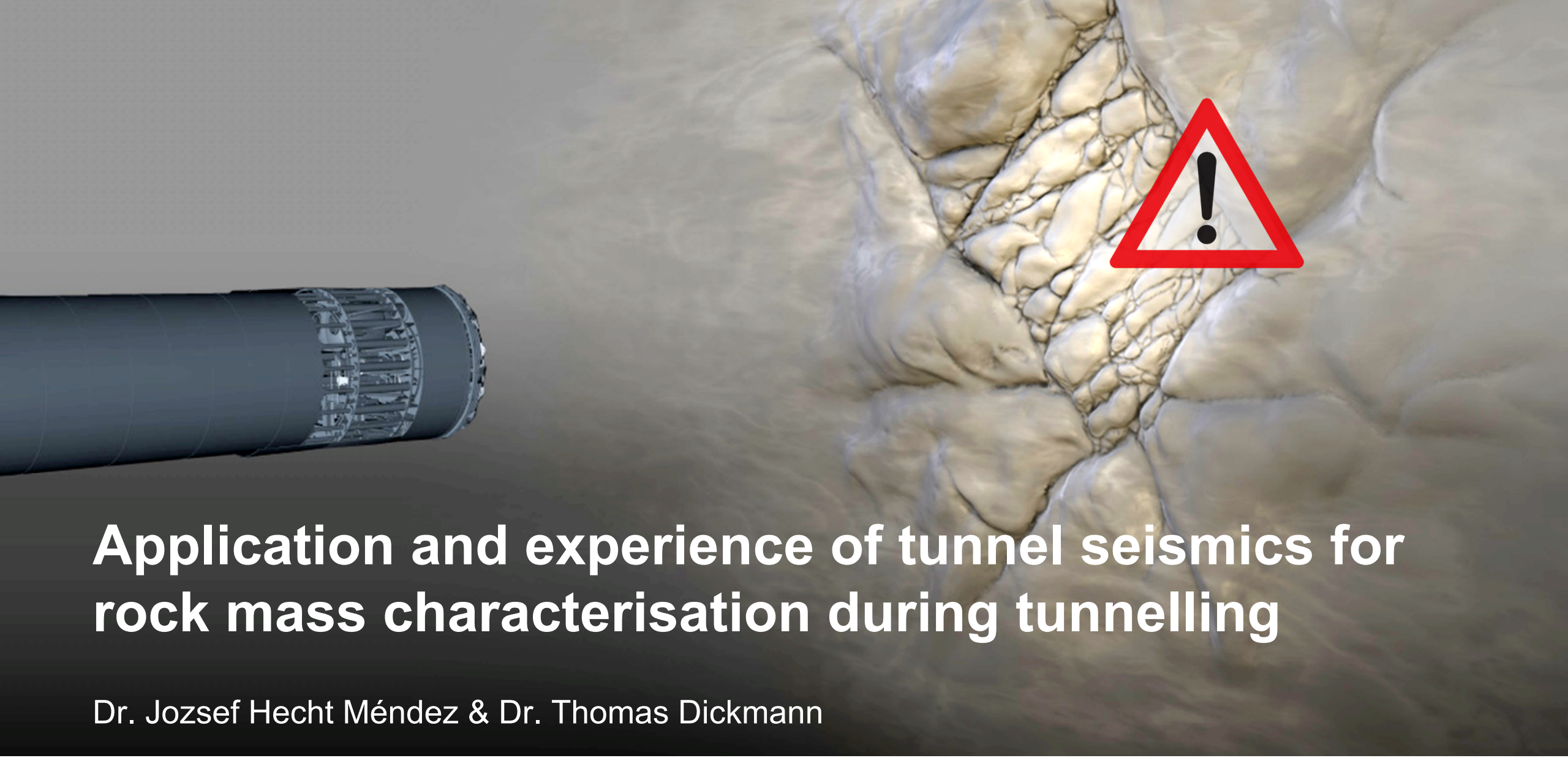

Application and experience of tunnel seismics for rock mass characterisation during tunnelling

Dr. Jozsef Hecht Méndez & Dr. Thomas Dickmann

Comité Français de Mécanique des Roches – CFMR
14th November 2019: “Reconnaissance and Fractured Rock Mass"

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AMBERG TECHNOLOGIES

Tunnelling – a risky job due to unknown ground conditions

- Squeezing (Venezuela)
- Water ingress (Sri Lanka – Colombia)

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Tunnelling – a risky job due to unknown ground conditions

- Squeezing (Venezuela)
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AMBERG TECHNOLOGIES

Tunnelling – a risky job due to unknown ground conditions

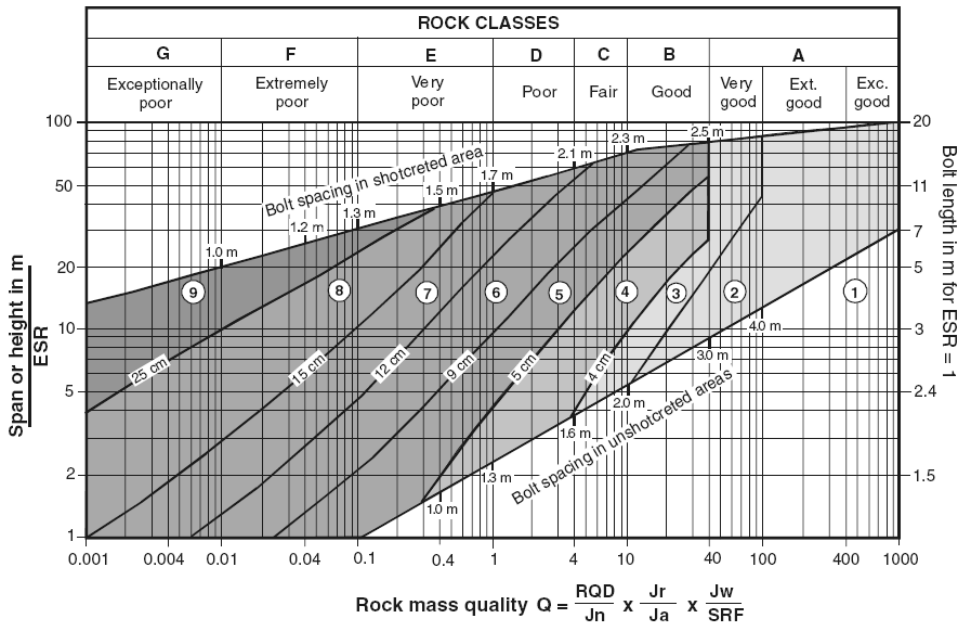
- Squeezing (Venezuela)
- Water ingress (Sri Lanka – Colombia)
- Face collapse (Peru)

Tunnelling – a risky job due to unknown ground conditions

- Squeezing (Venezuela)
- Water ingress (Sri Lanka – Colombia)
- Face collapse (Peru)
- Large brake out (n/a)

Geology investigation stages

1. Desktop studies
2. Preliminar investigations
3. Detailed studies → Definition of geological and geotechnical units
   - ✓ Rock mass classification system (RMR Bieniawski, Q-Barton)
   - ✓ Selection of primary rock support

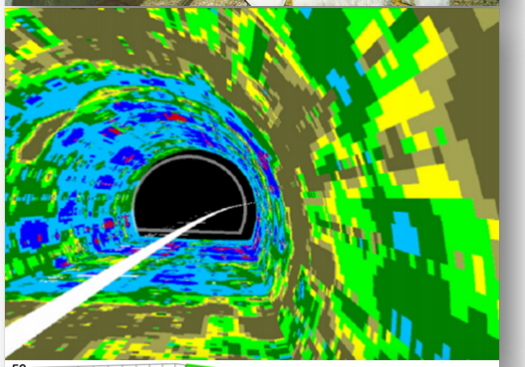


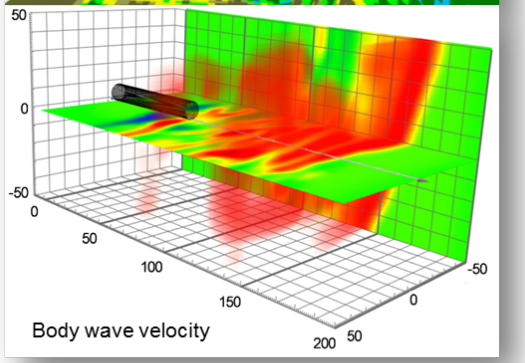
REINFORCEMENT CATEGORIES:

1) Unsupported
2) Spot bolting
3) Systematic bolting
4) Systematic bolting, (and unreinforced shotcrete, 4 - 10 cm)
5) Fibre reinforced shotcrete and bolting, 5 - 9 cm
6) Fibre reinforced shotcrete and bolting, 9 - 12 cm
7) Fibre reinforced shotcrete and bolting, 12 - 15 cm
8) Fibre reinforced shotcrete, > 15 cm, reinforced ribs of shotcrete and bolting
9) Cast concrete lining

Geology investigation stages

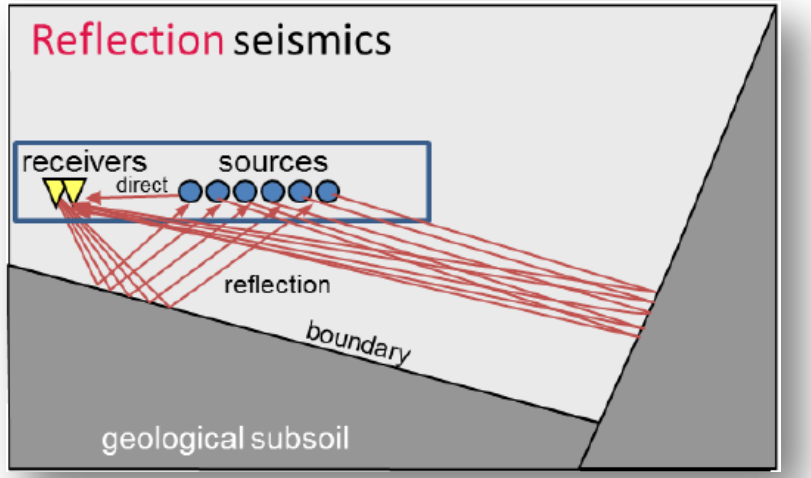
1. Desktop studies
2. Preliminar investigations
3. Detailed studies → Definition of geological and geotechnical units
4. **Construction**
   - ✓ **Destructive investigation methods**
   - ✓ **Non-destructive investigation methods**





