Results from the DESMEX semi-airborne EM survey at the Gosetal/Rammelsberg (Harz Mountains, Germany)

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SUMMARY

The nowadays depleted world-class SEDEX Rammelsberg deposit and its adjacent areas are a prime location to test and demonstrate new geophysical exploration methods. Here, we present preliminary results of a semi-airborne EM survey centered at the Gosetal and the Rammelsberg, which was conducted in September 2020 as part of the DESMEX II project. Previous airborne EM exploration surveys, carried out about a decade ago in that area, revealed a high-conductivity anomaly in the Gosetal, but subsequent drillings could not verify its existence. Therefore, the results of the airborne EM survey remained enigmatic. Semi-airborne EM has the potential to image deeper than pure airborne EM and may detect conductivity anomalies from the near surface to about $1000\,m$, including a possibly deeper root of the enigmatic Gosetal anomaly.

We installed four electrical dipole transmitters of 2-$3\,km$ length and injected an alternating current with a fundamental frequency of 9.26 and $4.63\,Hz$ and covered an area of about $45\,km^2$ with the Helicopter induction coil DESMEX system. EM Transfer functions were derived in the frequency range up to $4\,kHz$. Analysis of the data is complicated due to the presence of steep topography and over $500\,m$ altitude differences in the surveyed area. Synthetic 3D modeling using the unstructured finite element code custEM shows that strong topographic effects are evident in the collected data and must thus be taken into account in any inversion. We discuss these effects as well as topography correction schemes for flat surface inversion models based on normal field corrections. Ongoing work is focused on comparison of 3D inversion applying the custEM code supporting complex survey geometry and the 3DINV code using corrected data on a flat surface model.

Keywords: semi-airborne electromagnetics; Rammelsberg mine; electrical resistivity; topography effects

INTRODUCTION

The Harz Mountains (Germany) are widely known for its long mining history. One of the outstanding sites in the Upper Harz Mountains is the Rammelsberg mine, a world-class SEDEX (sediment exhalative) deposit highly enriched in Zn- and Pb-sulfides (Large and Walcher, 1999). Nowadays, the mine is fully exploited but past airborne EM surveys revealed a shallow high-conductive anomaly in the adjacent Gosetal. However, subsequent drillings up to $500\,m$ depth could not verify the existence of an ore body and the Gosetal-anomaly remained enigmatic. Considering the mining background of this region, it is perfectly suited as location for a demonstration survey for novel geophysical exploration methods. The DESMEX project seeks to develop and establish such methods, including semi-airborne electromagnetics (EM), for exploration of deep-seated ore bodies. Previous DESMEX surveys (Smirnova et al, 2019, 2020) demonstrate the capability of semi-airborne EM in flat terrain. The Gosetal area features high altitude differences of more than $500\,m$ and very steep valleys making the location a challenging environment for EM data evaluation.

The Gosetal survey was conducted in September 2020. Four grounded dipole transmitters (Tx) of 2-$3\,km$ length were installed in the survey area (see Figure 1). We injected a rectangular current waveform with fundamental frequencies at $9.26\,Hz$ (Tx1, Tx2), $4.63\,Hz$ (Tx3) and $9.6\,Hz$ (Tx4) and a $100\,\%$ duty cycle. Flight areas were chosen for each Tx individually and with an overlapping area at the survey target. Tx were operated sequentially and flight lines are $250\,m$ apart and control lines have $1\,km$ spacing.

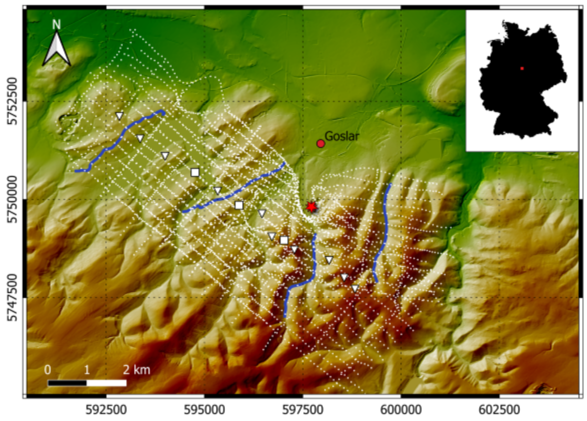

Figure 1: Survey Area: Blue lines show Tx locations (Tx1 to Tx4 from NW to SE), white dotted lines depict flight lines. Triangles and squares mark telluric and full-MT ground site positions. The red star shows the position of the Rammelsberg mine.

