Underground Resource Prospecting Using a Semi-Autonomous, Multi-Instrumented Robot

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Agenda

- Introduction
- Target Resources and Repositories
- GeoBot
  - LiDAR
  - Hyperspectral
- Conclusions

Introduction

In-Situ Resource Utilization (ISRU) is the identification, acquisition, and utilization of local resources

The first component in creating a complete ISRU capability comprises:

1. Destination Reconnaissance
2. Prospecting
3. Mapping

Target Resources

Resources that are targets for ISRU include:

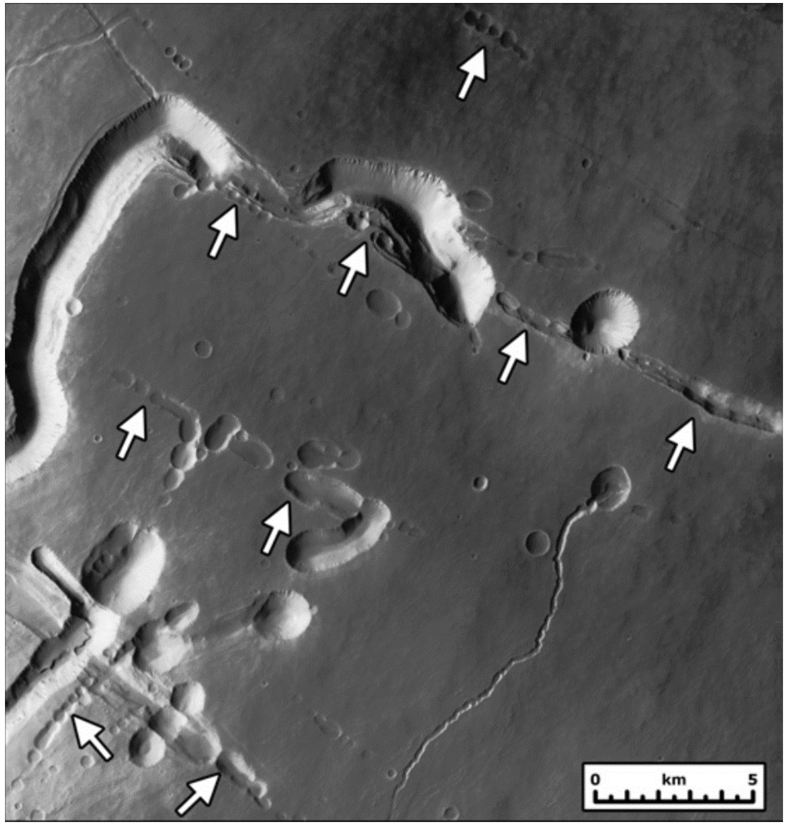
1. Water
2. Phyllosilicates –Smectite Family of Clays
   - Montmorillonite
   - Nontronite
3. Sulfates
   - Gypsum
4. Methane Hydrates ?
5. Base Metals ?

Resource Repositories

In addition to utilizing regolith, resources that are targets for ISRU may be located in:

1. Caves
   a. Lave Tubes
   b. Dissolution
   c. Tectonic
2. Shaded craters

Caves are also of interest for habitation and in the search for life



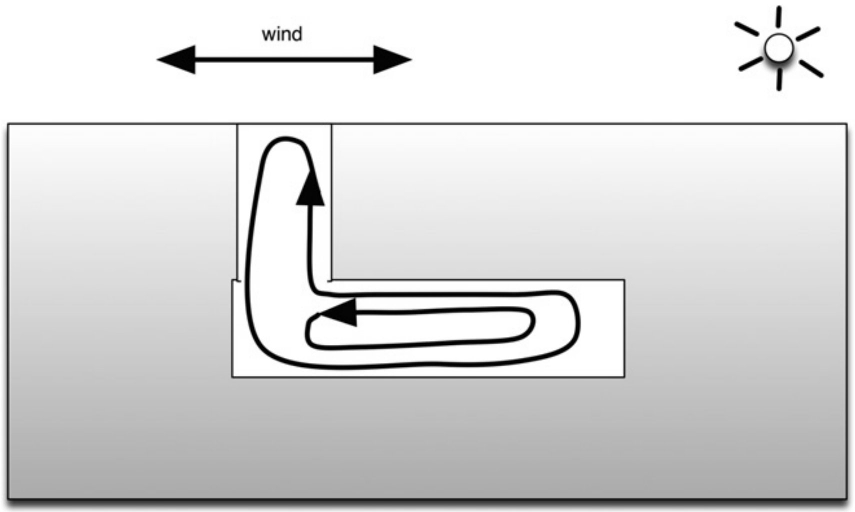
Pitted Martian Crater Chains

Williams, McKay, Toon, and Head (2010)

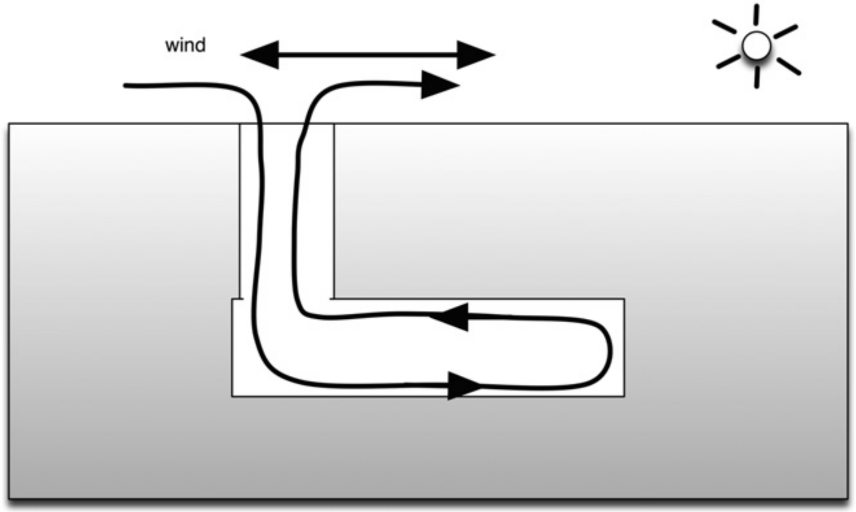
Cold Sinks

Williams, McKay, Toon, and Head, (2010) proposed that
ice caves may be stable on Mars:

Caves act as cold sinks on Earth and may also act as cold sinks on Mars



Summer circulation pattern showing no outside air exchange.

