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Life from Outer Space: Overview on the Presence of DNA, RNA Associated Bio-Molecules – Amino Acids, Nucleobases, Sugars and Water Molecules in Meteorites and Carbonaceous Chondrites

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ABSTRACT: Life requires various compounds, such as sugars, amino acids, nucleobases, vital elements, and water, to thrive on Earth's seemingly inert rock surface. These compounds not only provide the necessary energy but also store the information essential for life and exhibit functions crucial for survival. Compelling evidence indicates the existence of these molecules and their precursors in interstellar objects. Analytical techniques such as X-ray diffraction, ion exchange chromatography, paper chromatography, high-performance liquid chromatography, and mass spectrometry have unveiled the presence of life-supporting molecules in meteorites and chondrite samples. Moreover, there are theories suggesting that Earth's water might be the result of impacts from cold, ice-bearing comets and asteroids. The analysis results, combined with these theories, strongly suggest that life-supporting compounds could have been transported to Earth, transforming this once lifeless rock into a thriving habitat. This article delves into the possibility that the origin of life on Earth may have been facilitated by the transportation of vital compounds from interstellar space through various celestial bodies.

Keywords: Astrobiology, Carbonaceous chondrites, Amino acids, Sugars, Outer space.

INTRODUCTION

Since ancient times, the idea that life might have originated from environments beyond Earth has been proposed. This concept dates back to the significant civilizations of the past, evident in inscriptions and scriptures. The Egyptian civilization, for instance, provides important statements, and an in-depth exploration of their beliefs reveals insights into their thoughts on the afterlife. Even many contemporary religions believe that life's inception occurred somewhere in the universe, orchestrated by their respective gods. However, from a scientific perspective, these ideas have been uprooted by the theories of evolution and the prebiotic soup.

Although we can construct an ideal roadmap from basic living organisms to more complex ones, the question of "How did the simplest cell form?" remains a mystery for scientists worldwide and a comfortable question for theists to challenge atheists. In 1924, Alexander Oparin of Russia proposed the 'Origin of Life' theory. He suggested that when the Earth was enveloped by primordial gases and substances containing heavy elements like carbon and iron, along with gases such as hydrogen, the interaction of hydrogen and carbon formed hydrocarbons. Further reactions with amines produced hydroxy amines, whose derivatives include carbohydrates and proteins. These substances mixed with primitive oceans, creating a gel-like substance that led to the formation of the first cell.

Various theories have been developed, modifying gases and substances with oxygen, methane, and ammonia, as seen in the Miller-Urey experiment. Attempting to replicate Earth's early conditions, Miller and Urey filled a glass flask with water, methane, ammonia, and hydrogen. By applying an electric spark and heating the water, they simulated the conditions conducive to the origin of life. The solution in the flask changed color over days, eventually turning deep red and thick. Analysis revealed amino acids such as glycine, alpha and beta alanine, aspartic acid, and alpha aminobutyric acid. Subsequent research has shown that almost 11 of the 20 amino acids essential for life were produced in this experiment.

Modern technologies and various biotechniques to detect life molecules in falling meteorites have provided insights into the possibility of life originating from outer space. This paper explores the fundamental biomolecules constituting DNA, such as amino acids, sugars, and nucleotides, found in nearly every life-form on Earth. It aims to demonstrate their presence in carbonaceous and non-carbonaceous meteorites, utilizing various techniques. Additionally, we review research outcomes attempting to establish the origin of water in a similar manner.

AMINO ACIDS

Over the past 50 years, the revelation of extraterrestrial amino acids in various meteorites has significantly transformed the field of Astrobiology. Amino acids serve as the building blocks and precursors to proteins, playing a pivotal role in supporting life on Earth (Cobb and Pudritz 2014). Acting as molecular machinery, amino acids catalyze nearly all the chemical reactions necessary for sustaining life. The substantial presence of amino acids in meteorites, a majority of which are not utilized in biological processes, serves as robust evidence for their extraterrestrial origin. While trace amounts of meteoritic amino acids may exist on Earth, those with chiral carbons are found in meteorites as racemic mixtures (Bada, 1991).

