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Microfossils and the Depositional Environment of the Gunflint Iron Formation

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Abstract

The Gunflint Iron Formation was deposited during the mid-Paleoproterozoic, shortly after the early Paleoproterozoic Great Oxygenation Event(GOE), when the atmosphere and oceans became oxygenated for the first time. The lowermost portions of the Gunflint Iron Formation contain black, early diagenetic chert with locally abundant microfossils. Reconstructing the life habits and ecology of the microfossil assemblages allows us to better understand the shallow water sedimantary conditions during the post GOE interval.

Eosphaera and *Kakabekia* are two distinctive genera that occur in the Gunflint, but they likely had different habitats. *Kakabekia* has a morphology similar to iron metabolizing bacteria that live today in anoxic soil microhabitats. In the Gunflint, *Kakabekia* occurs in association with filamehts and coccoidal microfossils that likely lived in or near stromatolites on the sea floor. The association with this likely iron bacteria and a benthic microbial community suggests that most of the Gunflint microflora was benthic and possibly living in ferruginous, anoxic conditions. In contrast, *Eosphaera* fossils are rare and not strongly associated with the main community components. *Eosphaera's* morphological similarity with the modern alga *Volvox* suggests that *Eosphaera* may also have hada photosynthetic metabolism. *Eosphaera* is plausibly interpreted as an oxygenic photosyhthesizer that lived in an oxic zone above the seafloor. If correct, this interpretation suggests close spatial proximity of oxic and anoxic environments in the Paleoproterozoic iron formations.

Contents

Figures

Introduction

The Great Oxygenation Event was the first time in Earth's history that free oxygen was common anywhere on Earth. It occurred approximately 2.3 Ga and was caused by photosynthetic microorganisms producing oxygen (Kah & Bartley, 2010). Despite low levels of atmospheric oxygen, the oceans remained largely anoxic because the dissolved oxygen would react with dissolved Fe2+, forming Fe3+ compounds that were largely insoluble. The record of Paleoproterozoic ferruginous oceans lies in Superior-type banded iron formations, which include North American iron units, such as the Gunflint, Biwabik, Gogebik, and associated iron formations in the Great Lakes region, and Australian iron formations such as the Hamersley Group, including the Duch Creek formation.

The Gunflint Iron Formation and other banded iron formations are records of what happened

environmentally and paleontologically during the time they were deposited. The oxygenated atmosphere was causing widespread chemical change throughout the surface of the Earth.

