Radiomagnetotellurics: A case study for geomorphological questions

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Abstract

The major task of the presented study is to answer geomorphologic issues concerning the evolutionary history of the terraces of the river Rhine in the Lower Rhine Bay. More precisely the task is to map the two boundaries between tertiary sands, fluvial gravel and loess. The second task is the realisation of the first measurements in Germany, using the new Radiomagnetotelluric-device of the Institute. The main technical improvement of this device is the enlarged frequency range from 10 kHz to 1MHz.

Geology of the survey area

The survey area is part of the terraces of the river Rhine, which are arranged in steps. More precisely, the area is characterized by the transition from the Niederterrasse (lowest terrace) to the Mittelterrasse (middle terrace), which is covered with loess. The location of this area is accentuated in Fig.1. Two main causes formed today's geological situation, namely the terraces arranged in steps and a complex system of valleys:
1. During the pleistozaen there was an alternation of Ice Ages and Interglazial periodes. In geomorphological terms, Ice Ages represent glazial erosion. In the interglazial periodes accumulation of fluvial sediments took place.
2. Since the miozaen (Savische Bruchbildung) the whole Lower Rhine Bay descents.

In Fig.1 a section of the middle terraces at the Lower Rhine north of Cologne is presented. As it can be easily seen, gravel and Loess cover the tertiary terraces. Therefore the original shape of the terrace can not

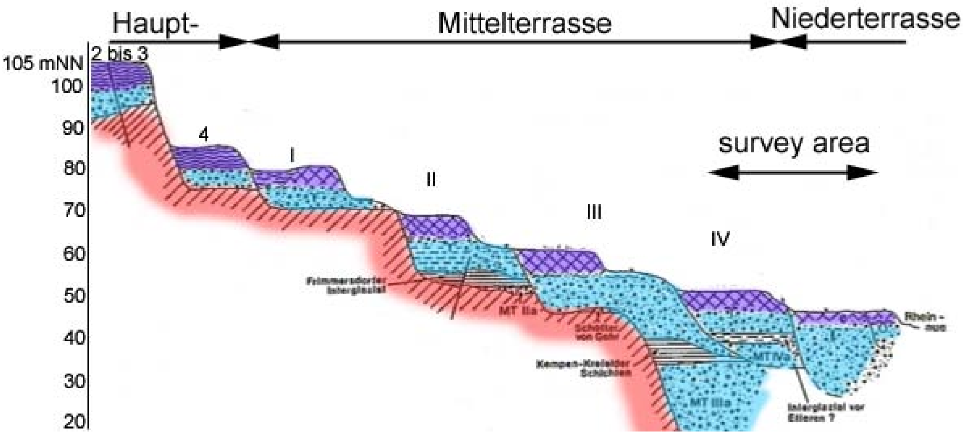

Figure 1:
Section of the Middleterraces north of Cologne [Brunnacker et al., 1978]. *Colorindex: Red = Tertiary sands. Blue = Fluvial gravel from Rhine. Violet = Loess.*

be recognized. The tertiary topography is not traceable from today's topography. The Geomorphological questions concern the location of the tertiary terraces and the spreading of the loess.

Geomorphologic questions

There are two main geomorphologic questions examined with RMT. See Fig.4 for the location of the two profiles given as examples below. The two tasks are:

1.The evolutionary history of a valley. First question is, whether the valley emerged before (Fig.2A) or after (Fig2.B) the covering with sediments.

2. Fluvial gravel and Loess cover the tertiary sands and pretend a wrong shape of the original terraces (cp. Fig.2C): The tertiary topography is not traceable from today's topography. The fact that today's top ground surface is not at the same place as the tertiary top ground surface can be seen in Fig.2C: it's shifted to the left.

Figure 2: Schematic scetch of the studied geomorphologic questions. Shown is the covering of the tertiary sands with fluvial sediments. A and B deal with the evolutionary history of a valley. C is about today's wrong shape of the original terrace.

