Applicability of prompt gamma-ray analysis to initial classification of meteorites

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Introduction: Bulk chemical compositions as well as petrology, mineralogy and oxygen isotopic compositions are used for classification of meteorites [1]. Major elements are notably of significance for such purpose [2]. Wet chemical analysis was extensively used for the determination of bulk chemical compositions of meteorites [3]. Advantages of this method are able to determine all major elements and to know the distribution of Fe among silicate, sulfide and metal. As this method is destructive and requires grams of samples, which can be of the same order of mass as whole meteorite for some cases, it cannot be always applicable to any cosmochemical samples. In place of wet chemical analysis, instrumental neutron activation analysis (INAA) and X-ray fluorescence analysis (XRF) have been often used for the bulk chemical analysis of cosmochemical samples. Although INAA is a non-destructive method and has high accuracy and precision for a not few elements, it is hard to determine Si, a major constituent element in rock samples. XRF requires only a small amount of meteorites (~120 mg) and enables to determine all major elements including Si, P and Ti [4]. In XRF, samples need to be powdered and fused with chemical flux, and therefore, samples once used by XRF could not be reused for other analytical methods. Inductively coupled plasma mass spectrometry (ICP-MS) is another bulk rock analysis technique. ICP-MS has been increasingly used in cosmochemical studies [e.g., 5]. Though ICP-MS has high sensitivity for many elements, samples need to be dissolved in solution for solution-based ICP-MS. Compared with these analytical methods, prompt gamma-ray analysis (PGA) is completely non-destructive analytical method and has capability of the determination of bulk chemical compositions, especially major elements including Si, for cosmochemical and geological rock samples. Because of its non-destructive analytical capability and negligibly low residual radioactivity after neutron irradiation, samples once analyzed by PGA can be reused for other analytical methods without any restriction [6]. Althoug PGA has these analytical advantages, it has not been routinely applied to cosmochemical samples due to the lack of fundamental data need for PGA such as library of prompt gamm-rays. In this study, evaluation of prompt gamma-ray energy for the practical use of PGA was performed by analyzing the Allende meteorite and four geological reference samples (JB-1, BCR-2, BHVO-2 and WS-E). After establishment of a routine procedure of PGA including a choice of suitable energies applicable to cosmochemical and geological samples, our PGA procedure applied to Martian meteorites and eucrites. Based on the analytica data obtained, we discuss how promisingly our PGA procedure can be applied to classification of meteorite samples.

Experimental: The cosmochemical and geological powder samples weighing about 150 to 250 mg were sealed into thin FEP film bags and were irradiated for 1 to 3 h by using cold neutrons or thermal neutrons guided out of the JRR-3M research reactor at the Japan Atomic Energy Agency.

Results and Discussion: As the energy range of prompt gamma-ray used in PGA is much wider than that used in NAA, prompt gamma-ray spectra are generally more complicated than those of NAA. First of all, selection of prompt gamma-ray energies suitable for the determination of elemental abundances by PGA was performed. Replicate analyses of the Allende meteorite and geological reference samples were carried out in order to evaluate accuracy and reproducibility of elemental determination with PGA using selected prompt gamma-ray energies. For the Allende meteorite and geological reference samples, our PGA data of thirteen elements (B, Na, Mg, Al, Si, Cl, K, Ca, Ti, Mn, Fe, Sm and Gd) are in good agreement with the corresponding literature values. For cosmochemical samples, S, Co and Ni also could be detected and our data for these elements are consistent with literature values. Reproducibility for most elements is less than 10% (1 s). Our PGA procedure was applied to Martian meteorites and eucrites. These samples analyzed in this study were previously analyzed by INAA. Our PGA data for these samples were consistent with INAA except for Cr and Co due to the spectral interferences of Sm and/or Gd. Each planetary body has different FeO/MnO and Na_2O/Al_2O_3 ratios. Our PGA data for Martian meteorites and eucrites are located in the corresponding area, which concludes that PGA data obtained in this study are reliable enough for the classification of these meteorites. In addition, subgroups of Martian meteorites and eucrites are divided into several groups based on PGA data (e.g., Mg/Si vs. Ca/Si and TiO_2 vs. FeO/MgO).

References

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