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More Than Just a Rock: Discovering Water and Organics on Asteroid Bennu

Biology * Space * Astronomy

Abstract

The successful return of the OSIRIS-REx Sample Return Capsule (SRC) in September 2023 has provided the planetary science community with an unprecedented reservoir of pristine extraterrestrial material. Analysis of the 121.6 grams of regolith from asteroid (101955) Bennu has revealed a celestial body of immense chemical complexity: a carrier of ancient presolar grains derived from supernovae, a host to water-soluble magnesium-sodium phosphates indicative of a paleoceanic past, and a reservoir of bio-essential organic compounds including ribose, glucose, and a novel nitrogen-rich "space polymer." These findings, published in a suite of papers in *Nature*, *Nature Astronomy*, and *Meteoritics & Planetary Science*, suggest that Bennu is not merely a static relic of the early solar nebula, but a fragmented survivor of a chemically dynamic, water-rich parent world that may have seeded the prebiotic Earth with the requisite components for life. This report synthesizes the initial findings, placing them within the broader context of solar system formation, astrobiology, and comparative planetology.

1. Introduction: The Harvest of a Rubble Pile

On September 24, 2023, a charred capsule streaked through the atmosphere above the Utah Test and Training Range, carrying within it a time capsule from the dawn of the solar system.[1] The NASA OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, and Security-Regolith Explorer) mission had completed its seven-year journey to the near-Earth asteroid Bennu and back, delivering the largest sample of an asteroid ever collected by the United States.[3]

While the mission's baseline success criterion was the return of 60 grams of material, the actual yield was a staggering 121.6 grams (4.3 ounces), effectively doubling the scientific return.[1] This abundance has allowed for a global distribution of samples to research laboratories and a robust archival strategy for future generations. Unlike meteorites, which are "finds" that suffer ablation during atmospheric entry and immediate contamination upon landing, the Bennu samples were collected via a precise Touch-and-Go (TAG) maneuver in October 2020 and maintained in a protected, nitrogen-purged environment until their retrieval.[6]

The significance of this pristinity cannot be overstated. It has allowed researchers to detect fragile, water-soluble components -- such as salts and sugars -- and complex organic structures that would otherwise be destroyed by terrestrial weather or masked by biological contaminants. The initial curation and analysis, conducted at NASA's Johnson Space Center (JSC) and shared with international partners including the Japan Aerospace Exploration Agency (JAXA) [6], have unveiled a mineralogical and chemical inventory that bridges the gap between stellar nucleosynthesis and the origins of biochemistry. Bennu, a "rubble pile" asteroid

likely reassembled from the debris of a catastrophic collision, serves as a frozen library of the cosmos, preserving materials that span from the death of ancient stars to the aqueous alteration of early planetesimals.[9]

2. The Aqueous History of Bennu: Evidence for an Ocean World Origin

One of the most profound narratives emerging from the early analysis is the unambiguous evidence of extensive, fluid-driven alteration. While remote sensing data collected by the spacecraft during its orbital phase (2018-2021) suggested the presence of hydrated minerals, the returned samples provided a mineralogical smoking gun that fundamentally alters our understanding of Bennu's parent body.

2.1 The Phosphate Surprise

Microscopic analysis of the returned regolith revealed millimeter-scale particles encrusted with a bright, water-soluble mineral identified as magnesium-sodium phosphate (MgNaPO_4).^[1] This finding was entirely unexpected; this specific mineral phase was not detected in the spacecraft's remote sensing spectral data, likely due to its localized concentration or spectral masking by darker matrix materials.^[11]

The presence of magnesium-sodium phosphate is chemically diagnostic of specific environmental conditions. On Earth, similar biochemical phosphates (often associated with struvite, $\text{NH}_4\text{MgPO}_4 \cdot 6\text{H}_2\text{O}$) precipitate from fluids rich in magnesium, ammonium, and phosphate.^[13] In the context of an asteroid, this mineralogy serves as a tracer for ancient fluid chemistry. The purity of the phosphate grains found in Bennu -- lacking the extensive inclusions often seen in meteoritic samples -- and their substantial grain size (up to hundreds of micrometers) suggest they precipitated from a large volume of liquid water.^[12]

