2025 Seismic Campaign at the EMR-site

Acquisition, processing and impact/interpretation of DAS-VSP and surface seismic reflection data

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Vincent Vandeweijer, Puck Verhooren, Maartje Koning, Bob Paap, Rob Jansen, Camille Chapeland (TNO)

Richard de Kunder, Girt Pijpers, Gijs van Otten, Jaga van den Broek, Ben Turner (Faraday Geophysics)

Einstein Telescope

11-14 November 2025

4th Einstein Telescope Annual Meeting, Opatija, Croatia

Outline

Acquisition: Design and Execution

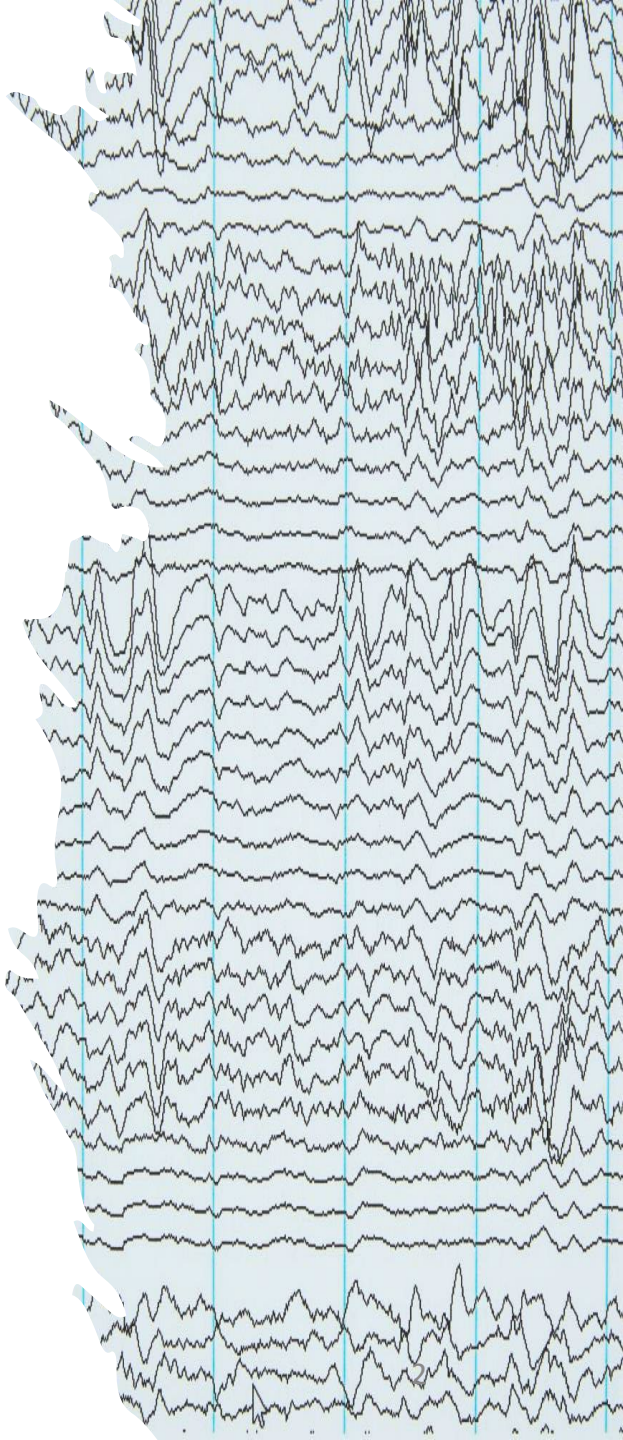
- Learning from 2022 campaign
- Testing source parameters, receiver sampling & offset range
- DAS-VSP recording parameters

Processing Challenges and Results

- Noise suppression and spectral balancing
- Statics and refraction tomography velocities
- Pre-stack depth migration

Interpretation & Impact

- Comparing sonic logs and check-shots from the DAS-VSP
- Seismic to well-ties
- Structural interpretation

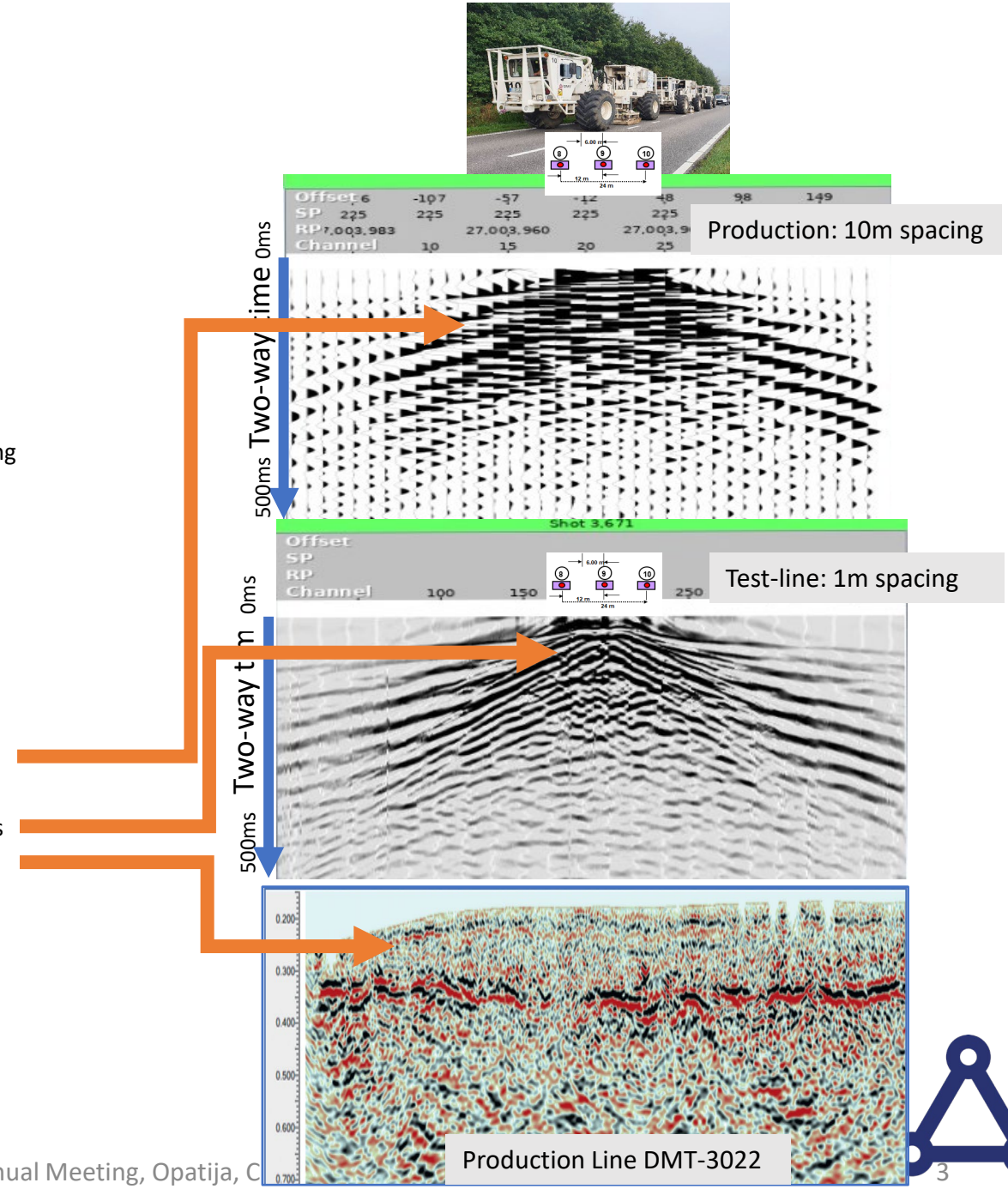


Learning from the 2022 campaign

- Key acquisition parameter of the 2022 were
  - Key source parameters:
    - 20m source point spacing
    - Per source point 3 Vibs sweeping simultaneously with a 12m spacing
    - 6-90Hz, 16s long, 4s listen time
    - 4 sweeps per source point
  - Key receiver parameters
    - 10m geophone spacing
    - 4000m max. offset
    - Single 1C nodes used
- Main observations
  - Noise and primary signals are significantly aliased
    - ➔ Noise suppression in the source & receiver domains very difficult
  - Use of 3 vibrators causes significant interference compounding noise issues
  - Source & receiver spacing too sparse to image the near surface 0-500m

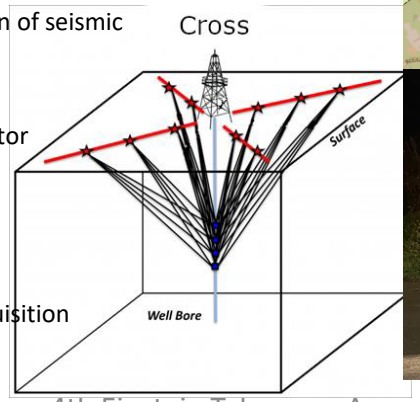
➔ Recommendation for 2025 acquisition

- Reduce receiver spacing and source point spacing
- Use only a single & lighter Vib at reduced power
  - No interference
  - Reduced harmonic noise
  - Allows to access smaller roads
- Start the sweep at a lower frequency to enable higher resolution



2025 active seismic program finished 11.04.2025

- ~ 90km of 2D lines acquired along potential legs of the ET
  - Enabling geological interpretation between boreholes
- Key acquisition parameters
  - Source parameters:
    - 4m source point spacing
    - 1 Vibs used
    - 2-129Hz, 24s long, 4s listen time
    - 2 sweeps per source point
  - Receiver parameters
    - 4m geophone spacing
    - 1200m shortest max. offset
    - Single 1C nodes used
- 5 DAS-VSP's
  - @Cottessen, Vijlen, Teuven, Obsinnich, Herbesthal Enabling:
    - Higher resolution imaging close to the well bore
    - Check-shot for time-to-depth conversion of seismic
    - Measuring absorption in 1-15Hz rang
  - Acquisition parameters
    - Instrument: FEBUS A1 LR DAS interrogator
    - Gauge length 8m
    - vertical sampling 2m
    - sampling freq. 1000Hz
    - 2-3sweeps
    - Surface line same parameter as 2D acquisition

