Stepwise Heating and Vacuum Crushing Analyses of Noble Gases in Martian Meteorites

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Introduction: Martian meteorites are valuable and possibly sole direct samples from Mars until future sample-return. Trapped noble gases in the meteorites are important, because they can provide not only strong evidence of their Martian origin [1][2], but also chemical and/or isotopic evolution of Martian atmosphere. However, noble gases in the meteorites are complicated mixtures of several sources; Martian atmosphere, Martian interior, radiogenic, cosmogenic, and terrestrial air (e.g.[3]–[9]).
In order to retrieve the exact Martian atmospheric records from the meteorites, one needs to know the trapping mechanism and trapped sites of the noble gases. As the first step, we have conducted combined stepped heating and vacuum crushing of several shergottites.
Samples: Tissint and SaU 008 are olivine-phyric shergottites. Tissint, fell in Morocco in 2011, is characterized by its numerous shock-melted glasses with small bubbles (<10 μm –ca. 100 μm), which might contain Martian atmosphere [8][10]. Heating analyses of pairs of SaU008 showed the incorporation of elementally fractionated terrestrial air (EFTA) in deserts [7][9]. EFTA effects were also observed in NWA 7397, a slightly weathered poikilitic shergottite [8][11]. NWA 10441 is a recently found highly shocked and moderately weathered shergottite. It is composed of ca. 15% of shock-melted glasses with a lot of vesicles [12].
Analytical Methods: The noble gas analyses were conducted with a VG3600 at the University of Tokyo. A ca. 100–200 mg chip of the each sample was separated into two groups; one for stepped heating and the other for vacuum crushing. The former fraction was heated in steps of 400°C, 600°C, 800°C, 1000°C, 1300°C, and 1800°C. The latter fraction was crushed with 2–10 MPa hydraulic ram to extract noble gases presumably from bubbles and/or fluid inclusions. The crushed samples were then picked-up and also stepped heated for comparison. All samples and vacuum lines were baked at ca. 200°C in vacuum for overnight before the analyses.
Results & Discussion: *Neon*: Most stepped heating data showed high contributions of cosmogenic Ne, while all crushing data indicated air-like Ne. This is due to either terrestrial air or Martian atmospheric Ne. It is difficult to distinguish the two because we do not know the exact ^{20}Ne/^{22}Ne of Martian atmosphere, although some plausible values are estimated [9].
Argon: Middle to high temperature heating showed high ^{40}Ar/^{36}Ar ratios. After corrections for cosmogenic ^{36}Ar and radiogenic ^{40}Ar, the trapped ^{40}Ar/^{36}Ar ratios indicate significant contribution of Martian atmospheric Ar. However, all crushing data were almost identical to terrestrial Ar. This may be attributable to either (i) expected bubbles in the shock-melted glasses did not contain Martian atmosphere or (ii) the crushing was not enough to extract gases from the bubbles.
Krypton and Xenon: As similar to Ar, high temperature heating showed excesses in ^{129}Xe/^{132}Xe ratios, indicating significant Martian contributions. All crushing data plotted on a mixing line between terrestrial air and EFTA (or Martian interior) in a diagram of ^{84}Kr/^{132}Xe$_{trapped}$ –^{129}Xe/^{132}Xe ratios. These data also support the possibility of absent of Martian atmosphere in the expected bubbles.

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