

MAGNESIAN PORPHYRITIC CHONDRULES SURROUNDED BY FERROAN IGNEOUS RIMS FROM CR CHONDRITE GRA 95229. K. Nagashima¹, A. N. Krot¹, G. Libourel², and G. R. Huss¹, ¹Hawai'i Institute of Geophysics and Planetology, University of Hawai'i at Mānoa, Honolulu, HI 96822, USA (kazu@higp.hawaii.edu), ²CRPG-CNRS, 15, Rue Notre-Dame des Pauvres, BP20, 54501 Vandoeuvre les Nancy, France.

Introduction: A genetic relationship between type I and type II chondrules is not well established. Previously published studies of CR chondrules indicate that fragments of type I chondrules were among type II chondrule precursors [1, 2]. We identified two type I chondrules surrounded by ferroan igneous rims in the CR2 chondrite Graves Nunataks (GRA) 95229. These layered chondrules indicate that some type I chondrules were recycled during formation of type II chondrules. Here we report on the petrography, major- and minor-element abundances, and *in situ* O-isotope compositions of these chondrules. Oxygen-isotope compositions of these complex chondrules can potentially provide constraints on variations and evolution of O-isotopic compositions of nebular dust and gas during chondrule formation.

Methods: The mineralogy and petrography of the chondrules in GRA 95229 were studied using the UH field-emission EPMA (JEOL JXA-8500F). Oxygen-isotope compositions of olivine, low-Ca and high-Ca pyroxenes were measured with the UH Cameca ims-1280 SIMS. We used ~1.0 nA primary Cs⁺ beam with 7 μm raster for grains larger than ~20 μm. Two Faraday cups (FCs) for ¹⁶O⁻ and ¹⁸O⁻, and an electron multiplier (EM) was used for ¹⁷O⁻. Smaller grains were measured with ~20 pA primary beam focused to ~1–2 μm using FC-EM-EM for ¹⁶O⁻, ¹⁷O⁻, and ¹⁸O⁻, respectively. Instrumental fractionation for olivine and low-Ca pyroxene was corrected using San Carlos olivine and terrestrial low-Ca pyroxene standards. The reported uncertainty (2σ) in O-isotope composition includes both the internal precision of an individual analysis and the external reproducibility for standard measurements.

Results and Discussion: *Ch#18-30* (Figs. 1a,b) consists of a type I POP host and an FeO-rich igneous rim. The host chondrule is composed of ferromagnesian olivine, magnesian low-Ca pyroxene (Fs₁₋₂), Fe,Ni-metal, sulfide, and rare glassy mesostasis. Olivine grains, especially at periphery of the host chondrule, often show normal Fe-Mg zoning. Fayalite contents in most olivine grains of the host chondrule range from ~2 to ~5. Olivines with Fa contents up to ~30 are present at the host-rim boundary, and appear to overgrow the magnesian olivines. The ferroan igneous rim consists of ferroan olivine, ferroan high-Ca pyroxene, Fe,Ni-sulfide, and glass, and is mineralogically similar to typical type II chondrules. Most ferroan olivines are finer-grained (<30 μm) than the olivine phenocrysts in the host chondrule and compositionally heterogeneous (Fa_{~25-38}), suggest-

ing a low degree of melting during rim formation. Some grains show significant Fe-Mg zoning and have very Mg-rich cores (Fa up to 3). Small grains of Na-bearing ferroan high-Ca pyroxene (Fs_{~13-19}Wo_{~23-38}; 0.3–0.7 wt% Na₂O) commonly replace the magnesian low-Ca, Na-poor pyroxene phenocrysts of the host chondrule (Na₂O below detection limit).

Ch#31-20 (Fig. 1c,d) is a type I POP chondrule surrounded by a ferroan igneous rim. The host chondrule consists of olivine, low-Ca pyroxene (Fs_{~1-2}), plagioclase, Fe,Ni-metal, sulfide, and glassy mesostasis. The olivine phenocrysts have a smaller range of compositions (Fa₁₋₂) than those in *Ch#18-30*. As in *Ch#18-30*, the olivines near the periphery show Fe-Mg zoning and FeO-rich parts of olivines have Fa contents up to ~33. The igneous rim consists of ferroan olivine (Fa_{~26-33}), ferroan high-Ca pyroxene, Fe,Ni-sulfide, and glass, and is finer-grained (<10 μm) than that of *Ch#18-30*. As in *Ch#18-30*, Na-bearing (~0.5 wt% Na₂O) ferroan high-Ca pyroxene replaces low-Ca pyroxene at the host-rim boundary. Texturally and compositionally similar ferroan high-Ca pyroxene replacing low-Ca pyroxene are observed in many type I chondrules from CO, CM, and CV chondrites [3]. The replacement of magnesian low-Ca pyroxene by ferroan high-Ca pyroxene may be a common process that could be responsible for the general lack of relict magnesian low-Ca pyroxene in type II chondrules; relict magnesian olivines are common.

