Magnetotelluric soundings in the Remiremont area, Vosges, France

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Introduction

The Remiremont area lies west of the Rhine graben which is a major element of the Cenozoic rift system of western and central Europe (Fig. 1). Since the middle Pliocene, activity in the southern Rhine graben has been dominated by left lateral shear on the N-S faults that run parallel to the graben axis (Abhorer, 1975). Magnetotelluric sounding (MTS) offer opportunity to detect crustal fluids along faults due to their high conductivity anomaly. Supposing that fluids deposited minerals in the conductive fractures (faults, dykes) decreasing the resistivity, the high seismicity in the area can be explained by the presence of these fluids. They play a role in the release of the stress accumulation in the earthquake mechanism (dilatency). The goals of our measurements are various. We would like to determine the precise location of the active fault(s), to study the connection of the Remiremont seismicity to the MT resistivity structure, and to support the idea of the influence of the fluid-bearing conducting fault(s) in the Remiremont area to the earthquake. MT profile was carried out across suspected fault(s) in the Remiremont region (Fig. 1), where one of the historical damaging earthquakes (1682) occurred in southern Vosges.

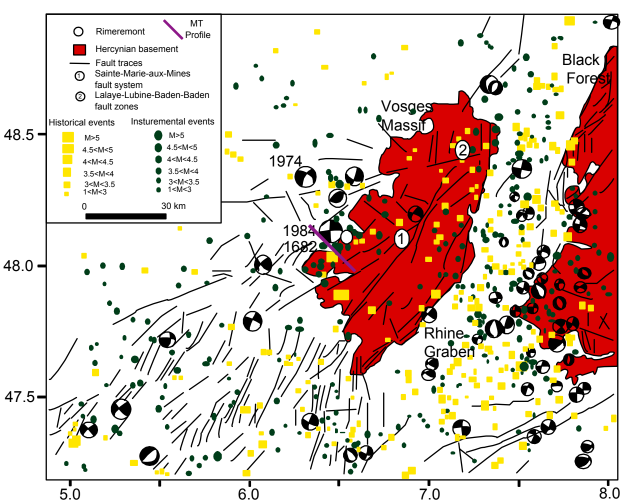

Figure 1 - Simplified tectonic map of the Remiremont area and southern Rhine graben, showing location of MT profile and corresponding fault plane solution of events.

Tectonic and geologic settings of the Remiremont area

The Hercyanian Vosges Massif is composed of two regions, Saxo-Thuringian Vosges and Moldanubian Vosges, which lie respectively south and north of the Lalaye-Lubine-Baden-Baden (LL-BB) fault zone (Fig. 1). The southern Vosges consists mainly of crystalline rocks (Hercynian basement) overlain with upper Devonian to Dinantian cover (Fig. 2). The Dinantian consists of volcano-siliceous deposits and grauwackes (sandstone), assembled in 'Culm' and characterises the Lower Carboniferous (Schneider, 1990). The Mesozoic is only represented by triassic clastic sediments. In Vosges, salt deposits are usually found in layers of the Late Triassic. Quaternary formations cover the most central part of the Remiremont area. It is represented by sandstone, argillaceous gravels and alluvial of Remiremont.

