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An Ion Microprobe Study of Chromium-54 Anomalies in Carbonaceous Chondrites

Wataru Fujiya[1]; naoji sugiura[1]; Hajime Hiyagon[2]; Naoto Takahata[3]; Yuji Sano[4]

[1] Earth and Planetary Sci., Univ. of Tokyo; [2] Dept. Earth & Planet. Sci., Univ. Tokyo; [3] ORI, Univ. Tokyo; [4] Ocean Res. Inst. Univ. Tokyo

The extent of isotopic homogeneity in the solar system has been an important issue. Refractory inclusions of CV3 chondrites (CAIs) have been known to display isotopic anomalies of up to 4 % in oxygen and in iron group elements such as Ca, Ti, Cr and Ni. These isotopic anomalies are interpreted to reflect nucleosynthetic signatures, hence, incomplete mixing of diverse nucleosynthetic components in the solar nebular.

While CAIs show isotopic anomalies of iron group elements, isotopic anomalies of ^{54}Cr have been reported in bulk meteorites, including both chondrites and achondrites. Especially, only carbonaceous chondrites show positive ^{54}Cr anomalies and the highest ^{54}Cr anomalies are found in the least metamorphosed (CI1) chondrites. Stepwise dissolution experiments have suggested the presence of carriers of ^{54}Cr anomalies, probably presolar grains. Presolar grains are very rare and very fine (less than a few microns in size) components with huge isotopic anomalies, and have been found in primitive meteorites. 'Presolar' means that the components with such huge isotopic anomalies could not form in the solar system and must have extrasolar origins. However, the carriers of ^{54}Cr anomalies have not been identified to date, because previous Cr isotopic measurements were performed mainly using TIMS or ICP-MS for solutions of bulk meteorites.

In this study, Cr isotopic compositions of Cr-bearing small grains (approximately 1 micron meter in size) contained in meteoritic samples (an organic residue from Murchison CM2 chondrite) were measured using the NanoSIMS in order to detect unidentified presolar grains with ^{54}Cr anomalies. To measure isotopic compositions of small grains, an imaging method was used, which allows to study distributions of various isotopes or elements on the surfaces of the sample in spatial resolution of 150 nanometers.

^{54}Cr has an isobaric interference of ^{54}Fe. It is impossible to resolve ^{54}Cr and ^{54}Fe, which makes it difficult to measure the abundance of ^{54}Cr using the SIMS. In order to correct for ^{54}Fe, the abundance of ^{56}Fe was measured to evaluate the abundance of ^{54}Fe by assuming a solar ^{54}Fe/^{56}Fe ratio. Instrumental mass fractionation of Cr and Fe were evaluated using terrestrial standards of chromite, Cr_2O_3 and Fe_3O_4.

Even after the large correction for ^{54}Fe, the d(^{54}Cr/^{52}Cr) values of Cr rich grains in Murchison could be determined with precision of about 20 permil in a short measurement time (about 5 minutes) using the NanoSIMS. Such a short measurement time allows to analyze a large number of grains efficiently. Therefore, the NanoSIMS has a potential to detect presolar grains with large ^{54}Cr anomalies (e.g. d(^{54}Cr/^{52}Cr) = 100 permil).

The number of analyzed grains in this study is about 240. No grain was confirmed to be a presolar grain with the ^{54}Cr anomaly. If the carriers of ^{54}Cr anomalies are enriched in Cr, the fact that no grain out of about 240 analyzed grains was confirmed to show ^{54}Cr anomaly indicates low abundances and huge isotopic anomalies of the carriers, and/or their extremely fine grain sizes. In the former case, from the results of this study, the maximum abundance of presolar Cr can be estimated to be about 0.5 ppm. This means that the minimum of the isotopic anomalies is about 500 permil.