A Mise-à-la-Masse experiment for detecting an electric network in cataclastic zones around the KTB-site

Johannes Stoll*

Contents

1. Summary

The casings of the KTB pilot- and main boreholes were used to inject an electrical current into the formation. The artificial potential field of this current was measured along a small profile close to the KTB drilling sites to detect changes in the potential. The observed changes indicate a connection of an electric conductor with one of the casings and support the assumption of a general conducting layer extending over distances of several hundred meters. From the tectonic map it is assumed that the detected conductive layer belongs to the prominent Nottersdorf fault zone, which is steeply inclined and crosses the main borehole between 250 and 1500 m.

* Johann-Wolfgang-Goethe-Universität Frankfurt, Institut für Meteorologie und Geophysik, 60054 Frankfurt/Main, Germany

2. Introduction

Results from several geoelectric soundings (direct current-, very low frequency resistivity-, audiomagnetotelluric measurements) around the KTB drilling sites suggest that the pilot (KTB-VB) and main (KTB-HB) boreholes are drilled into a several hundred meter wide NNW-SSE striking zone with an extremely low electrical resistivity (Haak et al., 1991). Whereas in the surrounding crystalline rocks resistivities of 10^3-10^4 Ωm were measured, this zone exhibits less than 10 Ωm locally. In comparison to crystalline rocks these very low values doubtless are based on graphitic and sulfuric (especially pyrite) accumulations on many cataclastic shearzones observed in both boreholes, which lower the resistivity by several orders of magnitude. Even graphite is exposed on the surface in some places. This increase of the conductivity inside crystalline rocks could be caused by graphite only if it forms an interconnected network. Such interconnections along shearzones of several hundred meters in vertical extent represent one of a few most important constituents to establish self-potential anomalies. An anomaly of about -600 mV has been detected close to the KTB site (Stoll, 1990). Following the theory of Sato & Mooney (1960), the graphitic shearzones serve as a bridging conductor, in which electrons are transferred from electrochemical reducing agents at depth to oxidizing agents near the surface. However, according to the graphite-bearing rocks around the KTB site this interconnection is still a basic question.

The Mise-à-la-Masse method is an appropriate possibility to use to verify this hypothesis. Since the casings of the boreholes are used as electrodes to inject the current into the formation, the penetrated shearzones will be electrically connected. It is assumed that the electrical current flows along these zones to the surface and changes the electrical potential field there. This change is measured.

