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

Johannes Stoll*

Contents

1 Summary

At the KTB-site the two casings of the pilot- and main borehole were used to inject an electrical current into the wallrock. The potential field of this current was measured along a small profile close to the KTB to detect changes in the potential. The observed changes indicate a connection of an electronic conductor with one of the casings and support the assumption of a general conducting layer extending over distances of several hundred metres. 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.

---

* Institut für Meteorologie und Geophysik der Johann-Wolfgang-Goethe-Universität Frankfurt, Feldbergstr. 47, D-6000 Frankfurt am Main 1

2 Introduction

Results from several geoelectric soundings around the KTB (DC, VLF-R, AMT) suggest that the pilot (KTB-VB) and main (KTB-HB) boreholes are drilled into a several hundred metre wide NW-SE 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 accumulations (especially pyrite) on many cataclastic shearzones in the KTB, which lower the resistivity by several orders of magnitude. Graphite even outcrops at the surface in some places. This increase of the conductivity inside crystalline rocks could be caused by graphite only if the graphite forms an interconnected network. Such interconnection along a shearzone of several hundred metres vertical extent represents one of the most important sources of self-potential anomalies. Such anomalies of about -600 mV would be detected close to the KTB (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. According to the KTB this interconection is still a basic question.

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

3 Mise-à-la -Masse in the KTB

3.1 The experiment

The two casings of the pilot and main drill holes will be used as electrodes to inject an electrical current into the wallrock. At the time of the experiment (24.3.1992) the casings had a vertical extention of 3850 m (KTB pilot hole) and 3000 m (KTB main hole). Since the high conductivity of the drilling fluid (0.2 Ωm) cannot be neglected, the complete extent of the boreholes (4000 m and 6000 m) will be taken into account. The electrical current is taken from the public net and is transformed in a direct current of 40 A at 14 V (without load resistor). Two cables which are fixed on the top of the casings conduct the current from the source into the rock (Fig. 1). The interstitial water between casing and wallrock supports the impedance matching, so the transition resistance amounts 0.212 Ω. The terminal voltage amounts to 10.23 V, the voltage between the casings 3.46V with 22 A. 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 outside the drilling area along a profile in radial distance of 100 m from the pilot hole (Fig. 2). Four copper-coppersulphate electrodes ($E_1..E_4$) were installed at a spacing of 50 m. The potential is measured with respect to a reference electrode (BE) during the experiment. The potential is measured before and during injecting the current in the rock by turning the polarity once. In the following the measured values are registered:

