Title: The Planet Within: Caves from Earth to Mars and Beyond

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Abstract: We can set foot on faraway planets, in a sense, by exploring the world beneath our
feet. Underground caves provide unique insights into what we might find beneath
alien landscapes. We are studying caves on Earth to understand how they
form, the spectacular minerals they produce, and the unusual creatures â€“ from
microbes to vertebrates â€“ that thrive in them.

By understanding the caves of our own planet, we can use them as models for the
subsurfaces of other planets. This work provides insights into the lava tubes
on celestial bodies including Mars and our Moon, as well as possible dissolved
caves on Titan, which orbits Saturn. There are many possibilities surrounding
cave formation on practically every type of object in the Solar System.

Some of the most extreme cave environments on Earth are inhabited by an amazing array
of microorganisms. Some of these creatures eat their way through bedrock,
some live in hyperacid conditions, some produce unusual biominerals and rare
cave formations, and many produce compounds of potential pharmaceutical and
industrial significance. We study these unique organisms and the physical
and chemical biosignatures they leave behind. Such traces can be
used to provide a â€œField Guide to Unknown Organismsâ€• for developing life-detection
space missions. Additionally, the lava tubes clearly present on Mars
and the Moon can provide the basis for future human habitations on those
planets.

The Planet Within

Caves from Earth to Mars and Beyond

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Subsurface Rock Habitats

The Planet Within

Caves & mines provide a window into a subsurface that is radically different from the surface

Rub al Khali (Empty Quarter)
Saudi Arabia, Oman, Yemen, and United Arab Emirates

Images by John Pint

Subsurface Environments

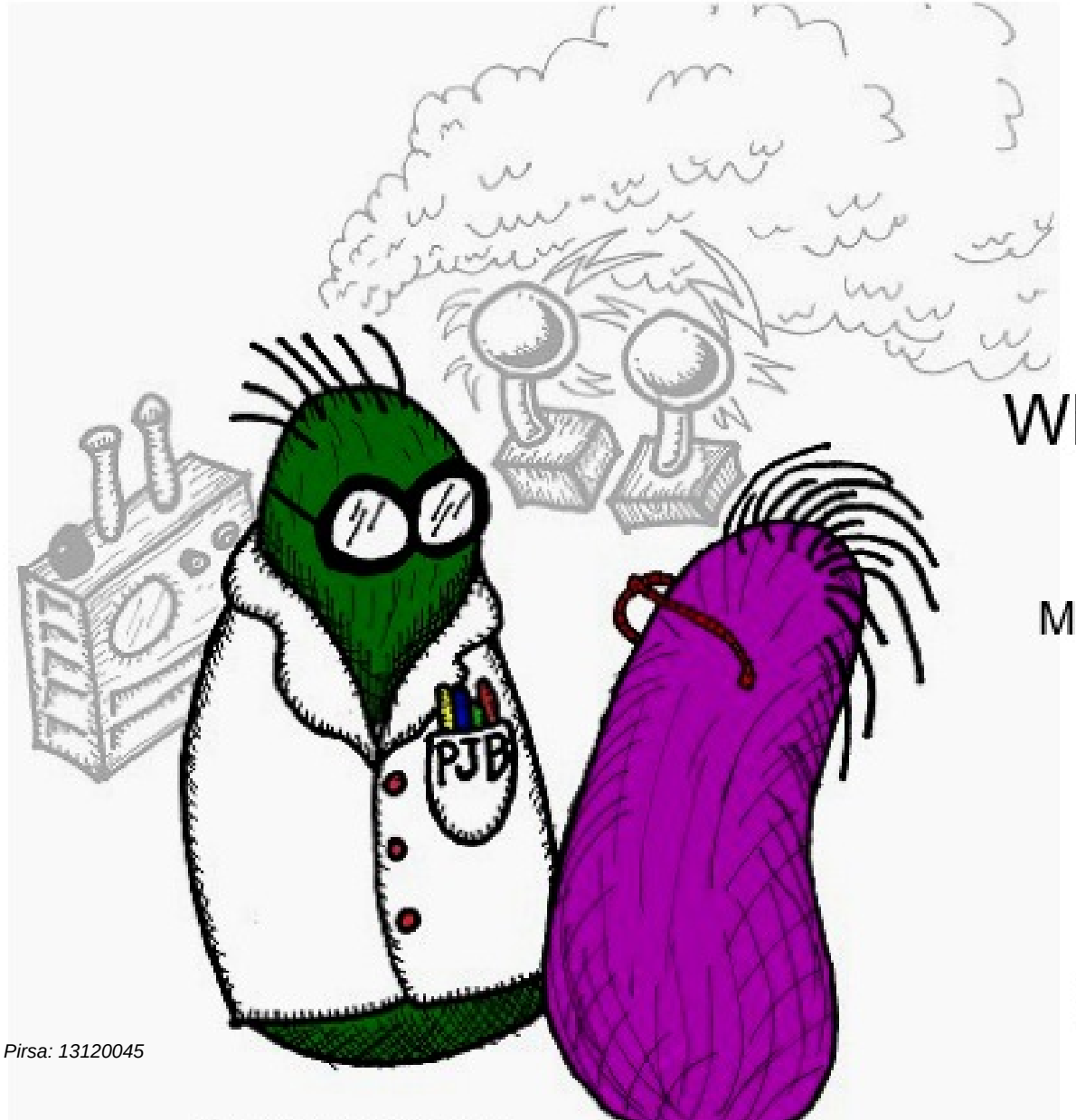
- No sunlight (past the twilight zone)
- High humidity
  (99-100% typical even in deserts)
- Temperatures constant
  (but large range globally & with depth)

- Low organic nutrients (usually)
- Mineral-rich (usually)
- Sometimes availability of extra chemical energy
  e.g. reduced gases, bedrock components

- No surface weather
- Splendid preservation environment!

Entrance Drop
Lechuguilla Cave, NM

What is Geomicrobiology?



Microorganism interactions with rocks and minerals

What do microbes do?

Major transformation of materials

Manipulate geochemistry, *e.g., pH, ORP,* O_2

Dissolve bedrock

Precipitate biominerals actively

Nucleate crystallization passively

Significance of Geomicrobiology

- Geological agents
- Economic minerals
- Unusual minerals & xtals

- Low temperature catalysis
- Pharmaceutical potential

- Novel organisms and metabolism
- Origins of life & early evolution
- Astrobiology


…the search for life in the universe…
Writing the Field Guide to
Unknown Organisms
Limits to life on Earth?
Relationship to Early Earth conditions?
Potential for life on other planets?

Extraterrestrial Caves

What Do We Know About ET Caves?

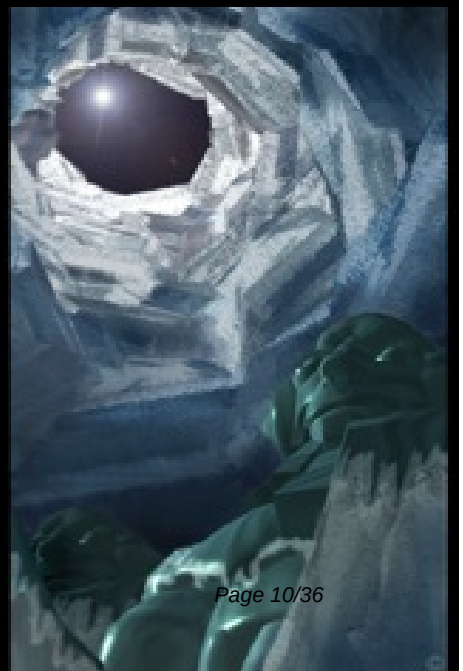
knowledge

speculation

- Lava tubes on a number of bodies

- Any planet with a surface will develop cracks
- Cracks provide the foundation for:
  solutional caves (e.g. limestone, gypsum, salt)
  tectonic caves
  more exotic cave-formation mechanisms

- Caves from entirely non-Earth mechanisms?
  e.g. sublimation of cometary ices or Martian poles?
  Titan karst in tholin organic goo?



