

Oxygen isotope systematics in a compound amoeboid olivine aggregate – chondrule object from Acfer 094 meteorite

Implications to O-isotope exchange between melt and gas during chondrule formation

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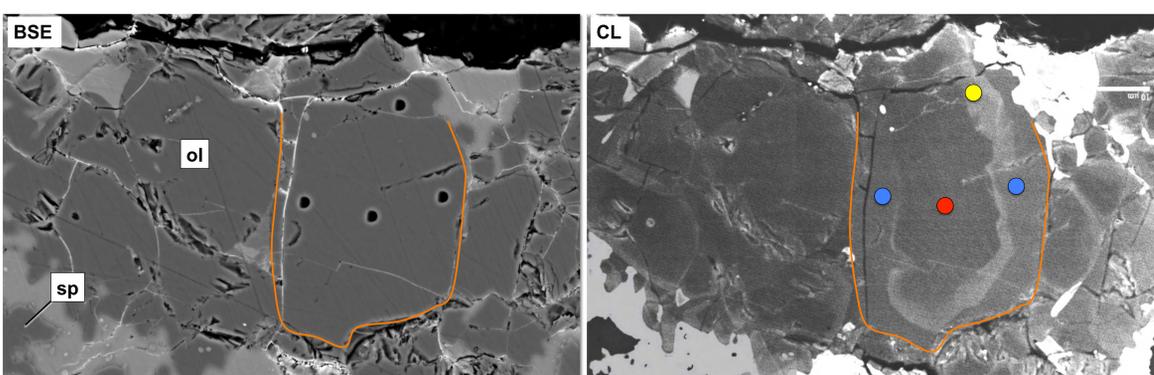
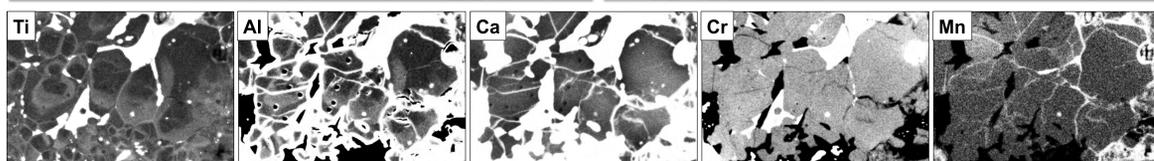
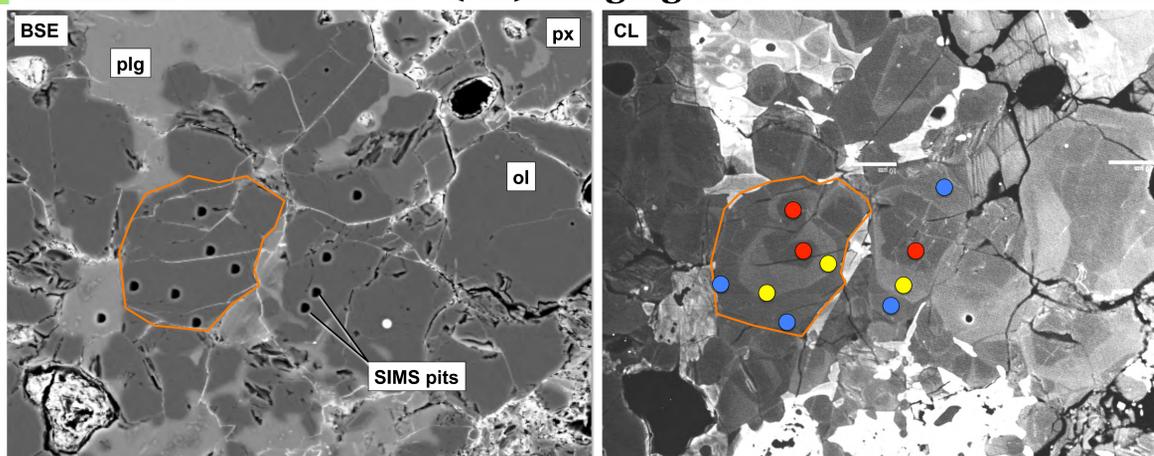
Introduction

- Closed vs. Open system during chondrule formation
 - if closed, the observed range in chondrule bulk chemistry and modal mineralogy was entirely inherited from solid precursors [e.g., 1]
 - if open, gas-melt interaction, including condensation of SiO from gas into chondrule melt, could have played a major role in evolution of mineralogy, chemical and isotopic compositions of chondrules [e.g., 2]
- The uniform O-isotope compositions ($\Delta^{17}\text{O}$) among single chondrules from the least metamorphosed chondrites could be due to precursors dominating O-isotope composition of chondrule melt and/or very efficient O-isotope exchange between the melt and the surrounding gas [e.g., 3]
- Majority of chondrule precursors could have been ^{16}O -poor, comparable to those of chondrules, and therefore it could be difficult to see whether O-isotope exchange was efficient
- A compound object consisting of an amoeboid olivine aggregate (AOA) and a type I chondrule in the Acfer 094 ungrouped 3.0 carbonaceous chondrite. Since AOAs have exclusively ^{16}O -rich composition ($\Delta^{17}\text{O} < -20\text{‰}$ [4]) distinctly different from those of most chondrules ($\Delta^{17}\text{O} > -10\text{‰}$ [5]), the object can be used to constrain O-isotope exchange during chondrule formation

