



DISCUSSION

REPLY TO COMMENTS ON RETALLACK 2011: PROBLEMATIC MEGAFOSSILS IN CAMBRIAN PALAEOOLS OF SOUTH AUSTRALIA

by GREGORY J. RETALLACK

Department of Geological Sciences, University of Oregon, Eugene, OR 97403, USA; e-mail: gregr@uoregon.edu

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JAGO *et al.* (2012) regard problematic fossils described by Retallack (2011) as dubiofossils or pseudofossils from modern weathering, yet fail to propose a specific plausible model for formation of the disputed fossils in a weathering profile. Nevertheless, their comments are helpful for many reasons. First, they emphasize the problematic nature of the fossils, which were formally named to attract additional attention. Second, they have prepared colour illustrations of these green and red fossils to supplement the original black and white versions (although only a tiny corner of the originally arrowed fossil is seen in their panel C, which is centred on an unnamed mottle). Third, two authorities on trilobites (Jago and Paterson), after close inspection of the type material, find no similarity between *Erytholus* and enrolled trilobites, a conclusion shared by Retallack (2011). Fourth, an expert on Ediacaran fossils (Gehling) finds little similarity between *Erytholus* and *Ernietta* or *Pambikalbae*, another conclusion of Retallack (2011). Fifth, they allow that the Cambrian Lake Frome Group includes palaeosols (Retallack 2008), as also proposed by Stock (1974) and Moore (1990). Sixth, they highlight comparisons between Ediacaran and the Cambrian fossils and palaeosols, one of the aims of Retallack (2011). Seventh, they allow me to affirm the orientations of the fossils which were either crack-out specimens from outcrop, or slabs and thin sections oriented (and illustrated) vertical to bedding (Retallack 2008, 2011). Jago *et al.* (2012) were evidently unfamiliar with orientation markings used on these irregular and massive samples of palaeosols, which are marked by a circle drawn in felt pen on the upper side to define a plane parallel to regional bedding (Retallack 2001).

The main claim of Jago *et al.* (2012) is that fossils named by Retallack (2011) lack regularity of form as a criterion of biogenicity. A more comprehensive list of criteria for assessing biogenicity of Precambrian proble-

matica (from Hoffman 2004) is as follows: (1) known provenance, (2) plausible environment for life, (3) same age as the rock, (4) plausible composition, (5) taphonomic series, (6) repeated complexity. All six criteria are addressed in the following paragraphs, with specific reference to the disputed Cambrian fossils of South Australia. Few of these criteria can be evaluated from a handful of holotypes deposited in a museum collection as a standard of comparison for future collections.

Retallack (2011) provided stratigraphic sections and locality photographs to specify the exact layers from which the described fossils were found within a long sequence of palaeosols, palaeochannels, tidal deposits, and marine shales and limestones (documented by Retallack 2008). The rocks with disputed fossils were not picked up from the surface as implied by Jago *et al.* (2012). All the fossils reported were quarried from palaeosol outcrops. The small size of some specimens is not owing to slaking or weathering in outcrop, but to fractures from closely spaced cutans (mainly clay skins), which split on quarrying (Retallack 2008, 2011). The fossils all came from hackly palaeosol beds and not from intervening shale, siltstone or limestone.

Palaeosols are a likely environment for life, and undisputed for the Lake Frome Group by Jago *et al.* (2012). Abundant life, at least at the microbial level, is the most likely explanation for many documented palaeosol features: surficial enrichment in clay, segregation of calcite nodules and gypsum crystals, and depletion of alkali and alkaline earth elements and phosphorus within the palaeosol profiles (Retallack 2008, 2012a).

The most convincing evidence that the disputed fossils are the same age as enclosing sediments is *Prasinema* in a redeposited clast of red palaeosol within a palaeochannel (Retallack 2008, fig. 9C). If this *Prasinema* were owing to post-Cambrian weathering, the entire 2 m

thickness of grey, trough-cross-bedded sandstone containing the clast would be red and bioturbated. Additional evidence that the fossils are Cambrian comes from their strata concordance though a local fold and fault in the creek-side outcrop described by Retallack (2011). Both *Erytholus* and *Prasinema* are restricted to multiple horizons <20 cm thick, which follow Ordovician folding (Foden *et al.* 2006), and bear no relationship to the modern land or outcrop surface. *Prasinema* dominates rock fabric wherever it occurs, both in outcrop and in cores available for inspection at the Glenside core facility of the Geological Survey of South Australia (Retallack 2011). Hundreds of *Erytholus* were observed in a single band dipping east into the creek. Both *Prasinema* and *Erytholus* include sediment similar to their matrix in texture, colour, grain size and chemical composition (Retallack 2008). They are not contaminants from later deposits, modern soils or deep Cenozoic or Mesozoic weathering. Such deep weathering suggested by Jago *et al.* (2012) is ruled out for the Flinders Ranges because the region is unusually seismically active for Australia (Quigley *et al.* 2006), and the sediments have illite-chlorite clays from deep (4–5 km) burial, rather than kaolinite-replaced feldspar and decalcification from deep weathering (Retallack 2012b). Furthermore, trilobite-bearing shales stratigraphically above and below fossiliferous red palaeosols remain black, pyritic and unweathered (Retallack 2008). There are a variety of paint-pot concretions, nodules and altered fractures in soils and deep weathering profiles (Retallack 2001), but no particular weathering feature known to me, or suggested by Jago *et al.* (2012), resembles the problematic fossils.