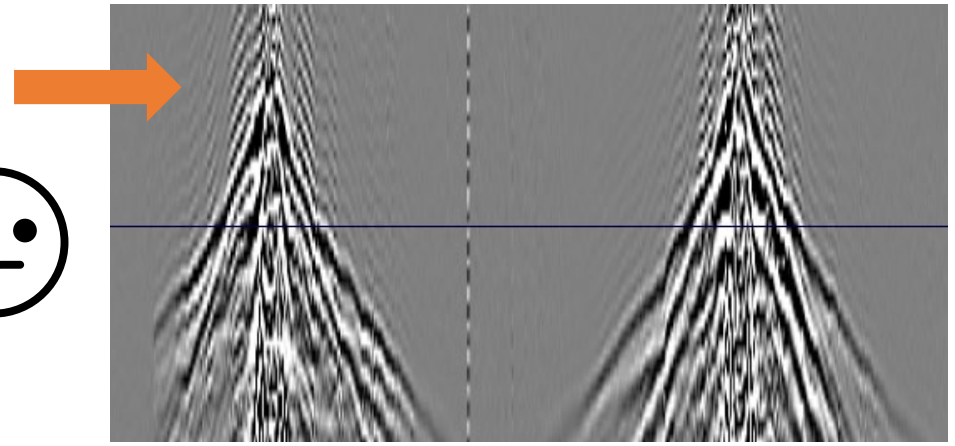


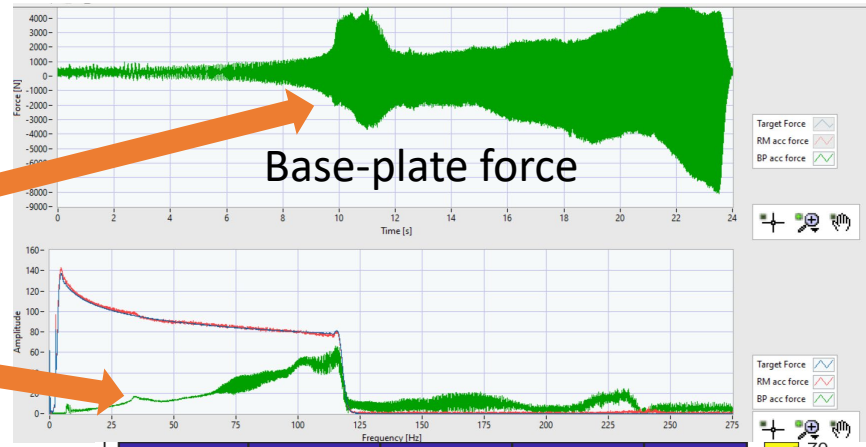
Issues identified during source testing

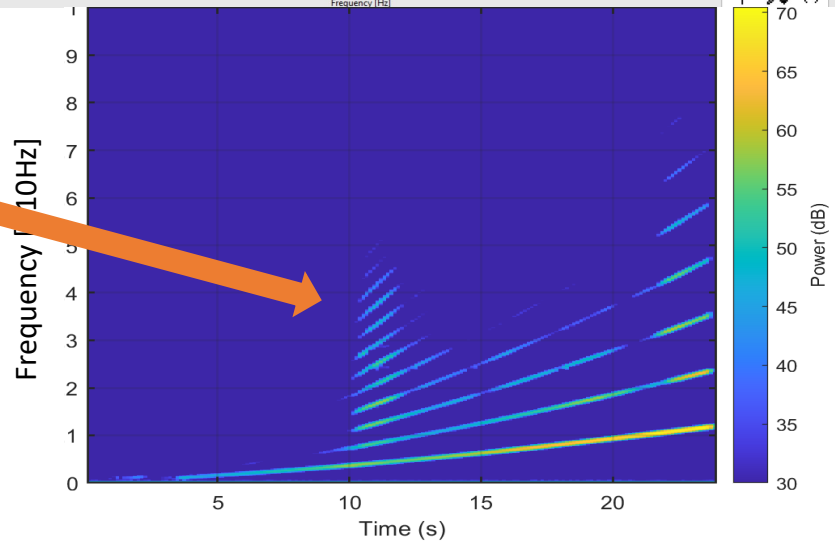
- Significant non-causal pre-cursor events

- Two reasons:
  - Base-plate decoupling at ~30Hz
  - Some source harmonics impacting the correlation

- Solution
  - Increase hold down weight by 1200kg
  - Reduce the force to ~70% of max. force







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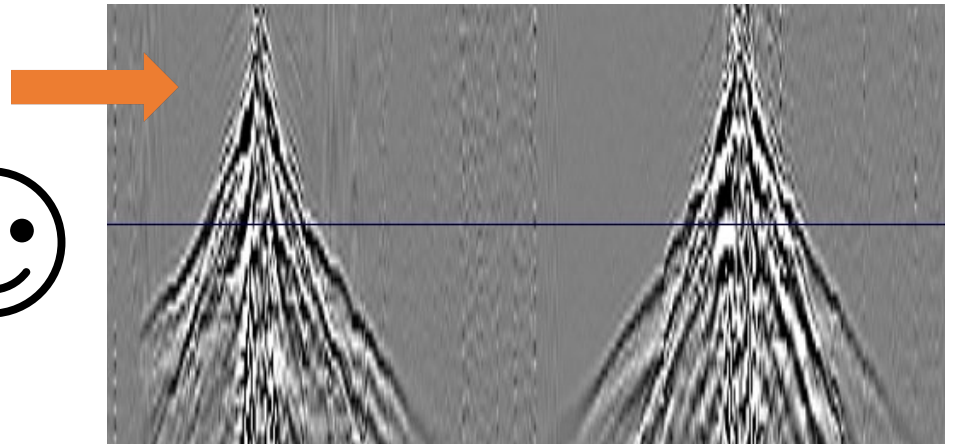
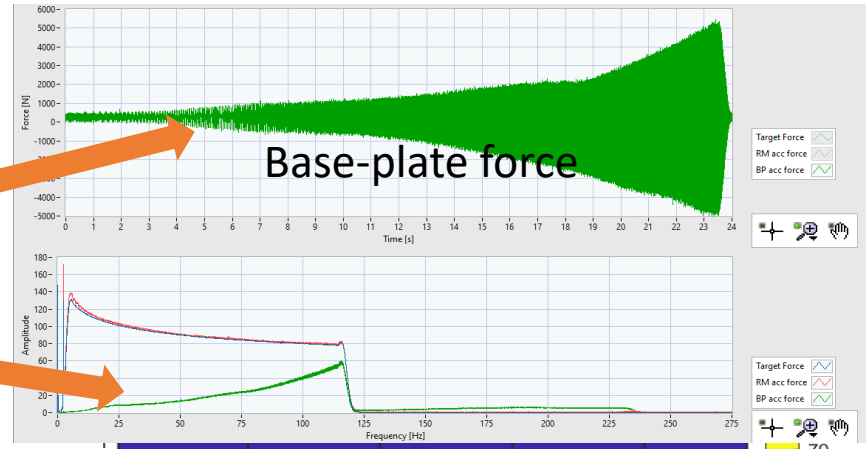
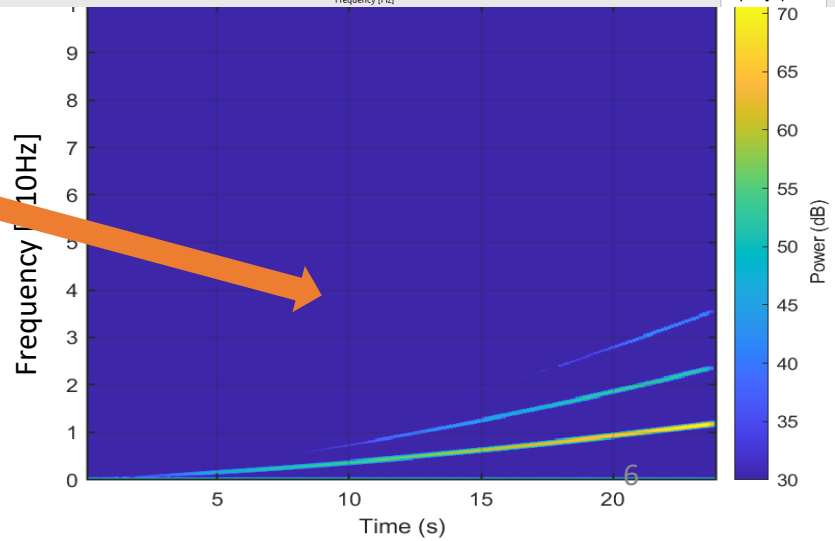
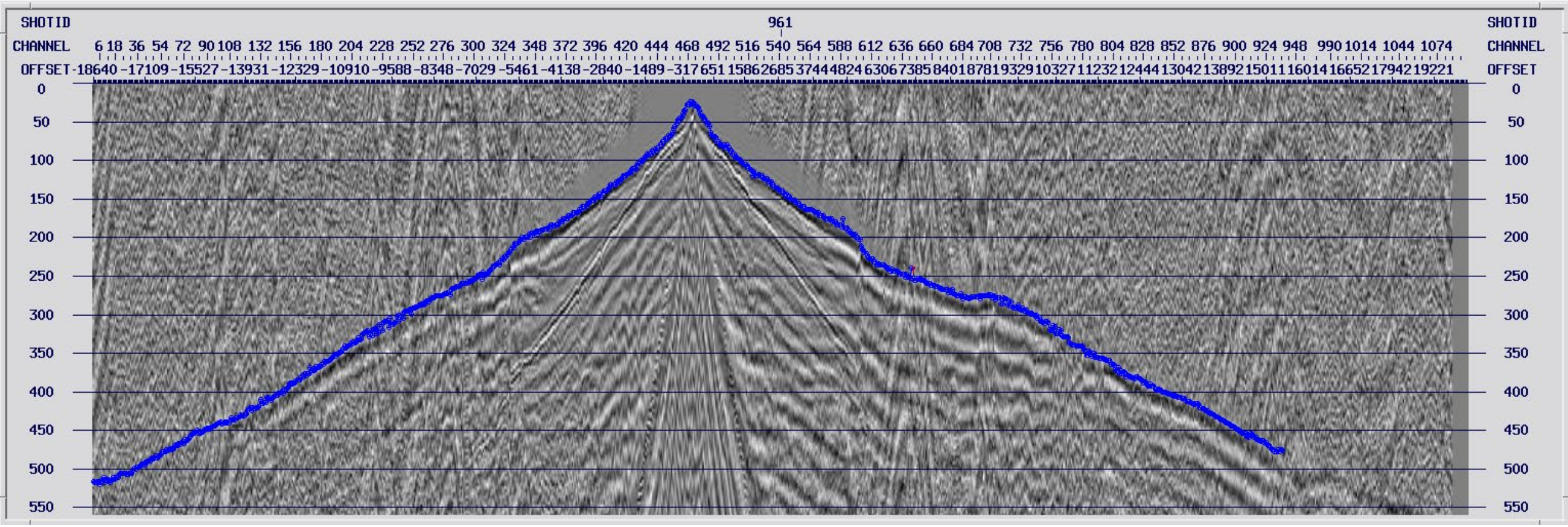




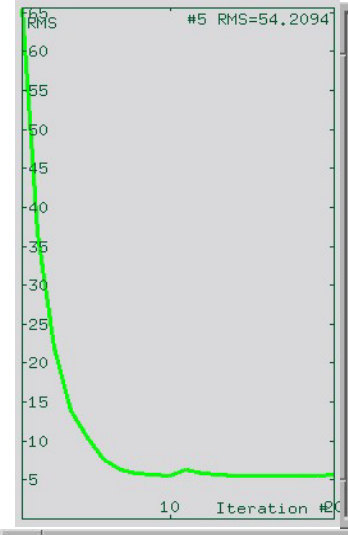


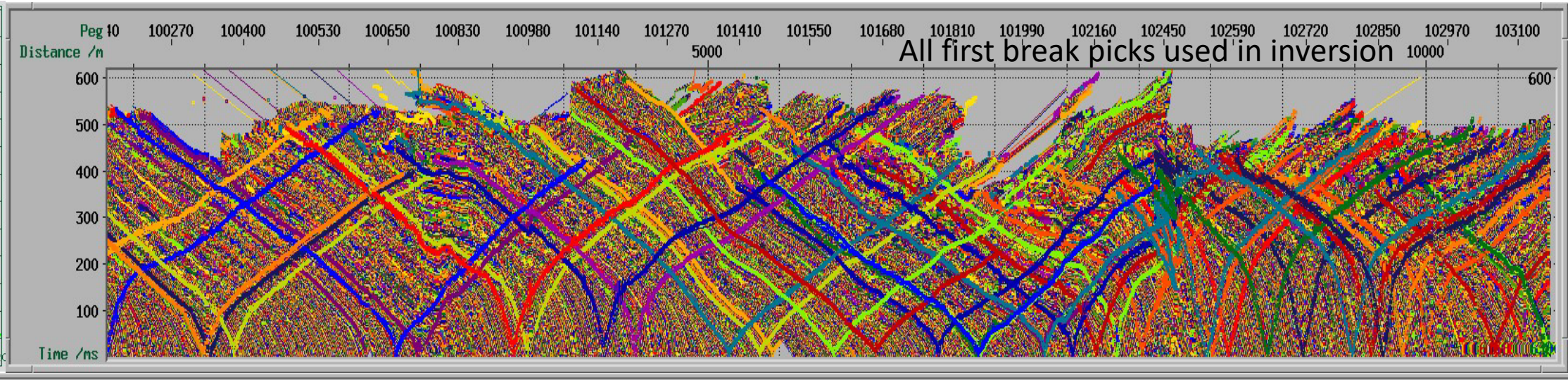
Line ET2025-001: Source point example

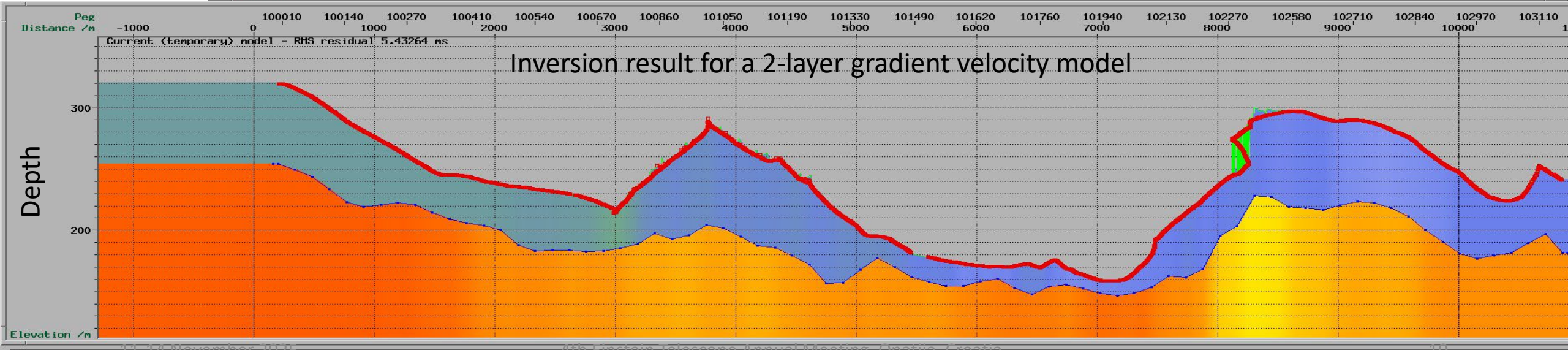
First break picking for tomographic inversion



