Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.36929

Agent-based modelling of microbialite formation: testing the emergence of laminated archives of Earth-life interactions

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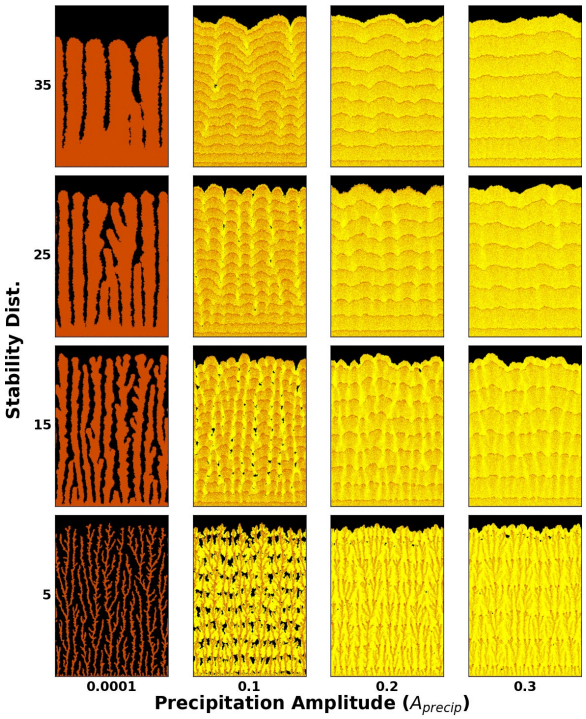

Microbialites represent some of the oldest macroscopic evidence of life on Earth, formed through complex interactions between microbial activity, sediment dynamics, and mineral precipitation. However, abiotic processes can produce morphologically similar structures, complicating the assessment of biogenicity in the geological record and in potential extraterrestrial environments. Here, we develop an agent-based model of microbialite formation that explicitly separates sediment trapping and binding from microbially induced precipitation, allowing laminated fabrics to emerge dynamically from environmental forcing rather than being imposed a priori. The model, implemented using an open-source high-level Julia framework, enables interactive simulations with real-time parameter exploration and reproduces a wide diversity of microbialite architectures, generating both external morphologies (e.g., flat, domal, columnar, conical forms) and internal mesostructures characteristic of stromatolites, dendrolites, or leiolites. The exploration of a subset of parameter morphospace (see Figure) demonstrates how the model input parameters control the emergence of distinct microbialite architectures. These results highlight that simple growth and attachment rules combined with external periodic forcing can generate laminated structures independently of specific biological mechanisms, emphasizing the limits of morphology alone as a biosignature criterion. This framework provides a new quantitative tool to explore how environmental dynamics and biological processes jointly shape microbialite archives across Earth history.