A field test of 3D reflection orientation analysis along a 2D crooked line in northern Finland supplemented with additional cross-spreads

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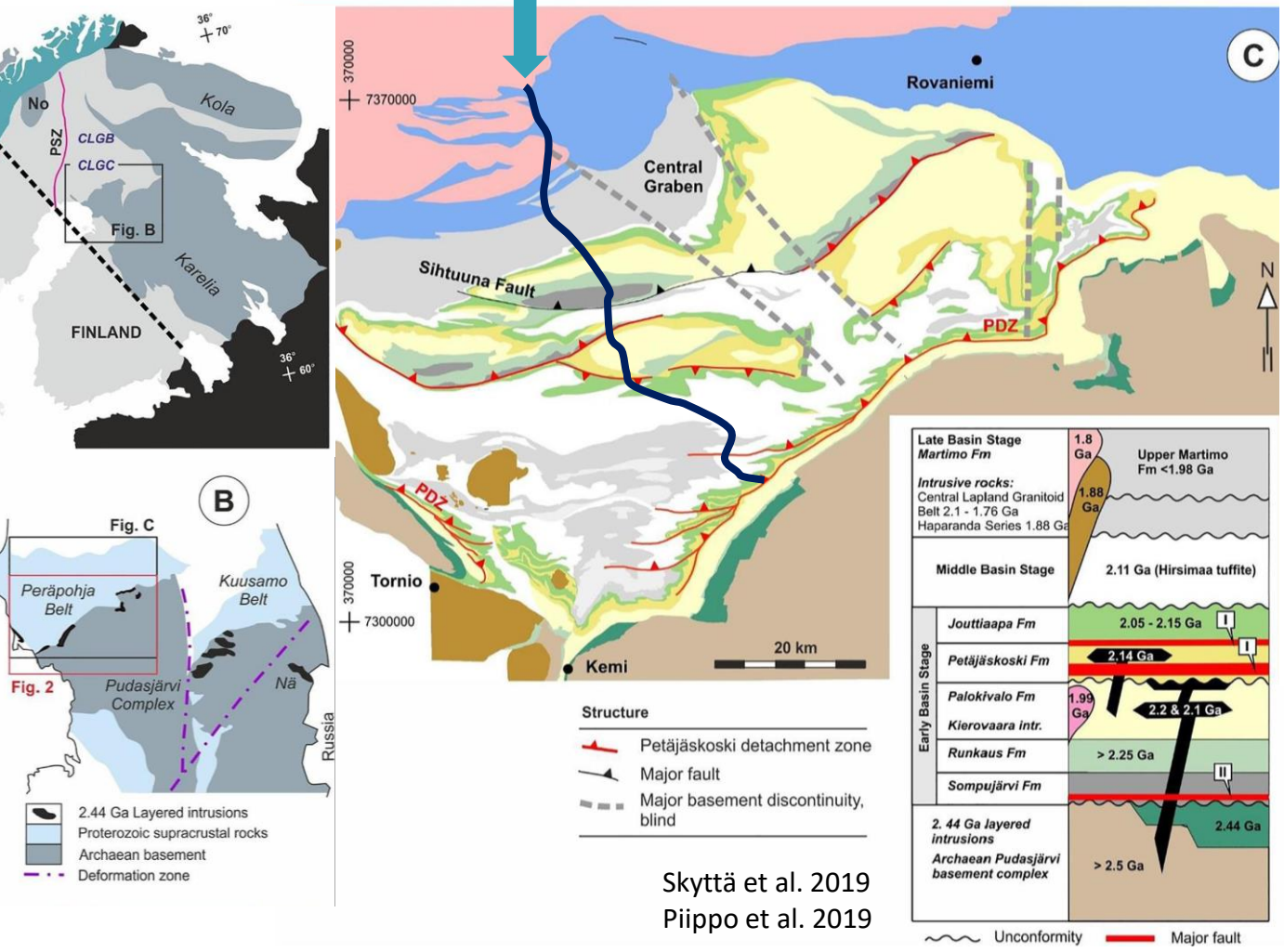
REPower-CEST project

- Clean Energy System Transition (REPower-CEST) project aims at studying energy system transition in Finland towards 2035 and beyond, including critical raw materials
- GTK is responsible for the work package on Critical Raw Materials
- “National exploration concept & bedrock research” task addresses obligations related to CRMA, including new regional geophysical data acquisition
- Peräpohja belt selected as a study area for its mineral potential

