Cyanobacterial extremophiles associated with the formation of the coloured sands on Fraser Island

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Abstract

Cyanobacteria are ancient prokaryotes that carry out photosynthesis for growth. Their long evolutionary history and success can be attributed to their capacity to evolve and adapt to their environment. Cyanobacterial extremophiles exist in some of the Earth's harshest environments, where they have developed strategies to protect themselves against high levels of UV, long periods of drought and extremes of temperature. On Fraser Island cyanobacterial communities have colonised on and underneath the silica sands and iron deposits. A study of the sub-surface cyanobacterial mats that were located on the marginal regions of the sand blows and fringes of exposed iron sediments showed there was a connection between their colonies and the coloured sands. Within these large-scale landscape processes micro-colonisation occurs with the distribution by wind and water of invisible fragments of cyanobacteria. The evidence points towards biogeochemical interactions occurring between cyanobacterial colonisation and underlying or exposed iron sediment layer with its weathered pedestal formations and ridgelines. Leaching of iron oxides occurs when cyanobacteria alter oxygen concentrations and raise the pH on a micro-scale basis. Cyanobacteria use ferrous iron to aid in its pigmentation and create protective layer against damaging UV rays. Eventually, well established cyanobacterial mats are formed stabilising the region on a larger scale and incorporating a diverse biological crust that includes a range of cyanobacteria, algae, lichens, mosses, liverworts, micro-fungi and bacteria. These are important ecosystems and need to be studied in more detail and protected from damage in critical environments.

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The evolution of cyanobacterial extremophiles

Cyanobacteria are photosynthetic prokaryotes that have a long evolutionary history dating back to the Proterozoic Era that is often referred to as the 'Age of Cyanobacteria' due to their abundance in fossil records (Whitton and Potts, 2000). The formation of stromatolites, rich with ancient cyanobacterial fossils, and huge Banded Iron Formations (BIF's) resulting from the oxidisation of iron, support the origin of oxygenic photosynthesis. Cyanobacteria are often referred to as extremophiles as they have evolved and adapted to surviving in the harshest environments on Earth. They can survive in extremes of temperature and light, conditions of limited moisture (e.g. hot and cold deserts), and in nutrient-deficient environments. Cyanobacterial colonies produce specialised pigmentation as part of their response strategy for survival in environmentally stressed conditions and as a defence against harmful UV radiation. Terrestrial cyanobacteria can remain in a desiccated (dried) state without damage to their cells, for many decades but recover their full cellular functions within minutes of rewetting. Cyanobacterial extremophiles exist throughout many of Earth's extreme environments and their success can be attributed to their long evolutionary history of adaptation.

Cyanobacterial communities of Fraser Island

On Fraser Island cyanobacterial have been found colonising a range of terrestrial environments including on top of and a few millimetres below the sands. These are harsh environments where temperatures could reach in excess of 70°C and moisture would rapidly infiltrate the sands or evaporate, leaving only small windows of opportunity for growth. FIDO has previously reported the importance of these cyanobacterial communities where they function to retain moisture, limit the erosion and contribute to the islands diversity. Furthermore FIDO had observed that cyanobacteria had colonised the regions of iron pedestals and seemed associated with the leaching of iron oxides and the formation of coffee rocks and coloured sands. This report is about the cyanobacterial mats occurring around the sand blows and dunes between the coastal dunes and inland lakes.

Initially, an area at the Hammersltone Sand Blow was traversed and several types of biogenic (cryptobiotic) mats were evident including later successional lichen-moss-dominated mats within the shrub areas. Of particular interest are the cyanobacterial colonies and mats occurring in the open regions where some emerging iron deposits are also evident. The question is raised as to whether the coloured sands found on Fraser Island are related to biogeochemical processes that include iron oxidation. This report focuses on the structure and attributes of the cyanobacterial mats to be followed up by further analytical work and site surveys.

Structure of cyanobacterial mats

The physical structure of these cyanobacterial mats varies somewhat depending on the location. There were two primary types of mat communities found in contrasting environments: (1) subsurface mats, occurring in marginal areas where sand deposition occurred periodically, there was direct exposure to high light intensities, temperatures and UV, and where there was an underlying iron deposit, and (2) thick dark surface mats, occurring in slightly more stable areas rarely with underlying iron deposits but potentially receiving runoff from adjacent regions.

Microscopic examination of these two communities showed the dominant cyanobacteria *Scytonema* to be common to both mats; however the structural differences in the mats appear relevant to this study. The thick dark surface mats appeared typical of many terrestrial cyanobacterial mats (containing several cyanobacterial species) and appears to be a successional type community in a transitional state. Along a transect from the dunes to the shrub community the community composition changes from cyanobacterial mats to a complex biological community of lichens, mosses, liverworts, algae and cyanobacteria. This transect could typically represent time and the successional changes that occur should conditions remain favourable to the long-term stabilisation of any particular area. These cyanobacterial communities deserve a more detailed study in order to understand the underlying processes of dune movement or stabilisation that are evidently taking place over many years.

