A high spatial resolution investigation of methanol soluble organic matter from carbonaceous chondrites by DESI-TOF-MS.

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While sample return missions, such as JAXA's Hayabusa2 and NASA's OSIRIS-REx, are delivering relatively uncontaminated materials from primitive asteroids to the Earth (1, 2), carbonaceous chondrites still represent by far our largest inventory of primitive solar system material available for study. Carbonaceous chondrite meteorites are fragments of asteroids that escaped their parent bodies and survived passage through the Earth's atmosphere. Petrographic type 1-3 carbonaceous chondrites, in particular, hold many clues about the formation and evolution of organic material, both prior to the initiation of the Solar System and throughout its history (3). For example, insoluble organic matter (IOM) and soluble organic matter (SOM) (e.g. amino acids and nitrogen heterocycles) have been suggested to form in the interstellar medium, protosolar nebular or on the icy planetesimal progenitor of a given asteroid (2, 4, 5). Accordingly, there is strong evidence that all of the above environments could both originate and evolve organic matter.

In all of the aforementioned environments, organic matter is thought to associate with mineral phases at some point, whether this is through gas-grain interactions in a molecular cloud or protosolar nebular or during organic matter synthesis involving mineral catalysts on an icy planetesimal (4, 6). Thus, understanding the relationships between organic matter and mineral phases offers a potential way to decipher the complex formation and alteration history affecting meteoritic organic matter. Accordingly, a number of previous studies have investigated the spatial distribution and mineral organic-matter relationships involving IOM (6, 7).

Despite the interest in IOM-mineral relationships, SOM-mineral associations have been much less well investigated. One reason for this is the lack of high spatial resolution techniques available for the characterisation of SOM distributions in carbonaceous chondrites. However, one technique in particular offers strong potential for investigating meteoritic SOM. Desorption electrospray ionisation-mass spectrometry (DESI-MS) has been utilized to study nitrogen heterocycle compounds in both carbonaceous chondrites and the Ryugu samples (2, 8, 9). Evidence of a geochromatographic effect was observed, where by the mineral matrix of carbonaceous chondrites may be causing homologues of a given organic compound class to separate during aqueous alteration of their progenitor planetesimals (8, 9). Moreover, a correlation between phyllosilicates and low molecular weight homologues was also observed that may infer these minerals could be protectors of such organic molecules during potentially destructive aqueous alteration (9). Yet the DESI-MS technique suffers from a lack of spatial resolution, being limited in the aforementioned studies to between 50 and ~30 μm^2.

Recently, Waters Corporation developed a DESI system capable of routinely achieving 20 μm^2 spatial resolution, when coupled to a time of flight mass spectrometer. Here we apply this system to the carbonaceous chondrites Orgueil (CI1), Murchison (CM2) and Aguas Zarcas (CM2), in order to decipher their mineral-organic relationships and understand the processes responsible.

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