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Meteorites and the Origin of Life

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Abstract
The role of meteorites in the origin of life is a scientific challenge that has been approached in multiple studies. In this article, the author provides information obtained from these studies and illustrates with different meteorites dating back to ca. 4.5 billion years ago (Chondrite, Mesosiderite NWA 13858, Sericho pallasite), 23,000 years ago (Achondrite "fossil" meteorite AI Haggounia 001) and 4000-5000 years ago (), and their possible implication in the origin and evolution of life on Earth and in other planets within and beyond the Solar System.

Keywords: Chondrite, Earth, Fossil, Mesosiderite, Meteorite, Pallasite

1. Introduction

1.1. The Origin of Earth

The Earth appeared in connection with the formation of the solar system ca. 4.54 billion years ago (Bya) [1]. The solar nebula compound of a massive cloud of dust and gas collapsed under its own gravity and as flattened into a rotating disc, particles began to stick together with eventual formation of larger bodies known as planetesimals. Through continuous collisions and gravitational attraction, the planetesimals combined to form the Earth and other planets. Then, the planet underwent differentiation with heavy elements like iron and nickel sank to the center to form the Earth's core, while lighter materials rose to the surface to create the rocky mantle and crust. The iron core became the Earth's magnetic field, which protects the planet's atmosphere from solar winds.Then, according to the Giant Impact Hypothesis or Theia impact, a Mars-sized protoplanet collided with the young Earth ca. 4.5 Bya to form the Moon [2]. During millions of years, Earth's surface cooled for the crust to solidify with intense asteroid and comet bombardments during this period which delivered water to the planet.

1. 2 .The Origin of Life

When the Earth surface water cooled below the boiling point, it condensed to form the early oceans in which single cell life forms emerged ca. 3.5 to 4.1 Bya. According to Vaz-Rodrigues and de la Fuente (2026) and based on stromatolites as among the oldest fossils on Earth from Sahara Desert in Morocco, its primary composition of cyanobacteria supports the origin of bacteria and complex microbial communities ca. 1.1 Bya [3-6].

These microbial communities became the major source of atmospheric oxygen for the development and evolution of more complex lifeforms through multiple events (Vaz-Rodrigues and de la Fuente 2026). The Permian-Triassic extinction event (known as "Great Dying") affected over 90% of Earth's species before the beginning of the Triassic period 252 to 201 million years ago (Mya). Life with new species then repopulated the planet filling the empty ecological niches (https://www.nationalgeographic.com/science/article/triassic). Then, at the end of Oligocene period (ca. 20 Mya), hominids evolved with a catastrophic selection event associated with the inactivation of the alpha-Gal synthesis that appeared in Mammalia during Triassic period ca. 225 Mya.

2. The Meteorites

Meteorites are solid pieces of debris from space-like asteroids, comets, and meteoroids that survive its route through the atmosphere of planets or moon and lands on the surface of Earth [7].

2.1. Chondrite

Chondrite meteorites from Sahara Desert in Morocco are often classified under the "Northwest Africa" (NWA) designation as the oldest known materials in the Solar System originating from the asteroid belt (Fig. 1) [8]. The Chondrites are identified by their stony, non-metallic dark composition and tiny, millimeter-sized mineral spheres called "chondrules" including silicate minerals with iron-nickel metal, giving it a noticeable magnetic response. (Fig. 1). These primitive rocks represent the early conditions of the solar system from ca. 4.5 Bya that have been preserved without melting or other significant alterations with diversity revealed by chromium, calcium and magnesium isotopes [9]. Chondritic meteorites are consideres as appropriate substrates for the colonization of terrestrial microorganisms but difficult to determine if organic compounds are intrinsic to the meteorite or come from external terrestrial contamination (Pinto et al. 2025).

