A detailed electromagnetic investigation of the Franconian Lineament/Bavaria

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SUMMARY

Audiomagnetotelluric (AMT) measurements on four profiles, combined with other near-surface geophysical investigations at the Franconian Line (FL) in the vicinity of the KTB reveal the complicated electrical structure of this fault zone, which marks the western border of the Bohemian Massif. The most prominent finding is a large conductivity anomaly associated with a $-700\,\mathrm{mV}$ SP minimum in the southern profiles crossing the SE1 reflector found by KTB 3-D seismics. This suggests graphitized shear planes subparallel to this fault zone as its origin. The part of the FL striking approx. normal to the present direction of maximal compression shows much weaker, and only near-surface indications of the fault zone. These results may be explained by meteoric fluids, possibly from the Mesozoic sediments in the SW present in the top 100 m of the fault.

1 INTRODUCTION

During the intensive site investigations of the Continental Deep Drilling Project (KTB) a large amount of geological and geophysical data were collected, which were later combined with the results from the borehole to give an integrated and also well-controlled view of the geology near the drilling site, as was documented in a special section of JGR (*Haak and Jones* 1997). The surrounding area, called Zone of Erbendorf-Vohenstrauß (ZEV), is situated at the western border of the outcrop of the Variscan Belt and has been proposed to be an allochthonous klippe transported to its current location from the south. The Franconian Lineament (FL) is a fault zone less than 10 km from the KTB site, separating the crystalline metabasites and gneisses of the ZEV from younger Mesozoic sediments. It is believed to be associated with late Variscan (early Triassic and Cretaceous) reactivation of an older strike-slip fault as a reverse thrust, resulting from a changed direction of stress (SW-NE compression, see *Wagner et al.* 1997). At present, the direction of maximum (compressional) stress is found to be at $-20 \pm 10\,^\circ$ (*Brudy et al.* 1997). In the southern part of the measuring area (marked by the rectangle in Fig. 1), the outcrops of the SE1 reflector identified by 3-D seismics (*Harjes et al.* 1997) mark the FL, while it coincides with SE2 in the North (see Fig. 1, top). In between an offset zone exists, which suggests a strike similar to the present large-scale stress direction.

2 MAGNETOTELLURICS AND OTHER GEOELECTRICAL MEASUREMENTS

Many magnetotelluric (MT) measurements were carried out in the area of the ZEV (see *ELEKTB group* 1997, for a list of contributors). In most profiles the Franconian Lineament appeared as a major feature marking the border between rather well-conducting sediments in the west and extremely inhomogeneous crystalline structures in the east (e. g. *Eisel* 1995). The Technical University of Berlin (TUB) carried out a number of small scale AMT surveys on this particular structure, which were documented in several unpublished Diploma theses (see *Schubert* 1997; *Schwalenberg* 1997). Unfortunately, at most sites only MT impedances in a frequency band between 1000 and 1 Hz are available, partly because of instrumental limitations, partly due to the low data quality resulting from cultural noise. Magnetic transfer functions were measured only at a small number of sites. Wherever possible, the sites were organized into profiles for 2-D treatment. As can already be seen from Fig. 1, only profiles A and D are dense enough to have sufficient overlap of induction volumes, while B and C should be treated as merely illustrative.

During the KTB investigations *Bigalke and Grabner* (1999) had found a very large self-potential (SP) anomaly in the same area, and the last profile (D) was placed to traverse the center of this structure. To gain three-dimensional information at least near the surface, an additional SP network, as well as VLF(R) and Radio-Magnetotelluric (RMT) measurements were carried out on this profile and in its surroundings.