Funded by the European Union
NextGenerationEU

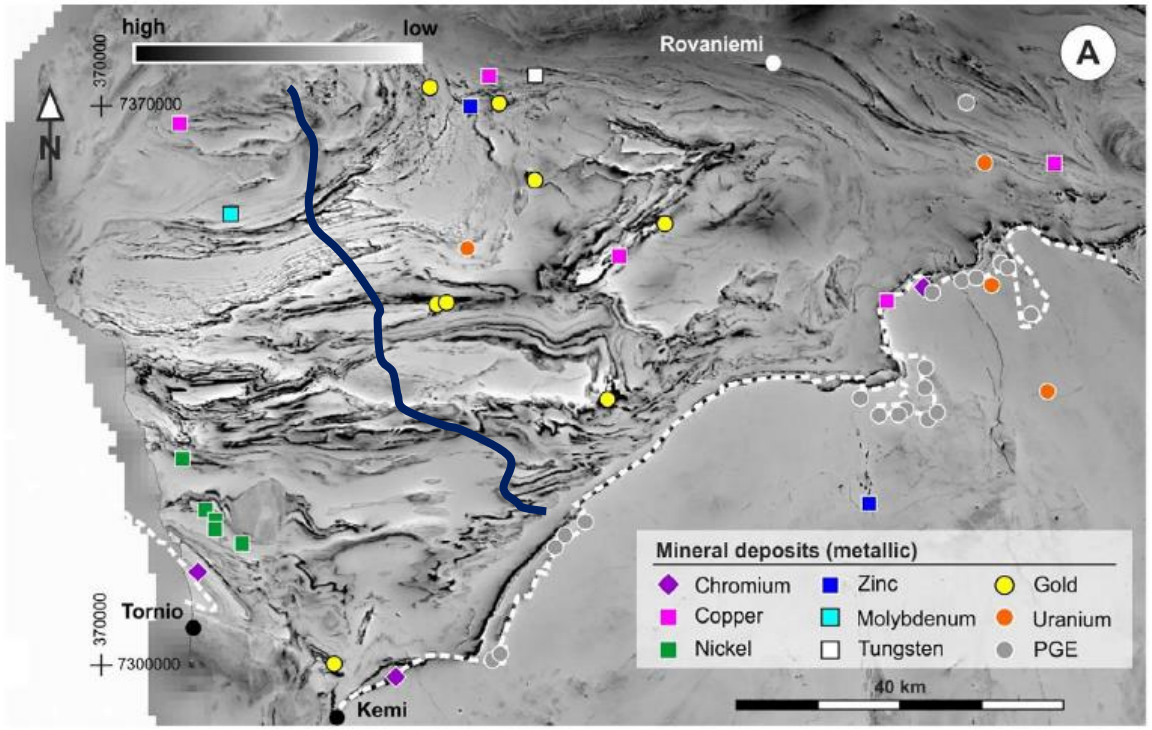
Geological background

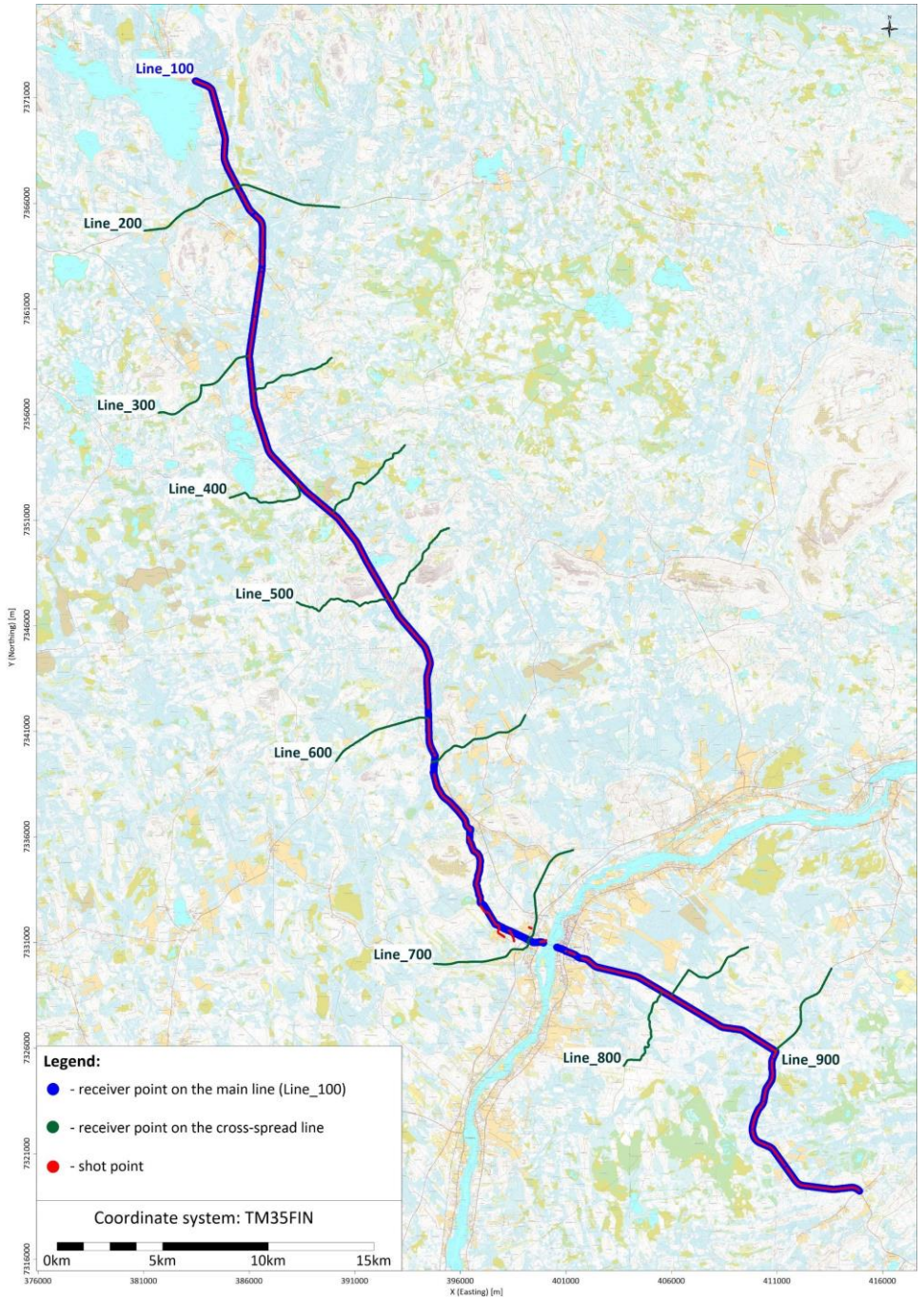
REPower seismic profile



Skyttä et al. 2019
Piippo et al. 2019

Magnetic anomaly map





Data acquisition

- 70-km long central profile with 8 cross-spreads (5 km arm length) to increase azimuthal coverage for reflection orientation analysis
- Acquisition between Sept 2 – Sept 21, 2024
- 12 days production with > 350 VPs/day

Acquisition parameters (1)

Photo credit M. Cyz

- Receivers: nimble nodes (Strydes) with piezo-electric sensors
- Receiver spacing = 5 m (central profile) or 25 m (cross-spreads)
- Nominal spread with 3000 live channels (6500 m offset)
- Total number of RPs: 17057

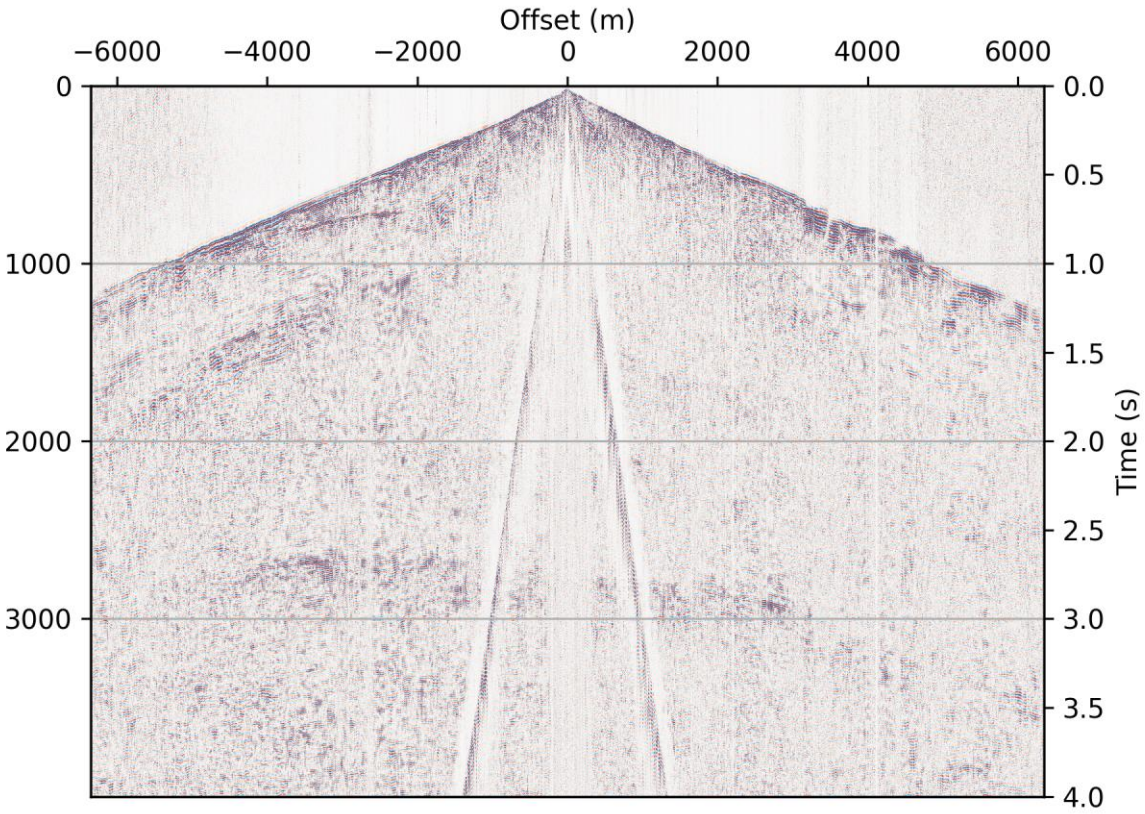
Acquisition parameters (2)

Photo credit M. Cyz

- Source: HEMI-60 Vibroseis truck (61,000 lbf peak force)
- VP spacing = 25 m (12.5 for recovery)
- Sweep parameter: 2-4 x 40 s, 10-150 Hz linear, 75% force (nominal) + low force in some areas
- Total number of VPs: 2809

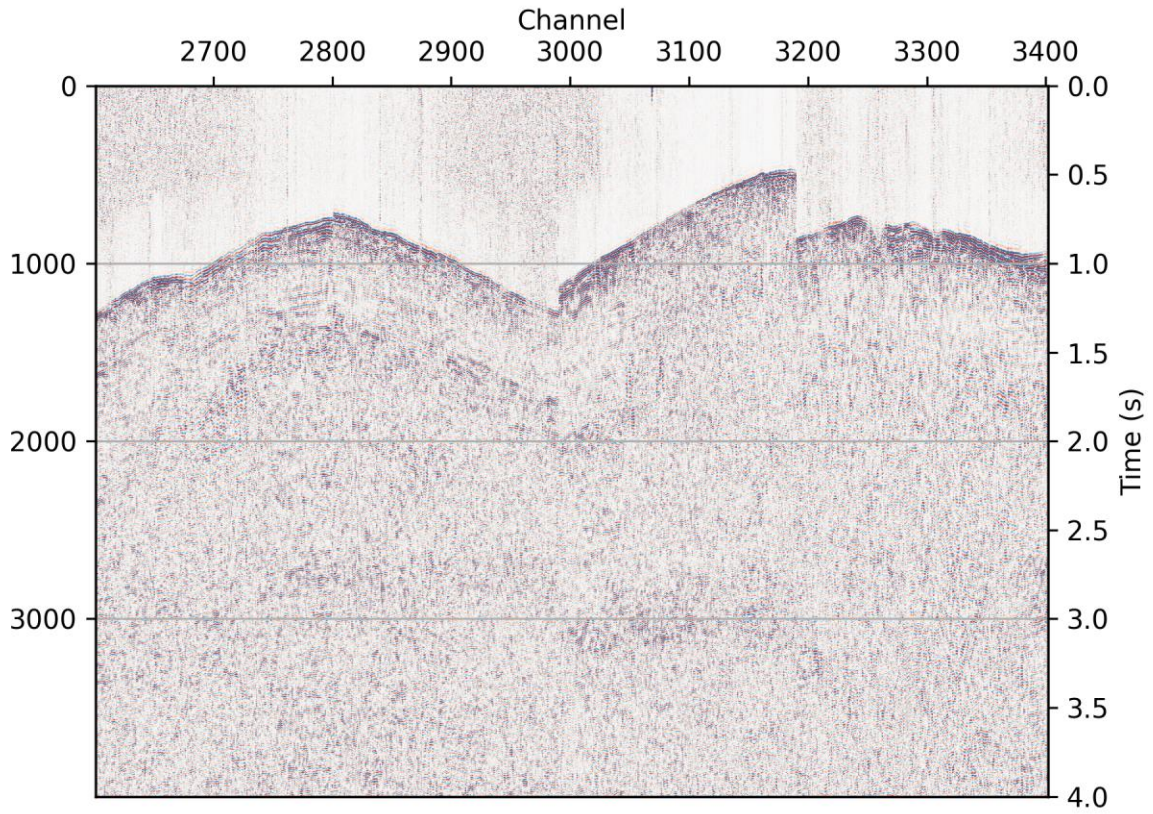
Shot gather example

Shot gather (inline, Δx=5m)



