THE RELATIONSHIP BETWEEN OXYGEN AND MAGNESIUM ISOTOPE RATIOS IN OLIVINE FROM THE COMET 81P/WILD 2: A COMPARISON WITH AOAS IN PRIMITIVE METEORITES. K. Fukuda[1], D. J. Joswiak[2], D. E. Brownlee[2], B. L. Beard[1], M. J. Spicuzza[1], T. J. Tenner[3], M. Kimura[4], N. T. Kita[1]. [1]Department of Geoscience, University of Wisconsin-Madison, Madison, WI 53706, USA (kfukuda2@wisc.edu), [2]Department of Astronomy, University of Washington, Seattle, WA 98195, USA, [3]Chemistry Division, Nuclear and Radiochemistry, Los Alamos National Laboratory, MSJ514 Los Alamos, NM 87545, USA. [4]National Institute of Polar Research, Tachikawa, 190-8518 Tokyo, Japan.

Introduction: Comets are thought to have formed at the cold, outer parts of the solar system, providing a different perspective on conditions of early solar system evolution, relative to meteorites. Comet 81P/Wild 2 samples returned by the NASA Stardust mission contain ^{16}O-rich, FeO-poor, Mn-enriched (LIME) olivine particles that are considered to be condensates from solar nebula gas [1-5]. LIME olivine is also found in amoeboid olivine aggregates (AOAs) in chondrites [e.g., 6, 7]. AOAs in the least metamorphosed meteorites are ^{16}O-rich [e.g., 8, 9], which suggests a genetic relationship between Wild 2 LIME olivine grains and AOAs. Some AOAs and Ca, Al-rich inclusions (CAIs) have negative δ^{25}Mg values [e.g., 10-12] relative to the Earth and bulk chondrites ($\delta^{25}Mg_{DSM3}$ = –0.13 [13]). The light isotope enrichments in these refractory inclusions may be the result of condensation from solar nebula gas due to kinetic isotope fractionation [14].

If ^{16}O-rich Wild 2 olivines are condensates from solar nebula gas, they may have negative δ^{25}Mg values. Here we report for the first time Mg isotope ratios of Wild 2 olivine particles with known oxygen isotope ratios from previous studies [2-3, 15]. We also measured oxygen and magnesium isotope ratios in AOAs from the Kaba (CV3.1) and DOM 08006 (CO3.01) chondrites in order to compare with the newly obtained Wild 2 dataset.

Samples and analytical procedures: Seven Wild 2 olivine particles were analyzed from four different tracks (T57, T77, T149, and T175). Mg#'s of the olivine particles range from 60 to 99.8 [1-3, 15]. Previous studies revealed that four out of seven particles are ^{16}O-rich (T57/F10, T77/F6, T175/F1, and T77/F50; δ^{18}O: –56 to –46‰; Δ^{17}O: –24 to –22‰) and the other three particles are ^{16}O-poor (T77/F4, T149/F1, and T149/F11a; δ^{18}O: 2.5 to 6.8‰; Δ^{17}O: –1.7 to –1.0‰) [2-3, 15]. We studied one Kaba AOA that is a dense object with little porosity (referred to as "compact" by [16]) and eight DOM 08006 AOAs with compact and/or more porous textures.

Magnesium three-isotope analyses were performed using the WiscSIMS Cameca IMS 1280 equipped with a radio-frequency (RF) plasma ion source. We used O_2^- primary ions instead of O^- to achieve higher secondary ion yield and better ionization efficiency [17]. A 2 µm diameter (25 pA) primary ion beam was used for Wild 2 olivine analyses. A 5 µm or 9 µm diameter (160 pA or 2 nA) primary beam was used for AOA olivine analyses. Secondary Mg ions ($^{24}Mg^+$, $^{25}Mg^+$, $^{26}Mg^+$) were detected on multicollection Faraday Cups (FCs) using three 10^{12} ohm resistors (25 pA and 160 pA) or one 10^{10} ohm and two 10^{11} ohm resistors for $^{24}Mg^+$, and $^{25,26}Mg^+$, respectively (2 nA). The typical external reproducibility (2 standard deviation: 2SD) of δ^{25}Mg for the San Carlos olivine (SC-Ol) standards was 0.25‰, 0.13‰, and 0.08‰ for primary ion beams of 25 pA, 160 pA, and 2 nA, respectively.

We prepared 13 olivine standards with a range of Mg# (100-60) for SIMS instrumental bias corrections. Mg isotope ratios in DSM-3 scale of three standards were previously obtained using solution MC-ICPMS [18]. Including these three, all 13 olivine standards were measured using a Nu Plasma II MC-ICPMS at UW-Madison with a Nd:YLF-pumped Ti:sapphire femtosecond laser. These fs-LA analyses revealed samples were internally homogeneous in δ^{25}Mg. We observed a complex SIMS instrumental bias for δ^{25}Mg in olivine as a function of Mg# (100-60). The bias changed smoothly for Mg# 100-89 and 86-60 by 1.6‰ and 0.7‰, respectively, while it jumps by 1.5‰ between Mg# 86 and 89. Excluding this narrow range of olivine compositions (86-89), the uncertainties of bias corrections were similar to, or smaller than, the external reproducibility of SC-Ol standards in each SIMS session.

