Application of Transient Electromagnetics for the Investigation of a Geothermal Site in Tanzania

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Introduction

In 2006 and 2007 geothermal exploration field surveys were carried out in Tanzania within the framework of the GEOTHERM programme. The project partners were the Tanzanian Ministry of Energy and Minerals (MEM), the Geological Survey of Tanzania (GST), the Tanzanian Electric Supply Company Ltd. (TANESCO) and BGR on behalf of the Federal Ministry for Economic Cooperation and Development (BMZ). GEOTHERM is a programme of technical cooperation initiated by the German government. It started in 2003 and promotes the use of geothermal energy in partner countries by kicking off development at promising sites (Fig. 1). East Africa is in the major regional focus of the programme. The project activities there are supported by the African Rift Geothermal Facility (ARGeo). Geophysical methods (Transient Electromagnetics (TEM), Magnetotellurics (MT) and Geoelectrics) have been applied in order to determine the electrical conductivity of the subsurface, therewith providing information on lithology and structure of the underground. Additionally, the area was investigated geologically and geochemically and counterpart colleagues were trained "on the job" in the exploration methods applied. First results of the TEM survey are presented here.

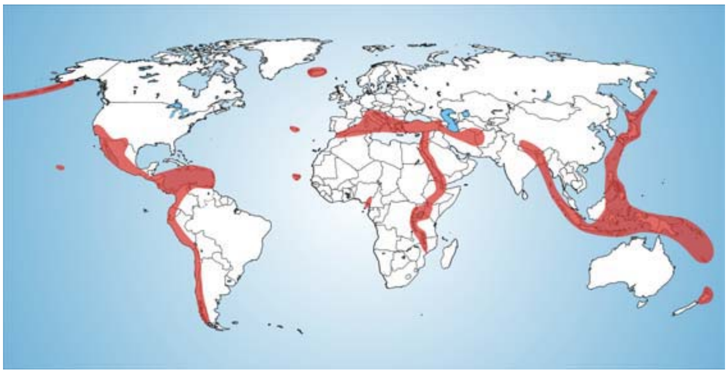


Fig. 1: The map shows the world wide distribution of areas with high geothermal potential. The GEOTHERM programme has a regional focus on East African countries which are close to the East African Rift Valley. The project countries here are Eritrea, Ethiopia, Uganda, Kenya, Tanzania and Rwanda.

1. Motivation and survey area

Electromagnetic and geoelectrical measurements provide information on the distribution of the electrical resistivity in the subsurface. In geothermal systems, electrical resistivity variations are predominantly caused by hydrothermal alteration zones. The hot fluids of a geothermal system lead to the formation of a sequence of hydrothermal alteration products depending on the temperature. At the top of a highenthalpy geothermal system a clay cap with expandable clay minerals uses to occur. Its resistivity is generally lower than in overlying rocks exposed to lower subsurface temperatures. Below the clay cap a higher resistive core is to be found representing the geothermal reservoir. Thus, the succession of a low resistive region (the clay cap) and a high resistive surrounding (the core below and low temperature alterations above) are somehow indicative for a geothermal reservoir (Fig. 2 and 3). Electrical resistivity methods are well suitable to detect this pattern. Fig. 4 illustrates the TEM method applied in this survey.

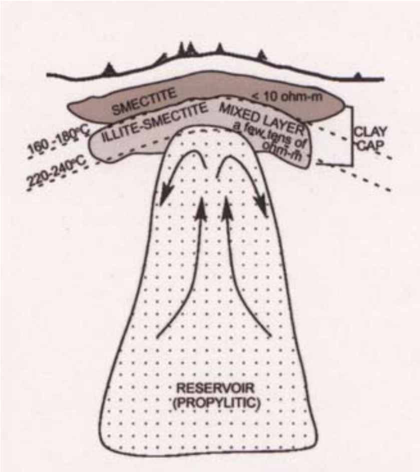


Fig. 2: Geothermal resistivity model, modified after Pellerin et al., 1996. Oskooi et al. 2005.

