Identification of bio-essential sugars in samples returned from asteroid Bennu

Yoshihiro Furukawa[1], Sako Sunami[1], Toshiki Koga[2], Yuta Hirakawa[2], Yasuhiro Oba[3], Yoshinori Takano[2], Hiroshi Naraoka[4], Daniel P. Glavin[5], Jason P. Dworkin[5], Harold C. Connolly, Jr.[6,7,8], and Dante S. Lauretta[6]

[1]*Department of Earth Science, Tohoku University*

[2]*Biogeochemistry Research Center (BGC), Japan Agency for Marine-Earth Science and Technology (JAMSTEC)*

[3]*Institute of Low Temperature Science (ILTS), Hokkaido University*

[4]*Department of Earth and Planetary Sciences, Kyushu University*

[5]*Solar System Exploration Division, National Aeronautics and Space Administration (NASA), Goddard Space Flight Center*

[6]*Lunar and Planetary Laboratory, University of Arizona*

[7]*School of Earth and Environment Department of Geology, Rowan University*

[8]*Department of Earth and Planetary Sciences, American Museum of Natural History*

Sugars (aldoses) are ubiquitous molecules in biology. In particular, ribose and deoxyribose are key constituents of nucleic acids (RNA and DNA) and biochemical intermediates. Glucose is essential to metabolism. Thus, the search for these compounds in extraterrestrial materials is important to understand the potential for exogenous contributions to the early Earth's prebiotic organic inventory that led to the emergence of life [e.g., 1,2,3]. Ribose and other linear aldopentoses have been found in two carbon-rich meteorites [4], but deoxyribose and glucose have not previously been found in any astromaterial.

A 6.425 g sample unsorted regolith from Bennu (OREX-800107-0) was powdered in an ashed quartz mortar and pestle in an ISO 5 flow bench at NASA Johnson Space Center. The homogeneity of the powder size distribution was verified by X-ray tomography, and a sample of ashed silica was prepared and analyzed in parallel as a blank. A 0.6 g aliquot (OREX-800107-108) was separated and shipped to Tohoku University for the detection of aldoses. Soluble organic compounds were extracted in dilute HCl solution and water by sonication at ambient temperature. The extract was purified, derivatized into aldonitrile acetate, and analyzed by gas chromatography–mass spectrometry (GC-MS).

Among substantial variations in GC-MS signals from a complex set of soluble organic compounds in the Bennu sample extract, we identified the derivatives of ribose, xylose, arabinose, lyxose, mannose, and glucose. We also searched for other sugars and related compounds, including trioses, 2-deoxyribose, sugar alcohols, and sugar acids. None of these compounds were detected. The bulk abundance of pentose sugars is approximately 10% of that in the Murchison meteorite [4]. This observation is consistent with mineralogical data indicating that the material composing the Bennu samples experienced more extensive aqueous alteration than the Murchison meteorite's parent body [5]. The relative abundances among the detected sugars are consistent with the expected abundances from formose reactions in aqueous solutions [6]. Their relative abundances are also generally consistent with their thermal stabilities in neutral solutions [7].

Formaldehyde, the carbon source in the formose reaction, occurs in comets, interstellar ice, meteorites, and the Bennu sample [e.g., 8, 9, 10]. Phyllosilicates in the Bennu sample indicate substantial aqueous processing in the parent asteroid [5]. Thus, sugar formation after accretion of the Bennu parent body, during hydrothermal alteration, is reasonable. The presence of glucose suggests that common metabolic substrates (particularly glucose) were ubiquitous in the early Solar System. Although we detected ribose, the more stable 2-deoxyribose (though more reactive, and thus possibly less abundant in the free form) [11], was not detected. This is consistent with a previous result from carbonaceous meteorites [4] and suggests a linkage between prebiotic sugars and RNA. With the detection of amorphous soluble phosphate [5] and nucleobases [10], these results support the hypothesis that RNA was the first biologic molecule before the DNA/protein–based world evolved.

References

[1] Cooper. G. et al. 2001. Nature 414: 879. [2] Kasting J. F. and Catling D. 2003. Annu. Rev. Astron. Astrophys. 41: 429. [3] Meinert C. et al. 2016. Science 352: 208. [4] Furukawa Y. et al. 2019. PNAS 116: 24440. [5] Lauretta D. S., Connolly H.C. et al. 2024. MAPS 59: 2453. [6] Ono C. et al. 2024. Astrobiology 24: 489. [7] Larralde R. et al. 1995. PNAS 92: 8158. [8] Altwegg K. et al. 2017. Mon. Not. R. Astron. Soc. 469: S130. [9] Aponte J. C. et al. 2019. ACS Earth Planet. Chem. 3: 463. [10] Glavin D. P., Dworkin J. P. et al., this symposium. [11] Dworkin J. P. and Miller S. L. 2000. Carbohydrate Res. 329: 359.

Acknowledgments

This material is based upon work supported by NASA under award NNH09ZDA007O and contract NNM10AA11C issued through the New Frontiers Program. The authors thank JAXA/ISAS for the support of our analyses. We acknowledge the entire OSIRIS-REx team for making the return of samples from asteroid Bennu possible.