Geology & Planetary Mapping Winter School

Landing humans on Mars: characterization of landing site resources and safety

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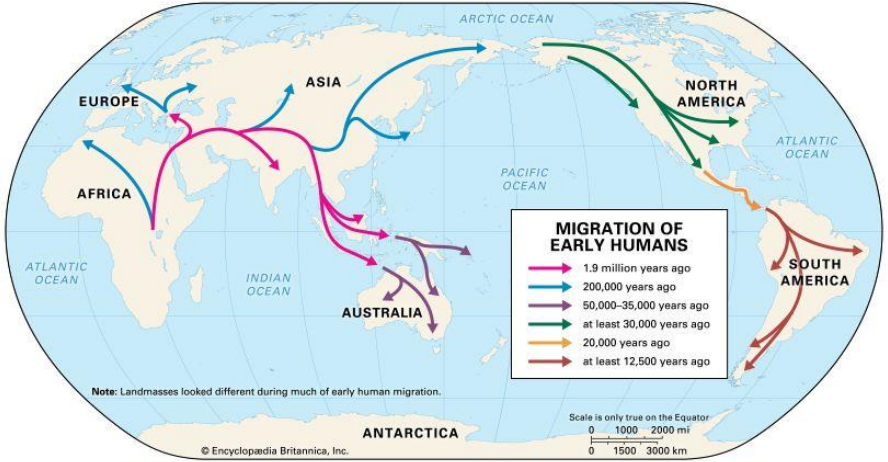
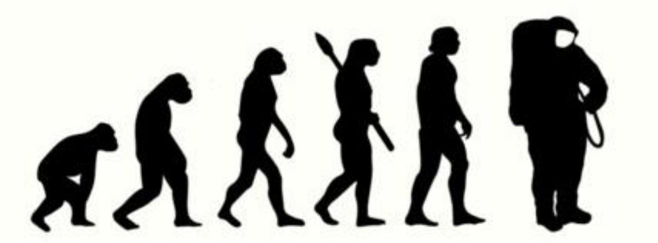
CONSTRUCTOR UNIVERSITY

Evolution demands exploration





"Every generation has the obligation to free men's minds for a look at new worlds . . . to look out from a higher plateau than the last generation."

- Ellison S. Onizuka, Challenger Astronaut

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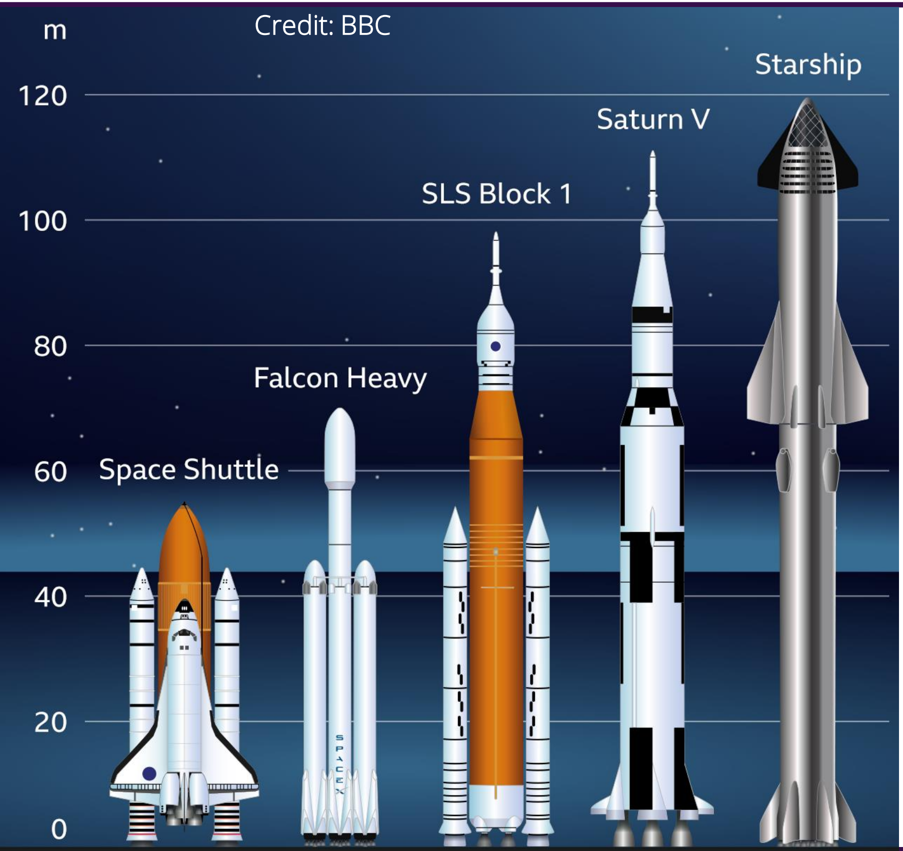
Credit: NASA

Our generation will bring humans to Mars.