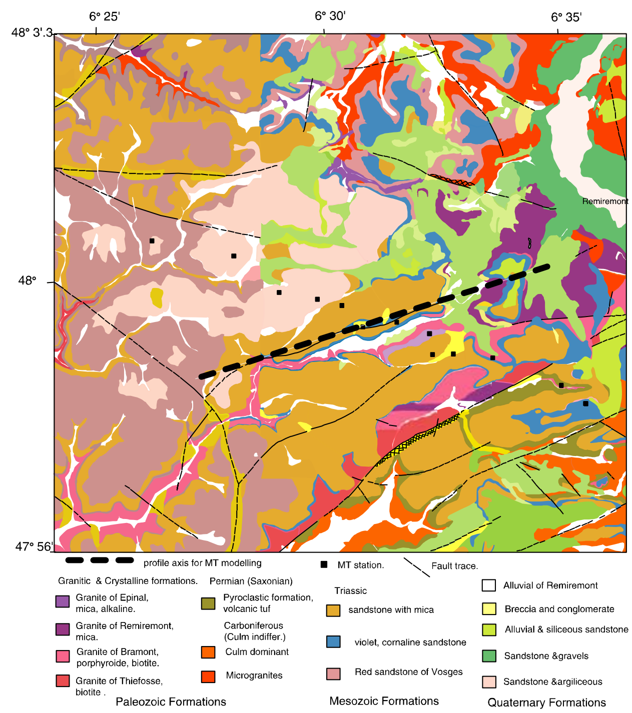

Figure 2. Geological and tectonic map of the Remiremont area (BRGM, 1979), showing the location of MT stations (dots) and the rotated MT traverse.

The major tectonic feature is the Sainte-Marie-aux-Mines that cuts the southern Vosgian Massif from NE to SW (Fig. 1). This fault is considered ductile left-lateral strike slip fault (Fluck, 1991). The long geological history has resulted in a complex fault pattern (BRGM, 1979).

Seismicity in Remiremont area

Seismic activity is occurring along the entire graben system and its borders (eastern and western). The seismicity in the southern Rhine graben represents the largest data set. The majority of events are located in or close to the Rhine graben fault system (Fig 1). Focal depth covers the range 5 - 23 km. Most of the earthquakes are strike-slip movement. There is also a significant number of normal faulting events. All mechanisms exhibit some oblique component of slip. The maximum compression axis acts in a SE-NW to SSE-NNW direction and the minimum compression axis in a SW-NE to WSW-ENE direction.

Seismicity is observed around Epinal (1973-1974) and Remiremont (1984-1985) areas (a M=5.4 quake occurred 10 km N of our profile on Feb. 22, 2003). Trends are NW-SE and NE-SW (Fig. 3). The seismic events of Remiremont having magnitude smaller than 4.8 are found to align along a 40 km-long fault zone flanking the southern Vosges Massif to the west (Fig 3). The b-value of the Gutenberg-Richter distribution is 0.83. The focal mechanisms in the area, including those related to the main shocks near Epinal and Remiremont, are consistent with a roughly N30°W principal compressive axis and N60°W minimum principal axis consistent with the World stress map (Delouis et al., 1993; Mueller et al., 2000).

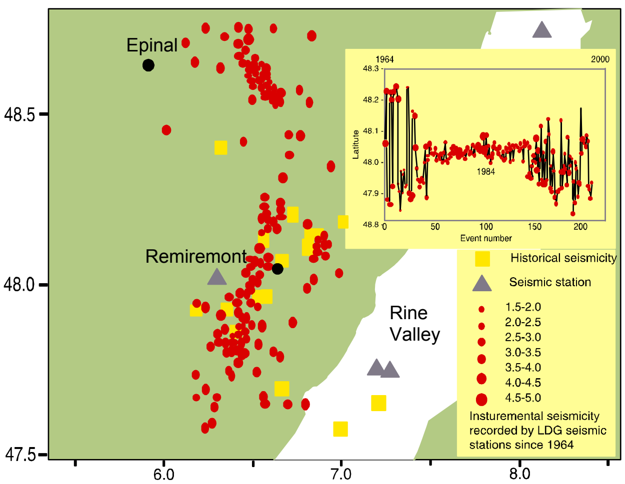

Figure 3. The seismic activity in southern Vosges, showing two cluster zones. Upper graph: Spatial and chronological seismic pattern in the area (Audin et al., 2002).

MT acquisition and analysis

The MT measurements took place in two field trips during August and September 2002. The profile extends 13 km from NW to SE (Fig. 2), consisting of 13 observational stations, with an average spacing of 1 km. Most stations were located at significant distance off the road. The 3 instruments used in this study were developed by the Group of Geomagnetism of our University. They feature ECA CM16 and CM11 coils. The MT data were measured in the NS and EW direction. The electrical dipoles were 50 m long. The recording of AMT and MT covers the period range 0.0046-420 s.

