MICROCHONDRULES IN UNEQUILIBRATED ORDINARY CHONDRITES: INSIGHTS INTO CHONDRULE FORMATION ENVIRONMENTS. J. N. Bigolski[1, 2, 3], M. K. Weisberg[1, 2, 3], H. C. Connolly, Jr.[1,2,3,4], and D. S. Ebel[2,3]. Dept. Phys. Sci., Kingsborough Community College CUNY, Brooklyn, NY 11235, USA. [2] Earth and Envi. Sci., CUNY Graduate Center, New York, NY 10016, USA. [3] Dept. Earth and Planet. Sci., American Museum of Natural History, New York, NY 10024, USA. [4]Lunar and Planetary Laboratory, University of Arizona, 1629 E. University Ave., Tucson, AZ 85721, USA. Email: john.bigolski@kbcc.cuny.edu,

Introduction: Microchondrules (dia. ≤40µm) are a subset of chondrules that are not as well characterized as other chondrule types. In ordinary chondrites (OCs), they exclusively occur as ubiquitous components of fine-grained chondrule rims (FGRs). Microchondrules are also found in carbonaceous chondrites, e.g., in dark inclusions in CR chondrites [1], and are the major chondrule type in CH chondrites (avg. ~ 20 µm). The chondrule fragments, as well as refractory inclusions, found in the comet samples returned by Stardust are also micron-sized [2, 3].

Since microchondrules are an important component of chondrites and potentially comets, we focused our study on Northwest Africa 5717 (NWA 5717) because it is a highly unequilibrated (type 3.05) OC, previously described as having chondrules with FGRs harboring microchondrules [4, 5]. We also studied Semarkona (LL3.0) and Bishunpur (LL 3.15). Our goals are to document the abundance, distribution, petrologic and chemical diversity of microchondrules in OCs.

Background and Definition: The term "microchondrule" was coined by Levi-Donati [6, 7] to describe chondrules ≤ 250 µm, that occur in some OCs. Microchondrules were reported in numerous OCs as spherules ≤ 100 µm [8]; the definition was later changed to chondrules ≤ 40 µm [*cf.* 8, 9, 10], which we follow here. The microchondrules in OCs were interpreted to form by remelting of host chondrule surfaces and/or flash melting of dust around chondrules [11]. Dust and microchondrules then accreted around chondrules to form FGR. Summarizing previous research, microchondrules in OCs may be the products of microenvironments that persisted around chondrules prior to emplacement in FGRs. In this scenario, FGR formation is the initial stage of chondrite accretion, occurring between the time of chondrule formation and final accretion of the host chondrite.

Analytical Techniques: FGRs and their microchondrules were studied in detail using the JSM-6390 LV/LGS scanning electron microscope (SEM) with Quantax 200 EDS at Kingsborough and the Hitachi S4700 field emission SEM and Cameca SX100 electron microprobe at AMNH.

Results and Discussion: The microchondrules we studied in OCs exclusively occur in rims (Fig. 1, 2). Though their sizes reach apparent diameters of 200 µm, as in [5], most are ≤ 40 µm, as in [11]. They have a variety of textures, which include cryptocrystalline (CC), microporphyritic, and glassy. Some have shapes that suggest plastic deformation and compound objects are also observed. In NWA 5717, ~ 60% of all chondrules have FGRs, and of these ~ 20% contain microchondrules. The latter may be an underestimate since it is based on observations on thin sections. Microchondrule-bearing FGRs are considerably less abundant in Semarkona. However, 3D scanning (tomography) is in

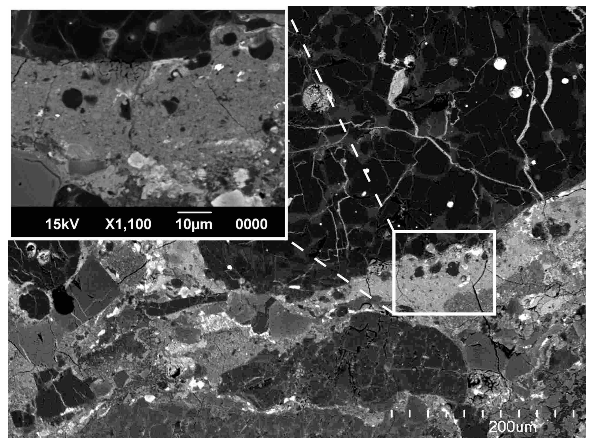

Fig. 1. BSE image of NWA 5717 showing a chondrule (725 µm x 680 µm) with a FGR (~30 µm thick). Inset shows detail of FGR with microchondrules < 10 µm in size.