This geochemistry provides strong support for the "Ocean World" hypothesis. The data indicates that Bennu was not always a dry pile of rubble. Instead, it is likely a splinter fragment from a much larger parent body -- a "long-gone, tiny, primitive ocean world".^[11] This parent planetesimal would have possessed sufficient internal heat (likely from the decay of short-lived radionuclides like Aluminum-26) to maintain liquid water interacting with a silicate mantle. This hydrothermal system would have leached elements from the rock, concentrating them into brines that eventually precipitated these exotic phosphates.^[13]

2.2 Implications for Prebiotic Chemistry

The detection of water-soluble phosphates has significant astrobiological implications. Phosphorus is a critical "limiting nutrient" for life as we know it; it forms the backbone of DNA and RNA and is the primary currency of cellular energy (ATP).^[17] However, in many astrophysical environments, phosphorus is locked within insoluble minerals (like apatite) that are biologically inaccessible.

The Bennu samples demonstrate that evolved, water-soluble phosphates were available in the early solar system. The high purity of these grains implies they were formed in a fluid environment that effectively fractionated phosphorus from other elements.^[12] If such phosphates were delivered to the early Earth via carbonaceous asteroids, they could have relieved the "phosphorus bottleneck" often cited in theories of abiogenesis, providing a readily available source of soluble phosphate

for the first replicating molecules.[12]

The specific phase of magnesium-sodium phosphate found in Bennu is distinct from those found in ordinary chondrites. While the JAXA Hayabusa2 mission also detected phosphates in samples from asteroid Ryugu, the Bennu phosphates stand out due to their unprecedented grain size and purity.[11] This suggests that while both asteroids share a carbonaceous heritage, the fluid history of Bennu's parent body may have involved different aqueous conditions, perhaps characterized by higher water-to-rock ratios or longer durations of fluid stability.[5]

3. The Organic Inventory: Sugars, "Space Gum," and the Seeds of Life

The organic analysis of the Bennu samples, detailed in papers published in *Nature Geoscience* and *Nature Astronomy*, provides the strongest evidence yet that the molecular toolkit for life was assembled in deep space and delivered to the inner solar system.[19]

3.1 Bio-essential Sugars: Ribose and Glucose

A team led by Yoshihiro Furukawa of Tohoku University utilized gas chromatography-mass spectrometry (GC-MS) to identify a suite of bio-essential sugars within the pristine regolith. Most notably, the team detected ribose, the five-carbon sugar that forms the structural backbone of RNA (ribonucleic acid).[19]

In addition to ribose, the analysis yielded the first confirmed detection of glucose in a pristine asteroid sample.[19] Glucose is the six-carbon sugar that serves as the universal energy source for terrestrial life. Its presence in Bennu, alongside other sugar derivatives and polycyclic aromatic hydrocarbons (PAHs), completes the inventory of the three major classes of biological macromolecules found in meteoritic material:

- * Amino Acids (building blocks of proteins) - previously detected in meteorites and Ryugu.
- * Nucleobases (genetic letters) - previously detected in meteorites and Ryugu.
- * Sugars (backbones and energy) - now definitively confirmed in Bennu.[19]

The RNA World Hypothesis:

Crucially, the researchers noted the absence of 2-deoxyribose, the sugar component of DNA.[19] The presence of ribose without deoxyribose offers compelling support for the "RNA World" hypothesis -- the theory that early life relied solely on RNA for both genetic storage and catalysis before the evolution of DNA and proteins. The specific distribution of these sugars is consistent with formation via the formose reaction, a polymerization of formaldehyde that occurs in alkaline, aqueous environments.[23] This aligns perfectly with the mineralogical evidence of an aqueous, carbonate-rich parent body where such reactions could proceed abiotically.

3.2 The "Space Gum": A Novel Prebiotic Polymer

Perhaps the most chemically exotic discovery was a nitrogen- and oxygen-rich "gum-like" substance, described by researchers as "space plastic".[21] Led by Scott Sandford of NASA's Ames Research Center, this study identified a material that was

likely soft and pliable -- akin to chewed gum -- during the asteroid's youth but has since hardened into a brittle polymer.[25]

Chemical Structure and Formation:

This material is not a simple organic sludge but a complex polymer containing carbamate functional groups.[22] The proposed formation mechanism involves the reaction of ammonia (NH₃) and carbon dioxide (CO₂) in the early solar nebula or within the parent body. This reaction produces carbamate, which is initially water-soluble. However, as the parent body warmed due to radiogenic heating, the carbamates polymerized into complex, water-insoluble chains.[22]

The chemical groups identified in this substance resemble those found in polyurethane on Earth.[26] This discovery is significant because it represents a form of "chemical scaffolding." Such polymers could concentrate and organize smaller organic molecules, acting as a matrix where more complex prebiotic chemistry could occur, protected from the harsh radiation environment of space.[25] The "space gum" suggests that polymerization -- a necessary step for building life's macromolecules -- can occur abiotically in asteroidal environments before the material is ever delivered to a planet.

