Helium solubility in ring site bearing minerals and implications for noble gas recycling

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Noble gas solubility in minerals is generally assumed to be low, leading to the assumption that noble gases are not recycled back in to the mantle (e.g. 1). However, applicable experimental data remain scarce. To explore possible mechanisms of noble gas recycling, we conducted a series of experiments defining He solubility in a suite of amphiboles and cyclosilicates using an externally heated, gas-pressure-medium apparatus. Analysis was conducted using by laser-ablation mass spectrometry. Helium was the pressure medium in all experiments. Pressures and temperatures ranged from 50 to 170 MPa and 650 to 800°C, respectively. Helium solubility in both cyclosilicates (tourmaline, beryl, cordierite) and amphibole (richterite, paragasite, actinolite) is remarkably high and correlates with the density of vacant (i.e., unoccupied by a cation) ring sites. Helium is >1,000x more soluble in vacant ring rich cordierite, beryl, and actinolite than in olivine.

The concentration of He dissolved into cordierite and beryl is linearly dependent on P_{He}, demonstrating Henrian behaviour, and thus applicable to natural systems. Depth profiles were completed on each phase investigated and showed that He concentrations are homogenous. This indicates a close approach to equilibrium and an absence of inclusions affecting the analysis. The observed solubilities are independent of experimental duration (7-27 hrs) and temperature (650 to 800°C).

The ring site is a lattice structure constituting six $Si/AlO_4^{4-/5-}$ tetrahedra linked in a hexagonal ring. It is large, hosting alkali cations, and has no net charge when vacant. Following lattice strain theory, the ring site is an energetically favorable environment for noble gas dissolution. Excess argon is commonly observed in natural samples of ring-bearing minerals (amphibole, mica, cyclosilicates) (2, 3), corroborating our conclusion that noble gas solubility can be associated with ring sites.

Ring-site-bearing minerals, including mica, serpentine, talc, and amphibole, are common in recycled lithologies (4) and may provide a possible mechanism for widespread recycling of noble gases back into the mantle. Moreover, ring-site bearing minerals are the major minerals responsible for recycling water and halogens. Thus, water and halogen recycling may be mineralogically linked to noble gas recycling.

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Trace element composition of a non-chondritic Earth: Potential solutions and geodynamic implications

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The bulk composition of the silicate part of the Earth (BSE) has long been assumed to be tied to chondrites, where refractory, lithophile elements like Sm and Nd are thought to exist in chondritic relative abundances in the Earth. However, recent work exploring the $^{142}Nd/^{144}Nd$ systematics of modern terrestrial samples identifies ratios that are 18±5 ppm higher than the chondrite reservoir that challenges the traditional BSE model [1]. Here we investigate a hypothesis that this terrestrial ^{142}Nd excess is related to a Sm/Nd ratio 6% higher than chondritic. We develop a non-chondritic BSE trace element model in which the elevated Sm/Nd requires a shift of BSE $^{143}Nd/^{144}Nd$ from 0.51263 to 0.51300 that demands, in turn, corresponding changes to $^{87}Sr/^{86}Sr$ and $^{176}Hf/^{177}Hf$, as well as the associated parent-daughter ratios—Rb/Sr, Lu/Hf. These modified parent-daughter ratios define a normalized trace element pattern, or spidergram, that is depleted in highly incompatible elements relative to the chondrite-based BSE. We use the ^{40}Ar abundance of the atmosphere, crust and depleted mantle to constrain the minimum K in the Earth (155 ppm), and anchor the spidergram to this K concentration to determine the concentrations of the other geochemically important incompatible elements, such as U and Th. An upper limit (170 ppm K) is estimated by assuming that abundances of the least incompatible elements (e.g., Lu) do not exceed chondrite-based BSE concentrations. This non-chondritic BSE trace element model requires that >78% of the mantle mass contribute to the formation of continental crust. The reduced concentrations in heat-producing elements U, Th and K in our new BSE compositional model implies a ~30% reduction in the current rate of radiogenic heating and, thus, a proportional increase in the heat flow delivered to Earth's surface by plate tectonics, the implications of which we explore in parameterized thermal history models.

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