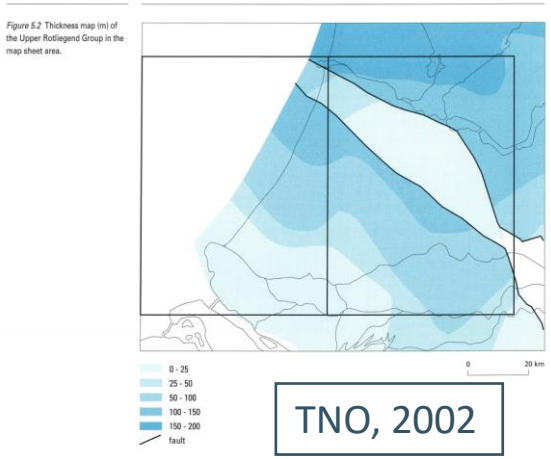
Thickness of the Permian Rotliegend reservoir

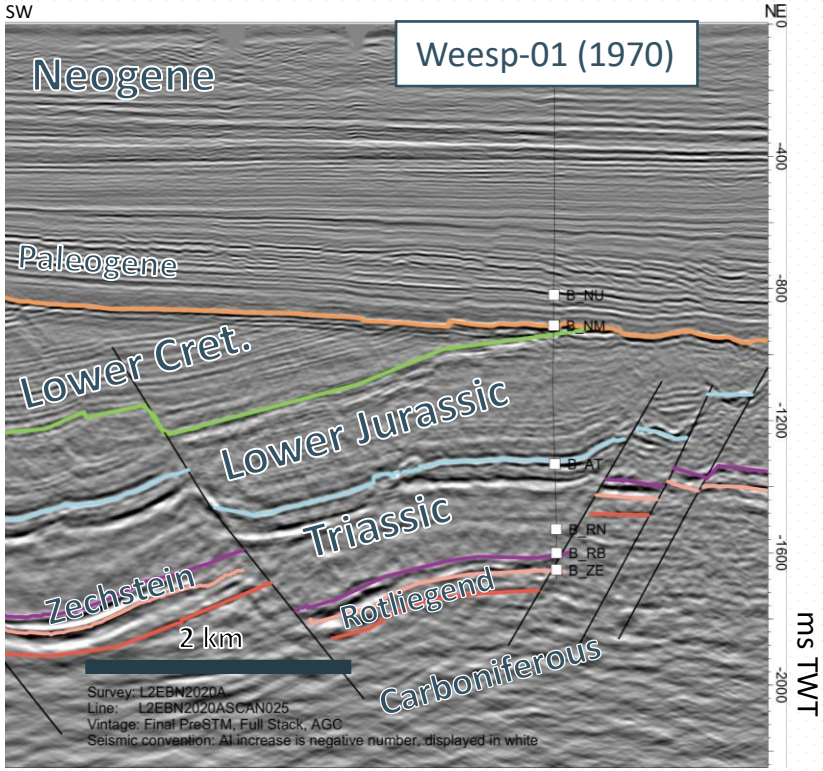
➜Thickness of the main geothermal reservoir in the Amsterdam/Almere area (Rotliegend) was uncertain prior to SCAN: according to some models hardly any Rotliegend was present

➜These models were based on the Weesp and Waverveen wells, drilled in the 1970s



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





➜Insufficient seismic data was present at the well locations.