3D Tunnel Seismic Prediction (TSP)

- Estimation of P & S wave velocity
- Detects geological changes ahead of the face
- Allows to estimate geomechanical parameters



- Ease of use
- Data acquisition within 15-90 min
- Up to 150 m prediction range ahead of the face
- Results within 4-5 hours after acquisition

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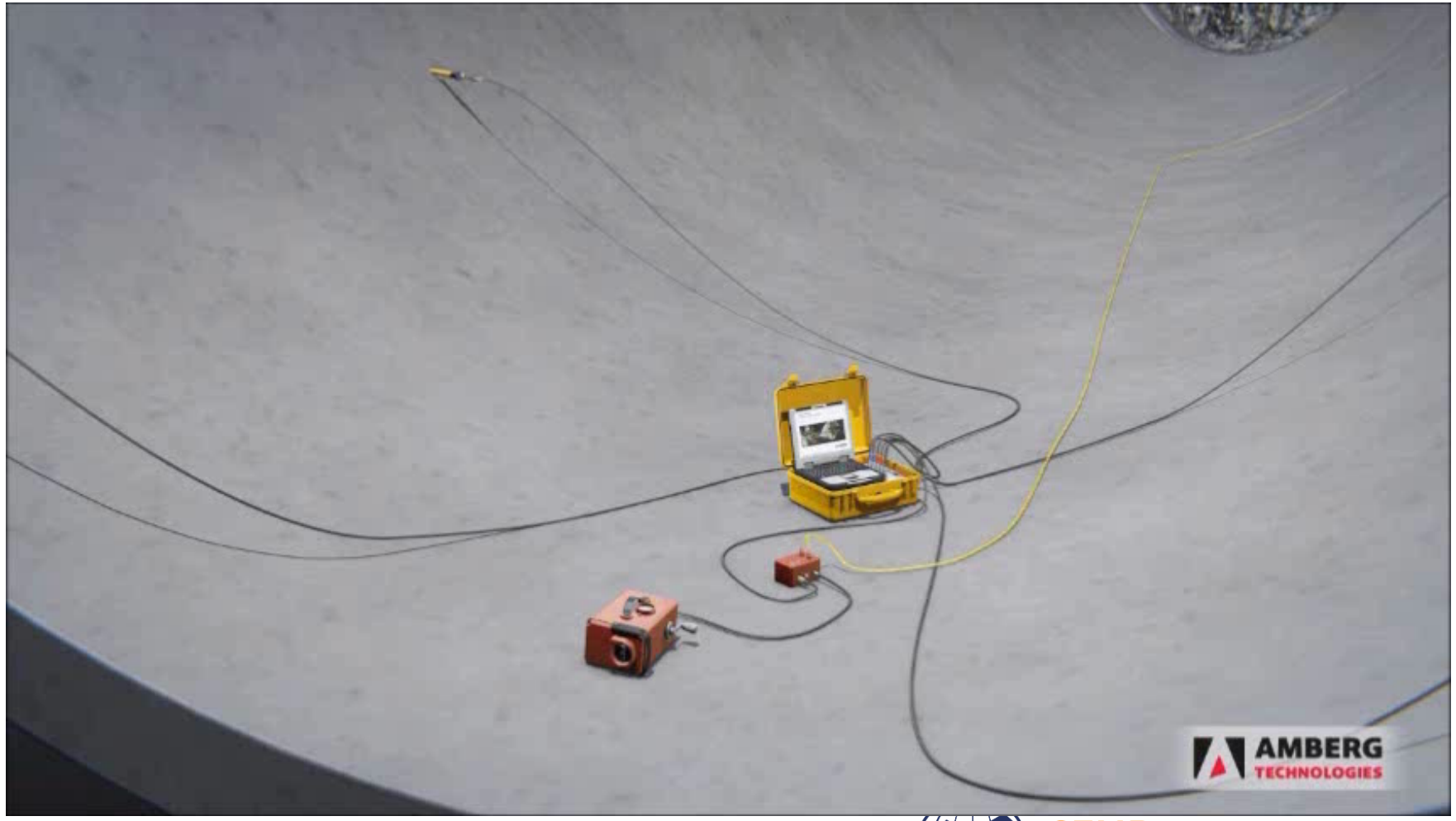
3D Tunnel Seismic Prediction (TSP)



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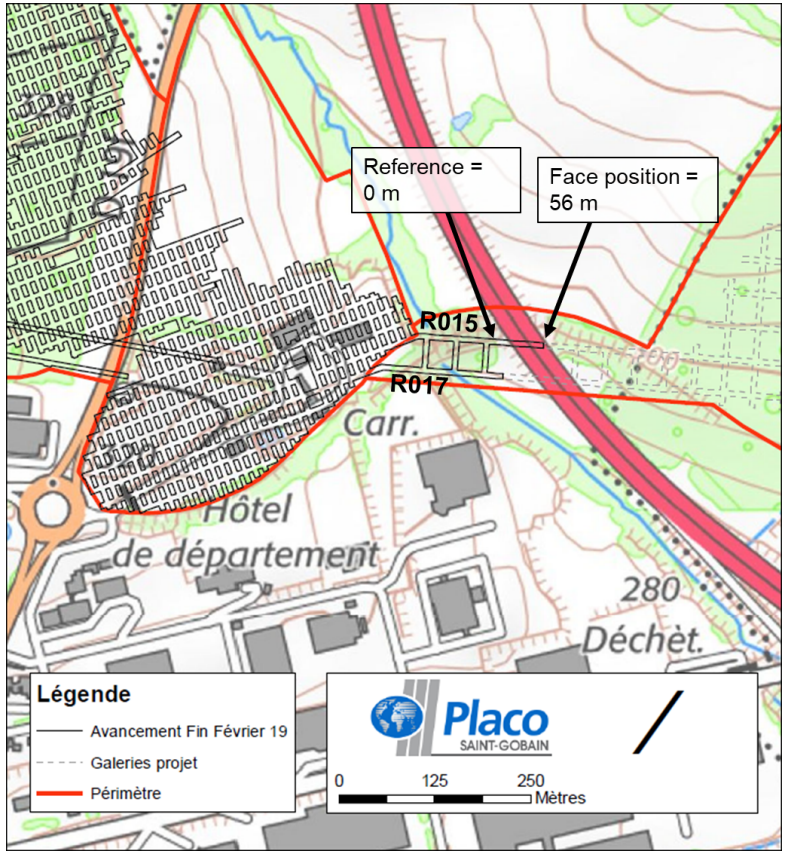
TSP Data acquisition

Faulquemont Mine Development – AMF

Mission target: water exploration/rock condition

- Operational aspects
  - ✓ Recording procedure: **single shot**
  - ✓ 26 + 14 shots
  - ✓ Explosive charge:
    - SL1: 0 – 60 gr
    - SL2: 20 – 60 gr



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Faulquemont Mine Development – AMF

Charge selection due to type of lithology and energy attenuation

Faulquemont Mine Development – AMF

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Förbifart Stockholm bypass, Sweden

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TSP seismic data quality control (QC)

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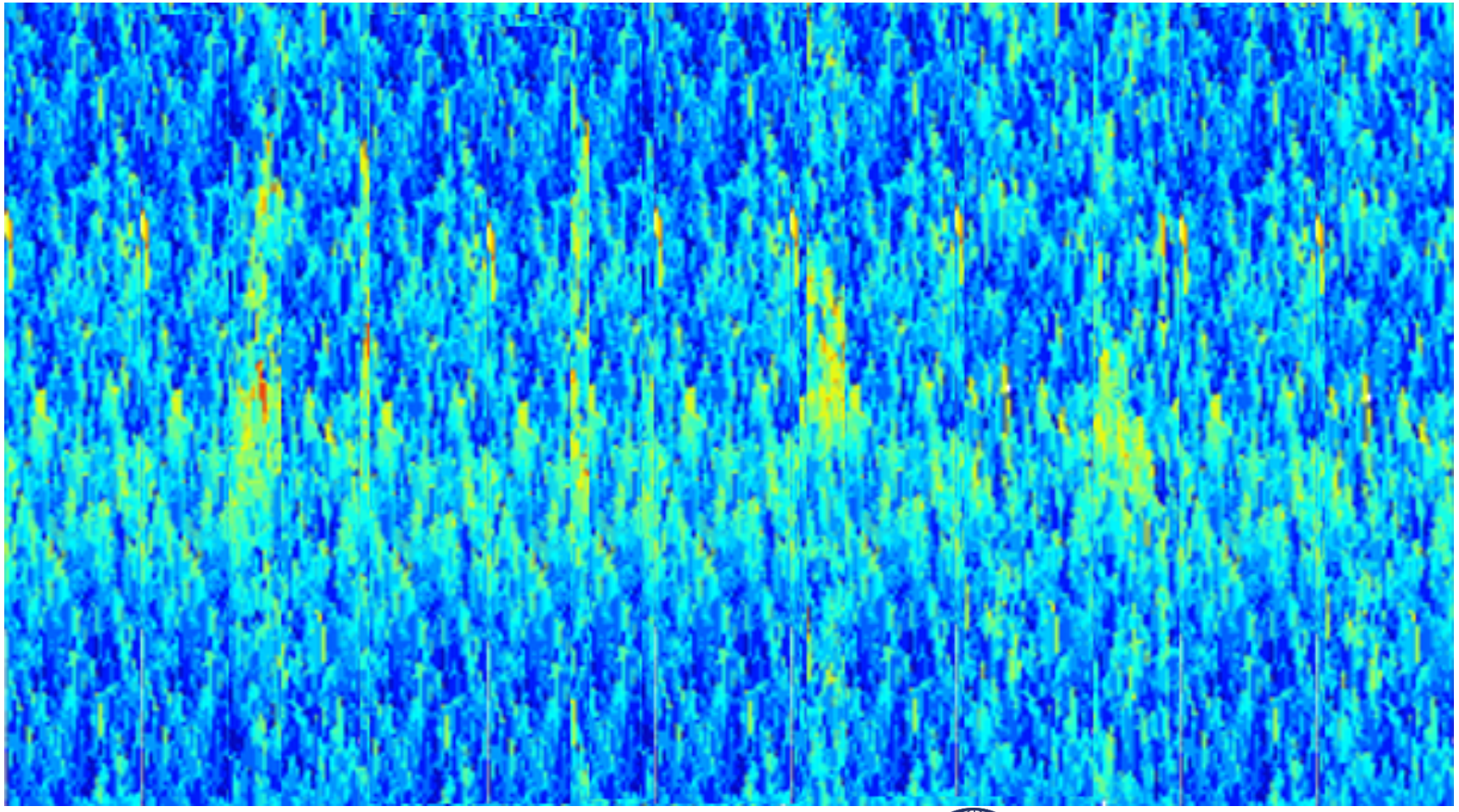
Seismic Data Processing



