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Earth Reflections

The needless search for extraterrestrial fossils on Earth

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Abstract

The search for extraterrestrial life was recently intensified because of new space missions. As long as life has not been found elsewhere in the universe, the best chances to discover extraterrestrial life are considered to be in the study of meteorites. The finding of traces of life on meteorites has been claimed several times, but all claims so far have appeared unjustified. One of the problems is that it is not known how possible extraterrestrial life developed, nor on the basis of which chemical, biochemical and energetic basis this may have taken place.

It is argued that possible traces of life that differ fundamentally from life on Earth will not be recognized with the knowledge we have nowadays; traces of life that do not differ fundamentally from those on earth will not be recognized as extraterrestrial, either because such life may have originated on Earth (and have made a space trip afterwards), or because life on Earth may have come from the same source from where the life forms on the meteorite were derived.

Keywords: Origin of life; Panspermia; Exobiology; Meteorites; Astrobiology

1. Introduction

Questions in natural sciences become increasingly fundamental, now that these sciences have reached a stage in which most of the common-day features and phenomena have been described, and their mutual relationships have been established (even though the underlying reasons for these relationships are not yet always understood). The earth sciences, too, are confronted nowadays with fundamental questions. One of them is also asked by biologists and biochemists: how did life originate on Earth? Biologists can approach this question from a more or less theoretical side taking into account present-day insights into evolution, and biochemists can rely on insights based on the chemical properties of the genomes (the term 'genome' has been defined as 'the entire nuclear DNA of an organism': Leitch and Bennett, 2003) of all sorts of organisms. Earth scientists have the advantage that they can look for traces of early life. This can be in the form of recognizable fossils or in the form of other traces (be

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it organic or inorganic). Precambrian ophiolites show, for instance, signs of alteration that are ascribed to biological activity (Furnes et al., 2003) and Precambrian paleosols show evidence for a biogeochemical cycle (Sheldon, 2003). The search for traces of earliest life is difficult, however, and previously widely accepted claims for life forms of some 3.45 billion years old (the cyanobacteria-like Warrawoona fossils from Australia: Fig. 1) are now being questioned; caution is ever more recommended for the interpretation of the earliest putative fossils (Knoll, 2003). It seems nevertheless that recent claims (Furnes et al., 2004) of traces of life of 3.48 billion years old in the

Fig. 1. *Primaevifilium amoenum*, interpreted as a cellular filamentous prokaryotic microorganism from the Apex Chert (approx. 3.465 Ga) of northwestern Western Australia. Photo courtesy of Bill Schopf.

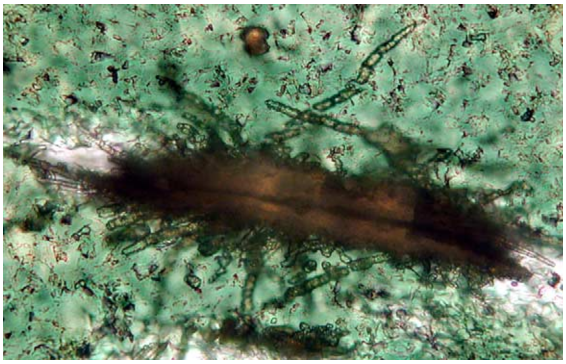

Fig. 2. Pillow lava of the 3.48 billion-year-old Hooggenoeg Formation (South Africa) with tubular structures thought to originate from glass-eating microorganisms. Photo courtesy of Harald Furness and Neil Banerjee.

form of tubular structures in pillow lavas (Fig. 2) have good chance of surviving the criticism that was heard immediately after this intriguing publication.

The difficulties in the search for early life result from the relative scarcity of old sediments, the diagenetic processes (and much more commonly strong metamorphism or even complete melting: Fowler et al., 2002) that have affected such sediments, and the lack of knowledge of what precise traces should be looked for (see Papagiannis, 1985). This latter aspect is, obviously, closely related to our lack of knowledge of how life on Earth originated, and how the earliest life forms may have looked like.

Theories about the origin of life on Earth have been numerous. Whereas Creationists base their standpoints not on scientific grounds but on the Book of Genesis in the Bible, early biologists and geologists used their scientific creativity for a long time, and the resulting speculations about earliest life on our planet reflect this well. When science progressed, it became clear that creativity is insufficient to deal with the origin of life in a scientifically adequate way, and that rather both (paleontological) field evidence and biological expertise should be used as the most fundamental building stones for theories about this topic.