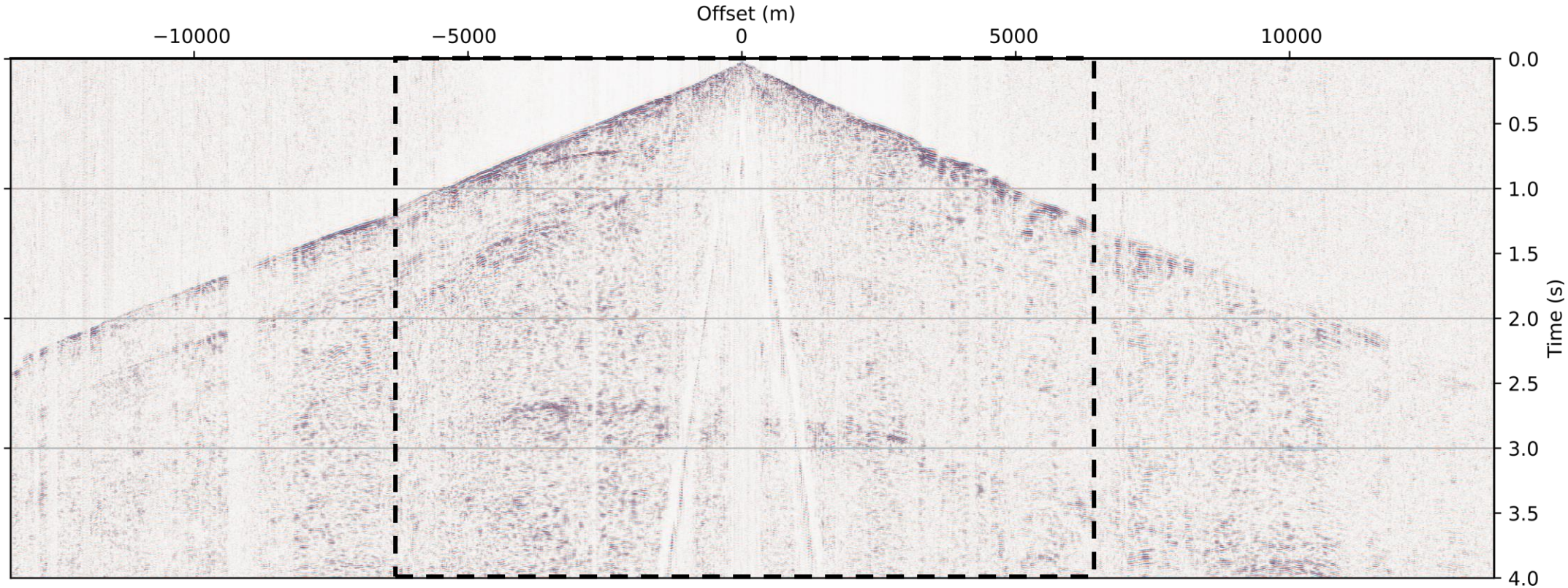
BP filter and AGC scaling applied

Shot gather (cross-spreads, Δx=25m)



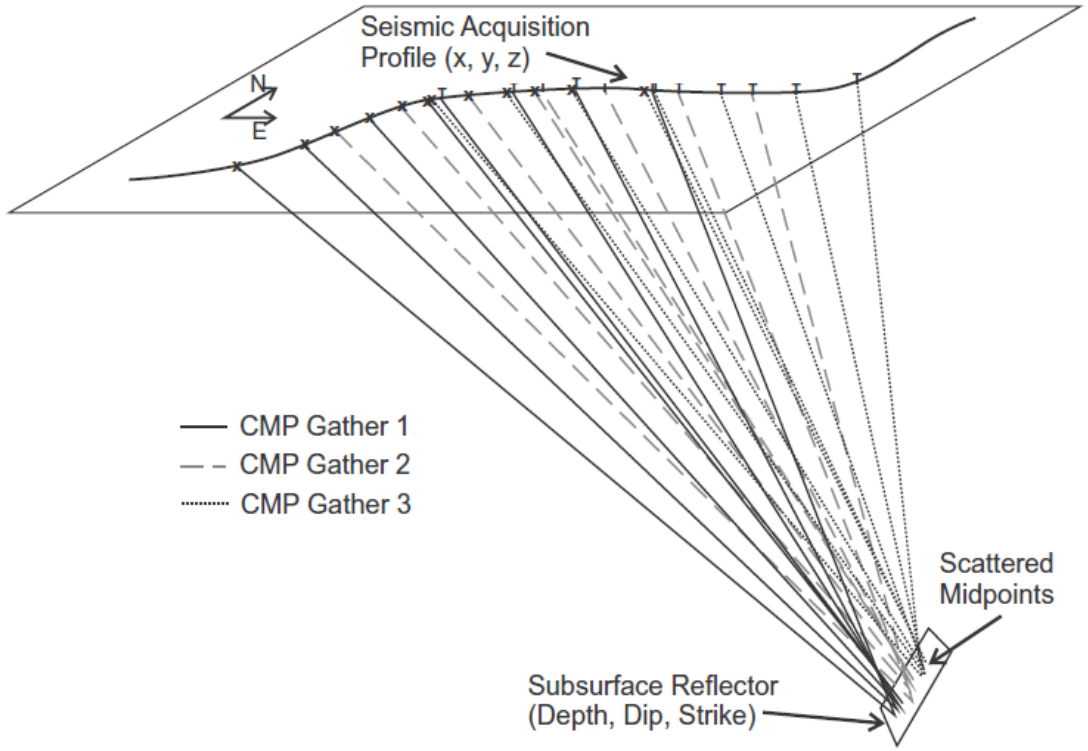
Recordings beyond the nominal spread

Shot gather (inline, Δx=5m)



BP filter and AGC scaling applied

Reflection orientation analysis



Reflection hodograph from planar reflector:

Dip Strike

$$T = \sqrt{T_0^2 + \frac{X^2\left(1-\sin^2\theta\cos^2\phi\right)}{V_{rms}^{\ 2}}}$$

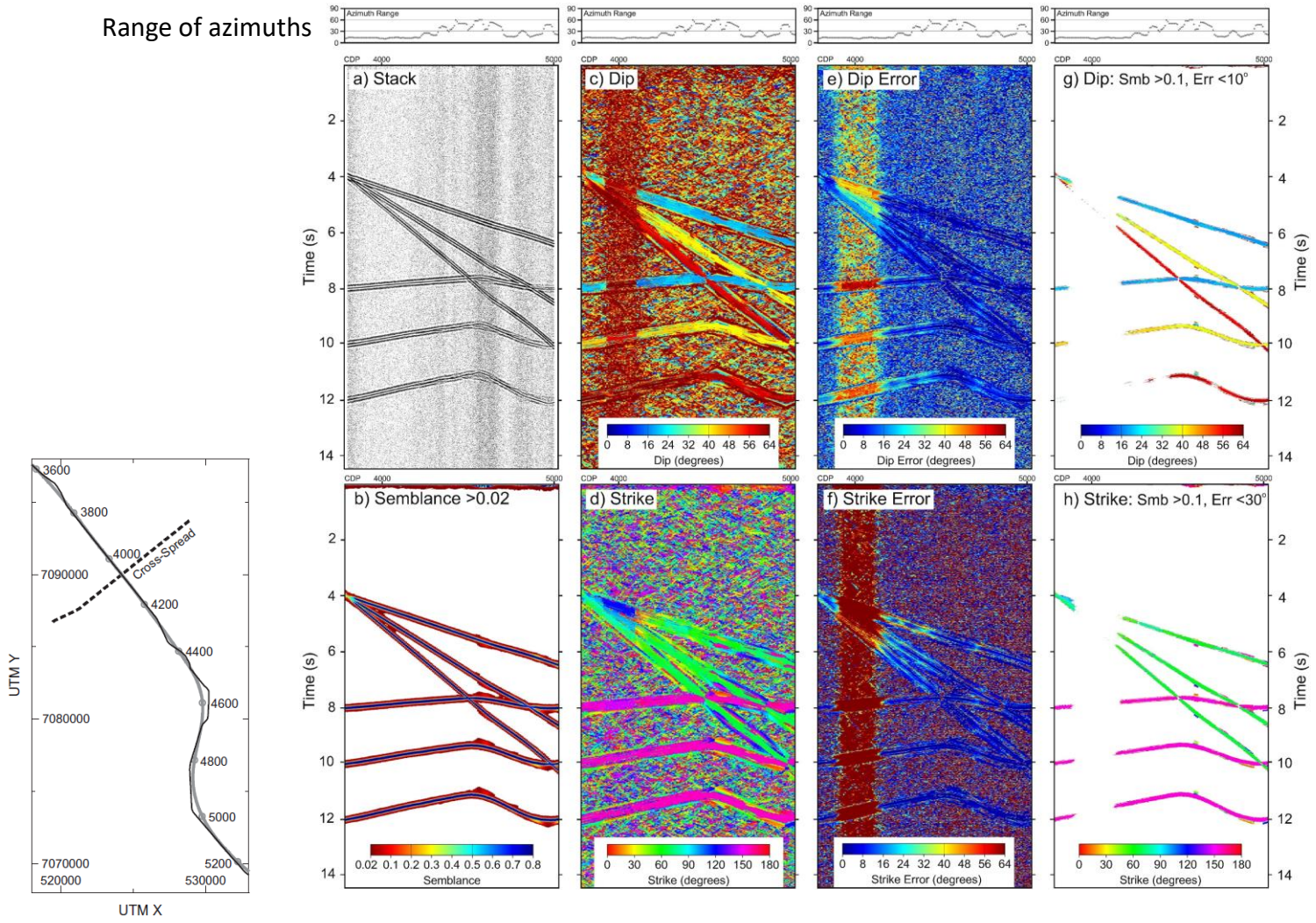
Zero-offset traveltime
(requires correction to bin center)