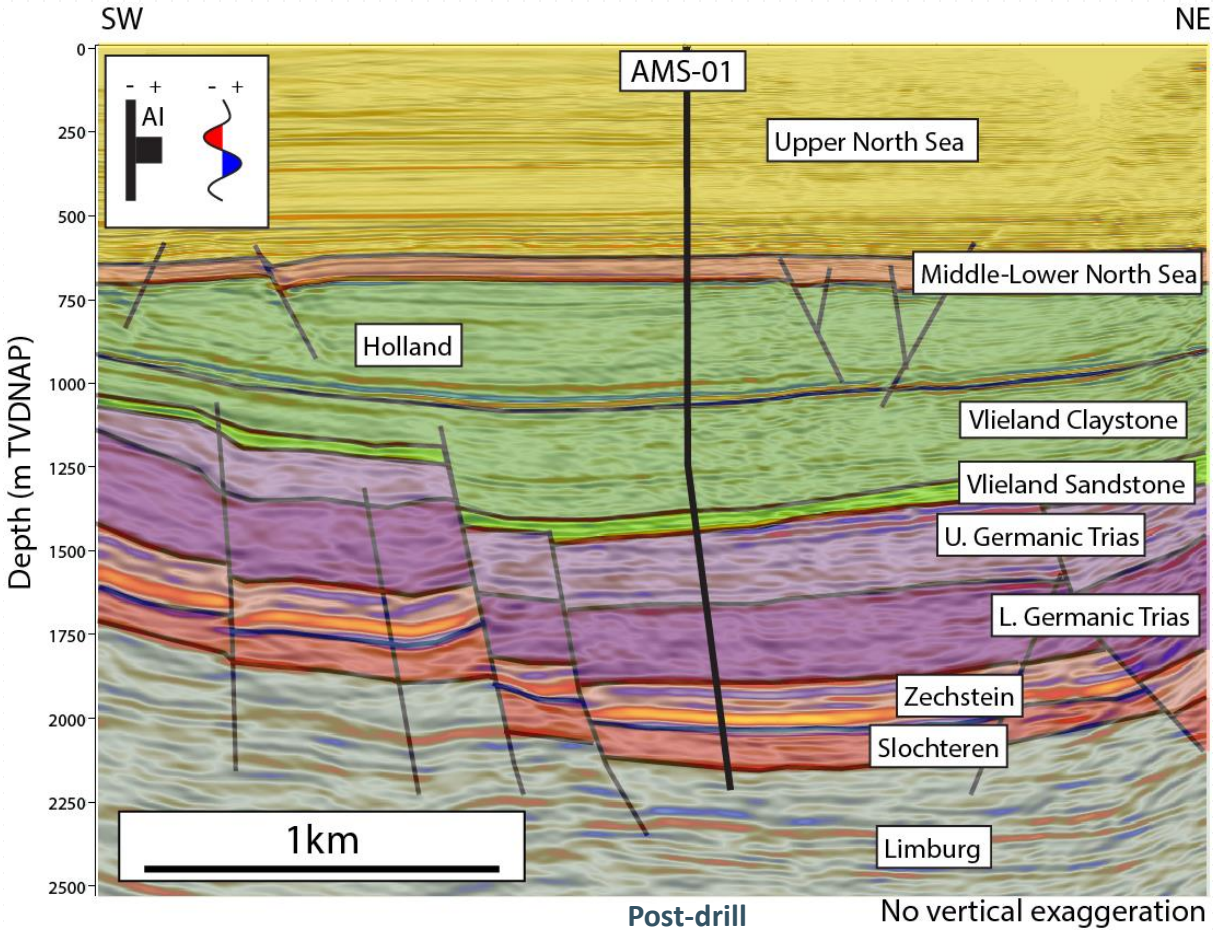
➜New SCAN-seismic data shows that the Weesp well drilled the Rotliegend at a location where the reservoir is truncated by a fault. The well is therefore not representative for the region.

➜Thickness de-risked, which is good news for the geothermal potential of the region

