A Preliminary Note on the Neoproterozoic stromatolite occurrences on Farm Windpoort No. 428, Kunene Region, Namibia

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Abstract: Stromatolites can be used to study environmental changes in earth's history and have been linked to the oxygenation of earth's atmosphere about 2.4 billion years ago. They have an exceedingly long geological record of no less than 3,500 million years. Their formation is influenced by biological, chemical and physical processes. Namibian specimens are known from the Neoproterozoic, and Cambrian. Although the country boasts many stromatolite localities, few detailed studies have been done on stromatolites from Namibia. Well-preserved, diverse Neoproterozoic stromatolites occur on Farm Windpoort No. 428 in the Kunene.

Key words: Stromatolite, Otavi Group, Neoproterozoic, Algae.

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Introduction

According to Burne & Moore (1987) microbialites are "*organosedimentary deposits that have accreted as a result of a benthic microbial community trapping and binding detrital sediment and/or forming the locus of mineral precipitation*". Microbialites can be classified into various forms according to their macrofabrics; as dendrolites, in which microbial carbonate outlines are dendritic and shrublike, thrombolites, in which the microbial carbonate outlines are irregular equidimensional clots that can elongate into branches, stromatolites, in which the microbial carbonate internal fabric is laminated and thinly layered, thrombolitic stromatolites, which are intermediate in structure between thrombolites and stromatolites, and finally leiolites, in which the microbial carbonate internal fabric is aphanitic (Riding, 2011a).

Stromatolites are laminated benthic microbial deposits (Riding, 2011a) and can take on various shapes, such as flat or domical, branched or conical, or columnar (Riding, 2011b; Bosak *et al*., 2013) and grow upwards through the accretion of laminae. They form at the sediment water interface in various environments, including freshwater, marine and evaporitic (Riding, 2011b).

Kalkowsky (1908) was the first to use the name "Stromatolith" for early Triassic playa lake oolites. Studies done by Walcott (1914) and Roddy (1915) suggested the first possible link of stromatolites to the activity of blue-green algae in the formation of freshwater tufas and Walter (1972) reported on the algal and bacterial contributions in the formation of stromatolites of hot springs and geysers of Yellowstone National Park (Walter *et al*., 1976). However, various researchers provided sufficient evidence that some stromatolites likely had abiogenic origins, such as seafloor crusts (Kerans, 1982; Grotzinger & Read, 1983), hot spring sinters, speleothems and even mixed contributions by both biogenic and abiogenic processes, called Hybrid Crust stromatolites (Riding, 2008, 2011a, 2011b). The more recent marine stromatolites of Shark Bay, Western Australia were reported in 1954 (Playford & Cockbain, 1976) and described by Logan (1961) and similar large columnar stromatolites were reported from the Bahama Banks (Dravis, 1930).

Fossil stromatolites can be useful in the study of various palaeobiological topics, such as the evolution of banded iron formations, atmospheric oxygen studies, palaeolatitudes, palaeodays per year, Earth-Sun-Moon dynamics, changing seawater chemistry to name but a few (McNamara & Awramik, 1992).

Abundant stromatolite occurrences have been reported from northern and southern Namibia in the Otavi and Nama Groups respectively. For example, Gürich (1930) mentioned seeing "Tütenmergel" or cone in cone structures in the Otavi Mountains, and Schwellnus & Le Roux (1944) reported on columnar, conical and dentate stromatolites in the Otavi Mountains between the towns of Tsumeb, Otavi and Grootfontein. A terminal Neoproterozoic biohermal pinnacle reef complex called Driedoornvlakte (~549 Ma), in the Nama Group Zaris Sub-basin of southern Namibia, preserves sponge-like metazoans such as *Cloudina*, *Namacalathus* and *Namapoikia* in association with thrombolite stromatolites (Grotzinger, 2000; Grotzinger *et al*., 2000; Wood *et al*., 2002; Wood & Curtis, 2015; Penny *et al*. 2014). But although northern Namibia is rich in stromatolite occurrences, associations with any biomineralised metazoans have not yet been found there. Miller (2008) provided a good overview of the stromatolites which have been found in northern Namibia's Otavi Group.

According to Miller (2008) columnar stromatolites comprise the form-genera *Tungussia*, *Conophyton* and *Jacutophyton*. *Tungussia*, which is pale pinkish in colour and massive-weathering, is common in the Ombombo Subgroup, occurring in the upper Devede Formation and in the upper Okakuyu Formation. In the lower Devede Formation, an 8 m-thick *Conophyton-Jacutophyton* biostrome occurs. *Conophyton* is well developed in the middle Devede Formation.

The middle Rasthof Formation (Abenab Subgroup) represents the post-Chuos cap-carbonate sequence and is dominated by a sublittoral microbialaminite (algal mats) lithofacies, with evidence that biomats were rubbery. Columnar stromatolites are common in the upper Ombaadjie Formation and include *Kussiella*, *Baicalia*, *Minjaria*, *Conophyton* and *Omachtenia*.

Hoffman & Halverson (2008) noted the occurrence of "plumb stromatolites" in the lower Maieberg Formation of the Tsumeb Subgroup. Large cylindrical stromatolites occur in the lower Elandshoek Formation along the northern edge of the Kamanjab Inlier. Söhnge (1957, 1971) noted the preservation of stromatolites, such as cryptozoon (ringel), *Collenia* (Tüten), *Hadrophycus* (crumpled, dome-shaped layers), *Arkhaeozoon* and concentrically laminated balls ('algal buns') in the upper Elandshoek Formation between Tsumeb and Nosib 655. The lower Hüttenberg Formation preserves columnar, domal, bulbous and wavy stratiform stromatolite beds, and there are three *Conophyton*-like marker horizons named Tüten I at the base of the formation, and Tüten II and Tüten III higher up. Wavy stratiform, domal, bulbous and columnar stromatolites have also been found in the upper Hüttenberg Formation. (Miller, 2008).

This paper will focus on some preliminary survey results and brief thin section analysis of the Neoproterozoic Otavi Group stromatolites from Farm Windpoort No. 428 in the Kunene Region.

