TEM on Lake Holzmaar, Eifel
A feasibility study

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Abstract

We developed a floating TEM setup with a transmitter size of 18 x 18 m^2. Due to its modular design it can be handled by two operators and is easy to transport. As lacustrine sediments in maar lakes provide paleoclimatic proxy data, an extensive TEM survey at Lake Holzmaar (Eifel) was carried out to investigate the sediment thickness. The data collected can be explained well by means of three dimensional Finite Element Modelling.

Introduction

Lacustrine sediments provide excellent paleoclimatic proxy data. Depending on the sediment rates, which vary between 0.1 and 6 mm a^{-1}, information about the last 200,000 years can be obtained with a yearly resolution. Lake sediments are mainly archives on paleoclimatic fluctuations, geomagnetic field variations and volcanic activities. Even human impact on soil erosion or heavy metal accumulation is preserved (*Zolitschka* [1998]).

Maar lakes act as superior sediment archives as they possess deep and undisturbed bodies of water with reducing conditions at great depth. Steep slopes and plane lake bottoms help to build up laminated sediments by steady deposition in a non-turbulent environment. Drilling cores of several european dry maars (silted up former lakes) and maar lakes have been recoverd up to a depth of 200 m. They can be correlated and absolutely dated based on warve counting and radiocarbon dating. To find the most promising sites and drilling locations, precoring seismic and geological surveys have to be carried out (*Negendank and Zolitschka* [1993*a*]).

It will be shown that sediment thickness can be estimated by applying electromagnetic methods on the lake's surface. Therefor, we designed a floating TEM setup which is combined with the existing units of Zonge Engineering and Research Organisation Inc. An extensive survey at Lake Holzmaar, Eifel, was carried out. Along two sections data was obtained at 16 sites across the water surface area.

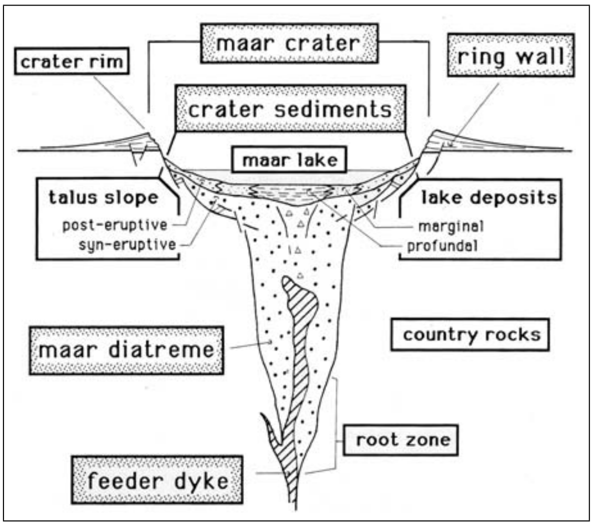

Figure 1: *Schematic plot of a maar showing crater, ring wall, crater sediments and diatreme. [Büchel [1993]]*

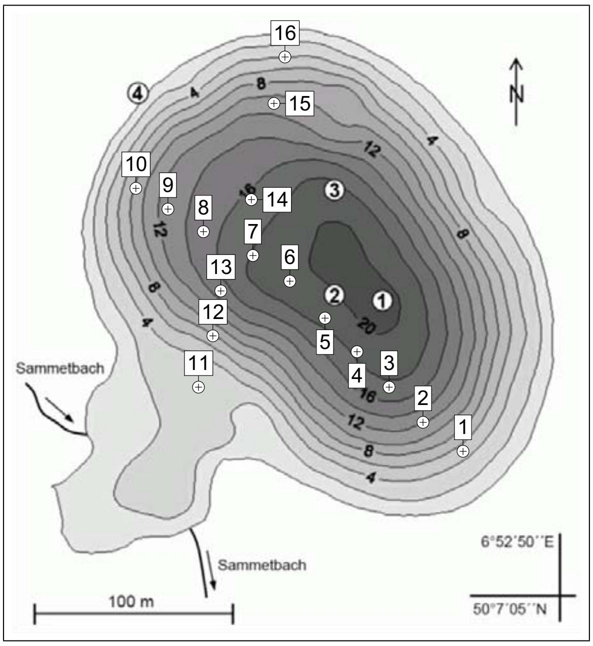

Figure 2: *Depth contours [m] and receiver sites* 1 *to* 16*. [modified according to Moschen [2004]]*

