Neha Baskar

Independent Study and Mentorship

Astrobiology

A Look Into Mars

Abstract

Are we alone in the universe? This question has been the center of scientific debate for a long period of time. The idea that there could be life flourishing elsewhere initially seemed absurd. However, the Viking Project, the ALH 84001 meteorite, and the Nakhla Meteorite have indicated the presence of detectable organic material on Mars. These discoveries has given rise to more scientific investigations and also criticism. By doing careful analysis on these studies, we can distinguish what we have found and what we have not found. We can also identify the factor that is halting us from discovering certain things. As I looked at many scientific journals based on these studies, I noticed that the main factors that were causing issues in getting solid evidence were abiotic reactions and contamination. If we can figure out a way to distinguish what parts were contaminated or influenced by nonbiological processes, then we can begin to accurately address the question of purported life outside the bounds of Earth.

What Has Been Done?

Viking Missions

The search for organic molecules began with the Viking Project in 1976. This was the first NASA mission to focus on the search for life on the red planet. While on Mars, both landers conducted three experiments to test if there is a possibility of life.

The three biological experiments that were done were: (1) Pyrolytic Release Experiment, (2) Labeled Release Experiment, and (3) Gas Exchange Experiment. The Pyrolytic Release Experiment's purpose was to see if there is was any indication of photosynthesis in the Martian soil. In the experiment, the probe took a certain amount of Martian soil and exposed it to either labeled $^{14}CO_2$ and ^{14}CO. These two gases contained Carbon-14. Scientists decided to utilize these specific gases because they were present in the Martian atmosphere. The soil was then enclosed in an incubation chamber and exposed to the labeled gases, with and without added water vapor. The probe then illuminated the sample by a lamp stimulating Martian light (- 300 - 1000 nm; visible light on Earth is in the range of -400- 700 nm). The reaction inside the chamber proceeded for 120 hours at temperatures ranging from 8-26°C. After the incubation period passed, the chambers were vented and the organics produced by heating soils at 625°C passed through a gas chromatograph/mass spectrometer. These instruments would detect any Carbon-14 that was present after the incubation period. If there were any photosynthetic organisms present in the soil, the Carbon-14 would have been assimilated into more complex organic compounds in the soil.

The next experiment that was done was the Labeled-Release Experiment. This scientific investigation was similar to a respiration experiment here on Earth because scientists looked for CO_2 emitted from any organisms present in the sample. Like the Pyrolytic Experiment, the probe acquired Martian soil but this time it added moist nutrient rich organic material to the sample. Scientists assumed that if water and organic nutrients are added then it would stimulate a metabolic process in the microorganisms. Since the nutrients were labeled with Carbon-14, if the microbes in soil metabolized the nutrients, they would discharge organic compounds labeled with Carbon-14. Before being used on Mars, the experimental apparatus was tested on various terrestrial samples on Earth. All samples that contained microbes tested positive. Additionally, as a control, selected soils were heated to 160°C to kill any bacteria and then re- experimented. The results from the control group was negative for every trial that was run. With that said, soils at both Viking Lander Sites tested positive for metabolic processes. However, to prove that the result was caused by a biological activity, the probe ran more trials. In order to do that, the probe heated the sample at 160°C for 3 hours and then cooled it right before it got tested. These factors would kill any bacterial life, proving the results from the first trial. Despite the results of the second trial, the Viking Biology team agreed that 50°C was a better control temperature than 160°C because bacterial life will be more affected in 50°C than oxidizing chemicals. As a result, the amount of CO2 gas released was significantly reduced. Multiple trials were conducted with similar constraints and resulted in similar results. This implied that the CO2 emission was caused by some sort of biological activity.

The last experiment that was conducted on Mars by Viking was the Gas Exchange Experiment. The experiment measured changes in the atmospheric composition. The atmosphere that was analyzed was located in the space above the Martian soil samples. Scientists proposed that any changes of evolved gases would be representative for biological activity. The chamber initially contained CO_2, helium, and krypton. Water and nutrient rich material were then added to the soil sample. The sample was exposed to this atmosphere for 12 days. Scientists hypothesized that when the Martian microorganisms were exposed to the chamber gases and the nutritional gases, they would immediately start metabolizing. The gases emitted from the organisms would then be recorded by the gas chromatograph. The instruments did indeed detect some gases but results were inconclusive due to the possible presence of oxidizing compounds.