Even this insight left ample space for a variety of theories (Dose, 1986), three of which are still being seriously considered: (1) the ‘primordial-soup theory’ (also known as the ‘eprimordial-soup theory’) hypothesising that life formed by incidental combination of ‘organic’ molecules formed under the then conditions in the oceans; (2) the ‘pizza theory’, hypothesizing that life formed on wet rocks at the margins of hot springs; and (3) the extraterrestrial theory. The last-mentioned one is—with some related speculations and considerations—the subject of the present contribution, also because this theory might find a factual basis (or, on the contrary, be proven highly unlikely) as a result of paleontological efforts to trace remnants of extraterrestrial life in sedimentary rocks (thus not solely on meteorites or related material coming from space). For this reason the pizza and the primordial-soup theories will not be dealt with here, however interesting and valuable they may be. Neither does this choice imply that the extraterrestrial theory is considered scientifically more valuable or likely than the other theories. Finally, the questions will be addressed whether it is likely that life on Earth has an extraterrestrial origin, whether it might be possible to recognize it as such, and (if so) whether it is worthwhile for earth scientists to start a structured search for extraterrestrial traces on Earth.

2. Extraterrestrial life

If life on Earth descends from life elsewhere in the universe, there must have been life in the universe, at one or more places. The chance that this life 'colonized' Earth and became extinct afterwards (everywhere in the universe except on Earth) seems so small that it would be scientifically justified to state that life then still must exist outside the Earth. In spite of sophisticated methods to detect signals that might have been sent by technologically highly developed life forms elsewhere, such signals have never been received (or, at least, they have not been recognized as such). This does not imply that technologically developed life does not exist elsewhere in the universe: it may be so far away that signals sent by them did not yet reach us or that they reached us in such a weakened form that they are undetectable with present-day equipment; civilisations may have developed so much earlier elsewhere than human life on Earth (and have become extinct in the meantime) that the last signals they sent reached our planet before we were able to detect them; 'nearby' civilisations elsewhere may be technically behind us, so that they are not yet able to communicate with life in other solar systems; and it is possible that extraterrestrial highly developed civilisations have chosen not to communicate with Earth's inhabitants.

'Technological' signs from the universe are, however, not the only possible indicators for extraterrestrial life. There has been an interesting debate in the past few years on the basis of tiny structures found on the ALH84001 Martian meteorite (Fig. 3). The crystals were originally described as being of a nature that is characteristic for a biological origin (McKay et al., 1996a). Only after heated debates the opinion most adhered to now is that the structures had been misinterpreted and have no biological background (see, among others: Anders, 1996; Bell, 1996; McKay et al., 1996b) or are contaminants (Jull et al., 1997). It is interesting in this respect that the Tataouine meteorite, which fell on Earth some 70 years ago and which also shows 'biological nanocrystals' (Fig. 4), was recently investigated taking into account

Fig. 3. The structures in the Martian meteorite ALH 84001 that have raised hot debates about a possible biological origin that might indicate extraterrestrial life. From Treiman (undated).

pedological aspects. It was then found that the crystals that might have caused just as much excitement as the Martian meteorite were formed during the 70-year stay on Earth, as a result of nanobacterial activity in the Earth's soil (Benzerara et al., 2003).

One must therefore conclude that no convincing indications for extraterrestrial life have been found on Earth this far. This lack of convincing evidence is, however, no truly valid scientific argument against an extraterrestrial origin of life on Earth. The search for extraterrestrial life therefore remains a scientific challenge. Earth scientists—but also biologists, experts in organic chemistry, and physicists dealing with isotope ratios—might look for such traces by careful analysis of meteorites. One should realize, however, that the search for primitive life forms on meteorites is extremely difficult: traces that may seem to be due to the activity of an organism, need not represent life: fossil-like structures have been 'cooked' in the laboratory (García-Ruiz et al., 2003; Kerr, 2003), and meteorites may be contaminated with material from Earth (Watson et al., 2003). One should also realise that the presence of carbon—and even organic compounds—does not say much: carbon in elementary form and organic compounds are fairly common in the universe (Khare et al., 2001) but need not indicate life. In addition, a search for extraterrestrial life forms requires first more or less generally accepted answers to a number of difficult—because rather philosophical—questions.

