# DESMEX airborne natural source EM demonstration survey in Gobabis (Namibia) using the three-component QAMT system

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## SUMMARY

Within the last decades, the search for ore deposits has become increasingly relevant. Likewise, the need for powerful exploration methods capable of detecting even deep-seated targets has risen. Since ore deposits are often characterised by good conductivity, airborne electromagnetic (EM) methods offer an efficient way for exploration in large-scale remote and even inaccessible terrain. Among those, airborne natural source EM has the potential of great penetration depth due to the far field source geometry using natural signal of atmospheric origin.

As part of the DESMEX project series, we optimized the QAMT helicopter platform to meet airborne natural source EM requirements. Furthermore, we developed a robust multivariate processing code and implemented the option for natural source EM inversion in the custEM code. For demonstration, we conducted an airborne natural source EM survey in the Kalahari-Copper-Belt (Gobabis, Namibia) covering over $1000$ km$^2$. We obtained spatially consistent and smooth sounding curves in a frequency range of $10$ to $1000$ Hz. Preliminary inversion results are in good agreement with other geophysical and geological information.

**Keywords:** Airborne natural source EM, Audio-frequency magnetics, Mineral exploration, Namibia, Kalahari-Copper-Belt

## INTRODUCTION

As deep-seated ore deposits become increasingly relevant for mineral exploration, the demand for time-efficient and powerful deep-sounding exploration methods rises. A suitable method for efficiently sensing ores at great depth is airborne electromagnetics (EM) using natural signal of atmospheric origin. The method relates airborne magnetic field recordings in the audio-frequency range to reference magnetic field recordings measured at a ground-based site and can achieve greater penetration depths when compared to controlled source airborne EM techniques.

Airborne natural source EM data are analysed in terms of frequency-dependent transfer functions relating the airborne magnetic flux density ($B^{air}$-field) recordings to ground-based (superscript $gr$) horizontal $B$-field data.

$$\begin{bmatrix} B_x^{air}(\omega) \\ B_y^{air}(\omega) \\ B_z^{air}(\omega) \end{bmatrix} = \begin{bmatrix} M_{xx}(\omega) & M_{xy}(\omega) \\ M_{yx}(\omega) & M_{yy}(\omega) \\ T_{zx}(\omega) & T_{zy}(\omega) \end{bmatrix} \begin{bmatrix} B_x^{gr}(\omega) & B_y^{gr}(\omega) \end{bmatrix} \tag{1}$$

Here, $\omega$ represents the angular frequency. Typically, the transfer function components are split into horizontal magnetic tensor $\mathbf{M}$ relating the horizontal components and vertical magnetic transfer function $\mathbf{T}$, relating vertical airborne to horizontal ground-based data. For graphical depiction we use induction arrows for $\mathbf{T}$ and quantity $\Re(M_a)$

$$M_a = \sum_{ij} M_{ij}^2 - 2, \tag{2}$$

which roughly approximates the vertical energy flux of the anomalous $B$-field (Thiede et al, 2024).

Within the DESMEX project series, we aim for advances in deep-penetrating airborne EM methods such as airborne natural source EM regarding instrumentation, processing and inversion. First focusing on the semi-airborne EM approach, the QAMT platform (Stolz et al, 2022) and the custEM toolbox (Rochlitz et al, 2023) have been developed and consistently improved/refined, now being able to meet airborne natural source EM requirements. A multivariate processing algorithm adapted to airborne natural source EM was introduced recently (Thiede et al, 2024).

We conducted a demonstration survey in eastern Namibia in the Kalahari-Copper-Belt (KCB). The Namibian Geological Survey carried out a large-scale low-resolution ZTEM fixed-wing survey in this region in 2014. The results indicate the presence of conductivity anomalies, including the area we selected for measurements. The area is sparsely populated suggesting a low-level of culture noise, thus supporting the demonstration of a novel airborne natural source EM instrument as well as testing our processing scheme and implementations in the inversion toolbox custEM.

