Streaming potentials in the KTB generated through hydraulic pump tests

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I. Introduction

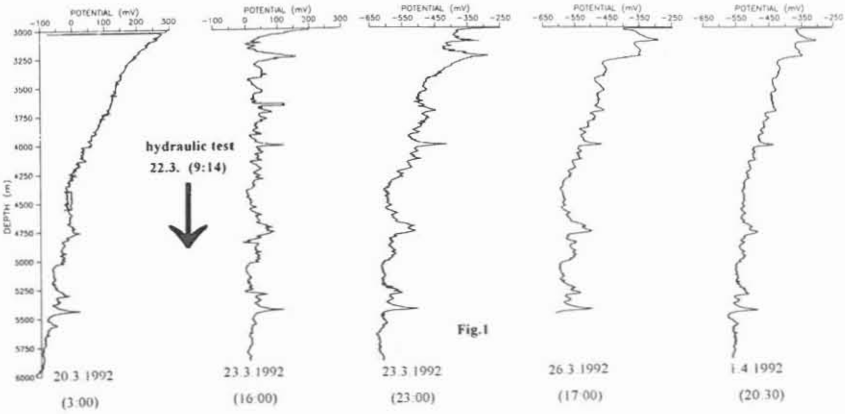
The frequent occurrence of electrical potential fields observed in boreholes can be attributed in most cases to electrochemical fluid-rock interactions. Electromotive forces, fluid motion and diffusion of ions in permeable rocks are the main driving agents, which induce electric currents between the formation and the borehole. The ohmic potential drop of these currents produces SP peaks, which cover magnitudes from a few millivolts up to 1 Volt. In this way these peaks reflect the presence of electrochemical processes acting within the earth's crust, which can be monitored through SP-logging.

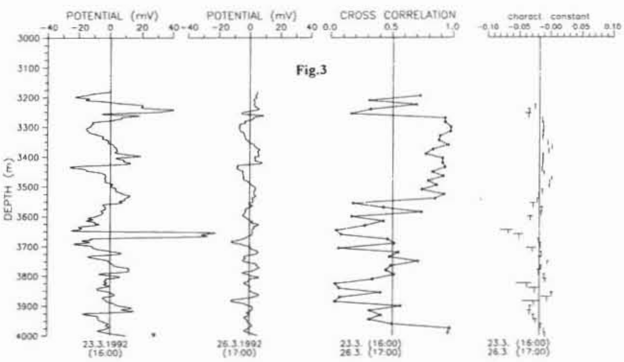
II. SP-Data

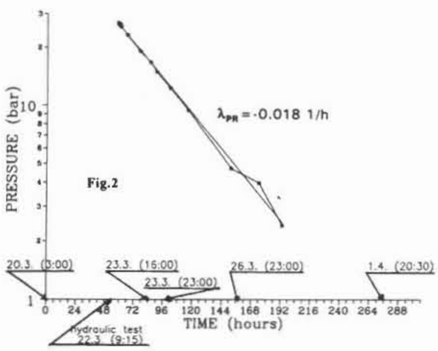
Five SP-measurements were logged before and during a hydraulic pump test in the KTB main drilling between a depth range of 3000 and 6000 m (fig.1). In contrast to the first SP-log measured **before** the hydraulic test the **subsequent** logs show distinctly a lot of individual SP-peaks. During the observed time interval of ten days the amplitudes of many SP peaks decrease like an exponential function with a characteristic constant λ_{SP}.

III. Hydraulic test

The drilling mud level was drawn down (22.3.1992; 9:15) to 540 m depth, which stimulated an inflow of formation fluids of about 30 m³ (Kessels and Kück,1993). Fig. 2 shows the difference of the hydrostatic pressure of the mud column as a function of time between the lowest level and its equilibrium after refilling the drilling mud through fluid inflows. The pressure course is related to an exponential function, which has a negative characteristic constant of λ_{PR} = -0.018 1/h.







| : mud resistivity log: Na⁺, Ca⁺, Cl⁻

◊: fluid sampler (Na⁺, Ca⁺, Cl⁻, CH₄ and CO₂)

□: geochemical on-line analysis: Na⁺, Ca⁺, Cl⁻, CH₄ and CO₂

IV. Fluid detection in the KTB with SP-logging

The progress in time of many individual SP-peaks depends on the level of the mud column. In that case the decrease of the SP-amplitudes corresponds to the characteristic constant λ_{PR} of the hydrostatic pressure of drilling mud. A reference line is obtained by high pass filtering the SP-logs to determine the amplitudes of all individual SP-peaks. From the decreasing procedure of each SP amplitude the characteristc constant λ_{SP} is calculated from one SP-log to the succeeding logs, which is done in stages of about 15 m (see fourth row of fig.3). Additionally the cross correlation coefficients between the SP-logs were also calculated from time to time in stages of 15 m (see third row in fig.3). The correlation with depth between two SP-logs is characterized by partly strong variations of the coefficient values. It may be stated that in depth ranges with correlations better than 0.5 the characteristic constants λ_{SP} of the SP-amplitudes are quite similar to λ_{PR} of the pressure course within the error bars. Within these zones fluid inflows occur, whose quantities depend on the mud column level. The fluid motion produces an electrical potential (streaming potential) as a consequence of electrokinetic effects acting between fluid-rock interfaces.

V. Comparison with geochemical results

The comparison of zones of inflows from SP-logging with lithology, geochemical on-line observations and fluid samplers from the KTB confirms the supposition, that the SP amplitudes indicate locations where fluid inflow occur. These locations are characterized by an increase of Na^+, Ca^+, Cl^- concentrations and CH_4 and CO_2 gas phases within the drilling mud, which are bounded to open fissures and fractures. The symbols in Fig. 4 indicate the depth ranges, in which fluid inflows were detected.

The redox potential logs (fig.4) which were carried out simultaneously to the SP logging, distinctly indicate local variations of the electrochemical conditions within the drilling mud after the pump test. It may be stated that the inflows of formation fluids change the composition of the drilling mud and produce locally variations of the redox potential. The measured values reflect the sum of all redox active species within the drilling mud. From this point of view SP- and redox logging may be used as a possibility to detect zones of fluid inflow.

Kessels, W and Kück, J., 1993. Hydraulic communication in crystalline rocks between the two boreholes of the Continental Deep Drilling Program in Germany. KTB Report 93-1, pp. 337-365

Fig.4