Human Utilization of Subsurface Extraterrestrial Environments

A NIAC Phase II Study

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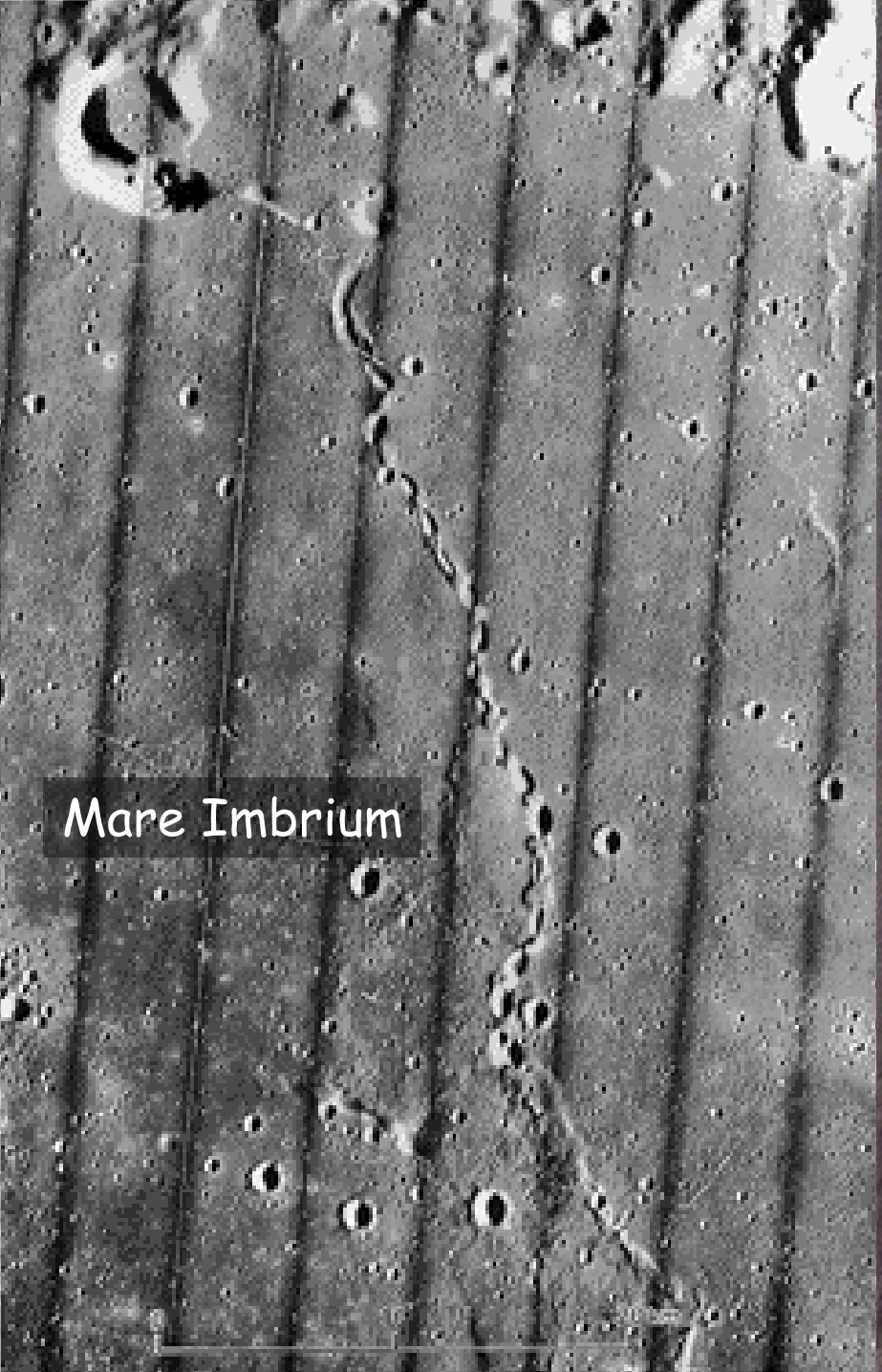
NIAC
NASA Institute for Advanced Concepts

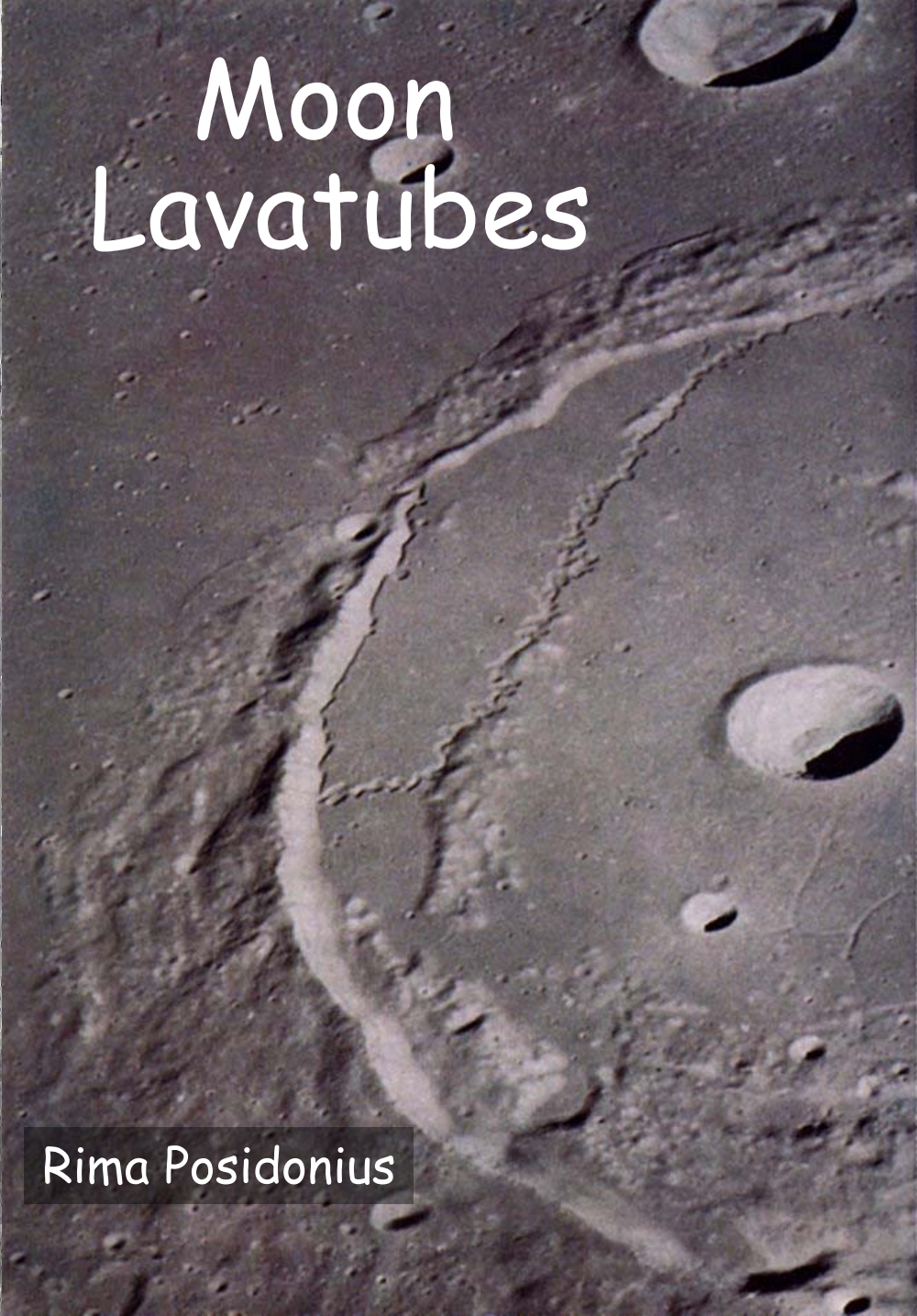
Why Caves?