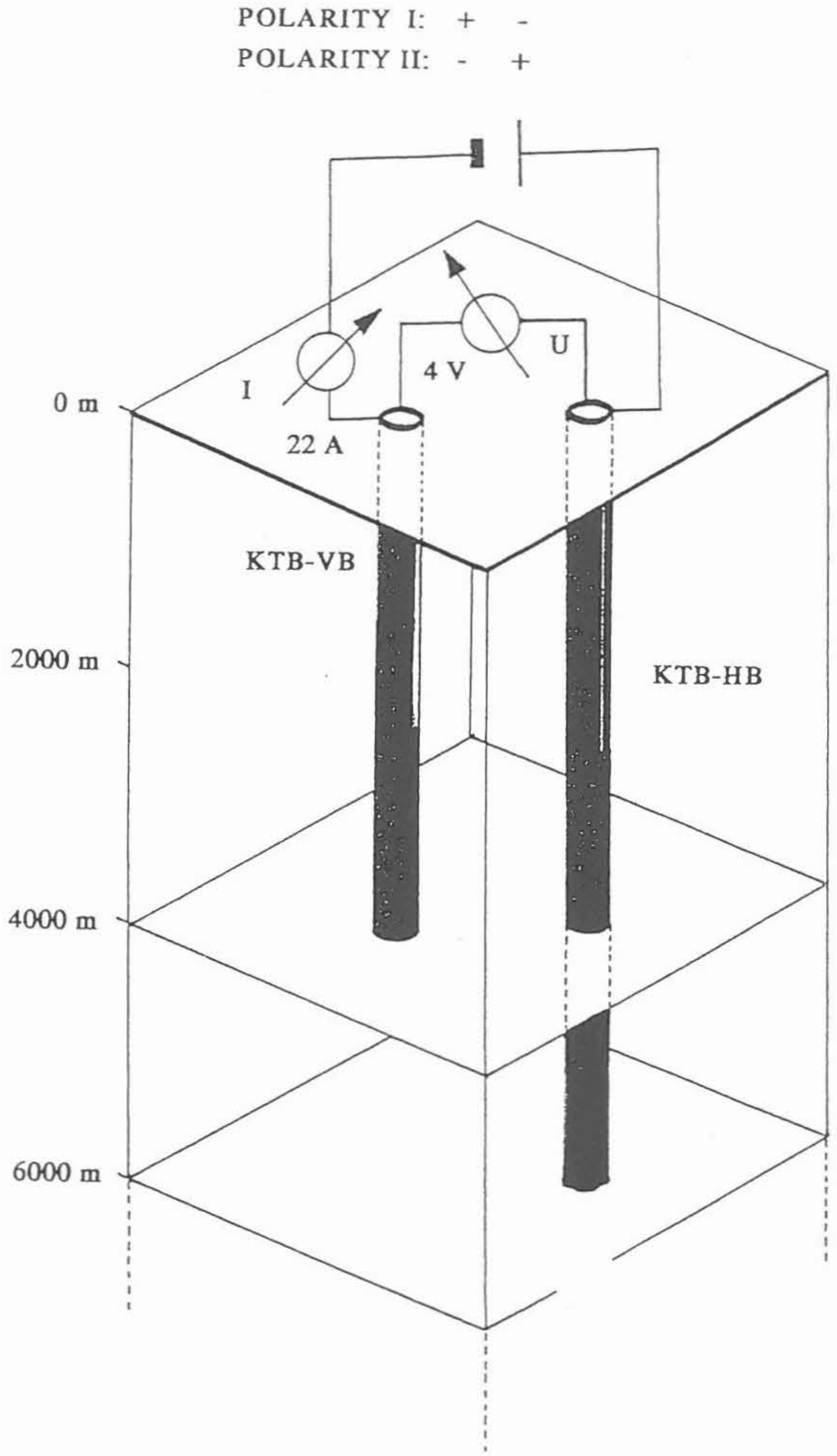

Fig.1

Circuit diagram of the Mise-à-la-Masse experiment in the KTB boreholes
U1: Injection voltage (10V)
U2: Voltage between the casings (4V)
I : Injection current (22V)

current source

3. Mise-à-la -Masse in the KTB boreholes

3.1 The experiment

The two casings of the pilot and main drilling holes will be used as electrodes to inject an electrical current into the formation. At the time of the experiment (24.3.1992) the casings had a vertical extension of 3850 m (KTB pilot hole) and 3000 m (KTB main hole). Because of the high conductivity of the drilling fluid (0.2 Ωm) the complete extension of the boreholes (KTB-VB 4000 m and KTB-HB 6000 m) can be considered as electrodes. The electrical current is taken from the public net and is transformed in a direct current. Two cables which are fixed on the top of the casings conduct the current from the source into the formation (Fig. 1). The interstitial water between the casing and the formation supports the impedance matching, so the measured transition resistance of the casings amounts to 0.212 Ω, which allows to inject strong electrical currents with moderate voltages. The terminal voltage amounts to 10.23 V and decreases because of the cable resistor to 3.46V (**U2** in Fig.1) with 22 A between the casings. Electrical polarisations of the casings increased this voltage to 4.2 V, while the current decreased to 18.18 A.
The potential measurements at the surface were carried out close to the drilling area along a profile in radial distance of 100 m to the pilot hole (Fig. 2). Four copper-coppersulphate electrodes (E1..E4) were installed at a spacing of 50 m. The potential is measured with respect to a reference electrode (BE) before and during injecting the current into the formation by reversing the polarity once. In the following the registered values are:

(A): without current; i.e. self-potential EP

BE -> E1 : - 61 mV
" -> E2 : -238 mV
" -> E3 : -306 mV
" -> E4 : -223 mV

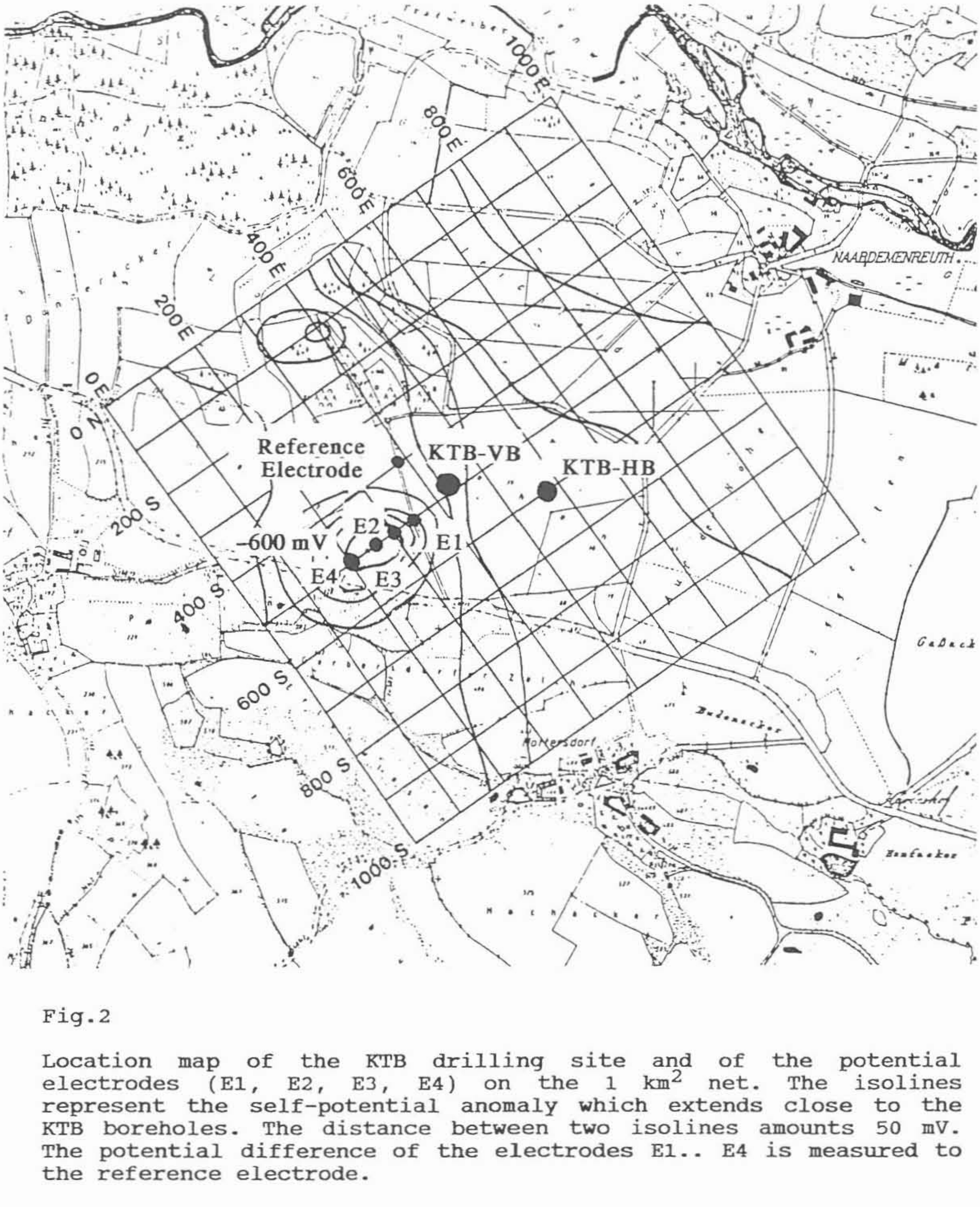

Fig.2

Location map of the KTB drilling site and of the potential electrodes (E1, E2, E3, E4) on the 1 km^2 net. The isolines represent the self-potential anomaly which extends close to the KTB boreholes. The distance between two isolines amounts 50 mV. The potential difference of the electrodes E1.. E4 is measured to the reference electrode.

(B): polarity I
with injecting current (KTB-VB positive, KTB-HB negative)

BE -> E1 : -538 mV
" -> E2 : -870 mV
" -> E3 : -953 mV
" -> E4 : -878 mV

(C): polarity II
with injecting current (KTB-VB negative, KTB-HB positive)

BE -> E1 : +465 mV
" -> E2 : +436 mV
" -> E3 : +383 mV
" -> E4 : +480 mV

3.2 Results

Before injecting the current into the formation the measured potential V_{meas} at the points E1, E2, E3, E4 represents the static electrical potential field. During the experiment this is superimposed upon by the potential field **DP** of the injected current.

$$V_{meas} = EP + DP$$

Subtracting V_{meas} for one polarisation from the other reveals **DP**.

