

THE FOSSILS OF **BELL ISLAND**



Rare sunny days showed off the cliff sedimentology, which was not always accessible without a boat. Freshwater Cove, was only accessible by climbing down a stream bed and using an abandoned fence (visible to the left) as a makeshift ladder

Burrowing animals helped kill off ancient seafloor matgrounds. **Catherine Mascord** reports on the role of shallow burrowers with links to the oxygenated surface in initiating this process

On the surface, Bell Island, Newfoundland appears unremarkable in geological terms. The island is relatively flat with few hills or other dramatic geography, and most of the rocky outcrops are limited to the cliffs along the island's coastline.

Throughout much of the early 20th century the island was host to one of the most productive iron ore mines in Canada. Today the mines are decommissioned, but the island's rocks still hold a great deal of scientific interest because they preserve a record of one of the most important events in the history of life on Earth, the Cambrian Substrate Revolution. The revolution saw the transition from a seafloor lined with microbial mats and limited burrowing by animals, to more extensive vertical burrowing, oxygenation

of the subsurface and the evolution of the animal-dominated seafloor we know today.

To better understand this record, I spent two weeks of fieldwork, in June 2018, examining the island's geology, using the research funding provided by the Geological Society. From the information gathered during the trip it seems that shallow burrowing animals were key to opening up the ocean substrate to more complex animals.

Subsurface reform

For much of Earth's history life on the marine seafloor was very different to the animal-dominated communities we know today.

A typical healthy, modern seafloor is home to a large number of burrowing organisms. These animals, particularly



The fossils and trace fossils preserved in the Precambrian and Cambrian are very different from one another. Precambrian (Ediacaran) fossils (left) include simple Rangeomorph (frond-like) animals, shallow surface trails and elephant skin textures produced by microbial mats on the sediment surface. By the Cambrian (right) the Rangeomorphs had disappeared, replaced by other, more complex animals such as Trilobites. The trace fossils were also more complex because animals capable of deep burrowing had evolved

those capable of producing deep burrows, are vital for maintaining oxygen levels in the sediment and recycling deposited material, because they mix oxygen and suspended material from the water column into the sediment as they burrow (McIlroy & Logan, *PALAIOS* 1999). However, most burrowing animals did not evolve until the early to mid-Cambrian, about 530 million years ago. The few burrowers around in the Precambrian were rarely capable of burrowing more than a few millimetres into the surface sediment (Gehling, *PALAIOS* 1999; Droser et al., *PNAS* 2002; Pecoits *et al.*, *Science* 2012).

Without the oxygenating effects of burrowing animals, the ancient seafloor was characterised by widespread anoxia (a low oxygen concentration) (McIlroy & Logan, *PALAIOS* 1999) and in the place of

animals, the seafloor was blanketed in a community of single-celled organisms known as a microbial matground. Matgrounds are formed when bacteria and other microbes stick themselves, and the host sediment together, using a biological glue (Parsons et al., *Geophys. Res. Lett.* 2016), allowing them to form a cohesive mass on the sediment surface. Despite the microscopic size of their constituents, matgrounds, if left undisturbed, can reach thicknesses of a few cm or more. By gluing themselves together, the bacteria also increase their resistance to erosion and can further facilitate sediment anoxia by limiting sediment mixing by wave action.

Matground traces or microbial-induced sedimentary structures, such as stromatolites, elephant skin fabrics and wrinkle structures, are relatively common

in the Precambrian fossil record. However, between 540 and 530 million years ago there was rapid transition from a matground-dominated seafloor to oxygenated, animal-dominated conditions. This transition—the Cambrian Substrate Revolution—is preserved in the fossil record as a rapid decline in fossilised microbial fabrics, and an increase in the number and diversity of trace fossils (Fedonkin, *Paleont. Jour.* 1978; Crimes & Droser, *Ann. Rev. Ecol., Evol. & Syst.* 1992; Jensen, *Int. & Comp. Biology* 2003).

