BOTAN EA. ***Examination of "organized elements" from the Orgueil meteorite by quantitative fluorescence microscopy.*** **Aerosp Med 1965; 36:1069–76**.

This Classic paper reports on an early effort to detect evidence of extraterrestrial life in a carboniferous chondrite meteorite. Earlier studies of the Orgueil meteorite had detected component organic compounds, while microscopy revealed "organized elements" resembling fossilized microorganisms 1–25 microns in diameter (2). A controversy ensued, with many scientists attributing the findings of the organized elements to contamination. The organic compounds had been proven not to be contaminants, but there was a controversy as to whether or not the compounds were formed by an abiotic process (9). In this paper, Botan sought to show a correlation between the organized elements and the presence of an organic molecule, tyrosine.

The author obtained several central core samples from the meteorite using a sterile drill and then made smears that again showed structures resembling single-cell organisms. Of particular interest was a large cell-like structure with possible mitotic morphology. Quantitative flourescence microscopy showed that these structures contained tyrosine, albeit at much lower levels than found in biological samples from Earth. The author admitted that the structures might be 1) extraterrestrial biological fossils, 2) abiotic in origin but of organic composition, or 3) contamination from life on Earth. He also noted that other researchers had detected only simple organic components in the meteorite rather than complex organic molecules such as chlorophyll, cytochromes, purines, pyrimidines, porphyrins, or pheophytins of undisputable biological origin.

Background

The Orgueil meteorite (OM) was named after the town in France where it fell on May 14, 1864, and is perhaps the most-studied meteorite in history. Investigators immediately found an abundance of organic compounds within the 14-kg meteorite and an intense, decade-long scientific discussion ensued as to whether the organic matter might have an extraterrestrial biological origin. Louis Pasteur himself obtained a central specimen at the time using a sterile drill and inoculated it into growth media, looking in vain for living microbes.

The OM is one of eight known meteorites belonging to the CI chondrite group, whose compositions are considered to be close to that of the nebula from which the solar system condensed. They typically contain a high proportion of water (up to 22%) as well as organic matter in the form of amino acids and polycyclic aromatic hydrocarbons. A 2001 study found that the OM contained many simple amino acids whose isotopic composition indicated extraterrestrial origin and probably were formed abiotically from hydrogen cyanide; the authors suggested that the OM may have originated from the nucleus of a comet (3). It was recently discovered that the OM contains isotopically anomalous xenon called "xenon-HL" carried by "presolar grains" of extremely fine diamond dust that is older than the solar system itself (7). A 2004 report that scanning electron microscopy of an OM sample showed a possible fossilized cyanobacterial mat has recently increased interest in this meteorite as evidence of panspermia (5).

Many of the issues faced by Botan in 1965 have arisen again in association with another meteorite, ALH 84001, which was found in Antarctica in 1984 and belongs to a different class thought to be of Martian origin. Radiometric dating indicates that this rock is 4.5 billion years old, a piece of the very early solar system, a time when liquid water may have existed on Mars. There is evidence that ALH 84001 was "shocked" by meteorite impacts on the surface of Mars some 4 billion years ago, but remained on the planet, only to be blasted into space by a another impact about 15 million years ago, falling through our atmosphere just 13,000 years ago (8).

ALH 84001 made its way into headlines worldwide in 1996 when scientists announced that scanning electron microscopy showed structures that looked like fossilized bioforms (6). Skepticism towards the biogenic hypothesis focused on the small size of the filaments (20-100 nanometres in diameter), too small to contain RNA, but evidence continues to grow that microbes of these dimensions do exist in nature (1). Both amino acids and polycyclic aromatic hydrocarbons have been found in ALH 84001, and 25% of its magnetite occurs as small crystals of uniform size that on Earth are associated only with biologic activity (11). As with the OM, debate continues over whether the organic molecules and the biomorphic structures on the Martian meteorite are in fact of exobiologic origin, are formed from abiotic processes, or represent Earth contamination. In November 2009, a team of NASA scientists reasserted that there is "strong evidence that life may have existed on ancient Mars" after having reexamined the meteorite using more advanced analytical instruments. The team concluded that "None of the original features supporting our hypothesis for ALH84001 has either been discredited or has been positively ascribed to non-biologic explanations. The biogenic hypothesis has been further strengthened by the presence of abundant biomorphs in other martian meteorites" (4).

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This Classic paper is quite interesting in that it demonstrates that researchers were looking for extraterrestrial life on meteorites several decades ago and that this was not an idea that initialized with the discovery of the famous AHL84001 meteorite in 1996. It also shows the difficulties in analyzing and interpreting the data surrounding exobiological meteorite research that still continues today.

The identification of biogenic features and especially microorganisms based on morphological features alone is nearly impossible. For example, the worm-like structure claimed to possibly represent a fossilized Martian microbe in ALH84001 (6) is more likely of inorganic origin. The strongest evidence for ancient life on ALH84001 remains the chains of magnetites whose composition and morphology are indistinguishable from those of magnetotactic bacteria on Earth (12). Other geochemical biomarkers such as the structures in the carbonate globules and spatially associated zones of reducing and oxidizing minerals enhance the case for ancient life on Mars as do similar findings in other Martian meteorites. However, there is no conclusive evidence.

The evidence is even poorer for the OM. While McKay et al. (6) were able to conclusively exclude contamination as a source of the organic material in ALH84001, this cannot be said for the OM. In fact, contamination is the likely source of the "organized elements" Botan found in the OM, especially given the similarities of some of the suggested biogenic structures to plants, lichen, and fungi—organisms which are too advanced and specialized to be expected to exist within an ancient meteorite.

A meteorite from Mars could conceivably contain living microbes because multiple studies have shown that microbes can survive the impact of a meteorite, transport in space if protected by a thin layer of dust, and re-entry into the atmosphere of a habitable planet. However, this is an unlikely scenario for the OM. While the presence of life appears to be plausible for early Mars (either by independent origin or via panspermia from Earth), this is not so for the OM, which we now know did not originate from a planet or major moon.

It is now generally accepted that some of the building blocks of life do form in space, as many organic compounds including amino

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acids have been detected in the interstellar medium and multiple meteorites (10). These organic compounds likely constituted the building blocks for life and surely assisted in the origin of life on Earth (and possibly Mars). These compounds were also likely to have been a readily available food source for the first heterotrophic organisms on Earth.

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