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# The influence of alteration on frictional behavior and the depth of ductile shear zones in volcanic arc geothermal reservoirs

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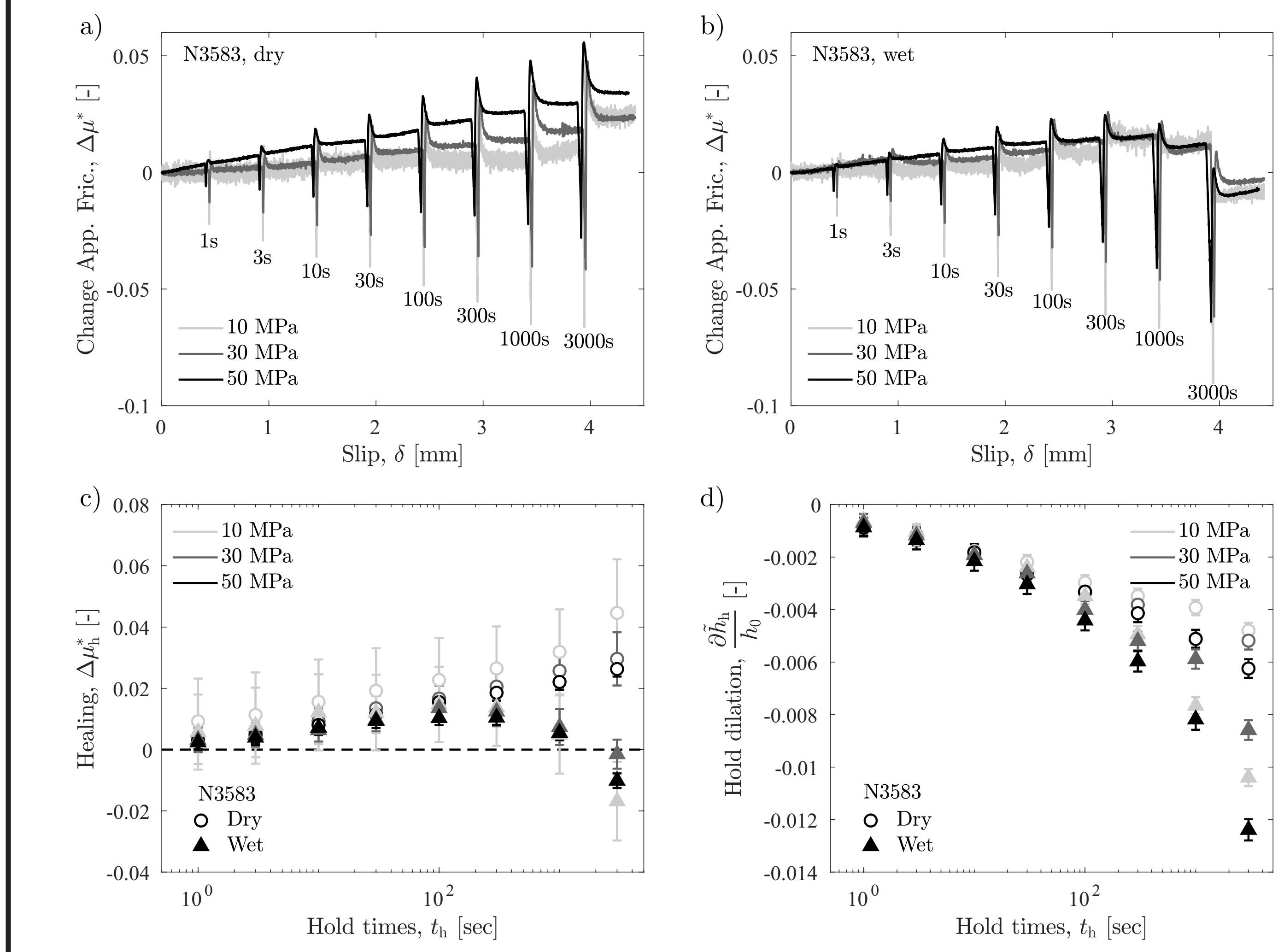
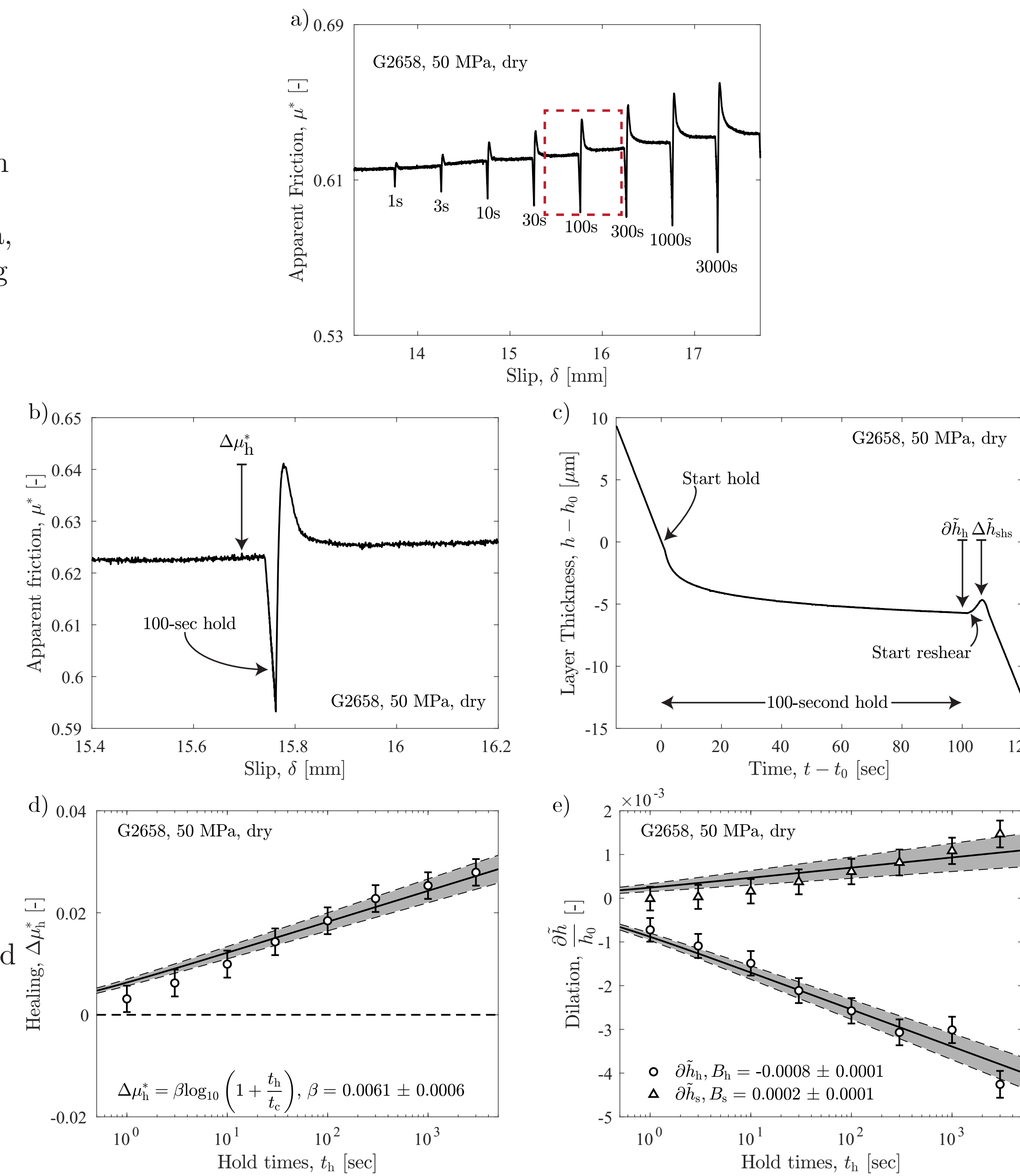
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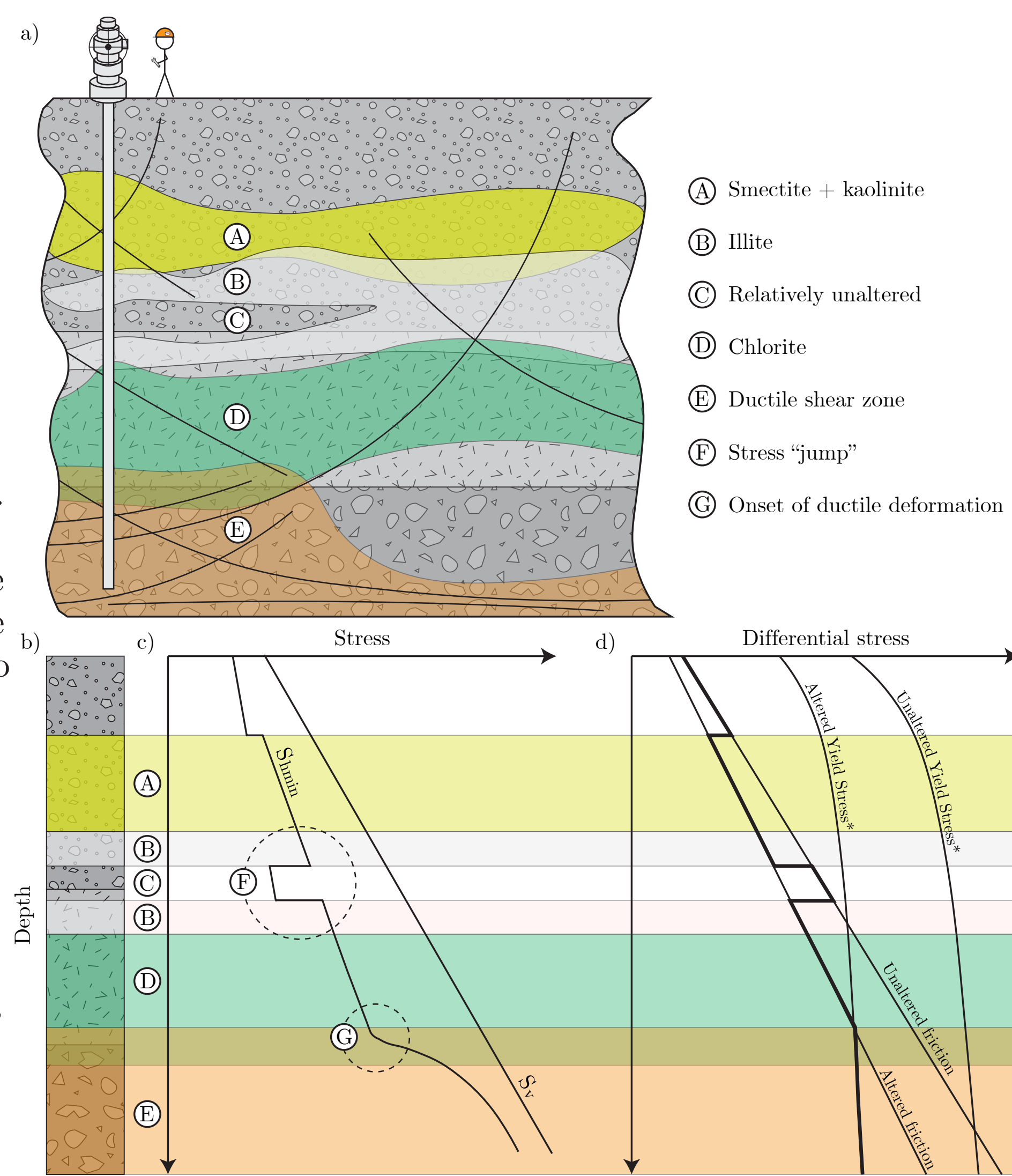
## Summary

The majority of geothermal energy is produced in tectonically-active volcanic-arc regions due to their high geothermal gradients. Reservoirs in these settings are often stratified with smectite/kaolinite-, illite-, and chlorite-rich zones, in order of increasing depth and temperature. Eighteen andesitic core and surface samples were taken from five geothermal fields in the Lesser-Antilles and Cascade volcanic arcs. The collected samples have experienced various degrees of alteration and can be considered, in their ensemble, to be representative of the previously-mentioned alteration zones. The influence of the alteration was assessed through biaxial rate-and-state friction experiments on prepared gouge. The samples were each tested at 10, 30, and 50 MPa normal stress in both nominally-dry and nominally-wet conditions. While significant water-induced frictional-strength reduction was observed, phyllosilicate content dominates frictional behaviour, with increased phyllosilicate content reducing frictional strength, promoting velocity-strengthening behaviour, and reducing frictional healing. Negative frictional healing is observed and likely related to the presence of expandable clays, leading to frictional weakness over long time periods. It is suggested that, by controlling frictional strength, phyllosilicate content influences the depth of onset of ductile shear zones, which often underlie these reservoirs and are critical for the horizontal advection and vertical sealing of geothermal fluid. Further, as these types of reservoirs are likely critically stressed, varying degrees of alteration within different reservoir zones can give rise to the formation of stress jumps.

