BAYESIAN INVERSION OF H/V SPECTRAL RATIOS FOR CONSTRAINING SHALLOW SUBSURFACE STRUCTURE IN GEOTHERMAL EXPLORATION

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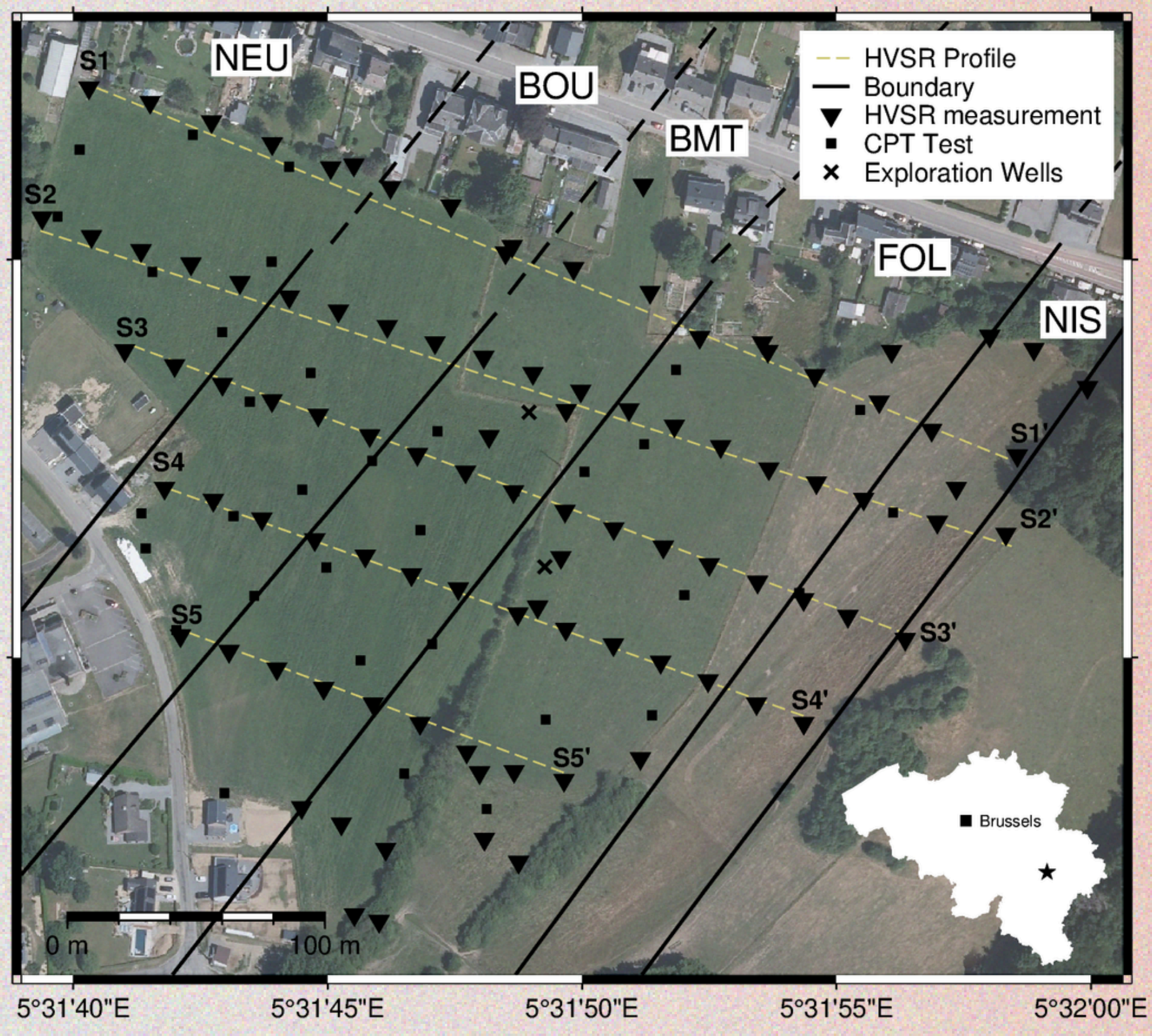
Summary

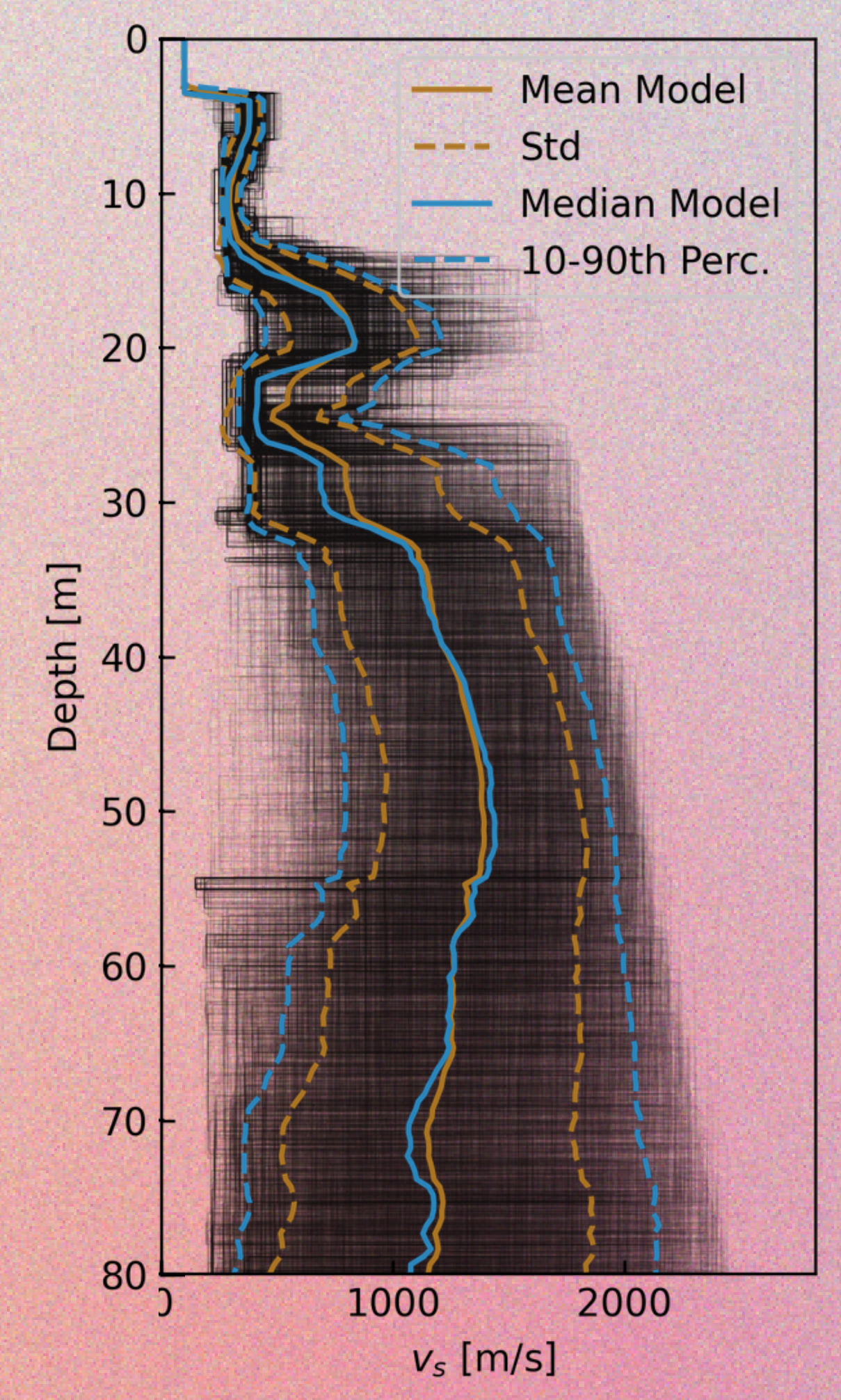
We use a **trans-dimensional probabilistic framework**[1] to **invert Horizontal-to-Vertical spectral ratio measurements** (H/V, HVSR) derived from a dense passive seismic survey above a prospective ATES system for a residential neighborhood. We construct shear-wave velocity slices and profiles to help **illuminate underground structures that govern local groundwater flow**. We demonstrate this approach as a valuable and cost-effective tool to support geothermal exploration in complex geological settings.

