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KTB Pilot Hole: Permeability Profile

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I.1 Introduction

In order to understand fluid movements in crystalline rocks it is essential to quantify the geometry of the fluid pathways. As a rough estimation one can distinguish between the microscopic and macroscopic permeability. The microscopic permeability is associated with microcracks and grain boundary permeability in the scale of a few millimeter or less and the macroscopic permeability is due to larger cracks. Because of experimental limitations of laboratory measurements on cores in the scale of a few centimeters, only microscopic permeability could be determined in laboratory.

I.2 Methods

The permeability of 50 cores (30 mm in diameter, 15 mm height) was measured as a function of a quasi hydrostatic pressure up to 80 MPa, using a gas pressure transient method. During the measurements the pore pressure was increased up to a maximum value of 5 MPa. For further details see HUENGES (1987). The transient curves were evaluated using a formula of ZOBACK & BYERLEE (1975).

In addition to these instationary measurements, 30 further experiments were performed on core samples (30 mm in diameter, 50 mm height) using the stationary d'Arcy method. These measurements were made at a constant confining pressure of 5 MPa. Because of the low pore pressure during the measurements the data had to be corrected for the effect of gas slipping along the matrix wall, the so called Klinkenberg effect. Further details regarding equipment and evaluation are given by PUSCH et al. (1986) .

I.3 Results

The results were published by WOLTER et al. (1989), WIENAND et al. (1989), and RAUEN et al. (1990). A significant dependence of permeability on pressure and on the direction of the flow in the foliated rocks could be observed. Thus it was possible to establish the factor of anisotropy ranging from 1 to 500 for permeability parallel and perpendicular to the foliation. Due to the fact that most of the measurements were performed in different orientations to the foliation and at various pressures an additional processing was necessary. So it can be established a common basis, the quasi in situ permeability, using all informations on pressure and orientation dependence of the permeability.

I.4. Quasi-in-situ permeability with respect to directions

Equation (1) describes the transformation of the permeability k_α to main axis permeabilities assuming a rotation ellipsoid. The direction is given by the angle α to the rotation axis with permeabilities k_p parallel and k_s perpendicular to the foliation plane. In a first step the data measured at the pressure closest to the in situ pressure were transformed to permeabilities k_p und k_s using equation (1) with minimum and maximum values due to the scatter of anisotropy factor from 1 and 500.

$$k_\alpha^2 = k_p^2 * \sin^2(\alpha) + k_s^2 * \cos^2(\alpha) \qquad (1)$$

The pressure correction is based on the empirical equation (2) (DEBSCHÜTZ et al. 1989), which describes the exponential decrease of the permeability $k(p_1)$ to $k(p_2)$ caused by the pressure increase from p_1 to p_2.

$$k(p_2) = k(p_1) * \exp(-(p_2 - p_1) / p_c) \qquad (2)$$

The parameter p_c was taken from the fit of equation (2) to about 50 pressure dependent data sets. P_c scatters from 10 to 35 MPa and is in a first approximation independent on lithology and direction of flow. Therefore this scatter was used for the maximal estimation of the permeability ellipsoid. Increased pore pressure was not taken into consideration.

The calculated quasi in situ main axis permeability is plotted in Fig. I.1. Some data have a small scatter because of isotropic core material, e.g. a lamprophyre in 2050 m, or because of complete measurements in two orientations to the foliation, e.g. a biotite gneiss of 3535 m. Most data have large error bars due to a lack of detailed information about the anisotropy and the pressure dependence of the permeability.

Because of the steep dip of foliation there is a higher permeability vertical than the mean value horizontal. This was shown by the transformation of the data to borehole coordinates using equation (1) and the dip angle of foliation.

In order to quantify additional "Klinkenberg-" and porosity-corrections for the instationary measurements, which were performed at about 3 MPa pore pressure, must be done. This leads to a decrease of the permeabilities within one half order of magnitude (SIEBERT & PUSCH pers. communications). Moreover the permeability of a (not gas) fluid is lower than the gas permeability (SCHOPPER pers. communication). The work on all these corrections is in progress. Therefore the upper limitation of permeability is used for first considerations.

The maximum estimation allows to conclude that the measured permeability in all directions is most lower than 1 µd. Assuming a reasonable pressure gradient for the environmental conditions one can expect that fluid movement on the scale of micro permeability is neglectible.