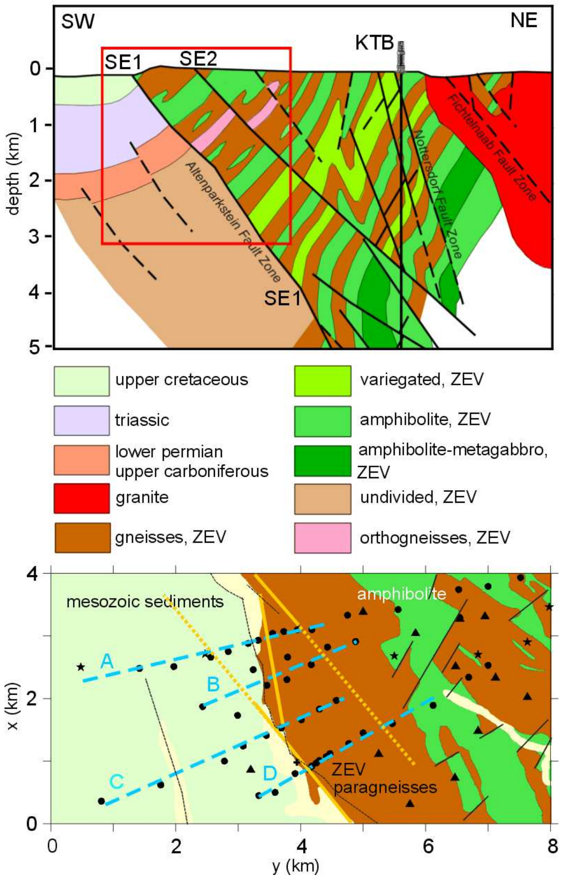

Figure 1. Top: Geological situation at the SW border of the Zone Erbendorf-Vohenstrauß (ZEV) (modified, after *Hirschmann* 1996). The approximate measuring area is marked. The reflectors SE1 and SE2 mentioned are also visible at the border of the crystalline ZEV. Bottom: Location of AMT/MT measurements and profiles A-D in the study area. All four profiles traverse the FL. At the surface, it separates mesozoic sediments in the SW and the metamorphics of the ZEV in the NE. Different symbols mark sites from different field campaigns and/or groups.

Figs. 2 and 3 show the SP results, with a large minimum of $< -700\,\mathrm{mV}$. The anomalies are aligned along the SE part of the fault zone mapped at the surface (see Fig. 1). 2-D modeling of the SP anomaly by inclined dipoles indicates predominantly one conductor with a dip similar to the FL (70°). Its top is located at a few tens of meters, while its depth extent is great (several hundred meters), but unresolved. The SE trace of the SE2 reflector into the ZEV also is associated with a significant SP anomaly, which was confirmed by recent SP and VLFR-measurements.

The shallow effects in high-frequency electromagnetics (VLF, RMT) are much weaker but nevertheless clearly visible (Fig. 4). The anomalies found here can be correlated on the profiles as conductive bands subparallel to the strike of the FL as given by the seismic reflectors. In general, the basement in the immediate vicinity of the Franconian Line proper seems to be strongly fractured, as indicated by generally low resistivities (not exceeding a few hundred $\Omega\mathrm{m}$).

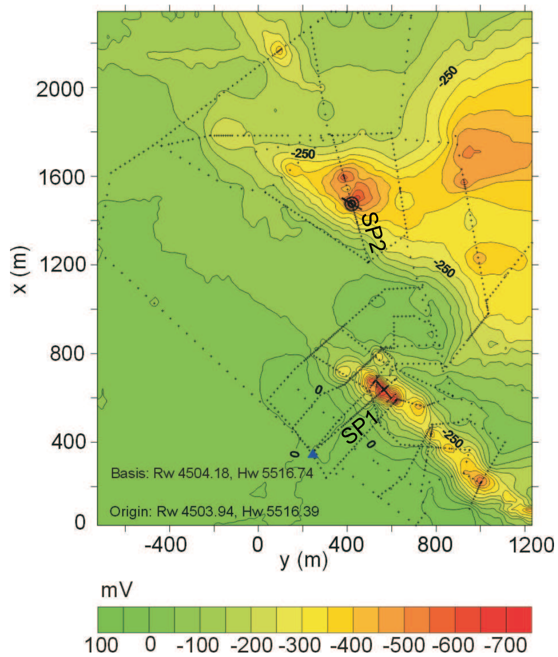

Figure 2. Self potential (SP) anomalies at the Franconian Line. The large elongated structure in the SE reaches minimal values below $-700\,\mathrm{mV}$. This anomaly is rather sharp, indicating a shallow origin. The anomaly in the NW is much weaker. Small dots indicate data points.

