A&A manuscript no.
(will be inserted by hand later)

Your thesaurus codes are:

ASTRONOMY AND ASTROPHYSICS

Could life have developed on other places in our solarsystem?

Olof A. van den Berg

Kapteyn Institute, Landleven 12, 9747 AD Groningen

February 7, 2000

Abstract. Life is able to travel through space and survive under extreme limits, but liquid water is the most import factor. Mars is the biggest candidate for extraterrestrial life, but in spite of much research, theories and models no decisive conclusions have been made. Jupiter's moon Europa may have a hidden ocean in which life could exist and Saturn's moon Titan could be a home to an unknown form of life. Only direct research on the objects will tell us the answers.

1. Introduction

Many people ask themselves if there is other life outside Earth. Because it is too difficult to research this question outside our solarsystem, I am looking inside our solarsystem. The first question for such an investigation is to ask what the chances for extraterrestrial life are and under which conditions life could develop. After that you can select the main objects of interest. This are Mars and the moons Europa and Titan. They have got the biggest chance of obtaining some sort of life. This life would be simple because of the harsh conditions, but life it would be.

2. Does life have chances of existing in other places in our solar system?

In order to find out whether life can exist on other places we first have to look how life originated on Earth and what the environmental conditions are for the origins of life. Then we can compare the other places with Earth to see whether they have the same characteristics to have a liveable biosphere.
Life on other planets is expected to be like life on Earth because various theories point out that life can travel interplanetary, spreading throughout our solarsystem, or even the entire universe. Arrhenius introduced the concept of panspermia spores from another planetary system which get propelled into space by the pressure of sunlight or is transported by meteors, asteroids or comets (called SNC meteorites) and have seeded the Earth and other places. Alternatively, panspermia may have operated within our solar system, traveling between planets, obviating the need to survive long periods in outher space. Impacts of asteroids and comets play a controversial role in the origin of life. Small asteroid impacts probably carried organic material for the origin of life. These asteroids do not only carry biological molecules, but also some amount of ice. Recent theories show that nearly all the water in Earths oceans might have reached Earth by these astroids and are therefore essential to life. On the other hand, large impacts can be very destructing. The impact that made the dinosaurs extinct (the K/T event) evaporated one meter of water from the oceans and clouded the Earth with dust for months was just a medium impact. Studies of the moon's surface reveals that the moon was struck by 10 to 100 of such impacts. Since the Earth is larger and heavier then the moon, there are about 10 times more impacts, and even bigger ones, which could have evaporated the oceans completely. Such impacts could only be survived by a few species, largely slowing down the growth of life. On the other hand they can be a pulse for evolution, the K/T event let the dinosaurs make room for the mammals.
If we want to find live on other planets, we probably will have to look for life like we know it on Earth. The environments in which life has developed on Earth are very diverse. From subfreezing cold to burning hot, life has developed methods to cope with the surroundings, even in deep underground wells where sunlight is abundant, live has adapted to a chemotrophic energy source. Nearly every niche on Earth is habituated with life, even if it lacks any favorable environmental conditions, and these lifeforms aren't important for the existance of the biosphere. Life has a really large adaptation ability and the limits of life are very large.

3. The limits of life

There are several environmental parameters that define the limits of life, these include:

1. Lack of water. Life requires liquid water. The existence of liquid water is probably the most important condition for the existence of life. There is no life form known to us that survives without liquid water. Water is used to transport nutrients, waste products, organels and organisms themselves. H_2O can also be needed as a biochemical consumable, a cofactor, a diluent, a catalyst, or a physical stabilizer. Organisms can probably extract water vapor from air at low relative humidity and can keep them thight with H_2O impermeable membranes, but that will be very difficult. Water is liquid between 273^o and 373^oK, so temperatures under or above the surface have to be between those limits to make it habitable for life. A major problem in a liquid-poor environment is the restricted interaction a microorganism can have with its environment. Transportation of the organism can be eolian, but then the organism will have to travel through the often violent atmosphere. The transport of nutrients and waste is nearly always through water, it is possible through diffusion, but that will be very slow. On Earth, in the Sahara desert, there do grow some plants only when rain falls, sometimes a few days in several years, so if the amount liquid water oscillates heavily, there still can be some (dormant) lifeforms.

2. Extreme ultraviolet irradiation can be devastating to life, due to it's high energy it can break various molecular binds that are needed for organic life. Most planets will not have an atmosphere that weakens UV radiation like Earth's ozone shield, therefor UV radiation forms a direct thread. Ways for organisms to shield themselves are: 1) developing resistant organic materials and/or efficient chemical damage repair mechanisms, but for Mars that may be not compatible. 2) making use of the natural environment to weaken UV with only minor weakening of visible light. 3) depositing and/or separate UV-absorbent organic pigments or minerals to protect interior cellular contents. 4) adopting a nonphotonic energy source, preventing direct sunlight.