From the late Cambrian and to the present-day, matground communities are rare, limited to anoxic, nutrient-deficient or polluted areas of the sea and lakes, where burrowing animals can't survive in large numbers. This is partly because burrowing animals will break a matground apart as they burrow, and can ►

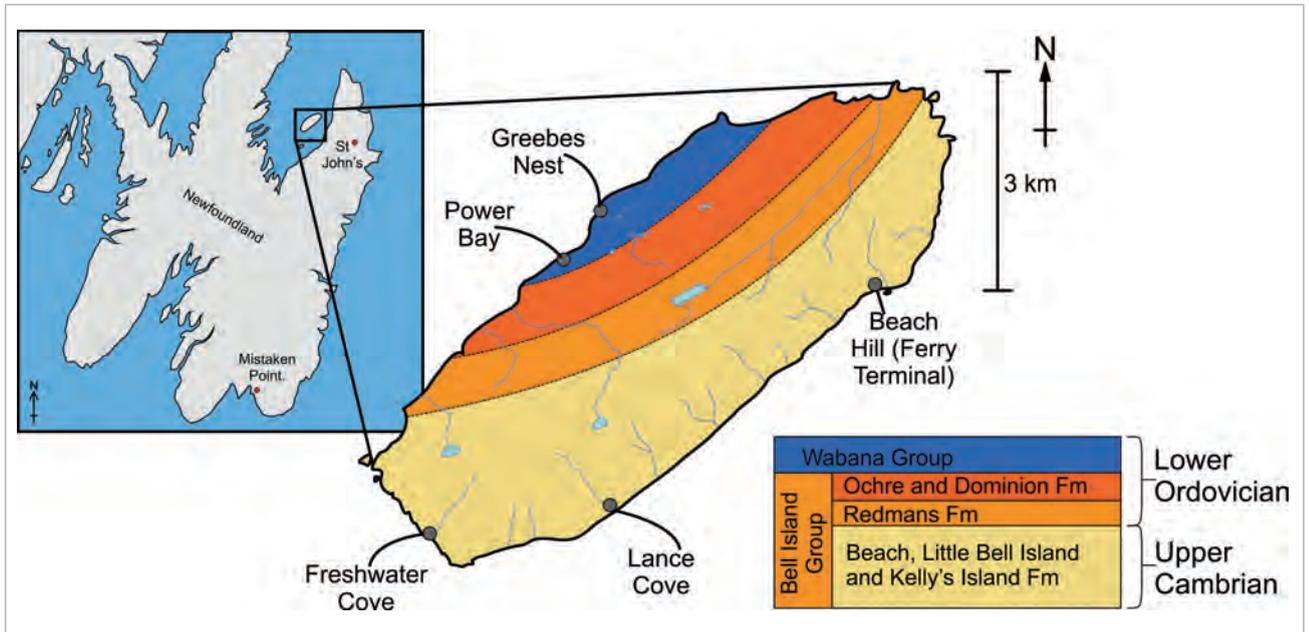
► feed on the microbes themselves, killing off the microbial community. However, matground-dominated seafloors, and thus the microbial-induced fabrics they create, do see a few resurgences in the fossil record after mass extinctions (Gerbersdorf *et al.*, *J. Soils & Sed.* 2009; Mata & Bottjer, *Geobiology* 2012), most notably after the End-Permian

mass-extinction (Feng *et al.*, *Earth Sci. Rev.* 2018; Buatois *et al.*, *Geobiology* 2013), where oceanic oxygen stagnation (Hotinski *et al.*, *Geology* 2001) likely led to a die-off of burrowing animals allowing matgrounds to thrive.

