EXPERIMENTAL REPRODUCTION OF ALUMINUM AND TITANIUM ZONING IN OLIVINE: A NEW METHOD FOR CONSTRAINING CHONDRULE THERMAL HISTORIES

J. P. Greenwood[1] and W. Herbst[2], [1]Dept. of Earth & Environmental Sciences, Wesleyan University, Middletown, CT 06459, [2]Dept. of Astronomy, Wesleyan University, Middletown, CT 06459.

Introduction: Discovery of aluminum minor element zoning in olivine from porphyritic and barred olivine chondrules [1], and its association with titanium zonation and relict ^{16}O-rich porphyritic olivine cores [2,3] argue that this zonation may be critical for understanding olivine crystallization in porphyritic and barred olivine chondrules. The minor element zonation of aluminum in olivine is the 'CL-activator' in cathodoluminesence (CL) images [1], and has been proposed to be due to changing melt composition of an originally Ca-Al-Ti-rich melt that became progressively enriched in MgO and SiO from the surrounding vapor during a high-temperature gas-melt stage [1]. We have previously reported on experimental reproduction of this minor element zonation during rapid heating and cooling of chondrules at nonlinear heating and cooling rates of 1100-12,000˚C/hr [4], heating and cooling rates derived from thermal models of heating of chondrule precursors during close passage or accretion to differentiated planetesimals [5-7]. Here we present new experimental results at linear and lower cooling rates (5, 500, and 5000˚C/hr) for a Type IA (FeO-poor, porphyritic olivine) chondrule composition.

Methods: We have developed new methods using a remote-controlled sample assembly to undertake reproducible heating and cooling rates at >3000˚C/hr, the maximum cooling rate used in previous chondrule experimental studies, as this is the maximum rate accessible with traditional 1-atm vertical quench furnaces [e.g. 4,8]. We use a precursor mineral assemblage consisting of peridotitic olivine admixed with feldspars to give the Type IA average composition from Semarkona [9] and buffer fO_2 with a mixture of CO-CO_2 gases. Experiments are heated rapidly (~12,000˚C/hr) to a maximum temperature of 1560˚C and then cooled linearly from 5-5000˚C/hr to a quench temperature of 1200˚C. Thus, these experiments are designed to understand the early, higher temperature history of olivine crystallization in chondrule melts, not the cooling history near the solidus.

Results: Oscillatory zoning of aluminum and titanium surrounding relict olivine cores is a common feature of our experiments from 5-6,000˚C/hr [4,8]. The experiments at 5˚C/hr do not reproduce chondrule olivine minor element zonation very well, with diffuse interfaces between zoning regions. Experiments undertaken at 500˚C-6000˚C/hr appear to show features observed in natural chondrules [1-3]. In particular, curving oscillatory zoning of aluminum and titanium overgrowths on relict olivine cores, and a transition from curving oscillatory zoning bands to euhedral olivine minor element zonation (at 500˚C/hr) show that minor element zonation in olivine can provide a new window into chondrule thermal histories.

Discussion: Here we show that minor element zonation of aluminum and titanium in olivine is a natural feature of olivine crystallization at high cooling rates and high degrees of olivine supersaturation. Aluminum and titanium minor element zonation in porphyritic and barred olivine chondrules is akin to the well known phenomenom of phosphorus zoning in olivine of terrestrial, lunar, martian, and Type II chondrule olivine-bearing liquids [10-12]. The origin of this type of zonation is not well understood, and both classical [12] and non-classical [10] crystal nucleation and growth theories have been invoked. While the origin of this type of zonation is still under debate, it is clear that a model involving exchange with an external gaseous reservoir is not necessary for explaining these features. Models that invoke rapid heating and cooling of chondrule precursors (>500˚C/hr) can reproduce the features found in chondrule olivine grains [e.g. 4-8; 13-15].

References: [1] Libourel G. and Portail M. (2018) *Sci. Adv. 4,* eaar3321. [2] Marrocchi Y. et al. (2018) *EPSL 496,* 132-141. [3] Marrocchi Y. et al. (2019) *GCA 247,* 121-141. [4] Greenwood J. P. and Herbst W. (2021) *LPSC 52* abst.#1617. [5] Herbst W. and Greenwood J. P. (2019) *Icarus 329*, 166-181. [6] Herbst W. and Greenwood J. P. (2016) *Icarus 267*, 364-367. [7] Herbst W. and Greenwood J. P. (2022) *LPSC 53,* abstr.#1577. [8] Greenwood J. P. et al. (2022) *LPSC 53* abst.#2019. [9] Jones R. H. and Scott E. R. D. *Proc. LPSC 19,* 523-536. [10] Welsch B. et al. (2014) *Geology 42*, 867-870. [11] McCanta M. et al. *MAPS 51,* 520-546. [12] Milman-Barris, M. et al. (2008) *Contr. Min. Pet. 155,* 739-765. [13] Abe K. et al. (2019) *82nd Metsoc.* Abst#6476. [14] Greenwood J. P. and Herbst W. (2019) *LPSC 50,* abstr.#2366. [15] Greenwood J. P. et al. *82nd Metsoc.* Abst.#6422.