Early Archean fossil bacteria from the Barberton greenstone belt, South Africa

An essay by E. J. Hall on the study by Westall et al. (2001)

1. Aim of the Study

This essay is based on a study by Westall et al. conducted in 2001. I will summarise their paper and then discuss it critically.

Westall et al. explicitly set out with the “aim of searching for microfossils, especially those close to the size of modern bacteria”. Their samples are various cherts taken from the Onverwacht group in the Barberton greenstone belt (BGB) in South Africa. The authors also try to make interpretations about the depositional environment of the rocks and about later hydrothermal activity. Throughout the paper, they make it clear that this is an ongoing project and that the interpretations are only preliminary.

The Onverwacht group and the overlying Fig Tree group have been intensively searched for microfossils in the past, with papers suggesting the presence of ca. 1 μm long, rod-shaped bacteria, up to 10 μm long, twisted, ropy filaments, up to 100 μm long, filamentous, partly hollow strands, spherical cells in the order of 10 μm, and more. However, in 1983, Schopf and Walter re-evaluated all of the then published possible microfossils in that area and classified most of them as non-fossils, modern contaminants, or dubiofossils.

Westall et al. now have improved SEM techniques and a greater understanding of how bacteria are fossilised, leading to the elimination of most artefact problems. Apart from their own study, they want to cast a new light on the previously reported microfossils that were later classified as non-fossils or dubiofossils. They suggest that many of these may in fact be valid trace fossils of microbial activity, and that their importance should therefore be reassessed.

2. Summary

In their paper, Westall et al. propose that they have found at least two different types of bacteria in the 3.3 – 3.5 billion year (Ga) old cherts. The cherts are taken from both the Kromberg and Hooggenoeg formations in the Onverwacht group, which itself mainly consists of mafic and ultramafic volcanic rocks.

From these formations, six rock samples were taken. They were analysed using a petrographic microscope, X-ray diffraction (XRD), a mass spectrometer for the stable carbon isotope value, and, after careful preparation and etching with HF (hydrofluoric acid), a scanning electron microscope (SEM). The analysed cherts have black, white, and/or green colours and are either finely or coarsely laminated, brecciated, or massive. The fine lamination is described as wavy and discontinuous.

Various fossil bacteria were purportedly found. One of the two types of proposed bacteria are 1 μm small spherules. The arguments that these spherules are indeed fossil bacteria are that they have uniform diameters, occur in large concentrations resembling colonies, have a wrinkled surface, and show complex structures resembling cell division (they occur in associations of two or more joined spherules showing linear, “zigzag”, or irregular shapes). Because of their morphology and size, they are classified as coccoid bacteria.

The other structures thought to be a type of fossil bacteria are 2 – 3.8 μm long “sausage”- or rod-shapes. The arguments that these are fossil bacteria, aside from their size, shape, and occurrence in colonies, are that they seem to lie on the substrate and therefore indicate pliable behaviour, that they are sometimes joined in a fashion that is untypical for twinning in minerals (indicating cell division), and that they have rounded, non-crystalline terminations. These structures are identified as possible bacillar bacteria.

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Apart from these two structures, the authors also name a number of other structures possibly representing fossil bacteria, bacterial trace fossils, or fossil biofilms. For example, they found 0.65 – 2 μm small, rod-shaped particles that resemble “rice-grains”. These particles appear in clusters (again resembling colonies), have a relatively uniform size range, and show possible cell division assemblages. However, they sometimes have slightly crystalline terminations which prohibit a definitive classification as bacteria. The authors however claim that these terminations might have resulted from a diagenetic overprint of the mineral replacing the fossil bacteria.

They further found about 1 μm small, round to oval, hollow and filled moulds. Some of these structures show characteristics of cell division and have the size and shape of coccoid bacteria. But these structures are
relatively rare and a definitive biological origin could not be demonstrated.

