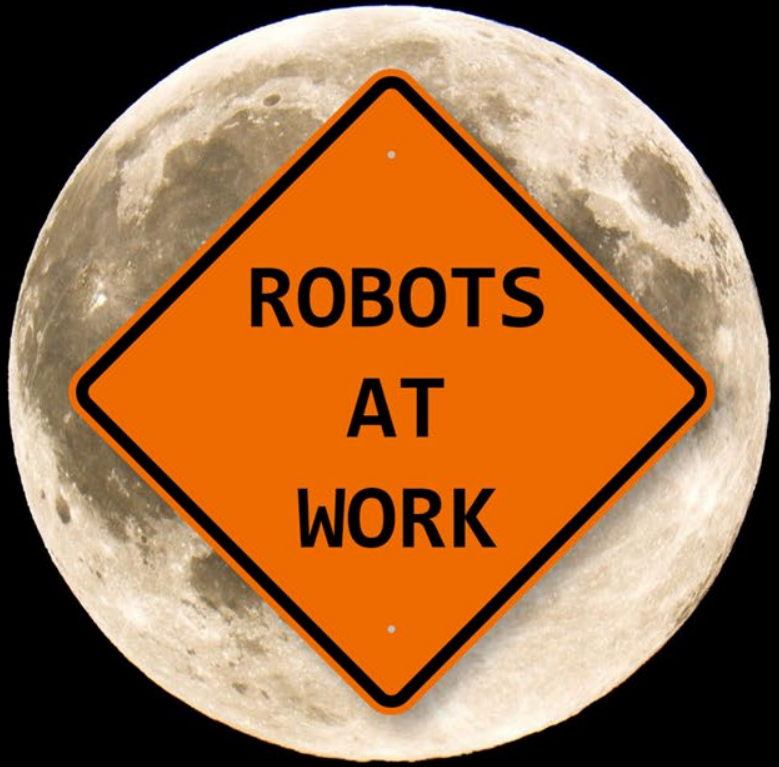
Field Robots on the Moon

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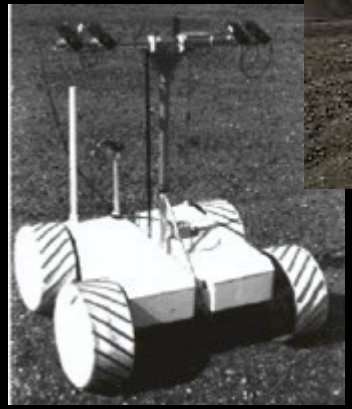


How do field robots differ from factory robots ?

- Vastly different applications
- Operate in natural environments
- Unpredictable variables in circumstances of task
- Self-mobile with onboard power
- Typically over-capable relative to task
- Operate in harsh environments

Likely roles of field robots on the Moon (i.e., most of the time most of a Moon Base will be robotic

- Base installation
- Site preparations
- Continuous site improvements
- Lander-to-Moon-base-and-worksite logistics
- Installing and expanding solar capacity
- Monitoring
- Maintaining
- Ops needing extended de-pressurization or loss of thermal regulation for mods or add-ons

What about the lunar surface exceeds our experience with field robots for construction sites, agriculture, mines, etc?

- Lunar epitomizes big work with smaller machines in low gravity
- Not having the extent of machine over-capability relative to task
- Dust effects that degrade cooling during site work will be profound
- Supervision, when required might be low bandwidth
- Almost every lunar challenge except reduced gravity will exceed Earth chalenges
- Lunar-relevant assembly, transport, dozing, high-lifting, compaction and hauling are beyond our terrestrial experience.

Joint human/robotic operations

- Terrestrial instances in manufacturing, surgery, bricklayi order picking, heavy lifting, ag, mining and …..
- What issues relate to robots operating around humans?
  - Safety, situational awareness and reliability
- What's unique about multiple robots operating together?
- What is the state of practice in the field for controlling such operations? Spatial deconfliction, force control, precision, design of task for shared roles, and extreme reliability

Joint human/robotic operations on the moon

Robot providing force offload to assist human with heavy lifting

Human rigging by attaching strap, cable or hook for robot lifting, then de-rigging after robot sets the load down after the lift

Co-assembly where astronaut inserts fasteners or pins while robot positions elements or parts

Elevating astronaut for high work

Humanoid-astronaut collaboration isn’t there, but terrestrial humanoids are far beyond Robonaut days. Commercial is driving this on Earth

Where to start ?

Demonstrate functionality of a robotic Workhorse with attachable implements

Demonstrate heavier offloading, transport & emplacement

Demonstrate road grooming and site prep functionalities

Demonstrate ramp descent if a subsurface base element is deemed important

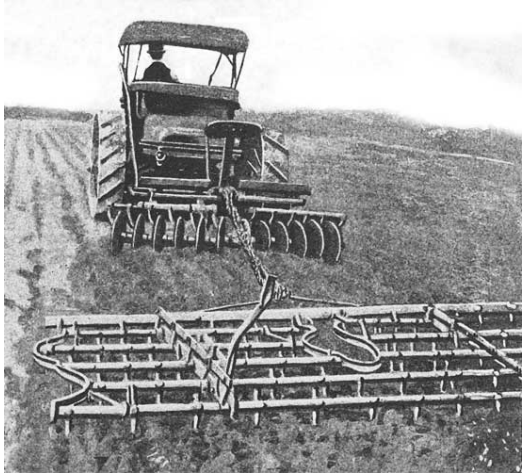
Skid steers with attachments are the most diverse terrestrial workhorses