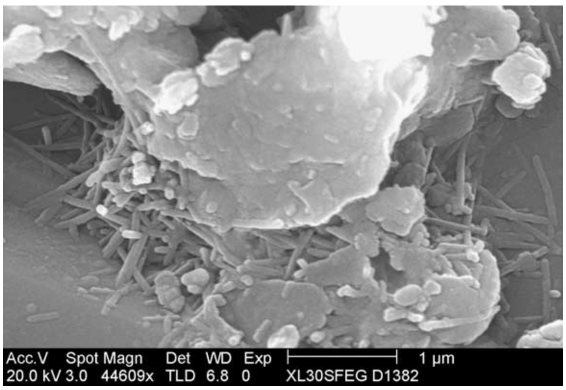

Fig. 4. Detail of the Tataouine meteorite, showing structures due to nanobacterial activity, which must, however, have taken place on Earth. Photo courtesy of Karim Benzerara.

3. Questions to be answered

The most important fundamental questions that have to be answered in the context of a possible search for extraterrestrial life are—obviously—partly closely interrelated. To mention only a few:

(1) If we want to recognize life forms on meteorites, in rock samples from other planets, moons or comparable space bodies (but also in the oldest sediments on Earth!), we must ascertain that debates on structures with a potentially biological origin are not hindered by different opinions about what is life. In other words: we need a clear and generally accepted definition of what should be considered as life, not only in the form of living or dead organisms (in the following, dead organisms and their remnants are for practical reasons included in the term 'life'), but also in the form of fossil traces.

(2) If life forms that differ fundamentally from those on Earth developed somewhere in the universe at some time, how would we recognize them, and how should debates about them be fitted in the 'biological framework' sketched in the previous question? It is interesting in this context that current research on exobiology or astrobiology (several terms are used for the study of life from elsewhere in the universe) pays unduly little attention to life forms that may be fundamentally different from those on Earth (see, among others, Horneck and Baumstark-Khan, 2002). Fortunately, some scientists (see, among other Crawford et al., 2001) realize that all life forms require energy, so that one might find signatures of 'exotic' life forms in the form of core chemical components of electron-transport chains used by such organisms to tap energy in controlled oxidation/reduction reactions between electron donors and acceptors along such a chain.

(3) How could one distinguish between terrestrial (we will use this term in the following in a geologically diverging way, viz. not as 'non-aqueous continental' but rather as 'related or belonging to Earth') and extraterrestrial life forms if they have fundamentally the same origin (viz., if life on Earth itself descends from the same or a highly comparable extraterrestrial

source of life or did develop on the basis of the same principles)?

(4) If life on Earth has an extraterrestrial origin, where does it come from?

(5) If fossil traces of extraterrestrial life forms could come from outside our solar system or even from outside our galaxy, is there any reason to assume that there is only one 'incidental' source of life in the entire universe (from where it spread successfully to all bodies where the conditions for such life were sufficiently favourable: the Panspermia theory) or should we assume various sources in the universe (and would this imply also different life forms that may have 'infected' Earth)?

(6) If life on Earth has an extraterrestrial origin, could it be possible that extraterrestrial life forms have 'infected' Earth several times in the geological past, and could this still happen nowadays?

Without satisfactory answers to these questions it will not only be very difficult to trace extraterrestrial life forms, but also to unravel the origin of life on Earth. In the following sections, the above questions will be considered; these considerations—partly in the form of personal viewpoints—are meant only as a starting point for more structured discussions than we have nowadays. It is certainly *not* the intention to provide definite answers here!

3.1. Definition of life

There are many definitions of life, but none seems generally accepted. This is because it has become evident that there is such a gradual transition between clearly abiotic structures and indisputable life forms, that any boundary drawn between them must, almost by definition, be based on a criterion that is questionable. Are viruses life forms? *Yes*, according to, among many others, Mindell and Villarreal, 2003; *no* according to, among just as many others, Van Regenmortel, 2003. The question becomes even more important since a giant virus, *Acanthamoeba polyphaga* (Fig. 5), has been discovered (La Scola et al., 2003), with a double-stranded DNA circular genome of about 800 kilobase pairs (which makes it genome larger than that of several bacterial species).