Induction arrows and strike determination

The geological strike is more safely obtained by measuring the vertical magnetic field induction coefficients (induction arrows, Schnegg 1998). The direction of the induction vectors, which are less affected by static effects than electric fields, safely indicate the geologic strike (or rather, a direction perpendicular to the strike).

In Figs. 4 the real and imaginary tipper arrows are plotted versus the logarithm of the period. In the upper part of the subsurface the real components at RED and REE point in opposite directions, suggesting the presence of a conducting structure, probably a fault between the two

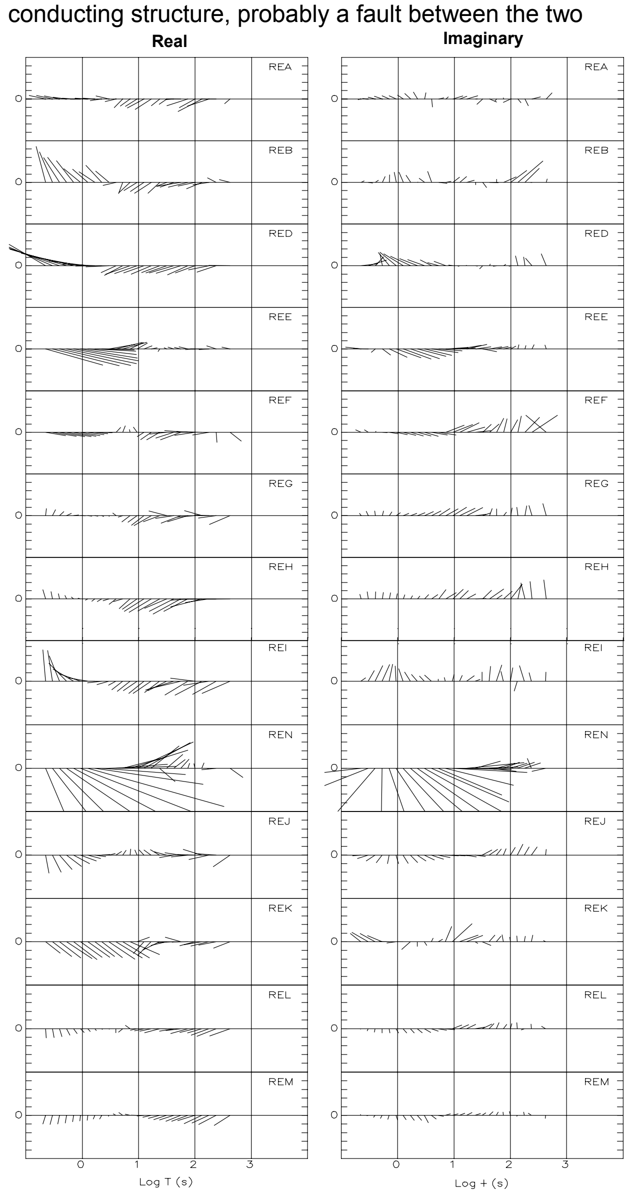

Figure 4. Real and imaginary components of the tipper at sites REA to REM (true north is perpendicular to the time axis).

sites. The same situation can be observed between REI and REJ, culminating at REN, a location with high 3D geology, according to its MT response.

The real and imaginary parts of the induction arrows at period 1.24 s are superimposed on known geological features. Note the difference in magnitude and azimuth suggesting strong surficial lateral and vertical variations in the resistivity structure. The subsurface behaviour was modelled using the short period end of the induction data. Two shallow, dike-like strong conductors are localised. One of them coincides with a known fault (Fig 5a, b, c).