Caveview of Saturn fromTitan by B.J. Johnson

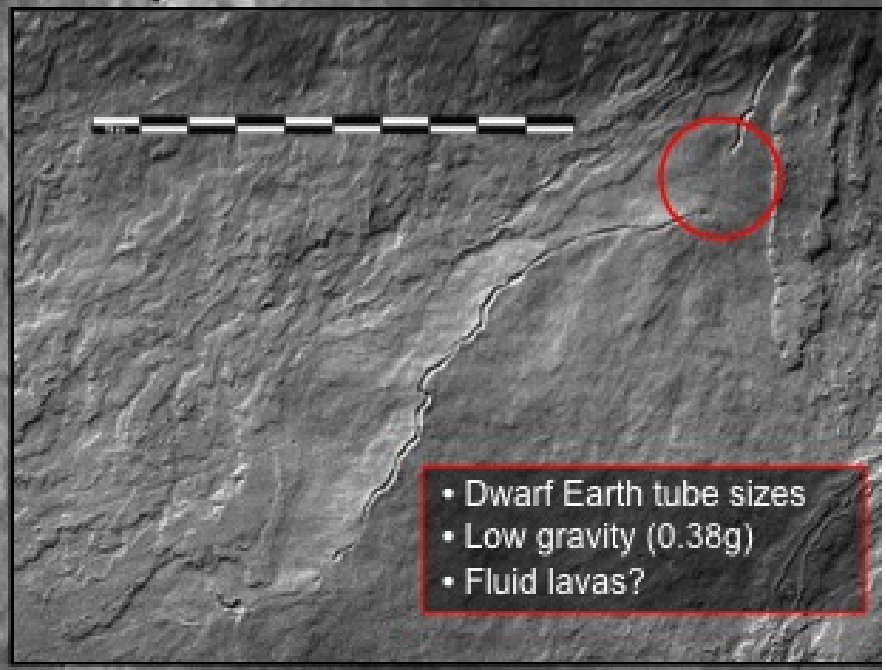
Acknowledgement of potential extraterrestrial cave-forming mechanisms dates to the dawn of the Space Age

Oberbeck, V.R., Quaide, W.L., & Greeley, R.. 1969.
On the Origin of Lunar Sinuous Rilles, *Mod. Geol. 1:*75-80,

The Moon - Vallis Schroteri , Aristarchus

Hawaii, Open lava channels forming

Elysium Mons



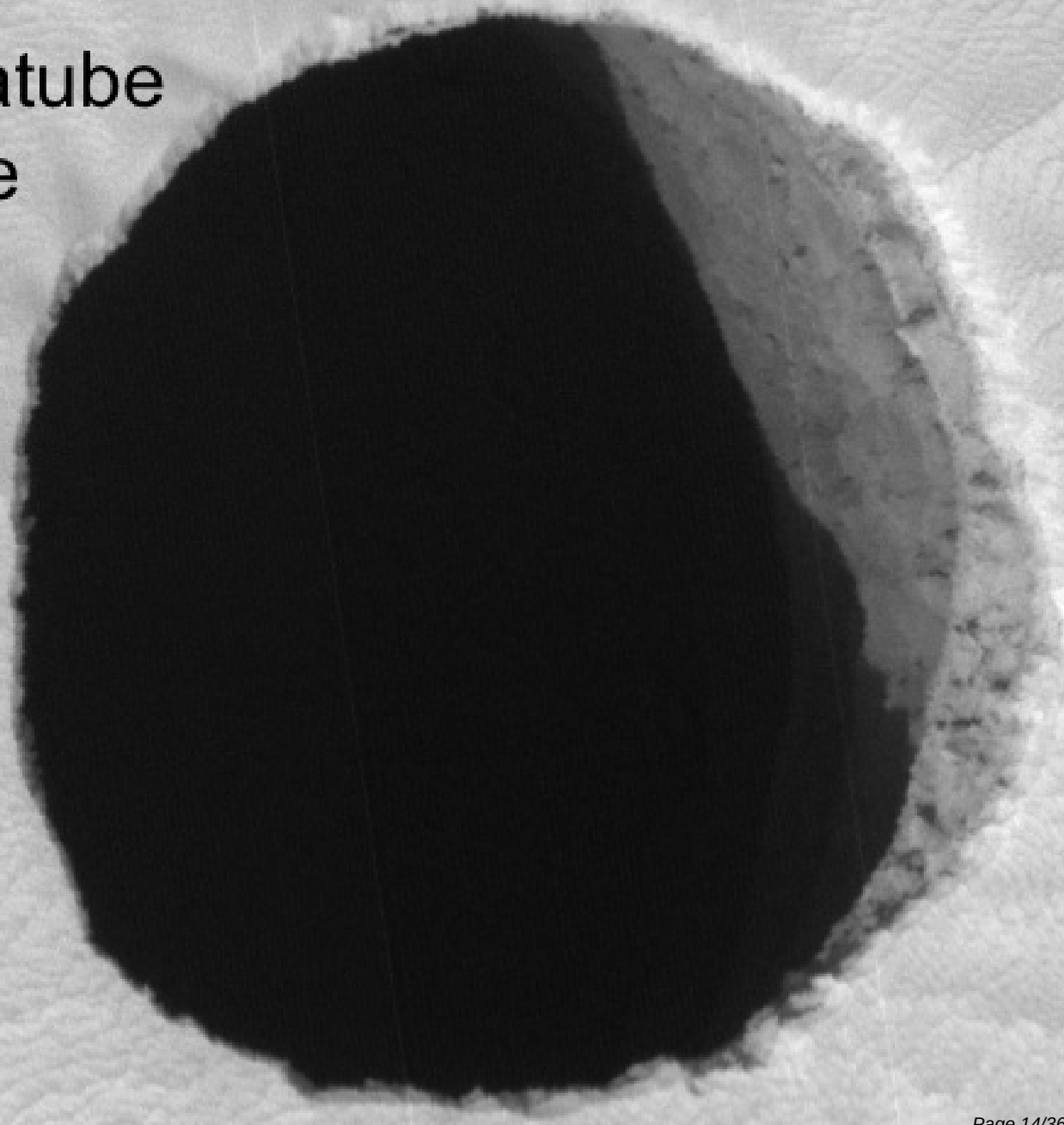
Mars Lava Tubes

Buried Lavatube Forming – Mt. Etna

Molten lava visible through skylight

Skylights and collapse pits mark paths of tubes

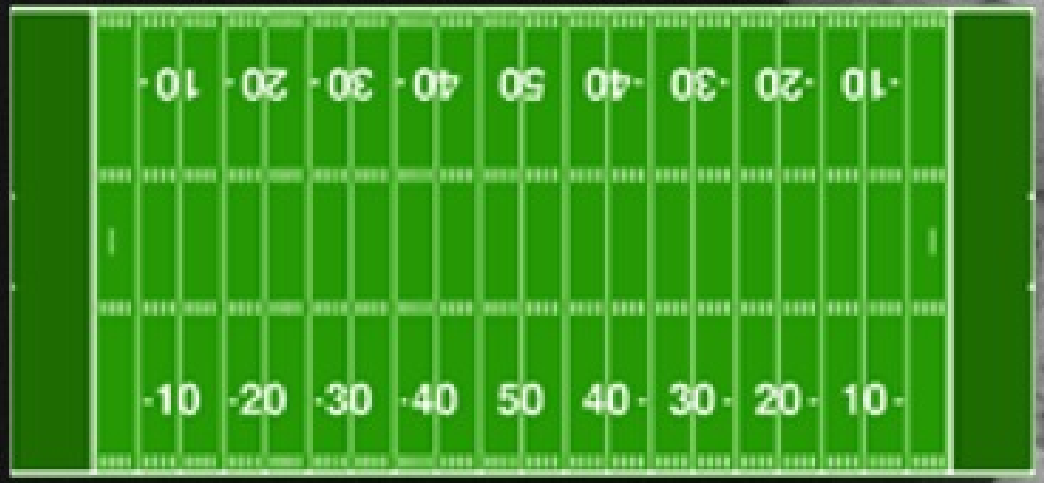
Martian Lavatube Entrance



HiRise data
30 cm resolution
Hole is 100 m across!

