



“What Samples Might Be & What Planetary Protection Might Be?”

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Walking the Herd

P.J. Boston, 2017

Ridiculously Hard Astrobiology Task #1:

Figuring out possible lifeforms from first principles!



"Ammonia! Ammonia!"

Drawing by R. Grossman; © 1962,
The New Yorker Magazine, Inc.

Planetary Protection

Protect Earth Life & Protect Extraterrestrial Life

Conundra

- Hard to do thoroughly.
- Essential to do thoroughly.
- Humans have short attention spans.
- **Cannot rely on human vigilance.**

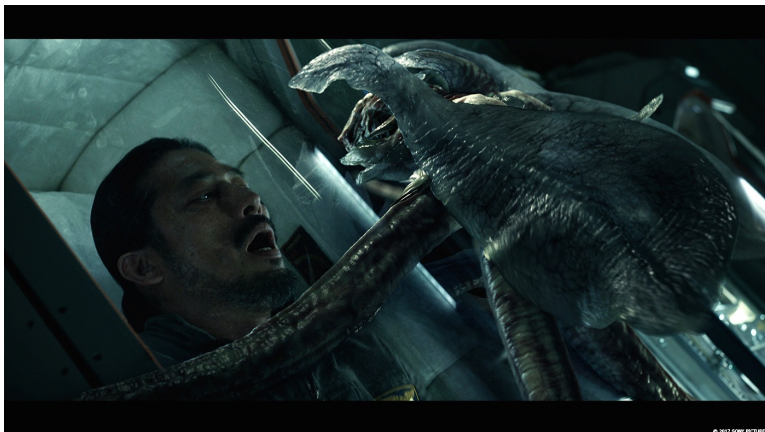
What can we work with?

- **Life detection & PP inextricably bound**
- **Tons of techniques out there.**
- Many not being considered.

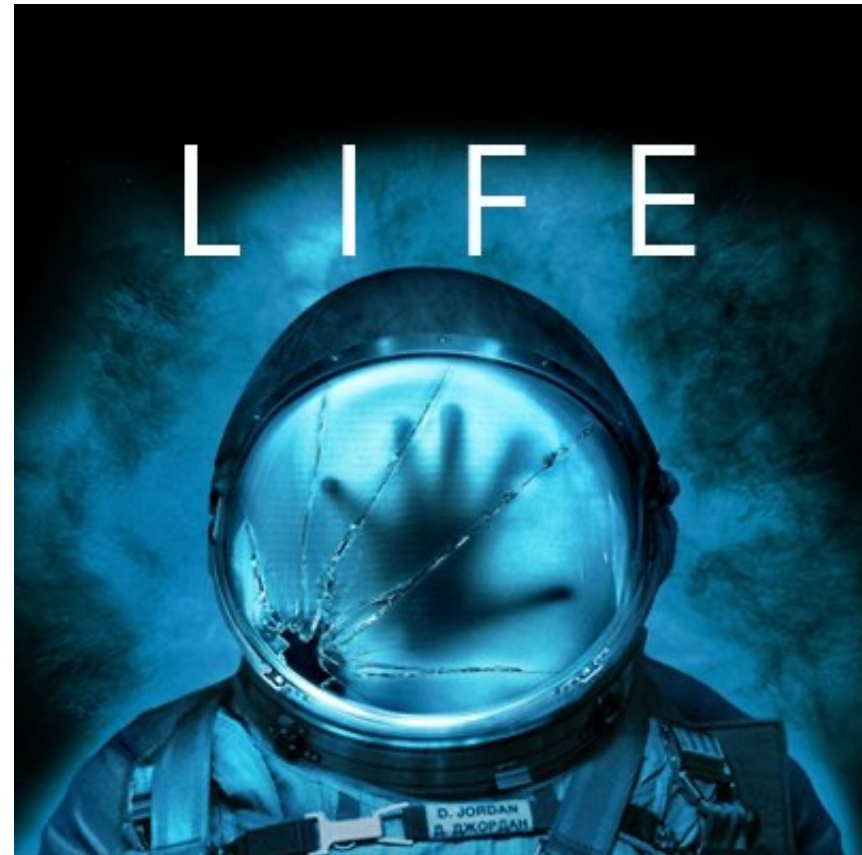
Astrobiologists must own this, too!

- It's not just somebody else's job....

"Don't let THIS happen to your space mission!"



Worst job of PP EVER???



Theatrical release poster, Columbia Pictures. Wikimedia Commons.

Field work reality meets protocol “best intentions”.



Life as we know it (& can even imagine it) is a complex phenomenon!

- ❖ No silver bullet, just a confusing set of beebie pellets.
- ❖ Identification in extreme Earth environments requires **many lines of evidence** to be convincing (e.g. Boston et al 2001; Cady 2002; Chan et al 2019).
- ❖ Detecting life on other bodies presents even greater challenges.
- ❖ **Rock-inhabiting communities present myriad sampling & analysis challenges.**
- ❖ **Maybe ices are easier??? Ice/rock interfaces tend to be life rich.**
- ❖ Patterns: Physical (in many wavelengths)
- ❖ Patterns: Organic & geochemical compounds
- ❖ Patterns: Geobiological textures
- ❖ Patterns: Elemental distributions
- ❖ **Data suites must be integrated to strengthen or refute claims of living entities.**
- ❖ Many but not all essential strategies & instrumentation to acquire datasets both abound in the literature & are the subject of ongoing studies.
- ❖ **Complexity requires implementation of mathematical & AI/ML approaches.**

Boston et al 2001. Cave biosignature suites: Microbes, minerals and Mars. *Astrobiology* 1(1):25-55.

Cady 2002. Formation and preservation of bona fide microfossils. In, *Signs of Life*, Nat. Acad. Press. Pp- 149-155.

Chan et al 2019. Deciphering Biosignatures in Planetary Contexts. *Astrobiology*, 19(9):1075-1102.

Biosignatures On Other Planets

✧ Life-produced Gases

- Oxygen
- Methane
- Ammonia
- Complex atmospheric spectrum

Extant Life



✧ Biological Molecules

- Live organisms!!!
- Chlorophyll on Earth
- Other photosynthetic pigments?
- “Sufficiently complex” organics....
- Molecular fossils

✧ Morphological Fossils

- True fossils (body fossils)
- Entombed original material
- Biominerals
- Biotextures
- Biopatterns

Extinct Life

✧ Geochemical Traces

- Isotopic fractionation
- Life chemistry alteration of rock record
- Life chemical traces trapped in geological materials



*Guardian by Joel Hagen
By courtesy of the artist*

Why Are Pattern Correlations Hard?

