CHEMISTRY AND ASTROCHEMISTRY OF SIMPLE SUGARS: IMPLICATIONS FOR ASTEROID, METEORITE, OR COMET DELIVERY N.E.B. Zellner[1], V.P. McCaffrey[2], E. Bennett[2], M. Gudipati[3], [1]Department of Physics, Albion College, Albion, MI 49224 (nzellner@albion.edu), [2]Department of Chemistry, Albion College, Albion, MI 49224, [3]Jet Propulsion Laboratory, Pasadena, CA 91109

Introduction: Detections of biologically-relevant compounds in molecular clouds have shown that they can form easily in space, with subsequent delivery to Earth or other planets by comets, meteorites, asteroids, or interplanetary dust particles. Almost 160 molecules have been detected by various investigators (as reported in [1]), and others have modeled how these materials are formed and incorporated into interstellar ice and grain mantles [e.g., 2, 3] and comets [e.g., 4]. Meteorites are some of the most well-studied delivery vehicles, showing us that a variety of molecules, including amino acids and sugar precursors [e.g., 5, 6, 7], are common in the extraterrestrial environment. Additionally, comet spectra [e.g., 8] and samples [e.g., 9, 10] show evidence for similarly complex compounds. Previous studies have investigated how impacts affect the survivability of amino acids [11, 12], PAHs [13], and biomarkers [14]. This study furthers these investigations by showing how simulated asteroid or comet impacts can affect simple two- and three-carbon molecules.

During impact events involving simple molecules that contain carbon, hydrogen and oxygen, monosaccharides, or possibly even complex sugar molecules, such as ribose and glucose, could be formed (Figure 1), and all are important molecules in biological systems. Glucose is a source of energy for cells and is an intermediate in many biological processes. Polymers of ribose comprise the backbone of both RNA and DNA, which contain the genetic code of life on Earth. When found in their cyclic conformations, these simple carbohydrates can react with other sugar molecules to form disaccharides such as sucrose (table sugar) and lactose (milk sugar). While evidence of sugars of more than three carbons has not yet been found in the interstellar medium, we are interested in understanding these compounds' stability under the high temperature and pressure conditions that would be found in the impact of an asteroid or comet. To that end, we are investigating the simplest carbon molecules under simulated terrestrial impact conditions.

Experimental Methods: Samples of glycolaldehyde (GLA) and dihydroxyacetone (DHA), the two simplest two- and three-carbon sugars respectively, were analyzed during Summer 2010 to understand their properties at standard conditions and to further understand how they reacted under a variety of conditions, including heat and pressure. Samples, both natural and subjected to these unique conditions, were analyzed by GCMS. Impact experiments were conducted at the NASA Ames Vertical Gun Range (NASA AVGR), with subsequent analyses of the shocked compounds conducted in the Dow Chemical Laboratory at Albion College.

Characterization Analyses: In order to understand these molecules in their natural state (to establish a baseline for these control samples) and to assess our analytical capabilities, as well as to optimize the reaction conditions, several samples of DHA and GLA were analyzed with GCMS. It was found that analysis of the compounds was very difficult without derivitizing the samples as silyl alcohols. Silylation of the samples had several benefits. First, the derivatization reactions "lock" the compounds and prevent further reactions from taking place. Second, silylation decreased the limit of detection, allowing us to detect and analyze very small masses (tens of milligrams). A complete silylation of GLA has been achieved (Figure 2) and we are currently developing a method to completely silylate DHA.

NASA AVGR Experiments: Three experiments that were designed to determine the potential for the survivability of simple sugars were conducted using the light-gas gun facility. A sample of neat glycolaldehyde, a sample of neat dihydroxyacetone, and a sample composed of both compounds were individually impacted by an inert projectile traveling at ~5 km/sec.

Chemical Analyses: Recovered samples were overnighted to Albion College at dry ice temperatures and immediately silylated in the Dow Chemistry Laboratory at Albion College. Here they were analyzed using GCMS. Further analysis of the samples was done using infrared spectroscopy and ^{1}H NMR. These techniques give valuable and complementary information about the number and identity of the species in the shocked mixtures.

Discussion: Analyses of simple two- and three- carbon molecules can be achieved with careful planning, and results of these preliminary investigations will be presented. The results of these experiments will help us understand how mono- and di-saccharides might be altered in impact events.

The delivery, preservation, and/or formation of these simple and complex compounds is exciting in the context of the origin of life. If we can better understand how organic molecules are affected during their delivery to Earth (or other planetary bodies), we might be able to better understand their role in the origin of life, or in the case of these molecules, their role in forming more complex molecules required for life.

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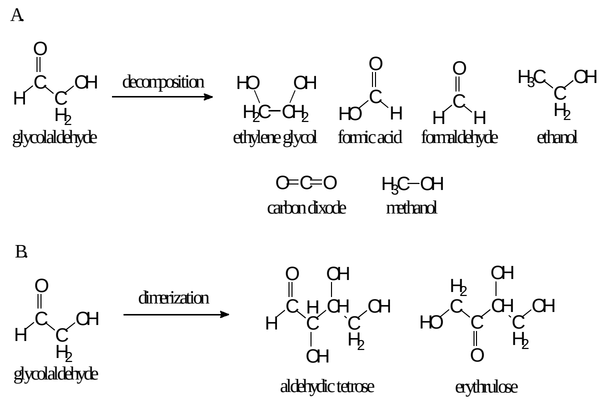

Figure 1. Structures of A. decomposition and B. dimerization products formed from the shock chemistry of glycolaldehyde.

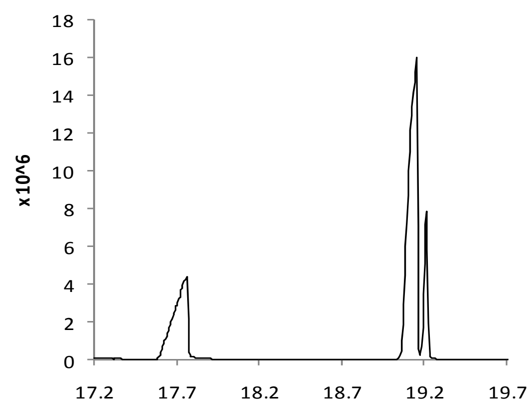

Figure 2A. Gas chromatograph of a silylated sample of the un-shocked GLA. The peak at 18.8 min corresponds to GLA-TMS, 19.0 min to GLA$_2$(6)-TMS$_2$, and 19.1 GLA$_2$(5)-TMS$_2$ [15].

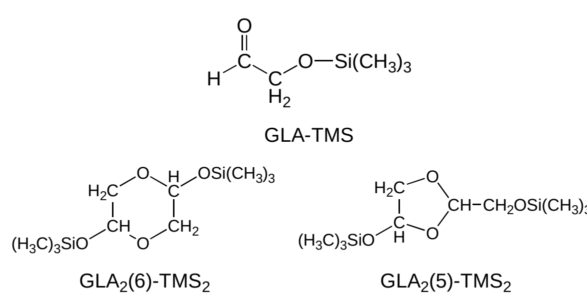

Figure 2B. Structures of the TMS-derivatized GLA monomer and the two dimeric forms found after the reaction.