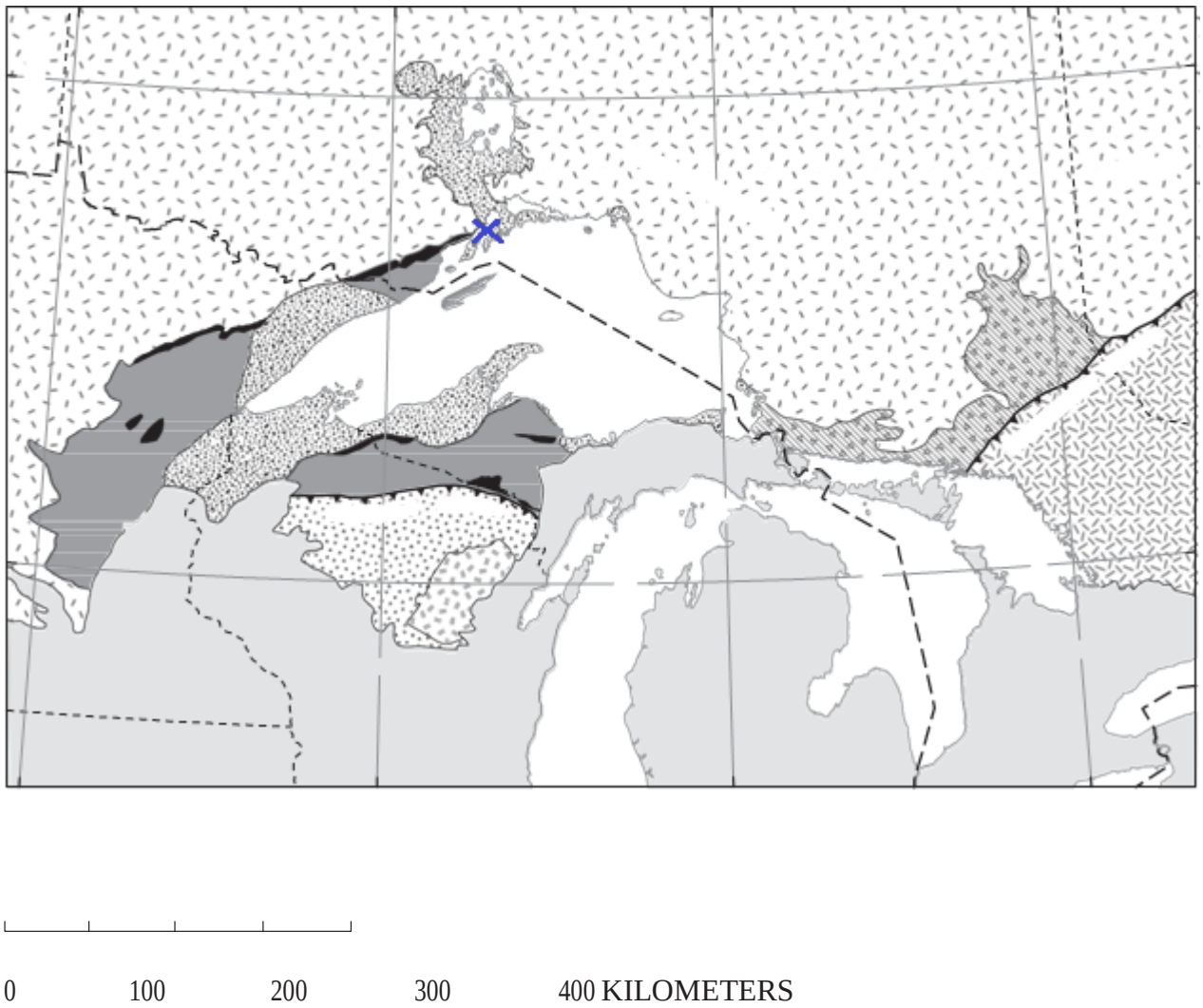
The Gunflint Iron Formation, deposited approximately 1.85Ga(Barghoorn and Tyler, 1954), contains one of the earliest diverse microfossil assemblages (Moore, 1993). There are several genera of spheroids and filamentous microfossils, such as *Eoastrion* and *Huronispora*. *Eosphaera* and *Kakabekia* are the only two microfossils in the assemblage that show unusual morphologies (Moore, 1993)In this project, I use morphological data from *Eosphaera* and *Kakabekia* to show that both oxic and anoxic water likely existed in the shallow ocean environment where the Gunflint Iron Formation was deposited.

Geologic Setting

The Gunflint Iron Formation is part of the Animikie Basin, a marine foreland basin that formed in front of the Penokean Orogeny (Cannon, 2008). Animike Basin sediments extend from northern Minnesota through Michigan, parts of Wisconsin, and southern Ontario. Foreland basin development provided accommodation space for the deposition of a diverse suite of sedimentary rocks. The major iron formations of North America were deposited along a NE-trending belt, now divided by rocks of the Midcontinent Rift system (Cannon, 2008).