3.3 Chiral Asymmetry and Amino Acids

Parallel studies on the amino acids within the sample have hinted at chiral asymmetry (homochirality). Life on Earth exclusively uses "left-handed" (L-) amino acids. Unexpected findings regarding the orientation of amino acid structures in the Bennu samples suggest that the preference for left-handedness might have extraterrestrial roots, potentially driven by polarized radiation in the presolar nebula.[27] If confirmed, this would imply that the "decision" for life to be left-handed was made before the Earth was even formed.

4. Presolar Grains: The Cosmic Genealogies of Dust

While the organic matter speaks to the potential future of life, the inorganic dust grains in Bennu speak to the ancient history of stars. A study led by Ann Nguyen of NASA's Johnson Space Center analyzed "presolar grains" -- microscopic dust specks that condensed in the atmospheres of dying stars long before our sun was born.[22]

4.1 Anomalous Abundance of Supernova Dust

The Bennu samples were found to contain a surprisingly high abundance of presolar grains. Analysis revealed that the regolith contains six times more presolar dust than typically found in other studied chondritic meteorites.[22] This enrichment suggests that Bennu's parent body accreted material from a distinct region of the protoplanetary disk that was heavily seeded with ancient stardust, or that the material has been exceptionally well-preserved against thermal metamorphism and aqueous alteration.[22]

Isotopic Signatures:

These grains are identified by their isotopic compositions, which deviate wildly from the solar system's average. The analysis identified two primary populations based on their stellar origins:

* AGB Stars: Silicon carbide (SiC) grains typically originating from Asymptotic Giant Branch stars (red giants). These stars puff off their outer layers gently, creating carbon-rich dust.[29]

* Supernovae: A significant population of silicate and oxide grains with isotopic ratios (e.g., ^{17}O , ^{15}N) indicative of formation in the explosive ejecta of supernovae.[25]

4.2 Isotopic Data and Grain Types

Detailed NanoSIMS analysis of specific particles (e.g., angular vs. hummocky fragments) revealed complex distributions of these grains. The following table summarizes the isotopic anomalies observed in specific presolar grain candidates found in the Bennu samples [32]:

Grain ID	Size (nm)	$^{17}\text{O}/^{16}\text{O}$ Ratio ($\times 10^4$)	Presumed Origin
DOM-14	282	8.20 ± 0.31	AGB / Supernova
DOM-17	363	23.63 ± 0.57	Supernova (High ^{17}O)
DOM-19	225	5.89 ± 0.34	Solar/Molecular Cloud
DOM-21	369	7.47 ± 0.37	AGB Star

Note: The solar system average $^{17}\text{O}/^{16}\text{O}$ is typically much lower or distinct from these excursions. High ^{17}O enrichments are characteristic of specific nucleosynthetic processes in evolved stars.

The presence of fragile presolar silicates is particularly telling. Silicates are easily destroyed by water. Their survival in the same sample containing water-soluble phosphates and clays indicates a heterogeneous alteration history -- some parts of the parent body saw heavy water flow (forming phosphates and clays), while others remained dry enough to preserve the delicate stardust.[22] This supports the "breccia" nature of Bennu, where materials from different geological contexts were jumbled together during the cataclysmic disruption of the parent body.

5. Comparative Planetology: Bennu vs. Ryugu

The almost simultaneous analysis of samples from asteroid Ryugu (returned by JAXA's Hayabusa2 in 2020) and Bennu (OSIRIS-REx) offers a unique opportunity for comparative planetology. Both are C-type (carbonaceous), diamond-shaped "rubble pile" asteroids, yet their returned samples reveal distinct evolutionary paths.