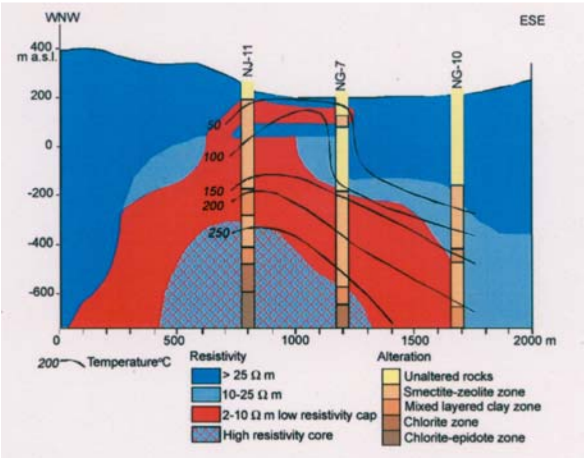


Fig. 3: Resistivity model results over a geothermal system in Iceland, after Arnason et al. 1986. Oskooi et al. 2005.

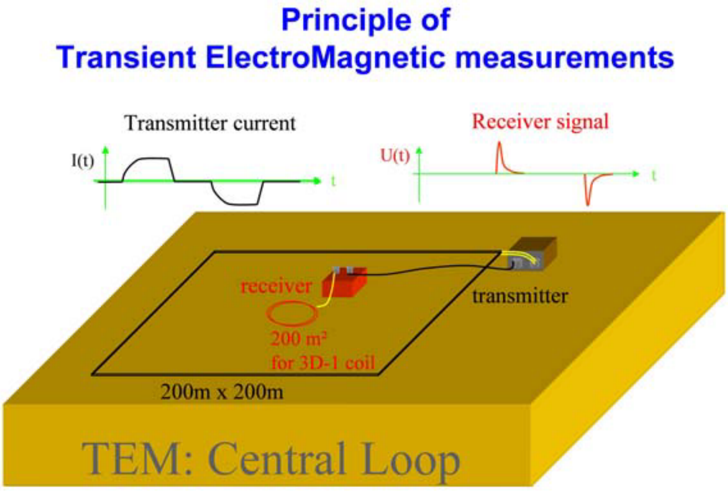


Fig. 4: Transient electromagnetic (TEM) measurements provide information on the distribution of the electrical resistivity of the subsurface. The TEM method uses transmitter and receiver coils with different sizes and configurations. A changing primary field caused by a short current impulse in the transmitter coil induces eddy currents in the ground, which are decaying with time causing electromagnetic induction in the receiver coil. The resulting decaying voltage is recorded over a certain time window; it contains information on the resistivities of the subsurface. The exploration depth depends on the local noise level, and therefore is influenced by the transmitter power. By varying coil size and time windows the TEM system is able to provide information on the resistivities at depths in the range from some metres to several hundreds of metres below surface.

The geophysical ground surveys were performed in the area of the Songwe valley and the Ngozi volcano (Fig. 5 and 6). Due to geochemical indications the area is supposed to contain a geothermal reservoir. The zone is expected to extend in north westerly direction from Ngozi volcano toward the Songwe valley. In this report only some main results of the TEM survey are shown.

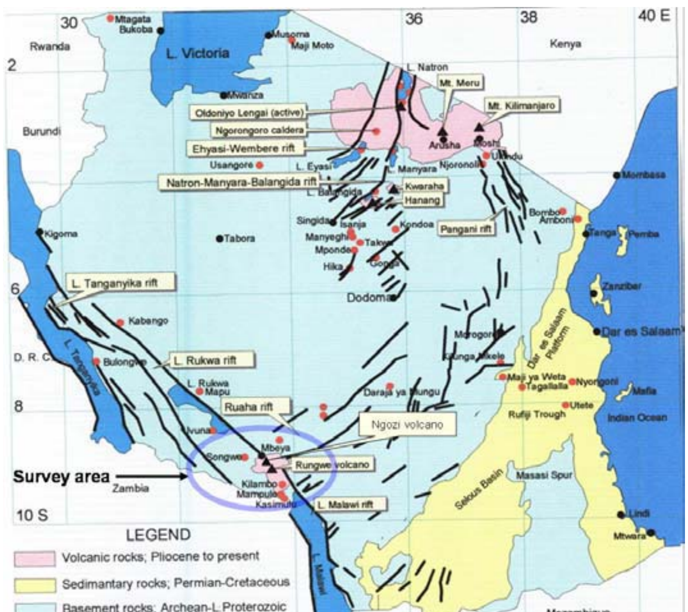


Fig. 5: Simplified geological map of Tanzania showing the major faults of the East African Rift System (EARS), hot spring locations and volcanic fields.