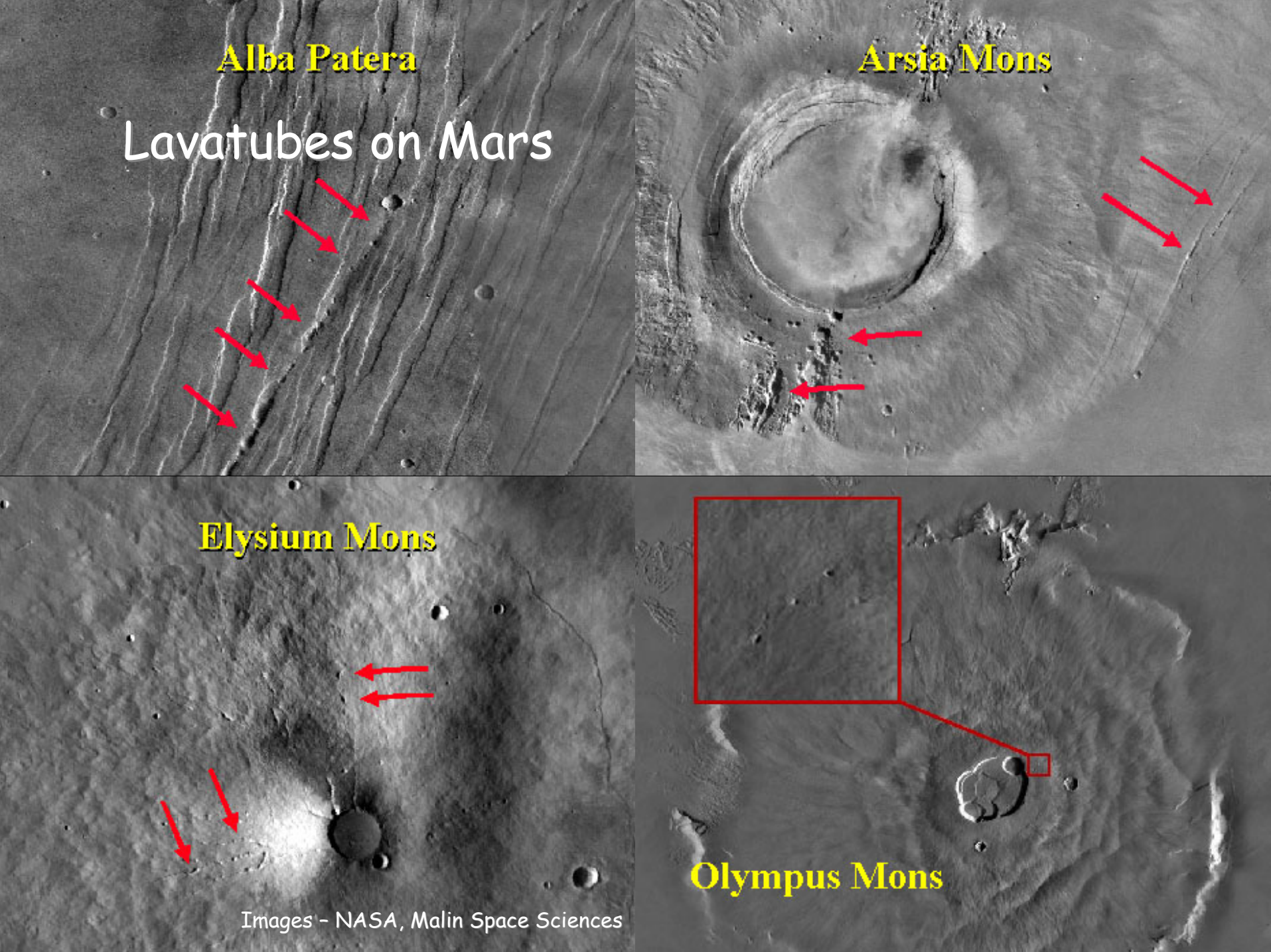

Are There Caves
On
Other Planets?
Adrian Hetmanski

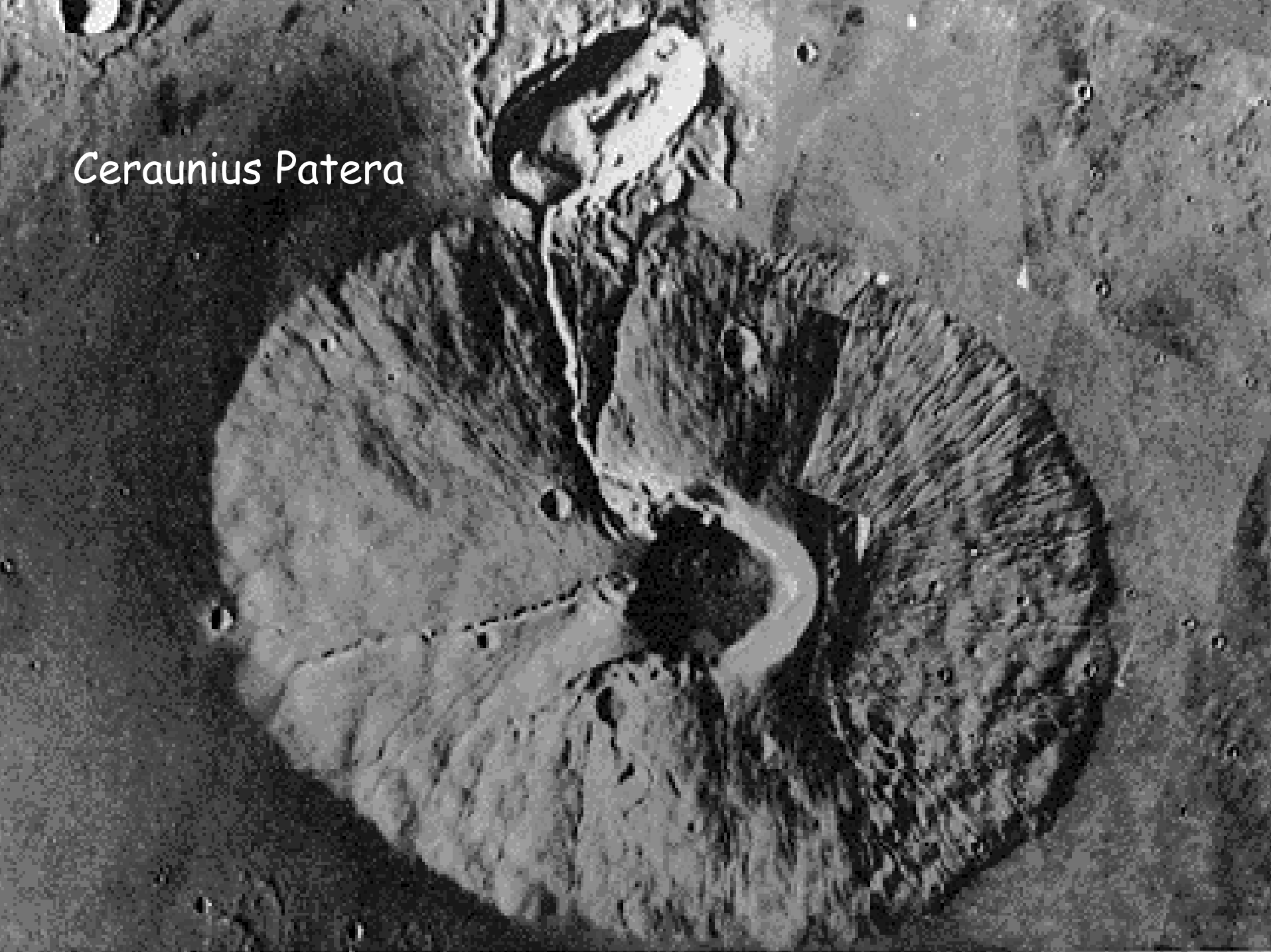
Collapse Pits Along Tube Path

Moon Lavatubes






Alba Patera
Lavatubes on Mars
Arsia Mons
Elysium Mons
Olympus Mons
Images – NASA, Malin Space Sciences


Ceraunius Patera

Lavatube Cave Environments

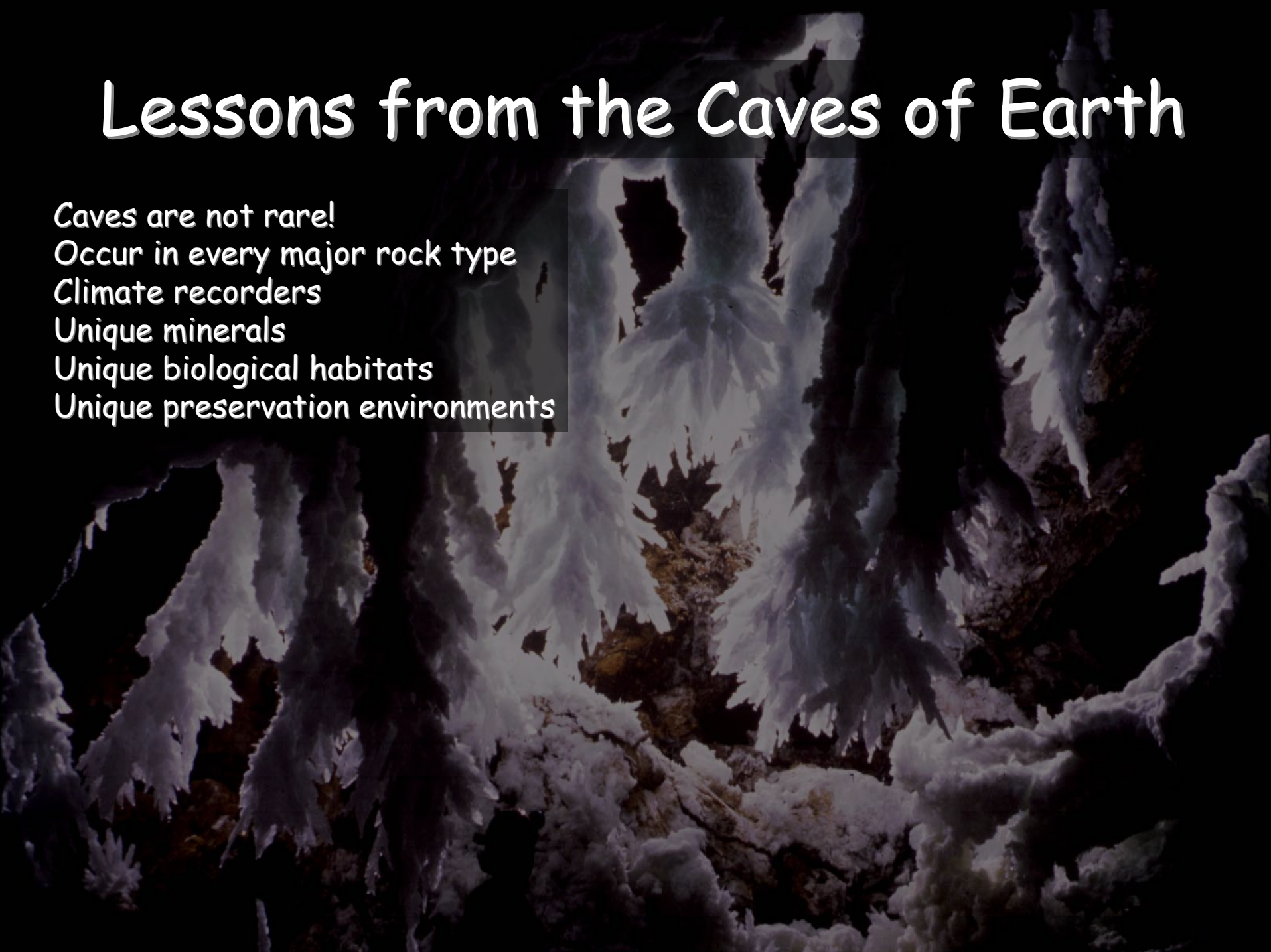
Actinomycetes common

Secondary mineral formations (speleothems)