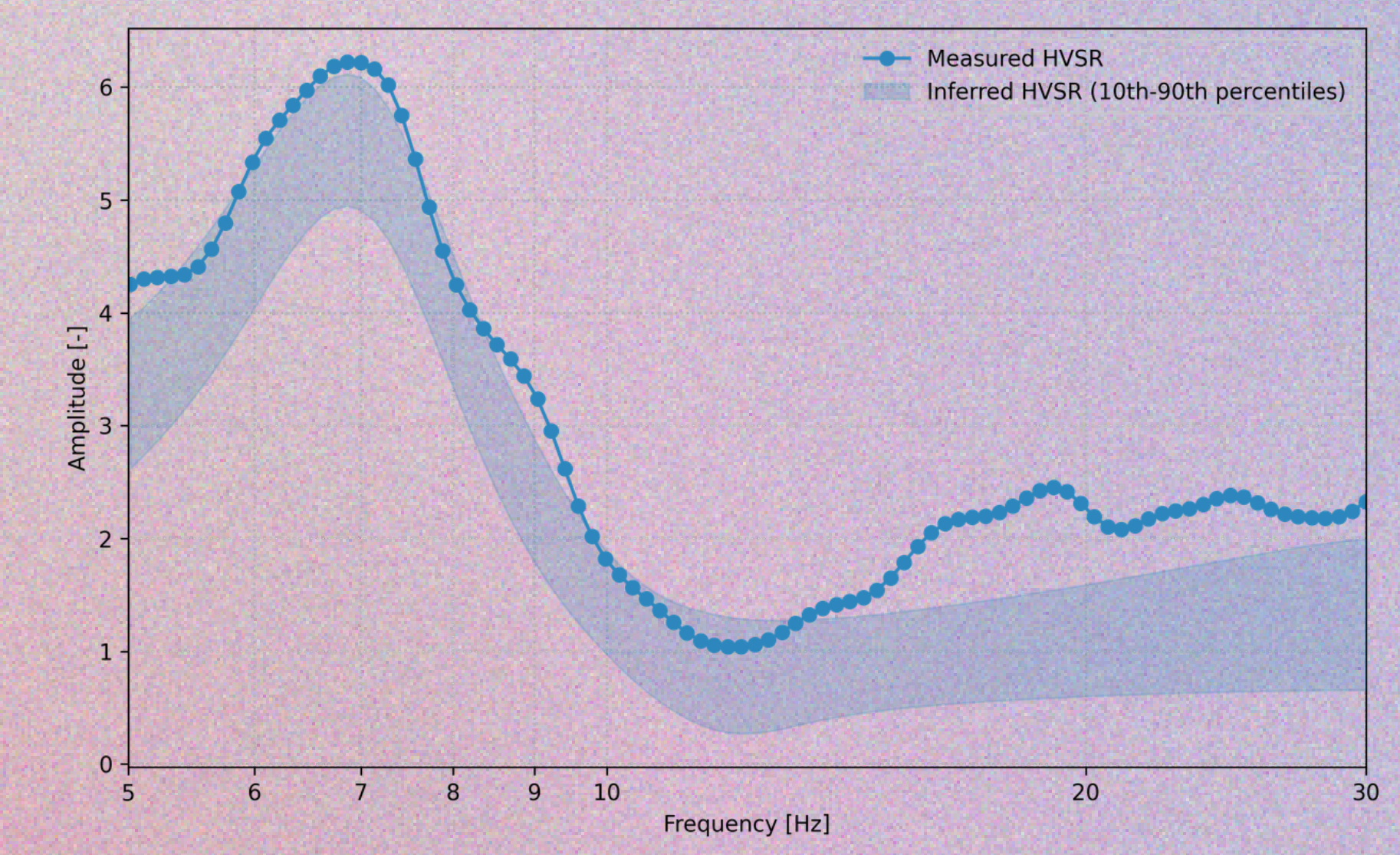


Context and data overview: HVSR survey points, estimated geological boundaries, location of cone penetration test and drilled exploration wells. BMT and FOL refer to two potentially aquifer hosting limestone units. NIS, BOU and NEU are shale-dominated aquiclude units.

Methods

H/V spectra were inverted using **Rayleigh-wave ellipticity** as the **forward model**[2], with subsurface models parameterized as homogeneous layers over a half-space and shear-wave velocity as the primary inversion target. We sample from the posterior distribution using 15 independent Markov chains comprising 1 million iterations each. Every 200th sample of each chains exploration phase is retained and the final velocity model for each station is computed as the mean of all saved models.

