deformation, such as loudspeakers and pressure sensors[3].

The idea of creating multiferroic materials that simultaneously exhibit magnetic and electric order was first suggested in the late 1950s, and they began to be constructed a few years later[4]. In these materials, the magnetic and ferroelectric properties are manifested together and, more importantly, the two types of order are often coupled to each other.

Why would such a coupling be useful? As an example, many computer memory elements are operated by electric currents. These currents limit the computer's processing speed, and produce so much heat that energy consumption and the need for cooling become serious problems. However, in a multiferroic memory element, a voltage pulse could be used to control the ferroelectric state and, through an internal magnetoelectric coupling, activate the ferromagnetic state that represents the memory bit. Voltage pulses can be transmitted more quickly than electric currents and consume less power[5].

Unfortunately, building a multiferroic material is difficult because the conditions that favour magnetic and electric order tend to be mutually exclusive[1]. As a result, the use of known multiferroics is technologically infeasible for various reasons — for example, the magnetization and electric polarization are too small to be used in devices, occur far below room temperature or are too weakly coupled. Even the most promising room-temperature multiferroic, bismuth ferrite ($BiFeO_3$), is intrinsically not ferromagnetic[6].

Mundy and collaborators' work introduces a way to engineer materials that have coupled magnetization and electric polarization. Early attempts to produce such multiferroics focused on bulk synthesis — magnetic and electric moments were brought together in the same unit cell (the smallest periodically repeating structure in a crystal), usually resulting in weak manifestations of multiferroic order[4]. However, spiral-like arrangements of magnetic moments across many unit cells provided a new and general source of such order[7]. A later development was to apply small changes to multiferroics at inter-atomic distances (for example, using external pressure[8]), which could modify the materials' magnetization, polarization or ordering temperature. Finally, moving from bulk materials to thin films of multiferroics had advantageous effects resulting from the limited thickness of the material and the presence of surfaces or interfaces[4].

Building on this earlier work, Mundy and colleagues create a multiferroic that has large magnetization and electric polarization at room temperature, and a strong coupling between the two up to at least 200 kelvin. They achieve this by combining two 'failed' multiferroics — $LuFeO_3$ and $LuFe_2O_4$ — unit cell by unit cell, such that the deficiency of each material is compensated for by the desirable property of the other. $LuFeO_3$ is multiferroic but lacks pronounced magnetization[9], whereas $LuFe_2O_4$ has magnetization but no ferroelectric order[10].

Using a technique called molecular-beam epitaxy, the authors build a film of repeating units that consist of a single layer of $LuFe_2O_4$ and nine layers of $LuFeO_3$ (Fig. 1). The $LuFeO_3$ has a corrugated structure, which acts as a template for the atomic arrangement of $LuFe_2O_4$, allowing the latter material to become ferroelectric. In turn, the multiferroic order of the entire structure is reinforced. The authors show that when an electric field is used to reverse the direction of the polarization, the magnetization direction is also reversed, which suggests that the multiferroic has a strong magnetoelectric coupling.

Such a coupling at the atomic level is reflected in the macroscopic properties of the authors' material. A sharp tip, to which a positive or negative voltage is applied, can be used to draw an electric polarization pattern in the material. The authors show that this pattern is complemented by an identical magnetization pattern, even though a magnetic field was not applied. The magnetization is determined entirely by the sign of the electric voltage, which is exactly the functionality that is required for magnetoelectric devices.

It remains to be seen whether Mundy and colleagues' atomic-template approach can be used to create multiferroics in general. However, their work seems to show that the box of tricks for improving such materials is not yet empty. Multiferroics are now migrating to a wide variety of research disciplines, such as electronics, photonics and even high-energy physics, in which they are studied for properties that are, at best, indirectly related to their multiferroic order[4]. Hence, although they originated as a specialist's topic, multiferroics are now a substantial part of materials research. ■

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GEOLOGY

Evidence of life in Earth's oldest rocks

When did life first arise on Earth? Analysis of ancient rocks in Greenland that contain structures interpreted as bacterial in origin suggest that Earth might have been an abode for life much earlier than previously thought. **SEE LETTER P.535**

ABIGAIL C. ALLWOOD

Did life on this planet begin only after a relatively long planetary evolution, until suitable environments emerged that allowed life to gain a toehold, or was the cradle of life ready and rocking when Earth itself was but an infant? An answer may come from a paper on page 535 by Nutman *et al.*[1] that analysed 3.7-billion-year-old rocks in the Isua Greenstone Belt in Greenland. These are not the kinds of rocks that palaeobiologists would consider a good prospect for signs of life, because they are not sedimentary like those that host most of Earth's fossil record. Rather, they are metamorphic, which means that they have been extensively deformed and altered by heat and pressure during deep burial and are no longer the sedimentary rocks they once were.

