Microscale Features in Modern Stromatolites from Hamelin Pool, Australia and Exuma Cays, Bahamas

By

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Under the supervision of Dr. Julie Bartley

ABSTRACT

Stromatolites, microbially-constructed sedimentary structures, provide a record of life on Earth for more than 3 billion years, across a variety of aquatic environments throughout Earth history. Stromatolites can serve as a record of the environment in which they formed; a thorough understanding of the formation process is vital to be able to interpret this record. Modern marine stromatolites are rare but are potentially key for interpreting their ancient counterparts; however, evidence thus far indicates that modern stromatolites have significantly different growth patterns than ancient stromatolites, which could significantly limit their utility as analogs. This study focuses on modern marine stromatolites with the aim of evaluating the hypothesis that modern and ancient stromatolites have fundamentally different modes of construction.

This study characterizes stromatolites from Hamelin Pool, Australia and Exuma Cays, Bahamas at micro- to macroscales using morphological analysis and optical microscopy to determine the relation between microfabric and final morphology of the stromatolite and to assess whether such correlations persist across localities in the modern world. Results from Hamelin Pool show a notable diversity of microfabrics in stromatolites with similar macro- or mesostructures. Stromatolites from Exuma Cays have a similar suite of microfabrics, but the proportions are strikingly different from stromatolites in Hamelin Pool.

Although the stromatolites from these two modern locations have been previously studied, this is the first study to compare microfabrics directly. This analysis provides a basis for comparison with ancient microfabric diversity and represents a first step in determining whether modern stromatolites are robust analogues for ancient forms.

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INTRODUCTION

Stromatolites are abundant across time and space, in all kinds of aquatic environments. Most notably, stromatolites have an extensive history in shallow marine environments, starting in the Precambrian and lasting into modern settings. The organisms comprising stromatolites are believed to have been responsible for the original oxygenation of the atmosphere during the Precambrian (Bosence et al., 2013). During the Precambrian, stromatolites were widespread and diverse, forming in a wide variety of marine (Kah et al., 1996 and Bartley et al., 2015) and nonmarine (Elmore, 1983) environments. For modern stromatolites, that is no longer the case. The only two localities where modern marine stromatolites are found is in Hamelin Pool, Australia, and in the Exuma Cays of the Bahamas. Modern stromatolites have competition for resources, as there are other creatures sharing the ocean space with them now that did not yet exist in the Precambrian.

Stromatolite growth is impacted by microbial communities, carbonate precipitations, and external sedimentation (Bosak et al., 2013). Almost all stromatolites are made of limestone, allowing for the potential record of environmental conditions - stromatolites can act as a record of the interactions of physical and chemical aspects of the environments in which they formed. Since the growth environment of ancient stromatolites is not comprehensively understood, it can be difficult to piece together the story that a stromatolite would be able to tell us. Modern stromatolites, if they provide robust analogs for their ancient counterparts, then have the potential to act as a stromatolite decoder ring.

The two main methods by which stromatolites grow are precipitation and the trapping and binding of grains. Precipitation is the *in situ* precipitation of calcium carbonate within or onto microbial mats as they grow upward to form the stromatolite (Fig. 1a). Trapping and binding occurs when sediment falls on top of a stromatolite and is captured by the growing microbial mat (Fig. 1b). Although both growth modes are observable in both modern and ancient stromatolites, precipitation is the primary builder in Archean and Proterozoic marine stromatolites, while in modern marine stromatolites, trapping and binding is the primary mode of formation (Dupraz et al., 2009).

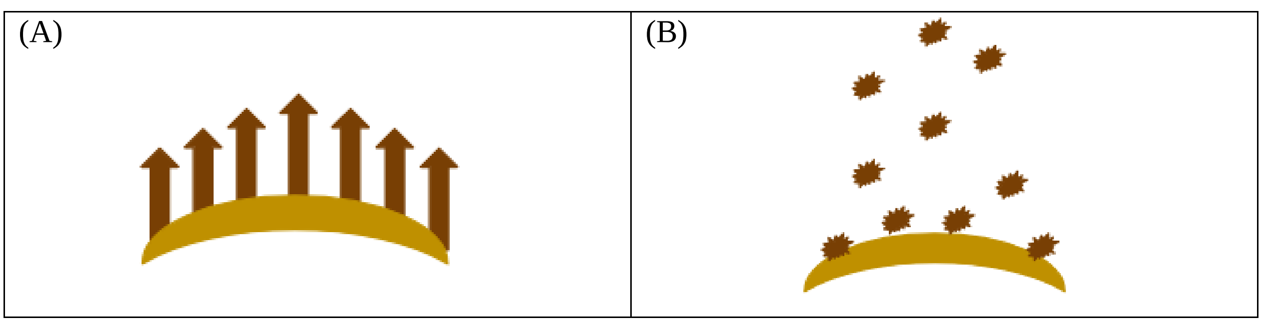


Figure 1: Stromatolite Building Blocks

Light brown signifies top microbial mat layer of stromatolite, dark brown shows growth mechanism. (A) Shows precipitation, in which the microbial mat topping the stromatolite precipitates in-situ calcium carbonate. (B) Shows trapping and binding, in which the microbial mat will grow up to cover sediments that are being deposited on top of it.

At first glance, stromatolites may seem like simple laminae in an outcrop; in actuality, they are complex structures composed of distinct fabrics and textures at various scales. Megastructures are outcrop-scale features. Macrostructures and mesostructures can be identified in a hand sample, at a cm to mm scale. Macrostructure identifies the shape of the feature, and mesostructure defines the lamina (or non-lamina) type that the shape is made of. Microscale features are the smallest scale features and are visible under a microscope. For this study, the focus will be on macro to micro-scale features. Ancient stromatolites consist of three dominant microfabrics: grumeaux (clotted micrite), uniform micrite, and isopachous cement. In modern stromatolites analyzed in this study, the three most common microfabrics are cemented grains, filamentous micrite, and massive micrite. This study will aim to determine whether any of the three from the modern are comparable to any of the three from the ancient, and whether similar textures between the modern localities are comparable to each other.