The reflection points are scattered over a planar reflector, allowing its orientation to be determined from the best fitting travel time curves.

Levin 1971
Bellefleur et al. 1997
Calvert, 2017

Reflection orientation analysis: no cross-spread

Range of azimuths

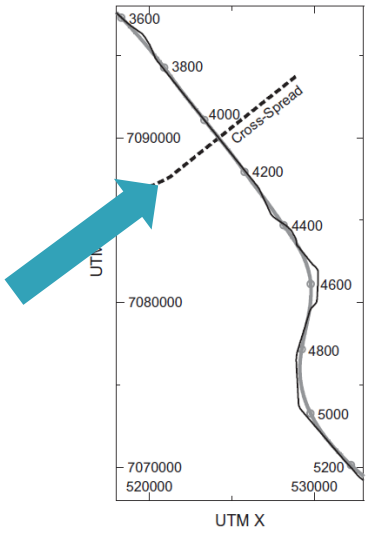


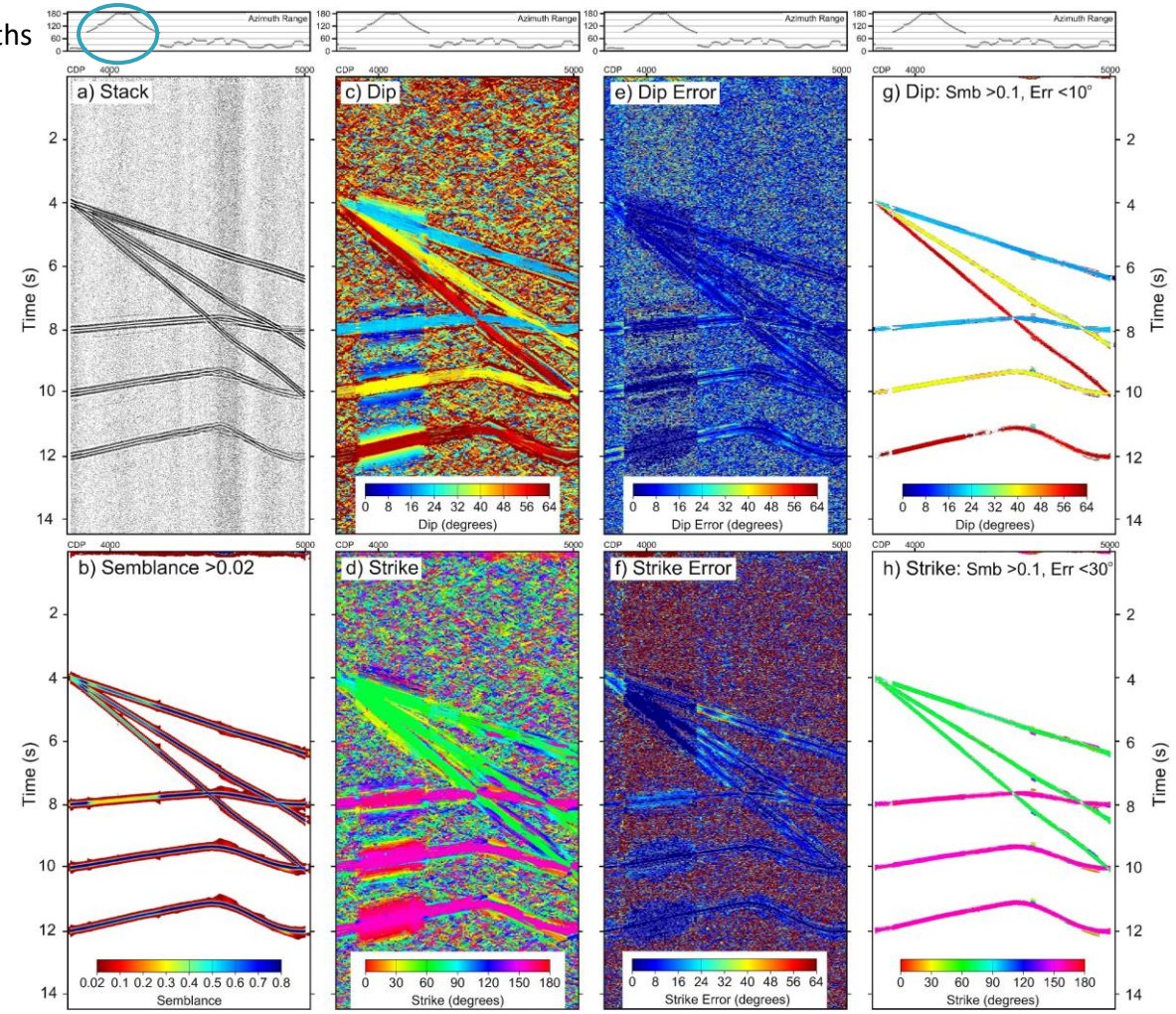
Method can fail if range of azimuths is too low (< 20°)