The experiments done on the Viking Landers definitely shaped our view on the red planet. To this day, the results from the Viking Landers are stimulating ongoing discussion. For example, one of the original researchers on the Viking missions, Gilbert Levin, recently published a paper called "The Case of Extant Life on Mars and its Possible Detection by the Viking Labelled Release Experiment. In this report, he re-evaluated the case for the first evidence for life on Mars.

Table 1. The Viking Biology Experiment[a]

Experiment	*Measurement*	*Nutrients added*	*Water added*	*Illumination*	*Results*
Pyrolytic Release	Incorporation of ^{14}C from ^{14}CO or $^{14}CO_2$ into organic matter[b]	None	None	Light and dark	Small ^{14}C yield Heating to 90°C has hardly any effect.
		None	Trace	Light and dark	Heating to 175°C reduced yield by 90%.[c,d,e]
Gas Exchange	Production of CO_2, N_2, CH_4, H_2, and O_2 and the uptake of CO_2 by soil samples[f]	None	Moist	Dark	Release of some CO_2, N_2, and Ar
		Concentrated solution of organic and inorganic compounds	Wet	Dark	Rapid release of O_2 upon humidification[f] Same as moist Additional CO_2 release upon recharge[f]
Labeled Release	Production of ^{14}C-labeled gas upon addition of nutrient containing ^{14}C-labeled organics[g]	Dilute solution of simple organic compounds	Moist	Dark	^{14}C-bearing gas produced Heating to 18°C had no effect. Heating to 40–50°C slowed production. Heating to 160°C stopped production. Storage at 10°C for 4 months stopped production.[h,i,j]

[a]Adapted from Klein, 1977.
[b]Horowitz *et al.*, 1972.
[c]Hubbard, 1976.
[d,e]Horowitz *et al.*, 1976, 1977.
[f]Oyama and Berdahl, 1977.
[g]Levin and Straat, 1976a.
[h]Levin and Straat, 1976b.
[i]Levin and Straat, 1977.
[j]Levin and Straat, 1979.

The table above shows what the probe was attempting to measure, the constraints the experiment was under, and the results of the investigation.

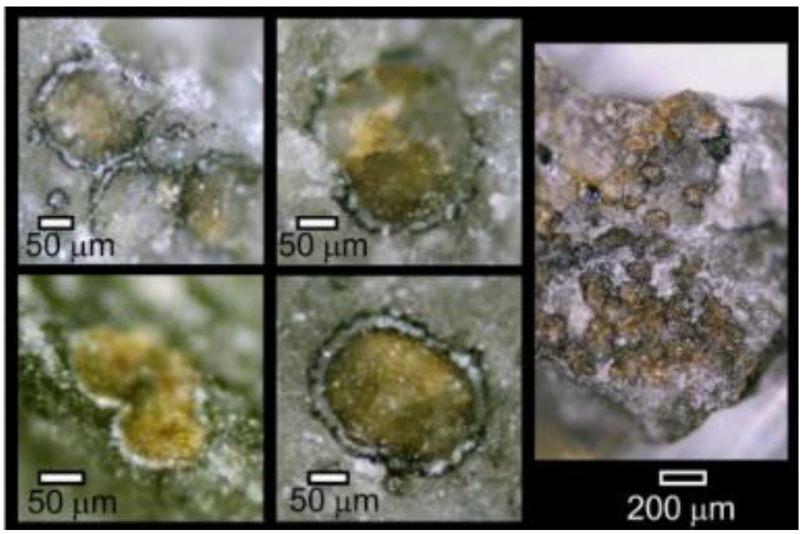
Martian Meteorite Allan Hills 84001 (ALH84001)