But how?



Technology

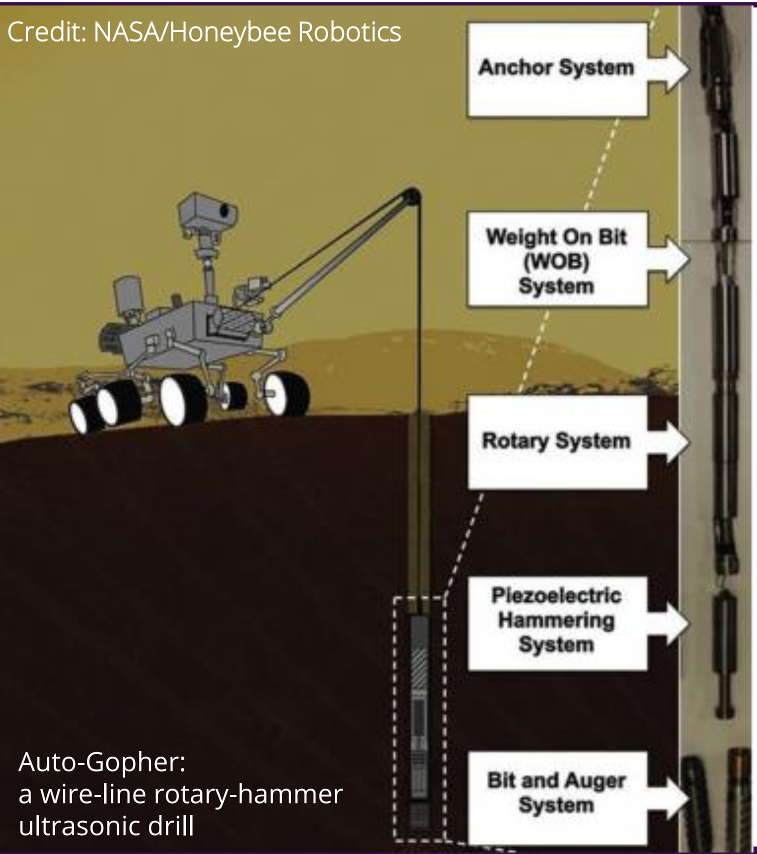
The SpaceX Starship rocket

- Fully reusable;
- Cheap (900$ per pound vs 100.000$ per pound);
- Increased payload.

Timeline

1. First uncrewed Starship, its payload will support the future base construction;
2. If landing is safe, and there is no trace of life, the crew arrives next with a second Starship;
3. In Situ Resource Utilization (ISRU) and building the infrastructure.


Credit: SpaceX



ISRU
(In Situ Resource Utilization)

- ISRU is required to enable a self-sustained human presence on Mars;
- Among the various resources, water ice is crucial for sustaining human life and for propellant production;
- We need to know in advance the possible ice depth and composition.