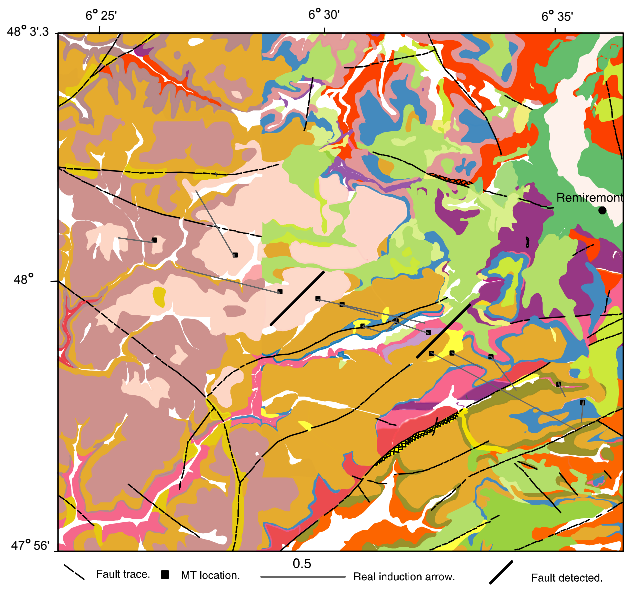

Figure 5a. Real tipper arrows (at period 1.24 s) at sites REA to REM, superimposed on a geological map of the Remiremont area. The solid black lines mark the detected faults

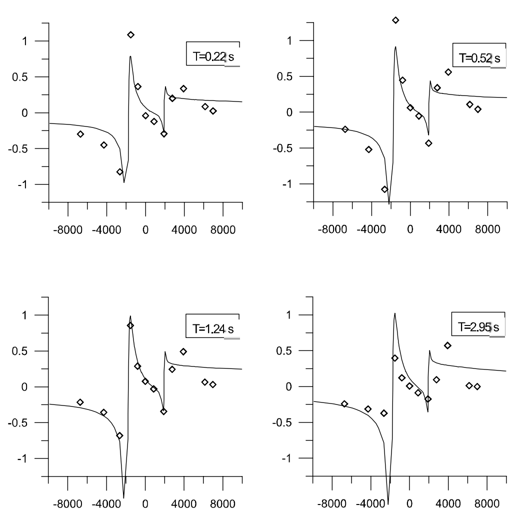

Figure 5b. Measured real arrows vs. profile distance and 2D model response at four periods in the short-period end. Model obtained by automatically fitting location, size and resistivity of two rectangular prisms.

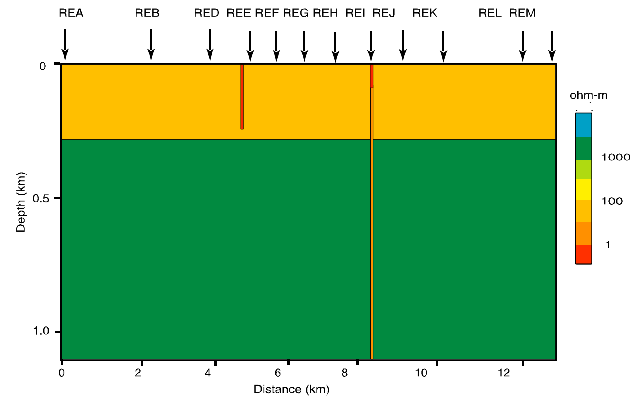

Figure 5c. Subsurface model obtained solely with the induction arrows showing two high-conducting features (~1Ωm), one of them (at site REI) coinciding with a documented fault. The background 1D geology is deduced from the short period MT data modelling.

Before computing the MT apparent resistivity and phase, the measuring axis rotates into an average direction (N20°W). After rotation, the two impedances yield Rhomax and Rhomin curves. The angle is fully consistent with the long-period induction arrows. Rhomax coincides with the strike, is designated as E-polarisation. Rhomin (H-polarisation) is perpendicular to the strike direction. All site locations are projected into a new profile perpendicular to the strike for further 2D modelling (Fig. 2).

2D MT modelling and interpretation

For 2D modelling, we have projected our rotated MT data on a profile perpendicular to the adopted strike (i.e. trending N20°W). Simultaneous inversion of TE, TM (Zxy, Zyx) modes and tipper was carried out using Rebocc inversion program (Siripurnvaraporn and Egbert, 2000). The static shift distortion parameters are let free so that the program can automatically adjust the values. A 3rd-strip selection is used. The results of the inversion are shown on Fig. 6. After 12 iterations, the inversion finds a model with an r.m.s. misfit of 2.1.