Martian Lavatube Entrance

Compared to an American football field



HiRise data
30 cm resolution
Hole is 100 m across!

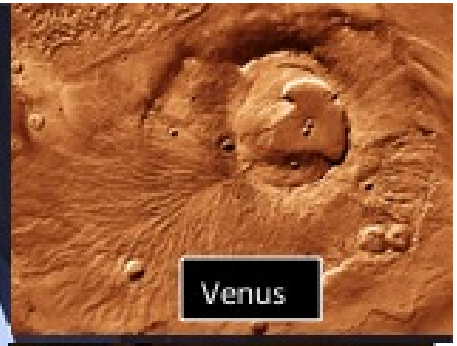
Martian Lavatube Entrance

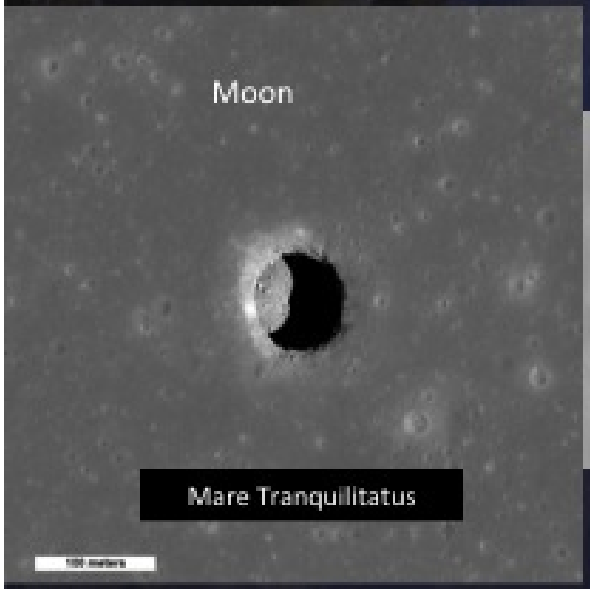
compared to an American sinkhole!

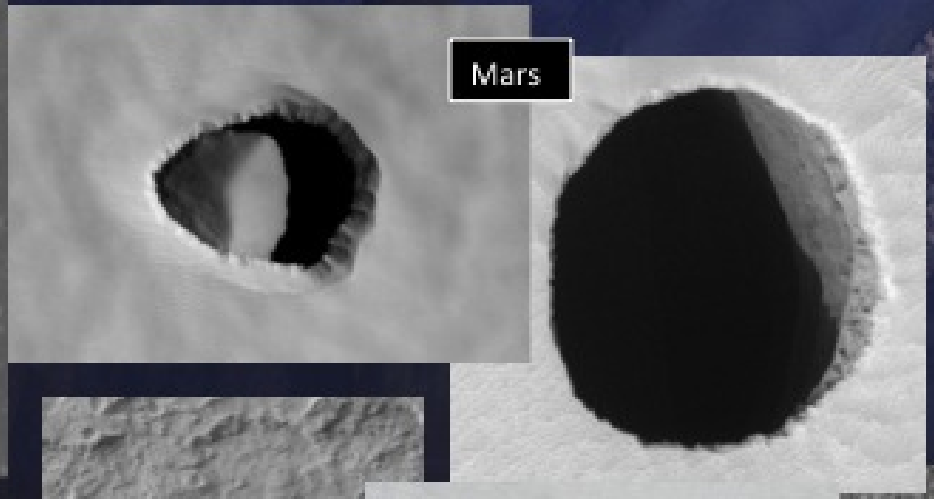
West Desert Sinkhole
Utah

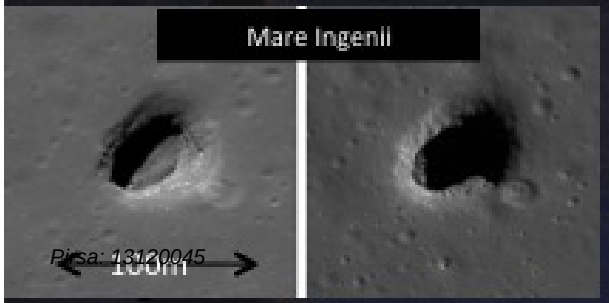

West Desert Sinkhole, Utah
39.204615 -113.270345
~22 meters diameter

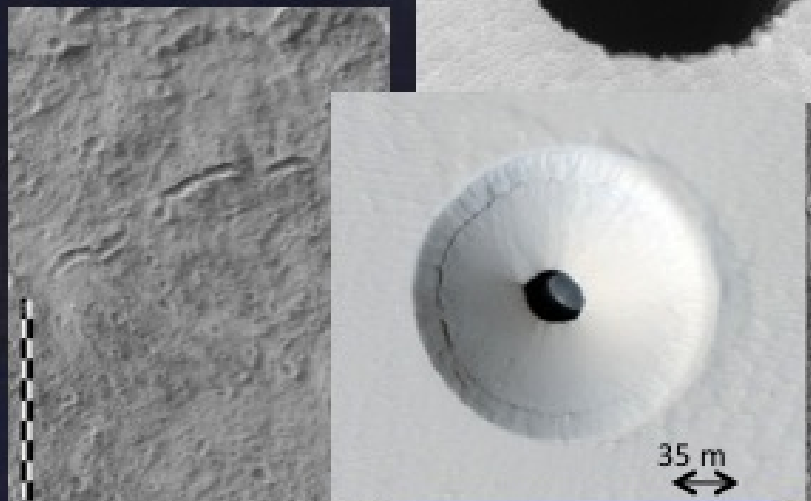
Extraterrestrial Lavatubes



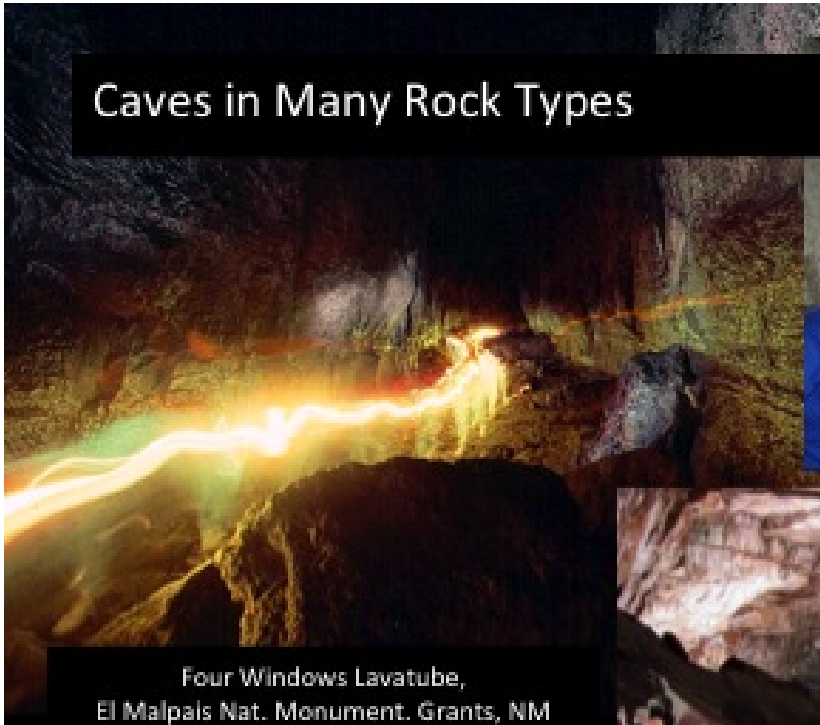








Caves in Many Rock Types



Four Windows Lavatube,
El Malpais Nat. Monument. Grants, NM

Granite spalling caves
Gallicia, Spain

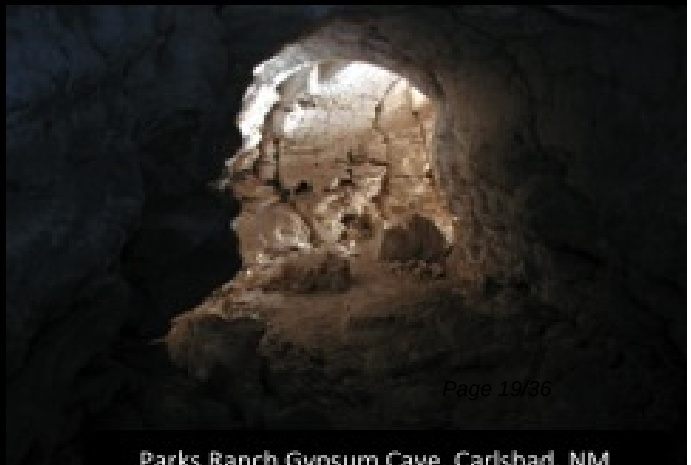
Lechuguilla Cave, Carlsbad, NM
created by sulfuric acid and limestone

