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GR focus review

Field and laboratory tests for recognition of Ediacaran paleosols

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A R T I C L E I N F O

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A B S T R A C T

Not a single paleosol had been described from rocks of Ediacaran age until 2011, but 354 Ediacaran paleosols have been described by 20 different authors since then. Some of these newly recognized paleosols have proven controversial, so this paper reviews 20 distinct tests to determine whether a particular Ediacaran bed could be a paleosol, or not. One problem has been that Ediacaran paleosols are not precisely like modern soils because they lack root traces, a diagnostic feature of Silurian and geologically younger paleosols. The principal problem for recognition of some Ediacaran paleosols is the occurrence in them of megafossils assumed to have been marine, although most of these fossils remain problematic for both biological and ecological affinities. Not all the tests discussed here are diagnostic of paleosols, some are ranked permissive or persuasive. Permissive conditions for paleosols include ripple marks, hummocky bedding, pyritic limestones, acritarchs or thalloid fossils, low strontium isotopic ratios, high δ^{26}Mg ratios, and red color. Persuasive tests include loessites, tsunamites, desert playa minerals, low boron content, high δ^{10}B isotopic ratios, high carbon/sulfur ratios, and very low total/reactive iron ratios. Diagnostic tests include matrix-supported lapilli or crystal tuff parent materials, ice wedges and other cryoturbation, sepic birefringence fabrics, evaporitic sand crystals, and negative geochemical strain and mass transfer, and highly correlated δ^{13}C and δ^{18}O. Like other geological periods, the Ediacaran is known from a variety of marine and non-marine paleoenvironments

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1. Introduction

Discovery of Ediacaran paleosols has been controversial (Retallack, 2013a; Xiao et al., 2013), because some paleosols are closely associated with Ediacaran fossils long considered marine invertebrates (Tarhan et al., 2015a) or marine algae (Xiao et al., 2013). Thus, some described Ediacaran paleosols have been dismissed without giving reasons (C. Liu et al., 2014; Liu et al., 2015), and other reviews have judged all evidence for described Ediacaran paleosols inconclusive (Callow et al., 2013; Tarhan et al., 2015a). Before the evolution of trees and large burrowing animals, Ediacaran paleosols may indeed have had some peculiarities (Retallack, 2012, 2013a), but there is a need to agree *a priori* on tests of whether a particular bed is marine or non-marine, a paleosol or not. This review outlines 20 distinct tests for the interpretation of individual Ediacaran beds as non-marine, or as paleosols. These various tests are triaged here into categories based on strength of evidence. First are permissive tests that allow for interpretation of paleosols but do not require a paleosol interpretation. Second are persuasive tests that favor a paleosol interpretation, but inconclusively, because of rare exceptions. Third are diagnostic tests that require a paleosol interpretation. My aim is to outline tools for future assessment, rather than adjudicate past disputes. For opposing interpretations of the South Australian Ediacara Member (Retallack, 2013a; Xiao et al., 2013), this review offers 8 additional lines of evidence not yet attempted, among a total of 20 outlined here.

Ediacaran non-marine facies have been recognized for some time in South Australia (Mawson and Segnit, 1949) and Mali (Bertrand-Sarfati and Moussine-Pouchkine, 1983). Surprisingly, no individual paleosols were described until 2011, but since then 354 paleosols have been described by 20 different authors (Retallack, 2011a-b; Retallack, 2012, 2013a-c; 2014a-d; Retallack, 2016; Maslov and Grazhdankin, 2011; Kolesnikov et al., 2012, 2015; Retallack et al., 2014; Marconato et al., 2014; Liivamägi et al., 2014; Vircava et al., 2015). This review summarizes this past research on distinguishing marine and non-marine Ediacaran rocks, as well as recognizing individual Ediacaran paleosols.