A: without current; self-potential EP

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

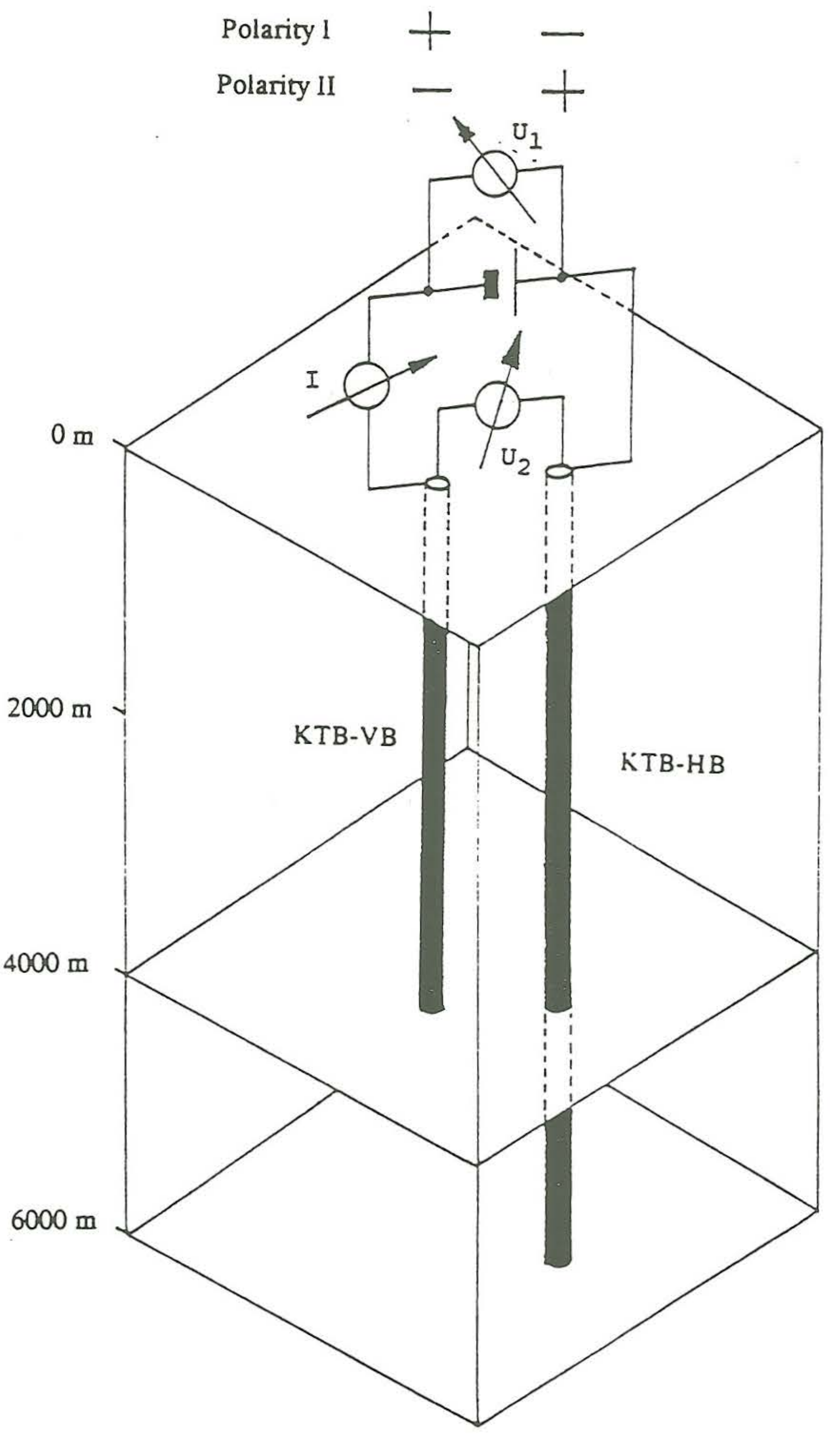

Fig. 1
Circuit diagram of the Mise-à-la-Masse-experiment in the KTB
U_1 : Injection voltage (10 V)
U_2 : Voltage between the casing (4 V)
I: Injection current (22 A)
—▮|— Source of direct current

