Fault Zone Diffusion of Pore Pressure During Production and Effect on Fault Stability*

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Abstract

Faults at many scales are amongst the most common structural heterogeneities which can impact production-related reservoir flow and may also focus deformation related to changing fluid pressures during field life. Problems related to fault zones include: (1) trapping initial overpressures during reservoir depletion, rendering the fault potentially unstable at the reservoir level during production and affecting sealing integrity (e.g. Cuisat et al., 2010), and (2) leakage of fluid into and up a fault zone during injection, leading to fault instability in the overburden and potentially severe risk of leakage to the surface or seafloor.

Faults are recognized as narrow zones of deformed rock with petrophysical properties largely different from those of the host reservoirs (Wibberley et al., 2008; Faulkner et al., 2010), often with a highly anisotropic permeability structure enhanced by fracture damage zone clustering around a low permeability fault core zone (Figure 1). Predicting their petrophysical properties, particularly the permeability of fault zones, is crucial to understanding their response to reservoir pressure changes during production (depletion, injection), and consequently their geomechanical behaviour in terms of fault stability. This presentation aims to demonstrate how advances made in the last decade have led to more consistent fault permeability estimates than previously existing methods and demonstrates their use in modelling fault zone pressure evolution during different cases of field development.

Discussion

For siliciclastic fields, a fault permeability algorithm developed over the last decade provides more robust estimates of fault permeability in both the across-fault and up-fault directions, which can be used in modelling pore pressure changes within the fault zone for different scenarios of depletion and injection. This algorithm has been tested with favorable results against independent estimates of upscaled fault permeability from cases where overpressure dissipation on the geological timescale, or the distribution of pressure changes on the production timescale, can be used to constrain the fault permeability (e.g. Figure 2).

Using a case study as an example, a simple scenario for depletion of a deeply-buried multi-layered siliciclastic reservoir is presented. Previously, end-member geomechanical models for the field showed that a purely undrained fault will rapidly arrive in the unstable domain in the reservoir during production-related depletion, whereas a perfectly drained fault will remain stable (Figure 3). However, modelling the pore pressure evolution within the fault zone during reservoir depletion, using the realistic fault permeability estimates, can constrain quantitatively the pressure response of the fault zone in between these two end-member fault zone pressure dissipation behaviours.

For the case study, the modelling shows that the main compartmentalizing faults within the field are predicted to trap, rather than dissipate, the relatively high initial in-situ pressures for significant periods of time during pressure depletion of the reservoirs, for the expected range of geometric parameters. This relative excess pressure in the fault zone would decrease the effective normal stress within the fault, leading to fault reactivation within the reservoirs during production.

During the development planning stages for fields involving injection, including for CO_2 storage, the behavior of faults cutting the reservoir and/or topseal needs to be examined in terms of possible leakage pathways and geomechanical response to injection. Whilst the stress-sensitivity of permeability for up-fault flows is very different to that for across-fault flow, a fault zone can nevertheless still be treated as a zone of sheared, anisotropic granular material of non-negligible permeability, particularly when the pressure is less than the minimum stress or another yield criterion (e.g. Mohr-Coulomb). Otherwise stated, a “frac” criterion can be over-optimistic in some cases, as illustrated by case studies from the overburden above producing fields, for which data, including 4D seismic, show evidence of up-fault fluid leakage at pressures below the minimum stress and also below fault shear reactivation. This is supported in a quantitative way by numerical modelling of up-fault pore pressure evolution during reservoir pressure increases due to injection, in order to evaluate the expected timescale of pressure transmission up the fault, and possibly to the surface. A case study is discussed in which calculations show how injection close to faults connecting shallow reservoirs to the surface can induce up-fault migration of a fluid pulse in a matter of months to a couple of years (Figure 4), even before the pressure increases to a Mohr-Coulomb reactivation criterion.

