TIMING OF FINE-GRAINED RIM FORMATION IN THE SUTTER'S MILL CM CHONDRITE. R. E. Beauford[1] and D. Sears[2]. [1]Arkansas Center for Space and Planetary Sciences, MUSE 202, University of Arkansas, Fayetteville, AR, 72701, USA. rbeaufor@uark.edu. [2]NASA Ames Research Center. E-mail: Derek.Sears@NASA.gov.

Introduction: The CM class primitive chondrites stand out among meteorite groups in preserving chemically delicate remnants of pre-accretionary nebular materials. As a time-capsule of pre-solar grains, volatiles, and organic materials originating in the early solar system, their matrix has been the subject of much study. Fine-grained rims (FGR) are dark halos of material that visibly surround chondrules (figure 1) within the matrix of many less-aqueously-altered examples of CM chondrites and in some other carbonaceous chondrites. They are often visible to the unaided eye or with a hand lens.

The way in which fine-grained rims (FGR) are related to the matrix of these meteorites has been the subject of some disagreement. Two primary viewpoints have dominated discussion. Some researchers, [1, 2, 3, 4] have presented arguments that FGR in CM chondrites represent pre-accretionary accumulations of nebular dust on chondrules, aggregates, and other particles in the nebular environment. This view places their timing of origin in the period after the formation of chondrules and prior to parent body accretion.

The pre-accretionary view has been challenged with post-accretionary explanations by the work of several other authors [5, 6, 7, 8]. This view explains FGR formation in terms of aqueous alteration on the parent body [5, 6] impact driven compaction in a wet targets, and differential aqueous alteration subsequent to compation and variants thereof. [7, 8]. These views state that FGR were not associated with chondrules, aggregates or other particles prior to parent body accretion, but that they are the visible result of post-accretionary diagenetic changes in the ordinary matrix that was captured with and surrounds the chondrules.

The Sutter's Mill CM chondrite, which fell in April of 2012, [9] offers potential new insights into the timing and formative context of these structures. Because the brecciated structure of the Sutter's Mill meteorite preserves, in its textural distinctions and inclusive relationships, a 3-dimensional record of the relative timing of its alteration, it can be used to constrain the timing of formation and circumstances of destruction of these delicate features.

The Sutter's Mill chondrite is a regolith breccia preserving visibly distinct clasts of at least 2 major accretionary lithologies that differ substantially in degree of aqueous alteration. These have been described as a chondrule-rich dark (CRD) and chondrule-poor light (CPL) lithologies. [9] and [10] The CRD lithology is less aqueously altered and preserves many inclusions. The CPL lithology is highly aqueously altered and has lost most distinguishable inclusion. These primary lithology clasts are termed 'primary' lithologies because they preserve the pre-brecciated, though variably metamorphosed, rock types that made up the CM parent body. The primary lithologies are preserved within a brecciated matrix composed of the comminuted remnants of these primary lithologies, breccia-in-breccia clasts, which are remnants of previous generations of plowed and indurated regolith, and potentially a minor component of at least one additional lithology.

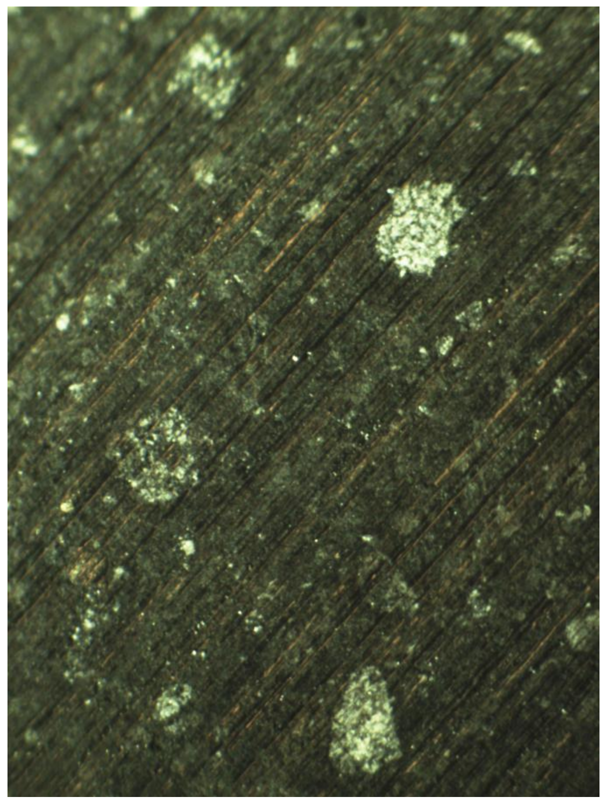

Figure 1. Fine grained rims are present around chondrules, CAI, and aggregates in clasts of primary lithologies within the brecciated Sutter's Mill CM chondrite.

Investigation: FGR-containing part slices of SM48, prepared with a wire saw by Marlin Cilz of Montana Meteorite Laboratory, were examined in macro photographs and photomicrographs using a Canon SD1300 IS digital camera and a Spencer binocular microscope with a 3.5MP digital camera. FGR structures were characterized using the Nova Nanolab FEG Scanning Electron Microscope and energy dispersive x-ray spectrometer at the University of Arkansas Nano-Bio Materials Characterization Facility.