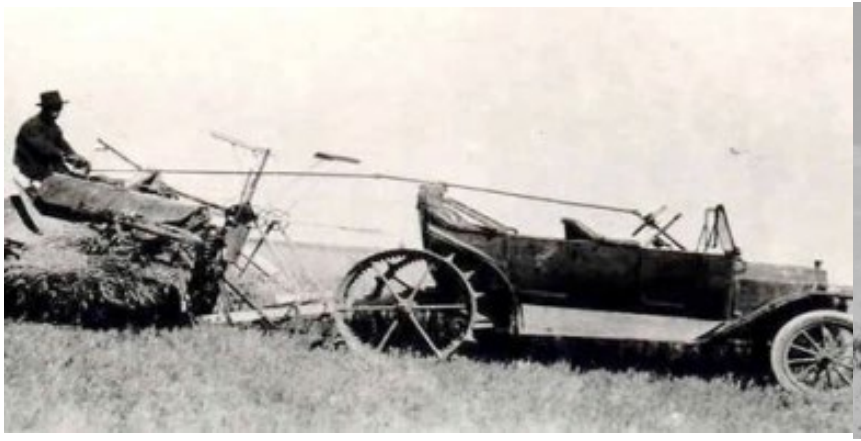
The Path to a Lunar Workhorse

LTV is evolving from cartoons toward reality of what is really required

Much Field Robotic needs won't be addressed by LTV

A great deal of work can be achieved by the right kind of driving around

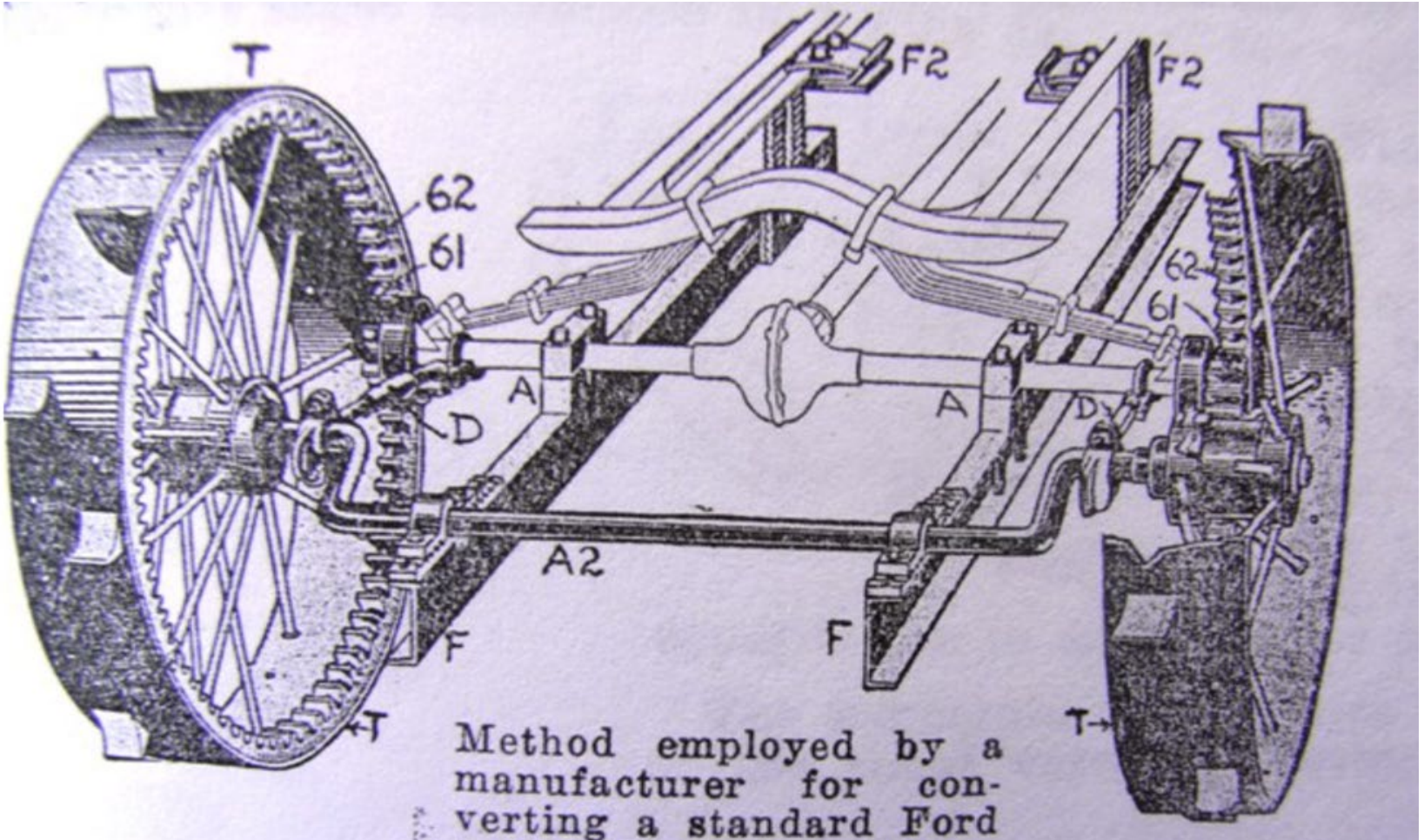




Torque + Grip + Weight = Traction & Reaction for Work

Mobility increases and sinkage decreases with increased radius & Rim width

Soft suspension of a rover for driving around is counterproductive to a work mahine for loading, grading, lifting & assembly



