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Microorganism-mediated preservation of *Planolites*, a common trace fossil from the Harkless Formation, Cambrian of Nevada, USA

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ABSTRACT

Specimens of *Planolites*, a tubular ichnofossil, from the Harkless Formation (Cambrian of Nevada) are commonly rimmed by thin layers of limonite, a probable pseudomorph after pyrite, suggesting that bacterially induced biomineralization played a key role in the preservation of the burrows. Organic material secreted by a vermiform, infaunal tracemaker is inferred to have formed the substrate for a biofilm that facilitated iron sulfide biomineralization by bacteria under localized anaerobic or dysaerobic conditions. Rapid, microbially mediated biomineralization of mucus-lined burrow walls is inferred to have promoted three-dimensional preservation of burrows by strengthening them against sediment compaction, and possibly providing sufficient support for burrows to allow time for sediment infill. Decomposition of organic materials in *Planolites* also left evidence in sediment layers immediately above the burrows: undulose sediment surfaces and small, round, pimpleform gas escape structures.

1. Introduction

Research in recent years has sought to elucidate the crucial role that microorganisms play in the taphonomy of body fossils and trace fossils. Increasingly we have come to appreciate how influential the types of microbes present in sedimentary environments, and the conditions controlling their metabolism, have been in the preservation of fossils (e.g., Allison and Briggs, 1991; Canfield and Raiswell, 1991; Raiswell, 1997; Shieber, 2002; Borkow and Babcock, 2003; Konhauser, 2007). Biofilms, or consortia of microorganisms that may include bacteria, fungi, and perhaps algae and archeans, are a pervasive feature of moist environments having nutrient sources. Biofilms can develop on a wide range of scales, from microscopic to macroscopic. In some aqueous sedimentary environments, biofilms formed by consortia of microorganisms are important in stabilizing sediment by trapping and binding it in microbial mats (e.g., Noffke, 2000; Shieber, 2004). Stromatolites, thrombolites, and coated grains show that microbial mat consortia have an evolutionary history extending into the Archean (e.g., Noffke et al., 2002, 2003; Konhauser, 2007; Babcock, 2009; Westall, 2009). Some examples of exceptionally preserved body fossils, notably the "death masks" of Ediacaran organisms (e.g., Gehling, 1999), and nonbiomineralized tissues that were secondarily phosphatized (e.g., Müller, 1983, 1985; Müller and Walossek, 1985, 1987; Briggs et al., 1993; Briggs, 2003; Babcock et al., 2005; Maas et al., 2006), or otherwise secondarily mineralized (Zhu et al., 2006) are apparently closely tied to early diagenetic precipitation of biominerals by microorganisms inhabiting biofilms. The same seems to be true of exceptional preservation of fossils in concretions (Borkow and Babcock, 2003; Ciampaglio et al., 2006; Babcock and Ciampaglio, 2007). Work by Shieber (2002) indicates that biofilms can play a role in the early mineralization and eventual preservation of some trace fossils. Actualistic taphonomic experiments suggest that bacterial biomineralization facilitates the preservation of nonbiomineralizing tissues either by promoting conditions that are favorable to secondary mineral precipitation (Briggs et al., 1993; Briggs and Kear, 1993; Sagemann et al., 1999; Borkow and Babcock, 2003; Weiner and Dove, 2003), or by replacing nonbiomineralizing tissues through authigenetic mineralization (Allison, 1988; Briggs, 2003). Authigenetic mineralization appears to be rapid, within a few weeks or months, as indicated by both experimental and fossil evidence (Briggs and Kear, 1993; Raiswell, 1997; Sagemann et al., 1999; Shieber, 2002; Borkow and Babcock, 2003; Briggs, 2003; Babcock et al., 2005; Ciampaglio et al., 2006; Babcock and Ciampaglio, 2007).

Research also suggests that sediment trapping and binding by microorganisms, presumably followed by precipitation of early diagenetic minerals mediated by the metabolic activities of those organisms, has been a factor in the development and preservation of sedimentary structures (e.g., Noffke, 2000; Noffke et al., 2001; Shieber, 2002, 2004). Decay processes have been shown to facilitate the buildup of gasses in organic-rich sediments. Sealing of gas-rich sediment layers by microbial mats can lead to the formation of gas domes and gas-escape structures (Noffke, 2000; Noffke et al., 2001).

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In this paper we draw attention to the evidence bearing on the taphonomic history of *Planolites*, which is a simple tubular burrow common in Ediacaran through Phanerozoic strata (e.g., Osgood, 1970; Pemberton and Frey, 1982; Marenco and Bottjer, 2008; Ahn, 2010). Material reported here is derived from the Harkless Formation (Cambrian: provisional Series 2, provisional Stage 4; see Albers and Stewart, 1972), Montezuma Peak section, Montezuma Range, Esmeralda County, Nevada. The tracemaker of *Planolites* is uncertain but the ichnogenus is inferred to record burrowing and feeding behavior of an infaunal vermiform animal. On account of the long stratigraphic range and wide environmental distribution of *Planolites* in aqueous environments, it is unlikely that this trace was constructed by a single type of animal over time. A variety of animals, all of which left similar traces in sediment, could have been tracemakers of *Planolites*. Specimens described here show taphonomic features that have so far been undocumented or poorly documented from other temporal positions and paleogeographic settings; however, a cursory examination shows that such features are present in some post-Cambrian *Planolites*.

