IGNEOUS RIMS ON MICROMETEORITES AND THE SIZES OF CHONDRULES IN MAIN BELT ASTEROIDS. M. J. Genge, Department of Earth Science and Engineering, Imperial College London, Exhibition Road, London SW7 2AZ, UK. Email: m.genge@imperial.ac.uk.

Introduction: Micrometeorites (MMs) are that fraction of the extraterrestrial dust flux that survives atmospheric entry to be recovered from the Earth's surface. Two general types of MM are observed amongst those collected by melting and filtering of Antarctic blue ice: (1) fine-grained MMs (fgMMs) that have textures and compositions with affinities to the fine-grained matrices of C1, C2 and C3 chondrites, and (2) coarse-grained MMs (cgMMs) that are dominated by anhydrous silicates within glassy mesostasis. Coarse-grained MMs, as fragments of chondritic igneous objects, have been suggested to be samples of chondrules from primitive main belt asteroids [1].

Composite MMs consisting of igneous objects within fine-grained matrix have been reported by Genge [2]. The textural and compositional similarity between the fine-grained matrices of such composite particles and fgMMs, and the similarity between the igneous objects within composites and cgMMs represents strong evidence that cgMM are present as small, chondrule-like igneous objects on the same parent asteroids as at least a proportion of fgMMs [1].

One significant problem with the interpretation of composite MMs as samples of chondrule/matrix interfaces are their relatively low abundance amongst MM populations. Composite MMs represent only a few percent of particles that survived atmospheric entry without melting, however, based on geometrical considerations approximately 1/3 of 100 µm particles derived by fragmentation of a chondrite containing 1000 µm chondrules should sample the chondrule/matrix interface.

Both cgMMs and fgMMs exhibit igneous rims formed during atmospheric entry. Igneous rims on fgMMs have been shown to form as a result of thermal discontinuities generated by endothermic decomposition of low-temperature, volatile-bearing mineral phases within the fine-grained matrix [2]. Igneous rims on cgMMs, however, cannot be explained by such mechanisms since the precursors of these igneous objects lack such low-temperature phases [e.g. 1].

In the current work the occurrence and composition of igneous rims on cgMMs and fgMMs is compared and it is suggested that igneous rims on cgMMs form by melting of selvages of fine-grained matrix attached to the outside of the particle. Coarse-grained MMs with igneous rims thus represent composite MMs that have partially melted during atmospheric entry.

Textures and Abundances of Igneous Rims: Igneous rims on both fgMM and cgMM have similar mineralogies and textures. Igneous rims are usually dominated by micron-sized euhedral olivine microphenocrysts within a glassy mesostasis with accessory submicron iron-oxides. They are often highly vesicular and are associated with an external rim of magnetite crystals that is commonly found on all but the most and least heated MMs [3].

In the current study 36% out of a total of 130 unmelted fgMMs (i.e. excluding melted scoriaceous particles and cosmic spherules) were found to have igneous rims. The criteria used to identify igneous rims are the presence of an outer microporphyritic layer >5 µm wide surrounding a core of unmelted fine-grained matrix. Particles containing several areas of relict unmelted matrix embedded in a scoriaceous groundmass are considered melted scoriaceous micrometeorites and were not included in this study. Since igneous rims probably represent the initial stages of melting of hydrous particles they are likely to grade into melted scoriaceous particles with relict unmelted matrix.

Amongst the MMs randomly selected for the current study 18% of cgMMs were found to have igneous rims. Most have microporphyritic textures similar to the igneous rims on fgMMs, a few, however, are glassy.

The apparent area of igneous rim compared with the total particle cross-sectional area were measured from backscattered electron images. In most cases particles were sectioned approximately across their middle, however, differences in the plane of section make apparent areas subject to large degrees of a uncertainties. The results, however, suggest that igneous rims on fgMMs comprise up to 60% by volume of particles whilst igneous rims on cgMMs are restricted to <25% by volume.

Compositions of Igneous Rims: The compositions of igneous rims on both fgMM and cgMM are most similar to that of the fine-grained matrix of MMs. Igneous rims on fgMM are, however, usually depleted in volatile and moderately volatile elements such as S, Na, K and P compared with the unmelted core of the particle, presumably due to partial evaporation during heating in the atmosphere. In a significant proportion of fgMMs igneous rims also have small enrichments in Fe relative to the unmelted core. Iron-enrichments are problematic but are probably related to the formation of the external magnetite envelope.