5.1 Spectral Dichotomy and Space Weathering

One of the pre-sampling mysteries was the spectral difference between the two bodies. Ryugu appears redder (spectral slope upwards) in telescopic observations, while Bennu appears bluer (spectral slope downwards).[10]

* Ryugu: Darker, chemically homogeneous, and shows evidence of intense aqueous alteration followed by thermal dehydration (heating). Its "red" spectrum is consistent with typical space weathering of carbonaceous chondrites.[9]

* Bennu: Shows more heterogeneity. The "blue" spectrum of Bennu was puzzling but now correlates with the abundance of specific clay minerals (phyllosilicates) and a

unique space weathering environment that may involve resurfacing events that expose fresh, unweathered material.[10]

5.2 Organic and Mineralogical Differences

While both contain prebiotic organics, the specific inventories differ, likely due to both geological history and analytical constraints.

* Phosphates: Both contain phosphates, but Bennu's magnesium-sodium phosphates are significantly larger and purer. This suggests a different fluid chemistry or a crystallization environment in Bennu's parent body that allowed for slower, undisturbed growth compared to the environment on Ryugu's parent.[11]

* Sugars: The detection of glucose in Bennu is a standout discovery. While Ryugu samples yielded amino acids, sugars were elusive in initial Ryugu reports. This is likely due to the sample mass limitation; the Ryugu sample was approximately 5.4 grams, whereas Bennu returned over 121 grams. The larger sample mass from Bennu allowed researchers to extract and concentrate lower-abundance molecules like sugars which were likely below the detection limit in the smaller Ryugu allocations.[24]

* Presolar Grains: Bennu appears to have a higher abundance of presolar silicate grains compared to Ryugu, suggesting that Bennu's material might have been less thermally processed or accreted from a slightly different nebular reservoir enriched in supernova dust.[35]

5.3 Technical Collaboration

The synergy between NASA and JAXA has been instrumental in validating these findings. In August 2024, NASA transferred 0.663 g of Bennu regolith to JAXA for comparative analysis using the same instruments used for Ryugu.[6] This "cross-calibration" ensures that observed differences are real geological features rather than artifacts of different laboratory techniques. Instruments such as the MicrOmega infrared spectrometer are being used to map these samples non-destructively to directly compare the hydration states of the two asteroids.[36]

6. "Blacksmithing at the Molecular Level": Analytical Techniques

The findings described above were made possible by state-of-the-art analytical techniques capable of probing matter at the atomic scale. Researchers described their work as "blacksmithing at the molecular level" to tease out these secrets from the black dust.[23]

* STXM-XANES (Scanning Transmission X-ray Microscopy - X-ray Absorption Near Edge Structure): This technique was crucial for analyzing the "space gum." It maps the chemical bonding state of carbon, nitrogen, and oxygen at the nanometer scale. It allowed Scott Sandford's team to identify the carbamate and polymer-like linkages in the organic matter, distinguishing it from simple abiotic sludges. By observing the X-ray absorption edges, they could determine the specific functional groups present, linking the material to polyurethane-like structures.[38]

* NanoSIMS (Nanoscale Secondary Ion Mass Spectrometry): Used by Ann Nguyen's team to map isotopic anomalies. By blasting the sample with a focused ion beam and measuring the secondary ions released, researchers could pinpoint the exact grains that

originated from supernovae based on their non-solar isotopic ratios (e.g., high ^{17}O).[41]

* GC-MS (Gas Chromatography-Mass Spectrometry): The primary tool for organic identification. Yoshihiro Furukawa's team used this to separate and identify the delicate sugar molecules. The detection of enantiomers (left vs. right-handed versions) requires this high level of separation resolution to confirm the abiotic nature of the sugars (racemic mixtures) versus potential terrestrial biological contamination (which would be homochiral).[24]

7. Conclusions: The Tip of the Iceberg

The initial papers published on the OSIRIS-REx samples [11] represent only the first phase of discovery. The fact that Bennu contains the "original ingredients" of the solar system -- presolar dust, primordial water, and prebiotic sugar -- validates the mission's core scientific objectives.