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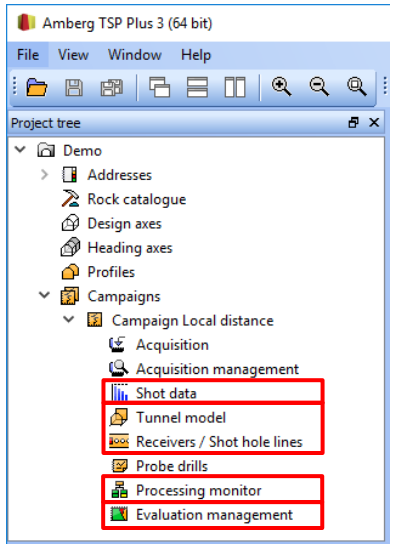
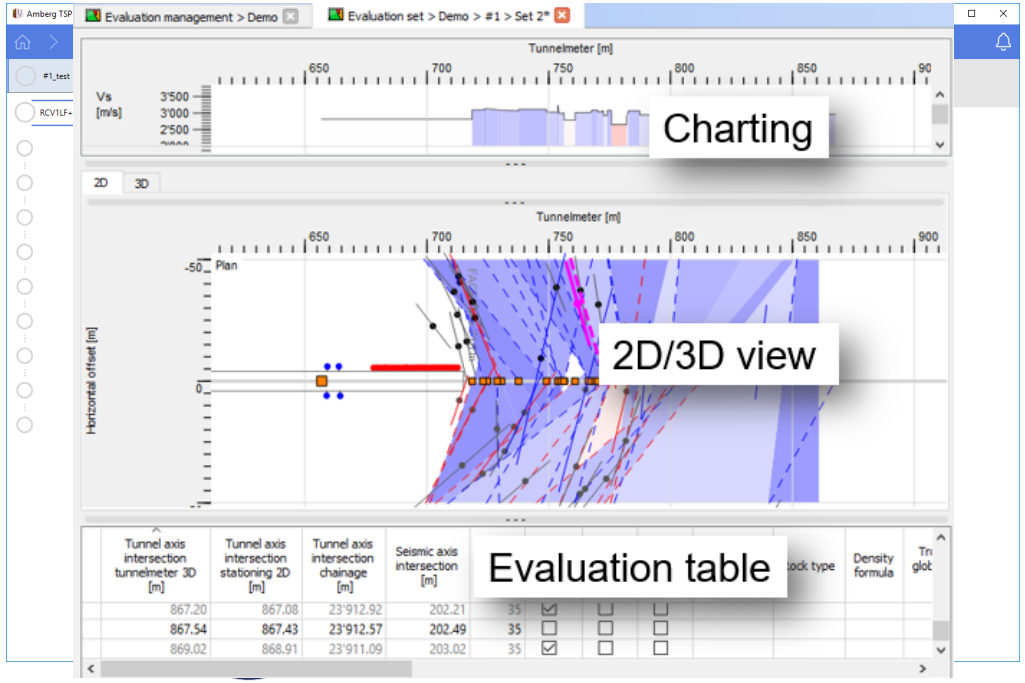
Overview TSP data processing steps

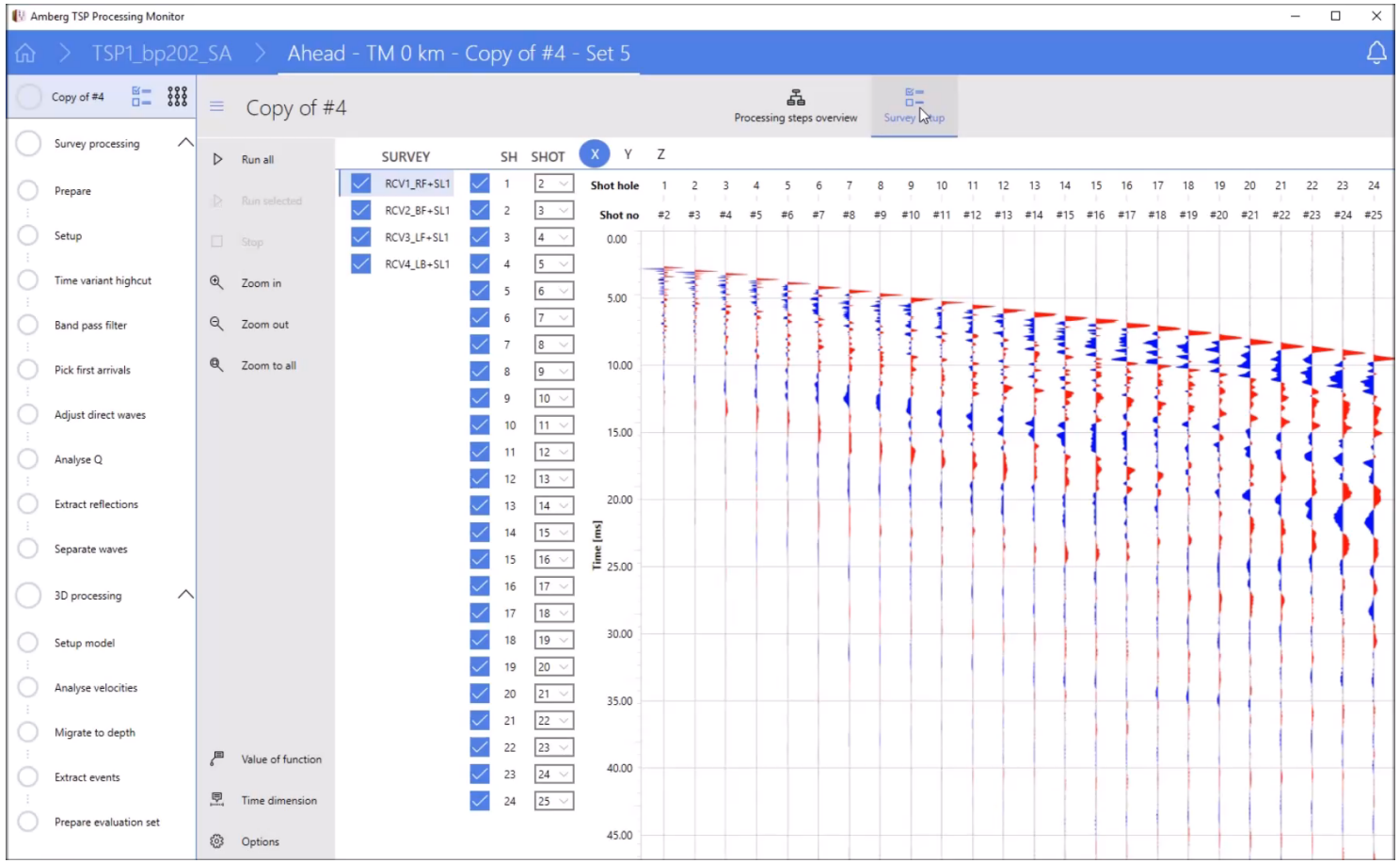
- Seismic data QC (office)
- Edit tunnel and seismic layout geometry
- Survey processing (trace processing)
- 3D processing (seismic modelling)
- Results evaluation





TSP survey processing

- Data preparation
- Filtering
- FAP, direct wave velocities (P&S)
- Event extraction
- Polatisation analysis



