3D imaging of the subsurface electrical conductivity structure in West Bohemia covering mofettes and Quaternary volcanic structures by using magnetotellurics

Platz, A.[1], Weckmann, U.[1,2], Pek, J.[3], Kováčiková, S.[3], Klanica, R.[3], Mair, J.[1,4], Aleid, B.[1,2]

1 Helmholtz Centre Potsdam - German Research Centre for Geosciences GFZ, Potsdam, Germany

2 University of Potsdam, Institute of Geosciences, Potsdam, Germany

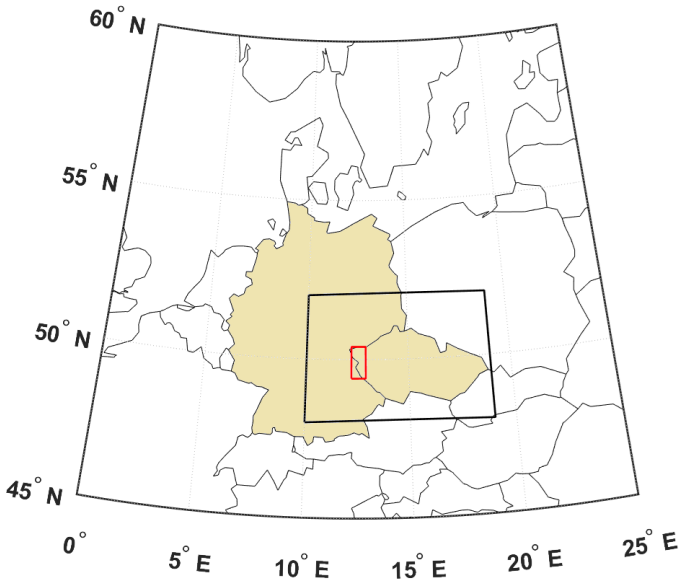
3 Institute of Geophysics of the Czech Academy of Sciences, Prague, Czech Republic

4 Freie Universität Berlin, Department of Earth Sciences, Berlin, Germany

Session: EMRP2.5 – D1212 | EGU2020-135

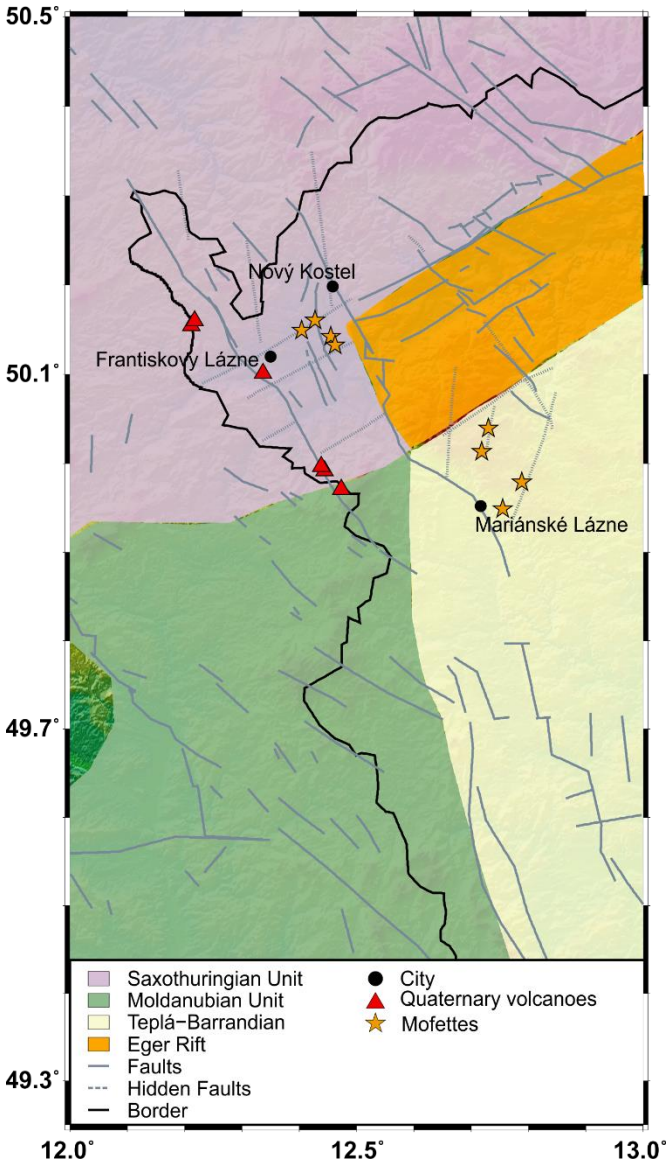
Region of interest:

- Our target area between the Czech Republic and Germany belongs to the western part of the Bohemian Massif.
- The West Bohemian Massif represents the easternmost part of the geodynamically active European Cenozoic Rift System.
- The Bohemian Massif was formed during the Variscan cycle between 500 and 250Ma.
- It can be divided into different tectonic units, the NE-SW trending Eger Rift and a multitude of different faults systems.



Region of interest:

- The entire region is characterized by ongoing magmatic processes in the intra-continental lithospheric mantle.
- These processes are expressed by e.g. the occurrence of repeated earthquake swarms and massive degassing of CO_2 in form of mineral springs and mofettes.
- Different Quaternary volcanic structures are possibly relics of active tectonics.
- An interdisciplinary drilling and research programme was funded within the scope of ICDP.