Key Takeaways:

* Bennu is a Fragment of an Ocean World: The magnesium-sodium phosphate discovery strongly implies a parent body with an active, water-rich hydrothermal system capable of concentrating salts.[11]

* The RNA World is Supported: The presence of ribose and lack of deoxyribose supports the hypothesis that RNA-based life preceded DNA-based life, and that the components for this world were synthesized in space.[19]

* Abiotic Polymerization is Ubiquitous: The "space gum" proves that complex polymers can form in asteroidal conditions, providing a mechanism to concentrate prebiotic building blocks before they even reach a planet.[25]

* Cosmic Mixing: The high abundance of supernova dust in a water-altered rock indicates that the early solar system was a chaotic mixing bowl, bringing together high-temperature stardust and low-temperature ices in the accretion disk.[22]

As Dante Lauretta, the principal investigator, noted, "The data we have presented here are only the tip of the iceberg".[44] With over 70% of the sample still in curation for future generations of scientists, Bennu will likely continue to rewrite the history of our solar system for decades to come. The asteroid is not merely a rock; it is a frozen library of the cosmos, holding the chemical narrative of how stars die and how life begins.

Appendix: OSIRIS-REx Mission Timeline Summary

Phase	Date	Event Description
Launch	Sept. 8, 2016	Launched aboard Atlas V from Cape Canaveral.[2]
Arrival	Dec. 3, 2018	Spacecraft arrived at asteroid Bennu.[7]
TAG	Oct. 20, 2020	Touch-And-Go sample collection maneuver.[3]
Departure	May 10, 2021	Departure burn to initiate return cruise to Earth.[4]
Return	Sept. 24, 2023	Sample Return Capsule landed in Utah.[3]

| Curation | | 2023-Present | | Analysis at JSC, distribution to JAXA and worldwide labs.[6] |

| Future | | 2029 | | Spacecraft (now OSIRIS-APEX) to rendezvous with asteroid Apophis.[3] |

Works Cited

- * Bennu Holds the Solar System's 'Original Ingredients,' Might have Been Part of a Wet World, accessed December 4, 2025,
<https://www.lpl.arizona.edu/news/spotlight/bennu-holds-solar-systems-original-ingredients-might-have-been-part-wet-world>
- * OSIRIS-REx | Lockheed Martin, accessed December 4, 2025,
<https://www.lockheedmartin.com/en-us/products/osiris-rex.html>
- * OSIRIS-REx - Wikipedia, accessed December 4, 2025,
<https://en.wikipedia.org/wiki/OSIRIS-REx>
- * OSIRIS-REx In Depth - NASA Science, accessed December 4, 2025,
<https://science.nasa.gov/mission/osiris-rex/in-depth/>
- * Asteroid Bennu sample suggests an ocean world origin - EarthSky, accessed December 4, 2025,
<https://earthsky.org/space/asteroid-bennu-sample-suggests-an-ocean-world-origin/>
- * JAXA curation for Bennu samples returned by the NASA's OSIRIS-REx mission, accessed December 4, 2025,
<https://cosmochemistry-papers.com/2025/10/23/jaxa-curation-for-bennu-samples-returned-by-the-nasas-osiris-rex-mission/>
- * Asteroid Operations - OSIRIS-REx Mission, accessed December 4, 2025,
<https://www.asteroidmission.org/asteroid-operations/>
- * Research Highlights OSIRIS-REx curation at JAXA ISAS, accessed December 4, 2025,
<https://curation.isas.jaxa.jp/en/topics/25-11-25.html>
- * Decoding Bennu: Groundbreaking 2024 research redefines life's origin - Scientia Magazine, accessed December 4, 2025,
<https://scientiamag.org/decoding-bennu-groundbreaking-2024-research-redefines-lifes-origin/>
- * Planetary scientist decodes clues in Bennu's surface composition to make sense of far-flung asteroids - Purdue University, accessed December 4, 2025,
<https://www.purdue.edu/newsroom/2025/Q3/planetary-scientist-decodes-clues-in-bennus-surface-composition-to-make-sense-of-far-flung-asteroids>
- * Surprising Phosphate Finding in NASA's OSIRIS-REx Asteroid Sample, accessed December 4, 2025,
<https://www.nasa.gov/missions/osiris-rex/surprising-phosphate-finding-in-nasas-osiris-rex-asteroid-sample/>
- * An OSIRIS-REx Asteroid Sample Has Surprising Phosphate Content - Astrobiology Web, accessed December 4, 2025,
<https://astrobiology.com/2024/06/an-osiris-rex-asteroid-sample-has-surprising-phosphate-content.html>
- * An evaporite sequence from ancient brine recorded in Bennu ... - NIH, accessed December 4, 2025, <https://pmc.ncbi.nlm.nih.gov/articles/PMC11779627/>
- * Apexite, NaMg(PO₄) * 9H₂O, a new struvite-type phase with a heteropolyhedral cluster, accessed December 4, 2025,
https://www.researchgate.net/publication/283722077_Apexite_NaMgPO49H2O_a_new_struvite-type_phase_with_a_heteropolyhedral_cluster