Calvert, 2017

Reflection orientation analysis: with cross-spread

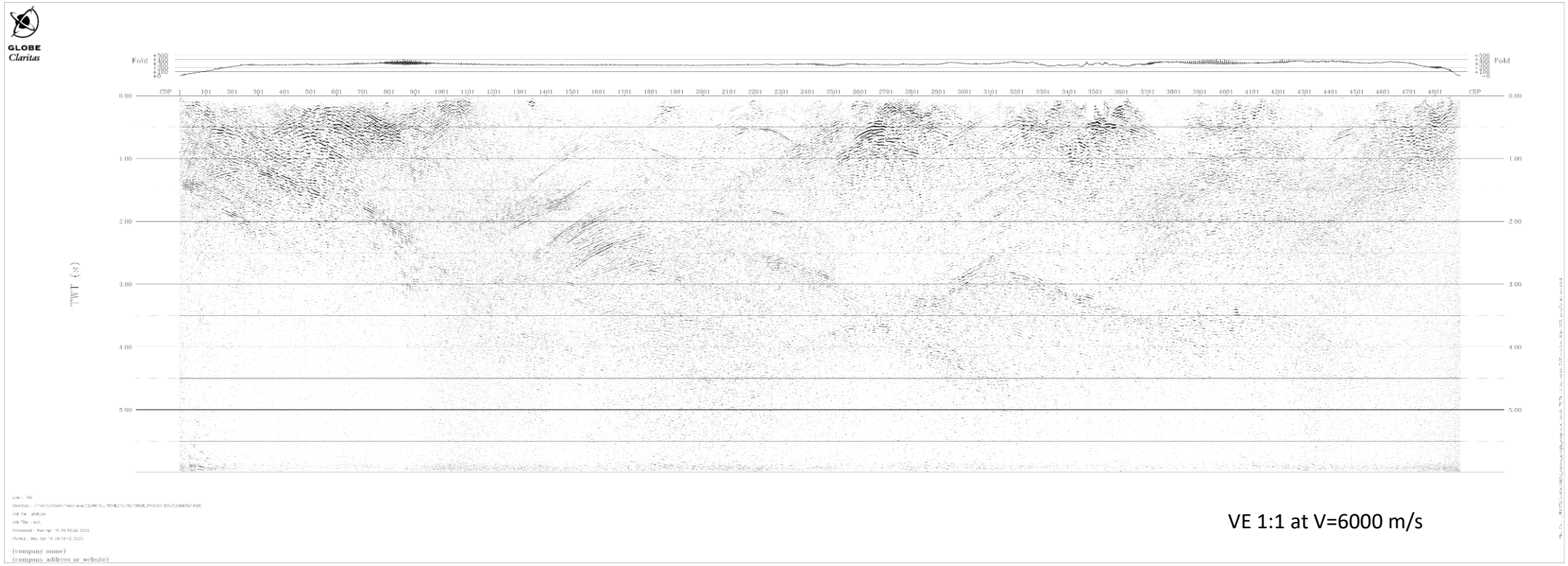
Range of azimuths





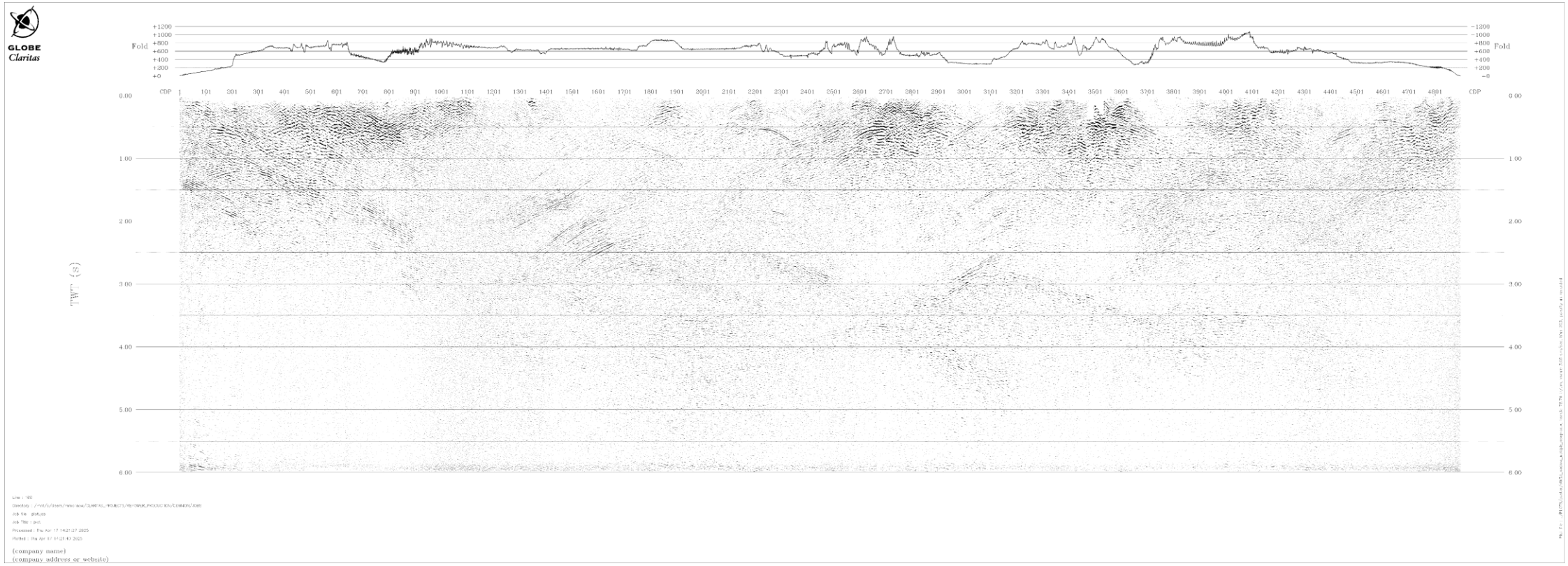
Calvert, 2017

Normal NMO stack (no cross-spreads)

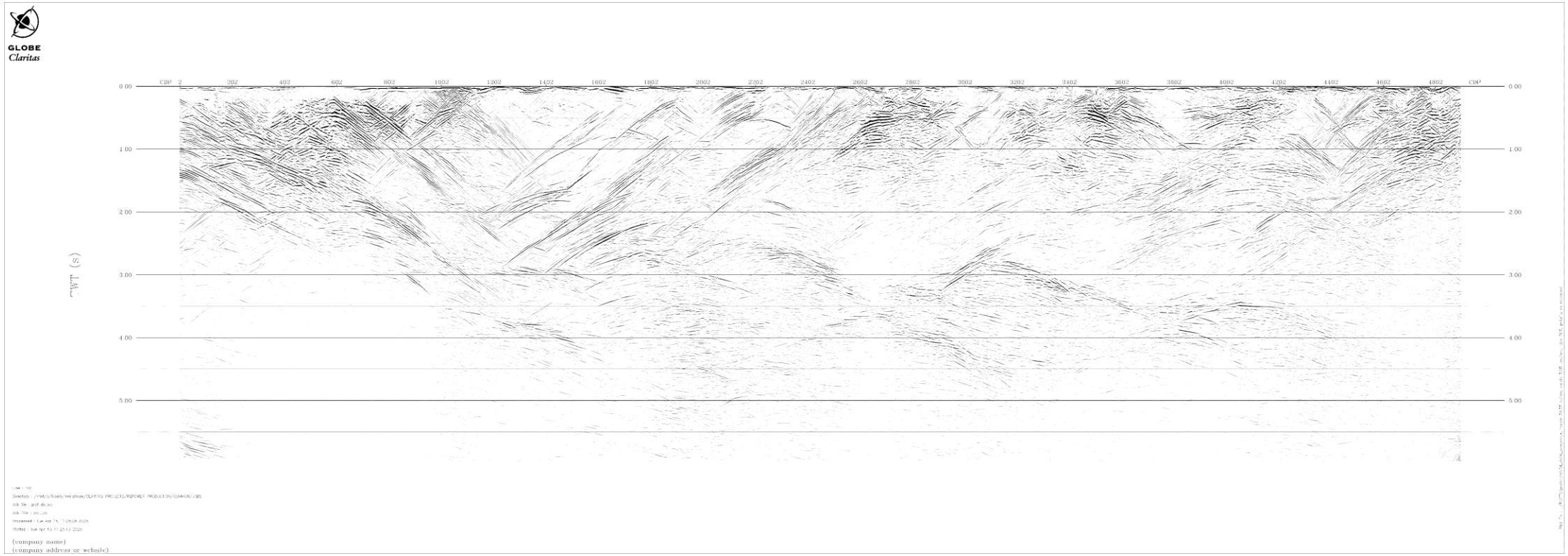


VE 1:1 at V=6000 m/s

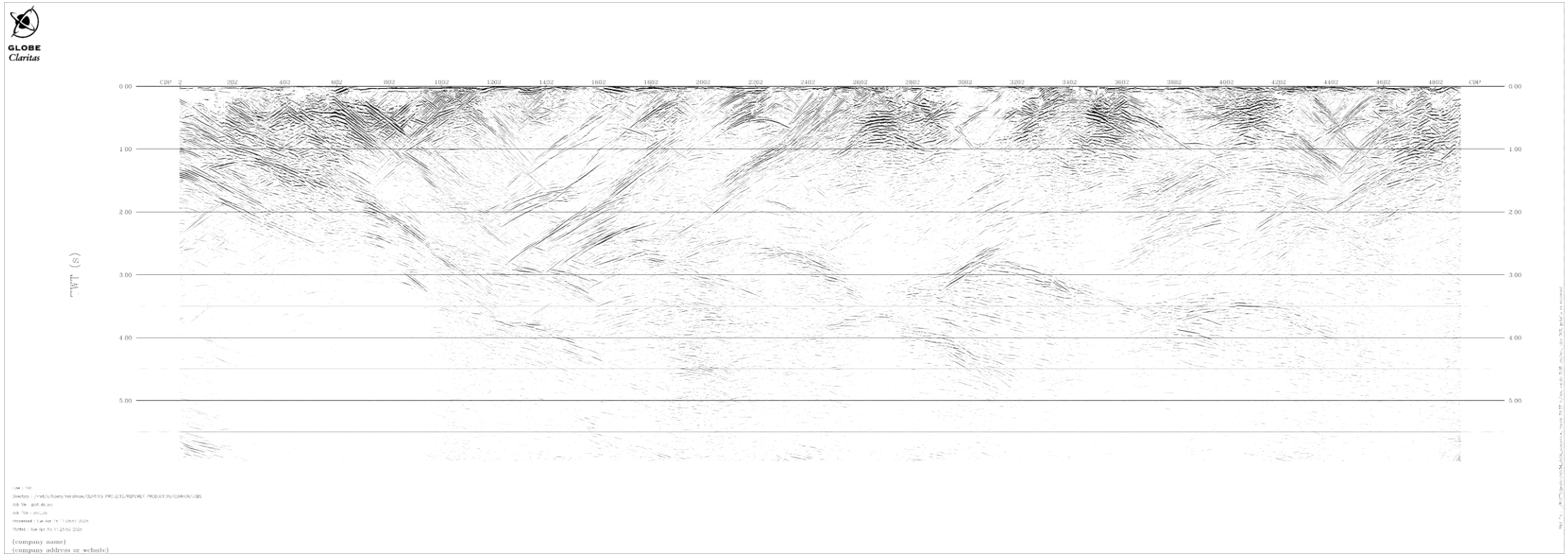
Normal NMO stack (with cross-spreads)