TSP survey processing

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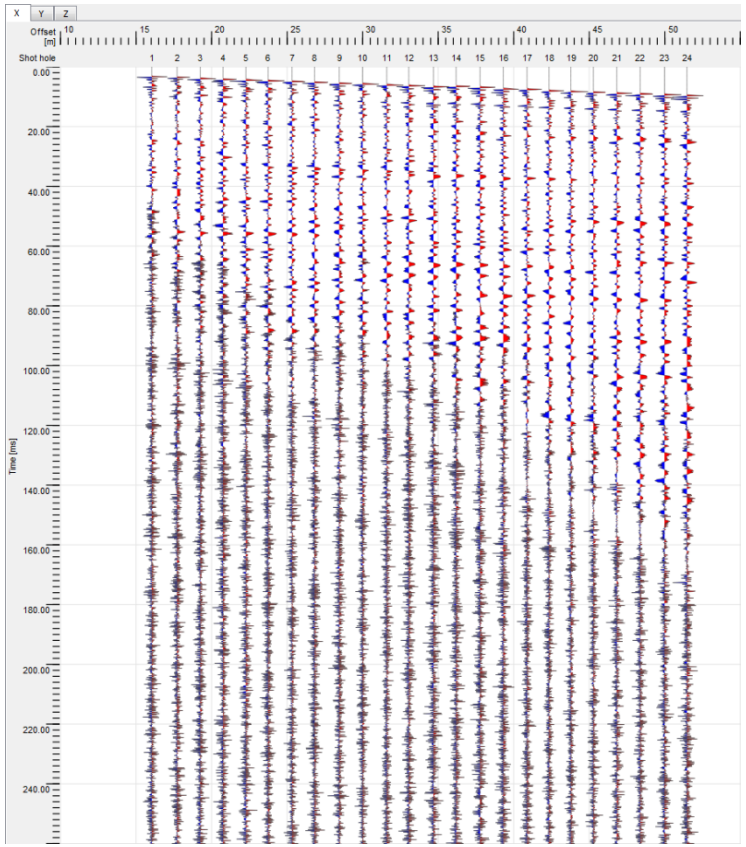
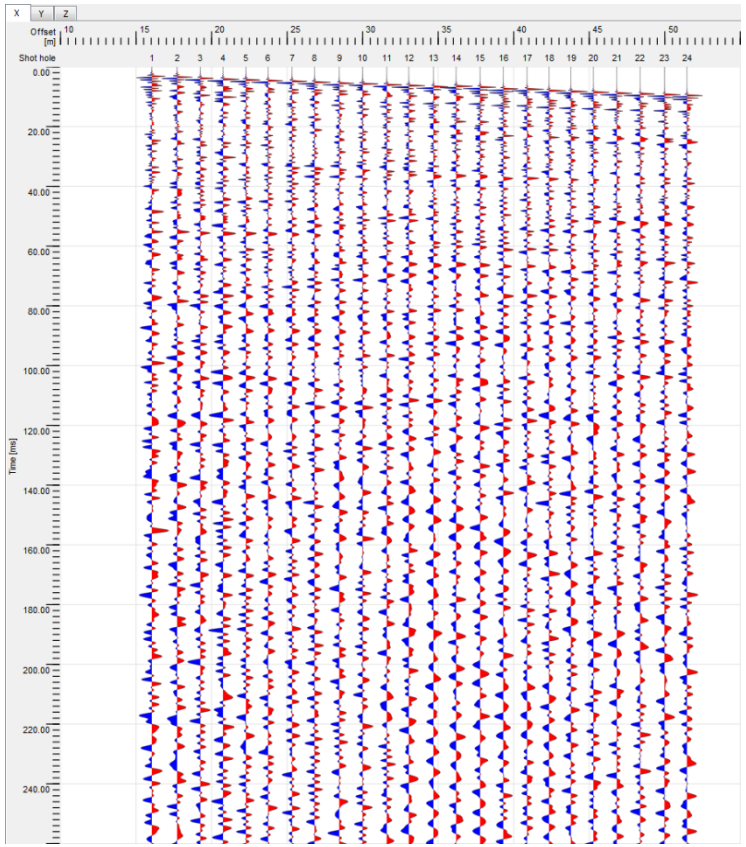
- Polatisation analysis

Raw data



Filtered data



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AMBERG TECHNOLOGIES

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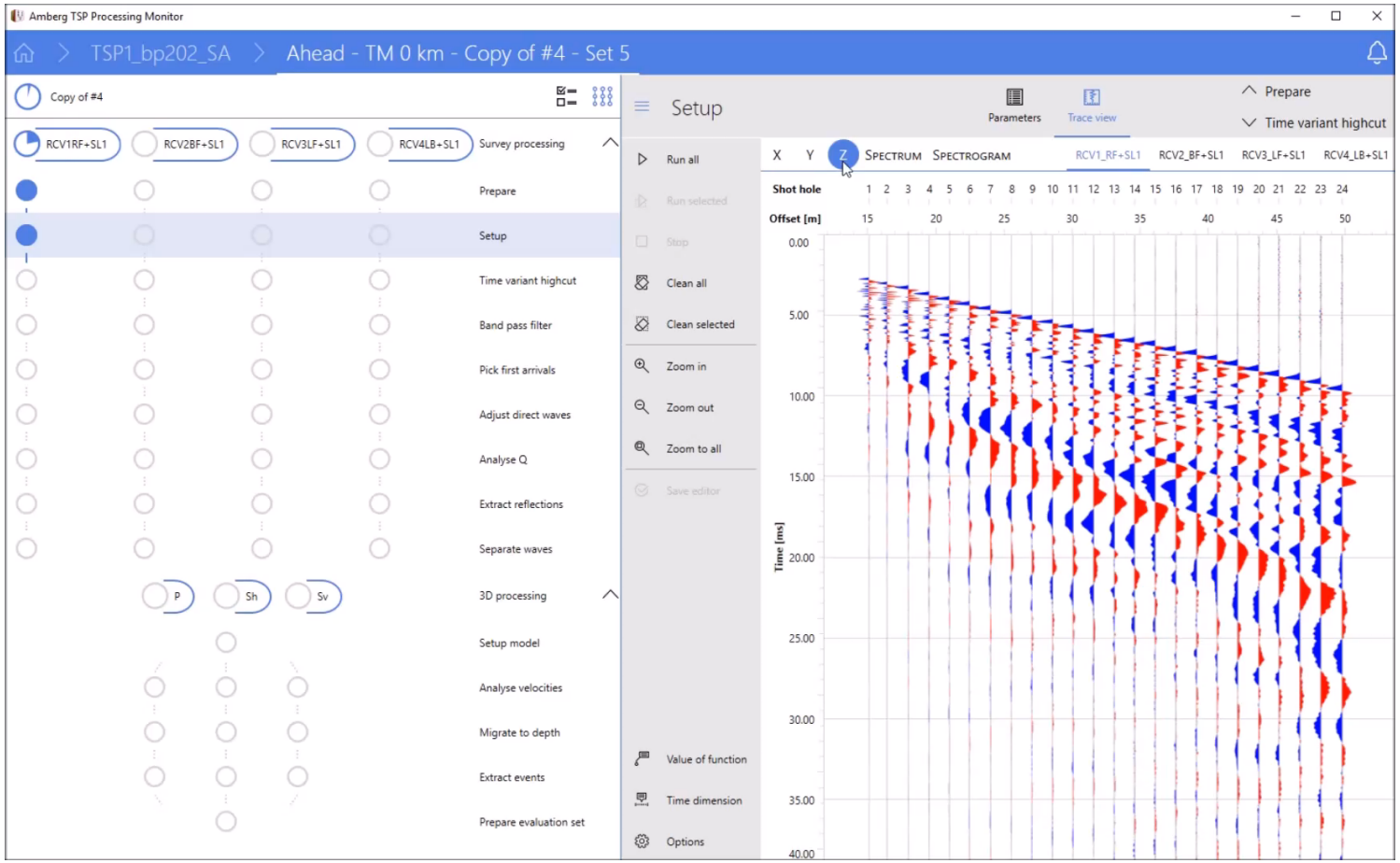

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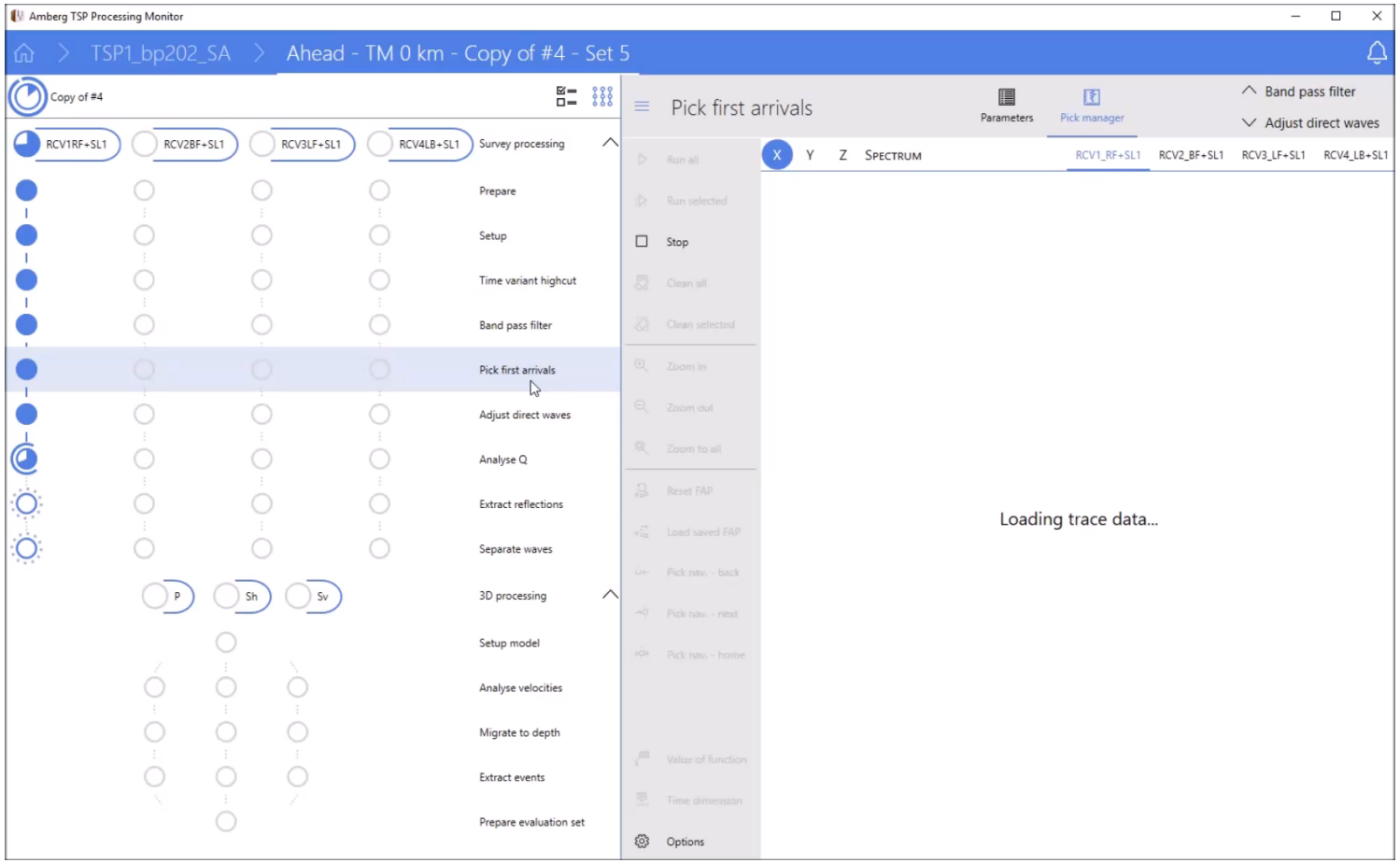