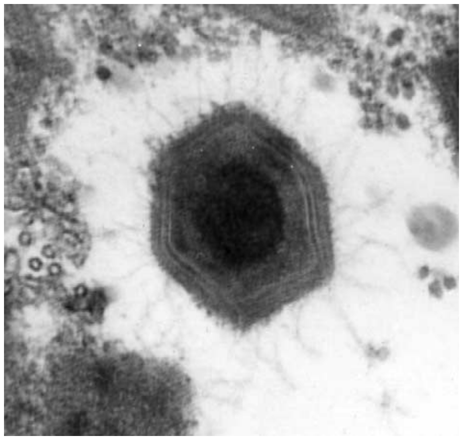

Fig. 5. The giant virus *Acanthamoeba polyphaga*, which has mature particles of 400 nm in diameter surrounded by an icosahedral capsid, to which 80-nm fibrils are attached. It resembles a bacterium but has characteristic viral morphology. Photo courtesy of Bernard La Scola.

Many biologists adhere to the view that the presence of DNA (or at least RNA, which is likely to have preceded the emergence of DNA: Lurquin, 2003) is a suitable criterion for life; in fact, our 'tree of life' is based upon it (Marshall Graves, 2003) and the dating of major branching points is also based on it (Benton and Ayala, 2003). If the DNA definition of life is justified, there can be no life forms without DNA; in fossils, however, the DNA has—as a rule—disappeared completely, either by destruction or by replacement. Defining life on the basis of the actual presence of DNA has therefore some dangerous consequences that evolutionary biologists do not always seem to realize.

A related fundamental problem is the first occurrence of RNA and DNA on Earth. If their presence is considered essential for life, the first RNA or DNA molecules on Earth cannot have been formed by an organism, because this organism could not be considered as a life form as long as it did not contain DNA. The definition of life as being determined by the presence of DNA therefore leads inevitably to the conclusion that (if life on our planet does not have an extraterrestrial origin) DNA molecules must—in the remote geological past—have been formed by abiotic processes. In the course of time, these abiotic DNA molecules must have acted as the cores for 'symbioses' of complex molecules that, at a certain moment, started to act as living organisms that could reproduce themselves. The question whether such a development could have been possible on Earth in the geological past is now under discussion, particularly in the framework of the 'manufacturing' of artificial life (see Rasmussen et al., 2004).

3.2. Non-DNA-based life forms

All life forms on Earth—at least as far as recognized as such—contain DNA. This remarkable molecule has, however, still numerous secrets. Why, for instance, are there four base pairs and not another number, why are they paired in always the same way, and why is the molecule capable of duplicating itself? One should realise that—as long as these questions have not been answered—the question why DNA is essential for life on Earth will remain fundamentally unanswered. Without an answer one cannot scientifically sound reason state that life could not be based on another (extraordinary) molecule. Life forms based on such another molecule would not resemble life forms as we see them around us; they thus could be present, but unnoticed.

However unlikely it seems at first sight that life forms could exist without DNA (and even with hardly any carbon), one can scientifically not exclude the possibility: even life forms that are not based on carbon may exist. The most likely 'substitute' for carbon would be silicium. Conditions for such life might resemble those on Earth under which crystals are formed and broken down again in magmatic melts, hot springs, or—not unlikely—they might not have a real counterpart on present-day Earth.

3.3. Distinction between terrestrial and extraterrestrial life forms

Earth has been hit by a giant quantity of large bolides in the past, particularly some 3.8 billion years ago (Gilmour and Koeberl, 2000; Plado and Pesonen, 2002). It is estimated that the total mass of extraterrestrial material falling on Earth during this so-called 'heavy bombardment' was 10^{18} to 7×10^{20} tonnes (Marty and Dauphas, 2002), and Earth accretes still nowadays with some 30,000 tonnes of extraterrestrial dust per year (Tomeoka et al., 2003), so that there has been ample direct interplanetary contact. If life on Earth derives from such a contact, the question remains whether all life has the same extraterrestrial origin, or whether there are several extraterrestrial sources. If there is only one single source of life in the universe (Panspermia), we need not recognize such extraterrestrial life: there would be no fundamental difference with primitive terrestrial life forms. If Earth has been infected by life from different sources that, ultimately, descends from one single source from where it spread out in the universe, we should not consider it as coming from different sources. If Earth would have been infected by life forms that developed independently of one another, one after another or simultaneously (in a geological sense), were these independent primitive life forms comparable (all based on DNA), or were they fundamentally different? If they were highly comparable, we will probably never be able to distinguish them from one another.