Permanent or transient ices

CAVE TYPE	Dominant Processes	Parent Materials	Earth Examples	Possible Extraterrestrial Variations
Solutional	Dissolving rock by solvent	Soluble solids plus a solvent	Classic karst, gypsum, halite	Non-water solvents, different thermal regimes
Erosional	Mechanical abrasion via wind, water, grinding, etc.	Any solid	Sea coast caves, Aeolian undercuts, etc.	Non-Earth erosional processes, e.g. radiation sputtering, frozen volatiles
Tectonic	Fracturing due to internally or externally caused earth movements	Any rocky solid	Gravity sliding caves	Tidal flexure from a massive primary, crater impact fracturing
Suffosional	Cavity construction by the fluid-borne motion of small particles	Unconsolidated sediments	Mud caves	Ground ice sublimation???
Phase Transition	Cavity construction by melting, vaporization, or sublimation	Meltable or sublimable materials capable of solidifying at planet-normal temperatures	Lava tube caves, glacial caves	Perihelionic sublimation of frozen volatiles in comets, frozen bubbles in non-water ices, non-basalt lavatubes
Constructional	Negative space left by incremental biological or accretional processes	Any solid capable of ordered or non-ordered accretion, or biogenic processing	Coralline algae towers	Crystallization in non-polar ices???
	P.J. Boston 2003. Extraterrestrial Caves. In, *Encycl.opedia of Caves and Karst, J. Gunn, ed.*			

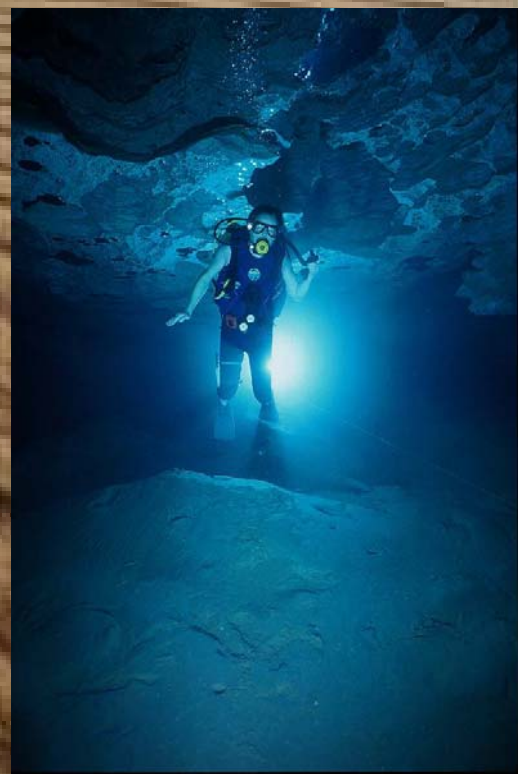
Lessons from the Caves of Earth



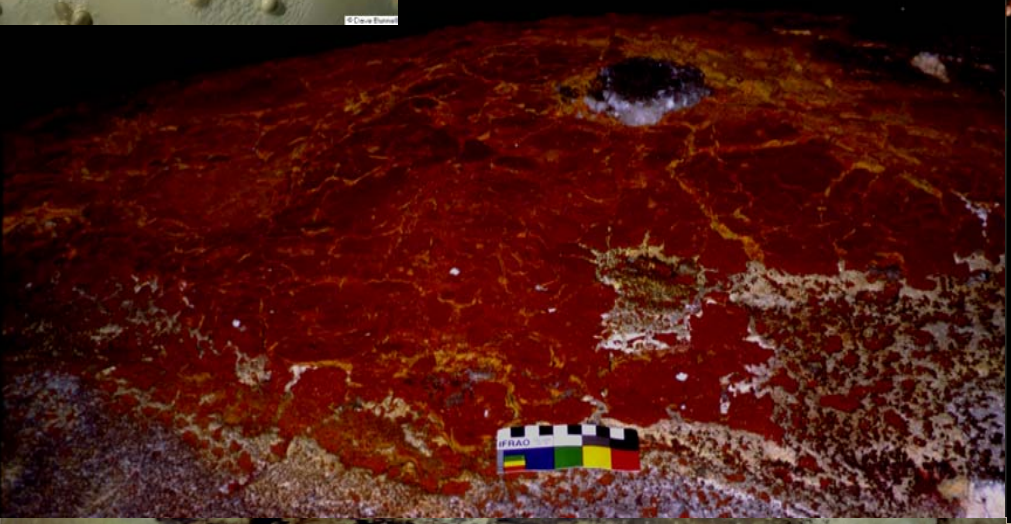
Caves are not rare!
Occur in every major rock type
Climate recorders
Unique minerals
Unique biological habitats
Unique preservation environments

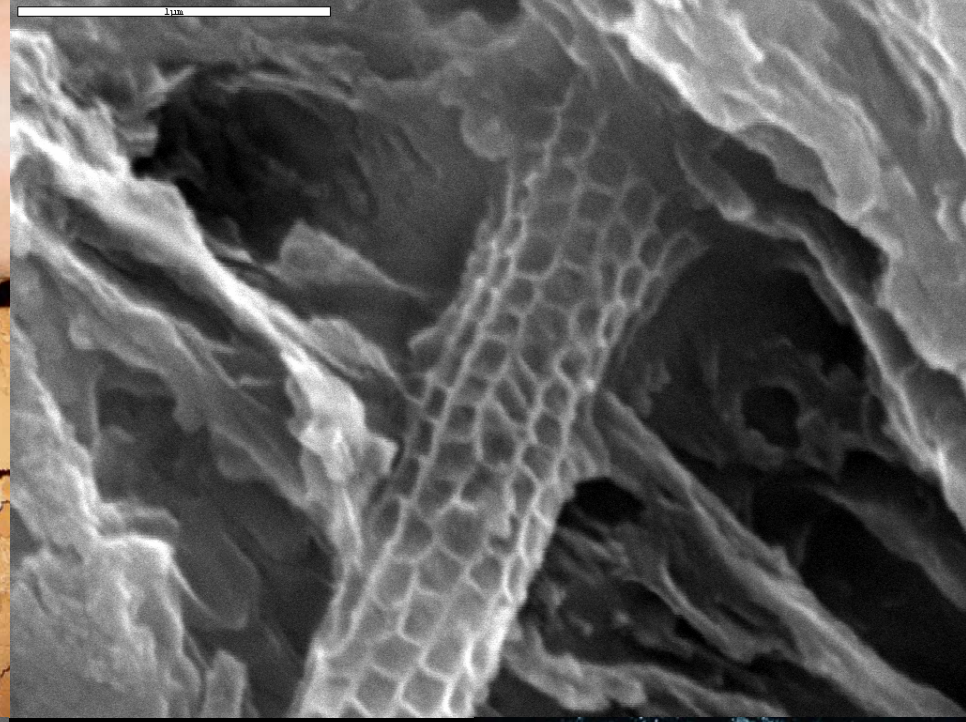
Cave Environments

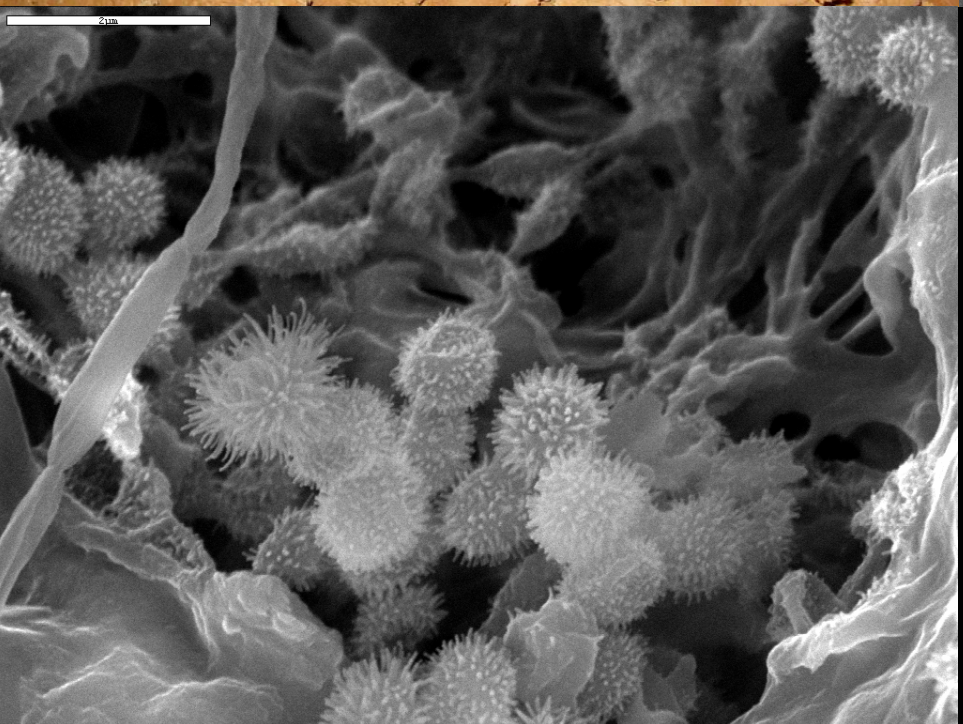
- Caves provide a window into the subsurface
- Caves can be radically different from surface
- Cave habitats ≠ non-cave subsurface habitats