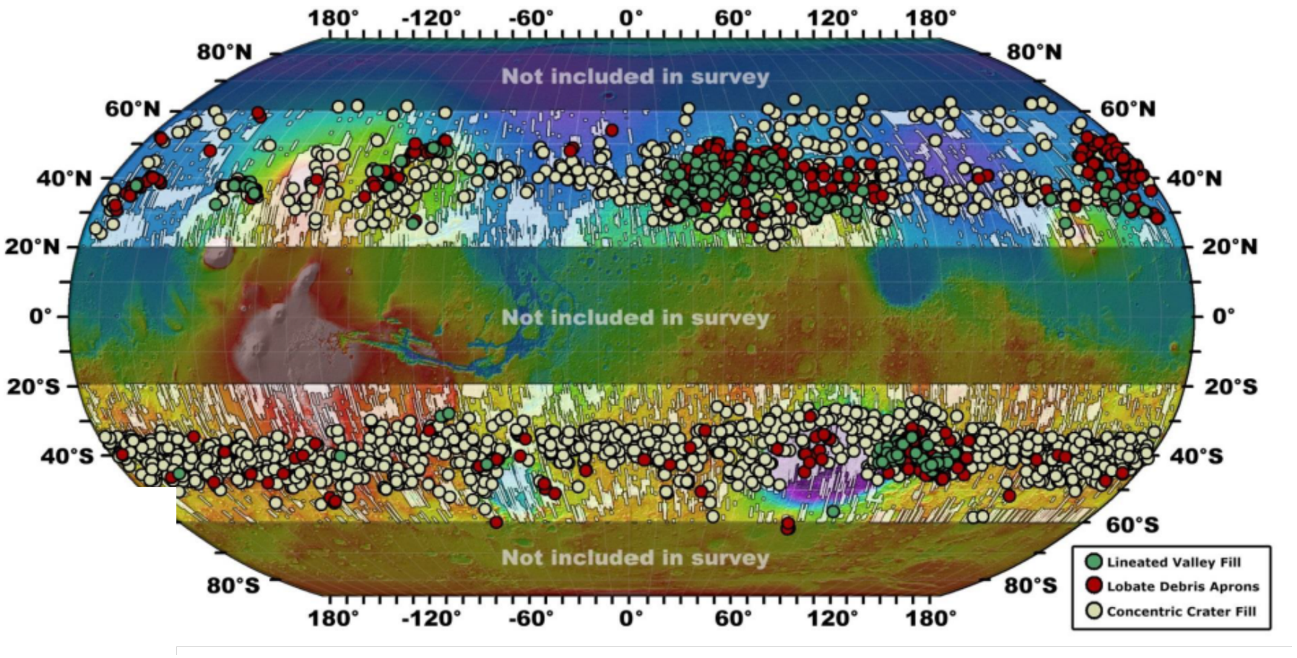


Winter circulation pattern showing active exchange with outside air.

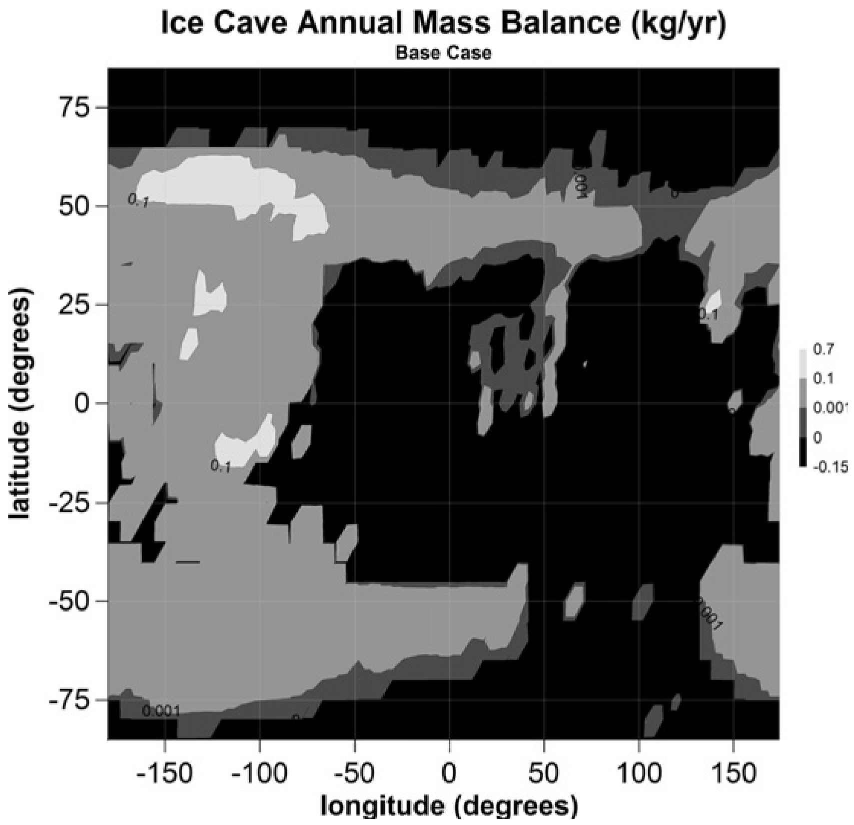
Williams, McKay, Toon, & Head, 2010

Ice Cave Stability

Light areas indicate regions on Mars where ice caves are stable or would grow



Glacial Features



Ice Cave Stability Regions

Abbud-Madrid et al. (2016)

Williams, McKay, Toon, & Head, 2010

Phyllosilicates – Clay/ Mud

Terrestrial Lava tube containing dried mud- clay?

As Mars became drier, lava tubes would most likely remain moist for some time after the surface

Additional time in a moist environment would allow for more weathering of basalts into clays

Methane Hydrates

Pellenbarg and Max (2003) proposed regions where methane hydrates would be stable.

Given the current 200 K average surface temperature and atmospheric pressure of Mars, hydrates are stable at pressures greater than ~ 140 kPa.

