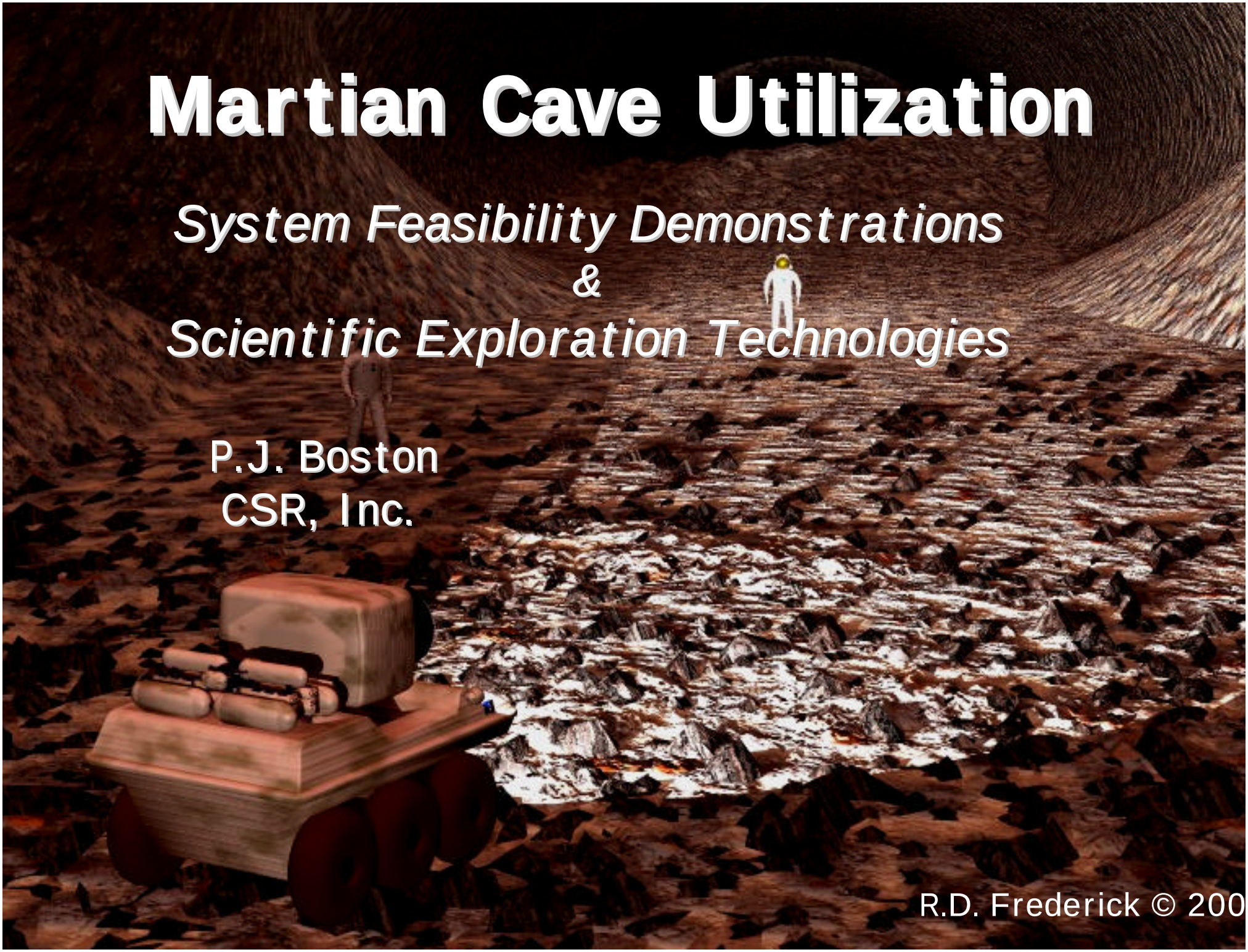
Martian Cave Utilization
System Feasibility Demonstrations
&
Scientific Exploration Technologies
P.J. Boston
CSR, Inc.
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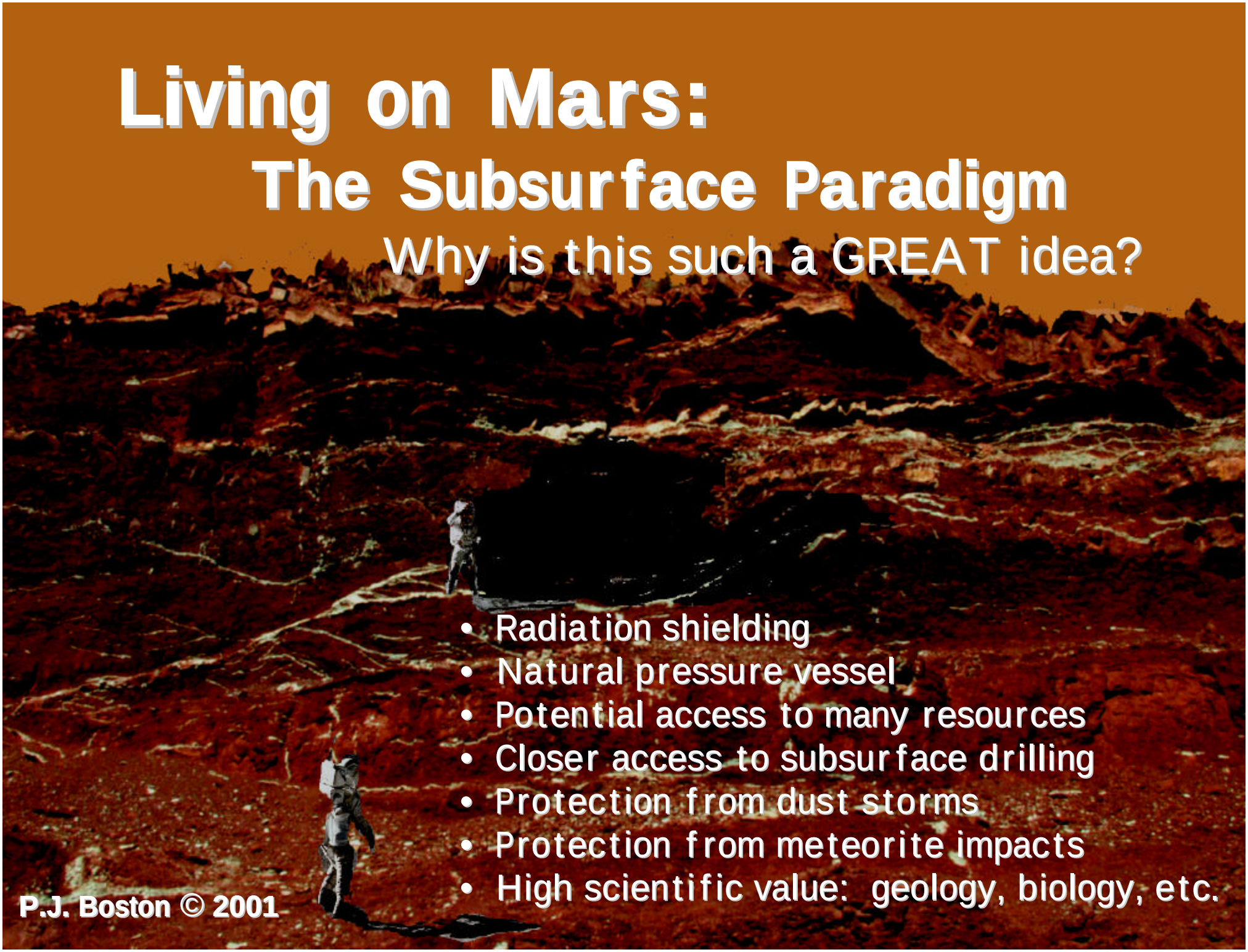
Living on Mars:
The Surface Paradigm
Why is this not such a good idea?
• Radiation shielding problems
• Payload mass intensive
• No obvious access to resources
• No protection from dust storms
• No protection from meteorite impacts

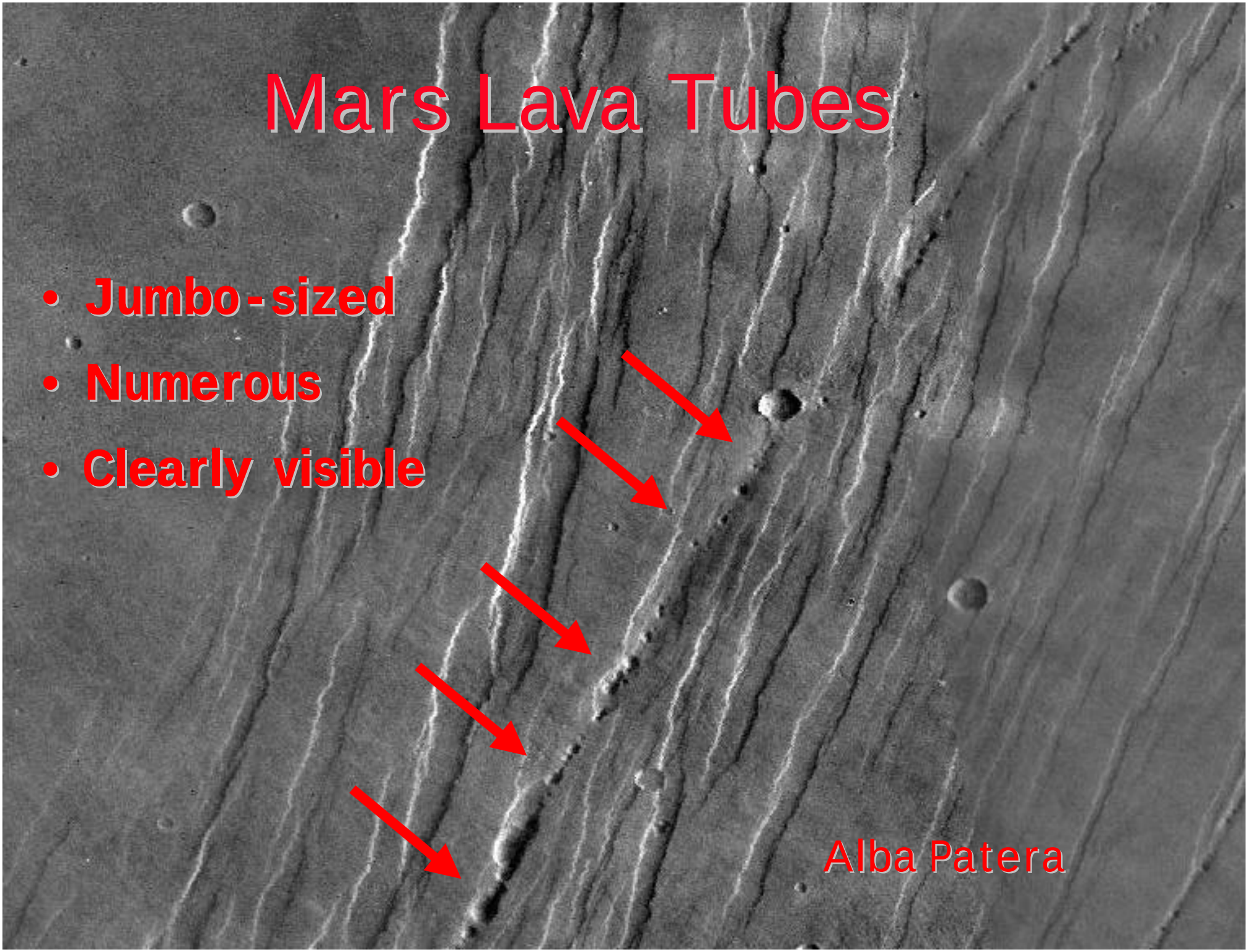
Living on Mars:

