Why Caves?

- Science
- Shelter
- Stuff
Are There Caves On Other Planets?

Adrian Hetmansiuk
Collapse Pits Along Tube Path
Lavatubes on Mars

Alba Patera

Arsia Mons

Elysium Mons

Olympus Mons

Images - NASA, Malin Space Sciences
Lavatube Cave Environments

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

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 Microbes
Preservation Environment

Physical fossils
Isotopic signals
Climate record
Geochemical traces
In situ lithification
Trapped Particles & Volatiles?

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?
Life in Mars Caves?

- Traces of Ancient Life?
- Presence of modern life?
Extraterrestrial Caves as Human Habitat
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

Volatile
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
Flat Crops

Azolla (waterfern)

Lemna minor (duckweed)
**Duckweed**

- 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

**Waterfern**

- 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% CO₂, 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”
Robertson's Cave

Station 1

Station 1a -45f / -13.8m

Station 2

36f / 11m

Station 3

90.5f / 27.58m

Station 3a

78f / 23.7m

Station 4

95.5f / 29.1m

Station 5

168f / 51.2m

Station 5a

162f / 49.4m

Station 6

207.5f / 63.25m

Entrance
3-D LIDAR Scanner

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

Fast
Autonomous
CAD-compatible 3D point cloud
General mapping & reconnaissance
Custom fit inflatable cave liners
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
Humans in Caves: The Present

Humans in Caves: The NIAC Future?