1) Geologic Setting and Background

Lava Beds National Monument (LBNM)
- Part of the Medicine Lake Shield
- Volcano, on the eastern side of the Northern California Cascades
- Primary basalt and basaltic andesite flows within LBNM
- Home to 100’s of lava tubes

Skull Cave
- Easily accessible, well-studied lava tube in LBNM
- Diameter ranges from 10-20m
- Length: 175m
- Overburden: ~5m
- Several co-located geophysical datasets including Ground penetrating radar (GPR), LiDAR

2) Lava tubes

- Formed by overstepping lava channels or inflation and drainage of lava flows
- Have been identified on Earth, the Moon, and Mars
- Lava tubes are important for space exploration and future moon missions:
  - Protecting shelters for astronauts or equipment from the sun’s radiation, dramatic temperature changes, and micrometeoroids
  - Key areas for ice reservoirs or possible habitable environments

Terrestrial lava tubes:
- Diameter: 1-20m
- Length: 100’s of m
- Overburden: <20m

Lunar lava tubes:
- Width: meter scale to up to several km, height: up to 100’s of m
- Length: >10s of km
- Overburden: up to 10s - 100s of m

3) Selected Co-located Geophysics

Co-located GPR and LiDAR can help guide seismic interpretation, GPR can give indications on overburden and width, LiDAR provides cm-scale tube geometry.

Ground Penetrating Radar (GPR)
- Collected by TubeX in 2017 & 2018 and GEODES in 2022
- Fast data collection method, very effective at detecting the ceiling for tubes with a few meters of overburden, waves attenuate quickly with depth
- GPR transmits low to strong reflection from the tube ceiling
- Tube height from GPR: 16.5m, overburden: ~5m

LiDAR Point Cloud of Tube Interior
- Point cloud provides 3D high resolution map of the tube interior
- Tube geometry and location is well constrained based on LiDAR
- Tube height from LiDAR: 15-16m

4) Data Collection

Existing dataset collected in 2017 from A-A’

 Acquisition geometry:
- 5-channel, 160 Hz, geophones
- Overburden: ~5m
- Overlapping sections

Survey parameters:
- CMP fold with survey geometry:
- Same profile location as 2017 survey
- 6 overlapping seismic sections
- 48 channel, 40 Hz geophones
- Geophone spacing 0.5m
- Shot spacing:
  - Lines 1 & 5, 1.5m, shot offset 0.75m
  - Lines 2-4: shots at 3m offset from start and end of line

New dataset from June 2022 from A-A’

 Acquisition geometry:
- CMP fold with survey geometry:
- Same profile location as 2017 survey
- 5-channel, 40 Hz, geophones
- Overburden: ~5m
- Overlapping sections

Survey parameters:
- Same profile location as 2017 survey
- 5-channel, 40 Hz geophones
- Geophone spacing 0.5m
- Shot spacing 1m, zero shot offset
- No stacking, 2 shots per geophone, picked best single shot per location

5) Data Processing

Data processed using University of Calgary’s CREWES MATLAB seismic processing tool:
- Kirchoff Migration (550m/s)
- Bandpass filter: low-pass 60Hz, high-pass 150Hz
- Pick less noisy of two shots at each location (for 2022 survey)

Processing workflow:
- Pick less noisy of two shots at each location for 2022 survey
- Import data
- Assign geometry
- Generate common mid-point (CMP)
- Bandpass 60-150Hz
- Normalizes traces to 1 by maximum amplitude value
- Phase muting - q wave (430Hz), surface wave (430Hz), p wave (700Hz)
- Automatic gain control (AGC)
- Normalize moveout (NMO); used constant velocity (640m/s)
- Stack
- Kirchoff Migration (640m/s)

Output after processing steps:

6) Seismic Profiles

2017 Survey:

 Shot spacing and offset/stacking pattern designed for a refraction survey, quicker data collection than 2022 survey.

No reflections detected Skull Cave

2022 Survey:

 Denser geophone spacing allowing for resolving shallow reflectors, lengthy survey time.

Reflections are present at Skull Cave location

7) Conclusions:

- Seismic reflection is an effective tool for imaging the subsurface to detect lava tubes, especially when used in conjunction with other geophysical methods.
- Seismic reflection is better suited at sites where a deep lava tube is probable - lunar lava tubes can potentially be much deeper than terrestrial lava tubes.
- Site specific geophone spacing and acquisition geometry is important for resolution and consistent CMP fold.
- For use in space exploration efforts data collection process can be streamlined by using multiple geophysics methods (e.g. Magnetics, Gravity, GPR) to target the location and depth of the lava tube with the appropriate method and acquisition parameters.

Next steps:

- Further processing:
  - Refined velocity analysis and migration
  - Assess polarity of cave reflectors
  - Apply LiDAR topography
  - Synchronize first arrival times

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References: