

AMOEBOID OLIVINE AGGREGATES (AOAs) IN THE EFREMOVKA (CV_R) CHONDRITE: FIRST SIMS TRACE-ELEMENT RESULTS. A. Ruzicka¹, C. Floss² and M. Hutson¹ ¹Cascadia Meteorite Laboratory, Dept. of Geology, Portland State University, 1721 SW Broadway, Portland, OR 97207 U.S.A., email: ruzickaa@pdx.edu. ²Laboratory for Space Sciences and Physics Dept., Washington University, St. Louis, MO 63130 U.S.A. email: floss@wustl.edu

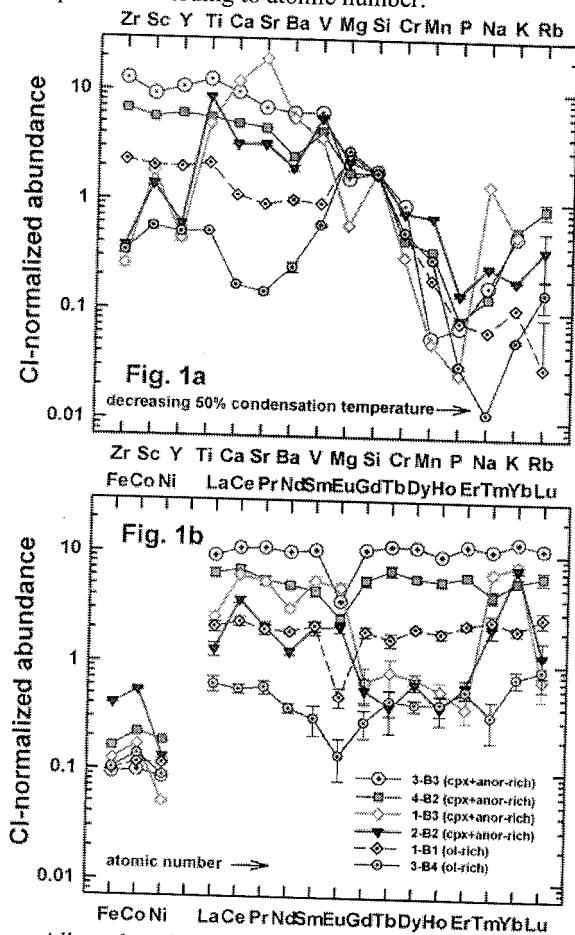
Introduction: Ameboid olivine aggregates (AOAs) are irregularly shaped, porous inclusions composed mainly of fine-grained (<10 µm) olivine grains, together with variable amounts of Ca-Al-rich material with a probable CAI affinity [e.g., 1,2]. AOAs are thought to have formed as solid-gas condensates in CAI-forming regions [e.g., 1-4]. CAI minerals such as melilite and spinel were partly replaced by Al-pyroxene and anorthite, possibly in the presence of solar nebula gas at high temperatures [1,2]. AOAs have bulk chemical compositions intermediate between CAIs and ferromagnesian chondrules [e.g., 1,2,4], implying they could have been precursors to chondrules.

We analyzed mineralogically pristine AOAs in the Efremovka, Vigarano and Leoville CV_R chondrites [4] using SEM, EMPA, and SIMS and here report the first results for 6 inclusions in Efremovka. Our SIMS trace-element data (up to 33 elements analyzed) are among the first such data obtained for AOAs. In our study, both narrow- and broad-beam EMPA (1 µm, 50 µm) and SIMS (15-20 µm, 40-50 µm) analyses were obtained, with the broad-beam analyses effectively representing bulk analyses of localized regions in the inclusions.

Petrography and olivine phase chemistry: AOAs in Efremovka have mineralogies, textures, and olivine compositions (Fo₈₈₋₉₉) typical of those previously reported [4]. Ca-Al-rich materials occur in pockets, mainly as Al-diopside + anorthite intergrowths, and less commonly as nodules or ribbons cored by spinel and/or melilite. Triple junctions between olivine are common and have been cited as evidence for annealing [4,5]. Although there is no obvious intragrain zoning, olivine ranges in composition from grain to grain. For example, variations of ~10 mol% Fo are common within inclusions, and adjacent grains can differ in Fo values by up to ~5 mol%. Minor element contents in olivine are also highly variable, and much of the variation appears to be intrinsic to olivine, although apparent locally high Al₂O₃ (>1 wt%) and CaO (>0.5) contents are probably caused by overlap with sub-µm inclusions of anorthite and Al-diopside. Even excluding analyses with likely phase overlaps, the intergrain compositional variability of olivine grains is a significant feature of AOAs, consistent with an aggregational

origin of the olivine and with limited diffusive equilibration during thermal processing.

Bulk trace-element compositions: Our broad-beam SIMS data imply that vapor-fractionation processes were important in the formation of AOAs. Fig. 1 shows CI-normalized data for representative analyses, with elements in Fig. 1a plotted according to 50% condensation temperature, and elements in Fig. 1b plotted according to atomic number.