Cueva de Charles Brewer
Quartzite Cave, Venezuela

Antarctic ice caves

Caves in Salt

Lilburn Marble Cave, CA



Parks Ranch Gypsum Cave, Carlsbad, NM

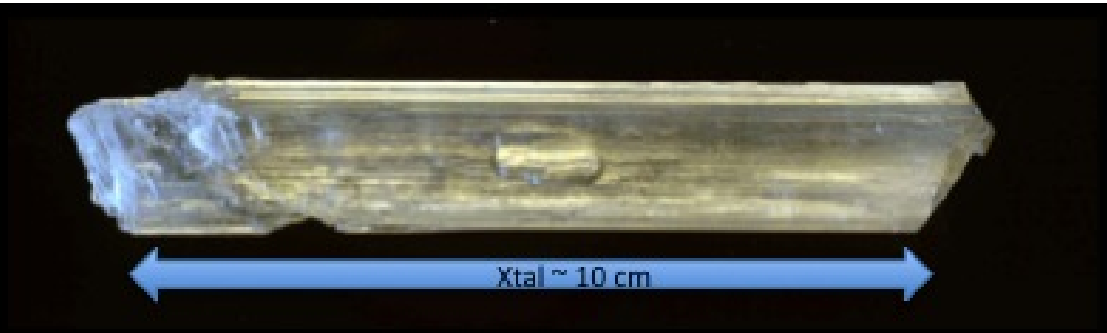
Whoa! Is this a photoshop hoax?

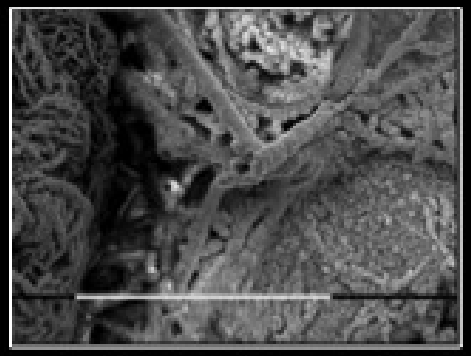
Giant Crystal Cave - National Geographic TV Special, Oct 2008
& National Geographic Magazine, Nov. 2008

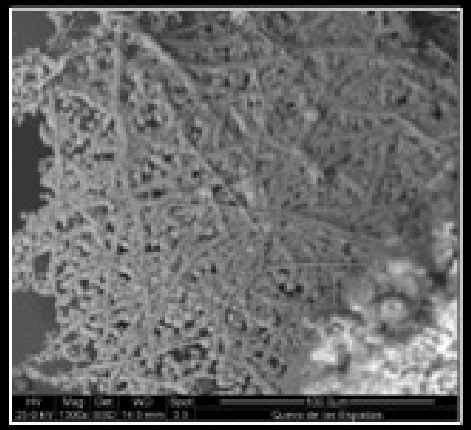
Image courtesy of Carsten Peters,


Naica Mine, Naica Cave System
Chihuahua, Mexico
❖ Giant selenite crystals
($CaSO_4$ same mineral as wallboard…)
❖ 40-60°C (whew!)
❖ Water drained for mining
❖ Saturated humidity
❖ Fe oxide deposits

- Crystal inclusions
- Solid & fluid
- Fe deposits on walls
- Mn deposits on walls & in xtals

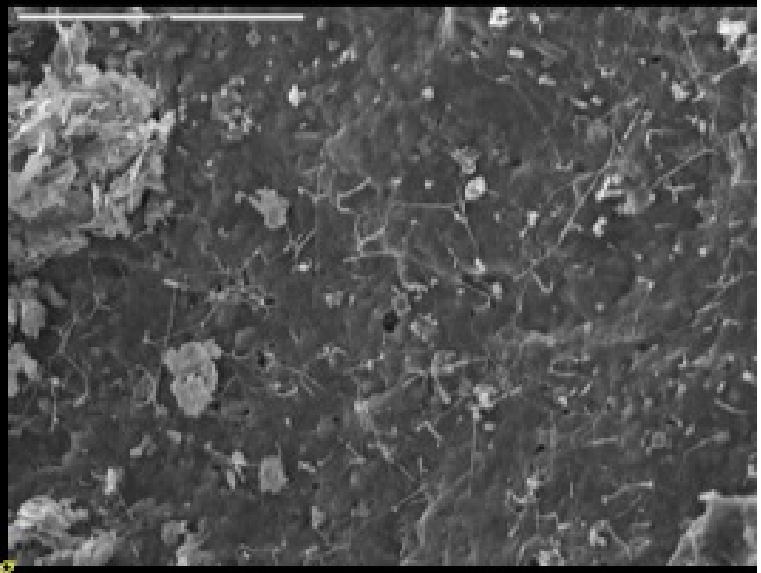






Microbial fossils in inclusions

←



Live microorganisms encrusting clay/Fe oxide walls

→

- Results so far….
- Xtals ~500, 000+ yrs old
  (Forti et al., Lauritzen et al.)
- Sampled inclus. ~10-50k yrs old
- DNA directly recovered
  & sequenced, ~ 40 strains
- 60+ live cultures growing!
- Many viruses present!
  (Suttle, Chan, Winget at UBC)

Entombed Longevity?

- ✧ *Highly controversial*
- ✧ *Ice & salt subject to plastic deformation & flow*
- ✧ *Difficult to demonstrate no contamination*

Earliest Claims of Great Microbial Antiquity:

Reiser, R., and Tasch, P., 1960, Investigation of the viability of osmophile bacteria of great geological age: Transactions of the Kansas Academy of Science, v. 63, p. 31–34.

Dombrowski, H., 1963, Bacteria from Paleozoic salt deposits: Annals of the New York Academy of Sciences, v. 108, p 453–460.

Norton, C.F., and Grant, W.D., 1988, Survival of halobacteria within fluid inclusions in salt crystals: Journal of General Microbiology, v. 134, p. 1365–1373.

The BIG Question – How Long Can You Last?