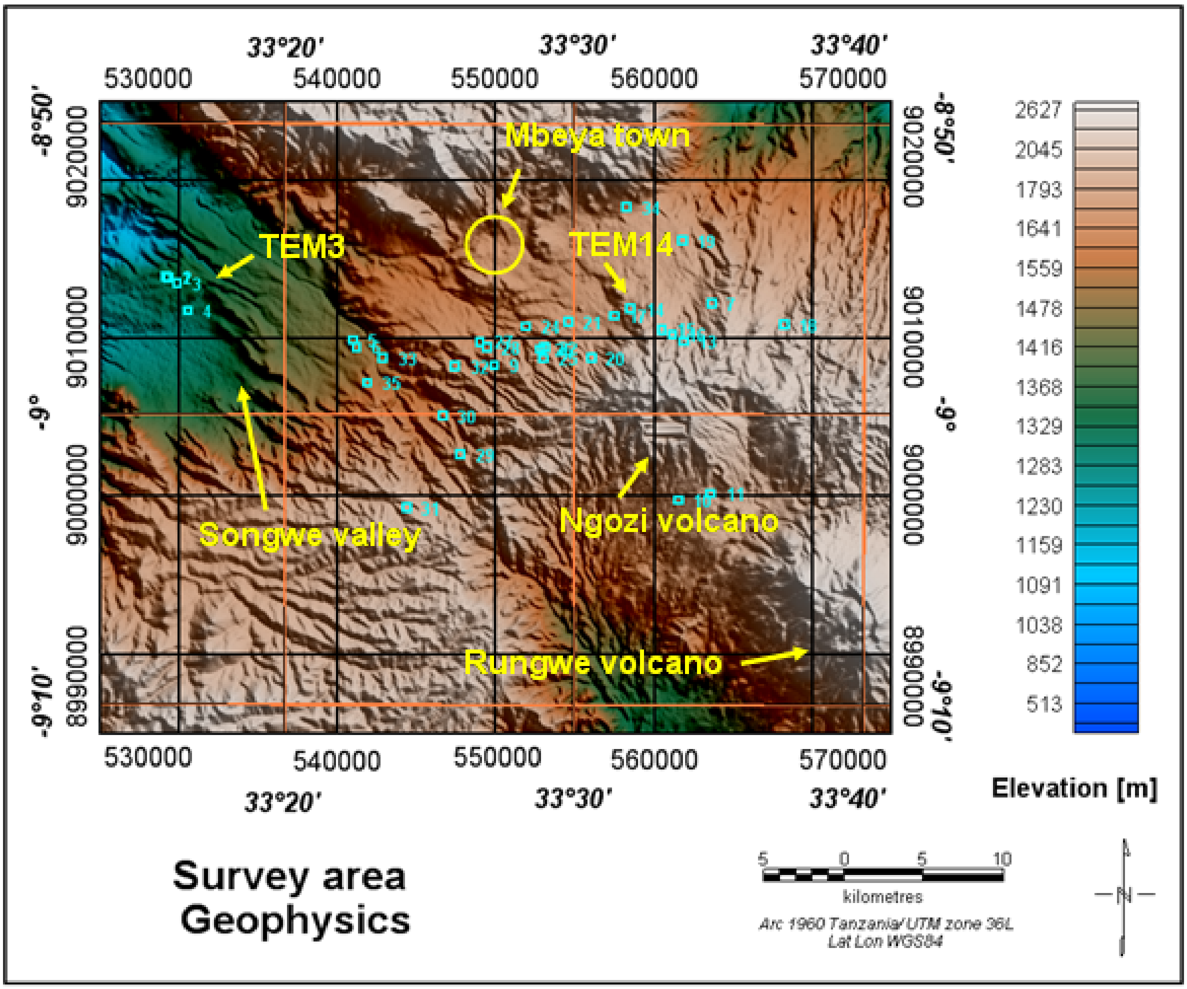


Fig. 6: Distribution of the TEM sounding sites (light blue boxes) in the Songwe valley and around Ngozi volcano.

The measurements yield apparent resistivities as function of the time after switch off of the primary current pulse. After data processing, true resistivities as a function of the depth of 1-dimensional models, consisting of horizontally infinitely extended layers are calculated. The resistivity provides information on the rock types and it also depends on their water content. It is expected, as already mentioned, that the alteration process created a low resistive clay cap which overlays a higher resistive core, the latter indicating the geothermal reservoir.

2. First results of the TEM measurements

Examples of measured (crosses) and model (continuous curves) apparent resistivities after inversion, and the respective 1D models are shown in Fig. 7, 8 and 9.

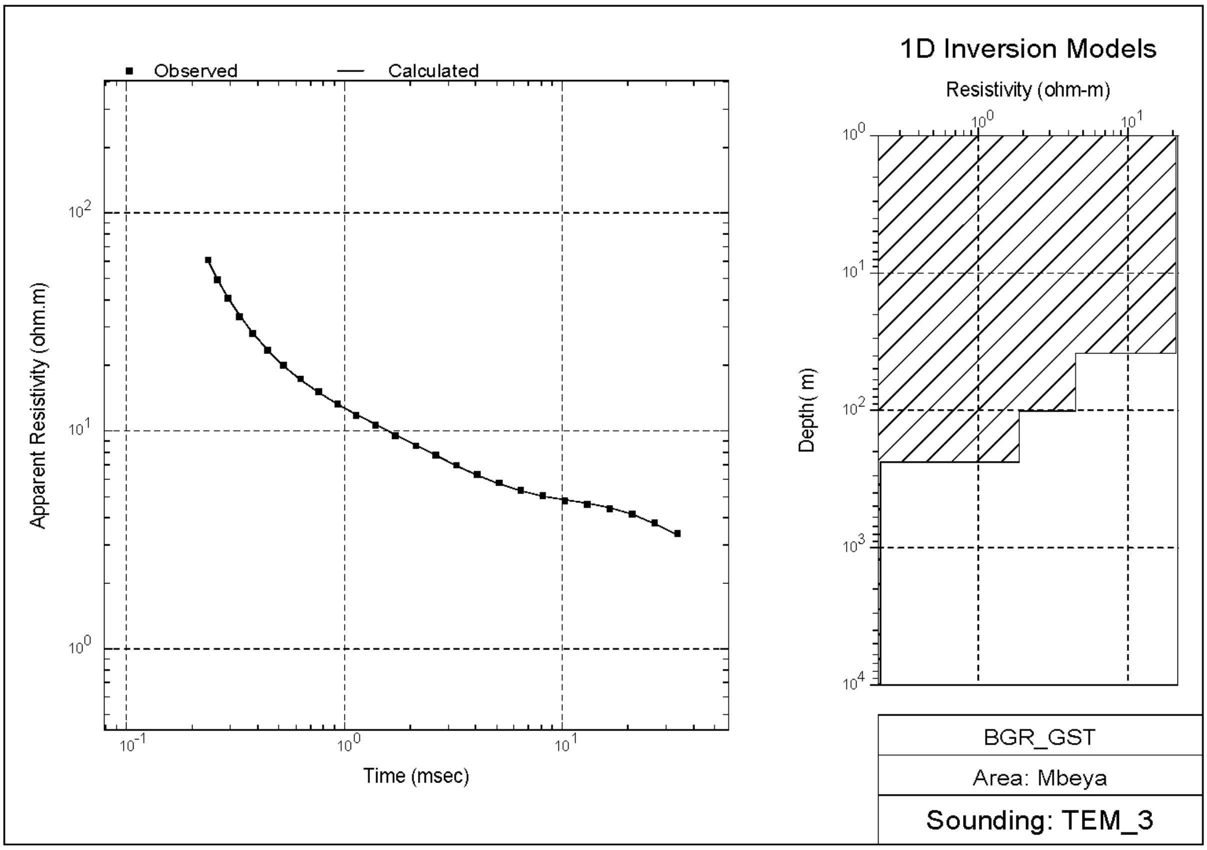


Fig. 7: Apparent resistivity curve and 1-dimensional model result at TEM site 3 in the Songwe valley.

