Organic Compounds in Carbonaceous Meteorites

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Carbonaceous meteorites are relatively enriched in soluble organic compounds. To date, these compounds provide the only record available to study a range of organic chemical processes in the early Solar System chemistry. The Murchison meteorite is the best-characterized carbonaceous meteorite with respect to organic chemistry. The study of its organic compounds has related principally to aqueous meteorite parent body chemistry and compounds of potential importance for the origin of life. Among the classes of organic compounds found in Murchison are amino acids, amides, carboxylic acids, hydroxy acids, sulfonic acids, phosphonic acids, purines and pyrimidines (Table 1). Compounds such as these were quite likely delivered to the early Earth in asteroids and comets.

Until now, polyhydroxylated compounds (polyols), including sugars (polyhydroxy aldehydes or ketones), sugar alcohols, sugar acids, etc., had not been identified in Murchison. Ribose and deoxyribose, five-carbon sugars, are central to the role of contemporary nucleic acids, DNA and RNA. Glycerol, a three-carbon sugar alcohol, is a constituent of all known biological membranes. Due to the relative lability of sugars, some researchers have questioned the lifetime of sugars under the presumed conditions on the early Earth and postulated other (more stable) compounds as constituents of the first replicating molecules. The identification of potential sources and/or formation mechanisms of pre-biotic polyols would add to the understanding of what organic compounds were available, and for what length of time, on the ancient Earth.

Recent results (submitted for publication):

Our analyses of Murchison (and the Murray meteorite) extracts show that a variety of polyhydroxylated compounds are present in carbonaceous meteorites (Fig. 1). The identified compounds include a true sugar, dihydroxyacetone; sugar-alcohols; sugar acids; "deoxy" sugar acids; and sugar di-acids. In general the compounds follow the abiotic synthesis pattern of other meteorite classes of organic compounds: decreasing abundance with increasing carbon number within a class of compounds and many (or all) possible isomers are present at a given carbon number. Qualitatively, Murchison and Murray are very similar in respect to the presence of individual compounds. Dihydroxyacetone is the first and only sugar definitively identified in meteorites. Results of analysis for the 2-carbon (2-C) analog of dihydroxyacetone, glycolaldehyde (recently identified in interstellar space), are ambiguous and further analyses are in progress. 6-C monomeric sugars were not identified, however we cannot rule out the presence of compounds containing them - suggestive evidence (mass spectra) is seen in all samples.

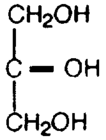
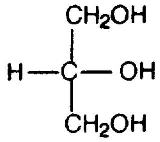
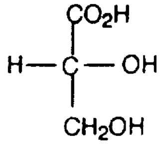
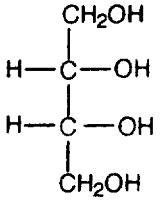
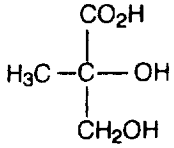
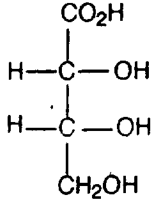
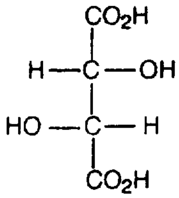
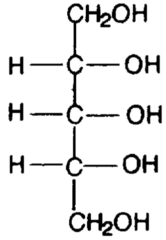
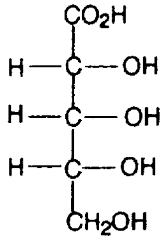
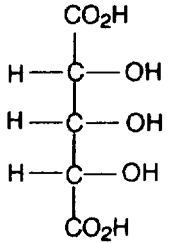
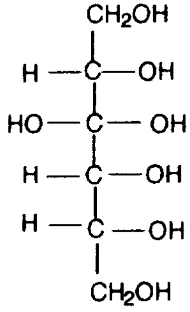
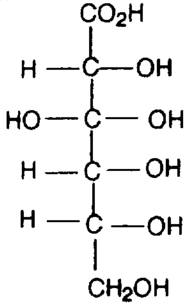
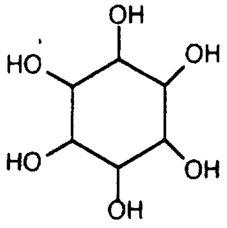
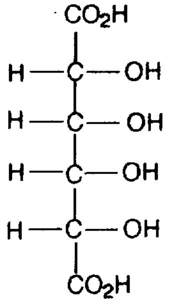
A plausible synthetic origin for at least of some of the polyols in Murchison and Murray is the photolysis of interstellar gases on interstellar grains. Another possible mode of synthesis of the polyols involves the aqueous chemistry of formaldehyde. Formaldehyde is a relatively abundant and ubiquitous molecule in interstellar space and comets, and has also been identified in Murchison. The most generally agreed upon mechanism for natural abiotic synthesis of polyols is the "formose" reaction. In this reaction formaldehyde (CH2O), in alkaline aqueous solution, reacts with itself to gradually build a variety of hydroxylated compounds including sugars of carbon number up to at least seven. Extracts of Murchison and Murray show that the aqueous solution on the parent body(ies) was slightly alkaline. Under alkaline and/or oxidizing conditions sugars can be oxidized to a variety of acids including those in Fig. 1.