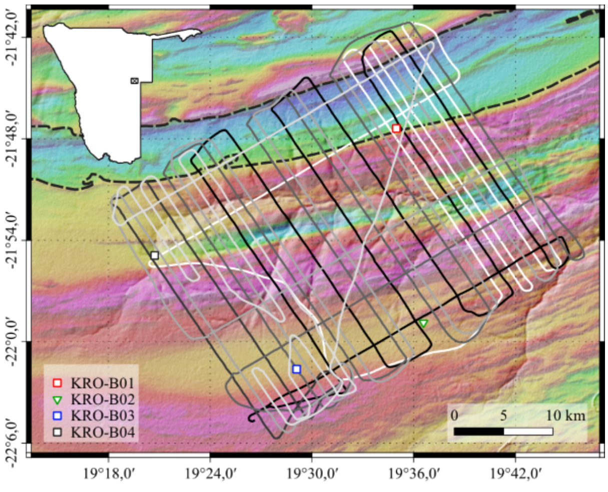

**Figure 1:** Measurement set-up. The lines show the flight paths, the shading corresponds to individual flights. Squares and triangles mark ground site positions. The background shows the total magnetic intensity (blue = low, magenta = high) and the dashed line marks a prominent magnetic-low feature.

## Geological Background

The KCB is a NE-SW trending belt extending from Botswana into Namibia between the Kalahari Craton to the south and the Damara Belt to the north. It is known for strata-bound copper deposits, mined at the Ghanzi-Ridge (Botswana), the Witvlei area and the Rehoboth province (Lehmann et al, 2015), but it is largely unexplored in Namibia because of a thick Kalahari sand coverage. The sparse KCB outcrops reveal highest amounts of Cu-bearing sulphides in the contact zone of D'Kar to the Ngwako Pan Formation. Existing potential field data (airborne magnetics) from this area illuminate geological structures that are oriented pre-dominantly in E-W direction (Figure 1). Based on this data, Lehmann et al (2015) predict the corresponding geological units to be found in the northern part of the survey area, coinciding with a magnetic low.

## Data acquisition

The survey was carried out in Feb 2023, i.e. during the annual signal high. To find the optimum position for a quiet reference site, we employed four full MT stations at different locations in the survey area. The QAMT system was used and an area of $30 \times 36$ km$^2$ was completed in 6 flights (Figure 1). Line spacing was set to $1$ km and $5$ km for flight and tie lines, respectively. Flight lines are oriented in approx. NNW-SSE direction and perpendicular to the expected geological strike direction. Some gaps were left because of obstructions during flight operations. Flights were performed between 2 p.m. and 7 p.m. local time when natural signal level was highest (Figure 2). The platform was towed at $300$ m above the ground on a 60 m long, damped tow rope with approx. $130$ km h$^{-1}$ flight speed.

The QAMT system consists of a special-designed wooden platform to avoid magnetic noise caused by flight maneuvers. It features SQUID (superconductive quantum interference device) magnetometers with very low sensor noise mounted on an inner platform that is stabilized by a sophisticated suspension damping that has been main subject to the optimization procedure. The platform is additionally equipped with an INS for attitude recordings, GPS time is used to synchronize airborne and ground measurements. The amplitude spectral density of airborne data is shown in Figure 2 featuring sensitivity to natural signal over a broad frequency range. Airborne data become noise-afflicted with decreasing frequency, resulting in an increased $B_x$-field level compared to natural source signal level recorded on the ground ($< 30$ Hz).

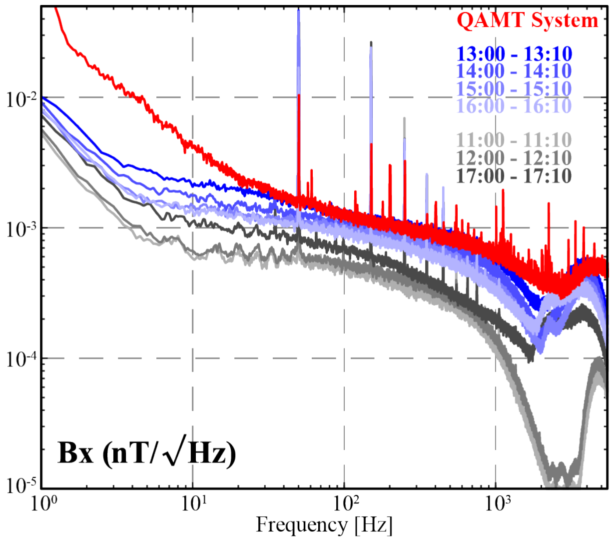

**Figure 2:** $B_x$ amplitude spectral densities of time-series from the QAMT platform (red) and ground site measurements (blue and grey). Ground recordings show time windows from 1 p.m. to 7 p.m.; time frames of maximum excitation are marked blue.

