Contemporary stromatolite formation in high intertidal rock pools, Giant’s Causeway, Northern Ireland: preliminary observations.

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ABSTRACT


INTRODUCTION

Stromatolites have been defined as “organosedimentary structures produced by the trapping, binding, and precipitation of sediments under the influence of microorganisms” (Awramik and Grey, 2005 p.1 ) or “microbial organo-sedimentary deposits with planar to sub-planar laminated internal macro-fabrics of benthic origin” (Jahnert and Colins, 2012, p118). They have been documented from a variety of contemporary environments and are most commonly associated with extreme environmental conditions that limit competition with and/or predation by other organisms. The best known (largest structures and most extensive) contemporary occurrences are from hypersaline coastal lagoons such as Hamelin Pool, Western Australia (Logan et al., 1974) and normal marine salinity fringing reef settings in the Bahamas (Dill et al., 1986). Stromatolites are, however best known from the geological record, and in particular the Archaean when they played an important role in early Earth history (Awramik and Grey, 2005).

The form and structure of stromatolites is variable and in modern coastal settings is believed to be influenced by the interaction between energy levels, evaporation rates, sediment supply and underlying topography (Jahnert & Collins, 2012). Modern stromatolites are typically found in the intertidal and subtidal zone, but contemporary occurrences in the supratidal zone are rare. Recently, however, Smith et al., (2011) described calcifying tufa stromatolites from rock pools on a high-intertidal supratidal rock platform in South Africa that bears comparison to the setting described here. Those occurrences were deemed to be a potential analogue for some Archaean stromatolite occurrences.

The aim in this paper is to document the occurrence of stromatolites in supratidal rock pools at the Giant’s Causeway. This occurrence is unique in Ireland and only one other case from Morgan Bay in South Africa (Smith et al., 2011) is known. The environment of deposition and the physical structure of the
stromatolites is described. The results are based upon field mapping, observation and thin section and Scanning Electron Microscope (SEM) analysis.

ENVIRONMENTAL SETTING

The study area is the Giant’s Causeway coast of Northern Ireland (Figure 1). Spring tidal variation is about 1.5 m and the coast is an Atlantic storm-wave environment, subject to modally high wave energy with long-term median significant wave heights of 2 to 3 m and periods of 8 to 9 seconds (Jackson et al. 2005).

Incident swell waves are refracted to give a broadly shore-normal approach at the coast. This, coupled with the indented nature of the coast, means that longshore drift is only locally developed (within individual bays) and is unimportant in the regional coastal sediment budget. The wind regime is also high energy with a dominant WSW (offshore) direction and a secondary peak in wind direction from the north to northwest quadrant (onshore). Relative sea level in the region exhibits a mid-Holocene highstand of 2-3 m above present (Cooper et al., 2002; Kelley et al., 2006).

The rocky north coast of Northern Ireland comprises Tertiary basalt flows (Lyle, 2002). The cliffs are up to 120m high and are fronted by rock platforms that exceed 100m in width (Figure 2). They are subhorizontal and terminate seawards in abrupt low-tide cliffs that drop 5-10 m vertically (McKenna, 2002). The upper surface of the rock platforms extend from the low tide level to 1-1.5m elevation. Their upper surfaces experience active erosion during contemporary wave conditions (McKenna et al., 2011), although the higher sections of the rock platforms are only inundated occasionally during storms (McKenna et al., 2012). At the rear of the shore platforms accumulations of fine, carbonate-rich sand occur as storm swash terraces (McKenna et al., 2012). These are often topped by salt marsh vegetation (Cooper and Power, 2003) and are maintained by a combination of salt spray (that limits competition from terrestrial plants) and freshwater springs emerging from the base of the cliffs (that create waterlogged conditions).

STROMATOLITE OCCURRENCE

Stromatolites were first discovered at the site in October 2011 in rock pools on the high, supratidal sections of the rock platform in three general locations (Figure 2). The setting in which they occur is consistent among the localities in that it involves a fronting rock shore platform, a storm swash terrace to landward, and springs

![Figure 1. Locality map of Giant’s Causeway on the North coast of Northern Ireland.](image1.png)

![Figure 2. Oblique aerial view of Giant’s Causeway site on Ireland’s northern coast. (Image from Google Earth, coast is NE-SW from left to right.) Localities 1-3 mark location of stromatolites in supratidal rock pools.](image2.png)

![Figure 3. Environmental setting of stromatolite-containing rock pools. A. The pools (arrowed) are at the junction of a wide shore platform and a high cliff from which emerge freshwater springs (note road for scale). B. Storm swash terraces (arrowed) composed of skeletal shell sands, provide a potential source of carbonate. View is to the south.](image3.png)
emerging from the base of the basalt cliffs (Figure 3). The stromatolites are found in shallow rock pools close to the junction between salt marsh (Figure 4) and the bare rock platform (Figure 5) where occasional marine inundation occurs only during storms. Rock pools further seaward contain only marine algae while those to landward are stagnant pools. Stromatolites occur as encrustations on the bedrock base of pools or on boulders in the pools.

