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Stromatolites in the ~3400 Ma Strelley Pool Formation, Western Australia: Examining Biogenicity from the Macro- to the Nano-Scale

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**Abstract**

The 3426–3350 Ma Strelley Pool Formation (SPF) is a silicified, dominantly sedimentary unit within the Pilbara Supergroup, Western Australia. It is found widely across the East Pilbara Terrane, and it forms a prominent marker horizon and separates the largely volcanic 3520–3427 Ma Warrawoona and 3350–3315 Ma Kelly groups. It has become one of the key formations for study by astrobiologists, following reports of some of the world's oldest stromatolites.

Abundant contextual and morphological evidence has been presented over the last decade in support of a biological role in SPF stromatolite formation. This evidence is reviewed here, and additional data are presented from recent fieldwork carried out across the ~25 km of SPF outcrops in the East Strelley greenstone belt of the East Pilbara Terrane. In addition to contextual and morphological evidence, a compelling claim for early life requires geochemical evidence for biological cycling. A potential avenue of approach to obtain such evidence for the SPF stromatolites (and other ancient examples) is discussed in the context of a pilot study in which nano-scale secondary ion mass spectrometry (NanoSIMS) was used. Key Words: Biogenicity—Archean—Stromatolites—Strelley Pool Formation—NanoSIMS. *Astrobiology* 10, 381–395.

**1. Introduction**

ONE OF THE MOST INTENSELY STUDIED expressions of microbial mat activity is that of stromatolites. But what exactly is a stromatolite? The term stromatolite can mean different things to different researchers. Many automatically associate the term stromatolite with the activities of microbial mats. This is understandable based on present-day analogues and given that the earliest use of the word stromatolite appeared in a description of laminated organic structures thought to be produced by "simple plant-like organisms" (Kalkowsky, 1908). This led to a genetic definition of the term stromatolite: "organogenic, laminated calcareous rock structures, the origins of which is clearly related to microscopical life, which in itself must not be fossilized" (Krumbein, 1983), which was cited as a translation from Kalkowsky (1908) but was actually a misquote (Riding, 2008). Others understand the term stromatolite in the nongenic sense, that is, as a description of the key textural and morphological characteristics of the structure without the implication of biological involvement: "an attached, laminated, lithified sedimentary growth structure, accretionary away from a point or limited surface of initiation" (Semikhatov *et al.*, 1979). This distinction is vital, especially when considering structures that formed on early Earth or may have formed in extraterrestrial environments where the participation of biology cannot be assumed. A comprehensive review of the history and usage of the term stromatolite can be found in Riding (1999, 2008). Bearing this in mind, it is not surprising that the earliest stromatolitic structures in the Archean rock record (reviewed in Hofmann, 2000) have proved contentious in debates concerning the earliest evidence of life on Earth.

Brasier *et al.* (2006, and references therein) suggested that three independent and mutually supporting lines of evidence are required to substantiate any case for early life and to falsify the "null hypothesis" of a nonbiological origin for any candidate structure: (1) evidence for a well-constrained age and plausible geological context; (2) evidence for a morphology unique to biology; (3) geochemical evidence for metabolic cycling. Here, evidence for age, context, and biological morphology applied to the ~3400 Ma Strelley Pool Formation (SPF) stromatolites is reviewed. New data are presented from the East Strelley greenstone belt, where stromatolite diversity and morphology is compared and

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contrasted to that observed at the more widely studied Trendall locality in the Panorama greenstone belt. Nano-scale secondary ion mass spectrometry (NanoSIMS) data from stromatolites of Holocene to Archean age, including an example from the Trendall locality, are also presented, which highlight the technique as a promising new tool to obtain evidence for metabolic cycling within stromatolites.

## 2. Regional Geology of the Pilbara

The Pilbara Craton of Western Australia (Fig. 1) contains some of Earth's best preserved stratigraphic successions of early Archean rocks, including some of the oldest indisputable carbonates and sandstones (e.g., Lowe, 1983). The craton comprises an Archean proto-continent (Smithies *et al.*, 2005), which was formed by mantle plume events and consists of granitic bodies emplaced into and overlain by the Pilbara Supergroup (Van Kranendonk *et al.*, 2001). The oldest part of the craton is the East Pilbara Terrane, which comprises ~3650 to ~2850 Ma granitic bodies and an almost contemporaneous ~3520–3000 Ma volcanogenic caespaze and associated sediments (Pilbara Supergroup) now preserved as several greenstone belts (Van Kranendonk, 2006).

The Pilbara Supergroup contains four unconformity bound stratigraphic groups—the ~3520–3427 Ma Warrawoona Group, ~3350–3315 Ma Kelly Group, ~3240 Ma Sulphur Springs Group, and the ~3200–3000 Ma Soanesville Group (Fig. 2). Each of these groups consistently dips away from the domal granitic complexes; dips gradually decrease with time, which suggests deposition as thickening wedges adjacent to the growing granitic diapirs (e.g., Hickman, 1984; Van Kranendonk *et al.*, 2002). The Strelley Pool Formation previously widely termed the "Strelley Pool Chert" occurs across 11 greenstone belts and a depositional area in excess of 30,000 km<sup>2</sup> in the East Pilbara Terrane. It comprises a distinctive assemblage of sedimentary facies within the otherwise predominantly volcanic Pilbara Supergroup, and the most recent review of mapping and lithostratigraphic evidence established the SPF as an important marker formation between the Warrawoona and Kelly groups (Hickman, 2008). In addition to the stromatolites of the SPF, older ca. 3490 Ma stromatolites occur in the Dresser Formation of the Pilbara Supergroup (Walter *et al.*, 1990; Van Kranendonk *et al.*, 2008). These structures were reviewed by Buick *et al.* (1981) in a study that attempted to define universal stromatolite biogenicity criteria and concluded that the Dresser stromatolites were "probable or possible" biogenic stromatolites. These structures will not be discussed further here.

## 3. SPF Stromatolite Pioneers

The SPF stromatolites came to prominence with the description of coralline forms by D. Lowe in 1980 from the "Strelley West" locality (now formally named McPhee Creek, Wacey *et al.*, 2010) of the East Strelley greenstone belt (ESGB) (Fig. 3). These structures were originally interpreted as bio-

Indian Ocean

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Indian Ocean

Port Hedland

De Grey Supergroup + granitic intrusions

East Pilbara Terrane

East Strelley Greenstone Belt

Trendall Locality

McPhee Creek

Kurrana Terrane

100 km

Legend:

- Roeboorne Group + granitic rocks
- Whundo Group + granitic rocks
- Regal Formation
- Kurrana granitic rocks
- Pilbara Supergroup + granitic rocks
- De Grey Supergroup + granitic intrusions
- Major fault

FIG. 1. Geological map of the Pilbara Craton in Western Australia (modified from Van Kranendonk *et al.*, 2007). The best-preserved stromatolite outcrops are found around McPhee Creek in the East Strelley greenstone belt and around the Trendall locality in the Panorama greenstone belt. Color images available online at [www.liebertonline.com/ast](http://www.liebertonline.com/ast).

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