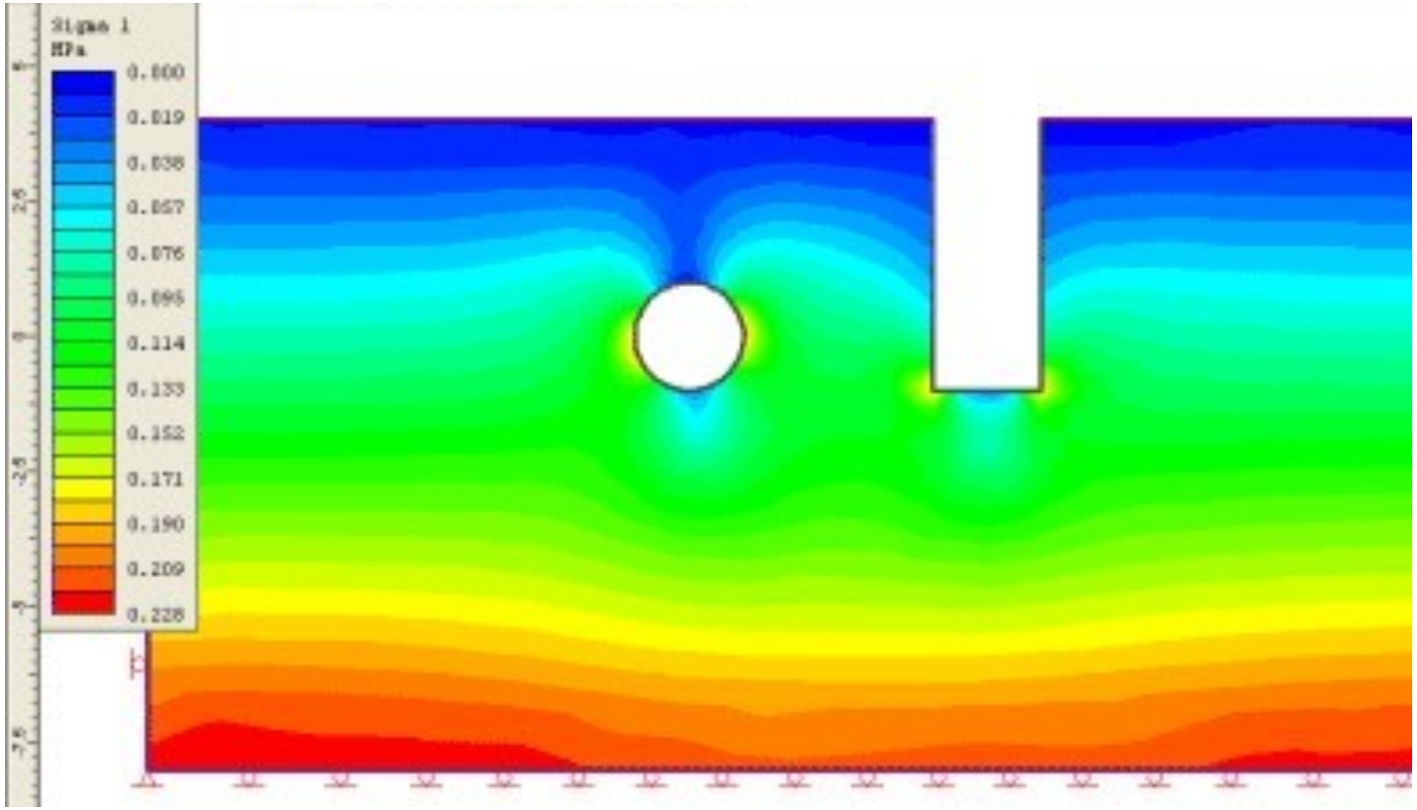
This corresponds to lithostatic pressure at a depth of approximately 15 m.

The hydrate stability zone is likely to be ~ 3 km thick at the equator and ~ 8 km thick at the poles

Methane Hydrates

Lava tubes could be used to access the hydrate stability zone

Numerical simulation of lava tube stress field



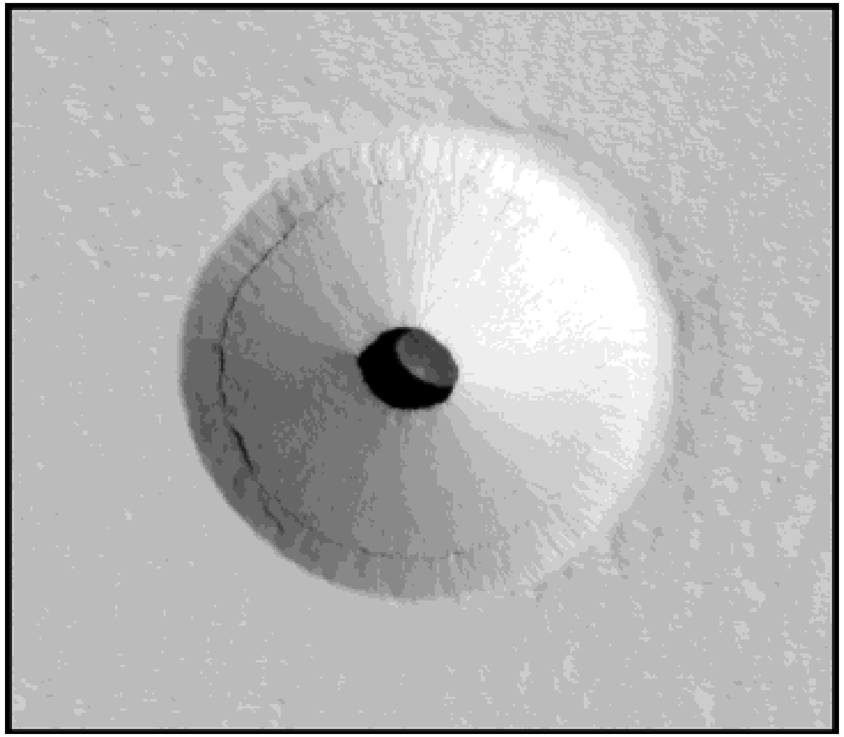
Caves –prime prospecting targets

- May contain:
  - Ice
  - Clays
- May provide access to the hydrate stability zone
- May provide habitation
- May contain life

Challenges to Prospecting in Caves

Challenges to prospecting in support of ISRU include:

1. Access
2. Exploration/ mobility
3. Modeling
4. Communications



Martian Lava Tube Skylight at the bottom of an impact crater

Whittaker (2011)

A semi-autonomous system

We propose a multi-instrumented system to address the challenge of modeling communications degraded environments such as extra-terrestrial caves

System would comprise:

1. Mobility Platform
2. LiDAR
3. Hyperspectral Sensor

Lave Tube Cave

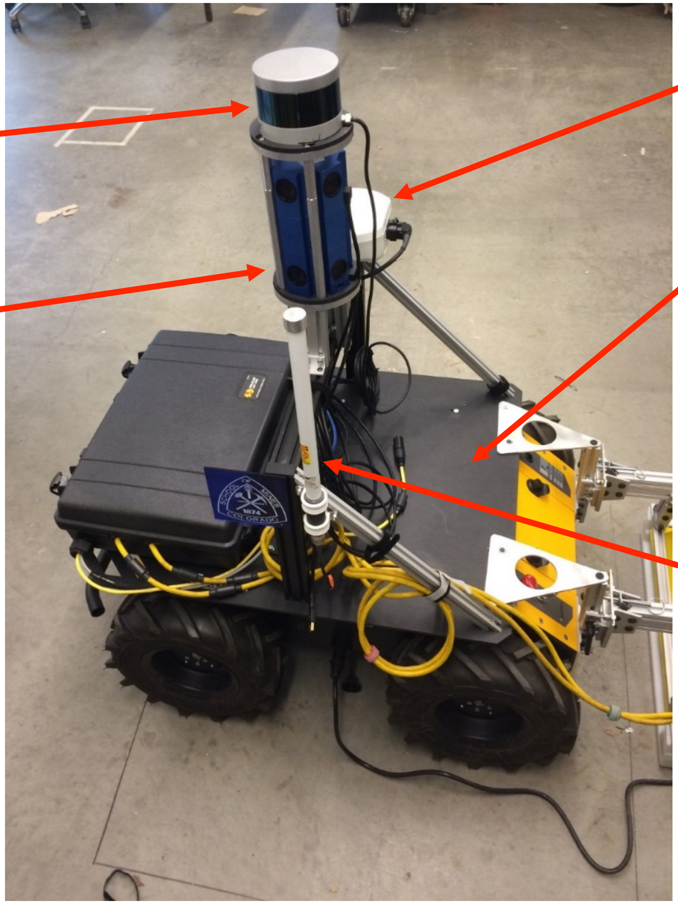
Whittaker (2011)

