MODAL MINERALOGY OF ASTEROID 162173 RYUGU BY X-RAY DIFFRACTION.

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Introduction: Water- and carbon-rich asteroids likely played an important role in the delivery of volatile phases to the inner regions of the solar system. The Cb-type asteroid 162173 Ryugu has very low reflectance and an absorption feature at ~2.7 µm suggesting that phyllosilicates are widespread on the surface [1]. The overall spectral properties of Ryugu are most similar to the aqueously altered CI and/or dehydrated CY carbonaceous chondrites [2].

In December 2020, JAXA's Hayabusa2 mission successfully returned >5 g of material from the surface of Ryugu to Earth, with preliminary investigation of the samples indicating a close affinity to the CI chondrites [3]. Previous X-ray diffraction (XRD) analysis has shown that bulk CI chondrites consist of abundant phyllosilicates (~80 vol.%), magnetite (~7 vol.%), and dolomite (~1 – 3 vol.%) having experienced low temperature (<100°C) aqueous alteration [4]. In contrast, the CY chondrites contain dehydrated phyllosilicates and/or recrystallized olivine (~70 vol.%), Fe-sulfides (up to ~20 vol.%), and sometimes metal (~1 vol.%) following post-hydration metamorphism at temperatures >500°C. [5]. Here, we have used XRD to characterize the modal mineralogy of a Ryugu particle and further constrain its aqueous and thermal history.

Methods: A powdered sub-sample of Ryugu particle C0002 (plates 3 and 4) was analyzed using position-sensitive-detector X-ray diffraction (PSD-XRD) at the Natural History Museum (NHM), London. The sample (<10 mg) was packed under a petrologic microscope into a custom-built aluminum sample well. This was done by slightly overfilling the well and pressing down using a clean sapphire plate. Excess material around the edge of the well was recovered before pressing again to ensure that the sample had completely filled the entire well and had an even, smooth surface. XRD patterns were collected from the Ryugu powder using a high-intensity micro X-ray source [6]. A graphite monochromator was used to select Cu Kα radiation and the size of the primary X-ray beam on the sample was restricted using a 100 µm pinhole. XRD patterns were acquired for 6 hours, with the sample rotated throughout the analysis. Pure standards (sourced from the NHM collections) of each phase detected in the Ryugu powder were analyzed under exactly the same conditions for 15 mins. The modal mineralogy was then determined using an established peak fitting method [e.g., 4, 7]. We assumed a CI chondrite composition for the phyllosilicates and uncertainties in the mineral abundances are on the order of ~2 vol.% [4].

Results & Discussion: The main phases detected in Ryugu particle C0002 (plates 3 and 4) are phyllosilicates, which are a mixture of Mg-rich serpentines and smectites, and present at an abundance of ~84 vol.%. Other phases identified from the XRD pattern include magnetite (~8 vol.%), pyrrhotite (~7 vol.%), and dolomite (~2 vol.%). Diffraction peaks from olivine and pyroxene were not observed suggesting that their abundance is ≤1 vol.% in the analyzed portion of C0002. Assuming a maximum anhydrous silicate abundance of 2 vol.%, the phyllosilicate fraction (PSF = total phyllosilicate abundance / [total anhydrous silicate + total phyllosilicate abundance]) of the Ryugu powder is 0.98. This corresponds to a petrologic sub-type of 1.1 on the alteration scale of Howard et al. [7].

The XRD pattern and modal mineralogy of Ryugu particle C0002 (plates 3 and 4) is very similar to the CI chondrites Alais, Orgueil, and Ivuna [4], with the only significant difference being the absence of sulphates and ferrihydrite in the former. In the CI chondrites, sulphates and ferrihydrite are thought to be terrestrial weathering products [8]. The analyzed Ryugu powder also has a comparable mineralogy to the recent $C2_{ung}$ fall Tarda. However, Tarda retains partially altered chondrules, resulting in a higher abundance of anhydrous silicates (~10 vol.%) [9, 10]. Finally, the XRD pattern and modal mineralogy of the Ryugu powder is clearly distinct from the CY chondrites, which contain dehydrated phyllosilicates that lack coherent diffraction, and abundant poorly crystalline troilte and secondary olivine [5].

Conclusion: The modal mineralogy of Ryugu particle C0002 (plates 3 and 4) is consistent with having formed through low temperature aqueous alteration. The fluid-rock reactions reached near-completion, resulting in a secondary assemblage of phyllosilicate, sulfide, magnetite, and Mg-carbonate that was not overprinted by a later episode of thermal metamorphism at temperatures >~400°C.

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