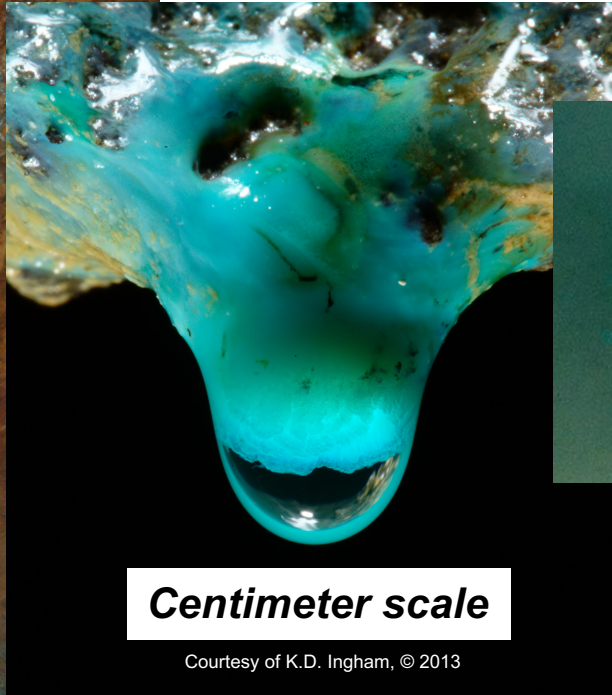
Correlations are only convincing when they are:

- 1) Found at **spatial & temporal scales appropriate** to the size of the life & its community structure.
- 2) Appropriate to life's extended activities (**aka extended phenotype**).
- 3) **Patterns co-existing in exact same sample, ideally.**
- 4) Multimodal simultaneous instrument suites capable of working on the same sample from non-destructive to more destructive analyses.
- 5) Especially true for environments with low biomass, slow activity, & cryptic often mineral-coated organisms!
- 6) **Clumsy “grab-grind-n’go” sampling destroys the delicate spatial & temporal relationships in such complex yet minute systems.**
- 7) **Longer-term monitoring** of some sites than current space mission architectures allow.
- 8) e.g. *In situ* stations recording slow physical and chemical changes of suspected biological phenomena over decades or longer.
- 9) Analytical methods that can overcome sampling deficits, e.g. Bayesian stats.

