
# INTELLIGENT ZIPLINE GREEN RECONNAISSANCE FOR LAVA TUBE SKYLIGHTS

Space Resources Roundtable
Planetary & Terrestrial Mining Sciences Symposium

Colorado School of Mines
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Exploration Architecture Corporation

# A Space Architecture Perspective

XArc provides design and development services for Architectural Systems in the aerospace domains of:

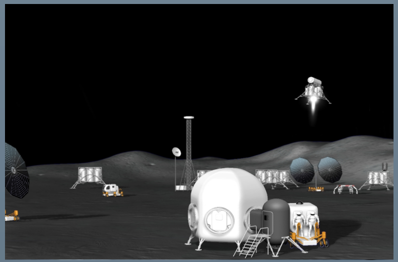
- *Orbital architecture*
- *Planetary surface architecture*
- *Earth-based space facilities architecture*

- Concept Design and Analysis
- Mission Planning & Integration
- Habitability Subsystems Design
- Human Factors Analysis and Engineering
- Operations & Utilization Concept of Operations
- Surface System Site Planning
- Analog Mission Development and Test

**Commercial Applications of Space Architecture for Human Spaceflight**

Aerospace Facilities Architecture
*Sub-Orbital Commercial Spaceport*

Orbital Architecture
*Private Space Station*



Planetary Surface Architecture
*Lunar Outpost*

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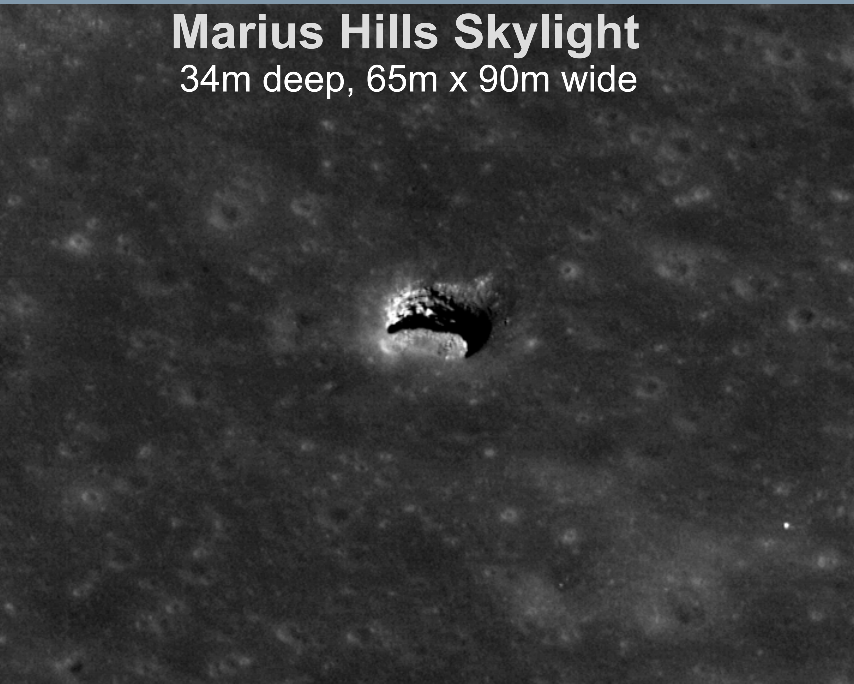
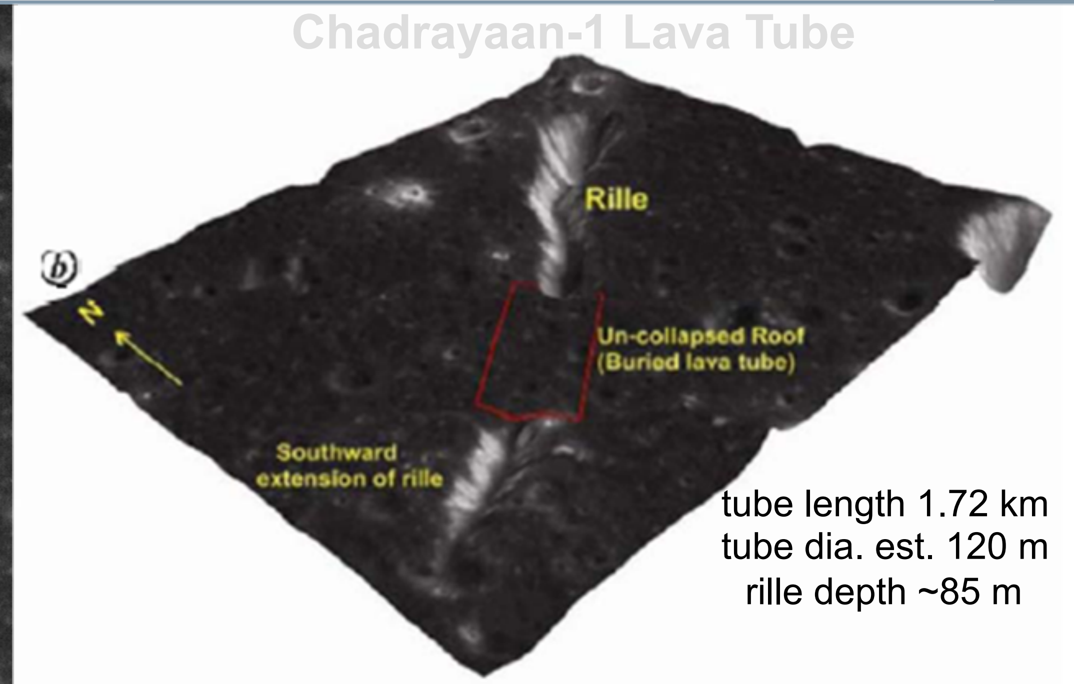
# Lunar Skylights, Pits and Tubes

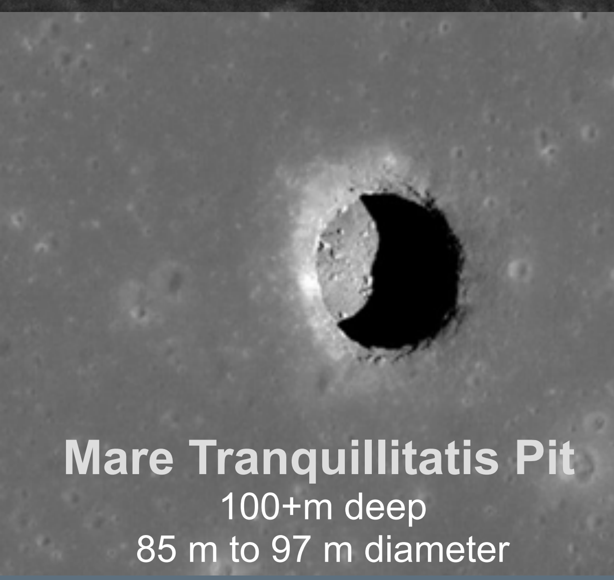


**Marius Hills Skylight**
34m deep, 65m x 90m wide

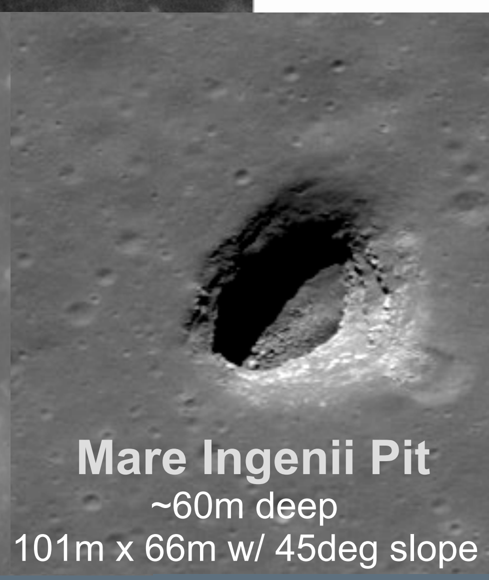



**Chadrayaan-1 Lava Tube**

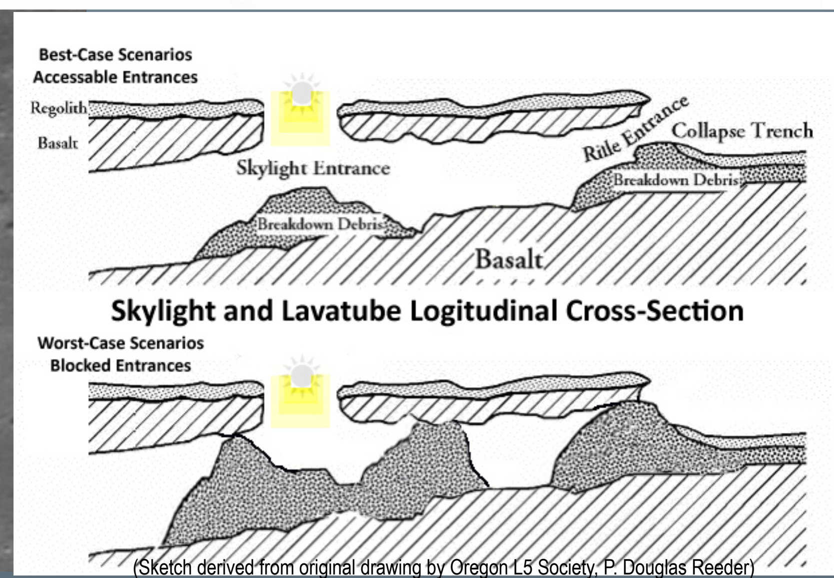
tube length 1.72 km
tube dia. est. 120 m
rille depth ~85 m