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AMBERG TECHNOLOGIES

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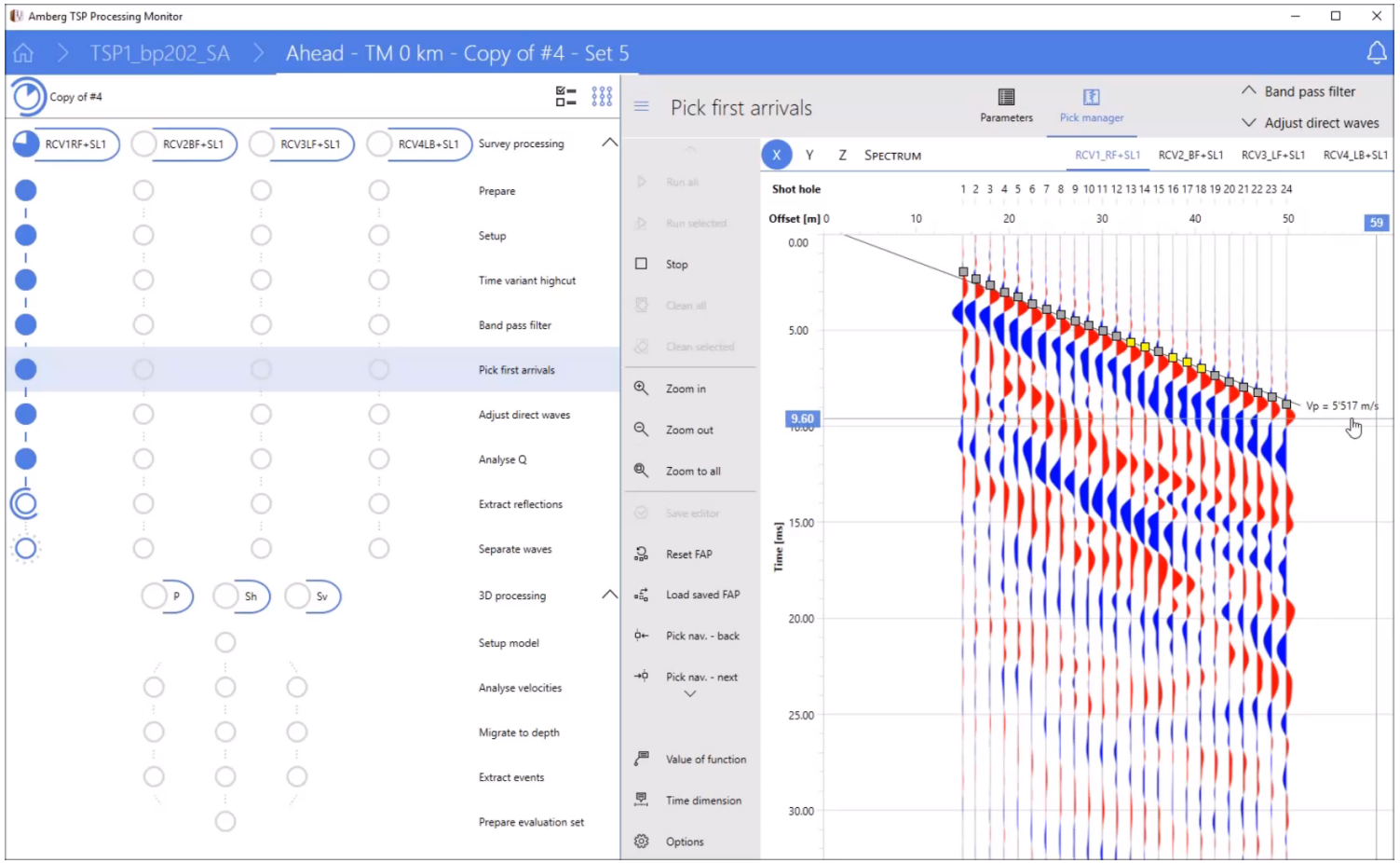

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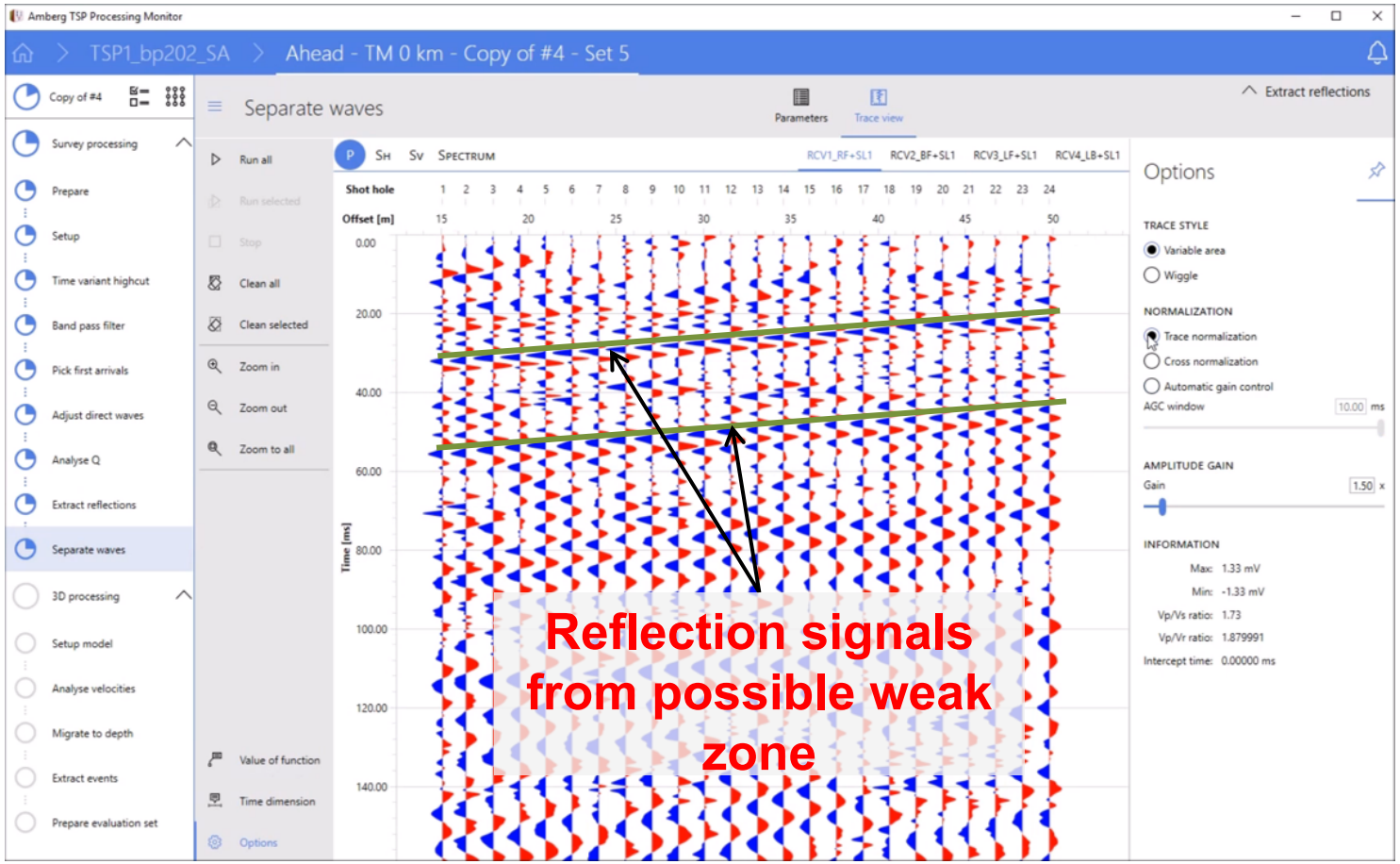
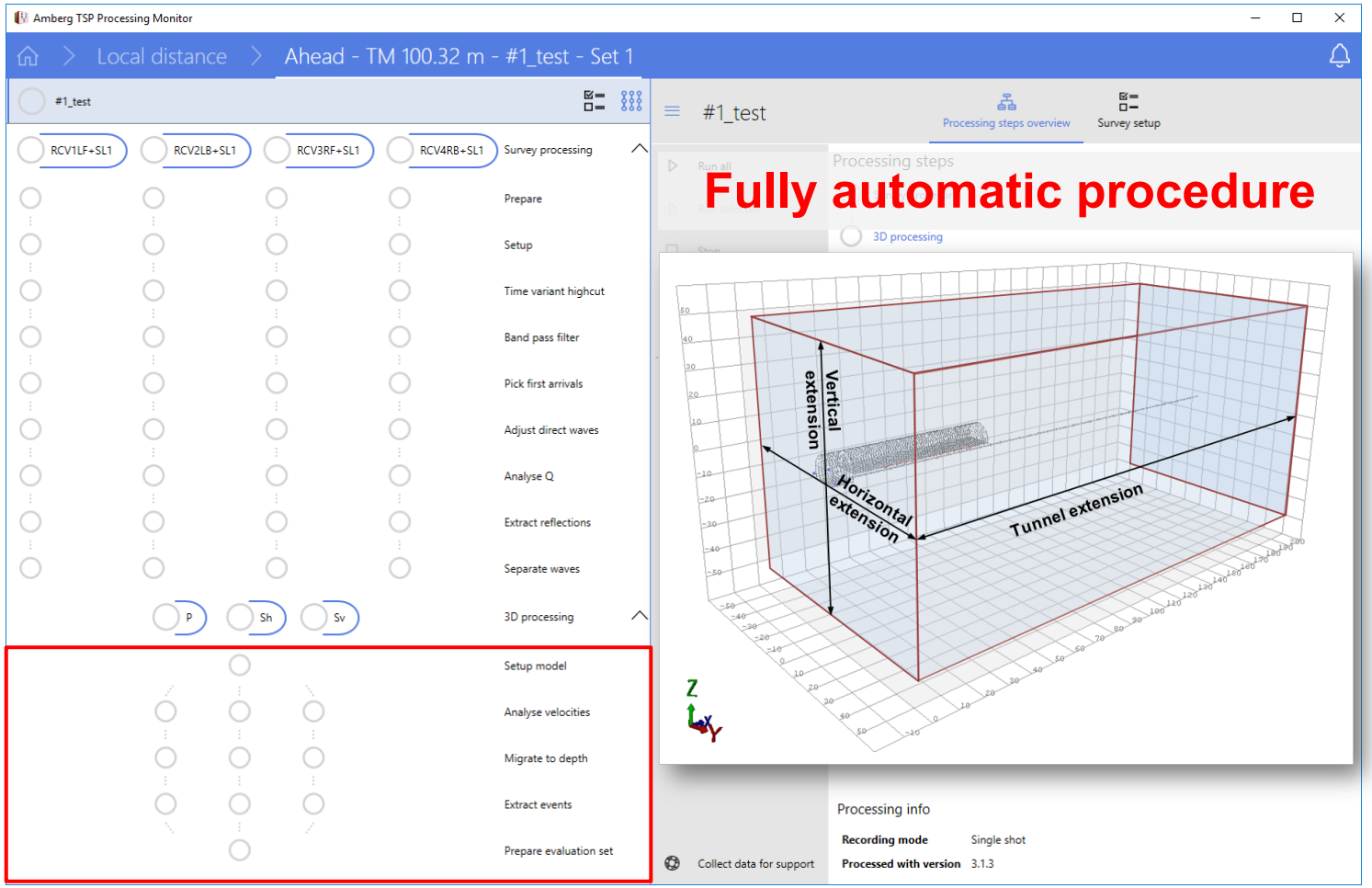