Physical background

The theory of radiomagnetotellurics (RMT) is similar to the well-known MT (*Cagniard [1953]*). Radiotransmitters located far away are used as transmitters. Planewave approximation is valid and displacement currents can be ignored for used frequencies and resistivities situated in the survey area. The relation of the incoming electric and magnetic fields is specified by the complex impedance tensor Z (eq.1). In the case of two-dimensional distribution of conductivity, the Maxwell equations can be devided into the two modi tangential electric and tangential magnetic. Two physical parameters can now be derived from Z for each mode. Eq.2 and eq.3 show the formulas for apparent resistivity ρ_a and phase ϕ for one mode.

$$\begin{bmatrix} E_x(\omega) \\ E_y(\omega) \end{bmatrix} = \begin{pmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{pmatrix} \cdot \begin{bmatrix} H_x(\omega) \\ H_y(\omega) \end{bmatrix} \quad (1)$$

$$\rho_a = \frac{1}{\mu_0 \omega} \cdot |Z_{xy}(\omega)|^2 \quad (2)$$

$$\phi_{xy} = \arctan\left(\frac{\Im(Z_{xy}(\omega))}{\Re(Z_{xy}(\omega))}\right) \quad (3)$$

Measurement device

The 4-channel measurement device RMT-F (Fig.3) records time series of all four horizontal field components (E_x, E_y, H_x, H_y) simultaneously. The processing software, appendant to the device, calculates the transfer functions from the recorded time series by using spectral analysis. One can select the correct transmitters for each mode via the selected transmitter-azimuth and the qualitativly best transmitter-signals via the coherence level between electric and magnetic fields in x and y direction.

One technical improvement of the new measurement device of the institute is the enlarged frequency range up to 1MHz. From the higher frequencies one gets exclusive information about the upper layers of the earth. The effects on the inversion of this additional information are examined by *Wiebe [2007]*. Apparent resistivities (Eq.2) and Phases (Eq.3) as a function of frequency are shown in Fig. 9 as an example to demonstrate the data quality of the new RMT device.

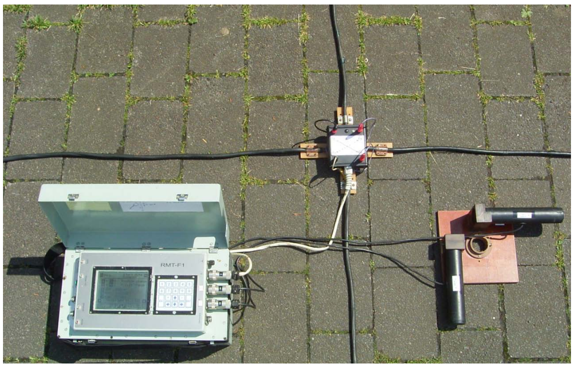

Figure 3: 4-channel measurement device RMT-F

Survey area

The survey area is located north-west of Cologne near the town Stommeln. The measured profiles are shown in Fig.4. For each geomorphologic question, given above, one example profile is picked and accentuated in the map.

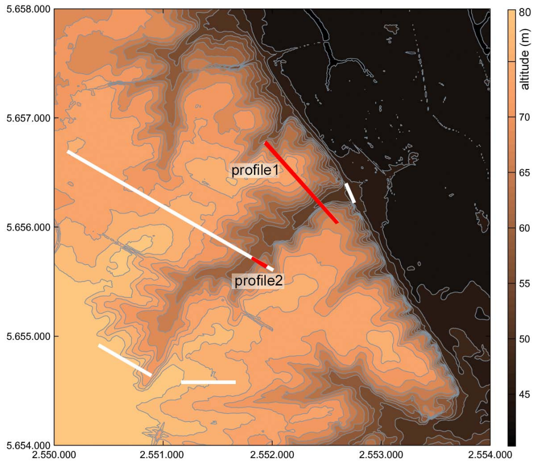

Figure 4: Map of the survey area. The two presented profiles are marked. The profile numbers correspond to the geomorphological questions above.

The drilling compresses the drilling core differently, depending on the position in the core. The core was sampled every ∼0.7m and the arithmetic mean of the measured ρ_a was calculated out of differently compressed samples and of different electrode positions in the measuring setup. The result is presented in Fig.6. This study provides an informative basis of the resistivities situated in the survey area. There is a strong contrast in resistivity between the near surface sediments ($30\Omega m$) and the deeper fluvial gravel ($600\Omega m$). The resistivity contrast between tertiary sands ($900\Omega m$) and the upper gravel is not distinct.

