USGS
science for a changing world

# The Lunar Environment: A 30,000' View

## A short course for the Keck Institute for Space Studies workshop

By Dr. Lori Pigue,
U.S. Geological Survey, Astrogeology

# TOPICS

Lunar formation and composition

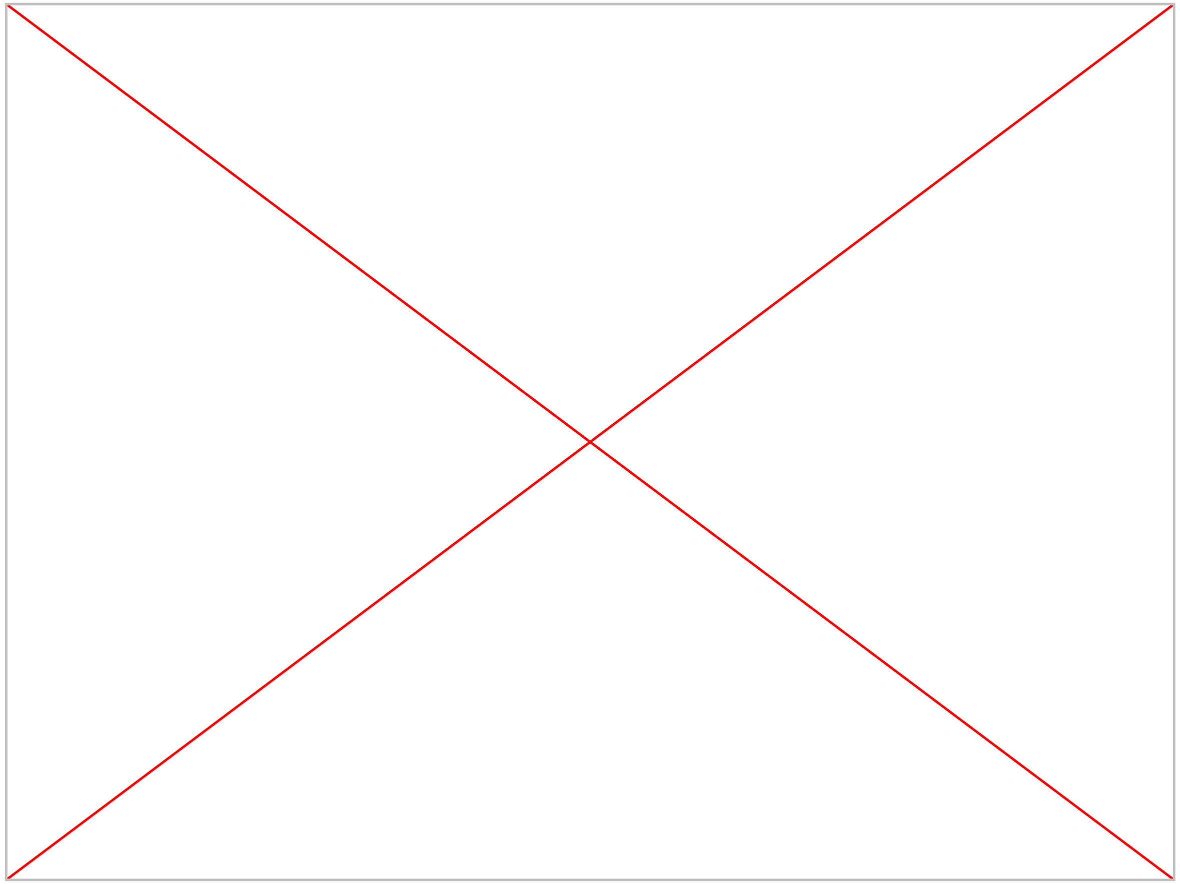
Thermal conditions and thermophysical properties

Dust lifting and regolith properties

Lighting and the horizon

# IN THE BEGINNING…

- Our modern system formed from a giant impact of a Mars-sized body and proto-Earth about 4.5 billion years ago
- Leaving the Moon molten and cooling
- Early in lunar history, the surface was covered in an ocean of magma
- As this ocean began to cool, the Moon differentiated into the surface features that we observe today

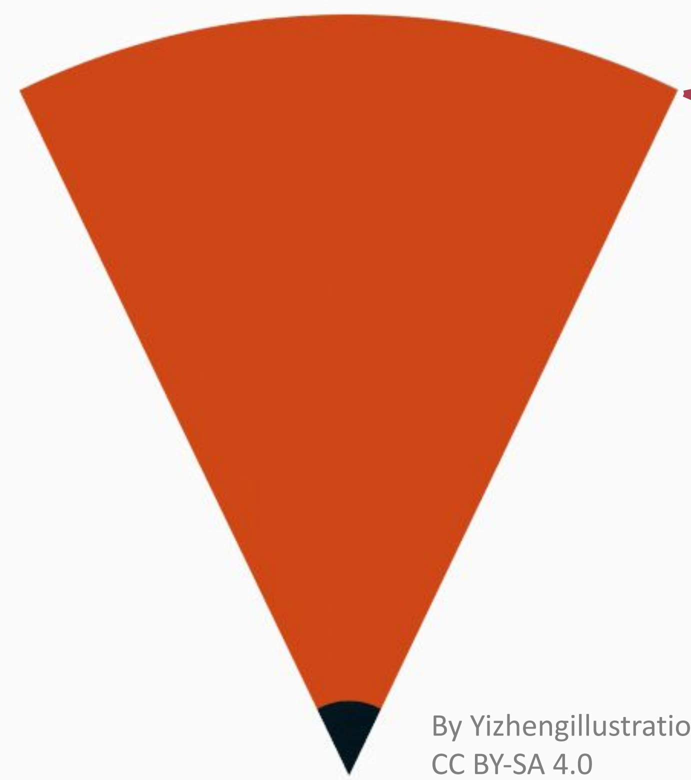


Simulation by Durham University's Institute for Computational Cosmology

# CRUSTAL FORMATION

## Lunar Magma Ocean

- Accumulation of heavy minerals continues until lighter elements and minerals start to crystallize out of the melt, accumulating at the top.