Various analytical methods have been employed to study these extraterrestrial amino acids. Ion-exchange chromatography, utilizing an automated amino acid analyzer (Kvenvolden *et al.*, 1971), gas chromatography coupled to both a mass spectrometer and an isotope ratio mass spectrometer (GC-MS/IRMS) (Glavin *et al.*, 2021), high-performance liquid chromatography (Glavin, 1999; Kminek *et al.*, 2002), and X-ray diffraction analyses (Pizzarello *et al.*, 2003) have collectively revealed the presence of several common amino acids in meteorites.

Degens and Bajor (1962) utilized paper chromatography to determine the sugar and amino acid composition of the Bruderheim and Murray meteorites. Their findings suggested that these compounds were likely indigenous to the meteorite and of abiotic origin, based on differences in abundance and distribution compared to terrestrial sediments.

Notable amino acids identified in the shergottite RBT 04262, such as Ɛ-amino-n-caproic acid, ɣ-ABA, β-ala, glycine, L-alanine, δ-amino-n-valeric acid, and D-alanine, were analyzed by Callahan *et al.* (2013) using the LC-FD/ToF-MS technique. Ion-exchange chromatography, gas chromatography, and mass spectrometry unequivocally demonstrated that the Murchison meteorite contains six amino acids commonly found in proteins, as well as eight that do not naturally occur in proteins (Kvenvolden *et al.*, 1971).

Mass spectrometry conducted by Simkus *et al.* (2019) identified 2-methylalanine and sarcosine, supporting the theory that the entire amino acid collection was abiotically created, as these are not typically present in proteins. Burton *et al.* (2014), analyzing 13 distinct Antarctic meteorites, identified the presence of C2 to C5 acyclic, aliphatic, primary amino acids, as well as -amino-n-caproic acid, using the LC-FD/ToF-MS technique.

The L-enantiomeric excesses of certain amino acids in meteorites, as shown in the table, demonstrate the extent to which one enantiomer is present in greater proportions than the other. Nanoliquid chromatography–high-resolution mass spectrometry, as utilized by Callahan *et al.* (2013), enables the analysis of micrograms of meteorite samples. Gas chromatography-mass spectrometry (GC-MS), high-performance liquid chromatography coupled to a UV fluorescence detector (HPLC-FD), and/or a mass spectrometer prove to be the most effective methods for extracting and characterizing meteoritic soluble organics (Simkus *et al.*, 2019).

Table 1: Occurrence of different amino acids and L-Enantiomeric excess of different meteroites

Meteorite	Amino acid	L-Enantiomeric excesses (L_{ee})	Reference
Murchinson	L-isovaline	18.5 ± 2.6%	Glavin *et al.* (2012)
	pyroglutamic acid	16% to 47.2%	Pizzarello *et al.* (2001)
	N-acetyl glutamic acid	8.6% to 41%	
	alanine, aspartic acid, and glutamic acid	~ 25–67%	Engel and Nagy (1982)
	L-isovaline, L-α-methylnorvaline, L-α-methyl-allo-isoleucine and L-α-methyl-isoleucine	2-9%	MacDermott *et al.* (2009)
Orgueil	L-isovaline	15.2 ± 4.0%	Glavin *et al.* (2009)
Tagish lake meteorite	Threonine	~99%	Glavin *et al.* (2012)
	Serine	~80%	
	Aspartic acid	~45%	
	Glutamic acid	~55%	
	Valine	<68.2%	

SUGARS

Sugar has perennially captivated gastronomers, who often exclaim its "out-of-this-world" quality. In recent years, detailed analyses of extraterrestrial bodies and their intriguing connection to our planet have shifted this context from dining tables to scientific workspaces. Meteorites, some dating back billions of years, such as the Fukang meteorite in China estimated to be 4.5 billion years old, have been present on Earth for millennia. However, comprehensive studies using advanced techniques like Gas Chromatography, Spectrophotometry, GCMS, XRD (X-ray diffraction), FE-SEM (Field Emission Scanning Electron Microscope), among others, have only gained prominence in the past four to five decades.