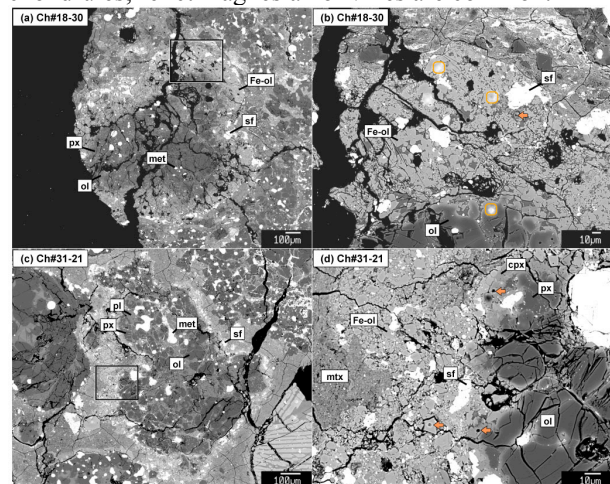


Fig. 1. BSE images of two type I chondrules surrounded by FeO-rich igneous rims in GRA 95229 CR2 chondrite. Regions outlined in (a) and (c) are shown in detail in (b) and (d), respectively. O-isotope spots are indicated by squares and arrows. cpx: ferroan high-Ca pyroxene; Fe-ol: ferroan olivine; met: Fe,Ni-metal; mtz: matrix; ol: magnesian olivine; px: low-Ca pyroxene; pl: plagioclase; sf: Fe,Ni-sulfide.

Figure 2 shows minor element concentrations (MnO, Cr_2O_3 , Na_2O , CaO) plotted against Fa contents in olivines in the host chondrules and their igneous rims. In both chondrules, MnO and CaO are positively correlated with Fa contents in olivines. Ferroan olivines contain detectable amount of Na_2O up to ~ 0.2 wt%. These element concentrations and their correlations with Fa content are very similar to those observed in type II chondrules with relict grains from various CR2 chondrites [2]. High concentrations of CaO and Na_2O in ferroan olivines are likely due to high partial pressure of Na in the nebula gas equilibrated with the ferroan igneous rims during their crystallization [4, 5].

On a three-oxygen-isotope diagram, compositions of magnesian and ferroan olivines, magnesian low-Ca pyroxene, and ferroan high-Ca pyroxene plot along a slope ~ 1 line. In Figure 3, these compositions are plotted as $\Delta^{17}\text{O}$ vs. Fa or Fs contents. Olivines in the hosts are tightly clustered around $\Delta^{17}\text{O}$ values of -2.5‰ and -8‰ in Ch#18-30 and Ch#31-21, respectively. Low-Ca pyroxene compositions in the hosts are similar to those of the olivine phenocrysts. In contrast, olivines in the igneous rims show significant variations in $\Delta^{17}\text{O}$ values that range from -24‰ to $+2\text{‰}$. The majority of the rim olivines are systematically more ^{16}O -depleted than those of the host olivines and low-Ca pyroxene, and within the range of type II chondrule olivines in CR2 chondrites [1, 2, 6]. Both the O-isotope and minor-element compositions in the rim olivines suggest that ferroan igneous rim formed in an ^{16}O -depleted gaseous reservoir ($\Delta^{17}\text{O} \sim 0\text{‰}$) under oxidizing conditions (elevated $\text{H}_2\text{O}/\text{H}_2$ ratios) similar to those most CR type II chondrules formed [e.g., 1, 2]. Oxygen-isotope compositions of ferroan high-Ca pyroxenes are similar to majority of ferroan olivines in the igneous rims, suggesting the ferroan pyroxenes co-crystallized with the ferroan olivines.

