Radiation damage and noble gas mobility in minerals

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Although the behavior of noble gases in minerals is often modeled as simple thermally-activated volume diffusion of interstitial impurities through ideal crystal lattices, radiation damage defects strongly affect noble gas mobility (and probably solubility). This is well recognized at high radiation doses in some minerals, but growing evidence also shows important effects at low doses. Evidence includes large differences between experimentally observed noble gas retentivity and that predicted from *ab initio* models, persistent deviations from simple Arrhenius behavior, and changes in anisotropy, apparent kinetic parameters, and bulk retentivity with increasing accumulated radiation dose.

Alpha, fission, and nucleogenic reactions produce point defects by alpha particles as well as large regions of disorder by recoil of massive nuclei. The distinct effects of these types of damage on noble gas mobility are poorly known. Vacancies associated with point defects and disorder regions may locally increase ionic porosity and interstitial apertures, thereby locally increasing noble gas mobility, but if these regions are not interconnected across diffusion domains they may actually decrease mobility (and increase solubility) by trapping/partitioning or increasing tortuosity through anisotropic apertures. It is therefore likely that radiation damage has different effects on bulk retentivity across the damage dose spectrum as isolated vacancies and high ionic porosity regions become interconnected. But which types of damage become connected at which doses, and how different damage types anneal with time and temperature are poorly understood.

The diversity of models describing radiation damage effects on noble gas mobility also reflects our primitive understanding. For example, most models for noble gas migration in metals and some other materials consider volume diffusion negligible, interpreting He release as controlled by first-order "single-jump" mechanisms describing detrapping or trap destruction; this has also been proposed for He in zircon. Another example is fundamentally different mechanistic models (trapping versus tortuosity) for qualitatively similar changes in He retentivity with accumulated damage at low dose in apatite and zircon.