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Noble gas diffusion in mantle minerals: High resolution UV laser depth profiling

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Noble gases in mantle derived materials are an important tool revealing geochemical and dynamic processes within the Earth's mantle. Knowledge of noble gas diffusion behaviour in mantle minerals is crucial to interpret noble gas behaviour during mantle melting events and the distribution of noble gases between different mantle zones. In addition, characterising diffusion rates will tell us whether mantle derived minerals could fully retain mantle signatures. So far, diffusion data only exist for a limited number of mantle minerals, e.g., He in olivine, clinopyroxene, and garnet [1,2], and were mostly measured by stepwise heating, whereas UV laser depth profile data are only available for Ar diffusion in k-feldspar [3]. Therefore, an extensive study is carried out here, revealing the diffusion behaviour for all noble gases in the major mantle minerals olivine (ol), clino- (cpx) and orthopyroxene (opx), pyrope (py), and anorthite (an).

Gem quality, polished crystals of ol, cpx, opx, an, and py were pressurised in cold seal bombs to 1.6kbar noble gas atmosphere (He:Ne:Ar:Kr:Xe = 1:1:1:1:0.25) and run isothermally at 1000°C for 356h [3]. The diffusion profiles were analysed by UV laser ablation microprobe using typical ablation pits of 200x200µm which achieved a spatial resolution of 0.1-1µm per scan. The resulting concentration profiles are modelled using the equation for 1d transport normal to surface of a solid assuming a semi-infinite medium.

The diffusion coefficients at 1000°C range for all noble gases from 10⁻¹⁴ to <10⁻¹⁶ cm²/s in ol, an, cpx, opx, and py and are thus 2 to 5 orders of magnitude lower than previous data from stepwise heating analyses [1,2]. He and Ne always diffuse faster than Ar, Kr, and Xe by a factor of at least 2 to 7. Thus, if diffusion controls the distribution of noble gases in the mantle it would cause elemental fractionation. Ar, Kr, and Xe show similar diffusion rates, though these are maximum estimates due to the shallow profiles. Furthermore, a significant correlation between the structural type of the silicates and the diffusion rate is observed. Diffusion is fastest in framework silicates, followed by orthosilicates. The slowest diffusion rates were measured in chain silicates. Future experiments over a range of temperatures will enlarge the diffusion data base in order to get a comprehensive picture of the behaviour of the noble gases in the Earth's mantle.

References

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Solubility of Ar into silicate and Fe-rich alloy liquids up to 22 GPa : Implications for the Earth's core

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The accretion of the Earth from primordial material and its subsequent segregation into a planet with core and mantle are fundamental problems in terrestrial and solar system. Many of the questions about the process, although well developed as model scenarios over the last few decades, are still open and much debated. For example, could the core be a reservoir for helium or other noble (rare) gases ?

In the present study we use the laser-heated diamond-anvil cell (LHDAC) to study the Ar solubility and partitioning at high-pressure and temperature between metal and silicate liquids. For these experiments, we used either compacted powder of a mix between a glass simulating that of model C1 chondrite and iron metal, or pure metal alloys (pur iron, FeNiCo alloy ...). Thermal insulation from the diamonds was achieved by solid argon pressure medium. Pressures were measured at room temperature with the ruby-fluorescence method. The samples were heated by a multimode YAG laser for an average of 15 minutes. Temperatures were determined spectro-radiometrically with a fit to a grey-body Planck function. Samples recovered after the runs were analysed by electron microprobe (the electron beam is less than 1 µm and the resolution is about 1 µm).

The preliminary results show a good agreement between our results and those of White et al. (1986) [1] on Ar solubility in sanidine (KAlSi₃O₈) or anorthite (CaAl₂Si₂O₈). For sanidine and anorthite melts, the Ar solubility increases up to about 5 GPa where it reaches about 3.5 and 0.5 wt%, respectively, then the solubility remains constant to higher pressures (up to 15 GPa), suggesting that some threshold concentration is reached. The same behaviour is observed for the mix of C1-chondrite composition and iron metal where the maximum solubility of Ar is around 0.25 wt% and 0.1 wt% for the silicate and metal phases respectively. These results imply that the solubility of Ar is intimately related to the structure of the liquids at high pressure. We will present and discuss our results on Ar solubility into « pure » silicate liquids of varying composition in the absence of metal phases, as well as the partitioning of Ar between C1-chondrite and iron-rich metal liquids up to 22 GPa.

References

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