THE DEEP-TIME TREASURE CHEST OF THE MAKHONJWA MOUNTAINS

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The Makhonjwa Mountains of Mpumalanga and Swaziland comprise some of the most sought after geo-real-estate in the world: priceless – for geoscientists – because the rocks of this c.120 km × 60 km corner of southern Africa, also known as the Barberton greenstone belt, date back to between 3.2 and 3.6 billion years (Ga). These are not the oldest rocks on Earth (those occur in Greenland and Canada), but they are the oldest, most well-preserved ensemble of rocks and, as such, best represent Earth in early Archean times, when it was still c.1 billion years young. In fact, these rocks are so well-preserved that, unless one radiometrically dates them, it is nearly impossible to distinguish them from many modern rocks.

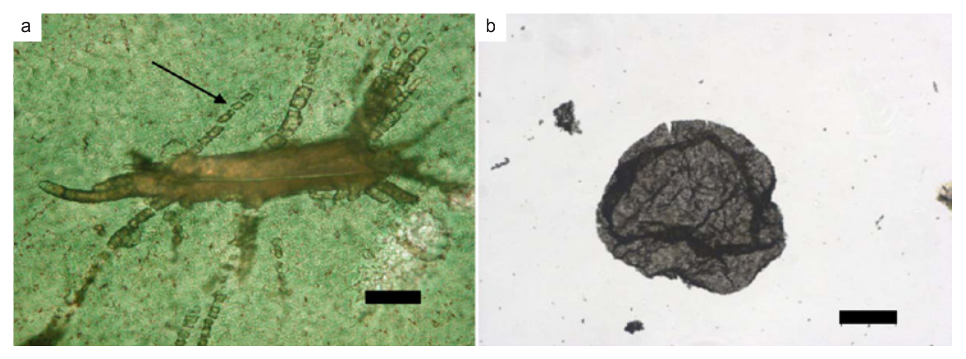
This exceptional preservation has ensured that the Makhonjwa rocks yield the oldest undisputed signs of life on Earth and, when compared to our present biosphere, also provide detailed clues about the hostile nature of the palaeoenvironments under which this life struggled to persist. One severe challenge entailed coping with more potent solar radiation, to which life is particularly sensitive, in a time when Earth's magnetic field was too weak to shield the planet efficiently from the relentless solar wind of lethal charged particles. Two recent discoveries[1,2] have stirred scientific debate about this early life and key aspects of the palaeoecology during the Archean Eon, enabling us to better understand how organisms persisted on our young Earth. The first suggests that we revise much further back in time, to when the Eukaryota – to which we belong – last shared a common ancestor with Bacteria. Insights from the second discovery help us reconstruct the survival conditions in this 'cradle of life'.

Ever since the first purported signs of microfossils were discovered here,[3] hordes of geologists have traversed the rugged Makhonjwa Mountains in search of more convincing clues. But signs of early life are difficult to find – not least because they are submicroscopic. The sophisticated equipment that is needed to detect and prove that such tiny fragments in rocks are organic and ancient – and not some younger contaminants – has become routinely available only in the last decade or so. Many structures detected before the mid-1990s, which were claimed to be fossils, have turned out to be abiotic false-alarms. Geoscientists have since dictated a number of stringent tests a sample must pass, before its tantalising microscopic features can be accepted as genuine biogenic features formed syngenetically with its ancient host rock. This is no simple task. For, after the field work is complete, these tests require dedicated and time-consuming visual and chemical experiments, using electron microscopes (SEM, TEM), X-ray analyses (XRF, XRD), lasers (Raman spectroscopy), as well as mass spectrometry for a range of light stable isotopes.

Over the last decade, three Barberton 'surprises' have emerged in the form of early Archean endogenous biogenic fossils, with all three having living equivalents in our modern world. Firstly, trace fossils of single-cell chemosynthesisers were discovered in igneous rocks from glassy margins of lavas formed at the bottom of Archean oceans.[4] These are dated around 3.47 Ga (Figure 1a). Similar signs of chemophilic bacteria that metabolise on, and devour, such igneous rock far removed from sunlight are abundant in the modern deep oceans.[4] Secondly, fossil microbes were found in 3.45 Ga hydrothermal deposits, such as those in and around modern geysers, for example, those found in Yellowstone National Park.[5]

Most recently, however, an astonishing new fossil discovery has been made in sedimentary rocks dated at about 3.2 Ga.[1] Using standard chemical extraction techniques, the Belgian scientist, Emmanuelle Javaux, and her North American coworkers have unearthed 'big' (100 µm – 300 µm) organic-walled arcitarchs in Barberton's shallow-marine to subtidal mudstones (Figure 1b). Further analyses by Javaux et al.[1] demonstrate, unequivocally, that these fossils are as old as their host rock. Prior to this discovery, the oldest known arcitarch were almost twice as young (1.4–1.8 Ga).

