Insight into Aqueous Alteration Processes on Bennu's Parent Body Through the Coordinated Analyses of Apatite

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The OSIRIS-REx mission returned pristine regolith samples from B-type asteroid (101955) Bennu on September 24, 2023. Bennu samples contain secondary mineral phases resulting from extensive aqueous alteration processes on Bennu's parent body. One such mineral is apatite, which precipitated directly from an aqueous fluid. The analysis of secondary minerals such as apatite can provide insight into the chemical characteristics of the fluid and whether several alteration events may have occurred. We report here the analysis of apatite grains in Bennu samples using a coordinated analytical approach to investigate their compositions, mineral associations, and microstructures.

We used a suite of electron beam instruments including scanning electron microscopy (SEM), electron probe microanalysis (EPMA), and transmission electron microscopy (TEM) to characterize apatite in Bennu aggregate particles (OREX-803079-0, OREX-803080-0). Generally, apatite grains in Bennu samples are <12 µm in size and are distributed throughout the phyllosilicate- rich matrix as either euhedral to subhedral single crystals, or anhedral polycrystalline assemblages as revealed by electron backscatter diffraction (EBSD). Apatite is commonly found associated with phyllosilicates, carbonates, magnetite, and sulfides. The chemical compositions of Bennu apatite measured by EPMA are halogen-poor, consistent with hydroxyapatite. Cathodoluminescence (CL) imaging of single crystals and polycrystalline assemblages reveal oscillatory and irregular zoning that are interpreted as primary growth textures. Such zoning results from the incorporation of trace elements (e.g. Mn^{2+}) and rare earth elements (REE, primarily Ce^{3+}, $Eu^{2+,3+}$, Sm^{3+}) into the apatite structure during crystal growth. TEM characterization of Bennu apatite reveals close association between phyllosilicates and apatite. Phyllosilicates are observed radiating from altered apatite crystal faces or oriented parallel to crystal faces that remain intact. Additionally, irregularly shaped pores are observed in the polycrystalline assemblage suggestive of dissolution-reprecipitation reactions.

The hydroxyapatite compositions observed here indicate that the fluid from which Bennu apatite formed was OH-rich and carried trace elements and REEs. Single crystals and polycrystalline assemblages likely reflect different stages of aqueous alteration, where single crystals are among the least altered and polycrystalline assemblages formed by several dissolution-reprecipitation events. The combined SEM-TEM microstructural characterization of apatite in Bennu samples suggest that several stages of alteration likely occurred on Bennu's parent body.