Geological setting

The Elandshoek and Hüttenberg Formations are shallow-water carbonates of the upper Tsumeb Subgroup of the Otavi Group (e. g. Söhnge; 1957; 1971), which have been deposited in a broad shelf region marginal to both the Kaoko and Damara Orogenic Belts (Northern Platform – NP). The Otavi Group is overlain paraconformably by clastics of the Mulden Group (Hedberg, 1979; SACS, 1980).

The Elandshoek Formation has a maximum thickness of 1500 m and is a monotonous stack of cherty, grainstone-dominated, dolomite cycles, which follows conformably on platy dolomite of T3 of the Maieberg Formation (Miller, 2008). The Elandshoek parasequences have an average thickness of 4.2 m (~130 cycles). There are numerous pseudo-columnar stromatolites (*Tütten*, as described by older authors) in the upper half of the formation, but they are less well developed than those in the Otavi Mountains.

The Hüttenberg Formation reaches a maximum thickness of ~500 m on the western margin of the Owambo Basin. In the western NP, deposition of the Hüttenberg Formation was initiated by a transgression (Miller, 2008). The lower half of the formation is made up of ribbonites but grainstones in the upper half record the final low-stand in the NP.

In addition, although the Elandshoek and Hüttenberg formations are rather similar lithologically, their carbon isotope compositions are quite distinct. In the Elandshoek Formation the δ13C ratio remains between -1 and -2 ‰ through most of the formation and only becomes positive near the top and reaches +7 ‰ at the top. The δ13C ratio fluctuates widely through the Hüttenberg Formation from +10 ‰ at the base to -5 ‰ a little higher up (Hoffman & Halverson, 2008).

The contact between the Elandshoek and Hüttenberg formations is a major flooding surface at the base of a nearly 300-m-thick recessive interval dominated by ribbonite (thin-bedded (<30 cm) carbonate silts and fine sands in which there is some evidence of bottom currents or wave action) (Miller, 2008).

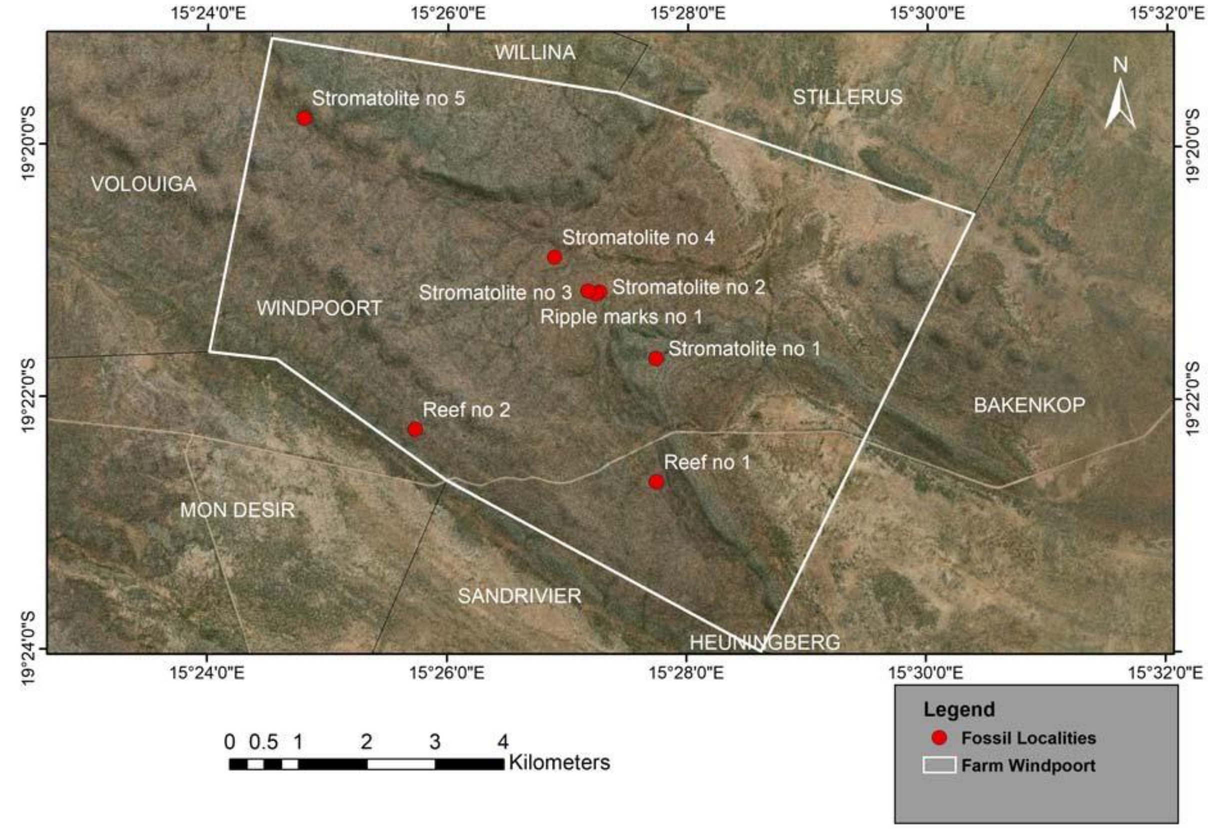


Figure 1. Localities visited on Farm Windpoort No. 428 on satellite map.