The 2D model is shown only for the top 9 km. The conducting material is located in the middle of the earthquake hypocenter distribution. It could be interpreted by the presence of crustal fluids involved in the triggering of the seismicity. The resistivity values are between 1-100 ohm-m for the faults. Note that the resistivity values are lower in the middle part (main fault) of the profile, around the seismicity area than the other faults. It extends to a depth of about 6km within the Hercynian Vosges basement. The faults discovered with the short period tipper extend between 250 - 1000 m. The increase in resistivity below those faults do not imply the absence of fluids, but probably increasing confining pressures reducing the porosity of the granite rock and the pathways available for electric current flow.

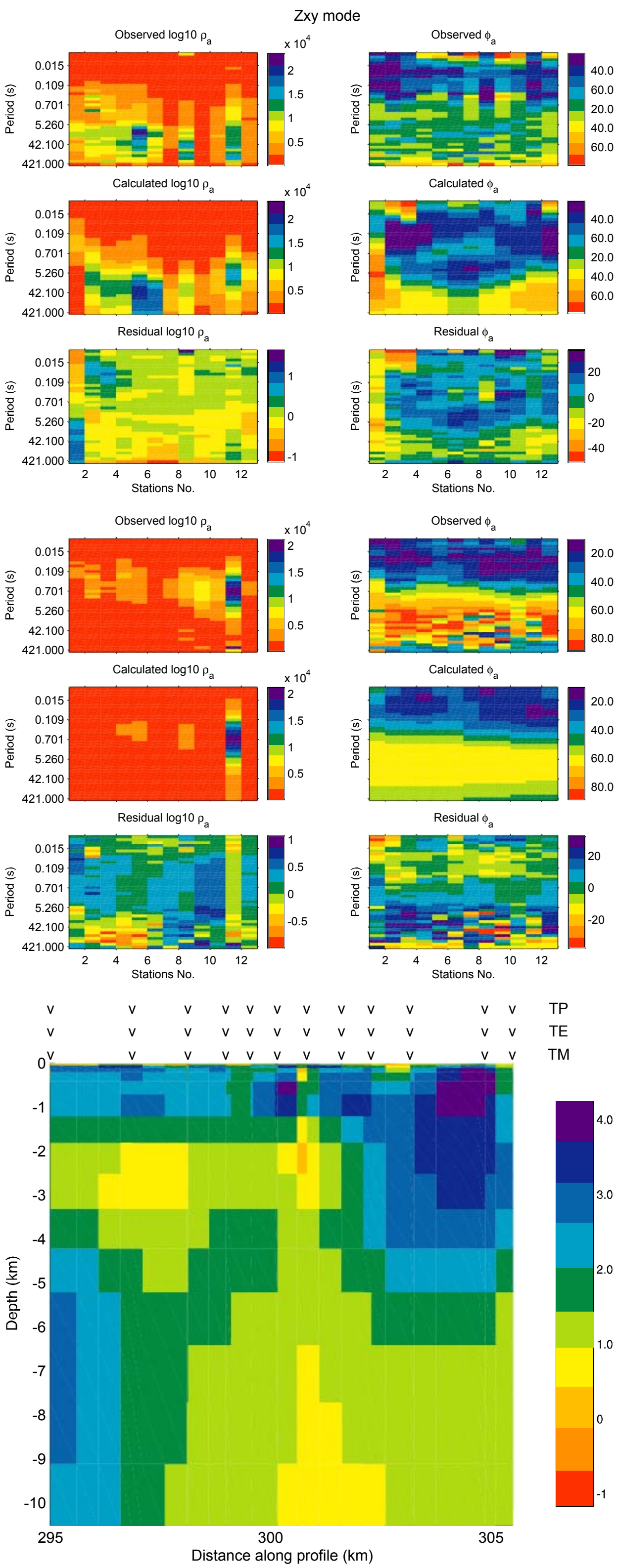

Figure 6a-b. Results from Rebocc inversion on MT data across the Remiremont fault(s) for Zxy and Zyx modes. c) 2D magnetotelluric model. The high-conducting (<10 Ωm) central zone coincides with the active fault of Fig. 5.

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