3. High ionizing radiation. Earths geomagnetic field forms a shield against ionizing radiation from the sun (Solar Particle Event) and outer space (Galactic Cosmic Ray). On planets with to much ionizing radiation, life may have to use protection of the soil to survive.

4. Lack of a metabolic energy source. Photosynthesis may be hard on planets with a large amount of UV radiation (Mars), or in places where no direct sunlight can reach, like deep lakes (Europa). Therefor it is usefull to adapt a biochemical or chemotrophic energy source. On Earth there are already species known that live in hot springs where no light can reach.

5. Nutrient availability. The most essential elements needed for life are C, H, N, O, P, S and some other heavier elements in small amounts. Life supporting planets will probably contain CO_2 and H_2O in the atmosphere or in frozen state and probably N_2, sulphur and phosphor can be found in rocks on the surface.

6. Highly oxidized compounds in the soil. Oxygen (O_2) or another oxidizing molecule can oxidize organic components, but can also deliver an metabolic energy source.

7. Highly oxidizing atmospheric species. Due to high UV radiation, the atmosphere of a planet may be causing a large concentration of free radicals, such as hydroxyl (OH.) and perhydroxyl (HO_2.), atomic oxygen (O.) and superoxide (O_2^-). These radicals are one of the most highly reactive molecules known, and are therefore very dangerous, which means again that life will have to live underground.

8. Soil toxicity. There can be various sorts of toxics in the soil of planets, but one organism's toxic element can also be another organism's lifeblood (like oxygen).

9. High ionic strength. High salt concentrates can be a problem for organisms, but like on Earth, where we have a large concentration Na^+, Cl^-, SO_4^{2-} and Mg_2^+, life can adapt to it and even depend on it.

From these conditions, we can conclude that the most important factor to make a planet liveable is the amount of liquid water on the surface and if there is an energy source that is capable of providing energy to biota and whether there are enough biogenic elements. Further we have to look for several hazards to life as described above.

4. Is there life on Mars?

The first possibility of other life in our solarsystem you can think of is our neighbor planet Mars. On Mars life is less extreme than on Venus and the conditions lie on the limits of life as we know it. The first missions in 1976 by the Viking lander showed negative results, but were also far from conclusive.

Life on Earth took longer to come alive because of the Moon-accident. Because of that the surface of Mars appears to be older. Mars itself died about 1.5 Gyr ago when it lost most of its atmosphere, but some remains of life could have survived. The existance of very old large volcanos is further evidence that Mars once had a more active surface.

An impact of a 500 km projectile would have sterilized the average subsurface down to at most a km or two below the subsurface. Mars was better able to survive such impacts because the duration of high temperatures was shorter and the habitable zone extended deeper on Mars. The thermal wave from the impact penetrates more deeply on Earth than Mars because the event lasts longer on Earth. A probable impact crater named Hellas, was created by a 200-km diameter object, could have sterilized the surface environments, but not the subsurface ones. To survive and to create life you need water. So you'll have to ask yourself the question if there ever existed water on Mars and if it was enough to survive.

4.1. Is there water on Mars?

There is no extensive cratering on the northern Martian plains, so it is possible that they were ancient oceans, 2 to 3.5 Gyr ago, with a calculated depth of at least 0.7 km to absorb impacts. The low crater density can also be interpret that Mars had a fairly dense atmosphere until 1.5 Gyr ago. Assuming that early Earth and Mars had more or less similar atmospheric compositions and structures, it is reasonable to suppose that warm Martian oceans like the ancient oceans of Earth would develop photosynthesis. Their fossil might be found along the borders of the northern lowland plains.
The higher ^{40}Ar content may indicate Mars' crust had a higher proportion of chrondritic material, which has a high water content. The water/nitrogen estimate requires knowledge of the primitive Martian atmosphere's nitrogen content. Suggestions give a primitive N_2 200 times the observed amount. This would increase the water estimate by a factor of 10.
Some models suggest that low-temperature hydrological systems could have existed on the surface of Mars for 0.5 Gyr or longer. Landforms that seem to be carved by water are widely distributed over ancient Martian terrains. Hydrological models indicate that a global groundwater system could still be present on Mars today. Ice-covered lakes could have survived the death of Mars, as was found similar lakes in Antarctica. These oases could be a favorable site for preserving a fossil record.