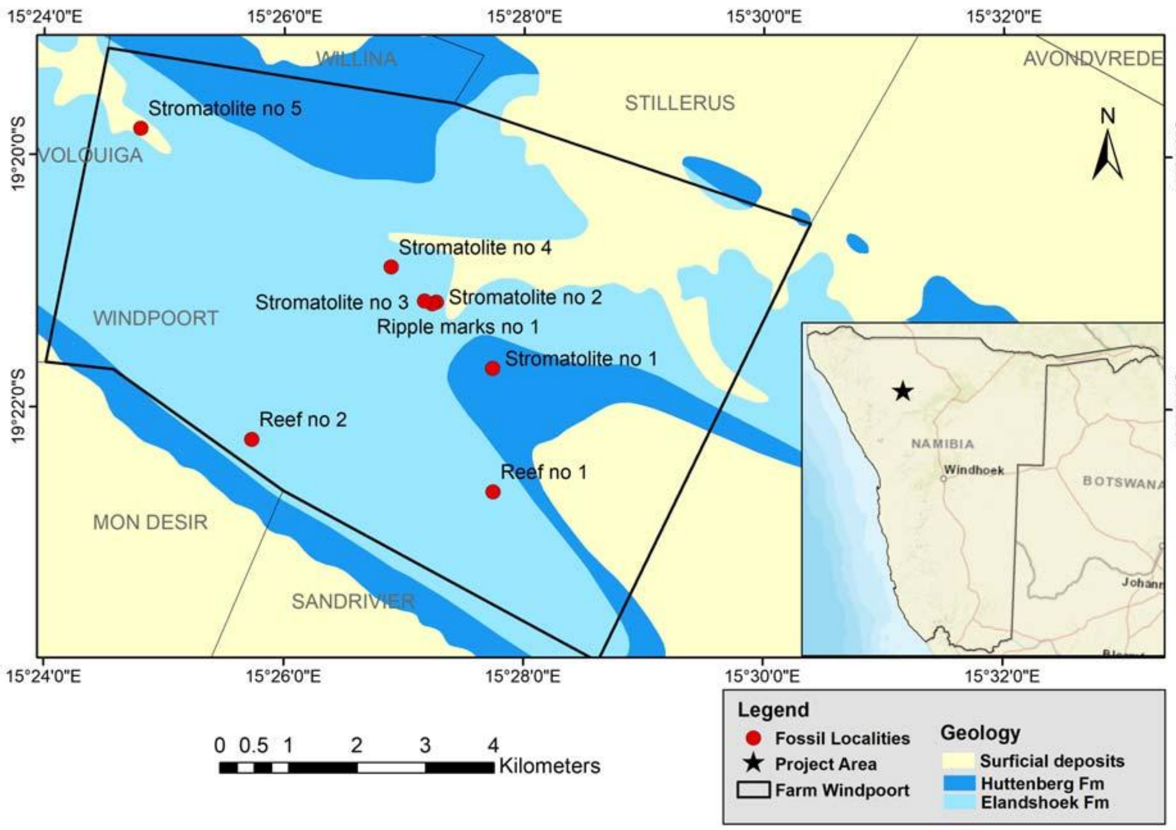


Figure 2. Localities visited on Farm Windpoort No. 428 on geological map.

GROUP	SUBGROUP	FORMATION	MEMBER / INFORMAL UNIT
OTAVI	TSUMEB	Hüttenberg	T8
			T7
			T6
		Elandshoek	T5
			T4
		Maieberg	T3
			T2
			Keilberg
		Ghaub	T1
	ABENAB	Auros	
		Gauss	
		Gruis	
		Berg Aukas	
		Chuos	
	OMBOMBO		

Figure 3. Stratigraphy of the Otavi Group, Namibia.

Material and Methods

From the 7-10 December 2019, a brief field survey was carried out on Farm Windpoort with the guidance of the owner, Mr. Tim Osborne. Localities based on the presence of stromatolites, but also on their overall diverse morphologies were recorded (Table 1). Stromatolites were photographed with a Sony DSC-H90 camera, measurements were made with a ruler and descriptions recorded.

Samples of Reef locality no. 2 were taken with a geological hammer. Three blocks and cross, longitudinal and transverse thin sections were made of the most representative and best preserved sample.

Blocks were prepared by first cutting the sample with a standard rock cutting saw in cross, transverse and longitudinal sections. Thereafter cut blocks were lapped with a Logitech LP50 and 600 grid Silicon Carbide powder. The smoothed blocks were then polished with a Logitech PM2 with DP Suspension M starting at 9 µm and gradually using smaller micrometer sizes 6 µm, 3 µm, 1 µm to ¼ µm. Mounting was done on a hot block with 2 parts resin and one part hardener. Finally, the cover glasses were mounted on the thin sections with Eukitt resin.

The thin sections were observed under an Olympus BX51 polarising light microscope, at 5x, 10x, 20x, and 40x magnifications, in both crossed polars (XPL) and plane polars (PPL). Photographs were taken with a mounted ColourView XS camera. The images were viewed with the Analysis Imager software.

Field Results

The study area, with geological units, and recorded localities on Farm Windpoort No. 428 are shown in Fig. 1-3. Five stromatolite sites, two reef sites and one locality which preserved ripple marks were recorded in December 2019. The GPS coordinates for all sites visited are provided in Table 1.

Table 1. GPS coordinates (in degrees minutes seconds) and elevations (metres above sea level) of recorded field localities.

Locality Name	Latitude	Longitude	Altitude (masl)
Stromatolite no 1	19° 21' 41.34" S	15° 27' 44.64" E	1235
Ripple marks no 1	19° 21' 09.78" S	15° 27' 16.38" E	1220
Stromatolite no 2	19° 21' 10.56" S	15° 27' 14.28" E	1224
Stromatolite no 3	19° 21' 09.24" S	15° 27' 10.44" E	1227
Stromatolite no 4	19° 20' 53.22" S	15° 26' 53.64" E	1219
Stromatolite no 5	19° 19' 47.46" S	15° 24' 48.12" E	1237
Reef no 1	19° 22' 39.90" S	15° 27' 44.94" E	1247
Reef no 2	19° 22' 15.24" S	15° 25' 44.04" E	1244

Stromatolite locality no. 1 is located just a few kilometres south of the main house and bungalows. This site is located in the Hüttenberg Formation. On average, the stromatolites are small in circumference with an average width of 5 cm with spaces of 8 cm or more between individual stromatolites. Each stromatolite has star shaped layers as seen from above. Some form raised columns and others are weathered down flat probably by water erosion from smaller flowing river gullies (Fig. 4).

The Ripple marks locality no. 1 is situated next to the bungalows and main residence. Ripple marks were also seen near Stromatolite locality no. 2 and 3, and sometimes form patches between stromatolites in other areas (Fig. 5). The ripple marks at Ripple marks locality no. 1 are probably slightly asymmetrical wave ripples. They display well-developed bifurcations, their crests are sinuous and regular, and they have sharp peaks and broad troughs. The sinuosity indicates that there was some increased energy in the environment, but this was only slightly higher than in environments where parallel crested waves form.