CSM GeoBot

Velodyne Puck® Scanning Laser Rangefinder

Occam Vision Group Omni Stereo, a 360^0 video camera

FUTURE INSTRUMENT- Hyperspectral Imager



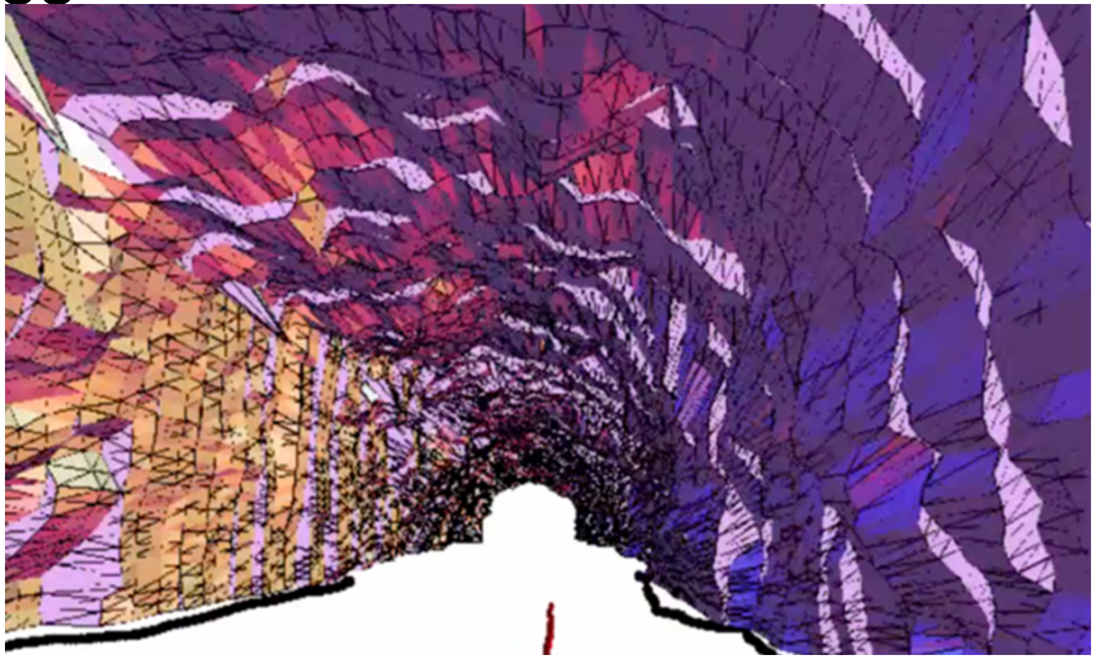
GPS

ClearPath Robotics® Husky A200 Platform

Wireless 802.11g antenna

LiDAR Point Cloud Data

- Captures digital point cloud data at 300,000 points/sec
- Data are processed to create a digital map of void with triangle mesh techniques



Digital map of CSM’s Edgar Experimental Mine

LiDAR - Planar Discontinuities

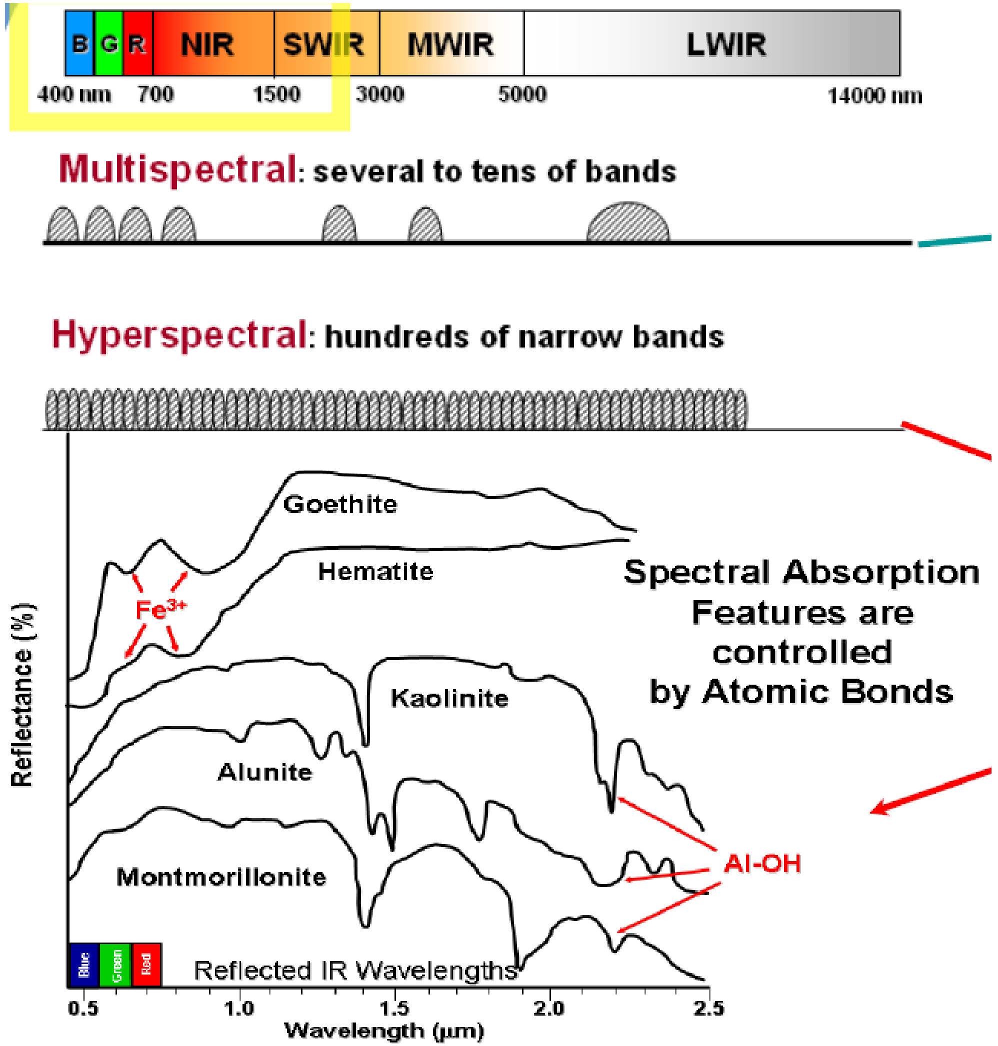
Planar Discontinuities

Underground gold mine with planar discontinuities.

