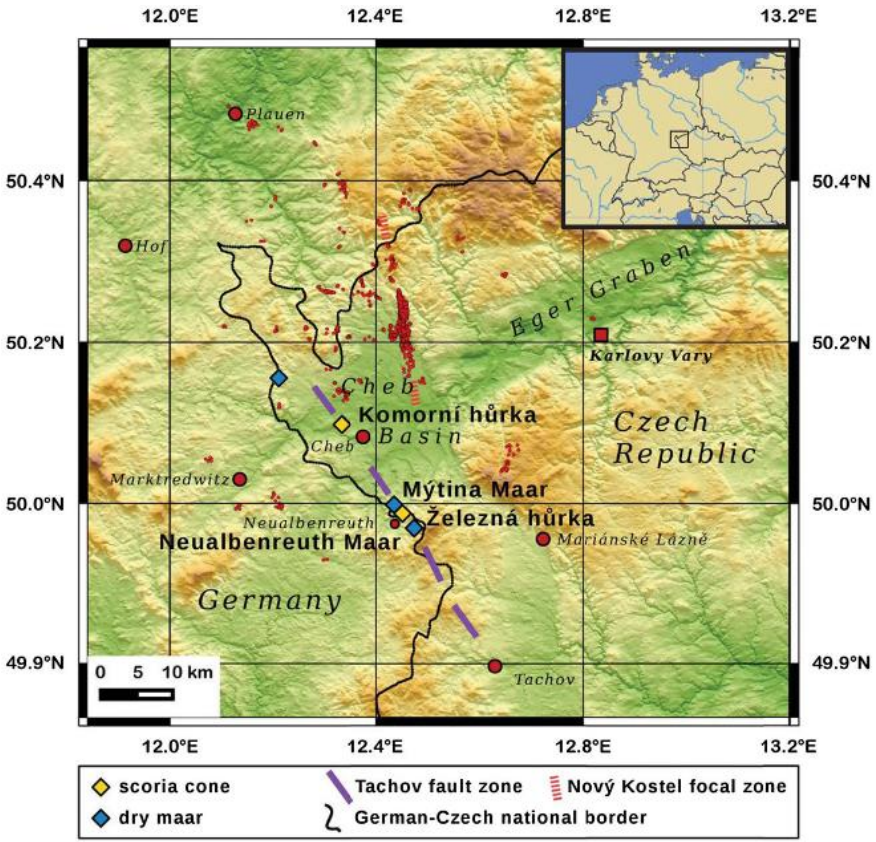
Near-surface conductivity structures of quaternary volcanic maars in the Western Bohemian Massif: 3D imaging using the Radio-Magnetotelluric method

G. Willkommen[1,2], R. Klanica[3], S. Kováciková[3], J. Mrlina[3], A. Platz[1], U.Weckmann[1,2]

[1] Helmholtz Centre Potsdam - German Research Centre for Geosciences GFZ, Potsdam, Germany
[2] Institute of Geosciences, University of Potsdam, Potsdam, Germany
[3] Department of Geodynamics, Institute of Geophysics of the Czech Academy of Science, Prague, Czech Republic