None of the described fossils were skeletonized with biominerals, and their substance was presumably organic. *Prasinema* threads are surrounded by drab haloes comparable in all respects except size, with early burial reduction haloes around root traces in post-Silurian red palaeosols (Retallack 2008). Chemical reduction of the drab haloes fuelled by bacterial decay of relict organic matter is indicated by characteristic scaling to the volume of original organic substrate represented by the central thread (Retallack 2011). Jago *et al.* (2012) are correct that the green areas have Fe^{2+} and red areas have Fe^{3+} , as demonstrated for these palaeosols by Pratt titration (Retallack 2008), but these are observations, not explanations. High correlations between thread and halo diameters ($r^2 = 0.7$ for $n = 237\text{--}430$; Retallack 2011) are evidence that these redox features are neither random nor meaningless. Furthermore, reduced haloes must be biological in origin because inorganic iron reduction requires temperatures in excess of 500°C (amphibolite facies or hydrothermal alteration: Retallack 2001), demonstrably untrue for Cambrian and Ediacaran sequences of South Australia from illite crystallinity indices (Retallack 2008, 2012b). *Erytholus* and *Farghera* do not show drab haloes, but have infiltration of red clayey

matrix into what appear to be compartments and rhizinous extensions of the originally rotted organic material (Retallack 2011), comparable with preservation of fossil leaves in palaeosols (Retallack and Dilcher 2012).

Prasinema, *Erytholus* and *Farghera* all show varying degrees of crispness of preservation, from fully inflated with sharp outlines or extensions to partly collapsed and withered or decayed examples (Retallack 2011). This is compatible with a sequence of decay of organic bodies, in an oxidized, well-drained, biologically active soil (Retallack 2001; Retallack and Dilcher 2012).

Hundreds of examples of both drab-haloed tubular features (*Prasinema*) and chambered globules (*Erytholus*) were observed and measured, and shown to have unimodal log-normal distributions, like comparable measurements of fossil vascular plant roots (*Radicitus erraticus*) from geologically younger palaeosols presented by Retallack (2011). These fossils do not show a level of structural complexity comparable with brachiopods and trilobites, but are comparable in complexity with such Ediacaran fossils as the bead-like *Funisia dorothea* (Droser and Gehling, 2008) and flanged pit-and-mound of *Coronacollina acula* (Clites *et al.* 2012). *Funisia* and *Coronacollina* may also have been soil organisms because they are found on cracked surfaces ('old elephant skin') characteristic of Ediacaran soil crusts (Retallack 2012a, b). Features of the fossils considered relict bedding by Jago *et al.* (2012) are not planar, but microfilamentous, as seen in oriented thin sections (Retallack 2011). These various criteria and comparisons are multiple lines of evidence that problematic megafossils in palaeosols described by Retallack (2011) were biogenic and a part of the Cambrian soil biota.

It is unclear to me why Jago *et al.* (2012) consider significant the 50 km distance between the locality of possible Ediacaran fossils in Parachilna Gorge noted by Mawson (1938, p. 259) and localities in the Ediacara Hills where Sprigg (1947) found more convincing fossils, considering the much wider distribution of these fossils at the same stratigraphic level throughout the Flinders Ranges (Gehling 2000). The implication by Jago *et al.* (2012) that Ediacaran fossils were not found in Parachilna Gorge is not true. The impressions compared with large brachiopods by Mawson (1938) may have been what would now be called partial specimens of *Dickinsonia costata*, and those compared by Mawson with bivalves may have been discoids, such as *Cyclomedusa davidi*. Both kinds of impressions are visible in cliff faces of the Rawnsley Quartzite in Parachilna Gorge, as observed by me when measuring sections there (Retallack 2008).

The fundamental questions advanced by Retallack (2011) were whether there was life on land in the Cambrian, and whether it may have been related to life in the

Ediacaran. Cambrian–Ediacaran comparisons of *Erytholus* with *Ernieetta* and *Pambikalbae* were considered ‘inappropriate’ by Jago *et al.* (2012), who were presumably unaware that *Prasinema* and palaeosols have now been reported from the Ediacara Member of the Rawnsley Quartzite throughout the Flinders Ranges (Retallack 2012a, b). Furthermore, the Ediacaran palaeosols are gypsum and calcic Aridisols generally similar to Cambrian palaeosols of the Lake Frome Group (Retallack 2008). Some aspects of Ediacaran and Cambrian terrestrial fossils are problematic, particularly their biological affinities, for which carbonaceous or permineralized material is needed. Some of the confusion of Jago *et al.* (2012) may be because palaeosols and their modes of fossil preservation are unfamiliar to Cambrian and Precambrian geologists (Retallack 2012a). Nevertheless, the way is now open for a comprehensive re-evaluation of terrestrial effects of Cambrian–Precambrian boundary events and the Cambrian evolutionary explosion of life using a variety of palaeontological, petrographical and geochemical techniques to study palaeosols.

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