4.2. Circumstances for life on Mars

There is probably sufficient energy available to support an origin of life on Mars but not sufficient energy to create a ubiquitious and lush biosphere. A prebiological atmosphere containing 1% of hydrogen gas could have been maintained for a geological significant period of time.
Increased partial pressure of CO_2 in an early dense Martian atmosphere may have provided the greenhouse effect necessary to keep the surface warm enough for liquid water to remain stable and to maintain Mars within the "habitable zone". Model studies have shown that about 1 bar of atmospheric CO_2 would be required to raise the surface temperature above the freezing point of water.
The polar caps are potential life sources, but there is probably not enough sunlight to obtain sufficient thermal energy.
It is possible that life on Mars developed completely different and we haven't been able to recognize it. The Martian meteorite in Antarctica, dating 1.4-1.6 Gyr ago, could have originated from biogenic processes and could be fossils remains. None of each test was conclusive, but together they can form evidence for primitive life on Mars. Life on Mars has to have existed before that time.

4.3. How life on Mars could exist

The conditions on Mars are on the limits of life. Mars has no effective ozone field to shield it from UV.
In kerogens and bands of ferric oxide, the signature of aerobic photosynthesis, you could find evidence of ancient life. If they're not found, then either complete chemical destruction of all organic remnant ocurred or Mars was sterile. If Mars was sterile, then our ideas of atmospheric evolution in the first 0.5 Gyr of the Earth's history will need extensive revision because it is commonly believed the the two planet had very similar early histories.
Life requires liquid water. Addition of certain chemicals can lower the freezing point of water. Methanol or ethanol in water is able to keep water liquid up to -51^{o}C. Organic compounds can also be extremely hydrophilic. Microorganisms could be able to raise its temperature by pigmented absorption of radiation. Lack of water causes microorganisms to have little contact with their environment, so it can't move easily to better environment. For that the liquid water has to be at least as big as the organism.
Mars has the minimum conditions for methanogenesis and photoferrotrophy - which would have an effective UV shielding mechanism.
Martian organisms could obtain their water through liquid films on soil grain surfaces. This implies high salt concentrations in the liquid phase. There is even evidence for the possibility of long time scale preservation of viable microorganisms in halite salt deposits.
On the surface of Mars lies duricrust, which contains a lot of salt, which ion mobility makes transport of aqueous nutrients possible.
Life on Mars will be limited to special environmental niches, because life on the surface is almost impossible. A Martian organism will have to derive energy and substrate either heterotrophically or chemoautotrophically. It has to keep its internal water liquid.
Phosphate plays a fundamental role in biochemical processes of all life on Earth. So to find life you'll also have to search for phosphates.

4.4. Possible life

Life on Mars developed under harsher conditions and during the relative long time the climate changed to its current state it could be able to adapt unto the currently inhospitable state and obtain progressive specializations. A combination of these adaptations could allow organisms,

either active or dormant, to survive at or the very near surface of Mars.
The kilometer deep subsurface appears to hold the greatest potential for extant life. This life, because of the negative environmental transformation of Mars, is either slowly going to its end or has a very slow metabolism due to lower temperature and energy suply, resulting in longer times between generations. As there is less life, there is less danger for predators or parasites. So this quasi solid-state organism doesn't need to change as earthlike organisms do. It may take long wintersleeps between warmer periods. Bacteria are able to survive this way. Life on Mars could be undetected because it is dormant and in hibernation.
Until this day there haven't been found any terrestrial analogs from which we could recognize life.

5. Is there life on Europa?

Life is also possible on Jupiter's ice-rich moon Europa. The ice must form a rock-hard skin. Under the icy shell is possibly a warm mobile interior. Is it possible that Europa's innards are warm enough to sustain an ocean of liquid water. Europa has dark wedgeshaped bands of which the other sides fit in each other. This looks like Earth's floating plates of sea ice. There are also very few impact craters. Calculating the impact number of Europa gives an surfage age of only 30 Myr. Calculations for Europa suggest less geochemical energy than Mars would have been available there.
Looking at her neighbors imply that there should have been some volcanic events to repave the craters. New evidence came from the discovery that Europa's neighbor Io is volcanic, because of it's strong elliptic orbit which causes great gravitational tides that causes internal heat activity. Europa is not much further away and calculations proved that Europa could be warmed enough to melt ice flow to a depth of 10-30 km.
When in 1995 the Galileo spacecraft past Europa it measured it's gravitational field from which the internal of Europa could be quantified. From these measurement the water crust is about 100 km thick. But gravity doesn't tell the state of the water. For this there was looked at the pictures. One evidence came from the acknowledging of the ridges of Europa. But there is also a strange pattern on the surface that can be explained if Europa's surface is rotating faster than its interior. This can only happen if there's liquid water under the high icecrust. This rotation takes at least 10.000 years and can only determined by long observations of changes. To make the craters to be swallowed, another part of Europa has to heighten, but this hasn't been identified yet. There are also domes on the surface that seem to have been pushed upward from below. They would naturally develop if Europa's icy crust floated on liquid water, because warm water wants to rise. Europa is probably very salty because many meteorites contain salt.
Europa lies in the powerful magnetic field of Jupiter. Measurement have led to the possibility that it's magnetic field is at an unusually steep angle to the rotation axis, making it's subsurface an electric conductor. The same has been found at Callisto, which had no interest before that. It could be typical for icy moons. But still there is no real proof.