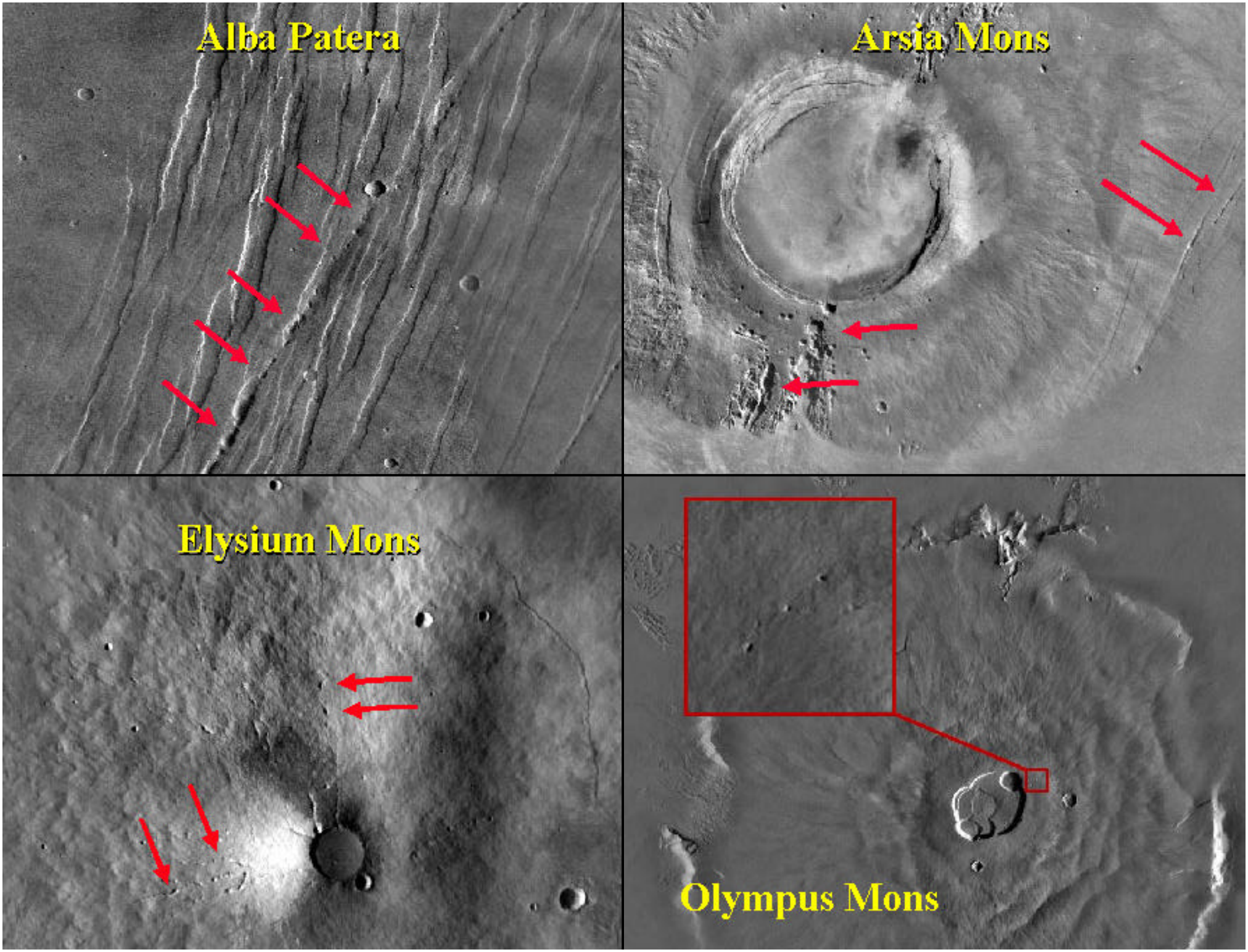
The Subsurface Paradigm

Why is this such a GREAT idea?

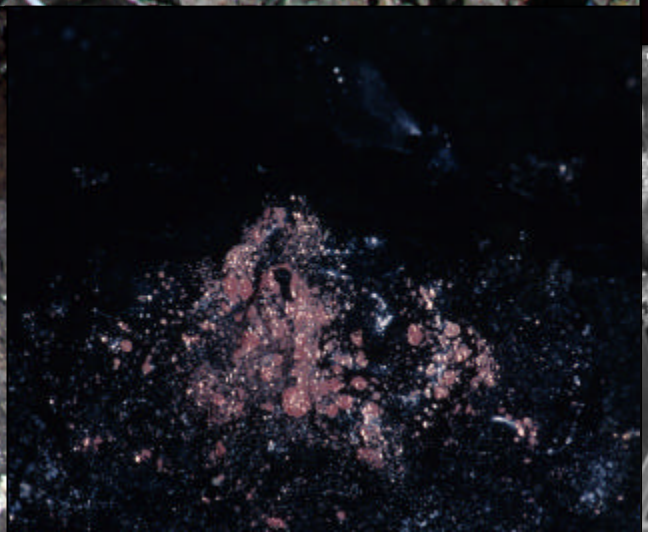


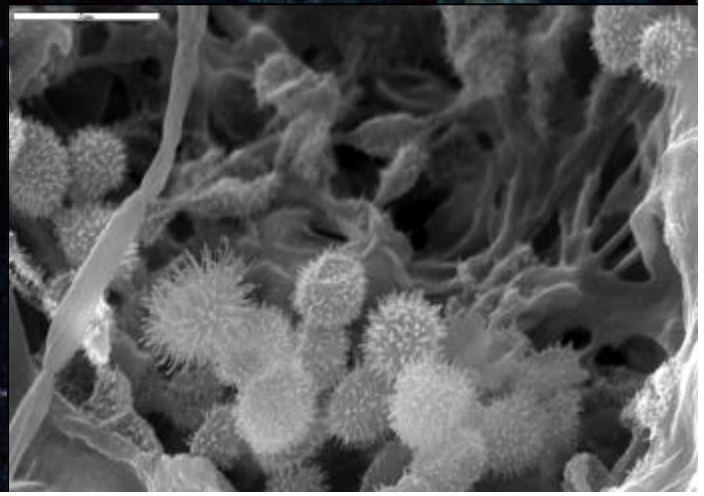
- Radiation shielding
- Natural pressure vessel
- Potential access to many resources
- Closer access to subsurface drilling
- Protection from dust storms
- Protection from meteorite impacts
- High scientific value: geology, biology, etc.


Mars Lava Tubes
• Jumbo-sized
• Numerous
• Clearly visible
Alba Patera

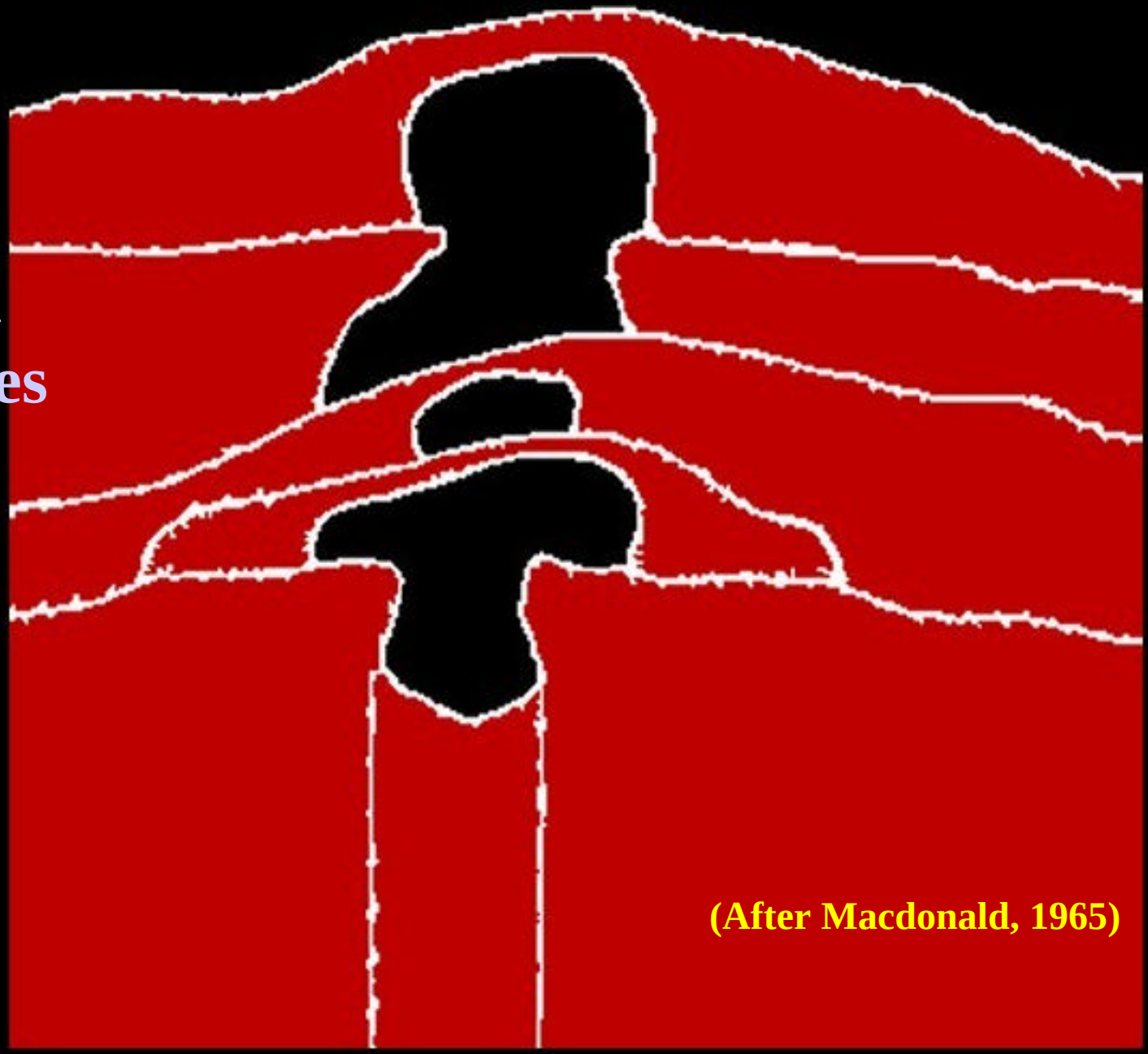

Alba Patera
Arsia Mons
Elysium Mons
Olympus Mons


Garden-variety
Earth Lava Tube





Rift Tube Serial Flows



Trapped
Ice Lenses

(After Macdonald, 1965)

Lava Tubes are often smooth!