**Mare Tranquillitatis Pit**
100+m deep
85 m to 97 m diameter



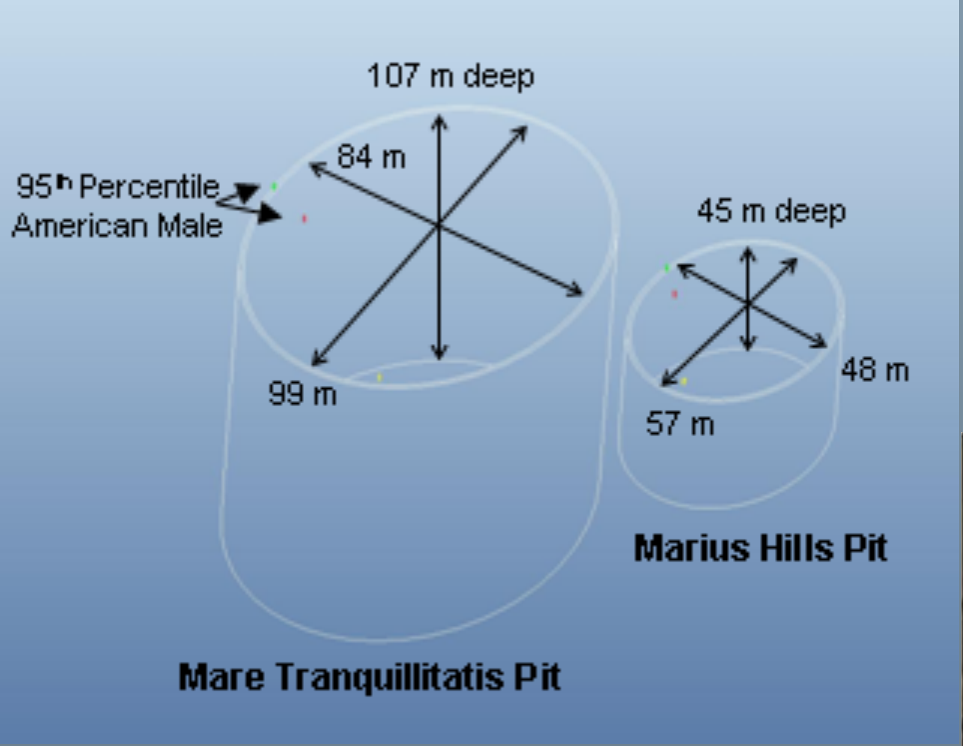
**Mare Ingenii Pit**
~60m deep
101m x 66m w/ 45deg slope




**Skylight and Lavatube Logitudinal Cross-Section**

(Sketch derived from original drawing by Oregon L5 Society, P. Douglas Reeder)

# Volume Comparison




## Compared to Largest Discovered Cave on Earth

Photograph by Carsten Peter

## Pit Dimensions Comparison

# Accessibility Challenges

JPL's AXEL Robot

**Human and robotic accessibility to planetary cave approaches is problematic and will require novel ingress/egress technology solutions**

# Why Explore These Features


**Scientific Value**

- Geologic processes of ancient lunar basaltic lava flows
- Mapping distribution & age of bedrock at the surface
- Composition & mineralogy of domains in Moon's mantle

# Why Explore These Features


**Habitability Value**

- Large volumes/ thick roofs
- Radiation Protection
- Micro-meteorite Protection
- Benign Temperature
- Lunar Dust Protection
- Use of Lite-weight Construction Materials

# Why Explore These Features

**Engineering Challenges**
- Surveying
- Massive engineering challenge for clearing entrances and debris fields
- Explosive shape charges
- Heavy equipment access

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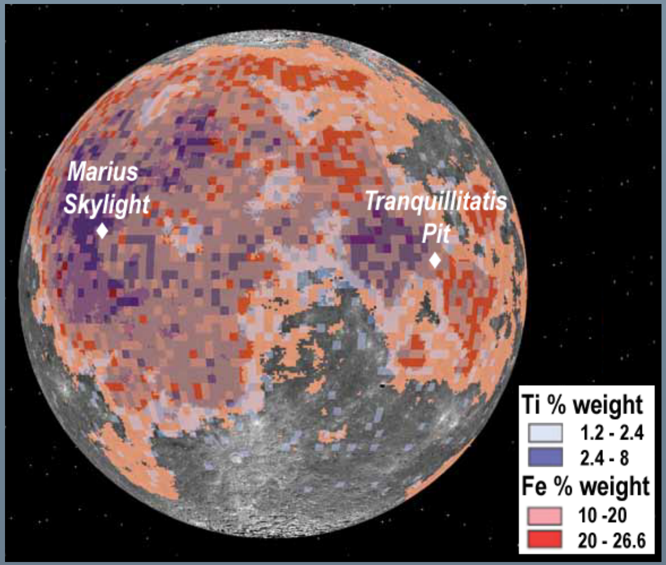
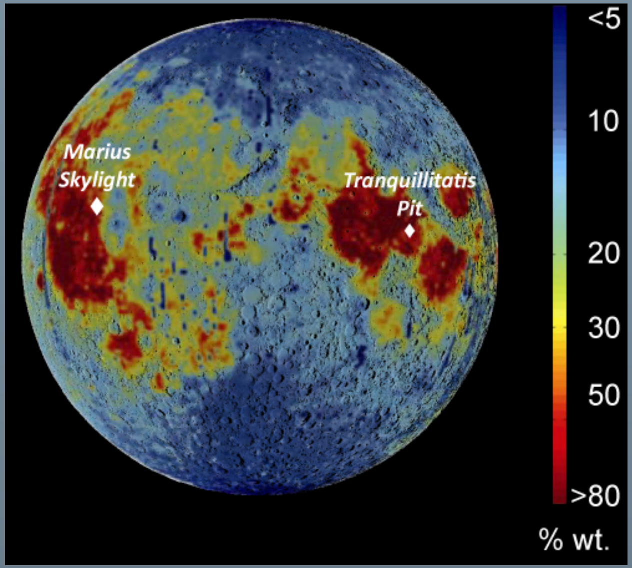
**Economic Value**
- Mining and industrial operations
- Settlement

# Lunar Resources at Pit Locations

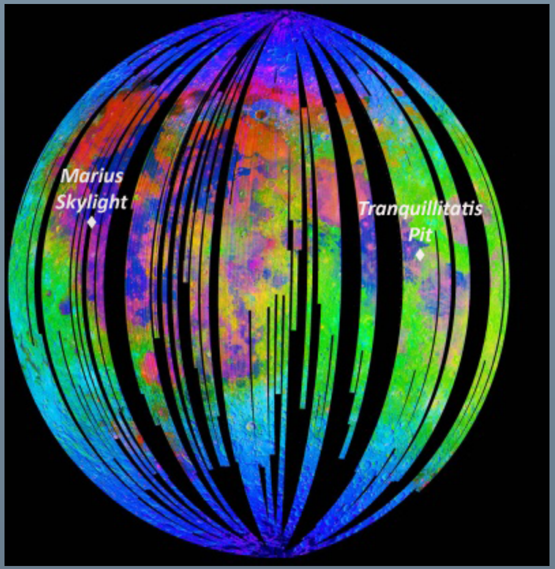
**Location of Marius Hill Skylight and Tranquillitatis Pit Relative to Lunar Mineralogical Resources**