The possibility of life outside of Earth was once unimaginable. However, that all changed when a group of meteorite hunters uncovered a gift from Mars in the cold desert of Antarctica. This gift was a 4.5 billion year old Martian meteorite, later named ALH 84001, discovered by Roberta Score in 1984. She described the meteorite as glowing green when she first saw it. Once the meteorite was taken into the curation facility at NASA Johnson Space Center, scientists back at JSC and Stanford University discovered something that changed how we viewed our universe. The scientists had observed four lines of evidence that could be best explained as a result of ancient microbial activity on early Mars. The four lines of evidence were: (1) presence of low temperature carbonate globules; (2) organic compounds called polycyclic aromatic hydrocarbons (PAHs) associated with the globules; (3) magnetite crystals embedded in the globules; and (4) features on or within the globules that resemble fossil or casts of past microbes. The first line of evidence was the presence of carbonate globules within ALH 84001. To better understand what carbonate globules are, we must look into Mars' past. As mentioned earlier, Mars was once thought to be a lot warmer and wetter. With this in mind, it is believed that the water, which contained CO_2, exchanged with the Martian atmosphere, seeped into cracks within the meteorite, leaving deposits of carbonate minerals in the form of carbonate globules. The majority of globules are shaped like pancakes with complex chemical zoning patterns. The globules contained multiple rings within it. Each ring would represent a different carbonate composition. The features that the carbonate globules presented in the meteorite was unlike anything found on Earth. Scientists believed that bacterial life may have assisted with globule formation because of their unusual shapes and compositions.

The second line of evidence was the presence of polycyclic aromatic hydrocarbons (PAHs). Polycyclic means that carbon atoms form a flattened ring structure and share electrons to make a very stable molecule. Aromatic means that the compound has one or more benzene rings and alternating double bonds in one atomic ring. Lastly, hydrocarbons are made up of hydrogen and carbon atoms. Dr. McKay and his team described the presence of the first Martian organic compounds. PAHs formed in the meteorites wasn't from Earth, supporting the claim that the formation of the polycyclic aromatic hydrocarbons were created from dead Martian organisms. Despite this discovery, there is still ongoing debate on whether the PAHs were formed biologically.

The third line of evidence was the presence of magnetite crystals within the globules. To understand the importance of mineral grains, we must consider Earth in the mid-1970. During this time period, Richard Blakemore discovered magnetotactic bacteria in a pond on the east coast of the United States. These bacteria produce chains of magnetite crystals within their cells. The important point is that the bacteria control the composition and structure of the magnetite crystals. So unlike magnetite crystals formed abiotically, the crystals formed by bacteria have distinct shapes and chemistry. Furthermore, since the mineral grains were found inside of the globules, it can be inferred that the grains are Martian in origin. Due to the small size of the magnetite crystals, they used a transmission electron microscope (TEM) to determine the composition and external shapes of these minerals that are present in the globules.

The fourth line of evidence in the meteorite were microscopic shapes similar to bacteria. Scientists described the shapes to be "tubular and rope like." This led them to believe that these were fossils or fossilized casts of Martian bacteria. In order to eliminate the possibility that the fossils were created from bacterias on Earth, Dr. McKay's team analyzed other meteorite samples from Antarctica to see if microorganisms entered the meteorite from Earth but they found no evidence of that. The team also made sure that their laboratory techniques and equipment didn't obscure the sample. Although the gold-palladium coating on the microscope left a small crack on the surface of the samples, it was very small compared to the fossilized bacteria. As a result, scientists concluded that the bacterial shapes weren't formed as a result of laboratory contamination. The study on the ALH 84001 meteorite set forth further investigation on the possibility of life outside Earth.

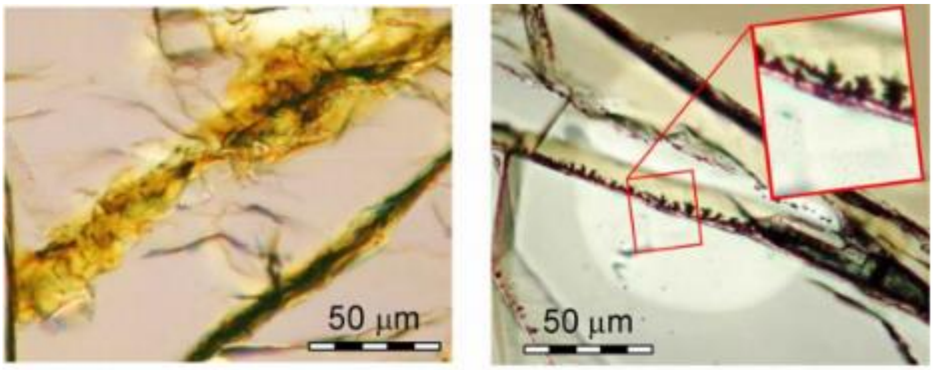


The image above is the carbonate globules that were found in the ALH 84001 meteorite. A large amount of carbonaceous matter were found either in or near these globules.