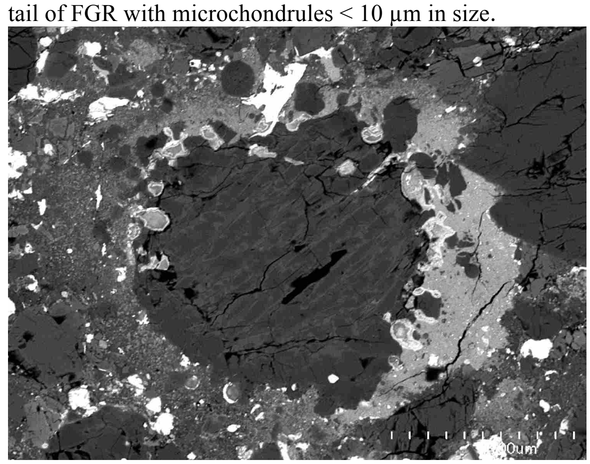
Fig. 2. BSE image of a barred olivine chondrule from Bishunpur (140 µm) that is surrounded by a FGR containing several microchondrules ranging from 5- 40 µm in size.

progress to better evaluate the physical properties and abundances of microchondrules. Chondrules from Bishunpur were previously reported to host FGRs which contain two types of microchondrules: abundant low-FeO, low-Ca pyroxene microchondrules and rare high-FeO olivine ($Fa_{52\pm9}$) microchondrules [11].

In these three OCs, ~90% of type I (Mg-rich) chondrules possess FGRs, while ~ 20% of type II (Mg-poor, FeO-rich) chondrules possess FGRs. This suggests differences (possibly in density of dust or energetics of chondrule formation) in the Type I and II chondrule forming environments. Bulk compositions of microchondrules by EPMA show a wide range of compositions. Averages (range) of 40 CC and glassy microchondrules (wt. %) are: SiO_2 – 54.6 (46.3-64.6), Al_2O_3 – 1.2 (0.2-12.3), Cr_2O_3 – 1.0 (0.5-1.8), FeO – 7.7 (1.4-18.0), MnO – 0.5 (0.07-1.1), MgO – 32.8 (7.8-39.3), CaO – 1.7 (0.2-9.4), Na_2O – 0.79 (0.05-7.8). Many CC microchondrules have compositions similar to low-Ca pyroxene, with Mg# (MgO/(MgO + FeO) ranging from 71 – 99 (avg. – 92; n=38). Some of these have compositions very similar to the low-Ca pyroxene phenocrysts inside the outermost edge of the host chondrule, as observed by [11]. Some CC microchondrules show evidence for partial or complete FeO enrichment (Fig. 3). Microporphyritic microchondrules have either olivine or pyroxene phenocrysts surrounded by a feldspathic groundmass, generally albitic in composition (Ab_{53}). Some olivine ($Fa_{59–87}$) compositions in microchondrules differ from that of olivine of their host chondrules. However, they occur in FGR regions where secondary FeO-enrichment is prevalent (e.g., Fig. 3). On the other hand, compositions of pyroxene phenocrysts and mesostases of many microporphyritic microchondrules are similar to those of their host chondrule, suggesting a genetic relationship.

Conclusion: We favor two hypotheses for microchondrule formation: 1) ablation of silicate liquid from the outermost portions of chondrule surfaces to form droplets; 2) melting of dust in a microenvironment to form droplets in the immediate vicinity of mm-sized chondrules. Thus, microchondrules may represent a stage of localized heating through which dusty microenvironments were subjected to multiple heating events and not just a single stage event as might be expected by a planetesimal-scale impact model for chondrule formation.

In shock wave models for chondrule formation [12], shock waves could have repeatedly processed regions of the nebula, allowing chondrules and surrounding dust to have been heated multiple times resulting in formation of the microchondrules. Chondrules could accrete the dust and microchondrules surrounding them within the nebula, forming the microchondrule-bearing FGRs observed in OCs. FGRs may also incorporate materials and microchondrules from other chondrule-forming regions.

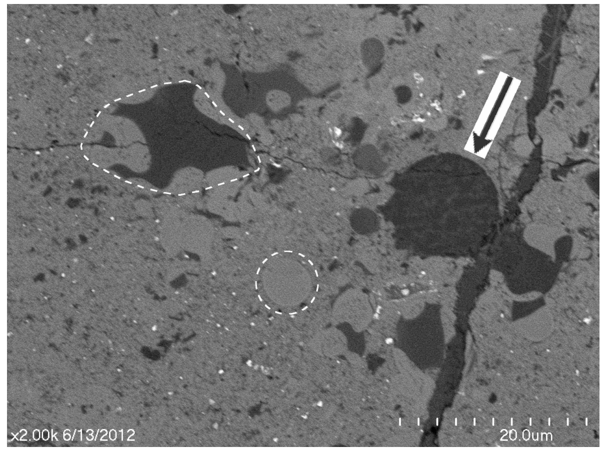

Fig. 3. BSE showing microchondrules in a FGR in NWA 5717. Microchondrules range 2-15 µm. Arrow denotes a microchondule with a microporphyritic texture. Some objects show varying amounts of FeO-enrichment (dashed outlines).

We are currently evaluating shock waves and current sheets as viable mechanisms of ablation of liquids from chondrule surfaces [12, 13, 14]. A workable model would predict widespread microchondrule formation in a dusty nebular region either during the initial stages of chondrule accretion, or during later stages of chondrule heating events.

We hypothesize that FGRs are records of the initial stages of accretion. The presence of plastically deformed objects suggests microchondrules were hot during rim formation. FeO-rich rinds around many of the CC microchondrules and other components in the FGRs suggest secondary alteration by vapor-solid reaction or fluids on the parent body.

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