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Decoding Bennu: Understanding the solar system and life’s origins

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Abstract

The OSIRIS-REx mission to an asteroid named Bennu collected a sample of its *regolith*—loose material on the surface of an asteroid—and returned to Earth in September 2023. The successful return and initial research on the sample revealed much data about the elemental composition of Bennu’s *regolith*. The findings offer new insights into the fundamental building blocks of life, potentially revolutionizing our understanding of life and our solar system. The sample contained organic compounds, key to the origin of life, and also elements like iron and magnesium in abundance. Mineral analysis showed the presence of water-rich minerals, a key factor in understanding the origins of our oceans. Analysis of the data helps further the understanding of the origin of our oceans. By understanding the composition of asteroids like Bennu that trace their origins to the early solar system, we can understand the conditions prevalent in those times. And most importantly, understanding the composition of Bennu also gives us key insights into the origin of life because of the discovery of organic compounds in the *regolith*. Gathering asteroid samples holds much importance in expanding our knowledge in multiple fields and in shedding on many unanswered questions regarding the origin of life, origin of oceans and understanding of the early solar system.

Introduction

On September 24, 2023, NASA's OSIRIS-Rex mission returned from a 7-year mission after collecting nearly 120g of *regolith* (Lauretta et al., 2024) from asteroid "101955 Bennu" (hereafter, Bennu). These asteroids are remnants of our early solar system. Understanding asteroids can give us critical information about the origins of our solar system, origins of life, and the possibility of life existing outside our planet.

Purpose

This exploratory paper's aim is to understand whether the composition of the sample from Bennu sheds more light on the origins of the solar system & the origins of life.

Thesis statement

The analysis of the OSIRIS-REx asteroid sample from Bennu provides crucial insights into the early solar system's formation, the origin of Earth's water and the origins of life. By examining the compositions found in the sample, researchers can deepen their understanding of the conditions and processes that shaped our solar system and explore the potential links between asteroid materials and the origins of life on Earth.

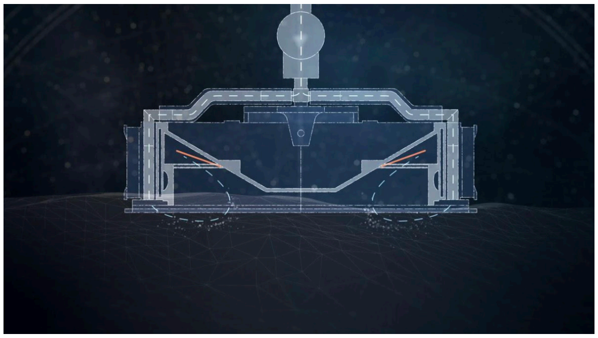
Background

Bennu has a near-Earth orbit with a *perihelion*—the point in the orbit of the body closest to the sun—of nearly 0.9 AU and an *aphelion*—the point in the orbit of the body farthest from the sun—of nearly 1.3 AU. It is a potentially-hazardous asteroid with a high impact probability in the year 2135. Its mass is around 8×10^{10} kg, and has a diameter of around 500 m. For comparison, the diameter of the moon is 3,500 km. However, even a small asteroid such as Bennu can cause significant damage if it impacts Earth. Its bulk density varies around 1,260 kg/m. It consists of *carbonaceous*—containing carbon and its compounds—material. It has a low *albedo*—the fraction of light that a surface reflects—and is a B-type asteroid (relatively uncommon *carbonaceous* asteroid). Its gravity is dominant in the Hill sphere radius—the radius around a larger body in which smaller bodies are attracted—which ranges around 31.7 km. Much evidence suggests that Bennu was formed due to a collision in its parent asteroid and from the fragments released (Lauretta et al., 2014).