**Titanium**

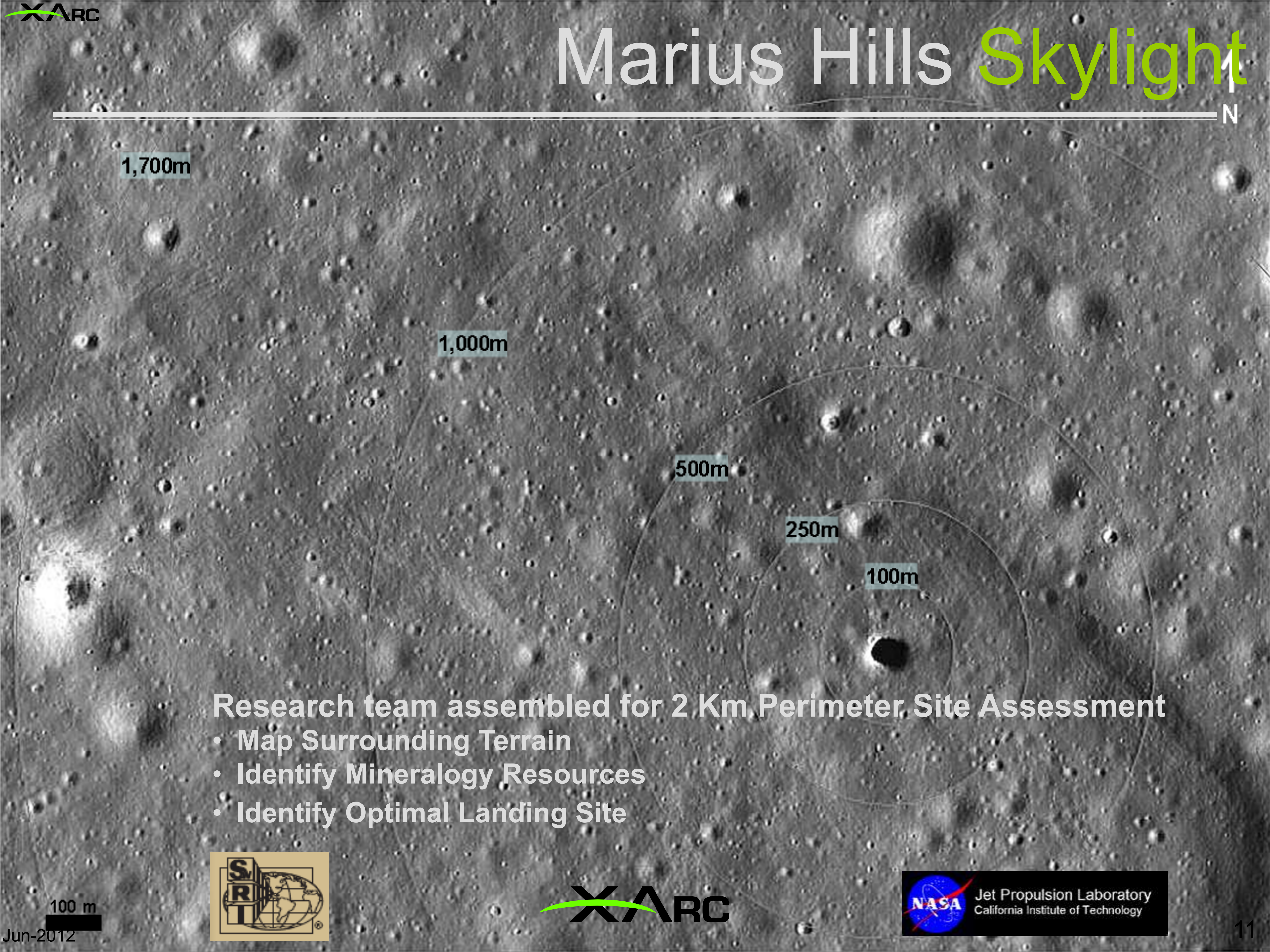



**$^{3}$He**




**Water Extraction**

# Marius Hills Skylight

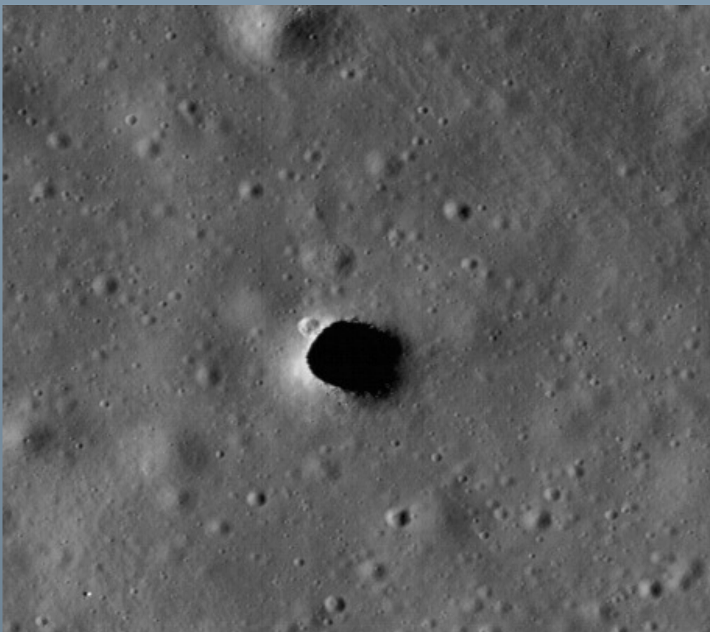


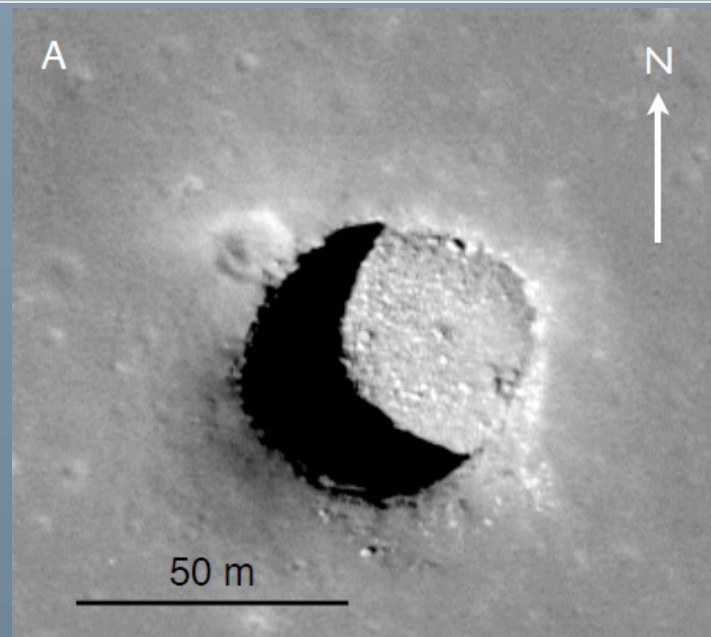

**Research team assembled for 2 Km Perimeter Site Assessment**

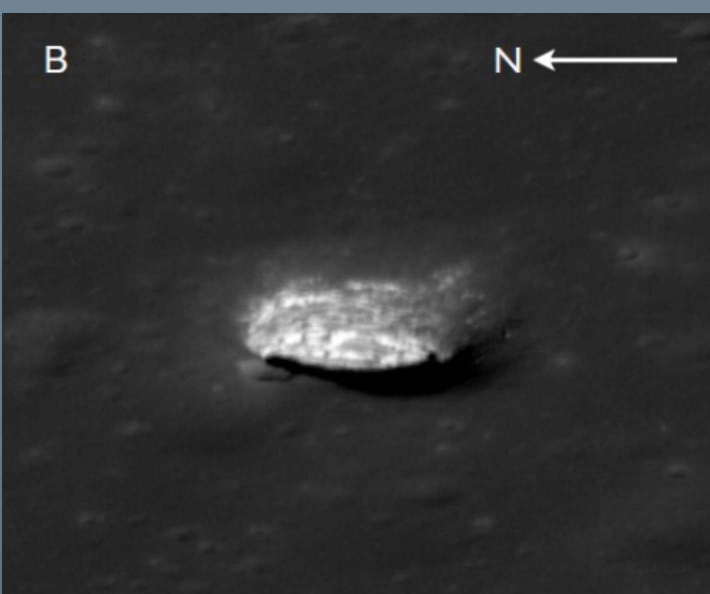
- **Map Surrounding Terrain**
- **Identify Mineralogy Resources**
- **Identify Optimal Landing Site**