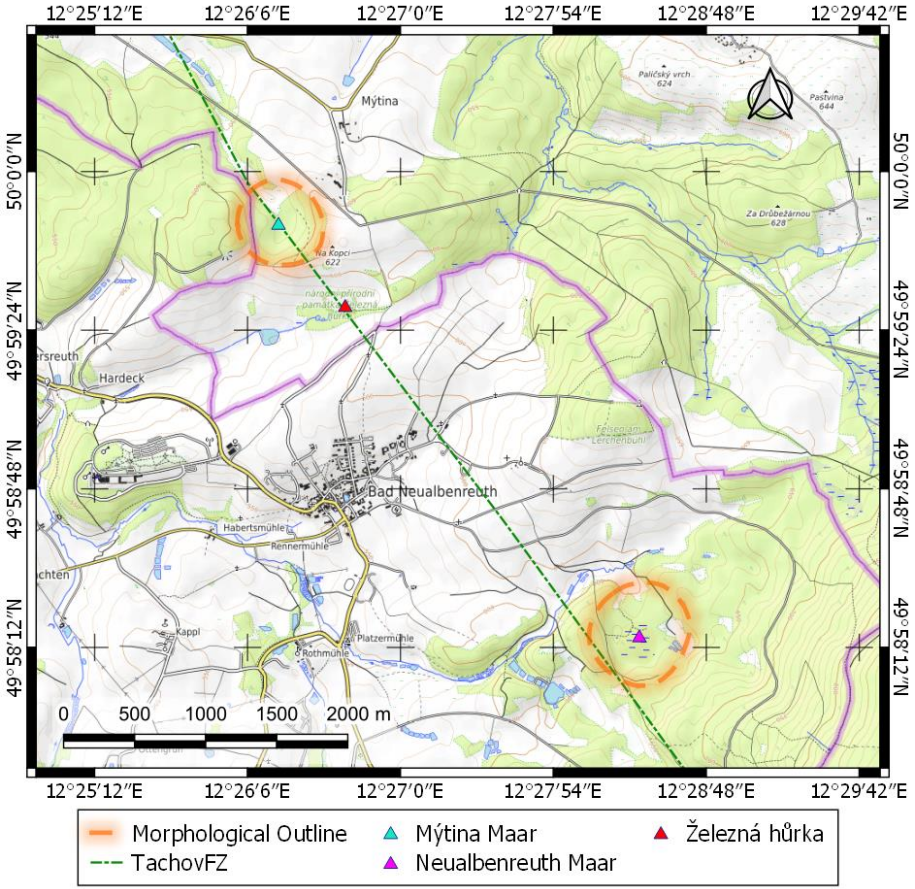
Motivation



Rohrmüller et. al., 2017

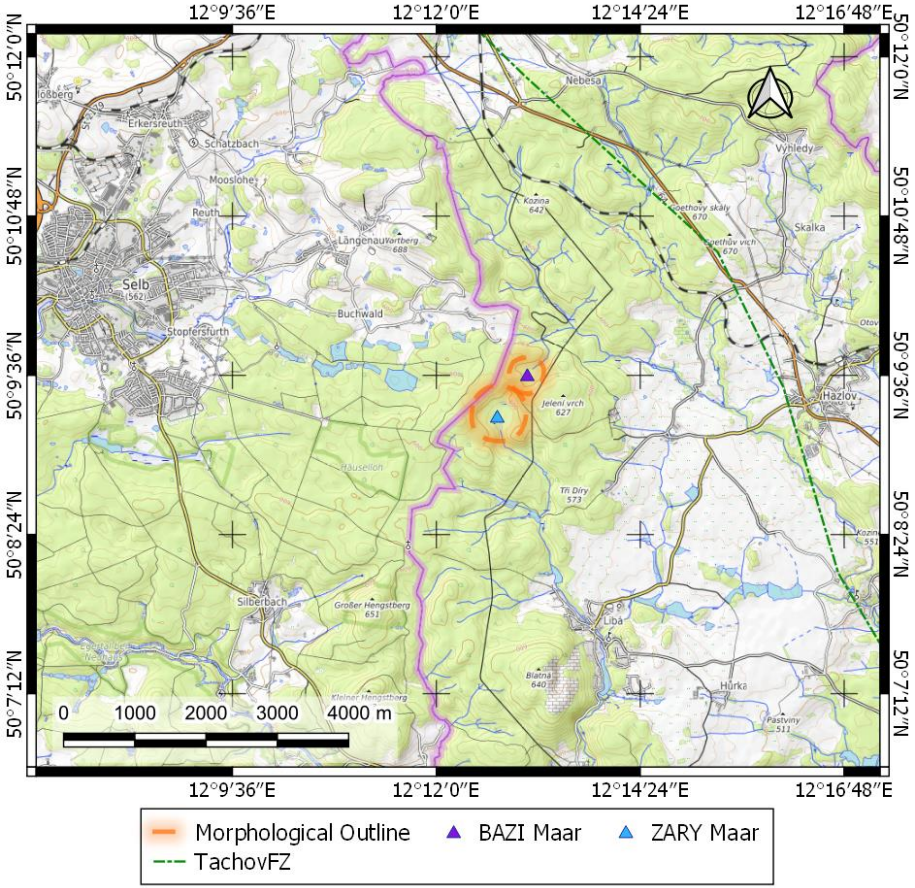
- The Cheb Basin is one of the most active areas of the European Cenozoic Rift System, characterized by degassing of mantle derived CO_2 in mofettes and mineral springs and by swarm earthquakes events near Nový Kostel.
- This geodynamic activity is driven by intra-continental magmatic processes originated in the lithospheric mantle.
- As part of the Bohemian Massif, the Cheb Basin is separated from the ENE-WSW striking Eger Rift to the west by the morphological prominent Mariánské Lázne Fault Zone (MLF) and has been formed during the Variscan orogeny.

Motivation



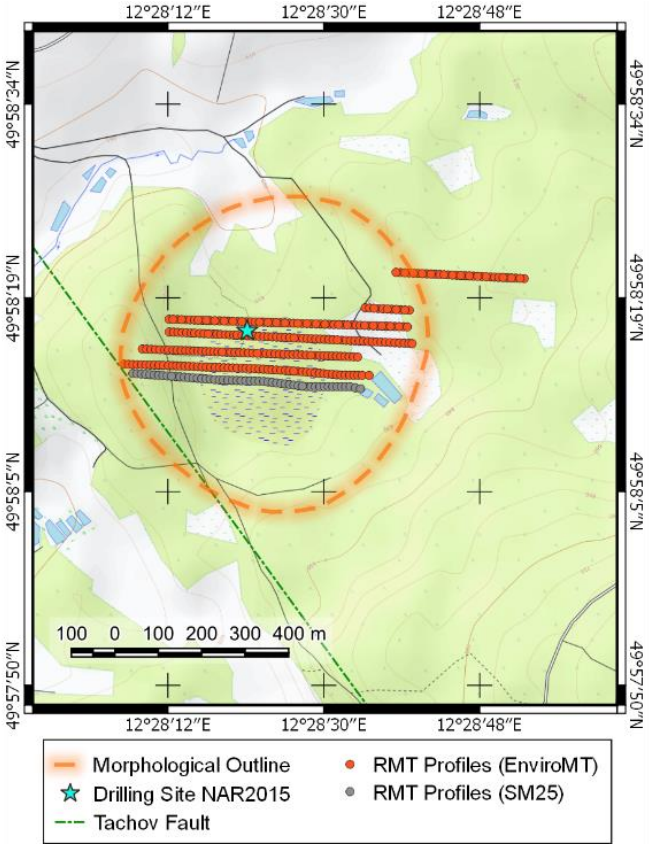
- Although there is no active volcanism at the surface, several quaternary volcanoes are known in the southern and in the western part of the Cheb Basin.
- Komorní hůrka near Cheb and Železná hůrka near Bad Neualbenreuth at the Czech-German Border are two scoria cones (Middle Pleisoscene, 0.7 – 0.3 Ma)
- In the vicinity of Komorní hůrka two maar structures has been found in the last 13 years: the Mýtina maar (CZ, 288 ± 17 ka, Mrlina et. al. 2007) and the Neualbenreuth maar (D, Rohrmüller et. al. 2017).
- These volcanoes are located along the Tachov fault zone.

Motivation



- Recently, two maar structures in the north-western part of the Cheb Basin were identified: the Ztracený Rybník maar and the Bažina maar (Hošek et. al., 2019; Mrlina et. al. 2019).
- An interdisciplinary Project "Drilling the Eger Rift“ within the international Continental Scientific Drilling Program (ICDP) targets the interactions between fluids, deep biosphere, CO_2 degassing and earthquake activity to shed light on the tectonic structure and related geodynamic processes.
- As a part of this project, Radio-Magnetotelluric (RMT) measurements were applied to image the near-surface electrical conductivity structure of these maar volcanoes.

