

RELICT GRAINS WITH A NON-LOCAL ORIGIN: EVIDENCE FOR UOC CHONDRULE MIGRATION INTO THE CM CHONDRITE CHONDRULE FORMING REGION. D. L. Schrader¹, K. Nagashima², J. Davidson¹, T. J. McCoy³, R. C. Ogliore⁴, and R. R. Fu⁵. ¹Center for Meteorite Studies, School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA (devin.schrader@asu.edu). ²HIGP/SOEST, University of Hawai'i at Mānoa, Honolulu, HI, USA. ³Dept. of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington, D.C., USA. ⁴Department of Physics, Washington University in St. Louis, St. Louis, MO, USA. ⁵Department of Earth and Planetary Sciences, Harvard University, Cambridge, MA, USA.

Introduction: The nature of the chondrule formation process is a subject of significant debate; numerous proposed models exist [e.g., 1–5]. Regardless of the process(es), it is agreed that chondrule precursors were flash heated to peak temperatures on the order of seconds to minutes, and cooled on the order of hours to days [e.g., 6–8]. Chondrules formed either from complete or partial melts [e.g., 7], and those that were only partially melted retained portions of their solid precursors, termed relict grains [e.g., 9–12].

The chemical and O-isotope compositions, and morphologies of these relict grains provide information about the nature of chondrule precursors. Typically, relict grains are thought to be fragments of earlier-formed chondrules, although there are chemical differences between some relict grains and their apparent source chondrules. The origins of relict grains are diverse [e.g., 11–16]. Relict grain types include dusty olivine (grains that contain μm -sized Fe metal blebs, Fig. 1) [9,10], which are thought to form by solid-state reduction of more FeO-rich olivine during chondrule formation/recycling [e.g., 13,17,18]. This relatively FeO-rich olivine is generally thought to originate from a previous generation of chondrules, including type I (FeO-poor) and/or type II (FeO-rich) chondrules [13].

We report the chemical and O-isotope compositions of relict grains in CM chondrites to determine the origin(s) of CM chondrite chondrule precursors.

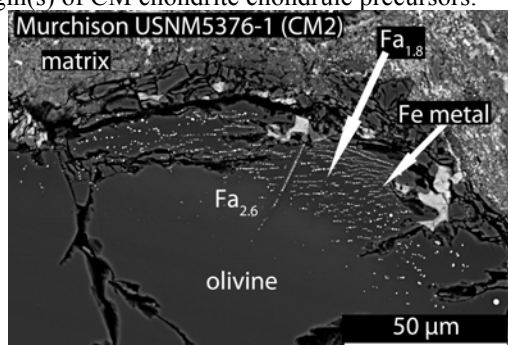


Fig. 1. BSE of dusty olivine chondrule in Murchison.

Samples and Analytical Procedures: Chemical and O-isotope compositions of chondrule olivine in the CM2 chondrites Murchison USNM5376-1 and Murray USNM1769-3a were studied with the Arizona State University JEOL-8530F and University of Arizona Cameca SX-100 electron microprobe analyzers and the

University of Hawai'i Cameca ims-1280 ion microprobe, respectively (details see [12,19]). Error on $\Delta^{17}\text{O}$ is typically 0.6–0.9‰ (2σ).

Results: A total of 54 O-isotope analyses across five type I chondrules ($n = 10$), five type II chondrules (one with an FeO-poor relict grain; $n=11$), and eight dusty olivine chondrules ($n=33$) were obtained in the CM chondrites (Fig. 2). *In situ* analyses in type I chondrules have a range in $\Delta^{17}\text{O}$ of -7.6 ± 0.8 ‰ to -0.2 ± 0.8 ‰. FeO-rich olivines in type II chondrules have a narrower range, with $\Delta^{17}\text{O}$ of -2.6 ± 0.8 to -1.7 ± 0.7 ‰; an FeO-poor relict olivine grain ($\text{Fa}_{0.6}$) has the most ^{16}O -rich value in type II chondrules of $\Delta^{17}\text{O} = -5.9\pm 0.9$ ‰ (Fig. 2). Dusty olivine chondrules have the widest range of O-isotope compositions of ferromagnesian chondrules studied here, their compositions range from $\Delta^{17}\text{O}$ of -9.2 ± 1.4 ‰ to 0.0 ± 0.9 ‰.

Dusty olivine grains in two chondrules ($\text{Fa}_{0.7-1.5}$) are more ^{16}O -poor than non-dusty olivine grains that may be phenocrysts (e.g., $\Delta^{17}\text{O} = 0.0\pm 0.9$ ‰ in dusty olivine overgrowths vs. -9.2 ± 1.4 ‰ in the non-dusty olivine, 2σ , respectively). In one chondrule with $\text{Fa}_{9.7-10.0}$, dusty olivine is more ^{16}O -rich than phenocrysts ($\Delta^{17}\text{O} = -5.9\pm 0.8$ vs. -2.3 ± 0.8 ‰, respectively). Four dusty olivine chondrules ($\text{Fa}_{0.9-8.2}$) are internally homogeneous in $\Delta^{17}\text{O}$ within 2σ uncertainties, but are resolvably different from one another (i.e., $\Delta^{17}\text{O} \sim -2.5$ vs. 0 ‰). One dusty olivine chondrule was only large enough for a single *in situ* O-isotope analysis.

