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Ion microprobe U-Pb dating of individual phosphate minerals in Martian meteorite: ALH 84001.

Mizuho Koike[1*], OTA, Yoshihiro[1], Naoto Takahata[1], Yuji Sano[1], naoji sugiura[2]

[1]AORI, Univ. of Tokyo, [2]School of Science, Univ. of Tokyo

Introduction:

Mars is the only planet we can take its surface material directly as meteorites. To date, a number of meteorites have been identified as Martian origin. ALH 84001 shows extremely old age among them and is believed to have valuable information concerning the ancient environment and the evolution history of the planet. Phosphates, volumetrically minor phases, are important careers of trace elements. In the previous study, in-situ U-Pb age of the phosphates in ALH 84001 was determined as ~4 Ga [1], which interpreted as impact-reset age.

Meanwhile, smaller-scale investigation such as interior of individual grain will provide further information on the physical and/or chemical history of the meteorite. Due to the limitation of grain size and spatial resolution, several grains were required for one isochron previously. In this study, we measured U-Pb ages of individual phosphate grains in ALH 84001 using a NanoSIMS.

Experimental:

Two polished thick sections of ALH 84001 were firstly observed by SEM-EDS to locate phosphate minerals. A ~50-100 micrometer sized phosphate grain were found on each section (named Grain 1 and Grain 2). The sections were polished again, gold-coated and baked overnight, and then analyzed by a NanoSIMS. For primary beam, ~2-10 nA O- ions were used with spot diameter of ~10-20 micrometer. An apatite from Prairie Lake circular complex, PRAP, with a known age of 1155 +/- 20 Ma [2] was used as a standard of ^{238}U-^{206}Pb dating.

Results & Discussion:

For both Grain 1 and Grain 2, the obtained ^{238}U-^{206}Pb age and ^{207}Pb-^{206}Pb age show well agreement with ~4 Ga, suggesting the U-Pb system is concordant. These are also consistent with the previous total U/Pb age [1], indicating this method provides accurate age information with smaller quantity of sample consumption.

To understand what these U-Pb ages mean, closure temperature of U-Pb system in the phosphate grains is calculated. The approximated relationship between closure temperature (T_c) and cooling rate (T') for thermally activated diffusion process can be expressed as the following equation [3]:

T_c=(E/R)/(ln[ART_c^2(D_0/a^2)/ET'])

where R is the gas constant, E is the activation energy of 55.3 kcal/mol, D_0 is the diffusion constant of 0.0002 cm^2/s [4], A is the geometry constant of 55, and a is 50 micrometer. ALH 84001 experienced an impact heating ~4 Ga and subsequent carbonates deposition [5]. While the deposition process is still controversial, the ~1 micron scale variations of Ca-Mg in carbonates provide some constraints in thermal process; (i) low temperature ($<$200 ^{o}C) with slow cooling (10^{-1} to 10^3 ^{o}C/Ma), or (ii) high temperature ($>$600 ^{o}C) with rapid cooling (10^7 ^{o}C/Ma) [6]. T_c is ~400 to 550 ^{o}C for the first case, and $>$ 800 ^{o}C for the second case. The deposition temperature did not exceed the T_c for the both cases, suggesting the U-Pb system in the phosphates closed during and after this event. The U-Pb system still may have been reset at a precedent heating, if any. While further investigation is required for appropriate interpretation, our results leave the possibility that these phosphates preserve the igneous information.

References:

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