Stromatolite locality no. 2 is located a few kilometres north-west of locality 1 within the Elandshoek Formation and against a slight elevation. Here the stromatolites still show clear layers, with round concentric rings as viewed from above. Stromatolites grow upwards up to 1.5 m or more and form thick columns of stromatolite layers with an overall hummocky appearance (Fig. 6).

Stromatolite locality no. 3, only a few metres from locality 2, preserves large bulbous stromatolites with diameters of 10 to 60 cm (Fig. 7) as well as hummocky stromatolites with depths of more than 1 m (Fig. 7). Ripple marks have been preserved between the stromatolites. Many stromatolites can be followed into the ground for more than half a metre.

Figure 4. Stromatolites from locality no. 1.

Figure 5. Ripple marks.

Figure 6. Stromatolite locality no. 2 with thick stromatolite layers.

Figure 7. Stromatolite locality no. 3, large bulbous individuals.

Figure 8. Columnar stromatolites from locality no. 3 with depths exceeding 1 m.

Figure 9. Stromatolite locality no. 4, small diameter stromatolites.

A


B


C

Figure 10. Loose stromatolite (A) lateral view (B) with broad oval top and (C) small base from Stromatolite locality no. 4.

Stromatolite locality no. 4 preserves stromatolite pillars with clear rings, but small diameters of about 3 to 5 cm on average. At the base of the pillars, more massive, badly weathered layers are seen from which these stromatolite pillars grew upwards (Fig. 9).

A loose stromatolite found at this locality preserves a small base from which inverted cups grew upwards increasing in circumference (Fig. 10 A, B, C). The top of this stromatolite shows an oval outline with the longest diameter at 8 cm and the shortest diameter at 4 cm (Fig. 10. B). At Stromatolite locality no. 5 the stromatolites have a more wavy appearance and growth seems to have been both lateral and vertical. The site is located on a gentle rise. The growth fashion of these stromatolites can be described as hummocky and once again they are as much as 1.5 to 2 m in height (Fig. 11).

Just a few kilometres south of Stromatolite locality no. 1, Reef locality no. 1 is located within the Elandshoek Formation. The millimetric to centimetric fine, wavy texture visible in the rocks visited was completely different from that of the stromatolites seen thus far (Figs 12 and 13). This reef occurrence was protruding up to 2 m or more above the soil surface and could be traced for many metres lengthwise, from East-West like a ledge. The effects of weathering are more pronounced in this reef compared to Reef locality no. 2.

Figure 11. Stromatolite locality no. 5.

Figure 12. Reef no. 1 locality with fine, wavy texture.

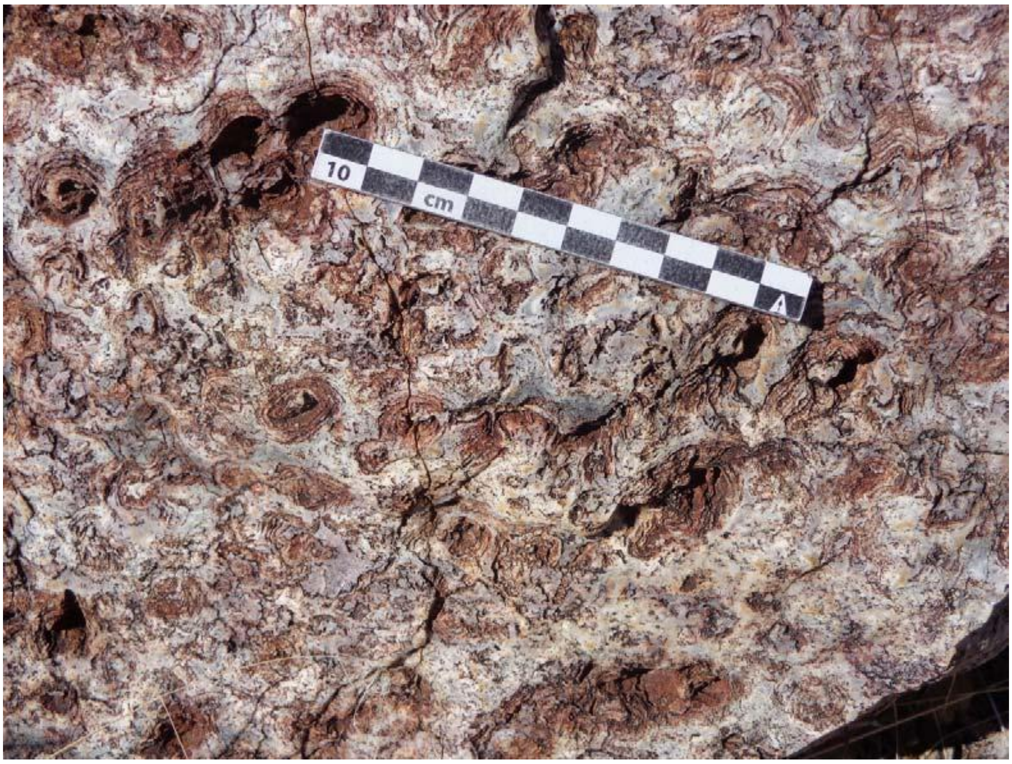


Figure 13. Reef no. 1 locality with small ringlet stromatolites.

Figure 14. Reef locality no. 2 with laterally extensive ledge.

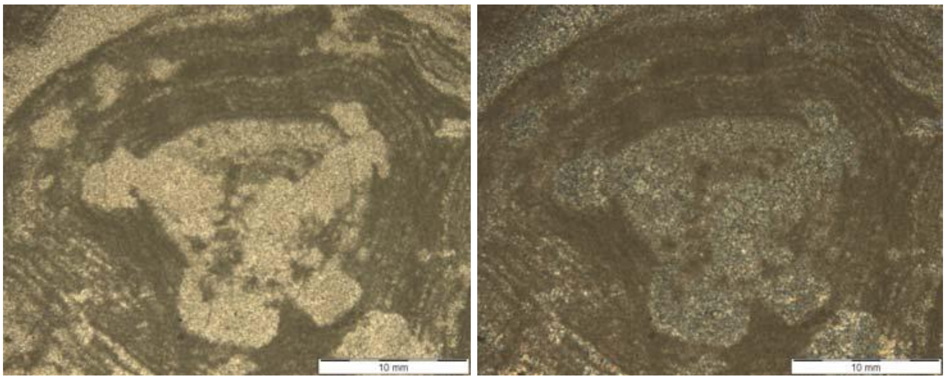
Figure 15. Reef locality no. 2 with a tightly compacted, ringlet-shaped texture.