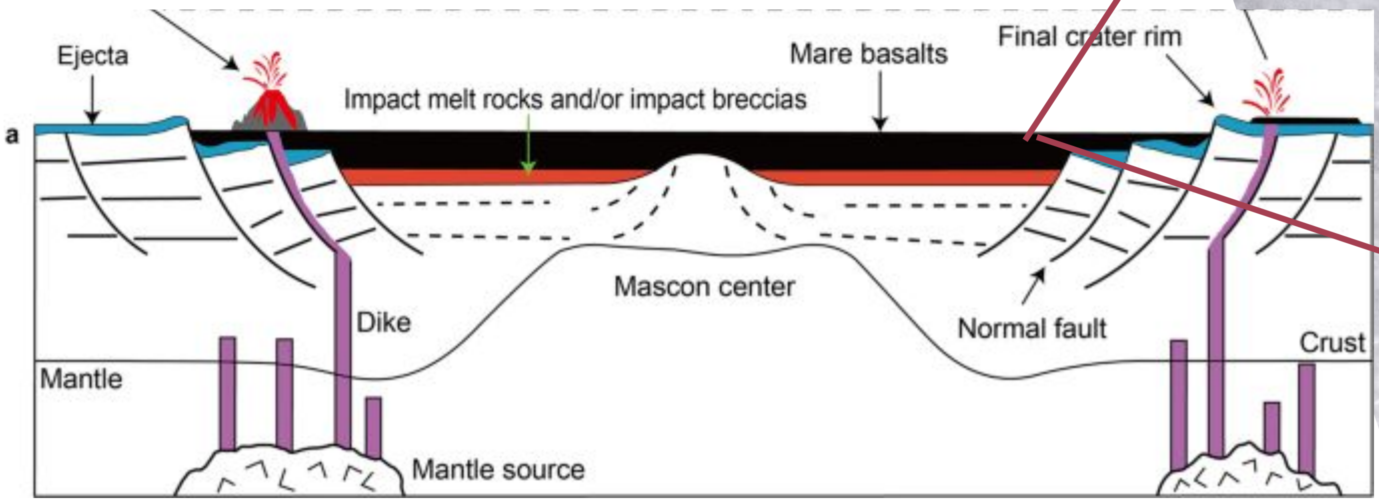
- Heavier elements and minerals (olivine, pyroxene) sink to the bottom during melt crystallization

# CRUSTAL FORMATION

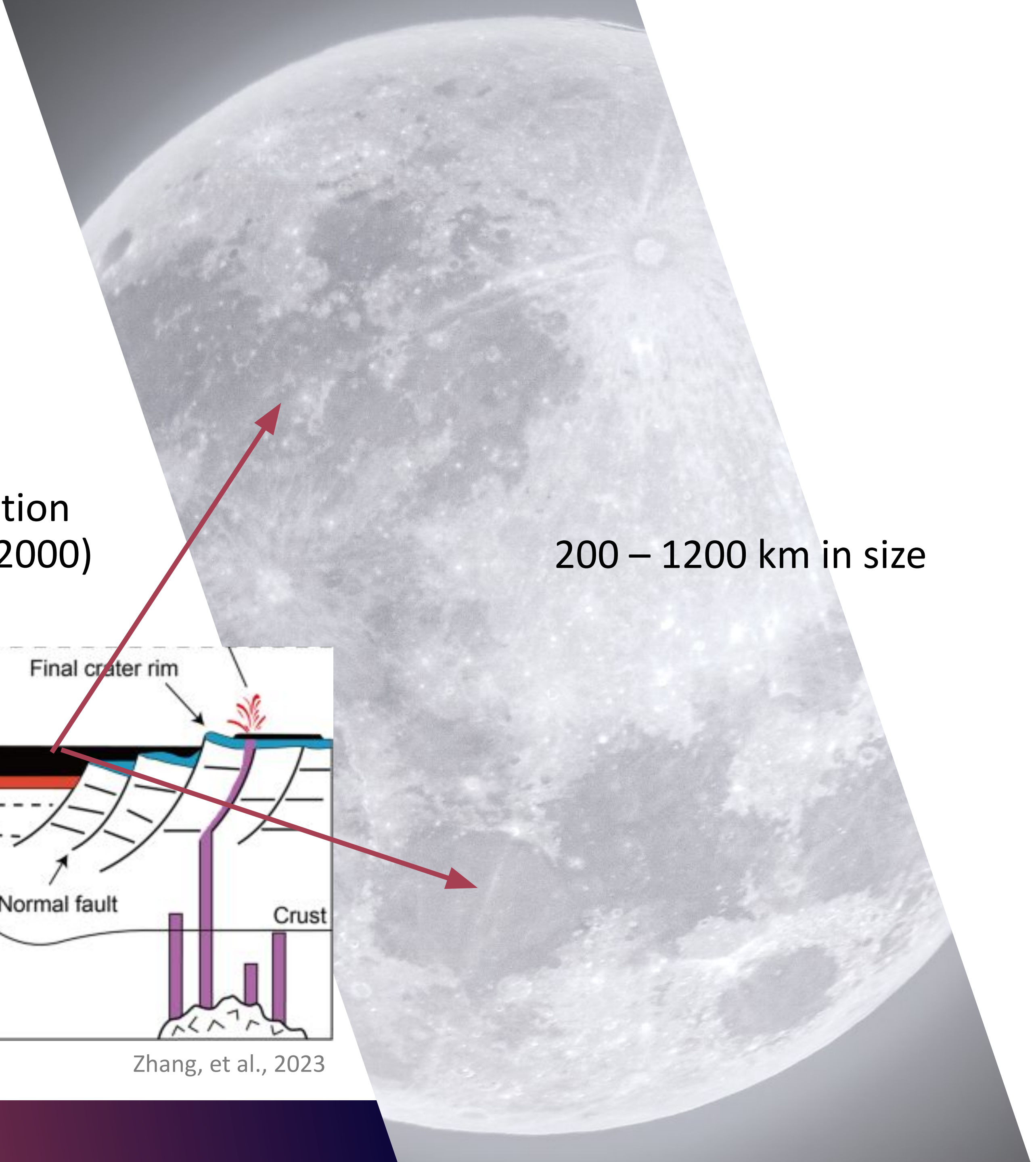
## Lunar Magma Ocean

## Basin Formation

- The specific relationship between basin formation and lava infill is still debated (Hiesinger et al., 2000)