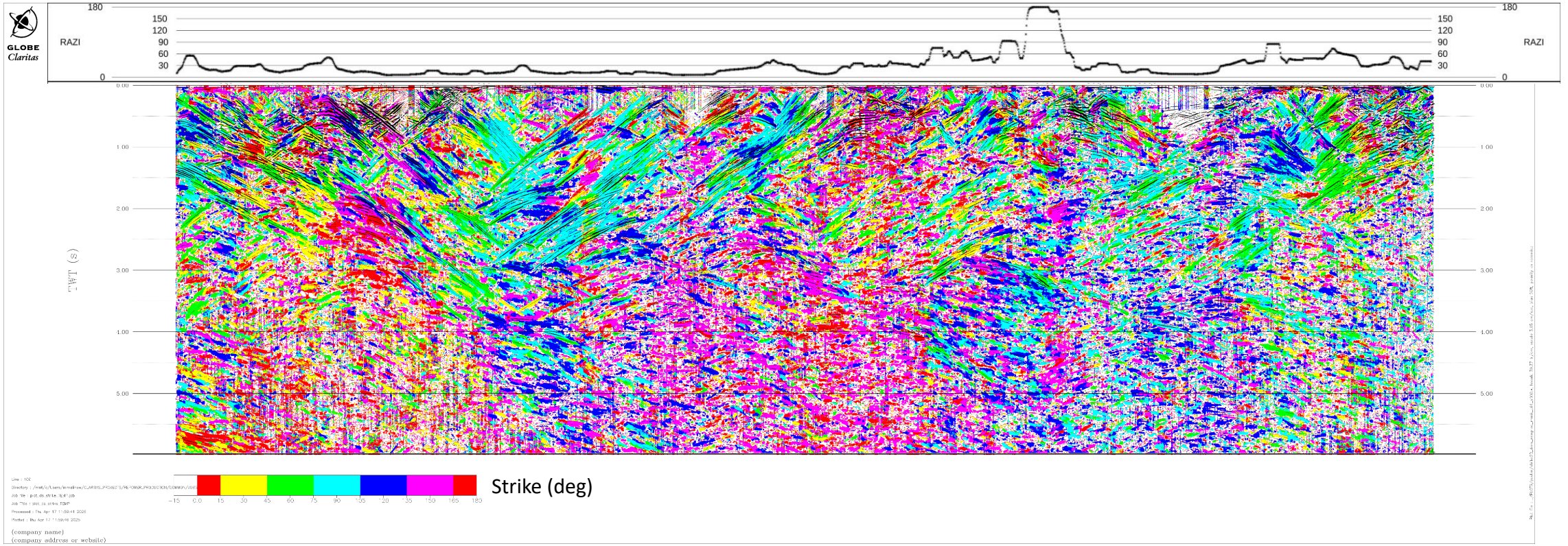
Optimum stack from reflection orientation analysis (no cross-spreads)



Optimum stack from reflection orientation analysis (with cross-spreads)

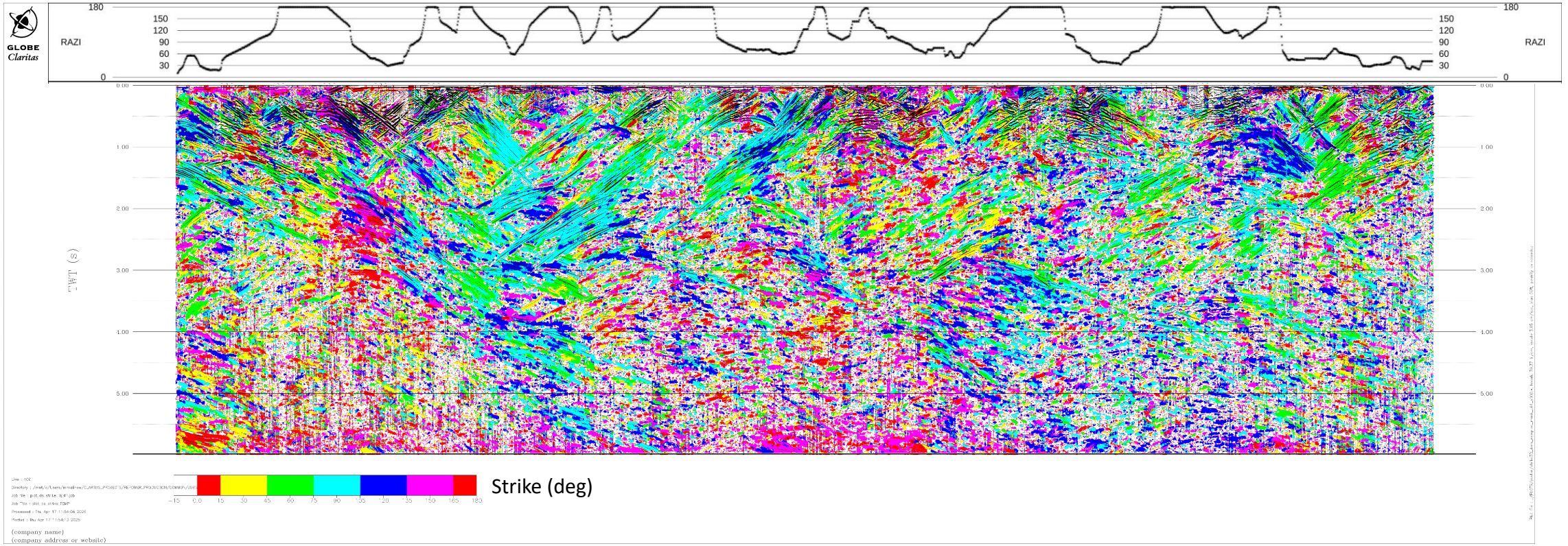


Reflection strike attribute (no cross-spreads)



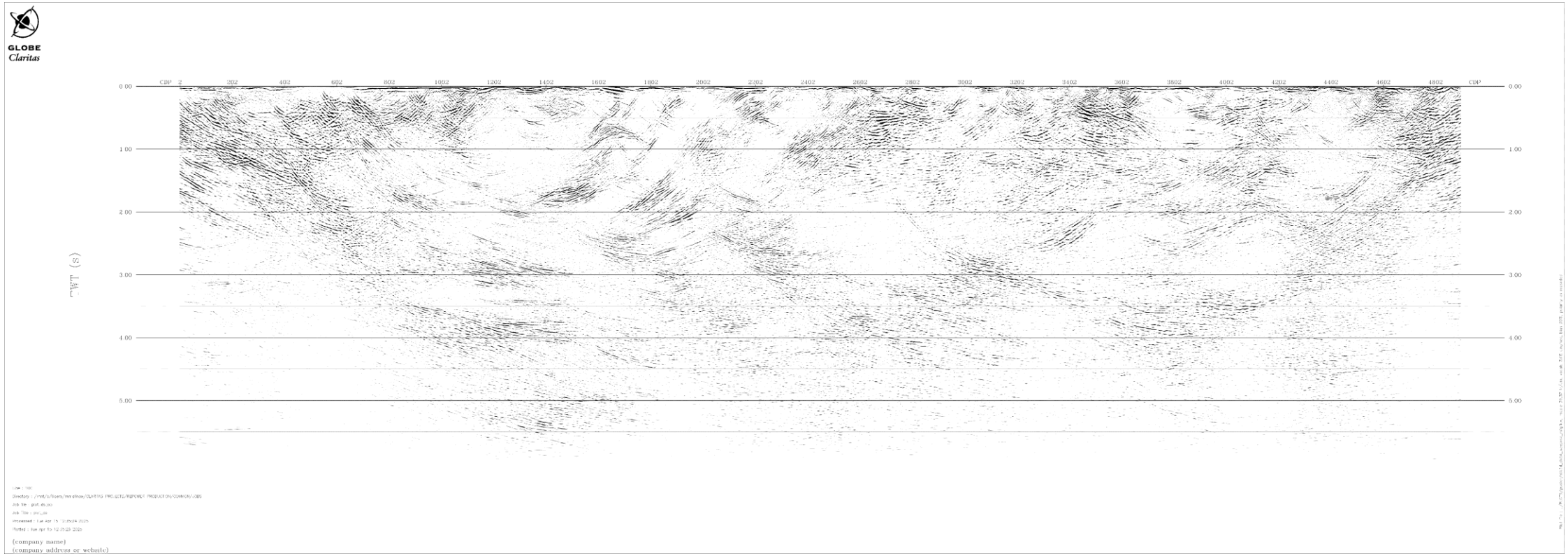
Error < 61 deg

Reflection strike attribute (with cross-spreads)