Observations: Fine-grained rims in the Sutters's Mill meteorite are present in less-aqueously-altered CRD clasts and are lacking in regions of comminuted matrix, except where they are conserved within entrained clasts. The lack of renewed development of FGR around clasts or inclusions in the regolithic matrix, combined with their presence in the meteorite's dark primary lithology, appears to constrain timing and location of FGR development to the initial stages of compaction and zonal aqueous alteration of the parent body, prior to the disruption and entrainment of these clasts in a regolithic environment. This is directly observed from the apparent fact that they were developed and indurated in this lithology prior to excavation and regolithic entrainment of the relict clasts. By contrast, the textural and optical remnants of FGR have been obliterated, along with most other textural features and mineralogical variation, in the more aqueously altered component of the meteorite. It is also observed, that while an impact derived fabric is visible encircling some clasts within the regolithic matrix, (figure 2), there is no visibly quantifiable evidence of darkening or clast size reduction in this zone, only the evolution of a fabric.

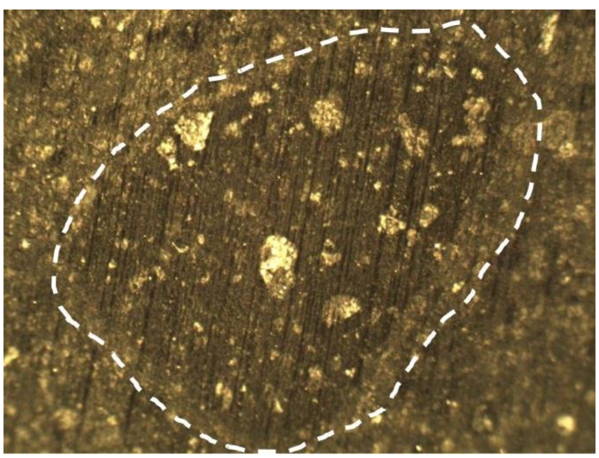

Figure 2. Fabric is visible around clasts in matrix, but shows no notably reduced grain size or darkening.

Discussion:

Based on these observations, several conclusions can be drawn.

Co-origin with CRD: Fine grained rims originate during or prior to evolution of primary lithologies. The FGR were in place and indurated prior to disruption, placing their timing in conjunction with the evolution of the primary lithologies recorded as clasts within our known suite of CM chondrite meteorites, and prior to the evolution of the regolith breccia that characterizes all of the meteorites of this type.

Cessation Prior to Brecciation: The process of FGR formation ceased prior to regolithic entrainment, and was not active in the regolith despite evidence of aqueous alteration active during this phase and within this context during parent body evolution. They do not appear to have formed around intact chondrules or clasts within the indurated matrix subsequent to brecciation. Where present, they are persistent around entrained chondrules and on chondrules associated with fragmented CRD clasts.

Relation to Fabrics in Regolith: The evolution of a fabric surrounding some clasts in the Sutter's Mill regolith breccia suggests that the mechanism of impact activity or compaction on matrix adjacent to hard surfaces may produce grain centered comminution or grain centered zones of decreased pore space, consistent with interpretation [7] of impact compaction effects. However, the fabrics present neither a darkening effect nor any noticeably substantial grain size reduction, suggesting that though the concept is valid, it may not constrain or inform the process of FGR development.

Conservation and Loss in Evolved Lithologies:

Two more observations may be made, though without immediate implication for the question of FGR development timing. First, during comminution, matrix fragments away from the chondrule-FGR grouping, rather than the matrix and FGR from the chondrule. And second, FGR are lost with increased aqueous alteration. These two facts mean that FGR may be conserved subsequent to mechanical disruption of lithologies but are less likely to survive aqueous evolution.

Acknowledgment: Thanks to Jerri Stevens for much support and assistance, to Steve and Qynne Arnold for the loan of research samples, and to the U. of Arkansas Nano-Bio Materials Characterization Facility for instrument access, and to Mourad Benemara for sharing his knowledge of electron microscopy.

References:

[1] Metzler, K. et. al. (1992) Geo. et Cos. Acta, 56: 2873-2897. [2] Metzler, K. (2004) MAPS, 39:1307–1319. [3] Zega, T. J. & Buseck, P. R., (2003) Geo. et Cos. Acta, 67:1711-1721. [4] Lauretta et. al. (2000) Geo. et Cos. Acta, 64:3263–3273. [5] Sears D. W. G., et al. (1992) Meteoritics, 27:288. [6] Sears D. W. G., et al. (1993) *Meteoritics,* 28:669–675. [7] Trigo-Rodriguez, J. M., (2006) Geo. et Cos. Acta, 70:1271-1290. [8] Takayama A. and Tomeoka K. (2012) Geo. et Cos. Acta, 98:1-18. [9] Jenniskens et al. (2012) Science, 21:338(6114):1583-1587. [10] Beauford R. E. et al. (2012) Met. Soc. Abstract #5091.