Overview of the OSIRIS-REx mission

The OSIRIS-REx mission was launched in September 2016 and it reached Bennu in October 2020. The objective of the mission was to collect a sample of the *regolith* from Bennu. Through the mission, researchers aimed to understand the nature of such *carbonaceous* B-type asteroids. OSIRIS-REx was designed to handle the specific temperature on Bennu using different parameters like *albedo*. Its approach was simulated, and parameters like Bennu's position, rotation state, gravitational forces and the *Yarkovsky effect*—the effect of the sun's radiation as a thrust—were used to calculate a precise approach (Lauretta et al., 2014). A Touch-and-Go Sample Acquisition Mechanism (TAGSAM) was used. To acquire the *regolith*, a jet of nitrogen gas was released from the TAGSAM head into the *regolith*. The pressure change caused the *regolith* under the head to mobilize, which was then collected. The whole process took only a few seconds (see Figure 1) (Lauretta et al., 2024).

Figure 1
Regolith collection in the TAGSAM head



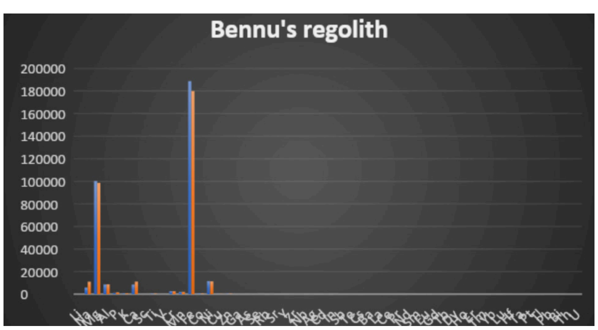
Note: Source: Lauretta et al., 2024

The samples reached Earth in September 2023. The original mission's goal was to attain 60g of *regolith*, but OSIRIS-REx collected 120g of the sample, doubling the goal.

Key findings

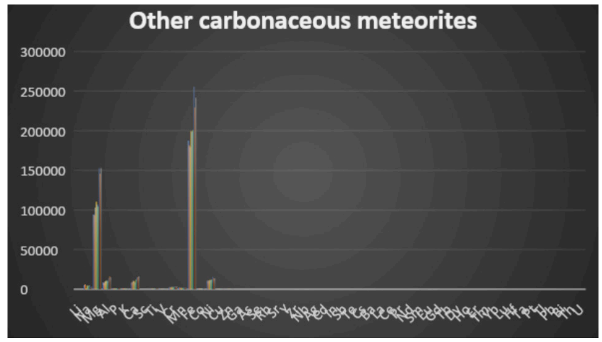
Finding 1. Analysis of the elemental composition showed that the composition of Bennu's *regolith* is similar to that of other *carbonaceous* meteorites (see Figure 2(a) and 2(b)). The elemental abundance is similar to that of the solar photosphere—the visible surface of the sun.

Figure 2(a)
Abundance of elements (in ppm) in the Bennu sample



Note: Source: Lauretta et al., 2024

Figure 2(b)
Abundance of elements (in ppm) in other *carbonaceous* meteorites



Note: Source: Lauretta et al., 2024

However, six elements in Bennu's samples were present in much greater abundance compared to other chondrite samples: Na, P, Ba, Sb, Th, and U (see Table 1) (Lauretta et al., 2024).

Table 1
Comparison of OSIRIS-REx Samples vs Other *Carbonaceous* Samples (in ppm)

	A	B	A/B
	OSIRIS-REx Samples	Other Carbonaceous Samples	
Na	8446	3844	2.2x
P	1310	992	1.3x
Ba	4.1	3.3	1.2x
Sb	0.31	0.11	2.7x
Th	0.07	0.04	1.8x
U	0.03	0.01	2.3x