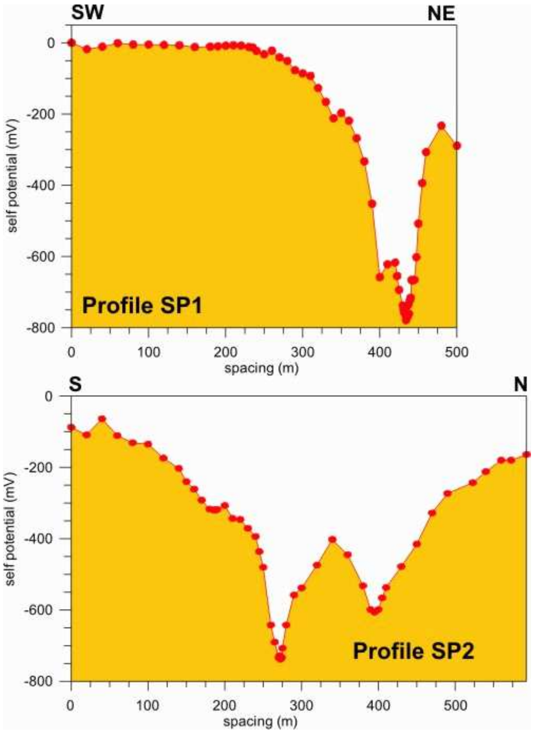

Figure 3. Self potential (SP) anomalies at the Franconian Line. Top: The large elongated structure in the SE of fig. 2 reaches minimal values below -750 mV (Profile SP1). This anomaly is rather sharp, indicating a shallow origin. Bottom: The anomaly in the NW is less localized and displays two distinct peaks. Simple dipole modelling revealed depths of 20-50 m to the top of the steeply dipping conductors. Although not well resolved, the depth extent is several hundred meters.

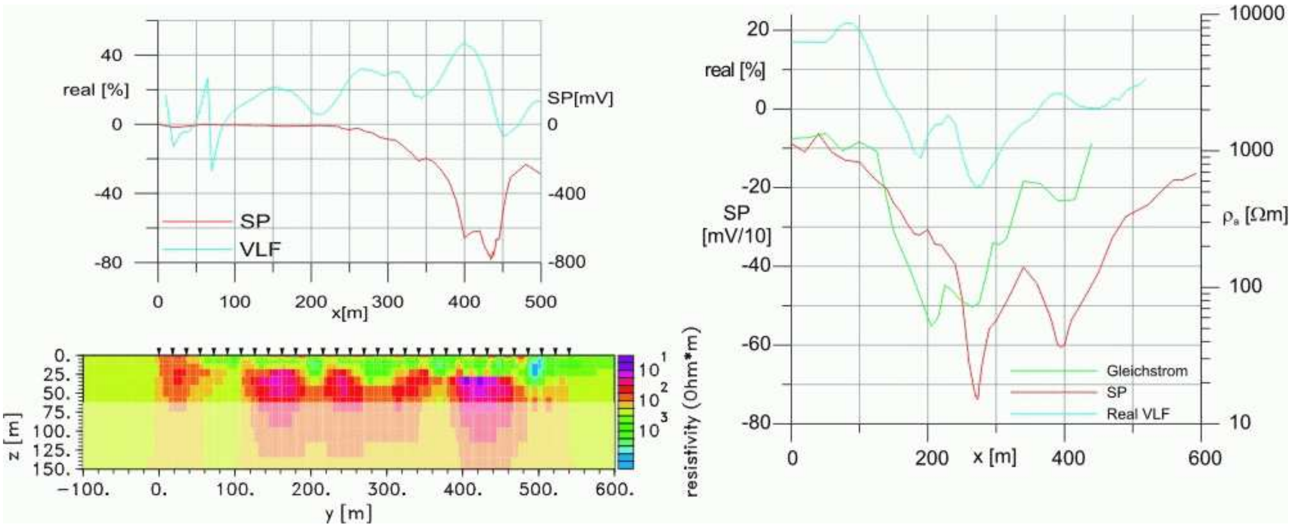

Figure 4. High-frequency electromagnetics on profile D. Left: SP anomaly and real part of VLF TE mode plotted jointly with 2-D inversion results for a RMT profile at the central part of AMT profile D (see above, identical with SP profile SP1, see fig. 3). Four radio stations at frequencies between 227 and 22 kHz were used. Geometrically, all these transmitters were approximately placed in B-polarization direction. The disjunct small anomaly at 0-50 m can be identified with the surface trace of the SE1 reflector, while the whole zone between S1 and S2 seems to be a succession of shallow subvertical conductors. Because of the small frequency range, and the missing E-polarized fields, the lower boundary is not resolved. Right: SP, VLF (real part), and DC geoelectric profiling (pole-dipole) on profile SP2.

