論文内容の要旨

論文題名：Noble gas study of Martian meteorites： New insights on Mars
（火星隕石の希ガス同位体研究：火星進化に関する新しい知見）

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Elucidation of noble gas isotopic compositions in the Martian atmosphere and interior is essential to clarify the Martian history of volatile element degassing from the interior and subsequent atmospheric evolution. In addition to the noble gas data for Mars atmosphere by Viking probe analyses, meteorites from Mars play an important role in elucidating the noble gas isotopic signature for the Martian interior and atmosphere. At present, the noble gas distribution in Mars is discussed in a framework of three end-members: atmosphere, elementally fractionated atmosphere, and the interior. Several new findings have been obtained in this work, which shed light to the noble gas distribution in the Martian interior and the Martian atmosphere, which gives new insight on Mars.

Nine shergottites (DaG476, -489, SaU 005, -060, -150, Dho 019, Dho 378, LA 001, Zagami), one nakhlite (MIL03346), and one chassignite (NWA2737) have been studied for noble gas concentrations and isotopic compositions using the mass-spectrometer system (Modified-VG5400/MS-II) in the Laboratory for Earthquake Chemistry. These Martian meteorites have been collected mostly in hot deserts and Antarctica. For noble gas extraction from the meteorites, a stepwise heating method (from 400 to 1800°C) and a total melting method (1800°C) were organized.

So far the first chassignite, Chassigny (fell in France, 1815) has been the only Martian meteorite regarded as a representative of Martian mantle, and perceived as the important end-member data on Martian interior. The second chassignite NWA2737 was discovered in Moroccan Sahara in 2000, which is a dunite with 90% dark olivine and similar in mineralogy and petrology to Chassigny (e.g., Mikouchi et al. 2005). Noble gas isotopic compositions of the NWA2737 chassignite are entirely different from those of Chassigny. Moreover, cosmic-ray exposure age of 15.1±1.7 Myr for NWA2737 indicates that this meteorite was ejected by an impact event different from that for Chassigny, accordingly from the site different from Chassigny's. These observations indicate a presence of mantle entirely different from that inferred from Chassigny with respect to noble gas isotopic compositions. This means that Mars has chemically heterogeneous mantle: e.g., $^{40}Ar/^{36}Ar$ ~1400 and $^{129}Xe/^{132}Xe$ ~2.4 for NWA2737; $^{40}Ar/^{36}Ar$ ≤200 and $^{129}Xe/^{132}Xe$ ~1.1 for Chassigny. It also supports the previously reported ideas of heterogeneous Martian mantle (e.g., Jones. 2003).

MIL03346 is nakhlites, which was found by a field party from the U.S. Antarctic Search for Meteorites program (ANSMET) on Dec. 15, 2003, on an ice field in the Miller Range of the Transantarctic Mountains. The collected mass was 715.2 g. It is composed of 74% of clinopyroxene, 22% of mesostasis and 4% of olivine. Unusual release profile was observed for this meteorite by the stepwise heating method: high $^{129}Xe/^{132}Xe$ ratios (1.5~2.2) were observed in both lower (400°C, 500°C, 600°C) and higher (1400°C, 1500°C) temperatures. At the middle temperatures, the ratios decreased to ca. 1.3. The characteristic feature of nakhlites is having altered olivine (iddingsite) and mesostasis. Because the iddingsite is an alteration product, the high $^{129}Xe/^{132}Xe$ ratios from the lower temperatures can be interpreted as a Martian atmosphere trapped on the weathered product on Mars. The high $^{129}Xe/^{132}Xe$ isotopic ratios from higher temperatures suggest the presence of Martian atmospheric components trapped in minerals or mesostasis while they grew at relatively shallow level in thick lava flow on Mars (e.g., Mikouchi et al., 2003). Cosmic-ray exposure age is about 11 Myr, which is identical with the ages for other nakhlites and Chassigny. They experienced the same impact event which ejected all the nakhlites and Chassigny.

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Cosmic-ray exposure ages for shergottites are about 1~3 Myr, except that of Dho 019. The Dho 019 shergottite has extremely long cosmic-ray exposure age of 20 Myr, which has never been reported for all Martian meteorites. The Ne isotope ratios of shergottites are mostly cosmogenic and partly affected by terrestrial contamination. However, Dho 378 shows an indication of Martian atmospheric Ne. Viking Landers could not measure Ne isotopes on Mars (e.g., Owen et al. 1976), and the $^{20}Ne/^{22}Ne$ isotopic ratio is poorly estimated as 10.1±0.7 (Pepin, 1991) and 7-10 (Garrison and Bogard, 1998). Pyroxene with glassy material from Dho 378 show Ne enrichments relative to those of Martian atmosphere with identical $^{20}Ne/^{36}Ar$ ratio at the extraction temperatures of 600°C, 800°C, 1000°C. Such enrichments of atmospheric Ne have been reported for terrestrial obsidians and tektites (Matsuda et al., 1989; Matsubara and Matsuda, 1991). The Ne isotopic ratios of Dho 378 at the three temperature fractions show a nice linear trend, which can be explained as a mixing line between cosmogenic Ne and another Ne component. The latter can be attributed to the Martian atmospheric Ne, and its $^{20}Ne/^{22}Ne$ is calculated as 7.32±0.07 assuming $^{21}Ne/^{22}Ne$=0.029. The Ne excess in Dho378 might have been caused by a gas-solid interaction after Dho 378 was in shock-impacted-melt status, when Dho 378 flew out through Martian atmosphere as an impact melting.

From the $^{84}Kr/^{132}Xe$ and $^{129}Xe/^{132}Xe$ ratios for shergottites, the higher temperature data show the trapped Martian atmospheric components. While the lower value of $^{129}Xe/^{132}Xe$ observed from the shergottites can be explained as terrestrial contamination due to desert weathering, though a possible source of Martian interior component cannot be eliminated. For the comparison, we also measured the terrestrial samples from the desert in Oman and Libyan Sahara, where those Martian meteorites were discovered, and fully-weathered olivine from Takashima in Japan. The noble gas data show heavy elemental fractionation of terrestrial noble gases, which can also explain the observed noble gas compositions of Martian meteorites at the relatively low extraction temperatures.

Noble gas study on Martian meteorites provides valuable information about the conditions of their formation on Mars. With lots of information from Mars explorations on Mars (although the project of bringing Martian rocks together with Martian spacecrafts will not be realized in the near future), the laboratory study of Martian meteorites will give us better understanding of Mars.