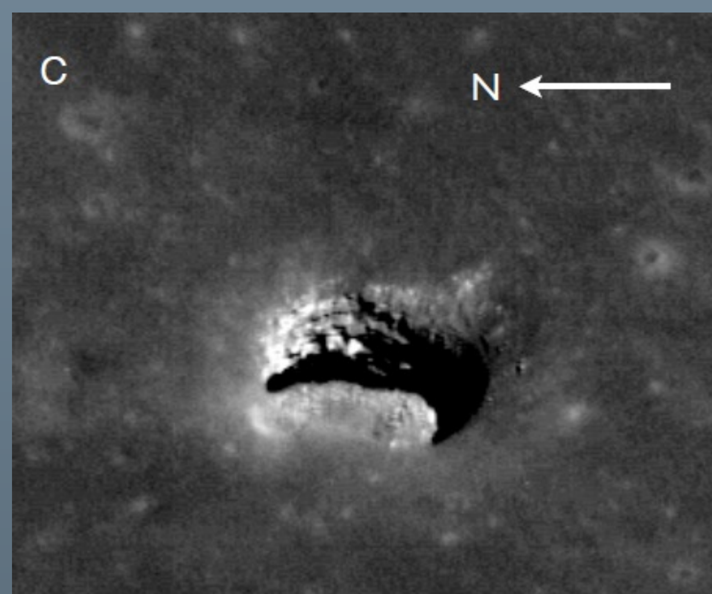
Jet Propulsion Laboratory
California Institute of Technology

# Reconnaissance Planning






(A) Near-nadir showing pit outline and rubble strewn floor (incidence angle 25°)

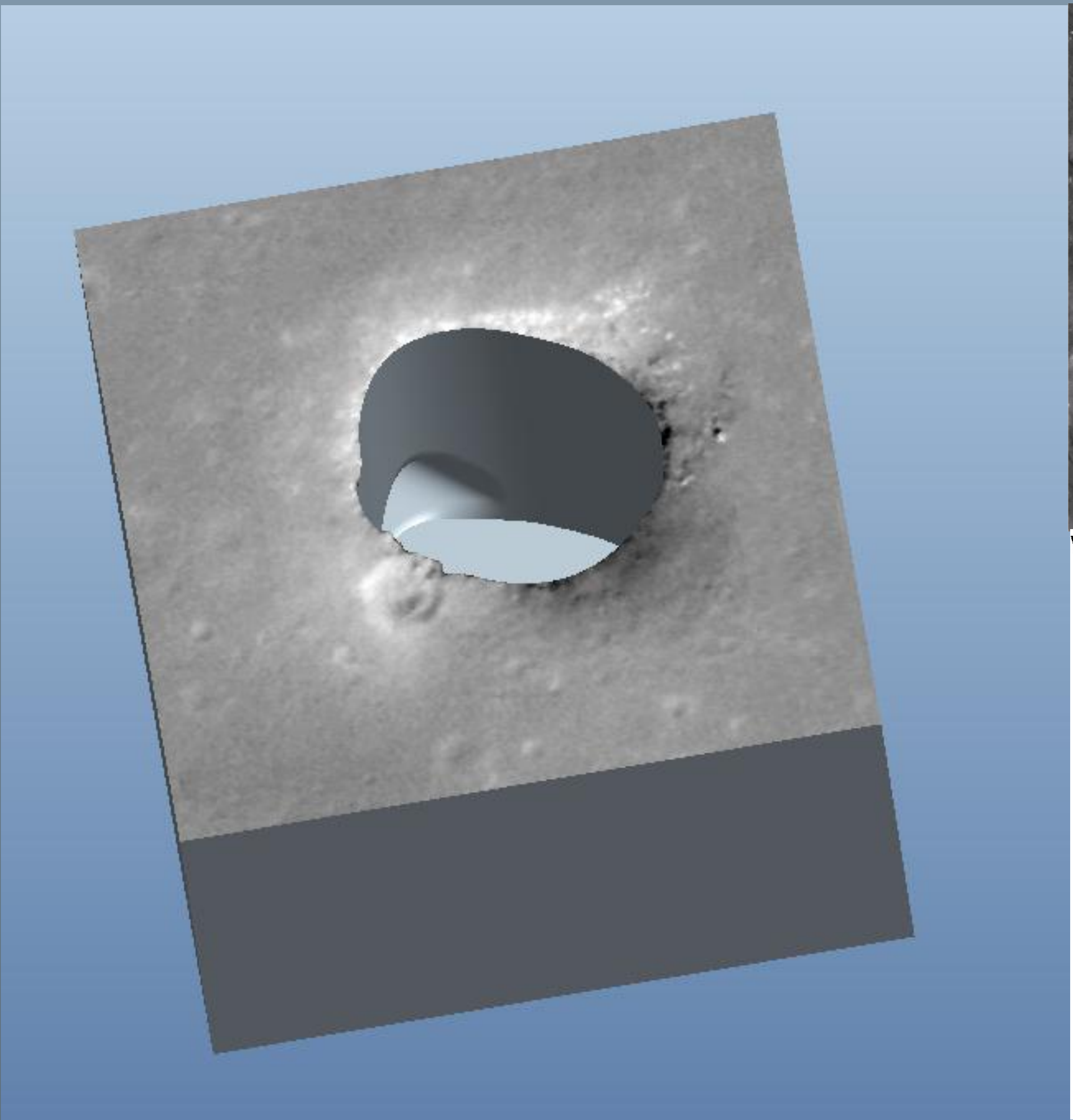
(B) Oblique image 60° incidence angle showing layering in eastern pit wall

(C) Pit imaged with a 34° incidence angle showing ~12 m of illuminated floor beneath cavern ceiling