3 2-D INVERSION

The inversion results of profiles A – D are shown in Fig. 5. The profiles were positioned with a conception of the FL as a simple fault zone of $\approx -40^\circ$ strike, which could be treated as two-dimensional. This assumption turned out to be only a rather crude description of the geological situation, and has to be shown to be consistent with the data. Conventional Groom-Bailey (GB) decomposition (*Groom and Bailey* 1989) yields values of regional strike of -40° at the central sites near the FL on the northernmost profile A, and -30° on profile D. Unfortunately, vertical magnetic fields of acceptable quality were only available at a few sites, inhibiting their consistent use in dimensionality analysis. Near the FL, however, they show the expected behavior for short periods, slowly changing to a more NS trend at frequencies of a few Hz. This corresponds to the regional trend in the long period data described by *Eisel and Haak* (1999).

In spite of these problems, all four profiles were interpreted by 2-D inversion using a variant of the algorithm given in *Rodi and Mackie* (2001). To deal with near-surface inhomogeneities, which cannot be found by GB decomposition, a phase-dominated inversion was used, downweighting ρ_a with respect to phases. This results in smooth and stable models, where sufficient coverage exists. Second-order regularization was used on all profiles. The weighting of the regularizing term was adjusted just above the smallest value to guarantee convergence and smooth behavior of the terms of the objective function.

The major features visible in the inversions are the following: In the SW, the mesozoic sediments appear as moderately resistive, overlaying a much better conductor, which could be interpreted as brine-saturated sediments of permo-carboniferous age. These are possibly source of the saline fluids present in the SE1 fault zone at depth (*Möller et al.* 1997). The basement is not resolved due to the lack of long-period data. The SE1 zone itself is only visible in profiles D and possibly C, while the other ones show only shallow conductors. On D, an extended zone of very low resistivity is found at SE1, i. e. f the proposed location of the FL main fault. Its depth extent is not resolved. This zone seems not to be restricted to the main fault, but there are indications that it consists of several structures, which reach considerably below the sediments in SW direction, and into the ZEV in the NE. On C, the large conductive body is located in strike direction of the SE1 reflector, which is supposed to continue below the sedimentary cover (*Harjes et al.* 1997).

4 DISCUSSION AND CONCLUSION

The electrical behavior of the FL revealed by the measurements presented here shows that this structure has a complicated geometry. It does not present a simple plane of deformation, but, at least locally, a wide zone of enhanced electrical conductivity. It is less pronounced as a prominent conductor in the NW (profiles A, B), while it seems to be associated with a large and deep-reaching anomaly in the SE (profiles C, D). Contrary to the results from SP and near-surface induction, its top is found by MT at depths $> 100\,\mathrm{m}$, with most of the conductor below $500\,\mathrm{m}$. This is possibly due to the low resolution at AMT frequencies and the fact that the SP is produced by the shortcut between regions of different redox potential, being insensitive to the conductive structures below.

Unfortunately, the internal structure of the electrical anomaly is difficult to resolve with electromagnetic methods. Though there are indications that it consists of several disjunct conductors, this can not uniquely be deduced from the data. Internal structure, depth, and, as a consequence, dip of the conducting body are not resolved. This can clearly be seen from the normalized sensitivities (*Schwalenberg and*