THE SEMI-AIRBORNE EM METHOD AND TRANSFER FUNCTIONS

The semi-airborne EM method combines advantages of purely airborne and purely ground-based controlled source EM methods. Using a powerful ground-based Tx, the method provides a great penetration depth of up to $1000\,m$ while maintaining the high efficiency and spatial resolution of an airborne system.

The injected current induces a magnetic field consisting of the normal field produced in a homogeneous halfspace and the anomalous field produced by anomalies therein. A linear relation can be stated between the observed magnetic flux density ($\vec{B}(\omega,\vec{r})$) and current amperage ($I(\omega)$) recordings

$$\vec{B}(\omega,\vec{r}) = \vec{\mathcal{B}}(\omega,\vec{r})I(\omega) \tag{1}$$

where ω is the angular frequency and $\vec{r}$ denotes the point in space. The transfer function $\vec{\mathcal{B}}$ relates both quantities and holds information about the subsurface conductivity structure.

Transfer functions were estimated in the frequency range up to $4\,kHz$ following the procedure described by Becken et al (2020). Figure 3 shows amplitudes of transfer function estimates at three different frequencies along a coincident flight line for Tx1 to Tx3. The amplitudes produced by Tx2 and Tx3 decrease abruptly at all frequencies when crossing the Gosetal which indicates a conductive anomaly in the valley.

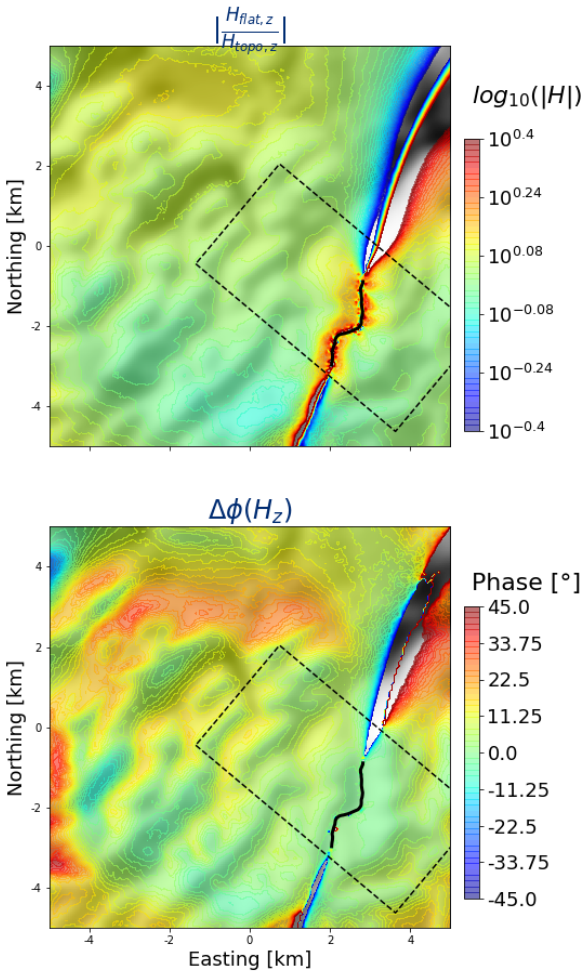

Figure 2: Amplitude ratio (top) and phase difference (bottom) of normal field responses ($\mathcal{B}_z$) for Tx3 (black line) received from models with and without topography using an electrical resistivity of $500\,\Omega m$. The dashed line gives the corresponding flight area.