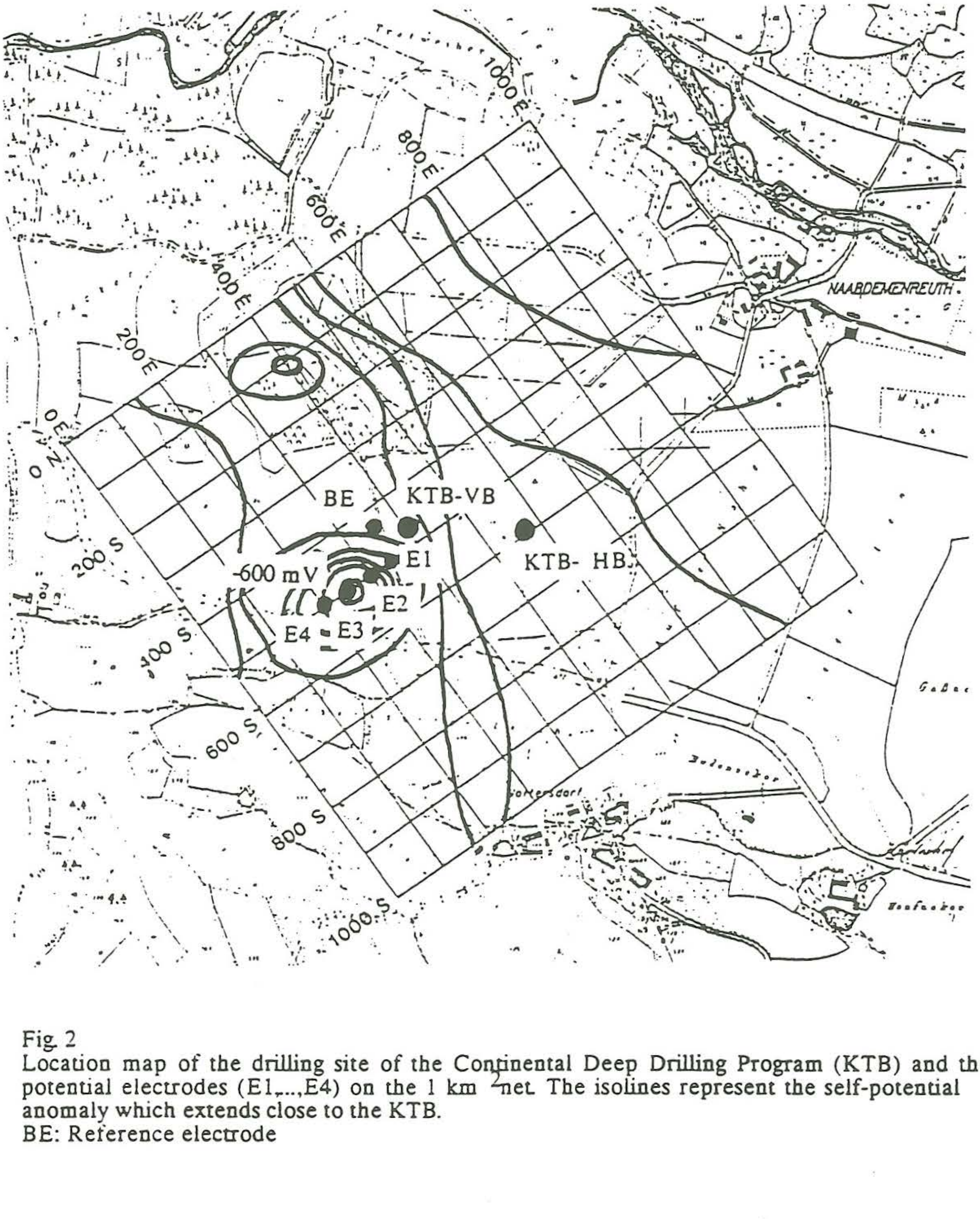

Fig. 2
Location map of the drilling site of the Continental Deep Drilling Program (KTB) and the potential electrodes (E1,...,E4) on the 1 km^2 net. The isolines represent the self-potential anomaly which extends close to the KTB.
BE: Reference electrode

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 in the wallrock 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 (CP) of the injected current.

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

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

$$V_{meas}(positive) = EP + CP$$
$$V_{meas}(negative) = EP - CP$$

$$CP = (V_{meas}(pos.) - V_{meas} (neg.)) / 2$$

Where it occurs, the potential CP is influenced by electronic 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 effect, the potential CP is compared with the calculated potential (UP) of the boreholes in a homogenous halfspace. The equipotential surface of every line electrode corresponds to the shape of a hyperboloid of revolution. They are calculated by the following equation (Keller and Frischknecht, 1982), which represents the superposition of both electrodes:

$$UP = \underset{\text{at:KTB-VB}}{UP^{+}} + \underset{\text{KTB-HB}}{UP^{-}} \quad , \text{ where } UP^{-} = -UP^{+}$$

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

where Z and r are cylindrical coordinates measured from the midpoint of the electrode; L is the electrode half-length, measured from the midpoint to one end of the electrode; o is the resistivity (Ωm) and I (A) is the current. For the boreholes in question, L = 4000 m (KTB-VB), L = 6000 m (KTB-HB)

For this arrangement the potential field was calculated inside a 1km^{2} area referring to both polarities and using an injecting 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 CP, which is disturbed by the electronic conductor, and the calculated potential UP. So far as possible the potential UP was matched to the CP by varying the resistivity using 310 Ωm at least. This value corresponds rather well to the resistivities which were observed at AMT stations close to the KTB site. Nevertheless a difference of about 75 mV of opposite sign for both polarities can be detected in the range of the electrode E2 (Fig. 5).