Stromatolite diversity has plummeted since the Proterozoic when it reached a peak of nearly 400 form taxa (Fig. 2). There are only two occurrences of modern marine stromatolites, those found in Hamelin Pool, Australia and those found in the Exuma Cays of the Bahamas. The cause of this decline through time is not specifically known. This drastic change in stromatolite abundance and diversity raises the question of whether the modern marine stromatolite we see today the same as those seen in the Proterozoic. Additionally, if they are considered the same, it is unknown how comparable the two are, and whether the modern can truly act as a 'decoder ring' of sorts for the ancient stromatolites.

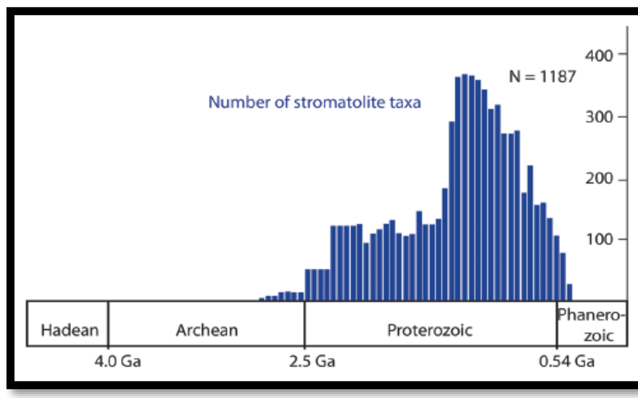


Figure 2: Stromatolite Diversity Curve
This figure (from Noffke & Awramik, 2013) represents the total amount of stromatolite taxa through time. At present, there are two modern marine stromatolites as compared to nearly 400 at peak diversity in the Proterozoic.

The two main hypotheses on the matter differ substantially. The first side of the argument claims that the modern marine stromatolites of Hamelin Pool and the Exuma Cays cannot be analogously compared to ancient stromatolites, due to a significantly different composition, in which the modern stromatolites are composed of grains, while ancient stromatolites are primarily made of micrite precipitated *in situ* (Riding et al., 1990). Additional reasoning for this argument is that the builders of the stromatolites are different between the time periods. Proterozoic stromatolites are built by cyanobacteria, while Hamelin Pool (and the Exuma Cays) stromatolites are built by a eualgal-cyanbacterial regime. (Awramik and Riding, 1988). The contrary argument on this topic says that there is indeed the potential for comparison between the ancient and the modern. Hamelin Pool stromatolites are not composed solely of cemented grains, as stated by Riding et al. (1990), but rather a significant portion of the subtidal stromatolites contain micrite that may be comparable to micrites found in ancient stromatolites (Reid et al., 2003).

These contrasting hypotheses demonstrate the need for systematic comparison between stromatolites that uses the same criteria to define features. Before the comparison between modern and ancient can be made, a comparison between the two modern stromatolite localities must be made to determine whether the two of them are truly similar to each other and to catalog the textures they contain. Only after that comparison is made can a connection between the present and the past be evaluated.

GEOLOGIC SETTING

Shark Bay, Western Australia

Australian stromatolites grow in the large, shallow embayment of Hamelin Pool in Shark Bay, on the west coast (Figs. 7 & 8); the basal geology here is a Pleistocene-to-Miocene limestone. The stromatolites occur in supratidal to shallow sub-tidal waters along 100km of shoreline, with the deepest stromatolites found in water depths ranging from 3-4 m. There is a daily average tidal range of 60 cm (tidal range fluctuates between .6 and 1.6 m per year). Water circulation between this pool and the rest of the bay is impeded by the Faure Sill (a bank overgrown with seagrass). Inflow of water comes from the occasional overflow of the Faure Sill, rainfall events, and occasional river and groundwater inflow. Being mostly closed off from the ocean and with high evaporation rates due to regional aridity, Hamelin Pool is hypersaline, with salinity ranging from 55-70‰. Salinity increases from the Faure Sill into the pool, with the highest salinity at the point near the Playford locality (Fig.7). This salinity inhibits the growth of grazers and competitors, while enhancing carbonate oversaturation, creating the perfect environment for stromatolites. (Reid et al., 2003; Sousaari et al., 2016).

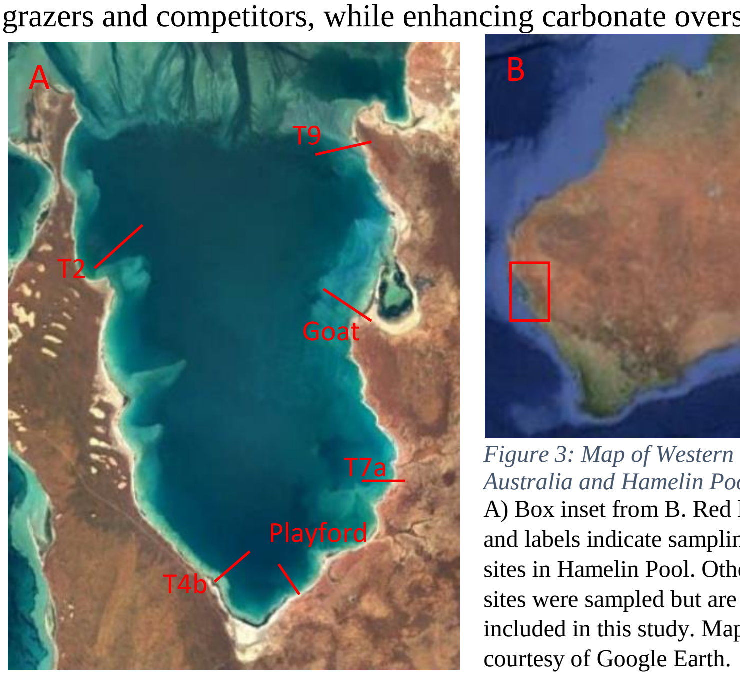


Figure 3: Map of Western Australia and Hamelin Pool
A) Box inset from B. Red lines and labels indicate sampling sites in Hamelin Pool. Other sites were sampled but are not included in this study. Map courtesy of Google Earth.