TSP 3D processing (migration & seismic modelling)

- Velocity analysis
- Seismic migration
- Reflector extractor



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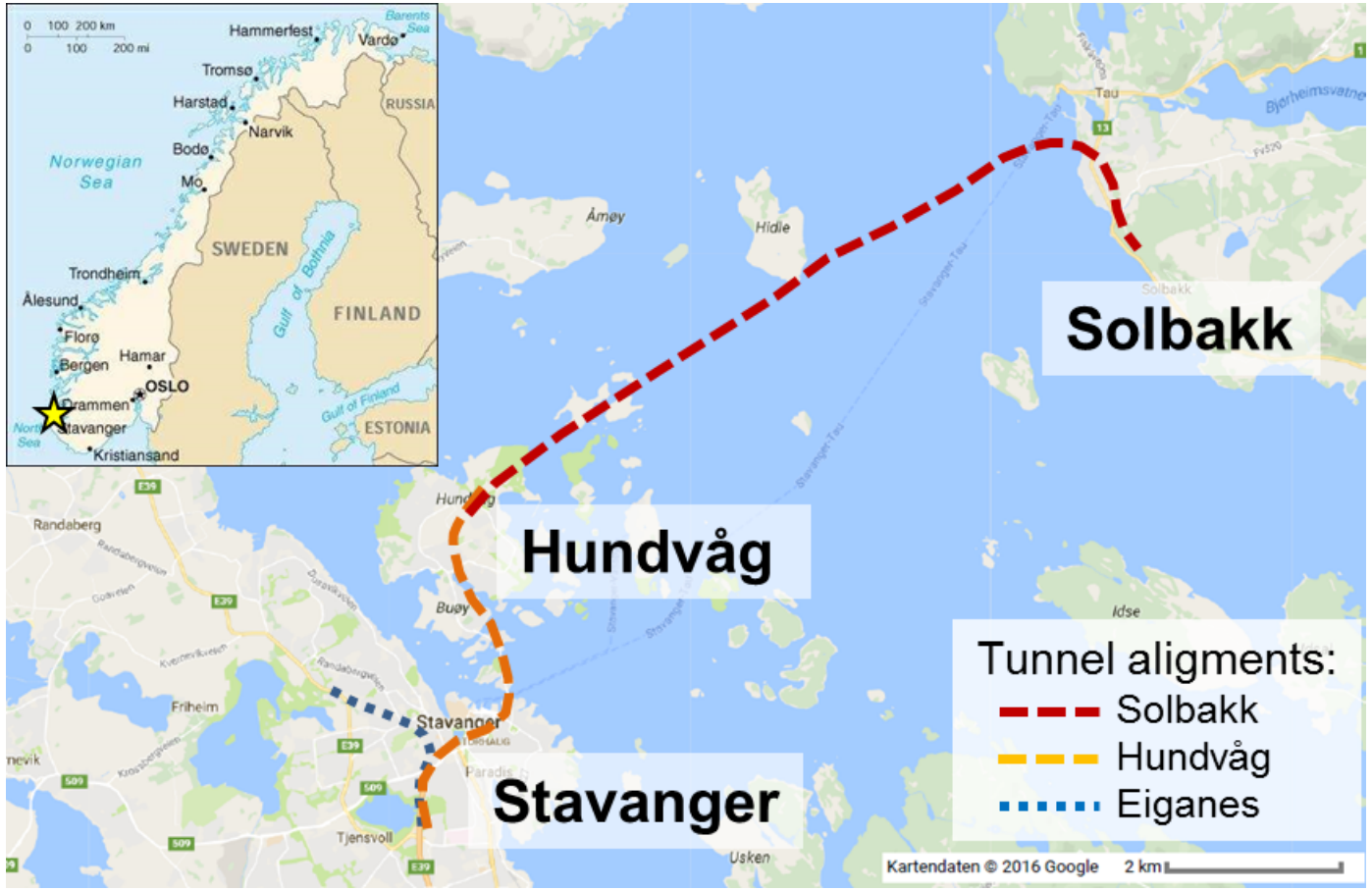
TSP Results – Case study

The Ryfast Project

Mission target: Test TSP capabilities in subsea tunnel/low overburden

- Two subsea road twin-tube tunnels and a city tunnel
- Length:
  - Solbakk, 14.3 km
  - Hundvåg, 5.5 km
  - Eiganes, 3.7 km
- D&B
- Contractors:
  Kruse Smith/Risa