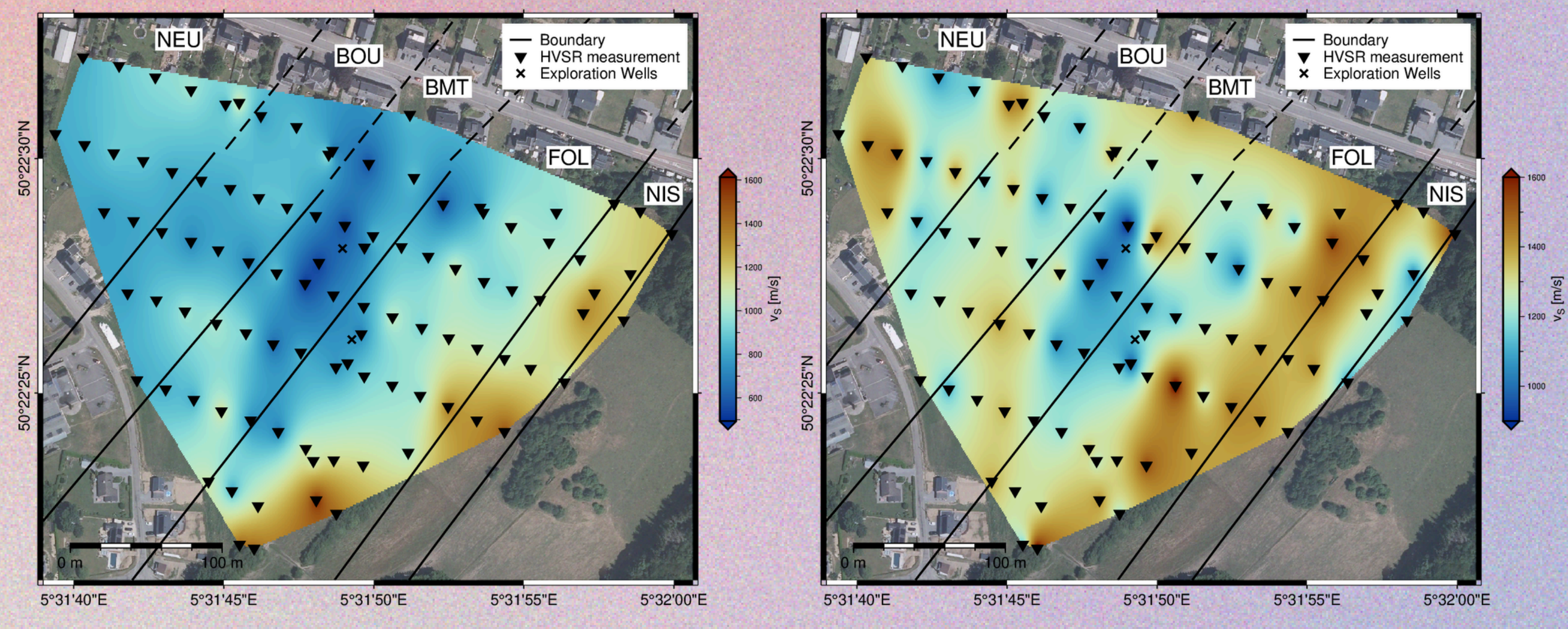




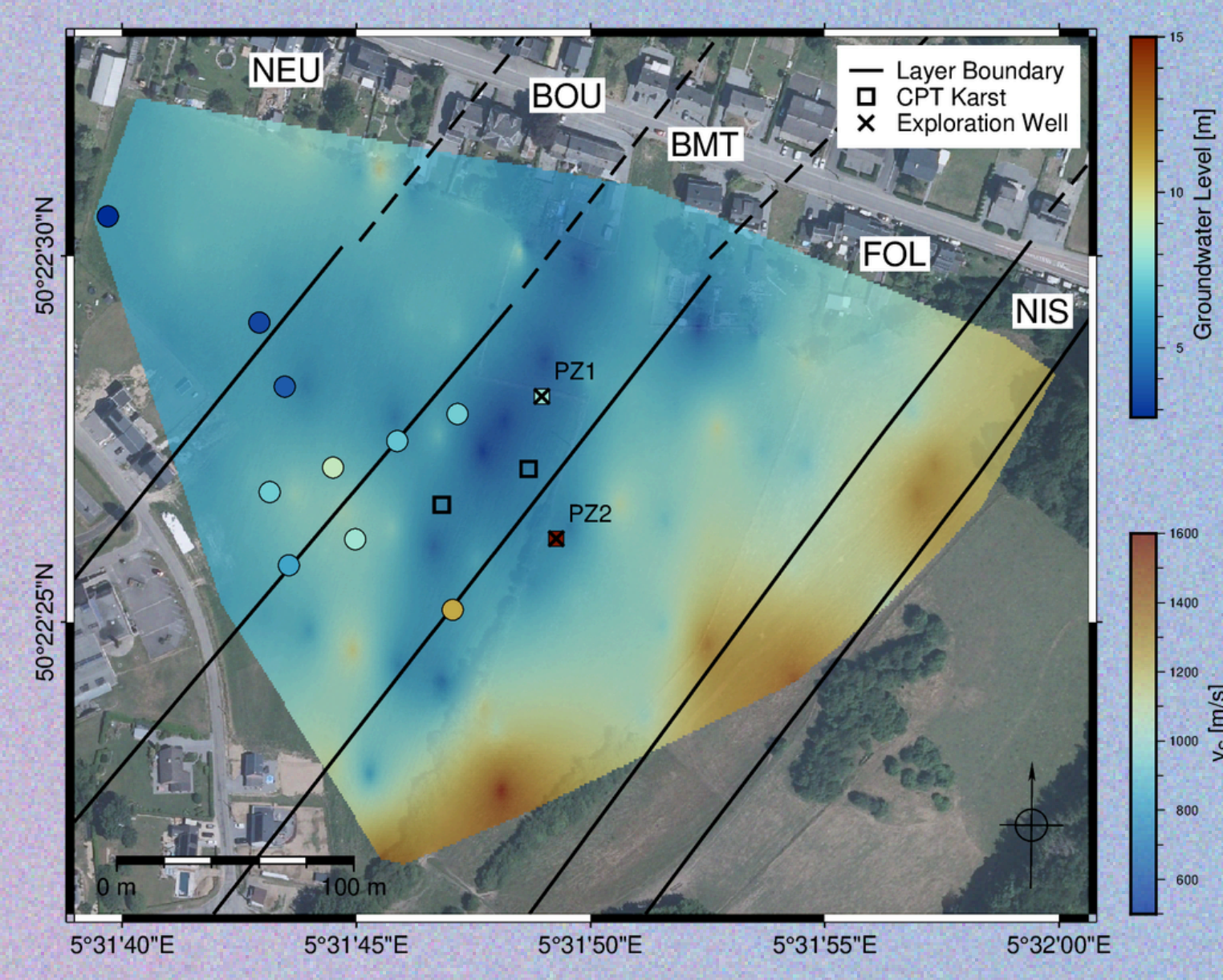
Left Panel shows the saved model states of a single Markov chain during the inversion of a representative H/V ratio.. Also shown are the mean model with its standard deviation as well as the median model and the 10th–90th percentile. Top panel shows the measured HVSR curve and the inferred 10th and 90th percentile curves. Poor fit in the higher frequencies clearly corresponds to poor exploration in the very shallow subsurface.

Results

Shear wave velocity slices show **distinct low velocity zones** in the center of the site, coinciding with limestone units known to be characterized by intense karstification. This **agrees with available geological maps** and is additionally evidenced by karstic features encountered during cone penetration testing (CPT). Geological logs and pumping tests in the drilled exploration wells further **confirmed the presence of highly fractured limestone with very high conductivity** at shallow depths.

