successful synthesis has been previously described. Tani and Stoltz[1] designed their approach so as to avoid aqueous conditions that would promote decomposition of the product. Accordingly, they focused on a route involving a molecular rearrangement, known as the Schmidt–Aubé reaction (Fig. 2), which is carried out in the absence of hydrolytic reagents. Because 2-quinuclidone is a base, and the reaction requires an acid, the product is obtained as a salt.

The authors outline in detail the studies leading to the optimal reaction conditions, and describe the spectroscopic and chemical properties of the product. An X-ray analysis confirmed the highly twisted nature of the amide. Tani and Stoltz's imaginative, unambiguous synthesis of 2-quinuclidone provides important confirmation of earlier predictions regarding its reactivity. This work will provide an invaluable insight into the nature of amides, and concludes a synthetic journey that began nearly 70 years ago. ■

Harry H. Wasserman is in the Department of Chemistry, Yale University, 225 Prospect Street, New Haven, Connecticut 06511, USA.
e-mail: harry.wasserman@yale.edu

1. Tani, K. & Stoltz, B. M. *Nature* **441,** 731–734 (2006).
2. Johnson, J. R., Woodward, R. B. & Robinson, R. in *The Chemistry of Penicillin* (eds Clark, H. T., Johnson, J. R. & Robinson, R.) 440–454 (Princeton Univ. Press, 1949).
3. Wasserman, H. H. *Heterocycles* **7,** 1–15 (1977).

PALAEONTOLOGY

Respect for stromatolites

Stanley M. Awramik

Is it time to stop worrying over whether the ancient structures called stromatolites are of microbial origin? 'Yes' is the answer to emerge from field and lab work on a 3,430-million-year-old marine ecosystem.

Writing in these pages earlier this year[1], Don E. Canfield wrote of an early Earth teeming with a variety of microorganisms. Stromatolites were mentioned as among the possible evidence of microbial life existing 3.5 billion years ago, but only as "probably" of biological origin. What is it about stromatolites that engenders caution when interpreting them as fossils? In their paper on page 714 of this issue[2], Allwood and colleagues provide good reasons to suppose that such reservations really aren't necessary.

Part of the caution in interpreting stromatolites stems from their nature. They are laminated sedimentary structures, with shapes that range from simple domes to elaborately branched columns, and they range from the millimetre scale to more than 10 metres in size. Modern analogues are known where photosynthetic microorganisms — principally cyanobacteria — are responsible for forming them. Only rarely are microfossils found in ancient examples, but many researchers consider stromatolites to be the products of microbe–sediment interaction, and so to be fossils[3].

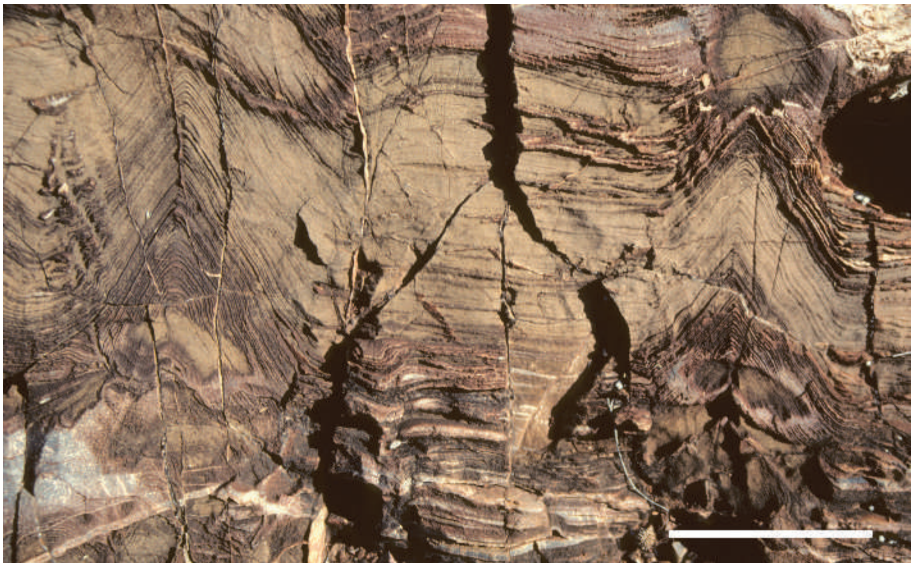
Confidence in the interpretation of stromatolites as biogenic structures was dealt a serious blow with the proposal that stromatolite structure could theoretically result from abiotic processes in sediment accumulation[4]. To make matters more bewildering, the very definition of stromatolite is contentious[3,5]. So there has been a long-standing debate about whether these laminated sedimentary structures are indeed indicators of ancient microbial life[5] — a debate that has intensified with for evidence of life on other planets, and so to the earliest record of life on Earth[6].