Neualbenreuth Maar (NAR)



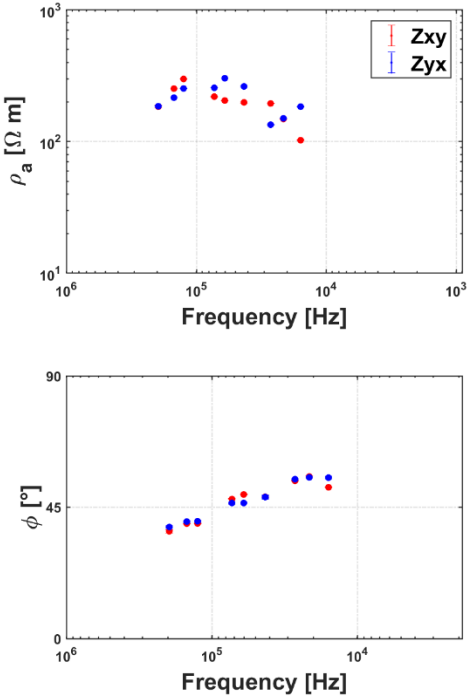
- In May 2018 we conducted a RMT field experiment across the Neualbenreuth maar. 5 profiles had a length of 450 – 550 m and a site spacing of 10 meters.
- To examine the hypothesis of a smaller maar structure next to the north-eastern rim (Rohrmüller et. al., 2017), 2 short additional profiles were measured.
- All sites were measured using the *EnviroMT* system, developed by the Uppsala University and METRONIX in 2001. This 5-component RMT system has a frequency range of 10 kHz – 250 kHz.
- An additional RMT system was used. Due to technical issues, the data recorded by this system could not be used.

EnviroMT system

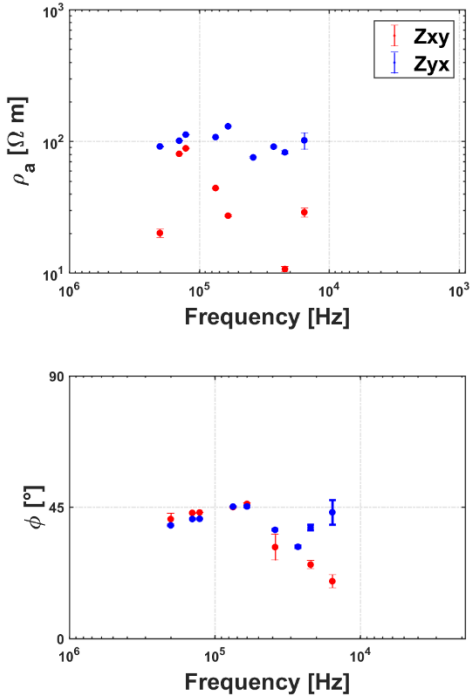
NAR – Data Examples (EnviroMT)

- The *EnviroMT* system has an internal bivariate processing, that stores full impedance tensor data. It is not possible to store time series data.
- The overall data quality of the internal processing was good. Between 15 and 30 radio transmitters could be used for data processing. Only few stations had poor data quality (e.g. station 413).
- Obvious outliers were removed manually prior to the inversion.

Station 230



Station 413

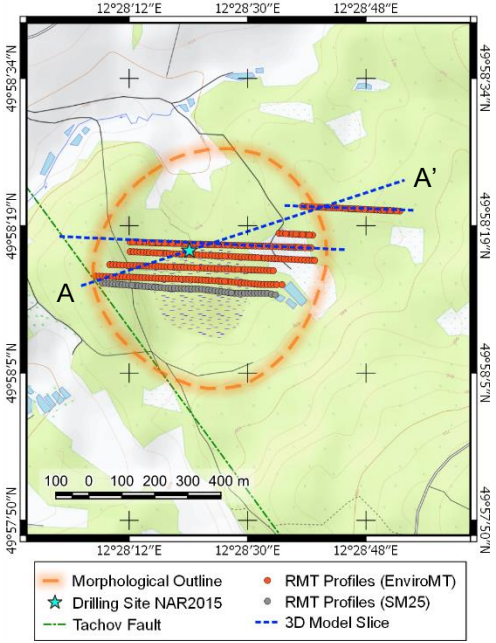


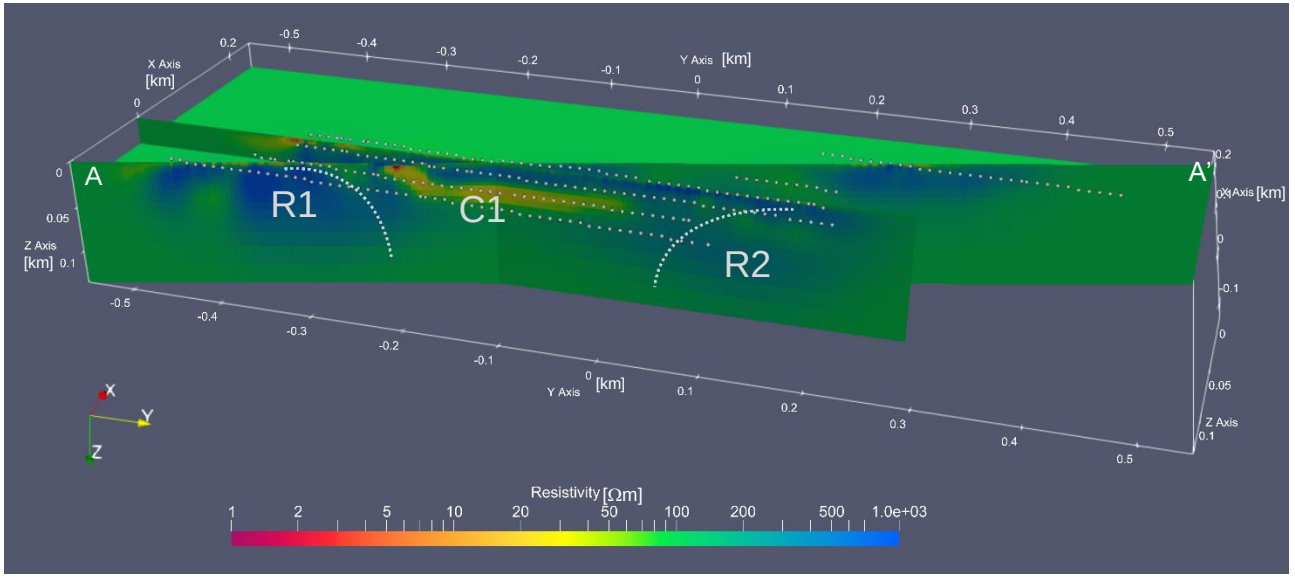
NAR – 3D Inversion (10-250 kHz)