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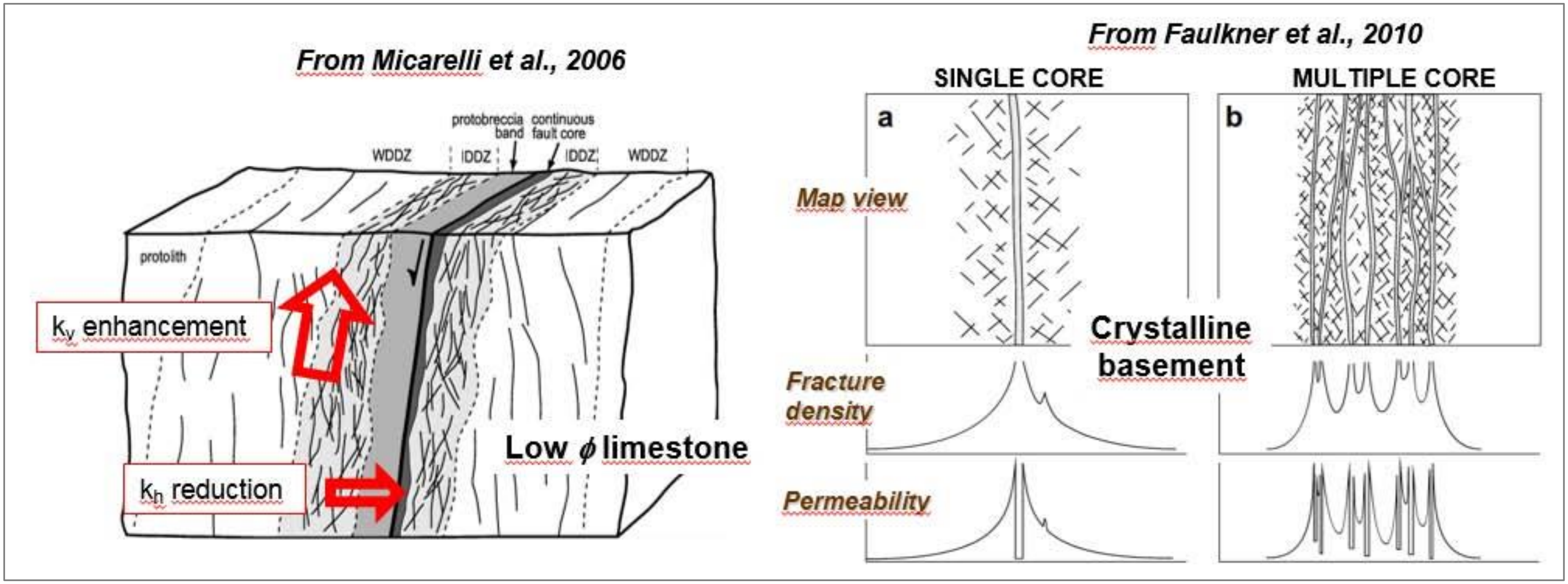

Figure 1. Models of anisotropic permeability structure of fault zones.