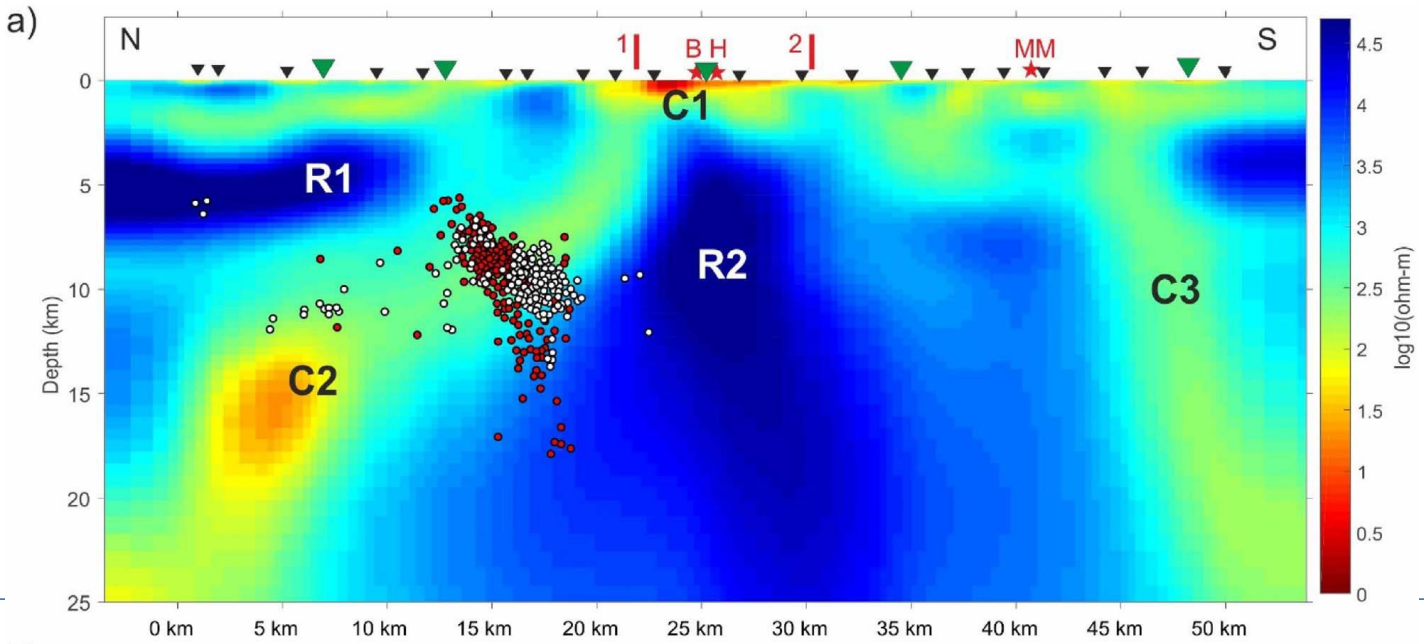


Key questions of the ICDP project:

- The drilling and research programme aims to study earthquake-fluid-rock-biosphere interactions, e.g. the
  - correlation between mofette degassing, gas composition, swarm and microbial activity
  - fault-valving mechanisms and their relevance for seismic hazard, degassing and the deep biosphere
  - Triggers of fluid-induced earthquake swarms
  - **Fluid pathways from the upper mantle to the surface**
- Magnetotelluric (MT) measurements are applied to image the subsurface distribution of the electrical conductivity from shallow surface down to depths of several tens of kilometres with the aim to map potential fluid pathways.

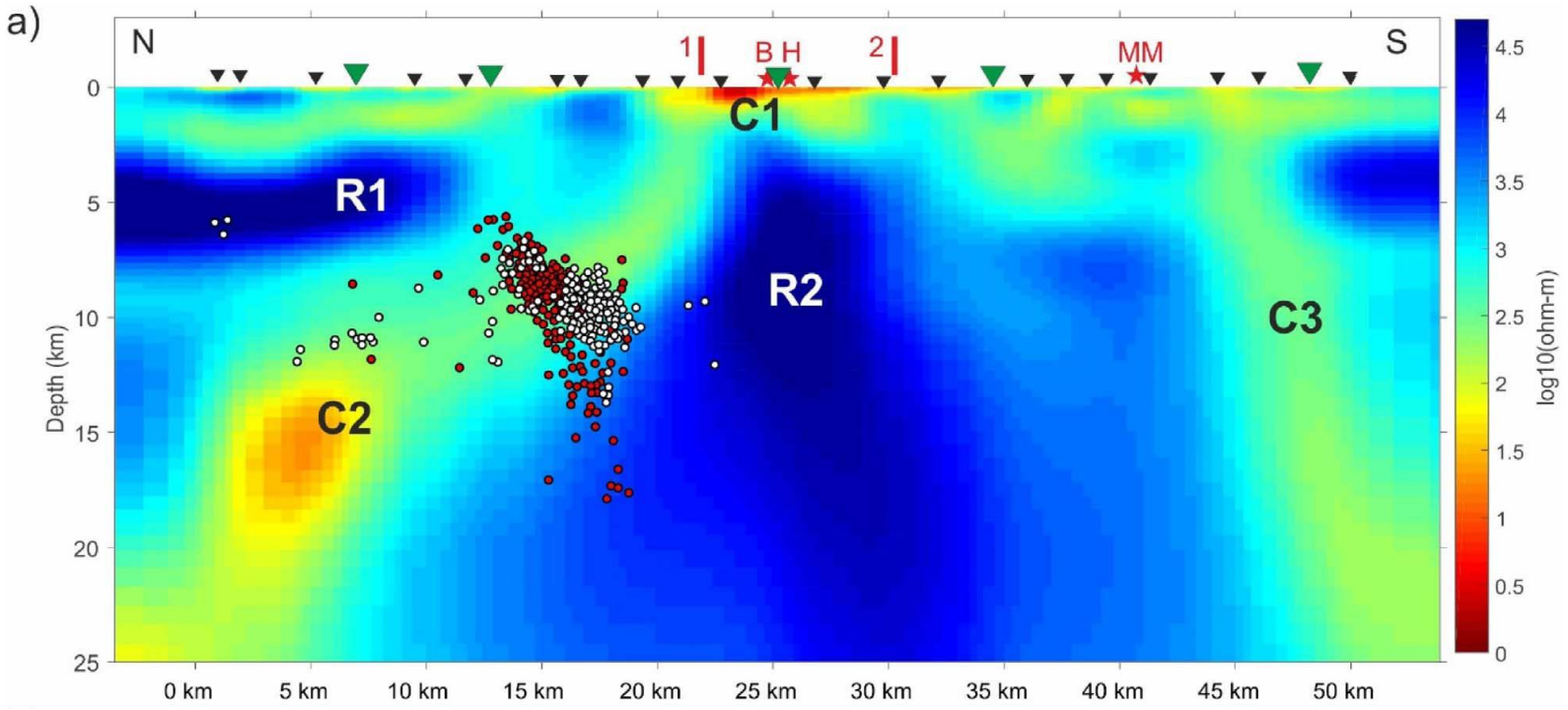
Previous magnetotelluric results:

- First MT measurements within this ICDP project were carried out in winter 2015/2016 along two 50 km long perpendicular profiles with 30 stations each and a denser grid of 97 stations close to the mofettes with an extension of 10 x 5 km^2.
- Muñoz et al. (2018) presented 2D images along a NS profile.