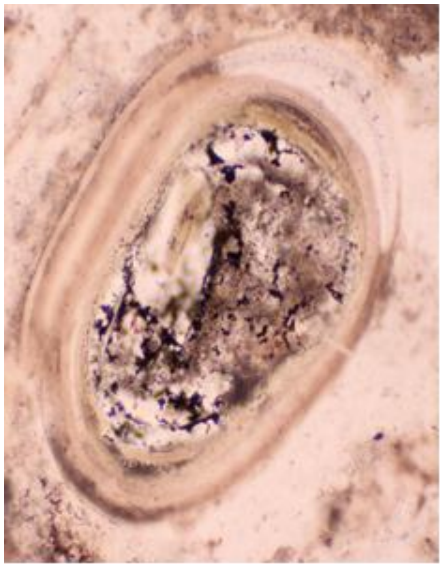
The Gunflint Iron Formation is a partially metamorphosed unit that was deposited between 1.85 and 2.1 Ga, in the Paleoproterozoic Era (Planavsky et. al., 2009). The outcrop belt(Figure 1) is approximately 200 km long, up to 35 km wide, and 100 to 180 meters thick in most places (Moore, 1993). The formation strikes northeast, from Gunflint Lake in northern Minnesota, where is is significantly metamorphosed, to Ontario, alont the north shore of Lake Superior, where the formation is essentially sedimentary rock (Barghoorn and Tyler, 1965). Since metamorphism damages microfossils, preservation is best at the northeast end of the outcrop belt, at locations like Schreiber Beach (Tyler and Barghoorn, 1954).

The microfossils are found in chert near stromatolites. The stromatolites and surrounding areas contain very little clastic sediment, which indicates that they were not deposited near the mouth of a river or any other source of clastic sediment. In our sampling locations, the Gunflint forms a nonconformity atop Archean igneous rock (Moore, 1993). In other locations, this unit is overlain with repeating layers of chert and cherty carbonates(Moore, 1993). The rock contains ooids, which indicate that they were deposited in shallow, moving water(Barghoorn and Tyler, 1965).



(Figure 1) (Cannon, 2008) This is a geologic map of the gunflint iron formation and the surrounding

area. The Schreiber beach locality is at the blue x on the map. The Gunflint Iron Formation is the black stripe that ends near Schreiber Beach (USGS. 1998) .



(Figure 2) An ooid found in Gunflint thin sections. The presence of ooids indicates that the sections of the Gunflint that were sampled were in fairly shallow water.

Methods

For this study, I obtained samples from a fossilized stromatolite in the lowermost Gunflint Iron Formation near Kakabeka Falls, Thunder Bay, Ontario, and from early diagenetic black chert in carbonates surrounding the basal stromatolites. Samples were collected by P. Fralick of Lakehead University and by J. Bartley of Gustavus Adolphus College.

In addition, I obtained samples from Schreiber Beach (Figure 1) during field work in 2011. These samples are associated with stromatolites in the basal Gunflint. Finally, samples were loaned from the Harvard University Collection. This sample suite includes samples and data collected along the north shore of Lake Superior by Barghoorn and Tyler in field seasons in the early 1950s (Barghoorn and Tyler, 1965; Tyler, unpublished data).

I examined the thin sections with a polarizing biological microscope with a 10X objective lens and a 10X eyepiece using an overlapping, sweeping pattern and took photographs of any microfossils or unusual structures I observed.

I used the program Wings3d to create a 3-dimensional representation of the organisms. Wings3d is an open source computer program designed to produce computer graphics primarily for art and games. Wings3d was useful because it allowed me to create a representation of *Eosphaera* in which the organism, shown as several spheroids, had the observed median proportions and

shapes (Tyler, unpublished data) (Figure. 4). The representation of *Kakabekia* is much more qualitative because it is not made up of easily discernible geometric shapes and the geometry of *Kakabekia* is not as well described (Moore, 1993; Seigel and Seigel, 1970). The representations helped to compare the shapes of *Eosphaera* and *Kakabekia* to other microorganisms in a meaningful way. It also helped visualize the microfossils I was looking for.