Criteria for landing site selection

Engineering & Human exploration

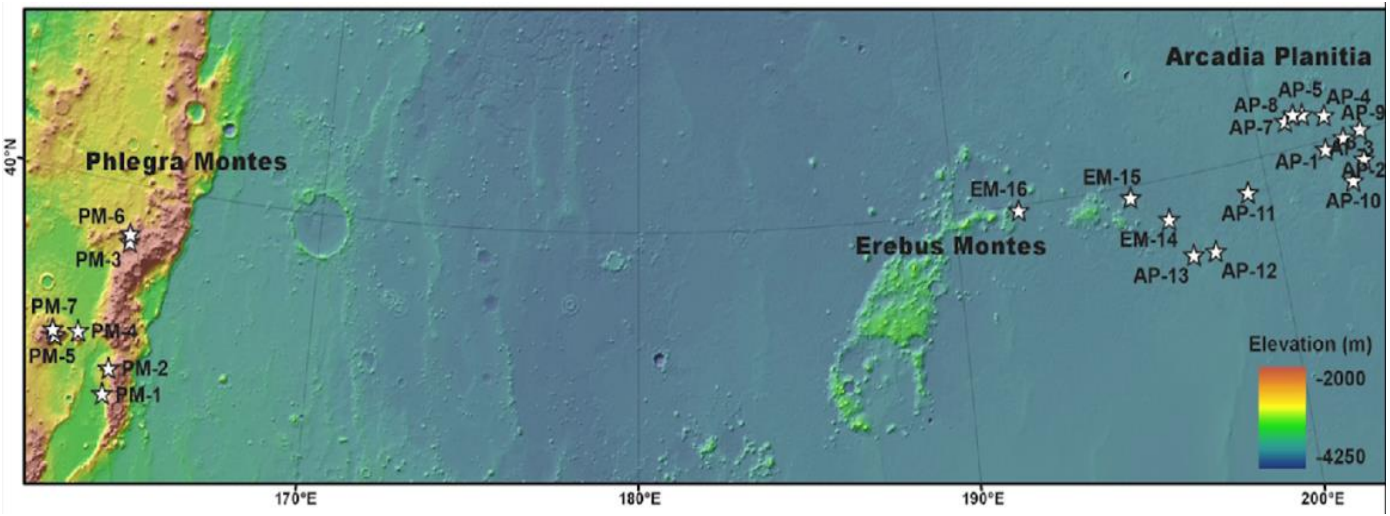
- Mid-latitude for illumination and thermal requirements;
- Presence of near-surface ice for science and ISRU;

Landing site safety

- Elevation < -2 km (-3 km preferred) with respect to the MOLA geoid to support the delivery of large payloads;
- Slopes <5° over a 10 m length scale and the chance of impacting a rock of 1 m diameter should be <5%;
- The landing site must be radar reflective to enable measurement of the distance to the surface during descent;
- The landing site must be load-bearing to support the spacecraft at touchdown.

(Golombek et al. 2021)

Landing site selection



Golombek et al. (2021)

Arcadia Planitia

- Flat and safe;
- Mid-latitudes;
- Evidence for near-surface ice.

Evidence for near-surface ice in Arcadia Planitia: multiple independent datasets

MONS
(Mars Odyssey Neutron Spectrometer) [1,2,3]

FREND
(Fine-Resolution Epithermal Neutron Detector) [4]

GRS
(Gamma Ray Spectrometer) [5]

CTX
(Context Camera)
and **HiRISE**
(High Resolution Imaging Science Experiment)
Imagery and elevation for geomorphological evidence
[7,8];

SHARAD
(SHAllow RADar)
[6,7]

THEMIS
(Thermal Emission Imaging System)
[7]

SWIM
Team combined datasets
[9, and references therein]

[1] Bramson et al., 2017. JGR: Planets; [2] Feldman et al., 2011. JGR: Planets; [3] Pathare et al., 2018. Icarus. [4] Malakhov et al., 2022. JGR: Planets; [5] Boynton et al., 2002. Science; [6] Bramson et al., 2015. GRL; [7] Ramsdale et al., 2019. JGR: Planets; [8] Hibbard et al., 2021 [9] Bain et al., 2019. LPSC abstracts.

Ice glossary

PERMAFROST

Perennially frozen ground (T ≤ 0 °C).

Ice within permafrost can occur as:

(1) pore ice;

(2) segregated ice;

(3) foliated or wedge ice;

(4) pingo ice;

(5) excess ice.

PORE ICE

The ice is filling (or partially filling in variable %) the pore space within a matrix.

Pore ice is believed to have formed via water vapor diffusion from a moist atmosphere.

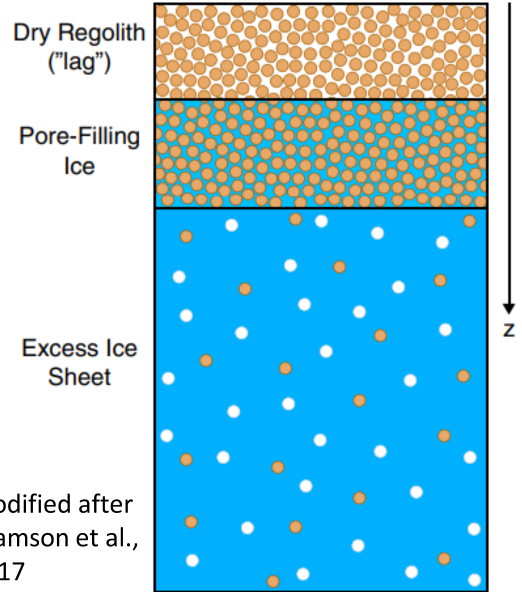
EXCESS ICE

Volume of ice > tot. pore volume of unfrozen ground.