Continuity of Scales

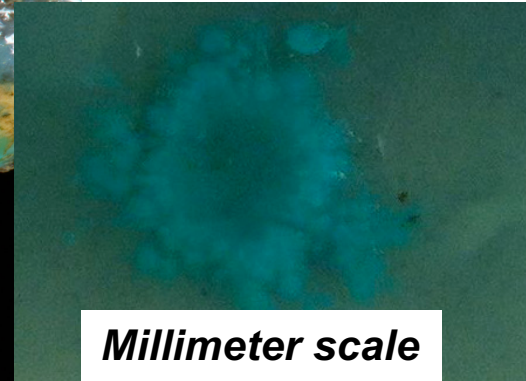


Meter scale

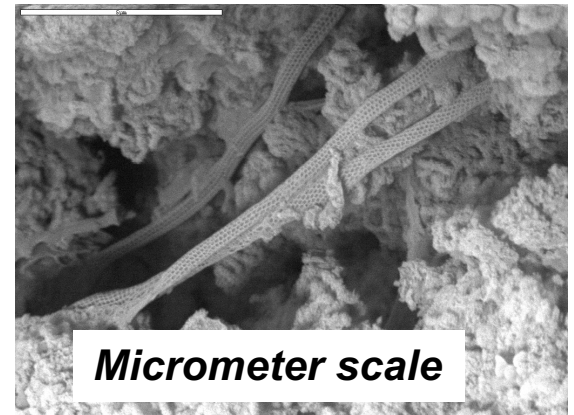


Centimeter scale

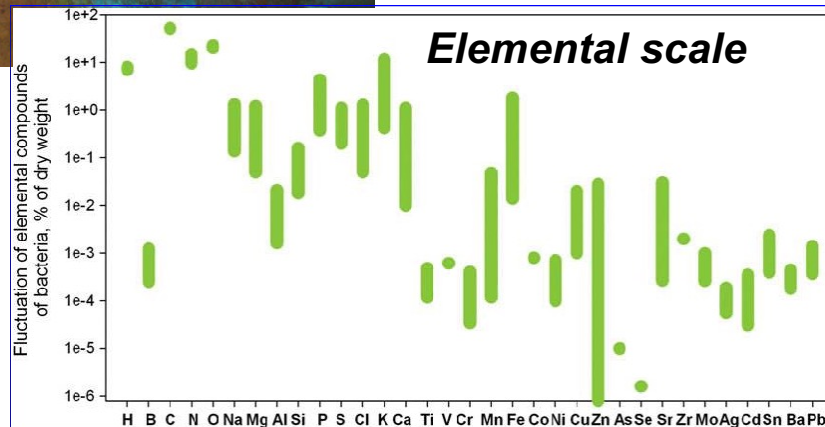
Courtesy of K.D. Ingham, © 2013



Millimeter scale



Micrometer scale

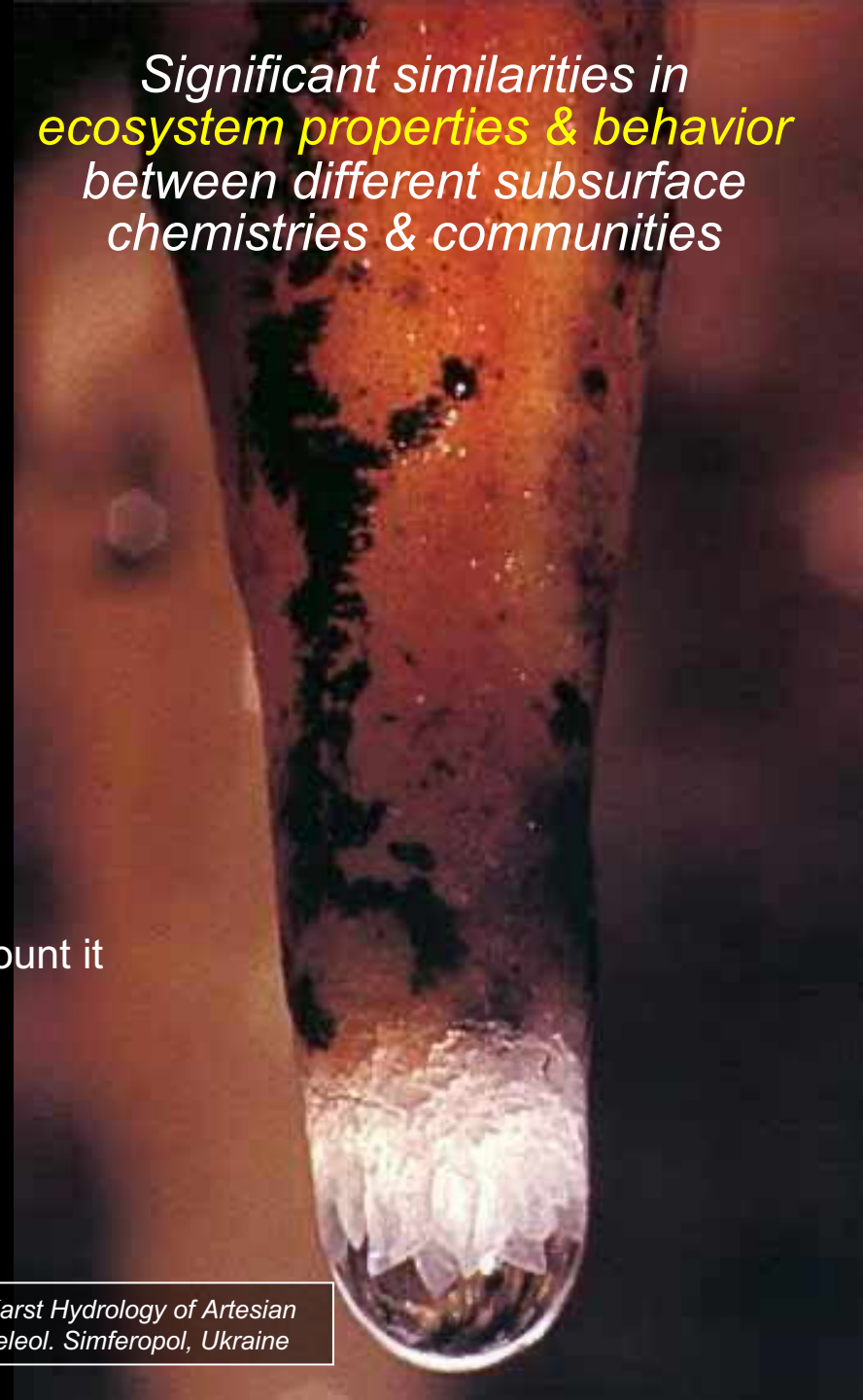


Elemental Composition of Modern Bacteria.
From: Novoselov et al 2013. From Cytoplasm to Environment: The Inorganic Ingredients for the Origin of Life. *Astrobiology* 13(3):294-303.

“Universal” Subsurface Lessons

- Ubiquity of biofilms & mats
- Functionally indivisible obligate multi-species communities
- Microbial pioneer species invade bedrock
- **VERY slow growth rates**
- **VERY low biomass**
- **Very small cell sizes**
(100 - 500 nm diam. common)
- Unusual preponderance of weird shapes
This means something....
- Stupefyingly large biodiversity as we currently count it
How much of this “matters” evolutionarily???
- Ubiquity of metal oxidation for energy
- **Mineral reprecipitation by (& on) organisms**
- ***In situ* self-fossilization**

*Significant similarities in
ecosystem properties & behavior
between different subsurface
chemistries & communities*