TOPOGRAPHIC EFFECTS AND PRELIMINARY INVERSION RESULTS

The semi-airborne EM data are strongly distorted by topography (see Figure 2). A comparison of simulated transfer functions of models with and without topography imply distinct differences even aside from the vicinity of the Tx and zero crossings. Calculated phase differences of $> 10°$ are in the same order of magnitude as field variations produced by anomalies and thus need to be taken into account for inversion.

Only few open source inversion codes can handle semi-airborne EM data and mostly do not allow for complex survey geometry such as in the Harz Mountains. Preliminary 3D inversion results are shown in Figure 4. We used the finite difference code 3DINV (Grayver et al, 2013) which only supports flat surface models. To reduce topography effects on the data, we applied a Normal Field Correction that substitutes the normal field $\vec{\mathcal{B}}_{topo}$ of a homogeneous half space with topography by the normal field $\vec{\mathcal{B}}_{flat}$ of a half space with a flat surface.

$$\vec{\mathcal{B}}_{inv} = \vec{\mathcal{B}}_{obs} - \vec{\mathcal{B}}_{topo} + \vec{\mathcal{B}}_{flat} \tag{2}$$

The residual $\vec{\mathcal{B}}_{inv}$ still includes topographic effects but these are expected to be less dominant. We estimated the normal field response of $\vec{\mathcal{B}}_{topo}$ and $\vec{\mathcal{B}}_{flat}$ using the unstructured finite element code custEM (Rochlitz et al, 2019) for $500\,\Omega m$ electrical resistivity. Corrected transfer functions $\mathcal{B}_{inv,z}$ were used as inversion input in a frequency range of 9 to $1000\,Hz$. The model box had a size of $9\,\times\,15\,\times\,4.02\,km$ plus padding cells with a $500\,\Omega m$ halfspace as starting model. The model was rotated to fit the general strike direction of $45°$. Data with a relative error $>\,20\%$ and in the vicinity of the Tx were masked. A RMS of 1.48 was reached after 10 iterations.

Inversion results indicate a 500 to $1000\,m$ deep conductor in the Gosetal slightly dipping to SE direction (**A** in Figure 4). However, the conductor is not a unique feature as assumed from raw data. Strong anomalies in the vicinity of the transmitter (**B**) as well as conductors following the structure of valleys (**C**) indicate incomplete topography correction. Other anomalies (**D**) seem to be artefacts placed at the model edges with low data point coverage and low sensitivity.

CONCLUSIONS

We conducted a semi-airborne EM survey in the mining area Rammelsberg (Harz Mounatins, Germany). Estimated transfer functions indicate the presence of a conductive anomaly in the adjacent Gosetal. Analysis of the data is complicated, though, by the presence of steep topography that needs to be taken into account. Available 3D inversion codes only support flat surface models so we tested a Normal Field Correction to reduce topography effects. Preliminary results using corrected data show a good conductor in the Gosetal at 500 to $1000\,m$ depth but remaining topography effects can lead to artefacts. Ongoing work is focused on 3D inversion using the unstructured finite element code custEM that was recently extended to perform inversions.

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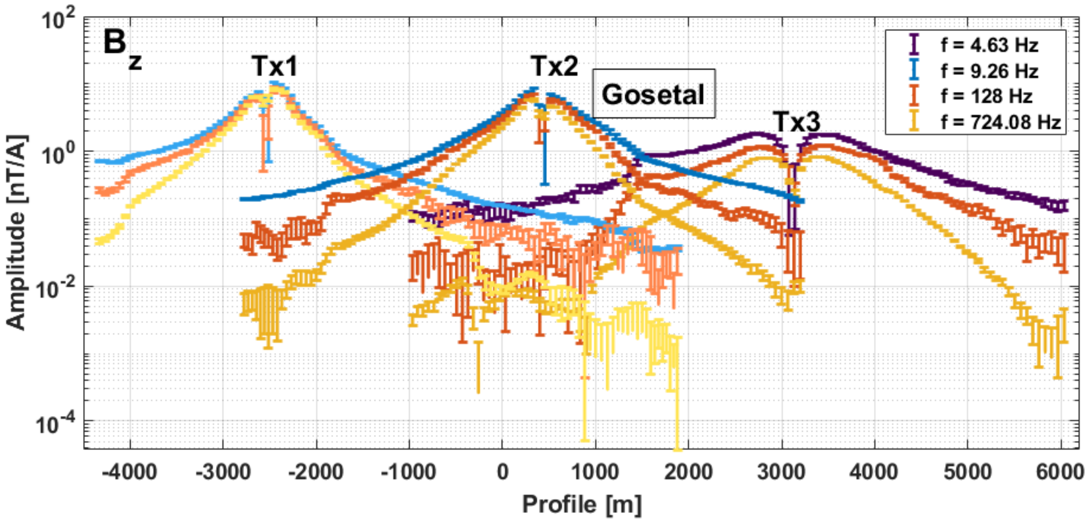