Martian Meteorite Nakhla

In the year, 1911, another meteorite from Mars fell over the city of El Nakhla el Baharia in Egypt. The Nakhla meteorite contained signs of hydrological processes with the abundance of carbonates and hydrous materials that were formed from aqueous chemical reactions. The Nakhla meteorite was younger than ALH 84001 with an estimated age of billion years. With that said, scientists found presence of water in the meteorite allowing them to conclude that liquid water was present on Mars for several billion years. Nakhla has been studied for decades by many different scientific groups. It is believed that this meteorite experienced little terrestrial contamination because it was picked up quickly after it fell to Earth.

In past studies, NASA scientists at the Johnson Space Center used an optical microscope and a scanning electron microscope (SEM) to analyze the samples of Nakhla which showed signs of bacterial shapes. Most recently, they also found large amounts of carbonaceous matter on the surfaces of freshly fractured pieces of the meteorite. The SEM analysis showed the presence of phyllosilicates and small amounts of sulfur and carbonate. Phyllosilicates contain chlorites, micas, talc, serpentine, and clay minerals. The abundance of this material gave evidence that Mars was once covered in water. In addition to this, scientists utilized scanning transmission x-ray microscopy examination on the sample. The team then viewed 30 regions from three different Nakhla pieces. One of the pieces contained a possible vein. This particular vein contained a faint amount carbon, carbonate, material containing a large amount of potassium, and organic carbon. An interesting aspect of this experiment is that Nakhla organic carbon had a strikingly similar C- XANES absorption with the ALH 84001 meteorite found in Antarctica. Both meteorites had similar organic matter. This eliminates the theory that the organic matter in the ALH 84001 meteorite was from Antarctica and not Mars. Overall, the studies done on the possibility of life elsewhere has deepened our understanding of Mars.



The image to the left shows the veins that were found in Nakhla. This particular vein contains the mineral, olivine. The image to the right contains dendritic elements which is shown inside of the zoomed in red box.

Criticism

Despite the extraordinary research done on the biology of Mars, there is still contentious debate within the scientific community on the interpretation of the data in support of life on Mars. The question is why. Are they not accepting it because of the techniques used, the high risk of contamination, the likelihood of reactions caused by something other than biology, or is it because people just aren't ready to confront the idea that there is extraterrestrial life. Through careful analysis of past studies, I have noticed that contamination and chemical reactions are posing as the obstacles.

There were multiple issues with the Viking Experiments that led to results as being either negative or inconclusive. The data outcomes of the Pyrolytic Release Experiment raised a lot of doubt due to the lack of organic matter present. Several scientist questioned how the data was showing that there were metabolic processes occurring when there was no organic matter present. In addition to that, the temperature that was used to heat the sample was much higher than the Martian climate. With that said, any bacteria that was present in the sample would have died when exposed to this heat. However, results were positive for metabolic processes. The Labeled Release Experiment also stimulate much debate about its results. The soil that was used again consisted of no organic molecules. Additionally, the Labeled Release Experiment conducted the investigation on the basis that all Martian life need water but Martian microbes could've adapted to the planet's lack of water. Some scientists also believe that the Gas Exchange Experiment is inaccurate because the sample contained a large amount of oxidizing chemicals. As a result, these scientists believe that the oxygen that was emitted was from a chemical reaction rather than a biological reaction. With that said, scientists believe that the results from all the Viking Experiments were the products of highly oxidizing matter on the Martian surface instead of microbial life.

Similarly, the ALH 84001 research also received rejection from several scientists, this group of scientists instead found another theory that provided support for the formation of carbonate globules. They theorized that the carbonate globules were formed from thermal decomposition or shock events. However, Dr. David McKay and his team stated that the thermal decomposition/ shock events theory is impossible from the evidence they found in the meteorite. According to the JSC Team, if the magnetites were formed through abiotic processes, it will contain small amounts of host material (contaminants). However the team found no evidence of contamination in the magnetites, which insists that biological processes played a major role.

