1. Introduction

- The CM carbonaceous chondrites were altered by low temperature (~100°C) aqueous alteration.
- Their original mineralogy reacted with fluids to produce a secondary mineral assemblage of Fe- and Mg-rich phyllosilicates, oxides and carbonates [1, 2].
- The CM chondrites cover a petrologic range from mildly altered to fully hydrated meteorites [1, 2].
- LAP 04514, LAP 04565 and LAP 04796 have been suggested as amongst the least altered CM chondrites [3, 4].
- We characterized the bulk properties of these CM chondrites in order to assess the extent of aqueous and thermal alteration and examine their relationship to primitive asteroids.

2. Experimental

<table>
<thead>
<tr>
<th>1. Sample Preparation</th>
<th>2. PSD-XRD</th>
<th>3. TGA</th>
<th>4. IR Spectroscopy</th>
</tr>
</thead>
<tbody>
<tr>
<td>~200 mg interior, fusion crast free chips were powdered.</td>
<td>Modal mineralogy was obtained using position-sensitive-detector X-ray diffraction (PSD-XRD). Phase quantification involved a profile-stripping method.</td>
<td>Hydrogen abundances were obtained using a TA Instruments SDT Q600 thermogravimetric analysis (TGA) instrument. Mass loss was recorded whilst heating <del>10 mg aliquots of the powders from 25 ~ 1</del>000°C at 10°C min~1 under an N₂ flow.</td>
<td>Infrared (IR) reflectance spectra were acquired using a Bruker Vertex 70v FTIR spectrometer. Spectra were collected from ~1.6 ~ 100 µm under vacuum (2hPa).</td>
</tr>
</tbody>
</table>

3. Results

- LAP 04514, LAP 04565 (a pair with LAP 04527) and LAP 04565 contain ~70 vol % Fe- and Mg-rich phyllosilicates.
- LAP 02333 contains a higher proportion of Fe- and Mg-rich phyllosilicates (9% vol%) and less olivine (7 vol%), enstatite (9 vol%) and magnetite (2 vol%).
- Minor phases (≤4 vol%) include tochilinite in LAP 04796, LAP 04565 and LAP 02333, and metal in LAP 04796 and LAP 04565.
- Mass loss from 300 ~ 800°C is caused by the dehydroxylation of the phyllosilicates and can be used to estimate H abundances in CM chondrites [5, 6].

<table>
<thead>
<tr>
<th>Meteorite</th>
<th>H Abundance (wt%)</th>
<th>5 µm band depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAP 04514</td>
<td>0.8 ± 0.04</td>
<td>0.11</td>
</tr>
<tr>
<td>LAP 04565</td>
<td>0.8 ± 0.04</td>
<td>0.13</td>
</tr>
<tr>
<td>LAP 04796</td>
<td>0.9 ± 0.1</td>
<td>0.46</td>
</tr>
</tbody>
</table>

4. Degree of Aqueous Alteration

- Using the phyllosilicate fraction (PSF) we can assign the samples a sub-type on the petrologic scale of [7].
- Based on the PSF, LAP 02333 is the most altered sample (sub-type 1.4). It also has the highest H abundance and largest 3 µm feature.
- LAP 04514, LAP 04565 and LAP 04796 are all sub-type 1.6.
- This alteration sequence is in agreement with the matrix oxide abundance, but not the total amorphous silicate abundance reported by [3, 4].

5. Thermal Metamorphism

- LAP 04514 contains the lowest H abundance and has the smallest 3 µm feature.
- Since its petrologic sub-type is the same as LAP 04565 and LAP 04796, it is interpreted as having undergone thermal metamorphism.
- The absence of tochilinite in LAP 04514 suggests that the peak metamorphic temperature was ~120°C.
- Fe-rich phyllosilicates in LAP 04514 have been partially dehydrated at temperatures of 300 ~ 450°C.
- We suggest that LAP 04514 has undergone thermal metamorphism at temperatures between 300 and 450°C.

6. Conclusions

- LAP 04514, LAP 04565 and LAP 04796 are amongst the least altered CM chondrites.
- Observations of these weakly-altered meteorites can provide insight into the accreted mineralogy of the CM parent body and initial conditions of aqueous alteration.
- LAP 04514 has undergone thermal metamorphism which was likely caused by impacts of smaller bodies and/or solar radiation.
- LAP 04514 may be a good analogue for the types of materials that will be encountered on the surfaces of asteroids by the OSIRIS-REx and Hayabusa-2 asteroid sample return missions.

This work would not have been possible without the collaboration of the Natural History Museum London, Imperial College London, and The University of Oxford. We thank ANSMET for the loan of the meteorites.

References