Comparison of pressure-induced changes of permeability and electrical conductivity from KTB drill core samples

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Beside other petrophysical parameters like porosity, specific surface, cation exchange capacity and the nuclear magnetic relaxation time exists a relation of the fluid flow permeability **k** to the electrical conductivity of a fully-saturated rock σ_r (PAPE, RIEPE, SCHOPPER 1981, 1982, 1985; SEN et al. 1990). The ratio of the conductivity of a saturant in a rock σ_e to σ_r is the formationfactor **F**, which is related to the porosity Φ by $\Phi = F^{-r}$. A version of this relation, called as ARCHIE´s law is adequat to the KOZENY-CARMAN equation regulating the interrelation between the permeability, the porosity and the specific surface.

Among many kinds of models and theories, which relate the permeability of a rock to the electrical conductivity a simple model is available. This equivalent-channel model (**ECM**) is established on the simplification that the pathways are the same for both fluid flow and electrical current, which implies the same tortuosity (the ratio of the length of the path to the sample length) for both transport processes. The **ECM** derived by PATERSON (1983) and independent by WALSH and BRACE (1984) connects the permeability and the formationfactor according to $k \propto F^{-r}$, where **r** ranges from 1 to 3.

This relation is used and also confirmed for sedimentary rocks (SEN et al. 1990; FREUND 1990; BERNABE 1991) as well as for crystalline rocks (BERNABE 1986, 1988; LOCKNER and BYERLEE 1985; KATSUBE and HUME 1987). The best fits of the relation $k \propto F^{-r}$ in a log-log plot are obtained from measurements of both parameters during one only run under high hydrostatic pressure conditions, namely on crystalline rocks (BERNABE 1988).

While for the determination of permeabilities >10E-5 mD the conventional steady-state flow techniques are performed, for ultra-low permeabilities in the range of <10E-8 mD the transient pulse methods are preferred. But those measurements are connected with high expenditure of time and experimental techniques, especially for high pressure in-vestigations, where the permeability reduction amounts to some orders of magnitude. Therefore we will trie to test the above mentioned relation (**ECM**) to extrapolate high pressure permeability data from low pressure measurements in comparison with a se-parate pressure run for getting the eletrical properties.

We investigated some samples of gneisses and amphibolites from KTB pilot hole (KTB-VB). The permeability were measured in the KTB field laboratory up to 30 MPa (sample 410F1w) and in the Mineralogical Institute of the University of Bonn up to 60 MPa (328B1g, 543A2f, 315F1g), respectively. The high pressure investigations for the behaviour of the electrical conductivity were performed in a hydrostatical equipment in the GeoForschungsZentrum in Potsdam.

After careful drying the samples were saturated with 0,1 molal KCl-solution for some days and placed in an arrangement which maintains that the pore pressure is equal to atmospheric conditions. For the measurements oft the electrical conductivity a simple two-electrode configuration has been used combined with an impedance-analyser to register the both real and imaginary impedances as a function of the frequency in the range from 10 Hz to 1MHz. In the lower-pressure range we kept the same pressure steps and the same time between these as was done for the permeability tests. Fig. 1