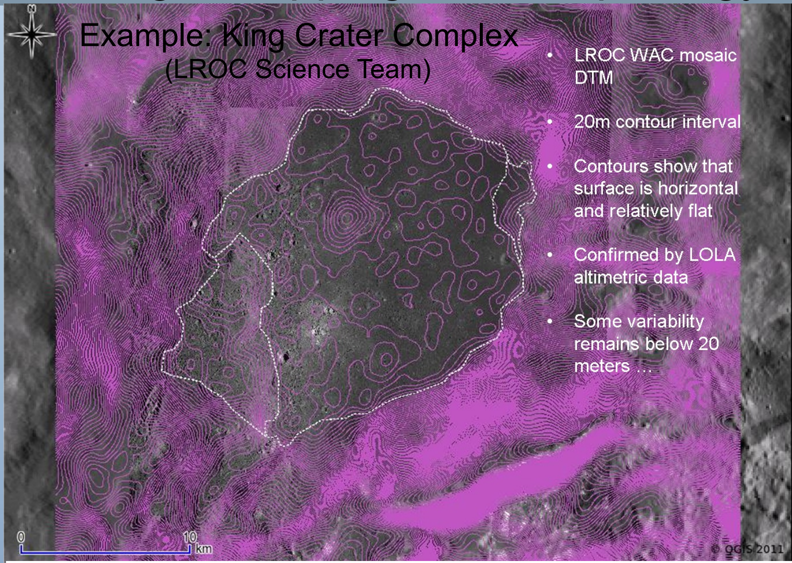
Images from LROC Narrow Angle Camera

# Marius Hills Skylight Modeling

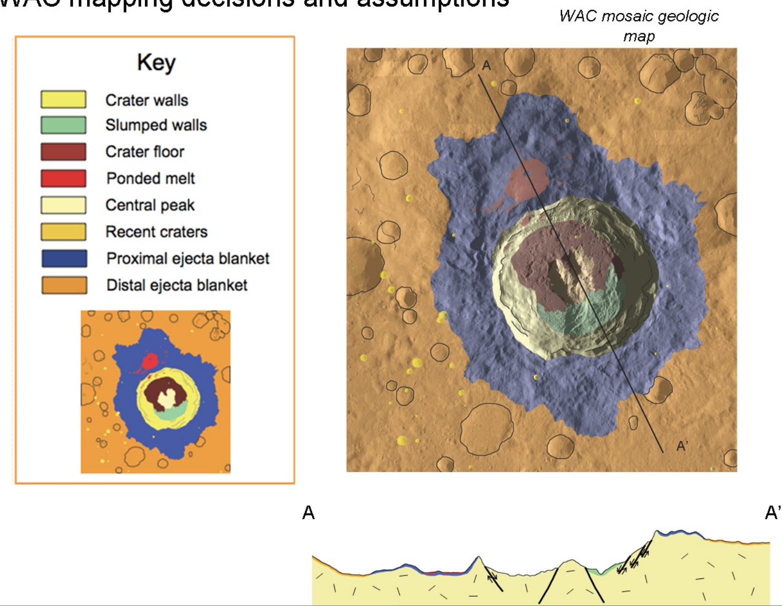
## 3-D Modeling



## Geologic Mapping and Morphology




WAC mapping decisions and assumptions



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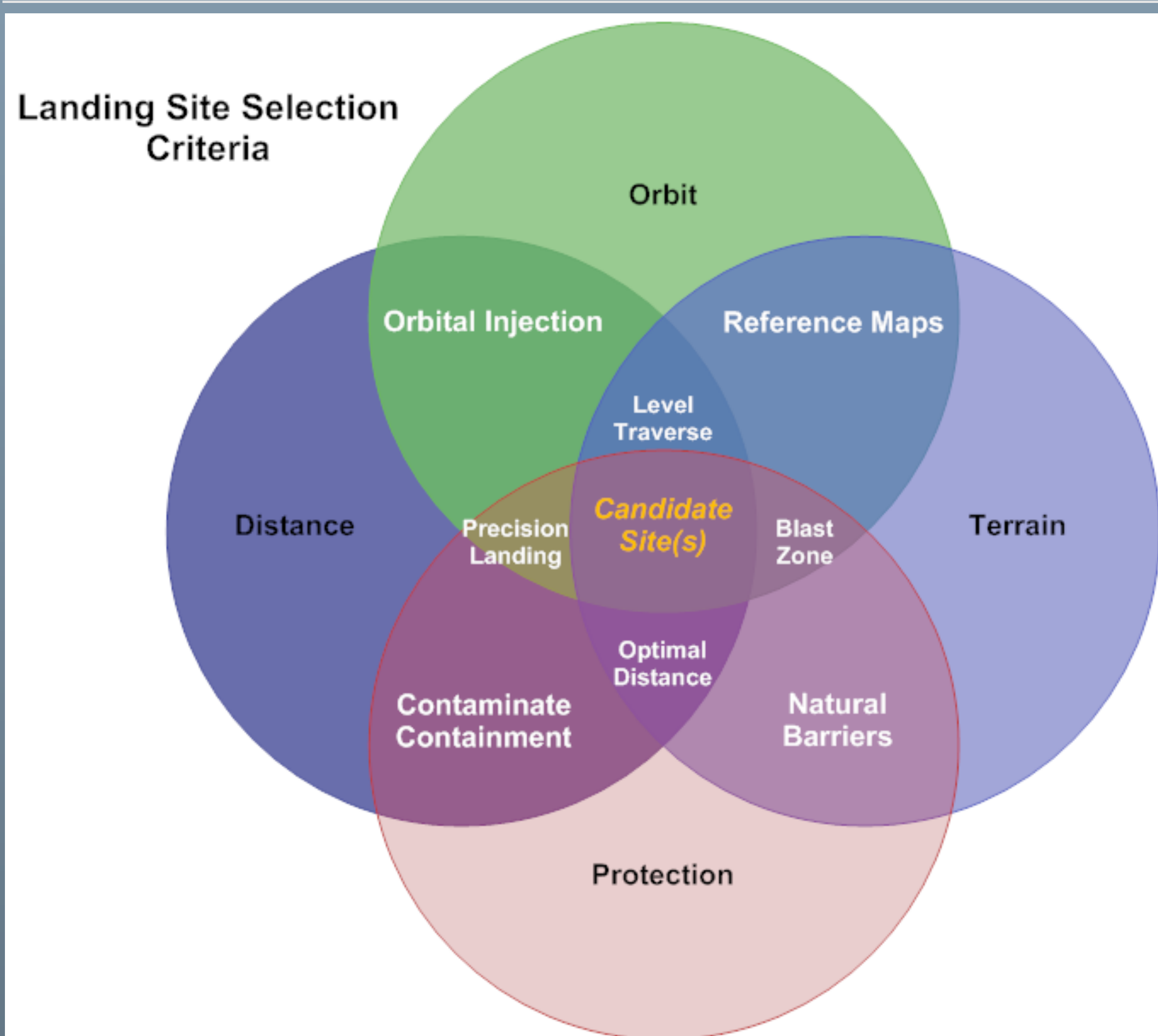
# Green Reconnaissance



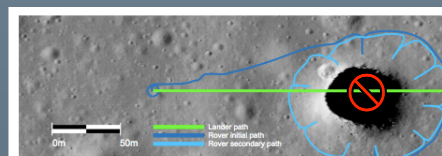

**Interrelationship of landing zone selection criteria for planetary protection of Marius Hills skylight**

## Green Approach

Employs criteria to minimize site contamination from lunar lander blast ejecta and fuel plume exhaust

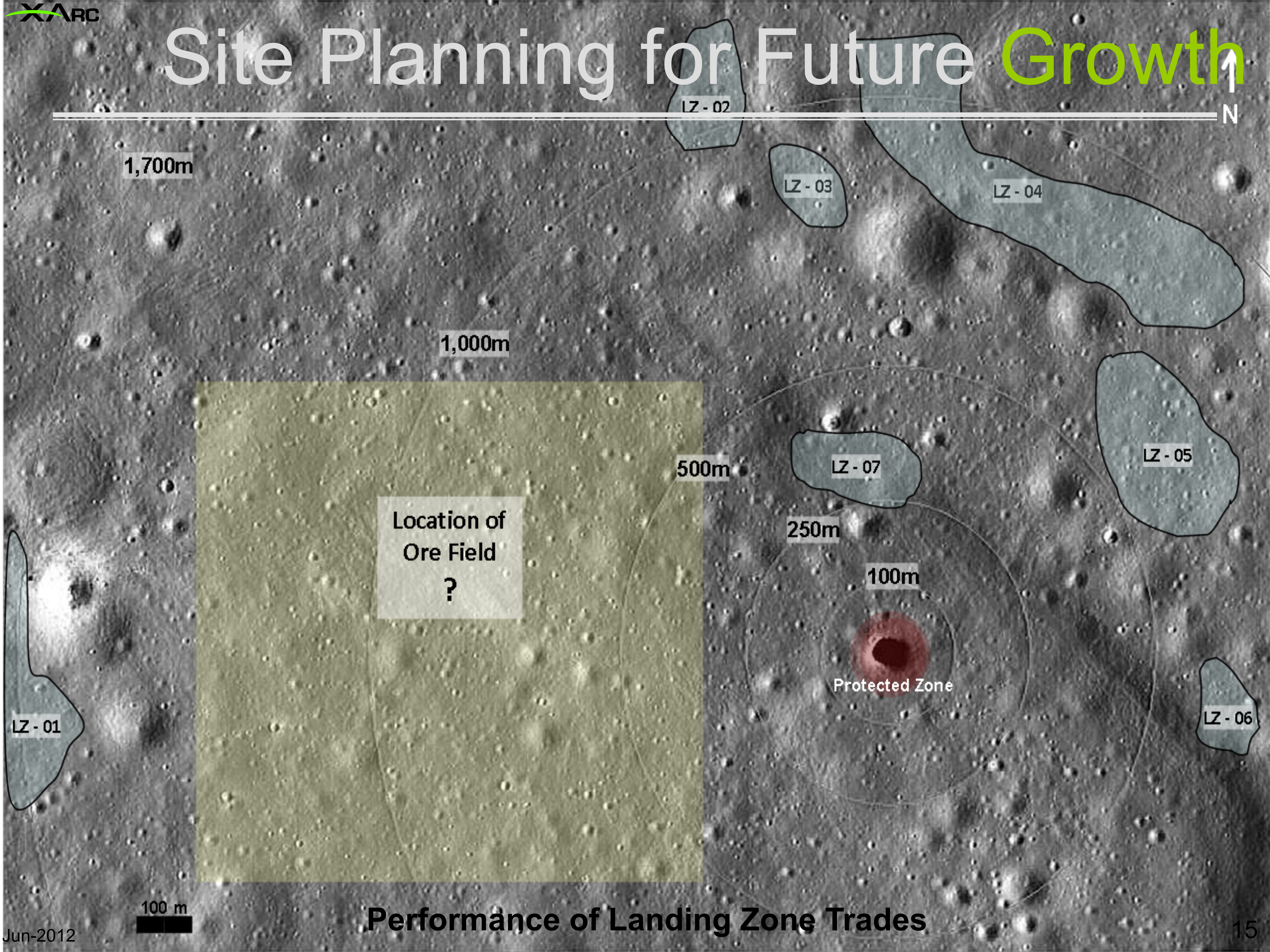
- Subsurface caverns preserve unique geologic environments with access to fresh, dust free outcrops of volcanic rock.
- In-situ science investigations of the site in its pristine state would be paramount for first contact exploration