- The inversion and modelling code *ModEM* (Meqbel, 2009; Egbert and Kelbert, 2012; Kelbert et. al., 2014) was used for 3D inversion.
- Different grid discretisations, starting models and error settings were tested.
- Impedances and vertical magnetic transfer functions were inverted together.
- Model grid:
  - 120 x 240 horizontal cells with a size of 5x5 m; 20 padding cells with an increasing factor of 1.3 in each direction.
  - 60 vertical cells with an increasing factor of 1.2. The first layer thickness is 50 cm.
  - Starting model: 100 Ωm halfspace
  - Error floor: 50% on $\sqrt{|Z_{ii}Z_{ij}|}$ for Z_{xx} and Z_{yy}
    5% on $|Zij|$ for Z_{xy} and Z_{yx}
    5% on T_{zx} and T_{zy}

NAR – 3D Inversion (10-250 kHz)

Neualbenreuth Maar

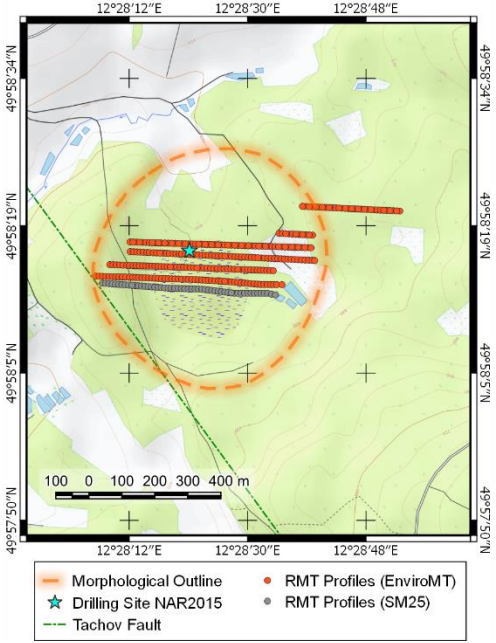


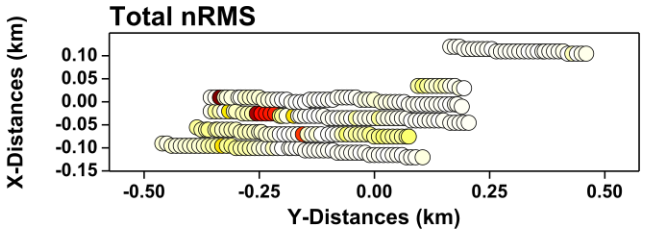


- The conductive formation C1 (< 100 Ωm) in the center of the maar diatreme shows the extent of the sedimentary infill.
- The surrounding host rocks, quartzitic phyllites and mica schists have higher resistivities of more than 500 Ωm (R1, R2).