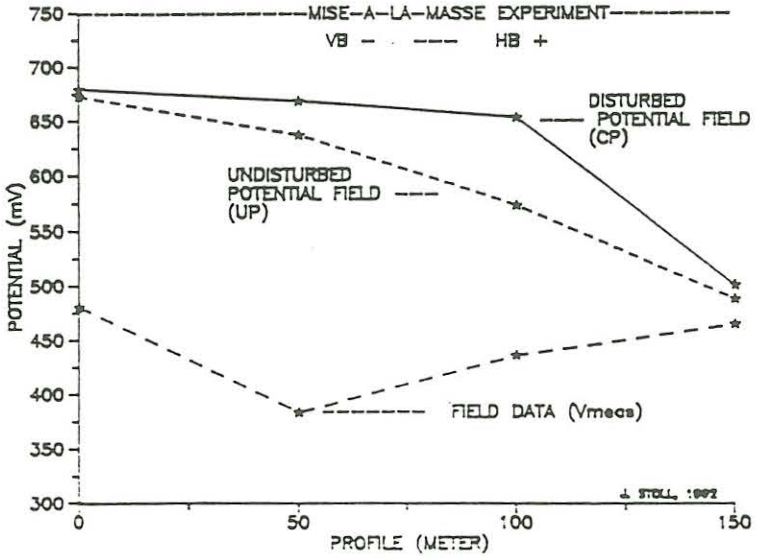

Fig. 4a
Calculated potential UP (undisturbed potential) on the 1 km^2 net

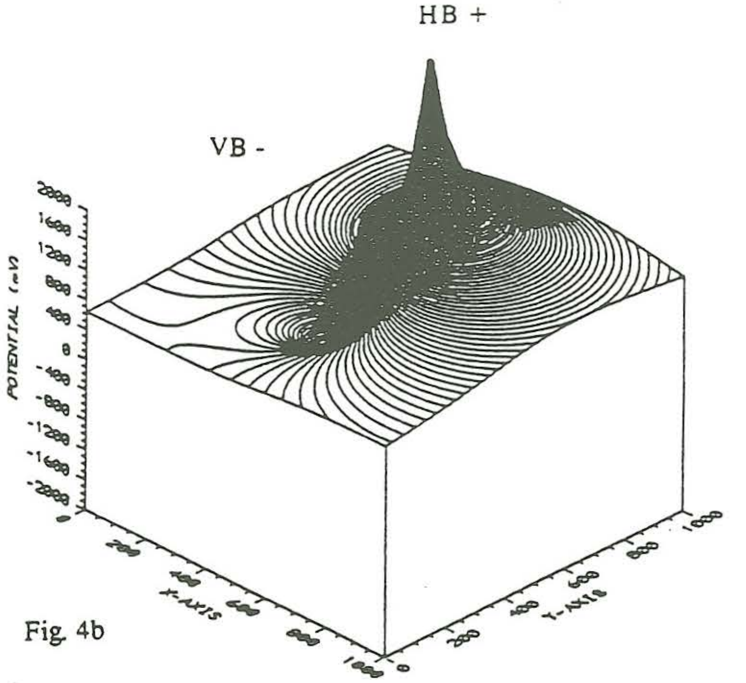

Fig. 4b

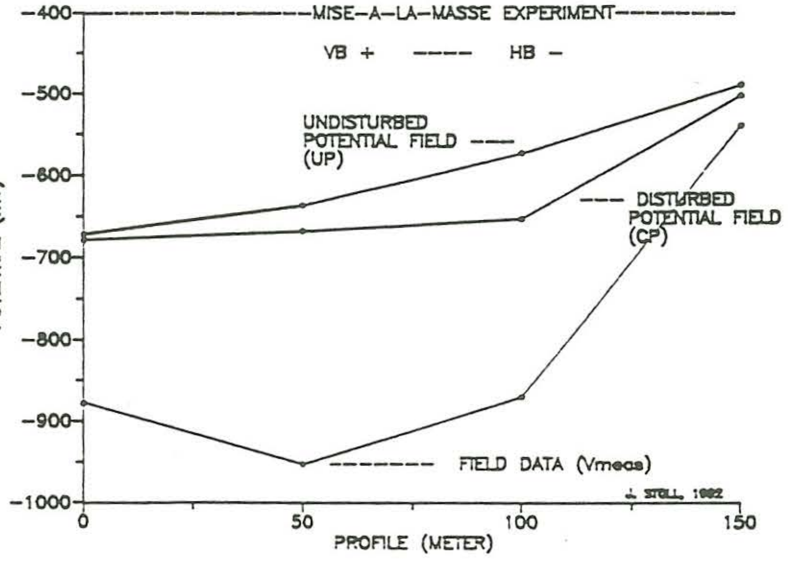

Fig. 3a
Calculated potential UP (undisturbed potential) on the 1 km^2 net.

