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Abundance, Enantiomeric, and ^{13}C Isotope Analyses of Meteoritic Aldehydes and Ketones

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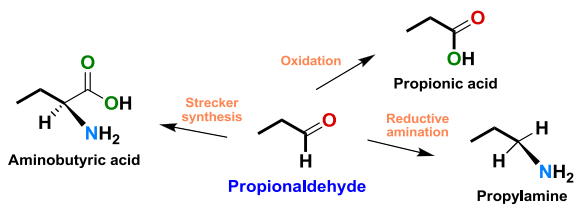
Abstract

The assessment of the molecular diversity of soluble organic compounds in carbonaceous chondrites provides information about the chemical inventory at the birth of the Solar System and the processes that occurred inside the parent body [1]. Here, we have analyzed the abundance, molecular diversity, and isotopic and enantiomeric compositions of aldehydes and ketones (carbonyl compounds) which may have been precursors for other meteoritic organics.

1. Introduction

Central to the study of meteoritic organic compounds is the isolation, identification and quantification of these prebiotic molecules. One of the most thoroughly studied meteoritic organics are aliphatic amino acids; however, even after over 60 years of research, their prebiotic origins remain a major subject of debate [2]. Meteoritic carbonyl compounds may be potential precursors of amino acids, and other compounds such as monocarboxylic acids (MCAs) and amines (Scheme 1). We have assessed the isotopic and enantiomeric composition of meteoritic MCAs and amines [3], [4]; now, we turn our focus to the analyses of carbonyl compounds.

Scheme 1: Potential synthetic relationship between aldehydes, ketones, amines and amino acids.



Several aldehydes and ketones have been previously detected from carbonaceous chondrites [5], [6]; however, the methodology used for these analyses hampered the assessment of their isotopic and enantiomeric distributions. We have developed and applied a novel gas chromatography coupled with mass spectrometry and isotope ratio mass spectrometry method, as well as a workup protocol suited for the simultaneous measurement of the abundance, enantiomeric composition, and compound-specific isotopic analysis of aliphatic short-chained carbonyl compounds (≤ 6 carbons) in CI, CM, CR and CV carbonaceous chondrites.

2. Results and Discussion

The total concentrations of aldehydes and ketones we found are shown in Figure 1. We measured total abundances of aldehydes that were higher than that of ketones; with acetaldehyde and formaldehyde being the most abundant aldehydes, and acetone the most abundant ketone across different carbonaceous chondrites. The total concentrations of carbonyl compounds among CI and CM chondrites ranged within similar values, while those in CR chondrites seemed to be more dependent on the levels of aqueous alteration occurred in the parent body. We observed higher concentrations of formaldehyde over acetaldehyde in the low aqueously altered CM and CR chondrites (EET 96029, LAP 02342, GRA 95229, and MIL 09657). These collective data support the theory that parent body processes in addition to the yet-to-be known organic-precursor budget of carbonaceous chondrites, play an important role in the abundance and molecular distribution of soluble meteoritic organics.

We observed racemic compositions of the chiral 3-methyl-2-pentanone and 3-methylpentanal; these results are consistent with racemic compositions found for meteoritic aliphatic MCAs and amines [7], [4]. The racemic compositions of the carbonyl compound suggest that these compounds were either racemic prior to their accretion inside the parent body, or that after accretion, aqueous processes racemized them or resulted in enhancements of any initial symmetric imbalance that are below our current detection limits.

The varying concentrations and unique molecular diversity, plus the racemic composition of carbonyl compounds in meteorites with distinct levels of

parent body processing, support an extraterrestrial origin for these compounds. However, we interpreted that the carbonyl compounds found in Allende (CV3) are product of terrestrial contamination based on the ^{13}C-depleted values measured and the high concentrations of biological MCAs we found in a previous analysis of the same material. The carbon isotope ($\delta^{13}C$) compositions of carbonyl compounds contrast with the $\delta^{13}C$ values previously reported for amino acids and amines [8], [4], but they fall within the $\delta^{13}C$ range of MCAs [3].

3. Conclusions

Aliphatic aldehydes are more abundant than ketones in the samples we investigated. The combined concentrations of both compound classes resulted similar in CI and CM chondrites, but more aqueous processing-dependent in CR chondrites. We observed higher abundances of acetaldehyde over formaldehyde in more aqueously altered meteorites. We detected racemic compositions of carbonyl compounds and $\delta^{13}C$ values that are within the range of MCAs. Future efforts aimed to unveil the complex synthetic relationship between various meteoritic organics are needed to implement constraints on their meteoritic origin.

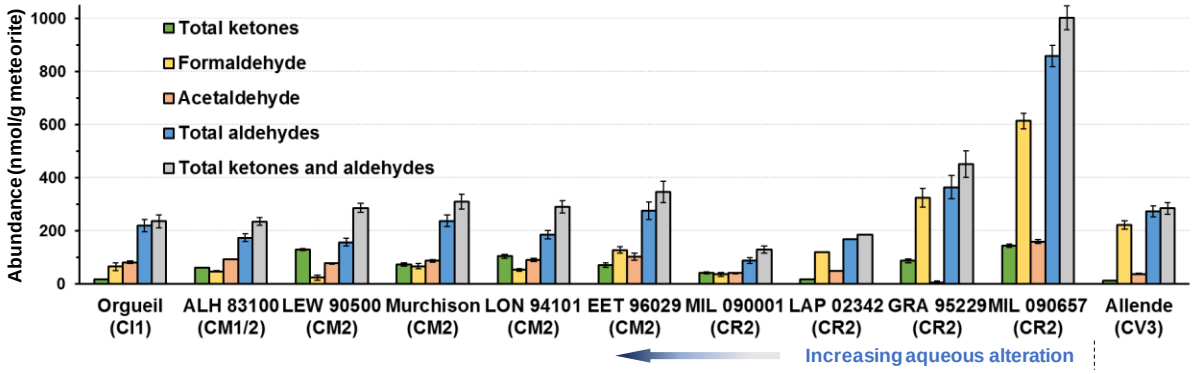


Figure 1: Abundance of carbonyl compounds in CI, CM, CR and CV meteorites. Meteorite groups are arranged according to their aqueous and thermal alteration.

Acknowledgements

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