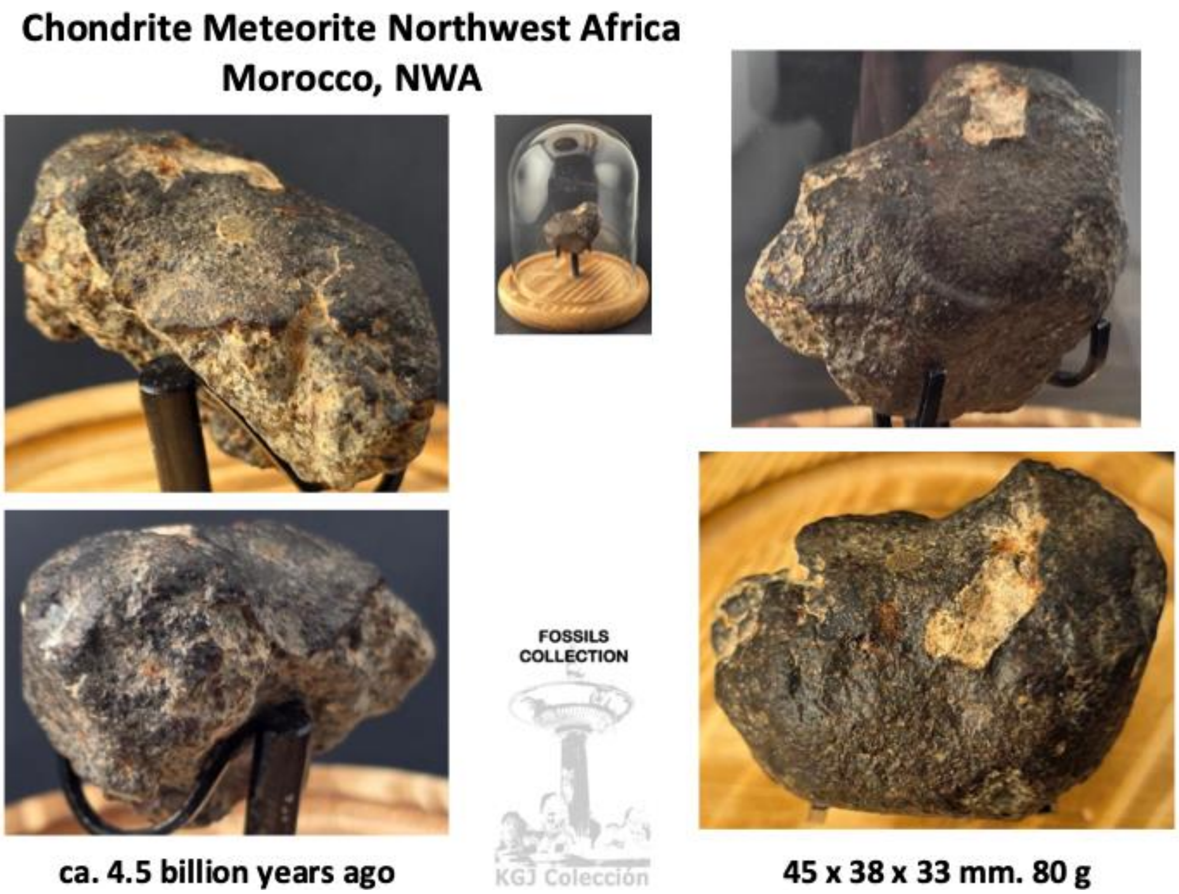

Figure 1: Chondrite meteorite NWA. Morocco, ca. 4.5 Bya. Provided by ArteTerra (Fossil-Mineral-Design, Italy).

2.2. Mesosiderite

Mesosiderite meteorites are a complex, jumbled mix (breccias) of igneous crustal rocks like basalt and metallic iron-nickel dating to ca. 4.5 Bya (Fig. 2). Mesosiderites were created when a core of a melted, differentiated iron asteroid smashed into the surface of another rocky body, fusing the metal and stone together. These stony-iron meteorites contain a mix of silicate minerals (ca. 75%) and nickel-iron metal (ca. 25%) when analyzed by X-ray spectroscopy (https://www.lpi.usra.edu/meteor/metbull.cfm?code=74121).