The fact that a suite of related sugar derivatives (oxidation products) and dihydroxyacetone are present in both Murchison and Murray makes it likely that more sugars were, at one time, also present. Other bodies (comets or asteroids), perhaps in different stages of aqueous alteration or oxidation, may have delivered intact sugars to planets in the early Solar System. However dihydroxyacetone alone, which we believe is indigenous to the meteorites, is capable of producing higher sugars in aqueous solution. As a model of prebiotic chemistry, the finding of these compounds in some of the oldest objects in the Solar System suggests that polyhdroxylated compounds were, at the very least, available for incorporation into the first living organisms.

ORGANIC COMPOUNDS IN THE MURCHISON METEORITE

Class	Concentration (ppm)	Compounds Identified
Monocarboxylic Acids	>300	20
Polar Hydrocarbons	100-120	10+
Amino Acids	60	74
Amides	55-70	49+
Aliphatic Hydrocarbons	>35	140
Dicarboxylic Acids	>30	38
Aldehydes & Ketones	27	9
Aromatic Hydrocarbons	>15-28	87+
Hydroxy Acids	15	51
Alcohols	11	8
Amines	8	10
Basic N-Heterocycles	7	32
Purines and Pyrimidines	1	5
Sulfonic Acids	71	8
Phosphonic Acids	2	4

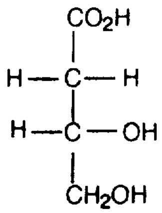
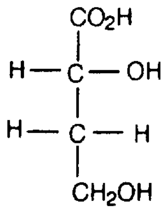
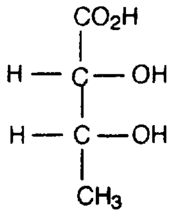
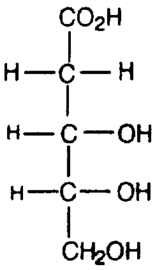
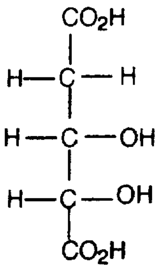
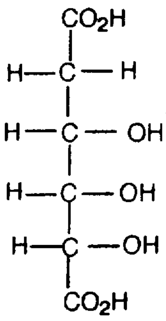
Figure 1 Polyols identified in carbonaceous meteorites.

Sugars	Sugar alcohols	Sugar acids		Dicarboxylic Sugar acids
 Dihydroxyacetone	 Glycerol	 Glyceric Acid		
——	 Erythritol and threitol	 Methyl glyceric Acid	 Erythronic and Threonic acid	 Tartaric and mesotartaric acid
——	 Ribitol + Isomers	 Ribonic Acid + Isomers		 2,3,4-Trihydroxy pentane dioic Acid
*	 Isomers	 Gluconic Acid + Isomers	 Inositol Isomers	 Isomers

* 6-C sugars (monomers) were not seen but may be present as compounds.

Although only 2 - 6 C compounds are shown, there are almost certainly higher carbon number compounds in the meteorites.

Cont. Figure 1. "Deoxy" sugar acids in carbonaceous meteorites

	Deoxy sugar acids	Deoxy sugar Di-acids
4C	 3,4 dihydroxy butyric acid  2,4 dihydroxy butyric acid  2,3 dihydroxy butyric acid (and diastereomer)	——
5C	 5-C isomers	 5-C isomers
6C		 6-C isomers