Unique Mineral Formations



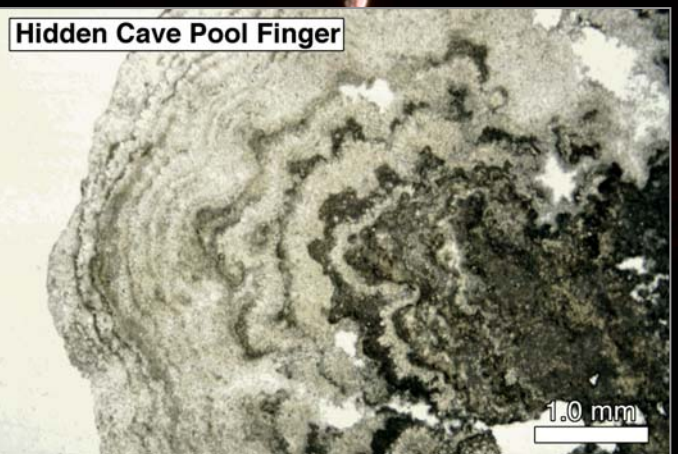




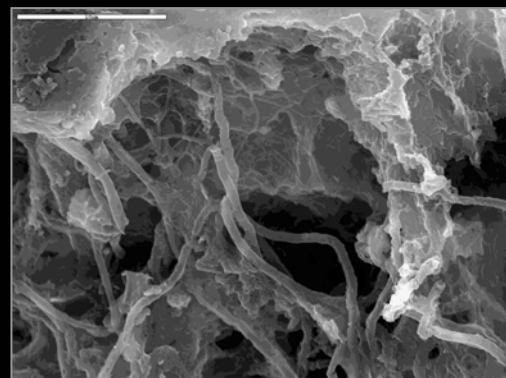
Unique Microbes

Preservation Environment

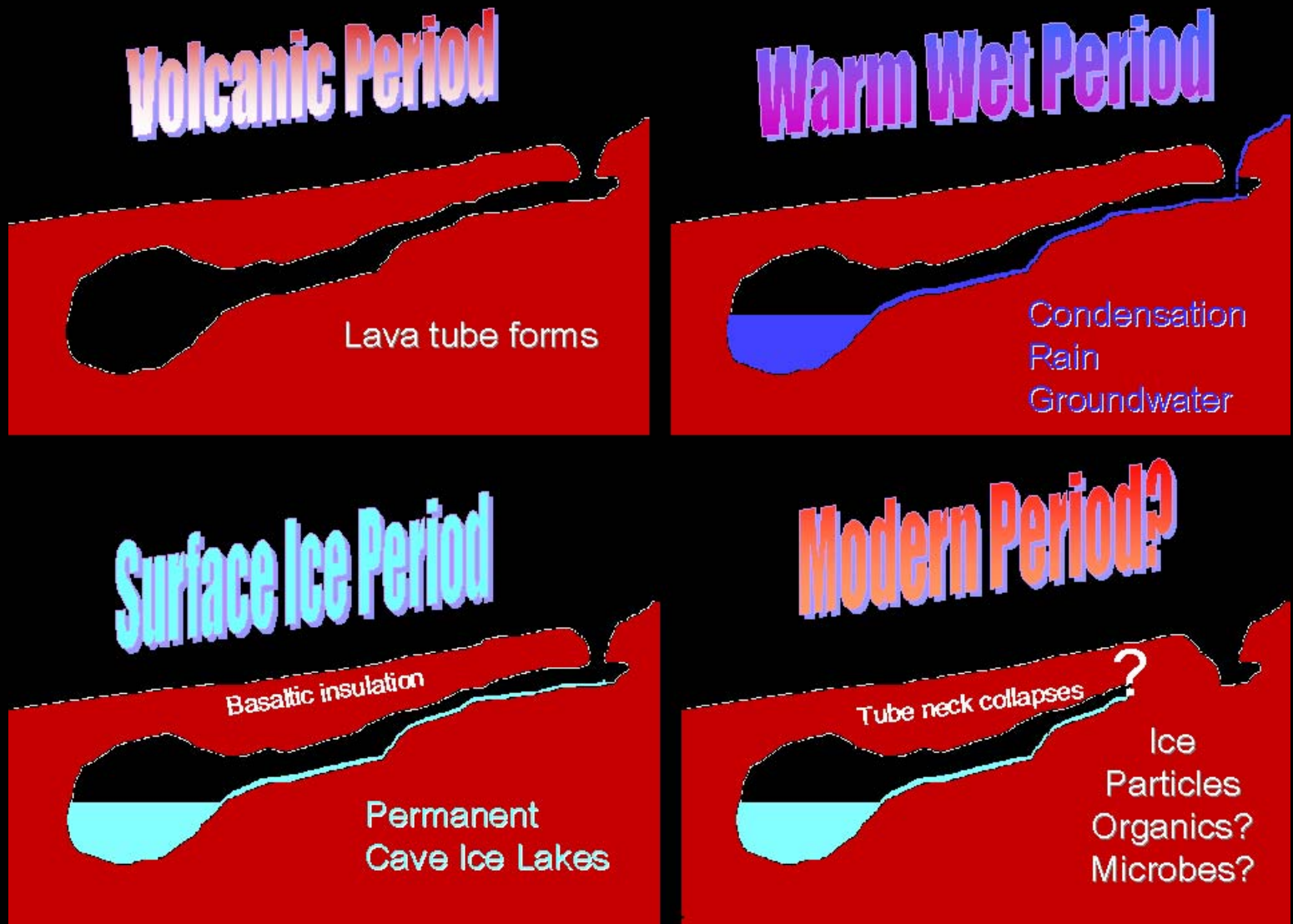
Photo by Larry McLaughlin



Physical fossils
Isotopic signals
Climate record
Geochemical traces
In situ lithification

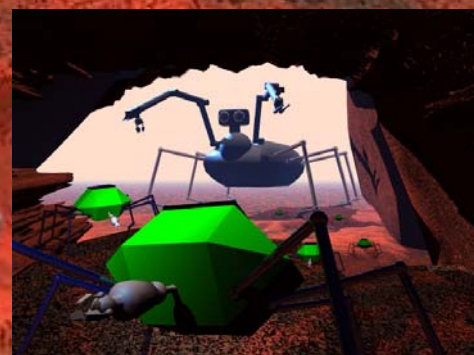


Trapped Particles & Volatiles?



Life in Mars Caves?

- Traces of Ancient Life?
- Presence of modern life?




Extraterrestrial
Caves
as Human Habitat
PELE BASE
BASE

Shelter on the Martian Surface

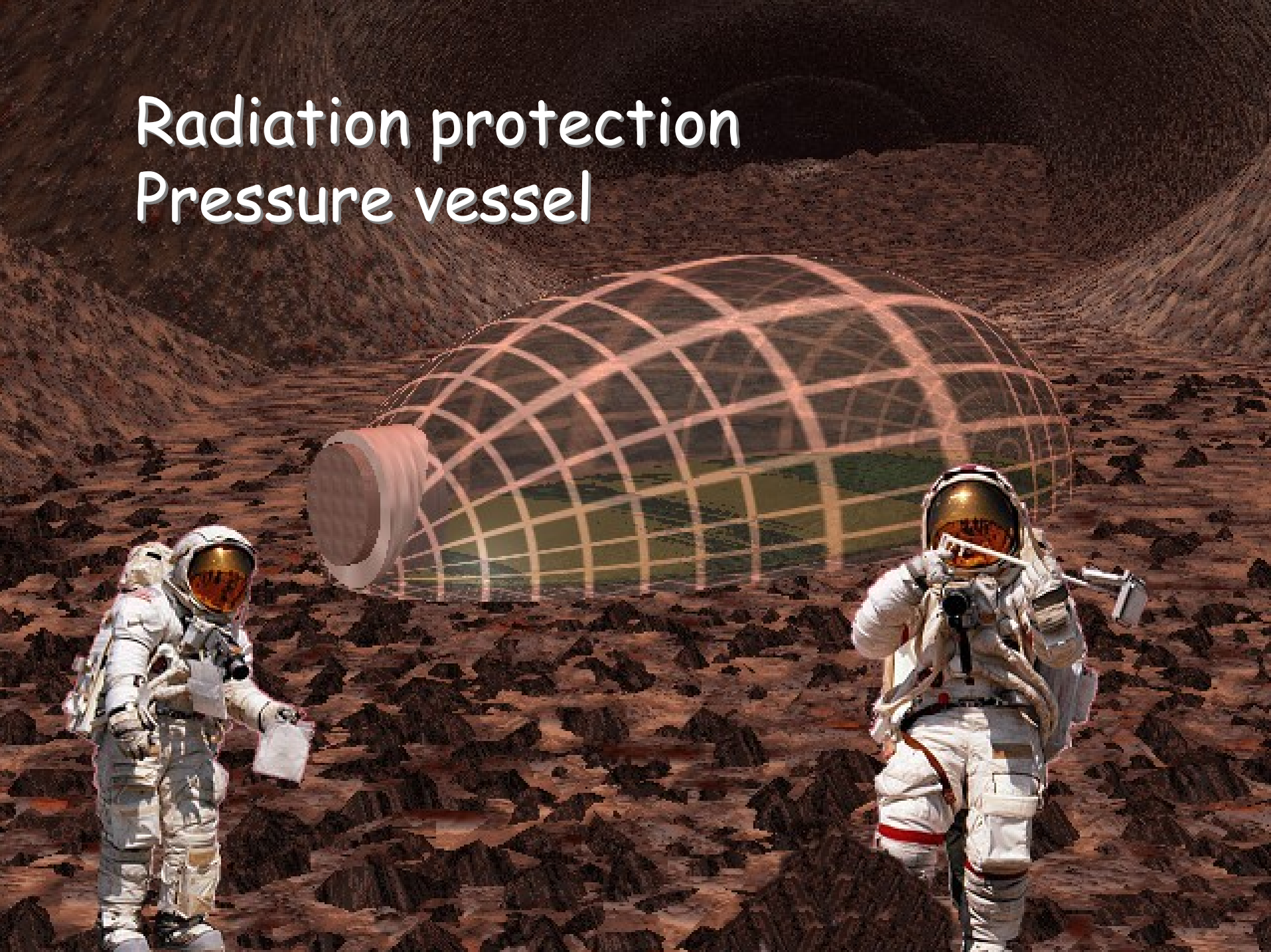
Extreme UV
Ionizing radiation
Galactic
Solar flares

...construction is expensive!
...digging machines are expensive!