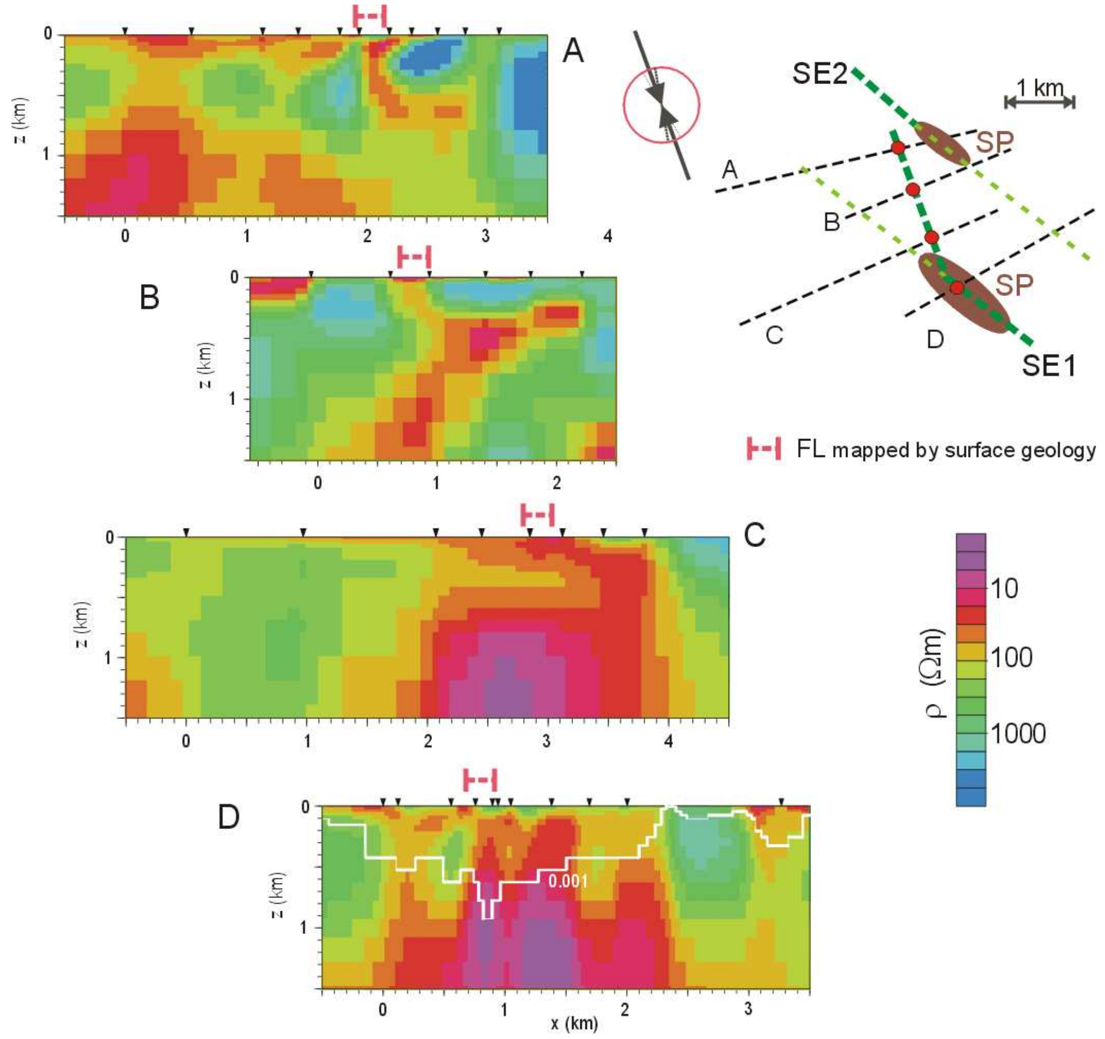

Figure 5. 2-D inversion results for profiles A – D across the FL (compare Fig. 1). The FL can easily be identified in all four cases: the area where it is mapped by surface geology is marked on each profile. There is a remarkable difference, however. In the two southern profiles (C and D), it is connected with a prominent conductivity anomaly at depths of a few hundreds of meters. This coincides with the large SP anomaly, which was not found further to the NE. The SP anomalies from Fig. 2 are marked in the schematic drawing on the right.

Rath 1998) in Fig. 3. The isoline marks the depth where sensitivity has decreased by a factor of 10^{-3} with respect to its maximum value.

Tentatively, the small, near-surface anomalies on (A-C) may be due to water influx – possibly from the surface – to a more recent fracture zone associated with the present $-20\,^\circ$ direction of maximal stress (*Brudy et al.* 1997). The large conductors found on C and D may be caused by the older graphitized shear zones of a more NW-SE strike, which in turn may be connected to the post-variscan episodes with the according stress direction (*Wagner et al.* 1997). This explanation is not the only one possible, as brine influx from the sediments to these fault zone has been postulated based on independent reasons (*Möller et al.* 1997).

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