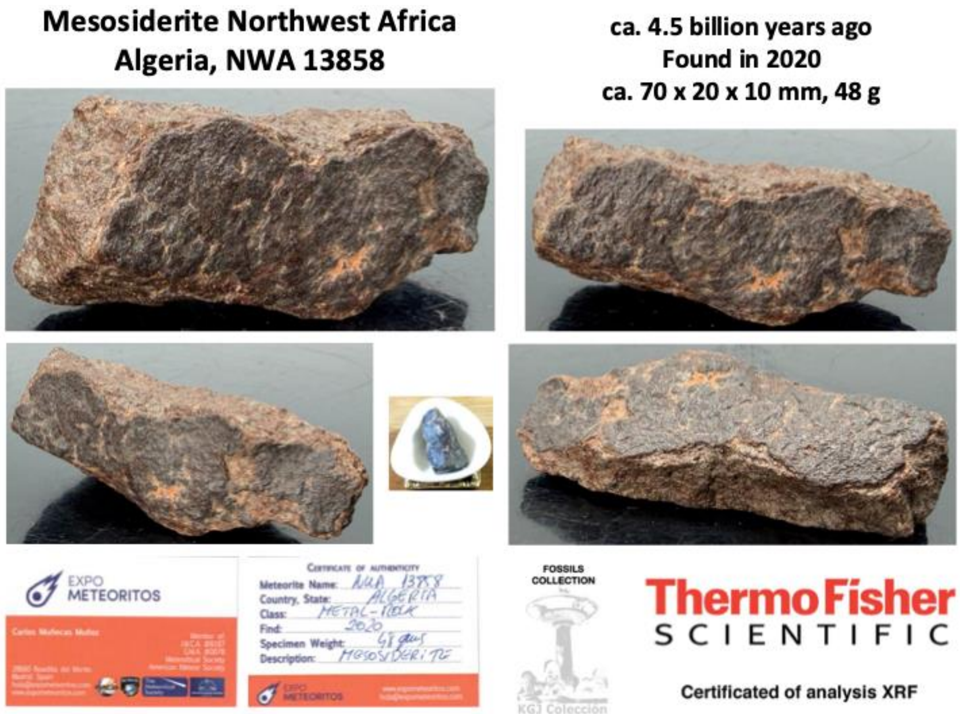

Figure 2: Mesosiderite NWA 13858. Algeria, ca. 4.5 Bya. The ExpoMeteoritos provider, Carlos Muñecas Muñoz (Boadilla del Monte, Madrid, Spain; www.expometeoritos.com) is member of the International Association of Meteorite Collectors (IMCA 8187), Global Meteorite Association (GMA 0078), Meteorical Society, American Meteor Society Collegiate Nº 8187, and authorized by IMCA for the issuance of official certificates. It was officially approved by the Meteoritical Society on May 6, 2021.

2.3. Sericho Pallasite Meteorite

The Sericho pallasite is an extremely rare stony-iron meteorite representing less than 0.2% of all classified meteorites that crashed in Isiolo County, Kenya, and was discovered in 2016 by camel herders (Fig. 3). Renowned for its beauty, it features translucent, gemmy yellow-to-orange olivine crystals suspended in a lustrous iron-nickel matrix (https://www.lpi.usra.edu/meteor/metbull.php?code=65717). Formed ca. 4.5 Bya and have originated at the mantle-core boundary of an ancient, differentiated asteroid that was later shattered by a massive collision.

Figure 3: Sericho pallasite. Kenia, discovered in 2016. Provided by Crater Meteorites (Roquetas de Mar, Spain) with authenticity supported by The Global Meteorite Association (#G0095), The Meteoritical Society (#6667), and The International Meteorite Collectors Association (IMCA Inc., #7412). Certificate of authenticity included.

2.4. Achondrite (Aubrite) “Fossil” Meteorite

The stony meteorite (enstatite, ca. 23,000 years ago) was partly excavated beneath a sabkha lake, while other pieces embedded in the rock were found in 2006 near Al Haggounia in Morocco, Western Sahara (Rubin 2016) (Fig. 4). Therefore, Al Haggounia 001 (https://www.lpi.usra.edu/meteor/metbull.php?code=44857) is referred to as a "fossil" or "paleo" meteorite as an object that fell to Earth thousands of years ago and has since been exposed to wind, water and other weathering processes, visible as the reddish-brown, weathered crust (Fig. 4) [10]. The petrography is dominated by enstatite and plagioclase, and troilite, graphite daubreelite, oldhamite, kamacite rich in Si and schreibersite are present. Al Haggounia 001 and paired meteorites are part of a vesicular, incompletely melted, EL chondrite melt rock (Rubin 2016).

Figure 4: Achondrite “fossil” meteorite AI Haggounia 001. Morocco, ca. 23,000 years ago. The Ancient Treasures (The Netherlands) provided a Certificate of Authenticity from The Meteoritical Society and the signed Specimen Identification Card.

2.5. Iron Meteorite - Siderite

Also known as siderite or ferrous meteorite, is part of a ca. 28-31 tons deposit in El Chaco – Santiago del Estero, northern Argentina (Fig. 5) [11]. The craters formed by M-type asteroids are from ca. 4000-5000 years ago and were first reported in 1576, but natives knew them before and claimed that the mass had fallen from the sky in a place they called “Campo del Cielo” (“Field of Heaven”) (https://en.wikipedia.org/wiki/Campo_del_Cielo). As shown in Figure 5, polished fragments show distinct Widmanstätten patterns formed by slow cooling in space. Siderites play a crucial role in biogeochemical cycles by serving as a microbial energy source, a recorder of ancient life, and a key component in prebiotic chemistry [12-15]. Historically, the iron from siderites was one of the earliest sources of this chemical element for humans.

Figure 5: Iron meteorite - Siderite. Argentina, ca. 4000-5000 years ago. Provided by Crater Meteorites (Roquetas de Mar, Spain) as in Figure 3.

