BULK MAJOR AND TRACE ELEMENTAL COMPOSITION OF AN AGGREGATE SAMPLE FROM ASTEROID BENNU.

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Introduction: On September 24, 2023, NASA's OSIRIS-REx mission returned a capsule to Earth carrying material from asteroid Bennu. This event was the first time a U.S. mission delivered pristine samples from an asteroid and is the largest asteroid sample return to date. As these samples represent some of the oldest, most primitive, and pristine materials available to us, and which originate from a known and well-studied asteroid [1], they allow us a rare opportunity to gain a better understanding of the formation and evolution of our solar system.

Key to understanding the material returned from asteroid Bennu is establishing its bulk chemical composition. Previous studies have shown that each chondrite group has a distinct elemental composition [2,3]. For the carbonaceous chondrites specifically, each group exhibits a distinct pattern of moderately and highly volatile elemental depletions, relative to CI chondrites [2,3]. CI chondrites are considered the most primitive chondrite group and broadly represent the solar photosphere composition [4]. The two most striking features of these depletion patterns is that the moderately volatile element depletions increase with decreasing 50% condensation temperature and then plateau out at abundances that roughly correlate with matrix abundance [2,3].

Due to these distinctive patterns, bulk elemental composition has become an important classification tool for establishing the different chondrite groups and the connections between them [5,6]. As such, determining the bulk chemical composition of the Bennu aggregates will help to test two mission hypothesis: *"Bennu's bulk elemental composition reflects that of its main parent asteroid and is similar to the composition of the Sun, with depletions in moderately to highly volatile elements"* and *"Bennu's dominant lithologies are comparable in bulk mineralogy, petrology, and composition to the most aqueously altered carbonaceous chondrites"* [7]. Furthermore as the carbonaceous and non-carbonaceous chondrites are thought to have likely formed in the inner and outer protoplanetary disk, respectively (e.g., [8]), determining the bulk chemical compositions of the Bennu aggregates will also help test the major mission hypothesis that *"Bennu's parent body formed beyond the snow line by accretion of material in the protoplanetary disk"* [7].

Regarding chondrite formation, observed elemental patterns have been successfully used to model how the mixing of volatile-rich and volatile-poor chondritic components can produce the observed carbonaceous chondrites groups [2,9]. They have also been significant in investigating how volatilization processes influenced chondrite formation [2,6,10]. As such, establishing bulk chemical compositions of the pristine Bennu samples is vital for understanding the asteroid, and solar system formation. To begin this processes, we analyzed the bulk major and trace elemental compositions of Bennu aggregates.

Samples: The elemental analyses were undertaken on aggregate sample OREX-803015-0 (20.66 mg of <1mm-sized particles), which was separated from the parent sample OREX-800033-0. Additionally, nine carbonaceous chondrite fall samples (14 – 69 mg) were run alongside OREX-803015-0 to both monitor data quality and provide direct comparisons to the Bennu aggregate. These nine chondrite analog samples consisted of two samples of Orgueil (CI1), Tagish Lake (C2-ung.), Tarda (C2-ung.), Winchcombe (CM2), Murchison (CM2), Lancé (CO3.5), Vigarano (CV3), and Karoonda (CK4).

Analytical Methods: Dissolution of all samples was undertaken on a hotplate using concentrated HF and HNO_3 at a 3:1 ratio, with HCl and H_2O_2 also used to remove fluorides and organics, respectively. All major and trace elemental analyses were conducted using a Thermo Fisher iCAP Qc ICP-MS. Linear calibrations were done using a synthetic CM chondrite standard run at multiple dilution factors (BIR-1 and BHVO-2 were also run alongside to monitor the CM chondrite standard). A 5 ppb internal standard of Re+Rh was run throughout the analysis session to correct for instrument drift. Samples were run three times each at total dilution factors of ~5,000 and ~50,000. The major element data were calculated using the ~50,000 dilution factor analyses, while the trace element data were calculated using the ~5,000 dilution factor analyses.

Results and Discussion: The nine chondrite analog samples measured here show good agreement with the literature data (e.g., [2,11]). All fifty-four of the elements analyzed for the Bennu aggregate sample lie close to the average CI chondrite [4, 11], and thus the solar photosphere composition, indicating that Bennu's bulk elemental composition is similar to that of the Sun and some of the most aqueously altered carbonaceous chondrites. Furthermore, the Bennu aggregate sample is distinguishable from the CM, CO, CV, CK and the two ungrouped carbonaceous chondrites (Tagish Lake and Tarda) that were analyzed at the same time. Compared to samples returned from asteroid Ryugu [12,13], this Bennu aggregate sample appears similar in elemental composition, yet without the small refractory element enrichments seen in Ryugu. Overall, these results suggest that Bennu is indeed a carbonaceous asteroid that formed beyond the snow line by accretion of material in the protoplanetary disk.

Acknowledgments: This material is based upon work supported by NASA under Contract NNM10AA11C issued through the New Frontiers Program. We are grateful to the entire OSIRIS-REx Team for making the return of samples from Bennu possible. We also thank Natural History Museum (UK), Smithsonian National Museum of Natural History, and Muséum National d'Histoire Naturelle for providing meteorite samples.

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