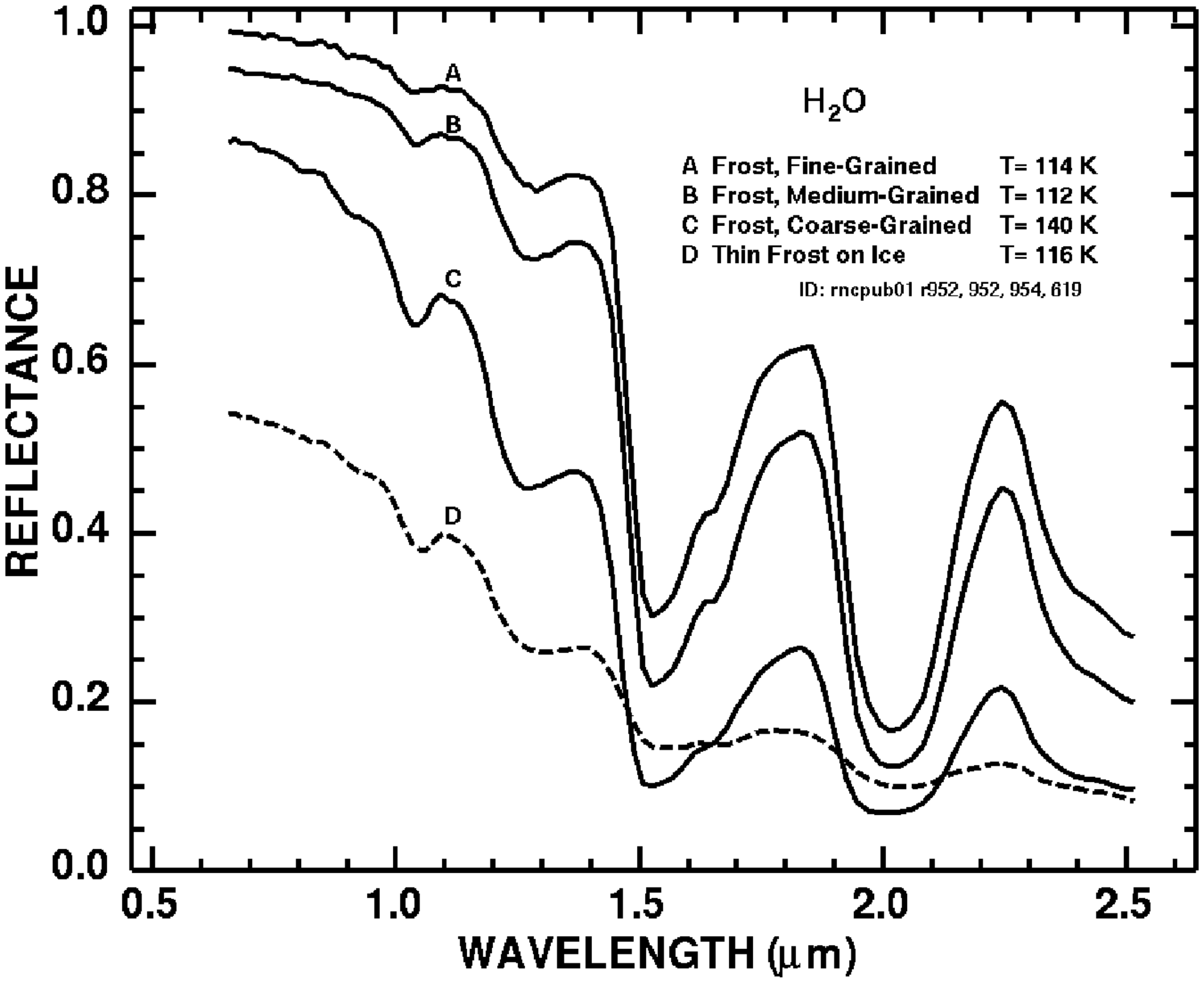
Orientation, spacing, and persistence are input parameters in rockmass classification systems.