Zhang, et al., 2023



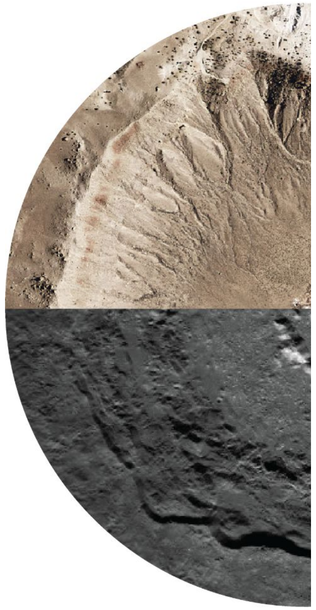
200 – 1200 km in size

# CRUSTAL FORMATION

Lunar Magma Ocean

Basin Formation

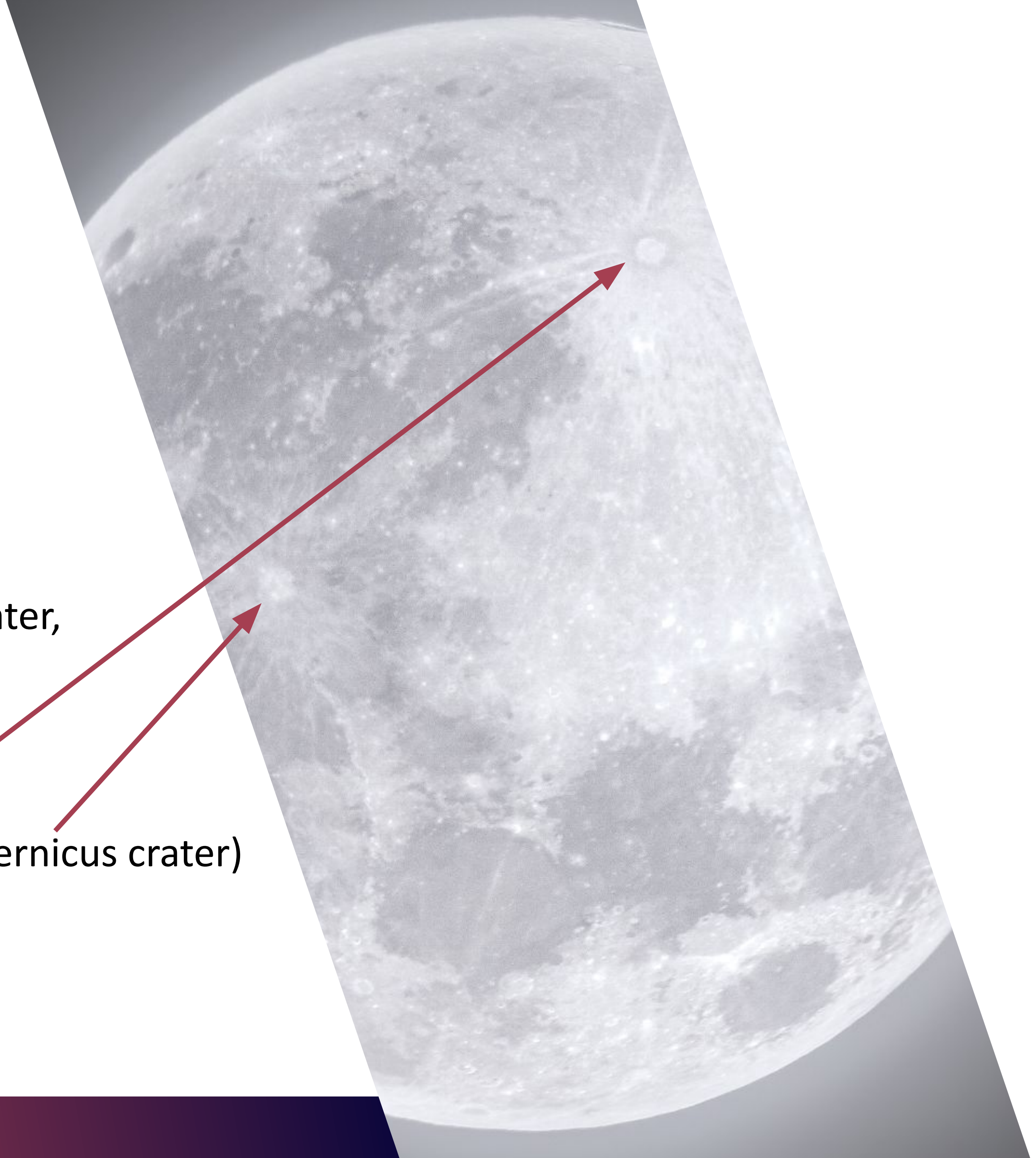
## Impact History



- Simple crater on Earth (Meteor Crater, Arizona)

- Complex crater on the Moon (Copernicus crater)

(not to scale to each other)