## Non-green Approach




**Bad idea - lander flight path trajectory over skylight hole.**

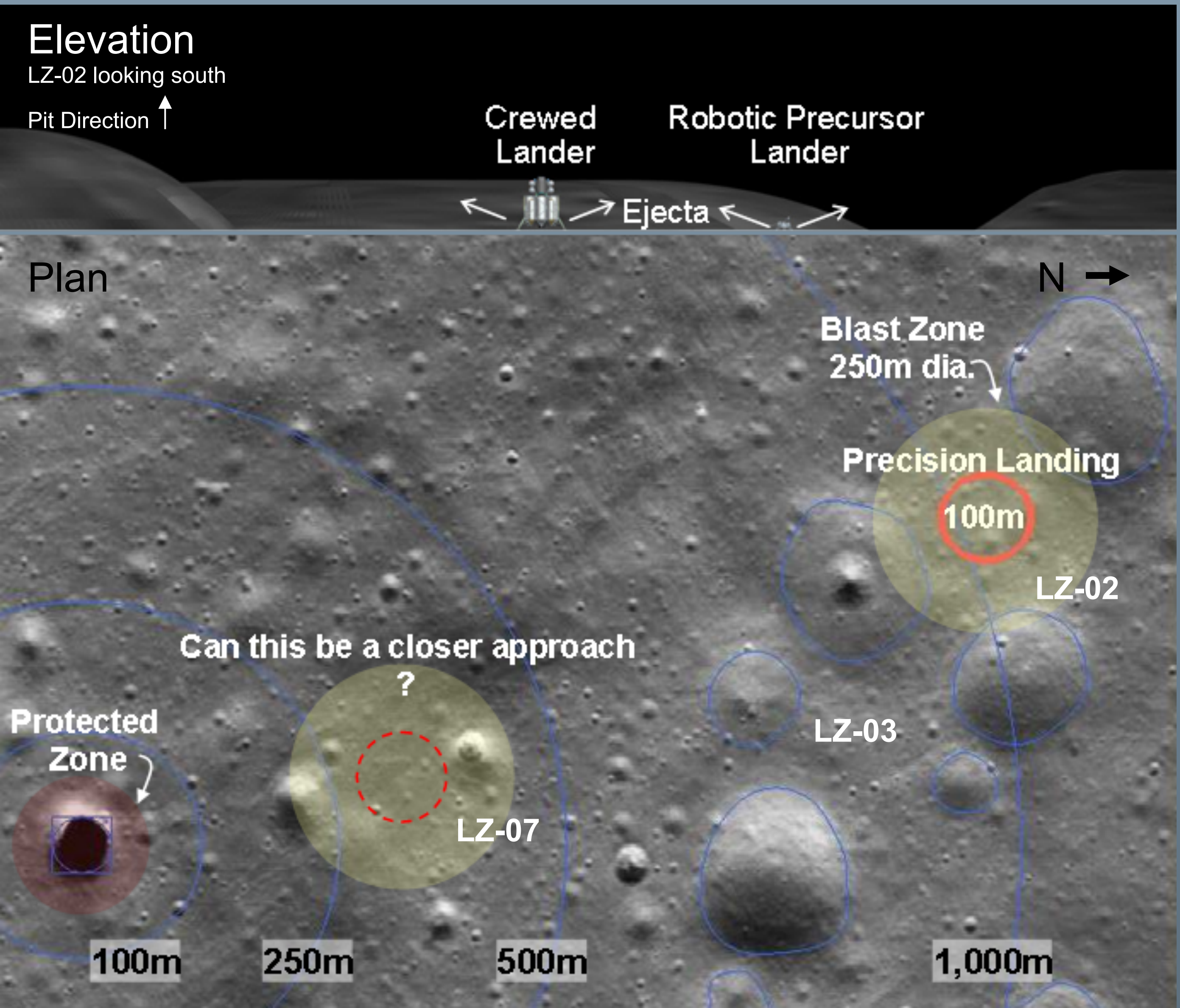
# Site Planning for Future Growth




**Performance of Landing Zone Trades**

# Landing Site Selection Criteria

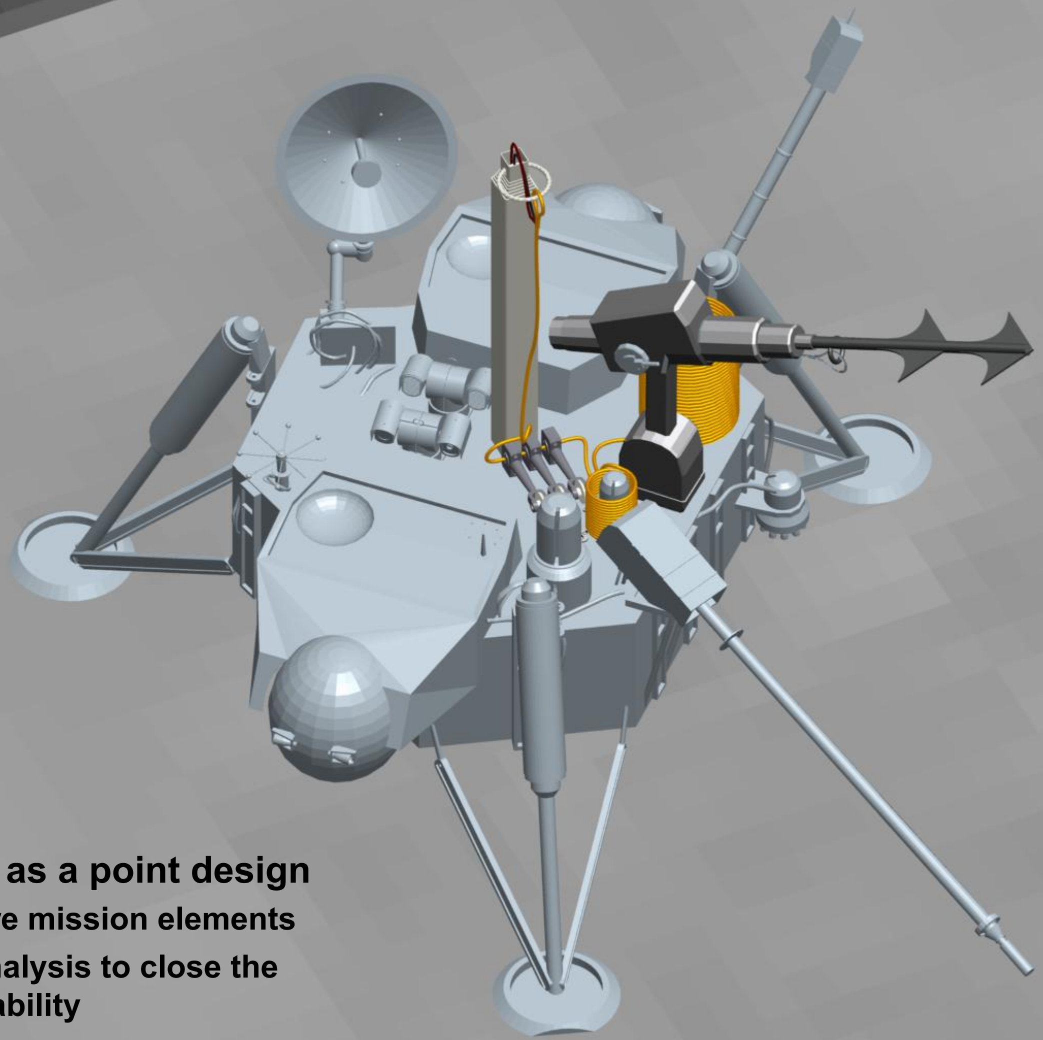
**Site selection trades consider debris pattern for various lander types**




- orbital injection/flight path optimized for precision landing
- minimum safe and contamination protected distance from pit
- optimized use of natural barriers for blast zone containment
- a level and unobstructed traverse from landing site to the pit edge
- best slope side of pit for approach
- accommodates for future growth patterns, i.e., surface mining and lava tube habitation operations

# Intelligent Zipline Concept

A system architecture for robotic deployment of an intelligent cable system that is "shot" across the expanse of a skylight's pit hole opening from a mobile platform, possibly a robotic lander with traverse capability which positions itself at an optimum anchoring site.

