CHONDRULE-CORED AGGREGATES IN CV CHONDRITES: ORIGIN BY CHONDRULE FORMATION FOLLOWED BY OLIVINE CONDENSATION

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Introduction: Chondrites are composed of various proportions of matrix, chondrules and refractory inclusions (RIs, defined here as including both Ca-Al-rich inclusions [CAIs] and amoeboid olivine aggregates [AOAs]). High-temperature crystallization events are recorded by chondrules, most of which formed by rapid melting and crystallization in the presence of a ^{16}O-poor gas, and by CAIs and AOAs, most of which formed by gas-solid-liquid interactions at high temperatures (>1300 K) in the presence of a ^{16}O-rich gas [1,2]. Gas-to-solid condensation was a key stage in the formation of AOAs and most fine-grained CAIs [1-3]. There might be an overlap in timing of formation of chondrules and of RIs, however, most chondrules formed after most RIs [4,5]. Furthermore, within chondrules, olivine tended to form prior to pyroxene; so, in porphyritic chondrules, olivine often occurs in chondrule cores surrounded by pyroxene (as a result of SiO gas – chondrule melt interaction [6]).

In this study, we describe a new chondrite component, referred to here as chondrule-cored aggregates (ChCAs), in which the typical sequence of crystallization events is reversed. Namely, in ChCAs, an early episode of pyroxene crystallization in a chondrule was followed by olivine condensation in a texture reminiscent of AOAs.

Methods: Two ChCAs and a related object--a convolute chondrule--were identified in a study of chondrite components in CV chondrites. The two ChCAs were found in one polished thin section (pts) of Allende and the convolute chondrule was found in a pts of Vigarano. Elemental maps (Na, Mg, Al, Si, S, K, Ca, Ti, Cr, Fe, BSE, ±P, ±Cl, ±Mn, ±Ni) were collected from the pts using a JEOL JXA 8900 electron probe micro-analyzer (EPMA) at Waseda University (WU). The ChCAs and convolute chondrule were characterized by quantitative analyses and imaging using the WU EPMA and a Hitachi S-3400N scanning electron microscope also at WU. Oxygen isotopic analyses of eight olivine grains from the Allende ChCAs were collected using the Cameca ims-1280 SIMS at University of Hawai'i (UH) under conditions similar to those described in [7].

Results: Textures and mineralogies of the Allende ChCAs were described by us last year, when we referred to these objects as unusual AOAs [8]; the convolute chondrule from Vigarano and the O-isotopic data are new. The Vigarano chondrule (object NW-30) is on the order of 1 mm across as viewed in thin section and has a highly convolute ("amoeboidal" to use a loaded term) external margin. It is similar to Allende ChCAs NE-27 and SW-7 in that its core is characterized by low-Ca pyroxene crystals similar in texture and composition (Wo_1En_{98}) to typical chondrule phenocrysts. Olivine occurs as Mg-rich ($Fo_{\sim 95}$) inclusions in relict pyroxene in the interior of NW-30, and in clusters of Mg-rich ($Fo_{\sim 90\text{-}95}$) grains, each on the order of 10 to 20 μm across, in contact with pyroxene near the margins of the object. FeO-rich veins cut across relict pyroxene in the interior of object NW-30, similar to the veins observed in the Allende ChCAs; however, vein olivine in NW-30 is very fine-grained (<1μm, stoichiometric analyses were not obtained by EPMA), whereas olivine laths, on the order of 5 μm across x 10's of μm in length, occur in veins from the Allende ChCAs. In the two Allende ChCAs, pyroxene-rich interiors are surrounded by a layer of granular olivine grains, texturally similar to AOAs. The convolute chondrule lacks a continuous outer layer of olivine, but one ~200-μm segment is draped by olivine grains.

O-isotopic compositions of the Allende ChCAs. Granular olivine grains from the Allende ChCAs have O-isotopic compositions that fall near the PCM and CCAM lines [9,10], with Δ^{17}O from -3.5 to -4.8‰ for NE-27 and from -5.5 to -8.0‰ for SW-7 (2σ uncertainties ≤ 1.0‰). These compositions are ^{16}O-poor relative to primitive AOAs and are similar to compositions reported for many chondrules [9,10].

Discussion: The two Allende ChCAs and the Vigarano convolute chondrule underwent an early stage of pyroxene ±olivine crystallization from chondrule melt, followed by formation of an olivine-rich layer. In the convolute chondrule, only a small portion of the object was mantled by olivine. In the ChCAs, the outer olivine layers are more continuous, and apparently formed by in situ condensation. O-isotopic compositions rule out condensation in a ^{16}O-rich setting typical of AOAs. FeO-rich rims on olivine grains and FeO-rich veins formed in all three objects during parent body metamorphism; thicker FeO-rich rims and coarser grain sizes in veins in Allende resulted from higher temperatures and/or durations of parent body metamorphism [e.g., 3].

References: [1] Scott E.R.D. and Krot A.N. (2005) in Krot A.N. et al. (eds.) *Chondrites & the Protoplanetary Disk*, p. 15-53. [2] Krot A.N. et al. (2009) *GCA* 73: 4963-4997. [3] Komatsu M. et al. (2015) *MaPS* 42: 1271-1294. [4] Kita N.T. et al. (2005) in Krot A.N. et al. (eds.) *Chondrites & the Protoplanetary Disk*, p. 558-587. [5] Connelly J.N. et al. (2012) *Science* 338: 651-655. [6] Krot A.N. (2004) *MaPS* 39: 1931-1955. [7] Nagashima K. et al. (2015) *GCA* 151: 49-67. [8] Fagan T.J. et al. (2016) *Meteoritical Society Meeting* 79: abstract #6292. [9] Yurimoto H. et al. (2008) in MacPherson G.J. (ed.) Oxygen in the Solar System *Revs. Mineral. Geochem.* 68: 141-186. [10] Ushikubo T. et al. (2012) GCA 90: 242-264.