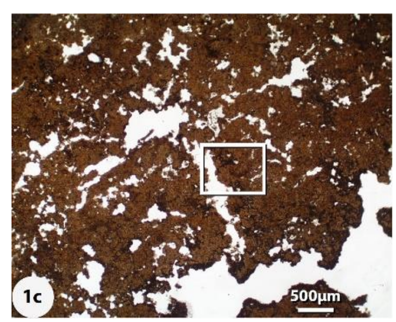
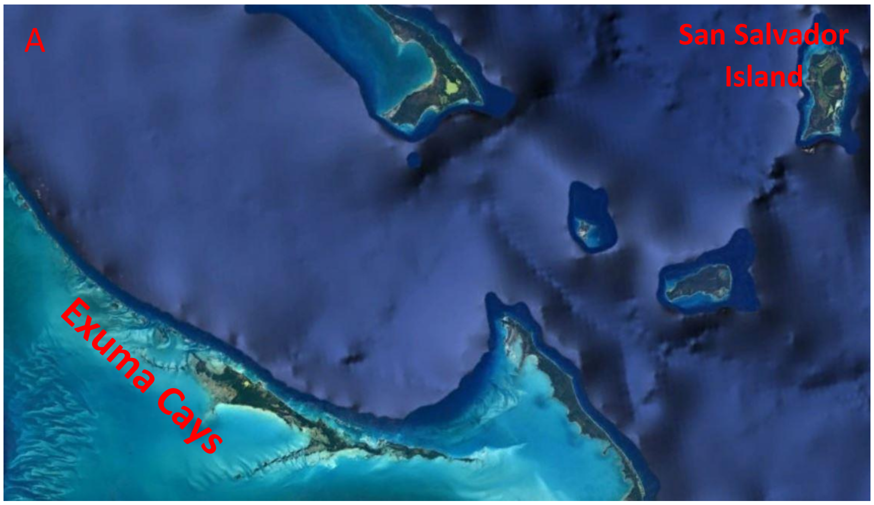


Figure 4
Example of thin section photo from Hamelin Pool (Goat locality), provided by Pamela Reid.

Exuma Cays, Bahamas

In the Bahamas, stromatolites are known to occur at several localities, in both marine and hypersaline lacustrine settings. The open marine stromatolites form along the Exuma Cays, located on the border between the Great Bahama Bank and Exuma Sound. The Great Bahama Bank formed as transitional wind- and water-deposited skeletal and reef facies of the Pliocene to Quaternary oolites and aeolianites (Carew & Mylroie, 1997). Samples for this study come specifically from Little Darby Island and Lee Stocking Island. An additional sample from the Bahamas is from the hypersaline Storr's Lake on San Salvador Island, located eastward of the Exuma Cays, in the open ocean (Fig. 3).



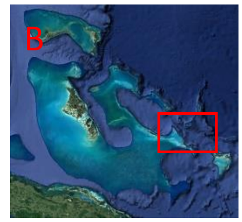


Figure 5: Map of Bahamas and Exuma Cays
A) Inset from B, showing Exuma Cays and San Salvador Island, Bahamas. Map courtesy of Google Maps.

Lee Stocking Island stromatolites (Fig. 4) were the first ones to be discovered in the Bahamas and are the largest and most well-understood. These stromatolites occur in subtidal waters 3-8m deep, between Lee Stocking Island and Norman's Pond Cay. Due to the depth of the water in this area, the stromatolites here grow much larger than in some other areas of the Exuma Cays. These stromatolites can express up to 2m of synoptic relief, with individual stromatolites reaching diameters of up to 25cm. The salinity of the water here varies from 37-40‰, depending on the tidal cycle, slightly higher than the open ocean salinity of ~35‰. These stromatolites are also subject to migrating submarine dunes and are periodically covered in sand, which gives them protection from grazers and borers, among other stressors (Feldmann and McKenzie,1998).

Figure 6
Sample used for analysis of Lee Stocking stromatolites. Sample provided by Pamela Reid. Black bar is unphotographed area.

On Little Darby Island, stromatolites occur in shallow subtidal waters parallel to the beach, located in two clusters, at different depths. The shallower set is in 1m of water (Fig. 5), and the deeper set is in water 2m deep (at low tide). The stromatolites vary in height and width from 30-50 cm, with some ranging up to 60 cm wide, and occur either solitarily or in reef-like clumps. The stromatolites act as a barrier to sand transport in the area, and sometimes have sand deposited atop them. These stromatolites are topped by active microbial mats; these mats cover the shallower set of stromatolites more extensively than the deeper set. These mats are the main builders of the stromatolites, growing upwards and slightly outwards by trapping and binding grains, as well as some in-situ precipitation (Reid et al., 2011).

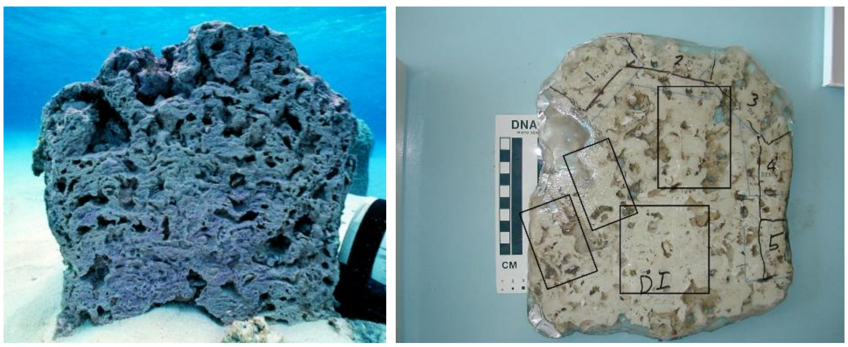


Figure 7
Stromatolite head collected from the shallower subset of stromatolites off Little Darby Island. All analyzed samples from Little Darby are from this head. Images provided by Pamela Reid.

On San Salvador Island, stromatolites are found in hypersaline Storr's Lake (Fig. 6). These stromatolites began growing approximately 2,000 years ago (Brigman et al., 2015) The water is Storr's Lake is rarely over 2 m deep (Mann & Nelson, 1989), and had a salinity of 76 ‰ at the time of sample collection.