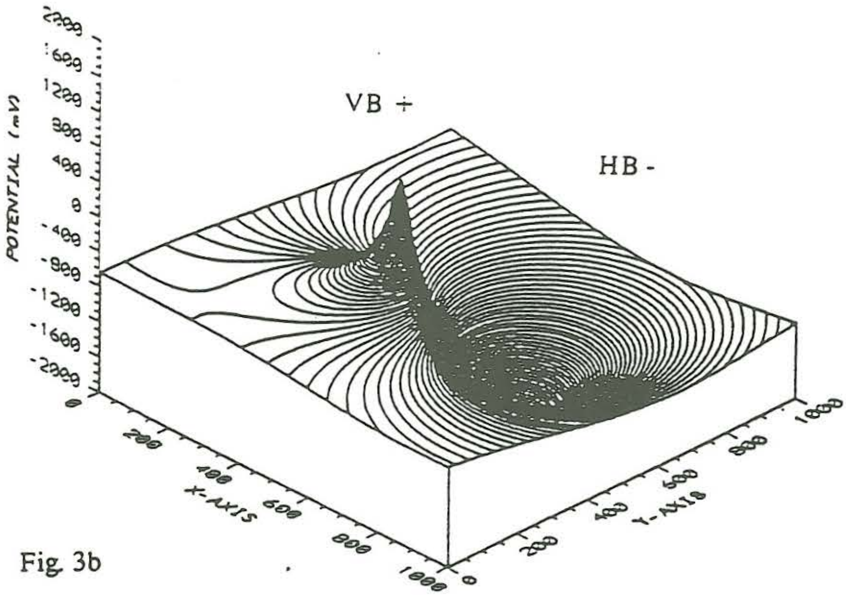

Fig. 3b

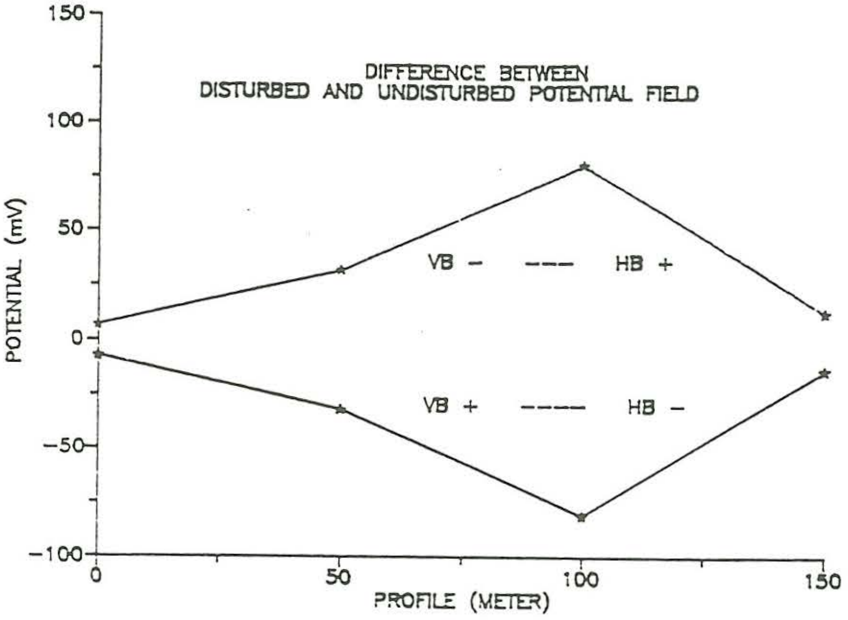

Fig. 5
Difference between the CP, which is influenced by the electronic conductor, and the calculated potential UP.

