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Early Jurassic microbial mats—A potential response to reduced biotic activity in the aftermath of the end-Triassic mass extinction event

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ABSTRACT

Wrinkle structures are microbially induced sedimentary structures (MISS) formed by cyanobacteria and are common in pre-Cambrian and Cambrian siltstones and sandstones but are otherwise rare in the Phanerozoic geological record. This paper reports the first discovery of Mesozoic wrinkle structures from Sweden. These are preserved in fine-grained and organic-rich heterolithic strata of the Lower Jurassic (Hettangian) Höganäs Formation in Skåne, southern Sweden. The strata formed in a low-energy, shallow subtidal setting in the marginal parts of the Danish rift-basin. Palynological analyses of fine-grained sandstones hosting the wrinkle structures show that the local terrestrial environment probably consisted of a wetland hosting ferns, cypress and the extinct conifer family Cheirolepidaceae. Palynostratigraphy indicates a Hettangian age, still within the floral recovery phase following the end-Triassic mass extinction event. The finding of wrinkle structures is significant as the presence of microbial mats in the shallow subtidal zone, (in a deeper setting compared to where modern epibenthic microbial mats grow) suggests decreased benthic biodiversity and suppressed grazing in shallow marine environments in the early aftermath of the end-Triassic mass extinction event.

1. Introduction

Microbes and eukaryotic algae dominate the Precambrian fossil record, but with the evolution of grazing metazoans and increasing rates of bioturbation in the early Phanerozoic, cyanobacteria became restricted to more marginal marine environments (Lan, 2015). However, during time intervals of severe environmental stress with extreme conditions, microbes could expand over a wider area of the shelf and contribute to the development of anachronistic facies (Sepkoski et al., 1991; Mata and Bottjer, 2012; Forel et al., 2013), atypical of metazoan-dominated Phanerozoic sea floors. This has been documented in association with the Late Devonian (Wood, 2000) and end-Triassic mass extinction events (Pruss et al., 2004; Kershaw et al., 2012; Forel et al., 2009), and the late Silurian Lau Event, a taxonomically small but ecologically important crisis (Calner, 2005, 2008). Younger examples of this phenomenon in association with mass extinctions have not been known until recently, when Ibarra et al. (2014) documented unusually extensive microbialites from the Triassic–Jurassic boundary interval in southwestern United Kingdom, and suggested a linkage to the end-Triassic mass extinction event.

Modern microbial mats are restricted to marginal marine environments, such as tidal flats and salt marshes where burrowing and grazing is minimal. Rapid fluctuations in salinity, water depth, currents and temperature form unfavourable conditions for benthic organisms, leaving the extremophile organisms to flourish. Fenchel (1998) showed that a four month old mat can be completely ingested in a time span of weeks by gastropods and other grazers. Post-burial burrowing may further obliterate mat laminae (e.g., Hagadorn and Bottjer, 1997; Mata and Bottjer, 2009).

Microbial mats are formed by cyanobacteria, generally by multilayer microbial communities composed of several cyanobacterium species (Ramsing et al., 2000). The morphology of cyanobacterial mats is a result of a combination of factors, such as: environment, sediment characteristics and dominant cyanobacterial species (Ramsing et al., 2000). An advanced biofilm of extracellular polysaccharide forming a laterally extensive, organic layer may be called a microbial mat (Noffke, 2010). Microbial mats form through the cooperation of individual microbes, which secrete a biofilm of strongly adhesive extracellular polymeric substance (EPS; Stoodley et al., 2002). Physically, they behave like viscoelastic fluids, in that they may both undergo elastic, reversible deformation as well as deform irreversibly if subject to sufficiently high shear stress for a certain amount of time (for most mats around 18 min; Thomas et al., 2013). These films can develop on almost any surface on Earth and their complexity even resembles that of eukaryotic tissue, facilitating optimal temperature, salinity and nutrition levels for the

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constituent microbes (Costerton et al., 1995; Noffke, 2010). Biofilms and EPS not only hamper erosion by binding sediment grains together; the smooth upper surface also has the effect of reducing the shear stress exerted by eroding currents (Paterson, 1994).

The preservation-potential of microbes differs depending on the depositional context. In carbonate depositional environments, stromatolites and oncoids may be formed. Owing to early cementation, these are rigid, generally easily distinguished structures with a long history of research (e.g., Walter, 1976; Tewari and Seckbach, 2011). Their counterparts in siliciclastic sediments are less well known, since the preservation potential of microbes on those substrates is lower and identification is more challenging leading to the under-representation of fossil cyanobacteria mats from siliciclastic settings in the literature. Nevertheless, over the past two decades, more research has focused on traces of microbial activity in siliciclastic settings as these are especially interesting for astrobiologists studying extra-terrestrial analogues.