Note: Source of information: Lauretta et al., 2014

Finding 2. The initial analyses of the Bennu samples mostly confirm what was predicted from telescope and spacecraft data. The samples have water (0.84–0.95% by weight hydrogen) and are rich in carbon (4.5–4.7% by weight carbon), with this abundance being higher than in any other meteorite analysis. 90% of the carbon is in the form of organic molecules. Ancient carbides and graphite remain intact. The

overall elemental composition is similar to that of the sun. The minerals in the samples are like those found in primitive, water-altered carbon-rich meteorites. The study showed that *phyllosilicates* were the dominant mineral phase. *Phyllosilicates* occupied 80% of the volume and sulphides occupied 10% of the volume. The minerals, listed from most to least abundant, include *phyllosilicates* (like *serpentine* and *smectite*), iron-nickel sulphides (such as *pyrrhotite* and *pentlandite*), *magnetite*, carbonates (including *calcite*, *dolomite*, and *breunnerite*), *forsteritic olivine*, low-calcium *pyroxene*, magnesium-sodium and calcium phosphates, and other minor phases.
The organic nanoglobules and polycyclic aromatic hydrocarbons (PAHs) found show no signs of significant heating. These results suggest that the materials making up Bennu's surface, while extensively altered by water, have preserved some characteristics from the protoplanetary disk and early solar system (Lauretta et al., 2024).

Finding 3. The hydrated magnesium-sodium phosphates, which resemble sodium phosphates found on Enceladus (Saturn's moon) and in Earth's soda lakes (lakes with high pH value and consisting of sodium carbonate), suggest that complex fluid chemistry might have been involved. This fluid could have added a unique chemical element, contributing to the differences in the elemental composition observed in one of the subsamples compared to the elemental composition of the sun (Lauretta et al., 2024).

Finding 4. The unique ratios of hydrogen, carbon, and nitrogen isotopes in Bennu's *regolith* raise questions about Bennu's formation and its changes over time. Studying these isotopic signatures more closely could give scientists important information about Bennu's history and the history of the larger body from which it originated (Lauretta et al., 2024).

Finding 5. The initial results show how important it is to bring samples back from asteroids like Bennu to understand their geology and chemistry. Bennu has low-density, friable material abundant in near-Earth space; materials that might not be well-represented in meteorite samples because such material burns up in our atmosphere when meteorites crash on Earth (Lauretta et al., 2024). So studying these samples is key to learning about the solar system's history and development. This data so far is just the beginning; there is likely much more to learn about the sample that has not yet been discovered.
Interpretation

Signs of hydration in the sample also help support the theory that Earth's ocean water was delivered by numerous comet strikes. Since the sample has retained characteristics from the protoplanetary disk, we can confirm the origins of Bennu and many such B-type asteroids from the early solar system. Organic molecules found on Bennu suggest a possible source of the organic molecules that form life as we know it today.

Significance

The composition of asteroid *regolith* dating back to the protoplanetary disk can give us a clearer image of what our solar system looked like during its formation. This can give us more insights on the formation of our planet. The variety of isotopes found on Bennu can tell us more about its history and help us understand the parent asteroid from which it was formed. That asteroid held closer links to the early solar system. Organic compounds and water-soluble phosphates are key to the formation of life. Finding these on the *regolith* of Bennu and researching them can give us new insights on the origin of life. Understanding the origin of life on Earth can help us assess the possibility of life existing elsewhere and how life on our planet evolved. The sample's mineral composition majorly matches data from remote-sensing instruments, thus confirming the accuracy of these instruments (Lauretta et al., 2024). Understanding the near-Earth neighbourhood, where asteroids with similar composition exist, will help us gain more insights into the history of Earth.

Conclusion

The OSIRIS-REx mission's return of samples from Bennu marks a major milestone in our understanding of the early solar system and the origins of life. Meteorite sample collection holds great importance as much of the low density material of meteorites that crash on Earth gets lost. Further research on the Bennu sample will release key information on how asteroid impacts could deliver the right organic materials and compounds for the formation of life. Collecting samples from other similar asteroids should corroborate the results found in Bennu. While the initial results are promising, they represent only a fraction of the potential knowledge to be gained from Bennu's *regolith*. Future research and continued analysis will be essential for uncovering the full implications of these findings, including their impact on our understanding of planetary formation, the origin of life, and the potential for life elsewhere in the universe.

Scope For Further Study

The analysis of the sample from Bennu and new possible findings can contribute to our understanding of the formation or composition of the solar system. Insights regarding the origins of life can be gained by researchers from analysis of the asteroid samples.

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