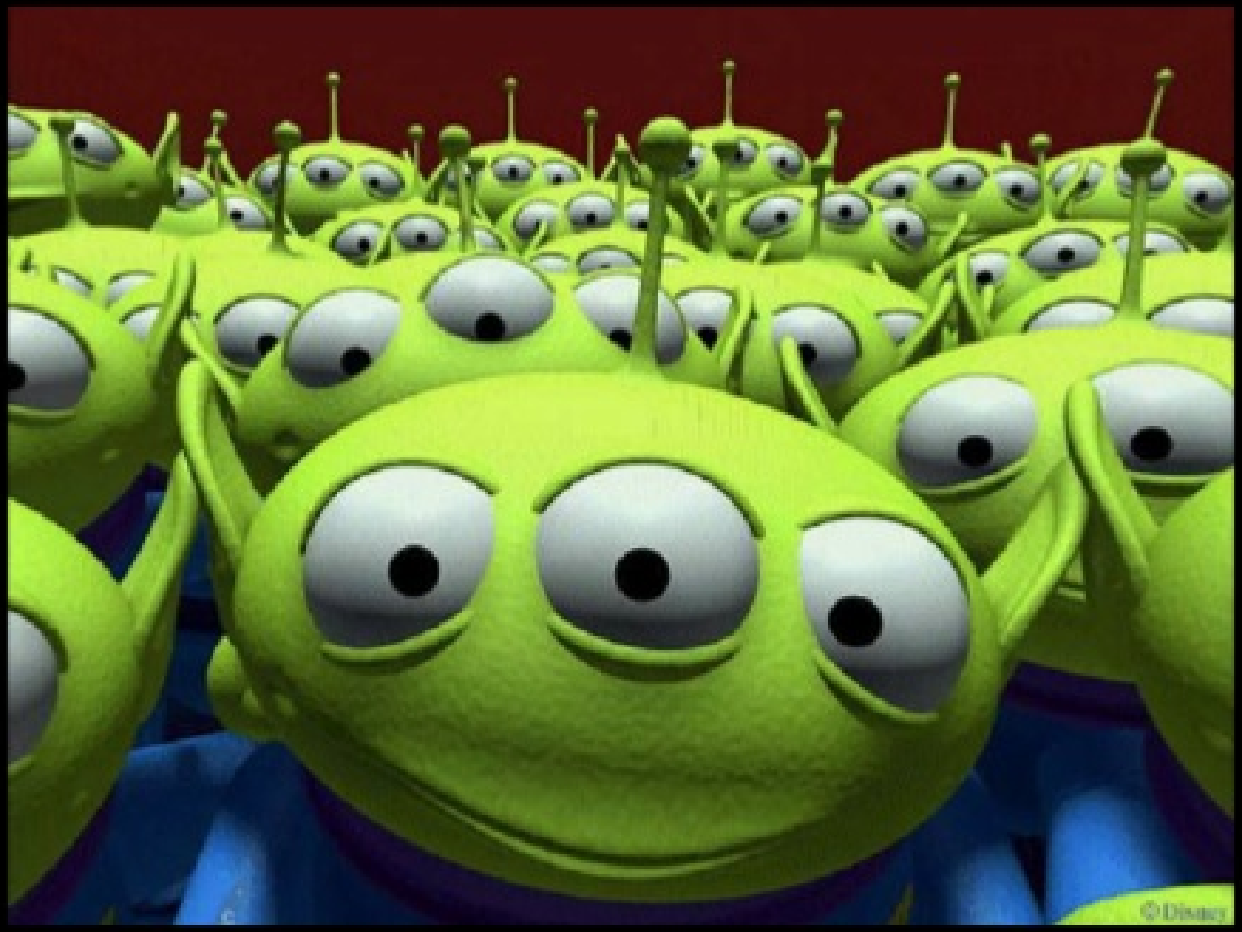
Meaning, can we find your still-living body?

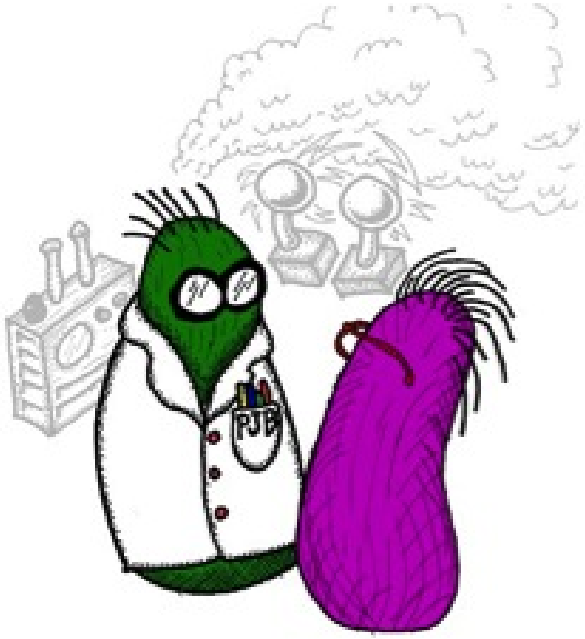
Or at least, can we find your DNA/RNA?

But! Even more importantly…..

How long can you be viable?

Meaning, can you still reproduce and create more of yourself?



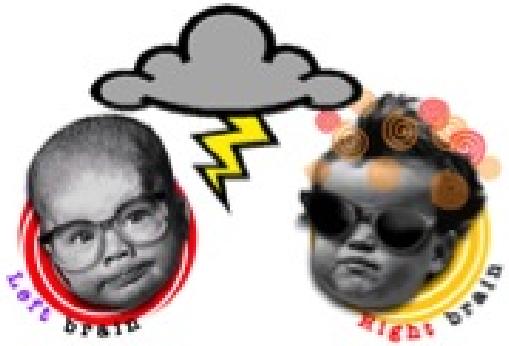


What We Know About Microorganisms on Earth

- Ubiquitous in “low temperature” geo-environments

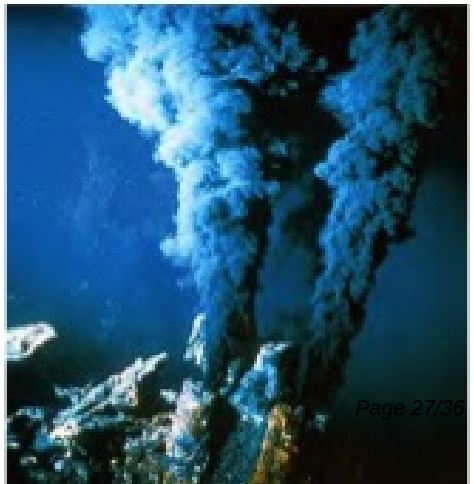
- Meaning ~ less than 150°C?
- We have confirmation of microbial growth to 120°C

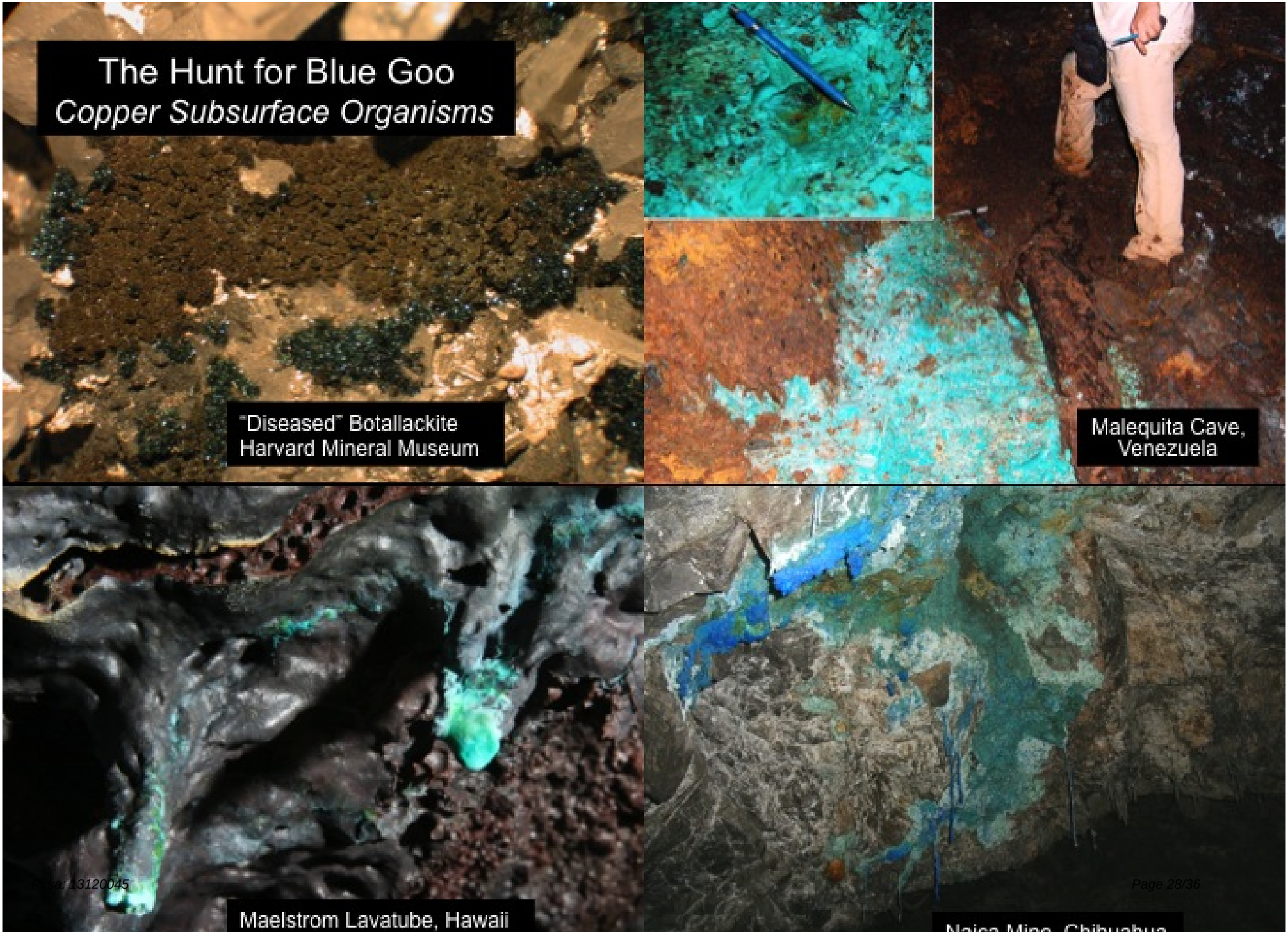
- The planet has been heavily biologically influenced for most of its history, ~ 3.8 bya and more