Lastly, possible trace fossils of bacteria were found. These include biofilms and EPS (extracellular polymeric substances) strands which are seen as smooth, ropy, granular, or cracked surfaces parallel to the bedding plane of the rocks. They contain evaporitic minerals such as gypsum, calcite, and halite (and even halite hoppers typical of evaporitic environments), rounded to sub-rounded hollows with raised rims which may represent gas-escape structures, and bubble-shaped or lenticular structures which may be trapped gases within the biofilms. Lenticular structures up to 100 μm long may represent gas-filled expansion lenses between thick biofilms. In addition, the biofilm material appears to be pliable. Round to sub-hedral pyrite is also associated with these films.

The XRD showed the dominant mineral to be quartz, with low amounts of muscovite, chlorite, and magnetite. The mass spectrometer measured an extremely low organic carbon content of 0.01 – 0.03%. There was only one sample with enough organic carbon to determine the δ^{13}C-value, which was measured to be -27‰. This δ^{13}C-value is similar to previously measured carbon isotope values in the overlying Fig Tree group and typical for bacterial fractionation.

With respect to the depositional environment, it was found that the cherts are interbedded with pillow basalts, which indicates deep marine conditions consistent with the postulated depth of > 900 m for nearby ironstone pods. However, as previously mentioned, Westall et al. found evaporitic minerals. Other arguments for shallow water or subaerial conditions are the fine, wavy lamination of some of the cherts, the probable fossil bacteria and biofilms within the cherts (at depth, the biofilms would be looser and more fragile), and the partly cracked surfaces of some biofilms which indicate contraction due to evaporation. Field studies have also identified nearby stromatolites and subaerial mudpools. Therefore, it is concluded that the samples have a shallow water origin with periodic subaerial exposure. This would be a suitable environment for microbial mats.

The authors also examined evidences of hydrothermal overprinting of the samples, concluding that an abundance of the mineral tourmaline as well as the silicification of the rocks indicate past hydrothermal activity. They refer to fluid inclusion studies (de Ronde et al. 1994, 1997a, 1997b, Channer et al. 1997) which identifies the source of the fluid to be seawater of evaporitic origin, as well as oxygen isotope data (de Ronde et al. 1997b) which has shown the silicification to be effected by low-temperature hydrothermal fluids (≤ 220 °C). Nearby ironstone pods (interpreted by de Ronde and Ebbesen (1996) as ancient seafloor vents) and banded iron formations are also indicators of hydrothermal activity.

Westall et al. were not able to exactly identify which types of bacteria were present in their samples. They write that the δ^{13}C-value of -27‰ in one of their samples may indicate the presence of cyanobacteria-like, photosynthetic organisms, but in a later update Frances Westall notes that this conclusion is not necessary.

Importantly, all of the rocks of the southern part of the Barberton greenstone belt (to which the examined samples belong) have been metamorphically overprinted in the lower greenschist facies (ca. 300 °C). Despite this, the excellent state of preservation of the rocks and the structures therein is repeatedly mentioned.

3. Discussion

Overall, the evidences for microbial activity in these samples seem convincing. There are some features like the “rice-grains” and the 1 μm small moulds that cannot be definitively attributed to life. But in the light of the other observations, it seems acceptable that they also represent microfossils.

For the spherules, Westall et al. offer two alternative explanations, namely that they are fluid inclusions or abiogenic spheres. However, they are quick to dismiss these interpretations because of the uniform size of the spherules, cell division structures, wrinkled surfaces, and occurrence in clusters which cross-cut the grain boundaries of the matrix quartz. It is pointed out that uniformly sized abiogenic spheres have been produced in the laboratory, but they do not show the linear or “zigzag” cell division structures and have not yet been demonstrated in nature. For the rod-shaped bacillar bacteria, no alternative explanations are offered in the paper.

The strongest argument for microbial activity is probably the presence of fossil biofilms and EPS strands. Especially the roopy, twisted appearance of some biofilms and the rounded hollows with raised rims are probably difficult to explain without microbial influence. The wavy, irregular lamination of some cherts is further support for the successive accumulation of biofilms, similar to the way stromatolites form.

However, one must keep in mind that it could somehow be possible for spherules and rod-shaped structures to precipitate abiogenically, and even wavy laminations like in stromatolites do not always have to be biogenic. Because of this, even the authors themselves are very careful with their interpretations and do
not make any absolute claims.