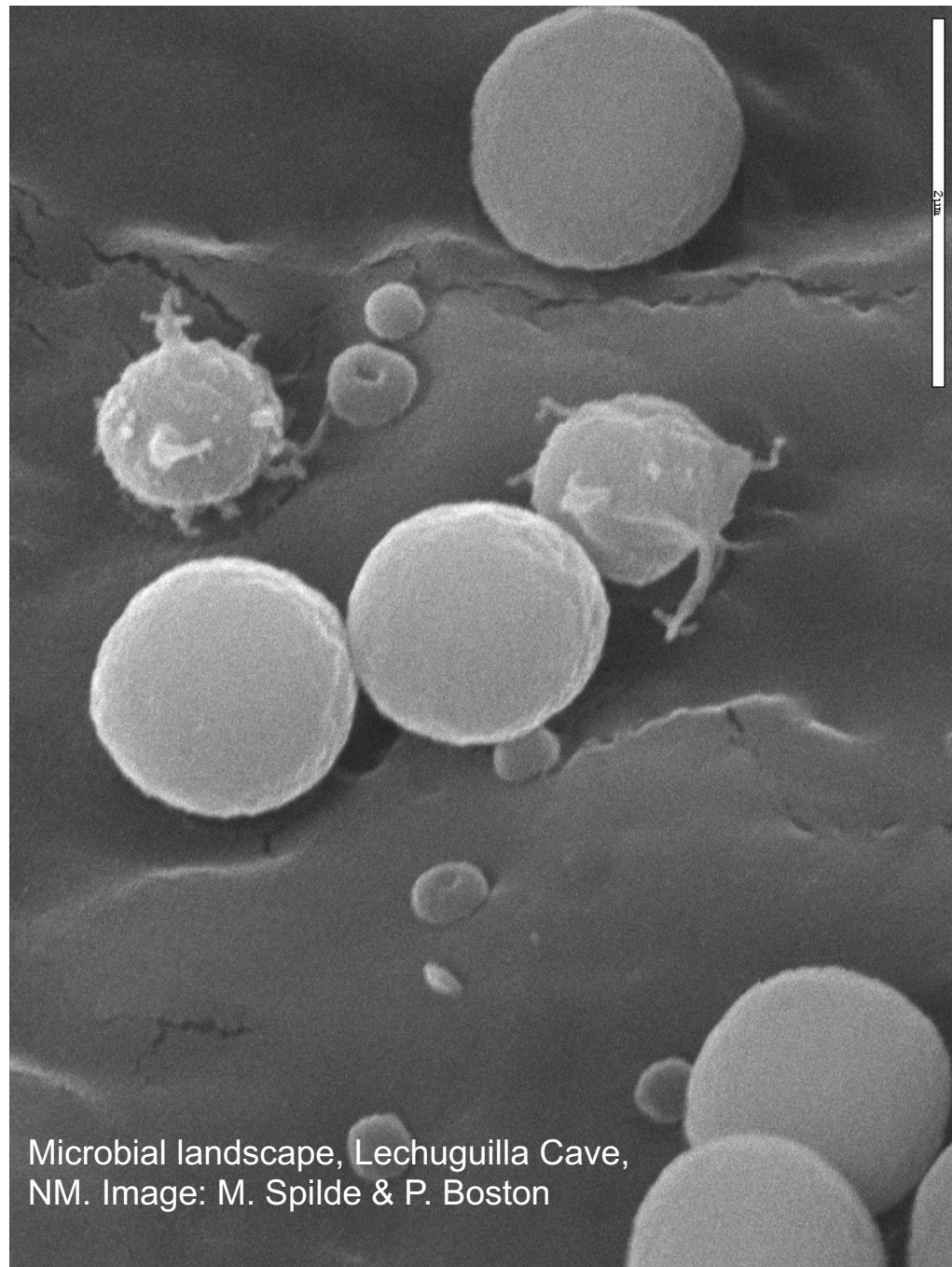


Community Context is Essential

The Vermin only teaze and pinch
Their Foes superior by an Inch.
So, Nat'ralists observe, a Flea
Hath smaller Fleas that on him prey,
And these have smaller yet to bite 'em,
And so proceed ad infinitum:
Thus ev'ry Poet, in his Kind
Is bit by him that comes behind.

Jonathan Swift - *On Poetry: A Rapsody*, 1733

- Distribution not just gradients!
- Self-organizing properties.
- ...and don't forget the viruses & virus-like entities.



Microbial landscape, Lechuguilla Cave,
NM. Image: M. Spilde & P. Boston

Mars Extant Life: What’s Next? Conference Report

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Good for Extant Life

- Caves
- Deep Subsurface
- Ices
- Salts

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CARRIER, BEATY, MEYER ET AL.

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Abstract

On November 5–8, 2019, the “Mars Extant Life: What’s Next?” conference was convened in Carlsbad, New Mexico. The conference gathered a community of actively publishing experts in disciplines related to habitability and astrobiology. Primary conclusions are as follows: A significant subset of conference attendees concluded that there is a realistic possibility that Mars hosts indigenous microbial life. A powerful theme that permeated the conference is that the key to the search for martian extant life lies in identifying and exploring

Meh for Extant Life

- General regolith
- Volcanic surface rocks
- Igneous surface rocks
- Sedimentary surface rocks

Meh for Extant Life

- General regolith
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Good for Extant Life

- Caves
- Deep Subsurface
- Ices
- Salts

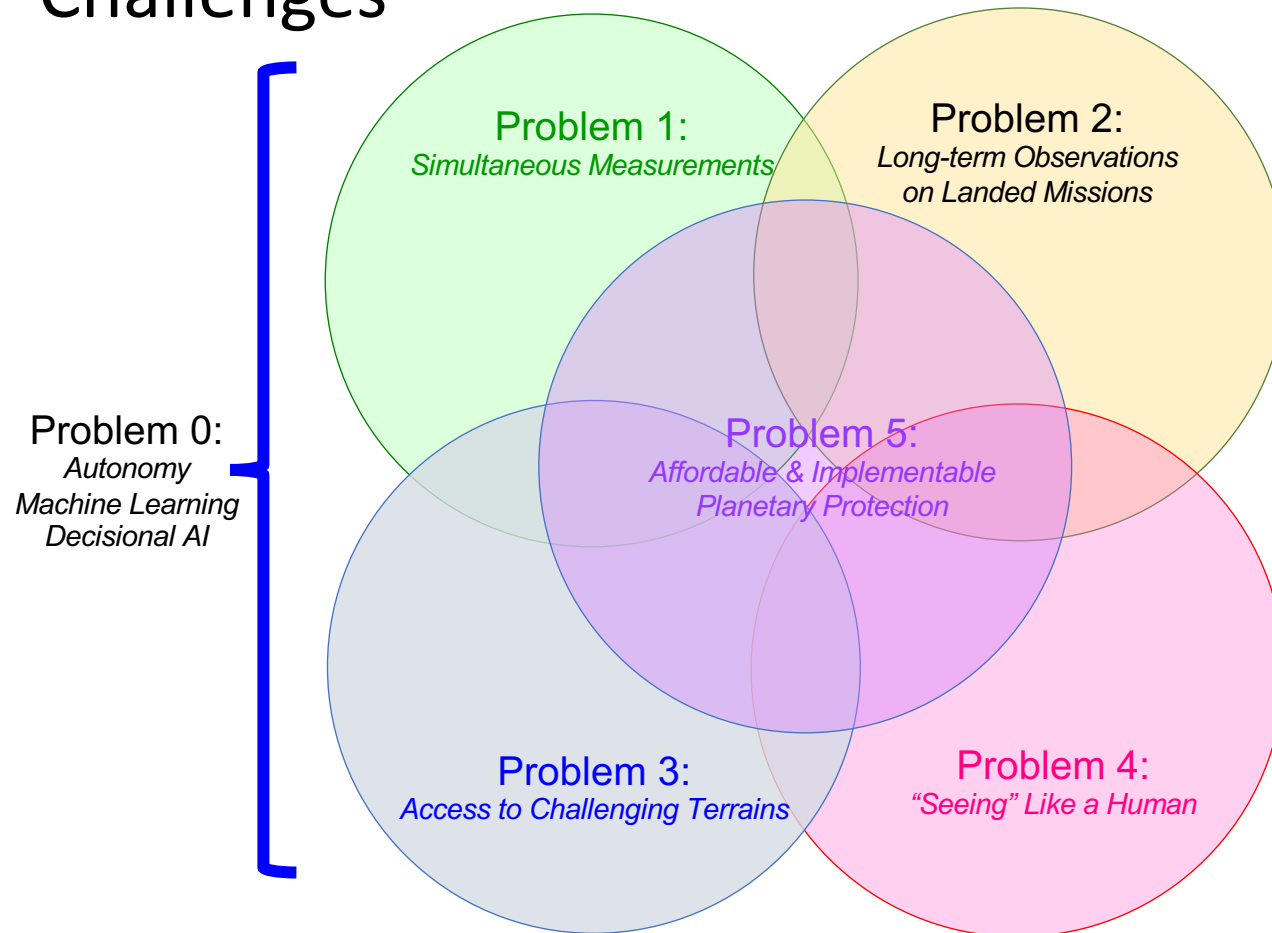
❖ Grid-based search?

