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Permeability of cracked rocks

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Fluid transfer in the upper crust takes place through cracks and pores network. For low porosity rocks (<5%), cracks play a major role. Such a situation may be relevant to an extension tectonic regime. At shallow depths, the temperature is low so that ductile deformation is not considered. Consequently we make in the following the assumption that permeability is controlled by cracks.

Basaltic ocean crust permeability were reviewed by Fisher (1998). The data point to a sharp permeability decrease from near surface values (100 mD) to much lower values (< 0.1 mD) at depths greater than 1 km. More recent data by Violay et al (2010), at slightly greater depths, show also a low porosity and the existence of a crack network. Given that pressure has a major effect on cracks, this leads to interpret the permeability-depth variation as resulting from crack closure. The controlling pressure here is the effective pressure P_e =P-p, where p is pore pressure.

Laboratory data on rock permeability have been measured in various conditions by many authors. In the case of low permeability rocks, the pressure effect is observed to follow an exponential law of the type $k = k_0 e^{-(\alpha Pe)}$. David et al (1994) have reported that the parameter α varies between 2 and 10 (x10^{-2} MPa^{-1}). Such a behaviour is consistent with a crack permeability. The exponential decrease may be explained by crack closure. Crack aperture w varies with Pressure as $w = w_0 (1 - bP_e)$, where b is a parameter depending on crack aspect ratio ξ and Young modulus E: $b = (\xi E)^{-1}$. Parameter α can be viewed as the inverse of a critical pressure P* that controls crack closure. High P* values means that cracks are difficult to close whereas small P* values means the opposite. Published data correspond to a range of P* values of 10-40 MPa. This corresponds to aspect ratios that are moderate (about 10^{-2}). The question is: what is the aspect ratio (and P*) of the cracks that could control shallow depth permeability? The incertitude on in-situ data is a limiting factor.

Another limiting factor could be that laboratory data do not cover all situations. In particular, data on permeability of very low aspect ratio cracks (10^{-4}) are not common. However, such data have been obtained recently (Ougier-Simonin, 2010) on synthetic glass samples. In that case, a connected network of low aspect ratio cracks has been introduced in the glass samples. It appears that the very low aspect ratio of cracks is indeed related to the absence of crystalline structure. Interestingly enough, the exponential law is again very well followed in that case, with a lower P* value, of about 2.4 MPa.

It can thus be concluded that crack permeability is well described by an exponential decrease over a broad range of critical pressures (2 – 40 MPa), corresponding to the first 2 or 3 kms. In-situ data could be interpreted using the previous results.