# CRUSTAL FORMATION

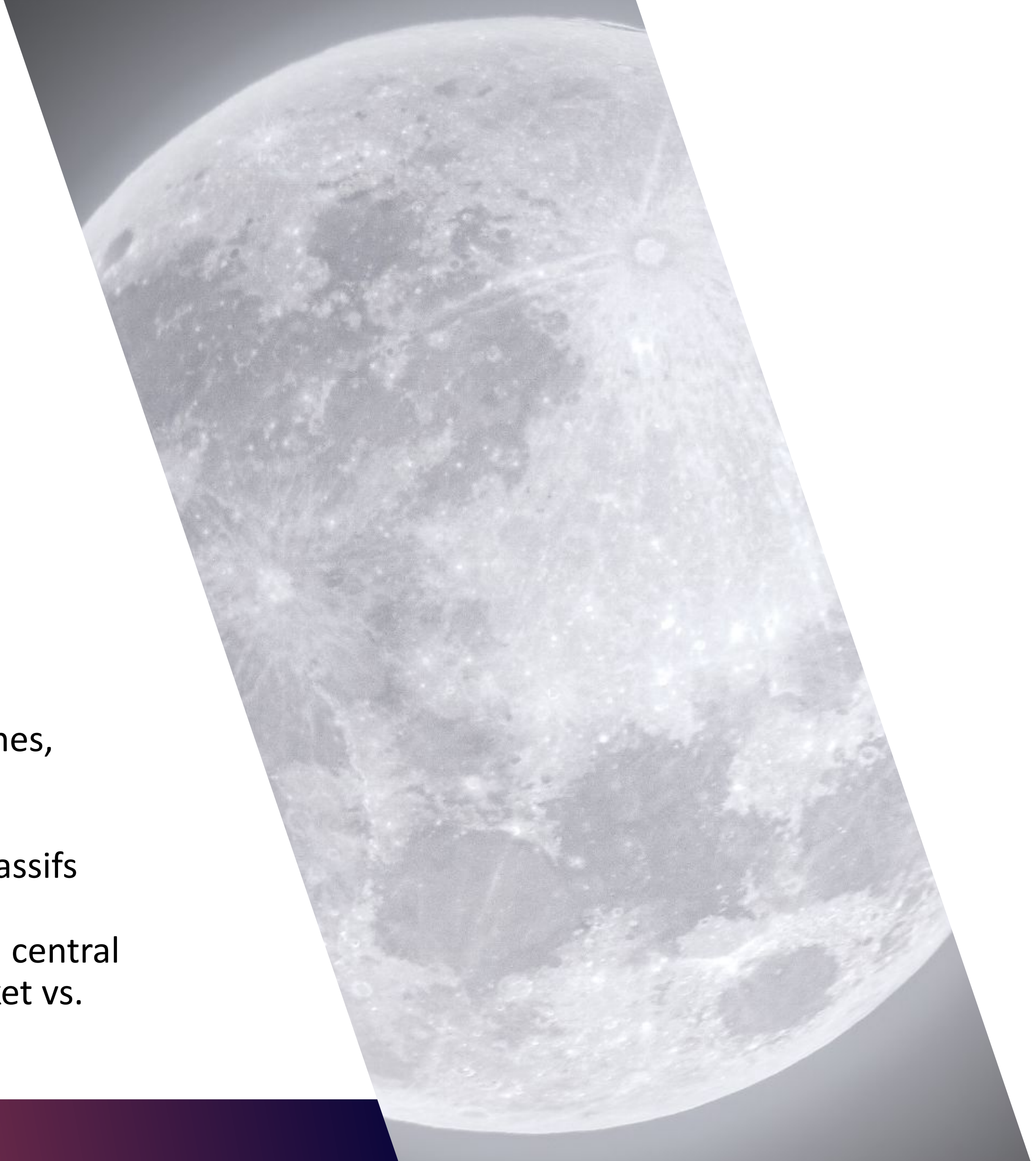
## Lunar Magma Ocean

## Basin Formation

## Impact History

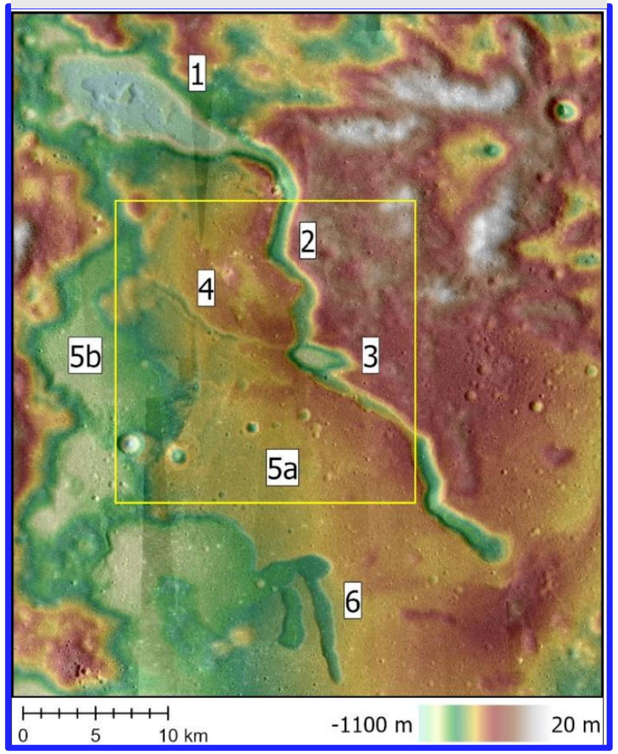
## Other Terrains

- Volcanic deposits: non-mare lava flows, lava tubes, pyroclastic deposits, irregular mare patches, lava domes, silicic domes
- Lunar swirls, thrust faults, wrinkle ridges, highland massifs
- Floor-fractured craters, multi-ring basins, craters with central peaks, impact melt vs. impact breccia vs. ejecta blanket vs. crater ray