- ❖ The most likely materials accessible to early human missions.
- ❖ The most likely materials to be constantly exposed to radiation, dessication, other Martian joys.
- ❖ Least likely to be PP sensitive.
- ❖ Good News: Can allow us to “practice” sampling and PP protocols.
- ❖ Bad News: Failure to find lifesigns could breed complacency for all future Martian samples.

❖ Feature-based search.

- ❖ All have accessibility challenges from moderate to extreme.
- ❖ Ices & salts might be accessible to early human missions.
- ❖ Ices are targets for ISRU.
- ❖ Do we have the attention span to remain vigilant about PP until we can access these types of sites???

Challenges



* Boston, 2017. Planetary Science Vision 2050 wkshp, LPI # 1989

Problem 5:

Affordable & Implementable Planetary Protection

- Planetary Protection can't be an afterthought.
- Even available life detection technologies are not part of the current cannon.
- Fundamental incompatibilities between PP and ultra-clean technologies.
- **I assert that fear of PP cost & complexity is overblown in the minds of some because future extrapolations from current technologies are not accounted for.**



Shells on a Foreign Shore

Design Planetary Protection requirements in at the highest levels, design systems and subsystems for PP methodology compatibility.

Explore novel technology ideas, e.g. in situ cruise-phase sterilization, microbe repelling or retaining materials, etc.

Why have I NEVER seen a PP related proposal to the NIAC program?????

So?

- ❖ Overwhelming array of measurements and comparisons.
- ❖ Limitations: mission access, expense, danger to humans at extreme environment sites on Earth, & to spacecraft on other Solar System bodies.
- ❖ Patterns of any sort suit artificial intelligence & accompanying pattern recognition methodologies.
- ❖ *“AI capability is more than is believed, but less than we want.” – Colleague in AI.*
- ❖ Such methods being applied to various problems in biology and medicine (e.g. Kim & Boutin 2015, nutritional status from math estimation).
- ❖ Simultaneous multiple neuronal networks to accomplish correlation of multiple sets of patterned data (e.g. Gomez-Flores et al 2020).
- ❖ Computing power currently limited in situ, but some decision & down-select already possible. **Astronauts MUST have these capabilities in situ.**

Gómez-Flores, W., Hernández-López, J. 2020. Automatic adjustment of the pulse-coupled neural network hyperparameters based on differential evolution and cluster validity index for image segmentation. *Applied Soft Computing* 97(105547).

Kim, J. & Boutin, M. (2015) Deriving Nutrition Information Using Mathematical Estimation: The Example of Phenylalanine in Sweets with Gelatin. *J Acad Nutr Diet* 115(9)1384-1386.

What do microbes do to rocks and minerals?

Transformation....