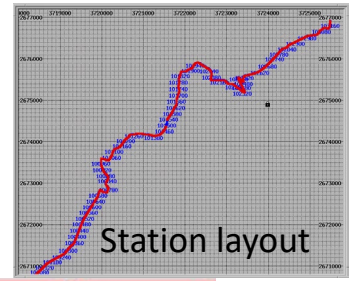
Generalized linear inversion of first break picks







Comparison of inversion results



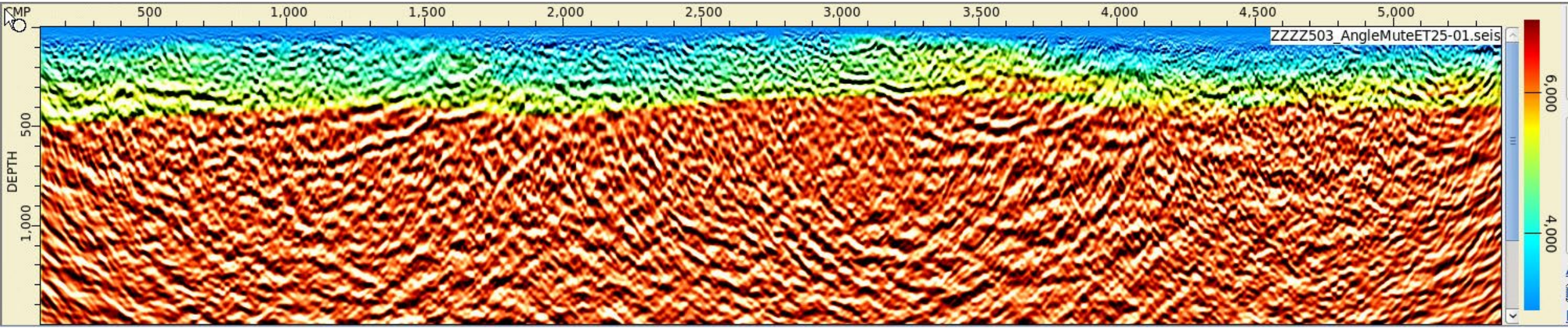
Depth

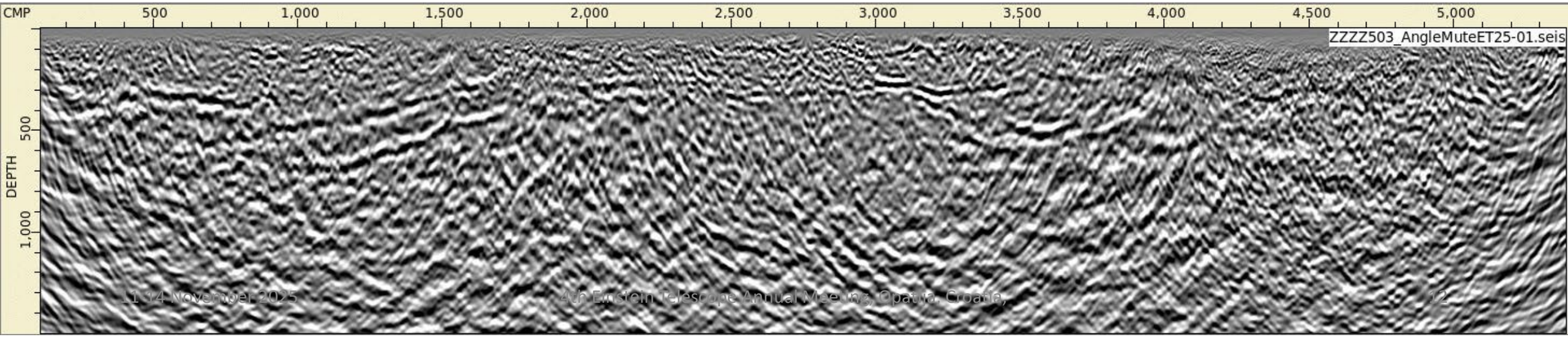
Generalized linear inversion result

Depth

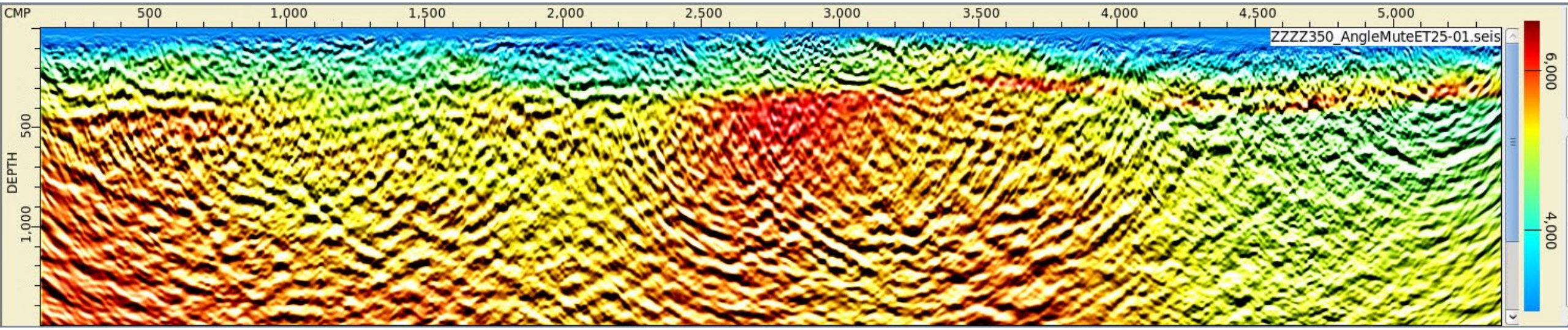
Non-linear tomographic inversion result

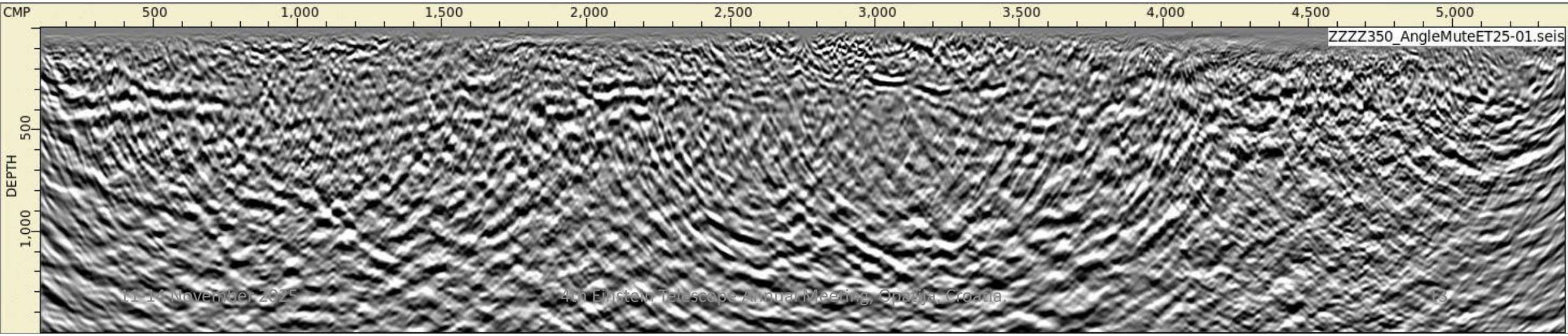
Pre-stack depth migration:
Tomo. Velocities shallow below flood with 6200m/s