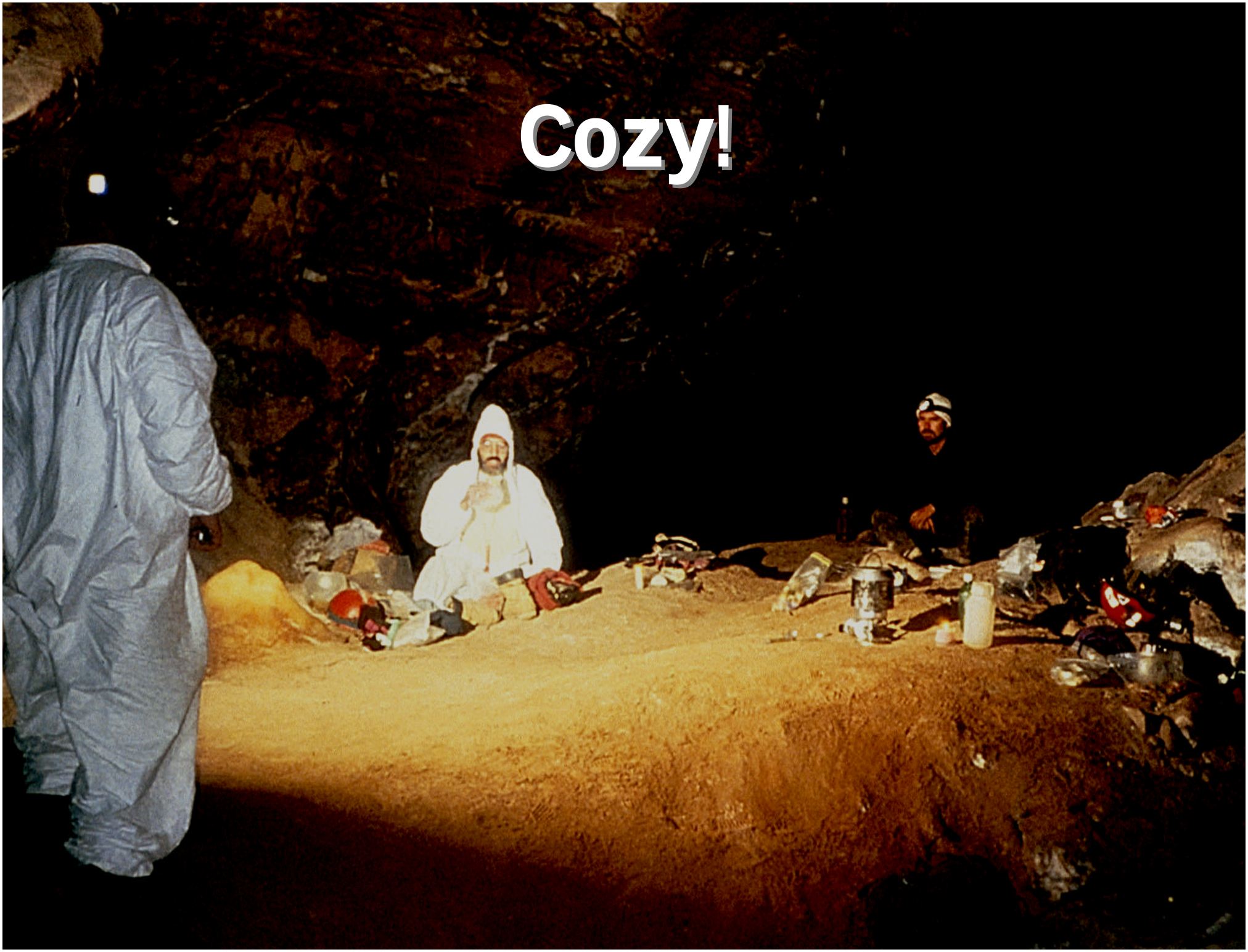
Desert Surfaces On Earth

- High intensity sunlight and UV
- Low humidity (5-40% typically)
- Temperature extremes
- Low nutrients (usually)
- Mineral-rich (usually)
- Extensive weather,
  e.g. high winds, flash floods, frost, etc.

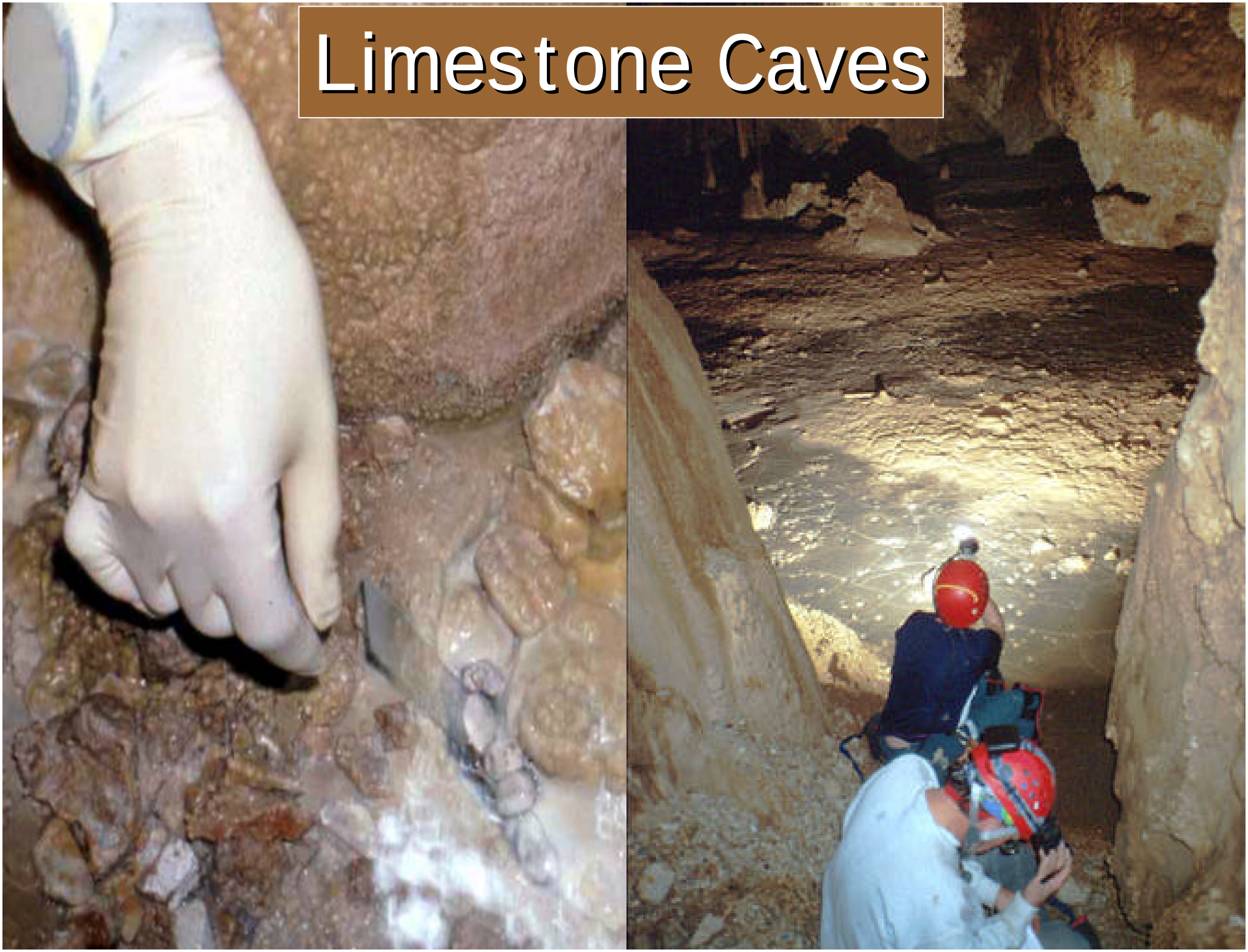
Desert Caves On Earth

- No sunlight
- High humidity (99-100%)
- Temperatures relatively constant
- Low nutrients (usually)
- Mineral-rich (usually)
- No weather

Photo by David Jagnow


Cozy!

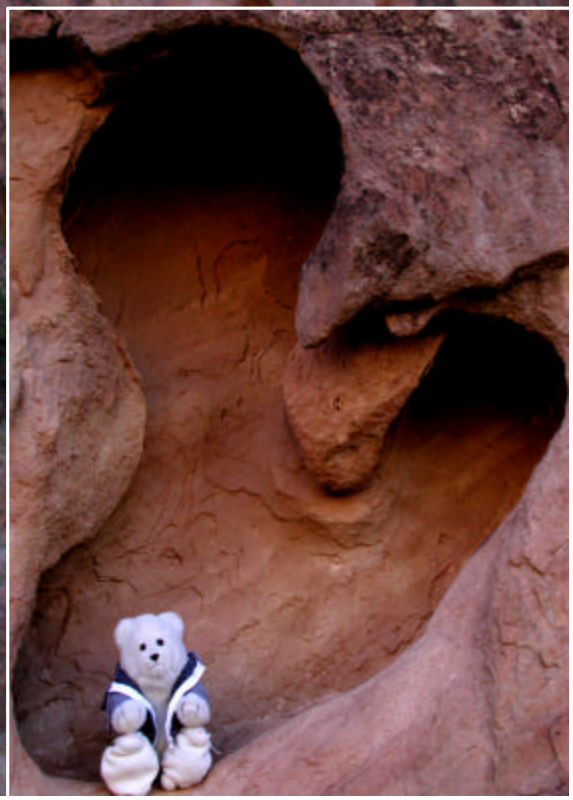
Limestone Caves



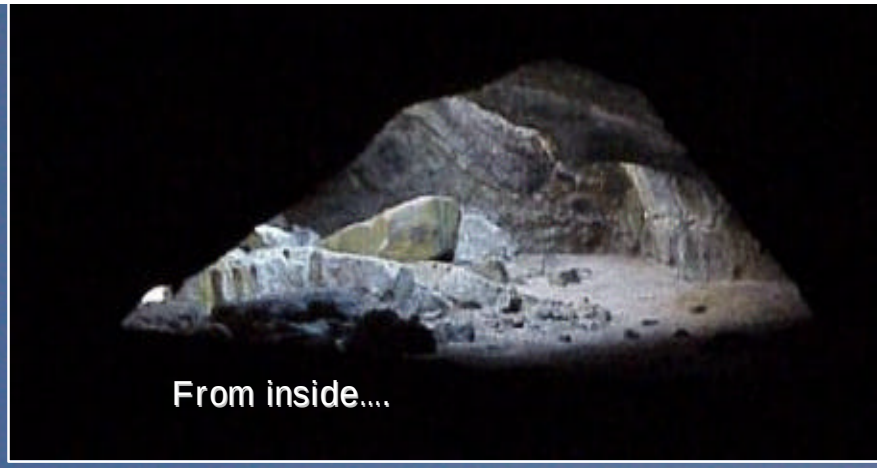
Tafonated Caves

- Typically in sandstones
- Desert environments
  - thermal weathering
  - aeolian weathering
- Seacoast water erosion

