TEM STUDY OF INSOLUBLE ORGANIC MATTER IN PRIMITIVE CHONDRITES: UNUSUAL TEXTURES ASSOCIATED WITH ORGANIC NANOGLOBULES

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Introduction: Insoluble organic matter (IOM) is an acid insoluble fraction of organic matter (OM) in extraterrestrial materials. IOM constitutes a major proportion, 70-99%, of total OM found in primitive meteorites [1]. It is present as solid macromolecular organic material that is largely made up of small aromatic moieties with short, highly branched aliphatic moieties that forms side chains on and cross links between the aromatic moieties [2]. Isotopic anomalies in IOM (enrichments in D/H and $^{15}N/^{14}N$ ratios relative to solar and terrestrial values) point to an origin in cold molecular clouds and/or the cold outskirts of the protoplanetary disk [3,4]. It is, however, not clear what species were the carriers of these isotopic enrichments that accreted onto the parent body. One characteristic component of IOM is nanoglobules: often hollow, carbonaceous spheres [5]. Some of these nanoglobules comprise of isotopic hotspots, invoking an origin in the solar nebula or interstellar cloud [e.g. 6].

IOM residues are aggregates of demineralized material making up a complex network of OM with submicron to nanometerscale variation. Although the petrographic context is lost in these residues, they provide the possibility of rapid TEM-based characterization of the major IOM morphologies. We previously determined that the abundance of manually identified nanoglobules does not systematically vary with petrographic grade among CR and CM meteorites [7]. However, Changela et al. [7] used image based fractal box counting analysis to suggest an average increase in feature size of the submicron IOM texture in the more altered CM and CR petrologic types. We report here unusual morphologies in the IOM also found from this study and briefly discuss their possible origins.

Samples and Methods: IOM residues from the following CM and CR chondrites were analyzed: MET (Meteorite Hills) 01070 (CM 2.0), Cold Bokkeveld (CM 2.2) and the CR chondrites, GRO (Grosvenor Mountains) 95577 (CR1), Al Rais (CR 1/2), EET (Elephant Moraine) 92042 (CR 2) and QUE (Queen Alexander) 99177 (CR 3). The IOM residues were prepared by the CsF method described in [2,3]. Several grains from each IOM residue were mixed with sulphur, embedded by melting the S based mixutre on a hotplate and then glued to epoxy stubs. A Leica EM UC7 ultramicrotome was used to obtain sections 70 nm sections and then placed on carbon film TEM grids. Annular darkfield (ADF) scanning transmission electron microscopy (STEM) imaging of the residues was performed with the Naval Research Laboratory's JEOL 2200FS.

Results: The demineralization process used to produce the residues obscures the original spatial distribution between IOM components. However, many discrete objects were found with a nanoglobule-like morphology, such as a round central void, but also containing additional unusual textures (Fig. 1). Their external boundaries vary between smooth (Fig 1a), petal-like (Fig. 1b), and irregular (Fig. 1c). Pores can be found in the nanoglobules varying from fluid-like arrays (Fig 1a), to mixed fine scale porous and dense textures (Fig. 1d, f). Nanoglobule objects (Fig. 1i) with rinds or multiple layers are also observed. They were mostly found in the IOM of the more altered chondrites.

Discussion: We previously attemped to classify the distinctive IOM morphologies in the CM and CR IOM into the categories of: (1) solid and hollow nanoglobules; (2) dense irregular material - uniformly dense, non-spherical material >50 nm across, and (3) fluffy, porous material. Matrajt et al. [8] classified the OM morphologies found in anhydrous IDPs. They identified dense and hollow nanoglobules but additional fine scale textures such as 'spongy and 'fluffy' material. Figure 1 shows an array of unusual IOM textures, as well as a characteristic hollow nanoglobule (e.g. Fig. 1c). These are similar to both nanoglobules and dense irregular material, but contain an abundance of fine-scale pore or vesicles. As all but the most aromatic globules [9] share the same general functional chemistry as the identified 'non-globular' IOM, this suggests that the morphological variations in these nanoglobules and the other distinctive morphologies (e.g. spongy or fluffy) are linked by a common process. A possible common process to explain these morphologies could have involved the mixing and/or cavitation of a medium such as a fluid or a multilayer emulsion. A common post-accretionary processing history is therefore favorable for such conditions. Surfactants and organic block polymers were previously suggested as possible chemical precursors for nanoglobules [5], and may also be important because they can account for the IOM morphologies seen here. Effects due acid dimeralisation on indigenous meteoritic OM should also not be ruled out. We note that these unusual features were more readily found in the more altered primitive chondrites. Additional studies, performed in situ, will be required and are currently underway [e.g. 10].

