SUGARS AND RELATED COMPOUNDS: COMPARISONS BETWEEN METEORITES AND THE RESIDUES PRODUCED FROM THE UV IRRADIATION OF ASTROPHYSICAL ICE ANALOGS.

S. A. Sandford[1], M. Nuevo[1,2], and G. Cooper[1], [1]NASA Ames Research Center, MS 245-6, Moffett Field, CA 94035, USA, [2]BAER Institute, 625 2nd St., Ste. 209, Petaluma, CA 94952, USA (E-mails: Scott.A.Sandford@nasa.gov; Michel.Nuevo-1@nasa.gov; George.W.Cooper@nasa.gov)

Introduction: Murchison as well as other carbonaceous chondrites contain a large variety of organics, which include amino acids **[1,2]**, amphiphiles **[3,4]**, nucleobases **[5,6]**, functionalized polycyclic aromatic hydrocarbons **[7,8]**, and sugar derivatives **[9]**. The presence of these compounds of prebiotic significance in meteorites suggests that molecules essential to life can form abiotically under astrophysical conditions. Among the sugar derivatives found in Murchison and Murray **[9]**, one sugar (dihydroxyacetone) and a large variety of sugar derivatives containing up to 6 carbon atoms have been identified.

Laboratory studies in the last two decades have routinely shown that complex organics are formed when simulated astrophysical ice mixtures consisting of H_2O, CO, CO_2, CH_3OH, CH_4, NH_3, etc., are irradiated with ultraviolet (UV) light at low temperature. The organic residues recovered at room temperature in these experiments have been shown to contain many similar organics to those found in meteorites **[10–17]**. However, the formation of sugars and their derivatives in such residues has only been studied very recently **[18-20]**.

Results: We have performed a large number of experiments in which ice mixtures containing H_2O, CH_3OH, CO, CO_2, and/or NH_3 were UV irradiated at 10 K, and carried out a systematic search for sugars and sugar derivatives in the resulting organic residues. Results confirm the presence of a wide variety of sugar alcohols, sugars, and sugar acids with up to 6 carbon atoms, including ribose. This work also shows the presence of several deoxy variants of sugar derivatives that have not been reported in previous studies, including 2-deoxyribose (the sugar of DNA) and several deoxysugar alcohols **[21]** (Table 1), and compares them with pre-existing and new meteoritic data **[9,21]**.

Table 1 Deoxysugar derivatives identified in the ice photolysis residues (regular and ^{13}C-labeled)

Compounds[a]	Formulas	R_t (min)[b]	Abundances in residues[c] (pmol)	Detected in meteorites?
Deoxysugars				
2-Deoxyribose	$C_5H_{10}O_4$	61.2, 61.4	217–3855	Undetermined[k]
2-Deoxyxylose[d]	$C_5H_{10}O_4$	57.0, 57.3	373–3636[e]	Undetermined[k]
Deoxysugar alcohols				
1,2-Propanediol[f]	$C_3H_8O_2$	9.9	≥8–375	Yes[l,m]
1,3-Propanediol[f,g]	$C_3H_8O_2$	36.9	≥19–27	No
2-Methyl-1,3-propanediol[g,h]	$C_4H_{10}O_2$	38.7	≤1038–3354[h]	No
2-(Hydroxymethyl)-1,3-propanediol	$C_4H_{10}O_3$	30.9	n.d.	Yes[l]
1,2,3-Butanetriol	$C_4H_{10}O_3$	14.5	6–39	No
1,2,4-Butanetriol	$C_4H_{10}O_3$	32.2	35–50	Yes[l]
Deoxysugar acids				
3,4-Dihydroxybutyric acid[i,j]	$C_4H_8O_4$	16.5	—	Yes[n]
Sugars				
Ribose	$C_5H_{10}O_5$	64.7, 65.0	237–2467	No

n.d., Not detected
[a]Compounds were detected using the (+)-2-butanol/TFAA derivatization method, unless otherwise stated
[b]Retention times (R_t) correspond to average values in the GC-MS chromatograms of the residues, or to standard chromatograms if compounds were not detected in the residues. Chiral compounds whose enantiomers are separated have two retention times
[c]Abundances for chiral compounds correspond to the sum for both enantiomers
[d]Tentatively identified by comparison of its mass spectrum with that of the 2-deoxyribose standard
[e]Abundances estimated based on the GC-MS detector response for the 2-deoxyribose standard
[f]Volatile compounds that may have been partially lost during the warm-up phase and/or the sample preparation. Abundances given thus correspond to lower limits
[g]Detected in samples derivatized with the MTBSTFA method
[h]Elutes with another unidentified compound with similar mass fragments, so abundances given are upper limits
[i]Tentatively identified by comparison with the NIST mass spectrometry library in samples derivatized with the BSTFA method
[j]May be present in its dimer form
[k]The presence of these compounds in meteorites is uncertain, and further analyses are required
[l]Detected in Murchison
[m]Detected in GRA 06100
[n]Detected in Murchison and Murray

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References: **[1]** Kvenvolden K. et al. (1970) *Nature*, *228*, 923–926. **[2]** Cronin J. R. and Pizzarello S. (1997) *Science*, *275*, 951–955. **[3]** Deamer D. W. (1985) *Nature*, *317*, 792–794. **[4]** Deamer D. W. and Pashley R. M. (1989) *OLEB*, *19*, 21–38. **[5]** Folsome C. E. et al. (1971) *Nature*, *232*, 108–109. **[6]** Stoks P. G. and Schwartz A. W. (1979) *Nature*, *282*, 709–710. **[7]** Bernstein M. P. Et al. (1999) *Science*, *283*, 1135–1138. **[8]** Ashbourn, S. F. M. et al. (2007) *Meteor. Planet. Sci.*, *42*, 2035–2041. **[9]** Cooper G. et al. (2001) *Nature*, *414*, 879–883. **[10]** Bernstein M. P. et al. (2002) *Nature*, *416*, 401–403. **[11]** Muñoz Caro G. M. (2002) *Nature*, *416*, 403–406. **[12]** Nuevo M. et al. (2008) *OLEB*, *38*, 37–56. **[13]** Dworkin J. P. et al. (2001) *PNAS*, *98*, 815–819. **[14]** Nuevo M. et al. (2009) *Astrobiol.*, *9*, 683–695. **[15]** Nuevo M. et al. (2012) *Astrobiol.*, *12*, 295–314. **[16]** Materese C. K. et al. (2013) *Astrobiol.*, *13*, 948–962. **[17]** Nuevo M. et al. (2014) *ApJ*, *793*, 125 (7 pp.). **[18]** Nuevo M. et al. (2015) AbSciCon 2015, Abstract No. 7132 **[19]** Nuevo M. et al. (2015) ACS Fall Meeting 2015, Abstract No. PHYS 272 **[20]** Meinert C. et al. (2016) *Science*, 352, 208–212. **[21]** Nuevo M. et al. (2018). *Nat. Commun., 9*, 5276.200