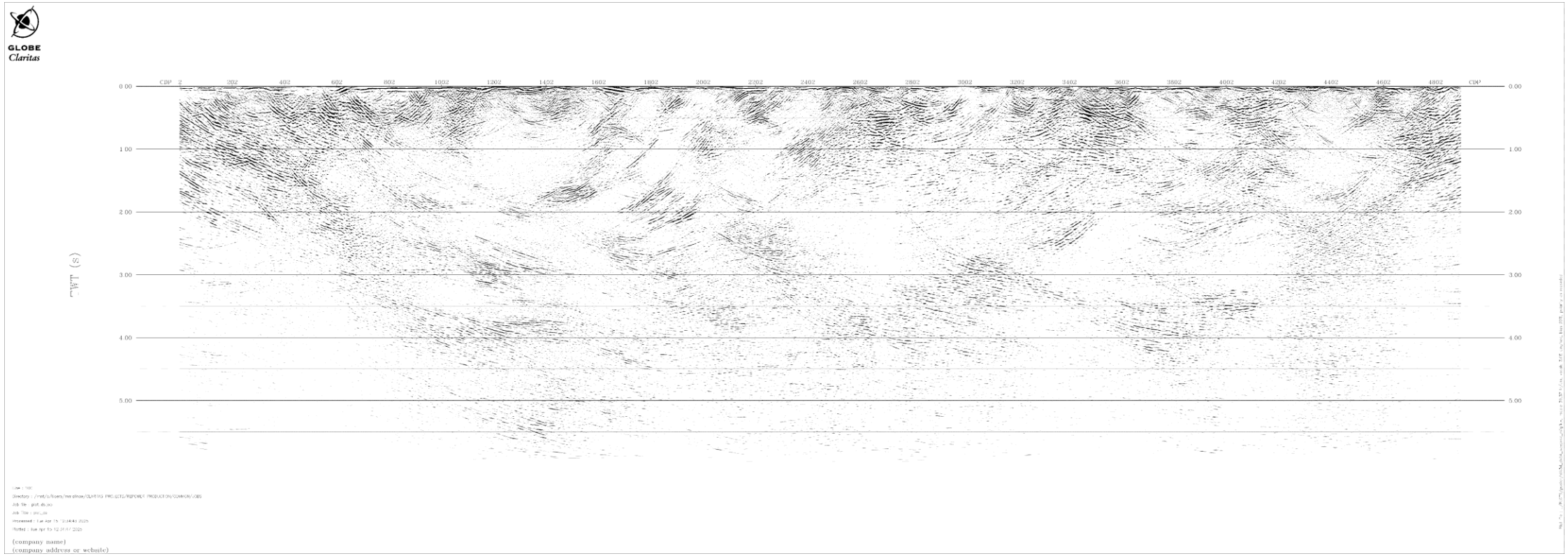


Error < 61 deg

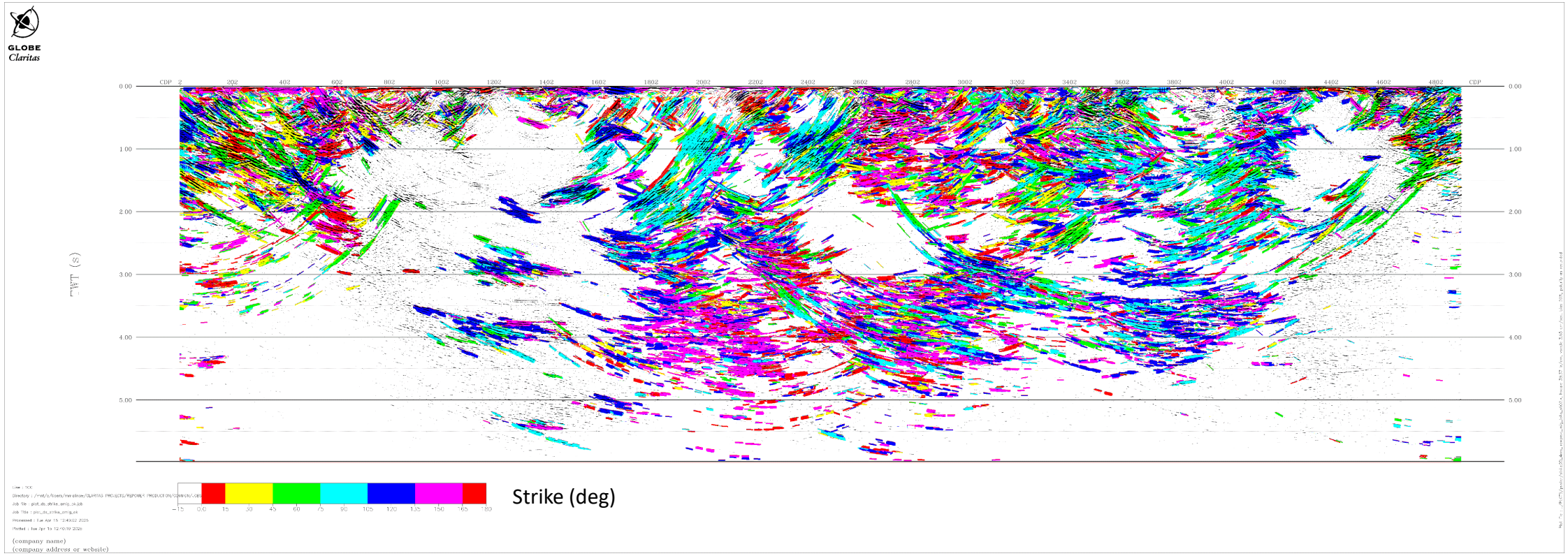
Migration of the optimum stack (no cross-spreads)



Migration of the optimum stack (with cross-spreads)

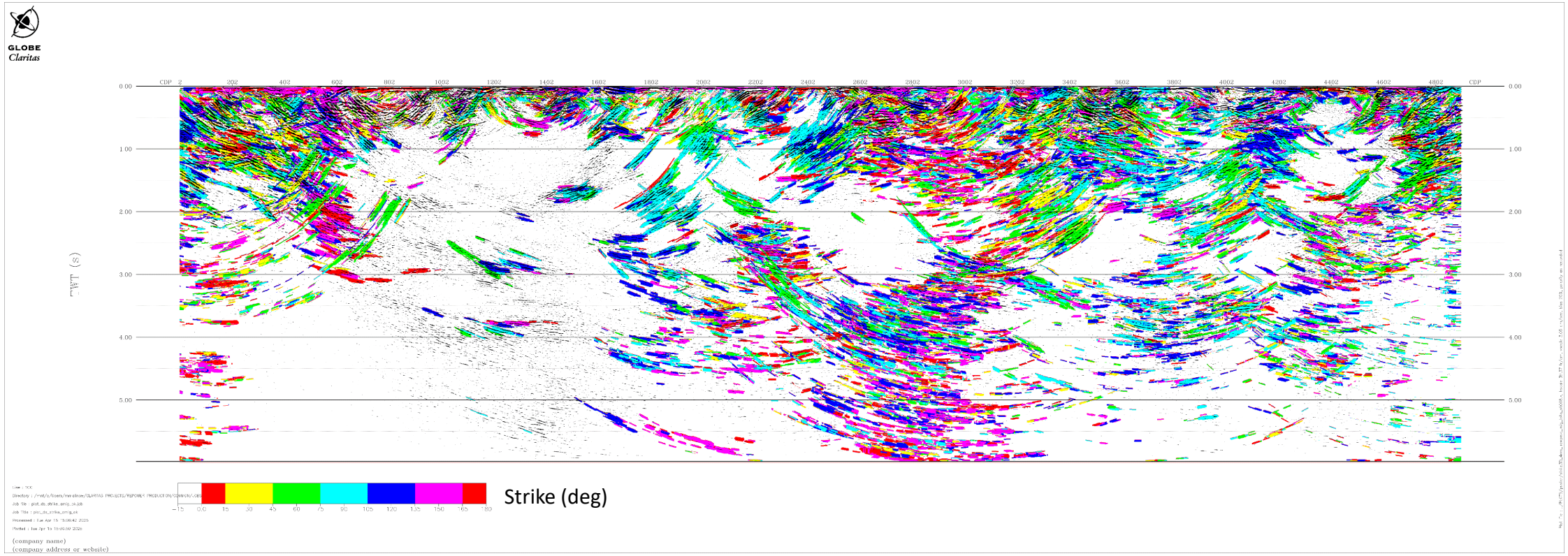


Migration of the strike attribute (no cross-spreads)