Hyperspectral Sensor

- Response in hundreds of bands from ~400- 2500 nm

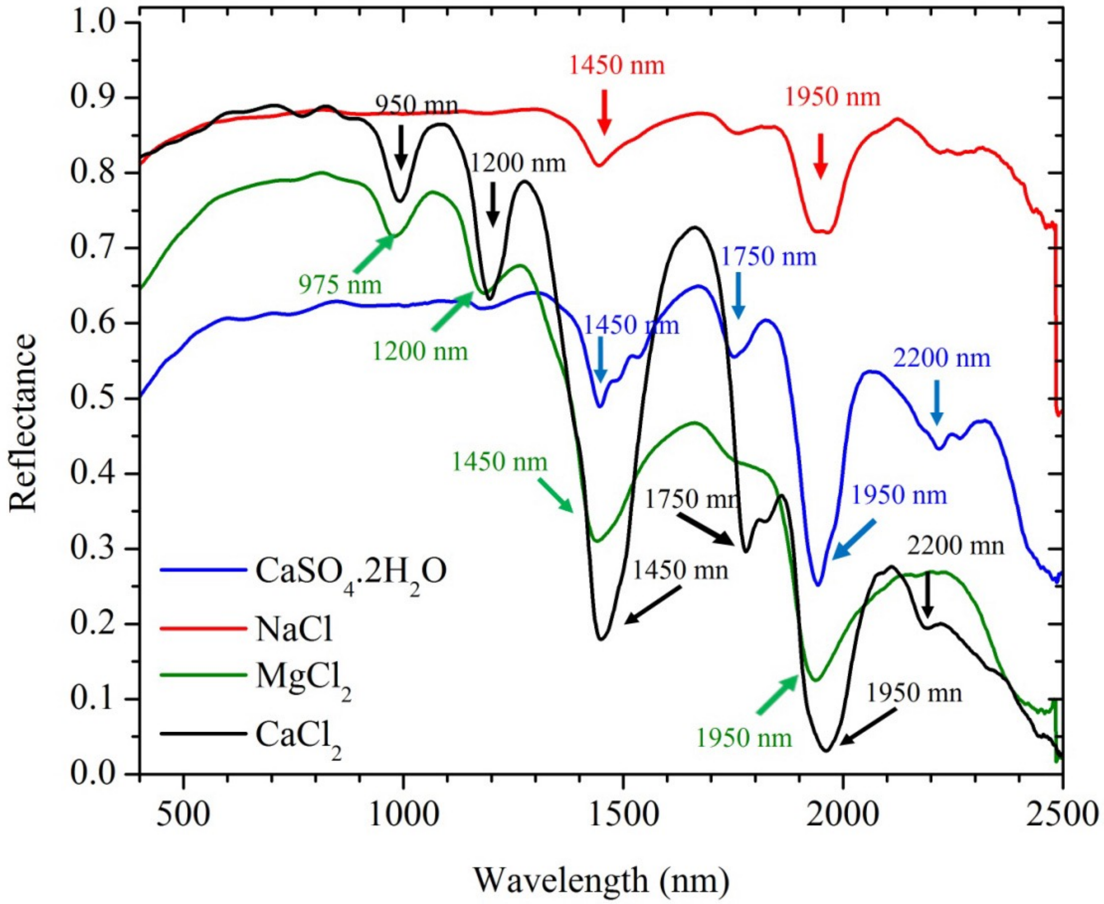


Hyperspectral Imaging- Ice



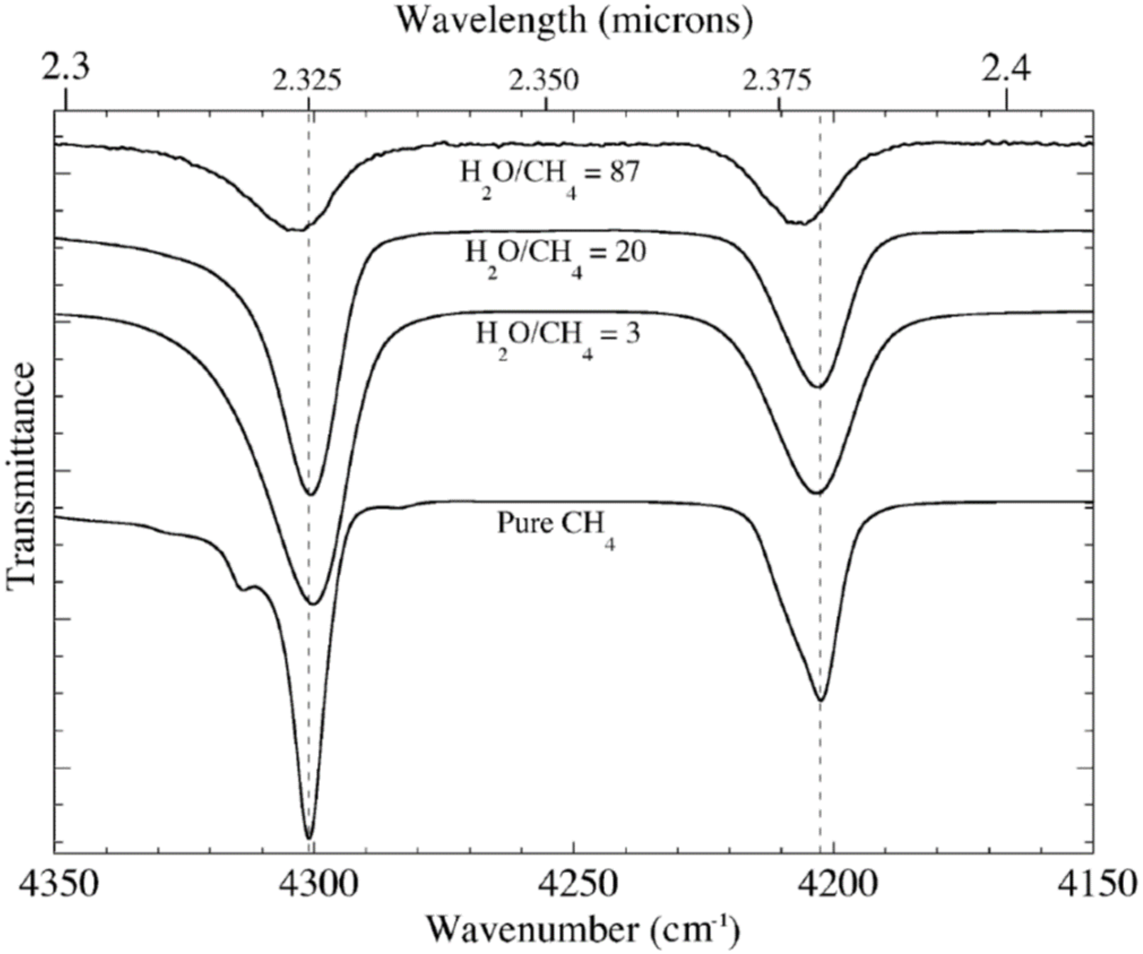
Clark, Swayze, Carlson, Grundy, & Noll, 2014

Hyperspectral Imaging- Gypsum



Moreira, dos Santos Teixeira, and Galvão (2014)

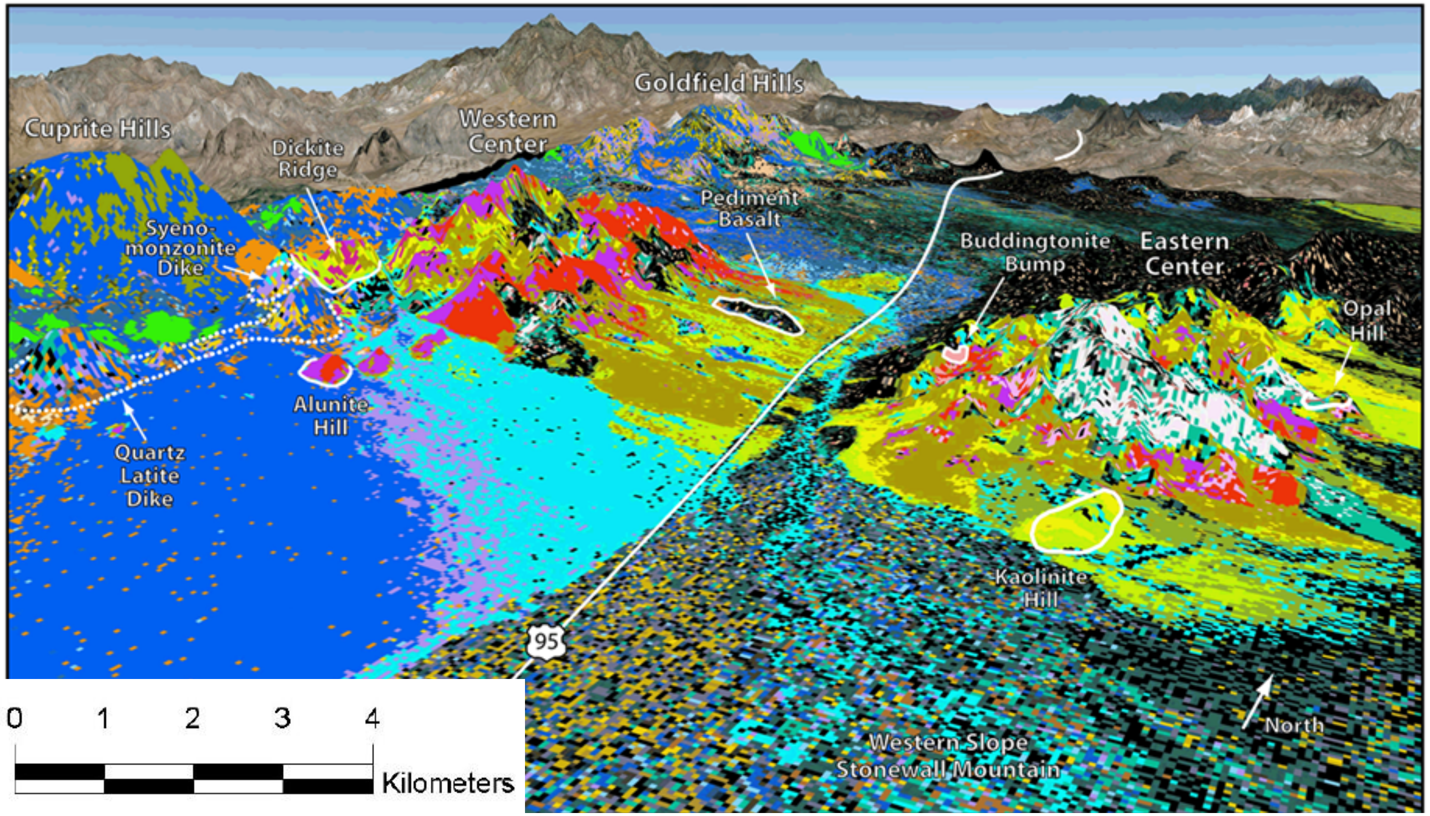
Hyperspectral Imaging-H_2O-CH_4 – at 15 K



