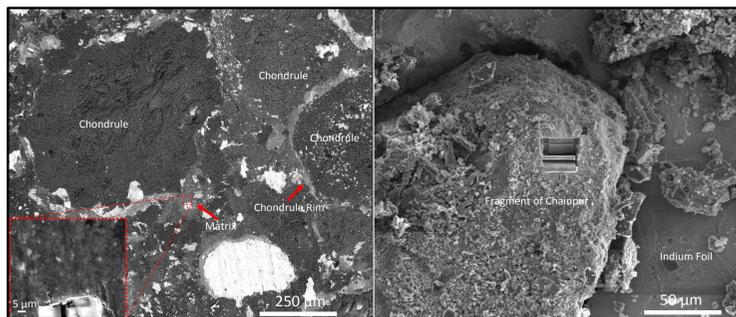
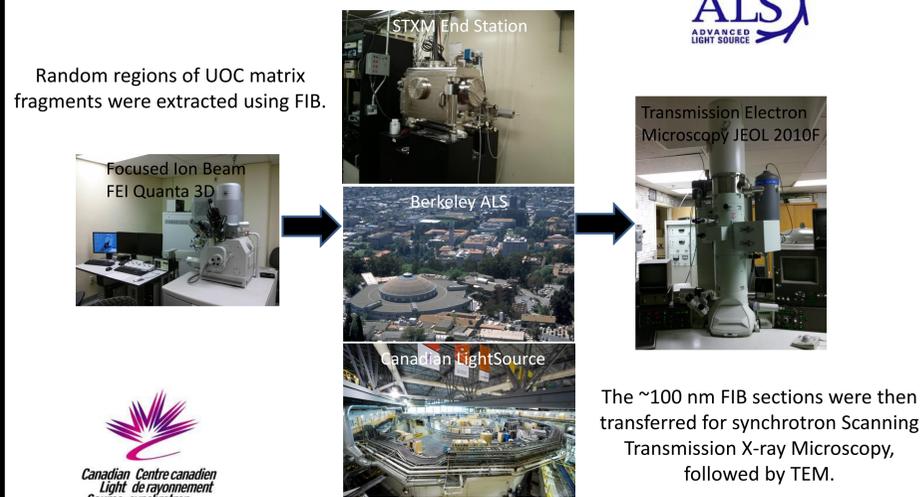


Organic Material in the UOCs

Organic material (OM) in carbonaceous chondrites (CCs) makes up to ~2 wt. % carbon that is insoluble and is mostly found in their matrices [1]. Solid OM inclusions are randomly distributed in CC matrices as submicron features with various morphologies. They typically display IOM-like aromatic (C=C) - ketone (C=O) - carboxylic (COOH) functional chemistry [2]. In contrast, less than 0.4 wt. % carbon is found in unequilibrated ordinary chondrites (UOCs) [1]. There are limited reported analyses of OM *in situ* [3]. Ultimately, *in situ* observations of OM in planetary materials will constrain its spatial context and distribution. In the UOCs, it will also allow the evaluation of the effects of aqueous alteration and thermal metamorphism at demonstrably higher temperatures/cooling rates than CCs [3, 4]. Previous studies have shown OM in the UOCs to be sensitive to its structural properties based on the metamorphic grade of the meteorite that it came from [5]. Some modifications of OM related to progressive aqueous alteration are apparent in the CCs, such as the redistribution of OM that is enriched in aliphatic and carboxylic functional groups [6]. We aim to determine the different forms of OM found in the matrices of different UOC petrologic types, and understand how they may vary. OM in the following meteorites have been investigated:

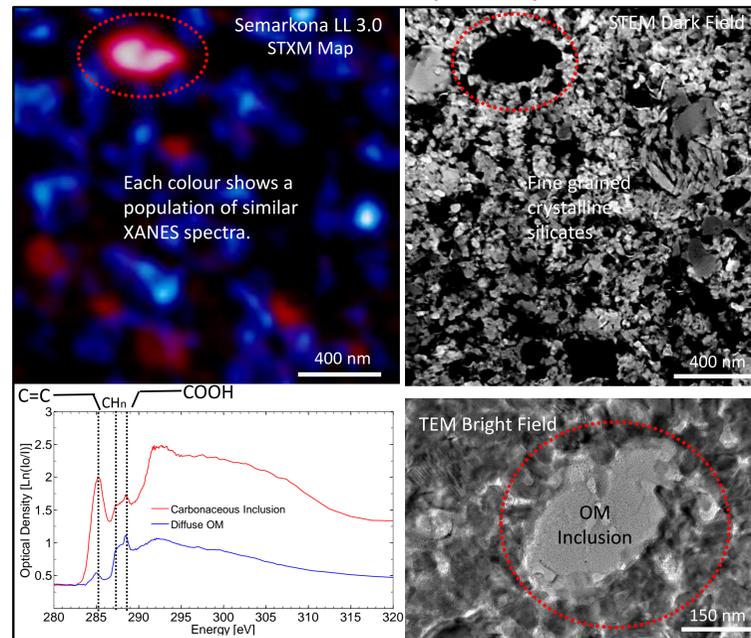
Semarkona (LL 3.0), *QUE 97008 (L3.05)*, *Bishunpur (LL3.1)*, *Chainpur (LL3.4)*, *LEW 87284 (L3.6)*

Methods



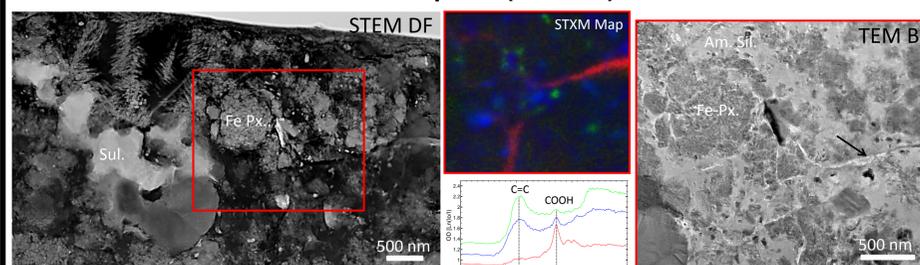
Above: BSE image of Bishunpur (left) showing a polished chip pressed in indium foil. Matrix regions are interstitial to chondrules and their rims. A fresh matrix fragment from Chainpur (right) pressed in indium foil. Trenches made for the FIB section are shown in the figures.

Semarkona (LL3.0)



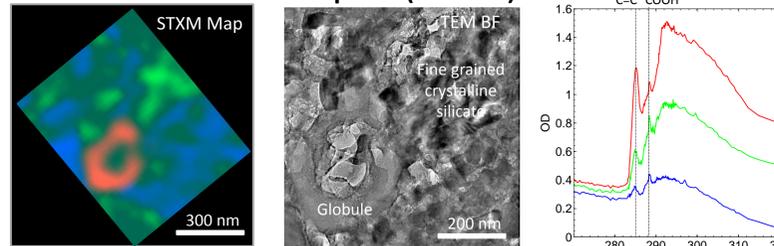
Semarkona (LL 3.0) Phase map (top left) showing the distribution of 2 spectral populations. Coordinated DF STEM montage (top right). Unnormalised XANES spectra of 2 populations showing the difference in their optical densities and the qualitative difference in the aromatic and carboxylic peaks relative to the total absorption. BF image of OM inclusion (red circle).

Bishunpur (LL3.1)