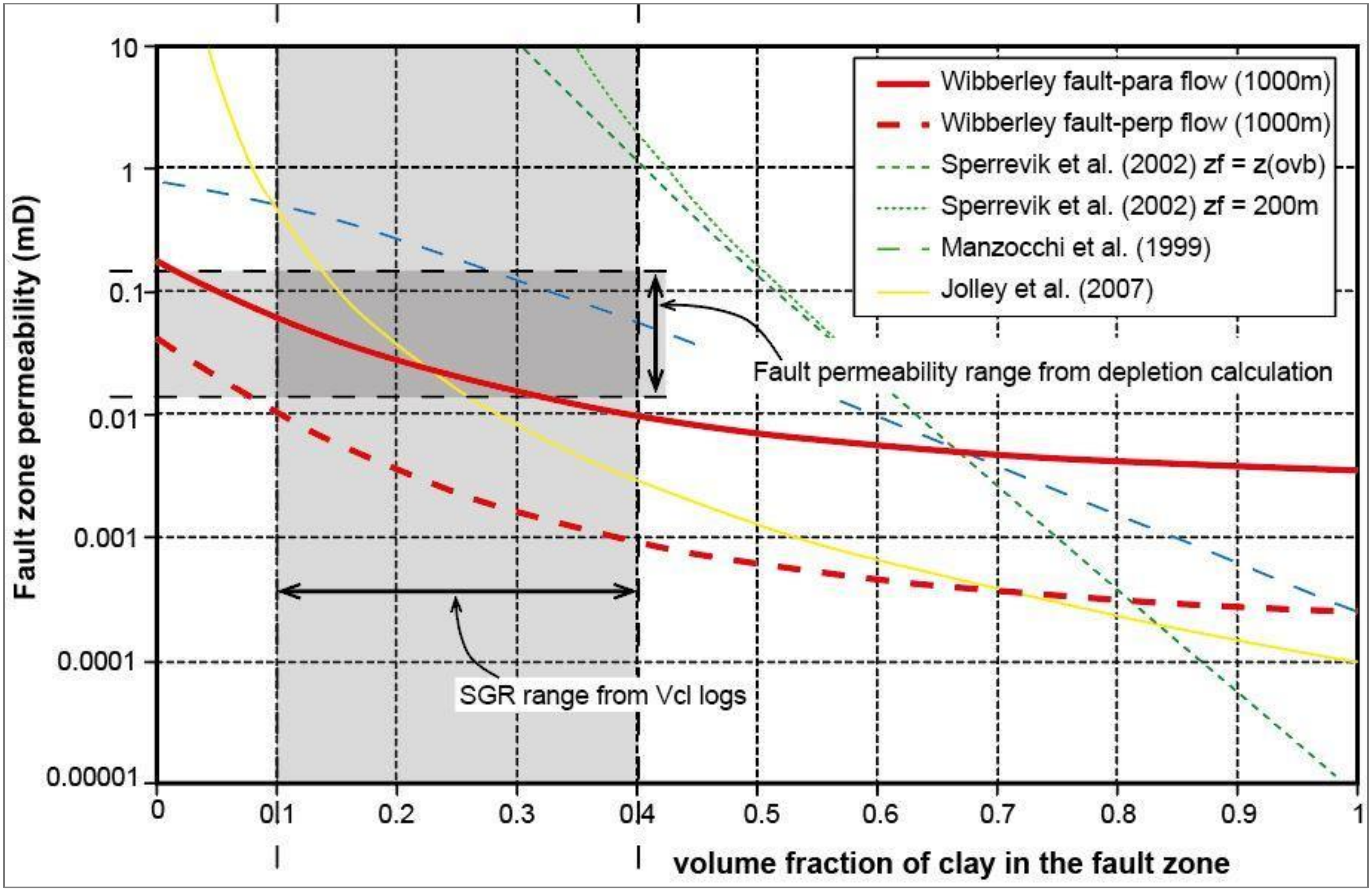

Figure 2. Example of the new fault permeability algorithm compared with previously published cases and an independent upscaled fault permeability estimate from a producing field case study (Wibberley et al., 2017).

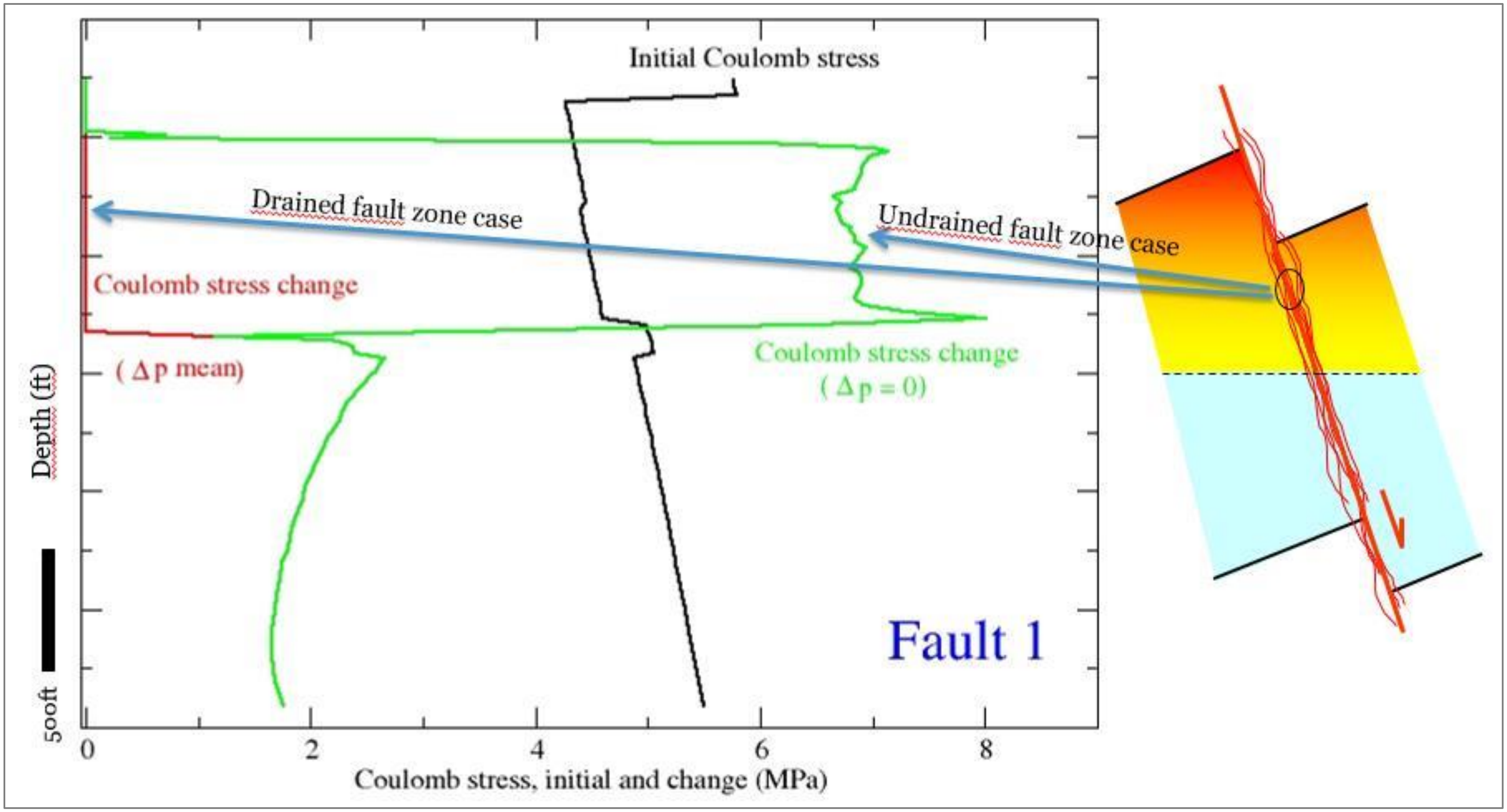

Figure 3. Example of a Coulomb shear stress profile on a fault prior to (black line), and during (red and green lines) production-related pressure depletion in the reservoir. The red profile is for the perfectly drained fault zone case, the green profile being for the undrained case.

