MORPHOLOGICAL STUDY OF INSOLUBLE ORGANIC MATTER RESIDUES FROM PRIMITIVE CHONDRITES. H. G. Changela[1], R. M. Stroud[1], Z. Peeters[2] L. R. Nittler[2], C. M. O'D. Alexander[2], B. T. De Gregorio[3] and G. D. Cody.[2] 1 Naval Research Laboratory, Code 6366, Washington, DC. 2 Carnegie Institution, Washington, DC. 3 NASA Johnson Space Centre /ESCG, Houston, Texas. Email: Changela@anvil.nrl.navy.mil

Introduction: Insoluble organic matter (IOM) constitutes a major proportion, 70-99%, of the total organic carbon found in primitive chondrites [1, 2]. One characteristic morphological component of IOM is nanoglobules [3, 4]. Some nanoglobules exhibit large ^{15}N and D enrichments relative to solar values, indicating that they likely originated in the ISM or the outskirts of the protoplanetary disk [3]. A recent study of samples from the Tagish Lake meteorite with varying levels of hydrothermal alteration suggest that nanoglobule abundance decreases with increasing hydrothermal alteration [5]. The aim of this study is to further document the morphologies of IOM from a range of primitive chondrites in order to determine any correlation of morphology with petrographic grade and chondrite class that could constrain the formation and/or alteration mechanisms.

Samples and Methods: IOM residues [1] from the CM and CR primitive chondrites: MET 01070 (CM 2.0) Cold Bokkeveld (CM 2.2), Murchison (CM 2.5), Bells (CM 2) and QUE 97990 (CM 2.6); GRO 95577 (CR1), Al Rais (CR 1/2), EET 92042 (CR 2) and QUE 99177 (CR 3) were embedded in S and glued to epoxy stubs. A Leica EM UC7 ultramicrotome was used to obtained slices at a nominal 70 nm thickness, which were then placed on carbon film TEM grids. Annular dark-field (ADF) scanning transmission electron microscopy (STEM) imaging of the residues was performed with the NRL JEOL 2200FS.

Morphological Classifications: IOM textures were classified as either having a 'globular' morphology, *i.e.*, spherical, non-porous regions approximately 50-1000 nm in size; 'fluffy', *i.e.*, porous material with fine scale heterogeneity extending to below 50 nm; and 'dense-irregular', *i.e.*, uniformly dense, non-spherical material >50 nm (Fig. 1).

Nanoglobule Fractions and Sizes: ADF images were taken of each residue, sampling ~ 100 μm^2 of each IOM sample. The different morphologies were manually identified from the images and masked with Adobe Photoshop. Area fractions were then obtained with ImageJ software. Because some small globules (<100 nm) are difficult to distinguish from the background of fluffy IOM, our results reflect a lower limit on globular abundances. The nanoglobule masks were also processed through ImageJ in order to measure their equivalent diameters. We identified ~100-150 nanoglobules across the IOM samples.

Fractal Box Counting: The overall variation in IOM textures among the different residues, including all identified morphologies, was investigated by means of image based fractal analysis, with the ImageJ plugin FracLac [6].

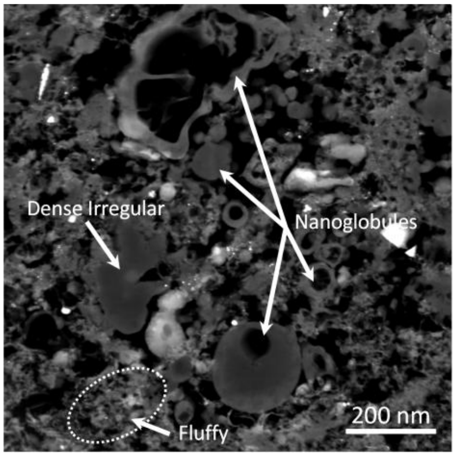

Fig 1. IOM residue from Bells CM chondrite. ADF image from Bells IOM showing the distinctive morphologies defined for chondritic IOM.

FracLac provides a measure of the complexity of the features in an image, represented by the fractal dimension DB. DB measures the ratio of increasing detail with increasing scale [6], allowing quantitative distinction between "coarse" and "fine" textures. The level of detail as a function of scale is determined by the box counting method. The boundaries of the IOM are defined from images thresholded with ImageJ. The boundary images are then subdivided into a two dimensional array of boxes so that the number of boxes that contain a boundary feature can be counted. This is repeated 6 times to cover box sizes of 2×2 px^2 up to 64×64 px^2 in a power law series. The individual images were all 1024×1024 in size, at 4.64 nm/px. All residues showed positive box counts at the largest size (64×64), but the more texturally "coarse" residues had fewer positive counts for the smaller box sizes. Approximately 10 images from each residue were analyzed to measure an average DB value, sampling ~ 2300 μm^2 of IOM.