A thought question….

Why are the closest genetic relatives of some of our cave organisms, cousins of the deep sea hydrothermal vent organisms?

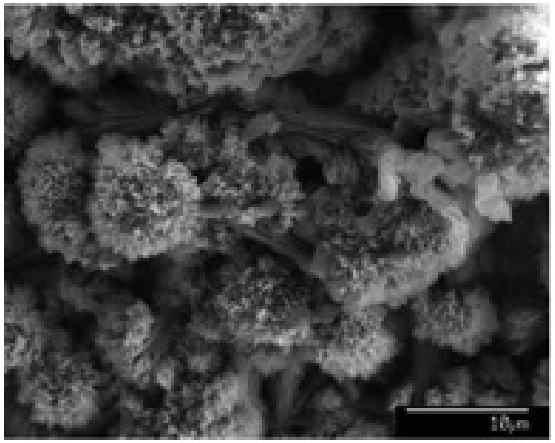



The Hunt for Blue Goo
Copper Subsurface Organisms
"Diseased" Botallackite
Harvard Mineral Museum
Malequita Cave,
Venezuela
Maelstrom Lavatube, Hawaii

30 months after inoculation growth is visible

4.5 years significant mineral precipitation

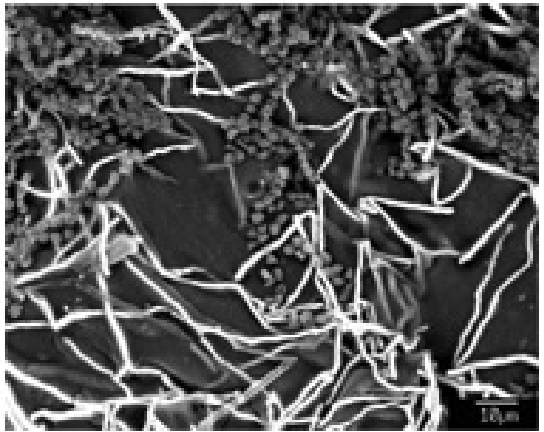
Fungal/bacterial consortium
Copper sulfide oxidizer bacteria
Elemental copper stored in fungal hyphae
Copper oxides produced (malachite, azurite)



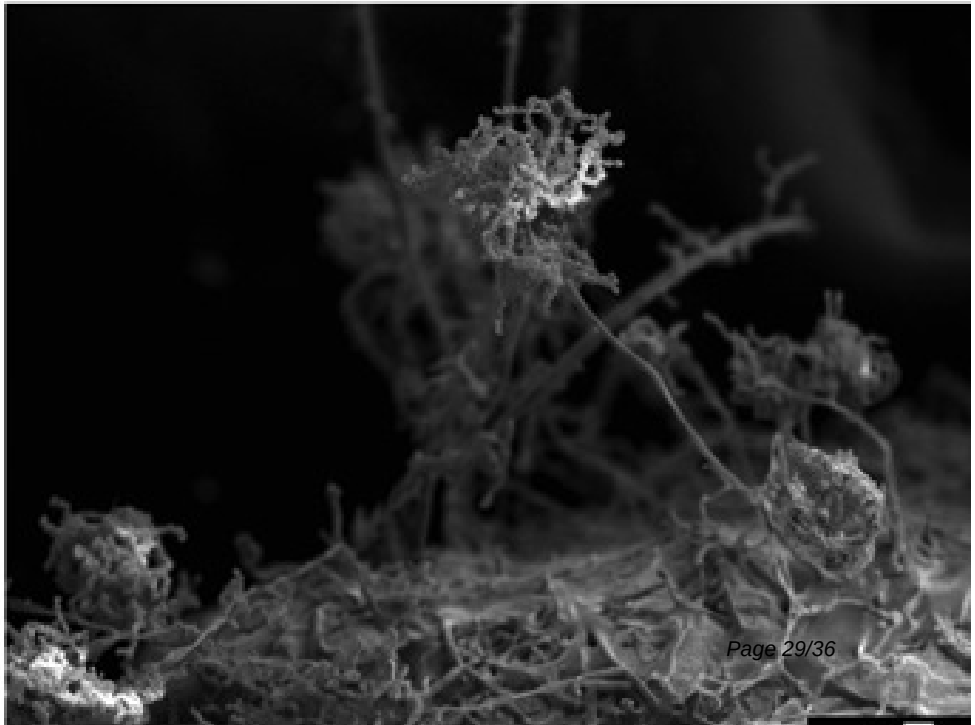
~~Now at 8 yrs~~...

Now at 12 yrs!

SEM backscatter

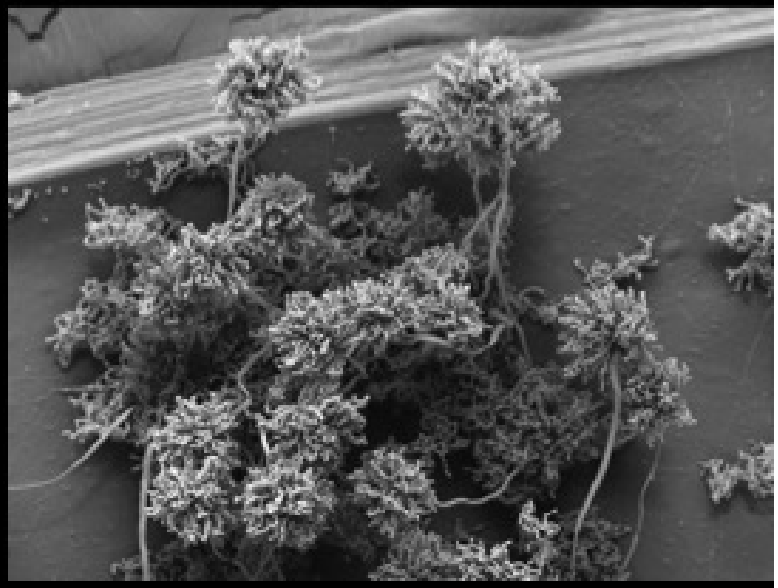


TEM



The Microbes That Wouldn't DIE!!!!!