Results and Discussion

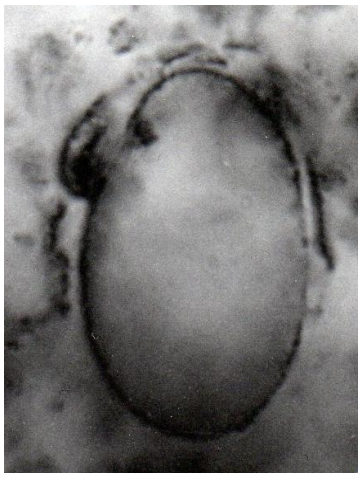
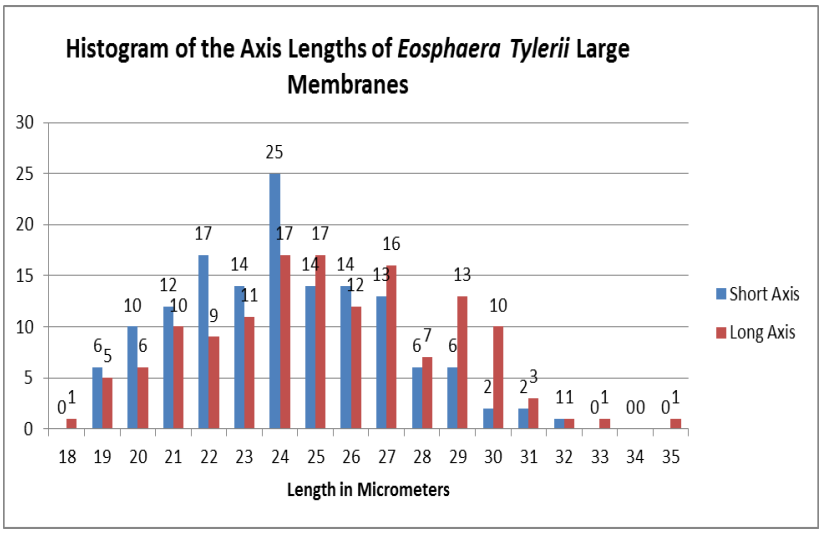


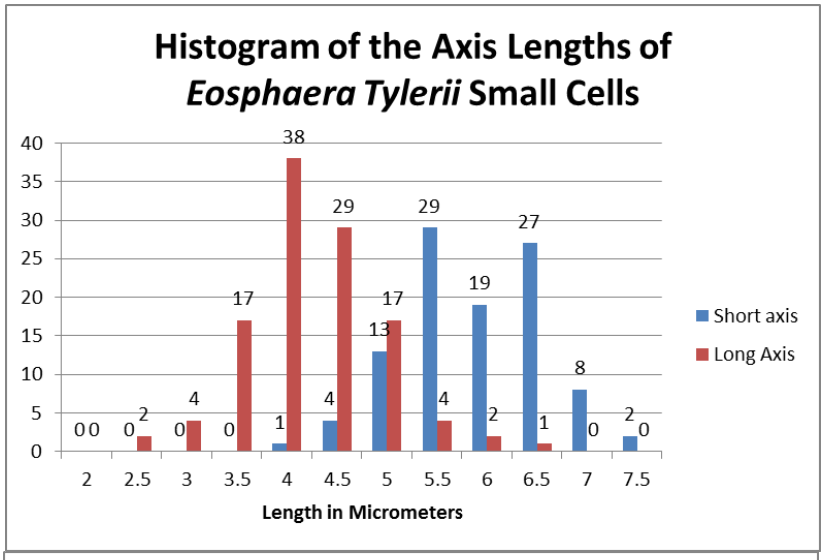
Figure 3: A well preserved *Eosphaera* (Moore, 1993)

Eosphera Tylerii is a spheroidal microfossil that is characterized by a thick spheroidal inner membrane, a thinner, but also spheroidal outer membrane, and a group of oblate cells in between. (Fig. 3) The inner membrane has a diameter of approximately 20 micrometers, and the outer membrane is approximately 25. The cells in between, being oblate, have one diameter of approximately 5 1/2 micrometers, and the other is approximately 6 1/2 (Moore, 1993)(Kazmierczak 1979).

It is highly unlikely that *Eosphaera* is anything but a multicellular microorganism. The fossils are made of the same material as the other microfossils of the Gunflint iron formation. The regularity of the size of the components also rules out the possibility that they are one large cell that gathered other cells or nonliving material around its membranes (Figs 3,5). The axial lengths of *Eosphaera* have a moderate amount of variation, which is something one would expect to see in a

living organism.