## DATA PROCESSING

We developed a multivariate multi-site processing algorithm, that uses a skin-depth adapted transfer function estimation to maintain spatial resolution. We estimated transfer functions for $19$ target frequencies starting from $8$ to $4096$ Hz (Figure 3). Processing results show reasonable results at frequencies ranging from $11$ to $1024$ Hz for $\mathbf{T}$ and $16$ to $1284$ Hz for the $\mathbf{M}$-tensor. Hence, the algorithm enables to extract transfer function estimates even at noise-dominated frequency ranges. Moreover, we were able to access lower frequencies (i.e. greater penetration depth) than with any other system/processing tool before.

## PRELIMINARY INVERSION RESULTS

We implemented the inversion for airborne natural source EM transfer functions in the custEM 3D finite-element toolbox. For first inversion tests, the data set was split in two segments to save computation time. Each segment was inverted separately using vertical magnetic transfer functions ranging from $22$ to $256$ Hz. Eastern and western segment converged to an root-mean-square error of $3.02$ and $0.82$ after $4$ and $3$ iterations, respectively.

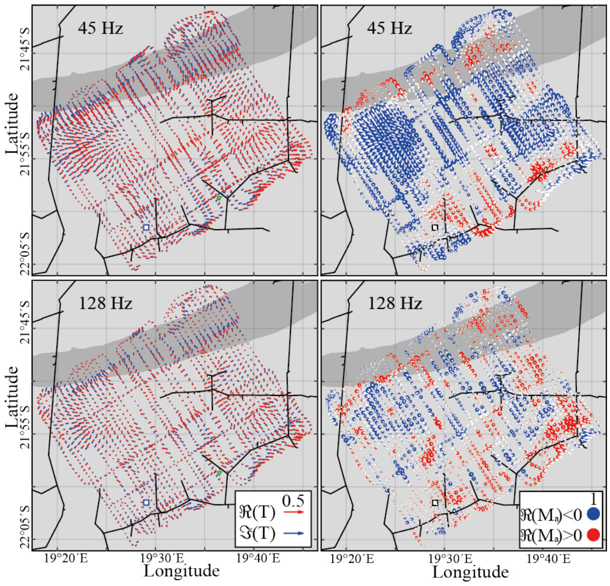

**Figure 3:** Transfer function maps of two representative target frequencies using the ground site marked by the square. Left panel: Induction arrow maps; right panel: $\Re(M_a)$ maps, values $> 1$ are masked. Real parts of induction arrows are depicted in white. Black lines show the power line grid and the dark area denotes the magnetic low.

Inversion results of both models are in good agreement in the overlap region (Figure 4). The combined model features a prominent E-W-trending conductor in the northern part of the survey area which coincides with the magnetic low (cf. Figure 1) and predicted boundary of D'Kar to Ngwako Pan Formation.

## CONCLUSIONS

The application to field data shows that the QAMT system is capable of deep-sounding natural source EM. By applying the multivariate approach, the system broadens the frequency range available to airborne natural source EM and thus increases the depth of investigation e.g. for mineral exploration. Preliminary inversion results are in good agreement with geological and other geophysical observations showing a good conductor at the predicted stratigraphic boundary known for hosting Cu-sulphides.

## ACKNOWLEDGMENTS

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## REFERENCES

Lehmann J, Master S, Rankin W, Milani L, Kinnaird JA, Naydenov KV, Saalmann K, Kumar M (2015) Regional aeromagnetic and stratigraphic correlations of the Kalahari Copperbelt in Namibia and Botswana. Ore Geology Reviews 71:169–190

Rochlitz R, Becken M, Günther T (2023) Three-dimensional inversion of semi-airborne electromagnetic data with a second-order finite-element forward solver. Geophys J Int 234(1):528–545