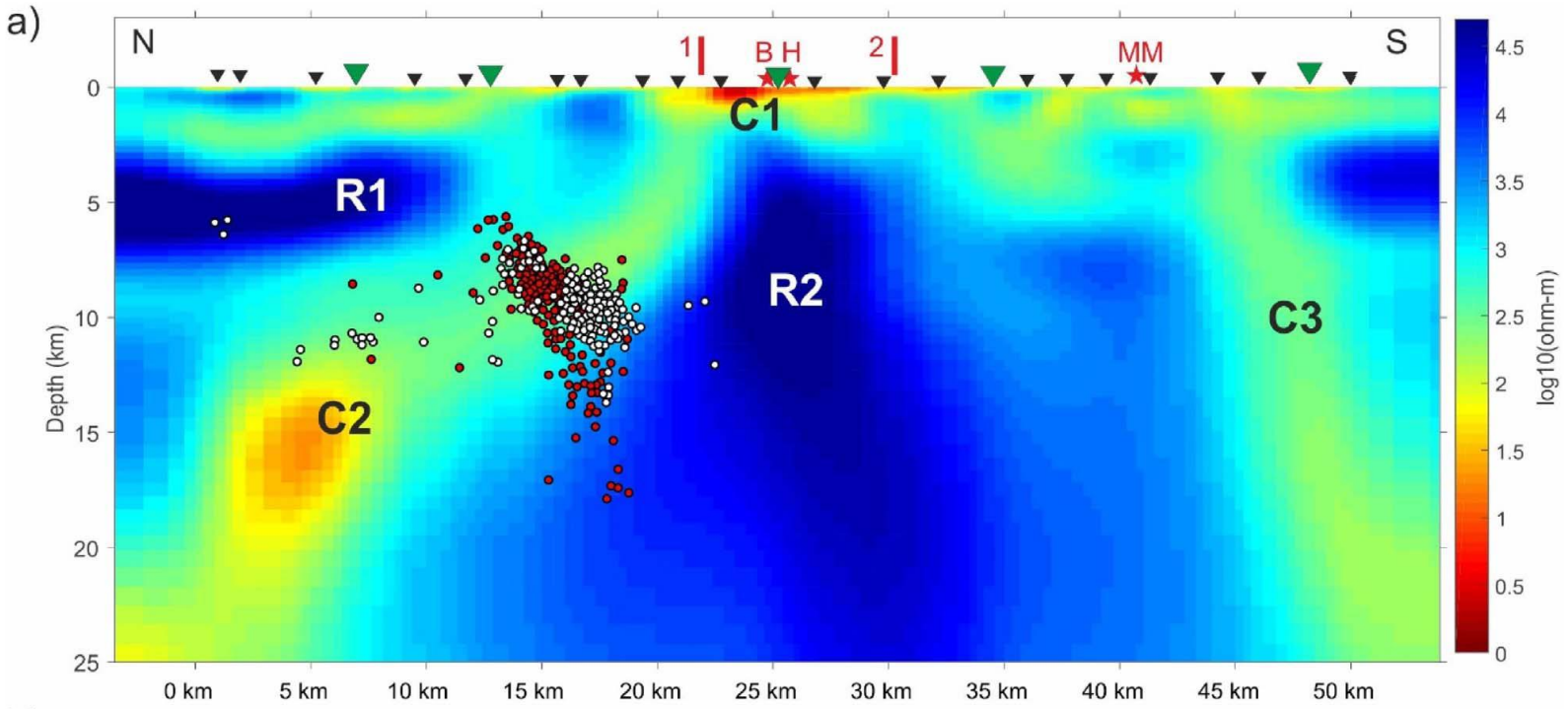
Previous magnetotelluric results:

- They reveal a conductive channel (C2) at the earthquake swarm region that extends from the lower crust to the surface forming a pathway for fluids into the region of the mofettes (B and H).



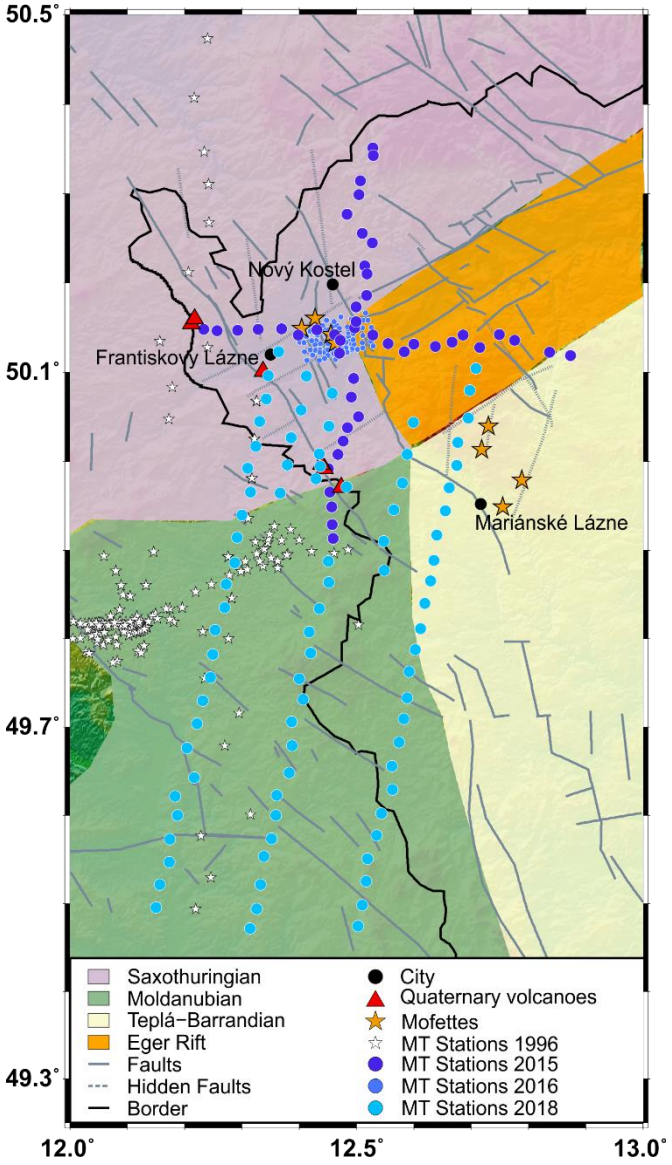
Previous magnetotelluric results:

- A second conductive channel (C3) is present in the south of the model.
- Due to the given station setup, the resulting 2D inversion allows ambiguous interpretations of this feature.



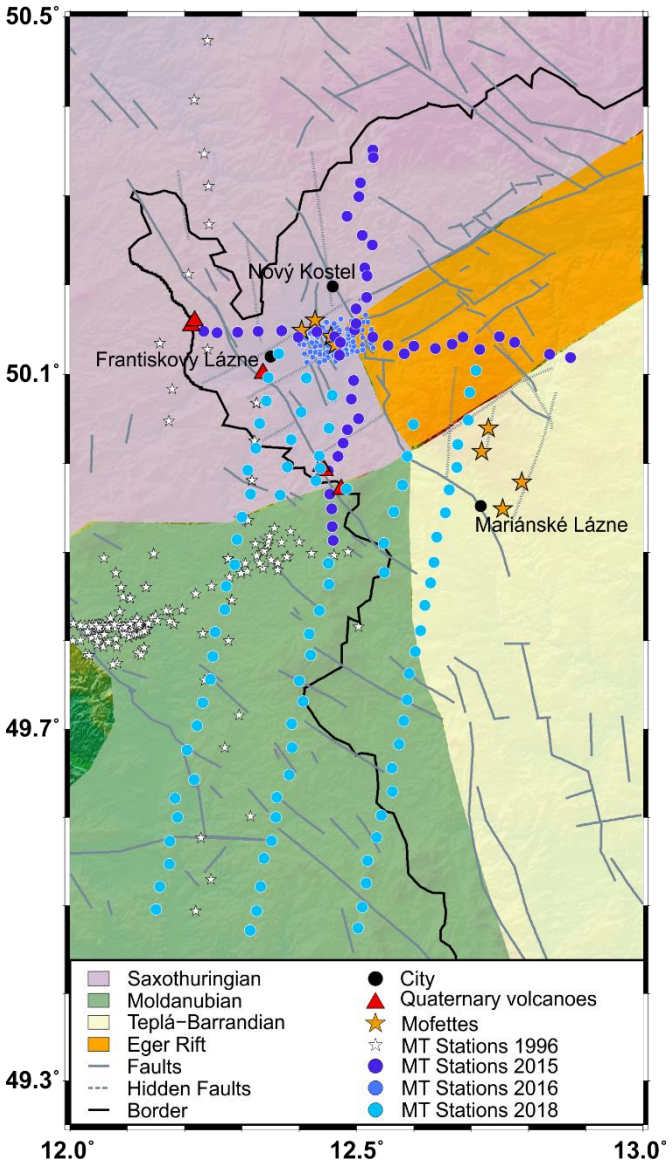
Measurements in 2018:

- 3D MT data and subsequent inversions are required to distinguish between different scenarios and to fully describe the 3D structure of the subsurface.
- A large MT field experiment was conducted in autumn 2018 extending the study area towards the south.
- Broad-band MT data were measured at 83 stations along three 50-75 km long profiles and some additional stations across the region of maars and important faults.



Measurement details:

- Five-component MT data were measured in the period range of 10^{-4}-10^{3}s using instruments from the Geophysical Instrument Pool Potsdam (GIPP).
- A site spacing of approximately 3 km along the profiles allows the resolution of regional as well as shallow features.
- As reference station we used the permanent reference station of the GFZ in northern Germany (~350km distance, Ritter et al., 2015) and a local station in Bavaria.



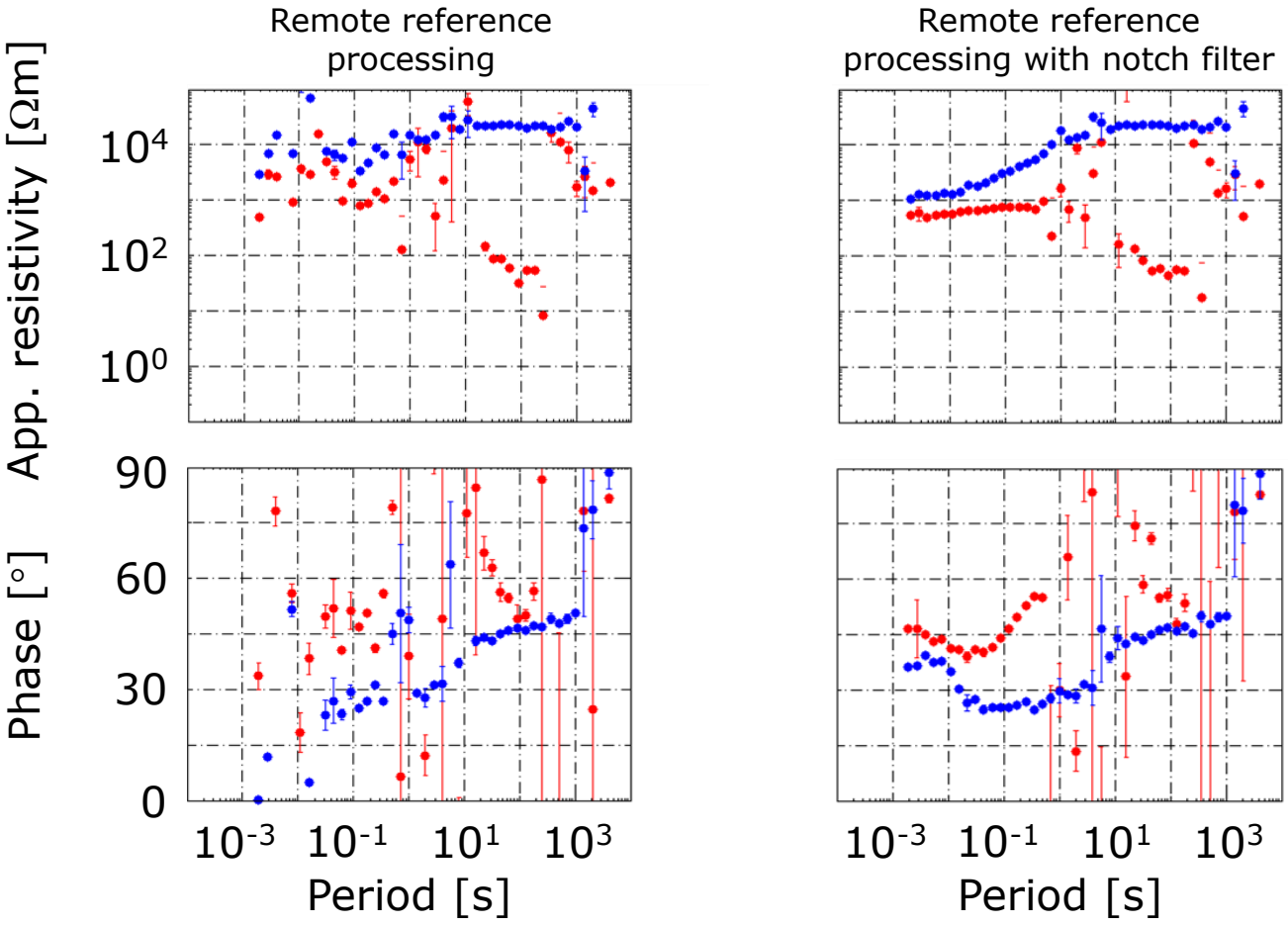
Processing details:

- The data were processed using the *EMERALD* software suite (Ritter et al., 1998; Weckmann et al., 2005; Krings, 2007)
- Severe EM noise in this heavily populated area required different advanced processing, e.g.
  - robust single-site processing
  - robust remote reference processing
  - different notch and delay-line filters
  - application of advanced data selection criteria (Platz & Weckmann, 2019)
- The most obvious outliers in the impedance data, the vertical magnetic transfer functions and the horizontal magnetic inter-station transfer functions were manually removed prior to the inversion.

Processing results:

- Smooth impedance data could be obtained in the period range of 10^{-4}s up to 10^{3}s for many stations by combination of the processing approaches mentioned before.
- In contrast to the MT survey in 2015/2016, we were able to obtain smooth and stable vertical transfer functions over a wide period range.
- Inter-station transfer functions were calculated for selected station combinations.
- The MT data conducted in 2015/2016 were reprocessed using the new approaches.