Method employed by a manufacturer for converting a standard Ford model T chassis into a tractor

Technical differences of planetary vs terrestrial field robotics (1)

- Disadvantaged without strength or simplicity of hydraulics
- Challenging cooling scenarios for work tasks
- Cooling is even more challenged by dust lofted onto radiators
- Perception is challenged by dust lofted onto optics
- GPS is denied
- Limitations of battery versus combustion for prime power
- Lubrication challenges given Moon’s vacuum and heat
- No elastomers for belt tracks, etc

Technical differences of lunar vs terrestrial (2)

- Penultimate standard of human safety
- Low bandwidth supervision when supervision is called for
- Extremely low-cadence patient work that would not be profitable on Earth
- Downtimes for recharging or cooling
- Perennial night survival cycles

Characterize such investigations with and without humans on site to participate

With Humans

- Value of highest situational awareness
- Rigging & Unrigging assistance
- Guidance for fine tolerance assembly
- Assistance with implement interchange
- High-bandwidth nearby remoting
- In-situ teleoperation
- Servicing such as optics and solar cleaning
- Effectiveness of adaptable operations

Without Humans

- Many months for workscope unachievabl in short human stays
- Need for completely automated tool change
- Need to increase customization of handling for hab, assembly elements & supplies

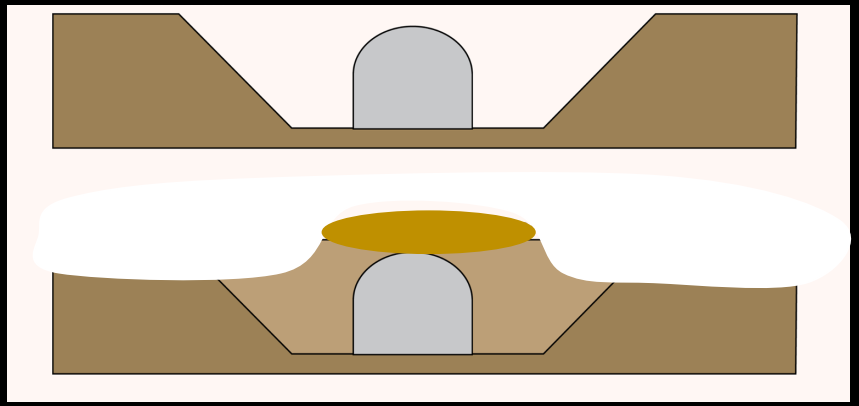
Value of a subsurface element to bi-level Moon basing

- Protection of assets from takeoff and landing blast
- Improving viability of perennial night hibernations and increasing longevity of equipment
- Human refuge for benefits of radiation, micrometeorite and thermal
- Long term advantages to a base

Establishing a subsurface element

If an accessible subsurface void (a suitable cavern within a pit) is found or cleared, then use it