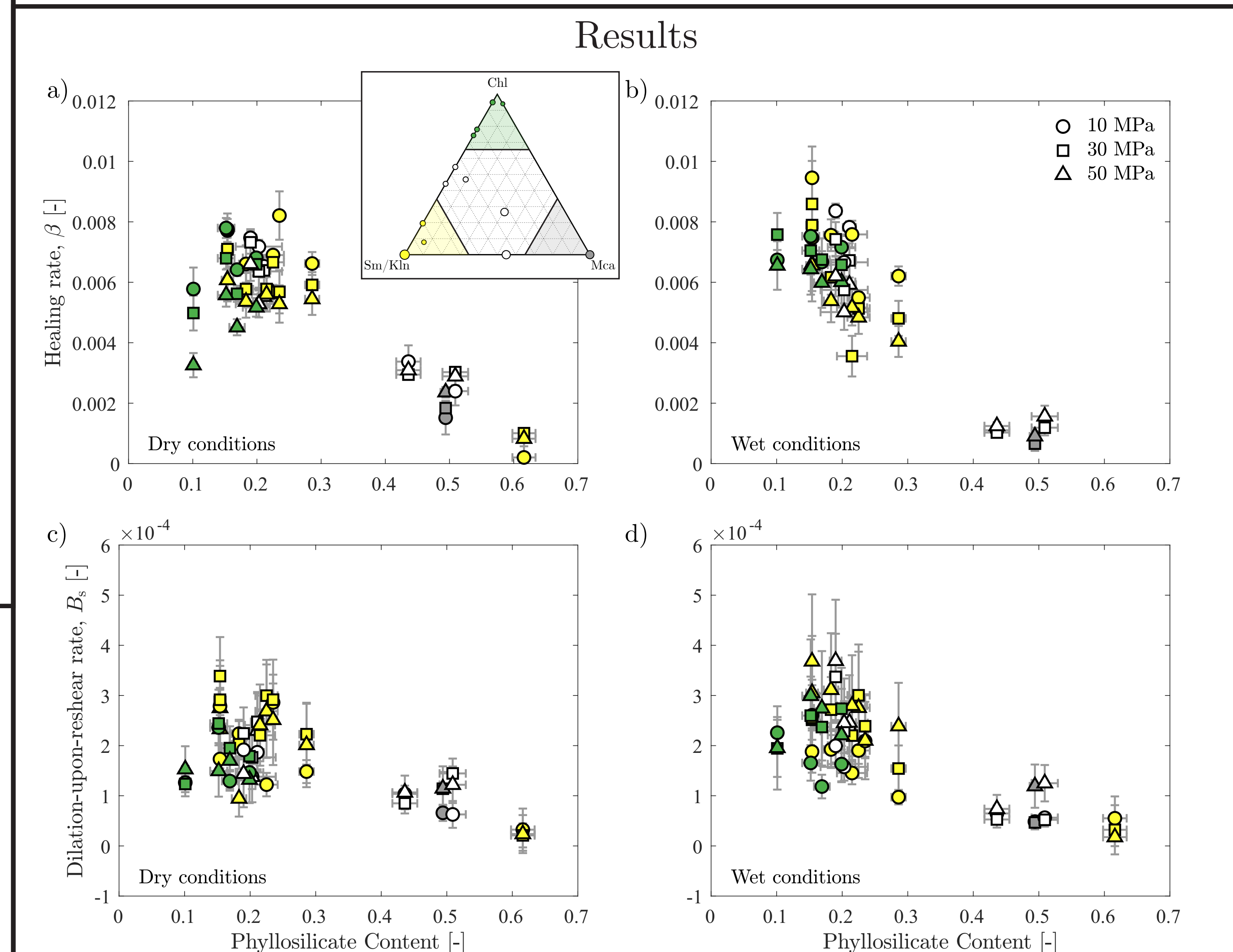
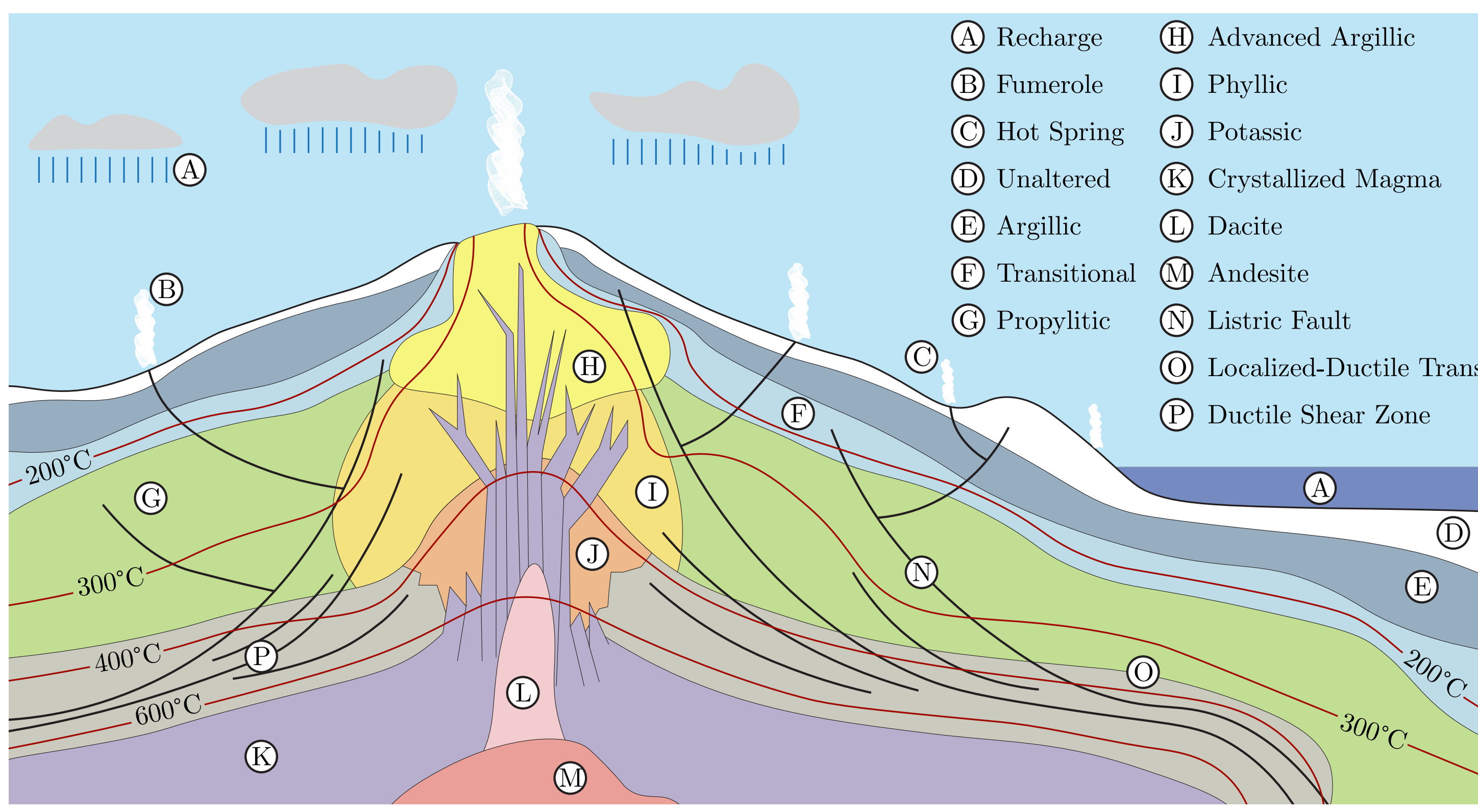
Right: A number of friction parameters were investigated. These include the dynamic coefficient on friction, velocity dependence through  $a$ ,  $b$ , and  $D_c$ , the healing of the gouge through  $\beta$ . Additionally, the dilation occurring during velocity steps and slide-hold-slides was also analysed. This was done in wet and dry conditions at all normal stresses tested. On the right, you can see an example experiment showing the slide-hold-slide sequence one of the gouges was subjected to. This has resulted in a very large, consistent data set, and can further be ideal for machine learning applications. Please contact me if this interests you.



Above: A unique behavior is observed where one gouge composition is seen to weaken in time. This phenomenon is termed «negative healing» and has only rarely been observed.