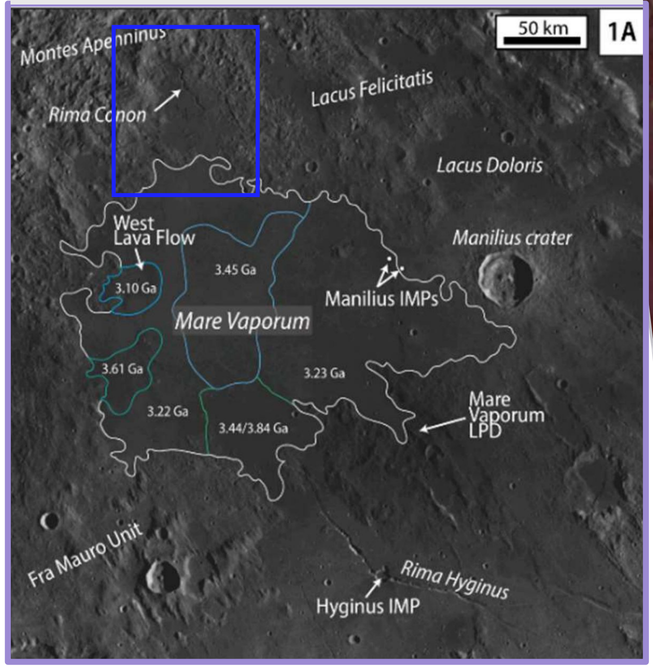


# Understanding your site will involve investigations at multiple scales

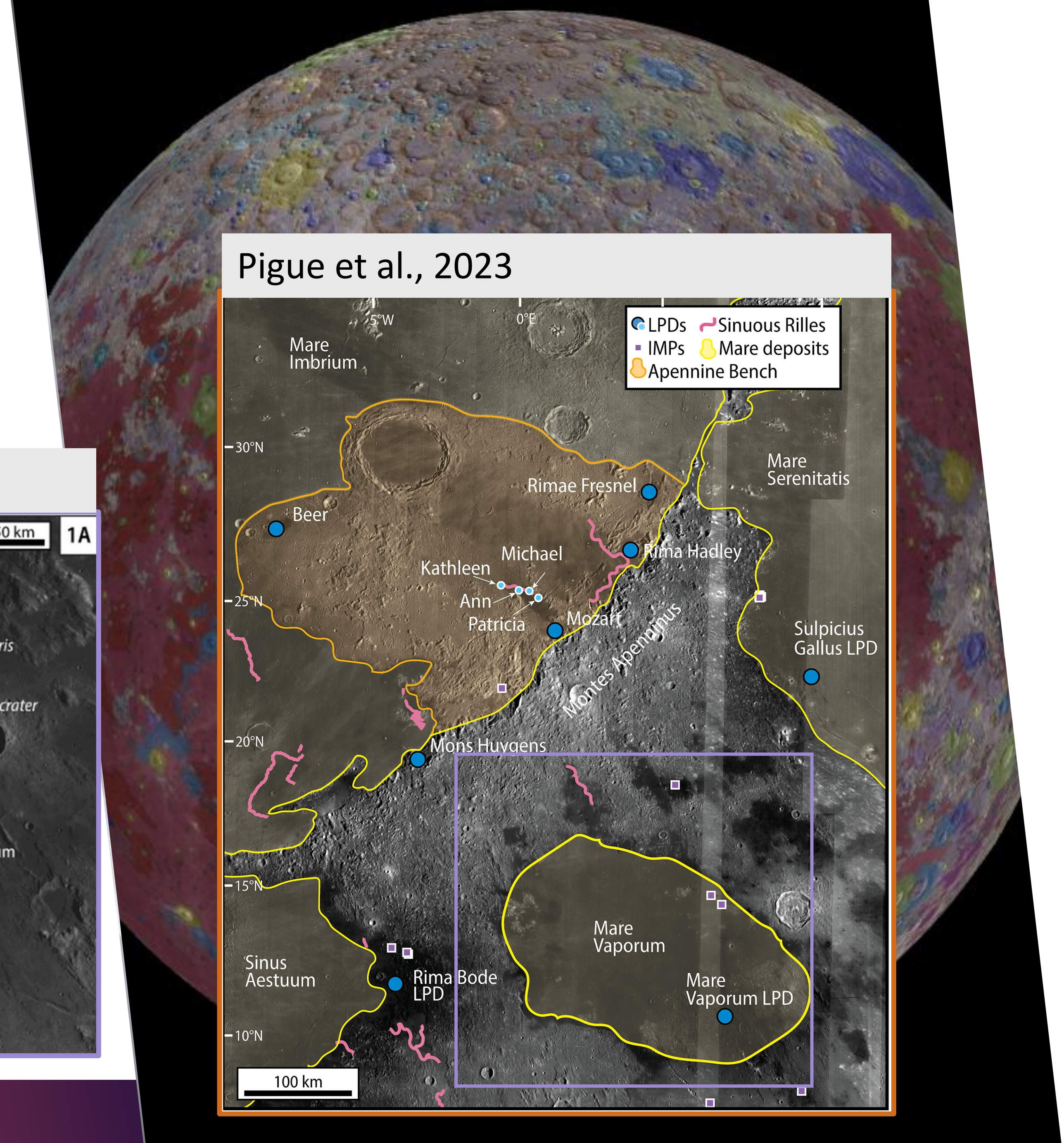
Fry et al., 2024



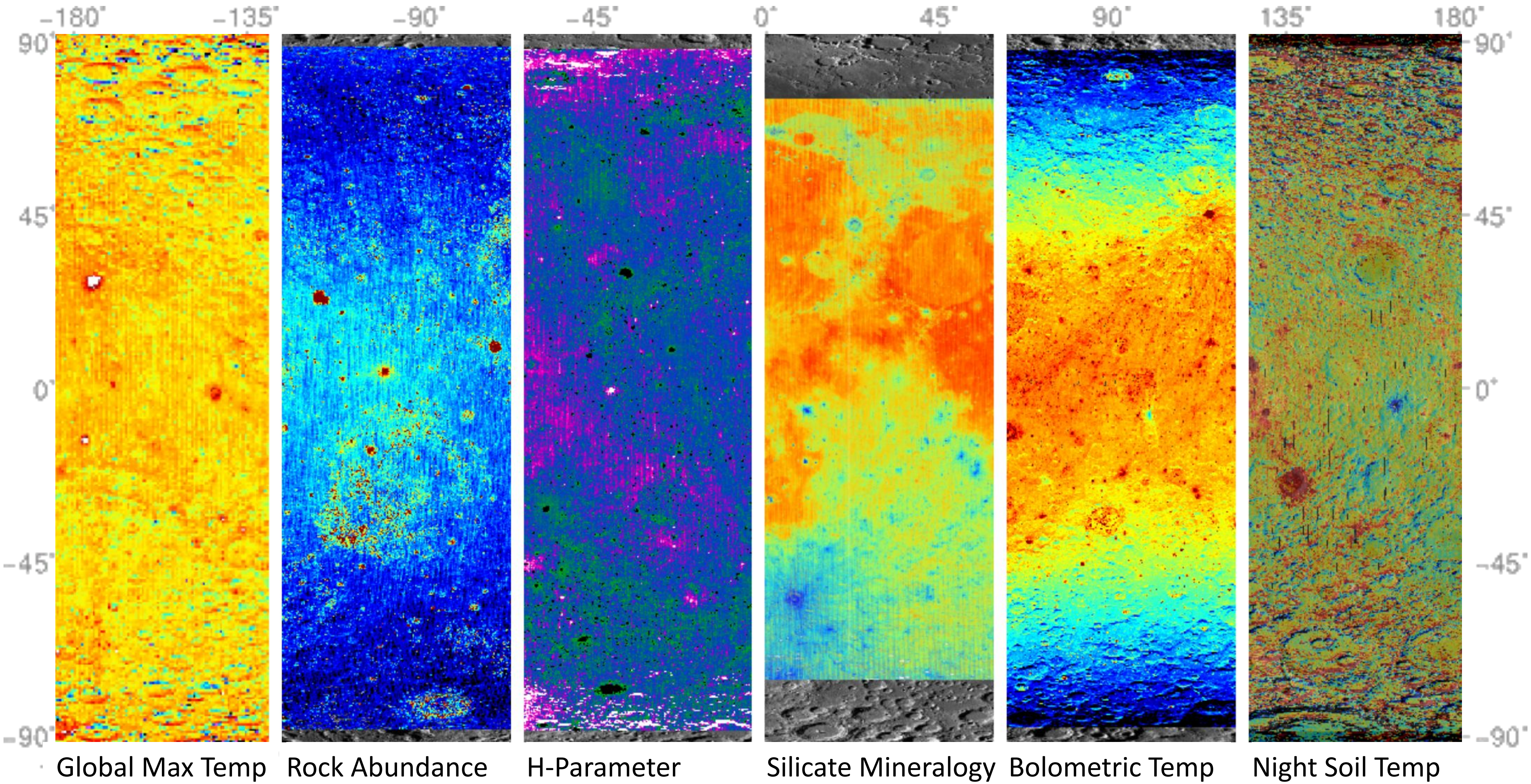

Pigue et al., 2024




Fortezzo et al., 2020



