HIGH-PRECISION AL-MG DATING OF ANORTHITE IN A COMPOUND OBJECT OF CAI-CHONDRULE FROM ALLENDE. S. Wakaki[1], S. Itoh[1], T. Tanaka[2] and H. Yurimoto[1], [1]Natural History Sciences, Hokkaido University, Sapporo 060-0810, Japan (wakaki@ep.sci.hokudai.ac.jp), [2]Department of Earth and Environmental Sciences, Nagoya University, Nagoya 464-8602, Japan.

Introduction: The decay of short-lived ^{26}Al is widely used as a high-resolution chronometer to date CAI and chondrule formations [1]. CAIs are believed to be melted very early in the solar system history [2], while chondrule melting is temporally apart from CAI melting for about 1~2 million years [3,4]. Despite the potential importance on linking the CAI and chondrule formation processes, formation age of compound CAI-chondrule objects is not well constrained, although there are few studies [5]. To define a precise Al-Mg chronology, especially for materials with low initial ^{26}Al abundances, precise Mg isotopic measurement of high Al/Mg phase such as anorthite is essential. We report high precision Mg isotopic analysis of anorthite in a compound CAI-chondrule inclusion in order to obtain a precise formation age. Low Al/Mg phase was also analyzed to obtain a reliable isochron.

Sample: CAI-025 is a compound CAI-chondrule inclusion from Allende. It is consisted of partially melted CAI-chondrule mixture (interior) and chondrule-like igneous rim [6] (Fig.1). The interior portion contains anorthite, spinel, olivine and Al-bearing low-Ca pyroxene.

Experimental: Al-Mg isotopes were analyzed in situ by Cameca ims-1270 SIMS at Hokkaido University. A linearized delta notation is used to express Mg isotopic compositions: $\delta^{i}Mg = \ln[(^{i}Mg/^{24}Mg)_{sample}/(^{i}Mg/^{24}Mg)_{reference}] \times 10^3$ (i = 25 and 26).

Spinel and olivine analyses. Spinel and olivine were analyzed with 10 nA $^{16}O^-$ primary ions. Typical spot size was 10 microns. Details of the analysis and the calculation of excess ^{26}Mg are described in [7].

Anorthite analysis (Faraday Cup multi-collection). Faraday cup (FC) multi-collection analysis of anorthite was conducted with 20-25 nA $^{16}O^-$ primary ions and typical spot size of 15-20 microns. Secondary ions of ^{24}Mg and ^{27}Al were collected by FCs with $10^{10}\Omega$ resistors, while those of ^{25}Mg and ^{26}Mg were collected by FCs with $10^{11}\Omega$ resistors, with mass resolution of ~2000. Miyakejima anorthite and Takashima augite was analyzed as terrestrial references. Anorthite was analyzed for 40-60 cycles of 30 s integration and augite was analyzed for 40 cycles of 10 s integration.

Typical count rate of ^{24}Mg for miyakejima anorthite, Takashima augite and sample analyses were 2.5 x 10^6, 4.0 x 10^8 and 1.5 x 10^7 cps, respectively. Because of the low counting rate of anorthite, accurate correction of the FC background noise is necessary to improve the accuracy of the analysis. FC background noise was measured every 5 minutes during the analytical session to monitor the possible changes of the noise level. Average of several background noise measurements were used for correction.

Excess ^{26}Mg (δ^{26}Mg*) is calculated using natural Mg isotope fractionation factor of 0.514 [8]. Precise gain adjustments of FCs were corrected by the Takashima augite. Errors are 2σ internal errors.

With the mass resolution of ~2000, isobaric interference of $^{48}Ca^{2+}$ to $^{24}Mg^+$ is not perfectly resolved (Fig. 2). The intensity of ^{24}Mg is about 40 times higher than that of $^{48}Ca^{2+}$ intensity for Miyakejima anorthite. With this condition, the contribution of $^{48}Ca^{2+}$ to ^{24}Mg is estimated as 0.03 %, which corresponds to δ^{26}Mg* shift of -0.3. The contribution of $^{48}Ca^{2+}$ to ^{24}Mg for the sample anorthite is estimated as 0.003 %, since the ^{24}Mg intensity of the sample is ~10 times higher than that of the Miyakejima anorthite. The corresponding shift of δ^{26}Mg* is -0.03, 10 times smaller than the typical analytical error of the sample anorthite.