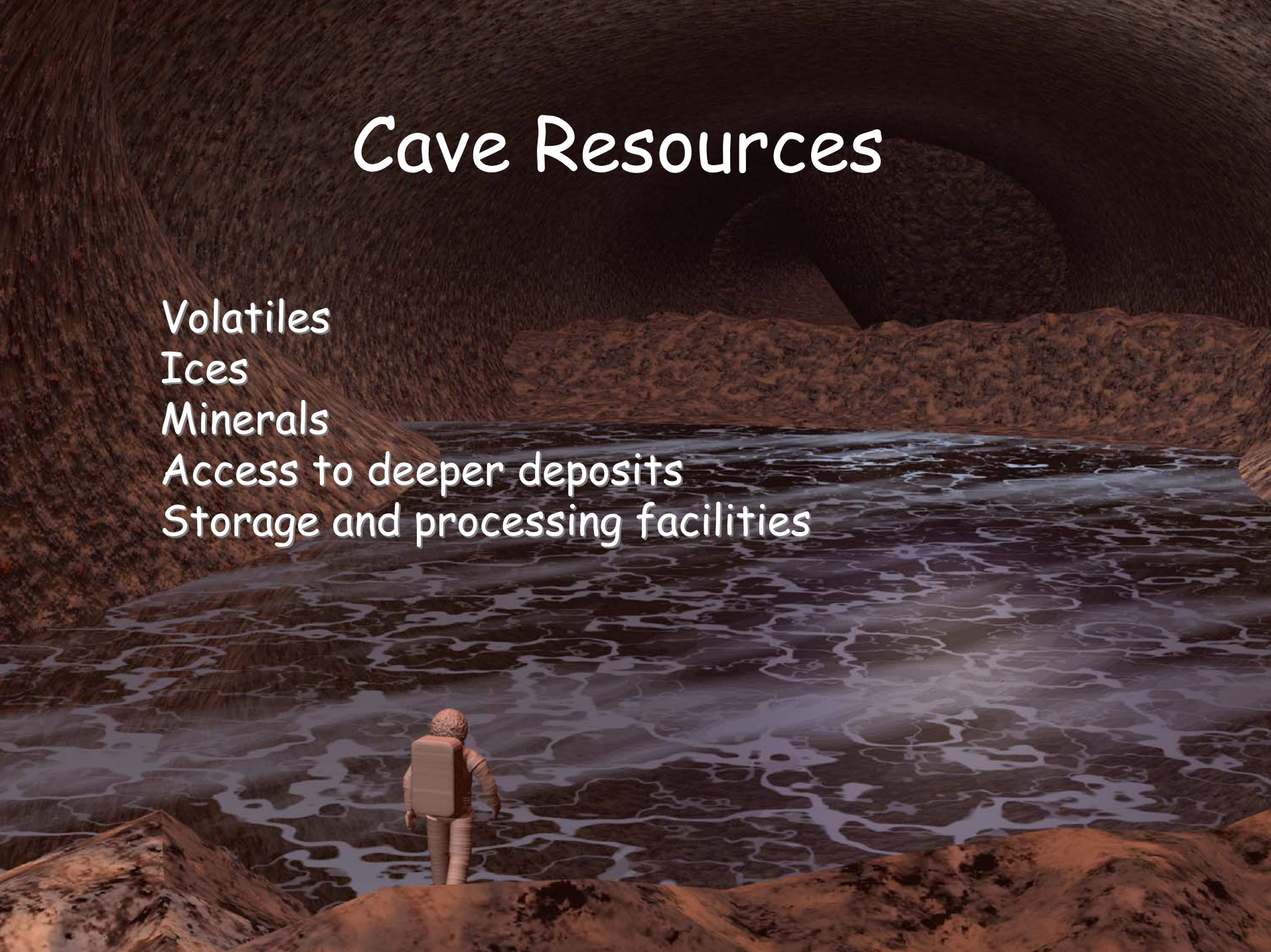
Danger
Work load
Time factors

Pressure vessel
Self-contained

Radiation protection
Pressure vessel



Cave Resources



Volatiles
Ices
Minerals
Access to deeper deposits
Storage and processing facilities

NIAC Phase I: Identification of Enabling Technologies

- Inflatable cave liners
- Foamed in place airlocks

- Inert gas pressurization
- Mars-derived breathing mix

- Self-deploying microrobots
  - Communication system
  - Automated mapping
  - Biologically sensitive sites

- Cave science "backpack"
- Non-invasive techniques

- Planetary protection protocol development

- Bioregenerative systems (unique cave aspects)

