Trace elements analysis and Ar-Ar dating for microgram-scaled extraterrestrial samples

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In order to elucidate the origin and evolution of planetary materials, it is important to determine the chemical composition and timing of geological events for specific minerals and microscopic portions, such as impact melt pockets, CAIs (Ca- and Al-rich Inclusion), and chondrules. Combination of EMPA, INAA, and noble gas analysis are one of the best way to determine chemical and isotopic compositions of extraterrestrial dust particles (micrometeorites) and spacecraft-returned samples.
As a first step, we have analyzed rock fragments (<several hundreds of micrometer in diameter) recovered from Holbrook L6 chondrite. Neutron irradiation and NAA experiments were conducted at Institute of Integrated Radiation and Nuclear Science, Kyoto Univ. Allende CV3 and Madagascar feldspar were used for standardization of INAA and Ar-Ar analyses, respectively. Each of the sample particles was individually placed in a conical dimple (ϕ1, depth ~ 0.5 mm) of a sapphire disk (ϕ5.5, 1.5 mm thick), and covered with a sapphire disk (ϕ5.5, 0.3 mm thick). Each of the sapphire container was wrapped with pure aluminum foil. These Al-wrapped containers were stacked and sealed in aluminum capsules to perform neutron irradiation at the hydro-irradiation port. After irradiation, the samples were recovered from irradiated glass containers, and moved to non-irradiated containers in order to reduce the radioactivity from the sapphire containers and Al foil. Gamma-ray measurements for short half-life nuclides were performed promptly after collection of the samples. Several months after the irradiation, some of the Holbrook samples were transported to Kyushu Univ. to measure noble gas isotopes.
Concentrations of Co and Ni in two Holbrook samples were determined to be 57 and 157, and 1260 and 13400 ppm, respectively. The Ni/Co ratios of the Holbrook samples are 22 and 85, which are similar to those observed in iron meteorites and chondrites (e.g., Ebihara et al., 2011). The result guarantees our NAA measurement.
Noble gas isotopes (^{36}Ar, ^{38}Ar, ^{39}Ar, and ^{40}Ar) were determined for different two Holbrook samples using stepwise heating method. The bulk ^{39}Ar concentration in the irradiated standard feldspar (K: 12.6 wt%) is 7E-6 cm^{3}STP/g, and the bulk ^{39}Ar/^{40}Ar ratio is 0.026. The result indicates that the neutron flux of KURRI is enough to determine ^{39}Ar for microgram samples with K>0.1 wt%. Using the neutron flux determined by the standard feldspar, with 450 Ma of K-Ar age (ranging 435-461 Ma; Flude et al, 2014), we calculated the Ar-Ar ages for two Holbrook samples (9.4 and 16.8 μg) to be 3795±368Ma (based on 3 plateau ages of 4 stepwise extractions) and 3714±128Ma (based on 4 plateau ages of 7 stepwise extractions). Noble gases extracted at the lowest and highest temperature steps are influenced by atmospheric Ar, resulting unreasonable old Ar-Ar age. Based on these results, we found appropriate extraction temperature for plagioclase-rich microgram samples to be 600, 800, 900, 1000, 1100, 1200, 1400, and 1600 °C.
Through this study we have established an analytical method that consists of a combination of EPMA, INAA, and noble gas analyses. The new method will be applied for Antarctic micrometeorites and the Hayabusa2 samples.

Keywords: Ar-Ar age, meteorite, micrometeorite, INAA, Hayabusa2