This is the background for Allwood and colleagues' report[2]. They investigated the relationship of stromatolite shape to depositional environment across more than 10 km of nearly continuous outcrop of the 3,430-million-year-old Strelley Pool Chert in Western Australia (Fig. 1). Rather than wade through long philosophical and semantic arguments (theirs are brief and to the point), Allwood *et al.* wade through the evidence. They conclude that the stromatolites are biogenic in origin, and were formed on a 'carbonate platform' — a broad, relatively flat expanse of carbonate sediments — that was subject to the influence of tides but generally remained submerged. Sea-level rise (transgression) was a major feature of this environment, but small fluctuations — transgressions and regressions (sea-level fall) — also occurred. At times, regression and restricted circulation with the open sea took place, leading to evaporation of water and the formation of evaporite minerals.

Allwood *et al.*[2] recognize seven distinct stromatolite facies (sedimentary rocks with distinguishing characteristics that correspond to the conditions of deposition). They identify distinctive stromatolite shapes in each facies, and the supplementary material for their paper presents a dazzling array of images and information. This is not the first report on stromatolites from this formation[7,8] and it probably won't be the last.

What is so striking about their scenario is that it is so 'normal' — in the sense that transgressive, tidally influenced carbonate platforms with stromatolites are common in the geological record[9,10]. Stromatolites are also known to form in similar environments today. Given this context, and combined with other features, Allwood *et al.*[2] argue that the most likely interpretation is that the stromatolites are biogenic. Among those features are the seven distinct stromatolite types and their facies (see Fig. 1 of the paper[2] on page 716); the geometries of the stromatolites; and the fine details of the sedimentary textures of the stromatolites themselves and the regions between them (the 'interspace' areas).

The sediment-grain compositions and textures of the stromatolites cannot be explained exclusively by mechanical processes. For example, the laminae of the 'complex cone' structures are not of the equal thickness that would indicate abiotic precipitation. And the sedimentology of the cones differs from that



S. M. AWRAMIK

Figure 1 | Structure in the Strelley Pool Chert, Western Australia. These and many other forms are the subject of Allwood and colleagues' analyses[2], from which they conclude that microorganisms were

S. M. AWRAMIK

Figure 2 | Cutting through the complexities of stromatolites. Modern stromatolites — such as those shown here at Lee Stocking Island, Bahamas, as well as from places such as Shark Bay, Western Australia — provide essential comparisons for interpreting analogues from earlier in Earth's history.

of interspace areas: sediment in the interspace area has a vertical gradation in grain size, indicating the operation of mechanical processes, whereas grains in the laminae are not graded. Rather, these grains evidently accumulated on the steep slopes of the cones[8], suggesting that there was some mechanism for trapping and binding them, like that found in microbially influenced sediment accretion. Allwood *et al.*[2] also point out that there are no known abiotic processes that could produce the facies-related stromatolites persistently and sometimes simultaneously on the carbonate platform.

No mechanical processes have been identified that form coniform stromatolites[11]. But we do know of modern coniform stromatolites that are built by microorganisms. Growth experiments[12] on the microbes that build the modern cones indicate that the cone shape results from gliding by a photosynthetic filamentous microorganism (a cyanobacterium). Horizontally gliding filaments interfere with one another, form a clump, and other gliding filaments encounter the clump. These are deflected upwards towards the light and a cone results. Such structures could become fossilized by trapping and binding of sediment and/or by precipitation of mineral matter while the cones are growing. Coniform stromatolites make up about 44% of ten types of stromatolite recognized from 35 geological units ranging from 3.5 billion to 2.5 billion years in age[13].

Hydrothermal environments have been favoured as the most likely places where life existed on the early Earth[14]. But the setting for the stromatolites of the Strelley Pool Chert indicates that microorganisms were adapted to and thriving in shallow marine environments, and that it is not necessary to invoke the presence of hydrothermal activity. The same conclusion applies to the microbial mats from the 3,416-million-year-old Buck Reef Chert in South Africa[15].

in environments that we know (carbonate platforms) and produced structures that we recognize (stromatolites; Fig. 2). Why do we have to demand evidence that is more absolute? The prudent use of well-understood ancient analogues and modern examples to interpret stromatolites is a powerful scientific tool[5]. Actualism has served palaeontology well.