- * Surprising phosphate discovery in Bennu asteroid sample - Space Daily, accessed December 4, 2025,
https://www.spacedaily.com/reports/Surprising_phosphate_discovery_in_Bennu_asteroid_sample_999.html
- * (PDF) An evaporite sequence from ancient brine recorded in Bennu samples, accessed December 4, 2025,
https://www.researchgate.net/publication/388495893_An_evaporite_sequence_from_ancient_brine_recorded_in_Bennu_samples
- * Surprise in NASA's asteroid rocks hints Bennu came from ocean world | Mashable, accessed December 4, 2025,
<https://mashable.com/article/nasa-osiris-rex-asteroid-phosphate>
- * First OSIRIS-REx paper, co-authored by Rowan's Connolly, suggests asteroid has properties necessary for life, accessed December 4, 2025,
<https://today.rowan.edu/news/2024/06/first-osiris-rex-paper-co-authored-by-rowans-connolly-suggests-asteroid-has-properties-neces>
- * NASA's asteroid sample just revealed new clues to life's origins ..., accessed December 4, 2025,
<https://sea.mashable.com/space/40975/nasas-asteroid-sample-just-revealed-new-clues-to-lifes-origins>
- * NASA's asteroid sample just revealed new clues to life's origins, accessed December 4, 2025,
<https://mashable.com/article/nasa-osiris-rex-asteroid-sugar-space-plastic-discovery>
- * Sugars, Gum-Like Substance and Stardust Found in Asteroid Bennu Samples, accessed December 4, 2025,
<https://www.deccanchronicle.com/science/nasa-finds-sugars-gum-like-substance-and-stardust-in-asteroid-bennu-samples-1921275>
- * Sugars, 'Gum,' Stardust Found in NASA's Asteroid Bennu Samples, accessed December 4, 2025,
<https://www.nasa.gov/missions/osiris-rex/sugars-gum-stardust-found-in-nasas-asteroid-bennu-samples/>
- * Sugars from asteroid Bennu complete the extraterrestrial inventory for life's building blocks, accessed December 4, 2025,
<https://watchers.news/epicenter/sugars-from-asteroid-bennu-complete-the-extraterrestrial-inventory-for-lifes-building-blocks/>
- * Bio-essential sugars in samples from asteroid Bennu - ResearchGate, accessed December 4, 2025,
https://www.researchgate.net/publication/398248320_Bio-essential_sugars_in_samples_from_asteroid_Bennu
- * NASA's OSIRIS-REx Samples Reveal Biological Precursors and 'Space Gum' - SatNews, accessed December 4, 2025,
<https://news.satnews.com/2025/12/03/nasas-osiris-rex-samples-reveal-biological-precursors-and-space-gum/>
- * Sugars And Stardust Found In NASA's Asteroid Bennu Samples - Astrobiology Web, accessed December 4, 2025,
<https://astrobiology.com/2025/12/sugars-and-stardust-found-in-nasas-asteroid-bennu-samples.html>
- * Life's Building Blocks Found in Bennu Samples - Eos.org, accessed December 4, 2025, <https://eos.org/articles/lifes-building-blocks-found-in-bennu-samples>
- * Prebiotic organic compounds in samples of asteroid Bennu indicate heterogeneous aqueous alteration | PNAS, accessed December 4, 2025,
<https://www.pnas.org/doi/10.1073/pnas.2512461122>
- * (PDF) Abundant supernova dust and heterogeneous aqueous ..., accessed December 4,

2025,

https://www.researchgate.net/publication/398247801_Abundant_supernova_dust_and_heterogeneous_aqueous_alteration_revealed_

* The variety and origin of materials accreted by Bennu's parent asteroid - OSTI.GOV, accessed December 4, 2025, <https://www.osti.gov/servlets/purl/2586666>