Dissolution

active mining
metabolic byproducts

Nucleation

alive
dead

Corrosion

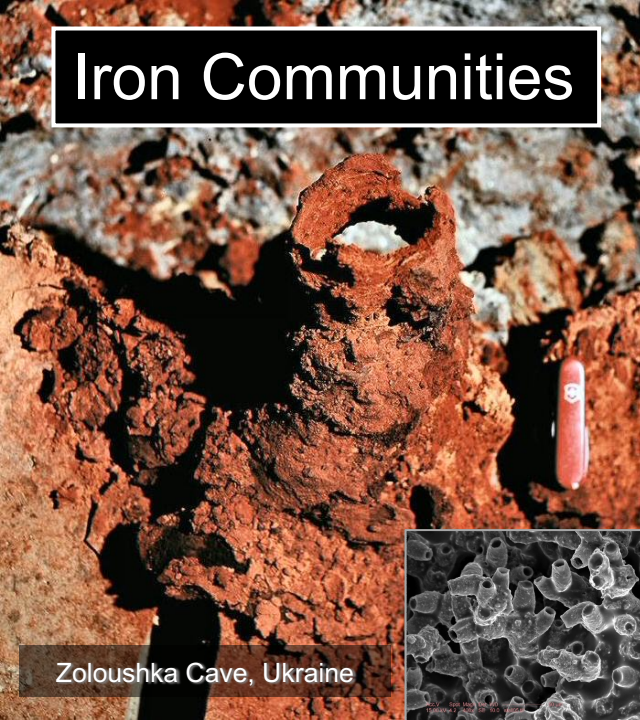
bedrock
minerals
metals

Precipitation

passive
active

*Picasso Rock, Lechuguilla Cave, NM
Image by Val Hildreth-Werker, by courtesy*

Iron Communities



Zoloushka Cave, Ukraine



Soudan Iron Mine, MN

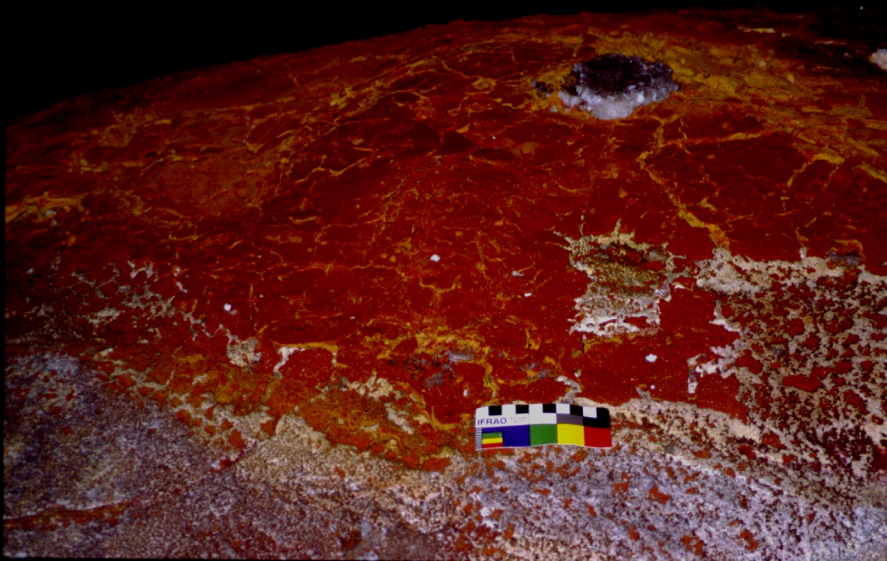


Cold Water Cave Iron Deposits, MN
By courtesy, David Jagnow



Zu Azufriel, Sardinia, Italy

Picasso Rock, Lechuguilla Cave, NM
Image by Val Hildreth-Werker

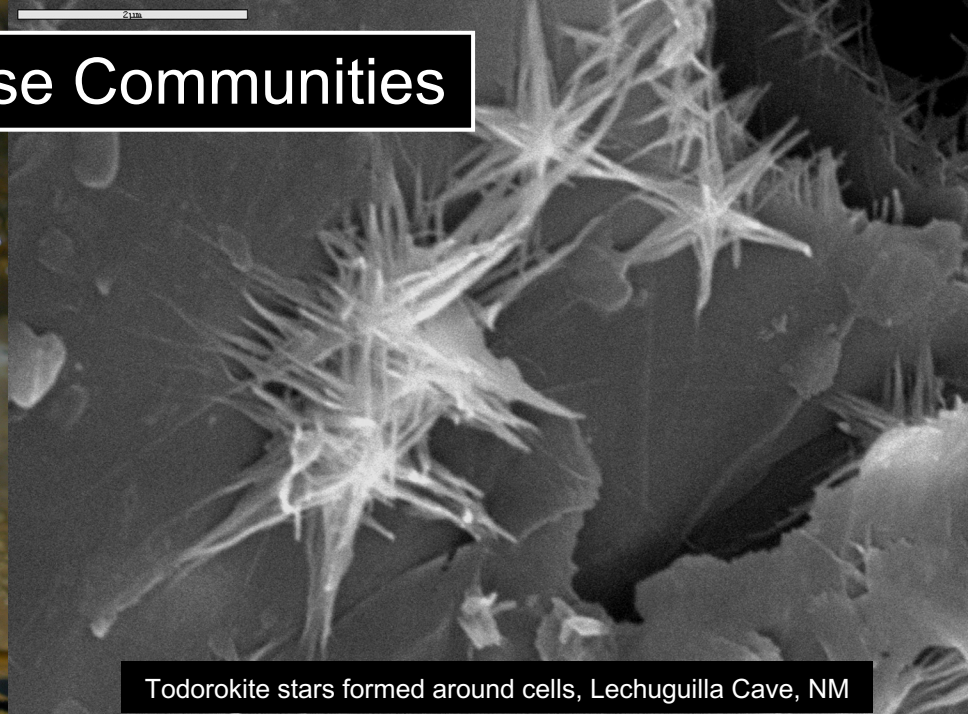


Pool fingers, Carlsbad Cavern, NM. By courtesy, Peter Bosted

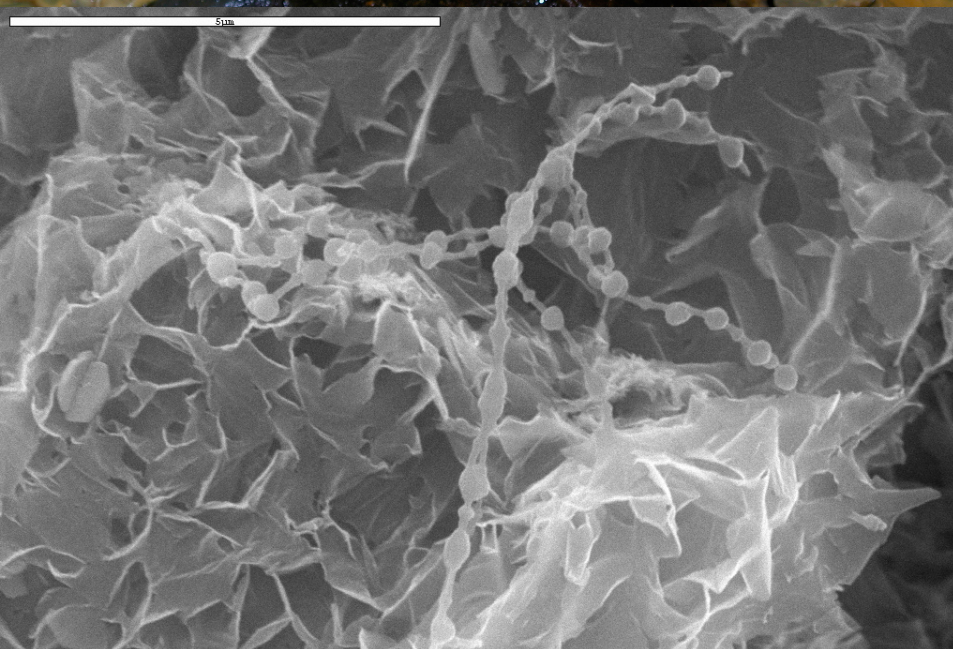
Manganese Communities



Manganese microbialite on abandoned miner's jacket, Soudan Mine, MN



Todorokite stars formed around cells, Lechuguilla Cave, NM