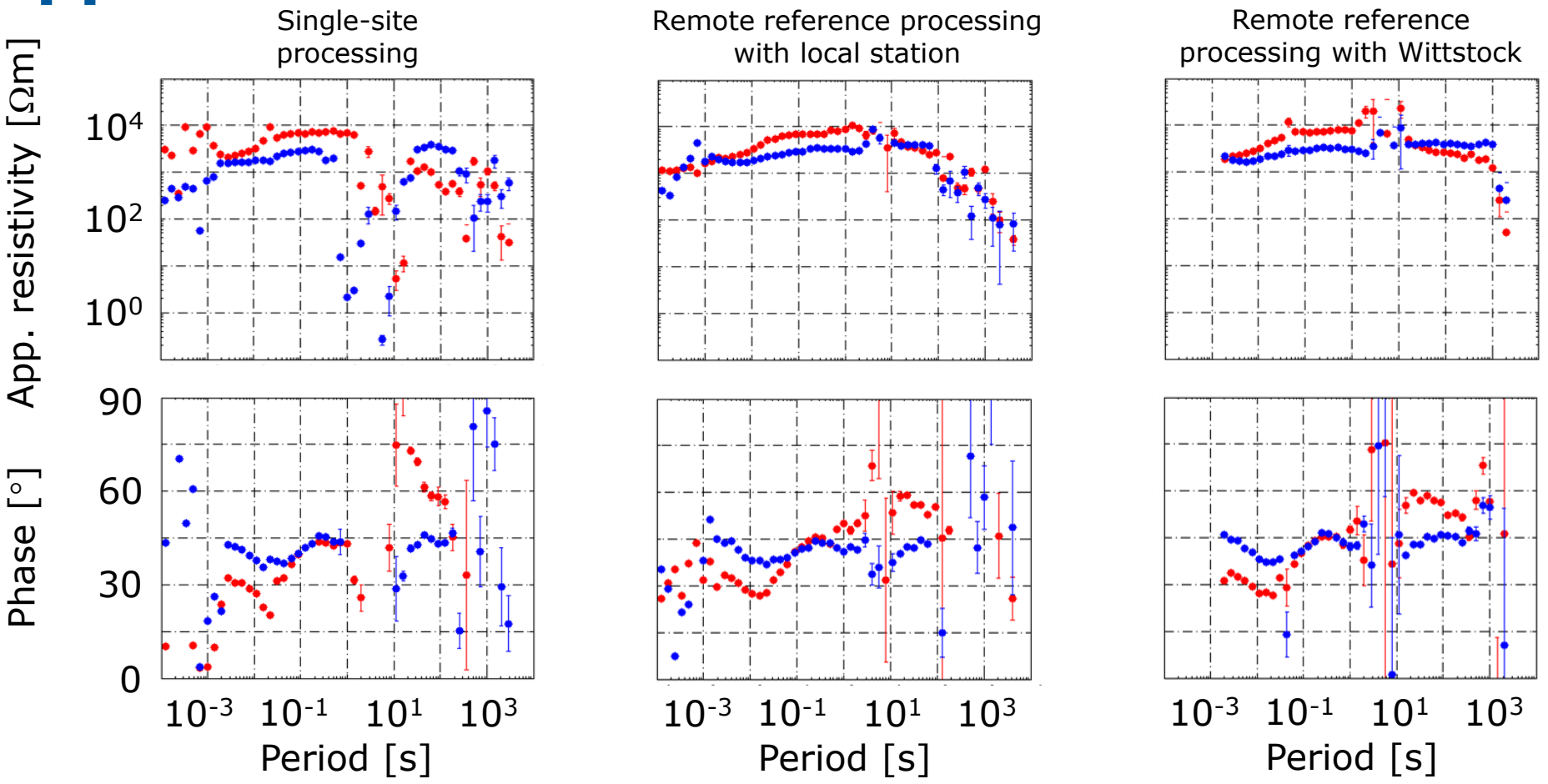
Influence of notch filter on the result:



- A coherence threshold of 0.85/0.9 (Z_{xy}/Z_{yx}) is applied in both cases. Notch filtered frequencies: 16.7 & 50Hz

- Z_{xy}
- Z_{yx}

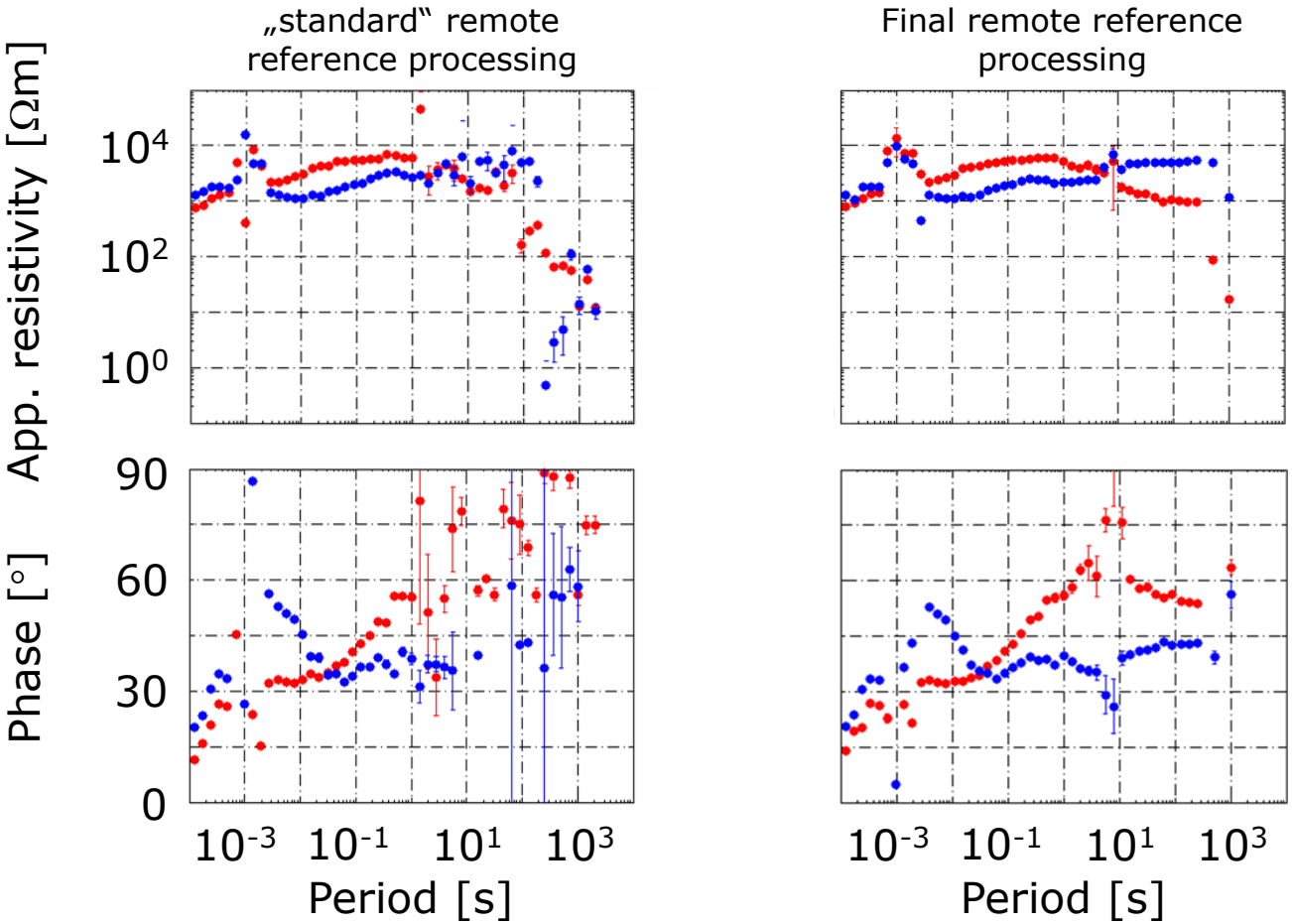
Comparison of different processing approaches:



- A coherence threshold and different notch/delay-line filters are applied in all cases.