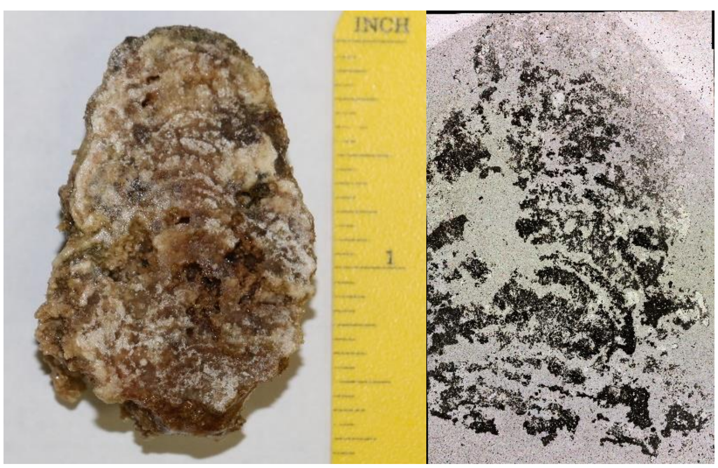


Figure 8
Storr's Lake sample 2, approx. 2 inches in height. Shown as an example of Storr's Lake stromatolites.

METHODS

Sample Collection and Processing

Stromatolite samples were collected from multiple localities in the Bahamas, as well as Shark Bay, Australia. Samples from Lee Stocking Island and Little Darby Island, as well as from Hamelin Pool were collected by Pamela Reid (University of Miami). Samples from Storr's Lake were taken by Brandt Gibson (Vanderbilt University). Samples taken are assumed to be representative of the stromatolites at their respective localities.

Petrographic thin sections were made from these samples, for morphological analysis. Only samples from Storr's Lake needed to be cut into thin sections; Bahamian samples from Pamela Reid were previously thin sectioned and did not need sectioning. Hamelin Pool samples were analyzed using thin section photos provided by Pamela Reid. Storr's lake stromatolites were embedded in Epothin Epoxy Resin (according to procedures on bottle), cut perpendicular to laminations (growing direction). Once cut, billets were commercially prepared by Precimat at a 30-micron thickness with a permanent cover slip and no staining. Thin sections were scanned to generate digital images. All images were analyzed to identify distinct fabrics. Selection tools in ImageJ permitted the areas represented by each fabric to be separately coded and grouped. Once each fabric was selected and color-coded, the thresholding tool of ImageJ was applied to compute percentages of area for each fabric on a thin section. Fabric percentages were normalized to account for lost space in images, and the normalized percentages of fabrics in each sample were compared.

Fabric Identification and Classification

The Hamelin Pool Microstructure booklet (Hagan et al., *unpublished*) provided by Pamela Reid was used as a starting point for fabric nomenclature. The following microfabrics were identified in this booklet:

- Micrite: Microcrystalline calcite formed *in situ* by mineral precipitation.
    - Red-Brown Micrite: Reddish-brown 'cauliflower-like' massive micrite, can have laminations and form 'crustal topping'.
    - Clotted Gray Micrite: Gray toned micrite forming in much finer/smaller clusters than red-brown micrite; clotted.
    - Dark Micrite: Often found bordering red-brown micrite, clot size difficult to determine due to darkness of shade.
    - Fibrous Micrite: Component of red-brown micrite that clearly exhibits distinct upwards growth.
- Cemented Grains: Grains are deposited atop a stromatolite which grows around them to include them in the final structure. Variable in size, shape, and composition.
- Quartz Inclusions: Quartz grains that are found within the stromatolites (similar to cemented grains).
- Botryoidal Aragonite: Secondary feature filling in void space, growing inward into voids, with fibrous structure.
- Dark Peloidal Cement: Secondary feature filling in void space, filling from within the void space slightly resembles dark micrite.

Microstructures of Exuma Cays stromatolites were determined by original nomenclature derived from the nomenclature found in the Hamelin Pool Microstructure booklet (Hagan et al., *unpublished*).

- Cemented Grains: Grains deposited atop a stromatolite which then grows around them to include them in the final structure. Grains are variable in size, shape, and composition, although the majority are sand-sized carbonate clasts (shells, etc.). Grains can have various levels of cementation, ranging from well- to poorly-cemented. Well cemented grains are found in stromatolites where the grains make up most of the fabric, with little visible micritic matrix. Poorly cemented grains have fewer grains in the stromatolite and a higher percentage of micritic matrix.
- Massive Micrite: Microcrystalline calcite formed in situ by mineral precipitation, clotted, similar to Hamelin Pool micrites.
- Filamentous Micrite: Filamentous micrite has the same basic texture as massive micrite, but different methods of formation. Filamentous micrite has an additional component of radial growth, while massive micrite is simply clotted micrite growing in no specific pattern.

RESULTS

Hamelin Pool, Western Australia

Hamelin Pool stromatolites are highly variable in both meso-and micro-fabric. Mesofabrics range from finely laminated to massive and clotted. In most cases, each locality has a similar range of mesofabrics, but some of the localities have a dominant mesofabric (Table 2). Only a subsample of all stromatolites collected from Hamelin Pool (Fig. 3) are represented here; this study serves as a starting point containing the full range of microfabric diversity present in the pool.