$$V_{meas}(positive) = EP + DP$$
$$V_{meas}(negative) = EP - DP$$
$$DP = (V_{meas}(pos.) - V_{meas}(neg.)) / 2$$

Where it occurs, the potential **DP** is influenced by electric conductors, especially if these conductors are close to the electrodes E1..E4 and are connected with one or both of the boreholes. In order to obtain this influence, the potential **DP** is compared with a calculated potential **CP** in a homogenous halfspace considering line electrodes which represent the casings under voltage. The equipotential surface of such line

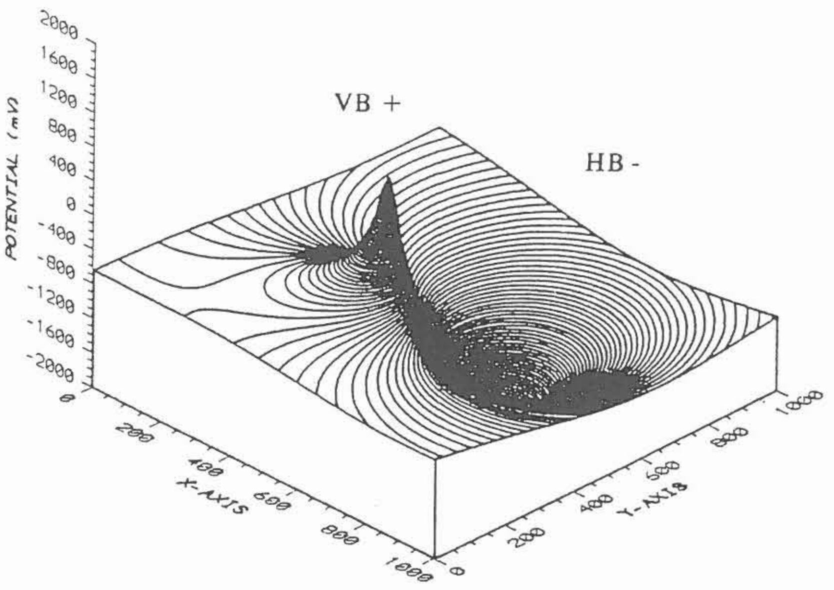

Fig. 3a

Calculated potential CP on the 1 km^2 net of Fig.2 considering electrodes with a length:
L (KTB-VB) = 4000 m
L (KTB-HB) = 6000 m

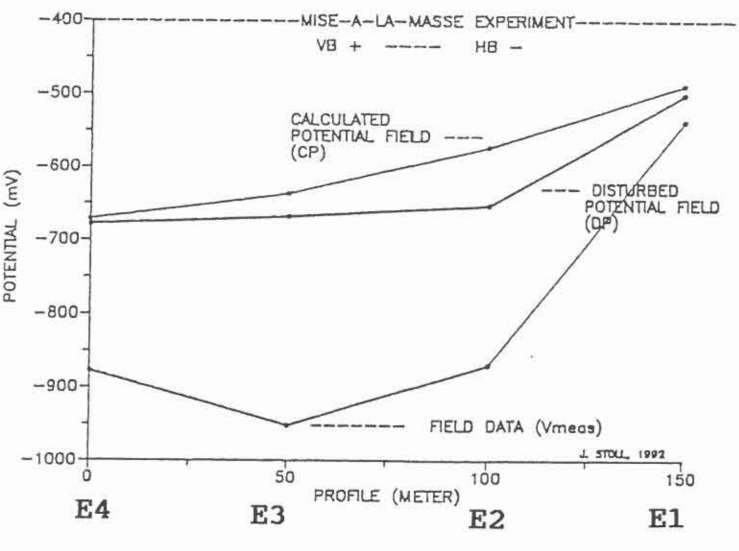

Fig.3b

Representation of the measured field data (V_{meas}) of polarity I. The disturbed potential DP is yielded by removing the self-potential (EP) from the field data Vmeas. These are compared with the calculated potential CP.