4 Discussion

The Mise-à-la-Masse experiment is designed to detect differences between the potential field (CP), which is influenced by electronic conductors in contact with the borehole, and the undisturbed potential field (UP). The simultaneous change in sign of this potential difference with a change in polarity, indicates that there is a conducting zone in contact with one of the boreholes. This concept is further illustrated by the following three possibilities:

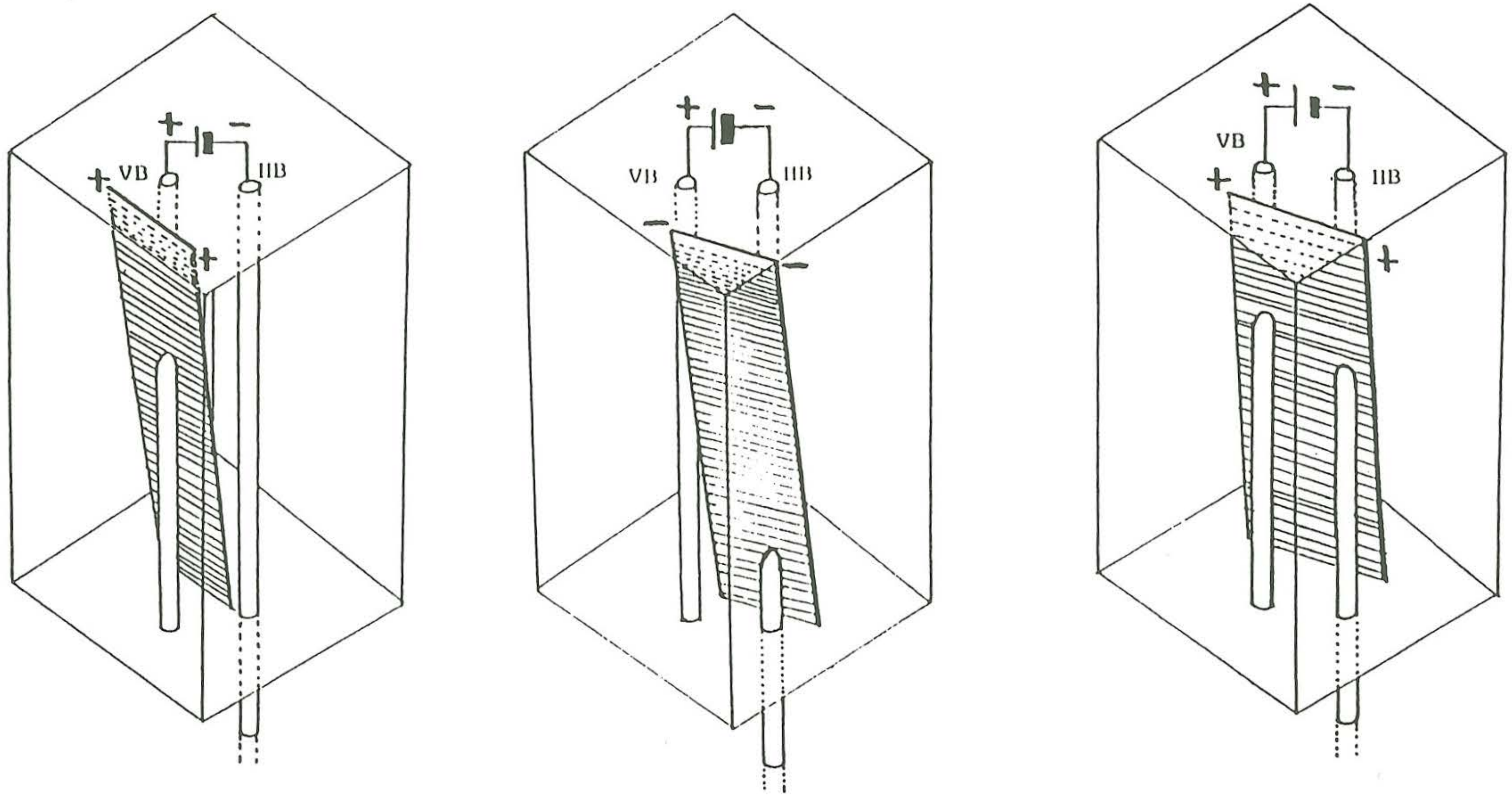

Fig. 6

conductive layer with contact to the KTB-HB

conductive layer with contact to the KTB-VB

conductive layer with contact to both boreholes

A: A steeply inclined layer has contact with the pilot borehole and outcrops in the range 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 range of the electrodes (6b). This produces a minimum in the potential field in the case of a negative polarity at the KTB-HB.