A last possibility, viz. that early Earth has been infected with life forms that have principally different designs, seems most unlikely. It would possibly have led to a competition between these fundamentally different types of life. If such a competition has taken place, indeed, apparently the DNA-based life forms have won. But why would these life forms have been competitive if they were fundamentally different (i.e., if they did not need the same type of food, etc.)? Could it be possible that divergent life forms left no traces at all? If so, why didn't they? Paleontologists have discovered numerous old, primitive fossils, so why would they not have discovered fundamentally different primitive organisms?

It thus seems that the chance that Earth has been infected by fundamentally different life forms from different places in the universe, is extremely small; so small that it does hardly seem worthwhile to start a project 'in the quest for extraterrestrial life of fundamentally different design.

3.4. 'Home' of extraterrestrial life

If terrestrial life originated somewhere else in the universe, the questions arise where and under which conditions this took place. Three possibilities should be considered: an origin elsewhere in our solar system, an origin somewhere in our galaxy, and an origin farther away in the universe.

Space missions, particularly towards Mars, had—and still have—the search for life as one of the prominent objectives. Thus far, the result has been negative. The preliminary conclusion must be that life does not originate 'automatically' (or at least: does not necessarily survive) on planets of which the conditions in the past had much in common with those on Earth. Even if Earth-like life would be encountered on one of the planets of our solar system, this would not prove that life on Earth has an extraterrestrial origin: it would be still unclear if Earth and the other planet(s) infected each other, if they were both infected by the same life from elsewhere in the universe, or whether life originated on Earth and the other planet independently. If, on the other hand, the life forms found on another planet would differ fundamentally from ours, we could be sure that life on the two planets did not infect the other planet (or, at least, not in a way that left traces). The question whether both life forms originated in our solar system or farther away, would still remain unanswered.

The possibility that life on Earth derives from life forms that developed elsewhere in our galaxy (outside our solar system) seems very unlikely. One reason is that such life forms would need much time to reach Earth: the stars closest to our solar system (α and Proxima Centauri) are some 4.3 light years away. If life would have travelled from a planet within that solar system to Earth—for instance attached to a large meteorite—in a straight way (which is, in fact, not possible), and if the average travelling velocity would have been 100,000 km/h (which seems high), the travel time would have been in the order of a few centuries; a travel time of millions of years seems, however, much more likely. It is not well imaginable that life forms could survive a voyage of at least some centuries under conditions of almost 0 K temperature, then reach Earth and still be capable of reproducing in such a quantity that life would really become established on Earth.

The chance that life from another galaxy could have infected our galaxy during a merge of galaxies (merging is not impossible: Wyse, 2003) and have survived, seems nil. The conclusion should therefore be that the chance that life on Earth derives from outside our solar system is extremely close to zero. An extra-galaxy origin is even more unlike if one realizes that all meteorites found thus far come from our own solar system.

Exchange of material between planets within our solar system (in the form of meteorites) has taken place (and still takes place). This implies that it will probably never be possible to find out on which of the planets life originated, so what the original 'home' of life in our solar system was.

3.5. One or more sources of life?

In the unlikely case that life on Earth would come from another solar system, one might question whether it comes from one source or from more than one. A multi-source origin can—as explained above—only be recognized if the 'design' of the life forms from the various sources is fundamentally different. The finding of such a life form would most probably not be in the form of a primitive fossil organism in a sedimentary rock; it would rather be in the form of traces/signs/primitive fossils on a meteorite. The reason is that a find in sedimentary rock would imply that the extraterrestrial life forms found suitable survival conditions on Earth. In that case, they would have spread most likely over the entire Earth, considering the most restricted environmental differentiation in the early history of our planet. No indications for such colonization of Earth by extraterrestrial life have ever been found.

Taken together, it must be deduced that the presence on Earth of life forms originating independently at different places in the universe cannot be fully excluded, but one must deduce from the lack of principally different life forms on Earth that a multi-source origin of life on Earth is extremely unlikely.