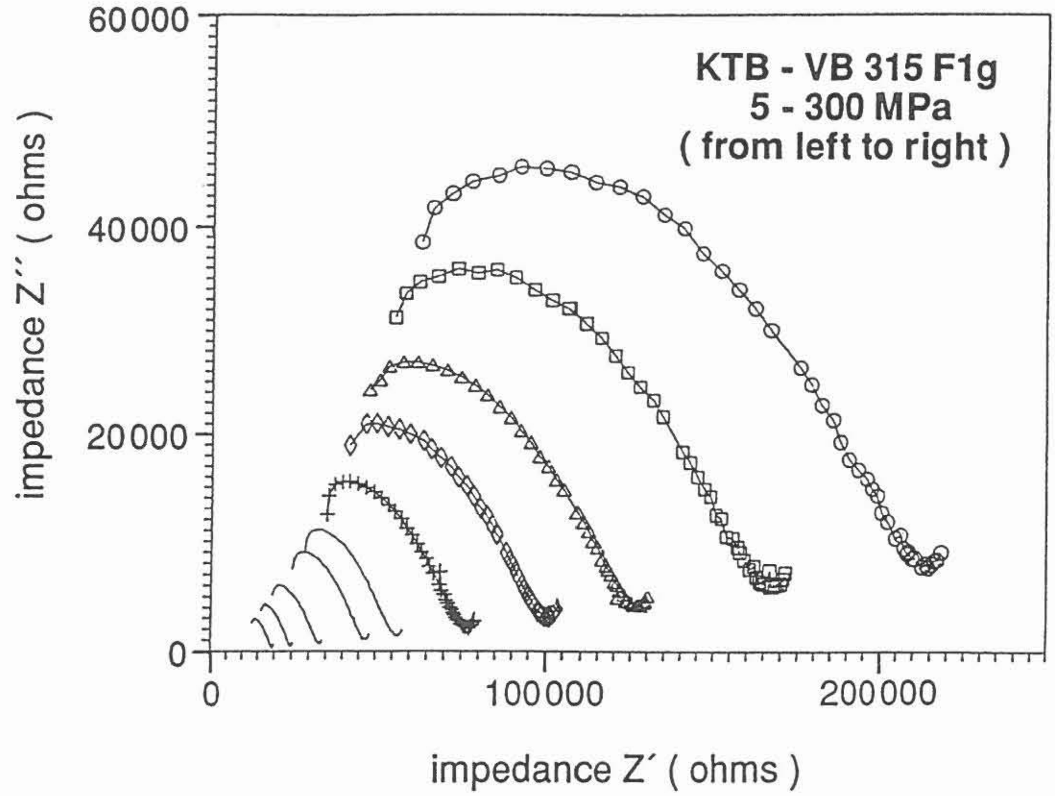

Fig. 1: Pressure dependent increase of the impedances **Z''** (imaginary part) versus **Z'** (real part) of sample KTB-VB 315F1g according to pressures from 5 to 300 MPa.

shows a presentation of the sweep-frequency measurement in the impedance plane for the sample KTB-VB 315F1g. From left to right both impedances **Z'** (real) and **Z''** (imaginary) increase according to higher pressures from 5 to 300 MPa. For the calculation of the formationfactor we used the real component (resistance) of the complex resistivity on his smallest phase angle (the lower turning point positioned above the intersect of the Z'-axis) which is nearest to a quasi direct current resistivity representing the bulk conductivity $^{-1}$, σ_e^{-1} (Will and Nover 1991; Nover and Will 1991, Börner 1991; Ruffet et al. 1991). On this way all F-data were calculated.

The low-pressure permeability data (sample 410F1w up to 30 MPa; sample 328FB1g, 543A2f, 315F1g up to 60 MPa) were fitted versus the corresponding data of the formationfactor. Fig. 2 shows this for sample 315F1g. From the least-square fits in a double-logarithmic scale we get the proportionality $k \propto F^{-r}$, where **r** is the slope of the straight line, signed as the exponent in Fig. 2. The data are very close to the lines (correlation coefficients R ranges between 0.97 and 0.99). Because the good linearity