C: At least a conductive layer has contact with both boreholes (Fig. 6c). 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 measurement site show a local minimum at the polarity I and a local maximum at the polarity II (Fig 5). With reference to the above three cases this implies an electrical contact of a conducting zone with the main borehole. There is some evidence from the tectonic map of the KTB surrounding (Hirschmann, 1992) for the existance of faults in the range of the potential electrodes (Fig. 7b). Some of these are limited to the north. Referring to the geological results they belong to the prominent bundle of the Nottersdorf fault zone (NSZ), which have an inclination of about 60^{O} 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 (Fig. 7a). Some of them cross the pilot hole in the uppermost part between 0 and 515 m. After Zulauf (1990) the inclination of the most faults to the SE are in very contrast to the NSZ, which are just so mineralized with graphite and pyrite.

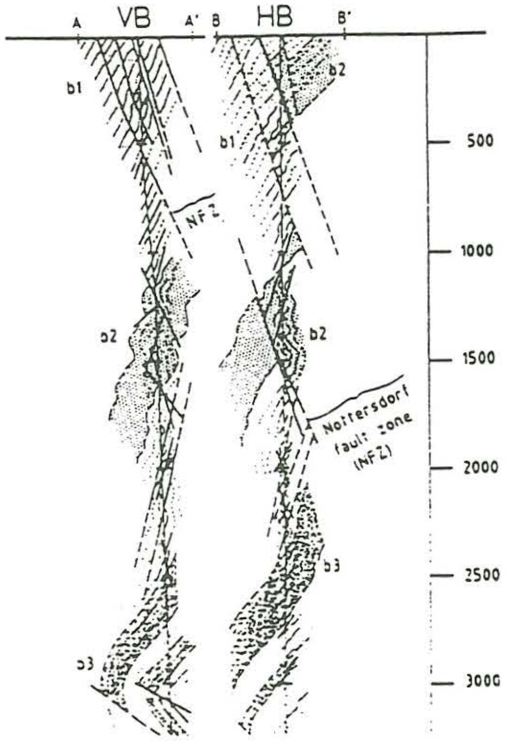

Fig. 7a
Structural interpretation of the pilot- and main borehole (Hirschmann, 1992)

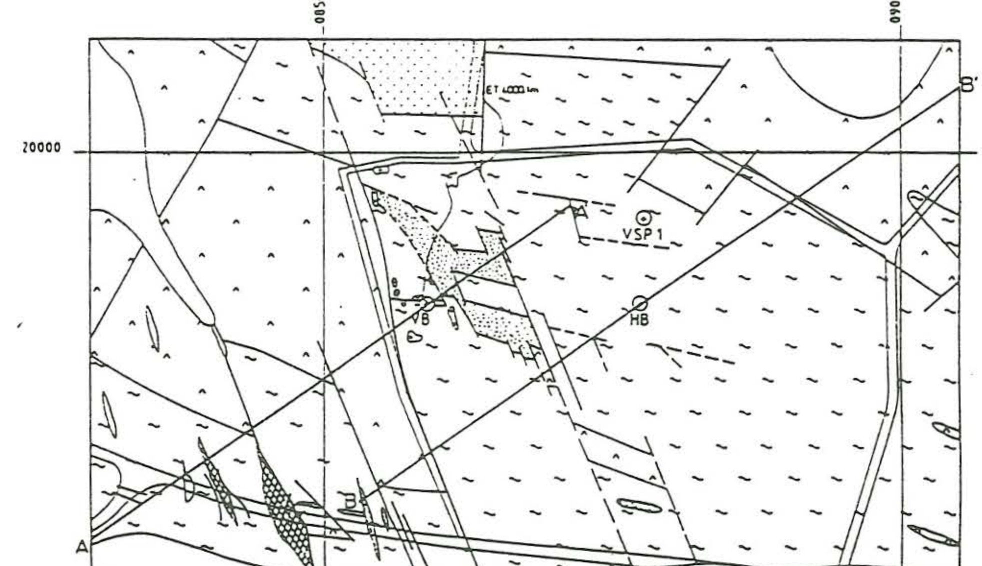

Fig. 7b
Geological map of the drill site and its imediate surroundings. The lines A-A' and B-B' correspond to the lines in Fig. 7a.

The oberservations lead to following conclusions:

a) Close to the KTB there exist general conducting layers extending over distances of several hundred metres to 1km

b) The conductivity of these layers is caused by strong, graphitic accumulations of up to several centimetres in thickness.

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

d) The steeply inclined layers, conductive across long distances are resposible for the low resistivity over a large depth range.

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

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