GEOLOGY

Proposed early signs of life not set in stone

Efforts to find early traces of life on Earth often focus on structures in ancient rocks, called stromatolites, that formed by microbial activity. One of the oldest proposed stromatolite discoveries has now been questioned. **SEE LETTER P.241**

MARK A. VAN ZUILEN

In 2016, Nutman *et al.*[1] reported the discovery of cone-shaped structures in 3.7-billion-year-old rocks in the Isua Supracrustal Belt, Greenland, that they identified as being stromatolites — structures that arise as a result of the presence of water-dwelling microorganisms. Previously, the earliest known stromatolites were reported to be those in 3.45-billion-year-old rocks in Australia[2]. Being able to accurately date the first signs of the emergence of life has important implications for understanding how life on Earth evolved. However, on page 241, Allwood *et al.*[3] now report their own independent analysis of these ancient rocks in Greenland, and argue that, in this particular case, the structures that Nutman and colleagues interpreted to be stromatolites instead arose by non-biological processes. This finding shows that a natural process that does not require any input from a living organism can mimic the formation of a structure that normally counts as a strong indication of previous biological activity.

Stromatolites have a laminated (layered) structure (Fig. 1a), formed by sediment trapping, binding and mineral deposition within microbial communities[4]. They can form in a range of shapes: conical, columnar or dome-like. Whether microorganisms have a role in the formation of certain types of stromatolite shape is unclear. There are models for how stromatolites can arise without input from a living organism[5], and various laminated structures that occur naturally without requiring any biological activity can be mistaken for stromatolites, such as silica deposits around geysers[4] or laminated carbonate crusts that form when water evaporates[6]. In well-preserved stromatolite specimens, a biological contribution to such structures can often be confirmed by the presence of complex branching, intricate laminar textures, cavities or, in some rare instances, preserved microfossils and moulds[1,7].

Conical stromatolites are a special case, however, because their shape alone can be sufficient to identify them as arising from biological processes. Their steep laminar slopes cannot arise from non-biological processes such as sedimentation or mineral precipitation. From the analysis of present-day stromatolites and laboratory experiments, it is known that conical stromatolites are the preserved remains of motile microbial communities that form vertical cones[1,8], and that this cone structure can be preserved by the trapping, binding and precipitation of non-biological material.

When stromatolite structures in the early rock record (which often have a centimetre-scale size) are analysed, their intricate laminations, textures and composition have usually already been partially or completely destroyed through a process called metamorphism, in which rock structure is substantially altered and deformed by heat and pressure, often when the rock is buried deep underground. Stromatolite shape therefore becomes the main way to identify signs of biological input in ancient stromatolite-like structures. In the strongly metamorphosed Early Archean rock record (formed around 3.2 billion to 4 billion years ago), the identification of stromatolites arising from biological processes thus becomes particularly difficult.

However, a convincing case was made for the presence of such biologically arising stromatolites in 3.45-billion-year-old rocks in Australia[2]. In addition to conical stromatolites, six other stromatolite shapes were found in the samples there; they all existed in specific parts of what was considered to be an ancient, shallow, marine, carbonate-rich environment. This diversity in stromatolite shape convincingly excluded a uniform non-biological formation process and suggested that ecological controls governed the overall stromatolite growth. Evidence of such a clearly defined ancient environmental setting is difficult to find in any older metamorphosed rock on Earth.

Nutman and colleagues reported the identification of ancient stromatolites in a newly described rock outcrop in Greenland, and also interpreted these structures as