3.6. The possibility of multiple '*infection*' *by extraterrestrial life*

One of the most intriguing questions is whether extraterrestrial life forms—in a state capable of infecting Earth—may have reached our planet at geologically clearly different times. If the chance that life forms capable of colonizing Earth reached us once is small, the chance that this happened more than once is exponentially smaller; it can, however, not be fully excluded. If it happened, there are two possibilities: either the meteorites bringing life at different moments came from the same body in space, and infected Earth with identical (or essentially comparable) life forms, or the meteorites had different sources. In the former case, it will be practically extremely difficult to distinguish the two infection phases. If the various meteorites involved left their 'mother planet' simultaneously (which is most likely, because the launching of planetary material into space requires exceptional conditions such as the impact of a large bolide), they will most probably have brought more or less identical primitive organisms. During the interval between the moments that the life-bearing meteorites reached Earth, the organisms from the first meteorite may have evolved on Earth, and the original types (species?) may have become extinct on our planet. Theoretically this opens the possibility to detect the renewed introduction of a primitive organism, but this would require a scientifically reliable proof that the two times during which the extraterrestrial organisms lived on Earth are separated by a time that they did not. This appears even impossible for much less problematic life forms (as proven by, for instance, the apparent absence in the sedimentary record of the coelacanth between the Mesozoic (Fig. 6A) and the 20th century (Fig. 6B). It thus seems impossible, with the means that we have nowadays, to detect such a 'multiple infection' with life from elsewhere.

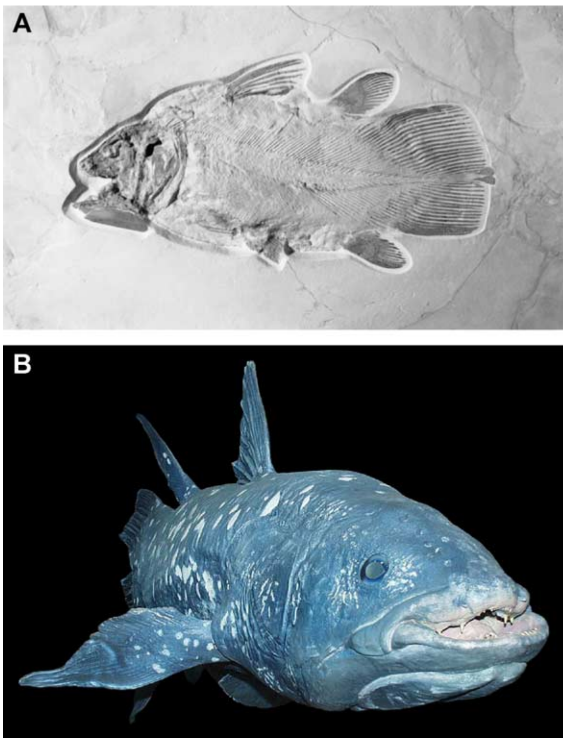

Fig. 6. The coelacant. Fossil remnants are absent in the geological record from the Cretaceous to the last century, but no paleontologist doubts the presence of this complex life form on Earth during this entire interval. Could, however, the most primitive forms originate multiple times? (A) A species (*Lybis superbus* Zittel 1887) from the Malm in Solnhofen (Germany). Courtesy of Teylers Museum, Haarlem, The Netherlands (loan Kramer Family). (B) A recent coelacanth (*Latimeria chalumnae*). © Thomas Seilnacht, www.digitalefolien.de.

A different situation would exist if two life-bearing meteorites might have left the same source planet at distinctly different moments in time. In this case, they might bear different species of primitive life, because life would have (most probably) evolved at the source planet between the two times that material was ejected into space. The evolution on the 'mother planet' may well have differed from the evolution of the extraterrestrial life forms on Earth. This thus would open the possibility that the organisms that reached Earth on the second meteorite will be recognizable as suddenly appearing life forms that cannot well be related to other lineages of primitive organisms on Earth.

If the two (or more?) meteorites that (theoretically) brought life to Earth came from different sources, a situation would have been created that has been discussed above (Sections 3.4 and 3.5). This needs therefore no further elaboration here.

4. Terrestrial or extraterrestrial life?

One of the main reasons why an extraterrestrial origin of life has been advocated is that the theories with regard to life originating on Earth itself are not entirely satisfactory. It is obvious, however, that a better understanding of the origin of life on Earth is not achieved by postulating an extraterrestrial infection, because this only raises the question how life originated at that body somewhere else in the universe.