- Z_{xy}
- Z_{yx}

Influence of advanced data selection tools:



- A coherence threshold is applied in both cases. Furthermore, we use the Mahalanobis distance and magnetic polarization direction criterion for the processing result in b) (see Platz & Weckmann, 2019).

- Z_{xy}
- Z_{yx}

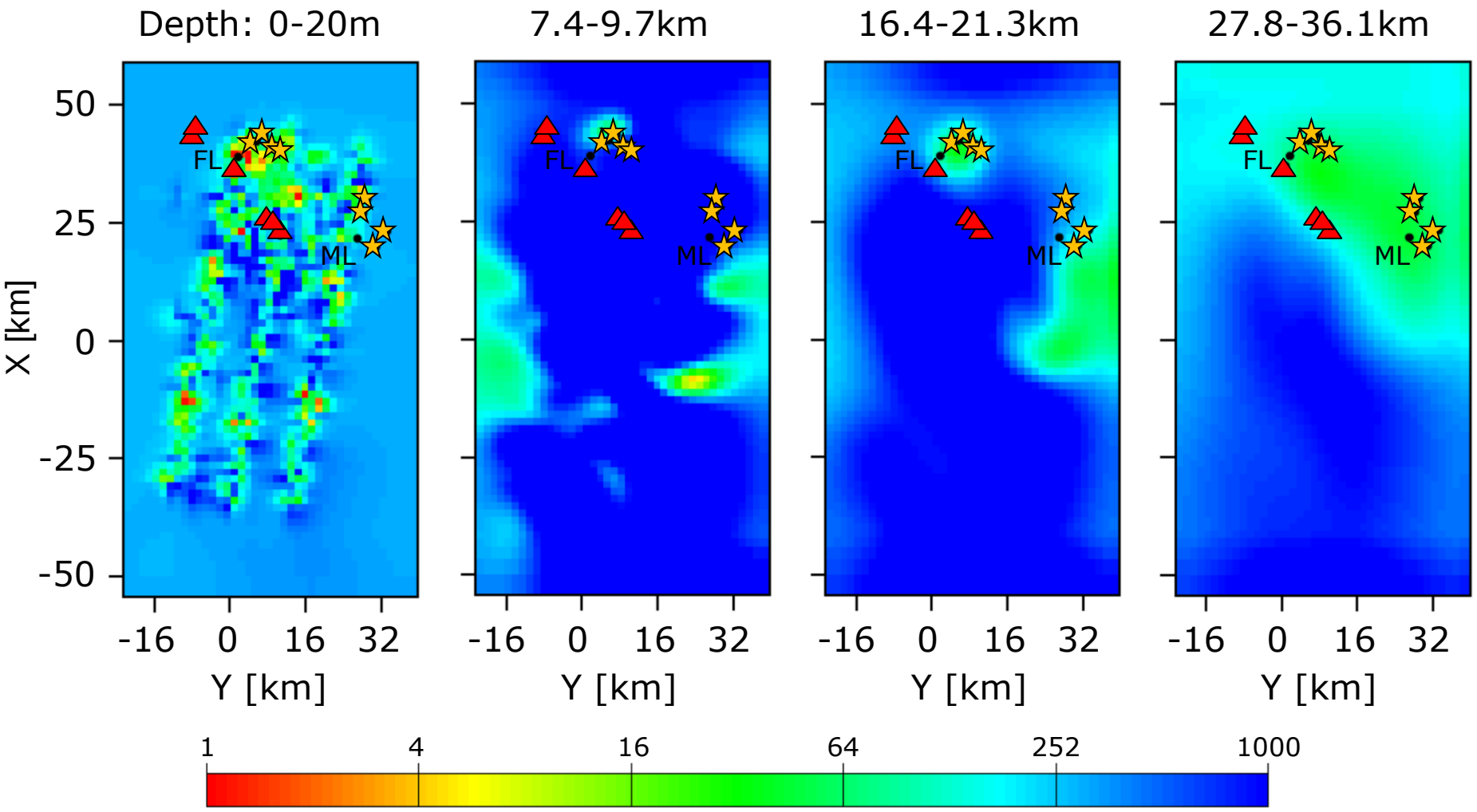
3D inversion settings:

- Inversion and modelling code: ModEM (Meqbel, 2009; Egbert & Kelbert, 2012; Kelbert et al., 2014)
- Data set: All data of 2018 + selected stations from 2015/2016 + selected stations collected within the framework of the site characterization in the surrounding of the KTB drilling
- We tested different:
  - grids, starting models and combinations of starting and prior model
  - combinations of data types (impedance, vertical transfer functions, horizontal magnetic inter-station transfer functions)
  - error settings and smoothing parameters
  - cascaded approaches (e.g. result of impedance inversion as starting model for impedance + vertical transfer functions inversion)

Details of the (currently) preferred model:

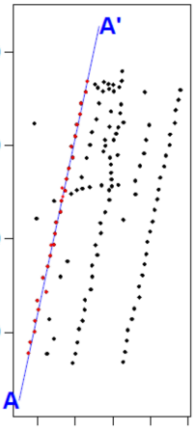
- Joint inversion of impedance and vertical transfer funtions
  - 25 frequencies and 128 stations
  - 50% error of $|Z_{ij}|$ for Z_{xx}/Z_{yy} and 10% error of $|Z_{ij}|$ for Z_{xy}/Z_{yx}
  - 5% (0.05) for vertical transfer functions
- Starting model = prior model
  - 300Ωm half-space + two sedimentary basins with 3Ωm and depths of 2km (Thuringian Basin) and 4km (Northern German Basin)
  - Model grid: 112x90x42 cells, inner part: 62x40x42 cells, edge length: 1.5km, thickness first layer: 20m, overall increasing factor: 1.3, outermost padding cells are fixed, smoothing parameter in all directions: 0.1
- RMS: 7.2 → **1.23** after 93 iterations