Locality	Head #	Mesofabric	Descriptor
Goat	H3	Unlaminated	Clotted
Goat	H4	Unlaminated	Massive
Goat	H5	Laminated	Fine
Playford	H1	Laminated	Very Fine
Playford	H2	Laminated	Very Fine
T2b	H1	Laminated	Coarse
T2b	H2	Laminated	Coarse
T4b	H3	Laminated	Very Fine
T4b	H3	Unlaminated	Massive + Sediment
T4b	H5	Unlaminated	Massive + Sediment
T4b	H6	Unlaminated	Clotted
T4b	H6	Laminated	Medium
T7a	H1	Diagenetic	
T7a	H3	Laminated	Very Fine
T7a	H4	Laminated	Very Fine
T7a	H4	Diagenetic	
T9	H1	Diagenetic	
T9	H2	Diagenetic	

Table 1: Mesofabrics in Hamelin Pool Stromatolites
First two columns represent location and identifiers for each head. The next two columns describe mesofabric, as identified by Reid. The final column identifies related photos in the microfabric booklet (Hagan et al., 2014)

The microfabrics of the Hamelin Pool stromatolites are also diverse, with ten definable fabrics, as well as void space, making up the stromatolites. Each stromatolite has a unique combination of microfabrics, but no microfabric is seen in every stromatolite; on average each stromatolite contains 2.8 microfabrics, with a maximum of 5 represented in a sample and a minimum of 2 (Fig. 9). The presence and names of these microfabrics were determined by Hagan et al. (*unpublished*) and evaluation of area and percentage are original data.

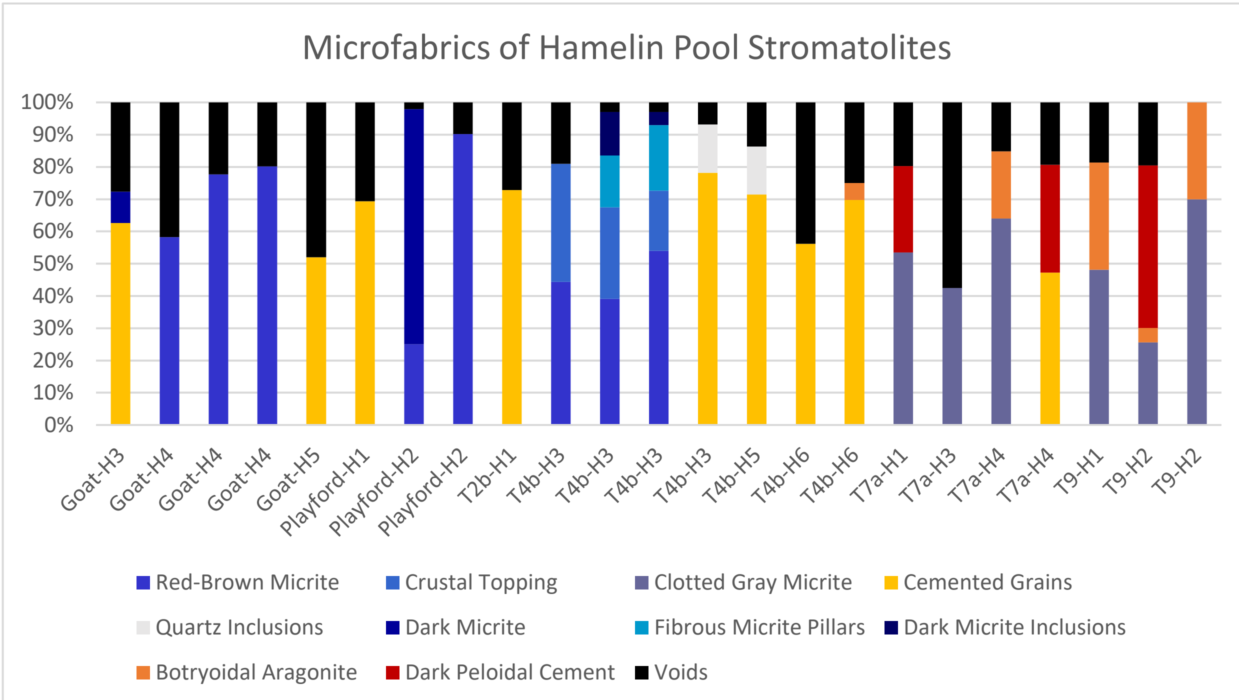


Figure 9: Microfabrics of Hamelin Pool Stromatolites

The normalized percentages of the microfabrics of Hamelin Pool are represented in this graph, following nomenclature of Hagan et al., *unpublished*, and are organized by location in Hamelin Pool.

Despite the large variety in stromatolites throughout the pool, there is a more distinct pattern observed between stromatolites in specific localities within Hamelin Pool, as evidenced in figures 10 and 11. Here, we see that stromatolites from the same location have similar microfabric composition, and that some of the general compositions match between localities. Figure 3 shows a map of the sampling sites in Hamelin Pool, and the locality names assigned to each site.

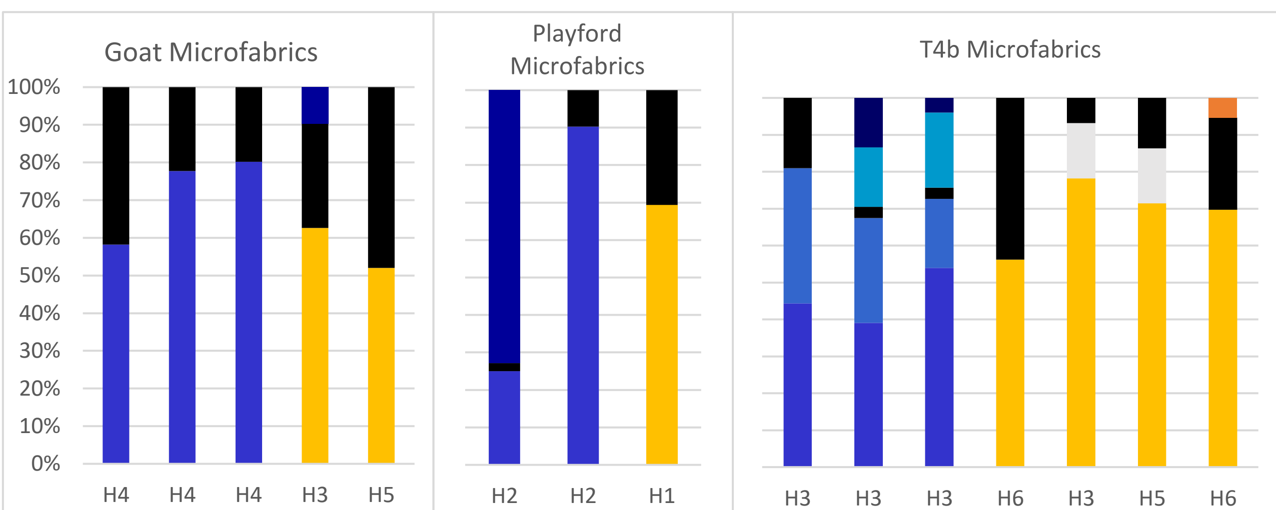


Figure 10: Microfabrics of Goat, Playford, and T4b localities

Goat, Playford, and T4b localities are all dominated by red-brown micrite and cemented grains, with other microfabrics forming smaller percentages. Colors of graph correspond to Fig. 4 legend.