Further studies

As a part of the presented study conductivity measurements at drilling samples from the survey area were done by using a laboratory geoelectric measuring setup (Fig.5). Current electrodes are at top and bottom of the sample. Four potential electrodes in the middle allow several configurations.

Figure 5: Laboratory geoelectric measuring setup.

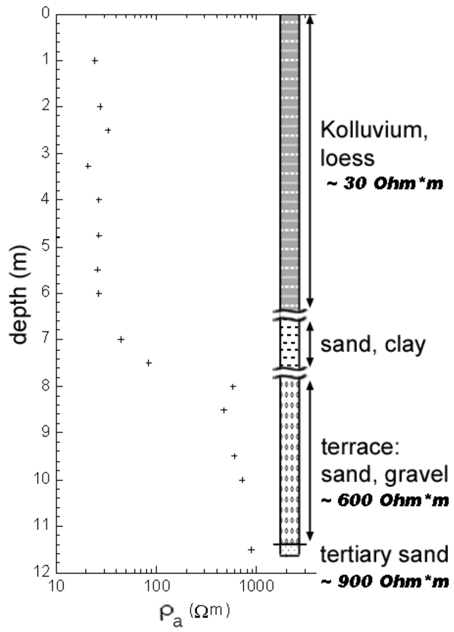

Figure 6: Results of the conductivity measurements at drilling samples and soil identification.

Inversion results

For the inversion of the RMT data the 2D-inversioncode by *Mackie & Rodi [2001]* was used. It uses a non-linear-conjugate-gradient algorithm with Tikhonov-regularization and a finite differences forward calculation. To get the optimal regularization parameter τ, every dataset was inverted seperately for several τ, and after that the optimal τ was choosen via a log-log L-Curve according to *Hansen & O'Leary [1993]*. This procedure was very time-consuming for the big amount of stations (230) and the big amount of inverted frequencies (up to 20 in some datasets). The inversion was done for the TE and the TM mode separately and a joint inversion for both modes. As a quality control for the results normalised sensitivity values are calculated for every cell. A comparison with the maximal depth of investigation according to *Spies [1989]* shows that both methods give similar depths for reliable results.

Model calculations showed that the effect of topography can be ignored.

As one can see in the inversion-results (e.g. Fig.7b) the boundary between the two resistive layers tertiary sands and gravel from the terrace is not very well reproduced: the boundary blurs to a region with lateral increasing ρ values. Whereas the two layers resistive gravel and covering conductive sediments are well separated. This fact was also observed in synthetical modeling with typical transmitter frequencies and resistivities situated in the survey area.

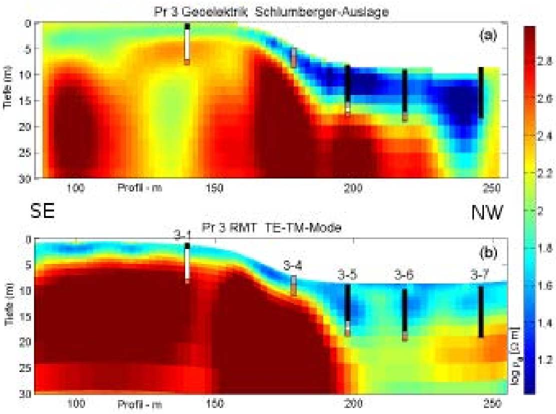

Figure 7: Profile 2 (cp. Fig.4): Comparision of Geoelectric and RMT inversion results: (a) Geoelectric, Schlumberger array (RMS = 17,5%) and (b) RMT (RMS = 4,48%). Both methods produce a similar image of the subsurface.

The RMT inversion results were compared with inversion results of geoelectric data. Both methods produce comparable images of the subsurface (cp. Fig.7). Also in Fig.7, one can compare the drilling and laboratory results by *P. Fischer [2003]* done in this area. Not every pedologic result can be reproduced by this two geophysical methods, but the main features, like tertiary sands and covering sediments are principally solved. Tertiary sands are presented in red in the drilling core, the covering sediments are black (Loess) and white (Kolluvium).