Figure 3: Amplitude of the $\mathcal{B}_z$ magnetic transfer function at Tx1 (light color), Tx2 and Tx3 (dark color). The lowermost frequency of Tx3 differs from the ones at Tx1 and Tx2 due to different base frequencies.

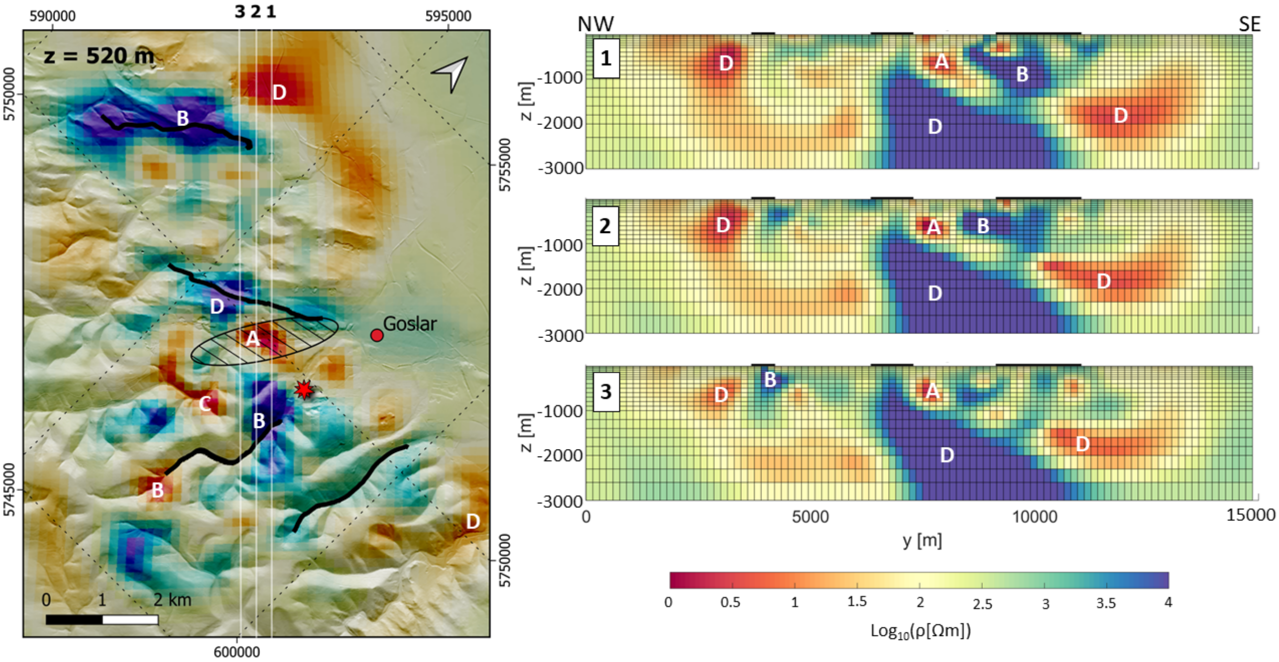

Figure 4: Horizontal slice (left panel) and cross sections (right panels) of the inversion results using normal field corrected data. The horizontal slice is shown on a topographic map to compare conductivity structures and mountain shapes. The hatched area and the red star mark the Gosetal and the Rammelsberg mine, respectively. Black lines show Tx positions.