Big enough for Teddy Bears…

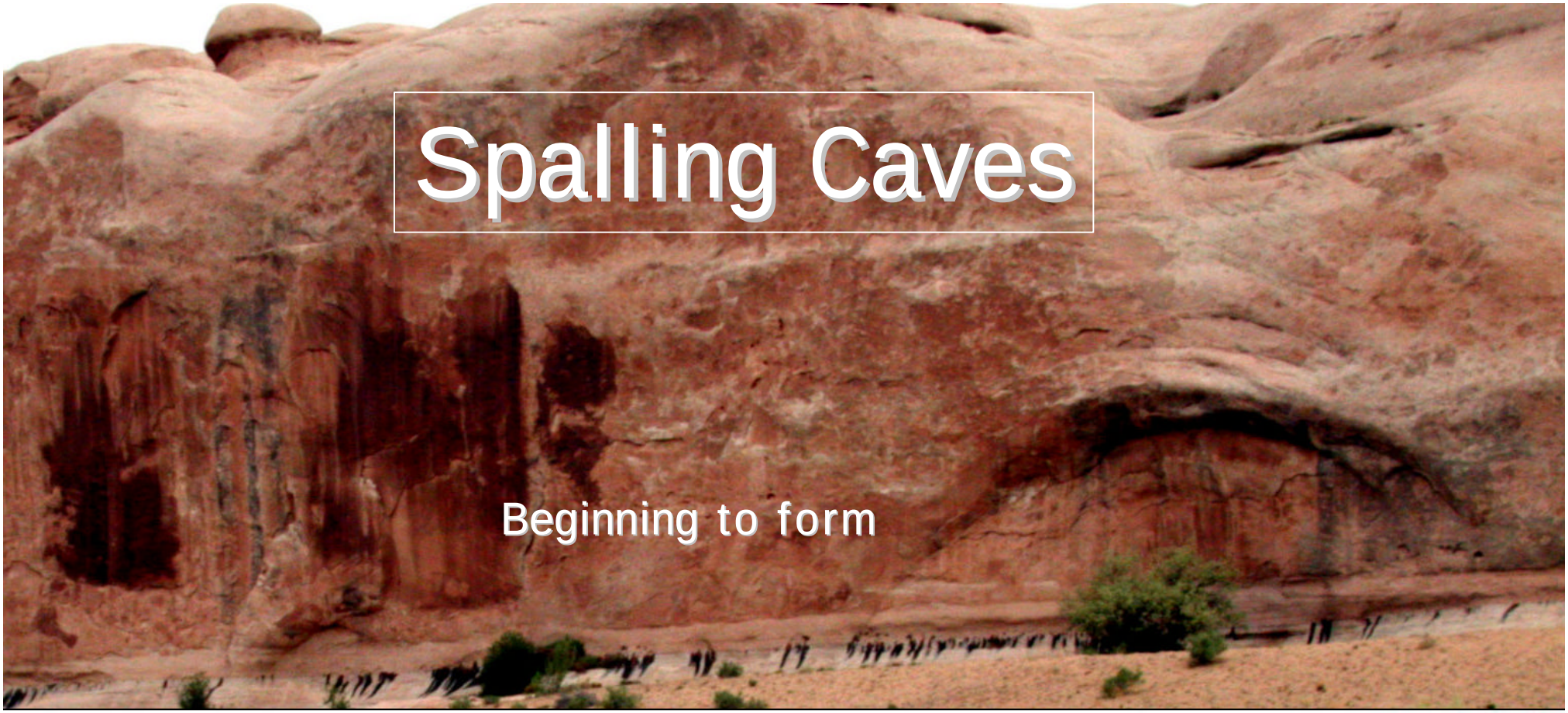


Big enough for Humans...



From inside....

Spalling Caves



Mineral Resources

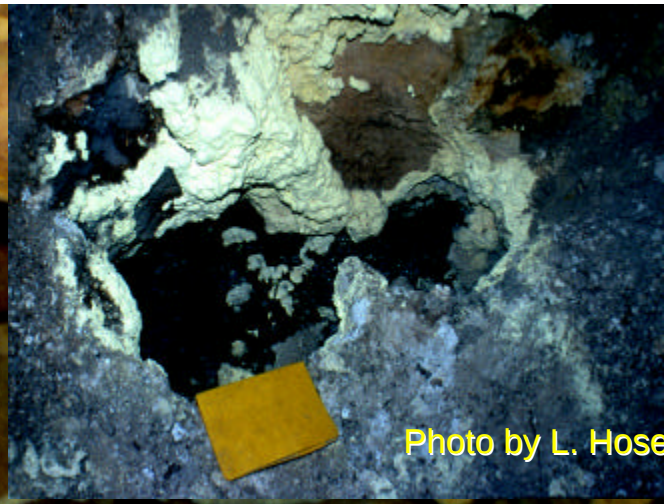


Photo by L. Hose

Photo by Kathy Duchene

Water on Mars:
Known Sources

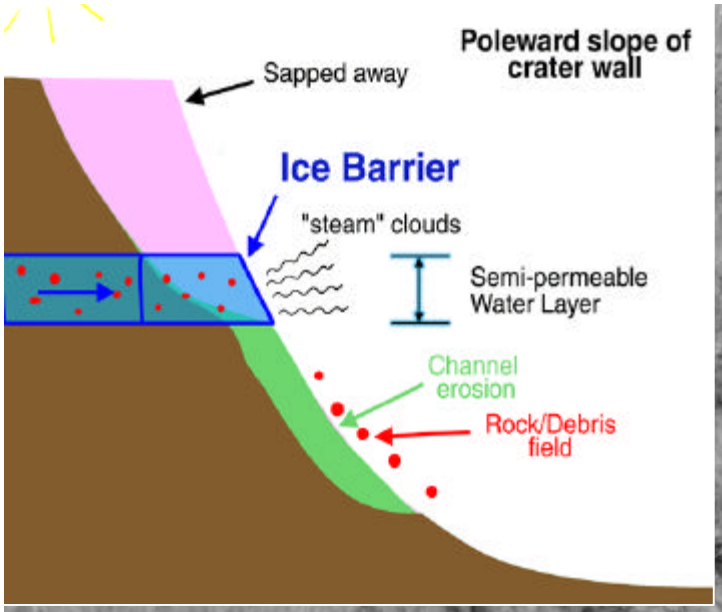
- Atmosphere is saturated at global mean pressure of 8.1 millibars
- Water vapour = 0.03% of current atmosphere (~1-3% for Earth)
- Water ice at north pole
- Water and CO_2 ice at south pole

Recent Surface Water Evidence

- When? Yesterday to a few million years ago
- How deep? 100-400 m (300-1300 ft)
- How much? 2500 cubic m, about (90,000 cubic ft.
- Where? 30^{o}-70^{o}

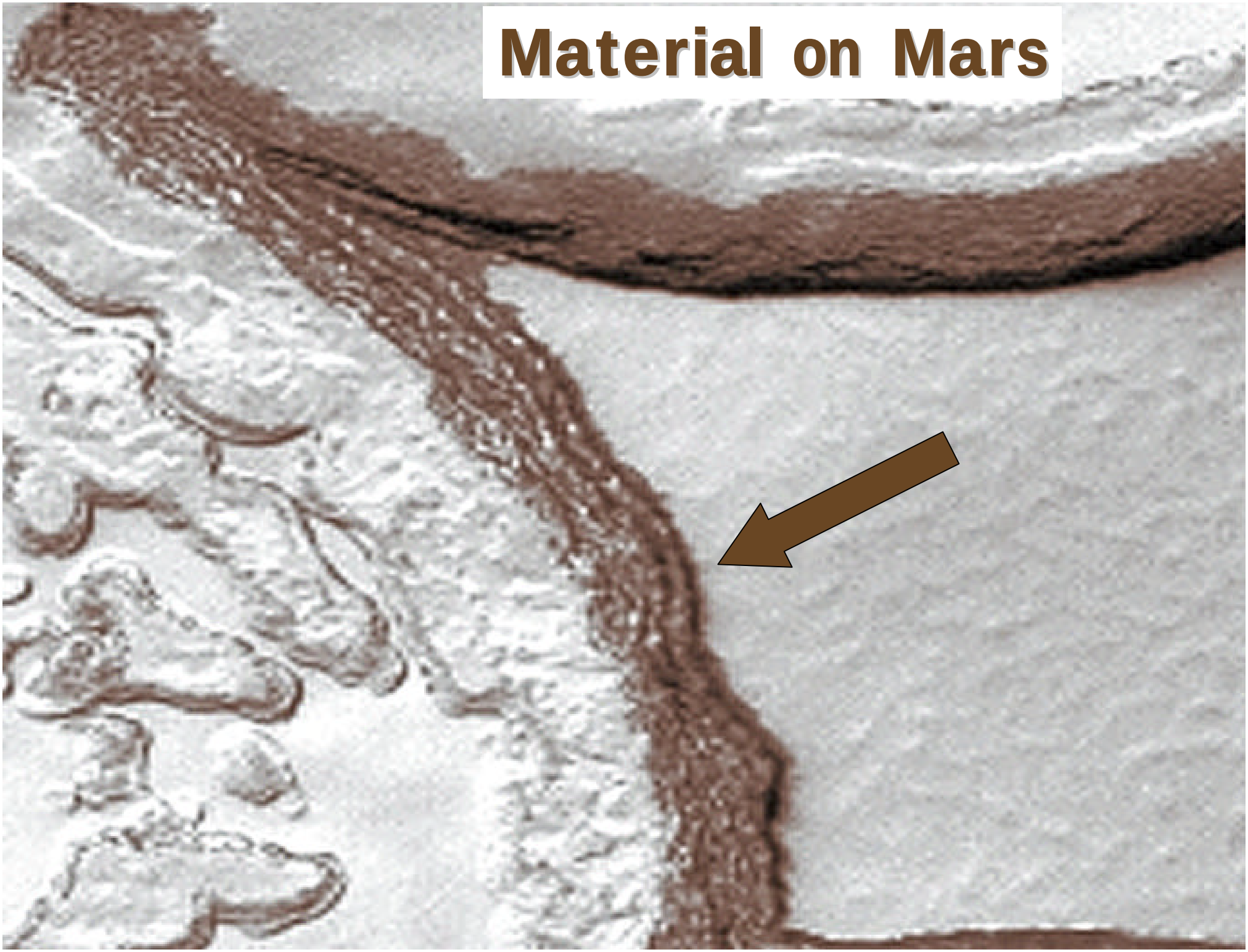
  Most in the south, a few in the northern hemisphere

Proposed Mechanisms



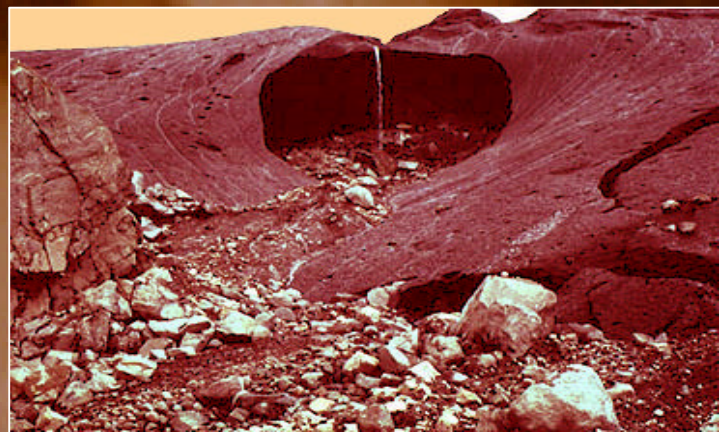
437 yd

Material on Mars



Material in Utah

Mars Polar Ice/Dust Caves?