It might be a much more appropriate approach to philosophize (and—if possible—to carry out experiments such as the famous one by Miller and Orgel, 1974) about the conditions required to create life. Only if one agrees about such conditions (and it cannot be excluded that the most primitive life forms were created under different conditions) it makes scientifically sense to discuss whether such conditions existed on Earth. If such conditions are likely to have existed long enough in the early history of the Earth, it seems only logical to assume that life then was formed. It is most interesting in this context that more and more places are found on modern Earth where extreme conditions exists (at least partly comparable to those that dominated early Earth). It is even more interesting that life forms (extremophiles) are found in almost all these places. Examples are strongly alkaline lakes, evaporite deposits, rocks that are buried several kilometres deep, hot springs, and deep-sea vents. (Fig. 7) The occurrence of life under such extreme conditions does, obviously, not prove that life can have also been created under these conditions, but it does prove that life forms cannot only have survived but even have reproduced and spread out over environments that we consider now as extremely hostile, and which may have existed in the time that life was created on Earth. Many researchers now think that there is a potential for life in hot, extraterrestrial environments (see, e.g., Kashefi and Lovley, 2003). There is still much debate, however, whether life—if it originated on Earth under aqueous conditions—developed under hot (deep?) or colder (more surficial) conditions (Whitfield, 2004).

If it is considered possible that the origin of life on Earth is not elsewhere in the universe but on Earth itself, it might therefore be useful to study in much more detail the organisms that now survive under conditions that may have been present on Earth when life was created. The remains or traces of comparable organisms might be encountered in the oldest fossil-bearing rocks on Earth.

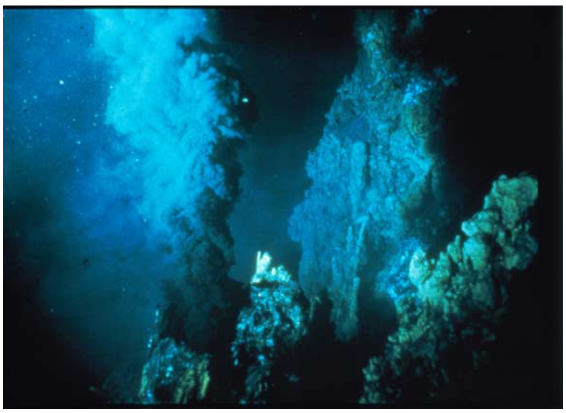

Fig. 7. A black smoker on the East Pacific Rise, at 2600 m depth. © Ifremer/Biocyarise, reproduced with permission.

4.1. Is life still being created on Earth?

An intriguing question is whether the conditions under which life may have been created on Earth still exist. If so, it cannot be excluded that new life is still being formed. This possibility has, as far as the present author is aware of, never been addressed in detail in the scientific literature, probably because we take present-day life as a result of long-term evolution for granted.

It is obvious, however, that the general environmental conditions on early Earth differed largely from the present ones: this is possibly best expressed by the different composition of the atmosphere. On the other hand, it is unlikely that life originated under subaerial conditions. Rather the original habitat of life was water, possibly in the neighbourhood of oceanic hot vents (Nisbet, 2002). If life could originate there in the past, why couldn't it do now? It is interesting in this context that a primitive organism (*Nanoarchaeum equitans*: Fig. 8) recently discovered by Huber et al. (2002) in such a hot vent, is described as "weird" by Boucher and Doolittle (2002), emphasizing that life forms like this one are "creatures that have drifted so far out of the biological mainstream that the usual PCR primers do not recognize or amplify their SSU rRNA genes" (in other words: their RNA cannot be recognized—let alone amplified—with the commonly used techniques). With roughly 500 kilobases this organism has possibly the smallest known prokaryotic cellular genome. The discussion in literature about this remarkable life form does not touch, however, on the intriguing question whether it could represent a descendant of a life form that originated relatively shortly ago on Earth, or whether it might even be the descendant of a 'weird' (but still DNA-based) life form that reached Earth through a bolide, and that found a livable habitat nearby the hot vent.

One should realize, however, that little—if anything—is known about the earliest life forms on Earth. Some scientists advocate, on the basis of genome analysis, the probable existence of the Last Universal Common Ancestor (LUCA) from which all present-