Geological background

Maars are volanic craters with up to 2 km in diameter. According to *Noll* [1967] maars are formed by strong hydrothermal eruptions. The uprising melt reacts with confined groundwater and fractures the host rock. As the overburden collapses and pressure is released, the superheated water evaporates and blows out the fractured material. The eruption process, which lasts several hours or days, results in a bowl-like depression cut into the surrounding host rock. Most of the maar tephra is transported up to several hundreds of kilometres. Only a small part builds up a confining ring wall as shown in figure 1. During the post-eruptive processes a maar lake will form for the groundwater level is undercut by the crater. Mass movements start to fill up the crater and decrease the inclination of its walls (*Büchel* [1993]). At its last stage a maar will only show the resistant diatreme filling as a carved out mountain if erosion and denudation are effective enough.

Lake Holzmaar

Lake Holzmaar, a 40.000 to 70.000 year old maar lake, is the smallest water filled maar of the Quaternary Westeifel Volcanic Field, which is situated 100 km south of Cologne. Its body of water is approximatly 290 x 210 m^2 wide with a depth of up to 20 m, steep slopes and a plane bottom. By building a weir in the late middle ages the natural water level rose about 3 m, causing the southwestern bank to become a shallow bay. The bathymetry is shown in figure 2. The resistivity of the water is known to be $\rho_w \approx 30\,\Omega m$ derived from in-situ measurements. From the late 1980's to the mid 1990's a total of 18 cores have been recovered from Lake Holzmaar, reaching to a sediment depth of 32 m below lake bottom. They can be dated back 13.000 years establishing a varve year calender of central Europe (*Negendank and Zolitschka* [1993*b*]).

Floating TEM deployment

The central loop TEM method is well known and widely used in geophysical prospecting. Common transmitter sizes vary from 10 x 10 m^2 in NanoTEM mode up to 400 x 400 m^2 for greater exploration depth. In the recent past water-borne TEM applications have been presented (*Goldman et al.* [2004], *Barrett et al.* [2005]).

Our aim was to develope a floating TEM deployment to work with the existing devices of Zonge Engineering and Research Organisation Inc. According to *Spies* [1989] the depth of investigation z_{max} (at a given resistivity σ) depends on the transmitter moment

$$z_{max} \approx 0.55 \left(\frac{I\ A}{\sigma \eta_\nu}\right)^{\frac{1}{5}}$$

where I is transmitted current, A the transmitter area and η_ν the noise level. As the transmitted current is limited to 18 Ampère by the Zonge unit, one has to maximize the transmitter size. This can be easily done land-borne, but floating device has to be mechanical rigid stable to avoid errors caused by changing transmitter-receiver geometry.