Stolz R, Schiffler M, Becken M, Thiede A, Schneider M, Chubak G, Marsden P, Bergshjorth AB, Schaefer M, Terblanche O (2022) SQUIDs for magnetic and electromagnetic methods in mineral exploration. Mineral Economics 35(3):467–494

Thiede A, Schiffler M, Junge A, Becken M (2024) Multivariate processing of airborne natural source electromagnetic data - application to field data from Gobabis (Namibia). Geophys J Int 238(1):573–589

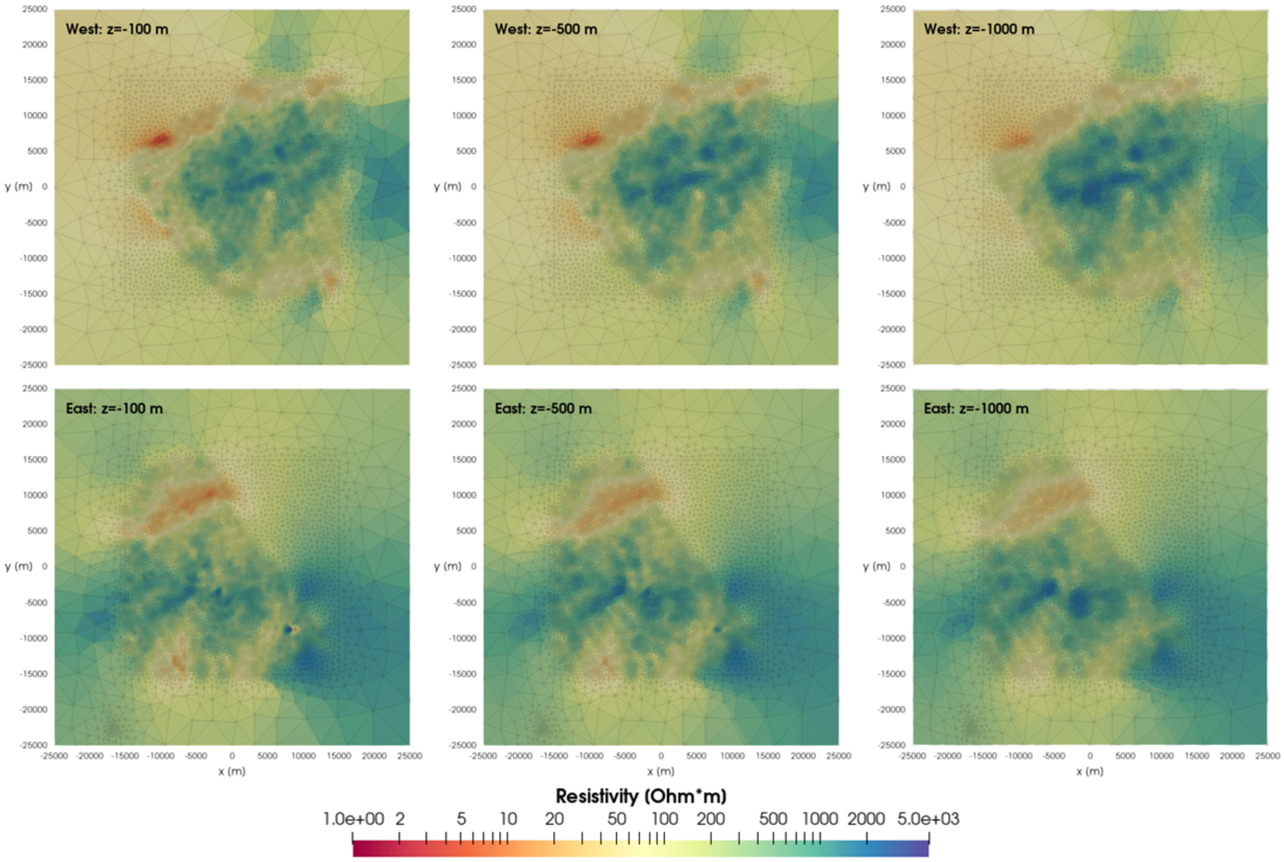

**Figure 4:** Depth slices of the preliminary inversion results at $100,\ 500$ and $1000$ m depth from left to right. Upper panel: Western segment. Bottom panel: Eastern segment. The models are in good agreement in the overlap region, showing a conductive E-W-trending structure in the northern part of the survey area.