- Bioluminescence/O2 light-piping system

NIAC Phase II:
Missions to Inner Space

Mouse Mission

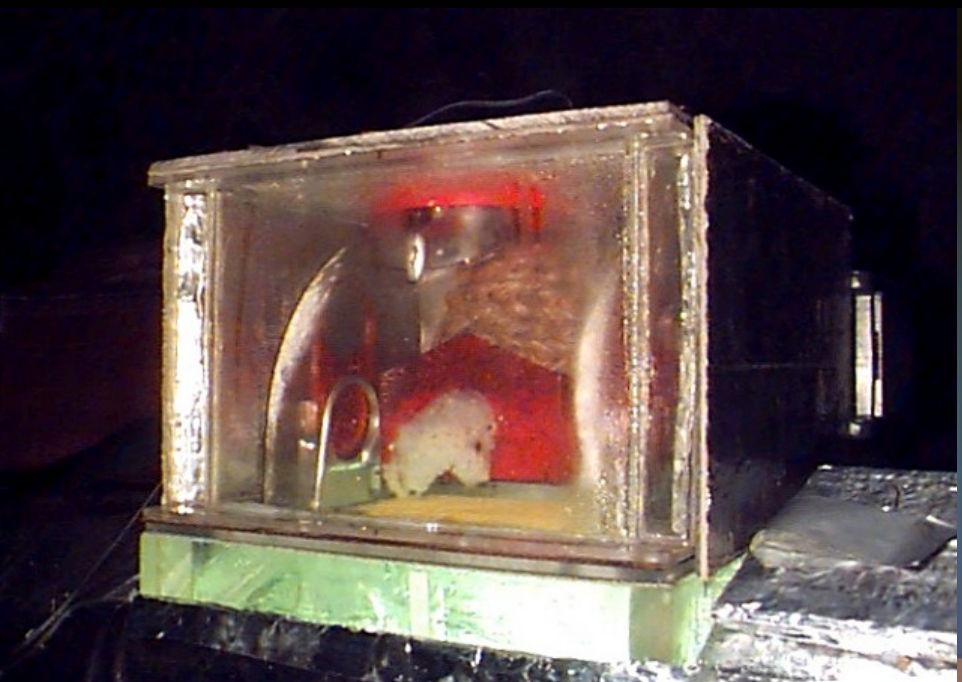
Development – 2002

Implementation – 2003

Human Mission

Development – 2003

Implementation – 2003/04



Mouse Mission to Inner Space

CEMSS

Pre-human trial

Education

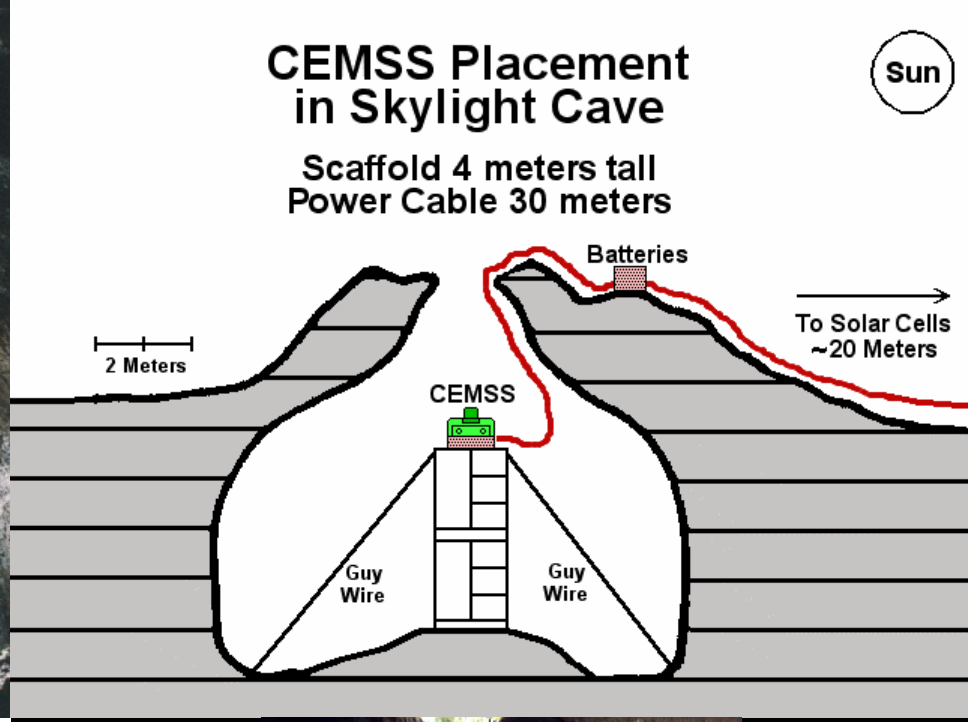
Mousetronauts

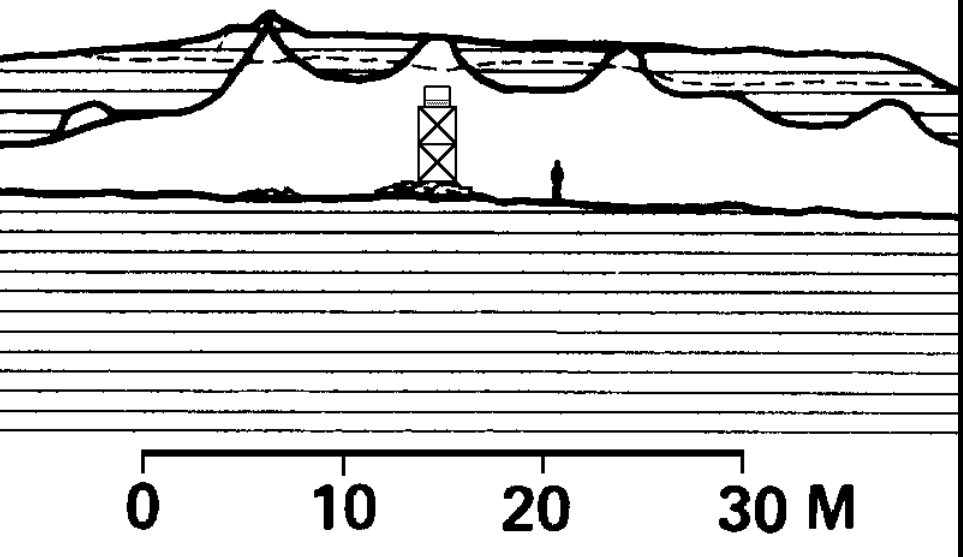
Trakball

Joystik

Mark I Prototype

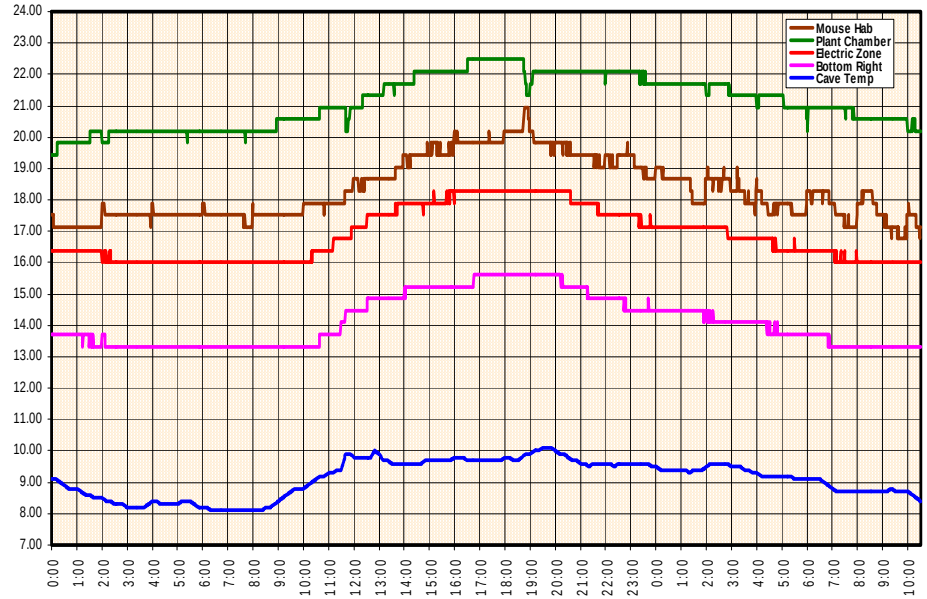

Skylight Cave, near Sisters


CEMSS Placement
in Skylight Cave
Sun
Scaffold 4 meters tall
Power Cable 30 meters
Batteries
To Solar Cells
~20 Meters
2 Meters
CEMSS
Guy
Wire
Guy
Wire


0
10
20
30 M

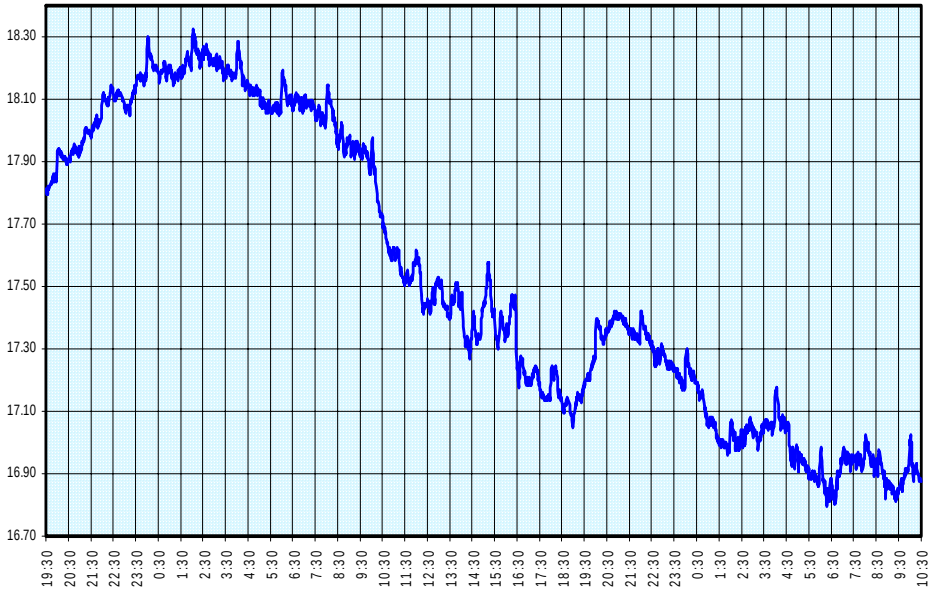
CEMSS Temperature

Degrees C - September 28-29, 2002



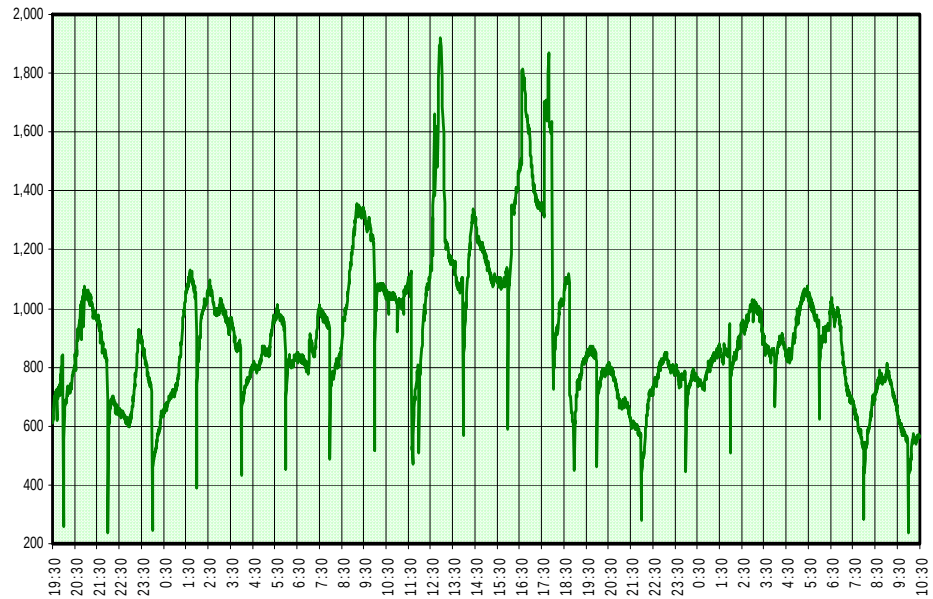
CEMSS O2 Levels

Percent - September 27-29, 2002



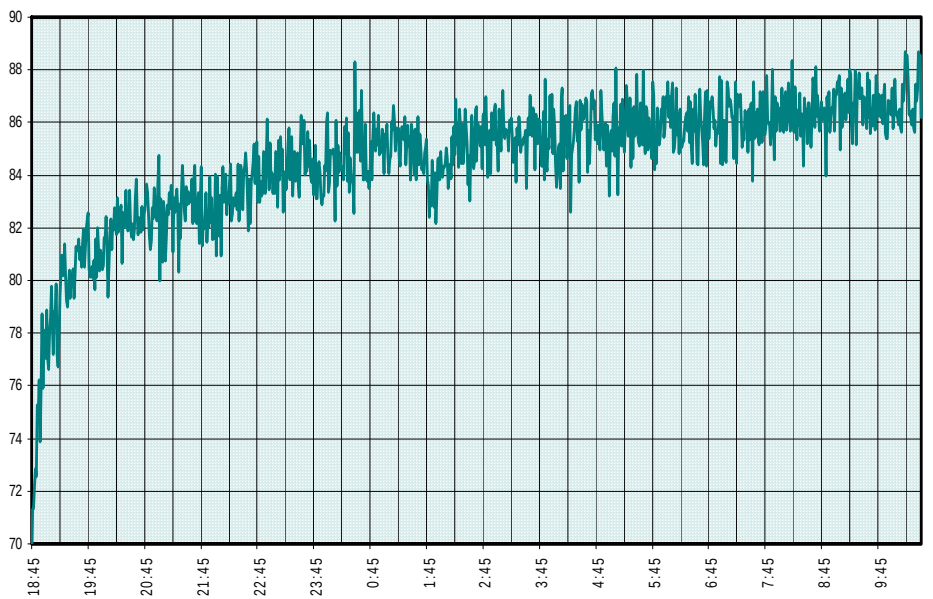
CEMSS CO2 Levels

ppm - September 27-29, 2002



CEMSS Relative Humidity

Percent - September 28-29, 2002




Argon-Breathing
Experiments

Flat Crops

Azolla (waterfern)

Lemna minor (duckweed)

Duckweed

Waterfern

- Rapid-growth, *(mass doubles in 16-24 hrs.)*
- Reproduce by budding or seeds/spores

- Wide pH Range, *(5.5 – 7)*
- Produces more protein per square meter than soybeans, *(dried)*
- Can purify & concentrate nutrients from wastewater

- Tolerates High UV levels
- Symbiotically fixes nitrogen from air

Integrated Mission

Argon breathing mix
Duckweed diet
Valley of Fires lavatube
16 December
1 week
10 mice

Human Mission to Inner Space

Liner & airlock
1-2 week duration
7% CO_2, 9-17% O2 *(HM Cave, AZ)*
In situ science tasks