The widespread accumulation of buried excess ice on Mars was explained by climate models as due to an extended period of snowfall and to the burial of the newly formed glacier during Mars' high obliquity (>35°)(Bramson et al., 2017; Head et al., 2003; Madeleine et al., 2009).

DRY LAG

Dry deposit insulating the underlying ice



Modified after Bramson et al., 2017

Geomorphological evidence for near-surface ice

Some periglacial/glacial morphologies can be considered a direct evidence for excess ice:

- Thermal-contraction polygons;
- Craters expanded by sublimation;
- Brain terrain.

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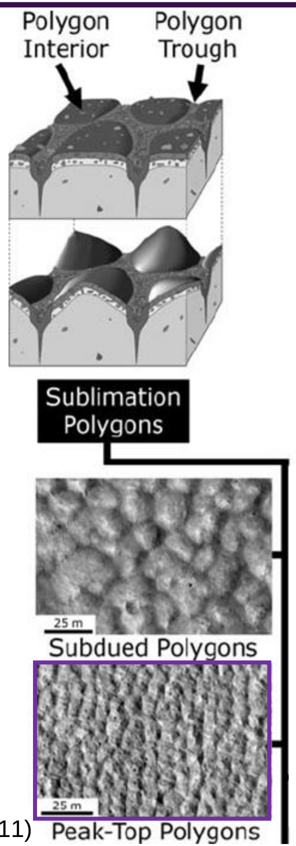
Thermal-contraction polygons

- Due to seasonal thermal contraction, the tensile stress exceeds the strength of the frozen ground, causing ice-cemented soils to develop honeycomb networks of fractures, thus relieving such stress (Mellon et al. 2008);

- Ice wedges or sand wedges develop within and beneath the cracks;

- Polygons can provide insights on:
  - Ice depth (related to their size)
  - Maturity stage (related to the angles between fractures)

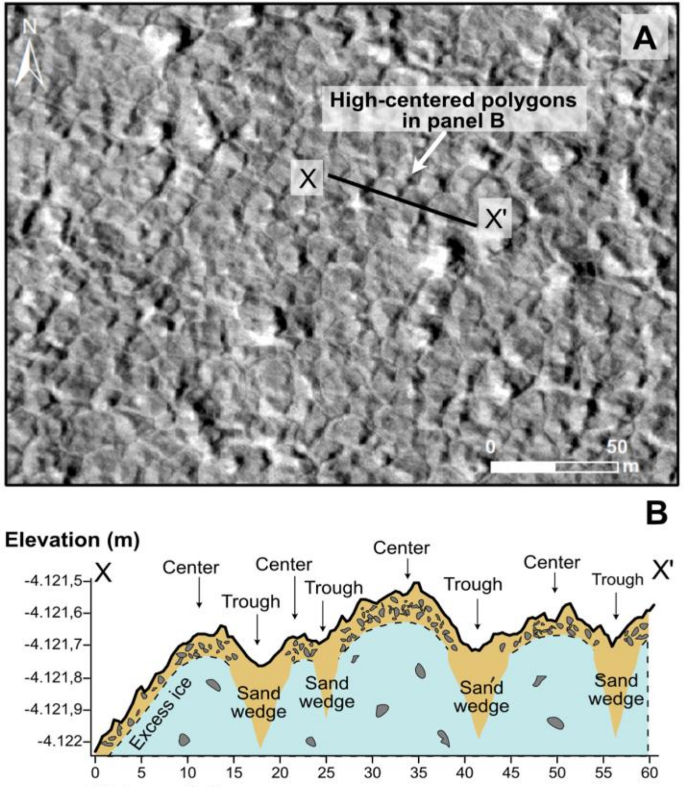


Levy et al. (2011)

Thermal-contraction polygons

- These polygons have sand wedges beneath the troughs and sorted coarse-grained material, which enhances sublimation in the margin of the polygon, deepening the troughs and making the polygons high-centered (Levy et al., 2011).

- This type of polygons are typical of cold and dry environments and are a proxy for excess ice.



Luzzi et al. (in prep.)

Thermal-contraction polygons

- Mellon et al. (2014) developed a numerical model to predict the ice table depth from the polygons' diameter in Antarctica: Results = 10 cm ice depth for 10 m diameter polygons (confirmed by ground truth).
- At the Phoenix landing site where we have ground truth on Mars, the ice below polygons with a diameter of 3-5 m is 6 cm deep (Mellon et al., 2008).
- We expect the depth of the ice table beneath the polygons in Arcadia Planitia to be on the order of 10 cm.