* NASA's Bennu asteroid holds secrets of life: Discovery of sugars, mysterious space gum, and ancient supernova star dust | - The Times of India, accessed December 4, 2025, <https://timesofindia.indiatimes.com/science/nasas-bennu-asteroid-holds-secrets-of-life-discovery-of-sugars-mysterious-space-gum-and-ancient-supernova-star-dust/articlefrom-Bombay-100.html>

* High Abundances of Presolar Grains and ¹⁵N-rich Organic Matter in CO3.0 Chondrite Dominion Range 08006, accessed December 4, 2025, <https://pmc.ncbi.nlm.nih.gov/articles/PMC5881170/>

* [2407.05258] Comparison of optical spectra between asteroids Ryugu and Bennu: II. High-precision analysis for space weathering trends - arXiv, accessed December 4, 2025, <https://arxiv.org/abs/2407.05258>

* First Look at Ryugu Asteroid Sample Reveals it is Organic-Rich - NASA, accessed December 4, 2025, <https://www.nasa.gov/centers-and-facilities/goddard/first-look-at-ryugu-asteroid-sample-reveals-it-is-organic-rich/>

* Two major new studies on samples from asteroid Bennu point to clues of the origins of the solar system, accessed December 4, 2025, <https://www.nhm.ac.uk/press-office/press-releases/two-major-new-studies-on-samples-from-asteroid-bennu-point-to-cl.html>

* MicrOmega is ready to analyze Bennu samples - Institut d'Astrophysique Spatiale, accessed December 4, 2025, <https://www.ias.u-psud.fr/en/content/micromega-ready-analyze-bennu-samples>

* Asteroid Bennu rocks sugar discovery guym substance early solar system - India Today, accessed December 4, 2025, <https://www.indiatoday.in/science/story/asteroid-bennu-rocks-sugar-discovery-guym-substance-early-solar-system-2829846-2025-12-04>

* Bennu's Ancient Brine Sheds Light on Recipe for Life, accessed December 4, 2025, <https://als.lbl.gov/bennus-ancient-brine-sheds-light-on-recipe-for-life/>

* DIFFUSE AND MINERAL CARBONATES FOUND IN SAMPLES OF ASTEROID BENNU RETURNED BY THE OSIRIS-REx SPACECRAFT. S. A. Sandford1,*, Z. G, accessed December 4, 2025, <https://www.hou.usra.edu/meetings/lpsc2024/pdf/1534.pdf>

* RELATING DIFFUSE AND MINERAL CARBONATES IN ASTEROID BENNU SAMPLES USING X-RAY AND INFRARED SPECTROSCOPY. S. A. Sandford1,*, Z., accessed December 4, 2025, <https://www.hou.usra.edu/meetings/metsoc2024/pdf/6219.pdf>

* Ann NGUYEN | PhD | National Aeronautics and Space Administration, Washington, D.C. | Astromaterials Research and Exploration Directorate - ResearchGate, accessed December 4, 2025, <https://www.researchgate.net/profile/Ann-Nguyen-8>

* presolar grains in angular and hummocky samples from asteroid bennu. an, accessed December 4, 2025, https://ntrs.nasa.gov/api/citations/20240016114/downloads/Nguyen_PSGs%20in%20Bennu_LPSC2025_v3.pdf?attachment=true

* (PDF) Abiotic sugars in (162173) Ryugu and the primitive CI carbonaceous chondrite Orgueil - ResearchGate, accessed December 4, 2025, [https://www.researchgate.net/publication/358111111_Abiotic_sugars_in_\(162173\)_Ryugu_and_the_primitive_CI_carbonaceous_chondrite_Orgueil](https://www.researchgate.net/publication/358111111_Abiotic_sugars_in_(162173)_Ryugu_and_the_primitive_CI_carbonaceous_chondrite_Orgueil)

https://www.researchgate.net/publication/392844501_Abiotic_sugars_in_162173_Ryugu_and_the_primitive_CI_carbonaceous_chondrites

* Phosphate in NASA's OSIRIS-REx asteroid sample suggests space rock Bennu hails from an ocean world, accessed December 4, 2025,

<https://www.space.com/nasa-osiris-rex-sample-return-phosphate-ocean-world>

* Mission Status, accessed December 4, 2025,

<https://www.asteroidmission.org/status-updates/>