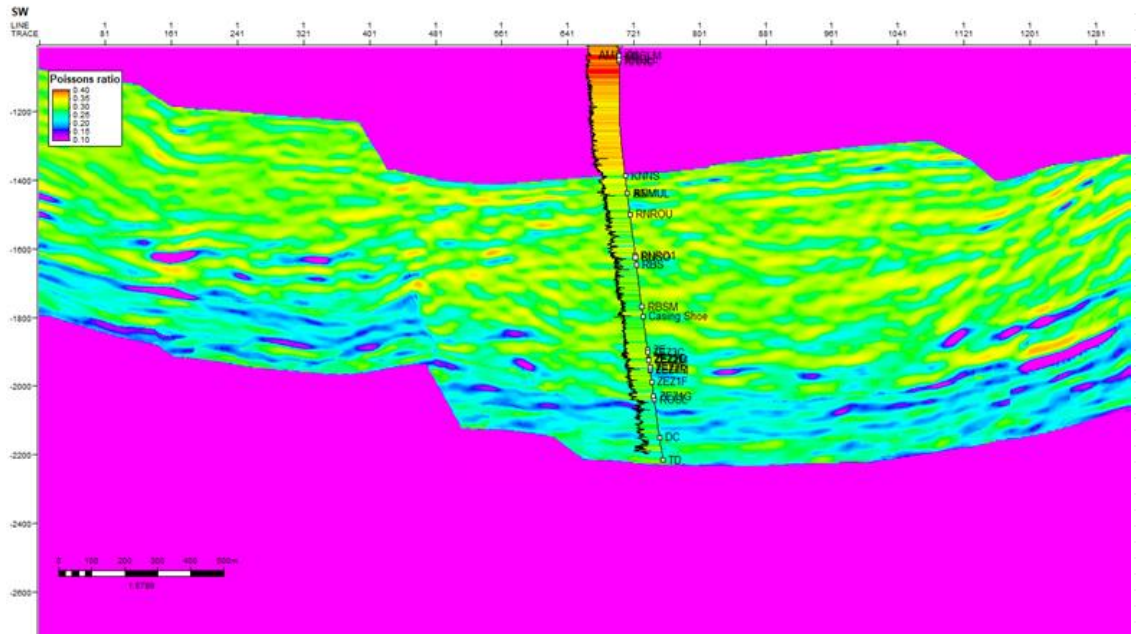
➜Reservoir quality uncertainties remained; AMS-01 data acquisition well

Key results AMS-01

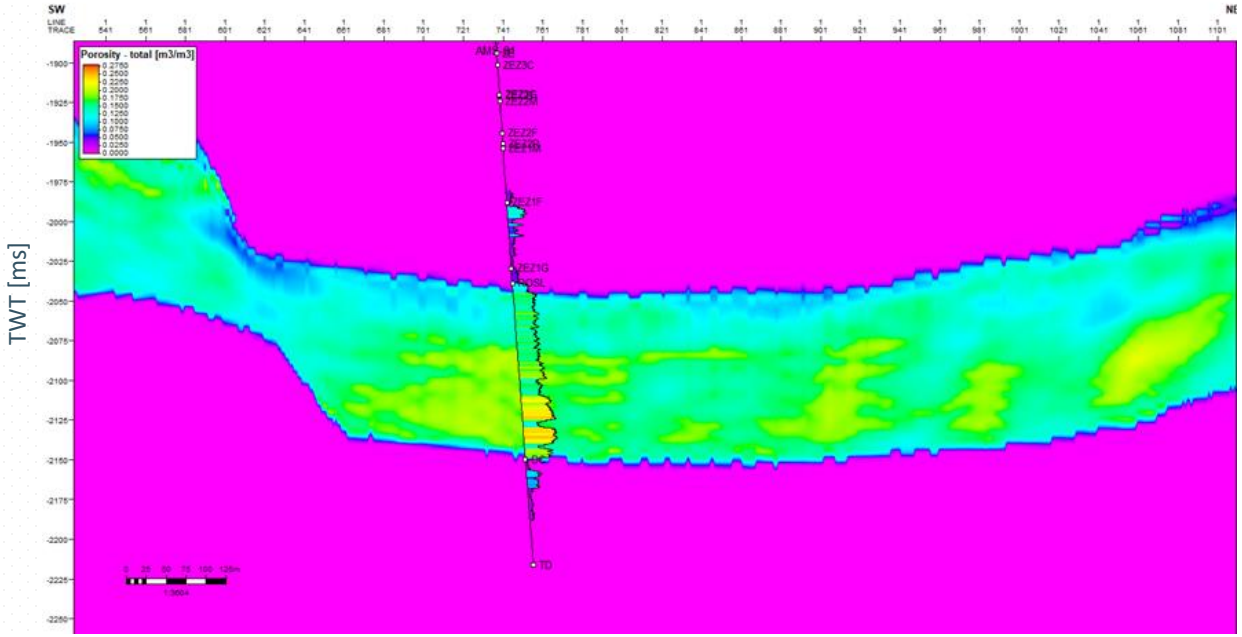
- ➜56 days operations, TD 2217.67m MD in Carboniferous Limburg Group
- ➜Extensive data acquisition performed throughout well, including over reservoirs, caprocks and overburden
- ➜Primary target Slochteren Fm:
  - ➜112 mAH thickness
  - ➜Average porosity 18%, up to 26%
  - ➜High permeabilities measured 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



