

Constraining the settings of aqueous alteration in the early Solar System by microfocus X-ray spectroscopy

Ashley J. King¹, Paul F. Schofield¹, J. Frederick W. Mosselmans², Sara S. Russell¹

¹*Department of Earth Sciences, Natural History Museum, London, SW7 5BD, UK*

²*Diamond Light Source Ltd., Didcot, OX11 0QX, UK*

Primitive meteorites record the formation and evolution of the Solar System, from the parent molecular cloud to the Sun, planets and moons we see today. One meteorite group, the CM carbonaceous chondrites, contain up to ~10 wt.% of H₂O and consist of coarse-grained high temperature silicates set within a fine-grained (<1 µm) matrix of hydrous phyllosilicates. Petrographic studies indicate that most of the phyllosilicates formed through extensive aqueous alteration of anhydrous precursor materials when accreted ices melted on the asteroid parent body(ies) ~4.5 billion years ago¹. However, a component of CM chondrites that remains controversial are the fine-grained rims (FGRs) of phyllosilicate found in direct contact with pristine, seemingly unaltered coarse fragments. The textures of the FGRs suggest they formed through accretion onto their host objects. What's not clear is whether hydration of the dust took place in a nebula^{2,3} or asteroid⁴ environment, which has implications for understanding the distribution and transport of volatiles in the nebula.

To constrain the settings of aqueous alteration in the early Solar System we are using microfocus X-ray spectroscopy at the Diamond Light Source to characterise the chemistry, mineralogy and Fe oxidation state of FGRs and matrix areas in a ~150 µm thick section of the Murchison (CM2) meteorite. Spatially correlated µ-XRF, µ-XRD and Fe K-edge µ-XANES data were obtained on I18 with a spot size on the sample of ~3 µm. XRD maps (100 × 100 µm) were collected in transmission, while XRF and XANES spectra were measured in fluorescence mode. For the XRD and XANES experiments a range of mineral standards were also analysed.

Minerals identified in the µ-XRD patterns from both the FGRs and matrix include Fe-Mg serpentines, magnetite, Fe-sulphides, carbonates and silicates. The chemical state of the Fe atoms in these minerals is predicted to be strongly influenced by the conditions of aqueous alteration^{5,6}. As a first approach we have determined the intensity weighted centroid position of the pre-edge feature, which shifts to higher energies with increasing Fe³⁺/ΣFe, from 73 points within the FGRs and 37 points in the matrix. The average centroid energy indicates an Fe³⁺/ΣFe ratio of 0.8 – 0.9, consistent with the alteration of Fe⁰ metal and Fe²⁺ bearing silicates into Fe³⁺ rich phyllosilicates and oxides. We find no difference between the average centroid position of the FGRs and matrix, suggesting that aqueous alteration of these components occurred in a similar environment. However, there are spatially correlated systematic variations in the Fe-XANES spectra within the FGRs, but not in the matrix. This corresponds to differences in the local mineralogy and crystal chemistry and may indicate that the alteration of the FGRs and matrix varied, at least at the µm-scale.

References

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Email corresponding authors: a.king@nhm.ac.uk