The Goat, Playford, and T4b localities (Fig. 10) all show similar compositions, with red-brown micrite and cemented grains acting as the primary component and other microfabrics (and voids) filling out the rest. At these localities, dark peloidal cement and clotted gray micrite are absent.

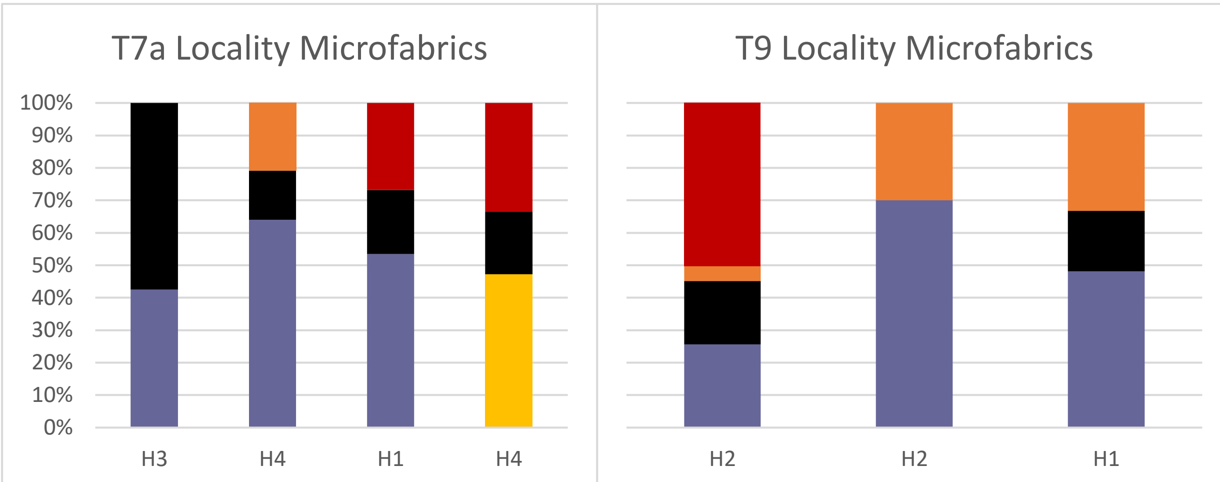


Figure 11: Microfabrics of T7a and T9 localities
T7a and T9 localities are both dominated by clotted gray micrite and dark peloidal cement. Void space, botryoidal aragonite, and cemented grains fill in the remainder of space in these stromatolites. Colors of graph correspond to Fig. 4 legend.

The T7a and T9 localities (Fig. 11) also show similarities, with clotted gray micrite serving as the main fabric, followed by botryoidal aragonite in these specimens (H4 being the exception). Voids are also present in all except H2. The majority of microfabrics exhibited in Goat, Playford, and T4b are missing at T7a and T9. The fabrics that were missing in Goat, Playford, and T4b (dark peloidal cement and clotted gray micrite) are prominent in T7a and T9.

Exuma Cays, Bahamas

The mesofabrics of the Bahamas are predominantly laminated, with fineness of laminae varying depending on the location and each sample specifically. Two general microfabric types dominate the stromatolites of the Bahamas: cemented grains and micrite. While similar to those seen in Hamelin Pool, there are differences between the two.

Only one sample from Little Darby Island was used for this analysis (from the shallower set of stromatolites) but given the proximity of all the stromatolites of Little Darby Island, it can be used to generalize the behavior of the whole set. The Little Darby Island stromatolites (Fig. 12) are highly dominated by cemented grains, with varying levels of cementation.

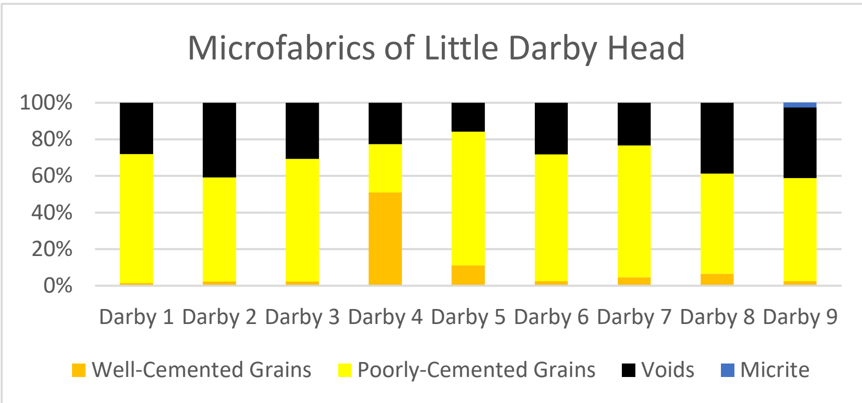


Figure 12: Microfabrics of Little Darby Stromatolites
The stromatolite sample from Little Darby Island is primarily composed of cemented grains. The level of cementation in these grains is variable. Only a small percentage (2%) of one thin section contains micrite.

Storr’s Lake stromatolites (Fig. 13) show a very different composition than Little Darby Island. Filamentous micrite makes up the majority of the microfabric percentages, with non-filamentous micrite filling in gaps, and cemented grains making up just a small portion of one sample.