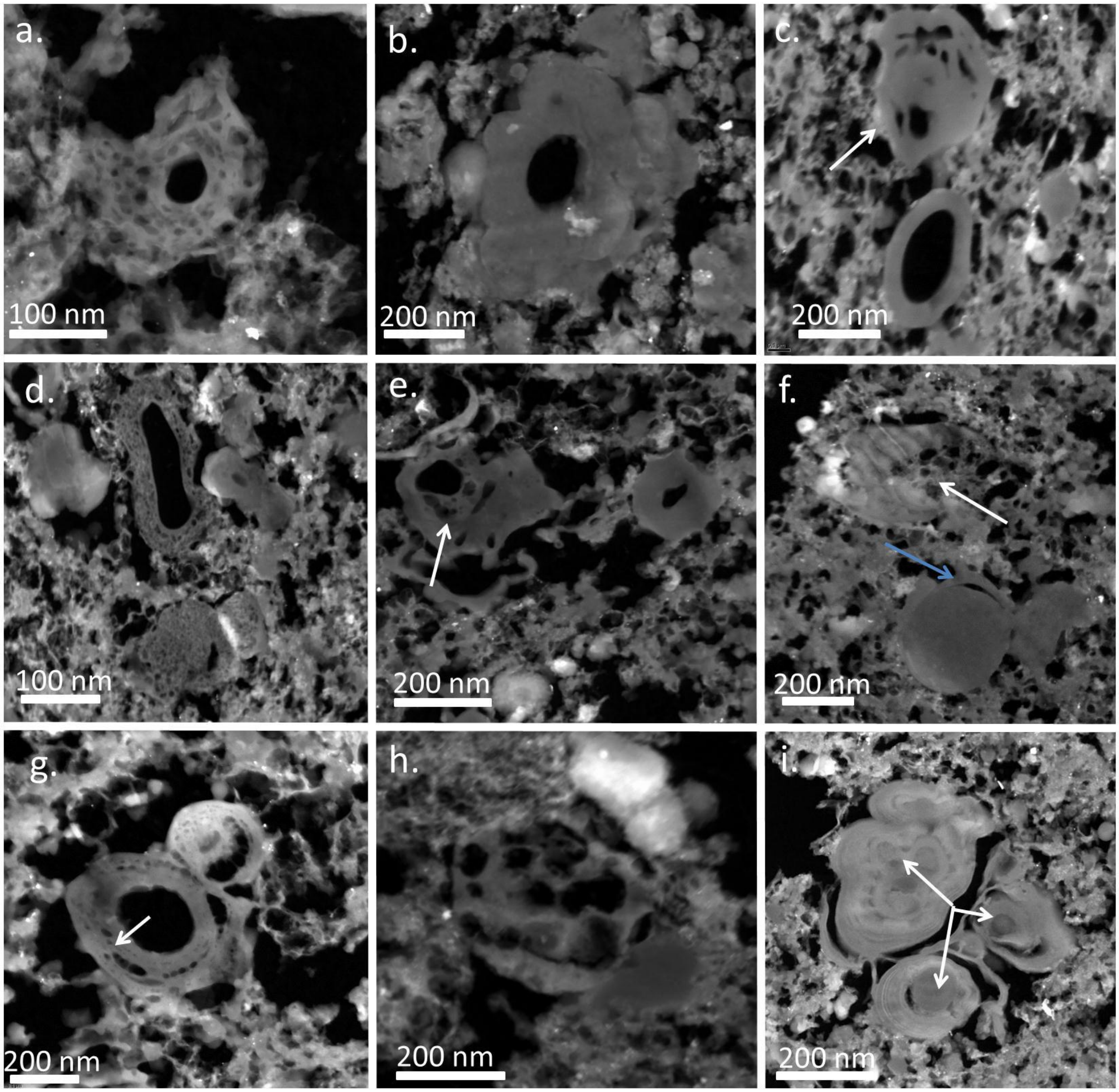

Figure 1. ADF images of some unusual nanoglobular features in CR and CM IOM. Dark regions in the images indicate void space. (a) A nanoglobule-like object in QUE 99177 IOM with a perfectly circular hollow core, containing an internal porosity which tapers off to a tail of finer pores. (b) A nanoglobule from EET 92042 having a perfectly round hollow core but a 'flower' shaped boundary. (c) A nanoglobule-like object in GRO 95577 adjacent to a typical hollow nanoglobule with multiple irregular pores (arrowed). (d)-(f) Al Rais. A hollow and solid globule with fine scale porosity in (d). (e) Two nanoglobules. The arrowed globule has pores along its rim and dense irregular material attached to it. (f) A solid globular feature seemingly degrading into fine scaled porous material. A thin rind (blue arrow) is also associated with a solid globule. (g) A pair of nanoglobules from MET 01070. The larger globule has pores in them equidistant from its center (arrowed). (h) An object from Cold Bokkeveld containing large pores (i) Objects with multilayers or rinds surrounding densely packed, nanoglobule-like material (arrowed).

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