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Double, double, (but mostly) toil, and trouble: A multidisciplinary approach to quantify the permeability of an active volcanic hydrothermal system (Whakaari volcano, New Zealand)

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Our multidisciplinary approach, which combines field techniques and traditional laboratory methods, aims to better understand the permeability of an active volcanic hydrothermal system, a vital prerequisite for understanding and modelling the behaviour of hydrothermal systems worldwide. Whakaari volcano (an active stratovolcano located 48 km off New Zealand's North Island) hosts an open, highly reactive hydrothermal system (hot springs and mud pools, fumaroles, acid streams and lakes) and represents an ideal natural laboratory to undertake such a study. We first gained an appreciation of the different lithologies at Whakaari and (where possible) their lateral and vertical extent through reconnaissance by land, sea, and air. Due to the variable nature of these altered lithologies (mainly lavas and tuffs), we measured porosity-permeability for in excess of a hundred rock hand samples using field techniques. We also measured the permeability of recent, unconsolidated deposits using a field soil permeameter. Our field measurements were then groundtruthed on a subset of these samples (∼40-50) using traditional laboratory techniques: helium pycnometry and measurements of permeability using a benchtop permeameter, including measurements under increasing confining pressure (i.e. depth). In all, our measurements highlight that the porosity of the materials at Whakaari can vary from ∼0.01 to ∼0.6, and permeability can vary by eight orders of magnitude. However, our data show no discernable trend between porosity and permeability. A combination of macroscopic and microscopic observations, chemistry (XRF), mineralogy (XRD), and mercury porosimetry highlight that the absence of a robust porosity-permeability relationship is the product of an insane variability in alteration and microstructure (pore size, particle size, pore connectivity, presence/absence of microcracks, layering, amongst others). While our systematic study offers the most complete porosity-permeability dataset for a volcanic hydrothermal system to date, we concede that understanding and modelling fluid flow and eruption scenarios will remain a challenge due to their extreme complexity.