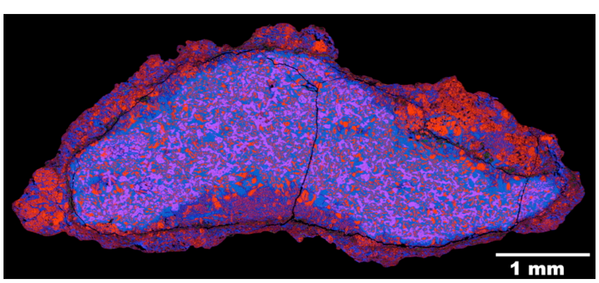

Fig. 1 Combined elemental map of Allende CAI-025 from Mg (red), Ca (green) and Al (blue) x-rays.

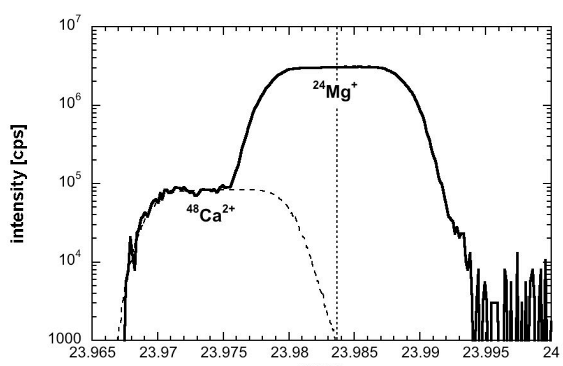

Fig. 2 Mass spectrum around mass 24 during FC multi-collection analysis of anorthite with mass resolution ~2000.

Anorthite analysis (peak jumping). Conventional peak jumping analysis of anorthite was conducted with 2.5 nA$^{16}O^-$ primary ions and typical spot size of 5 microns. Secondary ions of ^{24}Mg, ^{25}Mg and ^{26}Mg were collected by electron multiplier (EM) and ^{27}Al was collected by a FC with mass resolution of ~4000. A measurement consists 40 cycles of 1, 3, 3 and 1 second integrations of ^{24}Mg, ^{25}Mg, ^{26}Mg and ^{27}Al, respectively. Typical count rate of ^{24}Mg for miyakejima anorthite was 3 x 10^4 cps. Excess ^{26}Mg is calculated using natural Mg isotope fractionation factor of 0.514 [8]. Errors are 2σ internal errors of a measurement.

Results: Olivines in the interior portion of CAI-025 show homogeneous and elevated δ^{26}Mg* with a weighted average of 0.32 ± 0.03 (2SE, n = 10; Fig. 3). Spinels show constant δ^{26}Mg* with a weighted average of 0.51 ± 0.03 (2SE, n = 11; Fig. 3). Average δ^{26}Mg* of the Miyakejima anorthite analyzed by FC multi-collection is -0.19 ± 2.26 (2SD, n = 11; Fig. 4). Dispersion of the Miyakejima anorthite analyzed by peak jumping is 2.36 (n = 16; Fig. 5). The results of CAI-025 anorthite are generally consistent between FC multi-collection and peak jumping analyses (Figs. 4 and 5). However, both the internal error of a measurement and the scatter of the data points are small in FC multi-collection analyses. Anorthite data obtained by FC multi-collection show clear excess of ^{26}Mg and an obvious linear distribution.

