3D Inversion of Transient Electromagnetic Data - Imaging the Roter Kamm Impact Crater, Namibia

H. Nienhaus[1], P. Yogeshwar[1], W. Mörbe[1], B. Tezkan[1], Y. Liu[2], B. Lushetile[3] and M. Melles[4]
[1]University of Cologne, Institute of Geophysics and Meteorology, Cologne, h.nienhaus@uni-koeln.de
[2]China University of Geosciences, Department of Geophysics, Wuhan
[3]Ministry of Mines and Energy, Geological Survey of Namibia, Windhoek
[4]University of Cologne, Institute of Geology and Mineralogy, Cologne

SUMMARY

The Roter Kamm Crater is a meteoritic impact crater in the Tsau //Khaeb (Sperrgebiet) National Park in southern Namibia. Access to the national park, a former diamond mining area, had been restricted for approximately one century until 2008. Since only a limited number of studies were carried out, we provide a new model of the Roter Kamm Crater's sedimentary infill and determine its geometry and maximum thickness. One transect of the Roter Kamm was explored using a fixed-loop transient electromagnetic (TEM) configuration. The fixed-loop set-up uses one large transmitter loop (200 x 200 m^2) to record data at multiple receiver positions. To complement this data set, we additionally carried out single-loop TEM and sparse audiomagnetotelluric (AMT) measurements to fully image the Roter Kamm Crater at two perpendicular profiles and ensure that we resolve all necessary depth ranges equally well. We inverted the TEM data from both set-ups using a novel 3D TEM inversion algorithm. The inversion of the fixed-loop data used significantly less computational resources than the single-loop inversion, because of a greatly reduced number of transmitters. The 3D TEM and 2D AMT results are in an exceptional agreement with each other. The resistivity models reveal a large planoconvex lens-shaped conductor within the crater rims. We interpret the lower boundary of it as the transition from sediments to brecciated bedrock and the decreased resistivity as higher moisture content of the aeolian sands deposited in the crater's sedimentary infill.

Keywords: Transient Electromagnetics, Magnetotelluric, 3D Inversion, Sedimentary Basin, Impact Crater

INTRODUCTION

The Roter Kamm Crater is located in the Namib Desert in southern Namibia (Figure 1). It was formed by a meteoritic impact 4-5 million years ago (Hecht et al, 2008). Until 2008 the Roter Kamm had been part of a restricted diamond mining area for a century, which has been declared the Tsau //Khaeb (Sperrgebiet) National Park since then. However, this allowed only for limited research (e.g., Fudali, 1973; Grant et al, 1997; Brandt et al, 1998).
The Roter Kamm (diameter 2.5 km) is extensively covered by aeolian sands and active sand dunes, however the crater rim remains exposed (Fudali, 1973; Reimold and Miller, 1989). Modelling studies based on gravimetric data suggest a sedimentary thickness of about 300 m in the center of the Roter Kamm Crater (Fudali, 1973; Brandt et al, 1998).
We carried out a TEM survey at the Roter Kamm crater in 2022 using two different measurement configurations: the single-loop and the fixed-loop set-up. The single-loop layout utilizes one conductor loop as transmitter and receiver and is thereby particularly time efficient. In order to record 3D multi-component TEM data for large Depth of Investigations (Spies, 1989) and improved resolution we additionally used a large fixed-loop TEM configuration. In the centre of the transmitter loop, strong horizontal components only exist in presence of a 2D/3D subsurface conductivity distribution, however due to the separate receiver positions, they can also be measured outside of the transmitter loop on any subsurface dimensionality. Furthermore, this set-up

is more suitable for a multidimensional interpretation approach, because of the limited number of transmitters needed to cover large areas and mobile receivers.

Survey

We conducted TEM and AMT measurements at the Roter Kamm Crater and focussed on two perpendicular profiles (Figure 1). Due to official regulations in the protected desert environment, access to the Roter Kamm by car was not possible.