While the Central Dogma and the RNA World hypothesis focus on nucleic acids as the point of origin for life on Earth, sugar, specifically aldopentose, serves as a crucial component of DNA and RNA as deoxyribose and ribose, respectively. Analyses of meteorite samples have revealed the presence of the same distinctive sugar and its derivatives. These findings have sparked fascination among researchers, contemplating the possibility that key ingredients of these life-sustaining biomolecules arrived on Earth from outer space through celestial bodies, reigniting discussions on the theory of Panspermia.

Studies in the 1960s and onwards, particularly on Murchison and Murray meteorites, involved TLC (Thin Layer Chromatography) and NMR (Nuclear Magnetic Resonance) for extraction and analysis. They reported the presence of six-carbon sugar, glucose, mannose, and traces of five-carbon sugars like xylose and arabinose. Comparative studies with known standards identified unique derivatives like 2-methylglyceric acid (2-MGA) and inositol (Cooper *et al.*, 2018).

Subsequent studies on Murchison extracts, using GC-MS, focused on compounds like polyols of trimethylsilyl (TMS) and tertiary butyldimethylsilyl (t-BDMS), extracted through acid hydrolysis and ion-exchange chromatography (Lerner and Cooper 2005).

Analyzing the enantiomeric form of sugar in meteoritic samples, researchers simulated prebiotic conditions using the magneto chiral technique, revealing the existence of D-enantiomeric forms of rare and common monoacids in sugar.

RNA, with ribose sugar, is considered the first biomolecule leading to the origin of life on Earth. Delta-13 isotopic studies on the Murray samples confirmed the presence of this bio-important sugar. Further simulations involving photo processing of Murchison ice samples with C-13 isotope-labeled water and methanol corroborated these findings (Aponte *et al.,* 2017).

Deoxyribose and its derivatives were also detected through UV ray exposure on ice samples, constraining pathways for abiotic synthesis. This method, utilizing GC-MS with a distinct derivatization approach, identified sugar using a tri-fluoroacetyl derivative, confirming the presence of 2-deoxyribose (Nuevo *et al.,* 2018).

Sugar derivatives, assumed to form through a formose-type reaction via photo-induced oligomerization of formaldehyde, were subject to questions regarding contamination. However, the specificity of the identified sugar and its derivatives in the sample dismissed such doubts.

With numerous experimental evidences and ongoing research in this realm, a plausible scenario emerges, suggesting the contribution of extraterrestrial sugar to the formation of functional nucleic acid biopolymers on Earth.

NUCLEOBASES

Nucleobases are nitrogen-containing heterocyclic biological molecules that constitute the fundamental building blocks of both RNA and DNA in various organisms. They include Adenine and Guanine, known as Purines, and Uracil, Cytosine, and Thymine, referred to as Pyrimidines. GC-QMS analysis of the Murchison meteorite has revealed the presence of specific nucleobases, such as Uracil and Xanthine, with δ13C values of 44.5 ± 2.3 and 37.7 ± 1.6, respectively (Martins *et al*., 2008). The formation of these nucleobases in extraterrestrial bodies may be facilitated by abiotic reactions in outer space conditions, involving pathways like hydrogen cyanide polymerization, high-temperature plasma quenching of $CO-N_2-H_2O$, and cyanoacetylene reactions. Additionally, there are possibilities of compound degradation from one form to another; for instance, cytosine degrades to uracil with a half-life period of 17,000 years, and guanine transforms to xanthine with a half-life period of 1.3 million years (Levy and Miller 1999).

A similar GC-MS approach applied to carbonaceous chondrites, such as Yamato-74662 and 791198 from Antarctica, revealed the presence of bases like Guanine, Xanthine, and Hypoxanthine at low concentrations. Notably, Guanine was more abundant compared to the others, while Xanthine and Hypoxanthine were detectable at lower levels. Conversely, no bases were detected in Yamato 793321 and Belagica-7904 from the same study (Shimoyama *et al.,* 1990).

