MISIP-2024 Project-2 – Interactions between minerals and organic matter in carbonaceous chondrites.

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In carbonaceous chondrites, organic matter is a subject of extensive study due to its role in the evolution of the solar system and its relevance to the origin of life on Earth, as these types of primitive meteorites may have helped to deliver organic material to the early Earth. They give an insight into the composition of the early Solar System as well as the Ryugu and Bennu asteroids as the composition of the asteroids resembles CI chondrites. We studied the interaction between organic matter and minerals, focusing on phyllosilicates and carbonates. The samples investigated were two CM chondrites, Murchison and Aguas Zarcas, and one CI chondrite, Orgueil. Equipment such as SEM-EDS, Raman spectroscopy, SIMS, and IRMS was used to look at the textures and composition of sites on the surface of the samples.

While investigating the phyllosilicate textures in Aguas Zarcas, Murchison and Orgueil, it was seen that Aguas Zarcas and Murchison are very heterogenous compared to Orgueil. The phyllosilicates were investigated using SEM-EDS and we found that there is a significant separation between the CI and CM phyllosilicates. Orgueil's matrix appears to be an intermix of Serpentine and Saponite and Aguas Zarcas and Murchison seem to have a mixture of Cronstedtite, Serpentine and Tochilinite in their matrix. This is consistent with previous findings. The matrix of Aguas Zarcas plotted in 2 distinct populations corresponding to light and dark areas of the matrix with the populations differing in Fe/Si ratio.

We set out to characterise the organic signatures using a micro-Raman spectrometer. We discovered that there were positive correlation trends between the D-band centre and the D-band FWHM in all 3 meteorites with Aguas Zarcas and Murchison plotting together and a clear separation with Orgueil. This appears to be a distinction between CM2 and CI1 meteorites. Orgueil plotted higher on both, further along on the same trendline that the CM2s show. This could be due to increased aqueous alteration. For the organic G-band peaks, we plotted G-band centre against G-band FWHM. In both Aguas Zarcas and Murchison, there is a clear separation by G-band centre value into 2 populations for the different areas analysed. This has not been observed before. Orgueil only has a single population trend, with a similar gradient. This single trend corresponds to the high G-band centre trend visible in the CM2 chondrites. The 2 population trends in the Aguas Zarcas and Murchison samples present as 2 trends of negative correlation that are semi-parallel, with the high G-centre trend usually presenting a steeper trend. The negative correlation line of the trends is thought to be a result of irradiation or heating. These populations of high and low G-band centre do not correlate with light and dark areas of the matrix, indicating that phyllosilicate texture is likely not the control on the organic matter populations. The populations in both the Murchison and Aguas Zarcas samples do however cluster into regions on the sample, resembling different compositional areas. Due to their lack of correlation with matrix textures, we believe that the 2 populations of organics present in Aguas Zarcas and Murchison could represent 2 distinct compositions of organics in their parent body. The heterogeneity could pre-date the parent body and would in this model be due to poor intermixing of the different organic populations accreted onto the CM2 parent body.

There was a distinction in composition between the carbonates seen in Orgueil, dolomite and magnesite, as compared with Aguas Zarcas and Murchison, in which only calcite was seen. Some carbonates were found to have strong interactions with the organic matter. Organic matter was found as an inclusion within an Aguas Zarcas calcite. This may have been a result of the carbonate forming around a pyroxene or CAI precursor aggregate, which was associated with organic matter and ice, containing water and possibly CO_2. Associated within a carbonate clast in Murchison is a zone of phyllosilicate with an unusually high calcium content, possibly smectite and high aluminium content relative to the matrix. This leads us to the conclusion that this carbonate grain may have formed from a CAI precursor. Another carbonate in Murchison is associated with a large grain of organic matter, which due to matching carbon isotopes on SIMS, may have served as the source for the formation of the carbonate grain. The conclusion of the carbonate investigation is that OM-rich dust grains react with ice to form a CO2 heavy fluid, which in turn reacts with Ca-rich phases to form carbonates.

Using SIMS, we determined that Aguas Zarcas and Murchison plot as 2 distinct populations separated along δ^2H, while having similar $\delta^{15}N$ and $\delta^{13}C$. Organic matter grains were found in Murchison and analysed. These have very high $\delta^{15}N$ (around 250 ‰) and $\delta^{13}C$ (around 60-75 ‰). This suggests that the source of these isotopes is primordial, deriving from the pre-accretionary isotopic signatures of the organic matter. The carbonates have similarly high $\delta^{13}C$ isotopes suggesting they could have formed from the organic matter. The light and dark phyllosilicate areas were also investigated for isotopic signature. In Aguas Zarcas, the light and dark areas of the matrix are separated by $\delta^{15}N$, with the darker areas having a higher $\delta^{15}N$. This is likely due to the dark areas of the matrix being richer in organic matter relative to the light ones. On the other hand, in Murchison the light and dark areas have similar $\delta^{15}N$ but are separated along the δ^2H axis. The darker areas have a higher δ^2H. One model to explain this is that the lighter areas potentially had greater aqueous alteration from water ice, which is depleted in δ^2H, because of varying amounts of ice through the meteorite, resulting in a lower δ^2H and the formation of tochilinite.

Altogether, this study reveals some interesting insights into the processes that governed the early solar system and offers ample opportunity for follow-up research to understand the relationship between phyllosilicates, carbonates and organic matter in carbonaceous chondrites.