Geophysical Imaging of Deep Climate Archives in Namibia using the Transient Electromagnetic Method

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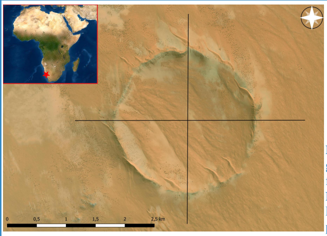
Introduction

The *Roter Kamm Crater* in southern Namibia is a meteoritic impact crater with an age of approximately 3.7 Ma [1]. The sediments, with which it is filled, hold valuable information about the past climate, and thus the evolution of the surface and the biota. In the framework of the *Collaborative Research Center (CRC) 1211: "Earth - Evolution at the dry Limit"*, which is funded by the DFG, the crater is going to be investigated using geophysical imaging techniques.
The two main objectives are the determination of the thickness of the sedimentary layer within the crater and the imaging of the geometry of the crater's basement. The primary geophysical method, which is planned to be applied, is the *transient electromagnetic (TEM) method*. To ensure the optimal outcome of this field campaign, however, additional *audiomagnetotellurics (AMT)* measurements will be conducted. Because little knowledge about the geology exists, extensive simulation studies have been carried out to find an optimal survey design and choose the appropriate equipment.

The Roter Kamm Crater



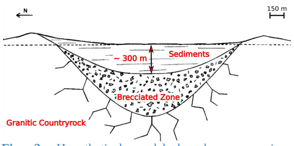


Fig. 2: Hypothetical model based on various geophysical methods along the NS-profile (modified from [1])
Fig. 1: Satellite Image of the Roter Kamm Crater and its location in Africa. The black lines indicate the profiles, proposed for the survey measurement.

- Only a very limited number of geophysical surveys at the Roter Kamm Crater
- Profound knowledge is scarce
- All available data indicates, that the crater has a symmetric, bowel shape [1,2]

Method	Depth to Brecciated Zone („Basement")	Depth of Granitic Countryrock
Seismics [1]	> 90 m	-
Gravimetry [1]	~ 300 m	Set to ~760 m
Magnetics [2]	-	~ 700 m
Aeromagnetics	(90 – 140) m	-

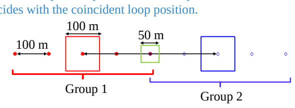
Table 1: Summary of the published, estimated depths of the layers of the Roter Kamm Crater, Namibia.

- **Thickness of the sedimentary layer: (90 – 300+) m**
- **No indications about the electrical resistivity of sediments**

Planned Field Survey

- Measurements are planned along two profiles crossing the whole impact crater (North-South and East-West direction (Fig. 4))
- Brecciated zone extents at least 500 m beyond the crater rim [2] → extension of one profile to observe the transition to the original geology
- Proposed setup of the TEM measurement is shown in Figures 3 and 4 and the AMT setup is along the same profiles (receiver distance of 250 m)

Fig. 3: Detailed view of the proposed TEM setup. In red and blue are two transmitter-receiver-groups of the fixed loop setup and in green is a single coincident loop. Group 1 and 2 overlap at the outmost receiver which coincides with the coincident loop position.



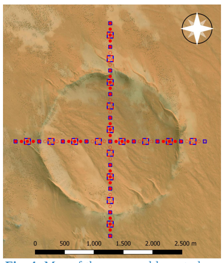


Fig. 4: Map of the proposed layout plan (TEM). The 17 fixed loop transmitter and their receiver stations (5 each) are marked in red and the (17+19) coincident loop location are blue. The squares are the transmitter and the circles the receiver.

Method	Setup	Transmitter	Receiver	Sensors
TEM	Fixed Loop	Zonge ZT 30	SMARTem24	Geonics Coils
	Coincident Loop	TemFast 48		Loop
AMT	-	-	SPAM Mk IV	Metronix MSF07 Coils/Ag-AgCl-Electrodes

Table 2: List of proposed transmitter, receiver and sensors.

References

[1] **Fudali, R.F.,** 1973, *Roter Kamm: Evidence for an impact origin*, Meteoritics, Vol. 8, No. 3
[2] **Brandt et al.,** 1998, *Geophysical profile of the Roter Kamm impact crater, Namibia*, Meteoritics & Planetary Science, 33, 447-453
[3] **Druskin, V. & Knizhnerman, L.,** 1988, *Spectral Differential-Difference Method for Numeric Solution of Three-Dimensional Nonstationary Problems of Electric Prospecting*. Physics of the Solid Earth. 24. 641-648.
[4] **Key, K.,** 2016, *MARE2DEM: a 2-D inversion code for controlled-source electromagnetic and magnetotelluric data*. Geophysical Journal International, 207(1), 571–588. DOI: 10.1093/gji/ggw290.

