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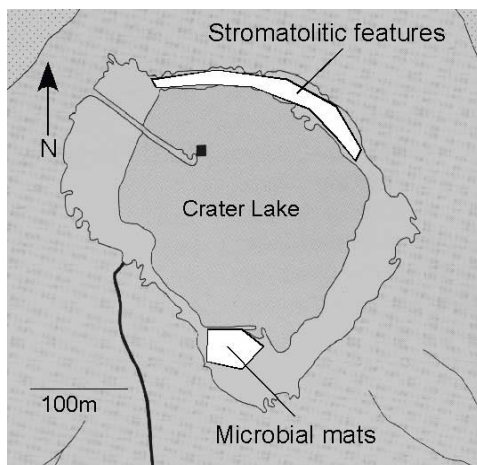
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MICROBIAL MATS IN THE TSWAING IMPACT CRATER: RESULTS FROM A SOUTH AFRICAN EXOBIOLGY EXPEDITION AND IMPLICATIONS FOR THE SEARCH FOR BIOLOGICAL MOLECULES ON MARS

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Introduction: The Tswaing impact structure is located at 25°24'30"S and 28°04'59"E in the South African bushveld, approximately 40km northwest of the city of Pretoria (Figure 1) [1]. It was formed 220±51 Ka ago. The crater, with a rim-to rim diameter of 1.13km, is 1,045 m above sea level and contains within it a meromictic, hypersaline lake with a salinity ranging from 10 to 40% depending on depth [2,3]. During January 2000 we undertook an exobiological investigation of South African impact structures as part of a scientific and educational exobiological expedition to the region.

Figure 1. Location of microbial features discussed in text.



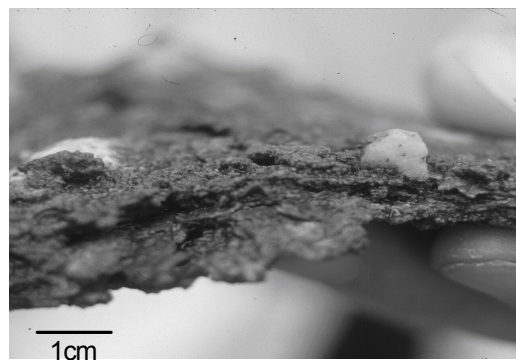
Around the southern edge of the impact lake we located luxuriant mats of *Lyngbya* sp. and along the north to north-eastern section, we found small stromatolites. The enclosed evaporitic basin resulting from the impact provides a habitat for microbial communities associated with hypersaline environments. The biota of the impact structure demonstrates the unique environments that can be locally formed by impact events and the importance of subsequent geologic processes in determining the fate of the climax ecosystem. For example, the Kalkkop impact structure in the Karoo desert near Graaf-Reinet, which was formed at approximately the same time as Tswaing, is almost fully eroded – we observed that the high-albedo limestone plug preferentially attracts basking lizards and has a

lower vegetation cover compared to environs of the structure, but no significant photosynthetic microbial populations. There is no free-standing water. The biological characteristics of the Tswaing lake are of particular exobiological interest. The cyanobacterial mats offer a potential analog for the types of biota, if any, that might inhabit evaporitic hypersaline environments within Martian impact craters. We suggest that these mats, which contain high concentrations of recalcitrant biomolecules, might be used as a basis for improving exobiological search strategies in martian paleolacustrine environments.

Description of the Mats:

The microbial mats are localized to the southern edge of the impact lake in a small inlet defined by two sandbars. They cover an area approx. $\sim 2.5 \times 10^{-3} \text{ km}^2$. The mats, which are irregularly distributed over the surface of the ground, displayed a rippled appearance. In the depressions in the mat, the brown organic-rich water from the lake collects.

Figure 2. *Lyngbya* sp. mats from the Tswaing impact crater.