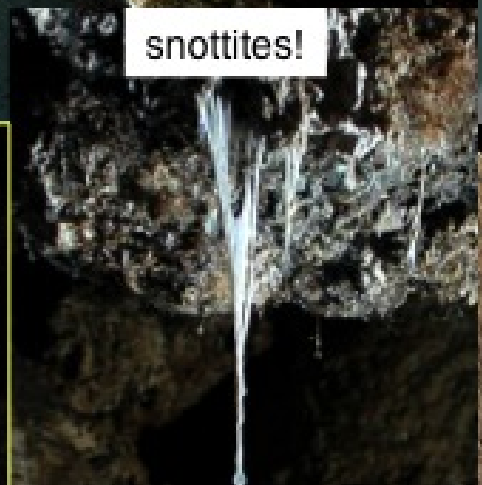
Air Dried
Vacuum Dried
Coated in Au/Pd
Zapped repeatedly w/ electron beams in a hard vacuum!!!
2 Yrs later, back from the dead



Energy Enriched: Shallow Sulfuric Acid Cave

Cueva de Villa Luz, Tabasco, Mexico

Biodiversity rich!
Biomass rich!
pH ranges from 9.2 down to 0 !
Energy:
Subsurface H_2S
Surface-derived organics



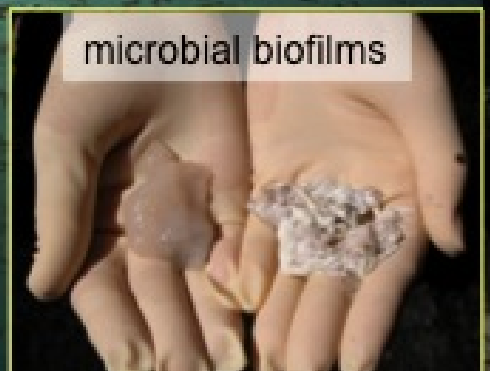
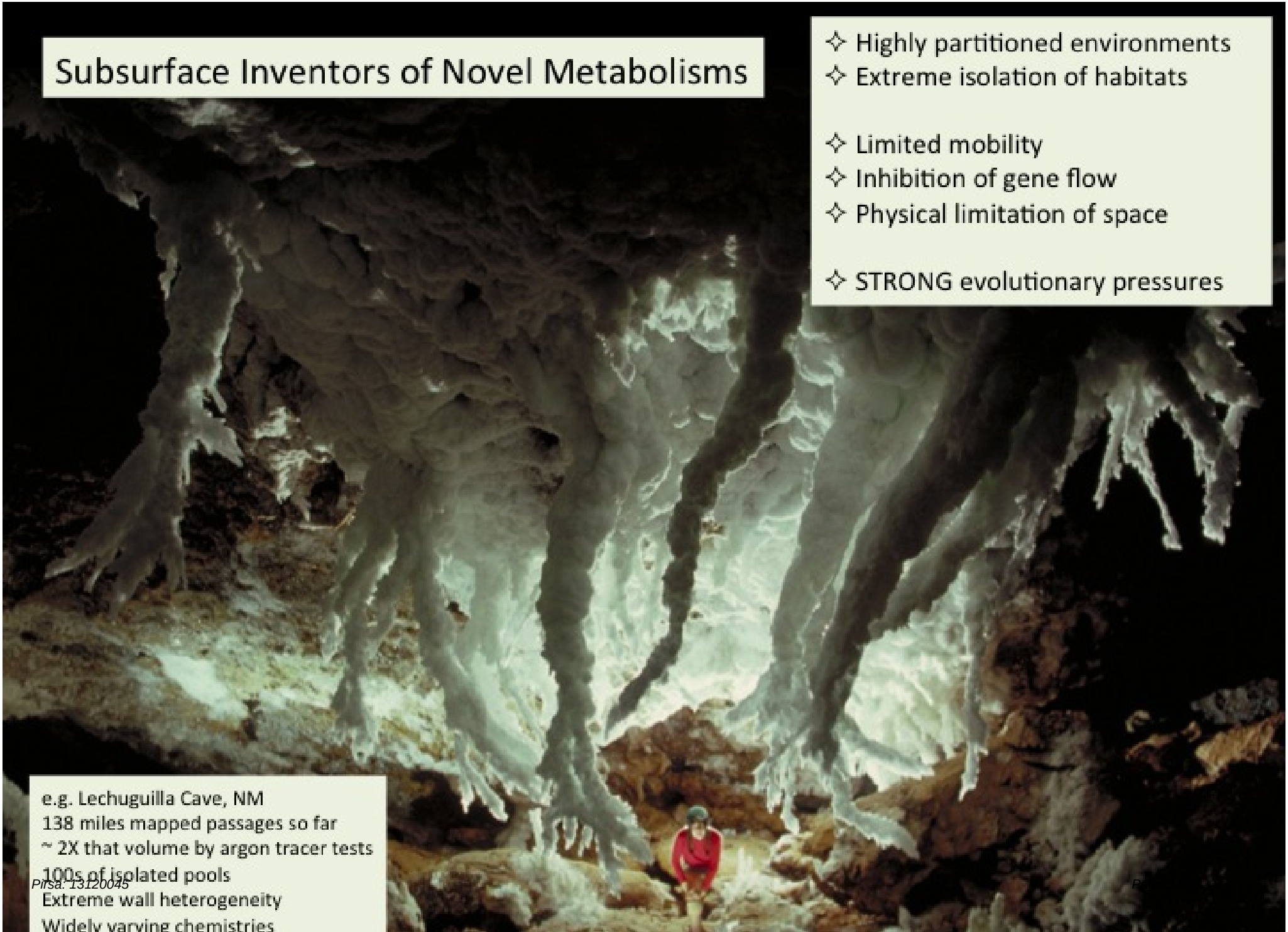


Photo by Steve Alvarez

Subsurface Inventors of Novel Metabolisms



- ✧ Highly partitioned environments
- ✧ Extreme isolation of habitats

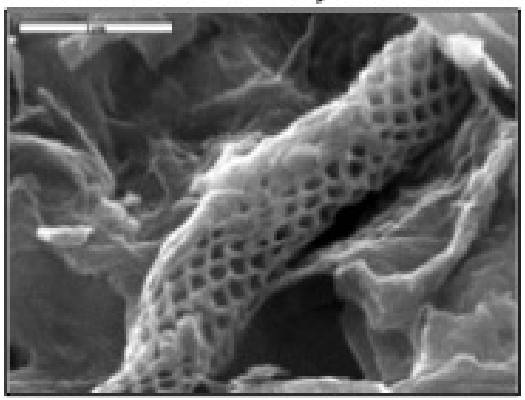
- ✧ Limited mobility
- ✧ Inhibition of gene flow
- ✧ Physical limitation of space

- ✧ STRONG evolutionary pressures

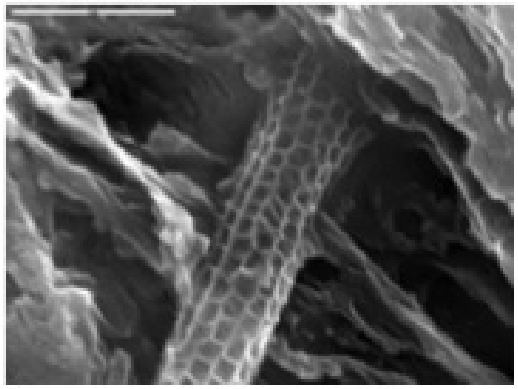
e.g. Lechuguilla Cave, NM
138 miles mapped passages so far
~ 2X that volume by argon tracer tests
100s of isolated pools
Extreme wall heterogeneity
Widely varying chemistries