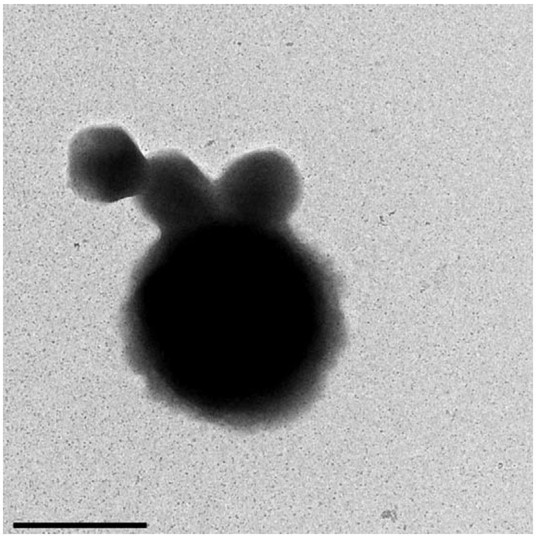

Fig. 8. Electron micrograph showing a cell of *Ignicoccus* sp. with attached three specimens of the 'weird' primitive organism *Nanoarchaeum equitans*, which has some gene characteristics that differ from those of all other known life forms on Earth. Scale bar 1 μm. Photo courtesy of Karl Stetter, Reinhard Rachel and Harald Huber.

day life forms are descendants (Lazcano and Forterre, 1999), but others think that some kind of 'gene pool' must have existed in the beginning, from which life forms that can hardly be specified took some genetic material more or less randomly (Whitfield, 2004).

4.2. How 'weird' should extraterrestrial life be?

The options sketched in Section 3 are all based on the assumption that life on Earth has an extraterrestrial origin. There is, however, no sound reason to consider this a likely option. On the contrary, the problems faced by life forms that have to travel through space seem much larger than the problems we face if the origin of life on Earth is considered. It seems, for instance, very unlikely that living organisms can survive a long journey through space, particularly 'aboard' of a small-sized body. If the body is large, the impact on Earth will, as a rule, be so catastrophic that it seems beyond imagination that life forms could survive: large bolides impacting with a speed of 10–70 km/s cause impact pressures of tens to hundreds of gigapascals and temperature rises of hundreds to thousands of Kelvin (Reimold, 2003). Could it be that extraterrestrial life forms survive all these because they have a fundamentally different design?

The newly discovered archeon *N. equitans* shows that even 'weird' rRNA does not lead scientists to the conclusion that the organism involved represents an extraterrestrial life form. Then, one might ask, what divergences from the 'normal' RNA or DNA are necessary to consider an extraterrestrial origin? If DNA-based (or RNA-based) life forms have developed somewhere in the universe, how 'weird' should their genomes be to be considered as potentially extraterrestrial? And why could such an organism not represent a life form that originated relatively recently in a hot aqueous environment on Earth under conditions that resemble those under which other life forms originated—or at least lived—in the early times of the Earth's history?

Numerous scientists accept the hypothesis that it cannot be excluded that life ever existed on Mars, or even that some primitive forms may have survived at some sheltered places up to now. That is why, in spite of previous failures (Klein, 1986), the 'hunt for life on Mars' now gets so much attention (Kawasaki, 1999; Horneck, 2000; Raulin and McKay, 2002), with even plans for manned spacecrafts visiting the red planet. The hunt got much impetus after photographs had revealed structures that can be explained as resulting from running water (and an ice age may have ended only some 400,000 years ago: Head et al., 2003), but as long as we do not know more about the origin of life, one may question the presence of water as a prerequisite of life. If life ever existed on Mars, did life on Earth come from the red planet, or might life on Mars have originated on Earth? Or did life on both planets come from one or more sources in the universe?

The only thing we know for sure is that life, whether it came from somewhere in the universe or whether it originated on Earth, was able not only to survive on our planet, but also to evolve into such a wide variety of organisms that we have no well founded idea of the number of species (see also Van Loon, 2003). Future space missions might provide an answer to the question whether complex ecosystems may also occur (or have occurred) elsewhere in our solar system. Such a find would, however, still leave the question open of where the source of life should be sought.

5. Conclusions

It must be deduced from the above that the possibility of life on Earth having an origin outside our solar system can practically be excluded, particularly since it is beyond imagination that living material can survive a long-lasting travel through outer space and/or the collision of a large bolide with Earth. If primitive life forms within our solar system are capable to survive travelling from one planet to another, it is most likely that all planets of our solar system have been infected numerous times by the life that originated on one of our planets (or other bodies). On most planets, the conditions will not have allowed life to survive for a long time, but where sufficiently favourable conditions existed, life will have developed. Considering the number of impacts on the Earth (and more particularly the Moon, where they are still much better visible because of the almost absence of erosion and sedimentation) the 'interplanetary traffic' has been so intense that exchange of life forms must have taken place numerous times. There is therefore no reason to assume that life on any body in our solar system—if present at all—will differ from that on Earth: the search for extraterrestrial fossils is doomed to fail. But the search for LUCA will remain an intriguing challenge.

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