Methods

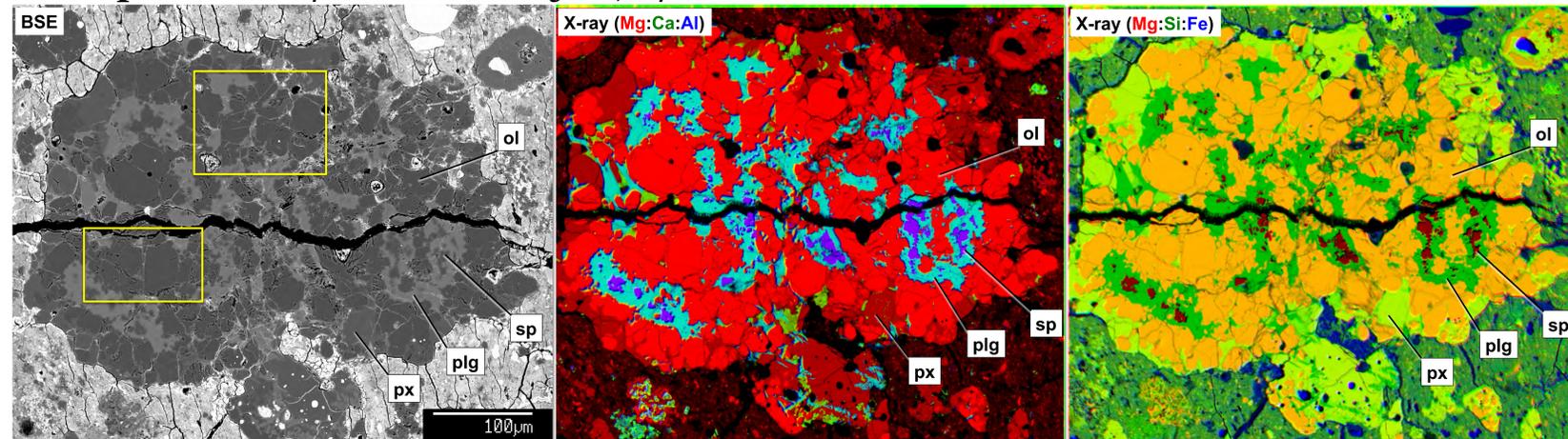
- Field emission gun EPMA (JEOL JXA-8500F) at Univ. of Hawai'i (UH)
- Field emission gun SEM (JEOL JSM-7000F) with Gatan MonoCL4 cathodoluminescence (CL) detector at CRHEA, France [5]
- Cameca ims-1280 SIMS with SCAPS detector at UH [6]
 - spot analysis with $\sim 2\ \mu\text{m}$ primary beam
 - $\delta^{18}\text{O}$ isotope maps