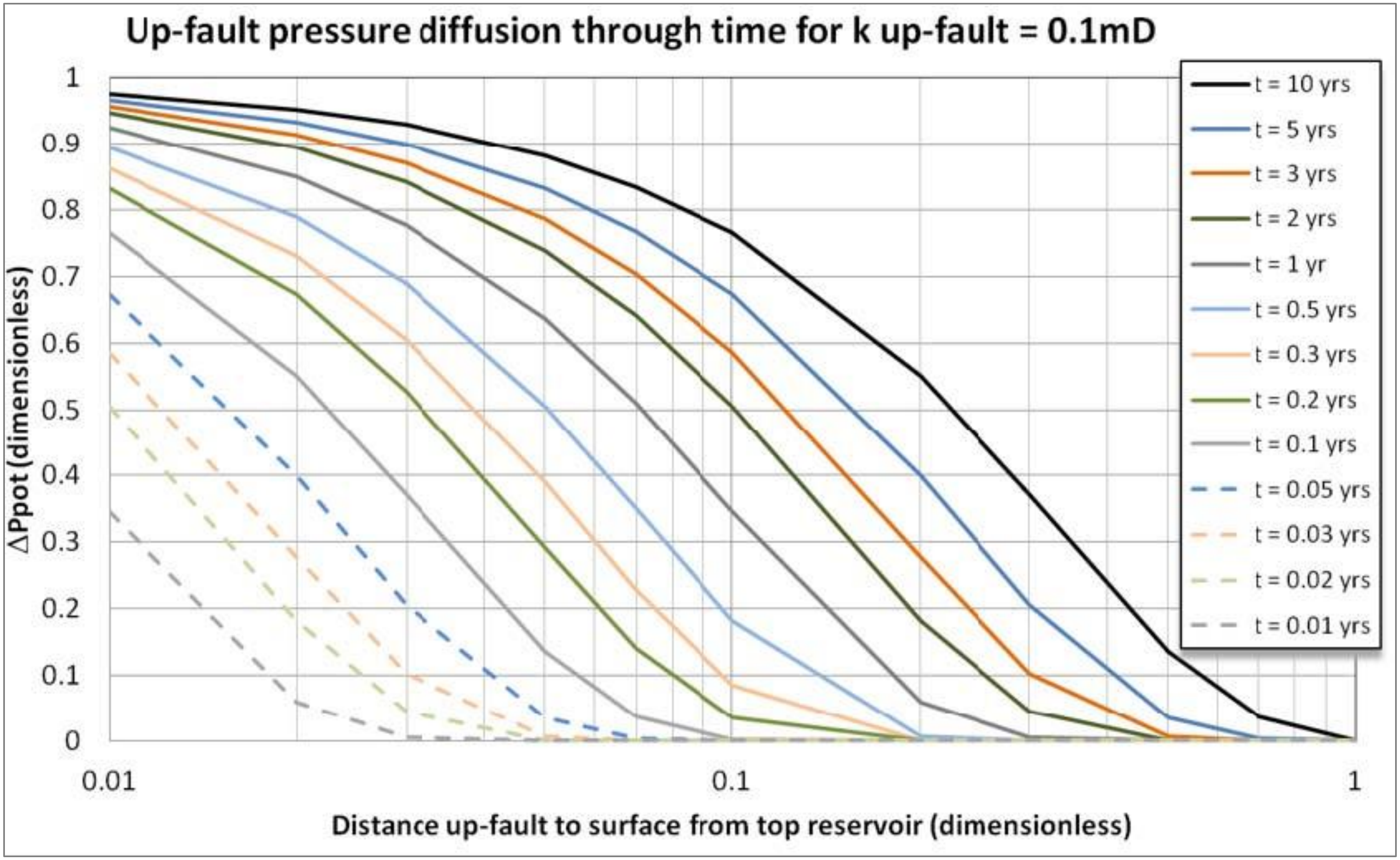

Figure 4. Example of numerical calculations for a case study of injection close to a fault zone, in which the timescales for propagation of a pressure potential pulse up a fault zone towards the Earth's surface are examined as a function of vertical fault permeability.