

EMERGENT PATTERNS IN CYANOBACTERIA-DOMINATED COMMUNITIES. D. Y. Sumner¹,¹Department of Earth & Planetary Sciences, University of California, 1 Shields Ave., Davis, CA 95616, dysumner@ucdavis.edu.

Introduction: Microbial ecosystems create organized structures that reflect the time-averaged outcome of environmental, organismal, and biochemical interactions. Prostrate, laminated mats are predominantly structured in response to geochemical gradients produced by microbial metabolism and exchange with the overlying water column. The interactions among metabolic processes and environmental boundary conditions often lead to the emergence of a dynamic but stable community structure where key microbes control niches within the community. In some cases, the same microbial communities create more complex structures such as ridges and pinnacles. Such structures more frequently emerge when interactions with grazing and burrowing organisms are reduced, erosive currents are absent, and sedimentation rates are low relative to microbial growth rates.

The Problem. It is very difficult to identify “why” microbial structures such as pinnacles form. Plausible mechanisms, such as migration toward light or to higher concentrations in a diffusion gradient, are frequently proposed, but essentially impossible to demonstrate in the field. Cyanobacteria sometimes form pinnacles even when they are so oversaturated with light that photosynthesis is inhibited, suggesting that phototactic migration upward would be a counterproductive response in this environment. Pinnacles can also form in flowing water with very thin diffusion gradients. In these settings, pinnacles do not typically keep forming when the diffusion gradient is a characteristic length that one could expect microbes to sense. Thus, although pinnacles influence diffusion and diffusion can influence pinnacle growth rates, diffusion gradients do not seem to “induce” pinnacle formation.

The absence of a single “cause” for pinnacle formation has led to more detailed consideration of complex interactions among the microbes and their environments. For example, surface growth and mass redistribution processes can describe the growth of microbial cones, and surface smoothing functions can be used to parameterize microbial, chemical, and sedimentation processes that affect stromatolite branching patterns. These approaches are relevant to understanding complexity in biological systems more generally because they highlight how small changes in interactions with the microbial mat can lead to significant variations in mat structure. The exploration of patterns emerging from dynamical systems provides insights into behaviors that lead to community structure.

Examples: Two examples are particularly relevant to understanding how complex patterns emerge from simple interactions in microbial communities:

Motility in Filaments. Most pinnacles and cones are constructed by communities volumetrically dominated by motile cyanobacterial filaments. Filaments move parallel to their elongation, and when gliding on a surface, they collide. These collisions lead to clumping and alignment of filaments, resulting in various patterns depending on the details of motion and flexibility of filaments. Under some circumstances, collisions result in well-defined ridges in a honey comb-like structure. With growth, these propagate into complicated 3d mat morphologies. Computational models, laboratory experiments, and field observations demonstrate that small changes in interactions dramatically influence the resulting morphologies.

Intrinsic Surface Roughness. Sometimes the abundance of a single organism changes the surface roughness of microbial mats. In many ice-covered Antarctic lakes, an abundance of the cyanobacterial morphotype *Phormidium autumnale* is always correlated to smooth mat surfaces. Where it is absent, mats surfaces commonly contain tufts and pinnacles formed dominantly of *Leptolyngbya* morphotypes. Both are filamentous, motile cyanobacteria, yet their influence on mat surface texture is opposite. This difference in mat surface textures propagates into the absence or formation of larger pinnacles if the community remains stable long enough. In one case, we have demonstrated that the loss of *P. autumnale* in a mat community through time led to the branching of columnar stromatolites.

Implications: The intricate interactions among microbes produce morphological structures with internal niches that can be viewed as having disparate geochemical functions, much like those in multicellular life. In microbial communities, emergent structures are not encoded in genomes, although the individual behaviors and responses are. One of the critical advances allowing multicellularity was the genomic encoding of cell motility and thus morphology.

Acknowledgements: The ideas presented here emerged over a decade of collaborations with colleagues and students including: J. Crutchfield, R. Shephard, D. Andersen, I. Hawes, A. Jungblut, T. Mackey, L. Kellogg, O. Kreylos, J. Mahoney, C. Harwood, M. Murphy, J. Grotzinger, N. Stephens, N. Stork, and many other undergraduates. Funding came from the Agouron Institute, NASA Astrobiology programs, the Petroleum Research Fund, and UC Davis.