Airlocks


Pressurized
Shirt-sleeve
Environment

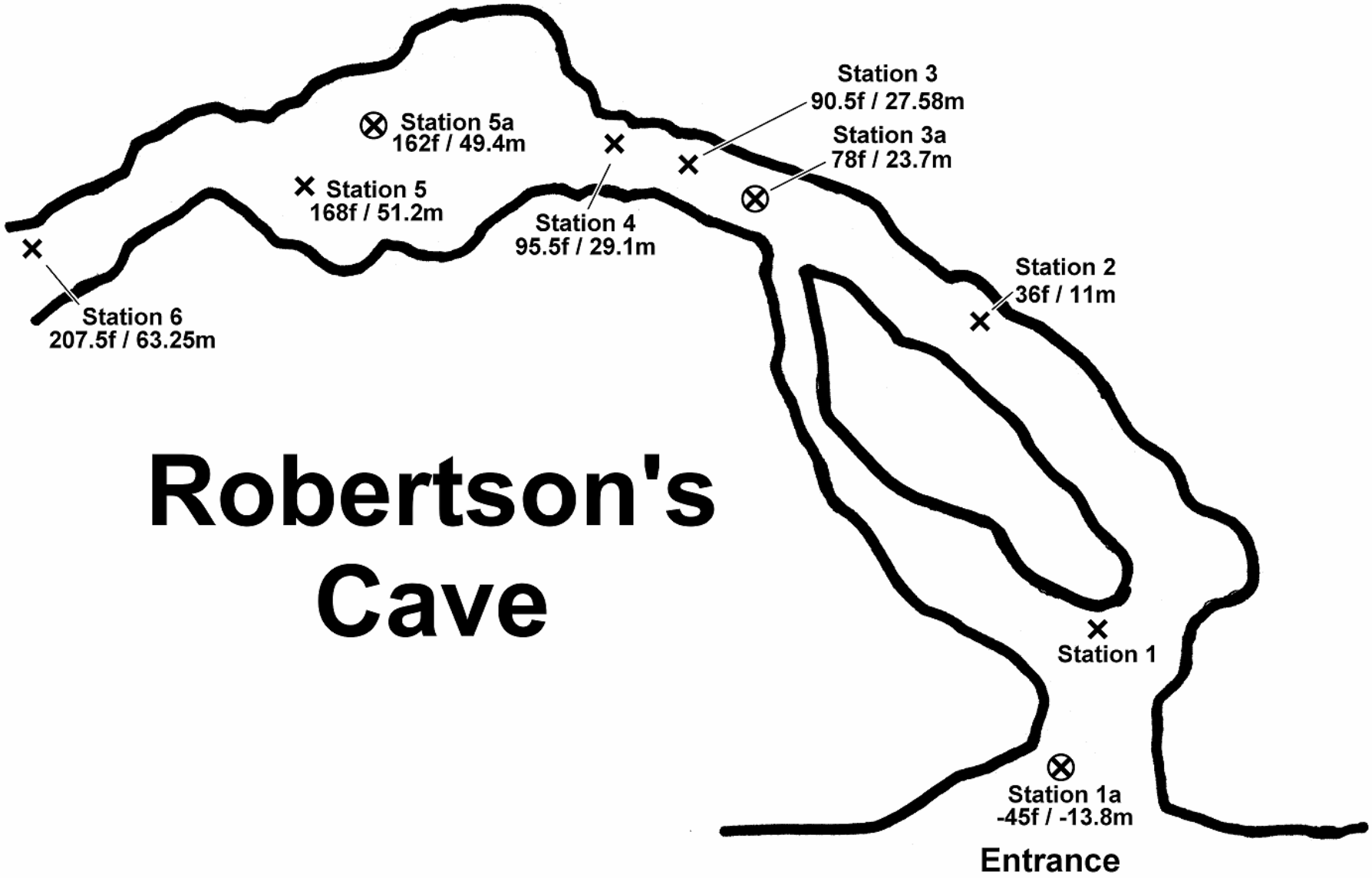
Self-deploying Com Network

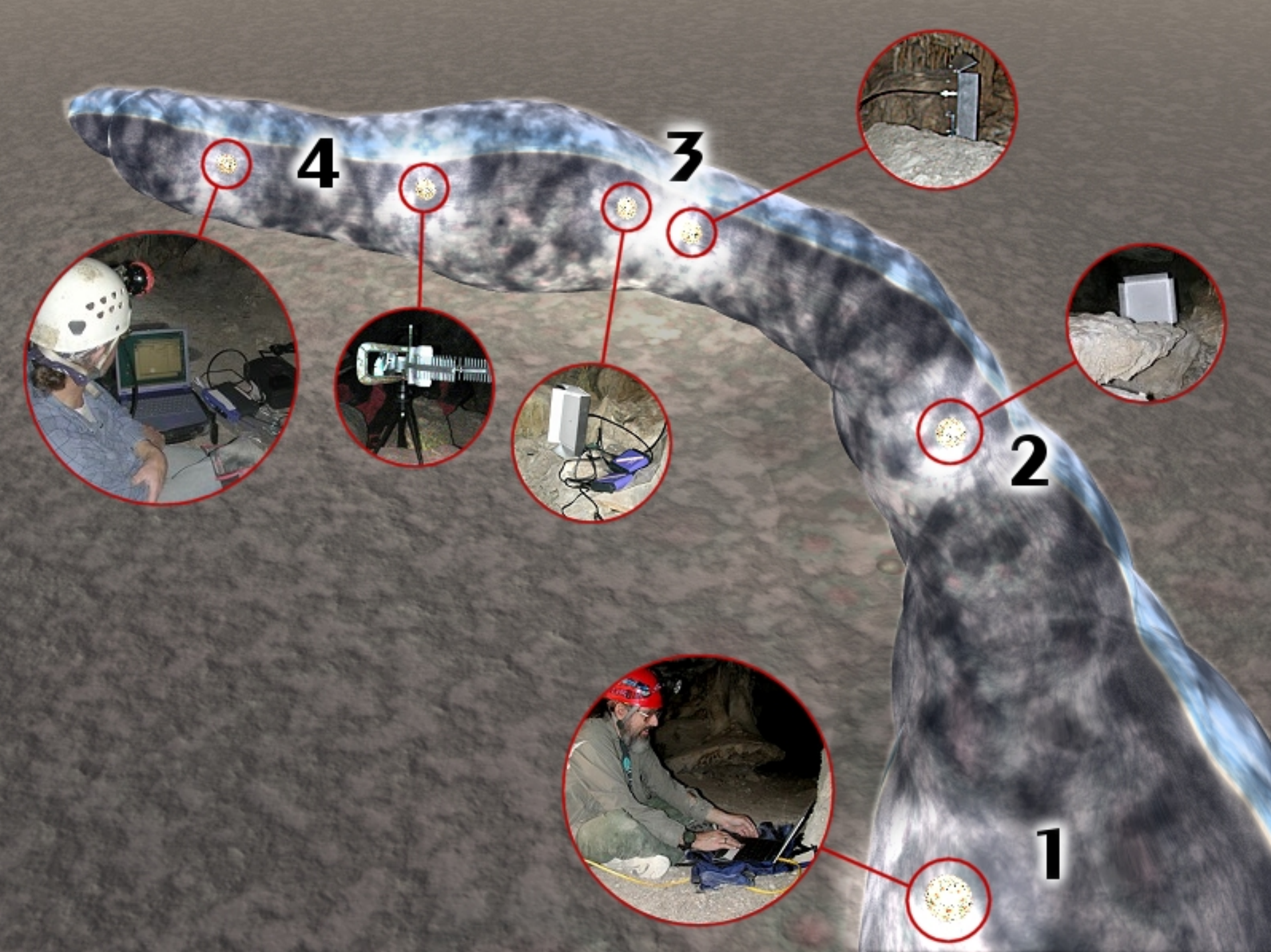
802.11 based prototype

Large, pristine cave testbed

(Cueva de Las Barrancas, NM)

Human cavers as "microrobots"

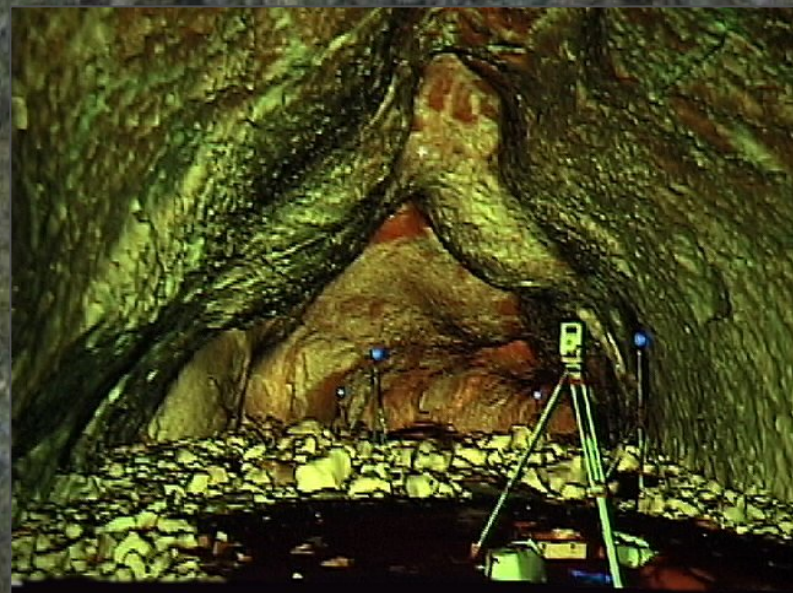

Station 3
90.5f / 27.58m
Station 5a
162f / 49.4m
Station 3a
78f / 23.7m
Station 5
168f / 51.2m
Station 4
95.5f / 29.1m
Station 2
36f / 11m
Station 6
207.5f / 63.25m
Robertson's
Cave
Station 1
Station 1a
-45f / -13.8m
Entrance