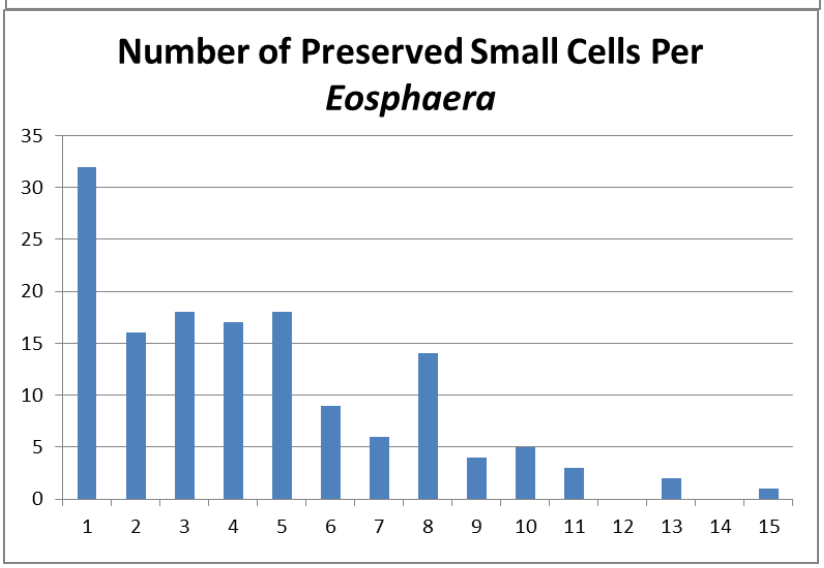


Figure 4, a set of three histograms describing *Eosphaera* samples (Tyler, unpublished Data). This data was very useful in the creation of the 3d representations.

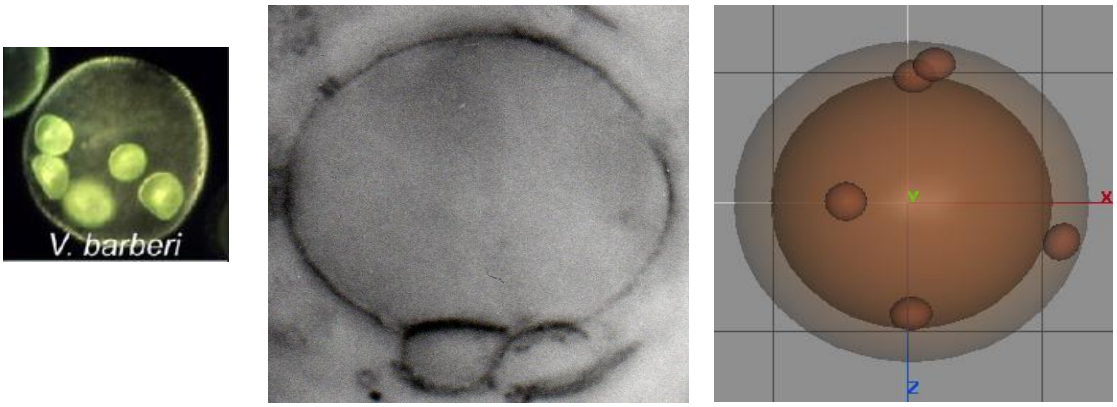


Figure 5 From the left- *Volvox Barberi* (Herron, et. Al, 2009), *Eosphaera Tylerii* (Moore, 1993), and a 3d computer representation of *Eosphaera* that uses the median measurements of *Eosphaera*, but looks very similar to them both.

Eosphaera is not closely related to any modern microorganisms (Kazmierczak 1979). It does, however, bear a morphological resemblance to *Volvox* which is a multicellular member of the Chlorophycae. (Herron et. al 2009) Members of the *Volvox* family evolved from unicellular to *Eospheara* shaped organisms within at most thirty million years. (Herron et. al 2009) *Volvox Barberi*'s structure is different from *Eosphaera* in that there is no thick inner membrane to press the inner spheroids to the outside, and it is on a larger scale than *Eosphaera,* containing hundreds to thousands of cells instead of one to sixteen. In *Volvox*, the outer layer of cells is clear, which lets light in for the cells inside to conduct photosynthesis. The overall structure is so similar that it is likely that they also had a similar niche in their environment, in this case, a floating photosynthetic microorganism (Herron et. al 2009).

