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Fault zone permeabilities over geological timescales: constraints from sedimentary basins

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Despite several recent investigations into the fine-scale permeability properties of fault zones, the upscaling of such permeability information to prediction of fault zone permeability at the large scale remains uncertain. Constraints on large-scale fault zone permeability are rare: those that exist are usually either from borehole injection tests over geologically instantaneous timescales (such as post-rupture studies on active faults), from non-unique production history matching of hydrocarbon wells either side of a fault, or are derived from time-integrated fluid flux estimates based on mass balance calculations of fault zone fluid-rock interactions, typically in the crystalline basement.

This contribution presents a novel method for estimating large-scale fault zone permeability of a basin-bounding normal fault (offset $\sim$ 400 m) over a 1.5 Myr timescale in the Haltenbanken continental shelf of offshore Norway. The area is currently the focus of debate on whether or not recent fault reactivation due to glacial loading has occurred. The fault provides a barrier to highly overpressured Jurassic reservoir units with the up-dip footwall reservoir draining to the hydrostatic domain, with a relatively clay-rich average composition of the offset units being due to the thick shales separating individual sandstone reservoir units. Using a simple transient pressure diffusion analysis and estimates of the maximum overpressure difference at the end of the late-Tertiary regional overpressure generation phase ($\sim$ 1.5 Ma), the maximum permeability allowing up-fault overpressure diffusion to the currently-measured value can be obtained, 6 – 9 x 10^{-20} m^2 (60 – 90 nD).

This value is in order-of-magnitude agreement with laboratory measurements of foliation-parallel clay-rich gouge permeability at comparable pressures, suggesting no

influence of possible open “damage zone” fractures often documented around faults in more sandstone-rich and/or crystalline basement settings. An interesting corollary of this result is that it suggests that the fault has not suffered recent reactivation – if the currently measured overpressure difference had been due largely to transient leakage during slip reactivation, the permeability during the remainder of the time would have probably had to have been unfeasibly low.