Results: Nanoglobule abundances range from ~ 2.3-7% of total IOM by area (Fig. 2). There is no obvious correlation between nanoglobule abundance and degree of alteration of CRs and CMs. However, small variations in the nanoglobule size distributions are observed: the most altered chondrites have slightly higher median nanoglobule equivalent diameters which is more noticeable in the CR chondrites (126, 108, 138

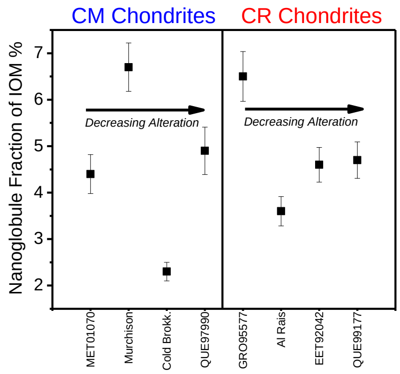

Fig 2. Nanoglobule area fractions. Nanoglobule abundances are broadly consistent across the CR and CM chondrites. Error bars are Poisson errors.

and 135 nm for GRO95577, QUE99177, MET01070 and QUE97990 respectively). The more altered chondrites such as GRO95577 and Al Rais have some additional morphologies with what seems to be porosity intermediate between fully dense and fluffy.

Fractal analysis of the IOM residue images shows a decrease in DB with increasing alteration (Fig. 3). This indicates that the IOM from more altered chondrites has less fine-scale detail, *i.e.*, it is coarser in texture, than the less altered chondrites.

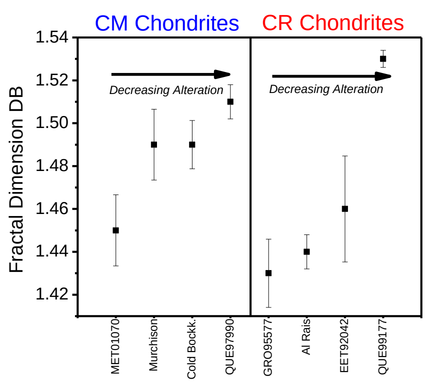

Fig 4. Average Fractal Dimension (DB) values of CR and CM IOM. Error bars are from variation of DB across ~10 images per IOM sample. Decreasing alteration is from left to right.

Morphological Variation of CR and CM IOM: The total range of CM and CR nanoglobule abundances is similar to that observed in different Tagish Lake stones (0.9% to 7.5%) [5]. However there is no simple correlation with degree of alteration. The variations in texture of the IOM from the CR and CM chondrites do, however, correlate with alteration.

Our results indicate that chondrites from an assumed common parent body contain IOM with distinctive properties related to petrographic grade, affirming that parent body processing played a key role in the final state of IOM, and consistent with interpretations made by [5].

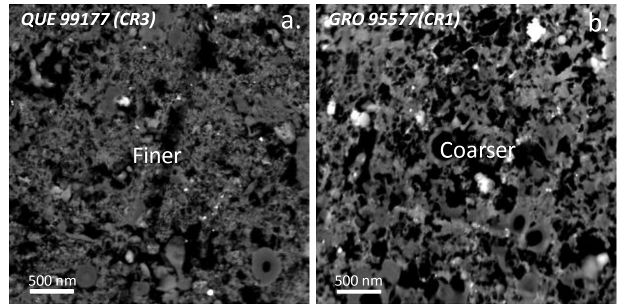

Fig 5. Representative ADF images of QUE 99177 and GRO 95577 IOM. (a) QUE 99177. (b) GRO 95577. The IOM from the more altered CR chondrite is distinctively coarser than that from its least altered counterpart, QUE 99177.

An effect of larger degrees of parent body alteration is to coarsen the texture of the IOM. The change in the feature size of the fluffy IOM is clearly visible, whereas because the globules are already larger than the fluffy component the relative change is small, only a subtle shift in globule size can be detected. The coarsening is presumably tied to parent body factors such as water/rock ratio, peak temperature and pH, but the mechanism(s) are not yet fully understood. Additional insight will likely require comparison with IOM texture studied *in situ*, in which the petrographic context, including the spatial relation of globules, fluffy IOM, dense irregular, mineral grains and voids or cracks is retained. Our parallel *in situ* study of organic matter (OM) in QUE 99177 has identified OM inclusions that are chemically and morphology consistent with IOM [7, 8]. They are also intimately associated with secondary mineralogy in the form of Ca carbonate and Ca sulfates. The observed morphologies vary from clusters or individual inclusions of distinctive hollow and solid nanoglobules, but also pockets of fluffy IOM [8]. In light of this study, fluffy components of OM found *in situ* within more altered CM and CR chondrites (*e.g.*, GRO 95577) should be analyzed to compare with the IOM results reported here. Moreover, studies for systematic variations in the petrographic context of the OM *in situ* should also be made.

References: [1] Alexander C. M. O'D et al. (2007) *Geochimi. Acta 71*, 4380-4403. [2] Pizzarello S. et al. (2006) *in Meteorites and The early Solar System II*, 625-651 [3] Nakamura-Messenger K. et al. (2006) *Science 314*, 1439-1442. [4] Garvie L. A. J. and Buseck B. R. (2004) *Earth Planet. Sci. Lett., 224*, 431–439. [5] Herd C. D. K. et al. (2011) *Science 332*, 1304 -1307. [6] A. Karperian (2005) FracLac for ImageJ-FracLac Advanced User's Manual. [7] Peeters et al. (2011) *Meteorit. Planet. Sci. 46*, A185. [8] Peeters Z. et al. (2012) this meeting.