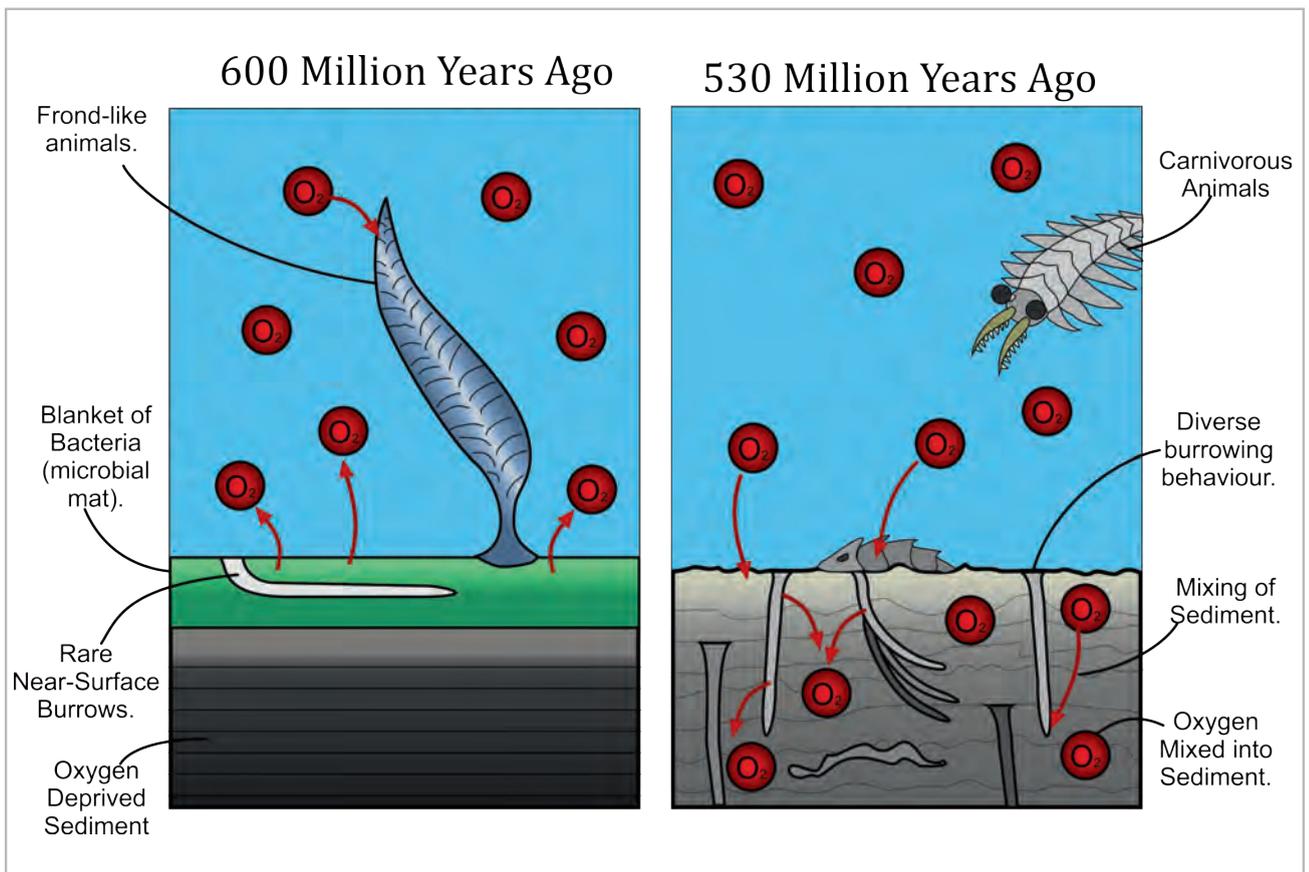
Understanding the mechanisms behind matground resurgence and decline could prove important to

future conservation efforts, as global climate change has led to an increase in oceanic dead-zones that may allow matgrounds to regain a foothold today. However, matground resurgence and decline, particularly in the context of the Cambrian Substrate Revolution, is poorly understood. For example, it is unclear how early burrowing animals, which

Located in Northern Newfoundland, Bell Island is part of the Wabana and Bell Island Groups, dating from 490 to 470 million years ago. The geology is based on the published map by King, A.F. (1988).



The change in the seafloor environment from the Precambrian to the Cambrian. In the Precambrian (late Ediacaran 580-540 million years ago) the seafloor was blanketed by a microbial mat, with the few burrowing animals present only able to burrow into the top few millimetres of sediment. By the middle Cambrian (about 510 million years ago), the matgrounds had been replaced by a diverse community of burrowing organisms mixed oxygen and other dissolved material into the sediment



To a sedimentologist the island's coastline holds a wealth of information, with the interlayered sands and muds preserving a record of the ancient tides. It also preserves a history of the island's mining activity with bands of red ironstone, visible at the base of the stack, and rusted equipment and mine outlets dotted along the cliffs



are likely to have lacked many of the more complex adaptations to anoxia, survived in the anoxic sediments of the Precambrian.

Extraordinary interaction

Most of Bell Island is made up of interlayered sandstones, mudstones and thick ironstones, deposited in a shallow sea just after the Cambrian Substrate Revolution, 490 to 470 million years ago, during the Upper Cambrian and into the Early Ordovician. Like many sedimentary rocks deposited in marine environments they preserve ripples and cross bedding produced by wave and current action.

What makes Bell Island important to the understanding of the Cambrian Substrate Revolution is the fossil community it preserves. These fossils are not the shells and bodily remains you would normally think of when fossils are mentioned—indeed, Bell Island has surprisingly few body fossils—instead, the island's rocks are characterised by a diverse community of trace fossils (fossils produced by the behaviour of an organism).

Bell Island's trace fossil communities are unusual because they preserve both complex fossil burrows and microbial-induced sedimentary fabrics in the same succession and on the same bedding

planes, recording an ancient community where both complex animals and matgrounds lived together. This rock archive therefore presents a unique opportunity to examine the Cambrian Substrate Revolution because it allows us to study an in-situ interaction between a well-established Precambrian-like matground and relatively complex burrowing animals—something that is rare in nature today.

