FORUM Palaeontology

Fossils come in to land

Fossils found in rocks of the Ediacaran period in Australia have been previously characterized as early marine organisms. But a report suggests that these rocks are fossilized soils. So did some of these Ediacaran organisms in fact live on land, like lichens? A palaeontologist and a geologist weigh up the evidence. SEE LETTER P.89

THE PAPER IN BRIEF

- The Ediacaran period, 635 million to 542 million years ago, immediately predates the Cambrian period, which saw an evolutionary explosion that led to all modern animal phyla.
- Fossils from an Ediacaran geological formation in South Australia have been classified as invertebrates, protists or fungi, but they have invariably been thought of as being marine.
- Retallack proposes, in a paper published in this issue (page 89)[1], that the Ediacara Member contains fossilized soils (palaeosols)*.
- The presence of palaeosols suggests that some of the fossils within them may have been lichen-like organisms or microbial colonies that lived on land, rather than in the ocean.

Muddying the waters

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Fossils in the Ediacara Member in South Australia have been traditionally interpreted as representatives of ancestral marine organisms[2]. But, breaking away from this tradition and pursuing his own radical interpretation[3,4], Retallack[1] now proposes that these fossiliferous beds are palaeosols and that some Ediacaran fossils are soil lichens or colonies of soil microbes. These propositions would represent a fundamental change in our picture of evolution, but they will probably face continuing scepticism because the evidence is unconvincing.

Definitive identification of palaeosols in the Ediacara Member is a challenge, because this unit was deposited before land plants arose and it thus lacks features that are diagnostic of ancient soils, such as traces of plant roots. But Retallack cites a host of observations as evidence that the fossiliferous Ediacara Member originated from soil formation (pedogenesis): its reddish colour, its elemental and stable-isotopic geochemistry, patterns of surface disruption, and the presence of sand crystals of gypsum and nodules of carbonate.

However, the evidence is ambiguous. For example, the reddish colour and depletion of certain elements in the Ediacara Member could be a result of weathering that occurred during the Cenozoic era (from 65 million years ago to the present), rather than resulting from chemical weathering of the rocks through pedogenesis during the Ediacaran period[5]. Retallack counters that Cenozoic weathering would have produced continuously reddish strata, rather than the observed alternation of grey and red beds, but he fails to recognize that weathering colours can vary with lithological characteristics of the rocks (such as mineralogical composition and permeability). In addition, carbonate nodules and sand crystals of gypsum are common features of marine sediments, and the isotope signatures of carbonate nodules in the Ediacara Member can be accounted for by post-depositional alterations that do not involve pedogenic processes.

> **"This ambiguous evidence for pedogenesis is outweighed by compelling evidence for the marine origin of the Ediacara Member."**

Retallack further illustrates his argument for palaeosols with examples of large-scale disruption structures characteristic of soils (see Fig. 2b of the paper[1]), but such structures are intriguingly similar to slumps or load structures resulting from subaqueous and post-depositional movement of sediments. He also depicts small-scale disruption structures, which he interprets as having been caused by millimetre-sized tubules that might be the fossilized remains of bacterial filaments, lichen rhizines (root-like filaments) or fungal hyphae (see Fig. 2c–g of the paper[1]). But I find this interpretation dubious, because the tubules are too irregular to be confidently interpreted as being derived from microbes.

In my opinion, this ambiguous evidence for pedogenesis is outweighed by compelling evidence for the marine (or at least subaqueous) origin of the Ediacara Member. For example, benthic Ediacaran organisms (those that lived on or within sediments), such as *Cyclomedusa davidi* and *Dickinsonia costata,* are preserved *in situ* on rippled bedding surfaces[5] (Fig. 1). In addition, some Ediacaran fossils show holdfasts (root-like structures) that were dragged in the same direction as the alignment of attached stalks[6]. These features could not have formed without the action of waves or currents. And detailed sedimentological analysis has revealed a suite of features characteristic of subaqueous deposition[5], including ripple marks and current lineations.

A palaeosol interpretation leads Retallack to reinterpret fossils in the Ediacara Member as the remains of soil lichens, microbial colonies, fungi, slime-mould trails or casts of needle ice (which forms in frozen soil). However, many Ediacaran species in Australia are also found worldwide in unambiguously marine formations, such as black shales and limestones. Furthermore, the Ediacaran fossil *Dickinsonia* shows evidence of intermittent locomotion — but lichen do not move. The Ediacaran fossil *Radulichnus,* interpreted as casts of needle ice by Retallack[1] but as traces of grazing organisms by others, has fanning sets of parallel scratches, an arrangement that cannot be explained by needle ice. And although Retallack proposes that Ediacaran trace fossils are trails left by land-cruising slugs or aggregating slime moulds, these organisms could not have made the burrows that are clearly visible in the Ediacara Member.

On a positive note, Retallack's persistent pursuit of the idea of soils and lichens does motivate us to rethink the possibility that lichens, whether terrestrial or marine[7], might have existed at this early time, and played a part in regulating the Ediacaran Earth before the rise of vascular plants. But we need

*This article and the paper under discussion[1] were published online on 12 December 2012.