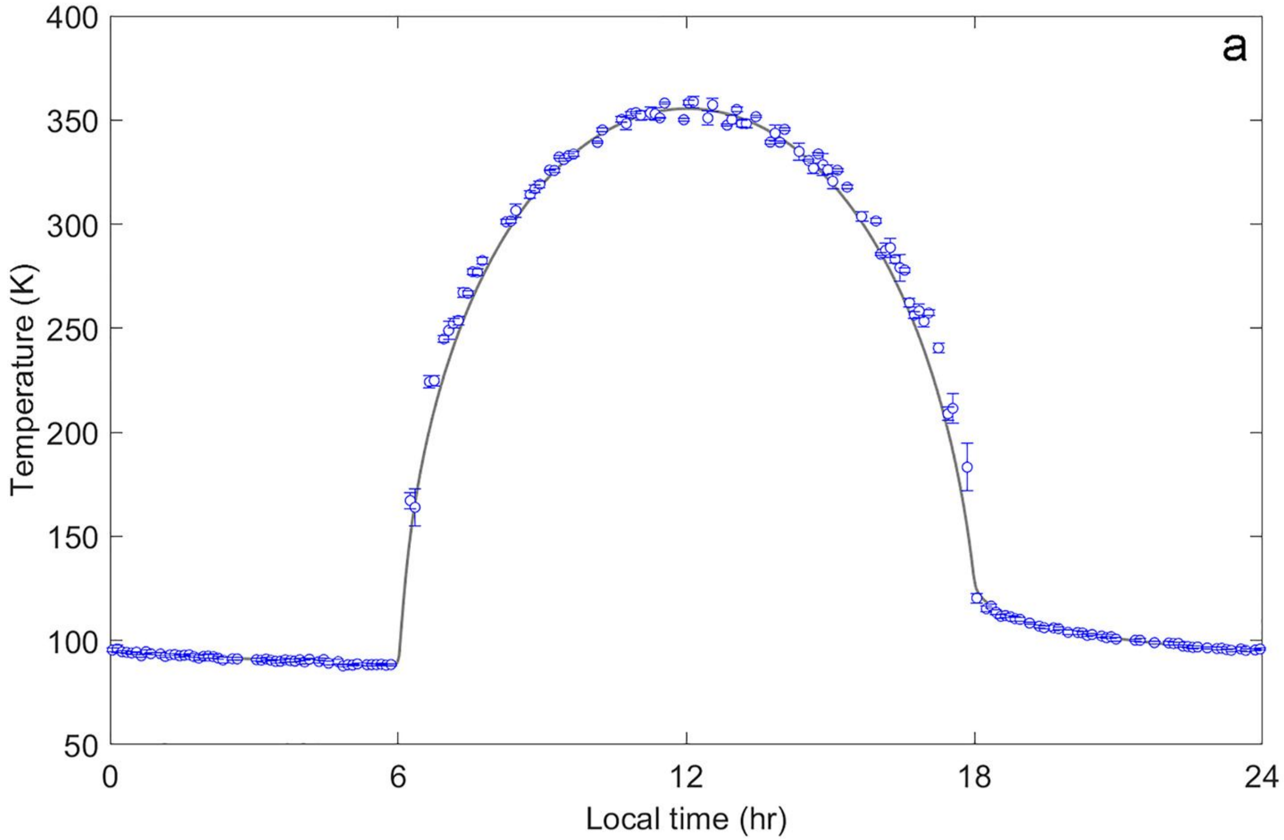
Pigue et al., 2023



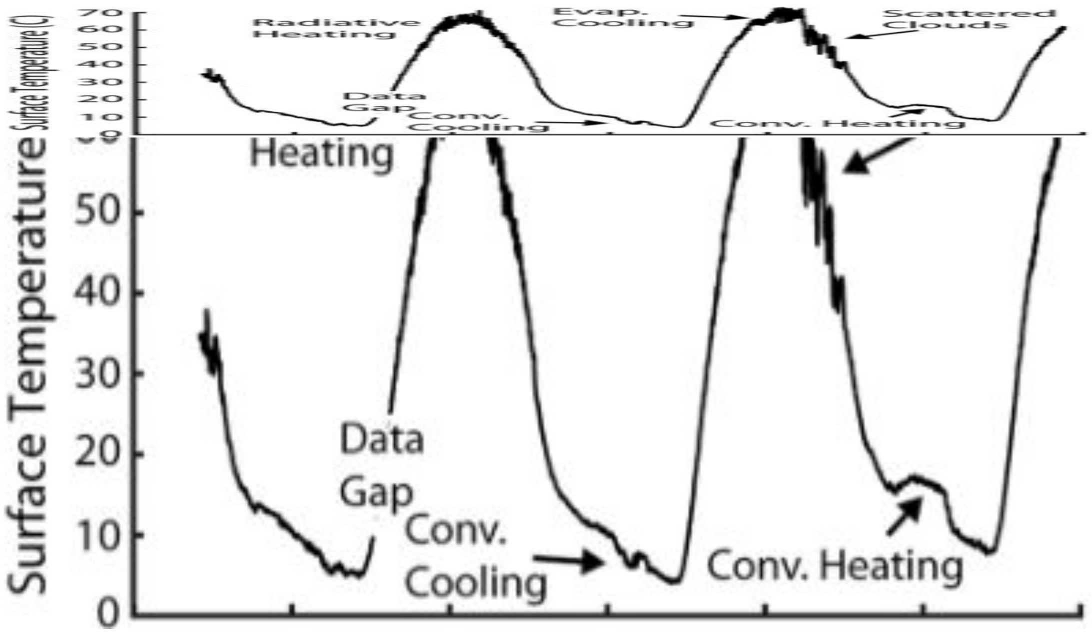

Williams, et al., 2017

# THERMAL AND THERMOPHYSICAL PROPERTIES

# Lunar surface temperatures have a wide range, unmediated by an atmosphere

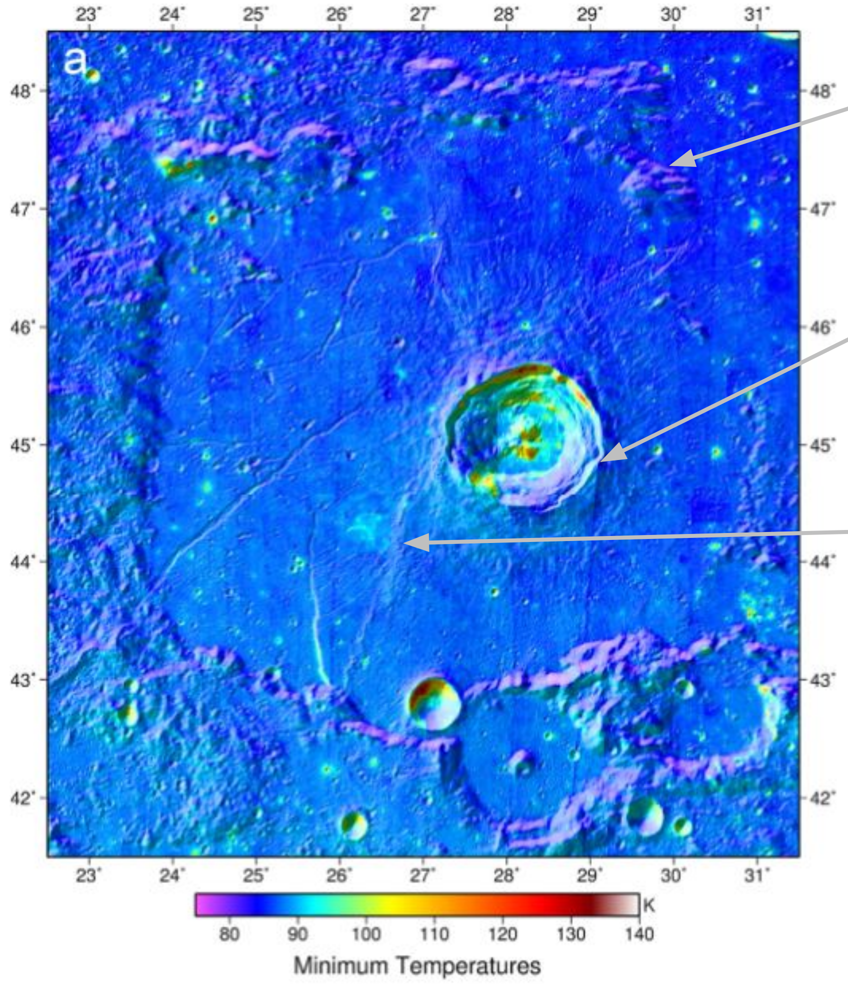