Antarctica

Polygon Diameter: 10 m

Ice depth: 10 cm

Phoenix

Polygon Diameter: 3-5 m, 15 m

Ice depth: 6 cm, 10 cm

Arcadia

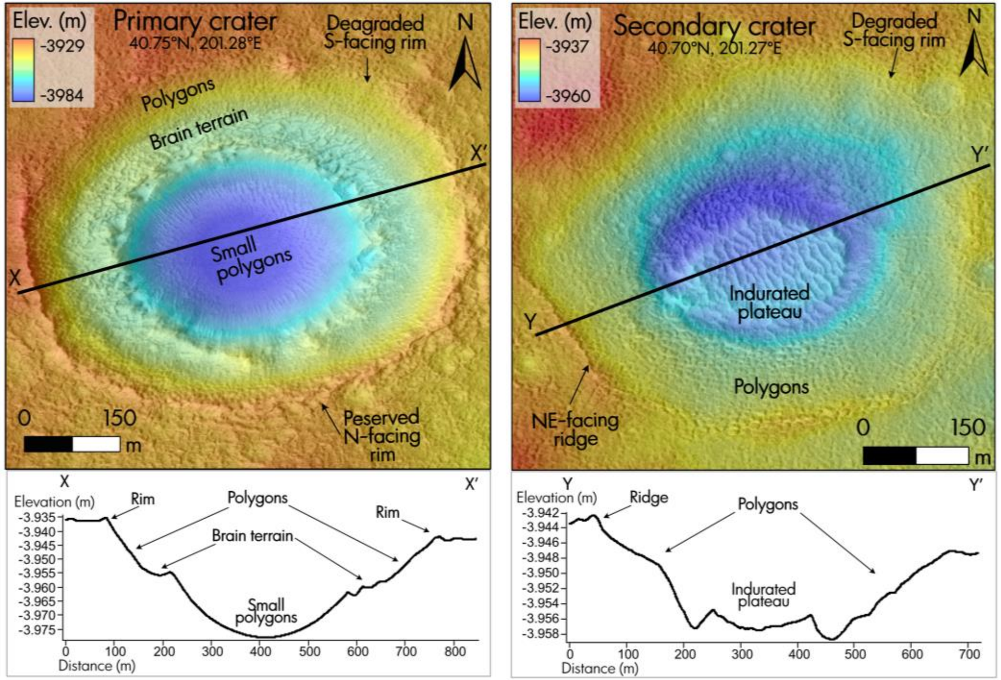
Polygon Diameter: 11 m

Ice depth: 7-10 cm

Craters expanded by sublimation

- Craters expansion is due to sublimation of the ice exposed by the impact;

- Expanded craters in this region exhibit a bounding ridge in the SW side: different ice ablation rates are likely due to the different orientation of the scarps (Williams et al., 2022);

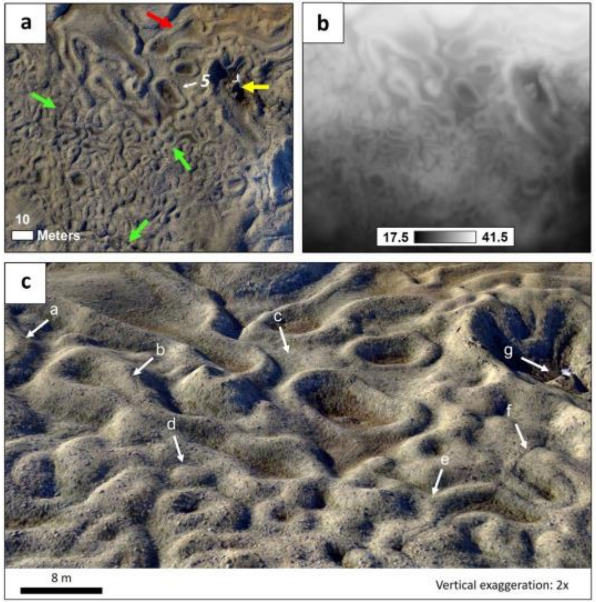


Luzzi et al. (in prep.)