Reef locality no. 2. is located further west but still in the Elandshoek Formation and has the same texture, height and lateral nature as Reef locality no. 1. Again, the ledge like reef protrudes up to 2 m from the soil surface and can be traced for some distance laterally (Fig. 14). Samples were taken for thin sectioning and microscope analysis. Reef locality no. 2 showed stromatolites with a tightly compacted, ringlet-shaped texture, which was not as clearly visible in Reef locality no. 1. Repetitive ringlets are mostly ~1 cm in cross section and seem to form a tight packing order (Fig. 15). However, some ringlets seem to have been disturbed, thus not forming a closed circular shape, but rather a more irregular shape. Some areas show ringlets forming short pillars up to 2 cm in height.

Thin Section Results

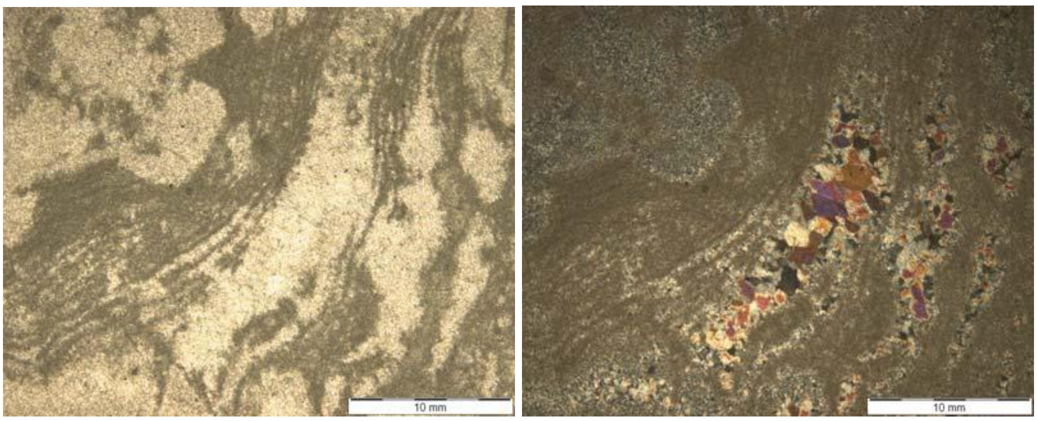
Certain photomicrographs were selected, as they indicate some interesting features. The stromatolite lamellae are especially well-preserved in cross section.

A cross section of stromatolite lamellae in Fig. 16 (A and B) indicates the formation of imperfect repetitive rings and 4 knob-like protrusions mostly filled with green “spongy” material. Many sections have shown several of these knob-like protrusions. The green “spongy” material is only visible as green in crossed polars. The lamellae themselves have a light brown colour.



A B

Figure 16. Photomicrographs of cross section of stromatolite lamellae forming imperfect repetitive rings and 4 knob-like protrusions mostly filled with green “spongy” material in plane polar view (A) and crossed polar view (B) (5x ocular magnification, 10 mm scale bar).

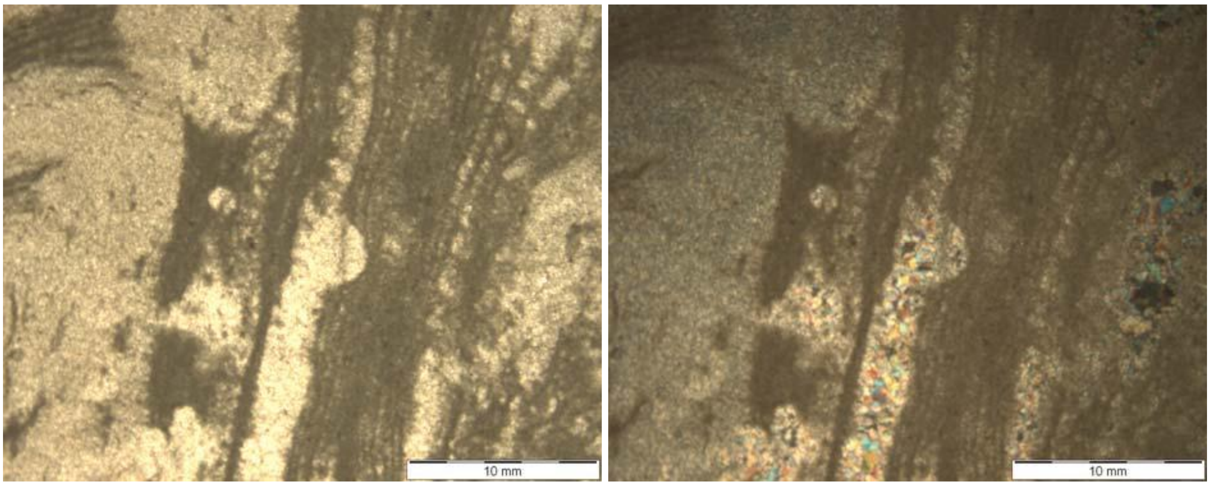


A B

Figure 17. Photomicrographs of a cross section of stromatolite lamellae with medium-small sized quartz grain infillings right, and green “spongy” material left forming knob-like structures in plane polar view (A) and crossed polar view (B) (5x ocular magnification, 10 mm scale bar).