Cathodoluminescence (CL) imaging and element distribution



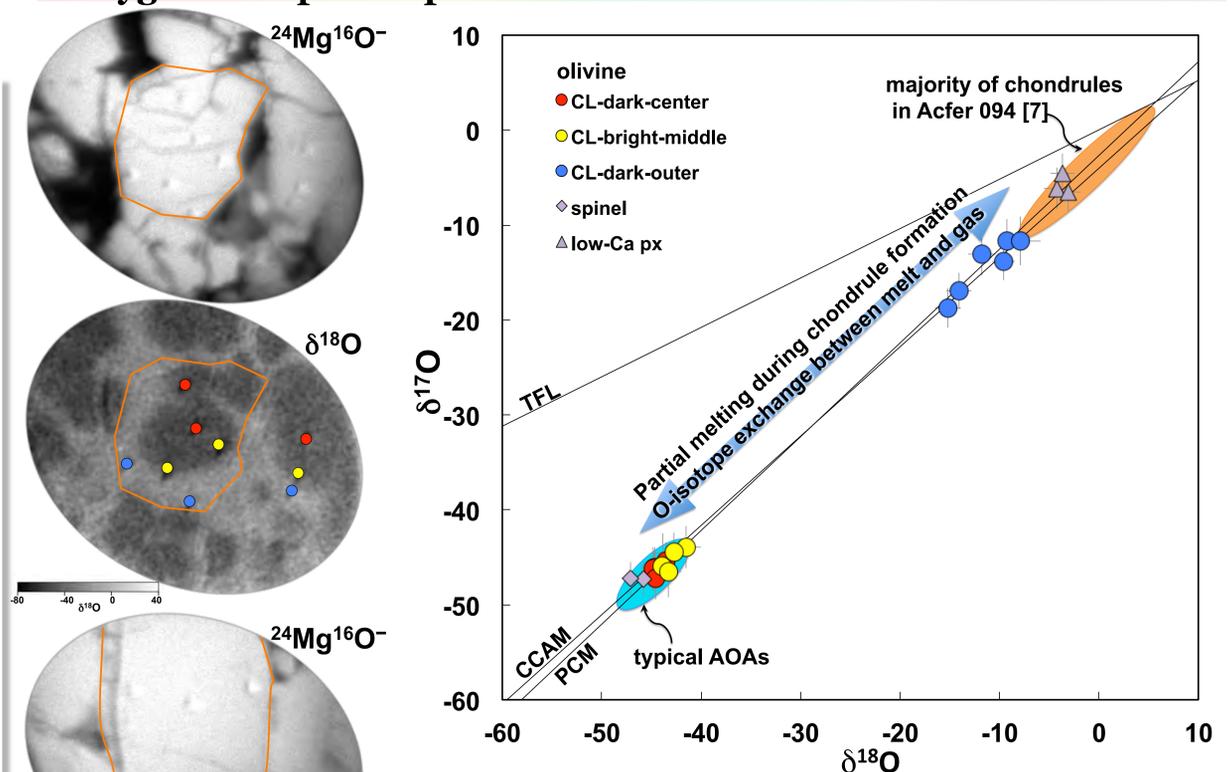
- Concentric zoning patterns in many olivine grains
- 3 domains (CL-dark-core, CL-bright-mantle, and CL-dark-rim)
- The CL patterns in olivines are correlated with distributions of Al and Ti
- Al and Ti enriched in CL-bright-mantle ($\text{Al}_2\text{O}_3 \sim 0.06\ \text{wt}\%$; $\text{TiO}_2 \sim 0.1\ \text{wt}\%$)
- Other elements (Mg, Fe, Ca, Cr, Mn) are rather homogeneously distributed in olivine grains
- Al and Ti are responsible for different CL emissivity in olivine grains
- These distributions imply sluggish diffusion of Al^{3+} and Ti^{3+4+} in olivine compared to that of divalent cations

Compound AOA/chondrule object, A/Ch#1



- A/Ch#1 has an igneous texture and consists predominantly of olivine, anorthite, low-Ca pyroxene; high-Ca pyroxene and Al-Mg spinel are minor
- Forsteritic olivine (Fo_{99}) is within the compositional range of olivines in AOAs from Acfer 094 [4]
- Anorthite (An_{99}) occupies interstitial regions between olivine grains and often encloses small ($< 10\ \mu\text{m}$) spinel grains
- Spinel contains relatively high Fe and Cr contents ($\text{FeO} \sim 0.6\text{--}1.0\ \text{wt}\%$; $\text{Cr}_2\text{O}_3 \sim 0.8\text{--}3.0\ \text{wt}\%$), significantly higher than those in the Acfer 094 AOAs [e.g., 4]
- Ferromagnesian low-Ca pyroxene ($\text{Fs}_{1.3}\text{Wo}_{5.8}$) occurs mostly in the peripheral region of the object

Oxygen isotope compositions and distribution



- O-isotopes in olivine are heterogeneously distributed with sharp isotopic boundaries & correlated with the CL patterns
- ^{16}O -rich compositions in spinel and core and mantle of olivine are consistent with AOAs, confirming the object contains AOA materials
- ^{16}O -poor compositions of olivine rim and pyroxene are consistent with those in type I chondrules from Acfer 094 ($\Delta^{17}\text{O} \sim -11\text{‰}$ to -1‰ [7])
- Original AOA materials experienced partial melting and transformed into the AOA/chondrule compound object during chondrule formation. This transformation was accompanied by condensation of gaseous SiO into AOA melt and O-isotope exchange between this initially ^{16}O -rich melt and ^{16}O -poor gas
- The CL-dark-core and CL-bright-mantle in olivine are relicts that avoided melting during this process
- The more ^{16}O -poor composition in pyroxene than CL-dark-rim in olivine
 - progressive O-isotope exchange between melt and gas during crystallization of olivine, and nearly complete equilibration between them by the time pyroxene crystallized
- If we assume $\Delta^{17}\text{O} \sim -4\text{‰}$ of pyroxene represents the gas composition, and $\Delta^{17}\text{O} \sim -23\text{‰}$ of spinel and ^{16}O -rich olivine represents composition of the initial melt prior to O-isotope exchange
 - $\sim 60\text{--}85\%$ of oxygen was introduced from the gas to produce the compositions in the rim, suggesting efficient O-isotope exchange between melt and gas
- The same O-isotope but different element compositions in CL-dark-core and CL-bright-mantle
 - > partial melting of AOA precursors in a ^{16}O -rich gaseous reservoir, prior to chondrule formation
- CL-dark-core is relict and CL-bright-mantle crystallized onto the core from relatively Al and Ti enriched AOA melt, possibly due to melting of some CAI materials together
- The object experienced two partial melting events in the ^{16}O -rich and ^{16}O -poor gaseous reservoirs