On the surface of epilithic carbonate deposits on bedrock and boulders there was a thick growth of olive-green hemispherical and spherical colonies of cyanobacteria trichomes. Taxonomic identification solely based on morphology placed them within the genus *Rivularia* (*Rivulariaceae, Nostocales, Cyanobacteria*) (Figure 4). Individual trichomes in the colonies were heteropolar with basal heterocysts, while their apical ends attenuated into very long and thin hair like cells (Figure 5). Recent genetic studies, however, have drawn attention to the urgent need of a taxonomic revision of *Rivularia* and *Calothrix* (Berendero et al., 2008). Non-organic particles contained within the colonies were presumed to be carbonates, because of their dissolution in 0.5M hydrochloric acid with simultaneous release of gas.

These cyanobacteria appear to have established a permanent presence on rock with carbonate deposits, and were found throughout the seasons. Typically for rock pools in the intertidal zone the amplitude of the water’s salinity is wide and can change very fast. Measurements of electrical conductivity $\kappa_{25}$ ranged from 1.1 mS/cm to 13.9 mS/cm. Freshwater was supplied by seepage water from adjacent cliffs. Deployment of a conductivity logger demonstrated that saline intrusions do not occur daily, but only episodically depending on the water level at high tide (Figure 6).

*Rivularia* strains have often been found to be associated with calcium carbonate deposits (e.g. Pentecost, 1987, Hägele et al, 2006). Two main stromatolite growth forms were recorded. Smooth encrusting forms (Figure 7) are present at site 2 (Figure 2). These form a thin (2mm) veneer, the outer layer of which consists of living cyanobacteria. Colloform stromatolites (Figures 8, 9) occur at Sites 1 and 3 (Figure 2). These again form a thin encrustation (2-4mm thick) of living cyanobacteria.
MICROSCOPIC ANALYSIS

Pebbles encrusted with stromatolites were prepared for thin section and scanning electron microscope (SEM) examination. Laminations are poorly preserved due to recrystallisation, but distinct laminae couplets (alternations of thick and thin laminae) were present in a number of samples. These contain up to four laminae couplets which exhibit a common motif. The thicker lamina (40 μm) is represented by vertically stacked diatoms (Fig. 10). It is likely that these were bound in this position by cyanobacteria that have not been preserved (or ground away during the thin-section process). The thinner lamina (10 μm ) is represented by trapped dust grains and diatoms with long axes parallel to the lamina.

The structure was further investigated using SEM (Figure 11). This showed the thicker laminae to contain vertical Rivularia filaments (parallel to the diatom orientation) while the thinner laminae were composed of flat lying filaments (Figure 12). The vertically orientated cyanobacterial filaments are 4.5 to 8 μm in diameter and extend more-or-less vertically (up to 0.4 mm) across the thick lamina. Flat-lying filaments are apparently thinner at 3 microns in diameter. Modern cyanobacterial filaments vary from 1 to 80 μm in diameter and are commonly in the 1-25 μm range (Schopf, 1977).
DISCUSSION

The stromatolites at the Giants Causeway appear to form in a fairly distinct zone that exists as a result of a particular combination of circumstances. The pools are located in the supratidal section of the rock platform where occasional marine inundation occurs. Pools further seaward regularly experience marine conditions and are unsuitable for cyanobacteria colonization due to high competition rates. Pools to landward are dominated by rainwater and are stagnant pools. The zone where stromatolites occur appears to be characterized by regular (likely perennial) discharge of stream water from the base of the cliffs and periodic inundation by seawater during storms. It is suggested that this combination of circumstances enables cyanobacteria to thrive in these few rock pools. It is deemed likely that the presence of carbonate-rich storm swash terraces immediately landward of the pools provides a suitable source of carbonate for stromatolite formation.

According to Reid et al.’s (2000) classification of growing stromatolites the thick Giants Causeway lamina conform to a Type 1 mat (vertical Rivularia filaments) whereas the thinner laminae are of Type 3 (including random Rivularia filaments) and Type 2 (mostly calcified biofilm and rare Rivularia filaments). Type 1 is regarded as a pioneer community whereas Types 2 & 3 are of a more mature nature. Reid et al. (2000) suggest that a Type 1 mat represents rapid filament growth, possibly during inclement weather (Smith et al., 2011) while Type 2 & 3 represent slower climax growth. Alternations between the two growth forms at the same locality are thus interpreted as a reflection of varying hydrodynamic conditions. The fact that the stromatolites are very thin suggests that conditions for their formation have only recently developed or that they are periodically destroyed by unsuitable environmental; conditions. This will be investigated during ongoing research.

The Giant’s Causeway stromatolites bear comparison to those described by Smith et al. (2011) from a supratidal rock platform at Morgan’s Bay, South Africa. The Morgan’s Bay examples are substantially thicker and better developed, but their environment of formation is similar to that recorded here. Both are high wave energy settings with basaltic bedrock (dolerite at Morgans Bay) forming cliffs and shore platforms. At Morgan’s Bay stromatolites occur in rock pools that are periodically inundated by marine storms, but which are fed by mineralized spring water. The source of the carbonate may be in the spring water, but carbonate-rich storm swash terraces are also present on the rock platform. At Morgan’s Bay the stromatolite zone extends further seaward to adjacent boulder beaches and boulders are periodically bound together by stromatolite cementation. This suggests more active and persistent periods of stromatolite-forming conditions at that site. We suggest that the Giant’s Causeway and Morgans Bay stromatolite occurrences represent a previously undescribed coastal facies. Both are also associated with the recently described storm swash terrace landforms but a genetic linkage has yet to be proven.
LITERATURE CITED