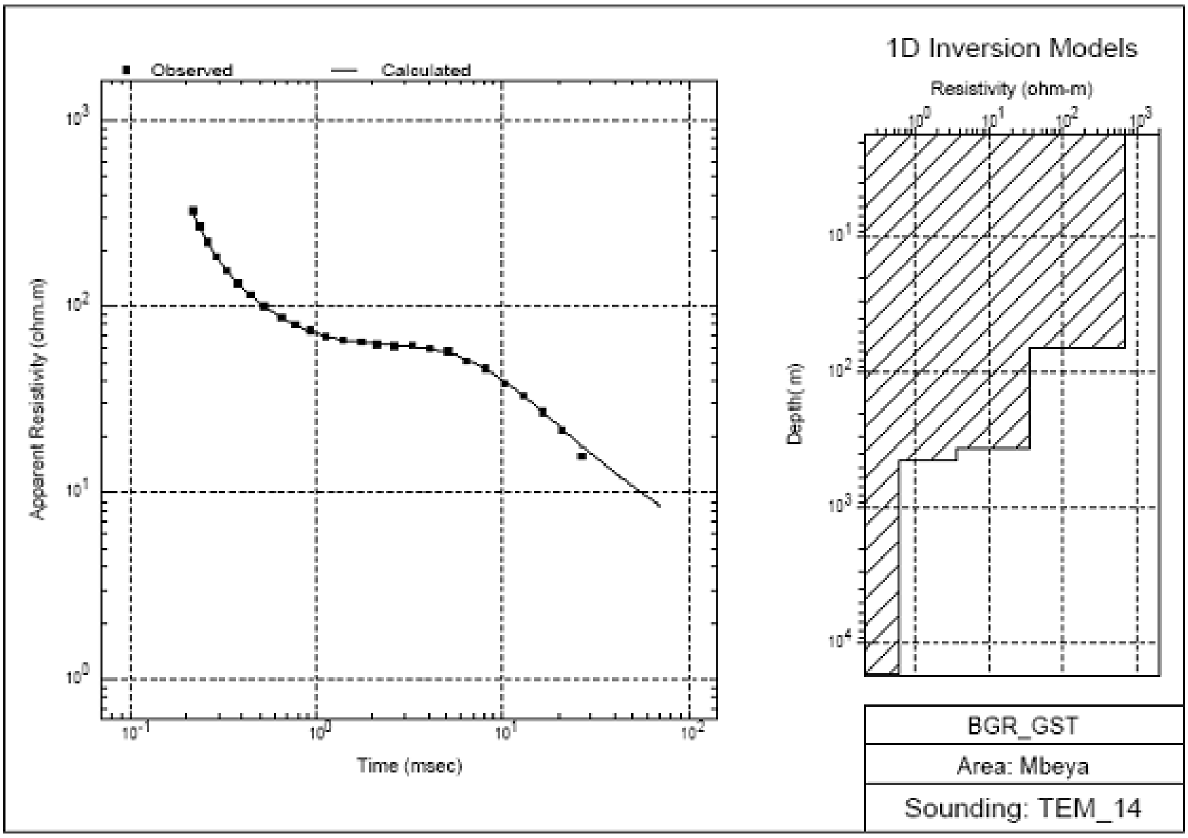