RMS

Neualbenreuth Maar

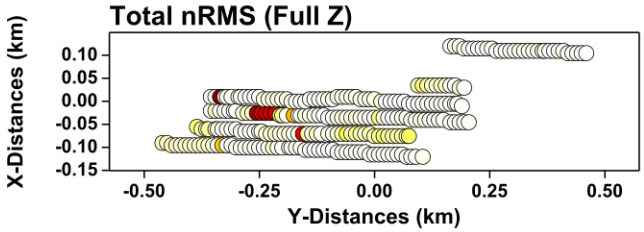


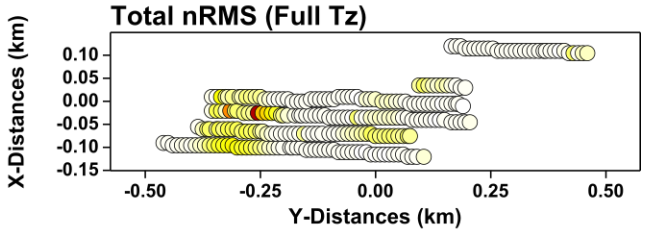


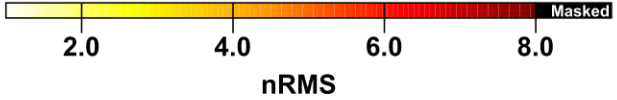
Overall nRMS = 1.68

Z nRMS = 1.78

T nRMS = 1.47





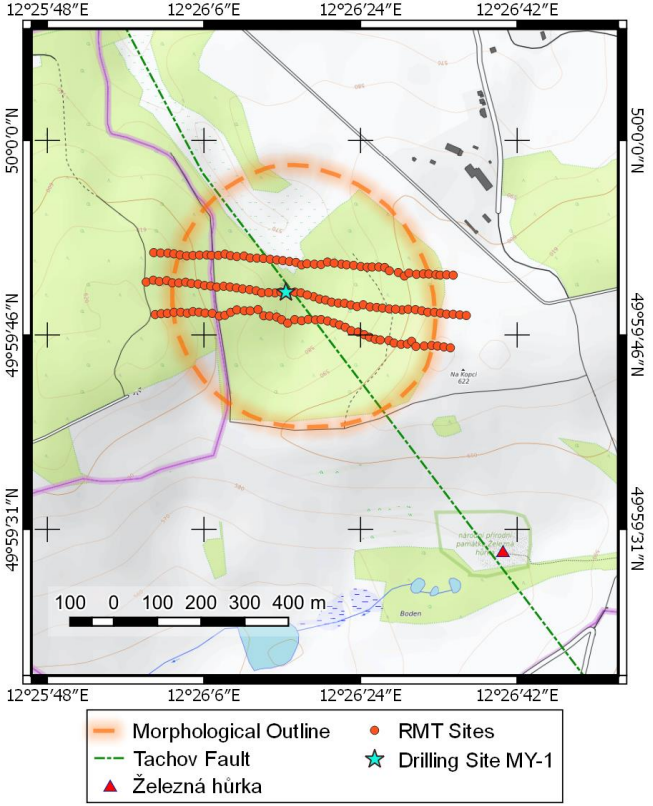


- Overall RMS decreased from 6.47 to 1.79 after 58 iterations

NAR - Conclusion

- **Neualbenreuth maar inversion results:**
  - The conductivity structure in the northern part of the maar structure is well resolved.
  - The lateral extent of the diatreme is 250 – 300 m.
  - 3D model corresponds well to the the lithological profile of the drilling site NAR 2015.
  - The lack of stations over the southern part does allow conclusions for the area beyond our profiles.
  - Good data fit.
  - There is no indication of a small maar-like structure to the north-west of the NAR maar.

Mýtina Maar (MYT)



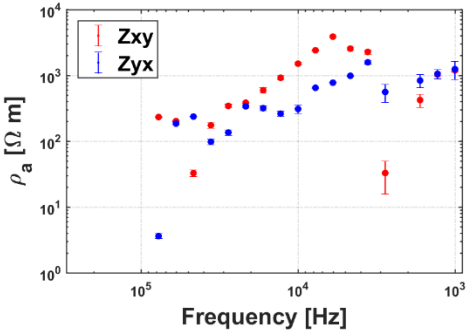
- End of November 2018 we conducted a RMT field experiment across the Mýtina maar. 3 profiles had a length of approximately 700 m and a site spacing of 15 meters.
- All sites were measured using the *MK5-SM25* system, developed by St. Petersburg University and MICROCOR in 2005 - 2015. This 5-component RMT system has a frequency range of 1 kHz – 1000 kHz.
- Data is recorded in 3 bands (1 – 10 kHz, 10 – 100 kHz and 100 – 1000 kHz) and stored as time series.

MK5-SM25 system

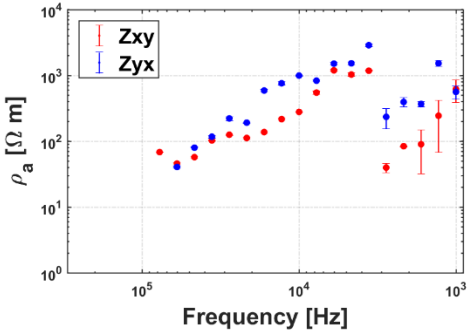
MYT – Data Examples (SM25)

- The data were processed using the *EMERALD* processing suite (Ritter et. al., 1998; Weckmann et. al., 2005; Krings, 2007)
- The initial data quality was rather poor. A longer fft window length of 16384 samples and the application of the Mahalanobis distance as an advanced data selection criteria (Platz & Weckmann, 2019) improved the data quality.
- Due to the lack of radio transmitters below 10 kHz, we had to exclude the frequency range from 1 – 10 kHz at most sites.
- We also had to remove the frequency range 250 kHz – 1 GHz at most sites, as there were too few radio transmitter for a bivariate processing.
- Obvious outliers were removed manually prior to the inversion.

Station 202



Station 337

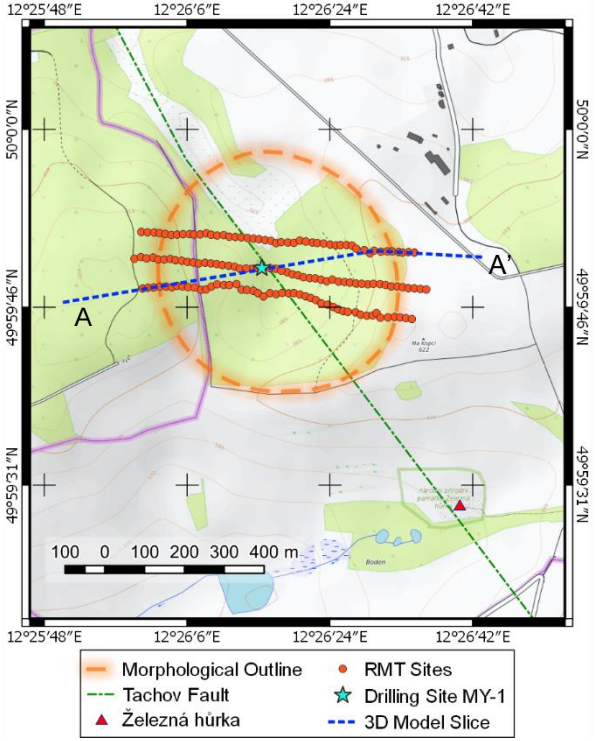


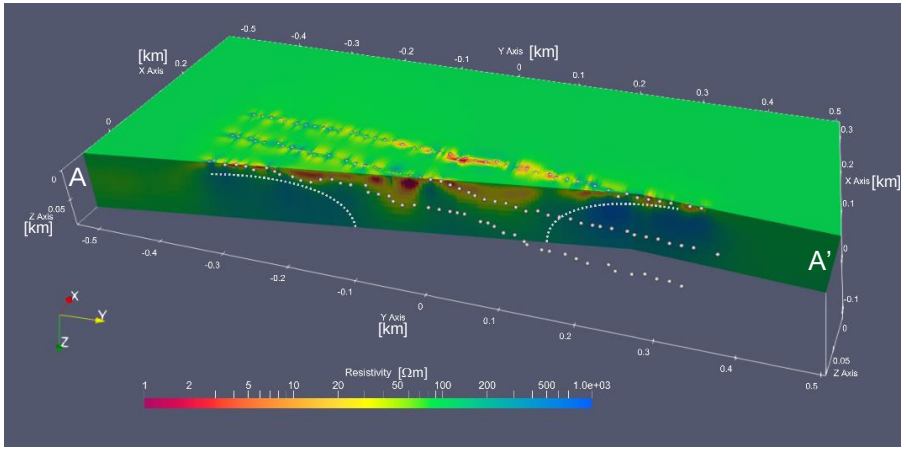
MYT – 3D Inversion (1-250 kHz)

