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Groundwater ages in Andean Southern Volcanic Zone geothermal springs: Contrasting U-Th/^{4}He and ^{14}C derived water ages

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Estimating the residence time of hydrothermal fluids within a volcanic arc context presents numerous challenges due to these regions' geological and hydrogeological complexity. Despite progress in dating methodologies, interpreting radiocarbon ages remains fraught with uncertainties, primarily due to the introduction of magmatic CO_2, a dead carbon pool that is difficult to estimate and subtract. Other age tracers, such as U-Th/^{4}He, present promising alternatives, especially in geothermal settings. To compare different age tracers within watersheds associated with volcanic activity, the Southern Andes Volcanic Zone (ZVS) provides a unique natural laboratory framed by volcanic and geothermal activity linked to regional fault systems. This study aims to evaluate and compare ^{14}C and U-Th/^{4}He age tracers, specifically elucidating the geological and hydrogeological complexities that influence groundwater chemistry and age distributions in geothermal reservoirs. Helium isotopic analyses were conducted at the Noble Gas Laboratory (GRAM) of Geotop, while radiocarbon dating was performed for the dissolved inorganic carbon fraction at the André E. Lalonde AMS Laboratory, University of Ottawa. U and Th analysis in rock samples was carried out at Activation Labs. The helium isotopic ratio ($R = {}^{3}He/{}^{4}He$) normalized to the atmospheric ratio ($Ra = 1.384 \times 10^{-6}$) or R/Ra of hot springs ranged between 2.49 and 4.98. The U and Th contents in located hosting aquifer rocks varied from 0.5 to 4.4 ppm and 0.9 to 23.4 ppm, respectively. Geothermal fluids are hosted in volcanic rocks and granitoids, with low porosity ranging from 1% to 4%. Assuming that the measured radiogenic ^{4}He originates from U and Th decay within the aquifer rocks, the U–Th/^{4}He groundwater residence times were calculated to range from 1264 to 19334 years with an uncertainty of 35%. Radiocarbon ages ranged between 4680 and 21900 years BP. Uncorrected radiocarbon ages mainly exhibited older values, possibly attributed to the occurrence of a magmatic ^{13}C pool in the hydrothermal reservoirs. Comparison of the dating methods revealed variations in groundwater ages, showcasing the advantages and limitations of each age tracer within the context of volcanic arcs.