THE FORMATION OF MN-RICH CHONDRULE RIMS IN CO3.0 CHONDRITES. J. K. Kirk[1], P. Hyseni[1], F. Jorge-Chavez[1], V. Mendoza[1], D. Burns[2], S. Simon[3] and M. Telus[1] [1]University of California, Santa Cruz, Department of Earth and Planetary Science (1156 High Street Santa Cruz, CA 95064, jikkirk@ucsc.edu), [2]Stanford University, Department of Geological Sciences, [3]University of New Mexico, Institute of Meteoritics.

Introduction: Chondrules are small, once-molten, spherical objects, found in the meteorite class called chondrites. These grains are some of the most primitive materials from the early solar system and they recorded signatures of the protoplanetary nebula. Chondrules are typically made up of pyroxene and olivine with textures representative of thermal conditions under which they formed [1]. Chondrule textures have been shown to require peak temperatures of about ~1700 to 2100 K and cooling rates between 10 to 1000 K/hour [2]. While the exact formation mechanism is not known, many have been proposed [3, 4]. Distinct rims on chondrules, a feature that can offer insights into the conditions and heating mechanisms in the early protoplanetary nebula, have been observed in many chondrite classes [5, 6].

In this study we analyze previously observed Mn-rich rims in CO3 chondrites [8] with the aim to identify how compositions differ across petrologic types in order to deepen our understanding of the complex history of chondrule and chondrite formation. Through this analysis we can understand if these rims formed via a nebular or parent body process. Moderately volatile elements (MVEs) are sensitive to environmental conditions as they can be easily volatilized [9]. By focusing our study on Mn (a MVE), we can gain insights into the specific environmental conditions at the time of rim formation. Additionally, in this study we review a favorable heating mechanism for the Mn-rich rim formation.

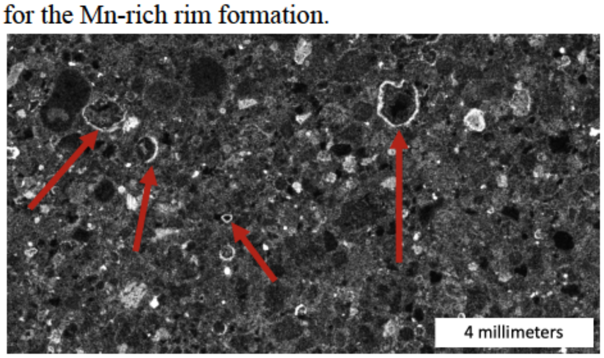

Figure 1. Mn synchrotron map [8] showing Mn enrichments along the rims of multiple chondrules from MIL 090038 (CO3.2). Rims pointed out with red arrows.

Methods: We analyzed four CO3 thin sections that host FeO poor chondrules with distinct Mn-rich rims: DOM 08006(40) (CO 3.0), ALHA 77307(58) (CO 3.0), DOM 10104(22) (CO 3.1), and MIL 090038(10) (CO 3.2). We identified chondrules of interest using previously created synchrotron X-ray fluorescence maps of thin sections from Telus et al. [8] (Figure 1). Samples were initially analyzed using the Apreo FE-SEM EDS at UC Santa Cruz followed by the JEOL JXA-8230 EPMA WDS at Stanford University for higher precision elemental analysis. With the EPMA, we analyzed three components (rims, host, and no rim chondrules) from a total of fourteen chondrules.

Results: Our initial SEM analyses revealed that the Mn-rich rims were primarily Ca-rich pyroxene around FeO poor chondrules. The pyroxene rims appear to be igneous due to the textures they exhibit (e.g., glassy mesostasis and FeS nodules).

The igneous rims are enriched in MVEs (Cr, Mn, Na, K) when compared to the host and unrimmed chondrules, as seen in Figure 2 [10]. There is not a large difference between samples of varying petrologic types. Clear differences exist between components. The host and no-rim chondrules exhibit many similarities.

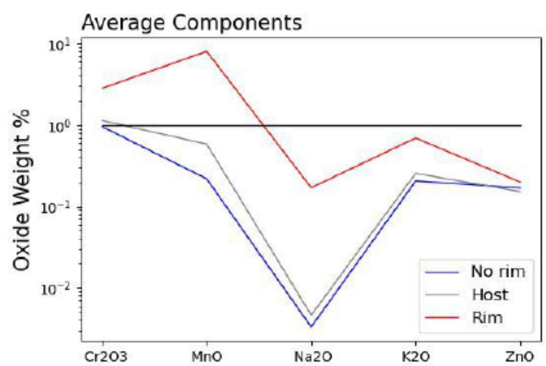

Figure 2. Plot showing average oxide weight percent for MVE of each component for measured CO3 chondrites. These values are normalized to CI and are the averages of each component across all samples studied. MVEs are in order of decreasing condensation temperature. Kirk et al [10] shows these data in more detail.