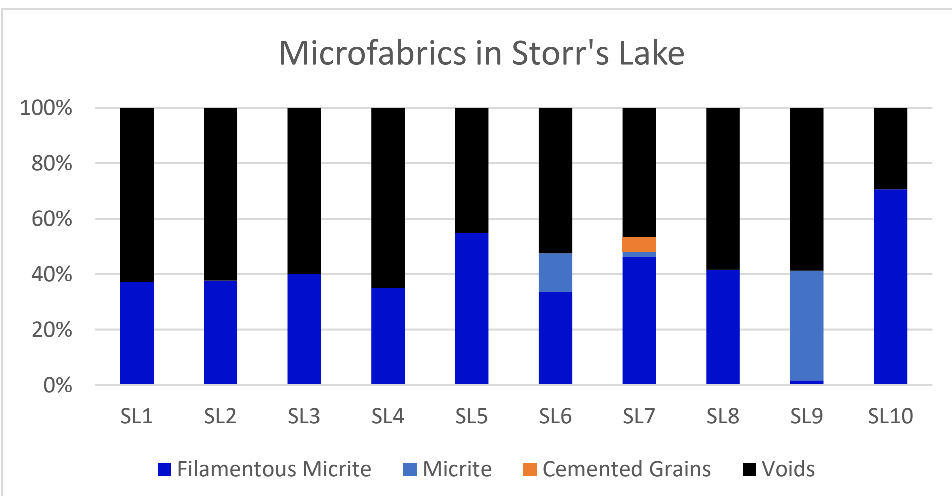


Figure 13: Microfabrics of Storr’s Lake stromatolites
The samples from Storr’s Lake are composed mainly of a filamentous micrite, with the presence of some cemented grains and non-filamentous micrite.

Only one sample from Lee Stocking was analyzed; showing a high percentage of cemented grains. In the Bahamas, it is most similar to the stromatolites of Darby, rather than the micrite dominated samples from Storr’s Lake (Fig. 14).

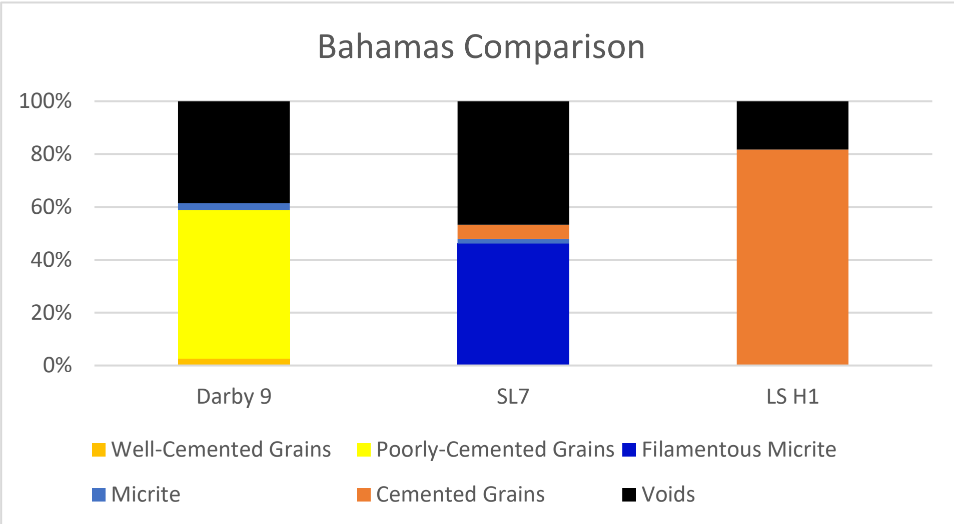


Figure 14: Microfabric Comparison between Bahamian Stromatolites
Lee Stocking and Darby show similar microfabric composition, both are dominated by cemented grains, while Storr's Lake is dominated by a filamentous micrite.

DISCUSSION

In order to determine whether modern stromatolites can accurately key to ancient stromatolites, it must first be determined whether the two modern stromatolites are indeed similar to each other. With the microfabric data collected in this study from Hamelin Pool and Exuma Cays, this can be decided, on a preliminary basis.

Hamelin Pool

In Hamelin Pool, cemented grains are the most prevalent microfabric, with red-brown micrite the second highest and clotted gray micrite coming in a close third. This high percentage of cemented grains shows that these stromatolites are built predominantly by the process of trapping and binding, with mineral precipitation serving as a secondary building block. The mineral precipitation that is observed here serves to stabilize the structure of the stromatolite and prevent grains from being washed away.

T4b, Playford, and Goat localities all show a similar microfabric array, consisting of red-brown micrite and cemented grains acting as the dominant fabric, with some exceptions. T4b and Playford are both located towards the landward of the pool, while Goat is closer to the bay mouth. T4b and Playford likely have similar environments, explaining the similar composition found between them. Goat is not located near the other two, but likely has similar environmental conditions as T4b and Playford.

T7a and T9 localities show similar microfabric compositions of clotted gray micrite dominating with a presence of botryoidal aragonite. T7a and T9 are located on the same side of Hamelin Pool (east) but are not in immediate vicinity of each other. Their similar composition was likely caused by environmental impacts that are similar, but not identical, influencing the growth of clotted micrite and botryoidal aragonite.

Bahamas

In the Bahamas, a significant difference in microfabric types is noticed between localities. The stromatolites of Exuma Cay, which are in an open marine setting, are composed mainly of cemented grains with subordinate micrite. The open marine setting allows for travelling subtidal dunes to occasionally cover stromatolites (Reid et al., 2011). The high presence of carbonate sand in these environments allots for the high percentage of cemented grains. Cementation likely stabilizes the trapped grains on the surface of the stromatolite. These grains also show evidence of boring, which can be explained by smaller organisms living in the environment.

In contrast, the stromatolites of Storr's Lake have a small percentage of cemented grains and are mainly composed of filamentous micrite. As there is less sand in the lake, the stromatolites are not being covered by dunes periodically, which explains the lack of cemented grains in the lacustrine setting. The salinity may explain the lack of boring in the Storr's Lake samples – small organisms that are likely the culprits of boring are not adapted to live in environments with such high salinity (76‰ at time of sample collection), and thus the stromatolites experience less competition and danger.

