Did an Impact Event Cause Shock Compression, which Limited Subsequent Fluid-Rock Interaction during Metamorphism of Reduced CV3 Chondrites? The Answer is Yes

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Introduction: The high abundance of Fe,Ni-metal and high Fo-contents of olivine led to the recognition that the CV3 chondrites Efremovka, Vigarano and Leoville formed at relatively low oxygen fugacities as reduced CV3s ($CV3_{red}$; [1]). In contrast, the CVs Allende and Axtell have little to no Fe,Ni-metal and olivine with relatively low Fo-contents, and are recognized as an oxidized CV3 subgroup ($CV3_{oxA}$ = Allende-like; a third subgroup, $CV3_{oxB}$, is based on the Bali chondrite, which has hydrous phyllosilicates and some fayalitic olivine; see [2]). The $CV3_{red}$ subgroup is characterized by lower metamorphic grades and lower porosities than the $CV3_{oxA}$ subgroup [3,4]. It has been proposed that the lower metamorphic grade of the $CV3_{red}$ is due to an early impact event that lowered porosities and expelled ices, thereby limiting fluid-rock interaction during metamorphism of the part of the CV3 parent body where the $CV3_{red}$ subgroup originated [5,6].

In order to test the early impact hypothesis, we (1) used elemental maps of thin sections to determine modal abundances of chondrules, matrix, AOAs and CAIs, and (2) used X-ray tomography of hand samples to compare shapes of chondrule-like objects in $CV3_{red}$ vs. $CV3_{oxA}$ chondrites. If the early impact hypothesis is correct, we expect the $CV3_{red}$ chondrites to have relatively low ratios of matrix/inclusions ("inclusions" = chondrules, CAIs, AOAs, opaque nodules) because primitive matrix is more compressible than chondrules. Furthermore, chondrules in the $CV3_{red}$ chondrites should be relatively flattened if they underwent shock deformation.

Methods: Elemental X-ray maps, BSE images and mosaics in plane polarized (PPL) and cross-polarized (XPL) light of polished thin sections (pts) were prepared at Waseda University. Data were collected from one pts of Leoville, two pts of Efremovka, three pts of Vigarano and two pts of Allende. The elemental and BSE maps were collected using a JEOL JXA-8900 electron microprobe (EPMA) using 15 kV, 20 nA, 1 or 2 µm spot sizes and step sizes from 6 to 11 µm. Individual maps were mosaicked together to cover the area of thin sections. Grids were overlain on layered elemental, BSE, PPL and XPL mosaics, and chondrite components were identified manually at each grid node. The chondrite components include matrix, chondrules, CAIs, AOAs, and opaque nodules. Lengths and widths of chondrules were measured using tools in Adobe Illustrator. Rose diagrams showing clustering of chondrule orientations were plotted using software downloaded from [7].

X-ray computer tomography was conducted using an ELE SCAN instrument at Kyoto University for one sample each of Efremovka, Vigarano and Allende. Materials with contrasting linear attenuation coefficient (LAC) were imaged and output as stacked two-dimensional tiff files. Boundaries of chondrule-like objects with low LAC values were traced using Adobe Photoshop for each tiff file. The traced files were re-assembled using SLICE software [8], which was used to approximate ellipsoidal fits to the traced objects, with a = minor, b = intermediate, c = major axes.

Results and Discussion: The $CV3_{red}$ chondrites Leoville and Efremovka have modal matrix/inclusion ratios (0.3 to 0.4) that are lower than in the $CV3_{red}$ Vigarano (0.55 to 0.75) and $CV3_{oxA}$ Allende (up to 1.45). Ebel et al [9] found similar values for Leoville, Vigarano and Allende, but did not analyze Efremovka. The matrix/inclusion ratios correlate with porosities determined by [4]: Efremovka 0.6%; Leoville 2.1%; Vigarano 8.3%; Allende 22% porosity.

The flattened appearance of chondrules in Leoville and Efremovka is apparent in some thin sections (Fig. 1), and is verified by X-ray CT results for Efremovka, which show a spread of sub-spherical to pancake-like shapes (Fig. 2a). The tomographic data also show that chondrules in Vigarano have more flattened shapes than the predominantly spherical chondrules of Allende (Figs. 2b,c).

Flattened chondrules and low matrix/inclusion ratios of the $CV3_{red}$ chondrites are consistent with the hypothesis that an early-stage impact compressed a part of the CV3 parent body, resulting in minor fluid-rock interaction during subsequent metamorphism [5,6]. Moderate matrix/inclusion ratios and porosities [4] suggest that Vigarano was not as strongly deformed as Leoville and Efremovka.