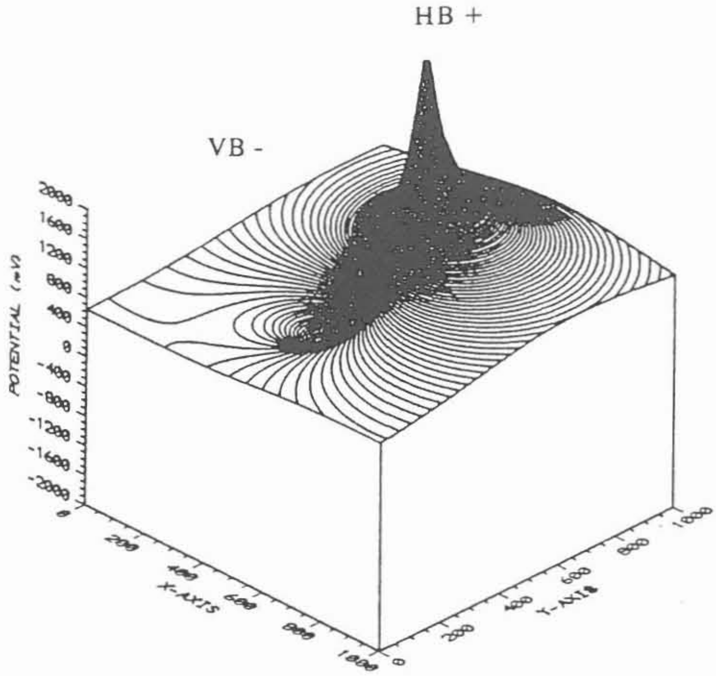

Fig. 4a

Calculated potential CP on the 1 km^2 net of Fig.2 considering electrodes with a length:
L (KTB-VB) = 4000 m
L (KTB-HB) = 6000 m

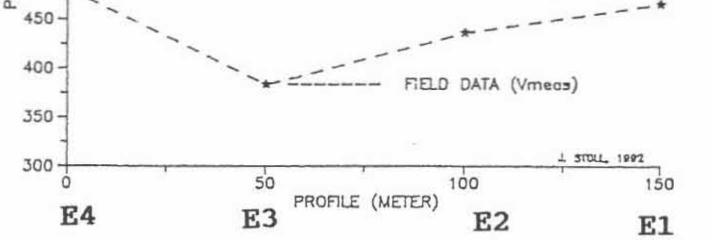

Fig.4b

Representation of the measured field data (V_{meas}) of polarity II. The disturbed potential DP is yielded by removing the self-potential (EP) from the field data Vmeas. These are compared with a calculated potential CP.

electrodes correspond to the shape of a hyperboloid of revolution. They are calculated by the following equation (Keller and Frischknecht, 1982):

$$CP = CP^{+} + CP^{-} \quad , \text{ where } CP = - CP^{+}$$

where

$$CP^{+}(Z,r) = \frac{\rho * I}{4 * \pi} \; LN \; \frac{Z + L + [r^{2} + (Z + L)\;]^{\frac{1}{2}}}{Z - L + [r^{2} + (Z - L)\;]^{\frac{1}{2}}}$$

Z and r are cylindrical coordinates measured from the midpoint of the electrode; L is the electrode half-length, also measured from the midpoint to one end of the electrode; ρ is the resistivity (Ωm) and I (A) is the injected current. For the boreholes in question, L = 2000 m (KTB-VB), L = 3000 m (KTB-HB)

For this arrangement the potential field was calculated inside a 1 km^2 area referring to both polarities and using an injection current of 22 A (Fig. 3a and 4a). The larger depth extension of the main borehole causes a greater width of the potential field. The figures 3b and 4b show the field data (V_{meas}) referring to both polarities, the potential DP, which is disturbed by the electronic conductor, and the calculated potential CP of a homogeneous halfspace. So far as possible the potential CP was matched to the DP by varying the resistivity of the halfspace using 310 Ωm at least. This value corresponds rather well to the resistivities which were observed at AMT stations close to the KTB site (Leonhardt, 1987). Nevertheless an absolute difference of about 75 mV of opposite sign for each polarities can be detected at electrode E2 (Fig. 5).