Arcitarchs are of unknown biological affinities and herein lays the most tantalising part of the discovery: What exactly are these fossils? To which branch of the three known domains of life – Archaea, Bacteria,



Sources: (a) Furnes et al. 2004; (b) Javaux et al. 2010
(a) Transmitted light photo of microbial generated tubular structures (indicated by arrow) found in 3.5 Ga lavas.
(b) Transmitted light microscope image of spheroidal acritarch extracted from 3.2 billion-year-old sediments. Transmission electron microscope images of their wall ultrastructures reveal a mono-layered organisation.
Scale bar = 50 µm.

Traces of early life in rocks of the Makhonjwa Mountains in South Africa

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or Eukaryota – do they belong? Javaux and her collaborators[1] point out that they do not yet know the biological affinities of these microfossils, but it is likely these microbes used sunlight for energy. They could be large prokaryotic colonial microorganisms, or even large unicellular cyanobacteria. However, Roger Buick[6], a well known early-life expert based in Seattle, USA, is more provocative in his review of this discovery. He suggests they may be eukaryotic protists, that is, single-cell eukaryotes.[6] If his interpretation is correct, then the early split between bacteria and eukaryote might be found within the 300 million year gap that exists between the igneous/hydrothermal bacteria and the new arctarchs of the Makhonjwa Mountains, which would be a stunning 'cradle of life' breakthrough. Intriguing as this may be, however, careful biomarker geochemistry is now needed and more definite eukaryotic features must be found before this can be confirmed. Either way, the discoveries over the last 10 years have revealed that a surprisingly diverse microbial biosphere already existed 3.5 billion years ago, some of it thrived in the deep oceans, some of it on the beaches.

It has been calculated that the Earth was subjected to X-ray and UV radiation from the young, rapidly rotating Sun, which was more intense than current levels of solar radiation by several orders of magnitude.[7] How, then, could such delicate organic structures have survived on the surface of the young Earth? What kind of life-protecting mechanisms were in place? The second recent Barberton discovery provides revealing evidence from Earth's deep history that allows us to understand how the solid Earth evolved to protect its organic surface veil from being destroyed by a wind of harmful charged particles expelled from the Sun.

Presently, the Earth deflects this 'solar wind' by means of a magnetic shield formed around it by a magnetic field generated within its iron core – our geodynamo. Facing the Sun, Earth sports a kind of magnetic 'space-umbrella' that deflects charged particles around it. But, during severe 'windy' conditions, particles can sneak deep beneath the umbrella, giving rise, for example, to the auroras near the poles (the Northern and Southern Lights). Without its magnetic field, life on Earth would cease to exist. So a legitimate and fundamental question, therefore, is when did Earth first acquire its magnetic field; when did our geodynamo first 'kick-in'? This goes to the heart of understanding the origin and evolution of Earth's iron core. And 'reading' this in the rock record – through deciphering palaeomagnetic signatures – is, arguably, even more challenging than finding signs of early life.

It has been known from numerous palaeomagnetic studies in Barberton that a magnetic field existed around the Earth by at least 3.48 Ga. That is the easy part. Determining the strength of this field, however, is much more challenging. Earlier research in the Makhonjwa Mountains has suggested that, by 3.2 Ga, the intensity of the Earth's magnetic field was around 50% of that of the modern Earth. But testing these models is difficult, in part because even slight weathering, along with recent lightning strikes, can easily reset the fossilised magnetic signatures in these rocks.

A current study[2] has broken new ground by measuring the magnetic strength and orientation of tiny, submicroscopic magnetic particles encapsulated in small quartz grains (0.5 mm – 2 mm) from volcanic rock dated at 3.45 Ga. This delicate work by US scientist John Tarduno and his coworkers, including geologists Axel Hofmann and Mike Watkeys from the University of Kwazulu-Natal, confirms the presence of a geodynamo between 3.4 and 3.45 Ga, but one that operated 30% – 50% less effectively than that at present.[2] When combined with a stronger solar wind, shielding by the Archean 'space-umbrella' was less effective than today, allowing particles to penetrate deep into the atmosphere and to much lower latitudes than is seen today. This must have affected temperatures and the composition of our atmosphere and oceans, forcing significant loss of hydrogen and water. Tarduno and his coworkers[2] argue that, by 3.5 Ga, our geodynamo was strong enough to stabilise chemical erosion of our atmosphere and nurture life as we know it. However, there is still much uncertainty about the meaning of the magnetic signatures, the geodynamo models and our Sun's energetics that far in the past.[7,8,9] There is also too little known, surprisingly perhaps, about the precise past chemical composition of our exosphere to predict how life may have been shielded farther from this potent young Sun.

Do the rocks of the Makhojwa Mountains retain enough pristine 'forensic' evidence with which to push these scientific boundaries further? New studies[10,11,12] are attempting to reconstruct the precise physical and chemical conditions of the ecosystems 3.5 billion years ago. These projects revolve around drilling deep into the rocks to ensure that samples are not contaminated by present-day surface processes.

The Makhonjwa Mountain treasure chest continues to yield unique observations with which to model how our planet transformed from a near molten ball, to a tectonic-plate-driven recycling plant. There is always a ripple of excitement at scientific meetings whenever the lid of the Makhonjwa Mountain chest is pried open farther, even if ever so slightly. Perhaps, then, it is time to declare these mountains a world-heritage site? ■

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