If not, then construct it



Surface

Subsurface

Precursor and hab siting

Solar Array siting

Comm

Base for forays, logistics and ops without descent to subsurface

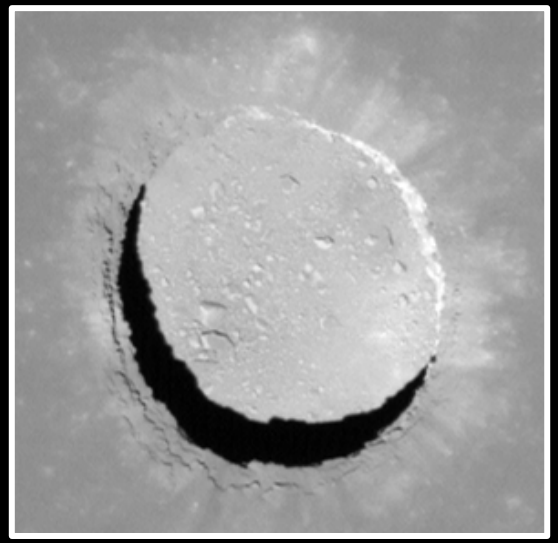
ISRU, etc

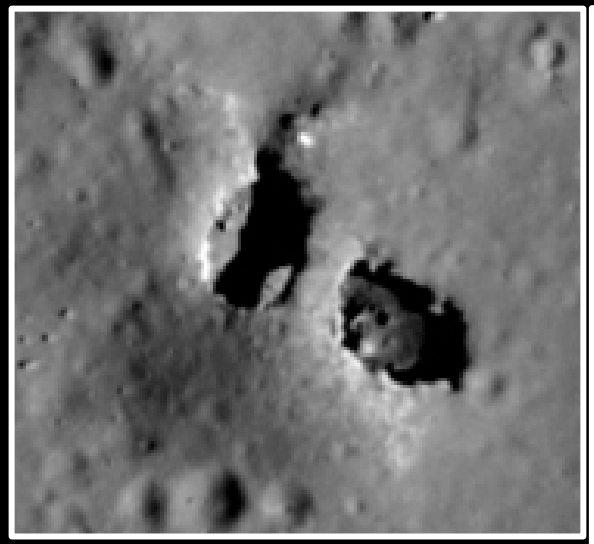
Protection from landing/takeoff blast

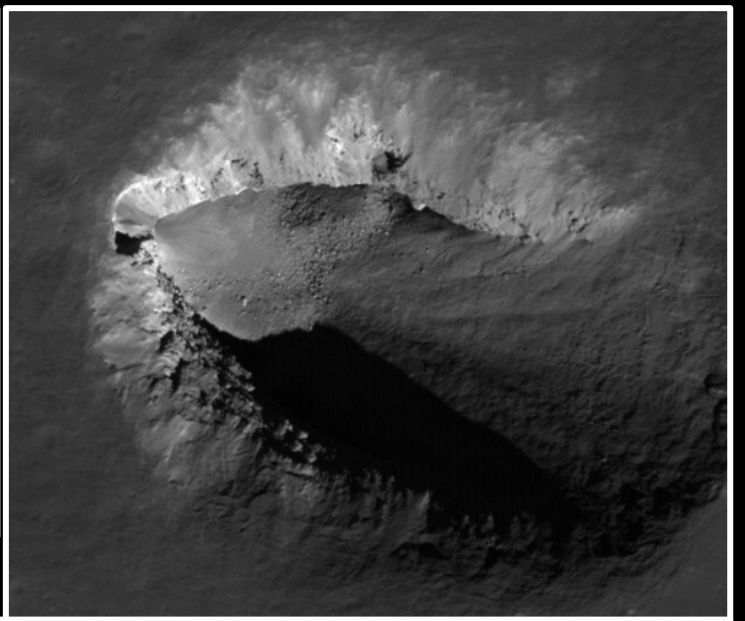
Site-Scale battery and water storage without intractable hot-cold temperature fluctuations

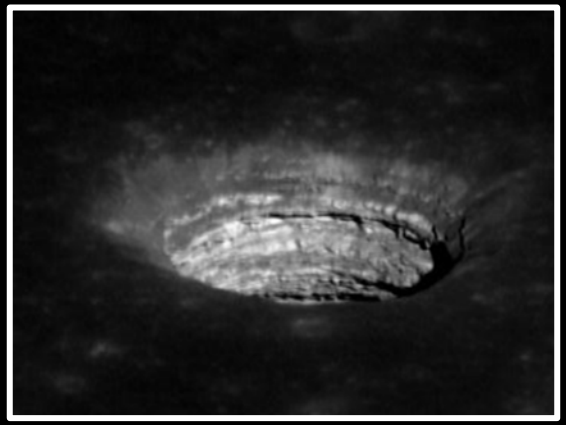
Radiation refuge

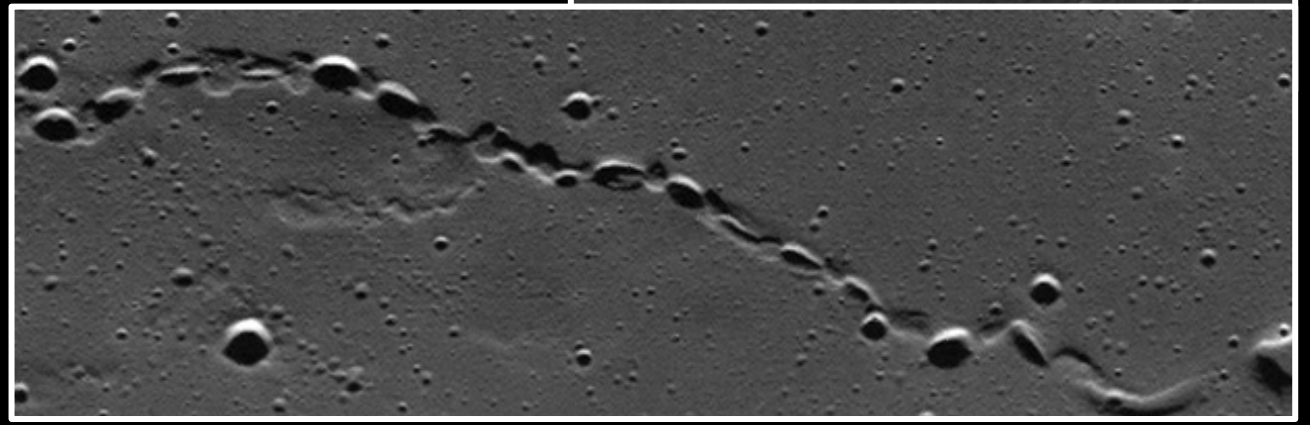
Overnighting for takeoff holds or for intended longer stays