Kekabekia is a moderately common microfossil in the Gunflint. It has a bulb shaped body with a long, narrow stalk connecting it to a large “umbrella shaped” mantle (Moore, 1993). The mantle appears to be composed of usually six to eight veiny structures with a thin sheet of tissue

stretched between them (Seigel & Seigel 1970).

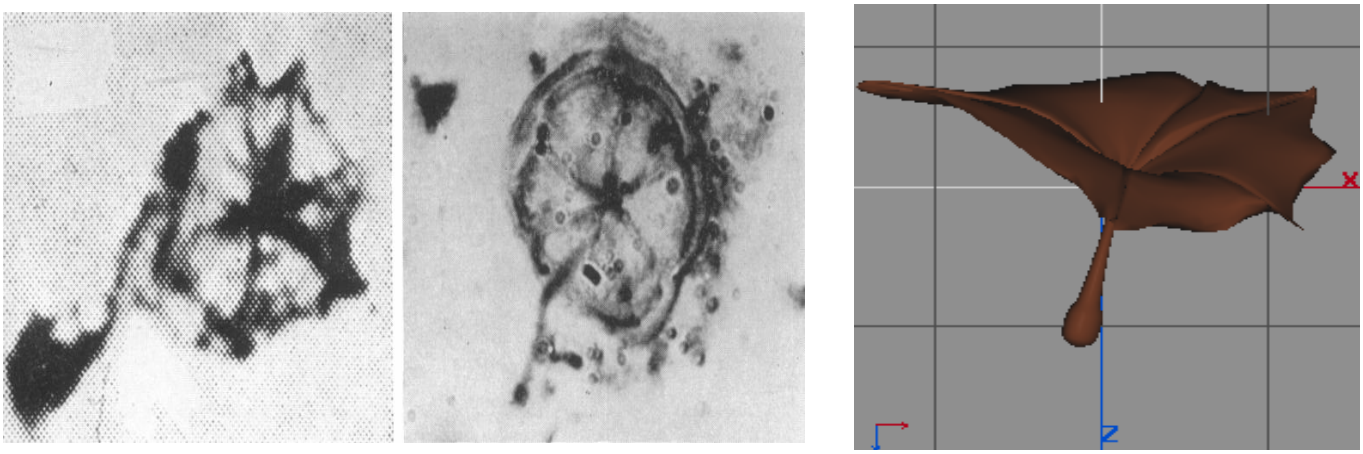


Figure 6 Gunflint *Kakabekia*(left) Modern *Kakabekia* (center) (Seigel & Seigel 1970), and a 3d computer representation of *Kakabekia.*

The *Kakabekia* genus has living members today. They are prokaryotes that live in Alaskan soil and thrive in ammonia rich environments. The modern *Kakabekia Barghoorniana* can live in an oxygenated environment, but that appears to be a relatively recent adaptation. (Seigel & Seigel, 1970) The largest noticeable difference between the organisms is that some fossilized *Kakabekia* have "incised" mantles, but the modern *Kakabekia* do not (Seigel & Seigel, 1970). The computer representation seems to fit either variety just as well, after the taphonomy of the Gunflint sample is taken into account (Figure 6).