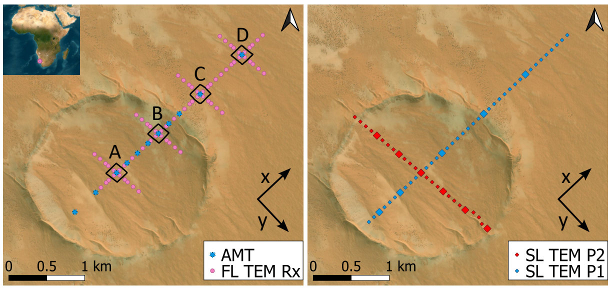

Figure 1: Roter Kamm Crater in southern Namibia. Left: The black lines indicate the fixed-loop TEM transmitter positions, the pink circles the TEM receiver locations and the blue stars the AMT sounding locations along profile 1. Right: All squares mark single-loop TEM sounding locations along profiles 1 and 2. The squares' size indicates the loop size.

The TEM sources had edge lengths of 50/100 m and 200 m, for single and fixed-loop transmitters, respectively. The single loops had a distance of 100 m between each other, while the fixed loops were 800 m apart. Each fixed loop had 21 corresponding receiver locations along two 800 meter long arrays, one array along the main profile and one perpendicular to it. Along the main profile we measured all three induced voltage components, while on the four perpendicular arrays only the dominant horizontal and the vertical components were collected. AMT was only sparsely recorded at 11 locations to ensure a reliable detection of the lower boundary of the sedimentary infill of the Roter Kamm Crater.

Results and Discussion

The TEM data was inverted using the novel TEM3Dinv algorithm (Liu et al, 2024). All measured components of the TEM data can be fitted well with the 3D inversion and yield to a conclusive conductivity model, describing the interior of the Roter Kamm impact crater (Figure 2). The inversion of the fixed-loop data was very fast and efficient compared to the single-loop data along the same profile distance with comparable horizontal receiver spacing (Table 1).

	Fixed-Loop	Single-Loop
Tx	4	16
Data Points	957	947
Cores	16	64
max. RAM/GB	105	599
Run Time/h	5.3	34.5

Table 1: Computational Resources needed for the 3D inversion of subsets of the single-loop and fixed-loop data along the common section of the main profile using the same inversion grid.

The model shows a planoconvex lens-shaped conductive structure ($\rho \approx 10\ \Omega$m) inside the crater surrounded by a resistive background material ($\rho > 500\ \Omega$m). It is situated at a depth of 100 m with a plane upper surface and a thickness of maximal 200 m in the center of the crater. The horizontal extension of the conductor is 1400 m. The subsurface conductivity shows no significant vertical variations at the location of the crater rim. Outside of the Roter Kamm a conductive layer with similar conductivities as observed in the crater is extending towards the North-east. It has a maximum thickness of 50 meter next to the flank of the crater (x $\approx$ 100 m) and seems to be varying in thickness along the profile with a minimum between x $\approx$ 600 m and x $\approx$ 1000 m. These results corroborate well with the 2D conductivity model derived from the AMT data, which was inverted using MARE2DEM (Key, 2016).
The hypothetical model presented by Fudali (1973) describes a 300-m-thick sedimentary layer covering the brecciated bedrock, which matches well with the lower boundary of the conductor explained by the TEM and AMT data. A possible explanation for the higher conductivity is higher moisture content in larger depth. The same explanation is valid for the conductor outside of the Roter Kamm Crater.

CONCLUSIONS

This study highlights the capabilities of fixed-loop TEM for multidimensional set-ups and 3D inversion. The fixed-loop 3D inversion requires substantially less computational ressources than the 3D inversion of central or single-loop data. Furthermore, the resistivity models of all conducted EM methods are in great agreement with each other and in conformity with previous modelling studies that expected a bowl-shaped impact crater, which is clearly indicated by the lower boundary of the conductive anomaly. However, these previous studies are strongly influenced by observations at similar impact craters (Fudali, 1973; Brandt et al, 1998), thus our study presents the first model of the Roter Kamm Crater that clearly identifies the true shape of the crater and the thickness of its sedimentary infill. Additionally, our results indicate water content in larger depths with no evidence for large-scale structures inside the crater filling. Similar resistivities outside of the crater suggest the presence of the same aeolian sand cover in and outside of the Roter Kamm.