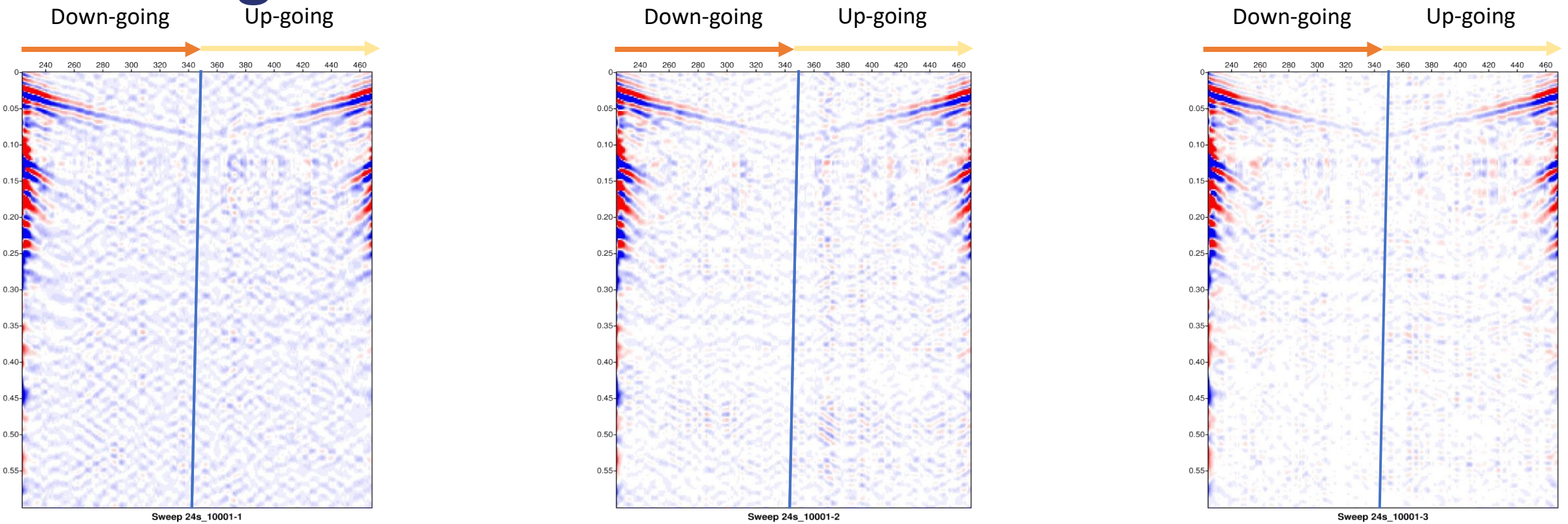


Pre-stack depth migration:
Tomo. velocities shallow below inv. PSTM velocities



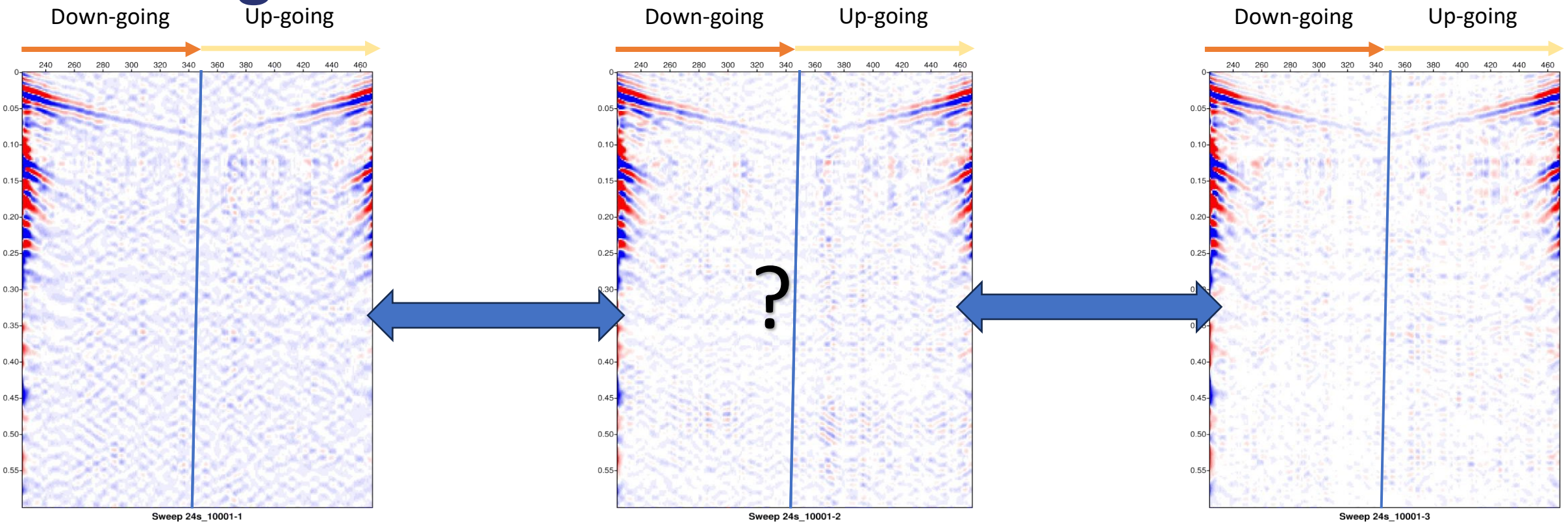


Horizontal striping identified during DAS-VSP testing at Obsinnich:



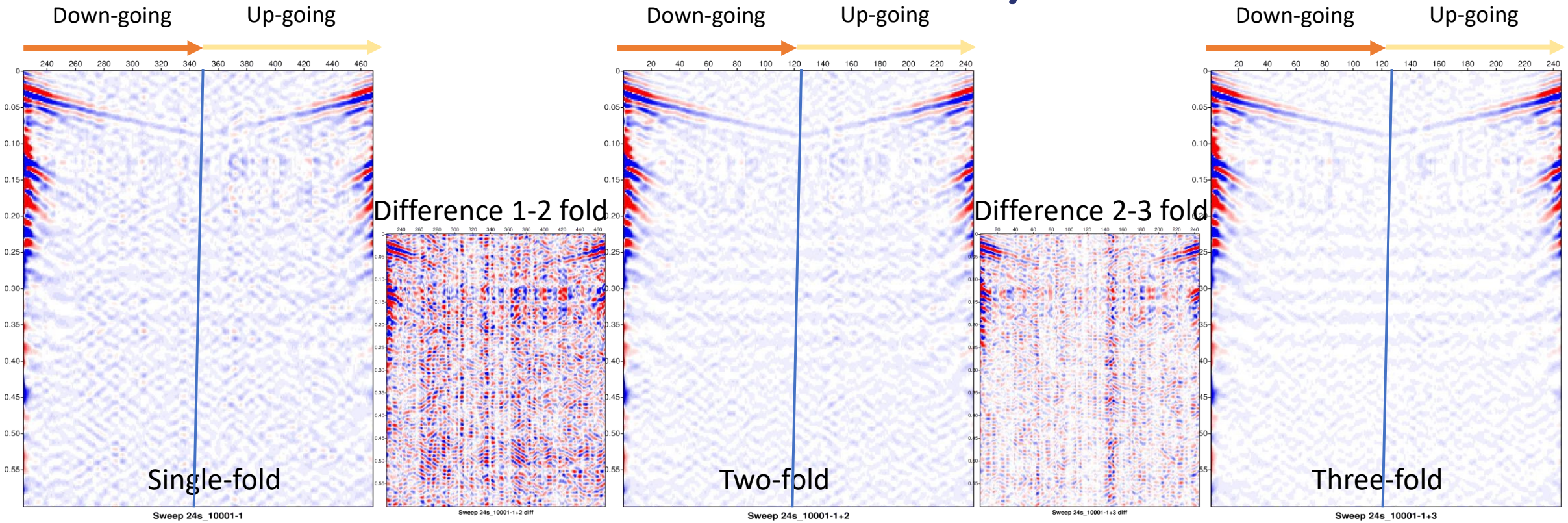
- Three 24s sweeps, 2-85Hz at the zero-offset source point
- Analysis was performed on a down and upgoing single mode fiber

Horizontal striping identified during DAS-VSP testing at Obsinnich:



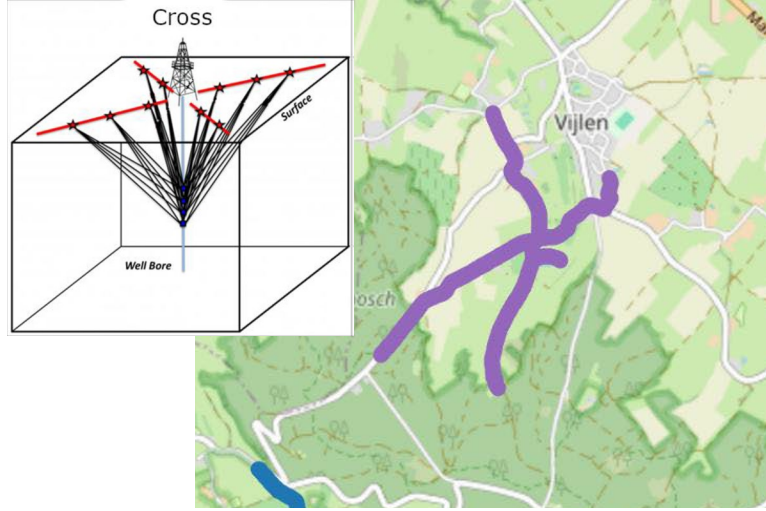
- Three 24s sweeps, 2-85Hz at the zero-offset source point
- Analysis was performed on a down and upgoing single mode fiber

Test at Obsinnich: 2-85Hz, 24s Sweep
Difference of 2 & 3 fold diversity stacks



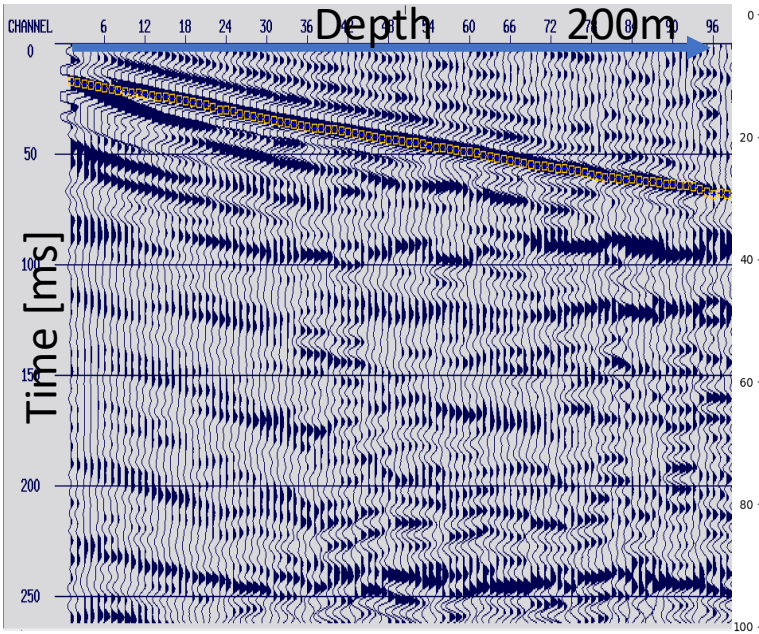
- Horizontal striping gets enhanced by the diversity stacking
  - ➔ "Non-physical noise", as it arrives at all borehole receivers at the same time
  - ➔ Introduced by the FEBUS-interrogator, Febus states it is "normal" instrument noise and not a small error in the timing in the recording of the data.
- Pragmatic solution by applying a k=0/m filter to remove

Check-shots information obtained from DAS-VSP at Vijlen

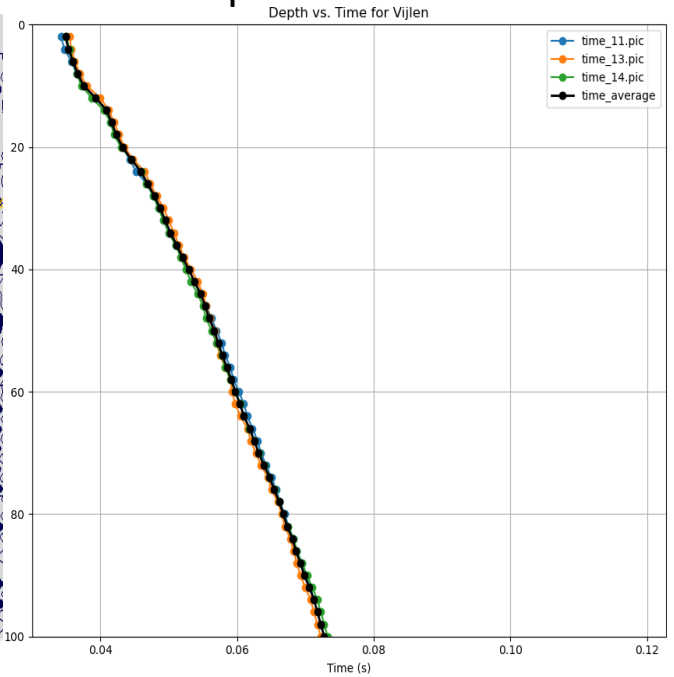


- Pick first breaks for all zero-offset source points
- Average the picks
- Calculate interval velocities and apply some smoothing