Moon
Williams, et al., 2022




Earth (basaltic cinder)
Koeppel, et al., 2024

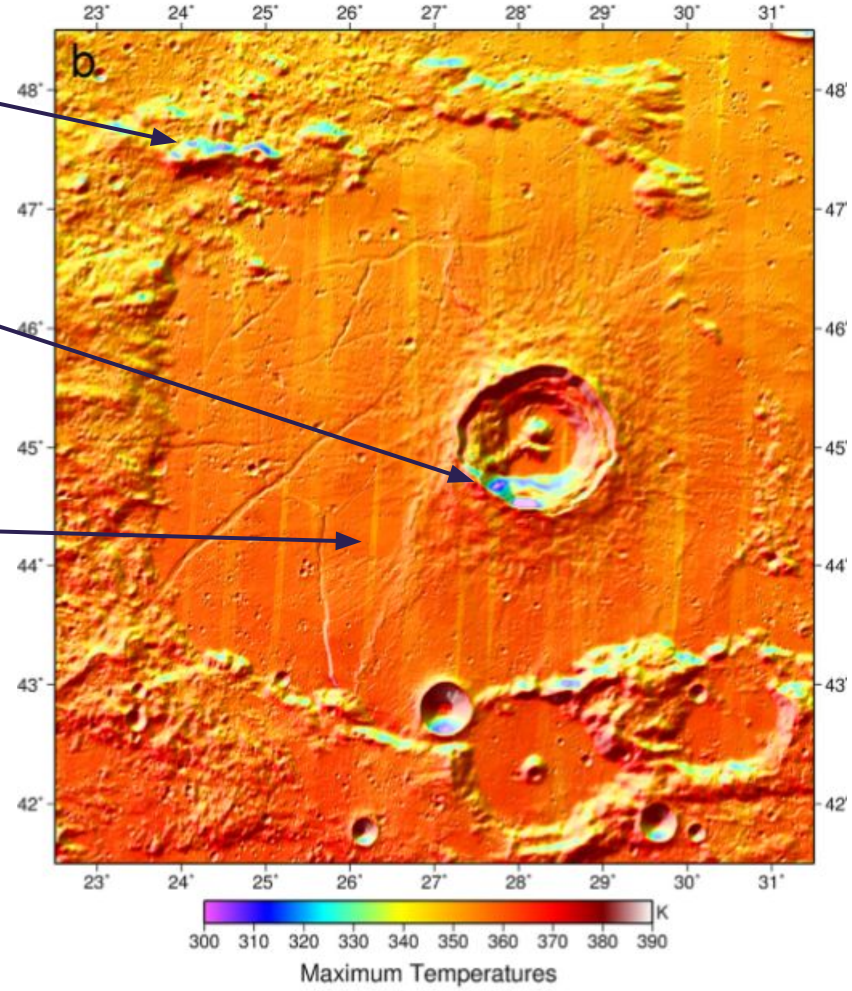
# Lunar surface temperatures have a wide range, unmediated by an atmosphere, and largely controlled by material properties.