1.1. Geologic setting

The Great Basin of the western United States exposes a classical succession of mixed carbonate-siliciclastic deposits spanning the

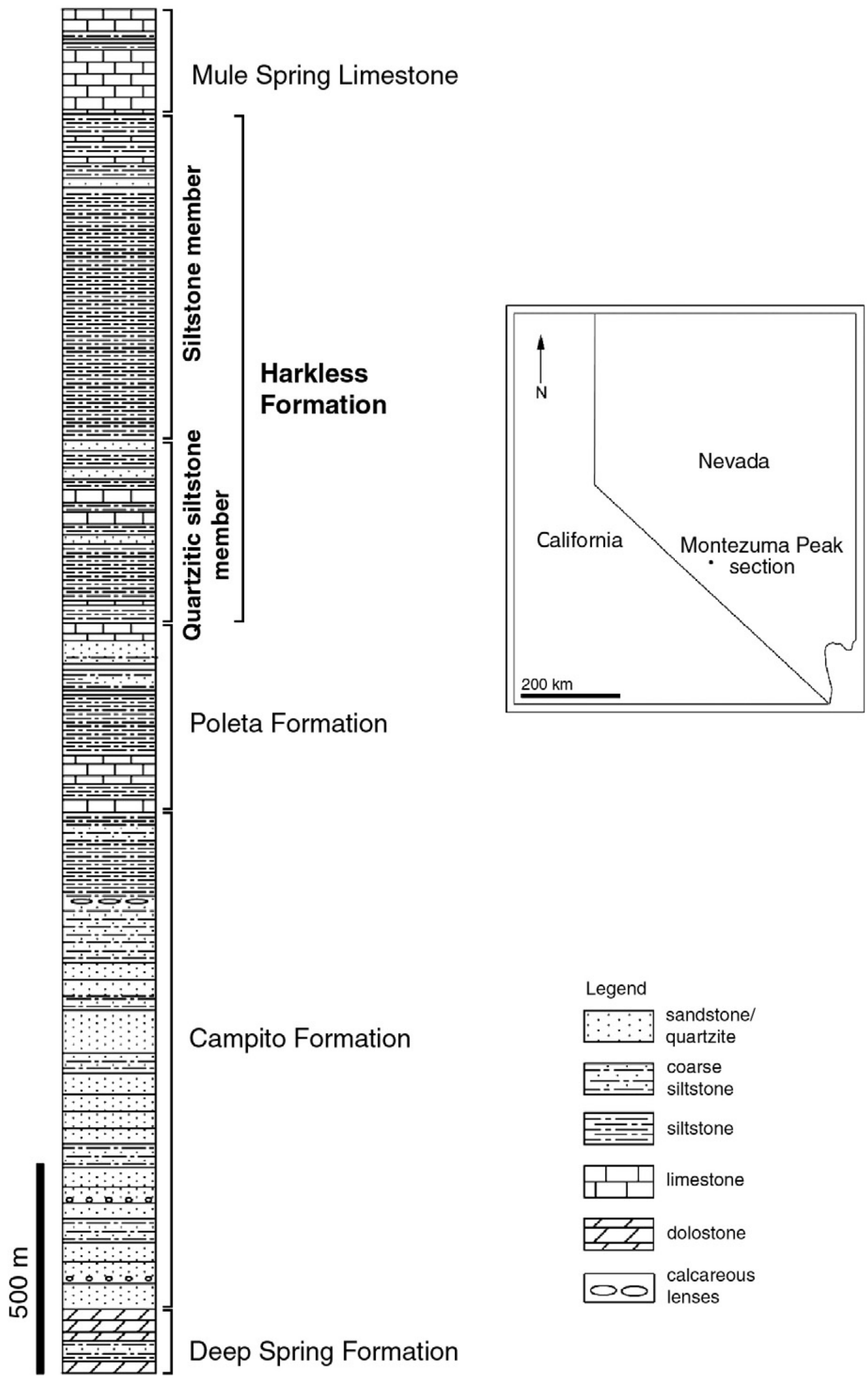

Fig. 1. Map of Nevada and eastern California, USA, showing location of the Montezuma Peak section, in the Montezuma Range, Esmeralda County, Nevada (right); and composite columnar stratigraphic section for Cambrian (Terreneuvian Series-provisional Series 2) strata exposed in Esmeralda County, Nevada (left; modified from Hollingsworth, 2005).