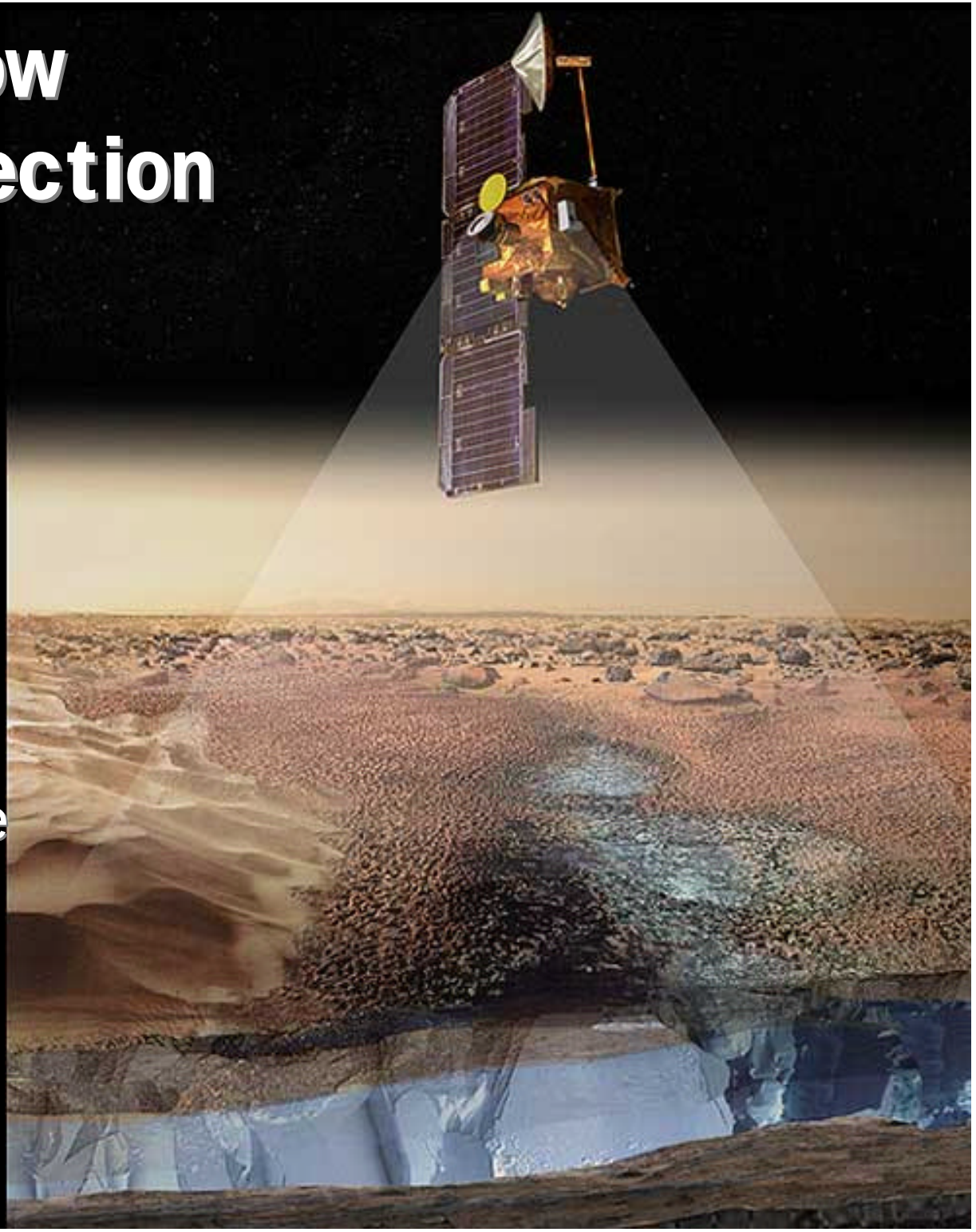
Iceland

New, Shallow Hydrogen Detection

Hydrogen is there

Is it in water ice?

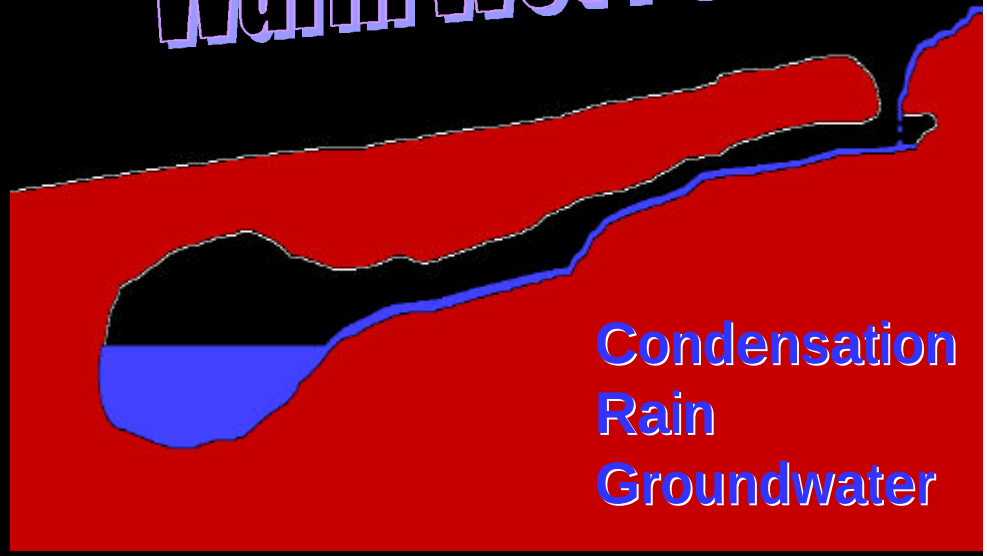
Are there subsurface liquid H_2O zones?



Volcanic Period

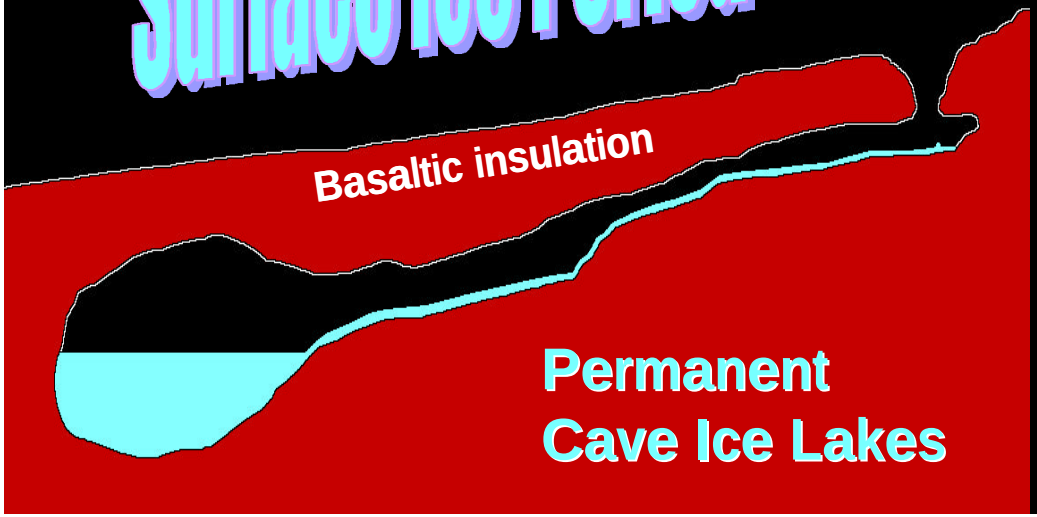
Lava tube forms

Warm Wet Period



Condensation
Rain
Groundwater

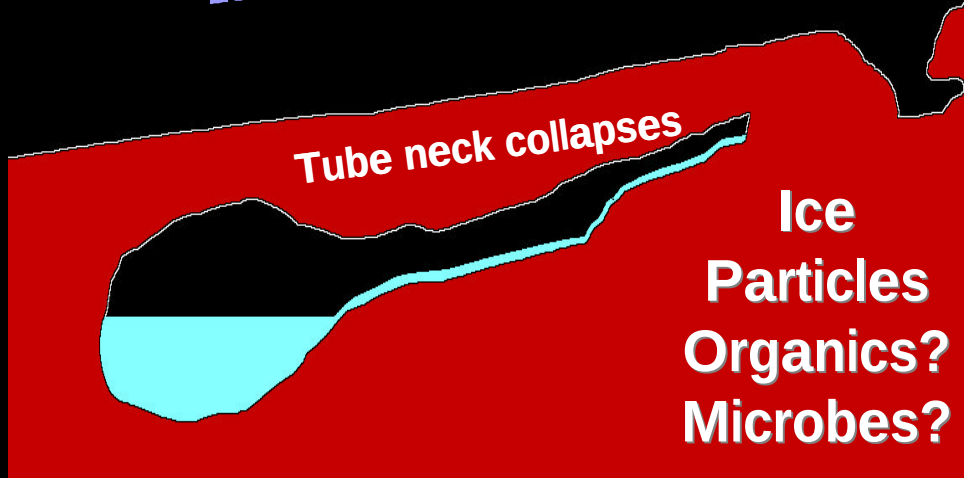
Surface Ice Period



Basaltic insulation

Permanent
Cave Ice Lakes

Modern Period?



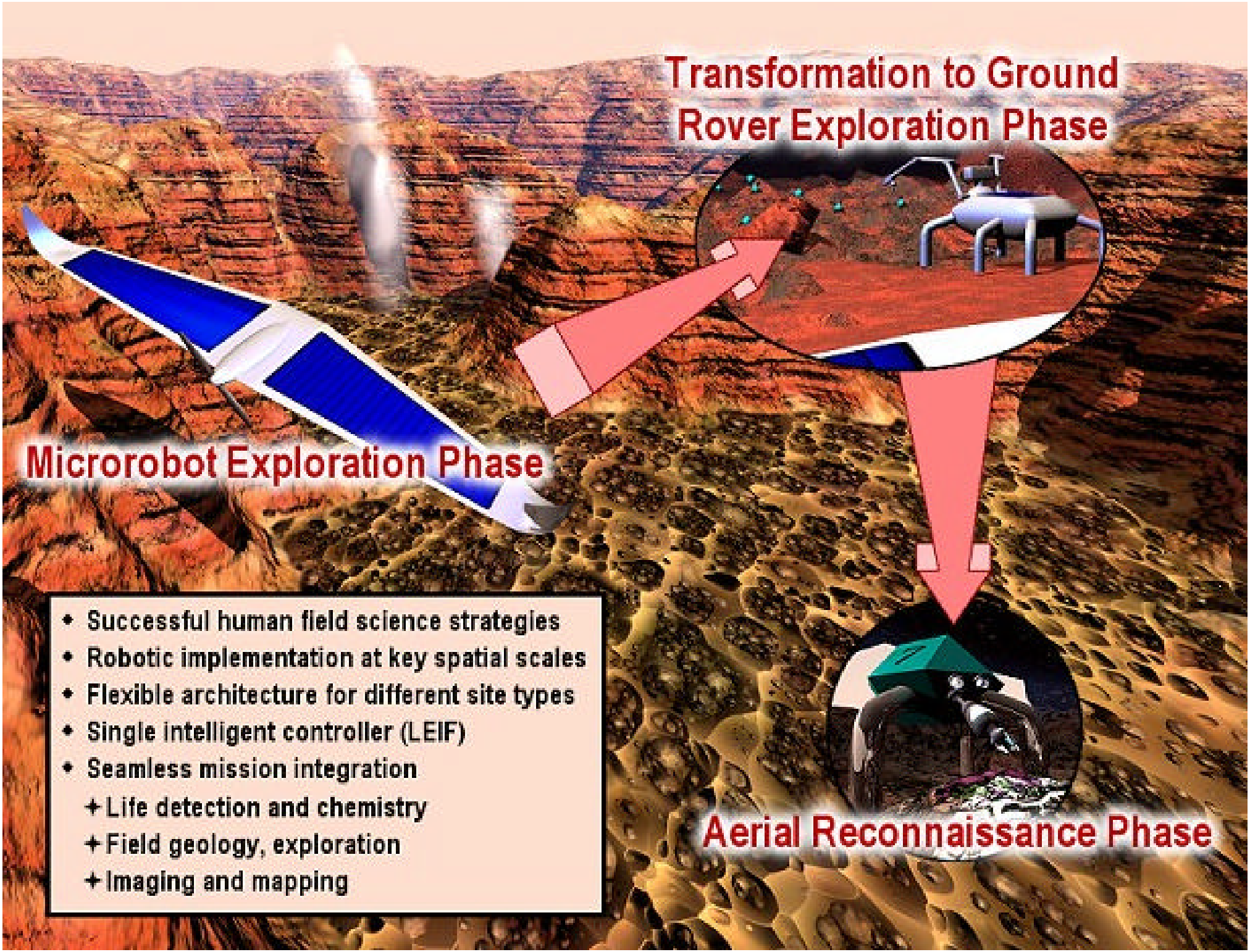
Tube neck collapses

Ice
Particles
Organics?
Microbes?