1D Resolution Studies

- Determination of necessary time range and transmitter loop size
- Perturbation of electrical resistivity and thickness of the second layer of a 3-layer-model to analyse the number of equivalent models (data misfit of $\chi = 2$ accepted for the perturbated models with added noise)

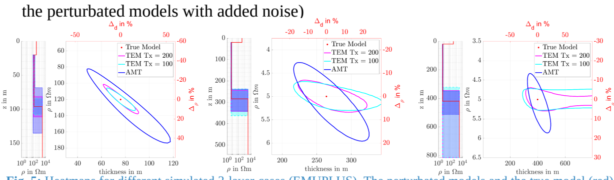
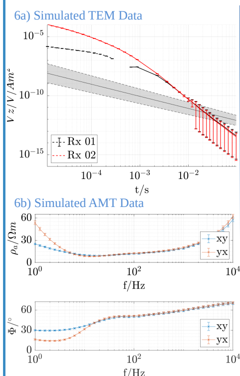


Fig. 5: Heatmaps for different simulated 3-layer-cases (EMUPLUS). The perturbated models and the true model (red) are displayed in the left-hand panels. In the 2D plot on the right side the parameter (thickness vs. resistivity) of the second layer of the equivalent models are presented. The AMT simulations are indicated in blue and the ones of the TEM simulations in magenta (Tx = 100 m) and cyan (Tx = 200 m).

- **Large TEM Loops are necessary (Tx = 100 m or 200 m)**
- **Thick conductors cannot be resolved with TEM (right plot Fig. 5) → AMT needed**

2D Modelling Studies

- Determination of receiver/transmitter distances, as well as transmitter-receiver-geometry (TEM) to image the slope of the crater
- Inversion of simulated data (same noise like in the 1D resolution studies added) for 4 different, simple models: conductive (ρ_s = 10 Ωm)/resistive (ρ_s = 100 Ωm) sediments and steep/shallow slope in a 350-Ωm-background and a surface layer with 300 Ωm



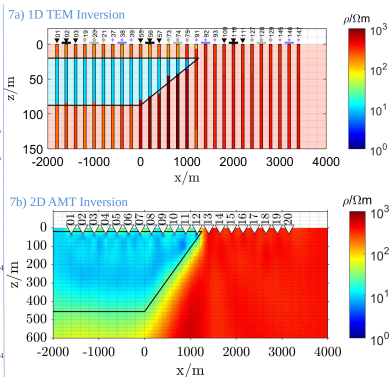


Fig. 6: Data Examples of the models presented in Fig 7. Panel a) shows TEM data (induced voltage) with the transmitter position 02 and receiver locations 01 and 02 (Fig. 7a). The simulated AMT data (apparent resistivity and phase) is displayed in Panel b) for receiver 01 (Fig. 7b).

Fig. 7: Inversion Models of the simulated 2D data. Panel a) shows the 1D Marquardt inversion results (EMUPLUS) of the simulated TEM data (sldmem3t [3], Tx = 100 m) and a fixed loop set up with a source-receiver-offset of 0 m and ±200 m. The transmitter positions are indicated by the bars and the corresponding receivers with symbols in the same color. Panel b) displays the 2D AMT inversion results (MARE2DEM [4]) with a receiver (white triangles) distance of 250 m.

- **Good resolution of electrical resistivity in 1D TEM and 2D AMT inversion**
- **TEM: fixed loop setup is possible with a receiver distance of 200 m and a transmitter distance of 600 m to image any kind of slope**
- **AMT: a station distance of 250 m seems sufficient**
- **TEM and AMT are complementary with TEM detecting a possible surface layer and AMT having a much larger depth penetration**

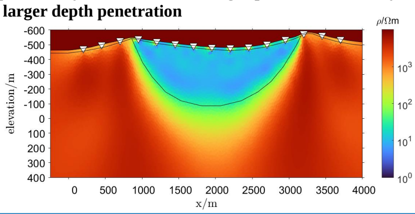


Fig. 8: 2D AMT inversion model of a synthetic model with a bowel-shaped crater based on the model presented in Fig. 2, including the topography. The electrical resistivities are the same as shown in Fig. 7 for a conductive sedimentary in-fill. Noise was added to the simulated apparent resistivity and phase (see Fig. 6b).

Conclusions and Outlook

- **Estimated thicknesses of the sedimentary in-fill in the Roter Kamm Crater vary significantly**
- **TEM is not suitable for imaging thick conductors**
- **Complementary AMT measurements necessary**

Outlook

- **Field Survey planned for February/March 2022**
- **Implementation of a 2D TEM inversion algorithm**