At stake with this work is whether the Ediacaran Period has only a record of ancient marine life, as in traditional reconstructions (Fig. 1a), or do some of these fossils represent freshwater (Fig. 1c), or fully terrestrial (Fig. 1c) ecosystems? These strange ecosystems have been portrayed as the "Garden of Ediacara" (McMenamin, 1986) and inspired the Ediacaran "savannah hypothesis" (Budd and Jensen, 2016), but could these epigrams have been descriptive rather than metaphorical? Were the strange quilted fossils of the Ediacaran a variety of worms, or were they sessile osmotrophic and photosymbiotic organisms like fungi and lichens (bottom versus top row of Fig. 2)? Ontogenetic series of fossils are evidence of growth by addition of quilts to the narrow end (Antcliffe and Brasier, 2008; Gold et al., 2015), but was the larger segment at the other end a holdfast or a head? Cephalization and advent of the "noösphere" in the sense of Pierre Teilhard de Chardin has been argued by regarding the big end as a neurologically differentiated head (McMenamin, 2001). By the other point of view, however, the big end was a holdfast or growth initial of an extinct clade of Vendobionta, and segments were added by a terminal meristem, like addition of leaves to a tree (Seilacher, 2013).

Were these problematic fossils the evolutionary stirrings of the Cambrian explosion of marine animals (Erwin et al., 2011; Droser and Gehling, 2015)? Or did they merely facilitate that adaptive radiation by providing shelter and resources (Retallack, 2013a; Budd and Jensen, 2016)? Paleosol evidence for terrestrial habitats applies only to the distinctive quilted vendobionts (Fig. 2), and not yet to calcareous shells, such as *Cloudina*, nor chitinous tubes, such as *Corumbella*, found in undisputed gray marine facies (Warren et al., 2011, 2012; Pacheco et al., 2015). Also favoring a terrestrial interpretation of vendobionts are discovery of Ediacaran fossils demonstrating nutrient extraction from substrates (Antcliffe et al., 2015), satellite vegetative propagules (Mitchell et al., 2015), limited interactions between fossils (Mitchell, 2015), and substrate-specific assemblages (Retallack, 2016), more like terrestrial vegetation than marine animal communities. Such sophisticated inferences are colored by interpretation of the substrates and geological context of the fossils, which is the main issue addressed here. Are there, or are there not, Ediacaran paleosols, and how can they be recognized?

2. Ripple marks (permissive)

A simple test proposed by Xiao (2013) is to consider ripple marks evidence of active sedimentary paleoenvironments (Fig. 1a), and thus a bed unaltered by soil formation. This would be true if the ripple marks were fresh, and lacked evidence of later alteration such as wind

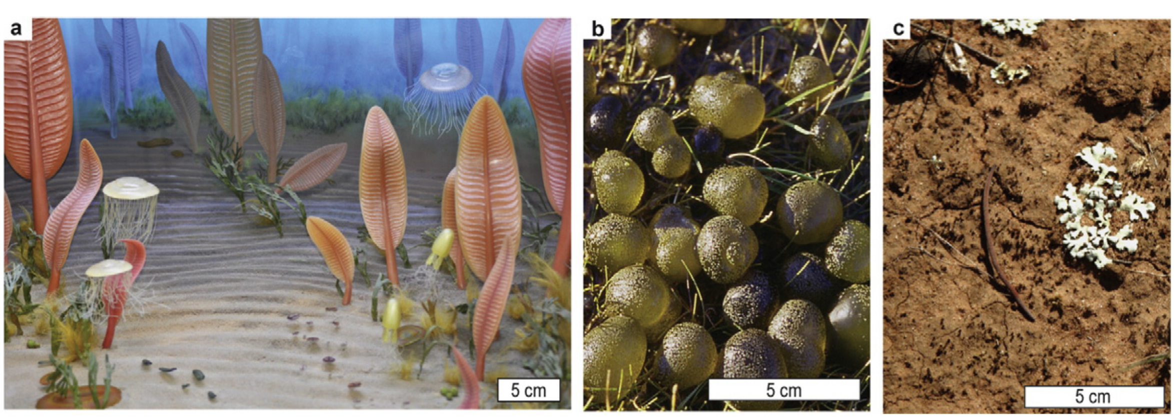

Fig. 1. Alternative interpretations of Ediacaran ecosystems as shallow marine tropical invertebrates (a), aquatic microbial colonies (b), and as terrestrial lichens (c); a, classical diorama of Ediacaran ecosystems of South Australia from Museum of the Earth, near Ithaca, New York; b, jelly balls of the cyanobacterium *Nostoc pruniforme* near the River Liene near Hannover Germany (by and with permission of Christian Fischer); c, foliose lichen (*Xanthoparmelia reptans*) on bare red soil between red mallee (*Eucalyptus socialis*) and porcupine grass (*Triodia scariosa*) near Damara station, near Balranald, N.S.W., Australia.