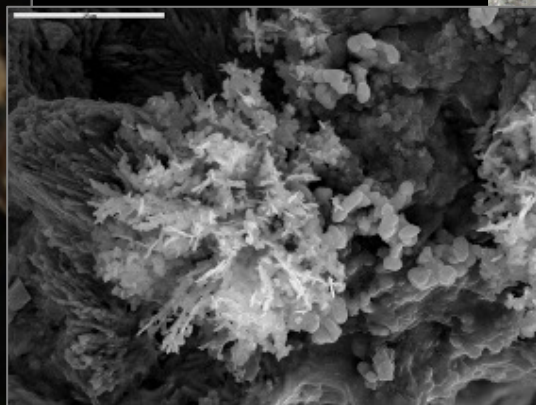


Beads on a string & birnessite, Ft. Stanton/Snowy River Cave, NM

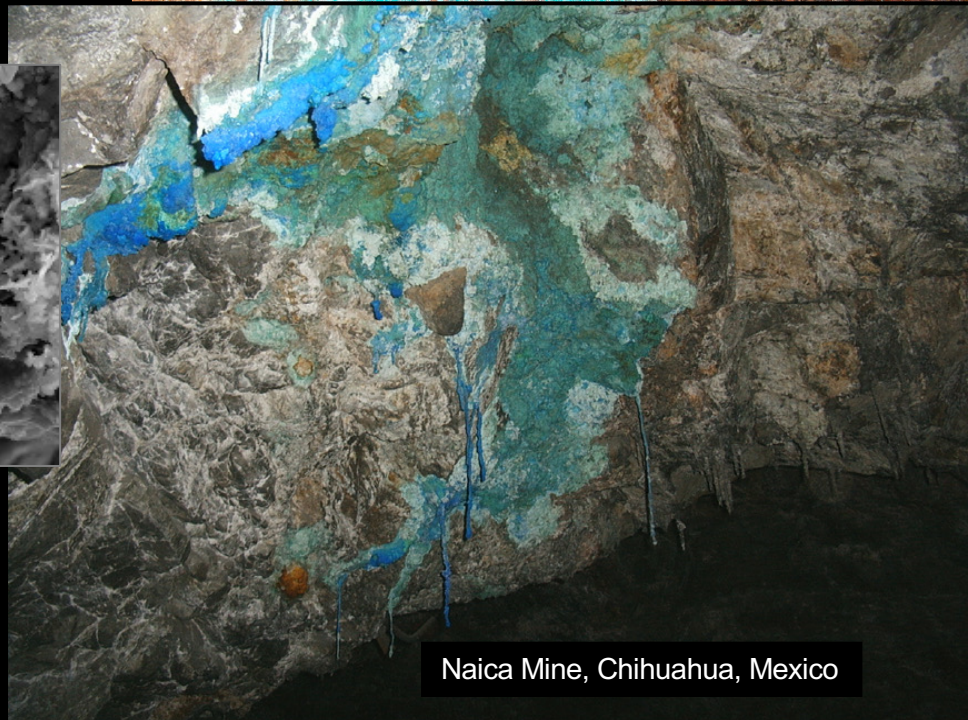


Mud manganese snottites, Zoloushka Cave, Ukraine

Copper Communities



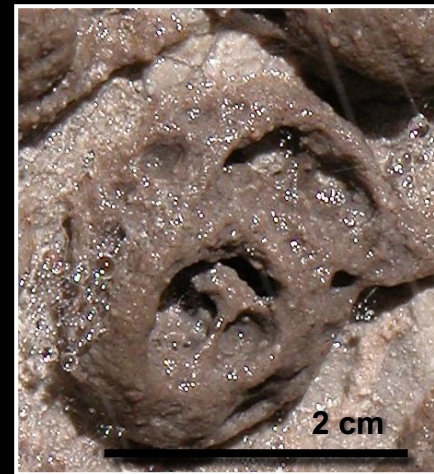
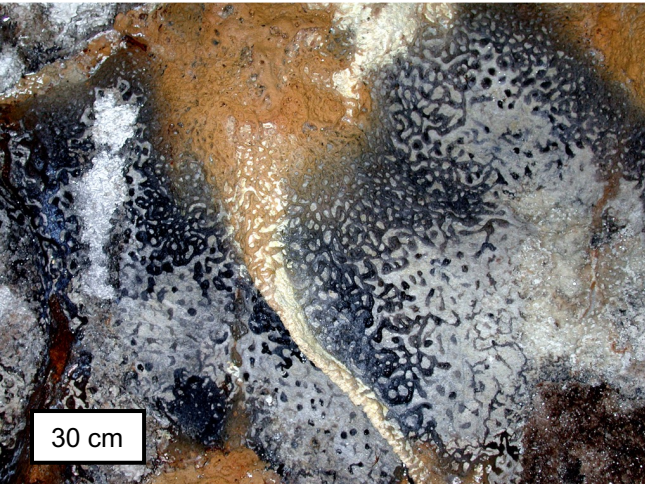
Chalcocite community, SEM



Biopatterning

- Hieroglyphic patterns
- Biovermiculations!
- **Behavior made visible!**
- First observed in sulfuric acid cave
- Also found in Mayan ruins, mines, caves of all types including lavatubes, cryptogamic soils, under Australian hypoliths, & higher vegetation in Israel!

Boston et al 2009, Strader et al 2010, Schubert et al 2011



Very 3D !

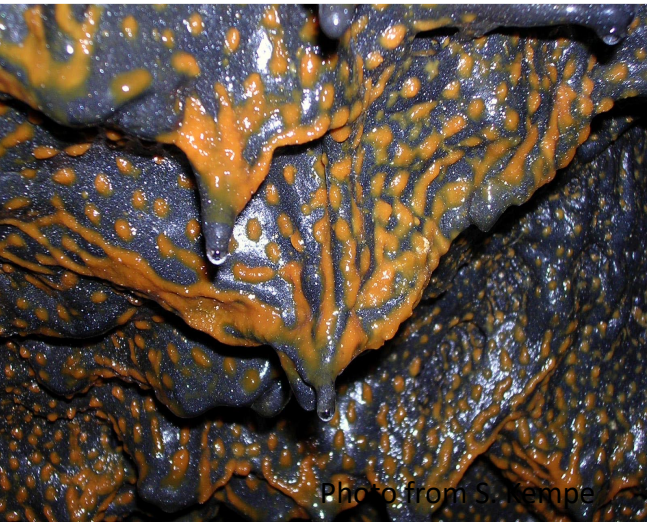
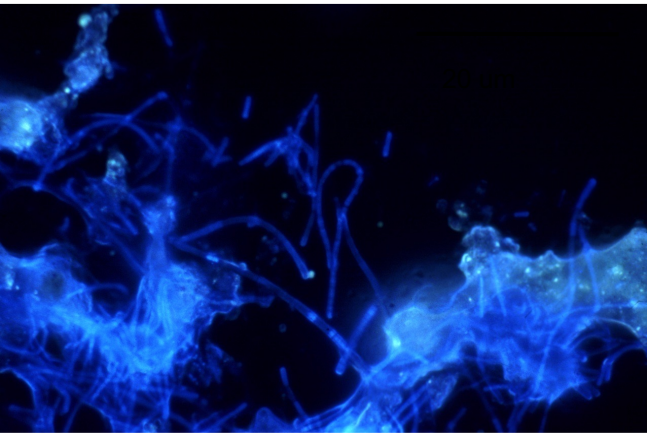
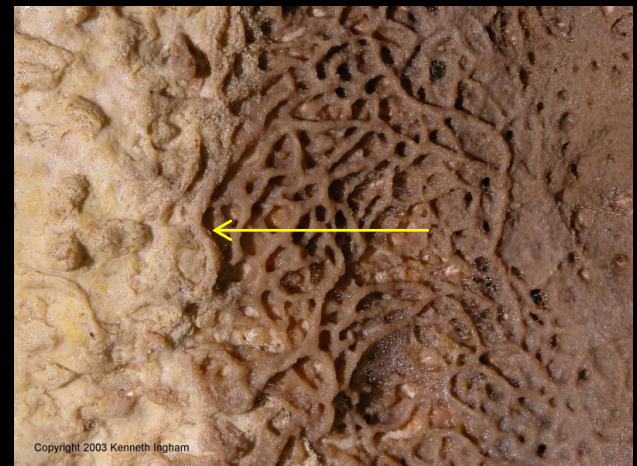