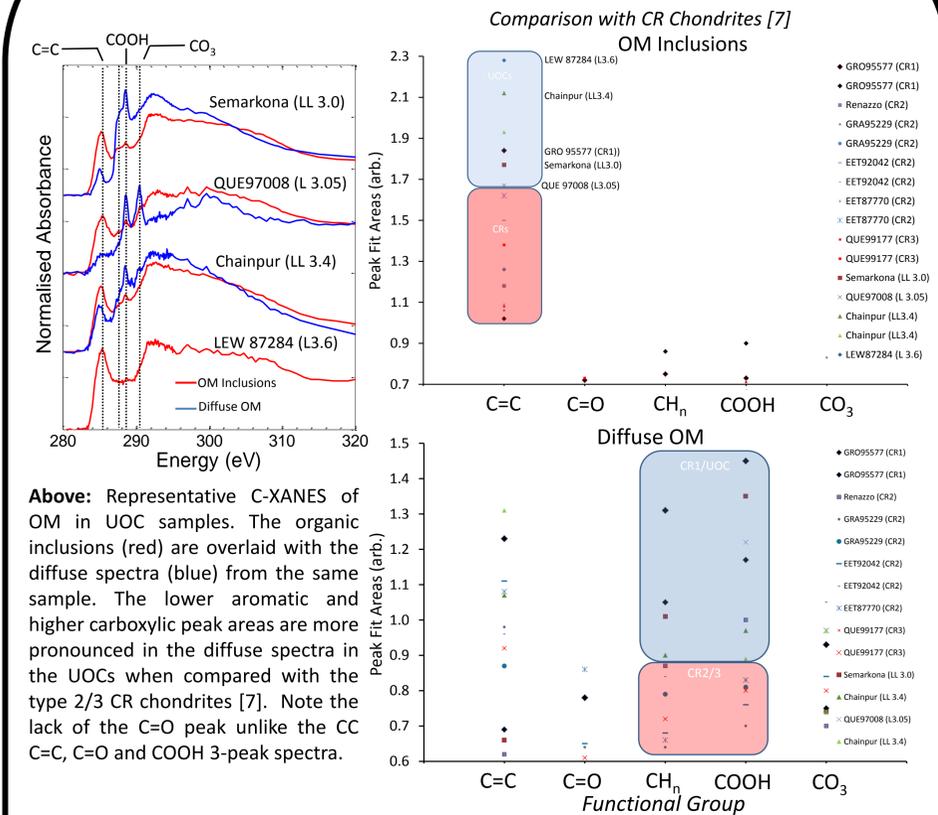
Bishunpur (LL 3.2) Phase map (middle) showing the distribution of 3 spectral populations. Note the very low absorption step in the spectra corresponding to the map. Errors are probably induced in the distribution map. The intense spots (green and blue) and bands (red) are the most representative locations of the different spectra. The BF-TEM image shows the red bands to be located in fractures (arrowed) as an intense carboxylic peak. The most diffuse population is the blue spectra which has a higher carboxylic peak than the green hotspots.

Chainpur (LL3.4)



Chainpur (LL3.4) A spherical hollow OM inclusion in Chainpur surrounded by two other distinct spectral populations that are in regions containing fine grained crystalline silicates. Qualitatively, the aromatic peak is lowest in the most diffuse (blue) spectra relative to the absorption edge, with the carboxylic peak in the reverse order.

Comparison with Carbonaceous Chondrites



Above: Representative C-XANES of OM in UOC samples. The organic inclusions (red) are overlaid with the diffuse spectra (blue) from the same sample. The lower aromatic and higher carboxylic peak areas are more pronounced in the diffuse spectra in the UOCs when compared with the type 2/3 CR chondrites [7]. Note the lack of the C=O peak unlike the CC C=C, C=O and COOH 3-peak spectra.

Right: Peak fits of OM inclusions and diffuse spectra from UOCs and the CR chondrites [7]. The aromatic peaks of the UOCs are in a field above the CRs. Their peak areas increase with increasing petrologic type. The COOH peaks in the diffuse OM are in a field above the CR3/2's but overlap with the CR1 GRO 95577.

Summary & Conclusions

- Organic inclusions with XANES spectra reminiscent of IOM residues (2-peak broad aromatic and slight carboxylic peak spectra) [5] have been identified *in situ* in random locations within samples of UOC matrix from petrologic types 3.0 up to at least type 3.6.
- Carbonaceous inclusions in the UOCs are more aromatic in character than in the CCs, and typically lack any ketone functional groups. This is consistent with higher temperatures experienced by the UOCs when compared with the CCs.
- The low abundance, but ubiquitous diffuse OM in the UOC matrices is both aromatic poorer and carboxylic richer than the discrete inclusions in UOCs, similar to the CCs. The carboxylic peaks in the normalised diffuse OM spectra are higher than the type 3 and type 2 CCs diffuse OM [7], suggesting that elevated temperatures or slower cooling rates during metamorphism may have preferentially lead to OM with higher carboxylic fractions in their spectra relative to the CR diffuse OM.

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