Discussions: Relatively high precision of the FC multi-collection analysis of anorthite revealed the linear correlation of anorthite in fig. 4 that also go through olivine data. Regression line through anorthite and olivine corresponds to an isochron with $(^{26}Al/^{27}Al)_0$ = 1.9 ± 0.3 x 10^{-6} and an initial δ^{26}Mg* of 0.32 ± 0.04. Phase equilibrium relationship of CAI-025 interior indicates simultaneous crystallization of anorthite and olivine, and supports the isochronous relationship of these two minerals. Spinel plots clearly above this Anorthite-Olivine isochron (Fig. 3). It indicates that 1) spinel is not in isotopic equilibrium with anorthite and olivine and 2) spinel is a relict phase of the olivine-anorthite crystallization event. This is consistent with the oxygen isotopic results, which indicate that spinel is a relict phase from CAI-precursor [6]. Besides relict spinel, crystallization of the two major phases in the compound objects defines the formation of the object. The initial $^{26}Al/^{27}Al$ ratio of the compound object measured in this study is slightly smaller than the initial $^{26}Al/^{27}Al$ ratios of chondrules from primitive carbonaceous chondrites ($(^{26}Al/^{27}Al)_0$ = 0.3-1.0 x 10^{-5}) [3,4,9]. The relative Al-Mg formation age of the compound CAI-chondrule object is 3.5Ma after CAI formation and 0.5 to 1.8 Ma after major chondrule formation.

References: [1] McPherson G. J. et al. 1995. Meteoritics 30:365-386. [2]Jacobsen B. et al. 2008. EPSL 272:353-364. [3] Kunihiro T. et al. 2004, GCA 68:2947-2957. [4] Kurahashi E. et al. 2008, GCA 72:3865-3883. [5] Krot A. N. et al. 2006. ApJ. 639:1227-1237. [6] Wakaki S. et al. 2010. Abstract #2057. 41th LPSC. [7] Itoh S. et al. 2008. Appl. Surf. Sci. 255:1476-1478. [8] Davis A. M. et al. 2005. Abstract #2334. 36th LPSC. [9] Villeneuve et al. 2009. Science 325:985-988.

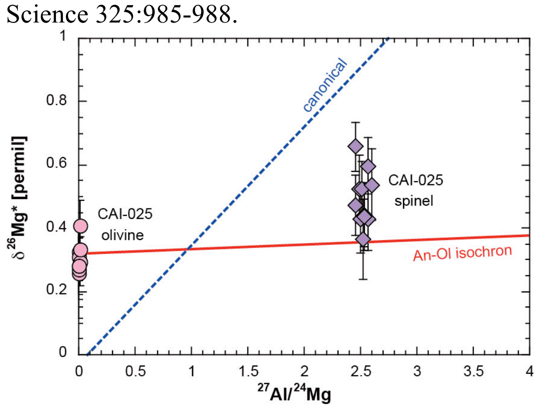

Fig. 3 Al-Mg isochron plot of olivine and spinel of CAI-025 by FC multi collection analyses.

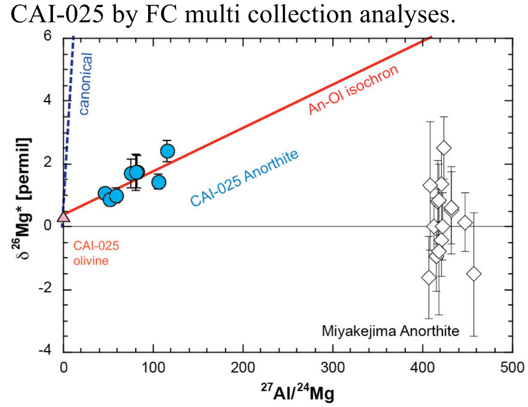

Fig. 4 Al-Mg isochron plot by FC multi collection analyses.

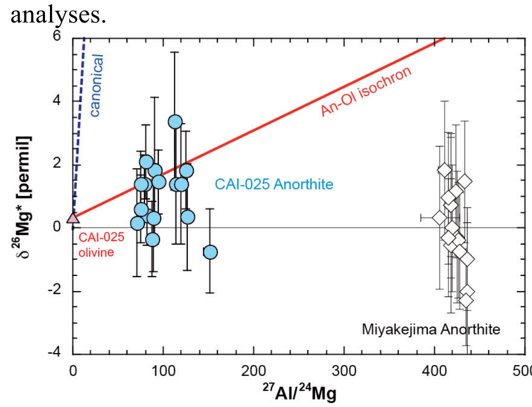

Fig. 5 Al-Mg isochron plot by EM-FC peak jumping analyses.