Diffusive fractionation of Helium isotopes during mantle melting

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Models by Torgersen and O'Donnell (1991) show how very different D_{He} and D_{Ar} (D=diffusivity) will result in He/Ar fractionation after fracturing; when a fracture opens, rapid He diffusion produces high He/Ar ratios in the fracture relative to bulk rock. He/Ar of fracture-filling fluids decreases over time depending on fracture spacing and D's.

A similar scenario likely exists in the mantle; localised melt flow in fractures or conduits is likely to occur (M^cKenzie, 2000), probably aided by shearing (Kohlstedt, 2002), therefore fractionation of He from Ar is predicted. In addition, fractionation of ^3He from ^4He ($D_{3He}=1.15*D_{4He}$) could occur during mantle melting. Whether or not this is significant depends on length and time scales of melting.

A simple model illustrating this is shown (Fig). This suggests detecteable fractionations of He isotopes and He/Ar ratios should occur in primary melts at geologically reasonable values of t/l^2. Deconvolving mantle fractionation from subsequent shallow level fractionation due to magmatic degassing is problematic: using Burnard (1999) to invert for degassing fractionation shows a positive correlation between $^3He/^4He$ and degassing corrected $^4He/^{40}Ar^*$ in MORBs. This is consistent with fractionation of He isotopes and He/Ar ratios during melting of the MORB mantle.

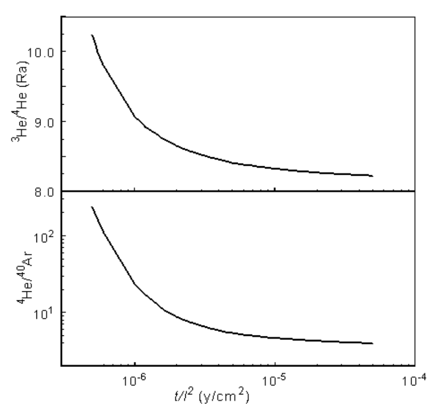

Figure 1. Diffusive fractionation during mantle melting *t*=residence t, *l*= conduit spacing $D_{4He}=9x10^{-9}$ cm^2 s^{-1} $D_{3He}/D_{4He}=1.15$ $D_{4He}/D_{40Ar}=3.2$

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Primordial solar noble gases in E-chondrites; A planetary connection?

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Introduction

Noble gases in terrestrial planets show affinities with solar composition. In contrast, primordial noble gases in meteorites - considered to be building blocks of planets - are distinctly non-solar. Here we show that the "subsolar" noble gas component in an enstatite chondrite contains a small part of unfractionated solar He-Xe, thought to be primordial.

Results

We analysed noble gases in a bulk sample of the E-chondrite St. Mark's by closed system etching (Busemann et al., 2003). The first steps show atmospheric and meteoritic gases of Q-like composition. Later steps, however, contain a mixture of Q-like or fractionated solar gases with elementally and isotopically unfractionated solar noble gases. In all probability, the solar gases are primordial and were not aquired later on a parent body, because St. Mark's is unbrecciated and the gas release sequence is very untypical for regolith breccias. The "subsolar" noble gas component in St. Mark's, and by inference that in other chondrites, does not exist per se but is a mixture of solar gases, Q-gases, and air.

Discussion

Podosek et al. (2003) discuss implantation of solar wind atoms onto planetesimals which later form the Earth. If this happened, meteorites with primordial solar wind might be common. However, evidence for this has been very scarce, a possible exception being the Washington County iron meteorite (Becker and Pepin, 1984). On the other hand, meteorites with "subsolar" noble gases are common, particularly among E-chondrites. We thus take the data here to indicate that primordial noble gases in terrestrial planets indeed could have been incorporated from solar-gas-rich planetesimals. Problems to be discussed in the framework of this hypothesis include the exquisite timing required (Becker et al., 1984; Podosek et al., 2003), the relatively high amounts needed (solar ^{36}Ar in the gas-poor St. Mark's falls short to explain the presumed original terrestrial inventory by ~3 orders of magnitude), and the simultaneous presence of large amounts of Q-gases in primitive meteorites. Since the carbonaceous phase-Q preferentially partitions into the metal phase, one might speculate that the Earth's core is rich in Q-noble gases.

References

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