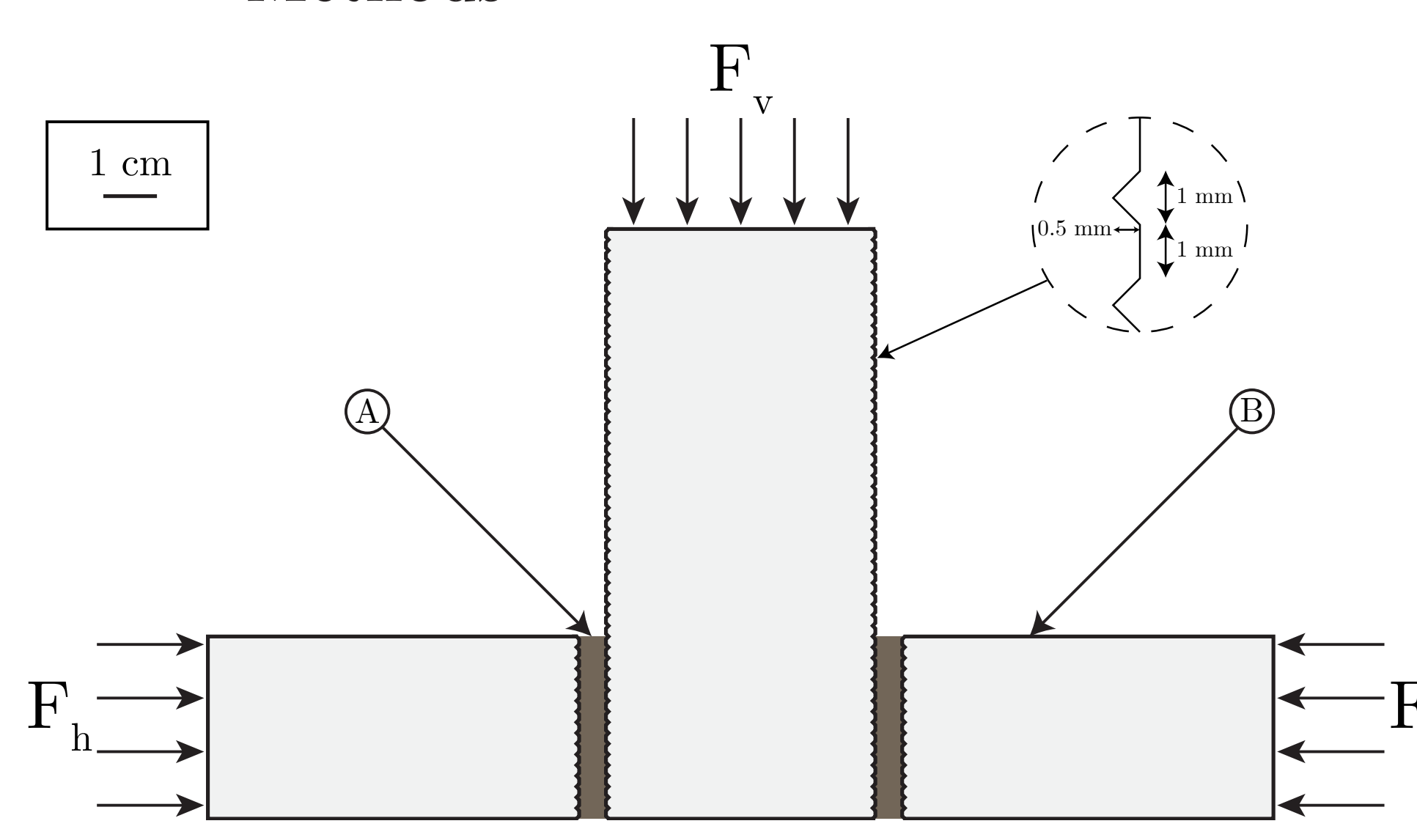
Right: A cartoon illustrating the likely stress profile for a geothermal reservoir in a volcanic arc setting based on our results. The degree of alteration controls the frictional strength of the rock. As these settings are critically stressed, this places a limit on the differential stresses possible in the reservoir, potentially giving rise to «stress jumps» where alteration changes sharply. Further, as the localized-to-ductile transition depends on both the yield stress and the frictional strength of the rock, a changing degree of alteration will affect the depth of onset of ductile deformation. This has important implications for fluid flow as these zones act as horizontal fluid conduits and vertical seals.



Above: The effect of phyllosilicate content on the healing rate and dilation upon reshear during slide-hold-slides. Phyllosilicate content reduces healing. Not shown, phyllosilicate content also results in lower friction coefficients and increased velocity strengthening behavior. This influence is independent of the specific phyllosilicate mineral present to a first order. This may allow for the simplification of hazard studies.

## Methods

Right: Classical rate-and-state friction experiments were performed on 18 core and field samples from 5 different geothermal reservoirs in volcanic arc settings. The samples are altered to various degrees and were tested under wet and dry conditions at 10, 30, and 50 MPa normal stress, resulting in 108 tests. Pre- and post-mortem microstructural analyses were performed along with XRD and granulometry investigations.



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