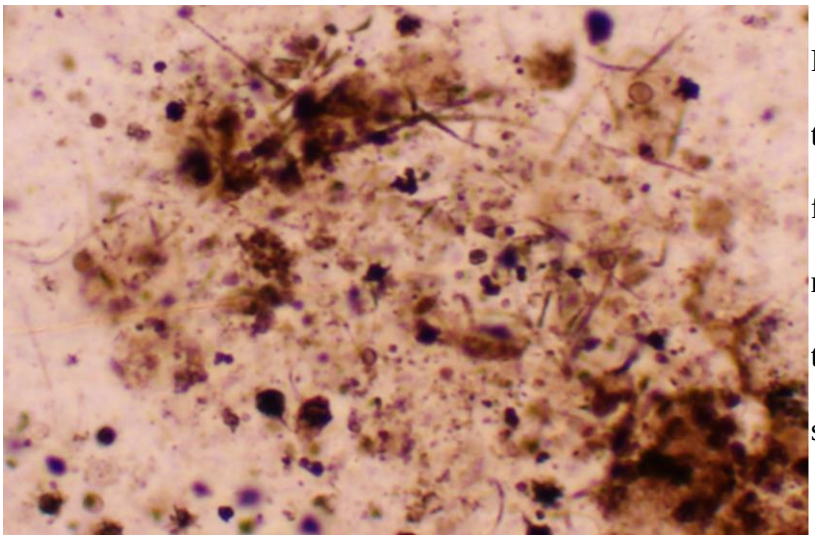


Figure 7. a typical group of filamentous microfossils from the Gunflint samples

The preserved filamentous microfossils in the Gunflint were likely transported a short distance because they do not appear to be in life position, but they were not heavily damaged (Figure 7). Since they are found in the same conditions as *Kakabekia*, it is reasonable to assume that they also developed in an anoxic environment and were moved about the same distance as *Kakabekia*.

The distribution and relative abundance of the microfossils seems to indicate that *Kakabekia* lived in the same places, and probably had a similar metabolism as the rest of the biomass in the Gunflint, while *Eosphaera* lived away from most of the other organisms. Kakabekia is common and likely to be found in places where there is a high concentration of the material that the microfossils are made of. *Eosphaera* appears to be uncommon and found mostly away from other biomass. This may be because *Eosphaera*, being nearly transparent in the samples, is harder to see when it is set against a high contrast background, like the fossilized biomass. *Kakabekia*, which is usually much darker than its surroundings, is nearly as easy to see in a high contrast background as it is in a transparent background. Nevertheless, *Eosphaera* is likely distributed more or less randomly throughout the thin sections from Schreiber Beach, but *Kakabekia* appears to be correlated with biomass. This indicates that it did not spend its life where the other microorganisms did. If they had a similar life habit to *Volvox*, they probably lived near the surface of the water and some of them fell into the sediment. This shows that that the Schreiber beach location was likely deposited in water that was shallow and anoxic enough for stromatolites with iron oxidizing metabolisms (Planavsky et. al, 2009) to form, but that there was oxic water nearby, possibly just at the surface.

The Gunflint Iron Formation was deposited at about the same time as the Duck Creek formation in Australia (Wilson et. Al, 2010). The Gunflint and Duck Creek formations have similar microfossils, such as *Eoastrion*, *Huronispora*, and *Kakabekia*, but the Gunflint formation has the only *Eosphaera*. They also have similar mineralogy and layering (Wilson et. Al, 2010) (Moore,

1993). This indicates that their depositional environments were very similar. It is likely that the Gunflint and Duck Creek formations are examples of the same ecosystem.

Conclusions

*Eosphaera'*s clade probably evolved multicellularity shortly before *Eosphaera Tylerii* evolved and died out without leaving any known descendants that are recognizable as such. The most plausible ecological niche for them was a floating photosynthetic organism. If that is accurate, this means that there was oxic water at or near the Schreiber Beach locality and the preserved *Eosphaera* were transported from this oxic water to the anoxic environment of the stromatolites.

Kakabekia lived in the same conditions as the other microorganisms in the Gunflint and Duck Creek formations. It lived with the stromatolites and had an iron based metabolism. This indicates that the stromatolites formed in an environment that had only a small amount of oxygen. The Duck Creek formation being so similar indicates that this generalizes to at least some shallow marine ecosystems at the time. The association of stromatolites, iron bacteria (Planavsky et. al, 2009), and iron formation suggests that even shallow waters had accessible ferric iron during the Gunflint's deposition, which is also the case at Duck Creek (Wilson et. al, 2010, although other Paleoproterozoic units, such as the Belcher Group, appeared to be fully oxic (Hofmann, 1976).

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