WATER- ELIXIR OF LIFE

Water stands as a vital compound for all living organisms on Earth, as none could thrive without it. A significant 71% of Earth's surface comprises water in the form of oceans (Genda, 2016). Unraveling the origin of water on Earth is intricately tied to the formation of planets in our solar system. Composed of two hydrogen atoms and one oxygen atom, water's constituents include the most abundant element, hydrogen, and the third most abundant, oxygen, in our solar system. Dust particles within our solar system coalesced to form kilometer-sized planetesimals, which, through collisions and accretion of nebular gases, evolved into protoplanets. While inner planets boast solid rock surfaces, gas giants like Jupiter and Saturn absorbed nebular gases, and outer planets, residing in colder regions, became colossal ice rocks (Alibert *et al.,* 2005; Murray *et al.,* 1981; Goldreich and Ward 1973).

The Earth's oceans, comprising 0.023% of the entire mass, contrast with the water content in various celestial bodies. Carbonaceous chondrites contain 10-20% water, while comets exceed 50% (Alexander *et al.,* 2018; Mason, 1963). A substantial portion of Earth's water may have originated from exogenous sources such as asteroids and comets (Morbidelli *et al.,* 2000). Although comets are predominantly water, recent research reveals distinctions between Earth's water and that in comets, evidenced by the deuterium/hydrogen ratio (Drake & Righter 2002). Asteroids, however, exhibit a closer resemblance to Earth's water, with comparable D/H ratios (Morbidelli *et al.,* 2000).

Meteorites that fell to Earth in 1998 contained liquid water older than the solar system, highlighting the potential exogenous origin of water (Zolensky *et al*., 1999). The presence of primordial water in meteorites like EC meteorites, containing hydrogen, suggests a potential source for Earth's seas (Piani *et al*., 2020; Chalecki, 2002). Asteroid impacts, supported by lunar craters resulting from asteroid impacts, indicate the likelihood of numerous asteroid impacts on Earth contributing to the formation of a significant amount of water. Additional evidence, such as water content in martian meteorites, lends further credence to the exogenous origin of water (Karlsson *et al.*, 1992; Taylor, 2000).

The mystery surrounding the origin of Earth's water persists, yet its essential role in the formation and sustenance of life over billions of years remains undeniable.

CONCLUSIONS

This review provides a thorough overview of the presence of biomolecules related to DNA and RNA in meteorites and carbonaceous chondrites, including amino acids, nucleobases, sugars, and water molecules. The investigation explores the potential for the existence of prebiotic components of life in extraterrestrial sources, shedding light on the fascinating field of astrobiology.

Numerous organic compounds necessary for life as we know it have been found in various meteorites and carbonaceous chondrites after careful analysis and examination. These samples contain amino acids, which are the building blocks of proteins and suggest the possibility of the formation of complex biomolecules. Nucleobases, the crucial components of DNA and RNA, have also been identified, further supporting the idea that the necessary ingredients for life may exist beyond our planet.

Moreover, these extraterrestrial materials have been found to contain sugars, which are essential for many biochemical processes. This discovery raises the prospect of chemical reactions as well as potential sources of energy required for the emergence of life. The discovery of water molecules in carbonaceous chondrites and meteorites also adds to the growing body of evidence supporting the favourable conditions for the emergence of life-supporting environments.

The results presented in this paper highlight the possibility for extraterrestrial sources to have contributed to the origin of life on Earth, even though research into the precise mechanisms and origins of these biomolecules in meteorites and carbonaceous chondrites is still ongoing. The panspermia hypothesis, which postulates the transfer of life's fundamental components from one planet to another, is complicated by the discovery of these biomolecules in such celestial bodies. These discoveries have implications that go beyond Earth, deepening our knowledge of the cosmos and opening up new avenues for life. Further research will undoubtedly shed more light on the existence and origin of these biomolecules in extraterrestrial sources, including in-depth analysis of additional meteorite samples, lab simulations, and space missions.

FUTURE SCOPE

The exploration into the extraterrestrial origins of essential compounds, such as amino acids, nucleobases, and water, presents a rich field for future research. The evolving field of Astrobiology can further investigate the complexities of these compounds on celestial bodies, expanding our understanding of the conditions and processes that may contribute to the formation of life-sustaining molecules. Advanced analytical techniques and space missions could provide deeper insights into the composition and origins of these compounds in different meteorites and celestial bodies. Additionally, comparative studies with new data from space missions, including sample returns and remote sensing, can offer a more comprehensive understanding of the distribution and diversity of these compounds in the cosmos.

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Conflict of Interest. None.

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