- The inversion and modelling code ModEM (Meqbel, 2009; Egbert and Kelbert, 2012; Kelbert et. al., 2014) was used for 3D inversion.
- Different grid discretisations, starting models and error settings were tested.
- Only impedances were inverted so far.
- Model grid:
  - 60 x 180 horizontal cells with a size of 5x5 m; 20 padding cells with an increasing factor of 1.3 in each direction.
  - 50 vertical cells with an increasing factor of 1.2. The first layer thickness is 50 cm.
  - Starting model: 100 Ωm halfspace
  - Error floor: 50% on $\sqrt{|Z_{ii}Z_{ij}|}$ for Z_{xx} and Z_{yy}
    5% on $|Zij|$ for Z_{xy} and Z_{yx}
    5% on T_{zx} and T_{zy}

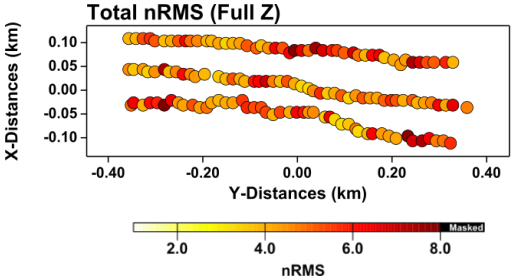
MYT – 3D Inversion (10-250 kHz)

Mýtina Maar





- It is more difficult to distinguish the conductive sedimentary infill (C1) from the surrounding quartzitic phyllites and mica schists (R1/R2). The transition between the conductive sediments and the resistive host rocks seems to be smoother than in NAR.
- A very shallow layer with very high conductivities can be seen. This layer corresponds to the a magnetic anomaly within MYT (Mrlina et al., 2009).

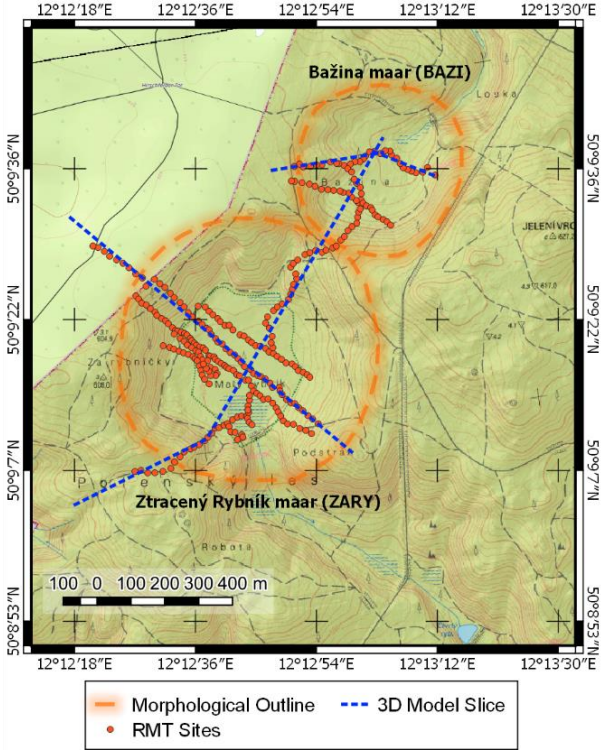


- Overall RMS decreased from 15.2 to 4.32 after 77 iterations

MYT - Conclusion

- **Mýtina maar inversion results:**
  - Conductivity structure of the maar could not be resolved well
  - Shallow layer with very high conductivities
  - Smooth transition between the host rocks and sediments compared to the other maars.
  - Data processing and inversion have to be improved
  - Bad data fit

Ztracený Rybník Maar (ZARY) & Bažina Maar (BAZI)



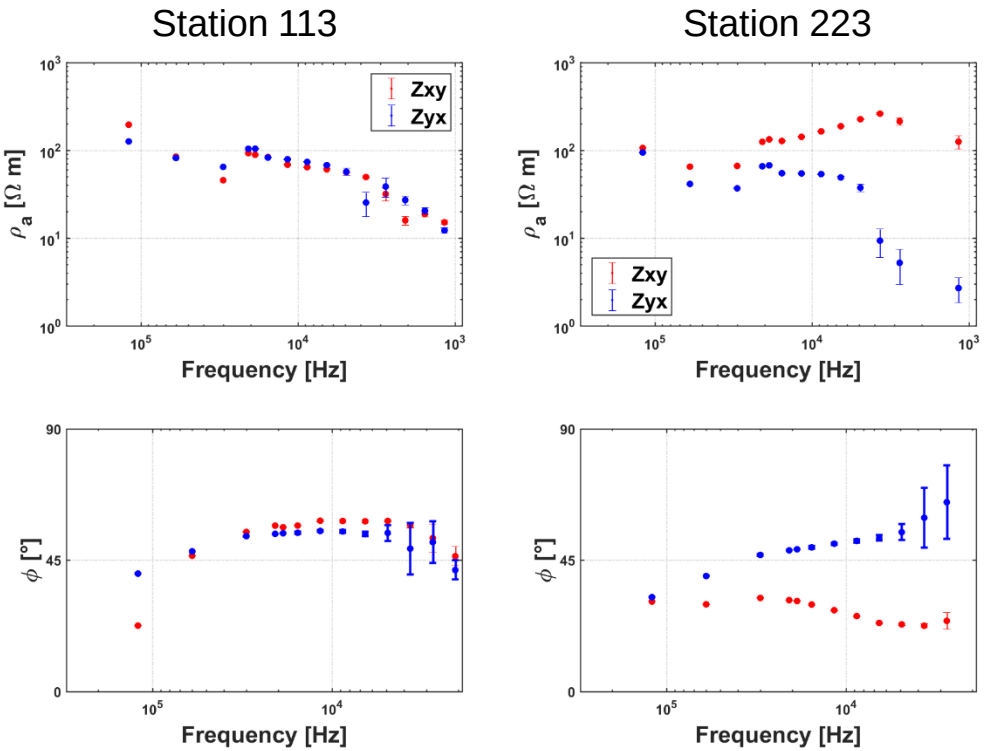
- In September 2019 we conducted a RMT field experiment across the Ztracený Rybník Maar (ZARY) and the Bažina Maar (BAZI)
- 5 profiles across ZARY and 2 profiles across BAZI had a length of 400 - 900 m and a site spacing of 15 meters. A 1300 m long profile perpendicular to the other profiles crossed both maar structures.
- All sites were recorded using a Metronix ADU-08e data logger, a 24/32 bit EM datalogger with 5 components and a Metronix SHFT-02e magnetometer, consisting of three induction coils with a frequency range of 1 kHz – 250 kHz.
- Data is stored as time series with a length of 10 seconds.