The thickness of the coherent mat sheet is $0.26 \pm 0.1 \text{ cm}$ based on the thickness measured at ten locations (Figure 2). On the dried surface of the mats are white deposits of salt, which will be primarily carbonates, calcite, aragonite and dolomite [3]. These salts might provide some UV protection for the underlying mats, but the organisms produce UV-A (315-400nm) and UV-B (280-315nm)-screening scytonemin in common with most terrestrial cyanobacterial mats. From a sample of ten 1 cm^3 mat cores we found a scy-

tonemin concentration of 0.62 ± 0.15 mg/g dry weight of mat. The concentration of free-radical quenching carotenoids was 0.23 ± 0.06 mg/g dry wt. The organisms also synthesize UVA/B screening mycosporine-like amino acids (MAAs). The chlorophyll *a* concentration in the mats was 0.41 ± 0.12 mg/g of dry weight. Within the filamentous mat matrix are other organisms, particularly diatoms, e.g. *Nitzschia* spp., which probably come from the lake [3,4]. We did not find these mats in ponds outside of the perimeter of the crater.

Stromatolites:

As well as microbial mats, we found small black stromatolitic features around the periphery of the lake, mostly along the north to north-eastern sector. The stromatolites range from 1 to 10 cm in diameter and are approximately 1 to 4 cm high. The structures are solid on the outside, but within them, they possess a black liquid and a pungent smell, presumably of anaerobic microbial activity. Under light microscopy the stromatolites possess a complex microbial consortia of filamentous cyanobacteria (primarily *Phormidium* spp.) as well as a diversity of chained coccoid forms and green algae. The surface of the structures (two samples from five separate structures) contained a scytonemin concentration of 0.56 ± 0.12 mg/g, a carotenoid concentration of 0.078 ± 0.020 mg/g and a chlorophyll concentration of 0.27 ± 0.08 mg/g dry weight. The stromatolites form a band of 1 to 2 m width, beginning 1-2 m from the lake, with 1 to 6 features / m².

Implications for the ecology of impact craters:

The crater depression caused by impact events can result in unique ecosystems, primarily caused by changes in the drainage and, thus, water availability, and in some instances, the altered lithology caused by disruption of the target rocks. Although impact craters cover a small percentage of the surface of the Earth, impact events represent the only extraterrestrial mechanism that can deliver a pulse of destructive energy into a localized region of the Earth. Thus, understanding patterns of biological succession and the climax ecosystem that results is of substantial interest for elucidating how impact events compare to other localized agents of ecological destruction [5]. In this case, the environment of the Tswaing lake results in the establishment of microbial mats normally associated with hyper-saline regions, demonstrating important effects of the impact depression on the nature of the microbial ecology. Although Tswaing can be defined as a climax ecosystem, it is still quite distinct from the surrounding ecosystem, 220Ka after the impact event itself. Other biological attributes of the crater, such as the vegetational anomaly, have been described elsewhere [2].

Exobiological implications:

The Tswaing impact crater is an evaporitic basin. According to the brine classification of Eugster and Hardie [4], the crater exhibits an Na-Cl-CO₃-type brine. On Mars, there is both theoretical and more controversial practical evidence of evaporitic deposits in impact craters [6]. We do not know if there was ever life on Mars. However, finding analogs of martian geologic features on Earth and studying the biota associated with them is our best hope for constraining the search for life on Mars and so providing the most trustworthy conclusion to whether Mars possessed a biota or not. Cyanobacteria are probably ancient organisms. Both coccoid and filamentous photosynthetic microbial forms that bear similarity to extant cyanobacteria have been found as far back as 3.5 Ga ago. Thus, cyanobacteria that inhabit evaporitic lakes in terrestrial impact craters are of great interest for constraining the search for life on Mars. For example, if the Tswaing impact lake dried up and the microbial mats in the southern quadrant became covered in sediment and dust, we estimate that the top sheet of the mats alone would represent ~110kg of subsurface prospectable fossil UV pigments, assuming that scytonemin and carotenoids represent the majority of the recalcitrant fossilizable pigments in these mats (UV screening and protection compounds are known to be particularly stable). The presence of approximately 40g/m² of UV protecting compounds in these mats could be used as a basis for the design of extraterrestrial remotely operated sensors in the search for molecules of biological origin on Mars.

Furthermore, we recognize that both the mats and the stromatolites have potential interest for understanding Archean (3.5-2.5Ga ago) Earth. Microbial mats and stromatolites normally associated with inter-tidal regions could potentially colonise hypersaline environments in depressions generated by impact events, or otherwise, on the emergent continental blocks of early Earth. The similarity of the shoreline biota of the crater lake with some marine inter-tidal regions shows that terrestrial ecosystems could potentially have been established on early Earth when the fossil record suggests inter-tidal mats and stromatolites existed, by a simple process of cross-transfer.

References:

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