Combined Lu-Hf and Sm-Nd isotope systematics of Martian meteorites

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The radioisotope systems of ^{176}Lu-^{176}Hf ($t_{1/2} = 3.71\times10^{10}$ yr) and ^{147}Sm-^{143}Nd ($t_{1/2} = 1.06\times10^{11}$ yr) are well suited to investigating Martian mantle evolution. All four of these elements are refractory and lithophile, so they should not have been fractionated during planetary accretion or metal-silicate separation during core formation. In contrast, silicate differentiation, e.g., melt extraction from the mantle, produces melts and residual mantle whose Sm/Nd and Lu/Hf differ from those of the parental reservoir. Over time, these secondary reservoirs diverge isotopically from the parental reservoir. To gain a better understanding of Martian mantle evolution, we are conducting a systematic investigation on Martian meteorites and their minerals, measuring both isotope systems on the same sample aliquot. Eleven bulk Martian meteorites (5 shergottites, 4 nakhlites, and 2 chassignites) have been examined so far. For each, 70 to 240 mg of powder were spiked with ^{176}Lu-^{180}Hf and ^{149}Sm-^{150}Nd, then digested in a closed Teflon vial with HF + HNO_3 (2:1) overnight on a hot plate, and again in steel-jacketed Teflon bombs for 5 days at 180 C°. After ion exchange chemistry, Lu and Hf isotopic compositions were measured by MC-ICP-MS (Isoprobe, Münster), and Sm and Nd were analyzed by TIMS (Triton, Münster). Initial ε^{176}Hf and ε^{143}Nd values range from +49.0 to +51.3 and +34.7 to +47.8, respectively, for depleted shergottites, -13.3 to -17.4 and -6.3 to -6.5 for enriched shergottites, +1.8 to +14.5 and +13.4 to +15.6 for nakhlites, and +16.3 to +24.9 and +15.3 to +15.4 for chassignites. These values from unleached samples agree well with those of previous studies [e.g., 1-7]. The initial ε^{143}Nd values of nakhlites and chassignites exhibit low variation relative to ε^{176}Hf. The time-integrated ^{176}Lu/^{177}Hf and ^{147}Sm/^{144}Nd of all investigated source reservoirs define a narrow trend within the terrestrial MORB + OIB field, with the sources of nakhlites and chassignites falling between those of depleted and enriched shergottites. Shergottites themselves display a large range of ^{147}Sm/^{144}Nd, with higher values at a given ^{176}Lu/^{177}Hf relative to MORB + OIB. The constraints placed by these data on the differentiation history, mineralogy, and dynamics of the Martian mantle critically depend on the accuracy of the samples' crystallization ages. In particular, the ages of shergottites have been debated (e.g., [2,3,7]). Evidence for young (474-150 Ma) and old ages, and the implications for models of silicate differentiation on Mars will be evaluated.

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Noble gas distribution and migration in the oceanic crust: new results from ODP Hole 1256D

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In an effort to understand the relative contributions of mantle, radiogenic, and atmospheric/hydrothermal noble gas components in the ocean crust, we have performed helium, neon and argon measurements on a suite of gabbros, granoblastic dikes, and diorite veins in Pacific oceanic crust. The samples were collected during IODP Expeditions 312 and 335 to Hole 1256D, a deep crustal borehole drilled into 15 Ma ocean crust formed at the East Pacific Rise during an episode of superfast spreading (>200 mm/yr). The measurements were carried out by coupled vacuum crushing and melting in order to determine the fraction of gases held by fluid inclusions. Total helium abundances in the whole rock gabbros range from 0.46 to 1.22 micro cc STP/gram, which is 2 to 5 times higher than literature data, all of which are from the slow spreading Southwest Indian Ridge (Kumagai et al., 2003; Moreira et al., 2003). These strikingly higher helium concentrations place constraints on the thermal crustal history (due to relatively rapid helium diffusivity) and are assumed to reflect fundamentally different emplacement/degassing processes within crust formed at a super-fast spreading rate. Contact metamorphosed granoblastic dikes have total helium contents lower than the gabbros (typically ~ 0.15 micro cc STP/gram), but significantly higher than the assumed degassed basaltic protolith, suggesting that metamorphism adds helium to the crust. The helium isotopes obtained by crushing of the gabbros and granoblastic dikes are dominated by mantle helium, with average ^{3}He/^{4}He = 6.5 ± .2 times atmosphere (Ra). This value is at the low end of the range for normal Pacific MORB helium data and is interpreted to represent the mantle source. Crushing in vacuum releases a larger fraction of total neon and argon (28 to 64 %), suggesting that atmospheric/hydrothermal/alteration neon and argon are loosely bound, most likely in secondary alteration minerals. Small mantle argon isotopic components are only found in a few samples, mainly during the heating experiments. These data suggest that the atmospheric noble gas components are most likely to be expelled during subduction of the ocean crust.

A transect across an amphibole diorite vein within granoblastic basalt reveals remarkable heterogeneity with respect to noble gases, on a centimeter scale. The amphibole and plagioclase at the vein center have 5-10 times higher abundances of He, Ne, and Ar, and slightly elevated ^{3}He/^{4}He and ^{40}Ar/^{36}Ar. The length scale of the variability, the age of the crust, and the present temperature of the hole, place an upper limit on the bulk helium crustal diffusion coefficient of ~2 x 10^{-14} cm^2/sec at 70 C. The abundances and isotopic compositions are consistent with hydrous melting models of ocean crust for production of diorite veins. The small He and Ar isotopic variations might be due to post emplacement radiogenic components, and distribution of K, Th, and U, suggesting possible applications to geochronology.