Bernstein, Cruikshank, and Sandford (2006)

Aerial Geologic Mapping - Hyperspectral

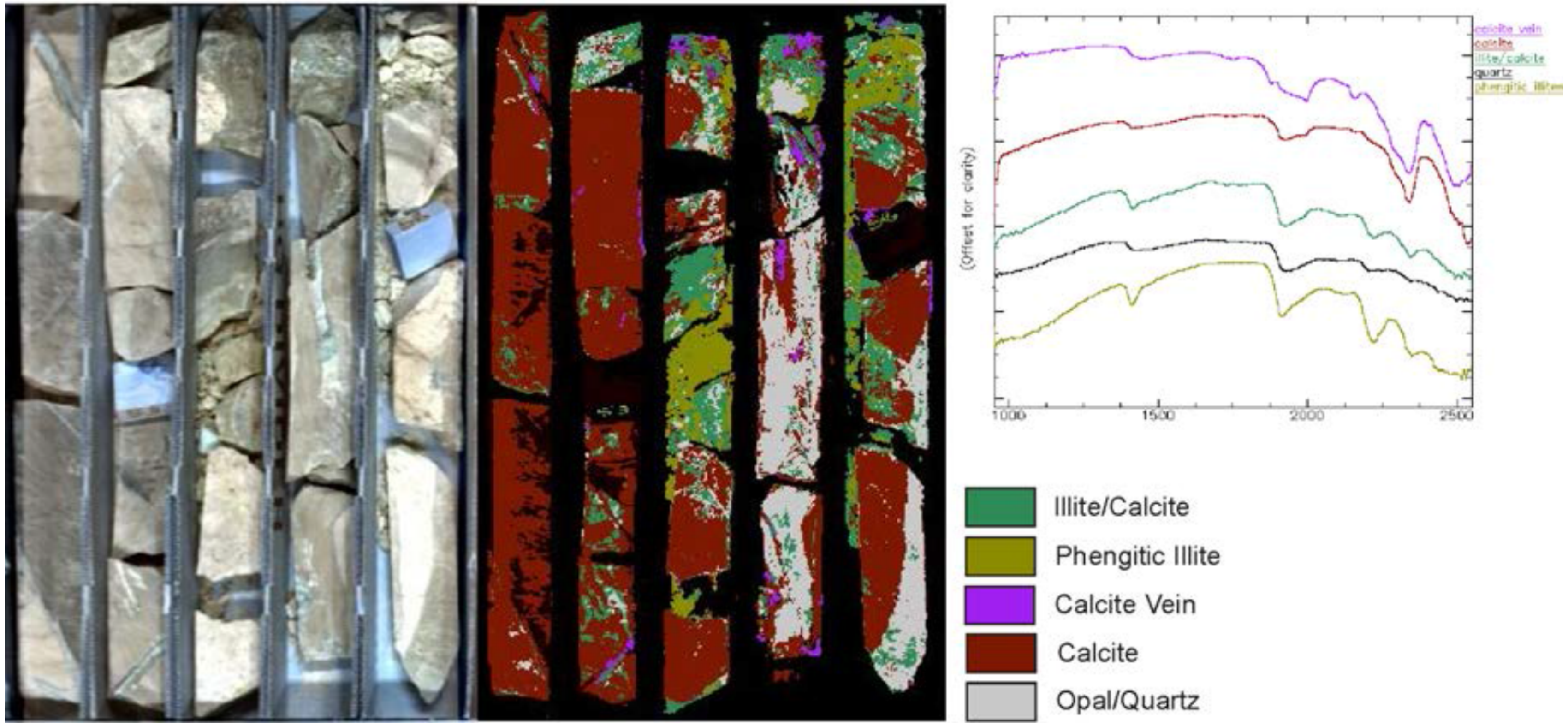
- Airborne hyperspectral maps are able to differentiate alteration assemblages which are used in exploration.



Swayze et al. (2014)

