Characterization of Crustal Gas Systems using Compositional Data Analysis of Noble Gas Isotopes and Gas Compositions

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Abstract

Paired noble gas isotopes and bulk gas concentrations are regularly used as tracers of fluid flow in Earth's crust. Noble gases (He, Ne, Ar, Kr, Xe) are ideal conservative tracers because they are chemically inert yet their different physical properties (e.g. solubility and diffusivity) make the proportions between noble gases sensitive to physical processes. The ratios of noble gas isotopes are highly variable due to primordial partitioning of elements between terrestrial reservoirs (mantle, crust, atmosphere), the subsequent radiogenic or nucleogenic production of certain isotopes, and any later stage mixing between reservoirs.

When examining crustal gas systems, noble gas isotope ratios (typically $^{3}He/^{4}He$, $^{20}Ne/^{22}Ne$, $^{21}Ne/^{22}Ne$, $^{40}Ar/^{36}Ar$ and sometimes Kr and Xe isotopic ratios) are used independently, or else in combination with concentrations of major gas components (typically CH_4 and other hydrocarbons, CO_2, He, Ar, Ne, N_2, O_2, H_2, and H_2S) to constrain the source and movement of the gases. Standard data analysis techniques usually include identifying trends in multiple plots of isotope ratio vs. isotope ratio, or isotope ratio vs. gas concentration ratio. Each plot represents a different incoherent subcomposition but each plot also tries to answer the same general question: What are the proportions of mantle, crustal, and atmospheric sources in the crustal gas accumulation? In the current approach multiple plots are needed, which make comparisons between subcompositions difficult and cumbersome.

Here we use a multivariate and compositional data analysis (CoDa) approach to examine all relevant noble gas isotopes and gas compositions in one analysis to more clearly interpret the processes creating noble gas isotopic variability in crustal systems, particularly mixing between gas sources (e.g. mantle, crustal, atmospheric). We use compiled data from high CO_2, high CH_4, and volcanic reservoirs throughout the world. In order to target gas processes within reservoirs, rather than regional variability, we only use data where there are multiple samples within a single gas field or a single volcano. Preliminary results show that it is possible to interpret, with a single biplot, the same physical processes that are typically inferred over multiple ratio-ratio plots. The goal of our approach is to provide CoDa tools for noble gas isotope and gas composition data that will allow for coherent and simpler interpretations.