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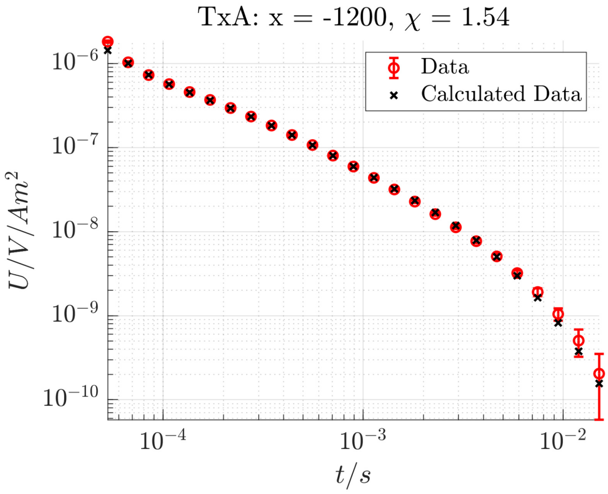
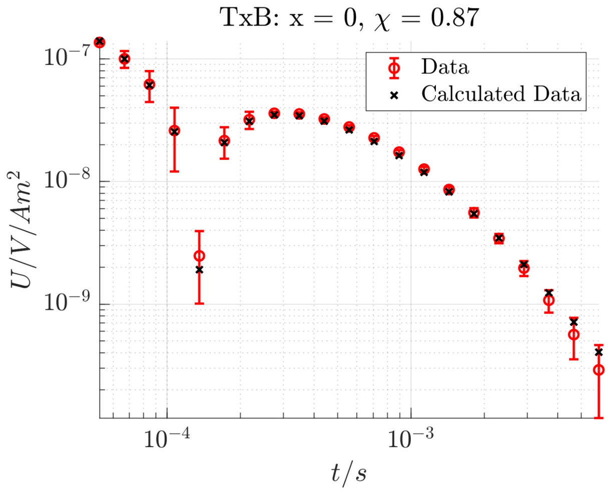
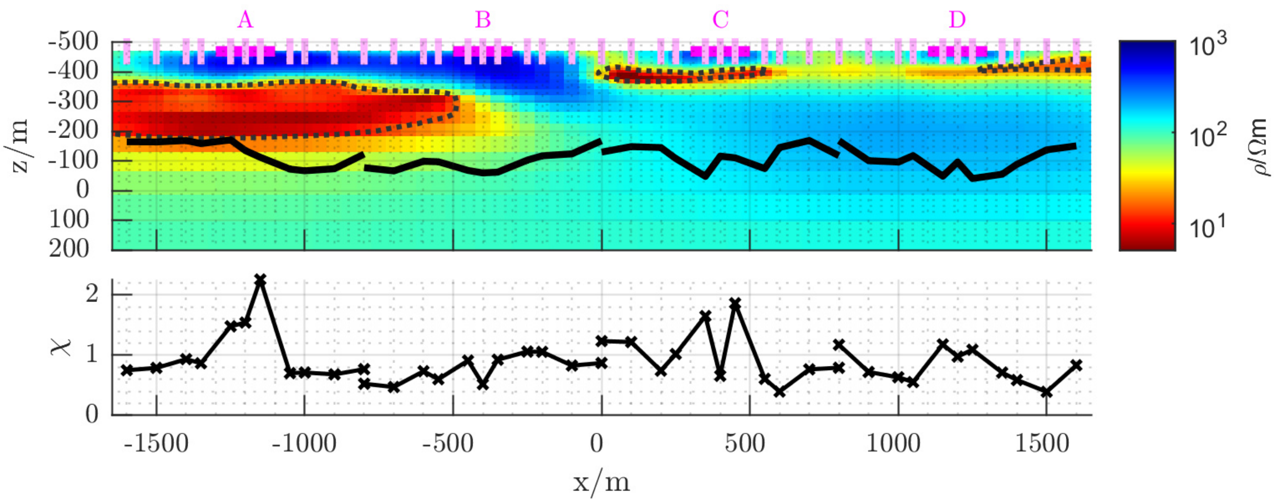


(a) Measured and calculated data at the crater's center.



(b) Measured and calculated data at the crater rim.



(c) Resistivity model (χ = 0.99) and datafit χ along the main profile calculated by TEM data. The center of the Roter Kamm Crater is located at x = -1200 m and the rim at x = 0 m. In the upper panel the dashed lines indicate a 20 Ωm contour line and the solid black line mark the Depth of Investigation (Spies, 1989).

Figure 2: 3D TEM inversion results of the fixed-loop TEM data (z-component) the main profile from the Roter Kamm Crater.