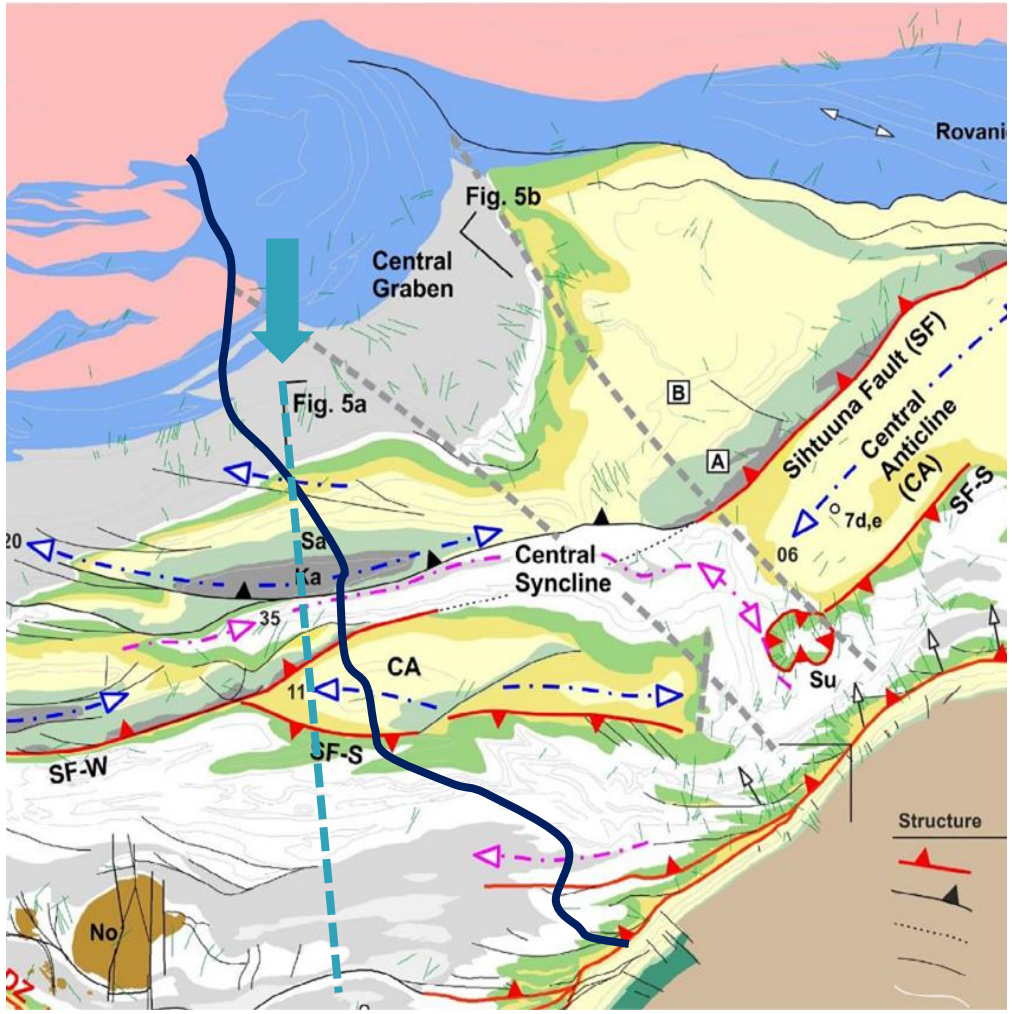
Error < 31 deg & semblance > 0.002

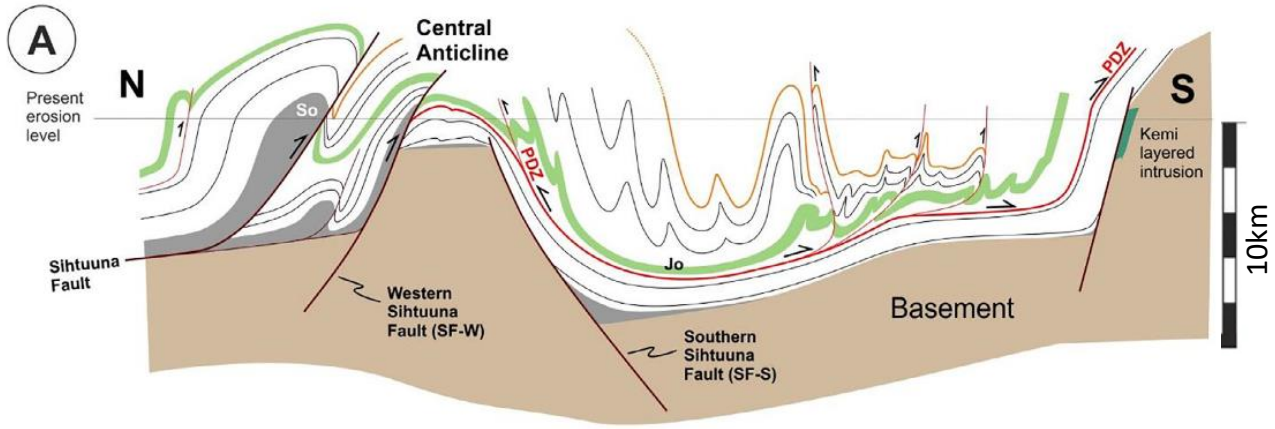
Migration of the strike attribute (with cross-spreads)



Error < 31 deg & semblance > 0.0008

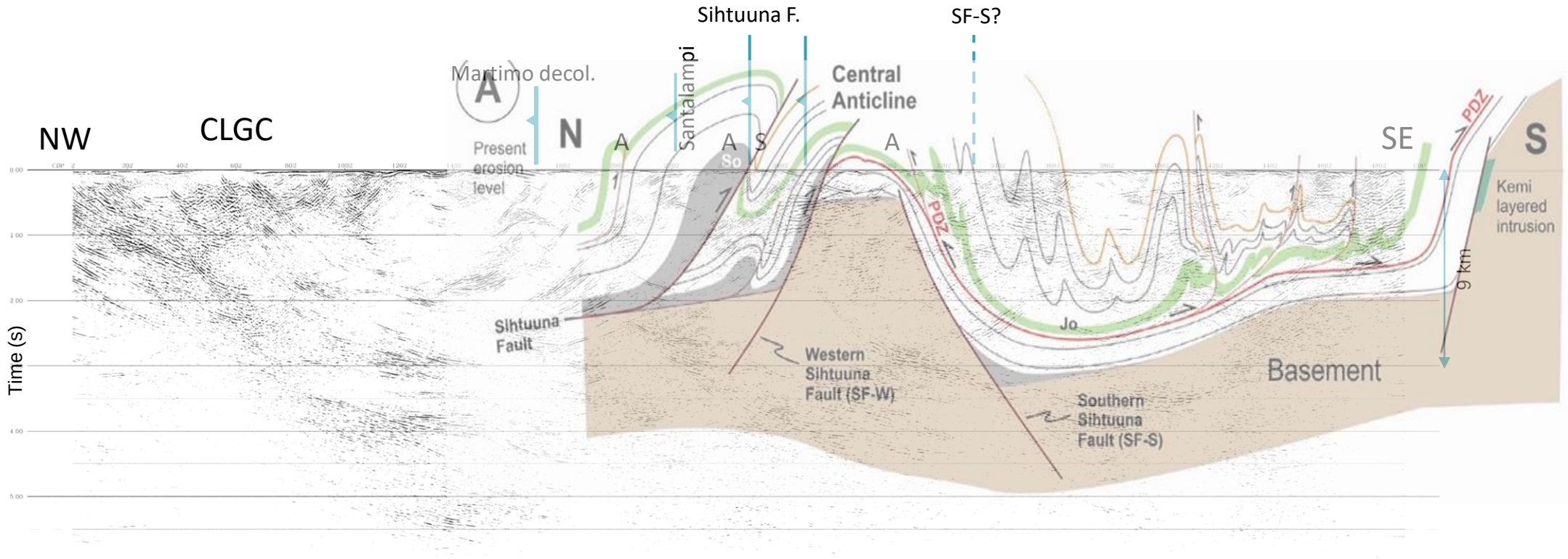
Previous interpretations





Piippo et al. 2019

Comparison with Piippo et al. model



A = anticline; S = Syncline; SF-S = Southern Sihtuuna F. in Piippo et al.

Note: scaling/positioning of the model is approximate!

Conclusions and outlook

- Reflection orientation analysis performed for the new profile acquired across the Peräpohja belt provided well-resolved attributes that can be used as constraints in building 3D geological model of the area
- Seismic data portrays the thrust-and-fold belt nature of the PB involving reactivation of the Archean basement structures
- There is an interesting decoupling observed in the strike attribute with reflections below 2.5-3 s TWT being subparallel to the profile. It may favour the idea of two deformation regimes (D1, E-W and D2, N-S oriented) shaping the PB (Lahtinen et al. 2023)
- Although the contribution from the additional cross-spreads is not obvious, as the profile was sufficiently crooked, the continuity of the reflections (and the corresponding attributes) seems to be better resolved in the shallow part when using the cross-spreads

Acknowledgements

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