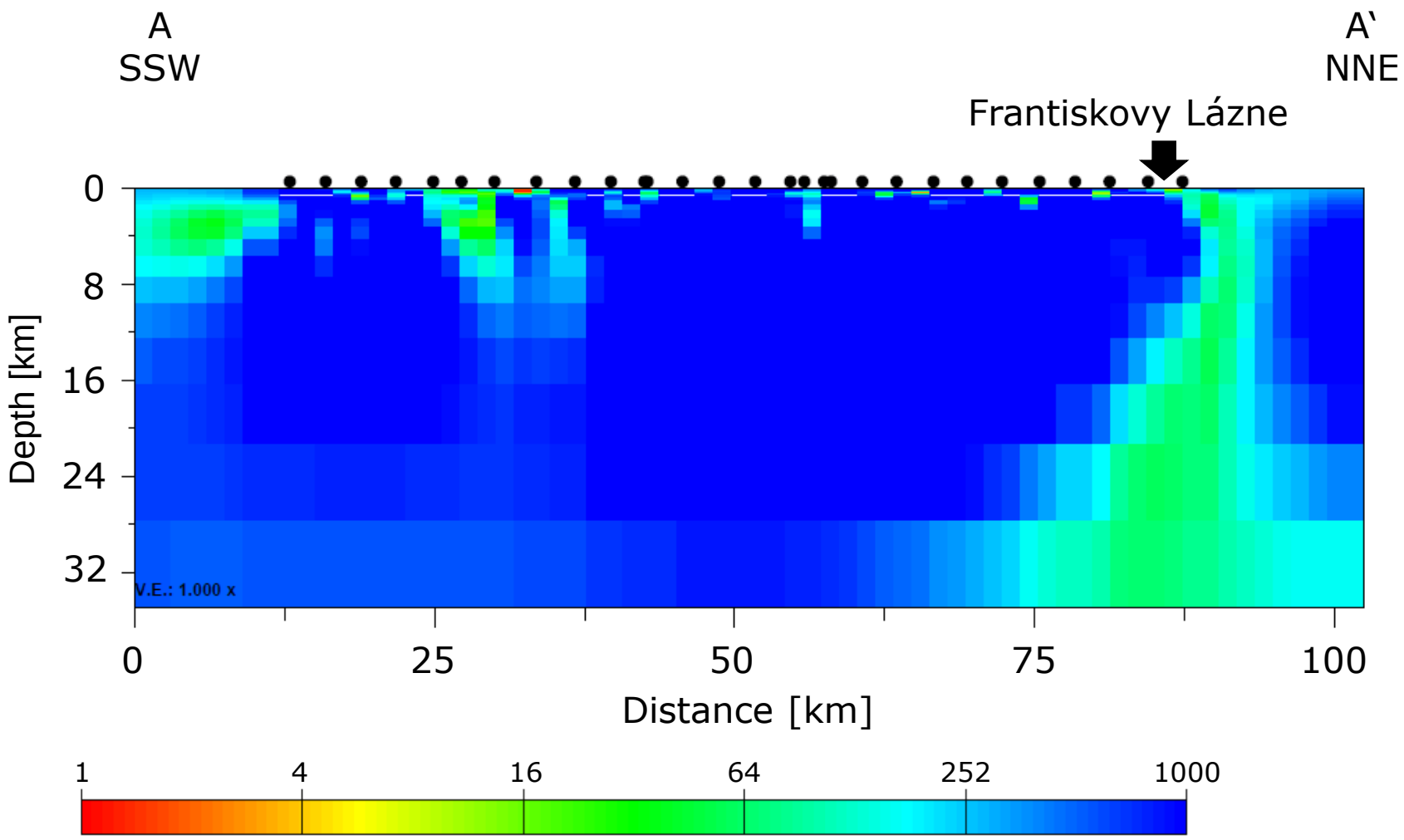
Map view:



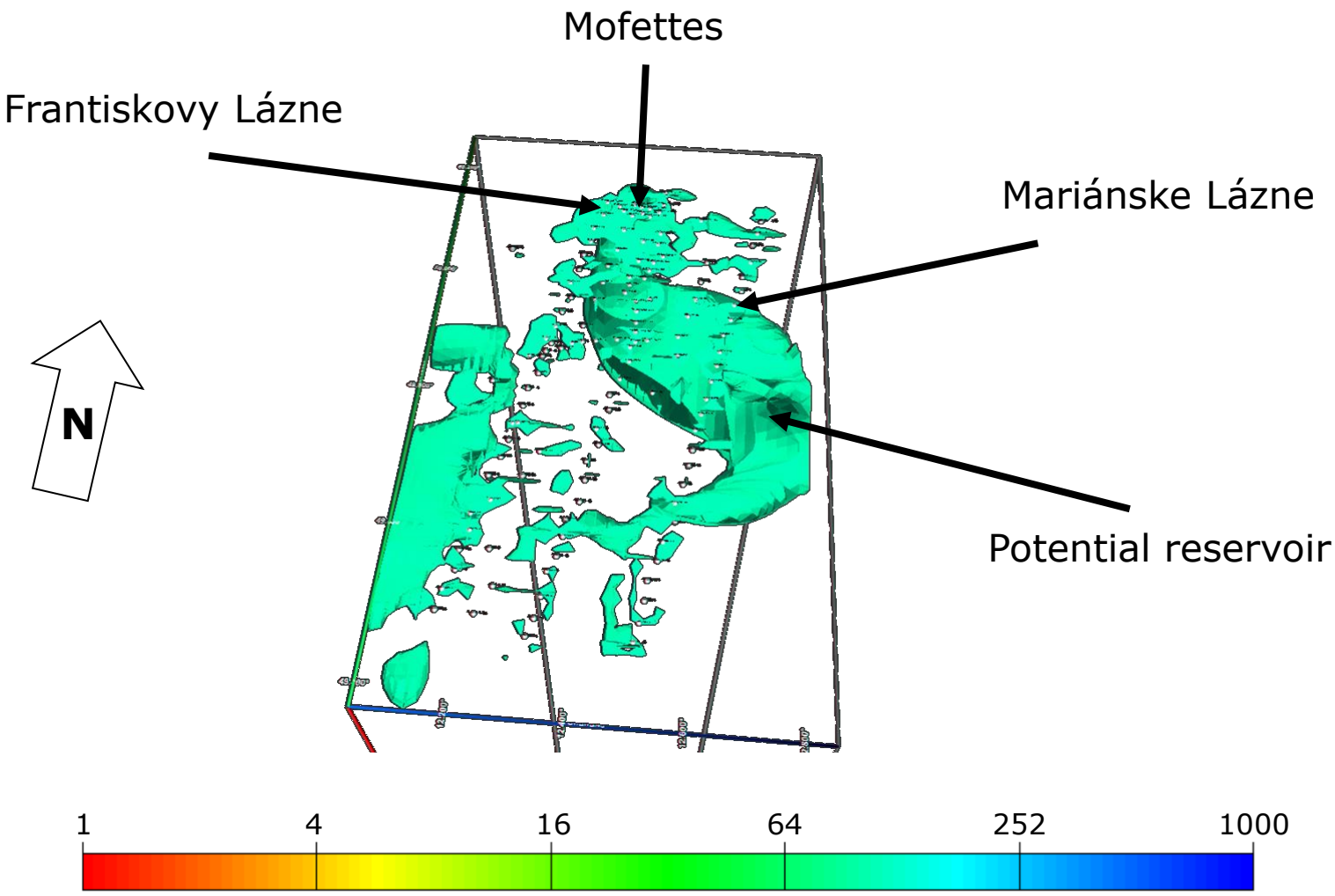
FL = Frantiskovy Lázne
ML = Mariánske Lázne
▲ = Quaternary volcanoes
★ = Mofettes