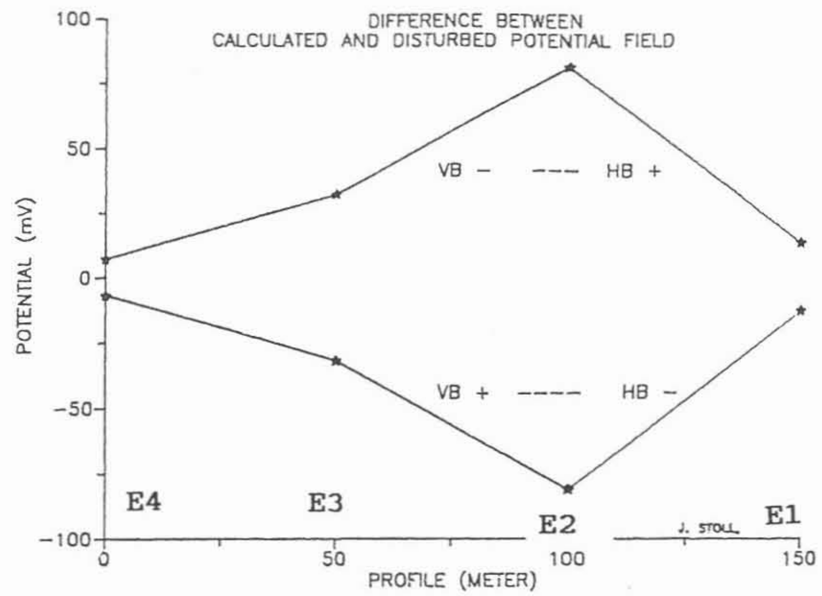

Fig.5

Differences between the CP, which contains the influence of an electric conductor (e.g. graphitic layers) close to the ground electrodes onto the injected potential field, and the calculated potential CP.

4. Discussion

The Mise-à-la-Masse experiment is designed to detect differences between the disturbed potential field (DP), which is influenced by electric conductors in contact with the boreholes, and an undisturbed potential field. This undisturbed potential is obtained by using the above formula. The essential observation consists in the simultaneous change in sign of this potential difference with a change in polarity. This indicates that there is a conducting zone in contact with one of the boreholes. This concept is further illustrated by the following three possibilities:

A: A steeply inclined layer has contact with the pilot borehole and outcrops in the vicinity of the potential electrodes (Fig. 6a). In consequence of the low resistivity of this layer the current is conducted close to the surface and causes a local maximum in the potential field when the KTB-VB has positive polarity.

B: A conductive layer has contact with the main borehole, and outcrops just in the vicinity of the electrodes (6b). This produces a minimum in the potential field in the case of a negative polarity at the KTB-HB.

