A POTENTIAL UNIVERSAL BIOSIGNATURE AT MANY SCALES?

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Introduction: We have found unusual sinuous, hieroglyphics-like patterning in microbial mats at spatial scales ranging from sub-millimeter to tens of centimeters located in caves, under translucent desert rocks, on saline streambeds, and on Mayan ruins entailing a wide variety of lithologies and biogeochemical environments. We have conducted modeling studies to reproduce those patterns [1,2,3,4,5]. Similar patterns have also been reported in desert higher plants [6]. We believe that the patterns seen have widespread ecological significance and are based on the vectors of competing needs for access to resources including nutritional compounds, light, fluid, space to grow, and adequate area to disperse waste. Potentially the patterns may be partially contolled by intracellular communication often termed *quorum sensing* [7].

Cellular Automata Models: We are employing the technique of cellular automata modeling to describe, model, and extract system understanding from the biopatterning phenomena observed. This type of model consists of a grid of cells that can each take on discrete values. Rules for how the cell values change are specified by the sum of all the cell values in some neighborhood. Cellular automata have been shown to be Turing complete, meaning that they can generate anything that a computer can. This ensures that the approach is general. Specifically, we have used a system where cells may be alive (1) or dead (0). The sum of all the neighbors within three cells of a cell is used asan index to a rule book, that specifies if that central cell will grow, die, or stay the same during the following interval. This summation and rule lookup process occurs for every cell, at every time interval. Sums can vary from 0 to 49, which quantifies how dense life is in a particular area. Zero is empty and 49 is filled. Most rules were left as *stay-the-same*, including both 0 and 49, which must be left at *stay-the-same* for stability. We have noted that in many natural systems there tends to be low density (sparse) regions, where only a few isolated organisms or small colonies exist, and high density areas (dense), where a solid mat is only broken up by isolated holes. These are generated by potential *wells*: the less dense area experiences net growth and the more dense area experiences net death. Growth rules in less dense areas thus increase the density towards the death rules in the more dense regions, generating a relatively stable pattern with a density centered on each *well*. Most patterns are comprised of a well series in different regions. Their effect can be directly explained.

For example:

1) A well in a low density region tends to cause the pattern to spread across the field and is thus necessary for life to perpetuate itself. This is almost certain to be the case in any system. Without such a process, a community would have enough members to survive.

2) A well in a high density region tends to prevent growth from making a complete coverage of the field, and thus keeps the community from using up scarce resources too fast. The "holes" in the pattern move, providing for a natural equivalent of crop rotation.

3) A well in the middle densities allows a mechanism for smooth transition between the high and low density wells, thus allowing organisms to adapt to a changing environment and depleting resources without changing the fundamental strategy (the rules).

Multiple iterations of these models have produced an amazing subset of the patterns we observe in nature. Ongoing time-lapse photography is in progress at study sites to observe the actual development of patterns, as are laboratory simulations attempting to reproduce the patterns under controlled conditions.

Summary: Developing a mathematical, physical, chemical, and biological understanding of these unique and widely distributed biopatterns that occur at a number of spatial scales may contribute to our community's armamentum of potential biosignatures for application to the interpretation of life on modern Earth, the early rock record of life on Earth, and to extraterrestrial destinations.

References: [1] P. J. Boston, et al (2009). *Proc Third IEEE Intl Conf Space Mission Challenges Inform Tech*, 221-226, EES Press. [2] K. E. Schubert et al (2010). *Proc 2010 Intl Conf Bioinformatics Comput Biol.* [3] B. Strader, et al (2010). *Software Tools & Algorithms Biol Syst*. Springer Verlag. 550p. [4] J. Curnutt, (2010.) Thesis. CA State Univ. San Bernardino, CA. [5] B. Strader et al (2010) *Adv. Experimental Medicine & Biology*, AEMB. Springer. [6] M. Rietkerk et al (2004). *Science* 305:1926-1929. [7] M. B. Miller & B.L. Bassler (2001) *Ann Rev Microbiol* 55(1):165-99.