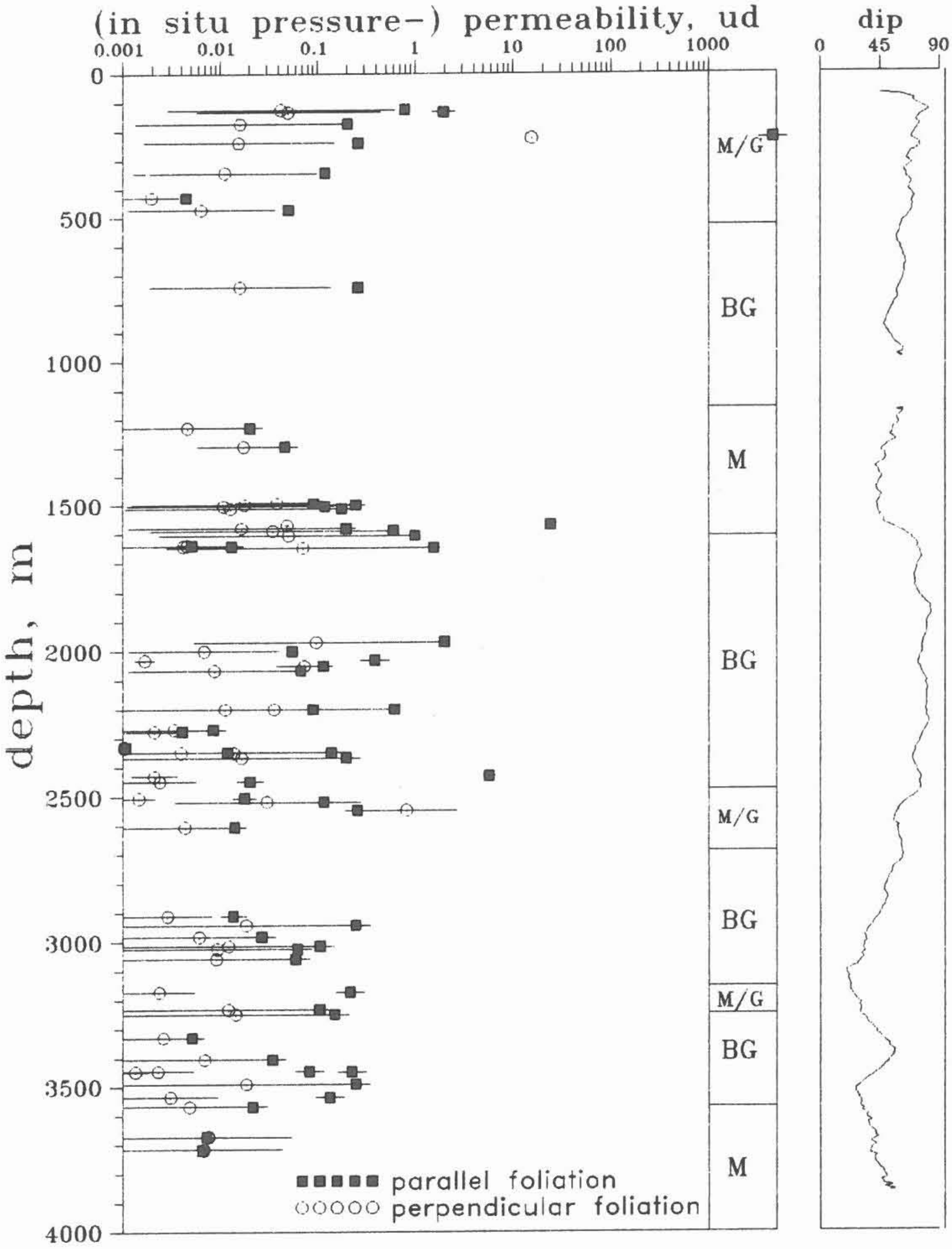

Fig. I.1 (Main axis-) Permeability of KTB core samples determined with the pressure transient method (core diameter ⌀ = 30 mm, height h = 15 mm; all data above 2800 m) and the d'Arcy method (⌀ = 30 mm, h = 50 mm below 2800 m). The scatter is calculated from a maximum estimation including all available pressure and orientation dependent measurements on KTB core samples. The values are corrected to in situ pressure and valid for gases. Simplified lithological profile (M = Metabasite, BG Biotite Gneiss) and dip angle of foliation in degrees.

I.4. References

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