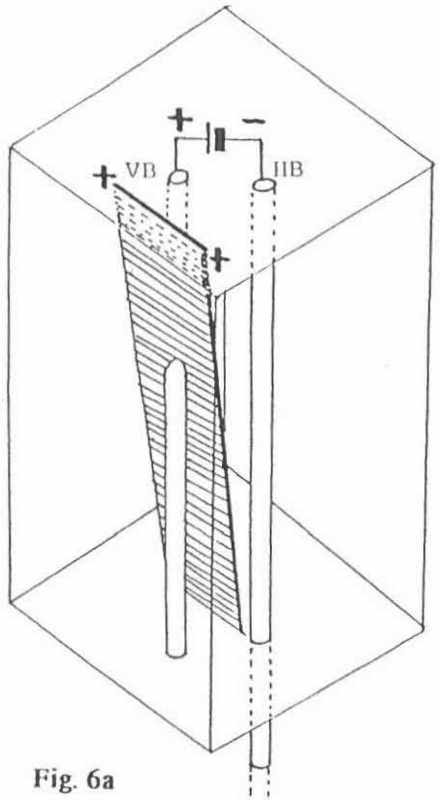

Fig. 6a

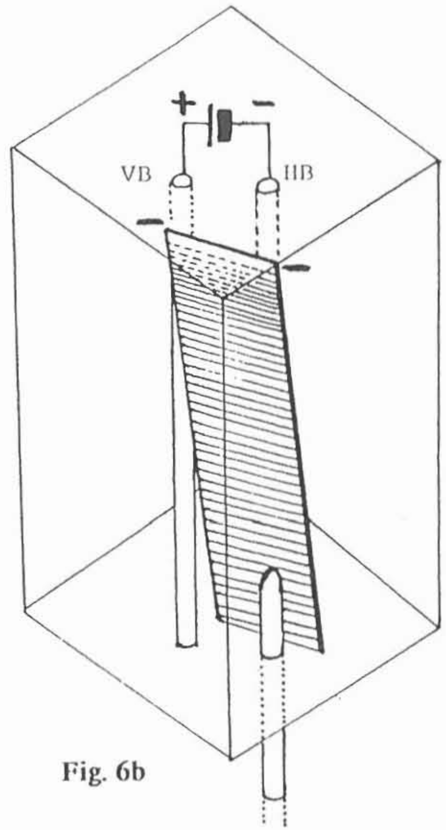

Fig. 6b

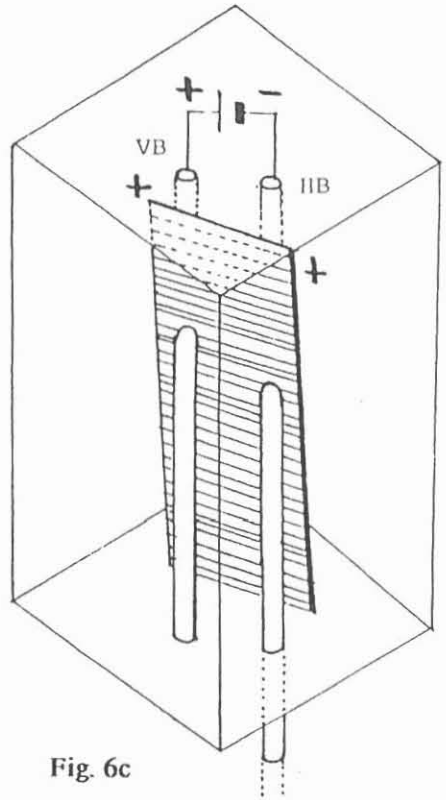

Fig. 6c

conductive layer with contact to the KTB-HB

conductive layer with contact to the KTB-VB

conductive layer with contact to both boreholes

C: At least a conductive layer has contact with both boreholes. In this case the potentials reveal a superposition of both contacts but the difference depends from the distance between the contact and the potential electrodes.

During the experiments the potential differences at the potential electrodes show a local minimum at polarity I and a local maximum at polarity II (Fig 5). With reference to the above three cases this implies an electrical contact of a conducting zone with the main borehole. From the KTB boreholes it becomes evident that graphite is bounded to a number of steeply inclined shear planes corresponding to cataclastic zones within the gneisses. It accumulates as fine dispersed grains within the rock matrix but abundantly occurs on polished slickensides with a thickness of up to some centimeters (Zulauf, 1990). There is some evidence from the surface tectonic map of the KTB site (Hirschmann, 1992) for the existence of faults in the vicinity of the potential electrodes (Fig. 7b). Referring to the geological results these faults belong to the prominent bundle of the Nottersdorf fault zone (NSZ), which have an inclination of about 60^0 to the NE, cross the main borehole in the upper section between 250 to 1570 m depth (Hirschmann, 1992) and show strong graphitic and sulphuric mineralizations in some extent. Likewise some of them cross the pilot hole in the uppermost part between 0 and 515 m.

These oberservations lead to following conclusions:

a) Close to the KTB drilling sites there exist general conducting layers, which obviously extend over distances of several hundred meters.

b) Obviously these layers belong to the Nottersdorf fault zone which crosses the KTB boreholes.

c) These layers are enriched by strong, graphitic accumulations of up to several centimeters in thickness and seem to be responsible for the high conductivity zone over a large depth extent.

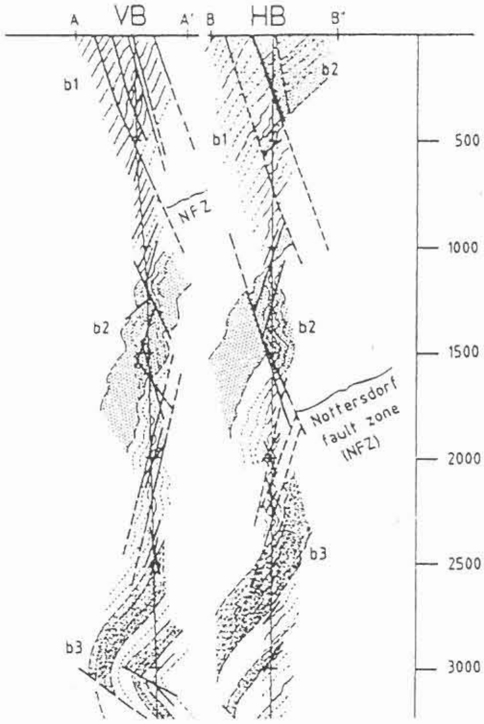

Fig. 7a

Structural interpretation of the pilot- and main borehole (Hirschmann, 1992)

