EXPERIMENTAL CONSTRAINTS FOR IMPACT INDUCED POST-HYDRATION HEATING ON C-COMPLEX ASTEROIDS

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Introduction: Mighei-like carbonaceous chondrites (CMs) originate from C-complex asteroids and have been aqueously altered, containing serpentine (Srp) and/or tochilinite (Thi) among other phases. Some CMs were heated after aqueous alteration in a process called post-hydration heating, whose cause is unknown, though possibilities include impacts and solar heating [1]. During post-hydration heating, volatile-rich phases become amorphous before forming anhydrous minerals [2]. The temperatures of each phase transition are known, but not precisely constrained. To better understand these phase transitions, we step-heated the CM Allan Hills (ALH) 83100, whose reflectance spectra is similar to the asteroid Bennu [1], and collected synchrotron powder X-ray diffraction (PXRD) data.

Methods: High resolution PXRD patterns were acquired from a powdered 100 mg sample of ALH 83100 on beamline III at Diamond Light Source. A PXRD pattern was collected from the sample at 26°C before it was heated from 200-950°C at 25°C intervals in an inert N₂ atmosphere. It was held at each temperature step for 1 hour before a PXRD pattern was collected using multi-analyzing crystal detectors. PXRD data collection took 1 hour for each pattern, making the total time ALH 83100 spent at each temperature step 2 hours, a timescale comparable to impact induced post-hydration heating [3]. The PXRD data was analyzed with Rigaku Smartlab II software.

Results: At each temperature, diffraction peaks change their widths and intensities as phase transitions occur. Key observations include: the weakening of Thi peaks at 200°C prior to its disappearance at 300°C, the appearance of an unknown phase with a broad peak at ~3.56 Å at 525°C due to incipient Srp decomposition prior to its recrystallization into olivine and low-Ca pyroxene (Opx) at 600 °C, and the appearance of clinopyroxene (Cpx) alongside small amounts of oldhamite at 700°C.

Discussion: The lowest temperature that Thi was previously reported to experimentally decompose at was 245°C after 185 hours of heating [4]. Given the weakening of Thi peaks at 200°C, it is likely not stable at 200°C; if Thi were held at 200°C for long enough, it should decompose. Thi disappears at 300°C and cannot remain at that temperature for even short durations.

This is not the first report of an unknown phase appearing due to Srp decomposition. Akai [5] observed an intermediate phase from Srp decomposition in the matrix of naturally heated CMs. Heating experiments on terrestrial Srp have shown it transforming into antigorite [6] or a talc-like phase [7]. This phase is likely present in more moderately heated CMs. This phase’s identity cannot be confirmed due to a lack of unique diffraction peaks.

Diffraction peaks matching Cpx appear at 700°C. Other heating experiments on ALH 83100 have also described Cpx forming [1]. Unlike Opx [2], Cpx is not a commonly reported product of post-hydration heating. The growth of Cpx was likely promoted by calcite decomposition while pyroxenes were still forming, which input Ca into the system. Why Cpx is not a commonly observed product of post-hydration heating could be due to two possibilities: 1) it is misattributed to other processes (e.g., primary, aqueous alteration) in heated CMs, 2) ALH 83100 did not have enough S to use up the Ca liberated from calcite to form exclusively oldhamite, and Cpx formed as a result.

Conclusions: The heating of ALH 83100 during PXRD data collection has revealed new insights regarding phase transitions during post-hydration heating. Thi is unstable at 200°C and Cpx can form from calcite and Srp decomposition. An intermediate phase previously reported by Akai [5] was observed forming from Srp decomposition. The timing of this experiment was similar to that expected if impacts were the primary cause of post-hydration heating. If longer timescales like those expected for solar heating were used, phase transitions would occur at lower temperatures and secondary anhydrous minerals would be more abundant.

Future Work: Long-duration experimental heating experiments will be conducted on Thi to better characterize its decomposition. Heating experiments with in situ micro XRD will be used to better identify the unique peaks for the intermediate phase, allowing for it to be identified and characterized.

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