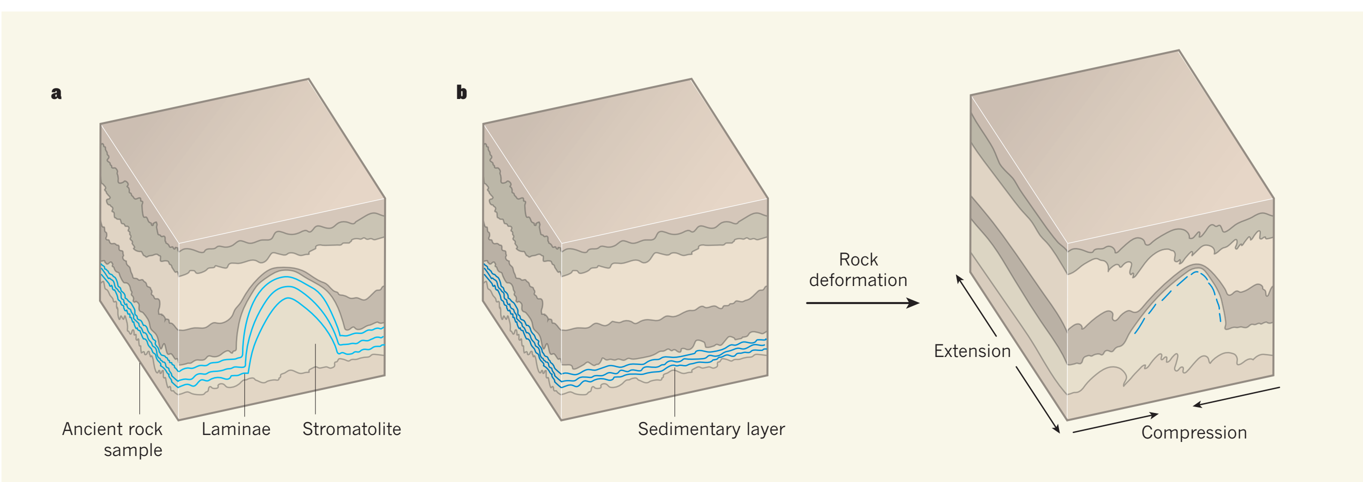

Figure 1 | Layered structures in ancient rocks. a, Conical structures that have internal layers (laminae) and are found in ancient rocks have been identified as a type of stromatolite structure — specifically, a stromatolite that forms as the result of the action of water-dwelling microorganisms. Such stromatolites, which typically have a size on a centimetre scale in these ancient rocks, have been cited as providing early evidence of life on Earth. However, the positive identification of stromatolites can be controversial, given that ancient rocks have been subject to deformations over time. **b**, Processes of rock extension and compression might create cone-like structures that look like stromatolites, and the deformation and replacement of layers of sedimentary rock might generate structures that look similar to stromatolite laminae that arise from biological activity. Allwood *et al.*[3] argue that structures previously identified[1] as stromatolites in 3.7-billion-year-old rocks in Greenland might have formed through such processes.

having arisen in an ancient, shallow, marine environment, on the basis of the textures of interlayered sediments and the distribution patterns of rare-earth elements. Such patterns have previously been interpreted to indicate the deposition of carbonate minerals from seawater[9]. The entire region in which these rocks are located was previously found to be metamorphosed rock that had been subjected to high temperature and pressure[10]. In the Australian rocks with ancient stromatolites[2], laminations are clearly visible; in the Greenland samples, however, the proposed laminations are less clear, and the degree of metamorphism is higher than that of the Australian rocks.

The lack of unambiguous, well-preserved laminated structures would preclude the identification of any intricate original textures that might indicate biological input to the structure. However, Nutman *et al*. identified remnant laminations and conical stromatolite-like shapes that they consistently interpreted as being microbially generated structures. Apart from these conical shapes, Nutman and co-workers also identified some dome-like shapes of proposed stromatolites. However, they did not find the diversity of stromatolite forms described in the Australian study. With few specimens, and a complex history of rock metamorphism, this raised the question of whether non-biological processes might have generated the dome-like and conical shapes in these ancient Greenland rocks.

Allwood *et al*. argue that the stromatolite-like shapes observed at the Greenland site arise from rock deformation. When they compared the front and side profiles of rock samples that contained stromatolite-like structures, they noted that one side shows a compressional deformation whereas the other shows an extensional deformation. This indicates that the structures are not stromatolite cones, but elongated ridges (Fig. 1b). Furthermore, the folding direction of the stromatolite ridges is parallel to the orientation of pressure-induced mineral textures on smaller scales in the same rock. These observations provide strong evidence for physical rock deformation and therefore offer a non-biological explanation for the observed structures.

In addition, Allwood and colleagues argue that the rock itself did not form in a shallow marine setting, but instead arose when carbonate minerals crystallized from fluids that circulated through an existing rock. If this is true, the observed dome-like and conical structures are definitely not stromatolites. Allwood *et al*. used a trace-element analysis technique that has high spatial resolution to show that the internal laminations in the conical structures represent the specific replacement of a type of silicate rock by fluid-derived carbonate minerals. The authors found that the rare-earth-element signal associated with the presence of seawater seems to be mainly concentrated in mica minerals in the rock, but is also present in the carbonate areas. Allwood and co-workers suggest that this is possible if the fluids from which the minerals crystallized during later stages of the rock's existence ultimately derived from seawater as well. So although Nutman *et al*.[1] and Allwood *et al*.[2] report similar patterns of rare-earth elements in the rocks, they offer diverging interpretations of what these patterns mean. This highlights the complexities in discerning primary chemical signatures in such highly deformed rocks.