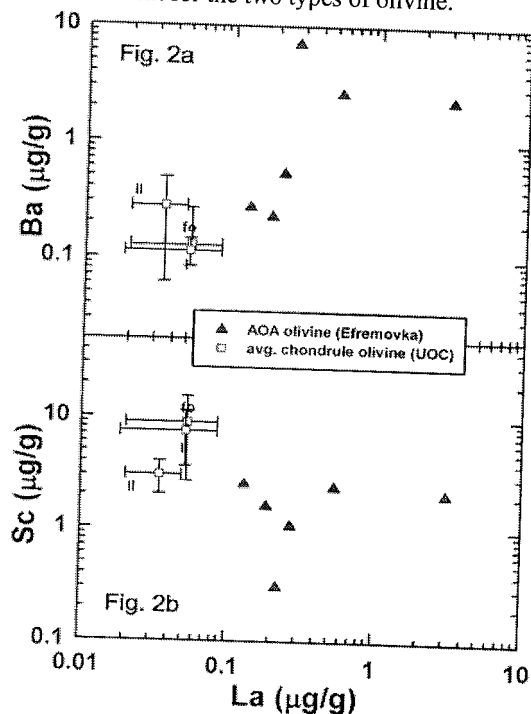
All analyzed regions are depleted in volatile elements (Cr-Rb in Fig. 1a), although alkali elements are sometimes less depleted than other volatile elements, probably as a result of local addition during alkali-halogen alteration. Clinopyroxene + anorthite-rich pockets show two types of abundance patterns, both of which are sometimes present in the same inclusion.

One pattern has relatively uniform REE abundances with negative Eu anomalies, and progressive enrichment to ~8-15 x CI-chondrites in elements with high condensation temperatures (e.g., analyses 3-B3 and 4-B2 in Fig. 1). This same pattern is observed for an anorthite-rich region (not shown). The other pattern has highly fractionated ("modified Group II") REE abundances, with most HREE (Gd-Er, Lu) depleted relative to LREE, Eu, Yb and Tm, and with refractory elements of intermediate condensation temperature (Ti, Ca, Sr, Ba, V) being more enriched than other elements (e.g., 1-B3, and 2-B2 in Fig. 1). A modified Group II pattern is also shown by a spinel + Ti-Al-pyroxene cored nodule (not shown). Both patterns are similar to those observed in CAIs [6] except for lower overall abundances of refractory elements in the AOAs, and except that Tm in the modified Group II pattern is not as depleted as most other HREE compared to Group II CAIs. We suggest these patterns reflect a CAI component diluted by the addition of more volatile material (e.g., Si, Mg), which was added from a gas phase that reacted with the CAI components to form anorthite and clinopyroxene. The observation that both types of abundance patterns can occur in the same AOA further supports an aggregational origin for the inclusions and suggests that elemental exchange following the incorporation of Ca-Al-rich materials in AOAs must have been limited.

Olivine-rich areas are enriched in Si and Mg, which have intermediate condensation temperatures (e.g., 1-B1 and 3-B4 in Fig. 1). These areas have relatively uniform abundances of more refractory elements, except for a negative (in one case positive) Eu anomaly in the REE pattern, and except for low abundances of Sr, Ba, and sometimes Ca and V (Fig. 1). We suggest that such olivine formed by fractional condensation from a gas at intermediate temperature that had previously experienced condensation of refractory material, analogous to Group II CAIs but with fractionation occurring at a lower temperature. Relatively low abundances of Eu, Ca, Sr and Ba in olivine-rich areas could indicate that these elements were previously removed in an earlier-formed condensate that contained melilite, which probably incorporates the same elements. Less likely, these elements may have been redistributed into plagioclase by reactions and diffusion during thermal processing in the inclusions, but such redistribution is at odds with the grain-to-grain compositional variability in olivine and the distinctly different refractory element patterns in Ca-Al-rich regions.

Olivine trace-element compositions: Narrow-beam SIMS data were obtained for olivine in AOAs to evaluate whether such olivine could have been a pre-

cursor to olivine in ferromagnesian chondrules, by comparing such data to similar data obtained previously for chondrules in UOCs [7-9]. Many elements have similar abundances in AOA and chondrule (especially Type I) olivine, but AOA olivine is depleted in Sc and V and enriched in La, Ce, Pr, Ba, Sr, and Zr (e.g., Fig. 2). High abundances of LREE, Ba, Sr, and Zr in AOA olivine could be explained by crystallization from a melt that cooled more rapidly than chondrules [8], but there is no other evidence that olivine grains in AOAs crystallized from a melt. More likely, enrichments in LREE, Ba, Sr, and Zr in AOA olivine reflect contamination with sub- μm inclusions of anorthite and clinopyroxene, or a different origin from chondrule olivine. More clearly, differences in Sc and V contents between AOA and chondrule olivine cannot be explained by cooling-rate or contamination effects. Evidently, either precursor compositions or the mode of origin were different for the two types of olivine.



- References:** [1] Krot A. et al. (2004) *GCA* 68, 1923-1941. [2] Krot A. et al. (2004). *Chemie der Erde* 64, 185-239. [3] Grossman L. and Steele I. (1976) *GCA* 40, 149-155. [4] Komatsu M. et al. (2001) *Meteoritics & Planet. Sci.* 36, 629-641. [5] Weisberg M. et al. (2004) *Meteoritics & Planet. Sci.* 39, 1741-1753. [6] MacPherson G. (2005) In *Meteorites, Comets, and Planets* (ed. A. Davis), pp. 201-246. [7] Ruzicka A. and Floss C. (2003) *LPS XXXIV*, Abstract #1243. [8] Ruzicka A. and Floss C. (2004) *LPS XXXV*, Abstract #1422. [9] Ruzicka A. et al. (2006) *Meteorit. Planet. Sci.* 41, 5266.