Cross-section along westernmost profile:

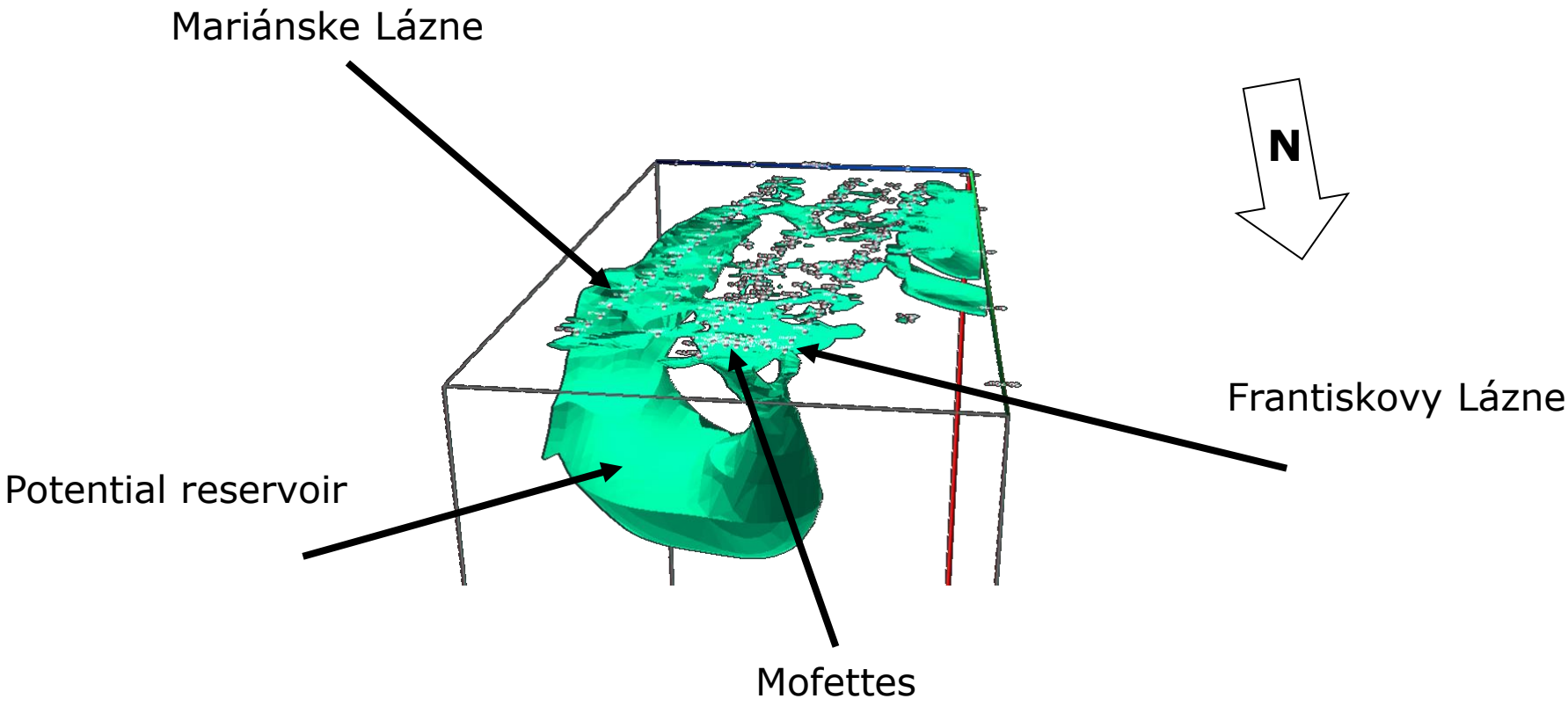




Isosurface plot of 100Ωm:



Isosurface plot of 100Ωm:



Summary:

- Good data quality of transfer functions due to extensive data processing with different processing approaches and advanced data selection tools
- Preliminary 3D model from joint inversion of impedance and vertical transfer functions:
  - Good data fit
  - Crystalline basement is resolved by high resistivities
  - Enhanced conductivities close to known mofettes and spa resorts (e.g. Mariánske Lázne)
  - Conductive channels are resolved to e.g. mofettes
  - Potential conductive reservoir in greater depths (~20-30km) is resolved

This work has been funded by the Deutsche Forschungsgemeinschaft (DFG) [grant WE2938/12-1].

References:

- Egbert, G. D. & Kelbert, A., 2012. Computational recipes for electromagnetic inverse problems. *Geophysical Journal International*, **189**(1), 251-267
- Kelbert, A., Meqbel, N., Egbert, G. D., & Tandon, K., 2014. ModEM: A modular system for inversion of electromagnetic geophysical data. *Computers & Geosciences*, **66**, 40-53
- Krings, T., 2007. *The influence of Robust Statistics, Remote Reference, and Horizontal Magnetic Transfer Functions on data processing in Magnetotellurics*. Diploma thesis, University Muenster, Muenster
- Meqbel, N., 2009. *The electrical conductivity structure of the Dead Sea Basin derived from 2D and 3D inversion of magnetotelluric data*. PhD thesis, Freie Universität Berlin, Berlin
- Muñoz, G., Weckmann, U., Pek, J., Kováciková, S., & Klanica, R. 2018. Regional two-dimensional magnetotelluric profile in West Bohemia / Vogtland reveals deep conductive channel into the earthquake swarm region. *Tectonophysics,* **727**, 1-11
- Platz, A. & Weckmann, U. 2019. An automated new pre-selection tool for noisy Magnetotelluric data using the Mahalanobis distance and magnetic field constraints. *Geophysical Journal International,* **218**, 1853-1872
- Ritter, O., Muñoz, G., Weckmann, U., Klose, R., Rulff, P., Rettig, S., Müller-Brettschneider, C., Schüler, M., Willkommen, G., Eydam., D. (2015): Permanent Magnetotelluric Reference Station in Wittstock, Germany (Datasets). GFZ Data Services
- Ritter, O., Junge, A., & Dawes, G., 1998. New equipment and processing for magnetotelluric remote reference observations. *Geophysical Journal International*, **132**(3), 535-548
- Weckmann, U., Magunia, A., & Ritter, O., 2005. Efective noise separation for magnetotelluric single site data processing using a frequency domain selection scheme. *Geophysical Journal International*, **161**(3), 635-652