As an example in Fig.9 two stations are shown. Their locations are marked in Fig.8. The solid lines are the results from the inversion, which fit the measured data well.

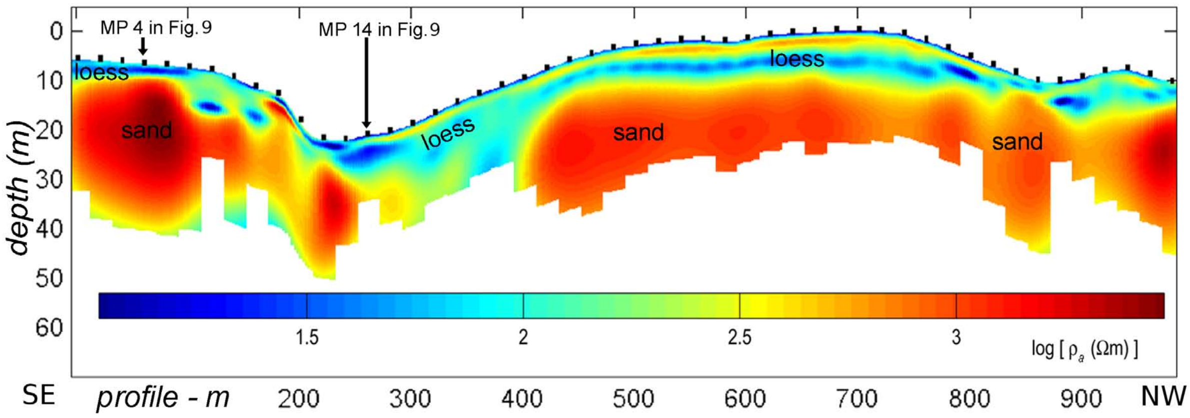

Figure 8:
*Profile 1 (cp. Fig.4): RMT joint-inversion of both modes. RMS = 1,81%. Areas below the maximal depth of investigation [*Spies [1989]*] are whitened.*

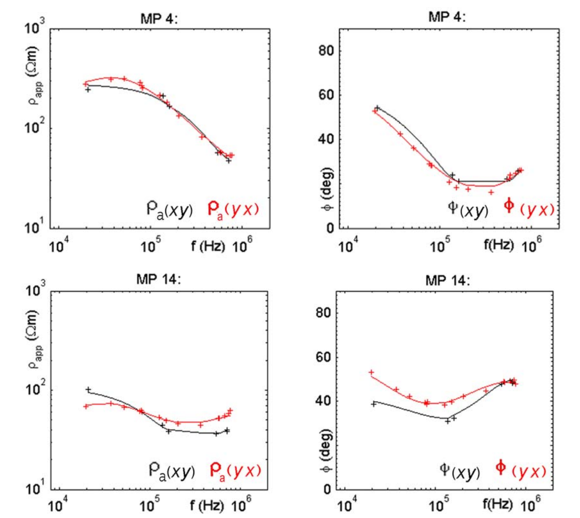

Figure 9: Data of two stations (cp. Fig.8). cross: measured data, line: calculated data.

Geomorphologic questions answered with Radiomagnetotellurics

By mapping the upper border of the resistive tertiary sands, RMT can answer the asked geomorphologic questions:

1. The evolutionary history of a valley can be revealed. In the RMT section presented in Fig.8 one can see that in this case the valley existed before the covering with sediments: one can see the original valley carved in the resistive tertiary sands. Furthermore one can see the asymmetric shape of today's valley, which differs from the tertiary valley. This asymmetric shape is typical for valleys emerged in glazial times (cp. e.g. *Fischer [2003]*).

2. The tertiary shape of the terraces can be mapped, although covered with sediments. An example therefor is the profile in Fig.7, where today's top ground surface doesn't correspond to the tertiary one.

Summary

The geophysical methods RMT and Geoelectric can be applied for some geomorphological issues. Concerning the mapping of the terraces, the results are comparable to drilling results. Of course, RMT can not substitute percussion drilling together with pedological laboratory studies. But RMT and Geoelectric give an adequate geological overview and can perfectly assist the choice of new drilling spots. The advantage is the measuring speed and the nondestructive measurement.

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