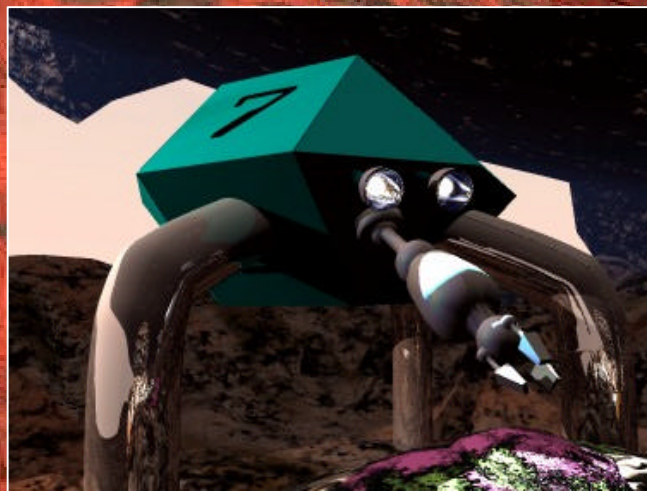
The Perfect Building Site

Cave Aquaculture?

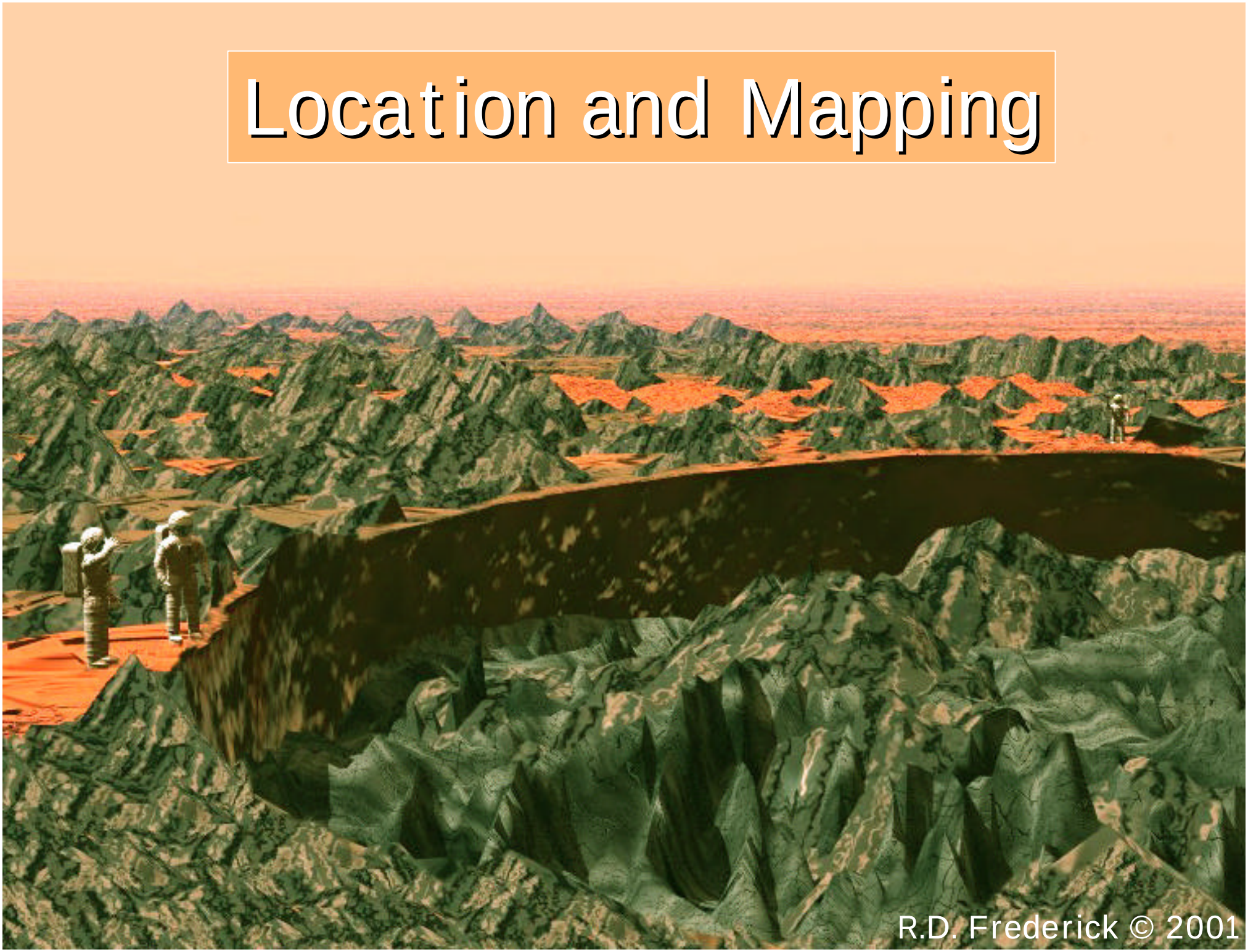
Photo by Steve Alvarez


Transformation to Ground Rover Exploration Phase
Microrobot Exploration Phase
Aerial Reconnaissance Phase
• Successful human field science strategies
• Robotic implementation at key spatial scales
• Flexible architecture for different site types
• Single intelligent controller (LEIF)
• Seamless mission integration
+ Life detection and chemistry
+ Field geology, exploration
+ Imaging and mapping