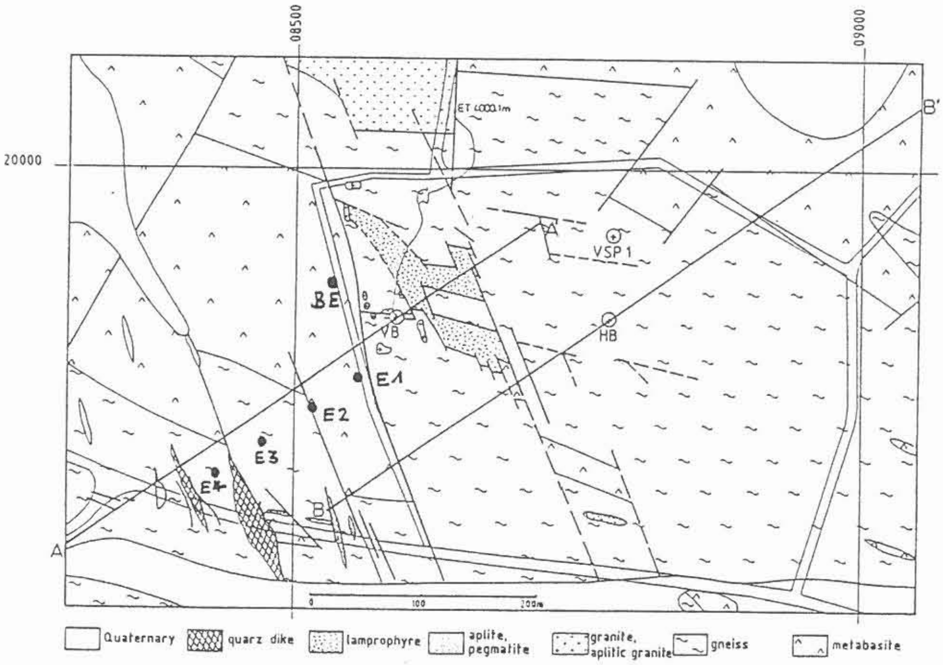

Fig. 7b

Geological map of the drilling site and its immediate surroundings. The lines A-A' and B-B' correspond to the lines in Fig. 7a (Hirschmann, 1992). The maximum and minimum of the difference curves in Fig.5 is located at electrode E2 and coincides with one fault of the Nottersdorf zone.

Acknowledgements

I would like to thank Dr. W. Kessels (Project Management of the KTB in the Geological Survey of Lower Saxony) for his initiative to carry out this experiment in the KTB and M. Sowa (KTB), who mounted the system and performed the injection of the current.

References

HAAK, V., STOLL, J. and WINTER, H., 1991. Why is the electrical resistivity around the KTB hole so low? Phys. Earth Planet. Int., 66, pp. 12-23

HIRSCHMANN, G., 1992. The geological section of the KTB-Hauptbohrung - Correlation with the KTB Vorbohrung and preliminary structural interpretation. in: R. Emmermann, H.-G. Dietrich, J. Lauterjung and Th. Wöhrl (eds.) KTB-Report 92-2 KTB Hauptbohrung, Results of the Geoscientific Investigation in the KTB field laboratory 0 - 6000 m, pp. B47 - B52

KELLER, G.V. and FRISCHKNECHT, F.C., 1982. Electrical methods in geophysical prospecting. International series in electromagnetic waves, Vol. 10. Pergamon Press

LEONHARDT, F.,1987. Audiomagnetotellurische Untersuchungen in der Oberpfalz. Diplomarbeit, Technische Universität Berlin, 91 pp.

SATO, M., MOONEY, H.M., 1960. The electrochemical mechanism of sulfide self-potentials, Geophysics, 25, 1, pp. 226-249

STOLL, J., 1990. Messung der Eigenpotentialanomalie im KTB-Umfeld und deren Interpretation. in: K. Bram (Hrsg.), KTB Report 90-3, Ergebnisse geowissenschaftlicher Umfelduntersuchungen, Elektromagnetische Tiefensondierung, S. 173 ff

ZULAUF, G., 1990. Spät- bis postvariszische Deformationen und Spannungsfelder in der nördlichen Oberpfalz (Bayern) unter besonderer Berücksichtigung der KTB-Vorbohrung. Frankfurter Geowissenschaftliche Arbeiten, Serie A Geologie-Paläontologie, Band 8