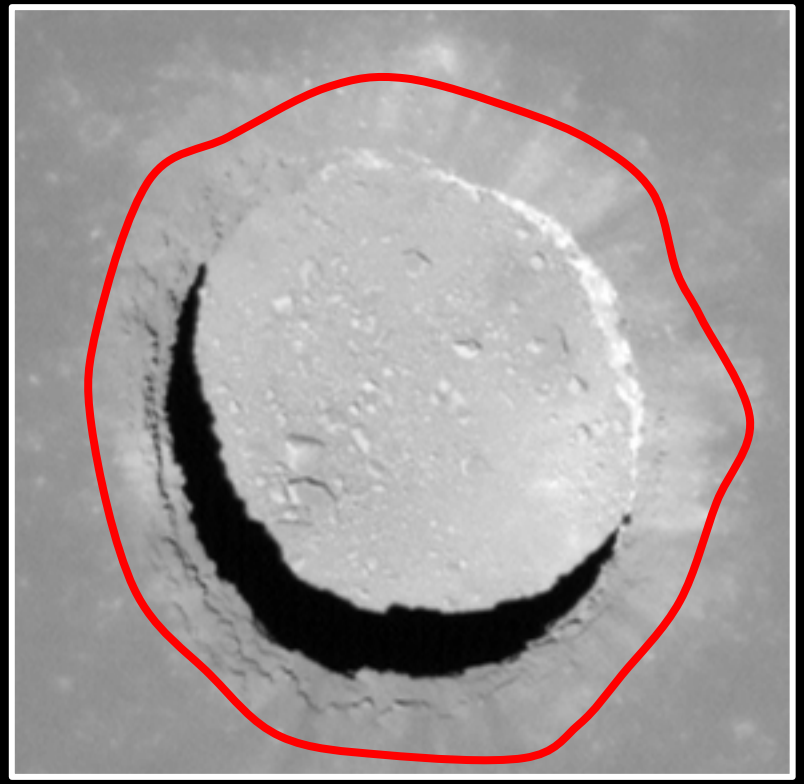


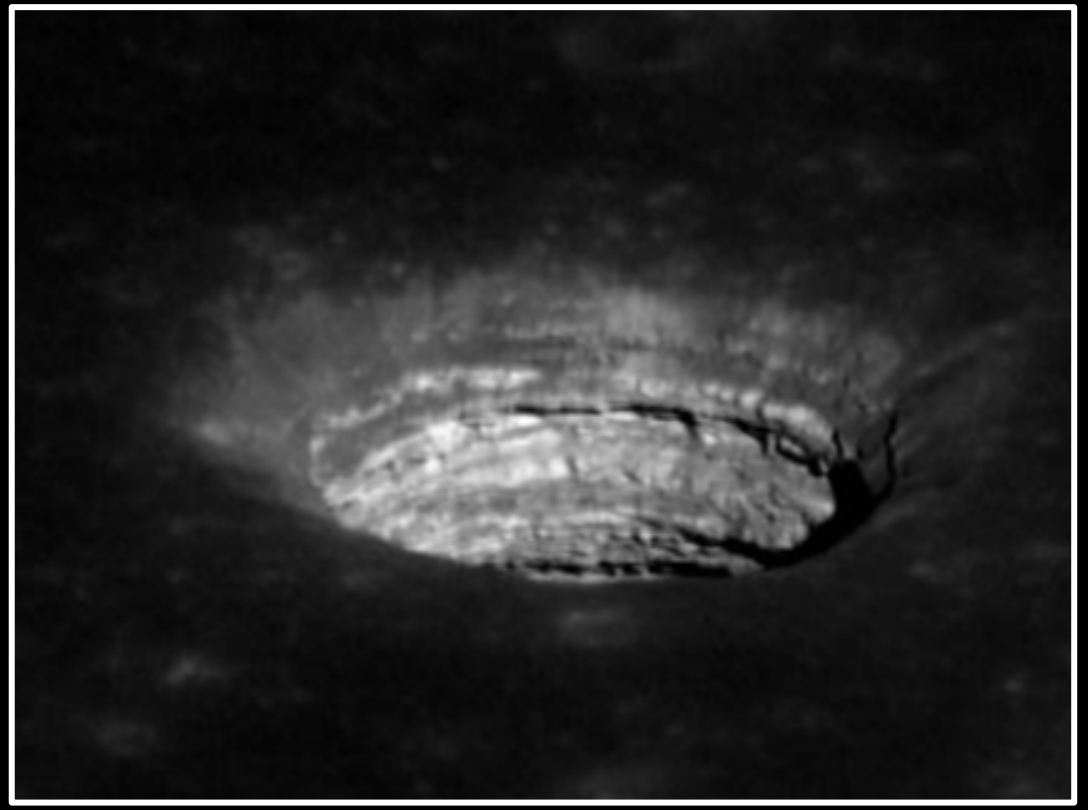


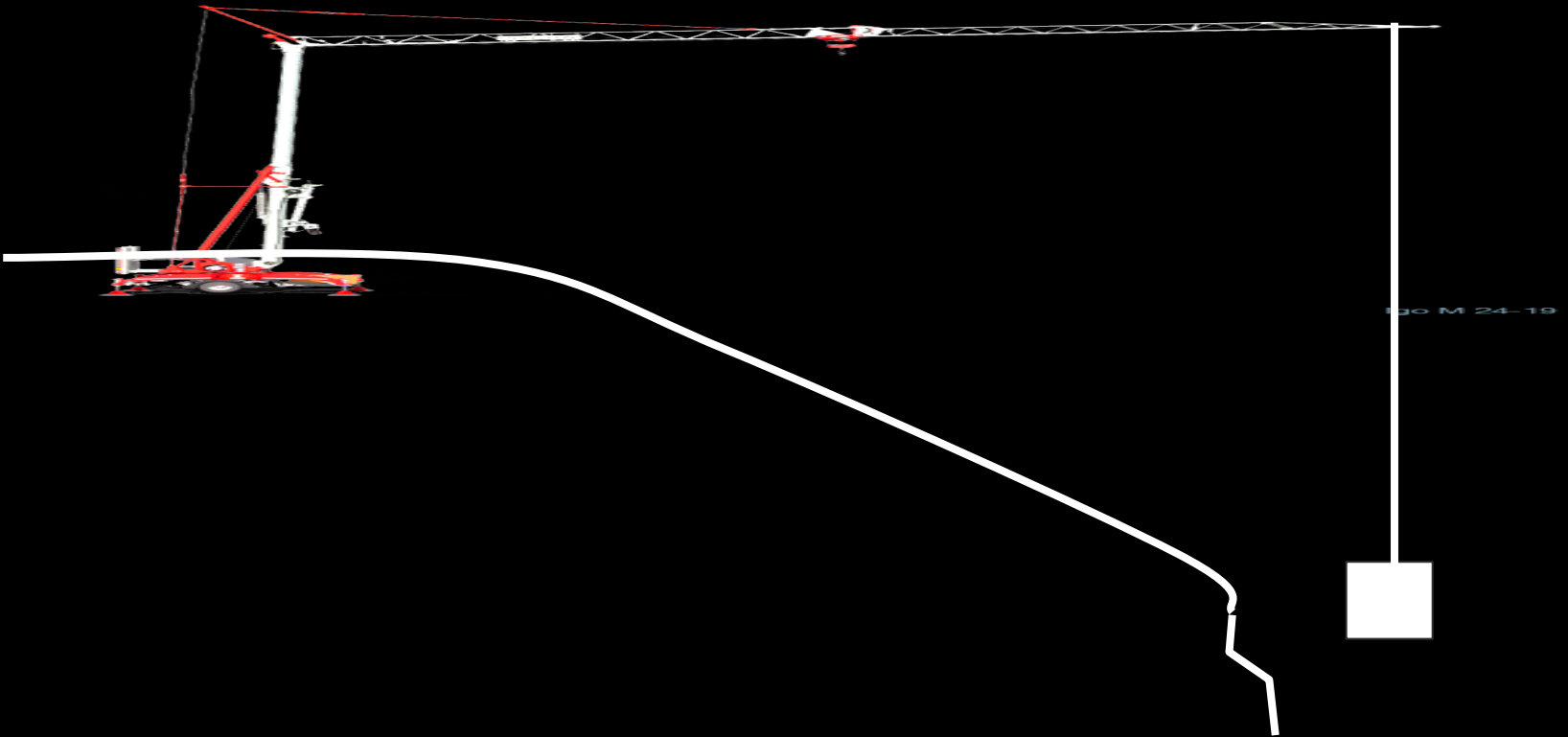





Probably not
Definitely not
on the Moon



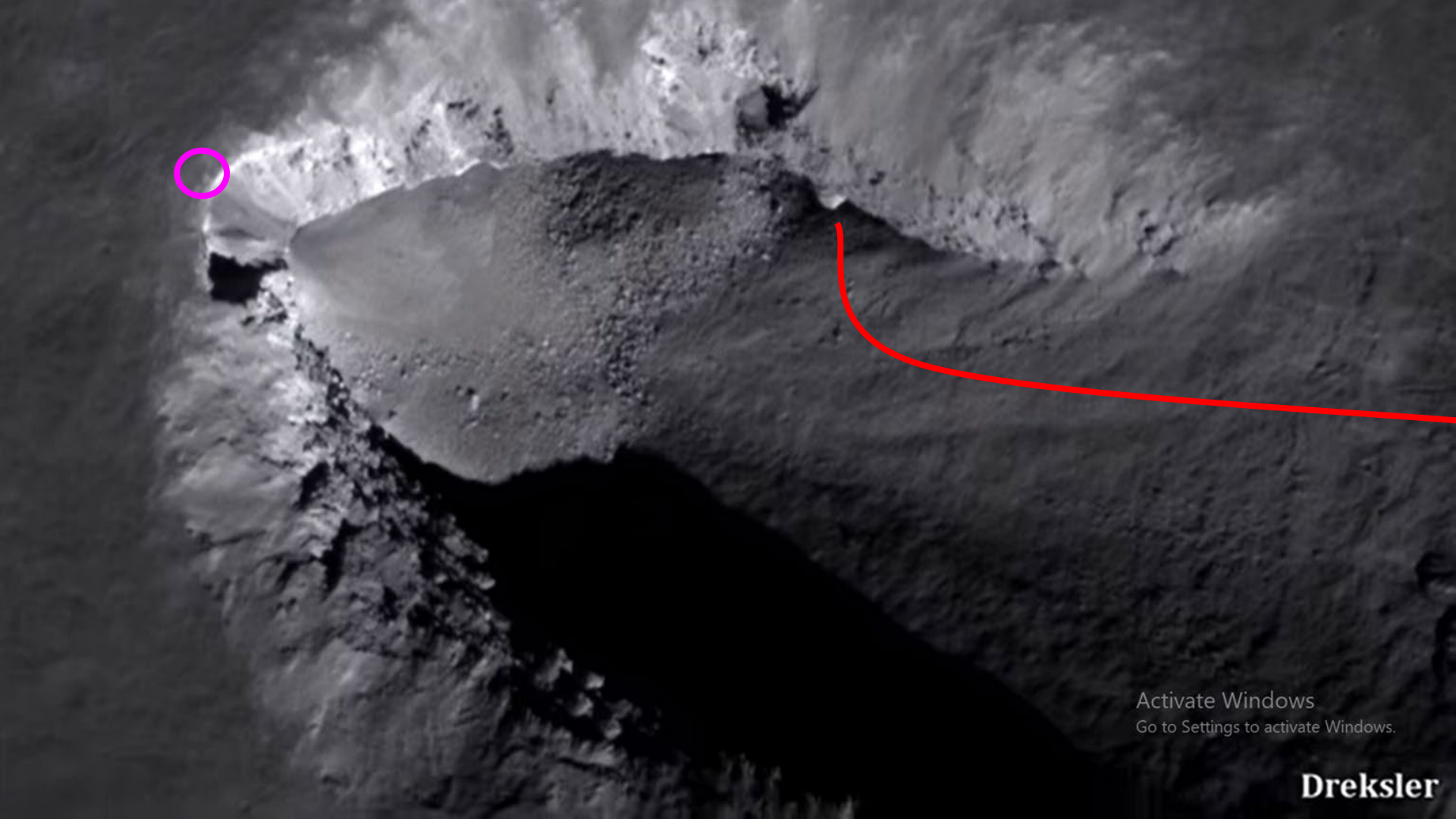




A ramped pit might provide access without risk of apron debris falling near the walls

Ideal candidates for both science and development of a subsurface asset would be a pit having (1) cavernous void, (2) accessible ramp, and (3) non-polar latitude where median temperature is reasonable (not cryogenic) at depth.