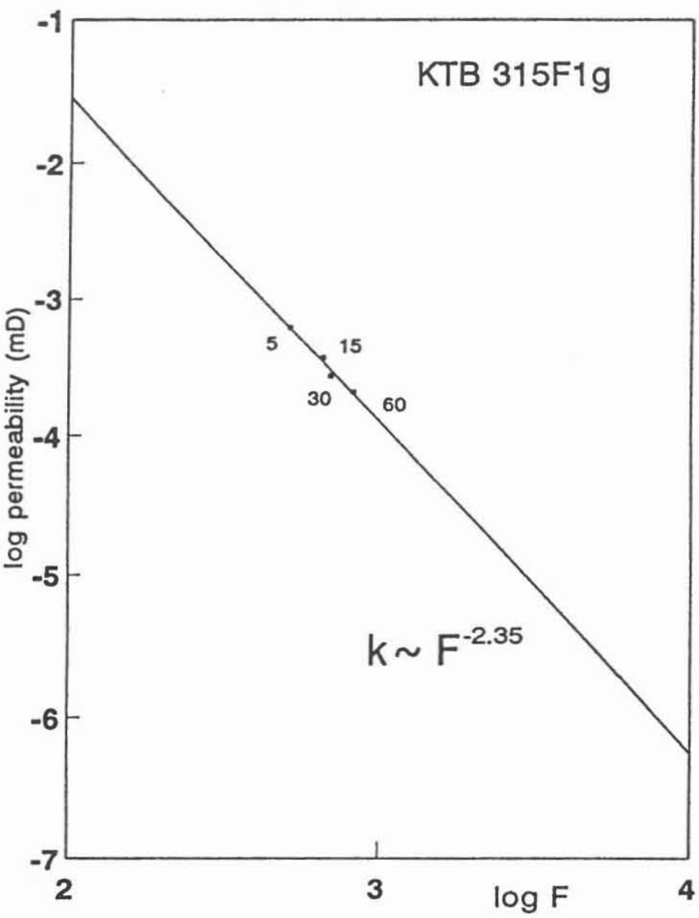

Fig. 2: $k \propto F^{-r}$ for sample 315F1g

we can use the regression equations combined with the F-data which were measured above 30 and 60 MPa, respectively, to extrapolate the high-pressure permeability.

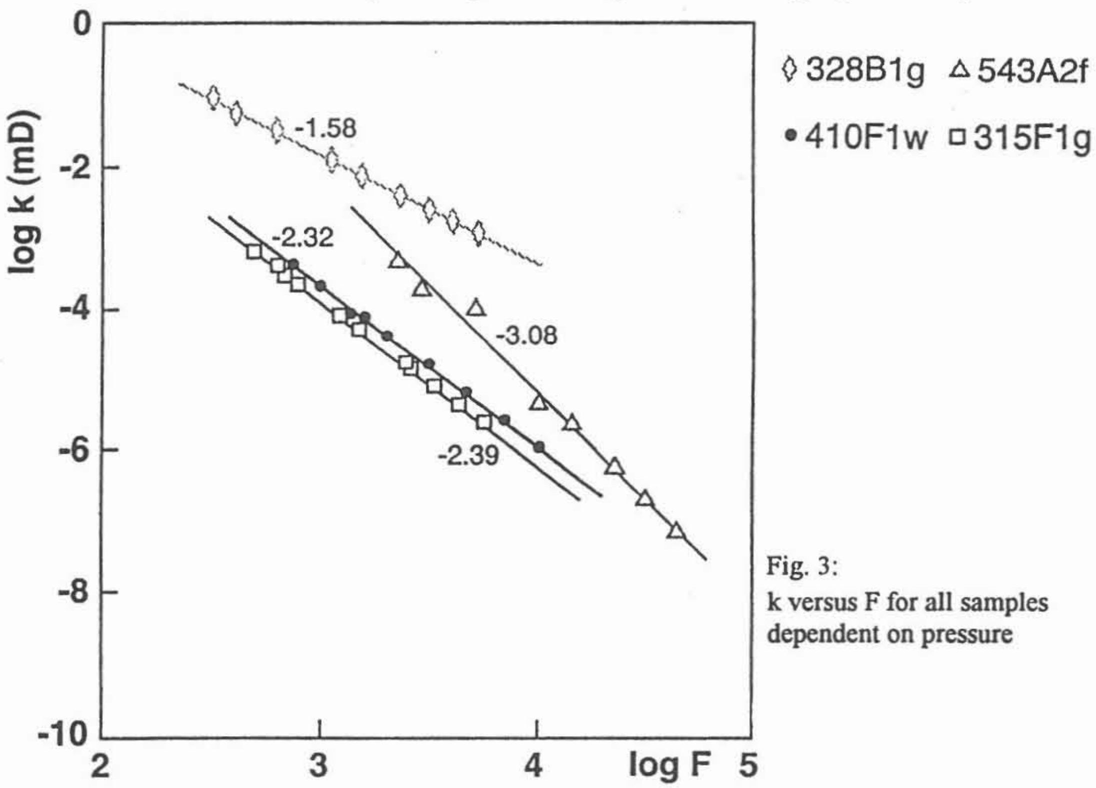

Fig. 3:
k versus F for all samples dependent on pressure

In Fig. 3 the permeability data (measured and extrapolated) of all samples are plotted versus the formationfactor. On this way it is possible to derive ultra-low permeability data down to 10^{-8} mD and pressures up to 300 MPa. The exponents fall in the range which is predicted by the equivalent-channel model. Further investigations on an extended sample collection will show whether it is possible to use the applicated method not only for a single sample of a crystalline rock but also for lithological suites.

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