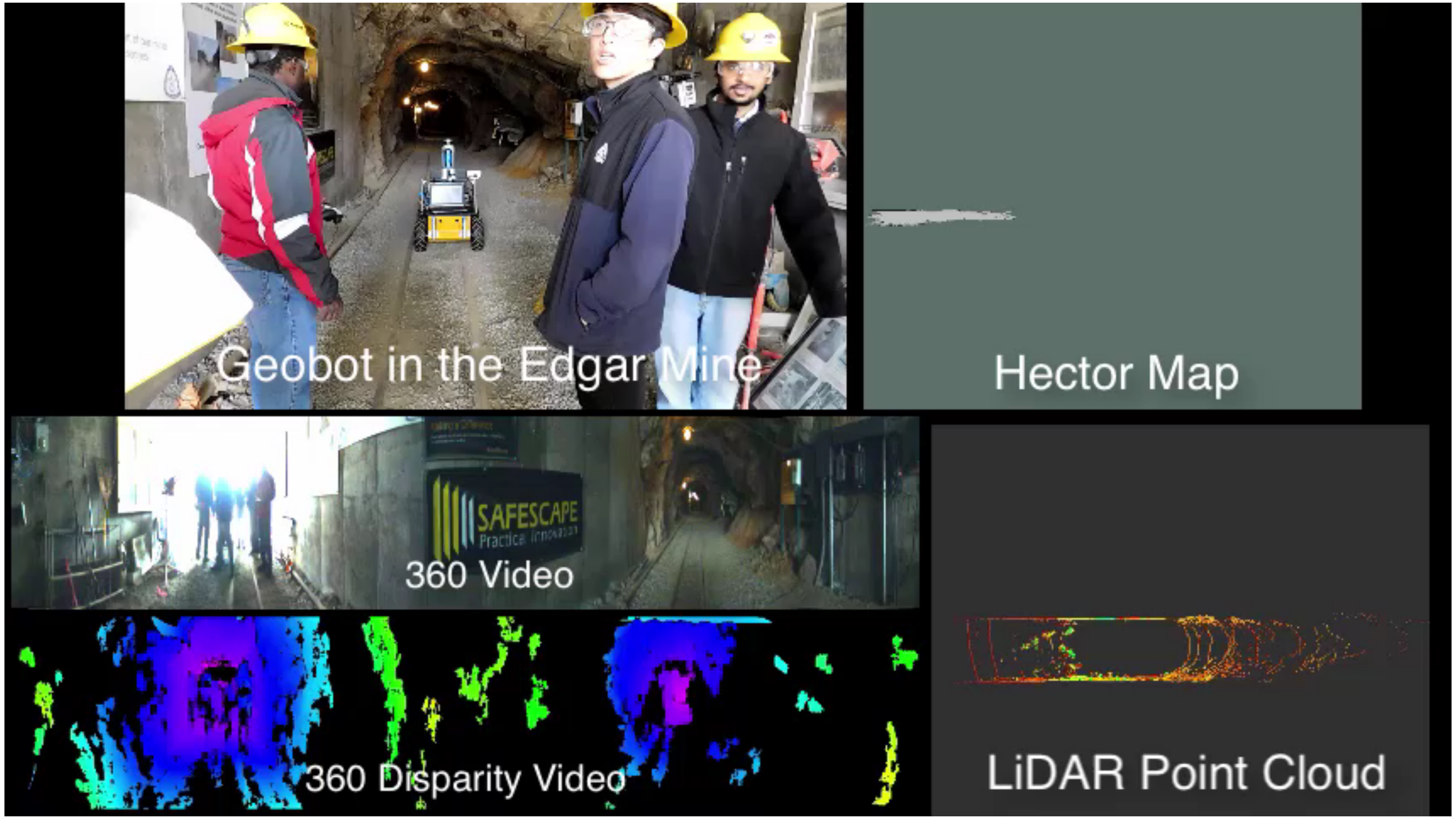
Hand Sample Geological Mapping - Hyperspectral

- Hyperspectral mapping of mineralogy at drill core scale.



CSM Edgar Experimental Mine

GeoBot – Data Collect in the Edgar Mine



Digital Map of Edgar Mine

Work Flow

- Robot inserted into lava tube
- Robot receives command line instructions
- Robot self navigates lava tube using SLAM and collecting LiDAR and hyperspectral data
- Robot returns to starting point, recharges and uploads data
- Data are processed in order to create an interactive digital map of lava tube

Conclusions

- A multi-instrumented robot will be able to navigate and characterize communication degraded environments such as lava tubes and other voids.
  - LiDAR will provide:
    - 1. Digital point cloud of the cave
    - 2. Self-navigation capabilities through SLAM
    - 3. Collision avoidance
  - Hyperspectral will provide
    - 1. Mineralogy maps
    - 2. Ice maps
    - 3. Methane hydrate maps
  - LiDAR and Hyperspectral data will be fused to create an interactive 3D map of the geometry and composition of the void.

Questions?

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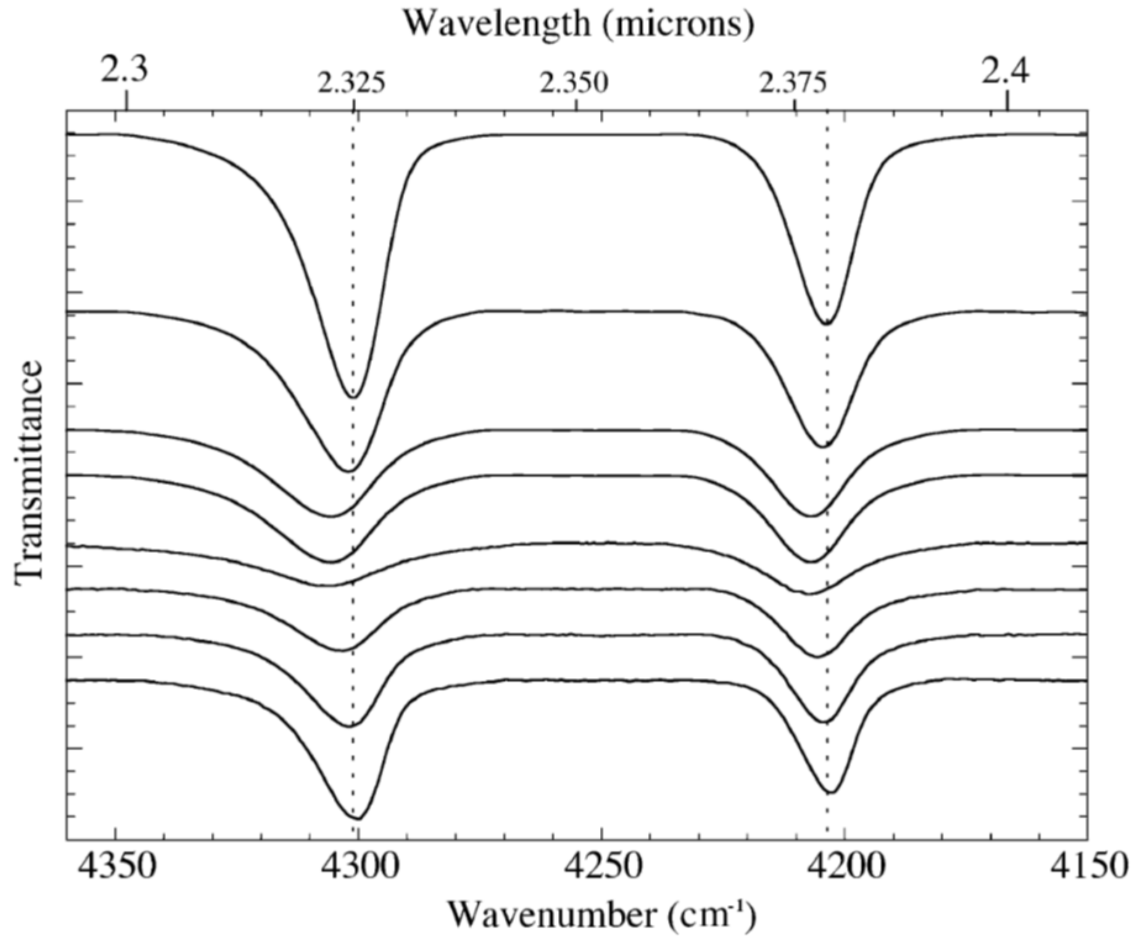
Hyperspectral Imaging-H_2O-CH_4 -

Temperature Dependence



H_20/CH_4 =20

15 K

150 K

30 K

Bernstein, Cruikshank, and Sandford (2006)

Ice Cave

Caves act as cold sinks on Earth and may also act as cold sinks on Mars

Scarisoara Ice Cave Romania