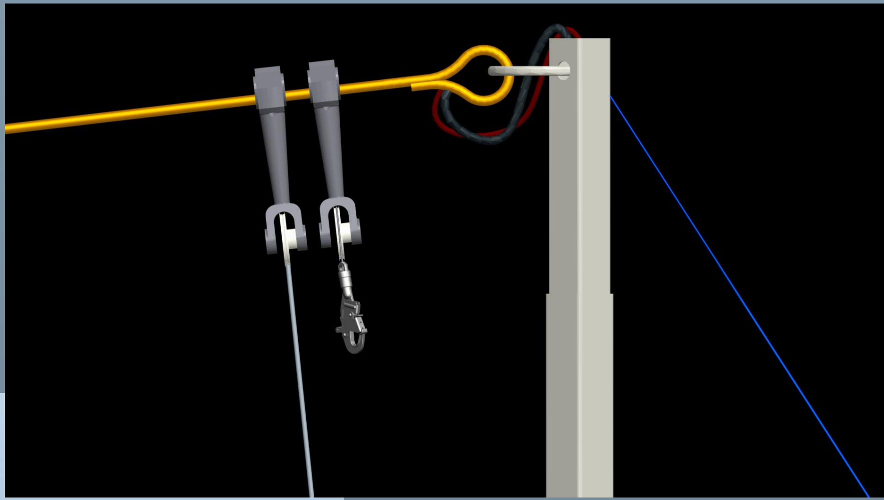


**Shown is not intended as a point design**

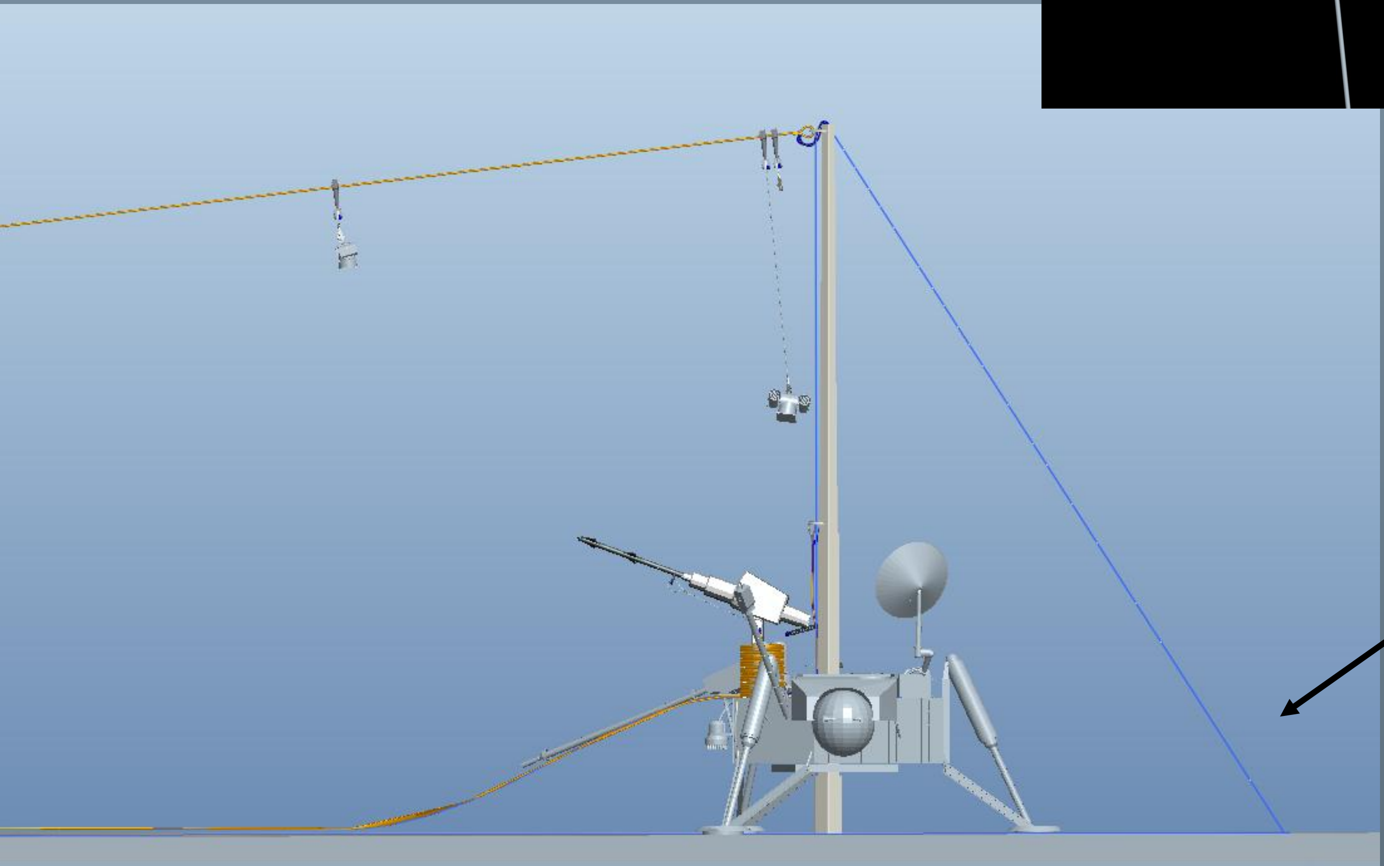
- **used for identifying core mission elements**
- **provide a quick-look analysis to close the ConOps for concept viability**

# Zipline Detail

- Intelligence is built into the harpoon projectile for targeting accuracy.
- Intelligence is built into the trolleys and cable for manipulating payload grappling, loading stress, braking, and tension along the zip line traverse.
- Power, data, & communications run through the cable.