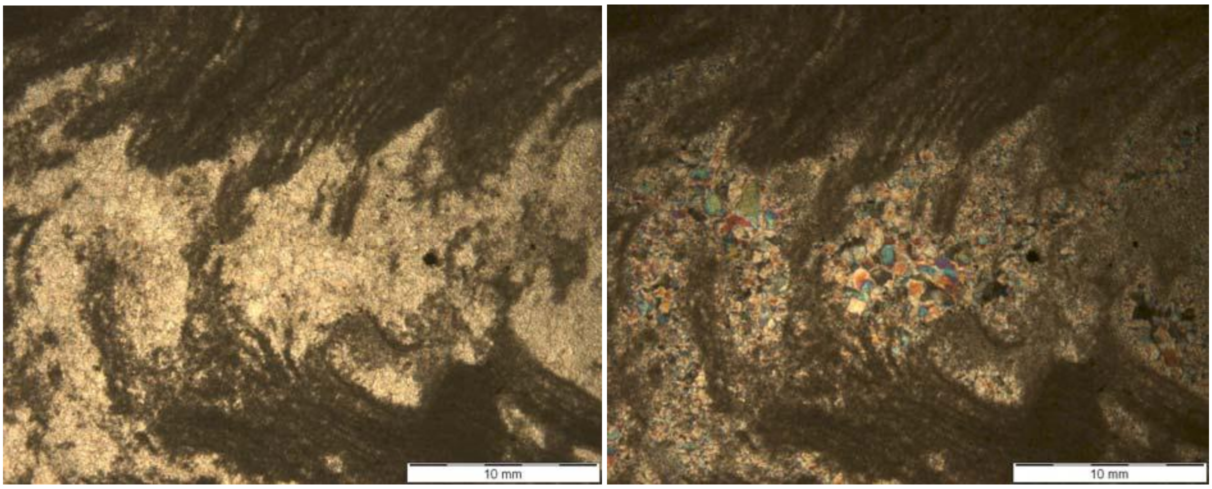
A mixture of medium to small anhedral quartz grains with angular edges and undulatory extinctions form infillings between stromatolite lamellae (Fig. 17 A and B). Quartz grains were incorporated between lamellae while the stromatolites were growing. The undulatory extinctions of the quartz grains possibly indicate influence by diagenesis.

Fig. 18 (A and B) shows a longitudinal section of stromatolite lamellae with an infilling of fine anhedral quartz grains between two lamellae in the centre of the photomicrograph and infilling a knob-like structure of the flower-shaped internal opening of a series of connected stromatolite lamellae. Once again quartz grains were incorporated between lamellae while the stromatolites were growing. Undulatory extinctions of the quartz grains are clearly visible. In the left half of the photomicrograph lamellae are preserved in patches, looking as though they might have been ripped apart.



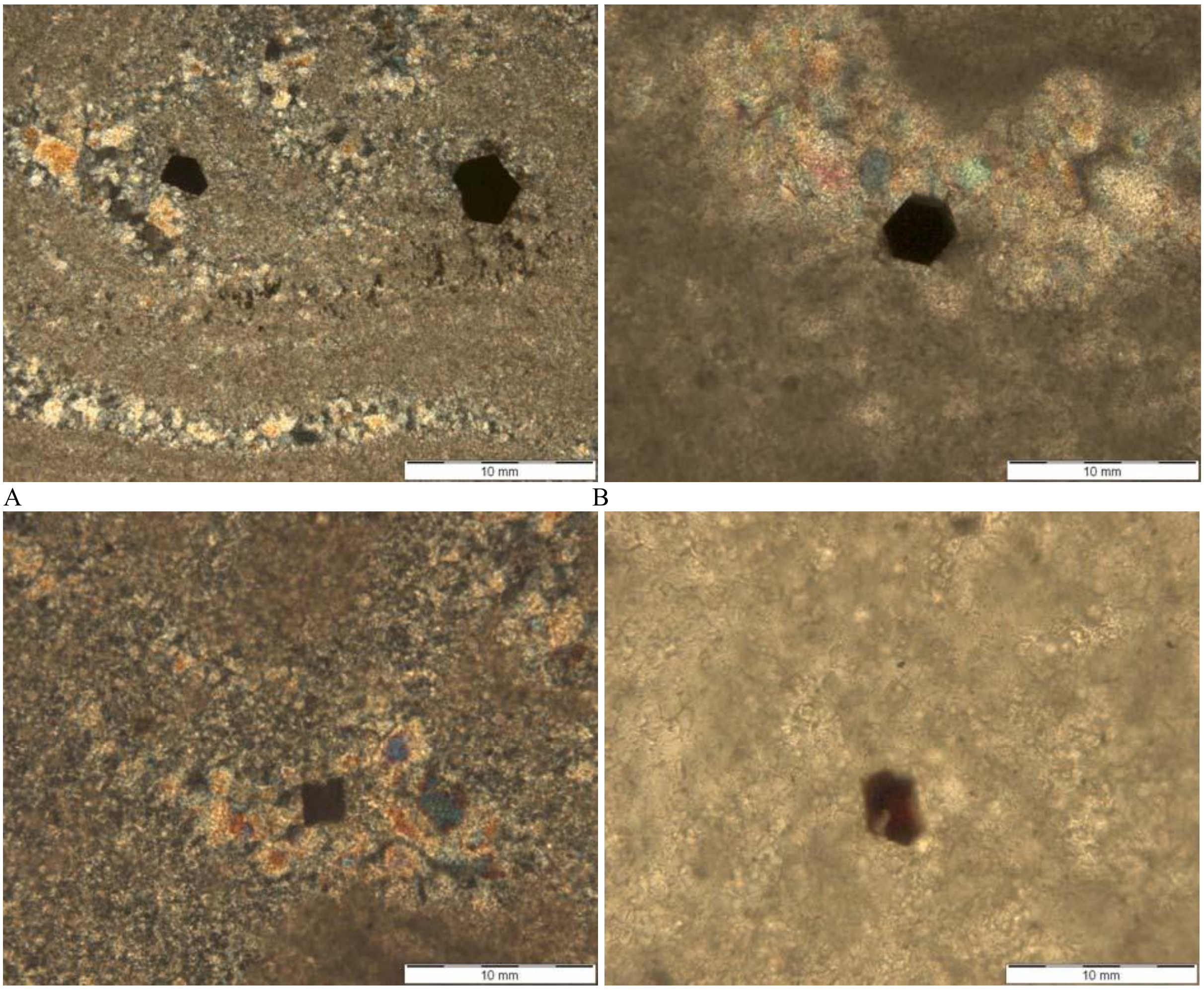
A B

Figure 18. Photomicrographs of a longitudinal section of stromatolite lamellae with an infilling of medium to fine quartz grains in the centre between two lamellae and infilling a knob-like structure. On the left green “spongy” material in plane polar view (A) and crossed polar view (B) (5x ocular magnification, 10 mm scale bar).