6. Is there life on Titan?

The third object of interest for extraterrestrial life in our solarsystem is the big moon of Saturn, Titan. Titan is covered by hazy atmosphere that block good observations.
Titan has a strong greenhouse-effect due to N_2, CH_4, H_2 and a high altitude organic haze layer. It is virtually transparent to thermal infrared wavelengths. This way Titan is heated by sunlight, but also cooled (less). Titan had probably surface reservoirs of CH_4 (lakes) but not a deep global ocean. The current form of the atmosphere is not good for keeping the most sunlight and making warmth, but better for making it cooler. Although Titan's temperature is very cold there could be some sort life under the atmosphere, but probably not as we know it.

7. Conclusions

The measurements and researches of the past decades haven't given any decisive conclusions, so the possibility of other life still lies open. Many models have been made, but they still are only models. In the years we are living in there is a lot of research about Mars, but failing missions delay significant progress. There are plans to bring an orbiter to Europa and let it dig into its crust. Maybe then we will finally know the secrets of the hidden ocean of Europa. There will also be send a lander to investigate Titan's atmosphere, but the possibility of life there is very small since the conditions for Mars en Europa are far better, and their liveableness is already small. There is still no answer, but the (hopefully near) future will tell us the final answer.

8. References

1. Clark, B.C.. Surviving the limits of life at the surface of Mars. In the *Journal of Geophysical Research*, vol. 103, no. E12, 28,545-28,555 (November 25, 1998)
2. Clark, B.C.. Barriers to natural interchange of biologically active material between Earth and Mars.
3. Davis, W.L., C.P. McKay. Origins of life: a comparison of theories and application to Mars. In *Origins of life and evolution of the biosphere* 26, 61-73 (1996)
4. Farmer, J.. Thermophiles, early biosphere evolution,

and the origin of life on Earth: Implications for the exobiological exploration of Mars. In the *Journal of Geophysical Research*, vol. 103, no. E12, 28,457-28,461 (November 25, 1998)

5. Helfer, H.L.. Of Martian atmospheres, oceans and fossils. In *Icarus* 87, 228-235 (January, 1990)

6. Horneck, G., H. Bcker. Can microorganisms withstand the multistep trial of interplanetary transfer: Considerations and experimental approaches.

7. Jakosky, B.M., E.L. Stock. The biological potential of Mars, the early Earth, and Europa. In the *Journal of Geophysical Research*, vol. 103, no. E8, 19,359-19,364 (August 25, 1998)

8. Klein, H.P.. The search for life on Mars: What we learned from Viking. In the *Journal of Geophysical Research*, vol. 103, no. E12, 28,463-28,466 (November 25, 1998)

9. Livio, M.. How rare are extraterrestrial civilizations and when did they emerge? In *The Astrophysical Journal*, 511:429-431 (January 20, 1999)

10. McKay, C.P., R.D. Lorenz, J.I. Lunine. Analytic solutions for the antigreenhouse effect: Titan and the early Earth. In *Icarus* 137, 56-61 (September 1999)

11. McKay, D.S., et al. Evidence for past life on Mars: . In *Science*, vol. 273 (16 August 1996)

12. Mojzsis, S.J., G. Arrhenius. Phosphates and carbon on Mars: Exobiological implications and sample return considerations. In the *Journal of Geophysical Research*, vol. 103, no. E12, 28,495- 28,511 (November 25, 1998)

13. Pappalardo, R.T., J.W. Head, R. Greeley. The hidden ocean of Europa. In *Scientific American*, 34-43 (October 1999)

14. Price, D.. Europa: life elsewhere?. In *IEEE Intelligent Systems*, 81-84 (September/October 1998)

15. Sleep, N.H., K. Zahnle. Refugia from asteroid impacts on early Mars and on early Earth. In the *Journal of Geophysical Research*, vol. 103, no. E12, 28,528-28,544 (November 25, 1998)

16. Tarter, J.C., C.F. Chyba. Is there life elsewhere in the universe. In *Scientific American*, 80- 85 (December 1999)