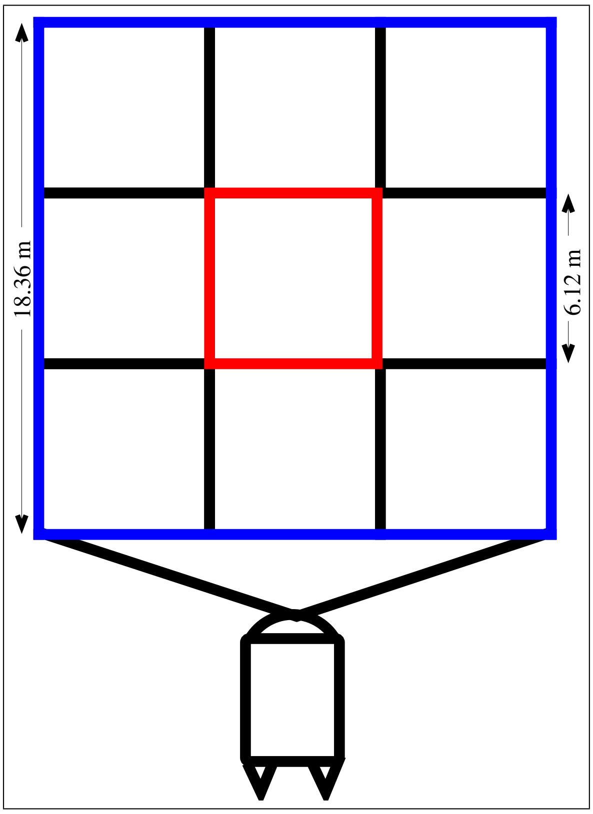

Figure 3: *Floating TEM deployment.*

The design presented consist of about 100 standard PVC tubes which can be combined in a modular way. Since the PVC tubes are only 2 m long, they can be put together and detached easily. The entire setup is reusable and can be transported in a van.

The deployment consists of 9 squares (6 x 6 m^2 each), which add up to a chessboard-like framework of 18 x 18 m^2 as shown in figure 3. The transmitter loop consists of an insulated wire inside the outer edges of the framework. The receiver antenna is placed inside the edges of the innermost 6 x 6 m^2 square. With 4 turns a total receiver moment of 144 m^2 is achieved.

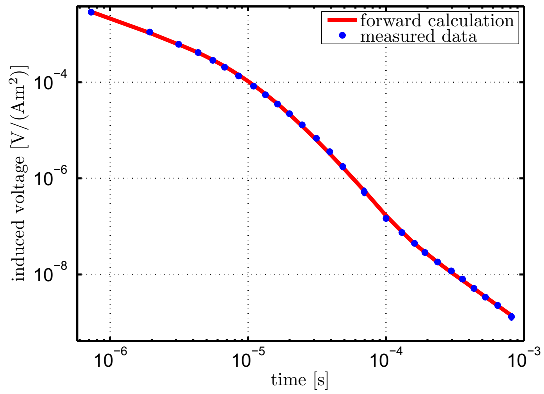

Figure 4: *Data from reference site.*

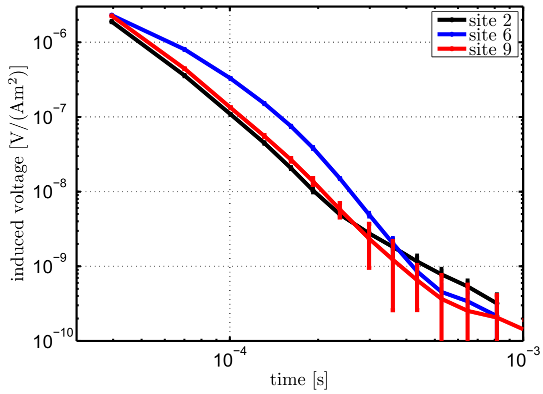

Figure 5: *Data of profile 1.*

#	resistivity [Ωm]	thickness [m]
1	1016	12
2	46	18
3	1877	112
4	64	∞

Table 1: *Model at reference site.*

Transmitter and receiver devices, batteries and equipment like GPS receivers are stored in the towing boat. The entire deployment can be set up within a few hours and is operated by two people.

Survey at Lake Holzmaar

As Lake Holzmaar is a nature reserve, any kind of combustion engine is strictly forbidden. We used an electric outboard motor to maneuver on Lake Holzmaar. At prior measurements it was figured out that the electromagnetic noise produced by the motor will impair the data quality significantly. Due to strong winds, ropes had to be drawn across the lake to avoid drifting while collecting data.

Two profiles with a whole of 16 sites have been investigated as shown in figure 2. In addition, data at a reference site 250 m outside Lake Holzmaar was collected.