A B

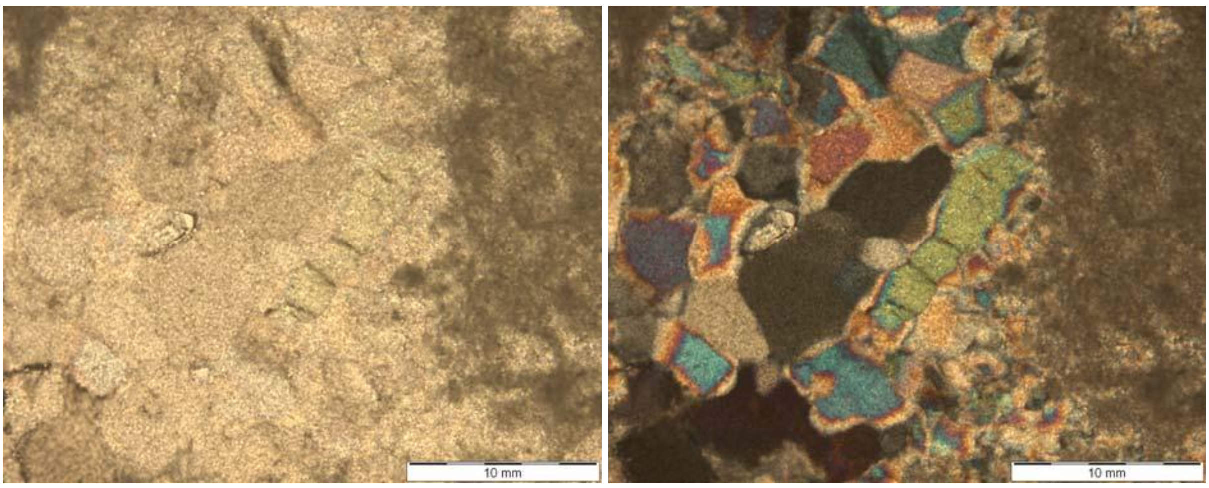
Figure 19. Photomicrographs of a transverse section of several severed stromatolite lamellae with infilling of medium quartz grains in plane polar view (A) and crossed polar view (B) (5x ocular magnification, 10 mm scale bar).



A B

C D

Figure 20. Photomicrographs of cross (A, 10x ocular magnification), longitudinal (B, 20x ocular magnification), transverse (C, 20x ocular magnification) and transverse (D, 40x ocular magnification) sections of opaque mineral grains (black), A, B, C in crossed polars and D in plane polar (10 mm scale bar).



A B

Figure 21. Photomicrographs of a transverse section infilling of quartz grains with undulatory extinction in plane polar view (A) and crossed polar view (B), and with large green grain with several black lines showing regrowth of grain in B centre, right (10x ocular magnification, 10 mm scale bar).

A transverse section of stromatolite lamellae in Fig. 19 (A and B) shows what looks like a bunch of lamellae that were once connected in the middle, now severed with fine-medium anhedral quartz grains infilling the space between.

Opaque mineral grains with mostly hexagonal outlines and sometimes cubic outlines have been observed (Fig. 20 A, B, C). These may be iron or goethite. At least two grains were seen with a red colour (Fig. 20 D) and one grain had a red trail.

The undulatory extinctions of the anhedral quartz grain infillings are clearly visible in Fig. 21 (A and B). The large green quartz grain in the centre of the photomicrograph shows several black lines, which could indicate phases of regrowth of the grain.

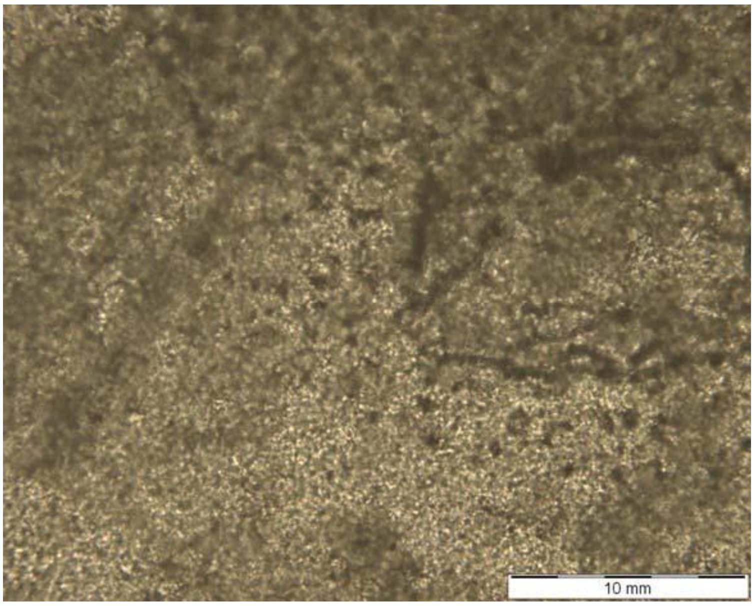
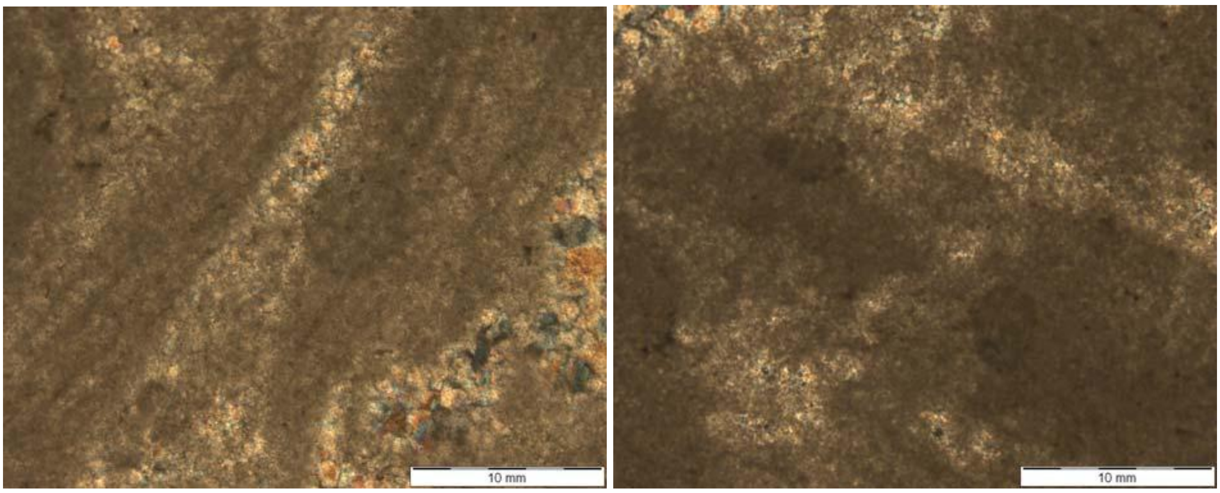


