Astrobiology on Mars: Organic Chemical Evolution on an Earth-like Planet

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Introduction

This white paper recommends that the next decade of Mars exploration prioritizes research into the origin, distribution, and chemistry of organic matter in martian geologic materials, both *in situ* and in samples returned to Earth.

The discovery of organic matter in several Mars meteorites and in lake sediments at Gale Crater were stunning successes of the last decade of Mars exploration. Martian organic matter was detected in the form of a macromolecular carbon (MMC) phase that includes polycyclic aromatic hydrocarbons (PAHs), as well as nitrogen-, oxygen and sulfur-bearing species. Pyrolysis products of Gale Crater lake sediments released between 500-820º C revealed the highly refractory organic MMC component. More volatile organic molecules might also be present in the sediments, based on the identification of chlorobenzene and dichloroalkanes by gas chromatography mass spectrometry. However, chemical analyses of this lower volatility component have been challenging due to the chemical reactivity of martian soil as well as instrument background sources.

Why focus on organic chemistry?

Life, when considered in a planetary context, is one end member in the continuum of organic chemical evolution. The origin of life is the result of a series of abiotic chemical reactions whereby increasingly complex organic molecules and molecular assemblages form from simpler ones, leading to the emergence of the first self-replicating organism. From that point onwards, biochemistry drives organic chemical evolution via chemical interactions between many informationally ordered organic macromolecules. These organic macromolecules are made of a relatively small set of simpler monomeric molecule types. The weak chemical interactions between macromolecules shape the ways in which the monomers, which compose them, are made. These interlinkages—between abiotic chemistry and biochemistry, macromolecules and monomers, reactants and products—are likely universal attributes of an origin of life.

The transition from geochemistry to biochemistry may have happened only once, on Earth, in the history of the Universe, or it may occur frequently wherever conditions allow. We do not know exactly when, where, or how this chemical singularity occurred on the Earth, as the geologic record of that period has largely been lost. For decades, research into this topic has relied on two approaches: laboratory synthesis of organic molecules under plausible environmental conditions, and analyses of primordial interplanetary organics. Both approaches have provided important clues regarding the initial types of possible prebiotic organic compounds, as well as the chemical pathways that might have led from small organic molecules to macromolecules, and eventually to life.

The discovery of organic matter in martian geologic materials is critical for the following reasons: (1) It supports the notion that organic chemical evolution, which we already know to be widespread in other Solar System environments, is also active on rocky planets; (2) It shows that organic chemical evolution occurred in martian environments that could have supported life; (3) It could expand the record of organic chemical evolution during the first billion years, helping reconstruct the lost record of organic chemical evolution in early Earth; and (4) It provides a third and new approach to study organic chemical evolution under planetary conditions that are considerably more complex and dynamic than typically studied in laboratory simulations, and may give context for the conditions that shaped organic chemical evolution in interplanetary materials.

In this white paper, we will: (1) Highlight unresolved questions surrounding organic chemistry and organic chemical evolution on Mars; (2) Propose specific science objectives for the next decade of Mars exploration that center on the study of organic matter on Mars; (3) List some of the measurements required to understand the sources, sinks, and possible transformations of organic matter on Mars; (4) Recommend general mission concepts or architectures to achieve those objectives; and (5) Identify technological gaps that need to be addressed to support organic chemistry research on Mars in the coming decades.

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