The biological input to ancient stromatolites is a long-standing controversy. The rocky outcrop on Greenland has not been discovered for long, and few researchers have studied this rock in relation to its geological surroundings. Future research might lead to a firm understanding of the primary versus secondary processes that shaped this rock. Clearly, the work of both Nutman *et al*. and Allwood *et al*. will form the basis for the interpretation of other possible stromatolites in the ancient rock record. ■

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1. Nutman, A. P., Bennett, V. C., Friend, C. R. L., Van Kranendonk, M. J. & Chivas, A. R. *Nature* **537**, 535–538 (2016).
2. Allwood, A. C., Walter, M. R., Kamber, B. S., Marshall, C. P. & Burch, I. W. *Nature* **441**, 714–718 (2006).
3. Allwood, A. C., Rosing, M. T., Flannery, D. T., Hurowitz, J. A. & Heirwegh, C. M. *Nature* **563**, 241–244 (2018).
4. Walter, M. R. (ed.) *Stromatolites. Developments in Sedimentology 20* (Elsevier, 1976).
5. Grotzinger, J. P. & Rothman, D. H. *Nature* **383**, 423–425 (1996).
6. Pope, M. C., Grotzinger, J. P. & Schreiber, B. C. *J. Sediment. Res.* **70**, 1139–1151 (2000).
7. Grotzinger, J. P. & Knoll, A. H. *Annu. Rev. Earth Planet. Sci.* **27**, 313–358 (1999).
8. Bosak, T. *et al. Geobiology* **10**, 384–401 (2012).
9. Bolhar, R., Kamber, B. S., Moorbath, S., Fedo, C. M. & Whitehouse, M. J. *Earth Planet. Sci. Lett.* **222**, 43–60 (2004).
10. Boak, J. L. & Dymek, R. F. *Earth Planet. Sci. Lett.* **59**, 155–176 (1982).

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QUANTUM PHYSICS

Quenching our thirst for universality

Understanding the dynamics of quantum systems far from equilibrium is one of the most pressing issues in physics. Three experiments based on ultracold atomic systems provide a major step forward. **See Letters p.217, p.221 & p.225**

MICHAEL KOLODRUBETZ

Although we live in a world of constant motion, physicists have focused largely on systems in or near equilibrium. In the past few decades, interest in non-equilibrium systems has increased, spurred by developments that are taking quantum mechanics from fundamental science to practical technology. Physicists are therefore tasked with an important question: what organizing principles do non-equilibrium quantum systems obey? On pages 217, 221 and 225, respectively, Prüfer *et al.*[1], Eigen *et al.*[2] and Erne *et al.*[3] report experiments that provide a partial answer to this question. The studies show, for the first time, that ultracold atomic systems far from equilibrium exhibit universality, in which measurable experimental properties become independent of microscopic details.

The researchers use low-density gases of rubidium[1,3] or potassium[2] atoms that are cooled to temperatures close to absolute zero. At sufficiently low temperatures, these atoms begin to show quantum-mechanical behaviour, forming a macroscopic quantum state known as a Bose–Einstein condensate. Starting from either such a condensate[1,2] or an uncondensed gas[3], the researchers rapidly change experimental parameters — a process known as a quench. Rather like a cartoon character that looks down to discover they have accidentally run off a cliff, the quench initiates far-from-equilibrium dynamics.

Such quenches are relatively easy to realize, but what the researchers see next is surprising. Consider all the variables that can be associated with a given experiment: power fluctuations of lasers, variations in the lab's temperature, microscopic details of atomic interactions, and so on. The researchers find that the dynamics of their experiments, despite involving strongly interacting atoms far from equilibrium, become independent of these variables.

Eigen *et al.* accomplish this universality by carefully eliminating all but two of the variables in their experiment: the density of the atomic gas and the scattering length. The latter describes how closely two atoms can pass without interacting. The authors then go one step further and eliminate the dependence of the scattering length on variables in a clever way.

First, to prepare the initial condensate, the