However, Nutman and colleagues came across a rarity in the Isua Greenstone Belt. In a small area newly revealed by snow melt, they found relatively well preserved rocks that have survived geological time with some of their original sedimentary attributes intact. In this tiny window into the deep past are subtle geochemical and textural clues to an ancient surface environment that is surprisingly familiar as a habitat for life. Within the rocks can be seen ancient ripple marks and piles of rock fragments deposited during an ancient storm. Combined with seawater-derived mineral chemistry, these features all point to a shallow marine, carbonate, mineral-depositing environment similar to those that have hosted

ALLEN NUTMAN

Figure 1 | A 3.7-billion-year-old rock with signs of associated life. Analysis of ancient rocks by Nutman *et al.*[1] have identified conical stromatolite-like structures (outlines indicated by dotted black lines) that are possible hallmarks of bacterial activity. Scale bar, 4 cm.

abundant biota throughout Earth's history.

In the middle of it all are structures resembling stromatolite*s*: layered structures that form through microbially influenced accretion of sediment. Seeing stromatolites in such a setting would hardly be surprising — if the rocks were half a billion years younger. Fossil stromatolites are familiar to palaeobiologists who study rocks that are around 3.5 billion to 0.5 billion years old, from the long stretch of time when Earth's biosphere was entirely microbial. Modern stromatolites exist in a variety of settings, including shallow marine environments, hydrothermal springs, lakes and even the ice-covered lakes of Antarctica.

The problem is that structures that look similar to stromatolites can form without the action of living organisms, and so the interpretation of stromatolite-like structures has been notoriously difficult in Earth's oldest rocks. The older the rocks, the more scarce, poorly preserved and difficult to interpret the stromatolites become. The approximately 3.5-billion-year-old stromatolites in sedimentary rocks of Western Australia[2] are currently regarded as the oldest evidence of life on Earth, and pushing the record further back in time had seemed unlikely because there is almost no rock remaining from the earliest period of Earth's history.

The only older rocks on Earth are metamorphic rocks such as those of Isua — a tiny, tortured remnant of Earth in its infancy. Proof of life seemed impossible in the palaeontological haze of these heavily deformed and altered rocks, although scientists have been searching for clues for many years. Until now, possible chemical vestiges of life have provided tantalizing clues[3,4], but these are controversial. The discovery by Nutman and colleagues will no doubt also spark controversy, but the significance of their work is that it is an entirely new form of possible biosignature that adds morphology and texture to the gamut of chemical clues in rocks of such astounding antiquity.

The case for a biological origin of the Greenland structures is limited by the information available in the tiny outcrop. There are very few structures available to study, and although the overall shape of the Isua structures has survived, textural and chemical details within them have degraded substantially. There are no organic or cellular remains. Despite these limitations, there are important clues that the structures are the product of microbial 'tinkering' in the sedimentary environment.

The structures have an overall conical shape and internal finely layered texture (Fig. 1). Sedimentary layers in between the cones look like sand piled up against the sides of the structures, indicating sediment grains that have accumulated in low areas between high-standing structures on the sea floor. These observations of shape and texture mean that the structures are not simply folded rock. In addition, the concentrations of titanium and potassium are higher in the structures than between them, indicating that a different type of sediment accumulated locally within the structure.

The structures are a beacon of localized modification of sediment deposition. Such contrasting composition and texture within the bounds of conical morphology are fairly credible hallmarks of microbial activity. Microbes might have mediated deposition of precipitated minerals on the structures against an abiotic background of particulate sediment deposition.

If these are really the figurative tombstones of our earliest ancestors, the implications are staggering. Earth's surface 3.7 billion years ago was a tumultuous place, bombarded by asteroids and still in its formative stages. If life could find a foothold here, and leave such an imprint that vestiges exist even though only a minuscule sliver of metamorphic rock is all that remains from that time, then life is not a fussy, reluctant and unlikely thing. Give life half an opportunity and it'll run with it.

Our understanding of the nature of life in the Universe is shaped by how long it took for Earth to establish the planetary conditions for life. Suddenly, Mars may look even more promising than before as a potential abode for past life. A plethora of Mars missions has shown that around the time that the Isua rocks were forming, Mars did not look too different from Earth from a habitability perspective, with standing bodies of water at the surface. Moreover, NASA's Curiosity rover found rocks formed in a body of chemically benign water[5] of comparable habitability to those that nurtured life on early Earth. But as habitable as those waters may have been, the question is, did they dry up well before any ingredients for life could give rise to living organisms? Given that the era of the late heavy asteroid bombardment in the Solar System ended just geological moments before (0.1 billion years earlier), was that enough time for life to emerge and make an appearance in the fossil record? We have only one example of life with which to address this. If the Isua structures are indeed microbial, then that example says 'yes'. ■

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