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Patterns of Complexity in Modern Freshwater Microbialites from Cenote Azul, Yucatan Peninsula, Mexico

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Microbialites are prime astrobiology targets because they appeared on and sustainably colonized the surface of the Earth from the Archean eon until today, thus represent an uninterrupted record of terrestrial microbial life. Their diverse depositional environments serve as exceptional proxies for both modern and ancient aqueous systems. Erosional landforms resembling karstic systems on Earth suggest analogous microbialite-depositing environments on Mars, potentially preserving fossilized microbialites and their biosignatures. In recent years, complexity as a universal biosignature has gained traction within the astrobiology community. This is because while the scientific community has yet to formulate a natural definition of life, it is often referred to as a “complex” phenomenon whose by-products and processes are expected to reflect, at least to some extent, this inherent complexity. This work investigates complexity as a biosignature in modern freshwater microbialites from Cenote Azul, Mexico, one of the many karstic sinkholes of the Yucatan Peninsula, by correlating the molecular complexity to the morphological complexity of a set of samples collected along a depth profile (-6 m to -70 m). For each sample, the molecular complexity was quantified by averaging the complexity of components of the lipid fraction (i.e., non-polar organics and PLFAs) analyzed via GC-MS using the Böttcher complexity index, and the morphological complexity was estimated using the 3D Minkowski-Bouligand fractal dimension and the local correlation dimensions computed from photogrammetric models. Results indicate that shallower samples have significantly greater biomass content, as reflected by higher PLFA contents, and a higher mean PLFA complexity than deeper samples. However, as biomass and PLFA complexity decrease with depth, there is an increasing trend in morphological complexity. Deeper microbial communities seem to adapt to limited light conditions by constructing microbialite structures that optimize light intake, resulting in more intricate shapes. This suggests that in harsher conditions, perhaps life is required to complexify in order to thrive/survive. Future work will investigate the reliability of molecular and morphological complexity as biosignatures and assess whether they can reliably differentiate biogenic from abiotic carbonates.