In our cave work, we are already dealing with sensitive “alien” biology…

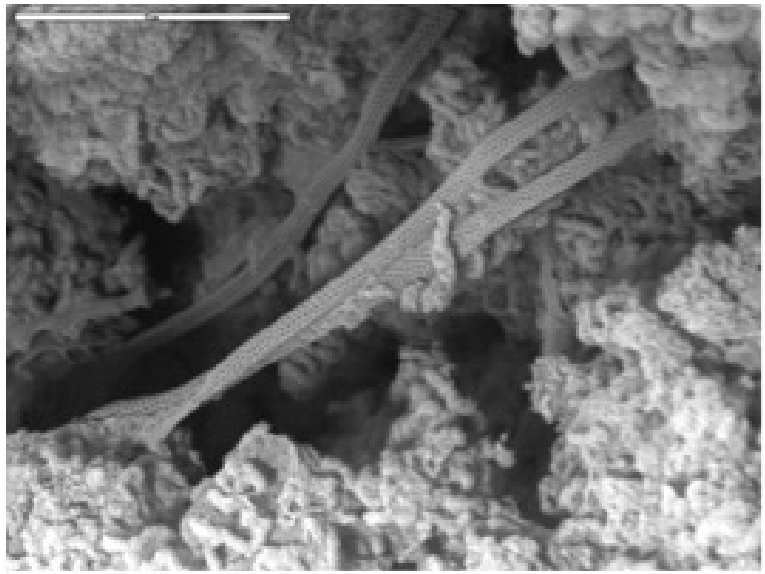
What are these??? Do you know? We don’t….



We are finding them in caves all over the world.



Subsurface geomicrobiology is helping us to prepare for the search for life on Earth, on Mars, & icy moons.



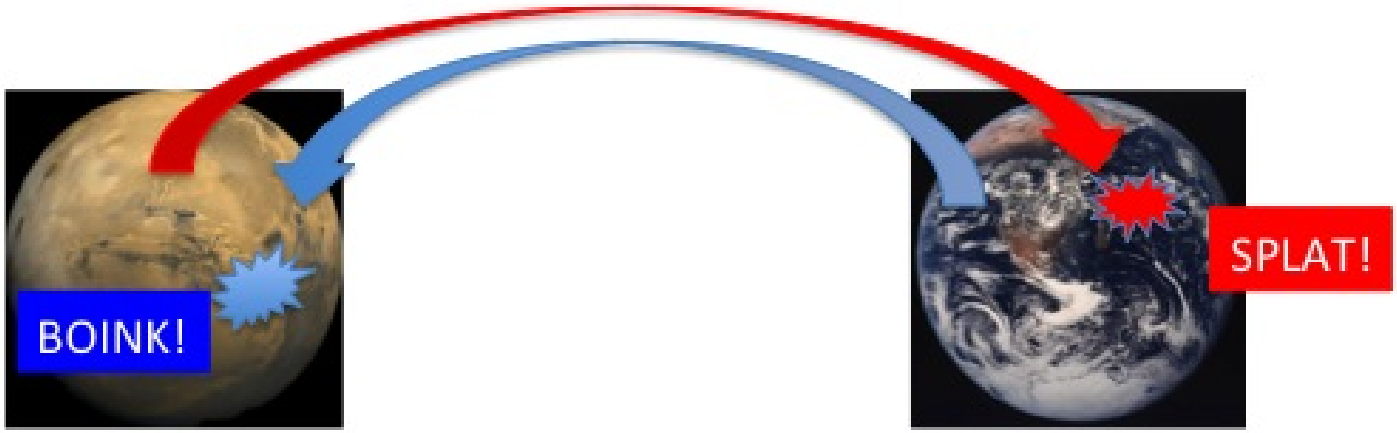
DNA analysis doesn’t help us… Too many organisms!

Spacegoing Microbes?

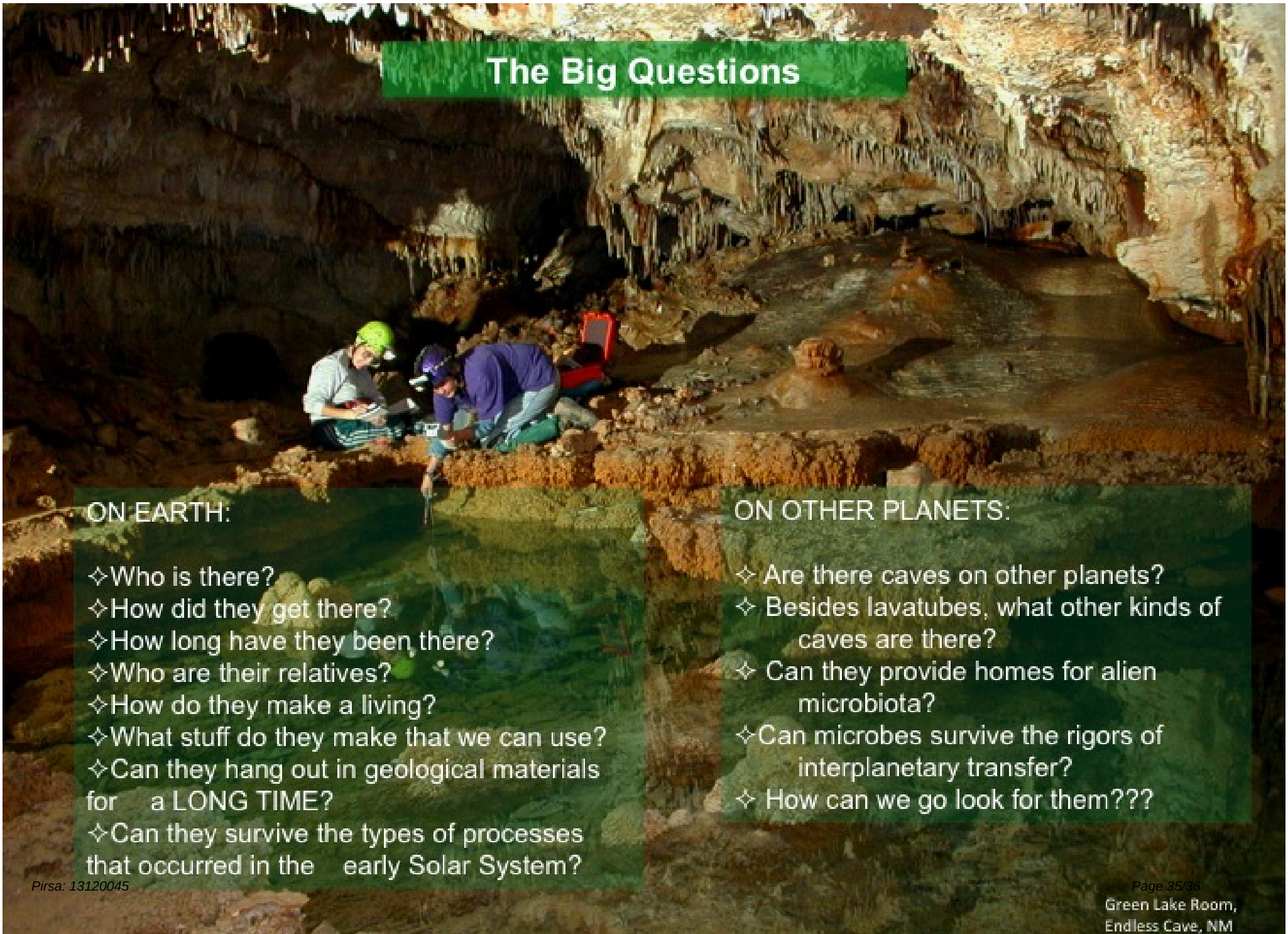
✧ *If **geogenetic latency*** on Earth driven by tectonics & other processes

✧ Microbial swapping from one planet to another?

- *Impact excavation of the geogenetic "bank"?*
- *Tapping into populations that would be the MOST likely to survive this*



Spit-swapping Amongst The Rocky Terrestrials



Green Lake Room, Endless Cave, NM

Touch the earth and listen to the rocks
For they remember…
They know and remember
All that has come
to pass here.

- *Lee Henderson*

Team Members:

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Laura Rosales-Lagarde
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NASA Astrobiology Program

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