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Figure 1 | Sand or soil. The picture shows Ediacaran fossils (*Dickinsonia costata*) on a rippled surface, found in the Ediacara Member in South Australia. Previous interpretations suggest that these fossils represent marine organisms that lived on the sea floor[5], but Retallack[1] proposes that they were land dwellers.

clearer evidence before we should consider redrawing the timeline of life's transition from sea to land.

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Not all at sea

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The last 700 million years of the Precambrian eon was apparently a time of major sea-level changes in which continental margins were alternately inundated and then left exposed to land-surface erosion. Ancient soils were being eroded into the sea[8], and some should have been preserved as palaeosols similar to those in strata from more recent times. But so far, reports of late Precambrian examples are lacking. This may simply reflect the difficulty of recognizing soil strata without the root traces so obvious in much younger rocks. Other diagnostic features are more subtle and are generally recognized only by those experienced in studying palaeosols. Retallack is one such specialist, and he is well positioned to argue for the existence of soil-inhabiting Ediacaran organisms.

Retallack has long pondered the nature of Ediacaran organisms, and controversially proposed that they were actually not animals but large lichens[3]. This heterodox interpretation would be greatly strengthened if he really has found examples that lived on land. Whether animal or lichen, the discovery would indicate that some organisms mastered the transition from marine to non-marine life much earlier than currently thought — or even support the possibility that the transition went the other way, to ultimately account for the Cambrian explosion in the sea[9].

So how strong are his arguments? Interpreting ancient depositional environments is a tricky business, and a stratigraphic layer without telltale root fossils may be a palaeosol only in the eye of the beholder. For example, what Retallack suggests are geological relics of soil deformation have been suggested by others to be water-escape features[10]. His cogent arguments that the red colour represents Precambrian weathering will be resisted by those familiar with the extensive red colour imparted to Australian rocks during modern weathering. In the absence of comparisons with Ediacaran examples that Retallack accepts as marine, it is debatable whether a lack of non-overlapping specimens really precludes wash-ups on a shore, as he suggests. Furthermore, the isotope data for the carbonate nodules that Retallack claims represent subaerial exposure are also compatible with coastal recharging of rainwater into subsurface aquifers known commonly to extend far offshore[11]. And finally, it is difficult to distinguish the sedimentary structures that the author interprets as sand deposited in a terrestrial valley from what could belong to a submarine canyon, as has been proposed[5].

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As is usual in sedimentology, observations can be construed in alternative ways, and interpretations for these strata have historically covered the gamut of geological possibilities — from lacustrine to lagoonal, coastal and open marine. It is appropriate that interpretations change or are superseded with the arrival of new observations, and that is why this publication is fascinating and timely and should be considered seriously. Although Retallack's ideas are at odds with the accepted dogma, these do not need to be mutually exclusive. Why should it not be possible that some Ediacaran organisms lived on land, even if most of the other sites in which they have been found are interpreted as marine? There is still uncertainty regarding exactly what kind of organisms they were, so eliminating a possible habitat on the basis of whether or not they are animals is unwarranted. Retallack considers new data and observations and provides comprehensive reasoning for each of his points. His considered case means that researchers sceptical of his interpretations will need to become experts in palaeosol characteristics to mount convincing counter-arguments.

The search for late Precambrian biological evolution in the non-marine realm is an exciting new frontier, especially considering carbon-isotope data that probably indicate a late Precambrian greening of land surfaces[12]. Ediacaran organisms living in soils would be further evidence that land areas in this interval of Earth's early history were not biologically barren surfaces as is commonly assumed. We were not there when all this happened and will never know for certain what actually happened when. So I say, until the forensic evidence for Ediacaran habitats becomes strongly compelling one way or the other, let multiple hypotheses thrive! ■

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1. Retallack, G. J. *Nature* **493,** 89–92 (2013).
2. Xiao, S. & Laflamme, M. *Trends Ecol. Evol.* **24,** 31–40 (2009).
3. Retallack, G. J. *Paleobiology* **20,** 523–544 (1994).
4. Retallack, G. J. *Sedimentology* **59,** 1208–1236 (2012).
5. Gehling, J. G. *Precambr. Res.* **100,** 65–95 (2000).
6. Tarhan, L. G., Droser, M. L. & Gehling, J. G. *Palaios* **25,** 823–830 (2010).
7. Yuan, X., Xiao, S. & Taylor, T. N. *Science* **308,** 1017–1020 (2005).
8. Kennedy, M., Droser, M., Mayer, L. M., Pevear, D. & Mrofka, D. *Science* **311,** 1446–1449 (2006).
9. Knauth, L. P. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **219,** 53–69 (2005).
10. Callow, R. H. T., Brasier, M. D. & McIlroy, D. *Sedimentology* http://dx.doi.org/10.1111/j.1365-3091.2012.01363.x (2012).
11. Hathaway, J. C. *et al. Science* **206,** 515–527 (1979).
12. Knauth, L. P. & Kennedy, M. J. *Nature* **460,** 728–732 (2009).