A POTENTIAL UNIVERSAL BIOSIGNATURE AT MANY SCALES?

P. J. Boston, New Mexico Institute of Mining & Technology, Socorro, NM & National Cave and Karst Research, Institute, Carlsbad, NM

K. E. Schubert, Baylor University, Waco, TX

E. Gomez, California State University, San Bernardino, CA

J. Curnutt, St Martin’s University, Lacey, WA
Biosignatures – How We Detect Life On Earth

Obvious

Not So Obvious
Biosignatures On Other Planets?

✧ **Life-produced Gases**
  - Oxygen
  - Methane
  - Ammonia
  - Complex atmospheric spectrum

✧ **Biological Molecules**
  - Chlorophyll
  - Other photosynthetic pigments
  - Molecular fossils

✧ **Morphological Fossils**
  - True fossils
  - Biominerals
  - Biotextures
  - Biopatterns

*Guardian* by Joel Hagen
But!

Most of these potential biosignatures are intensely chemistry dependent.

How “universal” could that possibly be?
Biovermiculations:

- Vermiculations = worm-like patterns
- Biovermiculations = sinuous, hieroglyphics-like patterns in biology
- Spatial scales from sub-millimeter to meter
We first discovered them in a sulfuric acid saturated cave in Mexico.

We thought they somehow had something to do with the sulfur chemistry.

But then we began to find them in many other cave and surface environments.

We found them on the walls of Mayan ruins.

In lavatube caves in Hawaii, New Mexico, the Azorean Islands, Mexico, Italy…
We found biovermiculations dominated by photosynthetic microorganisms in lighted cave entries, and on the bottom of a saline desert stream....
We found living biovermiculations lithifying to become fossils.

We found very tiny scale (sub mm) biovermiculations in cyanobacterial hypoliths on the undersides of translucent rocks in deserts in Australia, Chile, California, and New Mexico.
We realized we were seeing the same patterns in cryptogamic desert soils.

We found a paper (Rietkirk et al. 2004) that reported similar patterns in higher vegetation in deserts. And we began to see those patterns also.
We decided that all this probably meant something real about biology...

We started to try to model the patterns.


The nature of the chemistry didn’t seem to matter.
(e.g. sulfur rich, carbonate, iron & manganese, heavy metals, hyperacidic and saline environments, etc.)

The nature of the bedrock didn’t seem to matter.
(e.g. basalt, limestone, granite, gypsum, soil, etc.)

The identities of the organisms didn’t seem to matter.
(e.g. prokaryotic photosynthesizers, heterotrophs, chemotrophs, protists, fungi, lichens, and even higher plants!)

So what DOES seem to matter……?
Approach - Cellular Automata Modeling

- Collection of cells on a grid of specified shape, 2D or 3D
- Follows a set of rules based on *nearest neighbor interactions*
- Rules are then applied iteratively for as many time steps as desired
- System evolves through a number of discrete time steps

- von Neumann one of the first to consider such a model, & incorporated a cellular model into his "universal constructor"
- Cellular automata were studied in the early 1950s as a possible model for biological systems

- Comprehensive studies of cellular automata, S. Wolfram since the 1980s
  - *A New Kind of Science* (Wolfram 2002)
Simulated Bioverms

Proliferation from single cell row at top

Cueva de Luna Azufre, Tabasco, Mexico
Simulated Bioverms

Rule Set: Radius=3, Grow={27-75}, Die={0-21,21+}

Cueva de Villa Luz, Tabasco, Mexico
The Grand Challenge:
Can we back out some science from the rules used to produce patterns?

Cyanobacteria-dominated growth in the Mayan Ruins at Palenque, Chiapas, Mexico

Most Promising Factors We Suspect...

**Physical factors**

1. Gravitational gradient, can be very subtle.
2. Laminar vs. turbulent fluid flow (moisture & nutrients governed by this)
3. Total amount of water through system
4. Percent particulate (clay, etc.) & size distribution
5. Binding phenomena, e.g. intrinsic viscosity, gluiness of biofilm, meshing of filaments
6. Nature of underlying rock surface or soil (not much of a big deal)
7. Surface roughness (not much of a big deal)
8. Presence or absence of light (not much of a big deal)

**Chemical factors**

9. Chemical parameters (pH, salinity, etc.) (not much of a big deal)
10. Nutrient availability (maybe a very big deal)

**Biological factors**

11. Intrinsic growth geometries of organisms (e.g. Eshel Ben Jacob, Univ. Tel Aviv)
12. Cell wall electrical properties (dunno yet)
13. Biotexture (e.g. filaments, clumping, etc.) (big deal)
14. Filamentous motility (Dawn Sumner and her team at UC Davis, probably a big deal)
None of the factors so far identified as major pattern controllers are tied to a specific chemistry.

*We suggest that any microbial system, even something made of silica compounds (!), would produce biovermiculation patterns, on some exoplanet far far away…*

- Fluid
- Particles
- Growing organisms
- Filamentous growth and/or sticky compound (like biofilm)
3 Underlying Assumptions

- Resources to support life are scarce
- Life adapts and tends to expand
- Cooperation makes survival easier
Cooperation

- Non shrinking features:
  - No birth rule in density bounds

- Non increasing features
  - No death rule in below upper limit

\[ R_{\text{feature}} < \frac{1}{2} R_{\text{CA}} \}\{1 - \pi R_{\text{feature}}^2\} \]

\[ R_{\text{feature}} < R_{\text{CA}} \}\{A\} - \pi R_{\text{feature}}^2, 1 - A \]

\[ A = 1 - \frac{R_{\text{feature}}^2}{2} (2\pi - \theta + \sin(\theta)) \]

\[ \theta = 2 \cos\left(\frac{R_{\text{CA}} - R_{\text{feature}}}{R_{\text{feature}}}\right) \]
Potential Well Density

- multiple feature sizes = multiple wells
  - 2 in this case
  - Not static but density is

Hose, et al., 2001
Ongoing Work

- Time-lapse photography of patterns *in situ*
- Laboratory simulations of some aspects
- Continued modeling
- **Most importantly!** Continued search for abiotic counter-examples