As shown in figure 4 the data recorded at the reference site can be explained well by 1-D Marquardt-Levenberg inversion resulting in a model with four layers as shown in table 1. The resistivity distribution agrees with the geology assumed. Pyroclastic eruptive rocks form a highly resistiv overlaying strata. The second layer might be a groundwater aquifer since the first boundary in a depth of 12 m corresponds to the maar lake's water level. Deeper layers consist of greywacke and shales (*Meyer* [1988]).

Figure 5 shows data from three sites of profile 1, which extends from the southeastern to the northwestern bank as shown in figure 2. Obviously the data is widely influenced by three dimensional effects. All of the transients recorded on the surface of the lake show a huge dynamic and some kind of rotational symmetry.

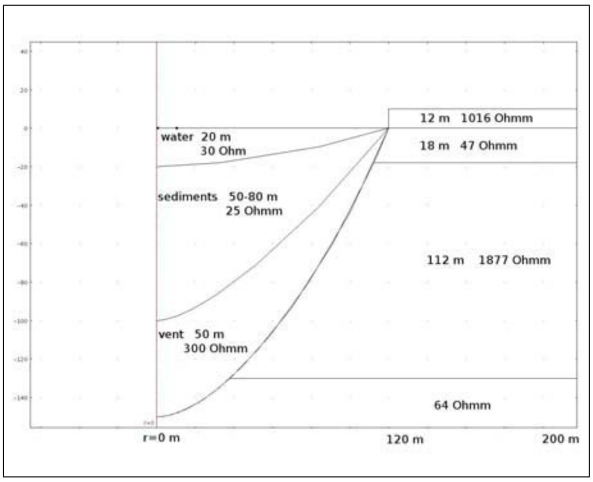

Figure 6: *Simple model of a maar lake with symmetry of rotation integrated into model as shown in table 1.*

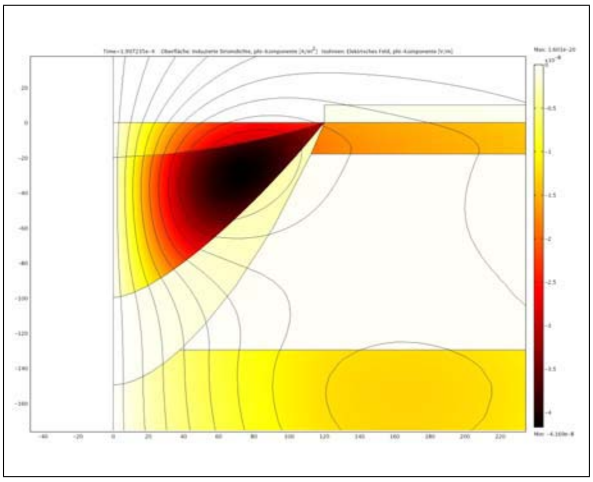

Figure 7: *Induced current density (coloured, $[A/m^2]$) and E_ϕ-component (isolines, $[V/m]$) at $t = 2\,e^{-4}s$ after switch off.*

To interpret the data multi-dimensional modeling is necessary. As site 6 is situated approximatly in the middle of the allmost circular lake, it can be analyzed by a model using symmetry of rotation.

A simple model of a maar lake was set up with COMSOL Multiphysics as shown in figure 6 and 7. The maar consists of a vent, sediments and water. It is integrated into the layered model obtained at the reference site as shown in table 1.

The symmetry of rotation implies several conditions for the fields along the axis of rotation (z-axis):

$$B_r = 0$$

$$\frac{\partial B_z}{\partial r} = 0$$

The fields are continous at all interior boundaries. The model space is 3000m x 3000m wide to avoid effects of its outer boundaries where the following con-