Figure 22. Photomicrograph of a cross section under plane polars of "spongy" green material showing wiggly morphology (20x ocular magnification, 10 mm scale bar).



A B

Figure 23. Photomicrographs of transverse sections of dark circles amongst stromatolite lamellae under crossed polars (A) and amongst "spongy" material under crossed polars (B) (10x ocular magnification, 10 mm scale bar).

Dark rings were noted amongst stromatolite lamellae (Fig. 22) and the green "spongy" material in two photomicrographs of transverse sections (Fig. 23 A, B).

Discussion

Miller (2008) noted that no detailed study of the Otavi stromatolites had been carried out since those of Cloud & Semikhatov (1969) and Krüger (1969). The survey of Farm Windpoort No. 428, in 2019, recorded a diverse group of stromatolites situated near the southern boundary of the Etosha National Park. These stromatolites were preserved in shallow-water carbonates of the Elandsfontein and Hüttenberg Formation platform facies of the upper Tsumeb Subgroup, Otavi Group, which formed when sea level gradually fell and the shelf regions started shallowing. Therefore, the Windpoort stromatolites most likely lived in the sub-littoral zone (Miller, 2008) of the Outjo Sea (part of Damara Ocean) where they were able to perform photosynthesis.

Mapping of the observed stromatolite localities, except for locality no. 1, indicates that all stromatolite occurrences are in the Elandshoek Formation. However, stromatolites at Stromatolite locality no. 1 have also been reported in the base of the Hüttenberg Formation. Therefore, depending on how detailed the mapping that was done in this area is, Stromatolite locality no. 1 may well be in the Elandshoek Formation. However, it has also been noted that these two formations are similar lithologically (Miller, 2008) and only their carbon isotope compositions are distinct.

The hummocky, columnar stromatolites from Stromatolite localities no. 2, 3 and 5 resemble *Conophyton* and *Jacutophyton*, while the "ringlet" shaped stromatolites found at the Reef no. 1 and 2 localities most closely resemble *Collenia* and *Cryptozoon*.

Some geologists suggested that microbialites from Reef locality no. 2 may represent sponges (pers. comm. Tim Osborne). However, no evidence of sponges were noted in the thin sections of Reef locality no. 2.

The green, "spongy" material (Fig. 22) resembles finer algal filaments that twist and turn over each other and have been found to fill the central flower-shaped opening of closed stromatolite clusters as in Fig. 16.

Round structures presumed to be those of coccoidal microbes have been noted by several researchers in Archean stromatolites from the Pilbara region of Western Australia and in the Barberton Mountain Land in South Africa (McNamara & Awramik, 1992). Could the dark circles seen amongst the stromatolite lamellae in Fig. 23 be coccoidal microbes?

The anhedral quartz grains show evidence of re-crystallization and effects of diagenesis due to their undulatory extinctions. The presence of quartz grain infillings suggests movement of water and the trapping of these grains as new lamellae grew/accreted over the quartz grains. No sea-floor cements were noted in any of the thin sections and the virtual absence of sea-floor cements has been noted in the entire Otavi Group, except for the post-glacial Maieberg Formation (Grotzinger & Knoll, 1995).

Unfortunately, some of the stromatolite species reported here were not identifiable, including the star-shaped stromatolites at Stromatolite locality no. 1, the large bulbous stromatolites from Stromatolite locality no. 3 and the stromatolite pillars with clear rings at Stromatolite locality no. 4. There is also the possibility that some stromatolites may represent different growth forms or stages of growth of the same stromatolite species. Stromatolite morphologies could have been influenced by habitat and certain environmental conditions, such as sheltered versus non-sheltered habitats, or energetic versus non-energetic conditions, or a combination of these.

Conclusions

Some of the structures visible in thin sections of stromatolites from Farm Windpoort, Namibia, such as the green, "spongy" material and the round structures located between some stromatolite lamellae could not be identified. Much more work remains to be done on such enigmatic structures visible under the microscope. In addition to this, further studies on the quartz grain infillings could reveal more about the climatic conditions that prevailed in this specific part of Namibia at the time of deposition.

Miller, 2008 indicated an age of ~609 Ma for the deposition of the Tsumeb Subgroup, post-Ghaub. Therefore, as the Otavi Group is older than the Nama Group by ~60 million years looking for calcified reef organisms, like those described from Driedoornvlakte Reef, in and between the Windpoort stromatolites, may prove to be fruitless.

Many stromatolite species have been reported from northern Namibia, such as *Tungussia*, *Jacutophyton*, *Collenia*, *Conophyton, Kussiella*, *Baicalia*, *Minjaria*, *Omachtenia, Cryptozoon, Hadrophycus* and *Arkhaeozoon* (Gürich, 1930; Schwellnus & Le Roux, 1944; Söhnge, 1957, 1971; Krüger, 1969; Cloud & Semikhatov, 1969; Pickford, 1995; Hoffman & Halverson, 2008; Miller, 2008). As many as 57 forms of the *Conophyton* type have been described (McNamara & Awramik, 1992). Many more stromatolites remain undescribed and hence a lot more work remains to be done.

Although no precise identifications were made (only preliminary identifications of species are given), the Windpoort stromatolite survey, indicates that some areas have good exposure and excellent preservation of stromatolites, indicating high potential for further studies.

Acknowledgements

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