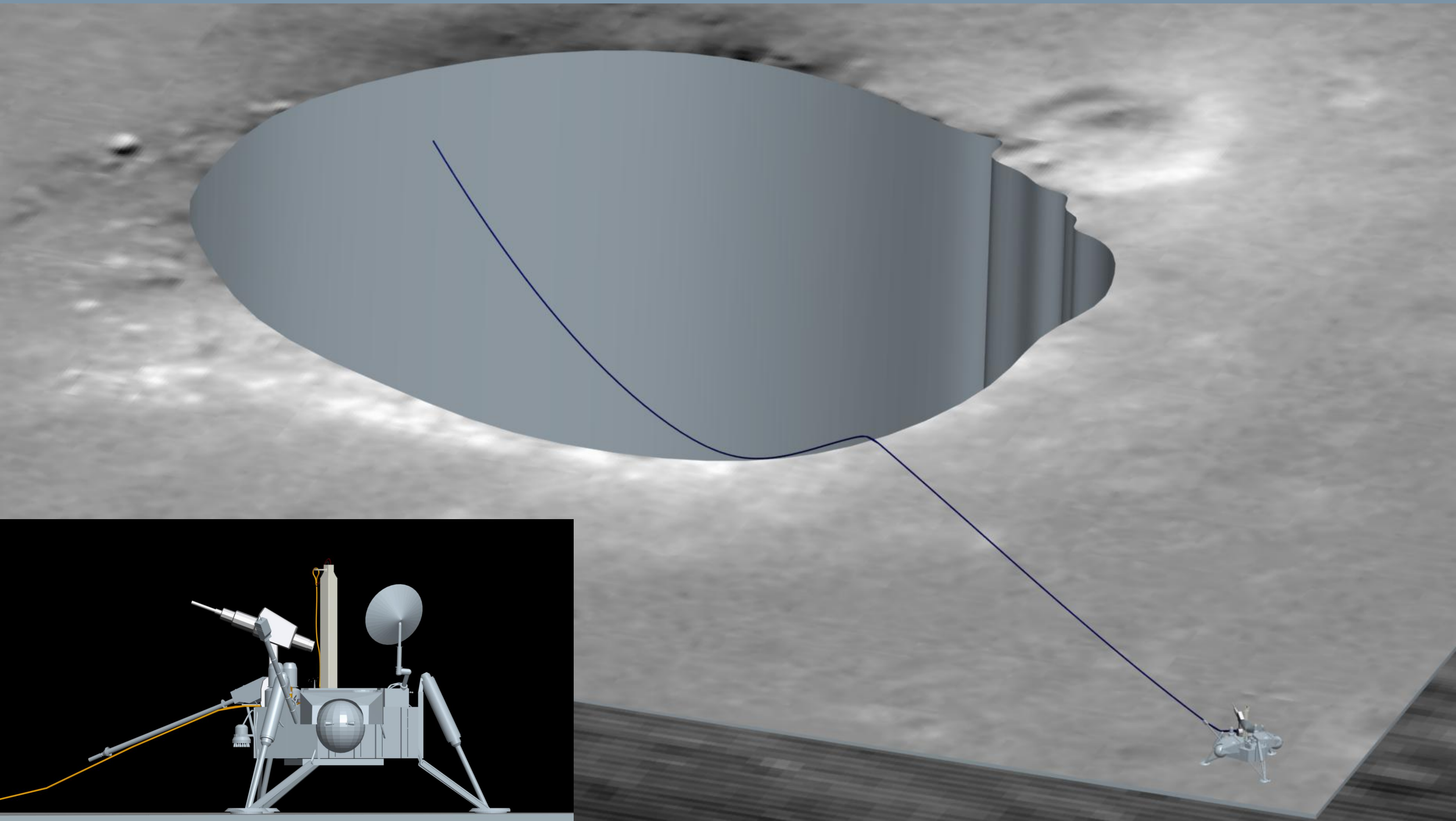


Smart trolleys & powered cable for bi-directional robotic traverse

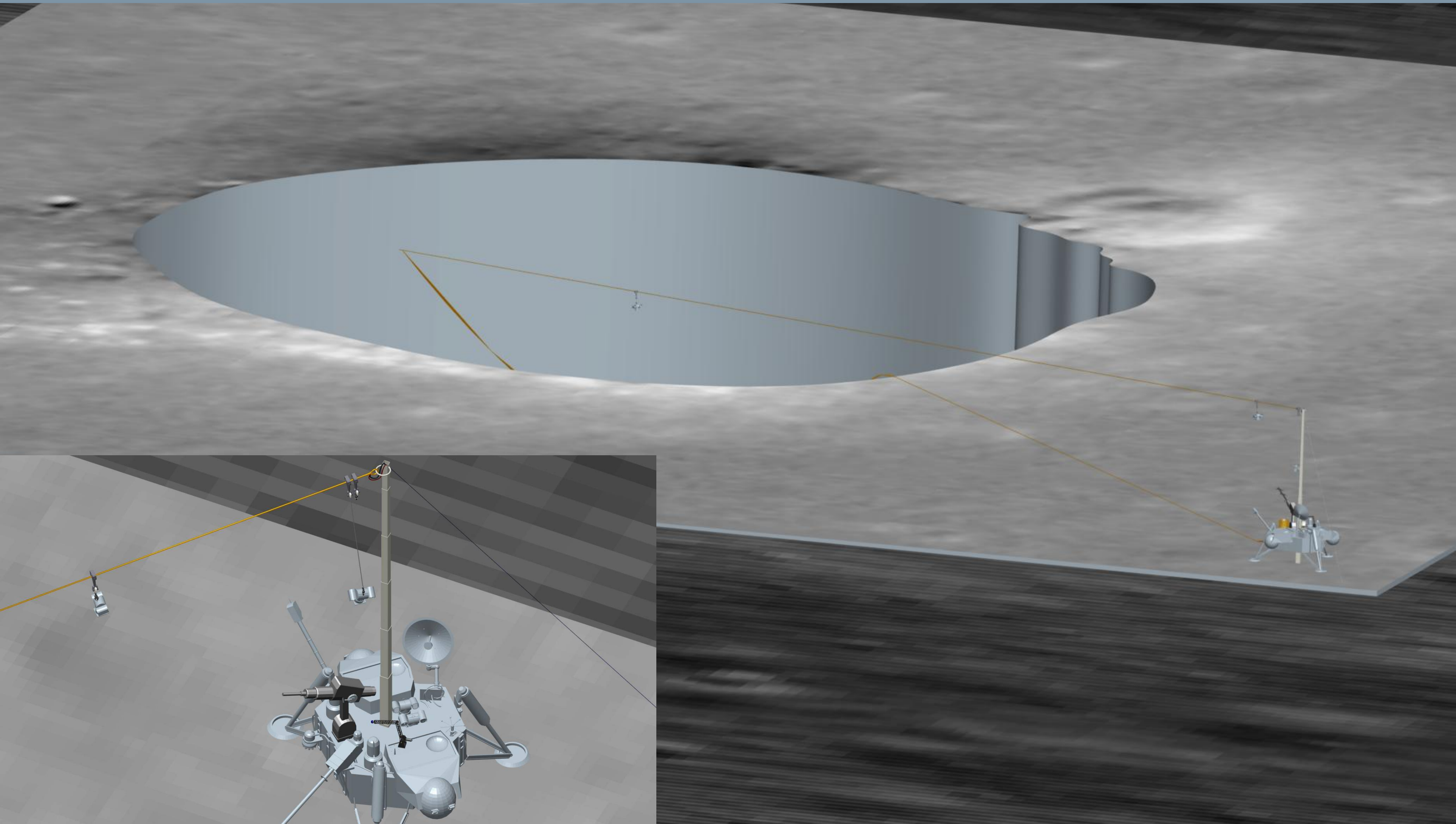


**ConOps for deployment and anchoring of guy line not closed**

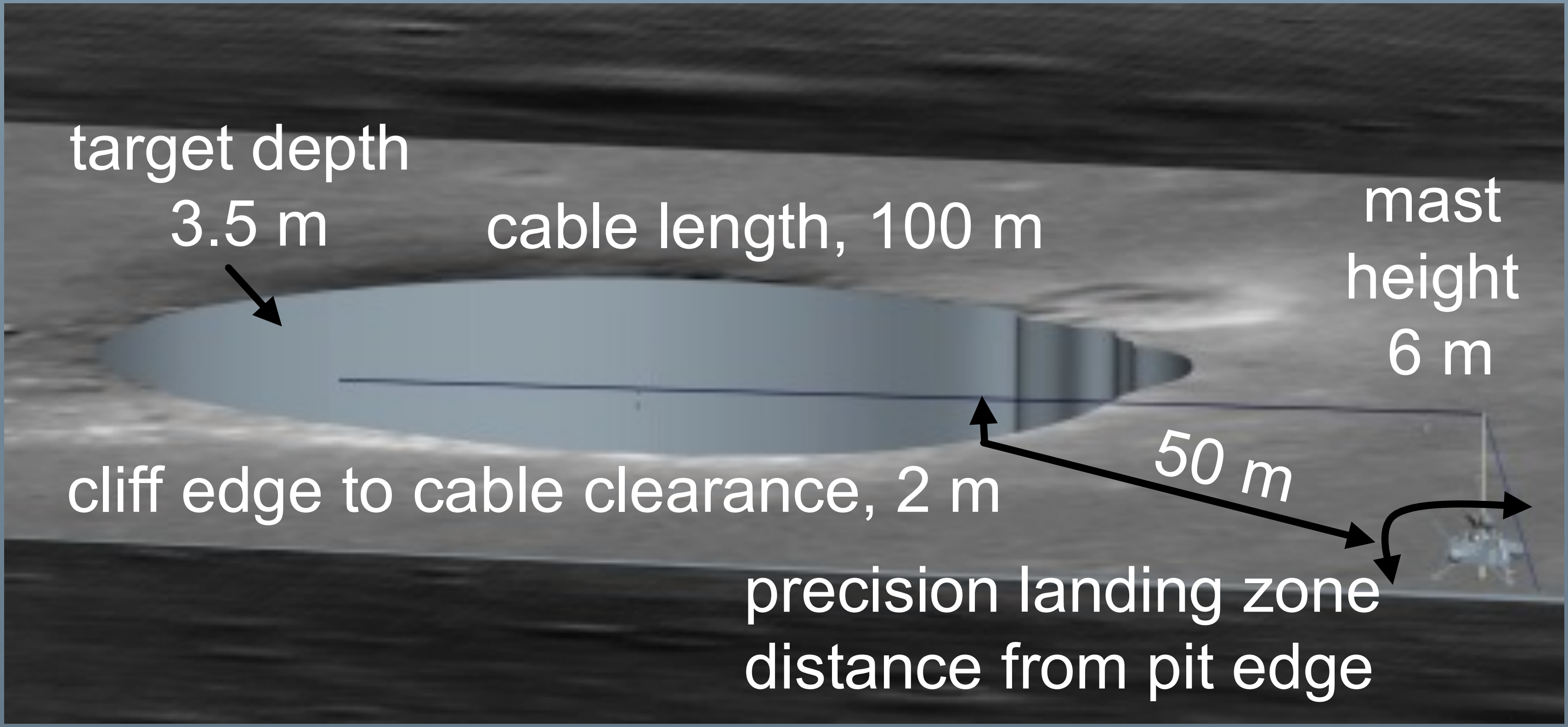
# Deployed Configuration



# Operational Configuration



# Operational Considerations



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# Zipline Forward Research

| System Element | Phase I - System Study Investigation |
|---|---|
| Harpoon cannon | Energy to penetrate optimum depth; sizing explosive charge; leverage GSFC comet harpoon technology |
| Harpoon | Smart targeting and guided trajectory with trailing cable; imparted energy vs. penetration depth; harpoon mass, tip geometry, cross section; anchoring and stabilization with cable tension |
| Intelligent cable | Cable type/size; tension/load sensing and auto adjust; comm-power-data interface; trolley/cable interface |
| Intelligent trolley | Robotic traverse up and down cable length, braking, speed sensing; drop line targeting; zip line & drop line comm-power-data interface; payload spin stabilization; payload grappling |
| Mast concept and deployment | Telescoping or other means of extension; lightweight carbon fiber materials; inflatable mast; guy cable deployment, anchoring, and horizontal load transfer to compressive load |
| Cable management | Spooling concepts; length and mass; clearances (spacecraft and pit edge); drape and sag deflection |
| Scientific instruments | Instrument/sensor types; planetary protection concepts; packaging; drop line interface, connection/release |
| Landing site proximity | Precision landing; ejecta field safe zone; optimal landing location based on topography and slope advantage |
| Spacecraft lander | Size, configuration, major element integration; cannon and mast offset geometry; crawl mode mobility for precise positioning; anchoring; comm-power-data requirement and interface to zip line and trolleys |

# Questions ?