Discussion: Chondrule rims must have formed rapidly, based on the enrichment of MVEs (Cr, Mn, Na, K); otherwise these elements would have been lost. The igneous nature of the rims indicates there was a heating event and a phase of crystallization, separate from the chondrule formation event. There are no clear distinctions between petrologic types, which indicates that this heating process occurred in the protoplanetary nebula as opposed to on the chondrite parent body. A parent body process would leave signatures in MVE composition as their abundance would correspond to the degree of thermal metamorphism (petrologic types), which we do not see. The unknown heating process must affect individual chondrules in the nebula, prior to parent body accretion. The host and no-rim chondrule compositions overlap considerably, indicating that these likely formed under similar conditions, separate from rim formation conditions, further supporting the nebular origin of these rims.

Igneous rims are observed in other chondrite classes, both carbonaceous and non-carbonaceous chondrites, specifically H, L, LL, CV, CO, and CR chondrites [5, 7, 8]. This indicates that the process forming these rims happened in many different places in the nebula [7, 11]. Krot et al [5] proposed that these rims originated from the accretion of material onto chondrule surfaces after their formation, followed by heating and melting of that material [5]. This likely occurred in a different environment from the chondrule host since they have different enrichments of MVEs.

Igneous chondrule rim formation: One possibility for igneous chondrule rim formation is that these igneous rims formed from planetesimal bow shocks that heated and melted nebular dust, a leading model for chondrule formation. Planetesimal bow shocks occur when planetesimals orbit on eccentric orbits, producing short-lived, strong, shock waves which melt nebular dust [12-15]. These shocks were likely common in the protoplanetary nebula as early planetary bodies are thought to have existed at many different locations prior to the formation of many chondrules [13, 16, 17]. Variations in the size of each bow shock would depend on the size of the planetesimal and could influence variations in rim thickness [14].

Chondrule rims indicate secondary heating events. Boley et al [13] modeled bow shocks and their associated secondary heating events, called tail shocks. This study predicted the presence of a tail shock after the initial temperature peak. These are seemingly a potential rim formation mechanism as they create the conditions necessary for chondrule rim formation as well as MVE enrichment (Figure 3). The authors modeled temperature profiles of 20 different particles as a function of time, using different potential bow shock velocities (7 km/s, 8 km/s, and 9 km/s) under adiabatic conditions. The tail shock temperatures overlap with the condensation temperatures of MVEs as well as with the temperature regime in which chondrule melting is expected (Figure 3). This indicates that tail shocks may be a potential source of secondary heating and the MVE enrichment along the rims.

Bow shocks could potentially create regions enriched in MVEs behind the bow shock due to some chondrules being accreted onto the planetesimal, releasing volatile elements into the environment [2, 13, 17]. Thus, planetesimal bow shocks seem to be a good candidate for Mn-rich chondrule rim formation.

Conclusion: In this study we show that the Mn-rich rims are a result of a nebular process rather than a parent body process. The results of this study also show that the Mn-rich rims seen on CO3 chondrites likely formed from a secondary heating process, separate from the initial chondrule forming event. A promising potential heat source for the Mn-rich rims seems to be the tail shocks associated with bow shocks as explained in [13], as the condensation temperatures of MVEs (Cr, Mn, Na, and K) overlap with modeled tail shock temperature ranges. We aim to further explore this phenomenon in future studies.

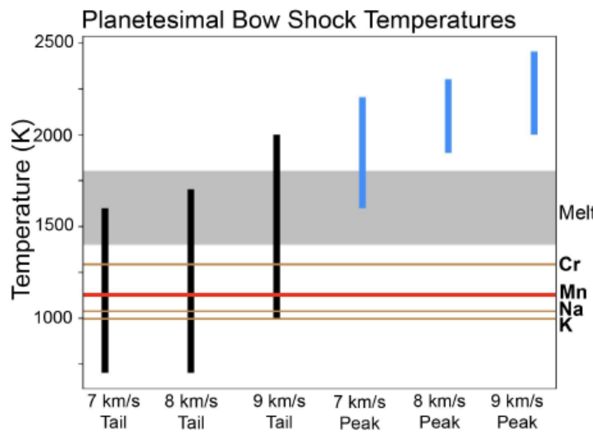

Figure 3. Temperature ranges of particles encountering the adiabatic bow shock front (blue) and tail shock (black) at various speeds [from 13]. Condensation temperatures of K, Na, Mn, and Cr and melting temperatures of chondrules are also shown [4].

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