Monitoring a glacial melt lake deep in a fumarole ice cave in the summit crater of Mount Rainier, Washington State, U.S.A.

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An integrated, multidisciplinary study of one of the largest and most complex fumarole cave systems in the world!
Why the Project?

• Characterize the nature of the fumarole cave systems
  • Detailed map
  • Scientific monitoring
  • Rescue planning
  • Resource inventory
• Relate volumetric changes in the caves and sub-glacial lakes to the hydrothermal system.
• Terrestrial analogy to potential extremophile conditions on other ice bodies in solar system.
• Outreach and education.
Glacier formed by snow & ice accumulation in high altitude crater

- **East Crater:**
  - Uncertain depth... Estimates between 150 to 200 meters.
  - Bucket: Contains a trapped crater glacier.
  - Ice accumulation roughly balanced by bottom melting.
  - Ice flows downward with horizontal & rotational components.

- **West Crater:**
  - Unknown depth
  - Ladle: Breach in south rim feeds flank glaciers
The Fumarole Caves

- These summit craters contain the world’s largest fumarole glacier cave system

- Low volume, variable fumaroles permit formation of complex passages up to 120 m below crater rim.

- Caves visited by climbers & researchers since the late 1800’s, including the 1st authenticated summit climb in 1870.

- Each crater houses its own cave system

- Caves do not connect; they are separated by the overlapping rims of the Columbia Crest.
CAVE SURVEY

- Conduct 3-D survey
- Annual volumetric survey at reference points
- Systematic representation of resource

<table>
<thead>
<tr>
<th></th>
<th>East Crater Cave</th>
<th>West Crater Cave</th>
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<tbody>
<tr>
<td>Length</td>
<td>2.2 miles</td>
<td>999 feet</td>
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<tr>
<td>Vertical Extent</td>
<td>463 feet</td>
<td>91 feet</td>
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Summit Caves
The Science
The Science
Hydrology & Geochemistry

• Lake Adelie is comprised largely of glacial melt
  • Temperature is close to freezing point, conductivity was very low <2 µS/cm, and pH was slightly acidic.
  • Low inorganic carbon in the lake water with $\delta^{13}C$ values (-9‰ to -13‰) suggesting a mixture of atmospheric CO$_2$ and fumarole gas.
  • Values of $\delta^2H/\delta^{18}O$ in the lake are a mixture of fumarole condensate (-155‰/-24.5‰) and glacial melt (-132‰/-19‰).
Carbon and Sulfur isotopes
Water isotopes

δD and δex profile of Climber's Refuge Room

δ18O (per mil - VSMOW)

δD (per mil - VSMOW)

Shift in isotopic ratio aligned with cooling of fumarole

Ice
Drips
Lake Adelie
2015 Drip
2015 Ice
1997 Drips
1982 Thermal Springs
1982 Fumaroles
1982 Drips
1982 Rivers
Linear (Ice)

Ice Springs Thermal Springs
Drips Fumaroles End Glacial Stream
Lake Adelie 2015 Fumarole 2015 Lake
2015 Drip 1997 Fumaroles
1997 Drips 1982 Fumarole 1982 Drips
1982 Thermal Springs 1982 Rivers

2015 Fumarole
2015 Lake
2015 Drip
1997 Fumaroles
1997 Drips
1982 Fumarole
1982 Drips
1982 Thermal Springs
1982 Rivers

Linear (Ice)
Climatology / Micro-meteorology

Course of fumarole temperatures (°C) of three fumaroles in the Glacial Caves of the East Crater of Mt. Rainier from 08/15 to 08/17
Continuous monitoring data

Oh what a story...

Red - Increase in water depth from accelerated melting. Observed visible water level change (0.7 m).
Yellow - Decrease in probe depth resulting, in part, from translational motion of anchor boulder (2.0 m).
Green - Increase in probe depth resulting, in part, from subsidence of anchor boulder (0.8 m).
Gray - Period of significant lake ice.
What‘s next/Future work

1. More substantial airflow and ablation studies (helicopter support!)

2. Annual trips to download logger data.

3. Annual laser scanning for detailed analyzing of volumetric changes

4. Monitoring of fumarole activity (temperature& volume)

5. Amassing more data on flanking springs and end-glacial streams
THANK YOU FOR YOUR TIME!
QUESTIONS?