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Insights into Volcanic Rocks as Petroleum Reservoirs from Laboratory and Field Permeability Measurements

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ABSTRACT

Measurements of porosity and permeability of volcanic rocks has been the focus of much research in physical volcanology and applied to geothermal energy. Here, we apply our ample data set to bring insights to the petroleum industry regarding the characterization of permo-porosity in volcanic rocks. We present three experimental and field data sets, the active hydrothermal volcano Whakaari (White Island), and the active geothermal fields of Ngatamariki and Rotokawa (all within the Taupo Volcanic Zone of New Zealand's North Island). These two data sets illustrate the variety and spatial distribution of lithologies in emergent and buried andesitic cone volcanoes. At White island, we sampled the main crater, filled with tephra deposits, and the volcanic amphitheatre comprising interbedded lavas, lava breccias, and tuffs. In the geothermal sites we sourced the samples from drill core. The geothermal reservoir samples were from wells with varying depths (800-3300 m) and spanning a range of intrusive, proximal volcanic slope, and inter-eruptive sedimentary facies. Lithologies included volcanoclastic lithic tuff, primary tuff, welded ignimbrite andesite lavas and breccias, rhyolite lavas and breccias, sandstones, and intrusive tonalities. In total, we measured P and S wave velocities, porosities, uniaxial and triaxial strength, and permeability on ~300 cylindrical plug samples. Our measurements highlight that the porosity of the materials at Whakaari varies from ~0.01 to ~0.7 (1 to 70 %) and permeability varies by eight orders of magnitude (from ~10-19 to ~10-11 m2) The porosity of the samples recovered from the geothermal drill cores varies from ∼0.02 to ∼0.21 (2 to 21%) and permeability varies by four orders of magnitude (from ∼10-19 to ∼10-15 m2). We also performed permeability measurements at varying confining pressures (analogous to depth) from 5-55 Mpa. Overall, our results highlight a huge variability in lithology in volcanic systems, further complicated by alteration style and intensity and burial depth. This, in turn, leads to complex and often disparate differences in rock microstructure. Indeed, the microstructure of the volcanic rocks can be grouped into two broad groups: microfracture-dominated and pore-dominated. The permeability of the pore-dominated (i.e. tuffs, breccias) and altered samples does not change rapidly as porosity changed or by systematically increasing the confining pressure (depth) on an individual sample. Additionally, these porous-dominated rocks were weak and brittle failure was limited to low confining pressure, at confining pressure equivalent to more than a few hundred meters failure became compactant (decreasing the porosity of the sample). In contrast, the microfractured-dominated lower porosity samples (i.e. lavas) rapidly lost permeability with decreasing porosity or confining pressure. Additionally, these samples were much stronger, and underwent dilatant (brittle) behaviour upon failure, even at high confining pressures. Our results imply that the permo-porosity variability of volcanic rocks show sustainable values to form petroleum reservoirs, as well as seals. Our data allows us to discuss variation in porosity and permeability with depth and alteration and the onset and implications of compactant and brittle failure suggesting that permeability in pore-dominated volcanic rocks can be strongly preserved during burial and compactation, and reduced in microfracture-altered rocks. The high variability on the results of P and S wave velocities on volcanic rocks suggest that interpretation of volcanic properties necessitates caution when based exclusively on seismic reflection data.