Evaluating biosignatures in planetary analogue systems

Frank A Corsetti
University of Southern California
Searching for signs of life in rocks on Earth in case that is useful for searching for life elsewhere

Frank A Corsetti
University of Southern California
Biosignatures

- Biosignature: a sign of life
  - broadly defined
  - living or fossil

- Fossil: record of ancient life
  - preserved in rocks
  - specific kind of biosignature
fossil

[fos-uh l]

Examples       Word Origin

See more synonyms on Thesaurus.com

noun
1. any remains, impression, or trace of a living thing of a former geologic age, as a skeleton, footprint, etc.

2. a markedly outdated or old-fashioned person or thing.
Fossil: Evidence of Past Life
Kinds of Fossils

• Body Fossils

• Trace Fossils

• Chemical Fossils
Body Fossils

• The physical remains of an organism
  • Shells
  • Bones
  • Petrified wood, compressed plants
  • Etc.
Body Fossils

• The physical remains of an organism (its body)

• Informs about the functional morphology of the past organism
  – e.g., what could it do when it was alive?
Trace Fossils

- Evidence of activity of the past organism
  - footprints
  - worm trails
  - borings
  - coprolites
  - etc.
Trace Fossils

- Evidence of activity of the past organism

- Informs about what the organism did, how it interacted with the environment.
Chemical Fossils

- Chemical evidence of past life preserved in the rocks
  - e.g., isotopic signatures
  - organic molecules attributed to life

- Informs the metabolism and the presence of certain clades
Stromatolite
Textbook Definition

• laminated

• organo-sedimentary structure

• built by microbes
microbial mat
(“pond scum”)
Ancient Life: Greatest Hits

- Oldest accepted strom
- Oldest putative eukaryotes
- Oldest animals

Hadean | Archean | Proterozoic | Phan.
Stromatolite Significance

- Oldest fossils in the world

Warrawoona Fm
Western Australia
3.5 Ga
Stromatolite Significance

• Macroscopic from Microscopic
A Tale of Two Stromatolites

CORSETTI, Frank A.¹, BERELSON, William M.¹ and SPEAR, John R.², (1)Department of Earth Sciences, University of Southern California, Los Angeles, CA 90089, (2)Division of Environmental Science and Engineering, Colorado School of Mines, Golden, CO 80401-1887, fcorsett@usc.edu
Conclusion, 2008

Stromatolites are not always evidence for life

“cautionary tale”

Abiogenic \[ \rightarrow \] Biogenic
Hallmarks of Life

1. Grains trapped beyond angle of slide
   • Frantz et al. 2015

2. Magnetic susceptibility patterns
   • Petryshyn et al. 2016

3. Bubbles!
   • Ibarra et al. 2016, Wilmeth et al., 2015, 2019
1. Grains trapped beyond angle of slide as a biosignature

• What can cyanobacteria trap and bind?

• Utility as a biosignature
Grain size

Fine: 0.125-0.250 mm

Medium: 0.50-1.0 mm

Coarse: 1.0-2.0 mm

Glass slide/Mat angles:
0°, 15°, 30°, 45°, 60°, 75°
Glass Slide
fine grain

Fraction of grains trapped

Incline angle (degrees)

better than abiotic

Fine Grains
Cyanobacterial Mat trapping

Fraction of grains trapped vs. time for different grain sizes:
- **Fine** grains: better than abiotic at certain times.
- **Medium** grains: better than abiotic at certain times.
- **Coarse** grains: better than abiotic at certain times.

Images of mats with different grain sizes and a dropper.
Implications for Biogenicity

- prominent grains trapped beyond the angle of slide constitute a biosignature
Implications for Biogenicity

- prominent grains trapped beyond the angle of slide constitute a biosignature

- But many ancient stromatolites are micritic/lack coarser grains
2. Magnetic Susceptibility as a Biosignature

- Most terrestrial environs have a magnetic fraction that has the potential to be trapped
- Very small amounts of magnetic material can be measured
  - Magnetic susceptibility…same theory, different method.
**Hypothesis (schematic)**

- **Abiogenic Systems**
  - **fine mag. particles**
  - **abiogenic ppt**

- **Biogenic Systems**
  - **microbial mat**

**Experimental Data**

- **Dip angle vs. (ρ/10)A/B**
  - **better than abiotic**
  - **χ/g (10^4)**

Petryshyn et al., 2016
Yellowstone Stromatolite
Biotic (watched it grow)

Petryshyn et al., 2016

Biotic better than abiotic
Petryshyn et al., 2016

Green River Stromatolite
Suspected Biotic
(grains trapped at high angles)

better than abiotic

\( \chi / g (10^4) \)

\[
\begin{array}{cccccccc}
0 & 15 & 30 & 45 & 60 & 75 & 90 \\
0.0 & 2.0 & 4.0 & 6.0 & & & \\
\end{array}
\]

dip angle

5 mm
Green River Stromatolite
Unknown (mixed fans and micrite)

Better than abiotic

Petryshyn et al., 2016
3. Bubbles as biosignatures!

- Mats can be gassy
  - Can we exploit gassy mats?

Bosak et al., 2009
Hourglass structures (Mata et al. 2012)
Triassic Cotham Marble
Lilstock Formation

Ibarra and Corsetti, 2016
hourglass-associated" fenestrae (Mata et al. 2012). Modern textures are formed in a similar fashion to cone-associated bubbles, with oxygen produced by photosynthesis contorting cyanobacterial filaments around growing bubbles (Bosak et al. 2009; Mata et al. 2012). These bubbles remain within their original laminae, often forming galleries of multiple fenestrae along a single layer. Filament bundles caught between two bubbles are thicker near over- and underlying laminae, pinching out to a few filaments in between, forming a distinctive hourglass structure. Filaments within bubble-separated bundles have no preferred alignment, which distinguishes hourglass structures from bundles of phototactic filaments. Similar hourglass structures are also observed in Proterozoic stromatolites, composed of micrite instead of microfossils (Mata et al. 2012).
Archean Stromatolite

2000 μm
Hallmarks of Biogenicity summary

1. Grains beyond the angle of slide

2. Magnetic susceptibility patterns

3. Bubbles! (Hourglass structures)

4. Others
Conclusions 2023

Stromatolites are not always evidence for life

“still a cautionary tale”
Additional complications: Diagenesis

Modern

Ancient
Additional complications: Diagenesis

Modern mesostructure, microstructure, DNA, RNA, pH, salinity, nutrients, isotopes, and everything else

mesostructure, microstructure, maybe some geochem?

Ancient mesostructure
formed by organisms (on purpose)

formed in the absence of life

Abiotic

Biotic
significantly influenced by organisms

not significantly influenced by organisms
The Grey Area
Biotic

- DNA and measured preserved OTUs
- Carotenoid pigments from biological processes

Biogenic

- Gradients in elemental observed chemistry used for nutrient cycling in fluid inclusions

Abiogenic

- Elemental chemistry present in fluid inclusions
- Entombed fluids that are from the original evaporite precipitation

Abiotic

- The evaporite mineralogy and fluid inclusions, if present
- Trace minerals within evaporites
Thanks!

Courtesy of Stan Awramik
see through the lens of diagenesis

use the modern to inform the ancient

Get it out, snappy! Liz the pregnant crocodile undergoes urgent operation to remove Coca-Cola can from her stomach

- Took 8 hours and several operations to remove can from the 9ft reptile