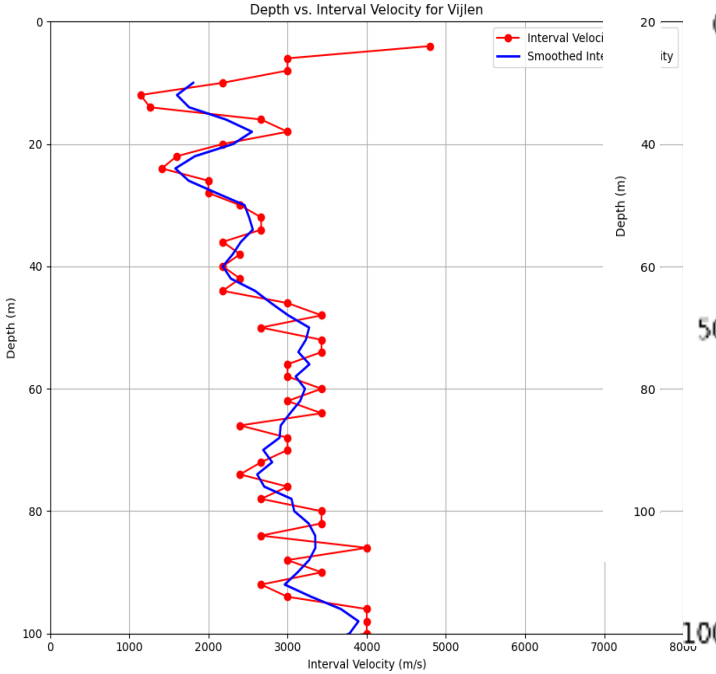
First break picks of one 0-offset VP

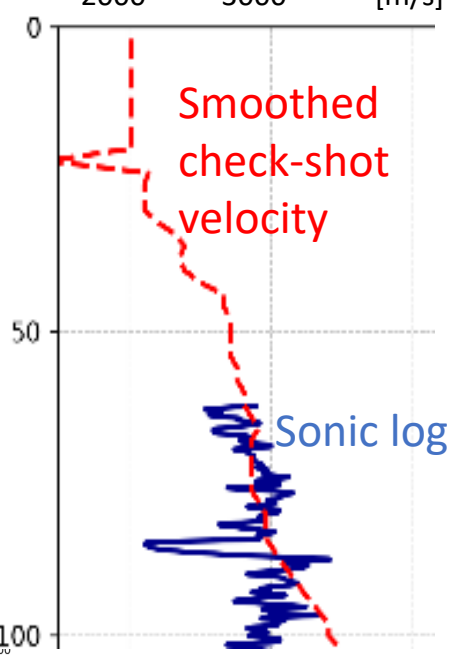


First break picks for all 0-offset VP's



Estimated interval velocities

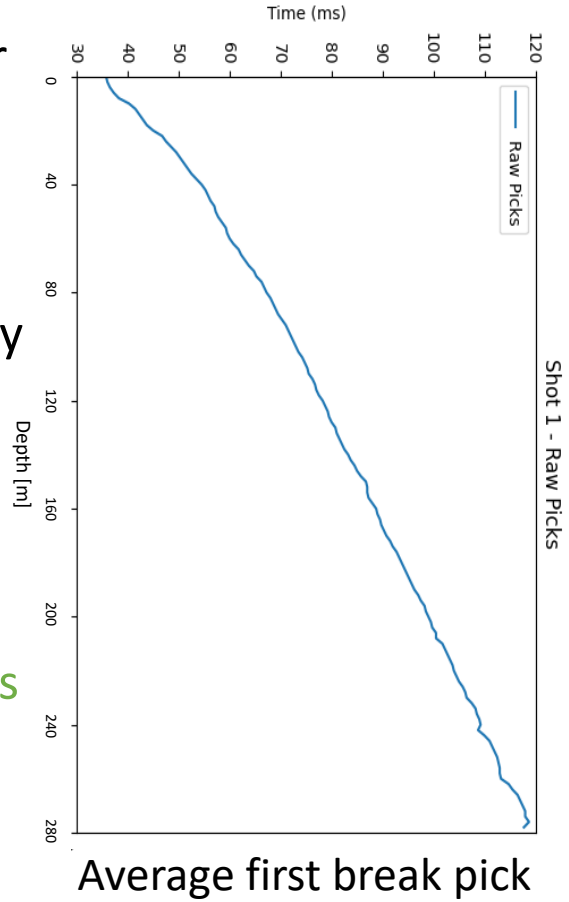




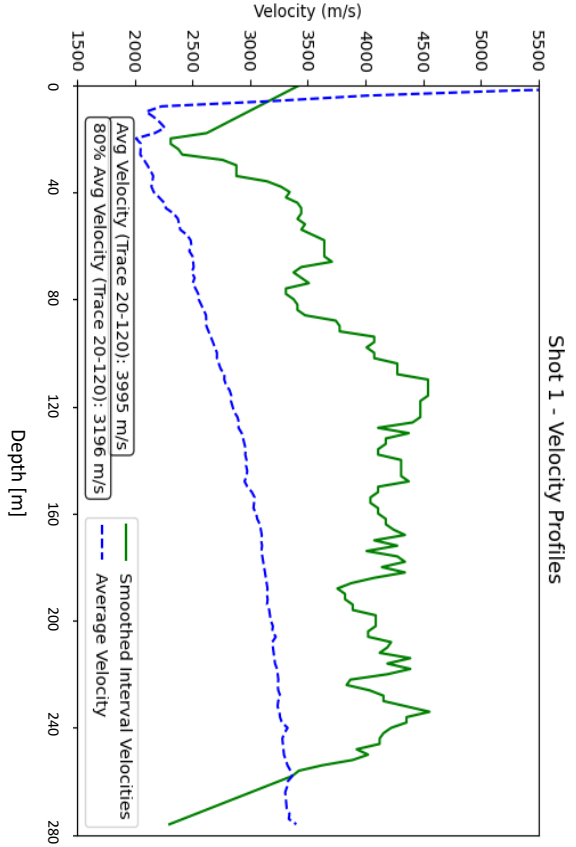
Check-shots information obtained from DAS-VSP at Vijlen

- Pick first breaks for all zero-offset source points
- Average the picks
- Calculate interval velocities and apply some smoothing

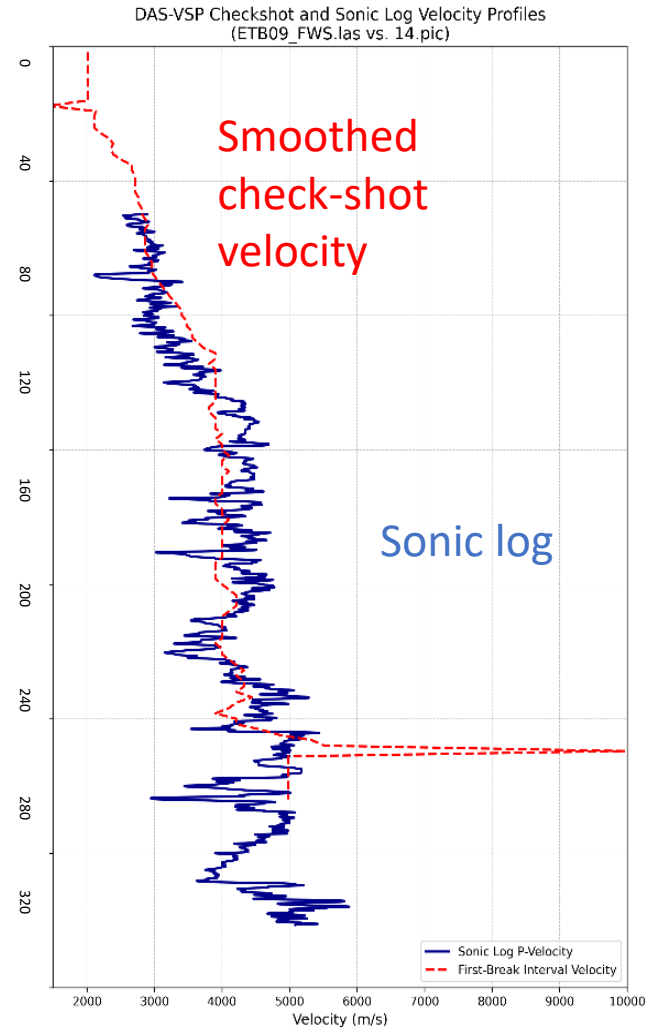
- Good match between sonic log and check-shot
- Check-shot extends closer to surface (~20m below top)



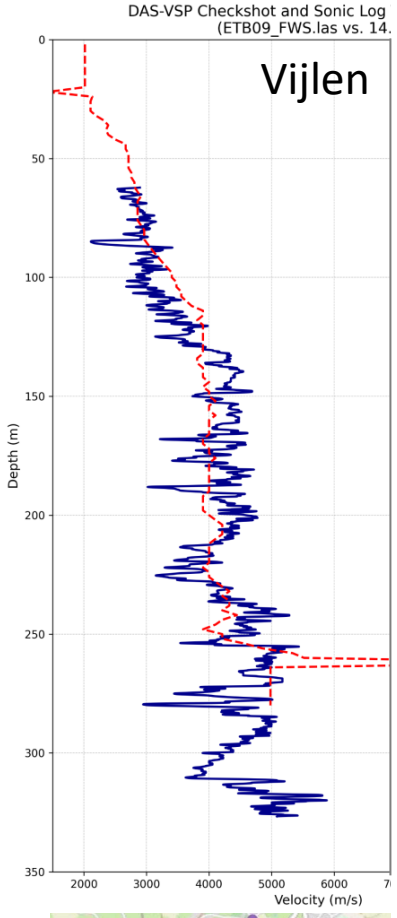
Average first break pick

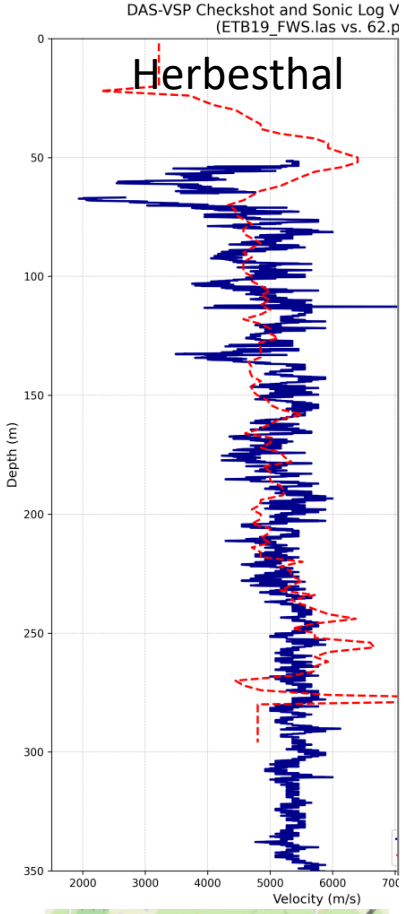


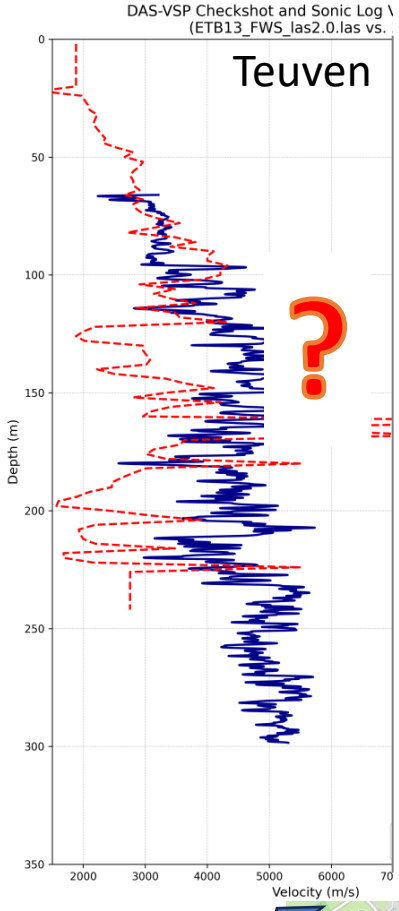
Interval velocities

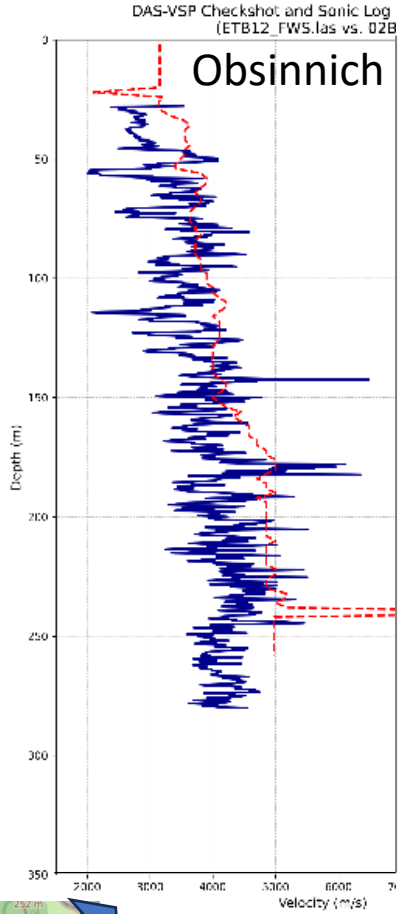


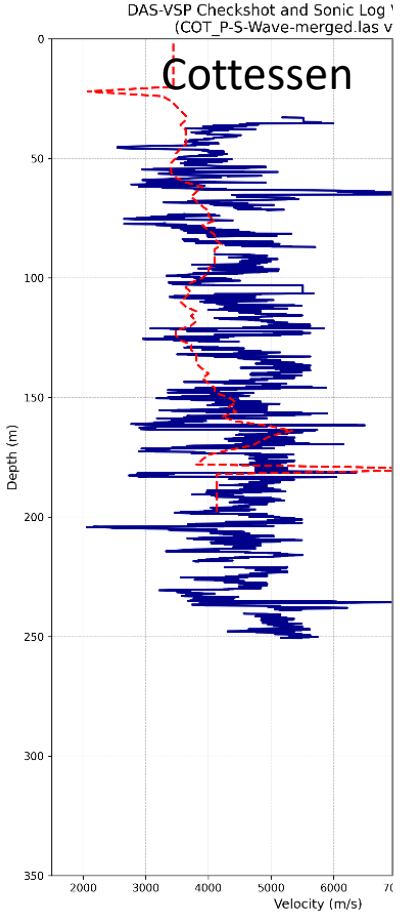
DAS-VSP check-shots compared to sonic-logs