ADU-08e

SHFT-02e

ZARY/BAZI – Data Examples (ADU-08e)

- The data were processed using the *EMERALD* processing suite (Ritter et. al., 1998; Weckmann et. al., 2005; Krings, 2007)
- The processing was similar to the *MK5-SM25* data. We used a fft window length of 4096 samples. The application of the Mahalanobis distance could not improve the data quality.
- Frequencies below 7 kHz were excluded.
- Obvious outliers were removed manually prior to the inversion.

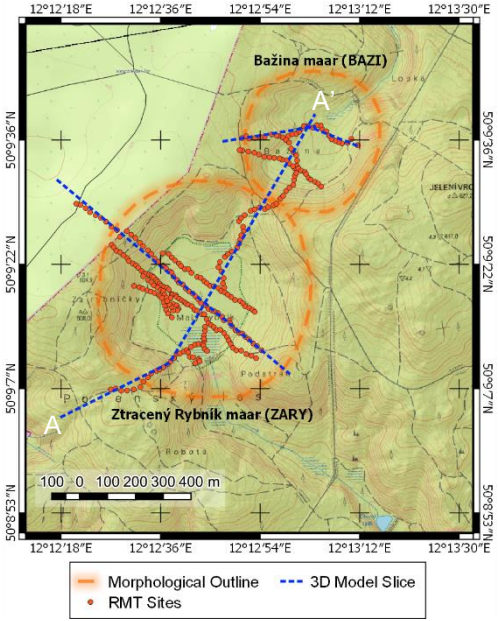


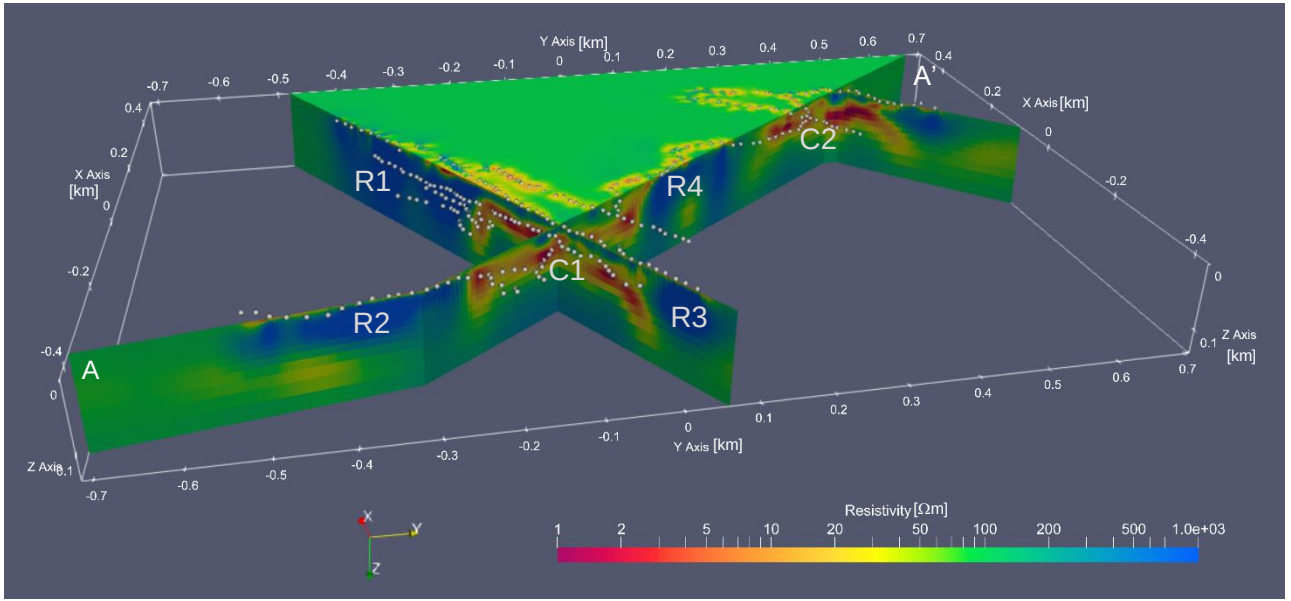
ZARY/BAZI – 3D Inversion (1-250 kHz)

- The inversion and modelling code ModEM (Meqbel, 2009; Egbert and Kelbert, 2012; Kelbert et. al., 2014) was used for 3D inversion.
- Different grid discretisations, starting models and error settings were tested.
- Impedances and vertical magnetic transfer functions were inverted together.
- Model grid:
  - 180 x 260 horizontal cells with a size of 5x5 m; 20 padding cells with an increasing factor of 1.3 in each direction.
  - 46 vertical cells with an increasing factor of 1.2. The first layer thickness is 50 cm.
  - Starting model: 100 Ωm halfspace
  - Error floor: 50% on $\sqrt{|Z_{ii}Z_{ij}|}$ for Z_{xx} and Z_{yy}
    5% on $|Zij|$ for Z_{xy} and Z_{yx}
    5% on T_{zx} and T_{zy}