Modern Stromatolite Comparison

In the Bahamas, there are two very different microfabric compositions, one that dominates open marine environments and one that characterizes a closed hypersaline lacustrine environment. At first glance, Hamelin Pool stromatolites seem to be more similar to the stromatolites of Storr's Lake than those of Exuma Cay. This is the probably correct: however, Hamelin Pool stromatolites contain a higher percentage of cemented grains than those in Storr's Lake. This is because Hamelin Pool has a degree of water flow with the ocean, while Storr's Lake is closed off from the marine setting. Thus, sand-sized skeletal material can be transported into Hamelin Pool, providing a source of trapped grains to the stromatolites. Overall, there is a variety of microfabric textures across these environments that can be generally compared to the others but are not similar enough to be called by the same name. However, certain microfabrics may still compare to microfabrics of ancient stromatolites. One hypothesis on the diversity between Proterozoic and modern stromatolites is a temporal change from precipitate-dominated to micrite/grain-dominated stromatolites over the course of the Proterozoic. (Kah & Knoll, 1996). This study corroborates this hypothesis, as evidenced by the increased amount of cemented grains seen in the modern marine stromatolites, while the hypersaline stromatolites have fewer grains overall. This is observable in the modern, but the connection between modern and ancient is more difficult to confirm based on this study.

There is potential for error in this study. The analysis of samples from Hamelin Pool was done without having thin sections or slabs available and were based on photos and photomicrographs sent to us. This may cause uncertainties in the exact percentages of certain microfabrics, as scanned images could not be personally verified. Threshold cutoff values in ImageJ can be difficult to determine, so a repetition of this study could result in slightly different values, though the general story would remain the same. Though the general conditions for Hamelin Pool are as described earlier (Reid et al., 2003 and Sousaari et al., 2016), the specific details (exact coordinates, salinity, water depth, etc.) for these samples is unknown, leading to some guesswork based on Figure 3.

CONCLUSION

The question leading this study is whether the microfabrics of stromatolites in Hamelin Pool and the Bahamas are the same, or similar enough to each other that they can be used to compare to ancient stromatolites. Three main microfabrics were identified in the modern stromatolites: cemented grains, filamentous micrite, and massive micrite. The three ancient microfabrics are isopachous cement, uniform micrite, and grumeaux (clotted micrite). It is plausible that the modern micrites are similar enough to the ancient micrites that they could be a match. However, the modern cemented grains and the ancient isopachous cement have no clear analogue across time.

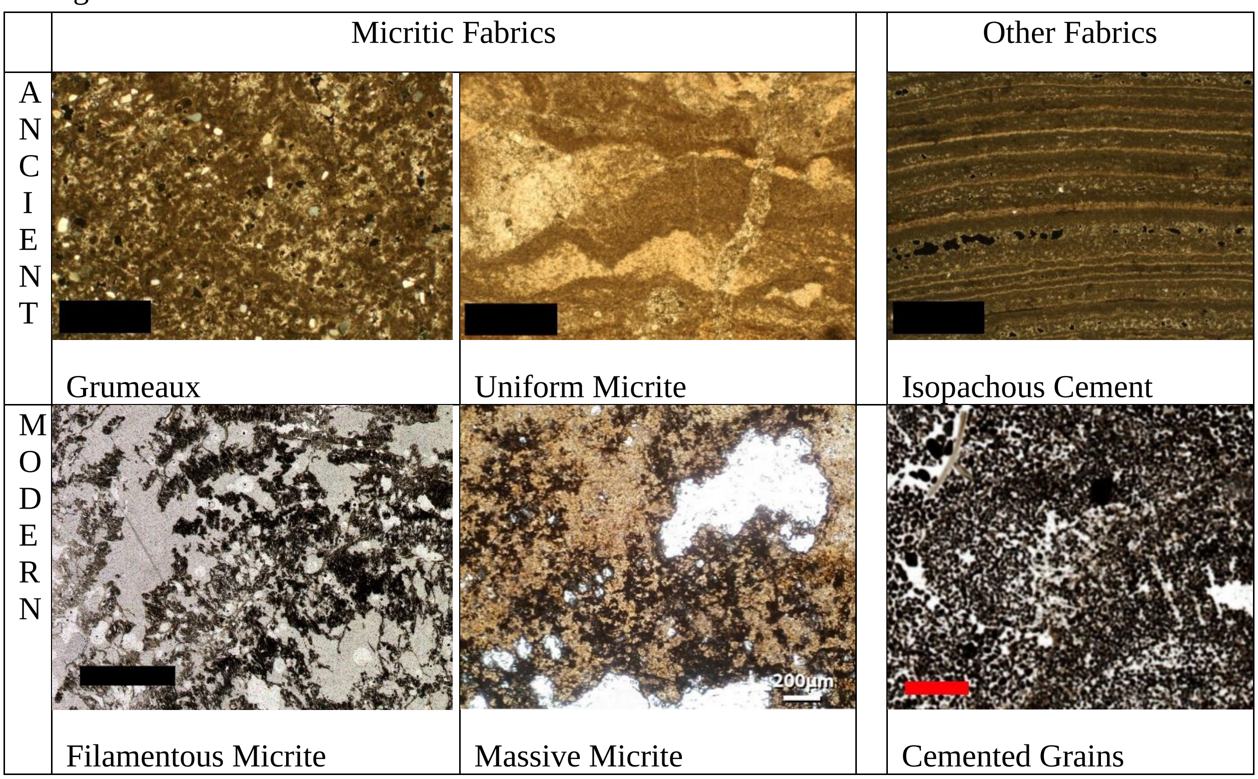


Figure 15: Relations between modern and ancient microfabrics
The uniform micrite and clotted grumeaux micrite of ancient stromatolites probably corresponds to the massive and filamentous micrite of modern stromatolites, but isopachous cement and cemented grains do not appear to have a clear analogue between them. Scale bars = 1mm except for massive micrite, where scale bar = 200µm. Massive Micrite photo from Hagan et al., *unpublished*. All ancient photos from Bruihler et al., 2017. Filamentous Micrite from Storr's Lake, Cemented Grains from Lee Stocking.

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