The Mineralogy of Asteroid Bennu from X-ray Diffraction Analysis

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Introduction: Carbonaceous asteroids likely played an important role in the delivery of water and organic matter to the early Earth [e.g. 1]. Fragments of these bodies naturally arrive on Earth as meteorites that can be studied in the laboratory. However, meteorites often lack geological context and are rapidly modified in the terrestrial environment [e.g. 2]. On September 24, 2023, NASA's OSIRIS-REx mission delivered to Earth a pristine sample collected from the surface of the carbonaceous asteroid Bennu. Remote observations indicated that Bennu consists of abundant phyllosilicates, carbonates, oxides, and carbon, similar to the composition of highly aqueously altered carbonaceous chondrites [3]. This prediction was initially confirmed during a "quick-look" analysis of fine dust coating the avionics deck of the sample canister and the outside of the sample collector [4]. Here, we characterise the mineralogy of returned samples using X-ray diffraction (XRD) and discuss its implications for understanding the geological history of Bennu.

Samples & Methods: Bennu sample OREX-500005-0 (~88 mg), which mainly consists of fine (<100 μm) particles recovered from the avionics deck, was mounted onto a zero-background substrate, and XRD patterns were acquired (ambient conditions, Co K_{α} radiation) using a Malvern Panalytical X'Pert Pro scanning XRD instrument at NASA Johnson Space Center (JSC). OREX-800107-103 (~49 mg), a sub-sample of a larger (~6 g) aggregate of material from inside the sample collector, was powdered and homogenised at JSC. This sample was packed into an aluminium well and then analysed (ambient conditions, Cu $K_{\alpha 1}$ radiation) using an INEL XRD with a curved 120° position-sensitive-detector at the Natural History Museum, London.

Results: XRD patterns for OREX-500005-0 and OREX-800107-103 show that both samples contain abundant phyllosilicates, with relatively broad reflections (~12.4, ~7.3, ~4.6, ~3.6, and ~1.5 Å) attributed to Mg-serpentine and Mg-smectite. Other phases identified include magnetite, Fe-sulfides (pyrrhotite + pentlandite), and carbonates (dolomite + calcite), plus a small, sharp diffraction peak that is likely from olivine. Diffraction peaks from Mg,Na-phosphate, which appears as bright phases in the Bennu samples [4], were not detected, possibly because it is poorly crystalline/amorphous [5, 6]. We also found no evidence for sulfate or Fe-(oxy)hydroxide phases. Quantitative phase analysis gives a bulk mineralogy of ~70 – 80 vol.% phyllosilicate, ~10 – 15 vol.% Fe,Ni sulfide, ~5 – 10 vol.% magnetite, <5 vol.% carbonate, and trace amounts of olivine. Based on the bulk mineralogy, we estimate that the Bennu samples have a grain density of ~2.8 – 3.0 g cm^{-3} and a porosity of ~40 % (assuming a bulk density of ~1.7 g cm^{-3} [4]).

Discussion: The similarity of the XRD patterns for OREX-500005-0 and OREX-800107-103 suggests that the fine dust outside of the sample collector is mineralogically representative of the bulk Bennu sample within it. Furthermore, the scarcity of sulfates [6] and absence of Fe-(oxy)hydroxides, which in carbonaceous chondrites are usually attributed to terrestrial weathering, confirms the pristine nature of the returned materials. Overall, the mineralogy of OREX-500005-0 and OREX-800107-103 indicates that Bennu's parent body experienced hydrothermal alteration. This body must have accreted water ice, with melting resulting in extensive water-rock reactions that transformed most of the original minerals into a secondary assemblage of phyllosilicates, oxides, Fe,Ni sulfides, and carbonates. The phyllosilicate fraction (total phyllosilicate abundance / [total anhydrous silicate + total phyllosilicate abundance]) corresponds to a petrologic sub-type of 1.1 [7], comparable to most aqueously altered meteorites [8] and samples returned from asteroid Ryugu by the Hayabusa2 mission [9]. However, the estimated low density and high porosity of the Bennu samples [4, 10] suggests that they would not easily survive passage through Earth's atmosphere, as was previously suggested for the weak boulders identified on Bennu's surface [11].

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References

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