The late American comedian Rodney Dangerfield[16] had a perpetual complaint: "I don't get no respect." The status of stromatolites as indicators of early life on Earth has suffered from a similar attitude. The work of Allwood *et al.*[2] will surely help to change that. ■

Stanley M. Awramik is in the Department of Earth Science, University of California, Santa Barbara, California 93106, USA.
e-mail: awramik@geol.ucsb.edu

1. Canfield, D. E. *Nature* **440,** 426–427 (2006).
2. Allwood, A. C., Walter, M. R., Kamber, B. S., Marshall, C. P. & Burch, I. W. *Nature* **441,** 714–718 (2006).
3. Riding, R. *Lethaia* **32,** 321–330 (1999).
4. Grotzinger, J. P. & Rothman, D. H. *Nature* **383,** 423–425 (1996).
5. Awramik, S. M. & Grey, K. *Proc. SPIE* **5906,** 59060P1–5906P9; doi:10.1117/12.625556 (2005).
6. Brasier, M., Green, O., Lindsay, J. & Steele, A. *Origins Life Evol. Biosphere* **34,** 257–269 (2004).
7. Lowe, D. R. *Nature* **284,** 441–443 (1980).
8. Hofmann, H. J., Grey, K., Hickman, A. H. & Thorpe, R. I. *Geol. Soc. Am. Bull.* **111,** 1256–1262 (1999).
9. Loucks, R. G. & Sarg, J. F. (eds) *Carbonate Sequence Stratigraphy* (Am. Assoc. Petrol. Geol., Mem. 57, 1993).
10. Grotzinger, J. P. & James, N. P. (eds) *Carbonate Sedimentation and Diagenesis in the Evolving Precambrian World* (Soc. Econ. Geol. Paleontol., Spec. Publ. 67, 2000).
11. Batchelor, M. T., Burne, R. V., Henry, B. I. & Slatyer, T. *Physica A* **350,** 6–11 (2005).
12. Walter, M. R., Bauld, J. & Brock, T. D. in *Stromatolites* (ed. Walter, M. R.) 273–310 (Elsevier, Amsterdam, 1976).
13. Hofmann, H. J. in *Microbial Sediments* (eds Riding, R. & Awramik, S. M.) 315–327 (Springer, Berlin, 2000).
14. Lindsay, J. F. *et al. Precamb. Res.* **143,** 1–22 (2005).
15. Tice, M. M. & Lowe, D. R. *Nature* **431,** 549–552 (2004).
16. http://en.wikipedia.org/wiki/Rodney_Dangerfield

PHOTONICS

Transparency on an optical chip

Robert W. Boyd and Daniel J. Gauthier

A two-laser trick that renders opaque media transparent can be achieved in systems of tiny optical resonators — with potentially profound consequences for optical communication and information processing.

The discovery of electromagnetically induced transparency (EIT) — an unusual effect that occurs when two laser beams interact within an optical material — and the use of novel techniques to fabricate ever smaller structures to control light have been recent exciting developments in optical physics. Writing in *Physical Review Letters*, Xu *et al.*[1] neatly combine the two, demonstrating an on-chip, all-optical analogue of EIT based on the response of coupled optical microresonators. The result may open up untrodden pathways in photonics, offering prospects of smaller, more efficient devices for the manipulation and transmission of light.

As originally implemented[2], EIT involves the interaction of laser light with a collection of atoms. It relies on the fact that when an incident photon has a 'resonant' energy equal to the difference in the energies of two levels of an atom, the photon can be absorbed by that atom and its energy used to excite the atom into the higher energy state. When two separate laser fields drive two such atomic transitions that share the same upper level (Fig. 1a, overleaf), destructive interference between the pathways connecting the upper level with the lower levels allows the quantum-mechanical probability that the atom is in the upper level to vanish. As there are no atoms in the upper level, there has been no absorption of the applied fields. The atom is thereby rendered extremely narrow frequency range (Fig. 1b). This interference process has analogies in classical physics, where the coupling between two oscillators results in a reduction in the amplitude of their oscillation[3].

The EIT phenomenon can be used to greatly strengthen nonlinear optical effects — such as the dependence of a material's refractive index on the intensity of the incident light — on which the operation of many photonic devices depend. In general, such nonlinear effects can be achieved by using as the source of the applied field a frequency-tunable laser tuned close to the resonance frequency of an atomic transition. Unfortunately, absorption of the laser light also increases at exactly these frequencies, and this effect undoes much of the benefit of working close to resonance. With two laser sources, however, quantum interference can be used to ensure that atomic absorption is eliminated, while retaining a large nonlinear response.

A downside of the 'traditional', atomic EIT effect — and more generally of nonlinear optics based on atomic resonance — is that it can be implemented only for light in a very small range of frequencies near fixed atomic transitions. An alternative way of achieving the transmission characteristics of EIT, as investigated by Xu and colleagues[1], uses small devices called optical microresonators[4] (Fig. 1c), whose resonance frequency depends on their physical size. In