The permeability of fault zones: statistical analysis, world-wide depth-trends and permeability contrasts

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Fault zones are a ubiquitous part of the Earth’s brittle crust, influencing a wide range of processes including hydrothermal circulation and ore deposition, crustal tectonics, and seismicity. However, despite the large amount of drilling and in-situ hydraulic testing worldwide, there are no comprehensive summary statistics of fault permeability. We conducted a meta-analysis of fault zone permeabilities globally for the upper brittle continental crust, using about 10,000 published research items from a variety of geoscience and engineering disciplines. Using 460 datasets at 340 localities, the in-situ bulk fault permeabilities (>10's meters scale, including macro-fractures) were analyzed, compared, and distinguished from matrix permeabilities (drilled core samples or outcrop spot tests).

The first result is the relationship between the paired permeability of fault damage zone vs. protolith. Regression analysis shows that much of the variation in fault permeability is explained by the protolith permeability. In relatively weak volcaniclastic and clay-rich rocks, up to 70 to 88% of the variation is explained, while only 20-30% of the variation is explained in plutonic and metamorphic rocks. The second result is the depth distribution of fault damage zone permeability. There is a large scatter of values and clustering of in-situ results between 1 and 3 km depth, but a bounding curve can be fitted to the maximum values. We propose a revision at these shallow depths to previously published upper-bound curves for the "fault-damaged crust" and the geothermal-metamorphic rock assemblage outside of major fault zones. The geothermal-metamorphic curve is near the upper limit of permeability values at many non-geothermal sites. The third result is depth-distribution of permeability ratio (fault damage zone / protolith). The permeability ratio is important for understanding and modeling of fluid flow in fault zones. The ratio is typically 100 to 1000, attains a maximum at a depth of about 2 km, and may decrease with depth.

In Japan, the permeability ratios at 32 geothermal and scientific drilling locations are all bounded by the proposed permeability ratio curve. At 12 Japanese locations where a permeability ratio (damage zone / protolith) could be estimated, the data are all within the proposed permeability ratio curve. In general, the fault zone permeability data from Japan at respective depth ranges are near the global average and well described by the calculated world-wide statistics.

Keywords: fault zone, permeability, hydraulic tests, geothermal, brittle deformation, statistics