ZARY/BAZI – 3D Inversion (1-250 kHz)

Ztracený Rybník Maar
Bažina Maar

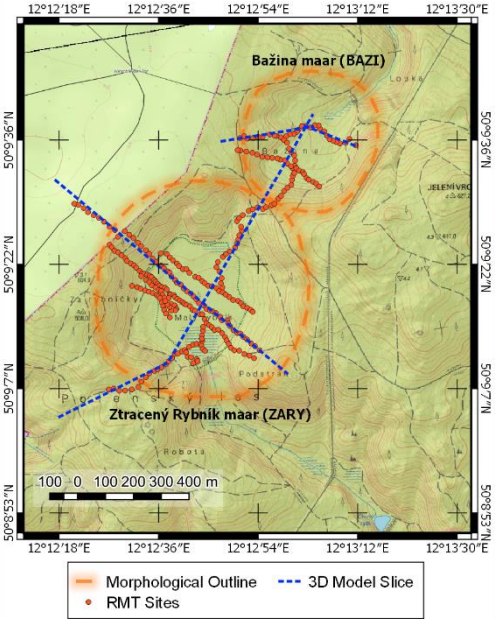




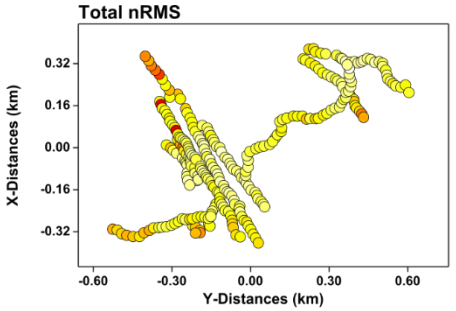
- The contrast between the host rock (granite, R1-R4) and the sedimentary infill of the maar diatreme is obvious. The transition is very sharp. While the granite has very high resistivities of more than 1000 Ωm, the sediments is extremely conductive close to 1 Ωm (C1/C2).

RMS

Ztracený Rybník Maar
Bažina Maar



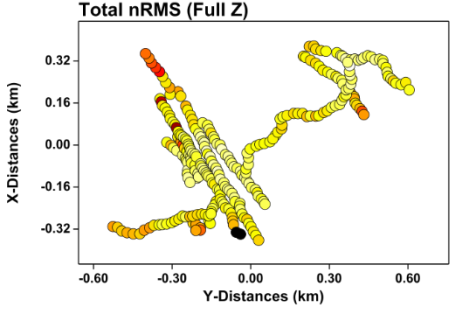
- Overall RMS decreased from 9.96 to 2.60 after 77 iterations

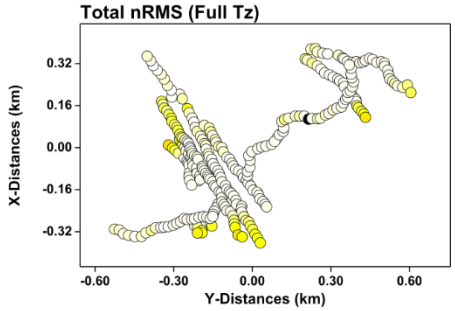


Overall nRMS = 2.60

Z nRMS = 2.87

T nRMS = 1.36





ZARY/BAZI – Conclusion

- **ZARY/BAZI maar inversion results:**
  - The conductivity structure of the maar structure is well resolved.
  - Very sharp contrasts between resistive host rock and sedimentary infill of the maar diatreme
  - Lateral resolution is very good
  - The areal site distribution allow conclusions for large parts of both maar structures.
  - The lateral extent of the Ztracený Rybník maar diatreme is approximately 400 m.
  - Data quality is lower than in Neualbenreuth
  - The depth of investigation below the high conductive layer (< 5 Ωm) is limited. The depth of the lower boundary of the sedimentary infill is uncertain.

ICDP core drilling project

- An ICDP core drilling is planned to recover the sedimentary infill of the maar diatreme.
- The lithological profile can act as a paleoclimatic calendar of the Quaternary period.
- Several factors are decisive:
  - An undisturbed sedimentary layering within the diatreme, that covers a long aggregational period. Here, the lower boundary of the sedimentary infill is a good indicator.
  - The lowest possible age of the top sediments.
  - A good access to the drilling site and low administrative barriers.

- The clear conductivity structures suggests a drilling in BAZI or ZARY or a deeper drilling next to the existing drilling in the Neualbenreuth maar.
- The lower boundary of the diatreme infills is not well resolved by RMT.

Summary

Conclusion

- **Neualbenreuth maar inversion results:**
  - The conductivity structure is well resolved.
  - Lateral extent of the diatreme is 250 – 300 m
  - Good data fit
- **Mýtina maar inversion results:**
  - Conductivity structure of the maar is not well resolved
  - Bad data fit
- **ZARY/BAZI maar inversion results:**
  - Data quality is lower than in Neualbenreuth
  - Very sharp contrasts between resistive host rock and sedimentary infill of the maar diatreme
  - Lateral resolution is very good, the extent of the ZARY diatreme is approx. 400 m
- **ICDP drilling project:**
  - A deep drilling within NAR, BAZI or ZARY maar is preferred by the well known conductivity structure.
  - The lower boundary of the diatreme infills is not well resolved by RMT.

Outlook

- Improving data processing and inversion of Mýtina data
- Joint inversion of Z and VTF for Mýtina data
- Improve RMT filtering and processing of SM25-timeseries data (Mýtina Maar)
- Combine RMT data with short period MT data

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Thank You!

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GFZ Helmholtz Centre Potsdam

HELMHOLTZ