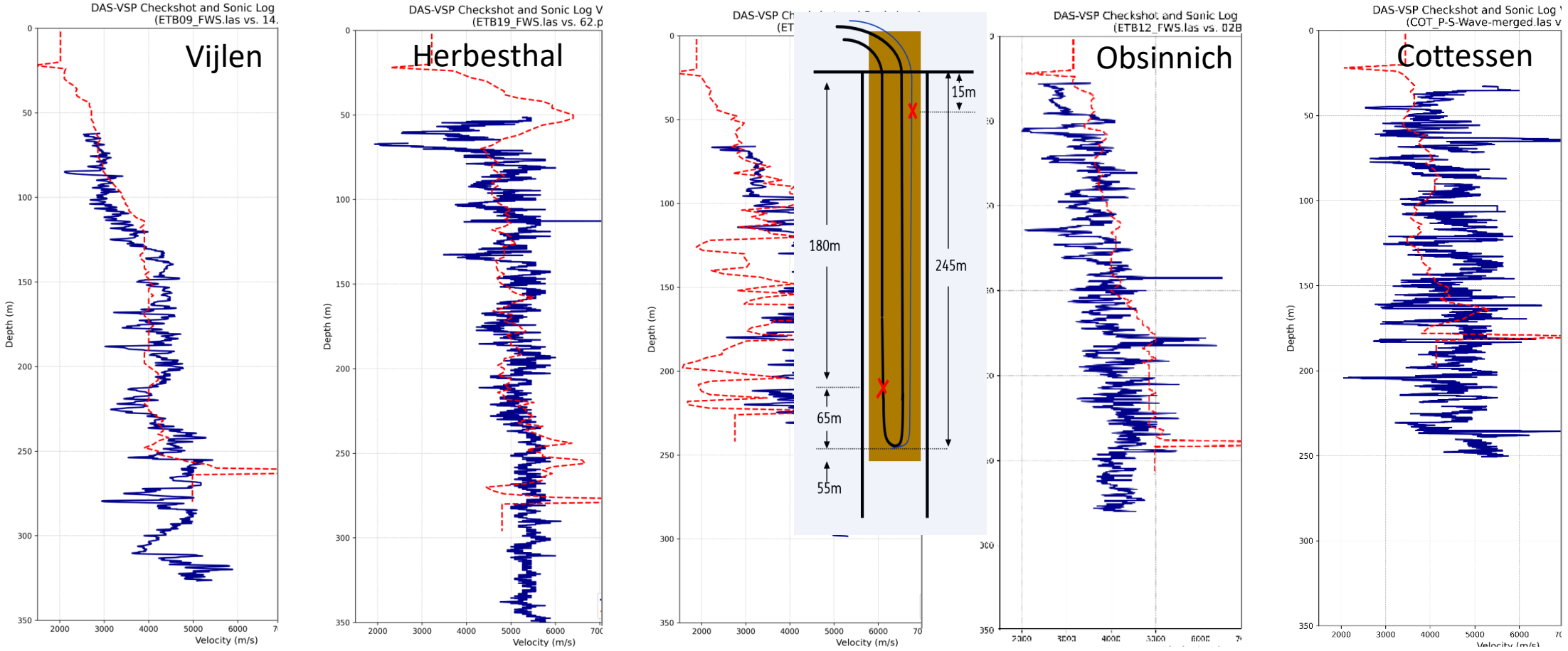






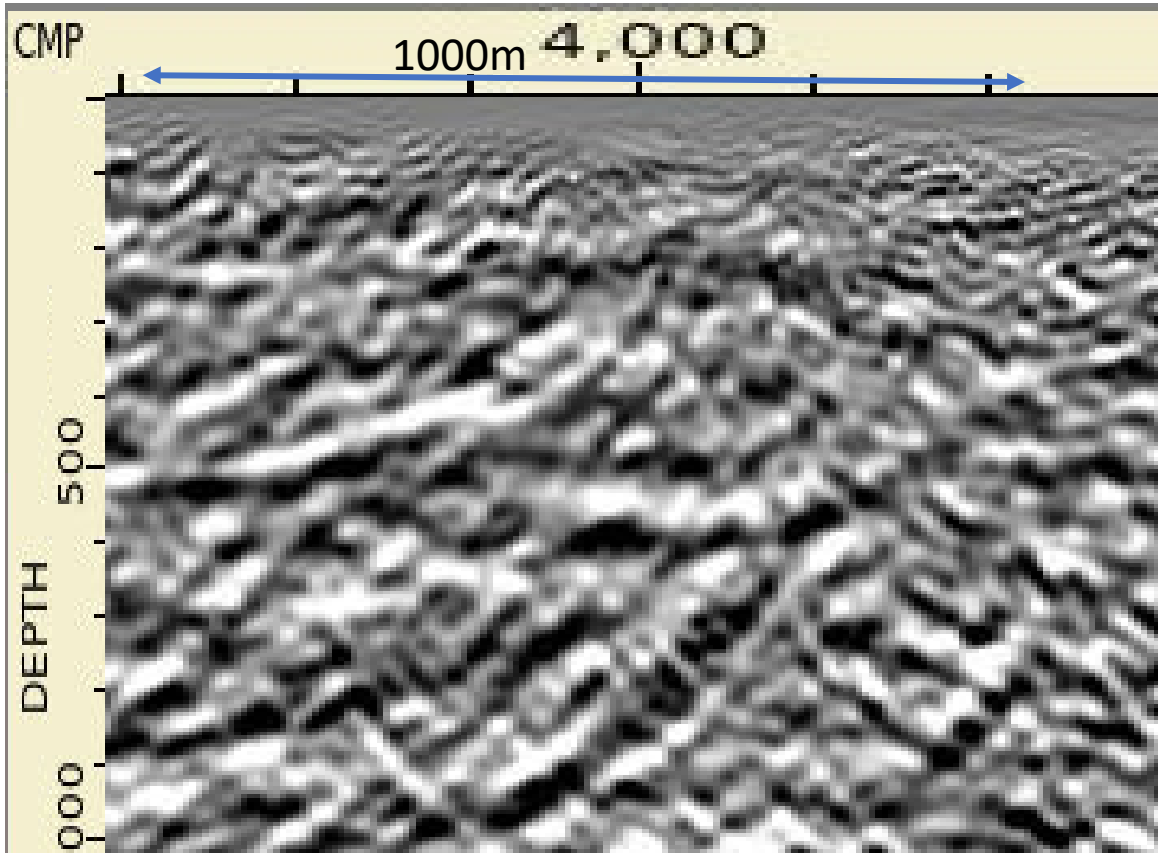


DAS-VSP check-shots compared to sonic-logs

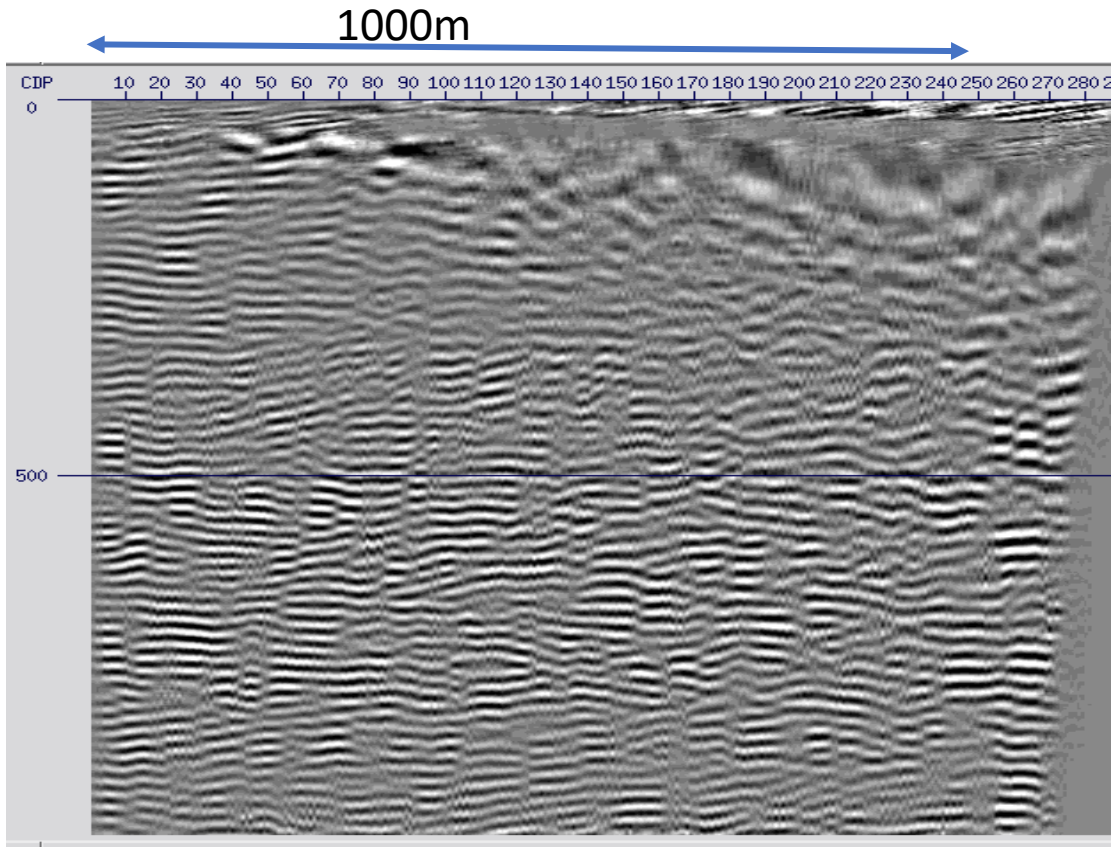


Schematic of FO Cable at Teuven. Both FO Cables were damaged during installation. For the DAS-VSP survey two SM fibres could be used. One fiber reaches the maximum depth of 245m and is cut on its way back up at 180 m depth. The other fiber is cut at 180m on its way down.