In contrast the subsurface colonies of cyanobacteria were stratified (micro-layered) communities that are conceivably both directly and indirectly creating the famous coloured sands and cliffs of Fraser Island. The stratification of cyanobacterial mats are well documented in the intertidal zones of marine environments; however the mats found here are primarily occupying a transitional ecotone and excluding natural extreme weather events, may exist as such for many years. One of the focal points within these areas is the underlying or exposed iron sediment layer with its weathered pedestal formations and ridgelines.

Cyanobacterial-mediated iron oxidisation banded formations

Marine microbial mats form distinct layers of oxidised iron and possibly account for BIF's mostly formed during the early Proterozoic age. One mechanism for BIF's is the chemical oxidation of ferrous iron with oxygen evolved from oxygenic photosynthesis by cyanobacteria (Stal, 2000). Additionally, ferrous iron will react with oxygen to keep the partial pressure of oxygen sufficiently low to allow efficient photosynthesis by cyanobacteria (Stal, 2000) thus creating favourable conditions for colonisation. Ferrous and ferric iron also plays an important role in the protection of UV. Its production and accumulation in cyanobacterial mats contributes to the properties of cyanobacterial UV protectants (scytonemin) and its dark 'rusty' colour. Large amounts of iron have been found to accumulate in the outer sheaths of the mat forming cyanobacteria *Microcoleus chthonoplastes*, bound by negatively charged polysaccharides (Stal, 1994). As cyanobacteria build new colonies they evacuate their sheaths leaving a scytomenin-rich network of empty tubes behind. These are gradually broken down and can result in an iron-carbon rich vein in the sands or BIF.

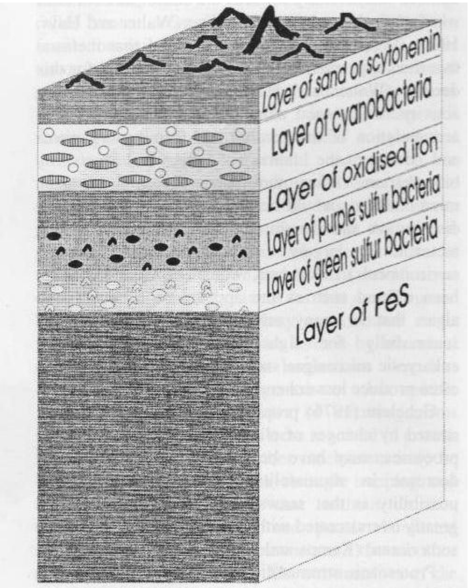

Figure * The structure of a typical microbial-cyanobacterial mat as depicted by Stal, (2000)

A study of the sub-surface cyanobacterial mats found on the marginal regions of the sand blows and fringes of exposed iron sediments indicated a link between their existence and the coloured sands. Although the chemical and biological processes of iron oxidation within this environment are not clear, the stratification and structure of cyanobacterial mats (Fig.*) provide one likely explanation for both the historical formation of the coloured sands and their ongoing existence. Biological stratification as a result of chemical and light gradients are found in almost all cyanobacterial mats, including distinct layers of oxidised iron between cyanobacteria and purple sulphur bacteria (Stal, 1994). Although outside the scope of this study there is little doubt that cyanobacterial-bacterial associations are also important in the processes.

The evidence points towards biogeochemical interactions occurring between cyanobacterial colonies and underlying or exposed iron sediment layer with its weathered pedestal formations and ridgelines. Over time weathering by wind and water take place shaping the dunes and sand blows. Within these large-scale landscape processes micro-colonisation occurs with the distribution of invisible fragments of cyanobacteria. These microscopic parcels of ancient plant-like organisms can quickly colonise suitable niches and make use of the limited resources. The ready availability of iron oxides from water washing over the exposed sediments or the capacity of cyanobacteria to raise the pH and oxidise iron initiates an essential step in its success as an early coloniser. Eventually, well established cyanobacterial mats are formed stabilising the region on a larger scale. This process paves the way for the entrapment of water and seeds. Once a stable environment exists there is a new successional sere with the establishment of a more complex biological crust. Over time other cyanobacteria, algae, lichens, mosses, liverworts, micro-fungi and bacteria will colonise suitable micro-habitats. This well developed crustal ecosystem now provides a strong defence against erosion and leaches nutrients into the surrounding substrate, in a form available to plants.

Essentially, the formation of these specialist cyanobacterial mats and biological crusts are an integral part of the dunes and shrublands of Fraser Island. Cyanobacteria are an important part in the formation of the coloured sands and to the stabilisation of mobile material. Studies of the diversity of these crust communities and the preservation of fragile ecosystems is extremely important to the management of this island landscape.

I strongly recommend FIDO seek to establish records of the biological crusts of Fraser Island. FIDO should encourage the continuation of the investigations of the biogeochemical processes that take place. An integrated research team of interested scientists could be set up and funding sought in order to progress this work.