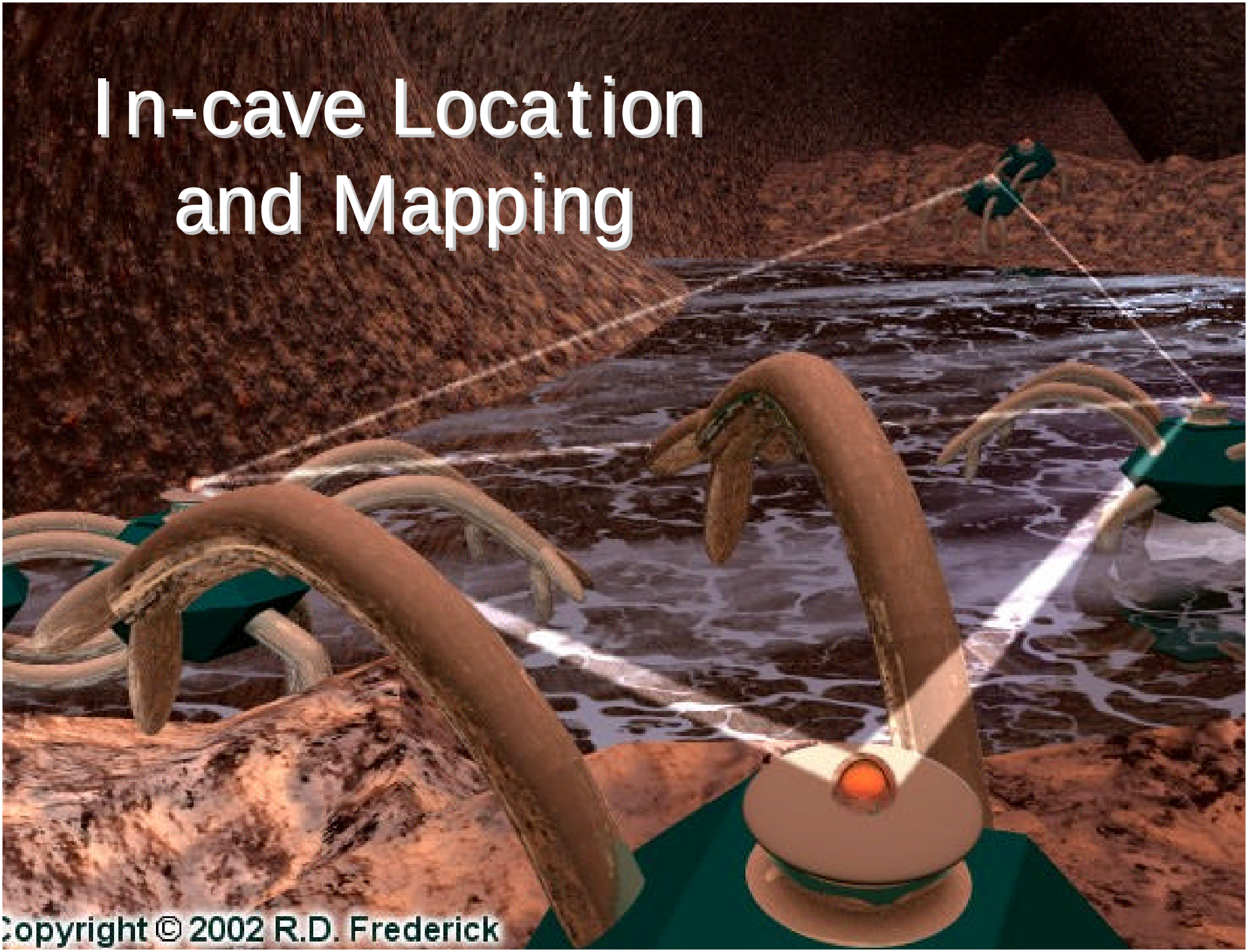
Robotic Cave Exloration



Location and Mapping



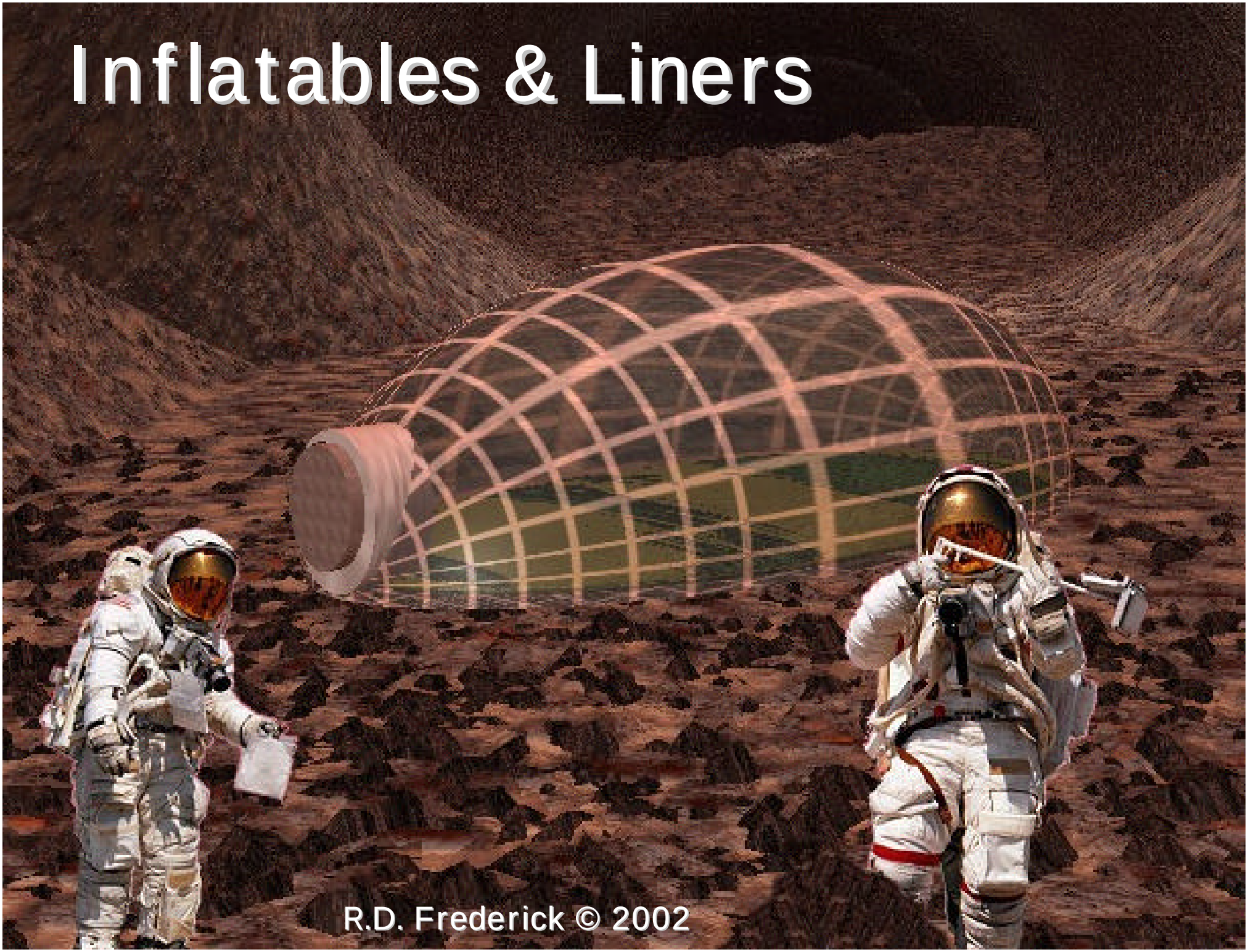
In-cave Location and Mapping



Access

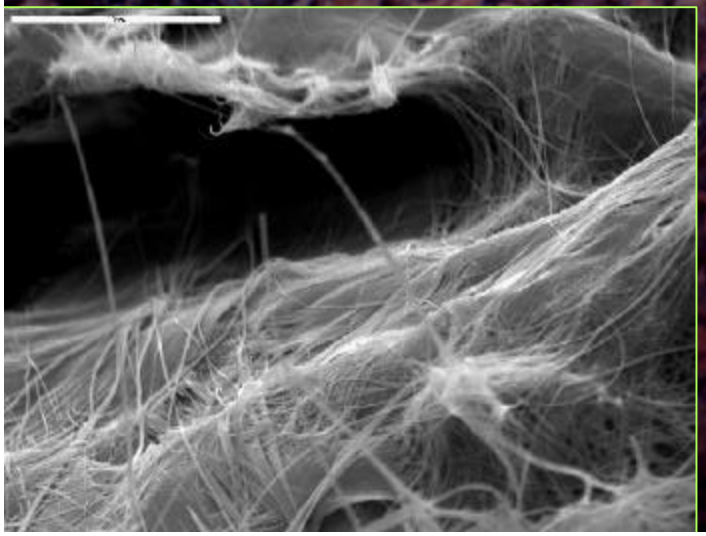
Operational Protocols

Inflatables & Liners



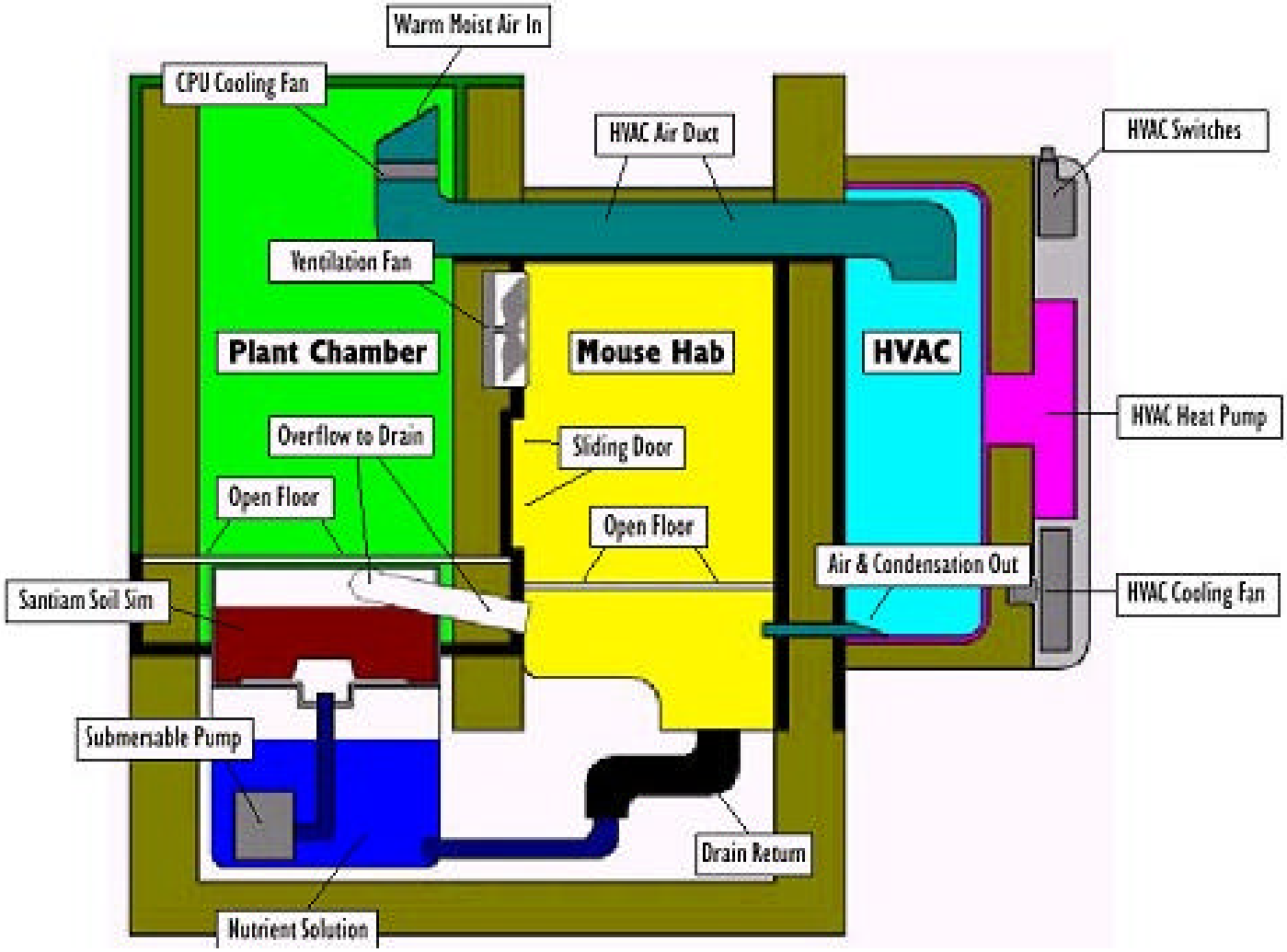
Novel Airlock Technology

Mars-derived Breathing Mixes



Mouse Mission to Inner Space

Controlled Ecological Mouse Support System



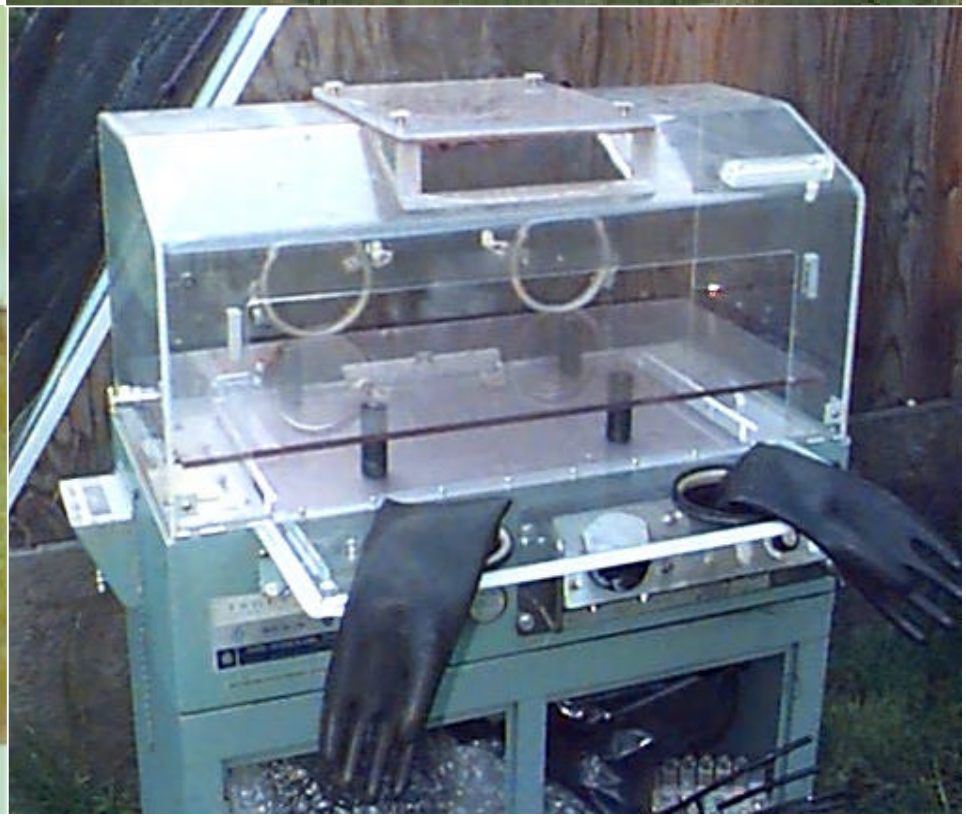
GREEN HARE

Brand

May Contain Less Than
1% Water Fern by Weight

Fancy Oregon Duckweed

Martian Mouse Approved

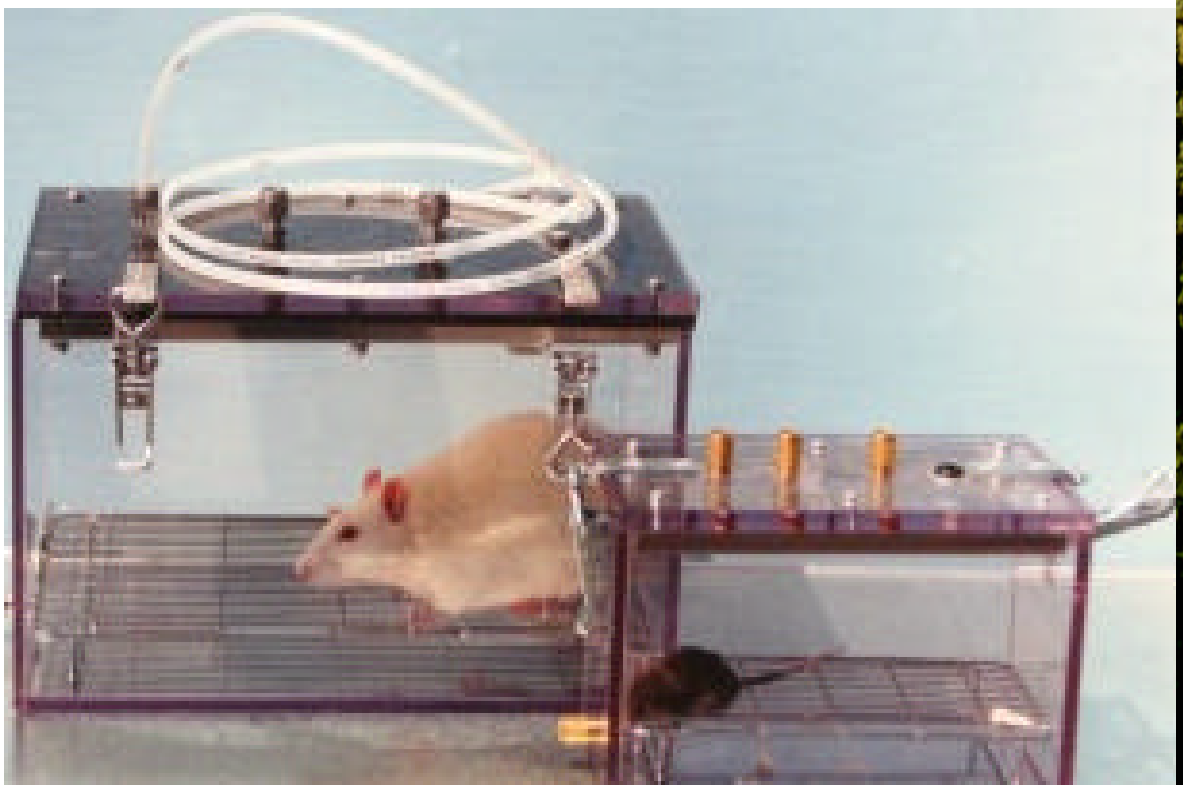


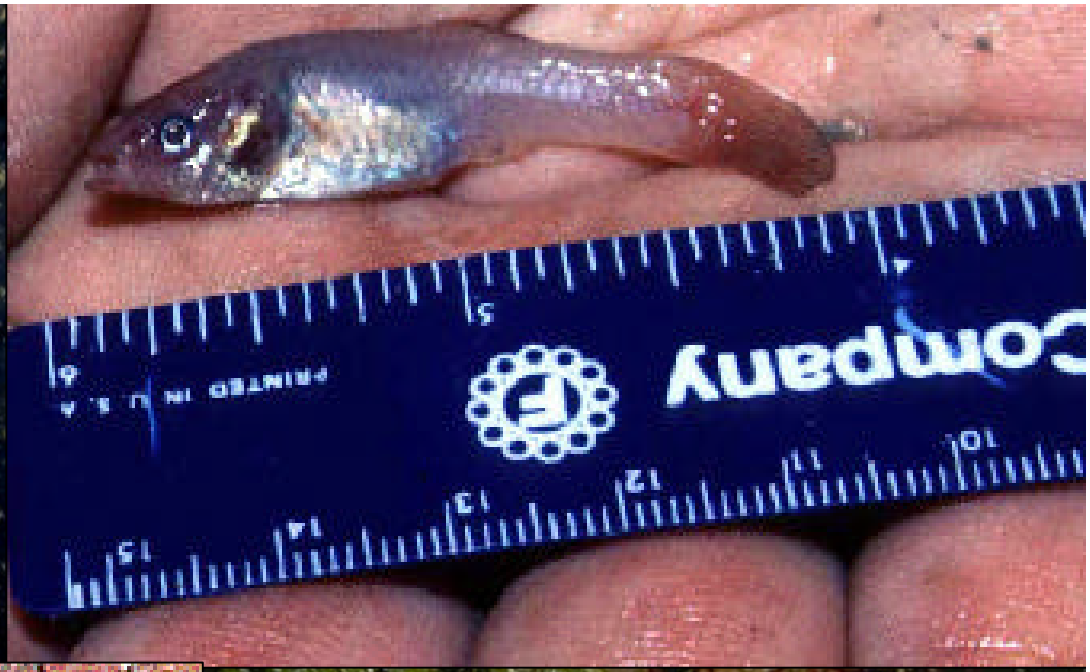
MATERIAL RESOURCES
The Atmosphere

	MARS	EARTH
CO_2	95%	0.03%
	(10 Bars outgassed)	
N_2	2.7%	78%
Argon	1.6%	0.93%
O_2	0.13%	20.9%
CO	0.07%	0.12ppm
Neon, Krypton, Xenon	ppm on both planets	

Mars-derived Breathing Mixes

40% N2
40%
Argon
20% O2

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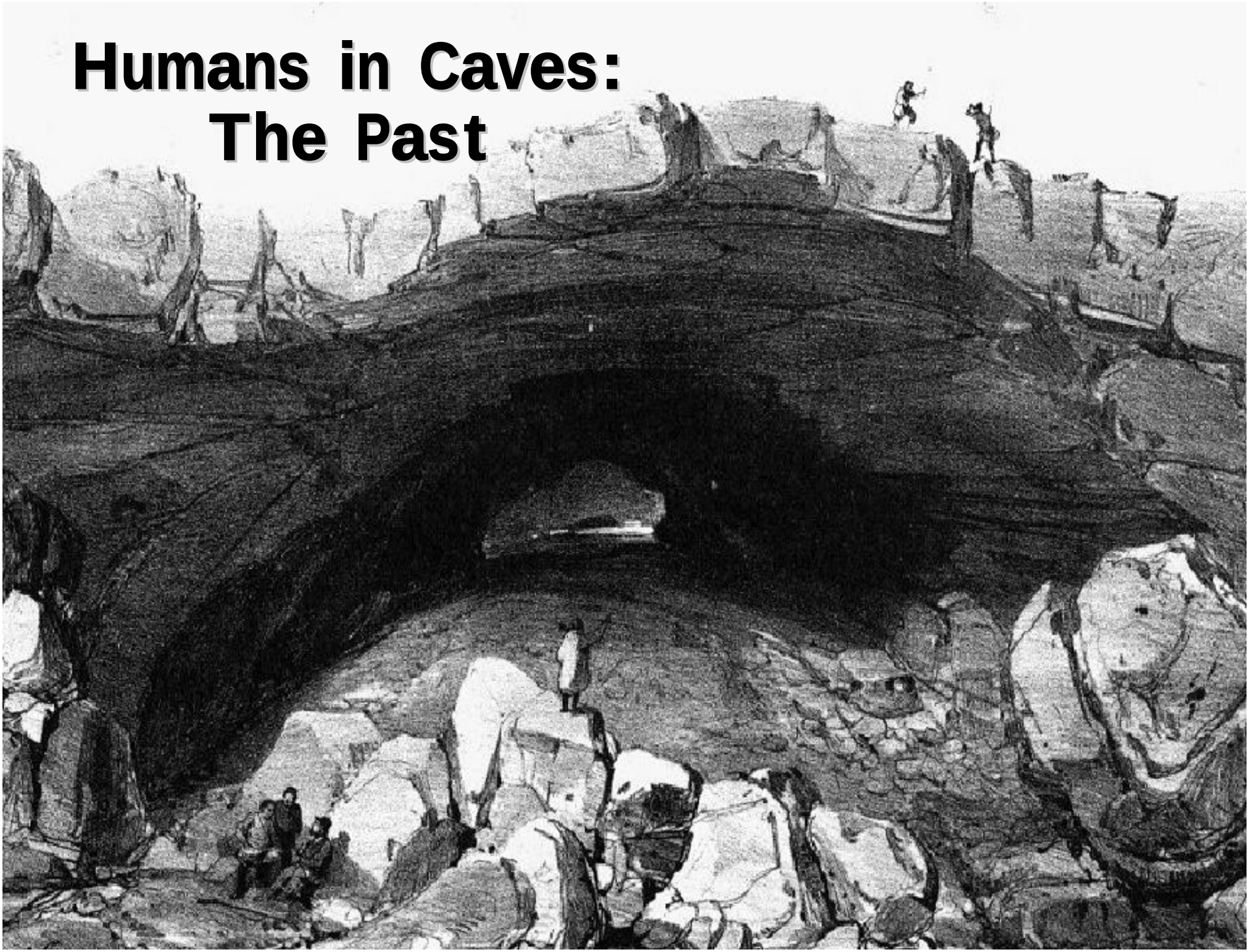
Company