Pre-drill seismic inversion AMS-01



Poisson's Ratio



Porosity

➜Pre-well average porosity prediction reasonable in line with well results

➜Prediction of higher porosity in lower half of reservoir is correct

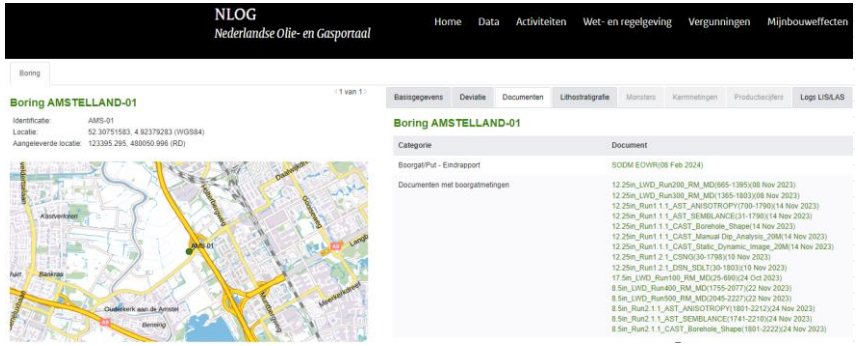
➜Basal sands of Rotliegend higher porosity than expected

SCAN data release

- ➜Data is released as soon as possible, after QC. All for free!
- ➜Seismic data on NLOG
  - ➜Separate subdirectory with Seismic Data
  - ➜SCAN acquired 2D lines, wide lines and 3D cross spreads
  - ➜Field data on request
  - ➜SCAN reprocessing 2D lines
  - ➜(Re-)processing reports
- ➜Well data on NLOG
  - ➜The usual well data pages of NLOG
- ➜SCAN website (scanaardwarmte.nl)
  - ➜News and background information
  - ➜Maps
  - ➜Links to data and reports
  - ➜Progress of data release

NLOG
Nederlandse Olie- en Gasportaal

Boringen
Seismische data
NAM 2D seismische data
SCAN 2D seismische data
Productie en injectie data
Gasvelden
Modellen, kaarten en datasets
Dashboards
Kernhuis van de Geologische Dienst
Data aanleveren op het Innameportaal



scan
Wat is SCAN
Nieuws
Activiteiten
Resultaten
Veelgestelde vragen

Welke data heeft SCAN hier verzameld?

Boorgatmetingen

Gegevenstype	Beschrijving	Status
Boorgatmetingen	Gammastraling, Spectrale Gammastraling, Geleidbaarheid, Sonisch (P&S), Dichtheid, Foto-elektrische Factor, Neutron, BHI	Beschikbaar op NLOG
Boorgatmetingen	NMR	In bewerking; boorkernen worden gebruikt voor kalibratie NMR-logs
Gecombineerd bestand boorgatmetingen	Composite LAS-bestand	Beschikbaar op NLOG
Verticaal Seismisch Profiel, (geofoons)	Verticaal Seismisch Profiel uitgevoerd met geofoons; data& rapport	Beschikbaar op NLOG
Verticaal Seismisch Profiel, glasvezel	Verticaal Seismisch Profiel uitgevoerd met fibre-optics; data& rapport	Beschikbaar op NLOG
Temperatuurmetingen	Temperatuurmetingen in boorgat op diverse momenten in tijd	Deels beschikbaar op NLOG, verwerking resterende gegevens gaande

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www.nlog.nl/scan

Ministerie van Economische Zaken en Klimaat