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Using heavy noble gases to understand mantle-crustal connections in southwestern US hot springs and CO_2 fields

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The EarthScope USArray seismic network has revealed a surprisingly heterogeneous mantle tomography across the continental U.S., where distinct zones of low seismic velocity throughout the tectonically-inactive central plains and eastern margin suggest a much greater segmentation of the continental lithosphere and interaction between the lithosphere and asthenosphere than previously considered. Most interestingly, unpublished helium isotopic data from the OSU database, which includes oil and gas reservoirs, groundwater wells, and natural thermal springs overlying low-velocity anomalies in the eastern U.S. show significant enrichments in mantle-derived fluids (e.g., ^{3}He, CO_2, $CO_2/^{3}He$, $\delta^{13}C$-CO_2), suggesting complex mantle-lithosphere dynamics even under passive margins, cratons, and ancient orogens. These results indicate increased mantle-surface connections in passive margins and cratons, and place lower limits on the time-scales of mantle perturbations following orogenic events. Nevertheless, at present, it is uncertain if the mantle-derived fluids are remnants of older tectonic and magmatic activity or the surface manifestation of recent mantle degassing.

Noble gases, particularly helium isotopes, are excellent tracers for identifying fluids in the subsurface as the enrichment of primordial ^{3}He can provide unambiguous indications of mantle-derived gases in continental settings. However, the helium isotopic composition ($^{3}He/^{4}He$) is easily diluted by the addition of crustal ^{4}He, making it difficult to accurately distinguish lithospheric vs. asthenospheric mantle contributions in many continental environments or to determine the timing and mechanisms by which mantle/lithospheric fluids migrated to the surface. For these reasons, heavier noble gases (Ne, Ar, Kr, Xe) provide a potential tracer that can help de-convolve the extent of mixing between crust and mantle, in addition to discerning between lithospheric and asthenospheric mantle fluids. Further, the low production rate of the radiogenic xenon isotopes (e.g., ^{134}Xe, ^{136}Xe) may provide some constraints on the relative residence time of mantle CO_2 degassing in continental settings, providing important constraints on carbon dioxide storage in the mantle and lithosphere in quiescent tectonic settings.

To test these hypotheses, we collected a suite of gas and water samples from bubbling or carbonic springs in the western Rocky Mountains (CO), the Valles Caldera/Jemez Region (NM), and along the Grand Canyon (AZ), in addition to produced gases from the McElmo Dome CO_2 field (CO). These were analysed for a suite of major gas (CO_2) and noble gas (He, Ne, Ar, Xe) concentrations and noble gas isotopic (e.g., $^{3}He/^{4}He$, $^{20}Ne/^{22}Ne$, $^{21}Ne/^{22}Ne$, $^{40}Ar/^{36}Ar$, $^{128\text{-}136}Xe$) compositions. Many samples, specifically those with high gas/water ratios, display resolvable excesses in ^{3}He and ^{129}Xe relative to air-saturated water with variable excesses in ^{40}Ar*, and radiogenic xenon isotopes. Excess ^{3}He and ^{129}Xe are consistent with mantle contributions, while variable radiogenic gases reflect the relative mixtures of air-saturated water, mantle, lithosphere, and the crust providing insight on their history during crustal emplacement.