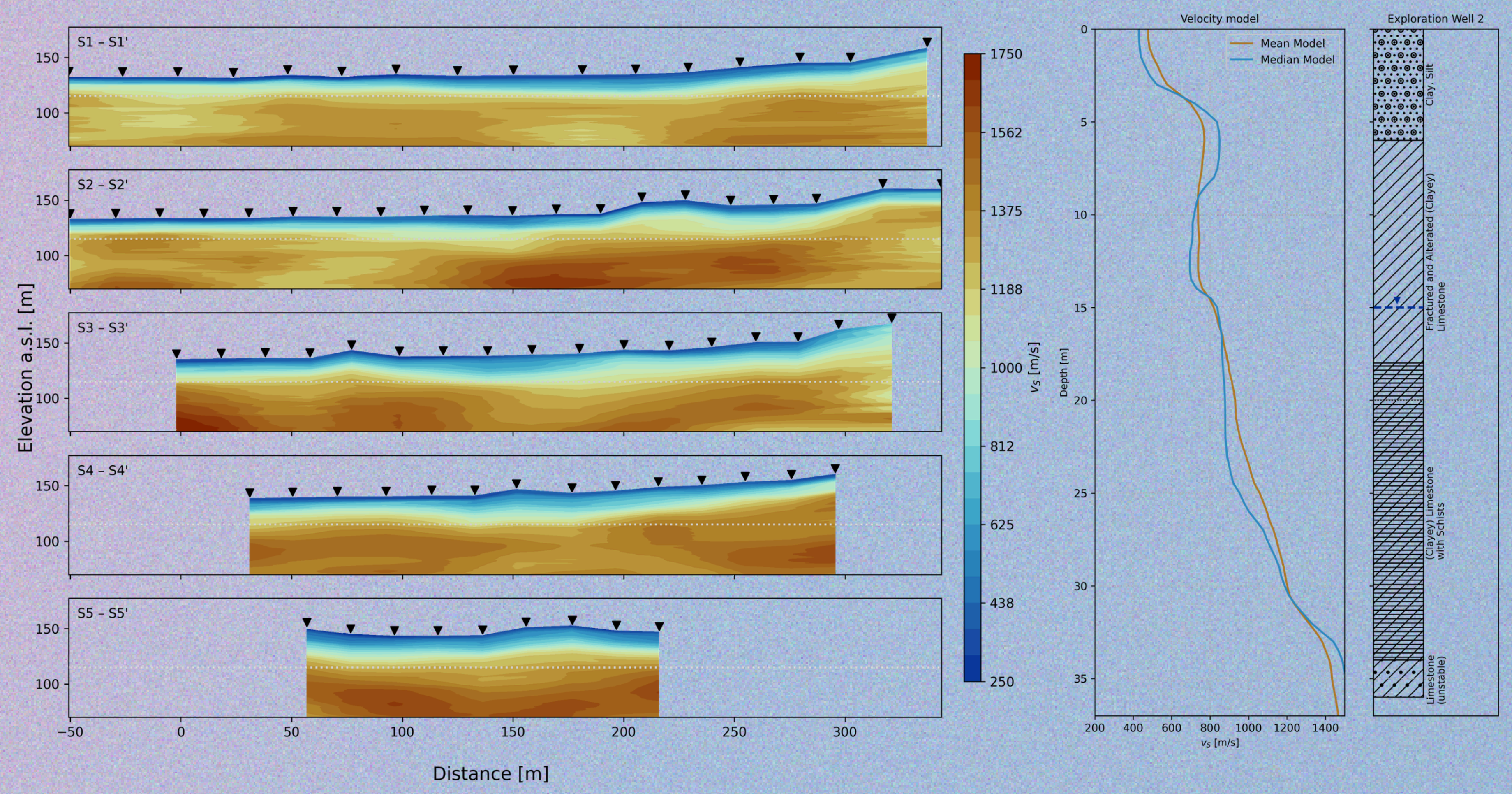


Maps show shear wave velocity slices at 135 and 115 m a.s.l. respectively and station distribution, values in between survey points are interpolated using spine interpolation.



Background shows velocity slice at 130 m a.s.l., filled circles and squares water table depths from CPT and as measured in the boreholes PZ1 and PZ2 respectively. Empty squares mark encoutered karstic features during CPT.

Groundwater depths, as measured during CPT and in the boreholes, follow a clear NW-SE trend, with the shallowest levels at the northeastern boundary and greatest depths in the central survey area. Lower shear-wave velocities coincide with deeper groundwater, suggesting a **strong structural link between lithology and groundwater depth**. This is **consistent with regional hydrogeological patterns** where flow occurs along limestone syncline axes and the fractured, highly permeable nature of the limestone units being reflected in generally lower water table levels.[3]



Left panel shows derived shear-wave velocity profiles along the five geophone lines revealing a complex subsurface topography and velocity distribution. Right panel compares the geological log of one of the exploration wells with the derived 1D v_s-model from the nearest seismic station.

Conclusion

HVSR analysis combined with probabilistic inversion provides a **non-invasive** approach to shallow subsurface characterization that requires **no prior knowledge** and captures inherent geological uncertainty. Validated by borehole and CPT data, the method successfully identifies permeable zones, thus demonstrating that passive seismics can serve as a **cost-effective exploration tool in support of geothermal development** and the energy transition.

References

[1]Magrini, F., et al. (2025). BayesBay: A versatile Bayesian inversion framework written in Python. Seismological Research Letters.
[2]Luu, K. (2024). disba: Numba-accelerated computation of surface wave dispersion
[3]Ruthy, I. & Dassargues, A. (2017). Carte hydrogéologique de Wallonie, Hamoir - Ferrières 49/5-6, 1/25.000 : [Notice explicative].

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