MAGNESIUM ISOTOPE RATIO HETEROGENEITY IN ALLENDE CHONDRULES DETERMINED BY UV LASER ABLATION AND MULTICOLLECTOR ICPMS. E. D. Young1, R. D. Ash1, A. Galy2, and N.S. Belshaw. 1 Department of Earth Sciences, University of Oxford, Parks Road, Oxford OX1 3PR, UK (ed.young@earth.ox.ac.uk). 2 Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge CB2 3EQ, UK.

Summary: We have developed a method for analyzing $^{25}\text{Mg}/^{24}\text{Mg}$ and $^{26}\text{Mg}/^{24}\text{Mg}$ in situ in silicates and oxides using UV laser ablation and multicollector inductively coupled plasma mass spectrometry (MC-ICPMS). Results for four chondrules from the Allende CV3 carbonaceous chondrite show systematic mass-dependent variations of up to 1.3 per mil per amu within individual chondrules, variations comparable to those for oxygen in these chondrules. Correlations between Mg isotope ratios and O isotope ratios suggest at least two mechanisms for Mg isotope heterogeneity in chondrules.

Methods: An ArF excimer laser is used to vaporize materials from cylindrical pits with diameters on the order of 100 $\mu$m. The pits are shallow with flat floors that are amenable to study by electron beam methods following isotopic analysis. The ablated material is swept from the analysis chamber by a flow of He gas. The He is then mixed with a flow of Ar and introduced into the inductively coupled plasma source of a Nu Instruments multiple-collector double-focussing magnetic sector mass spectrometer (MC-ICPMS). The system was calibrated relative to the SRM 980 international Mg standard by analyzing mantle olivine and pyroxene with known $^{25}\text{Mg}/^{24}\text{Mg}$ and $^{26}\text{Mg}/^{24}\text{Mg}$ [1]. We also analyzed portions of a CAI from the Allende meteorite and obtained results comparable to those from previous studies. So-called “matrix effects” that can arise from the presence of several major elements in the plasma source were evaluated by doping the Ar flow with variable amounts of Fe, Al, Na, and Ca during ablation of a forsterite working standard. We found no resolvable matrix effects at concentrations exceeding those in the minerals analyzed. At high [Ca] there is a significant interference from $^{48}\text{Ca}^{+}$ but the effect is below detection for the meteoritical materials analyzed.

Results are reported as $\delta^{25}\text{Mg}$ and $\delta^{26}\text{Mg}$, or per mil deviations in $^{25}\text{Mg}/^{24}\text{Mg}$ and $^{26}\text{Mg}/^{24}\text{Mg}$ from the SRM 980 international standard. Replicate analyses of working standards indicate a precision of +/- 0.15 per mil (2$\sigma$) for $\delta^{25}\text{Mg}$ and +/- 0.25 per mil (2$\sigma$) for $\delta^{26}\text{Mg}$.

Samples: Here we report results for four chondrules from the Allende meteorite. Laser ablation oxygen isotope ratio data exist for each chondrule and each was described previously by Ash et al. [2]. C6 (Figs 1 and 2) is a course barred olivine chondrule exhibiting alteration at its edges. The mesostasis consists of feldspar, enstatite, and nepheline. Mesostasis and portions of the edge of the chondrule are altered as evidenced by enrichments in Cl and Fe. C8 (Fig. 3) is a porphyritic olivine chondrule with relic grains of forsterite and patches of alteration characterized by Cl, alkali, and Fe enrichment. C9 is a porphyritic olivine pyroxene chondrule with olivine poikilitically enclosed in pyroxene and a devitrified mesostasis that is Cl, alkali, and Fe rich. C13 is a fine barred olivine chondrule.

The samples represent two groups of chondrules from Allende defined on the basis of their oxygen isotope ratios. C6 and C9 lie on the Allende Mass Fractionation line (AMF) [3] with a $\Delta^{17}\text{O}$ of ~2.8 per mil that is the same as the matrix of the meteorite. C8 and C13 have variable $\Delta^{17}\text{O}$ values.

Results: Chondrule C6 exhibits relatively uniform $^{25}\text{Mg}/^{24}\text{Mg}$ and $^{26}\text{Mg}/^{24}\text{Mg}$ throughout most of its interior with $\delta^{25}\text{Mg}$ varying from 1.9 to 1.7 per mil. At the margins $\delta^{25}\text{Mg}$ is significantly lower with values ranging down to 0.3 per mil (Fig. 1). The low $\delta^{25}\text{Mg}$ values appear in both olivine and pyroxene at the margins.

Fig. 1 Laser ablation $\delta^{25}\text{Mg}$ analyses of chondrule C6. Note low values at margins in both pyroxene (dark grey) and olivine (medium grey). The round excimer laser ablation pits are 100 $\mu$m in diameter and serve as indicators of scale.
Oxygen isotope ratios in olivine and pyroxene are uniform throughout the chondrule. Differences in $^{18}\text{O}/^{16}\text{O}$ (and $^{17}\text{O}/^{16}\text{O}$) appear between altered mesostasis and olivine/pyroxene (Fig. 2). For chondrule C6 $\delta^{25}\text{Mg}$ at the margin is $>1$ per mil lower than the interior while $\delta^{18}\text{O}$ is uniform to within 0.5 per mil (compare Figs. 1 and 2).

Chondrule C8 has more uniform $\delta^{25}\text{Mg}$ than C6. In this chondrule there is a correlation between the presence of relic refractory grains of forsterite, low $\Delta^{17}\text{O}$, and high $\delta^{25}\text{Mg}$ (Fig. 3). Inside the refractory-rich unaltered regions $\delta^{25}\text{Mg}$ averages 1.9 $\pm$ 0.1 per mil and $\Delta^{17}\text{O}$ is $-7.2$ per mil. Outside these regions mean $\delta^{25}\text{Mg}$ is 1.6 $\pm$ 0.1 per mil and mean $\Delta^{17}\text{O}$ is $-4.4$ $\pm$ 0.8 per mil. The correlation between high $\delta^{25}\text{Mg}$ and low $\Delta^{17}\text{O}$ is qualitatively similar to that defined by bulk analyses of chondrules from Allende reported last year [4].

Chondrule C9 exhibits variations in $\delta^{25}\text{Mg}$ and $\delta^{18}\text{O}$ similar to those in C6. Chondrule C13 is essentially uniform in $\delta^{18}\text{O}$ with 9 analyses yielding a mean of 1.7 $\pm$ 0.1 per mil.

All of the $\delta^{25}\text{Mg}$ and $\delta^{26}\text{Mg}$ values for these chondrules are on the terrestrial mass fractionation line.

**Fig. 2** Oxygen isotope analyses for chondrule C6. Values of $\delta^{18}\text{O}$ near 1.0 $\pm$ 0.5 per mil characterize pyroxene and olivine for margin and interior while analyses that include mesostasis (light grey to white) range up to 3.3 per mil.

**Discussion:** The chondrule laser ablation Mg and O isotope data are consistent with two sources of isotopic heterogeneity. One is the presence of refractory chondrule precursors with high $\delta^{25}\text{Mg}$ and low $\Delta^{17}\text{O}$ relative to bulk Allende [4]. The other is a lowering of $\delta^{25}\text{Mg}$ values concentrated at chondrule margins where alteration is most prevalent. The new laser ablation Mg isotope data are not consistent with evaporation of the chondrules, suggesting ambient pressures were high during crystallization [1], but could be explained by condensation. Evaluation of the likelihood that low $\delta^{25}\text{Mg}$ values could be the result of aqueous alteration will require studies of terrestrial systems.