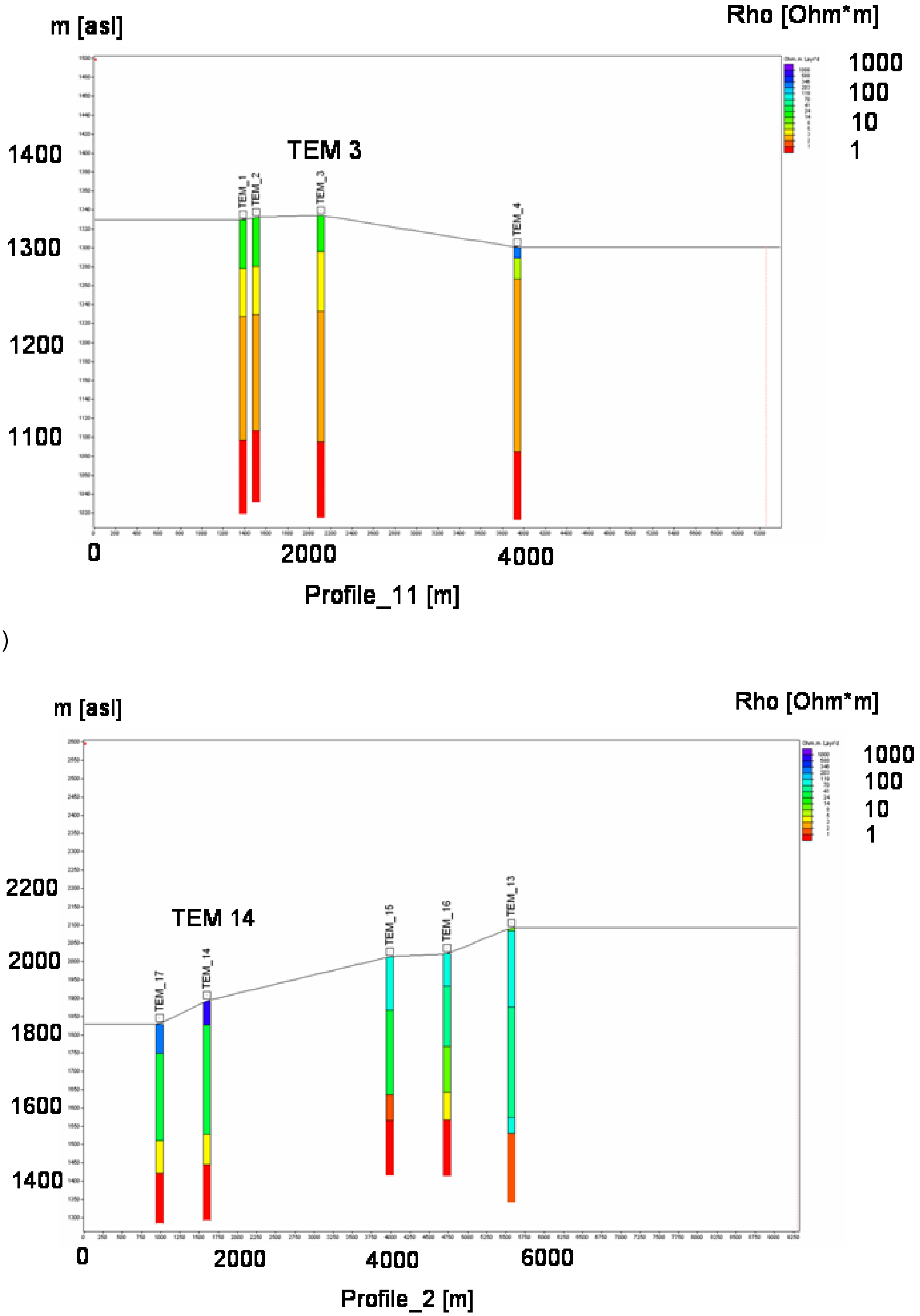