Discussion and Implications: Some dusty olivine grains in the CM chondrites are consistent with an origin from CM chondrite type II chondrules. However, the majority of dusty olivine grains require olivine precursors that are unrelated to CM chondrite chondrules. For comparison, the dominant populations of CM chondrite type I chondrules are $\Delta^{17}\text{O} \sim -6$ ‰, and type II chondrules are $\Delta^{17}\text{O} \sim -2$ ‰ (Fig. 2; this is consistent with CM type I and II chondrule data of [20,21]). Two dusty olivine chondrules have $\Delta^{17}\text{O}$ values (~ -2 ‰) identical to those of olivine in type II chondrules, potentially indicating they originated from CM type II chondrules (Fig. 2). Another dusty olivine chondrule (Murchison Ch23) has non-dusty, potentially phenocrystic, olivine with $\Delta^{17}\text{O} \sim -2$ ‰, and is relatively FeO-rich ($\text{Fa}_{9.5-10.3}$) for a dusty olivine chondrule, indicating it was reduced from olivine with

Fa>10, possibly a type II chondrule. However, the single O-isotope analysis of a dusty olivine grain in this chondrule (Murchison Ch23) has $Fa_{9.7}$ and $\Delta^{17}O = -5.9 \pm 0.8\text{‰}$, which is too ^{16}O -rich to be from a type II chondrule, and is instead closer to that of type I chondrules (Fig. 2). Since the FeO content of this dusty olivine grain is inconsistent with an origin from a CM type I chondrule, its origin is uncertain and requires precursor olivine with $Fa > 9.7$ and $\Delta^{17}O \sim -6\text{‰}$. The origin of this olivine is unknown, as it does not match any chondrule composition currently known (compared to data compiled in [22]).

The O-isotope compositions of five dusty olivine chondrules are tightly clustered at $\Delta^{17}O \sim 0\text{‰}$, and are distinct from the dominant populations of both type I and type II chondrules (Fig. 2). The distinct O-isotope compositions of these chondrules indicate that they contain components formed from an O-isotope reservoir unrelated to CM type I or type II chondrules. These ‘foreign’ olivines, or xenocrysts, must have been more FeO-rich than the current olivine compositions (e.g., $>Fa_{0.9-9.7}$). Murchison Ch25 may be an unaltered remnant of this precursor material. It is a chondrule fragment 0.175 mm by 0.491 mm (mean = 0.333 mm), which is larger than the mean size of CM chondrite chondrules of 0.27 mm [23,24]). Therefore, the chondrule it originated from was likely much larger than the CM chondrite chondrule mean size. Its O-isotope composition of $\Delta^{17}O = -0.2 \pm 0.8\text{‰}$ is similar to that of the $\Delta^{17}O \sim 0\text{‰}$ dusty olivine population, but with more FeO-rich olivine with a Fa content between 7.3 and 8.1 and shows no evidence for reduction. It is possible it is either an unaltered fragment of the material that migrated into the CM chondrule formation region that was then reduced to form the dusty olivine chondrules with $\Delta^{17}O \sim 0\text{‰}$, or an unrelated impact fragment delivered after CM parent body accretion.

The potential source(s) of the ‘foreign olivine’ that was incorporated into five out of eight CM chondrite dusty olivine chondrules could be chondrule fragments that migrated from another chondrule formation region(s), or fragments from partially/fully differentiated planetesimal(s). Chondrules from other meteorite groups with $\Delta^{17}O$ of $\sim 0\text{‰}$ are from: (1) the LL chondrites [25], (2) rare type II chondrules from the CR chondrites [e.g., 16,19,22], and (3) rare FeO-rich material from enstatite (E) chondrites [26,27]. Early-formed planetesimals could be the source of the $\Delta^{17}O \sim 0\text{‰}$ material; e.g., the brachinites contain FeO-rich olivine with a mean $\Delta^{17}O$ of $-0.24 \pm 0.08\text{‰}$ [28]. Although we do not find this likely due grain size and chronology [29, 30]. While FeO-rich material in the E chondrites is ubiquitous it is not abundant [26], therefore it may not be a likely precursor material. Both the UOCs and CR

chondrites are feasible candidates for the source material for the $\Delta^{17}O \sim 0\text{‰}$ grains found in CM chondrite dusty olivine chondrules. As type II chondrules are abundant in the UOCs [11] and rare in the CRs [16], we find that a source from UOCs is most likely.

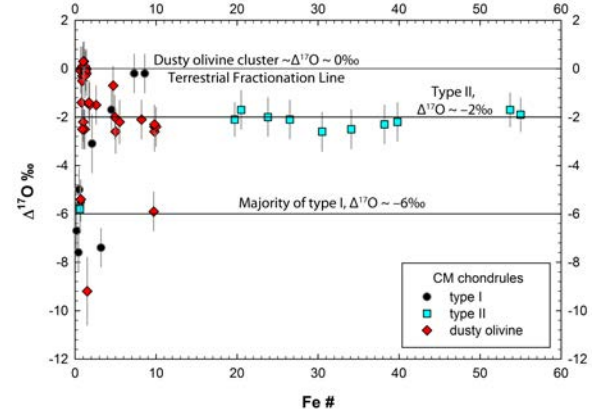


Fig. 2. $\Delta^{17}O$ vs. Fe# for olivine in CM chondrites.

The population of $\Delta^{17}O \sim 0\text{‰}$ dusty olivine grains in the CM chondrite chondrules that require a non-local source is intriguing, and argues for outward migration of UOC chondrules into the CM chondrite chondrule forming region. Determining the extent of chondrule migration among different meteorite groups will aid our understanding of radial migration in the early Solar System.

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