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On the Comparative Hydraulic Conductivity of Thin, Planar Cracks in Shale, Sandstone and Granite as a Function of Shear and Normal Stress

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ABSTRACT

Conductivity of fluids along fractures is a key process, complementing fluid flow through matrix permeability. Crack conductivity is reduced by increasing normal stress across the crack, and this has previously been experimentally verified, but the conventional view that the onset of shear failure along planar cracks enhances fluid flow owing to a small amount of dilatancy has not been unambiguously demonstrated. Fluid flow in cracks is usually modelled from the bottom up, beginning with the ‘cubic law’ relating flow rate along a parallel-sided channel to its width, then adding complexity due to crack roughness and tortuosity of flow paths, when it becomes difficult to define a crack ’width’. Here we determine experimentally how increasing normal and shear stress affects fluid flow along cracks using an electrical analogy, in which the crack is replaced by a slab of homogeneous material of greater permeability. This greatly simplifies the problem. We used argon gas to measure conductivity of planar cracks in Bowland shale and a higher viscosity synthetic oil for the much more conductive Pennant sandstone and Westerly granite. In all cases conductivity is reduced by increasing effective normal stress (over a range of 80 MPa), and is recoverable during pressure cycling. Shear stress was increased at constant resolved normal stress until the onset of frictional sliding. In all cases, at this point the conductivity decreases markedly and permanently, evidently due to the formation of a very thin layer of very fine-grained (10 micron) fault gouge as crack surface asperities are broken through and granulated. The positive normal stress sensitivity of friction stress indicates that there is local dilatancy, but from the point of view of conductivity, this is clearly swamped by the formation of the fine, low conductivity gouge matrix and its compaction. The combination of increasing normal stress and shearing can reduce conductivity by up to 5 orders of magnitude. Presently, we have not accessed any physical conditions which might lead to sufficient dilatation to permit an increase in conductivity with incipient shear displacement. These results can impact greatly on approaches to the modelling of fluid flow through rock masses containing crack arrays, necessary for the design of hydraulic fracture treatments, geothermal energy extraction, the design of waste repositories in a range of rock types and the flow of reservoir fluids.