Surface seismic vs DAS-VSP image at Cottessen

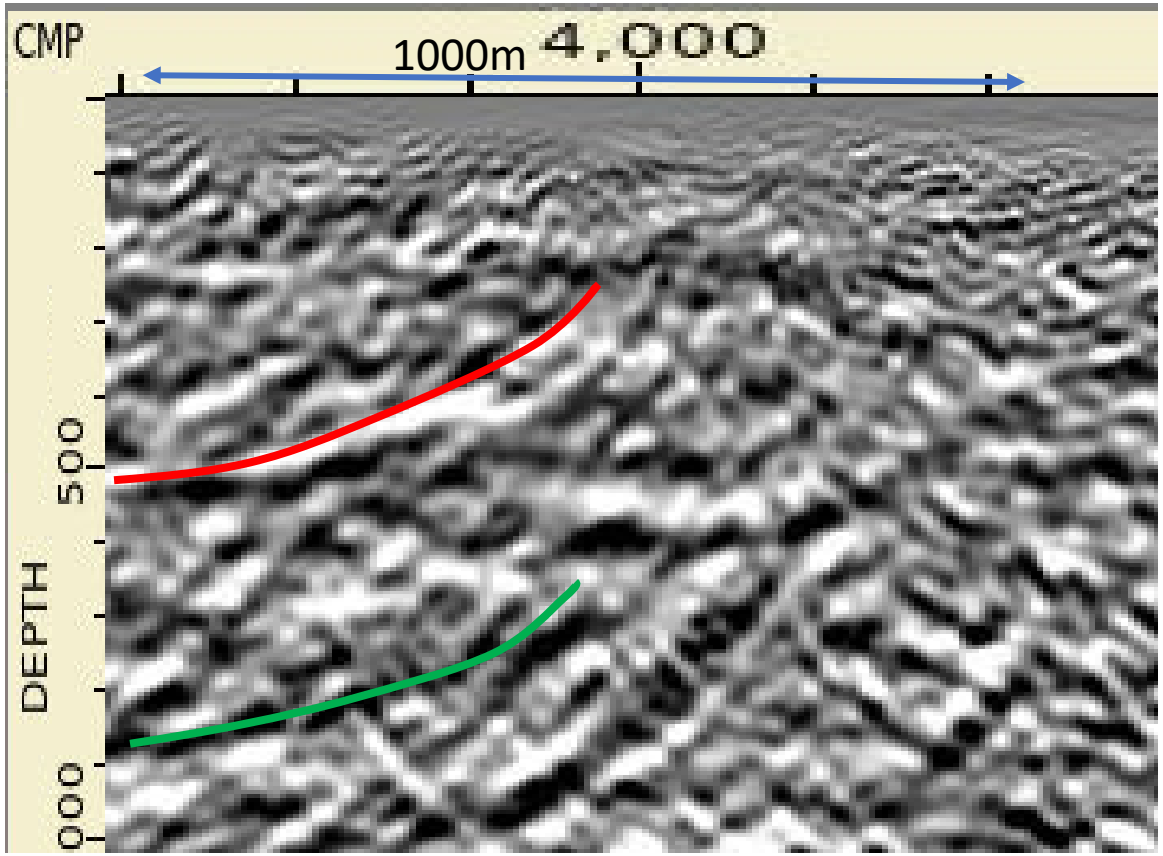


2D surface line close to Cottessen

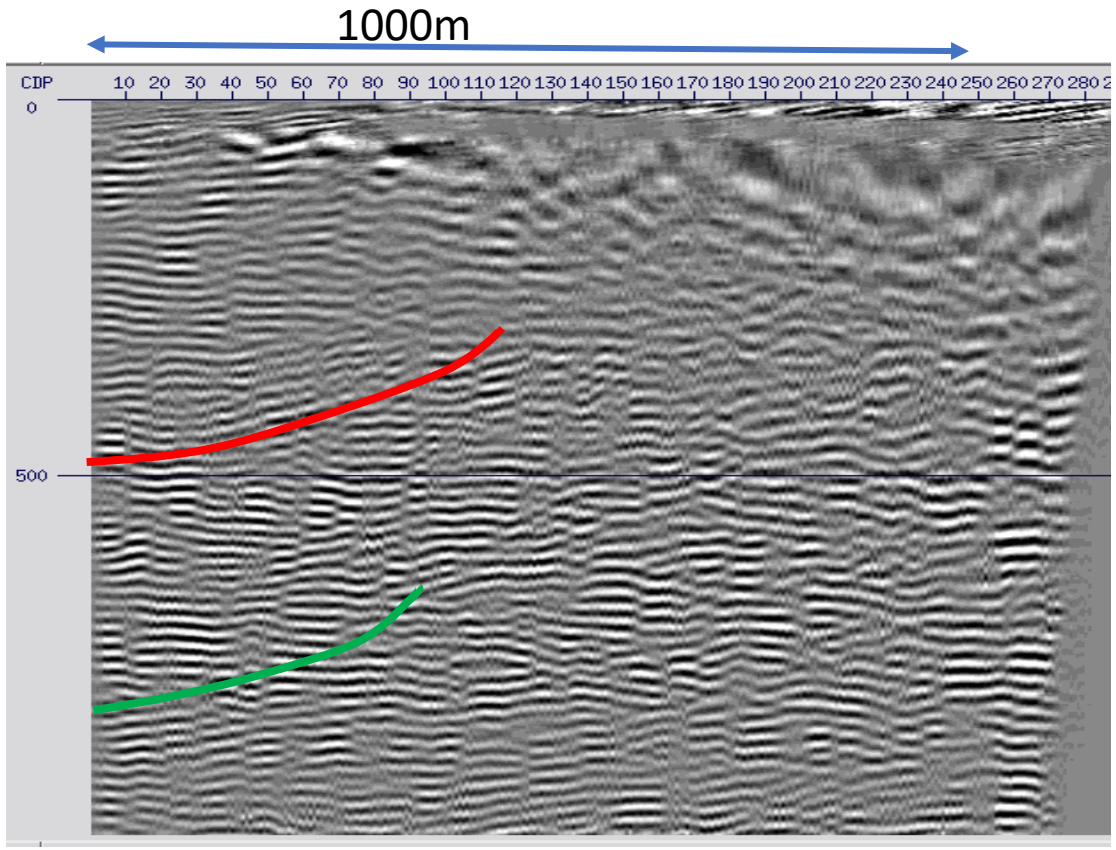


DAS-VSP depth image

Surface seismic vs DAS-VSP image at Cottessen



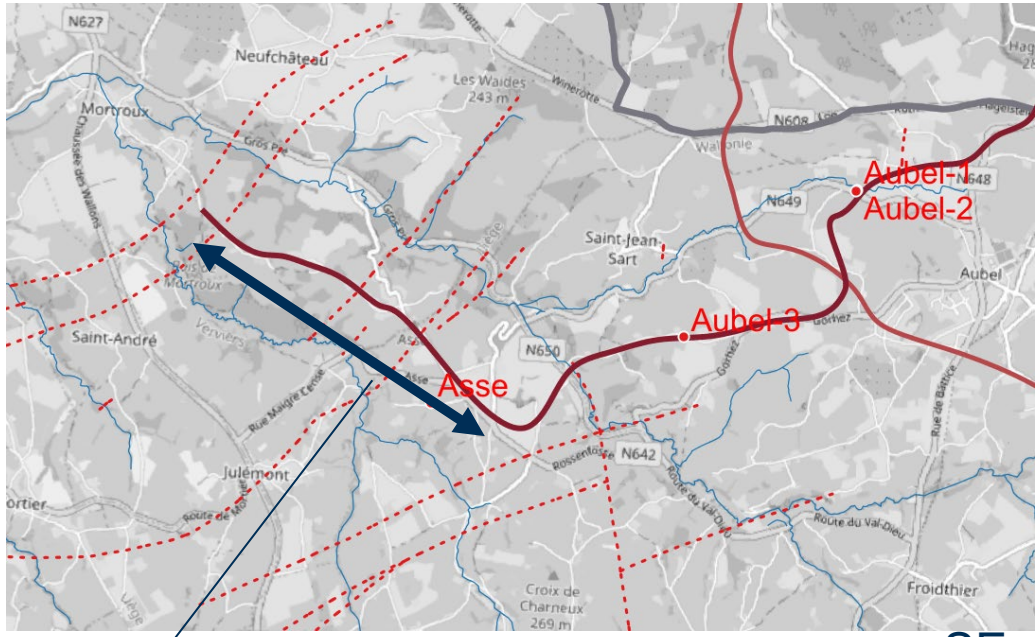
2D surface line close to Cottessen



DAS-VSP depth image

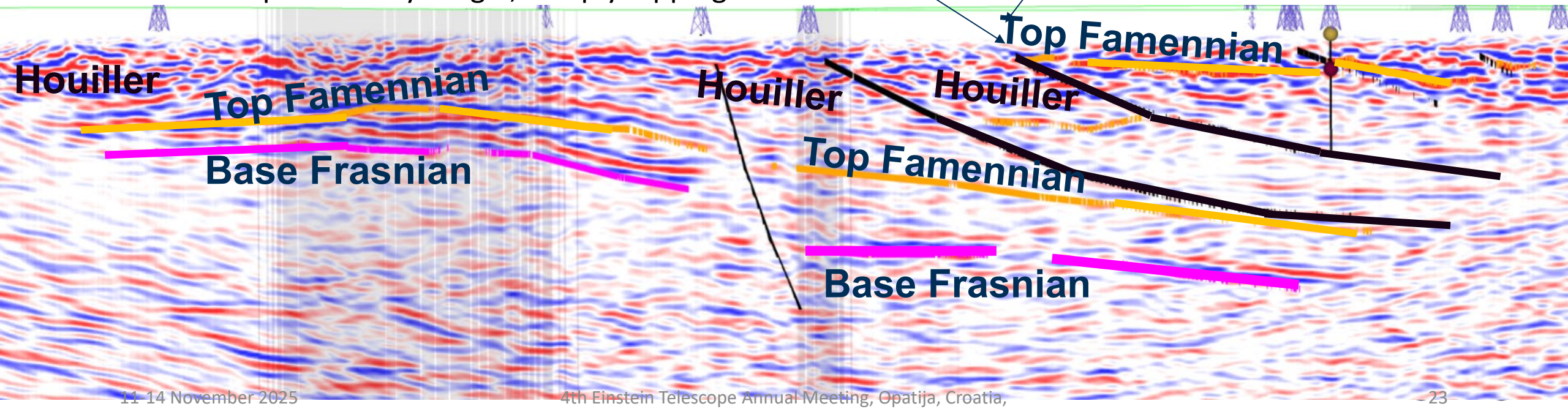
Seismic Interpretation ET 2025-003

- Booze – Le Val Dieu structure
- Interpretation based on nearby outcrop data + seismic facies
- Nearby observation of Asse thrust fault, with Famennian outcrop south of younger, steeply dipping Namurian



