THE VARIETY OF MACROMOLECULAR ORGANIC MATERIAL IN PRIMITIVE CHONDRITES

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Introduction: Primitive chondrites – meteorites retaining the most pristine record of primary nebular and interstellar components – provide the most accurate record of early Solar System prebiotic evolution. Microanalytical studies of soluble (SOM) and insoluble (IOM) organic bulk meteorite separates coupled with the characterization of organic material OM *in situ* provide a comprehensive account of OM [1]. Carbonaceous chondrites (CCs) have the highest concentrations in both SOM and IOM with up to ~3 wt % total organic carbon (TOC) [2]. Generally, hydration in the CCs positively correlates with the abundance of TOC [3]. In the most hydrated CCs such as the CI, CR, and CM groups, although their organic mass fractions are minor to trace in bulk [3], their volumetric distributions in their matrices are ubiquitous on the nano-scale [4]. Micron to submicron organic particles [5] occur in primitive chondrite matrices consistent with the composition of IOM. IOM is acid insoluble, solid macromolecular organic material largely made up of small aromatic groups with short, highly branched aliphatic moieties forming side chains on and cross links between the aromatic moieties [1]. As well as CCs, unequilibrated ordinary chondrite (UOC) matrices contain macromolecular organic material at least up to petrologic type 3.6 [6]. The focus of this study is its characterisiation *in situ*, summarising the variety in morphology, distribution and functional chemistry in primitive chondrites, and the implcations this has on understanding the nature of macromolecular organic carbon from the carbonaceous Asteroid 162173 Ryugu (Ryugu from here on in) sampled by the *Hayabusa*-2 mission.

IOM Occurences: *Carbonaceous Chondrites*. In CC matrices, macromolecular organic particles are mostly surrounded by either submicron (Fe, Mg, Al) hydrated amorphous- or phyllo- silicate grains and finer Fe, Ni sulphide grains (e.g. [5]). Organic particles have rounded morphologies and compositions consistent with IOM. They mostly display the 3-peak aromatic/olefinic (C=C) – carbonyl/phenol (C=O) – carboxyl/ester (COOH) functional chemistry of IOM by C X-ray Absorption Near Edge Strcuture (XANES). Less abundant 2-peak (C=C)-(COOH) particles also occur which display higher aromatic peaks than the 3-peak organic particles [7]. A diffuse organic component carboxylic-richer but aromatic-poorer than organic particles, sometimes with an additional carbonate (CO3) peak OM, occurs within volumes of amorphous silicates and phyllosilicates [4].
Unclassified CCs. Macromolecular organic carbon can be found unique to that typically found in CCs. For example, in the unclassified CC Ningqiang, OM occurs as a distinct groundmass surrounding mostly fayalitic olivine [8]. The organic material also contains nano sulphides and chromites in an organo-mineral assemblage. Carbon XANES shows the characteristic 3-peak (C=C)-(C=O)-(COOH) functional chemistry but higher carboxyl/ester peaks than organic particles in CCs. Such spectra shares similarities with oil mature bitumens on Earth [9].
Unequilibrated Ordinary Chondrites. Every organic particle reported in UOC matrices [6] are 2-peak, with exception to a broad aromatic XANES from a grain in LEW 87284 (L3.6). Furthermore, the aromatic peak area increases with higher petrologic type up to UOC 3.6 [6], after which organic particles do not occur. UOCs record higher mild metamorphic petrologic peak temperatures as well as within the IOM [10] implying that the aromatic 2-peak population of organic particles evolved by elevated mild metamorphic peak temperatures.

Relevance to Asteroid Ryugu: Preliminary examination results e.g. [11,12] show that C-XANES 3-peak and 2-peak organic particles occur, characteristic of most organic particles found in primitive chondritic IOM. Of particular note is that 2-peak organic particles in Ryugu seem to be in a higher abundance [12] than those found previously in CCs *in situ* [e.g. 4,5,7]. This may reflect elevated thermal effects associated with C1-type alteration on Ryugu than those found in e.g. the CR1 GRO95577 [5] and recorded by the aromatic 2-peak aromatic organic particles in the low petrologic type UOCs such as Semarkona [6]. Temperatures as a function of time causing these effects are however are unclear. Further studies of the macromoleular organic varation *in situ* in primitive chondrite matrices of varying petrologic type and Ryugu may shed some more light on its evolution on carbonaceous asteroids.

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