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Permeability and poroelasticity of fractured granites

Ichiko Shimizu[1], Celia Tiemi Onishi[2], Shin-ichi Uehara[3], Kazuo Mizoguchi[3], Toshihiko Shimamoto[4]

[1] Geological Inst., Univ. Tokyo, [2] TGC-JNC, [3] Earth and Planetary Sci., Kyoto Univ, [4] Dept. of Geol. & Mineral., Graduate School of Science, Kyoto Univ.

The relation between permeability and poroelasticity were investigated, using drill core samples of the Cretaceous Toki Granite in Gifu Prefecture, Central Japan. The core samples were taken from a borehole penetrating a reverse fault of the Tsukiyoshi Fault at the depth of 700 m. The Toki Granite suffered various degrees of cataclasis and alteration by hydrothermal activities, from the country rocks of fresh biotite granite to foliated cataclasite at the center of the fault zone.

Permeability measurements were performed by a HPT gas apparatus developed by one of the author (T. Shimamoto). The samples were cut to cylindrical shapes with diameter of 20-25 mm and the length of 10-40 mm. All experiments were done under room temperature with Nitrogen gas as a pore fluid. Confining pressure Pc was increased up to 200 MPa. For the permeability measurements, the flow meters were used in the low Pc range (up to 10 MPa), whereas the oscillating pore pressure method (Kranz et al., 1990; Fisher & Paterson, 1992) was used in the higher Pc range, with pore pressure kept around 20 MPa.

In all experimental runs, permeability (k) was decreased with increasing effective pressure (Pe) and came close to steady values at the highest Pe (= 180 MPa). Reverse tests show some hysteresis in permeability. The data were best fitted by log-log plots, rather than the relation proposed in the theoretical model of Walsh (1981). The power (b) in the relation k = APe^(-b) is about 2 in the compression path and about 1 in the decompression path. The difference is probably due to irreversible deformation.

Pressure dependence of permeability is considered to be governed by closure/opening of microcracks in a quasi-elastic manner. Instantaneous change of pore pressure at the downstream reserver caused by stepwise change in confining pressure indicates poroelastic behavior followed by relaxation of pore pressure gradient by permeable flow. Ignoring the volume change of crystals, effective compressibility and effective bulk modulus of fractured granite were estimated. The compressibity of each sample decreasesi with increasing confining pressure, and is about 10x10^(-5) [1/MPa] at the highest Pe (ca. 180 MPa). The effective bulk modulus increases from several giga pascals at low Pe to about 10 GPa at the highest Pe, but the latter is still much smaller than those of constituent minerals (quartz, feldsper, and biotite) and their Voigt or Reuss means (ca. 50 GPa). The presssure dependence of the effective bulk modulus K is also approximated by a power law K = BPe^(-m) with the exponent of m~1/2. Therefore, permeability and the effective bulk modulus are related as k = CK^(b/m).