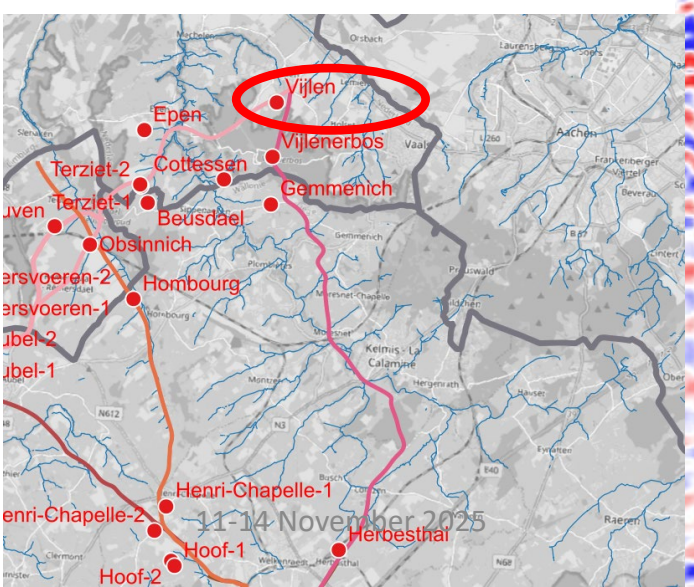
NW

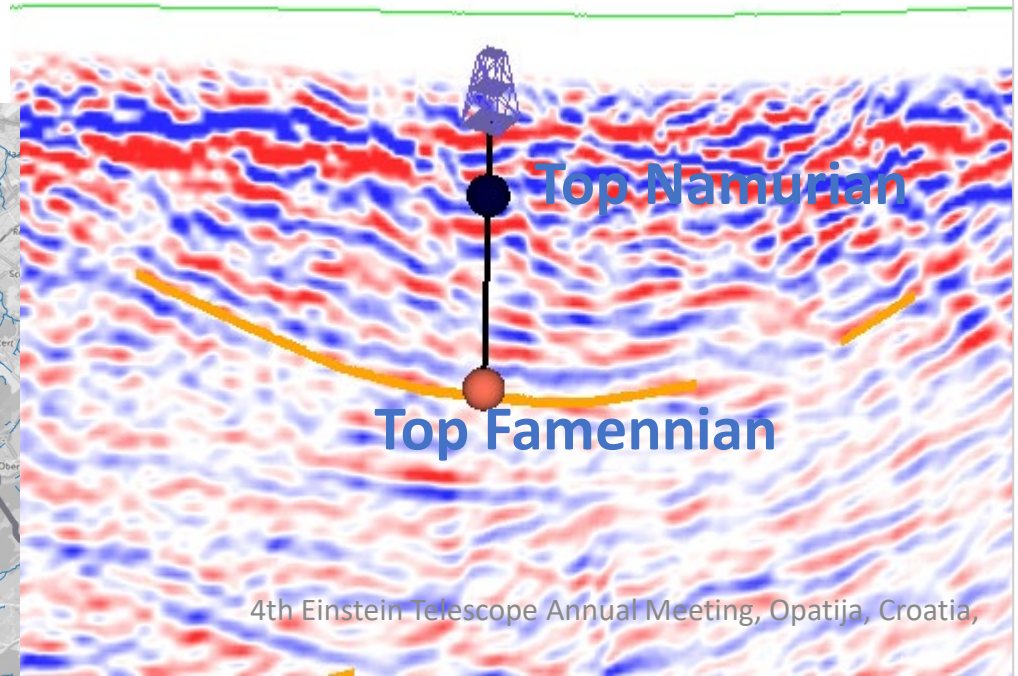
SE

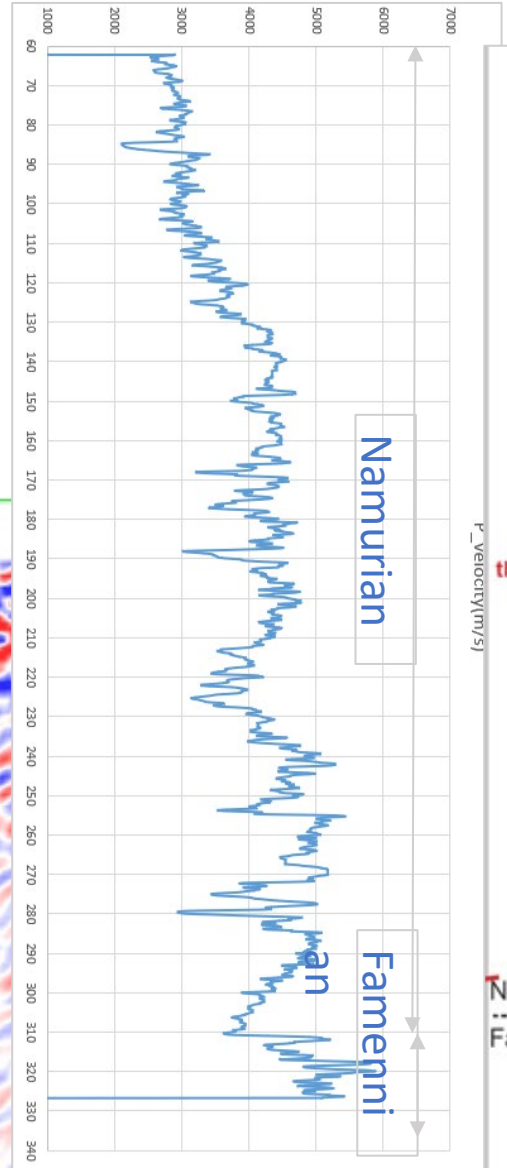


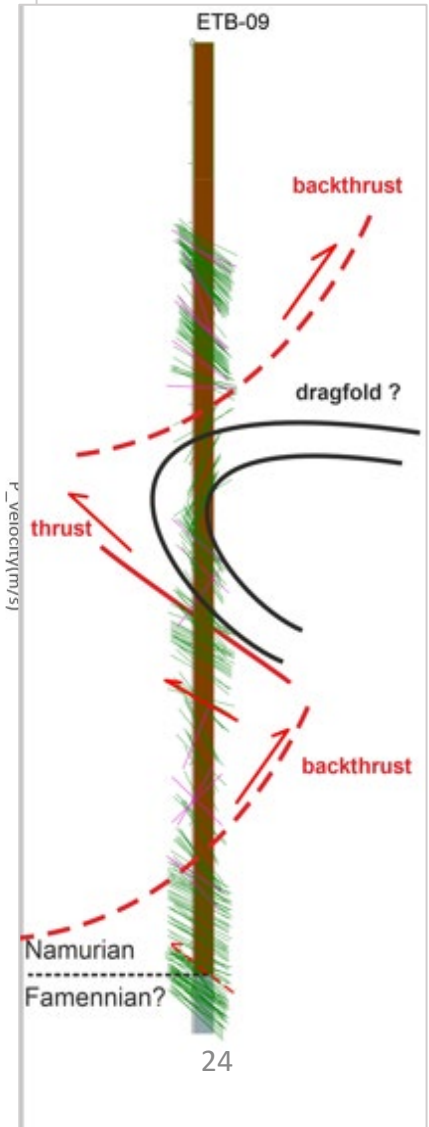
Seismic interpretation ET 2025-001

- Vijlen borehole:
  - Thick Namurian (260 m) on top of Famennian
    -> still “high” area prior to Namurian (similar to Epen)
  - No major acoustic velocity contrast between Namurian and Famennian -> moderate amplitude reflection

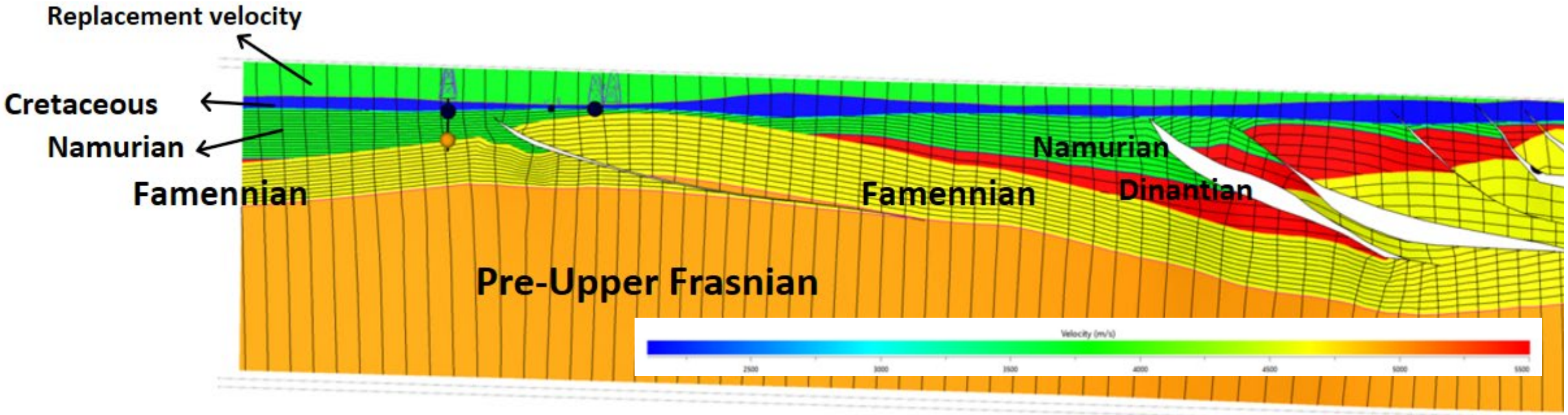








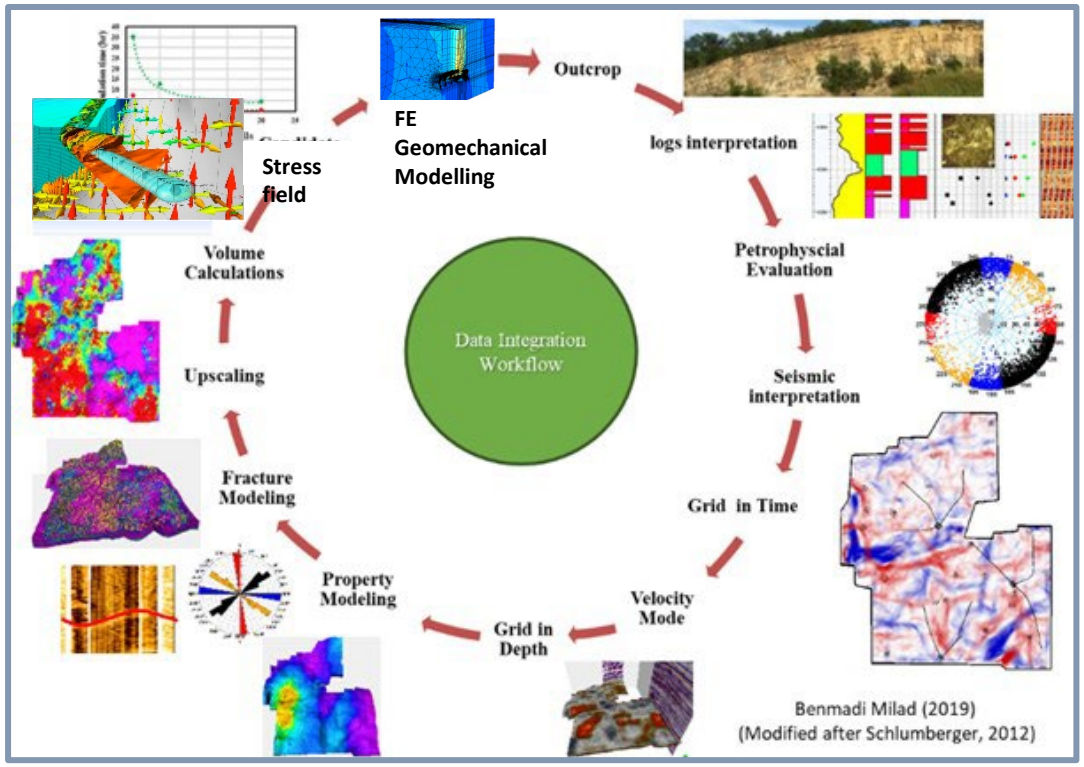
Construction of a 3D subsurface model ongoing



- Structural framework based on:
  - Outcrop
  - Seismic
  - Borehole data
  - Gravity data
- Volume properties derived from:
  - (geophysical) logs
  - Seismic
  - DAS-VSP:
  - Empirical relation ships:

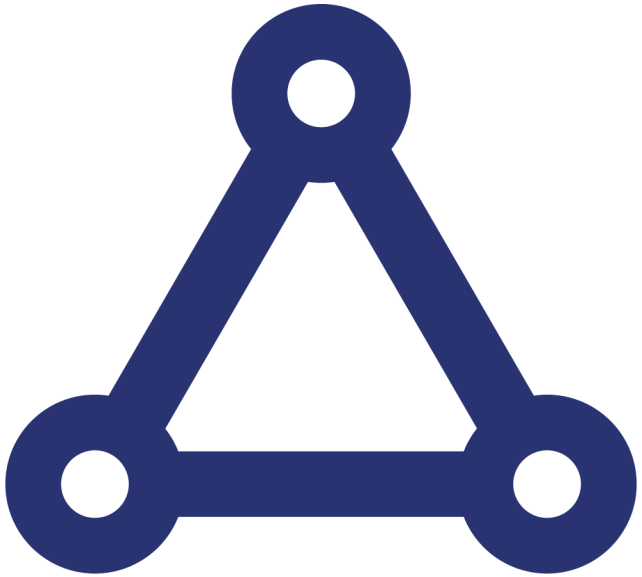
Summary and some future steps

- Successful seismic acquisition campaign in Q1 2025
  - Acquired some 90km of 2D data, showing near surface reflections
  - Acquired 5 VSP's including low-fold cross-spreads
    - Cottessen, Vijlen, Teuven, Obsinnich, Herbesthal
- Finalized seismic processing
- Check-shots overall agree with sonic logs
- Reasonable seismic to well-ties
- Interpretation of VSP's and seismic lines ongoing
- Supports creation of an integrated 3D subsurface model for:
  - Geotechnical and civil engineering
  - Hydrological modelling
  - Geophysical modelling



To be continued…

Question?



Einstein Telescope