Field days

Braving the cold rain and high winds of the North Atlantic summer, I found myself spending much of June, 2018, nose pressed against the coastal rocks, hand-lens at the ready, examining ancient trace fossils.

Accommodation on the island was limited for most of our time in Newfoundland, so most days we caught an early morning ferry from the mainland across the short stretch of the Labrador Sea to reach the island. The ferry trips gave us fantastic views of the island and its geology. The island has near-continuous exposure along the coastline, and even from a distance the sedimentary layering of the cliffs was visible, however many of the island's outcrops are inaccessible without a boat.

We identified five main accessible field sites, some with fantastic coastal geography, including rock columns and bedding platforms extending out to sea. At each site we looked at the components of the fossil and trace fossil assemblages (communities of different species), as well as how these assemblages are distributed relative to one another, both in terms of their position in the stratigraphy and their relative locations on the bedding planes.

Fossil assemblages

Broadly speaking, Bell Island's fossils can be divided into three main assemblages (communities): microbial mats, simple shallow-burrowers and complex deep-burrowers. These assemblages may occur alone in a bedding plane or together, particularly in the case of the microbial mats and the shallow-burrowers.

The matgrounds are preserved either as wrinkle structures or as elephant skin fabrics. The two textures can be seen on the same bedding plane and can blend laterally into one another, indicating that they form part of the same matground community. These matgrounds may be crisscrossed by simple surface trails (trace fossils) that rarely penetrate deeper than a few mm into the sediment.

The simple, shallow-burrowing ►

► assemblages are mostly made up of horizontally oriented burrows, which reach a maximum depth of 20 mm. More complex burrows are also present in these assemblages, albeit much rarer. These include U-shaped burrows, and larger, horizontally oriented, branching burrow networks. While the shallow-tier community can occur on its own on a bedding plane, it is more commonly found concentrated around the edge of, or directly beneath, the microbial mats. When in proximity to a matground, these shallow-tier communities form intense bioturbation zones—areas with a high burrow density.

Deeper-tier trace fossils are usually limited to layers well above the sandstones that preserve microbial textures (wrinkle structures and elephant skin fabrics). These deeper-tier communities include simple, horizontally oriented burrows similar to those seen in the shallow-burrowing assemblage, however they also include vertically oriented burrows produced by organisms capable of deep burrowing and producing more complex burrow morphologies. These vertical burrows include simple non-branching forms and complex branching burrows produced by

methodological sediment removal.

Essential surface connections

Judging by these initial data, it seems that more complex, deep-tier burrowers were unable to survive in, or were less effective at colonising, matground sediments. So, the Precambrian matgrounds were likely to have initially been invaded by simpler, shallow-tier burrowers. Alternatively, the simple trace fossils we see associated with the matground may have been produced by deeper-tier burrowers that modified their burrowing behaviour in response to the presence of the matground. Either way, the trace fossils indicate that burrowing organisms that remain close to the sediment surface and the oxygenated water column are more likely to survive in, and effectively exploit, matground communities.

Close proximity to the sediment surface may have been the factor that allowed shallow burrowers to survive in the anoxic conditions and break-apart the matgrounds. By maintaining easy access to the oxygenated water column above, these animals could ‘dive’ into the anoxic sediment for brief periods of time, allowing them to feed before resurfacing for oxygen. They

may also have been exploiting ‘waste’ oxygen produced by photosynthesising microorganisms in the matground itself (Meyer *et al.*, *Palaeo3* 2014). By exploiting near surface oxygen, simpler organisms could have acted as one of the key pioneers in the Cambrian Substrate Revolution, breaking up the microbial sediment and opening up new ecological niches for more complex animals.

Today shallow-tier burrowers may be critical for preventing microbial matgrounds from re-establishing themselves on the modern seafloor as modern climate change continues to affect the global marine environment. ♦