Ramp might be groomed for descent & ascent that avoids dangers near walls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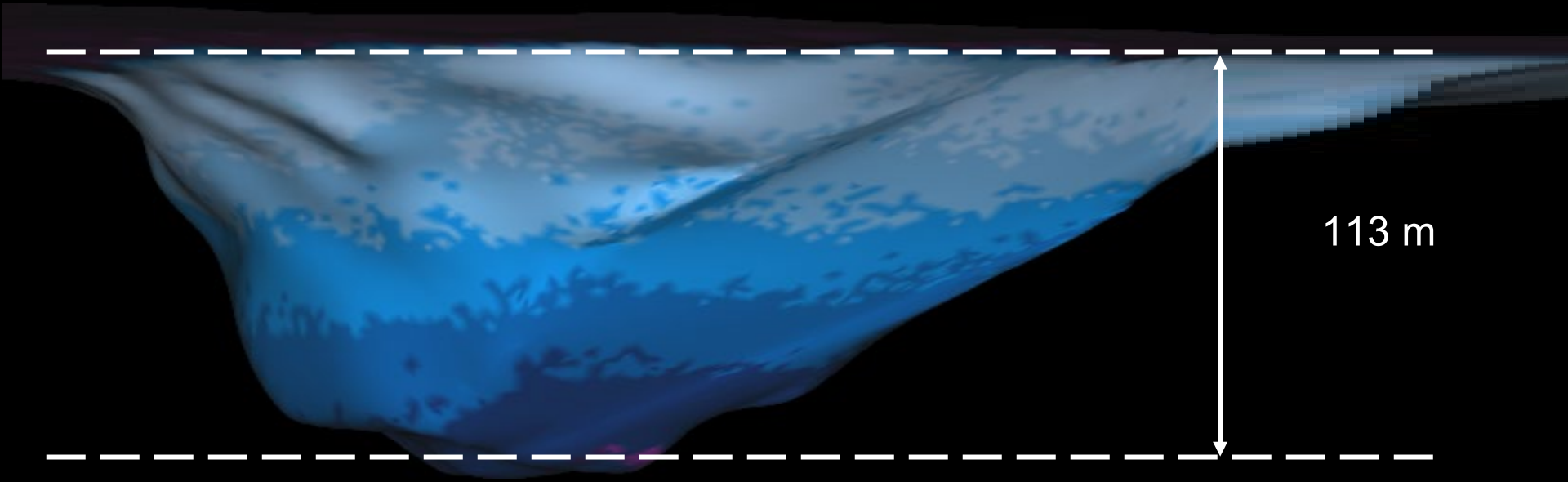
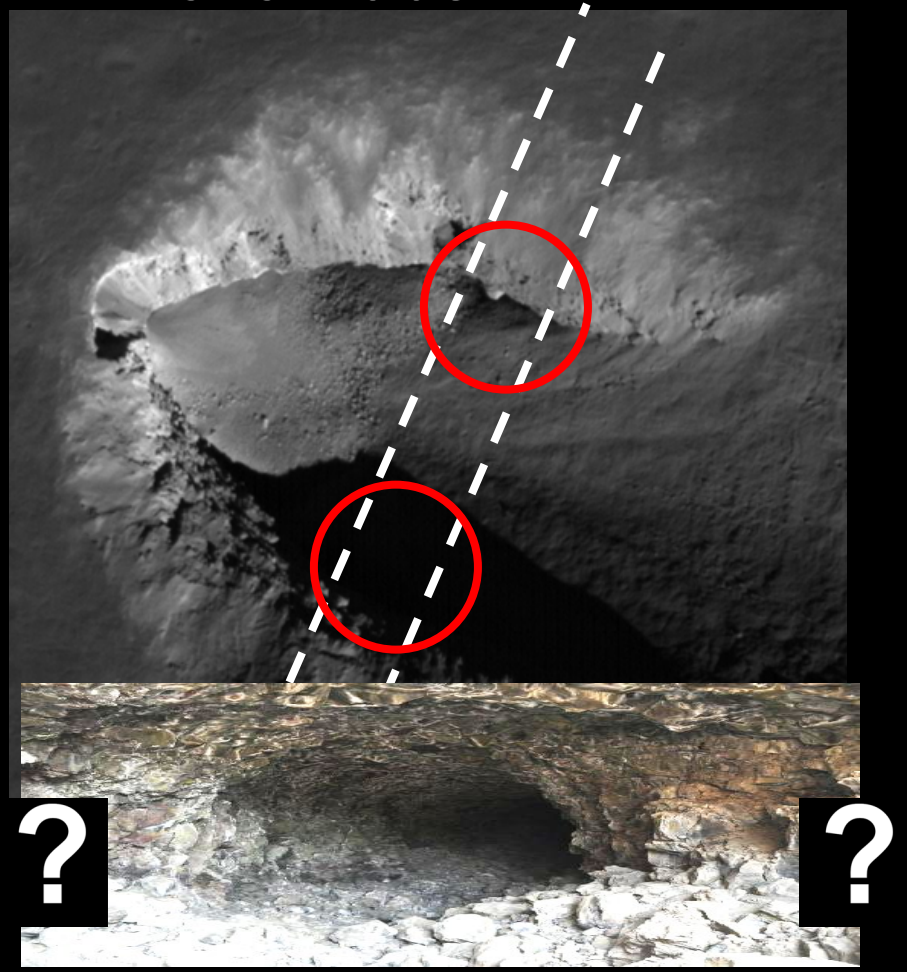
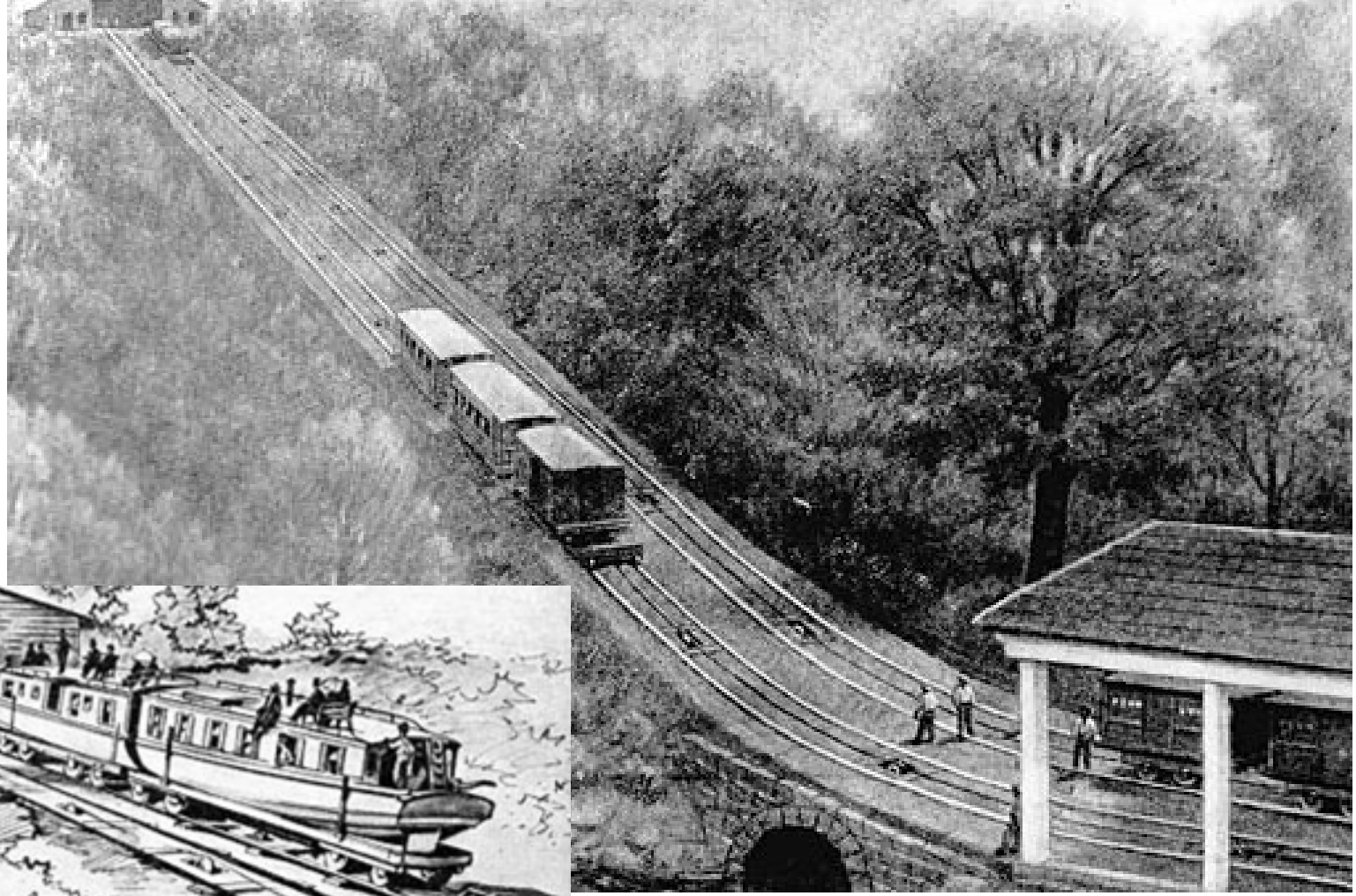
Robotic exploration would yield decimeter accuracy and sub -decimeter pit resolution



Lava Tube?





What field robotics capabilities would this require?

Anchoring

Route grooming

Tether-assisted descent/ascent

What can we not learn at Artemis polar sites?

- Anything related to benefits of moderate subsurface temperatures for bi-level siting and ops. Polar is a region where thermal moderation would otherwise be most advantageous.
- Anything related to safely-accessible, naturally-existing cavernous voids.
- No pits are known to exist at high polar latitudes
- Subsurface temperatures at Artemis sites are cryogenic.
- (Subsurface temperatures are the diurnal average of surface temperatures).

What lunar field robotics carry over to science?

Pit science if a pit were considered as a subsurface element for a bi-level base

Cavern and lava tube science that becomes accessible

Descent/ascent system to safely put astronauts into pits

Development and operation of infrastructure of all manner to support permanent science installations

Assembly of such installations

What regarding lunar field robots carries over to Mars?

At least everything that is required on the Moon

Pre-installation of viable means for water, atmosphere, shelter, and food production

Lunar agenda can be post-arrival and much more evolutionary, but much less so for Mars

Field Robots on the Moon