Fig. 8: Apparent resistivity curve and 1-dimensional model result at TEM site 14 north of Ngozi volcano.

Most of the apparent resistivity curves are decreasing with time. At most of the sites a very low resistive layer can be determined, e.g. at about 200 m in the Songwe valley (supposed to be alluvial sediments) at TEM site 3 (Fig. 7) and at about 500 m at TEM site 14 north of Ngozi volcano (Fig. 8). For some sites it was not possible to find a model which fits the apparent resistivities at late times. Therefore some curves were cut at the end (Fig. 8). Fig. 9 (a, b) shows vertical resistivity sections for two profiles (no. 11 and no. 2) in these areas. Both show the mentioned low resistive layer.



a)

b)

Fig. 9: 1-dimensional vertical resistivity sections from TEM data for the Songwe valley along profile 11 (a) and north resp. northwest of Ngozi volcano along profile 2 (b).

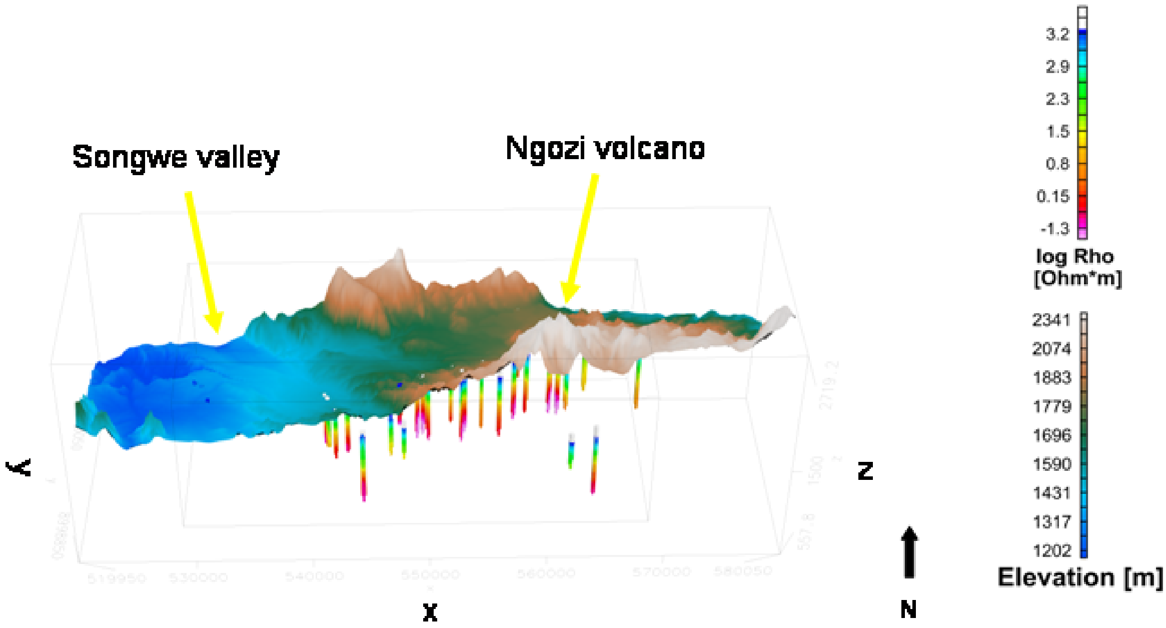


Fig. 10: 3-dimensional display of the 1D inversion results for the TEM sites in the whole survey area.

Fig. 10 shows a 3-dimensional visualization of the 1-dimensional inversion results. Volume pixels (Voxel) with certain cell sizes, depending on the desired resolution were used for it. Too big cell sizes cause interpolation into parts of the area, where no survey sites exist. Therefore a smaller cell size of 100mx100mx25m was chosen. The SRTM topography is drawn over and cut along a west easterly line crossing the Ngozi volcano. Below the volcano and at most parts of the survey area as well a low resistive region is indicated at depths of around several hundred metres. Its lateral extension cannot be determined very well because of the limited number of measurements. The limitation is mainly caused by the rugged terrain.

3. Conclusions

Most of the resistivity curves within the entire survey area show a decrease to later times, indicating lower resistivities at greater depths. This result may be indicative for the existence of a clay cap at depth, but has to be proven by the results of MT measurements, which simultaneously have been carried out in the same area. The horizontal expansion of the low resistive structure, found by the TEM, is not very clearly determined; the 3-dimensional display has also to be treated with caution because of possible interpolation artefacts, which may fill many parts of the survey area, where no data exist.

Many of the MT sites also coincide with the TEM sites. For extending the 1D model to greater depth a combination of the results of the two geophysical surveys is intended. The interpretation of the MT survey, however, is still unfinished at the moment. The geochemical and geological results too have to be considered for the interpretation of the low resistive layers. These results also are still in preparation.

Literature

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