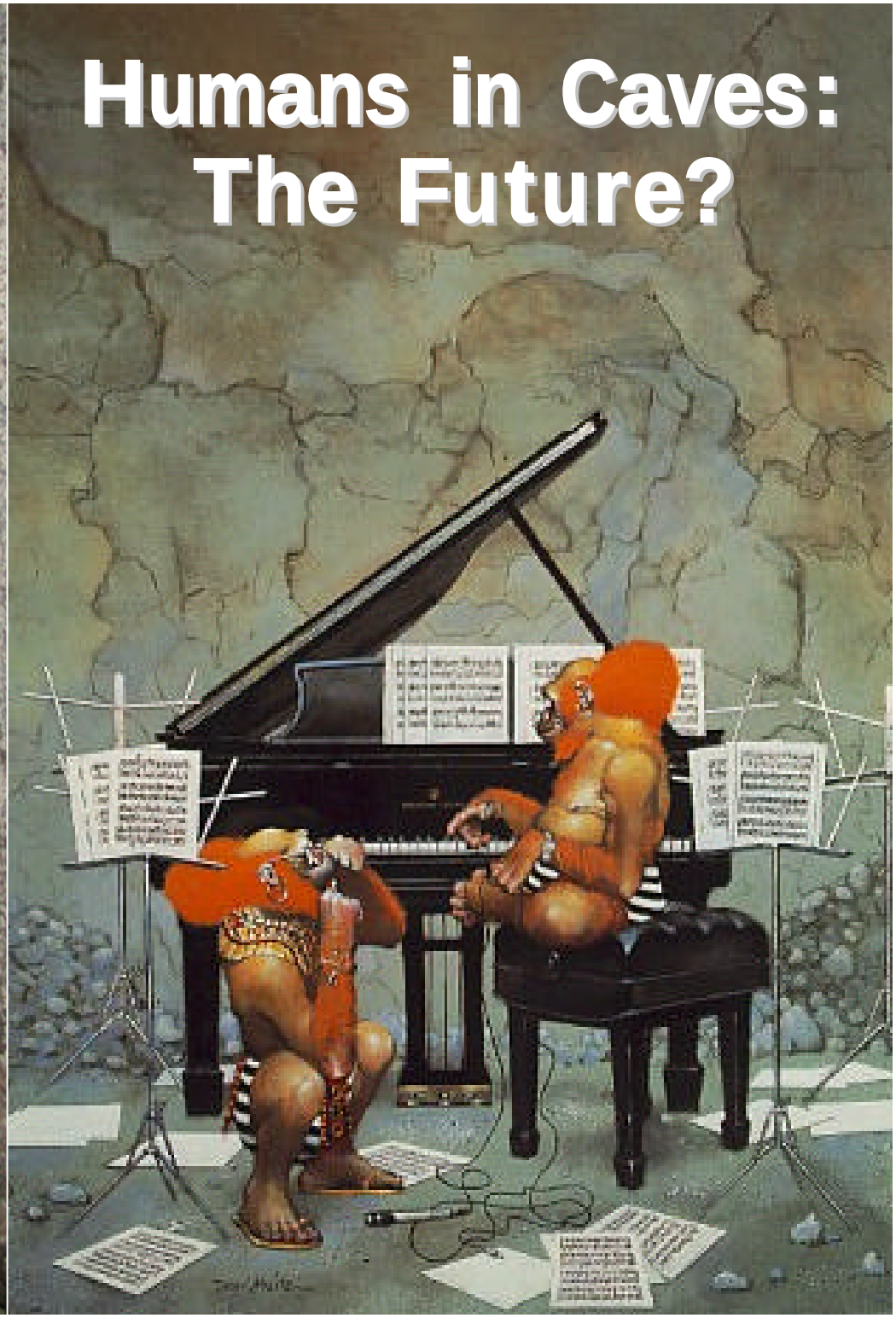
Progress Summary

- **Mouse Mission to Inner Space**
  - Version 1 in testing
  - Version 2 under construction
  - Duckweed experiments advanced
  - Lighting for plants in design and planning
  - Breathing mixture experiments beginning
  - Gas balance, water & waste recycling in design
  - Cave selection continues
- **Human Mission to Inner Space**
  - Inflatables in design
  - Airlock in design
  - In cave communication system in design
  - Access via suits – HOPING FOR HELP!!!!!
  - Operational protocols developing in real-time
  - Lighting system in prototype
  - Cave selection narrowed to 3

Humans in Caves: The Past




Humans in Caves:
The Present


Humans in Caves:
The Future?

Other Collaborators:

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Institute of Meteoritics, UNM
USDA Forest Service
The Mars Society

Illustrations:

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Hajime Sorayama

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