There are ideas in this study, some of which are listed below, that I find somewhat unclear or problematic. Firstly, the rocks have all been overprinted by lower greenschist metamorphism, and yet the microfossils are remarkably well preserved. I guess this is possible if the silicification through hydrothermal fluids took place before the metamorphism (the authors label the silicification process “penecontemporaneous” and “precocious”). However, I still find it astounding that the microfossils show no sign of metamorphic overprint, and would ask whether they could possibly also be the result of later, post-sedimentary and post-metamorphic microbial infiltration.

Secondly, a diagenetic overprint is postulated for the “rice-grain” structures (resulting in slightly crystalline terminations), but not for the 2 – 3.8 μm long, “sausage”-shaped bacteria. If the structures all have the same sedimentary history, it would seem more reasonable to me if either both or none of them had crystalline terminations, or if the “rice-grain” structures would explicitly be categorised as non-fossils.

Thirdly, only one sample contains enough organic carbon to determine a $\delta^{13}$C-value. However, one measurement is like no measurement and therefore can only be used as a supportive argument but shouldn't be taken too seriously until more measurements are made. As a fourth point, the authors see tiny spheres of pyrite as support for microbial activity. Pyrite can be biogenically produced, but since the atmosphere was still reducing at that time (3.3 – 3.5 Ga ago), rounded pyrite could also be abiogenic and detrital.

Moreover, the authors show images of the “discontinuous, wavy laminae”, but the laminations look more or less straight in their images. Only with larger magnification does the lamination start to look wavy, whereas with stromatolites, the discontinuous lamination is already visible at the macroscopic scale. Finally, the authors mention that bacteria typically occur in consortia with more than one species, but fail to present any clusters (interpreted as colonies) with more than one type of fossil bacteria present.

Personally, I believe that Westall et al. found early Archean bacteria because their arguments (uniform size, cell division structures, the presence of biofilms etc.) seem convincing to me. However, the above (and possibly more) points would need further clarification and investigation.

### 4. Meaning for the Origin of Life

If the investigated structures are real microfossils, they belong to the earliest fossils ever found. So far, the oldest largely undisputed fossils are the microfossils in the Strelley Pool Chert in the Pilbara craton, Australia. This chert is dated to be 3.4 Ga old, and the presence of life is largely undisputed mainly because of macroscopically visible, stromatolitic laminae. The postulated fossils in the Barberton greenstone belt (BGB) would have ages of 3.3 – 3.4 Ga (Kromberg formation) and 3.4 – 3.5 Ga (Hooggenoeg formation), making them roughly the same age as the Strelley Pool Chert microfossils, and possibly even older. Certainly, a more precise dating of the formations would be helpful.

However, even if the BGB microfossils are not the oldest fossils in the world, their significance for the understanding of early Archean biology and the evolution of the earliest life forms would be immense. Westall et al. only describe the morphology and possible habitat of the bacteria, but further studies in that area could give us more information about them. They could investigate how many different types of bacteria lived at that time, how they behaved under various environmental conditions, how they evolved throughout the Onverwacht and Fig Tree groups, and more.

In their paper, Westall et al. compare their findings with similar findings from the Pilbara craton in Australia. They point out that the Swaziland Supergroup (in the Kaapvaal craton, South Africa, where the BGB is located) and the Pilbara Supergroup have roughly the same age and might have been joined together in the Archean. A number of bacteriomorph structures have been found in the Pilbara craton, some of them similar to the ones described by Westall et al. (however, some of them have also been classified as dubiofossils by Schopf & Walter (1983)). There seems to be a wide range of different microfossils in the early Archean, as well as a wide variety of habitats, ranging from shallow water to pelagic to hydrothermal.

It is probable that life already existed earlier than the oldest available microfossils. This makes sense because there cannot be a sudden appearance of a wide variety of microbial life-forms, even though it might be possible within the rather large uncertainty of the radiogenic dating. The authors suggest that life could have formed as early as 4.2 Ga ago, when the earth's surface first cooled down below 100 °C, allowing for liquid water. Subsequent major meteorite impacts until about 3.8 Ga ago would have sterilised the planet multiple times over, but it is possible that life survived in the relative protection of the deep ocean. How soon and at what temperature the earth could have sustained oceans deep enough to protect life remains open to speculation.
5. Sources