Tunnel seismic investigations in the Hundvåg tunnel

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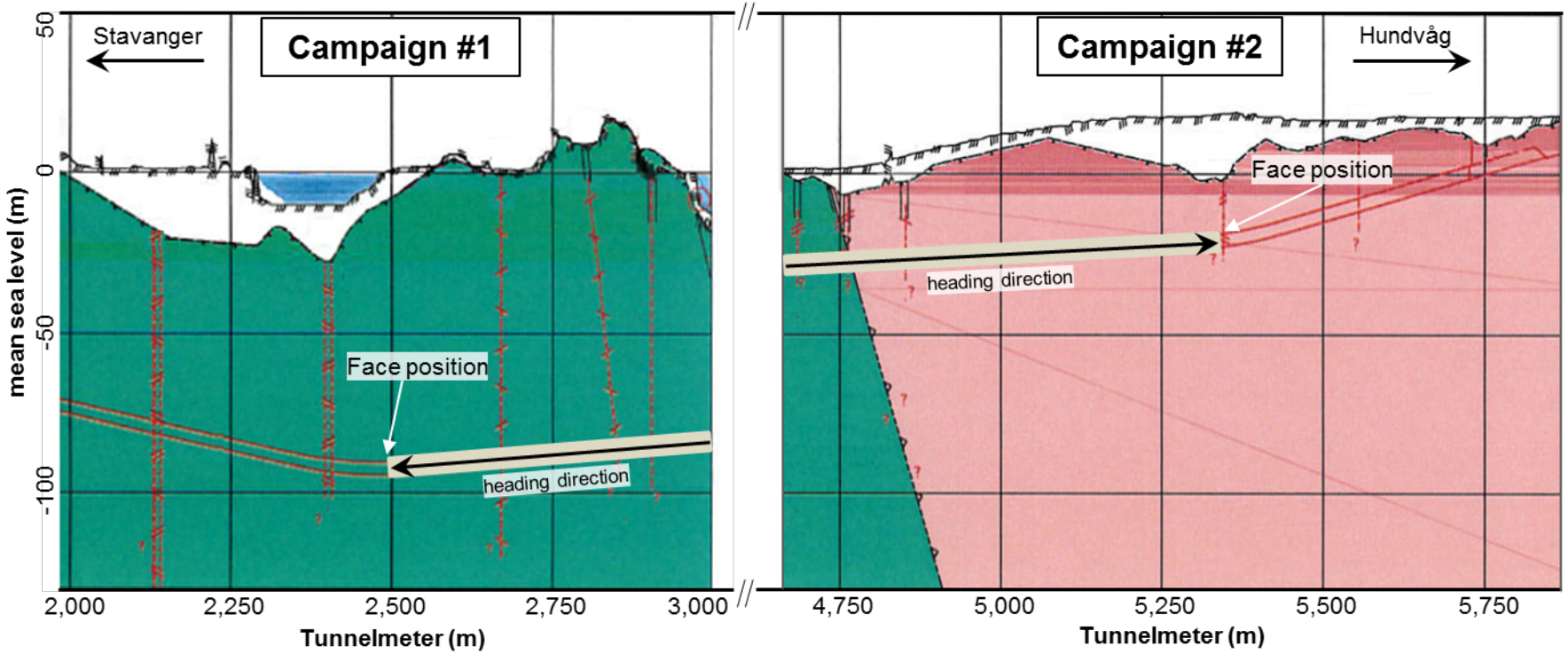
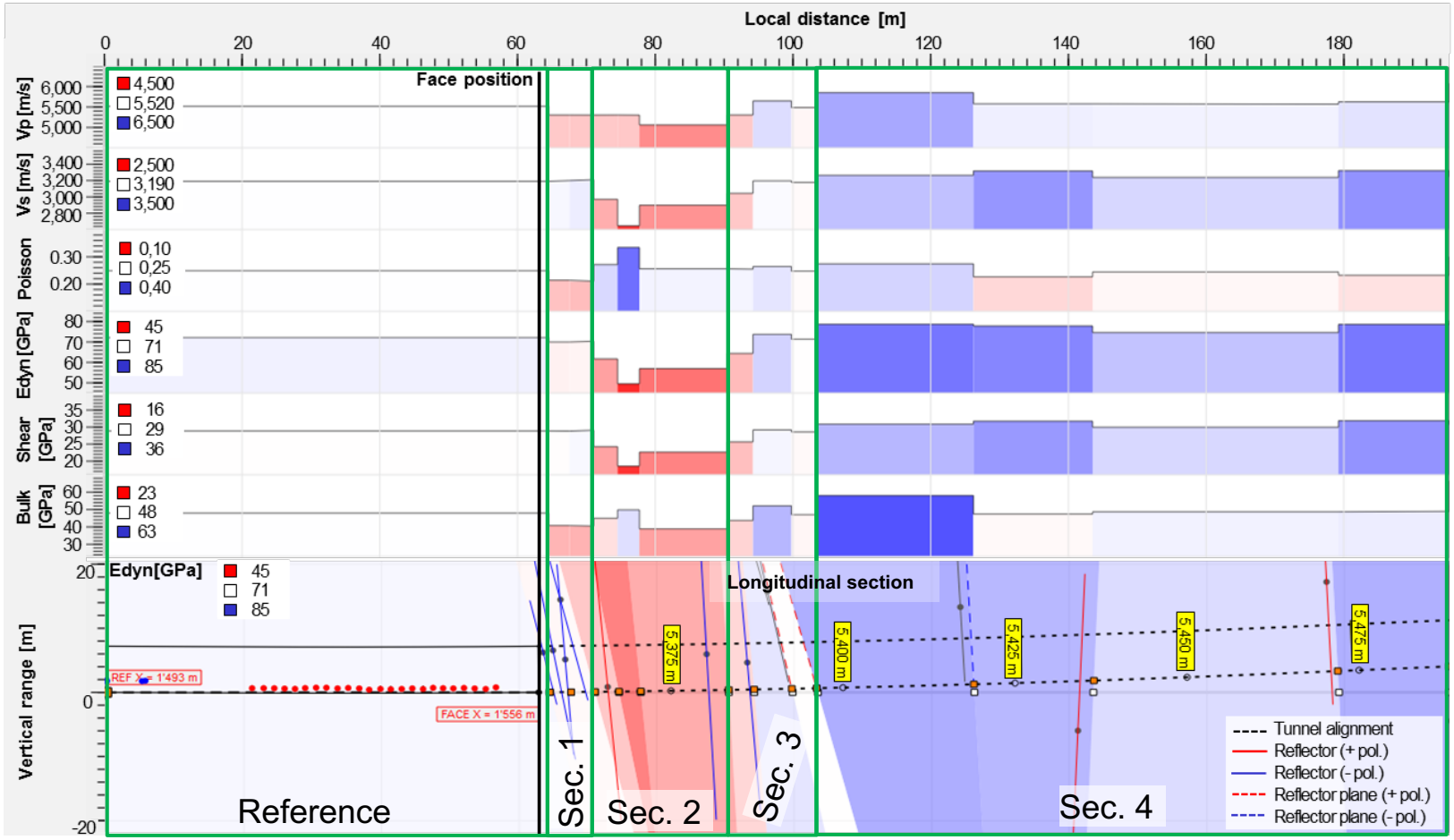
Geological model and location of the TSP campaigns



Legend:

- Phyllite of the Lower Nappe Sheet
- Gneiss, Boknafjorden Nappe Complex
- I, assumed weakness zone, somewhat inferior quality
- II, assumed weakness zone, inferior quality
- III, assumed weakness zone, poor quality
- IV, assumed weakness zone, very poor