Wrinkle structures have been attributed to the sediment-stabilizing ability of these microbial mats and is an umbrella term used for so called runzelmarken, Kinneyia ripples and "elephant skin" (Hagadorn and Bottjer, 1997, 1999). They are microbially induced, commonly oversteepened surface irregularities developed on sand- and siltstones (Hagadorn and Bottjer, 1997, 1999). Kinneyia-type wrinkle structures (or just Kinneyia structures) feature minute flat-topped, winding crests separated by troughs or pits, resembling small scale interference ripples (Martinsson, 1965; Porada et al., 2008). Hagadorn and Bottjer (1997) suggested that wrinkle structures reflect the actual crinkled upper surface of a living mat, whereas Noffke et al. (2002) and Noffke (2010) argued that they form due to post-burial deformation of the mat by the pressure exerted by the overlying sediments. The overload causes dewatering as the liquid bound in the mat escapes laterally, thus crinkling the mat. Porada et al. (2008) on the other hand, proposed a model with tidally induced oscillations in ground water, which liquefy and reorganize sediments trapped under the sealing layer of a microbial mat. This effect would be strongest in the shallow subtidal zone. Laboratory experiments with viscoelastic films carried out by Thomas et al. (2013) developed this model further. As the water and the biofilm both have different viscosities and behave like two immiscible fluids, they respond differently to shear stress. A harmonic so called Kelvin–Helmholtz instability is induced at the interface, giving rise to the characteristic Kinneyia ripple pattern in the biofilm.

This study aims to describe Early Jurassic wrinkle structures from shallow marine, siliciclastic strata at the Kulla Gunnarstorp coastal cliff section (Fig. 1), in the southernmost province of Sweden. We further interpret the depositional environment and, through palynological analyses, investigate the temporal relationship between these wrinkle structures and the end-Triassic mass extinction event. The global record of Mesozoic MISS is very sparse, and Swedish MISS have thus far been documented only from Palaeozoic strata (e.g., Martinsson, 1965; Calner, 2005; Calner and Eriksson, 2011). Thus the Early Jurassic structures of this study are the youngest yet described from Sweden, and

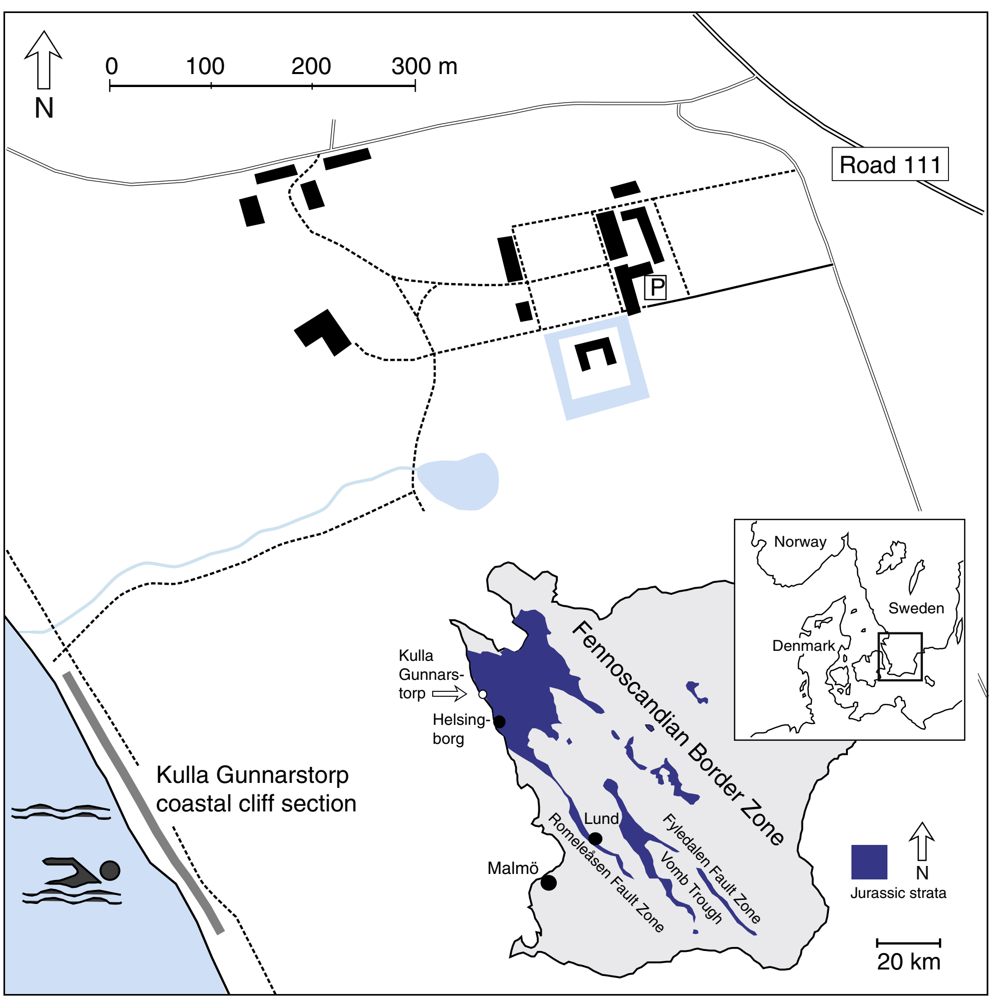

Fig. 1. Geological map of southern Sweden (with Sweden inset), Jurassic deposits highlighted in blue. The beach exposure at Kulla Gunnarstorp is marked with an arrow. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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