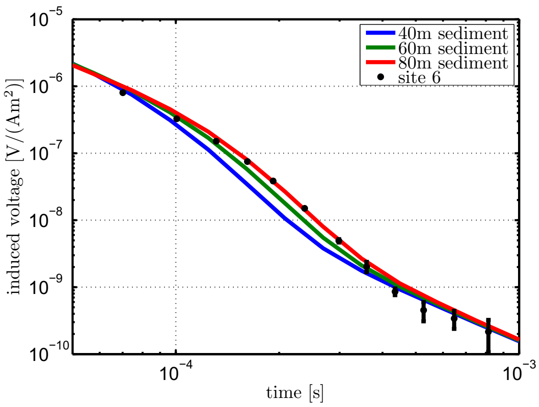

Figure 8: *Effect of sediment thickness.*

ditions for **E** and **H** have to be met:

$$\mathbf{n} \times \mathbf{E} = 0$$

$$\mathbf{n} \cdot \mathbf{H} = 0$$

Forward calculations for several resistivities and sediment thickness were carried out by means of Finite Element modeling.

As shown in figure 8 the data of site 6 can be reproduced well by sediments with

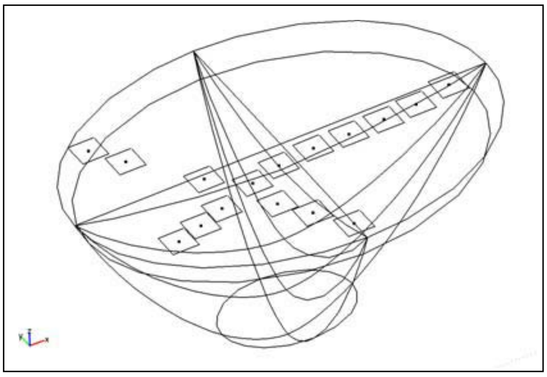

Figure 9: *Elliptic model with exact receiver sites.*

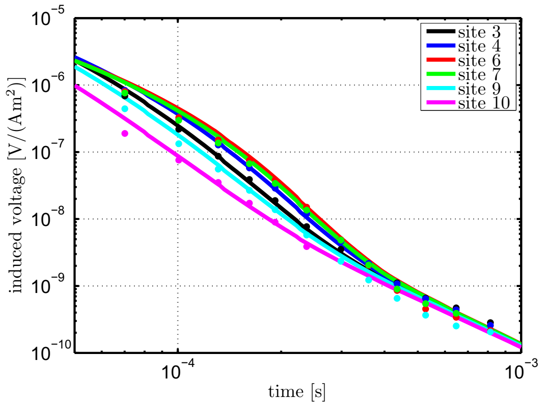

Figure 10: *Synthetic (lines) and measured data along profile 1.*

a resistivity of 25 Ωm and a thickness of 80 m. These values should be considered as a guess since a lot of simplifications have been made.

The intense decay of the induced voltage between $t = 2\,e^{-4}$s and $t = 6\,e^{-4}$s after transmitter switch off can be explained by the induced current system being 'trapped' in the highly conductive sediments. Instead of moving down- and outwards the electric field is deformed due to the shape of the maar as shown in figure 7. The maximum of E_ϕ is caught at shallow depth until leaping into the the surrounding geology causing a huge decrease of the induced voltages as seen in figure 8.

3-D modeling

By taking advantage of the rotational symmetry short computation time can be achieved. To explain the data of both profiles and illustrate the effect of the shores as shown in figure 5, 3-D modeling is indispensable. An elliptical model of 290 m x 210 m, which is also integrated into the layered model obtained at the reference site, allows to calculate synthetic data at the exact receiver locations as on Lake Holzmaar (see figure 9). It revealed that the systematic change in the induced voltages measured along the profiles is consistent with the simulation. The best fit for all sites was achieved with a model showing 55 m of sediments with a resistivity of 20 Ωm . Synthetic and measured data for several sites of profile 1 is shown in figure 10.

Conclusion

A water-borne central loop TEM system has been developed. It worked well at several test sites and allowed to carry out a survey at Lake Holzmaar. Due to the small diameter of the lake the data is strongly influenced by non 1-D effects and can only be explained with 3 dimensional modeling. The bottom of the sediments seems to be below 70 m. As the lake's radius is just about 130 m the value is vague. Effects caused by the banks and the surrounding geology conceal the sediment thickness.

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