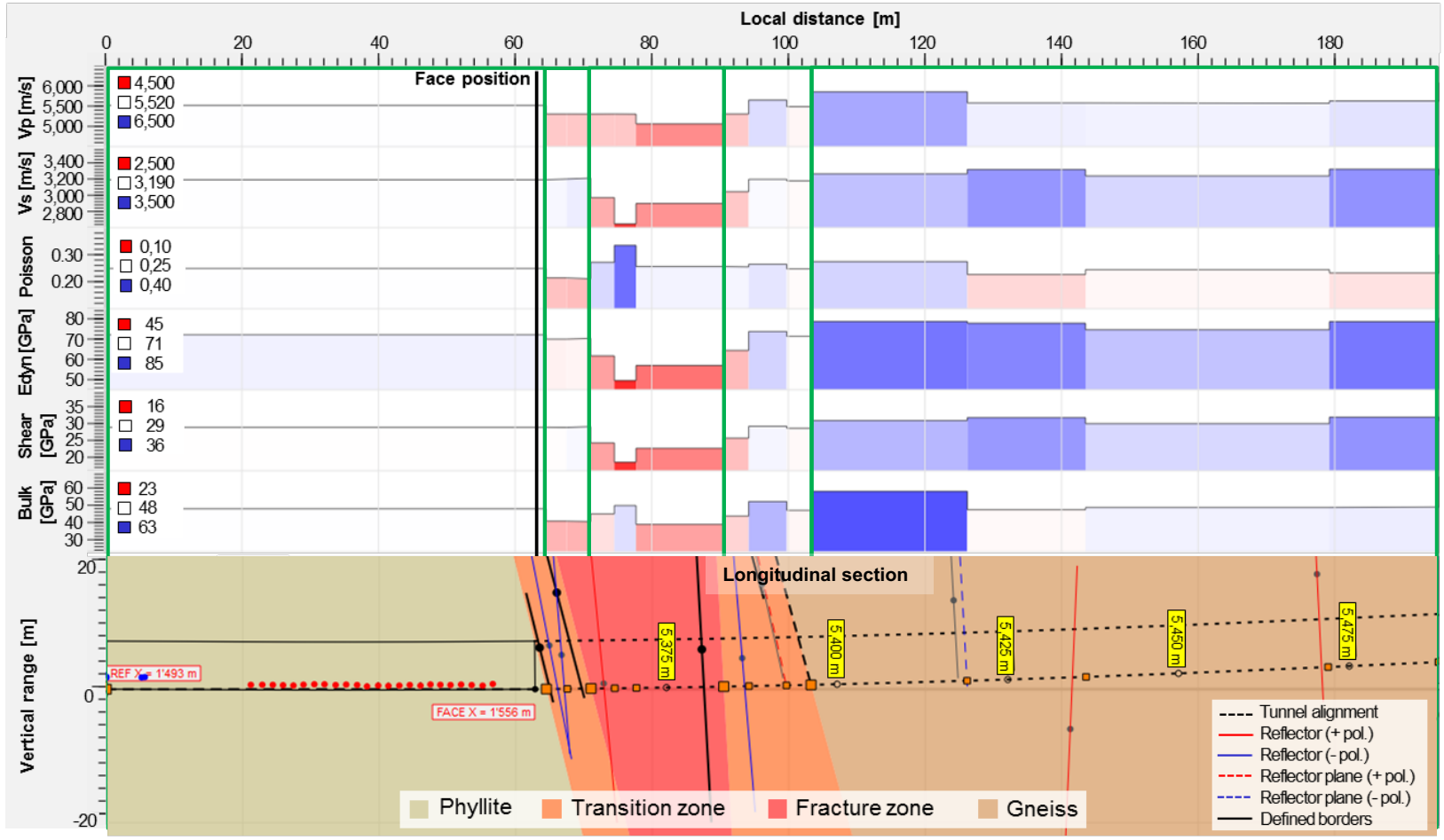
TSP results campaign #2



Rock stiffness ----------

\- -- + ++

TSP results campaign #2

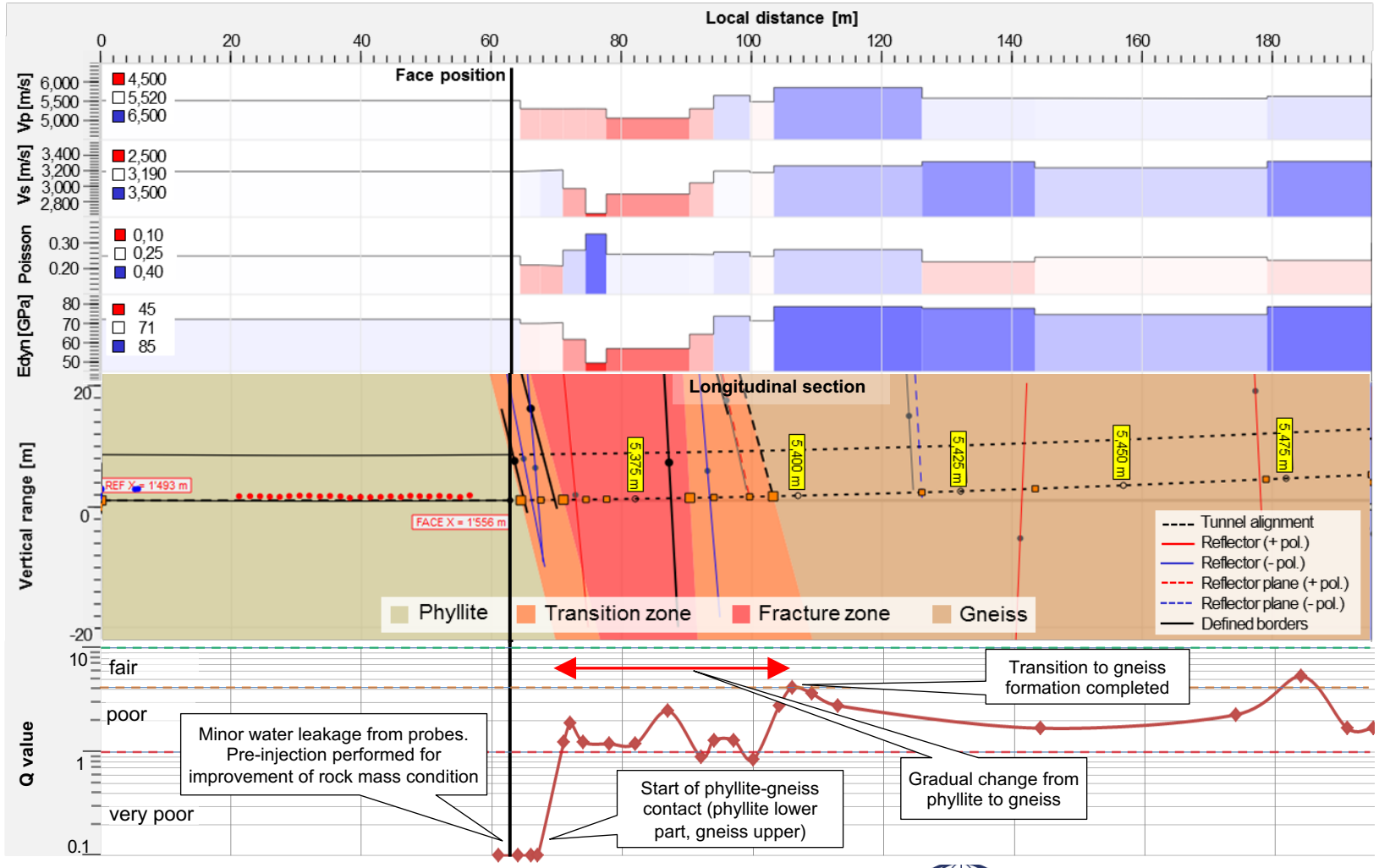


Rock stiffness ----------

\+ ++

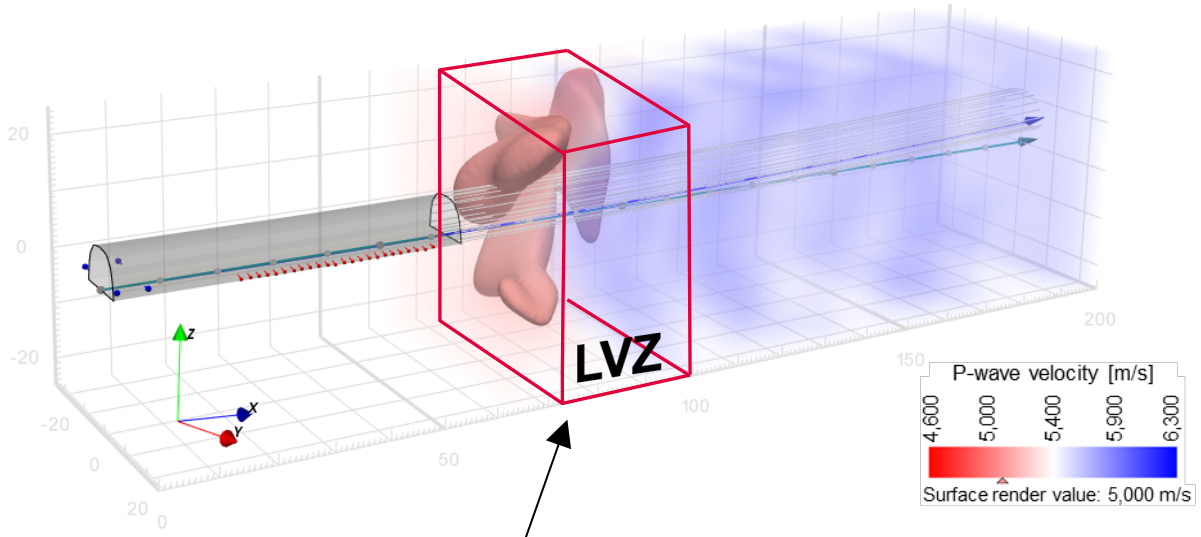
\- --

TSP results vs geological findings after excavation

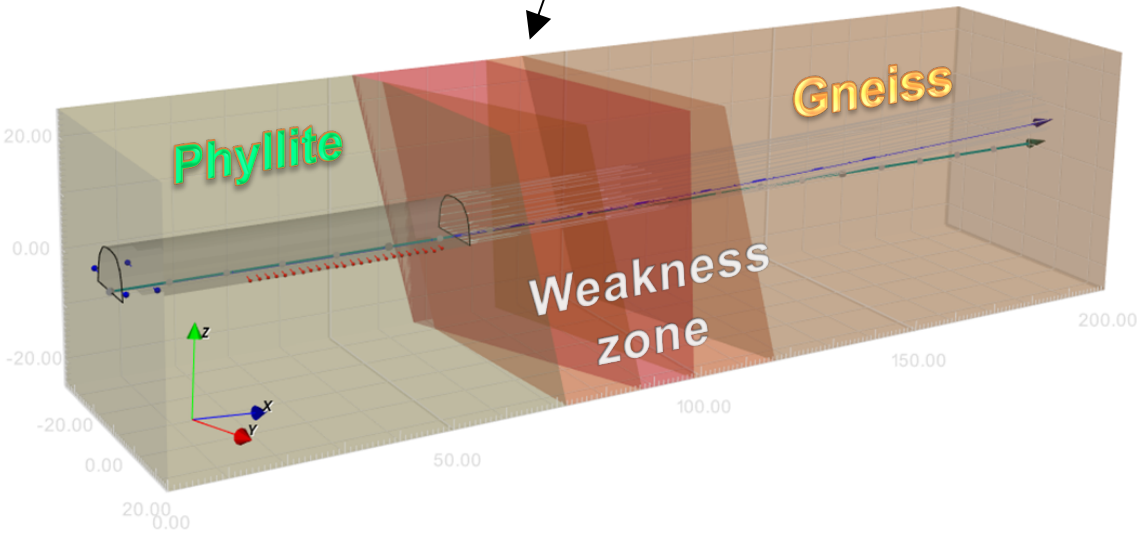


Results 3D models – Campaign #2

P-wave velocity distribution

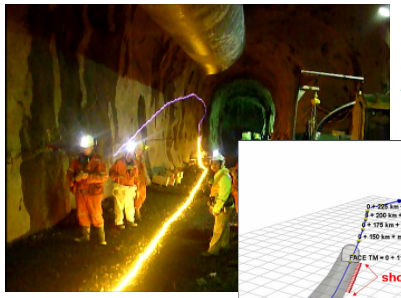


Geological model

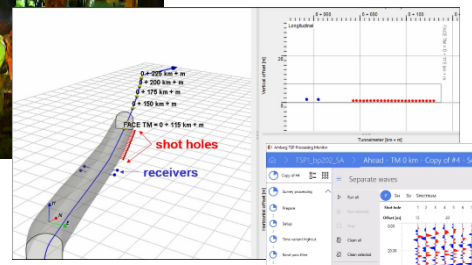


ERG LOGIES

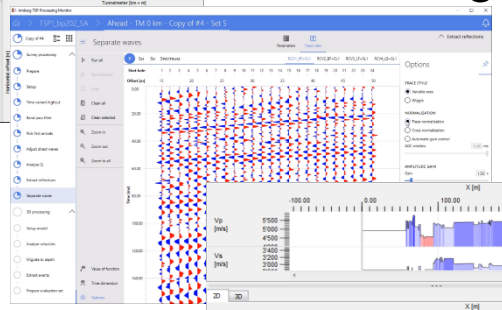
Major steps for a successful TSP evaluation



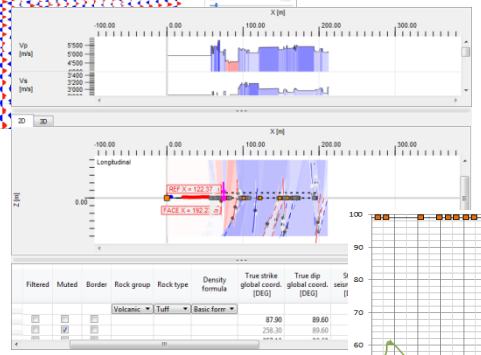
✓ Data acquisition



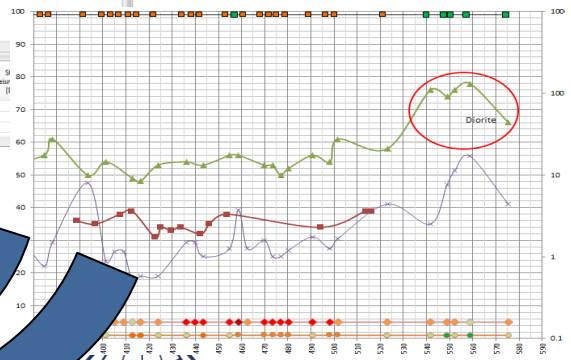
✓ Model geometry



✓ Data processig



✓ Results interpretation



✓ Validation

Conclusions

- Sesimic methods should be used in both pre- and construction phases in tunneling works.
- Results should be carefully validated
- Seismic results generally correlates very well with geological findings and rock mass classification after excavation.
- Such techniques are complementary to traditional probe drill

… tunnelling, not necessarily a risky job !

Mathematical relations of elastic parameters

Poisson’s ratio:

$$\frac{Vp^2 - 2Vs^2}{2(Vp^2 - Vs^2)}$$

Dyn. Young’s Modulus:

$$\rho Vs^2 \left(\frac{3Vp^2 - 4Vs^2}{Vp^2 - Vs^2} \right)$$

Dyn. Shear Modulus:

$$\rho Vs^2$$

Dyn. Bulk Modulus:

$$\rho Vp^2$$

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