Oxygen three-isotope analyses of AOAs were performed using the IMS 1280 with three FCs [19]. A 8 µm diameter (0.7 nA) Cs^+ primary ion beam was used for analyses. Synthetic pure forsterite was used as a standard and bracketed the unknown AOA analyses. The external reproducibility (2SD) of the running standard during the session was 0.4‰, 0.8‰, and 0.8‰ for δ^{18}O, δ^{17}O, and Δ^{17}O, respectively.

Results: In an oxygen three-isotope diagram, the Kaba and DOM 08006 AOAs form a tight cluster on the primitive chondrule mineral (PCM) line [9]. All AOAs measured in this study yield averaged δ^{18}O and Δ^{17}O values of –45.8 ± 0.7‰ (2SD) and –24.0 ± 0.4‰ (2SD), respectively.

The δ^{25}Mg values of Wild 2 olivines and AOAs from the Kaba and DOM 08006 chondrites are shown in Fig. 1. Wild 2 olivine particles show small variations in δ^{25}Mg ranging from –0.7±0.3‰ (2σ: T175/F1) to 0.4±0.4‰ (2σ: T149/F1). As T149/F1 and T149/F11a have Mg#'s around 86, we cannot exclude the possibility that their δ^{25}Mg values are slightly inaccurate, due to the larger instrumental bias uncertainty for the specific range of olivine compositions (Mg# 86-89). The mass independent fractionation Δ^{26}Mg values of all Wild 2 olivines, which are calibrated using the exponential law [20], are normal within analytical uncertainties (≤0.8‰: 2σ). Variations in δ^{25}Mg are larger for AOAs (–2.6 to 1.2 ‰), than those of Wild 2 olivines, especially among AOAs with porous textures. Note that the DOM 08006 AOA 501 contains areas with both compact and porous textures, which show positive and negative δ^{25}Mg values, respectively.

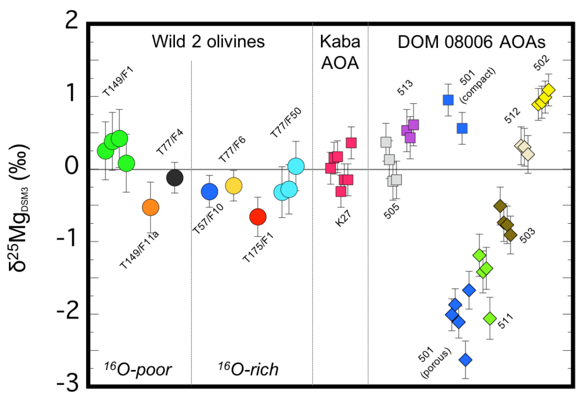

Fig. 1. δ^{25}Mg values of the Wild 2 olivine particles and meteoritic AOAs analyzed in this work. Square and diamond symbols represent compact and porous AOAs, respectively.

Discussion: All Wild 2 olivine particles have near-chondritic Mg isotope ratios, indicating there is no significant Mg isotope heterogeneity between Wild 2 olivine forming regions (^{16}O-rich and ^{16}O-poor) and meteorites and Earth forming regions [13].

AOAs show significant variations in δ^{25}Mg, despite their narrow ranges of ^{16}O-rich oxygen isotope ratios. T175/F1 and some porous AOAs have negative δ^{25}Mg, with values similar to those previously reported in other AOAs and CAIs [10-12]. This signature is indicative of condensation from nebula gas [14]. In contrast, ^{16}O-rich Wild 2 olivine particles, except T175/F1, do not show clear negative δ^{25}Mg values. The nearly chondritic Mg isotope ratios of ^{16}O-rich Wild 2 olivines could imply that: (1) Wild 2 olivines formed by nearly equilibrium condensation from nebular gas; (2) after condensation from nebular gas, Wild 2 olivines experienced isotopic exchange with a chondritic component having a planetary Mg isotopic composition, and/or (3) Wild 2 olivines experienced parent body alteration. Previous studies revealed that three of the ^{16}O-rich Wild 2 olivines (T57/F10, T77/F6, and T77/F50) have Mn-rich chemical compositions, indicating these olivines formed by condensation from nebula gas [1-6], which would support the first scenario. Note that some AOAs studied here, especially AOAs with a compact texture, show nearly chondritic or slightly heavier δ^{25}Mg values (Fig. 1). This textural and isotopic relationship suggests that compact AOAs experienced reheating processes in nebula gas. If some Wild 2 olivines experienced similar reheating processes, the second scenario may apply. Self-diffusion coefficients measured for Mg in forsterite compared to those for oxygen [see 21 and references therein], imply that the third scenario cannot be excluded at this time.

Summary: The absence of large negative δ^{25}Mg values in Wild 2 ^{16}O-rich particles suggests either formation involved equilibrium condensation with nebula gas, or that they experienced reprocessing in nebular and/or planetary settings. Large negative δ^{25}Mg values in porous AOAs indicates a condensation origin involving kinetic mass fractionation.

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