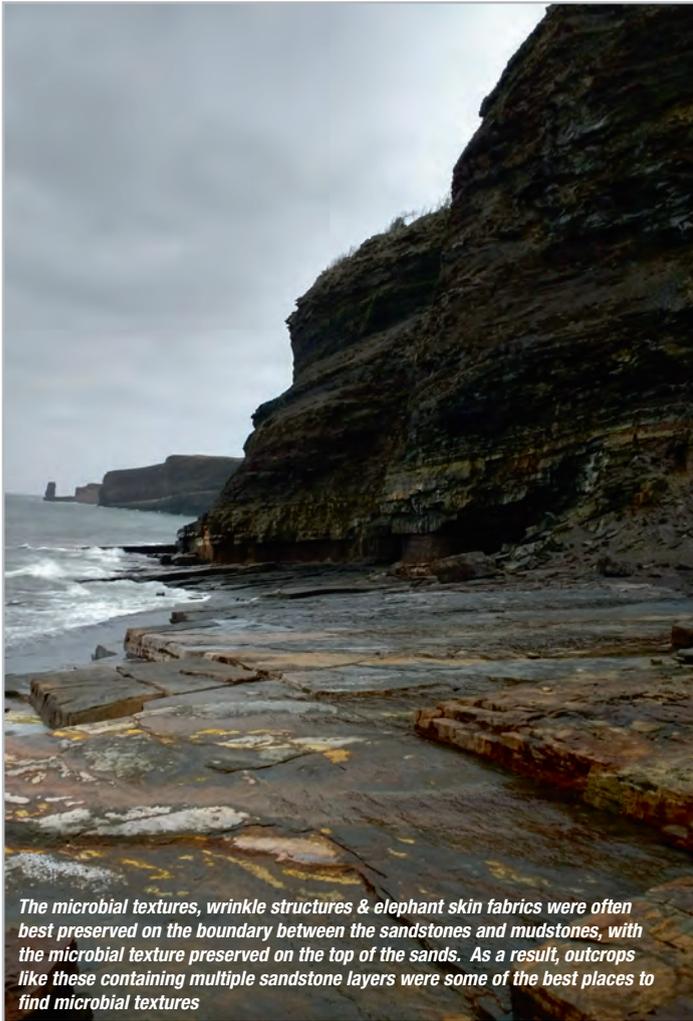
ACKNOWLEDGEMENTS

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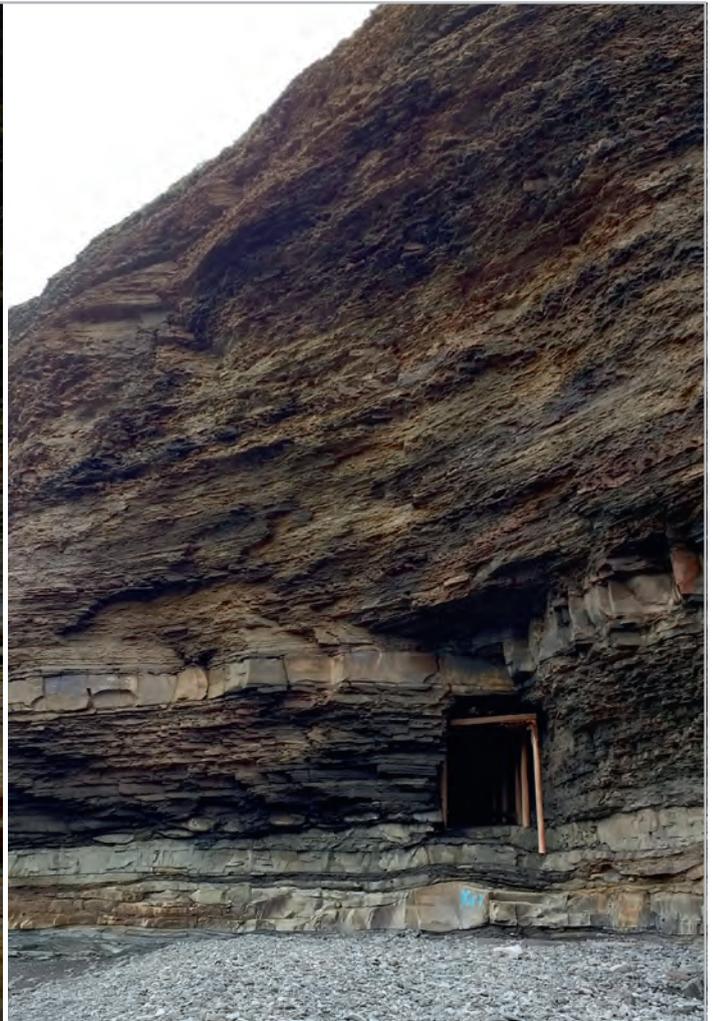
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Wrinkle structures, here cross cut by simple fossils trails, (left) and Elephant skin fabrics (right) are microbial-induced sedimentary features produced by the binding of sediment (due to the secretion of a biological glue) and decay of a microbial matground



The microbial textures, wrinkle structures & elephant skin fabrics were often best preserved on the boundary between the sandstones and mudstones, with the microbial texture preserved on the top of the sands. As a result, outcrops like these containing multiple sandstone layers were some of the best places to find microbial textures



Even in the overcast and rainy weather typical of the North Atlantic, the near continuous exposure of rock along Bell Island's coastline is apparent from the mainland, with the sandstone-mudstone layering particularly visible on the right of the photograph