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Modelling the Signatures of Supercritical Geothermal Resources under Thermally-Inhibited Permeability Constraints

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Geothermal systems in the Taupō Volcanic Zone (TVZ), New Zealand, are sustained by large-scale convection of groundwater that is mainly confined to the brittle upper crust. The depth and temperature of the brittle–ductile transition (BDT) is hypothesised to demarcate the lower boundary of fracture-hosted permeability and hence fluid circulation. Thus, we expect the thermal structure of the convection cells, both at their base and the geothermal resource at drillable depths, to be influenced by the BDT temperature. As direct observations below 3 km are difficult to obtain, the objective of this study is to test whether temperatures in the upper 2 km of hydrothermal systems are correlated with BDT temperature and could hence serve as a proxy constraint on deep thermal and permeability structure.

This work uses numerical models of hydrothermal circulation that couple Darcy flow and heat transport in a 2D axisymmetric domain. The models assume a deep basal “hotplate” of 800 to 1300°C at 15 km depth and then allows the permeable domain to be dynamically determined as a function of temperature. Following the work of Hayba & Ingebritsen (1997) and Scott et al. (2016), we use a logistic/sigmoid model of rock permeability that decreases smoothly across a prescribed BDT temperature range and whose mid-point temperature was varied between 350 and 650°C. The models reproduce the expected dominance of fluid convection at shallow depths where temperatures are sufficiently low to not inhibit permeability. A convective-conductive boundary forms at a depth that is self-determined by the system balance between shallow convective and deep conductive heat transfer.

Analysis across a range of model parameters and anisotropy conditions confirms a correspondence between the rock’s BDT temperature range and hydrothermal fluid temperatures at 2 km depth. Across a range of BDT temperatures and anisotropy assumptions, we recover a linear relationship between the hydrothermal upflow temperature at 2 km depth and the applied BDT temperature (e.g., 338°C at 2 km depth corresponding to a 400–500°C BDT range). Modelled convection cells range in power outputs from 60 to 285 MW, which is consistent with the range of estimates for TVZ geothermal fields. These findings suggest that shallow temperature observations can be used to infer rock rheology and permeability properties in hydrothermal provinces.