Igneous rims on cgMMs have compositions that bear a closer similarity to the compositions of matrix in fgMMs than the bulk composition of the unmelted core of the particle. One of the 9 cgMMs reported in the current study (CP94-100-166) has a core dominated by fine-grained radiating pyroxenes within a glassy mesostasis and yet the composition of its igneous rim is not pyroxene normative but in the range of the compositions of rims from fgMMs. The igneous rim on CP94-100-166 evidently did not form by direct melting of its core.

The Formation of Igneous Rims: Flynn et al [2] explained the formation of igneous rims on hydrated interplanetary dust particles by the presence of surface-correlated thermal discontinuities supported by endothermic decomposition reactions of hydrated silicates. This mechanism, in which thermal decomposition acts as an energy sink, is consistent with the precursor mineralogy of fgMMs, which is thought to be similar to C2 and C1 chondrites. Coarse-grained MMs, however, lack low temperature phases that could support thermal gradients. Igneous rims on coarse-grained micrometeorites are, therefore, unlikely to have formed by direct melting of the core of the particle.

The composition of igneous rims on cgMMs is within the range of those of fgMMs for 15 major and minor elements examined in the current study. Fine-grained matrix attached to the outside of the coarse-grained core may, therefore, have melted during atmospheric entry to form igneous rims. Fine-grained matrix has a solidus temperature of ~1350°C significantly lower than the melting temperature of the constituents of cgMMs. Selvages of fine-grained matrix on cgMMs will, therefore, have melted during atmospheric entry prior to the fusion of the core of the particle and potentially could have wetted the external surface.

Composite MMs consisting of a coarse-grained MM with attached fine-grained matrix have been previously identified by Genge et al., [1]. These particles usually consist of a large cgMM core with a volumetrically minor proportion of fine-grained matrix. This is consistent with the observation that the igneous rims on cgMMs comprise <25% by volume of the particle.

The Sizes of Chondrules: Based on their mineralogy and composition Genge et al., [1] has argued that the majority of cgMMs represent fragments of chondrules. Composite MMs, which contain both igneous objects and fine-grained matrix were also suggested to represent samples of the chondrule-matrix interface.

The ratio of composite MMs/cgMMs provides a means of estimating the average size of chondrules on the parent asteroids of MMs. The proportion of cgMMs that sample chondrule/matrix interface, if these are derived by random fragmentation of spherical precursors, can be calculated from equation 1, where R is the radius of the precursor chondrules and r is the radius of the collisional debris.

$$f = 1 - \frac{(R-r)^3}{(R+r)^3} \quad (1)$$

Eighteen percent of cgMMs in the current study have igneous rims and 8% are composites. Approximately 26% of cgMMs 50-100 µm in diameter examined in the current study, therefore, are likely to sample chondrule/matrix interfaces. By considering the fraction of particles expected to sample the interface, given by equation 1, the average radius of chondrules in the parent asteroids of MMs can be estimated as between ~500 and ~1000 µm broadly similar to those within chondritic meteorites. Since this estimate is based only on the abundances of cgMMs it relates specifically to those parent bodies that contain chondrules and probably excludes the parent asteroids of C1 type fgMMs [4].

Several cgMMs have been identified that preserve smooth curved surfaces that are likely to represent the external boundaries of their precursor chondrules. These objects are usually radiating pyroxene cgMMs and often lack selvages of fine-grained matrix or melted rims. The presence of such particles indicates that the estimate of average chondrule size given above is an upper limit to the average.

Conclusions: The mineralogy, texture and composition of igneous rims on MMs strongly suggests that rims on cgMMs form by melting of selvages of fine-grained matrix. Coarse-grained MMs with igneous rims, therefore, represent samples of the interface between chondrules and fine-grained matrix from primitive asteroids and thus are heated equivalents to composite MMs. The abundance of these samples of chondrule/matrix interfaces allows an estimate of the average chondrule size in the parent asteroids of MMs to be determined and suggests sizes similar to those of chondrites. If MMs are a more extensive sampling of main belt asteroids than meteorites then these observations suggest that chondrule formation was not only widespread within the solar nebula but also resulted in a limited range of chondrules sizes.

References: [1] Genge M. J. and Grady M. M. (2001) MAPS, 36, A63, [2] Flynn G. J. (1995) LPS XXVI, 505. [3] Genge et al., (1997) GCA, 61, 5194, [4] Genge M. J. & Grady M. M. (2002) *LPS XXXIII*, Abstract #1010.