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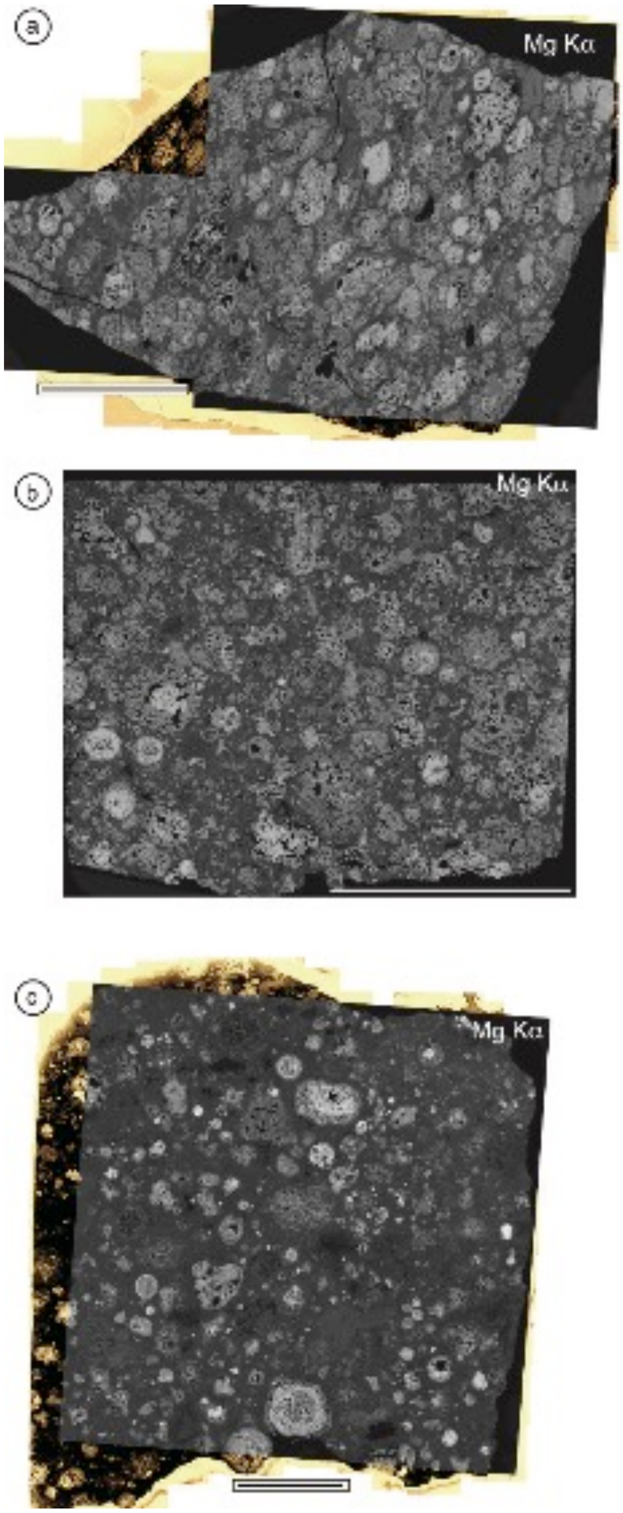

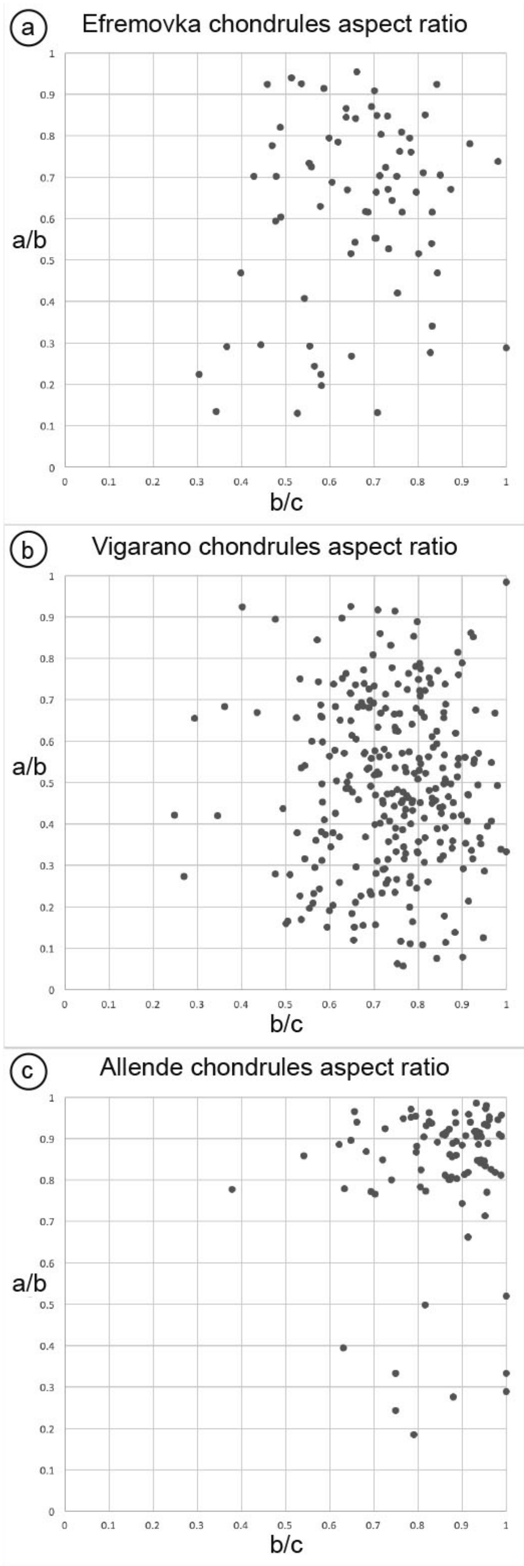

Fig. 1. Mg Kα X-ray elemental maps of CV chondrites: (a) Leoville, $CV3_{red}$; (b) Vigarano $CV3_{red}$; (c) Allende $CV3_{oxA}$. Note the deformation fabric of Leoville (a). Scale bars show 5000 µm.

Fig. 2. Shapes of chondrule-like objects determined by X-ray tomography for: (a) Efremovka $CV3_{red}$; (b) Vigarano $CV3_{red}$; (c) Allende. Ellipsoid axes are a = short, b = intermediate, c = long. Spherical objects plot in upper right, pancake shapes in lower right; cigar shapes in upper left, and bladed shapes in lower left of each plot.