The ^{16}O -rich olivines in the igneous rims are probably relict, consistent with a low degree of melting of the ferroan rims. Oxygen-isotope compositions of the ^{16}O -rich ($\Delta^{17}\text{O} \sim -24\text{‰}$) olivines are very similar to those in amoeboid olivine aggregate (AOAs) and could be related to them although these olivines are ferroan. It is possible that relict magnesian olivines become FeO-rich without significant change in O-isotope composition due to fast Fe-Mg exchange and slow O-self diffusion in olivine. This is supported by that ^{16}O -rich compositions are mainly found in olivines with Fe-Mg zoning, and the constant O-isotope composition ($\Delta^{17}\text{O} \sim -2.5\text{‰}$) in the host olivines with variable Fa-contents in Ch#18-30 (Fig. 3a). The relict ^{16}O -rich olivine grains probably formed in a different nebula region, and were subsequently transported into the chondrule-forming region, and incorporated into the igneous chondrule rim precursors. Compositionally similar ^{16}O -rich olivines occur in

chondrule igneous rims in CR2 and K (Kakangari-like) chondrites [7, 8] and in some chondrules [e.g., 9, 10]. These observations may indicate ^{16}O -rich olivine grains were rather common in the chondrule-forming regions.

We conclude that some of the type I chondrules were recycled in the type II chondrule-forming region to form the ferroan igneous rims from fine-grained precursors with diverse O-isotope compositions.

References: [1] Connolly, Jr. H.C. and Huss G.R. (2010) *GCA*, 74, 2473–2483. [2] Schrader D.L. et al. (2013) *GCA*, 101, 302–327. [3] Jogo K. et al. (2013) *MAPS*, in press. [4] Libourel G. (1999) *CMP*, 136, 63–80. [5] Hewins R.H. (2012) *GCA*, 78, 1–17. [6] Krot A.N. et al. (2006) *GCA*, 70, 767–779. [7] Nagashima K. et al. (2003) *MAPS*, 38(Suppl.), #5140. [8] Nagashima K. et al. (2011) In *Formation of the First Solids in the Solar System*, #1639. [9] Jones R.H. et al. (2004) *GCA*, 68, 3423–3438. [10] Ushikubo T. et al. (2012) *GCA*, 90, 242–264. [11] Tenner T.J. et al. (2012) *LPS*, 43, #2127. [12] Schrader D.L. et al. (2013) *LPS*, 44, this volume. [13] Libourel G. and Chaussidon M. (2011) *EPSL*, 301, 9–21.

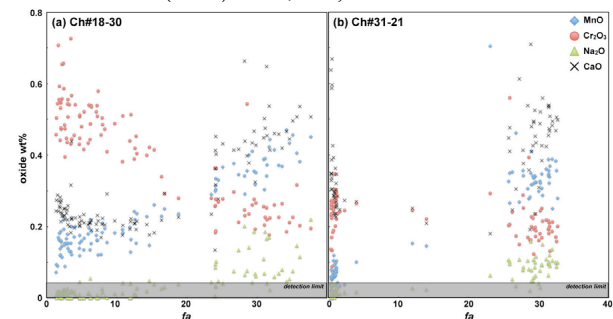


Fig. 2. Minor element compositions of olivines in the host chondrules and their igneous rims. Shaded regions indicate below detection limit.

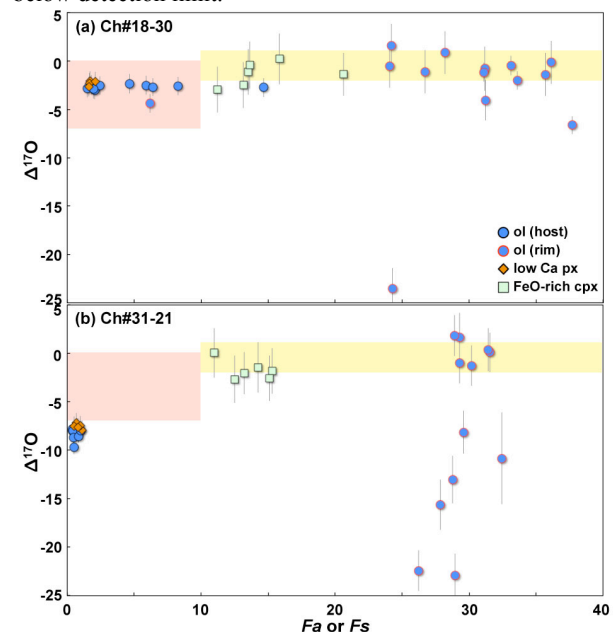


Fig. 3. O-isotope compositions of olivine and low-Ca pyroxene in the host chondrules, olivine in the ferroan igneous rims, and ferroan high-Ca pyroxene at host-rim boundaries. Pink and yellow bands show ranges of compositions observed in type I and type II chondrules (excluding relicts) in CR2-3 chondrites, respectively [1–3, 11–13].