Brain terrain

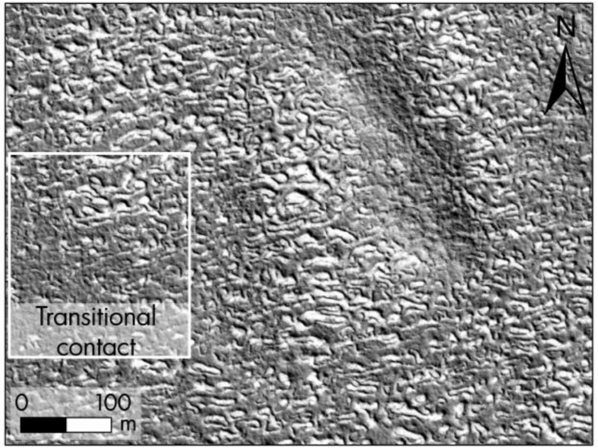
- Anastomosing pattern of ridges and troughs, arranged in a "brain-like" pattern;
- Recently, Hibbard et al. (2022) associated it with terrestrial Vermicular Ridge Features (VRFs);
- VRFs are the result of ablation of buried glacial ice.

VRFs on Earth



Hibbard et al. (2021)

Brain terrain in Arcadia Planitia



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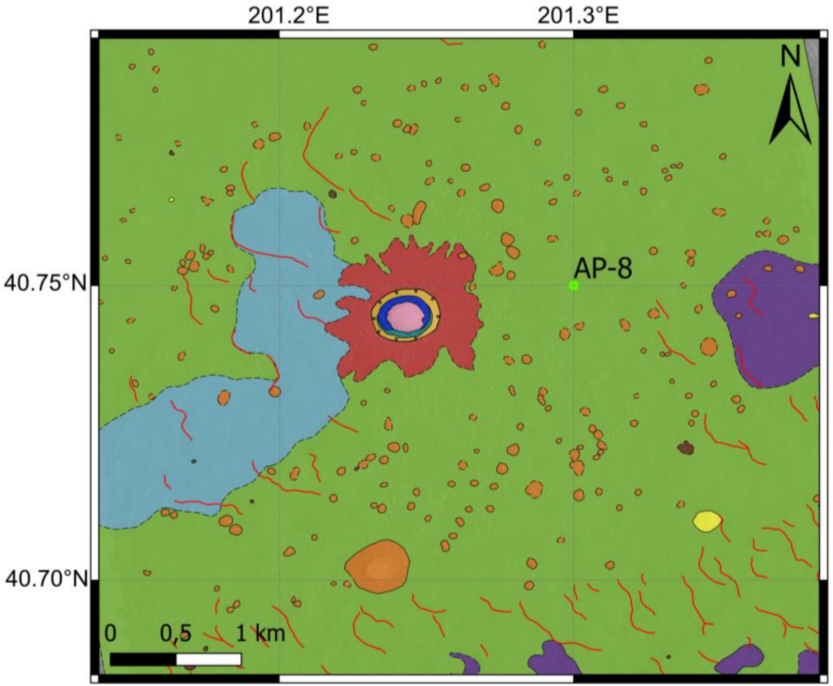
Here comes the map!



Legend	Description
Brain terrain	Anastomosing patterns of sets of high-albedo ridges and troughs resembling a brain. Located within the terrace of a terraced crater
Crater floor	Polygonized crater floor, covered by numerous dunes
Crater wall	Polygonized scarp. The measured slope is ~10-13°
Ejecta	Remnants of the ejecta from the impact crater, overprinted by heavy modification due to thermal contraction
Expanded secondary crater	Polygonized expanded secondary craters
Hummocky Unit	Polygonized low-albedo terrain, with dense clusters of mounds, rarely affected by arcuate ridges
Knobby Unit	Polygonized low-albedo terrain, with knobby surfaces locally affected by arcuate ridges
Mound	Isolated and small high-albedo conical mounds
Pingo-like feature	Large and polygonized collapsed mounds, with radial and concentric fractures
Smooth Unit	Polygonized and smooth low-albedo terrain with sparse knobs. Heavily affected by arcuate ridges, especially in the SE sector
Terrace	Polygonized terrace within an impact crater

Crater rim — Certain contact
Arcuate ridge — Inferred contact

Take-home messages

- Technology is taking giant steps forward to enable human settlements on Mars;
- ISRU is key for successful exploration missions, and multiple types of remote sensing data can provide useful information to help us prepare for the most spectacular journey in the history of mankind;
- The candidate landing sites located in Arcadia Planitia meet multiple conditions favorable to human exploraton: mid-latitude location, evidence for near-surface ice (crucial for ISRU), flat topography for a safe landing, etc.;
- Maps are an incredibly valuable contribution, so I hope you paid attention during this week;
- If you have any question, go for it!

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Thank you!

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