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Integrating Monte Carlo into noble gas production models; it's time to stop rolling the dice

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In the brittle continental crust, pressing environmental, resource and societal issues demand a better understanding of the biogeochemical and physical processes driving fluid origin, evolution, and migration. Documenting these processes is essential for responsible management of groundwater inventories, development of traditional and emerging economic resources such as hydrocarbon, natural hydrogen and helium exploration, as well as fundamental research questions about non-photospheric-driven habitability models, and long-term and large-scale biogeochemical cycles of CHONS.

Noble gases provide key insights and constraints for the physical mechanisms underpinning these processes, and have a well-established ability to reveal fluid origin, mixing, and migration. Beyond this, noble gases can add a temporal dimension in the form of fluid residence times. Specifically, natural radioactive decay of U, Th, and K in host rocks can produce measurable excesses of ^{4}He, ^{40}Ar, ^{21}Ne, $^{131-136}$Xe (and associated molecules such as H_2) which accumulate over time in the fluid phase and can thus be used to estimate the 'age' or mean residence times of fluids within a system (1-2). One of the main challenges faced by this approach, however, is adequately incorporating natural variability in crustal production models for subsurface environments. For example, variation in the host rock radioelement concentration and porosity significantly influences the rate of noble gas production and concentration of these noble gases in the fluid phase.

To address this, we demonstrate how existing models can be substantially improved by integrating a Monte Carlo approach (3). Instead of selecting single values for input parameters or relying on maximum and minimum values, we highlight how a representative range for multiple inputs can be simultaneously integrated, evaluating the full range of noble gas production and accumulation rates in natural settings. This provides a new probabilistic perspective which can serve as a basis for a new class of high-resolution noble gas-driven models for crustal settings.

References

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