# Fracture properties in geothermal systems from stable and radiogenic isotopes

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The precise and accurate characterization of fracture attributes, such as spacing and surface area, in geothermal systems is essential for increasing geothermal energy production. Fracture characterization is particularly important for enhanced geothermal systems (EGS) where fracture permeability must be increased and sustained compared to pre-development conditions to make EGS economical. Natural and synthetic geochemical tracers are a promising tool for fracture characterization.

We present results of recent and active research projects which utilize isotope ratios of Sr, O and uranium series nuclides ($^{238}U$, $^{234}U$, $^{226}Ra$ and $^{222}Rn$) to determine the spacing, aperture and surface area of hydraulically conductive fractures in geothermal reservoirs. Our approach is to identify elements and isotopes that exchange between geothermal fluids and reservoir rock on differing length scales, allowing the determination of reservoir properties. Reactive transport models of geothermal fluids are validated with hydrothermal column experiments, flowback tests in stimulated reservoirs and samples from natural geothermal systems.

The $^{87}Sr/^{86}Sr$ is sensitive to isotopic exchange between the reservoir minerals and hydrothermal fluids in the rock matrix which diffuse to fracture surfaces. The change in the fracture fluid $^{87}Sr/^{86}Sr$ along the flowpath is used to calculate the spacing of conductive fractures. In contrast to $^{87}Sr/^{86}Sr$, the $^{222}Rn$ activity of a fracture fluid is mainly controlled by the interfacial chemistry and surface area due its short half life. Since the residence time of the fluid is much greater than the half life of $^{222}Rn$, the activities measured at wells can be assumed to be steady-state activities.

We demonstrate our model by applying the $^{87}Sr/^{86}Sr$ fracture spacing and reservoir sweep volume with $^{222}Rn$ fracture apertures to the Long Valley geothermal system. Calculated spacing of fractures is 10 m and fracture apertures are 0.1-0.5 mm, depending on the amount of $^{222}Rn$ lost during fluid boiling. We calculate a total geometric surface area of $10^5$ $m^2$ per linear meter along the flow path.