Another reason why certain scientists are finding this discovery problematic is due to the chance of terrestrial contamination in the sample. Results from the Nakhla meteorite also have been debated. A contamination study on Nakhla showed that 75% of the carbonaceous matter was native to the meteorite while 25% was not. This indicates that terrestrial contamination occurred when the meteorite impacted the surface of Earth. The contaminate part of the sample could've skewed the data. If we could figure out a way to distinguish what is contamination and what isn't, then we can provide more accurate data. It is noteworthy that any extraterrestrial sample that falls to Earth is considered contaminated. With more research on these samples, while it may be difficult to differentiate terrestrial contamination from Martian features, it is not impossible.

The Future

Even though we gained a lot of information about astrobiology from past studies, we still don't have solid evidence that life existed on Mars. Fortunately, NASA has multiple missions planned to provide better evidence.

Just recently, NASA launched the OSIRIS- REx spacecraft to collect samples from an asteroid and bring it back to Earth for further study. With that said, scientists and engineers at NASA picked Bennu to extract samples. This asteroid is rich in organic matter. Therefore, it will help us understand how carbonaceous matter got to Earth and possibly Mars. Since the sample will be extracted directly from Bennu, while in space. Therefore, there will be very little contamination.

In addition to this, NASA will launch a rover to Mars in the year 2020. The proposed plan for this rover is to probe Mars for regions where life could have existed in the past. A unique aspect to this mission is that samples collected from Mars could be brought back to Earth for further investigation. This will allow astrobiologists to obtain more crucial information about the biological processes that took place on Mars.

Lastly, NASA is planning on sending astronauts to the red planet in the 2030s. This will be revolutionary as it will allow for scientists to get direct access to samples. Astronauts will also obtain more control of experimental methods and procedures, allowing them to produce more accurate results. At this point, we no longer need to rely on rovers to conduct scientific experiments. Overall, the future for astrobiology looks promising.

Personal Contribution

In the spring of 2017, I will be traveling to the Johnson Space Center to search and characterize organic matter in Nakhla. I plan to use optical and fluorescence microscopy, SEM, and energy dispersive X-ray spectroscopy (EDX) to determine the morphology and the chemical composition of this organic matter. I also plan to identify new regions of interest and characterize surrounding mineral phases to obtain a better idea of how the organic matter formed.

Conclusion

By doing analysis on past studies, we can now figure out the specific steps we need to take to understand elements we still don't know about Mars. If we do that, we can learn things about the red planet. Under those circumstances, the cold,dry, and lifeless planet we once thought of Mars may not actually be true. Once life starts, it is difficult to extinguish. There may be discrete regions, possibly in the subsurface, where cases of life existed and still exist today on Mars. After carefully analyzing the studies that have been done, I strongly believe that Mars was habitable at some point. If we successfully find evidence that Mars is habitable for life, the chances for human survival go up tremendously. To better understand this, if all humans were to be on Earth at a time where a disastrous event takes place, most if not all living things will perish. However, if a large population of humans were on Mars at the time, we would still have a sustainable population. In addition to this, scientists predict that in 2.5 billion years, the Earth will no longer be in the habitable zone due to the sun's increasing luminosity. Instead, the habitable zone will move to Mars. As a result, Mars will be much warmer and could potentially foster life. Again, with that said, Mars is one of the only ways we can survive as a species.

Citations:

1. *Ball, John. The Meteorite of El Nakhla El Baharia. Cairo: Printed at the National Printing Dept., 1912. Print*
2. *TOPORSKI, JAN, and ANDREW STEELE. "Observations from a 4-year Contamination Study of a Sample Depth Profile through the Martian Meteorite Nakhla." Toporski, J. N.p., n.d. Web. 02 Jan. 2017.*
3. *Thomas-Keprta, McKay, Clemett, Gibson, and Wentworth. "INDIGENOUS CARBONACEOUS MATTER AND BORON ASSOCIATED WITH HALITE CRYSTALS IN NAKHLA. K."NASA. NASA, n.d. Web.*
4. *Levin, Gilbert V., and Patricia Ann Straat. "The Case for Extant Life on Mars and Its Possible Detection by the Viking Labeled Release Experiment." Astrobiology 16.10 (2016): 798-810. Web.*
5. *Kate, Inge L. Ten. "Organics on Mars?" Astrobiology 10.6 (2010): 589-603. Web.*
6. *Flynn, Keller, Jacobsen, and Wirick. "ORGANIC CARBON IN MARS METEORITES: A COMPARISON OF ALH84001 AND NAKHLA:." Lunar Planetary Science Conference. NASA, n.d. Web.*
7. *Mckay, D. S., E. K. Gibson, K. L. Thomas-Keprta, H. Vali, C. S. Romanek, S. J. Clemett, X. D. F. Chillier, C. R. Maechling, and R. N. Zare. "Search for Past Life on Mars: Possible Relic Biogenic Activity in Martian Meteorite ALH84001." Science 273.5277 (1996): 924-30. Web*

8. *Thomas-Keprta, K.l., S.j. Clemett, D.s. Mckay, E.k. Gibson, and S.j. Wentworth. "Origins of Magnetite Nanocrystals in Martian Meteorite ALH84001." Geochimica Et Cosmochimica Acta 73.21 (2009): 6631-677. Web.*
9. *GCA. "Press Release." N.p., 9 Sept. 2009. Web.*
10. *"Viking Pyrolytic Release (PR) Experiment." Viking Pyrolytic Release (PR) Experiment. N.p., n.d. Web. 02 Jan. 2017.*
11. *Klein, H.P. "The Viking Biological Investigation: Preliminary Results." The Viking Biological Investigation: Preliminary Results. N.p., n.d. Web. 02 Jan. 2017.*
12. *"The Viking Files." Astrobiology Magazine. N.p., 29 May 2003. Web. 02 Jan. 2017.*
13. *Williams, D.R. "Viking Mission to Mars." NASA. NASA, n.d. Web. 02 Jan. 2017.*
14. *"What Is ALH 84001?" What Is ALH 84001? N.p., n.d. Web. 02 Jan. 2017.*
15. *Treiman, A.H. "Fossil Life in ALH 84001?" Fossil Life in ALH 84001? N.p., n.d. Web. 02 Jan. 2017.*
16. *Thomas, K.L, S.J Clemett, C.S Romanek, C.R Macheling, E.K Gibson, D.S McKay, R. Score, and R.N Zare. "Polycyclic Aromatic Hydrocarbons in the Martian (SNC) Meteorite ALH 84001: Hydro." Polycyclic Aromatic Hydrocarbons in the Martian (SNC) Meteorite ALH 84001: Hydro. N.p., n.d. Web. 02 Jan. 2017.*
17. *Childs, Arcynta Ali. "One Hundred Years Ago Today, A Mars Meteorite Fell in a Blaze."Smithsonian.com. Smithsonian Institution, n.d. Web. 02 Jan. 2017.*
18. *"Nakhla Meteorite." Nakhla Meteorite. N.p., n.d. Web. 02 Jan. 2017.*
19. *Breitman, Daniela. "Today in Science: Egypt's First Meteorite." EarthSky. N.p., n.d. Web. 02 Jan. 2017.*

20. Grady, M.M, I.P Wright, and C.T Pillinger. "1994LPI....25..451G Page 452."1994LPI....25..451G Page 452. N.p., n.d. Web. 02 Jan. 2017
21. Nelson, Stephen A. "Phyllosilicates." Phyllosilicates. Tulane University, n.d. Web. 02 Jan. 2017
22. "Viking Labeled Release (LR) Experiment." Viking Labeled Release (LR) Experiment. N.p., n.d. Web. 02 Jan. 2017.
23. NASA. Ed. Karen Northon. NASA, 15 July 2016. Web. 02 Jan. 2017.
24. "Why Bennu?" OSIRIS-REx Mission. N.p., n.d. Web. 02 Jan. 2017.
25. Dunbar, Brian. "What's Next for NASA." NASA. NASA, n.d. Web. 02 Jan. 2017.
26. Sheehan, William. The Planet Mars: A History of Observation & Discovery. Tucson: U of Arizona, 1996. Print.