Photo from S. Kempe

Sediment incorporation from
fault gouge clays



Lithification Front



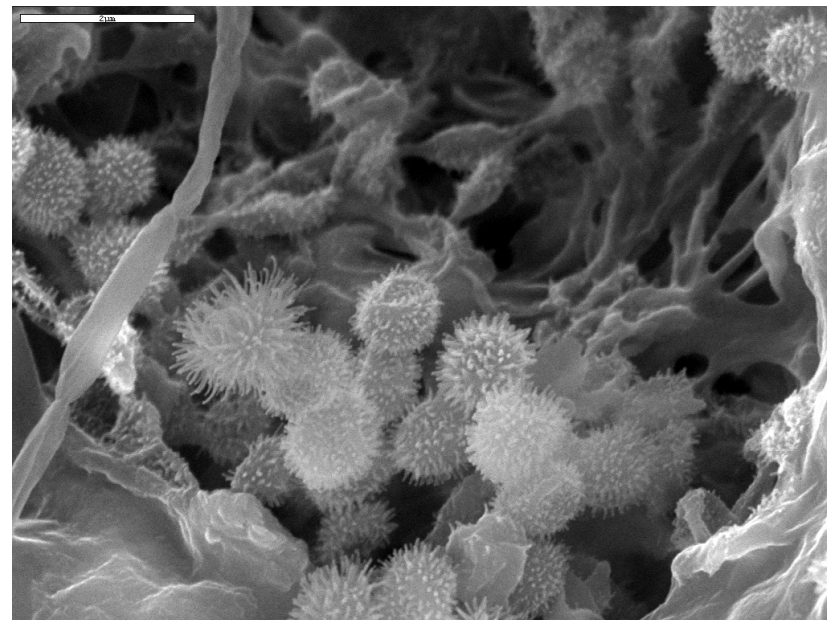
Copyright 2003 Kenneth Ingham

“Life Detection” by Circumstantial Evidence....



Wikimedia Commons

- ✓ Suspiciously complicated organic compounds
- ✓ Co-location of possibly biological compounds
- ✓ Patterns of molecular occurrence



*Micro-chrysanthemum Garden, Un-named lavatube, Canary Islands
By M.N. Spilde & P. Boston*

- ✓ Suspiciously complicated structure
- ✓ Co-location of numerous units
- ✓ Patterns in structures (macro & micro)

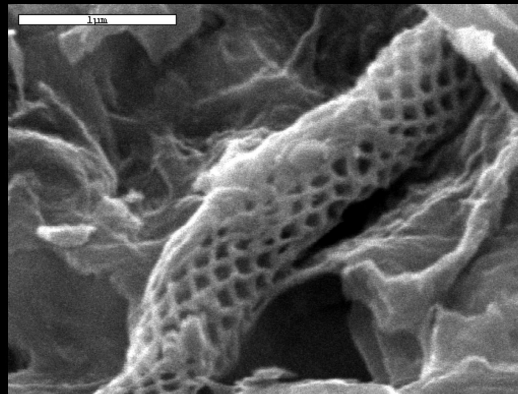
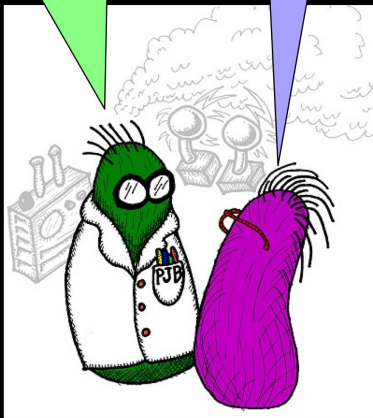
Bionoise on Earth

- Some detection & identification could be easier on Mars
- Logical connections between different analytical modes.

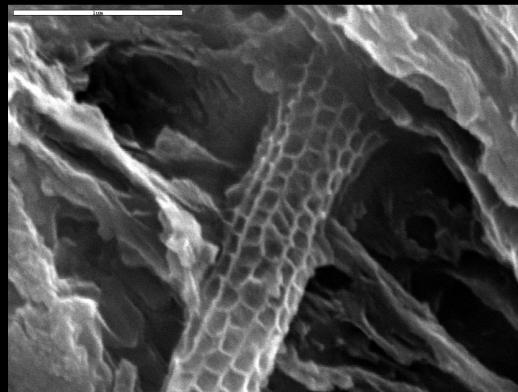
In many caves, we operate in extreme environments with sensitive "alien" biology...

What are these, o Wise Omnipotent Professor Boston?

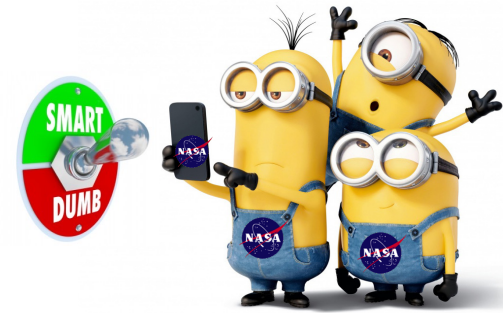
Gosh, Eager Young Student... I haven't the foggiest...



What are these???
Do you know?
We don't....



Take-home Messages



- ❖ **We can practice PP at Earth analog sites!**
- ❖ Extremophile & other planetary analog sites should become high priority test beds for Planetary Protection technologies & operations.
- ❖ Detection claims of extraterrestrial life or Earth's demanding habitats cannot rely on a few tantalizing but relatively weak lines of evidence.
- ❖ Must be the target of intensive, time-clustered interrogations of biological, chemical, physical, & potentially even behavioral phenomena.
- ❖ ALH84001 martian meteorite (McKay et al., 1996) as a cautionary tale.
- ❖ **A modest suite of individually promising lines of evidence failed to convince the scientific community that biology was involved.**
- ❖ Still being pondered today (e.g. Steele et al., 2022).

