A Sideways View of Stromatolites: Complexity Metrics for Stromatolite Laminae

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ABSTRACT

Stromatolites offer a unique window into 3.5 billion years of evolution of the microbial communities that built them within the context of an evolving Earth. Our interest is not in the microbial life or their external matrix as independent entities, but the appearance and evolution of complexity itself within this biogeological system. We adopt the canonical definition of complexity as the emergence and detection of previously unseen properties (structures, functions, information), and we propose that the defining emergent property of stromatolites apparent to the human expert eye is the lamination.

To develop a quantitative complexity metric for stromatolites, we must ask what makes it possible for the human brain to perceive lamination? Our visual system operates optimally as a difference machine rapidly identifying variations in signal intensity and redundancy in neighboring regions. In stromatolites, such differences are detected by first scanning parallel to the growth surface and then placing layers in context by scanning orthogonal to that surface. We propose that the fundamental metric for stromatolite complexity resides in the laminae themselves and that easily measured differences in luminance, variability, and redundancy between alternating laminae is an emergent feature of stromatolite complexity. The metrics calculated for laminae in photomicrographs revealed significant differences between putative biotic/abiotic laminae. The statistical indices calculated can contribute to stromatolite recognition, description, and classification. The indices are easily calculated in the laboratory or in the field on personal computers. We propose that such statistical information metrics be included as a standard component in the description of extant and fossil stromatolites.

Keywords: Stromatolites, complexity, emergent properties, quantitative metrics

INTRODUCTION

Stromatolites [*Awramik*, 1971; *Walter*, 1976; *Riding*, 1990; *Riding and Awramik*, 2000] are classically viewed as laminated organo-sedimentary structures formed by microbial trapping and binding of sediment or precipitation of dissolved minerals [*Awramik et al.*, 1976; *Burne and Moore*, 1987]. However, some researchers prefer a descriptive definition leaving biogenicity an open question [*Semikhatov et al.*, 1979; *Grotzinger and Knoll*, 1999; *Brasier*, 2006]. The increased attention to the Archean fossil record and how it might assist in the search for evidence of past life elsewhere in the universe have heightened concern for unambiguous signals of biological activity [*Awramik and Grey*, 2005]. Stromatolites as indicators of microbial activity have fallen on hard times. However, a persuasive case for biogenicity in some 3.45 Ga-old stromatolites can be made when multiple lines of evidence are presented that can only be explained by one hypothesis, which invokes microbial activity [*Hofmann et al.*, 1999; *Allwood et al.*, 2006]. These then would provide our most ancient record of life on Earth and rival or even surpass the reliability of microbial fossils, which are also controversial [*Brasier et al.*, 2002; *Schopf et al.*, 2002; *Brasier*, 2006]. Most Archean and Proterozoic stromatolites are composed of fine grained material and commonly display sub-mm scale laminations [*Walter*, 1972; *Grey and Corkeron*, 1998]. They often lack unambiguous microscopic evidence for microbial activity [*Grotzinger and Knoll*, 1999]. Some abiotic precipitates have been put forward as similar in morphology to selected pre-Phanerozoic sromatolites and modeled using simple accretion rules and common diffusion [*Sumner and Grotzinger*, 1996; 2000] equations based on the "random walk" (e.g., Brownian motion) of particles without invoking biological processes [*Grotzinger and Rothman*, 1996]. However, conical stromatolites with very steep surface angles continue to defy such modeling attempts unless high coefficients of

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