4
3
2
1

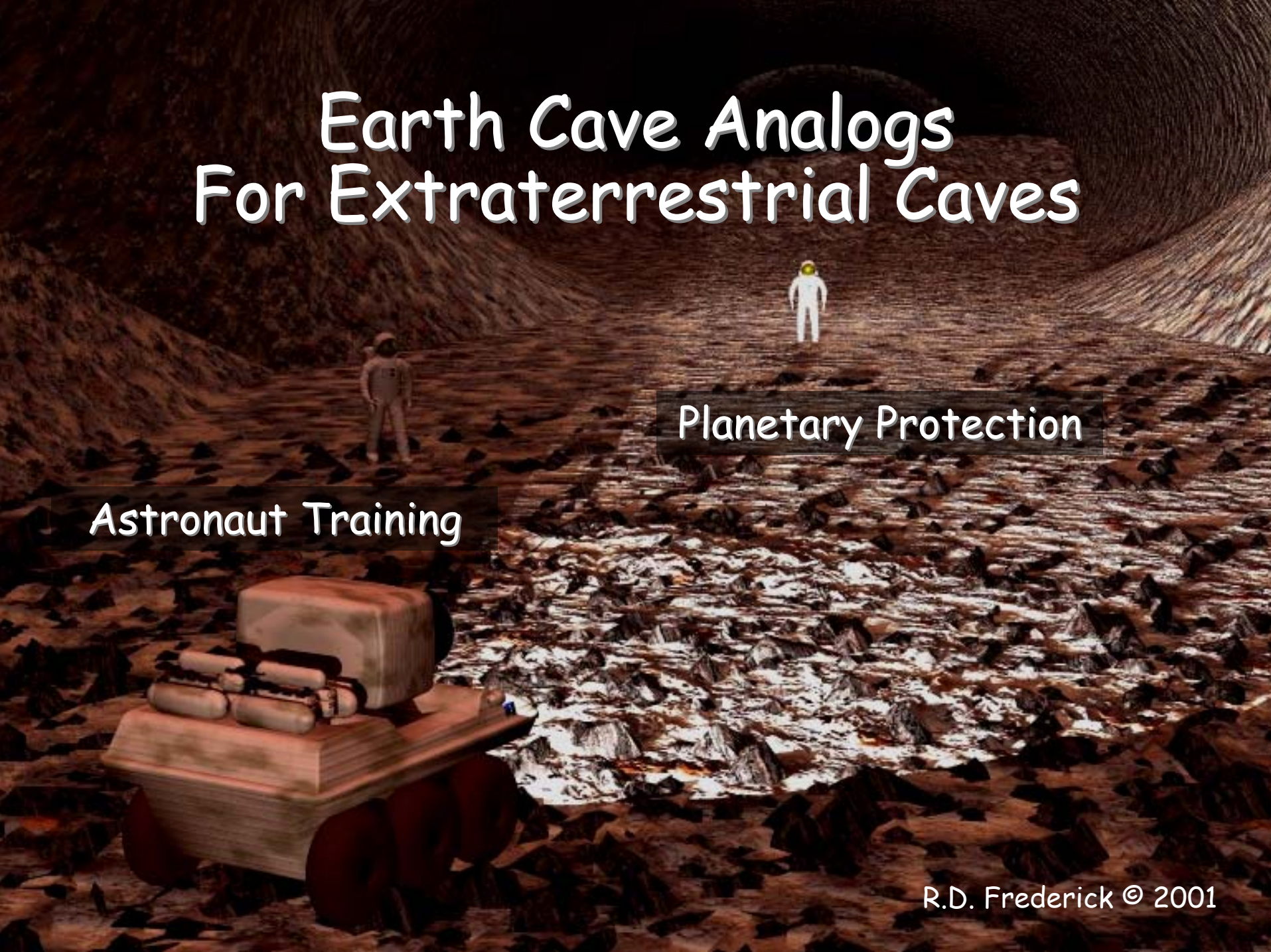
3-D LIDAR Scanner

Cyrax 2500 3D Laser Scanning System - Cyra Corp.
Courtesy Pacific Survey Supply, Medford, OR

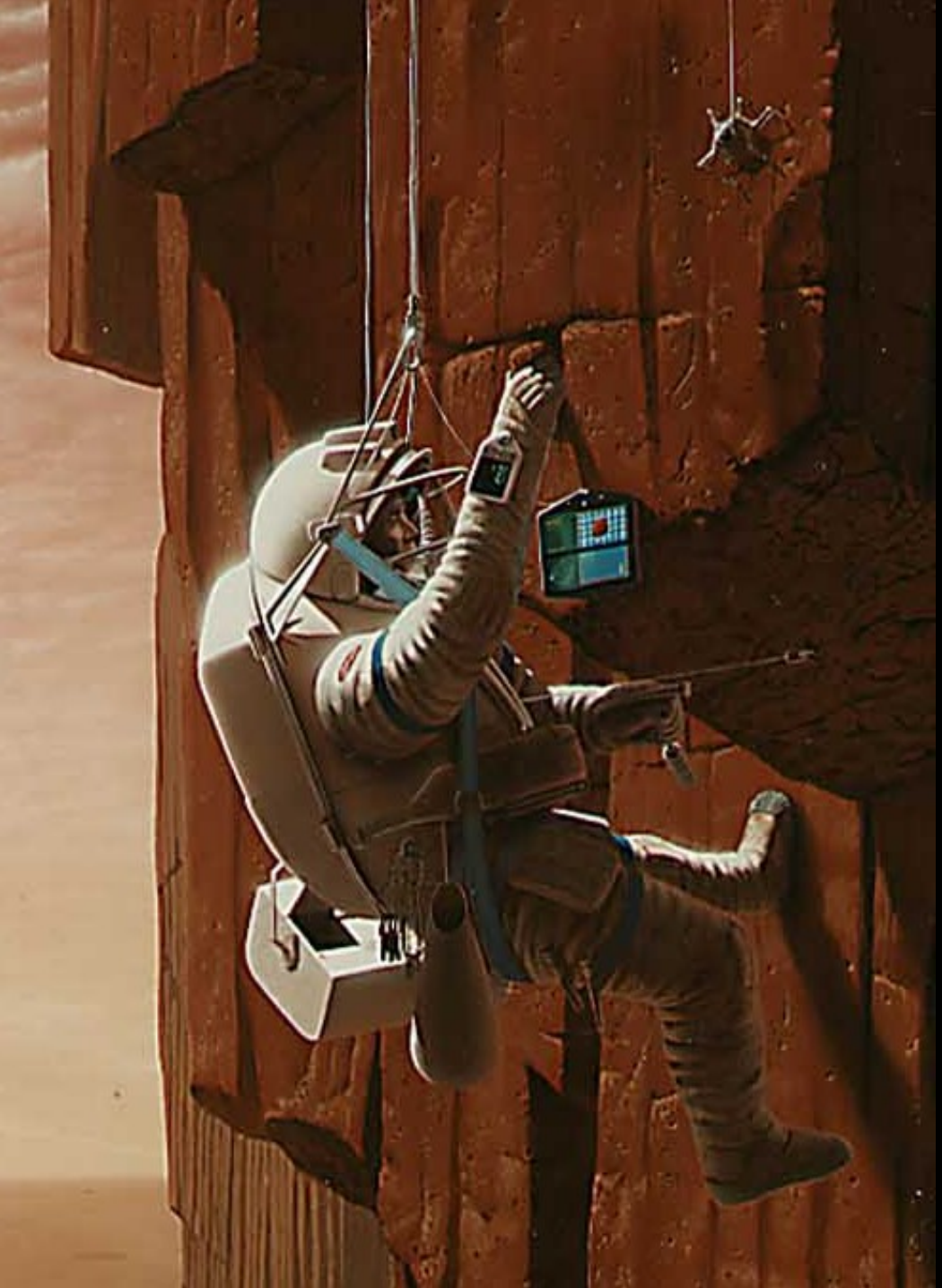
- Fast
- Autonomous
- CAD-compatable 3D point cloud
- General mapping & reconnaissance
- Custom fit inflatable cave liners



Earth Cave Analogs For Extraterrestrial Caves




Logistics



Logistics

Protection

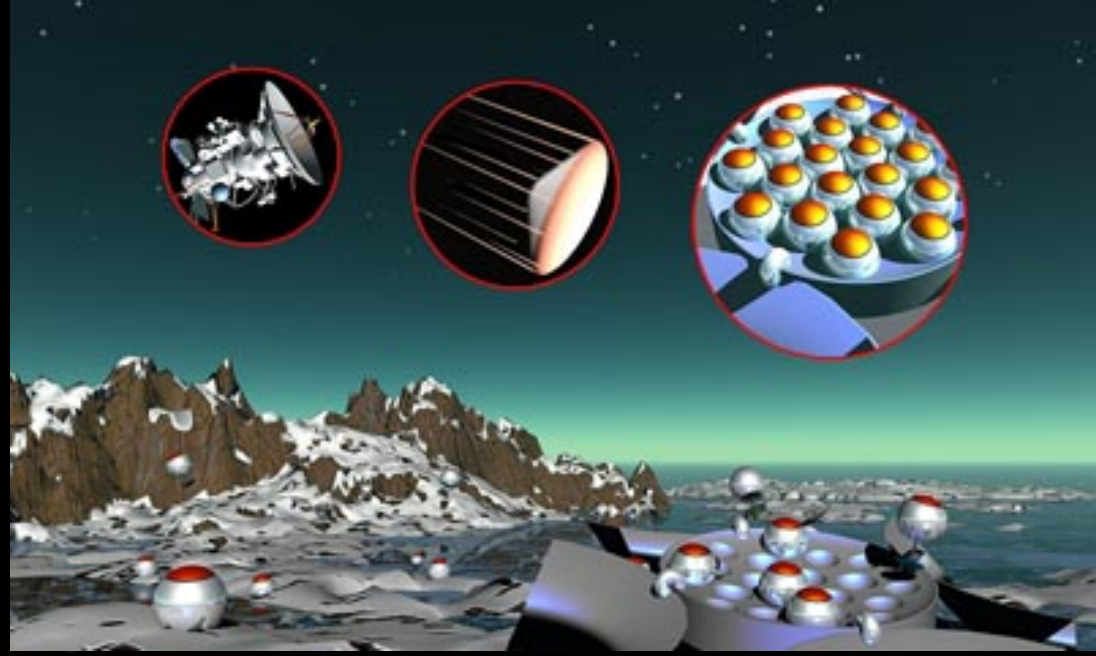
Mobility

Instrumentation

Emergency response

Abrading environment

Planetary Protection



Potential biological sites
Aseptic reconnaissance
Long-term monitoring
Non-invasive techniques
Chain of asepsis


Next?
NASA ASTEP
new start 1/04
ISU Cave
Class Project
Adrian Hetmanski

Humans in Caves: The Present

Humans in Caves: The NIAC Future?