3. The Role of Meteorites in the Origin of Life

Studies have shown that Achondrite "fossil" meteorites like AI Haggounia 001 (Fig. 4) can act as catalytic surfaces to help synthesize organic molecules such as nucleosides when exposed to high-energy radiation, but this is a chemical reaction involving raw building blocks and not biological life (Saladino et al. 2015). As discussed by Ferus et al. (2015), the formamide-based synthesis of biomolecules catalyzed or initiated by extraterrestrial minerals is relevant in prebiotic chemistry [16]. The studies showed that formamide irradiation by protons to simulate the solar wind in the presence of meteorites can results in the synthesis of many basic components of the primordial soup during the early solar system such as nucleosides, nucleic bases, amino acids, sugars, and carboxylic acids [16]. Meteorites may contribute to start life on Earth by delivering key organic building blocks, including amino acids, water, and catalytic metal particles [17]. Carbonaceous chondrites, ancient carbon-rich space rocks, frequently contain these prebiotic molecules, showing that the raw ingredients for biology existed early in the solar system [18].

The role of meteorites in the origin of life is supported by studies of carbonaceous chondrites such as a large carbon-rich meteorite that fell in 1969 near the town of Murchison, Victoria, Australia that contained extraterrestrial amino acids, nucleobases, carboxylic acids, sugar acids, nitrogen heterocycle and other organic molecules found in life [19]. These results support the role of meteorites in the exogenous delivery of components that have been crucial in the origin of life on Earth. However, although these samples provide the only record of early Solar System chemistry prior to the origin of life, the contribution of organics from extraterrestrial sources like meteorites is not sufficient to support their role alone for the emergence of life (Glavin 2018). Accordingly, it is considered that any bacterial RNA/DNA or biological matter detected inside Al Haggounia 001 and other meteorites arrived after the space rock landed on Earth.

According to Jiménez-Serra et al. (2026), the detection of ribose, glucose and other monosaccharides in asteroids and meteorites suggests an exogenous origin, possibly in the interstellar medium (ISM) before meteoritic parent-body formation. In this study, they report the discovery of sugar, erythrulose, a chiral four-carbon ketose in the ISM interstellar erythrulose which could have contributed to the sugar inventory available for early metabolic and replication processes [20-23]. The results from these studies support the role of meteorite impacts on subaerial and submarine abundant hydrothermal-sedimentary settings on Earth with delivery and/or generation of many of the necessary chemical ingredients for life and catalytic substrates such as clays (Osinski et al. 2020). Nevertheless, the role of impact events on the origin and evolution of life on Earth is still a challenge that may contribute to understand the existence of life in other planets within and beyond the Solar System (Fig. 5).

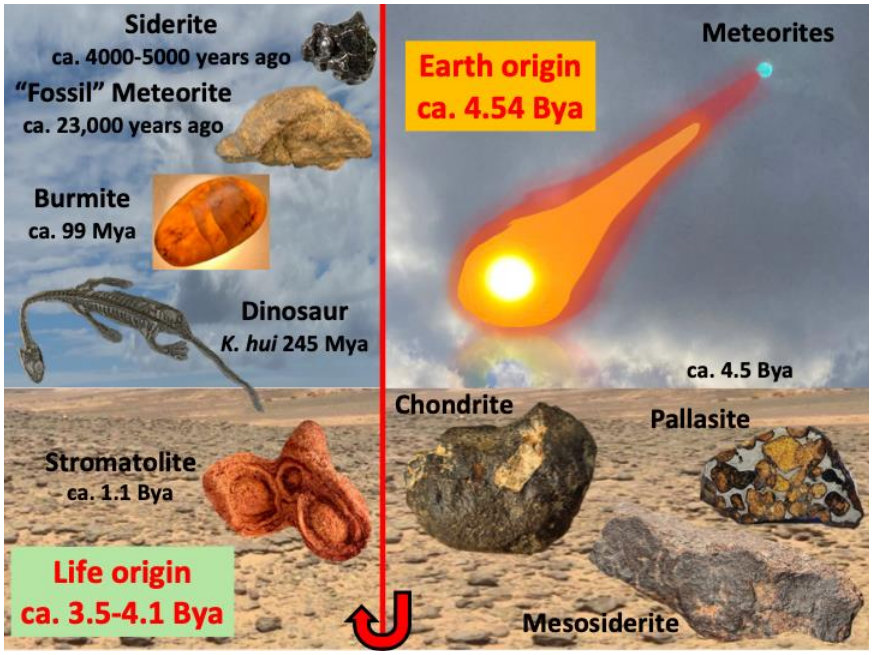

Figure 6: Interactions between meteorites and the origin and evolution of life on Earth since billions of years ago (Bya).

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