Polar-facing slopes

Exposures of variable compositions

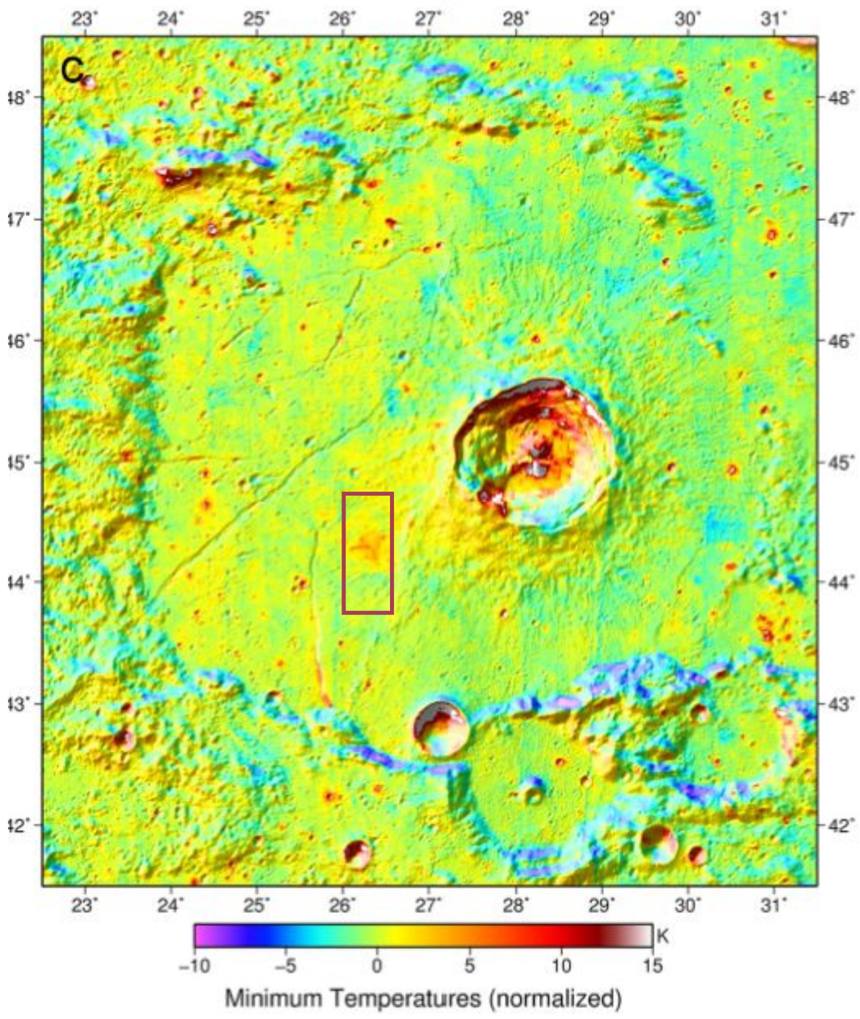
Variable albedo

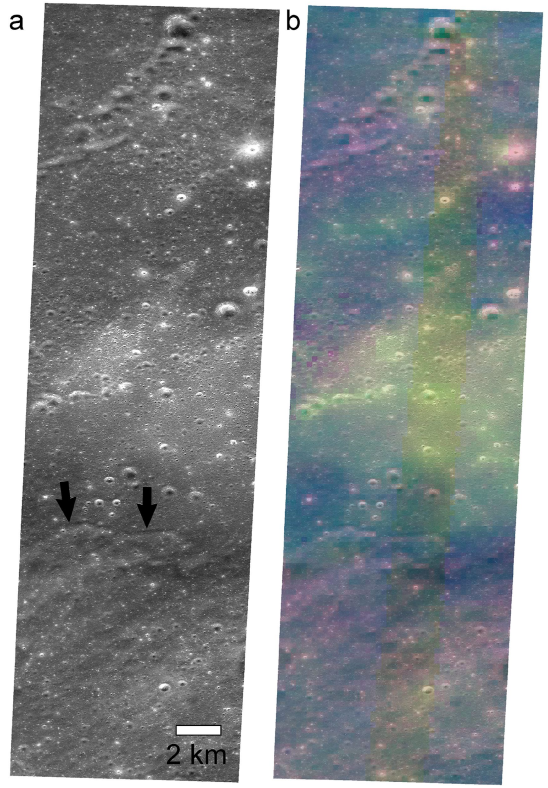



N

Williams, et al., 2022

# Variability in daytime maximum temperatures and nighttime minimum temperatures can be used to evaluate surface conditions



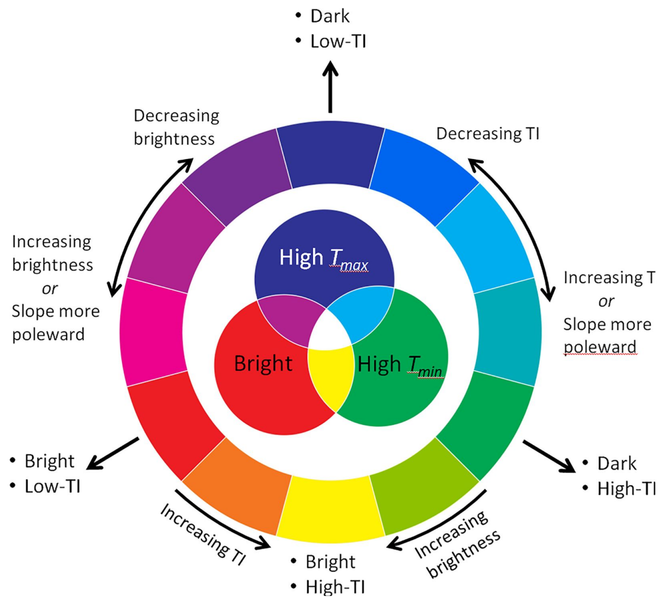

*LROC NAC*

**RGB Composite:**

R: Brightness

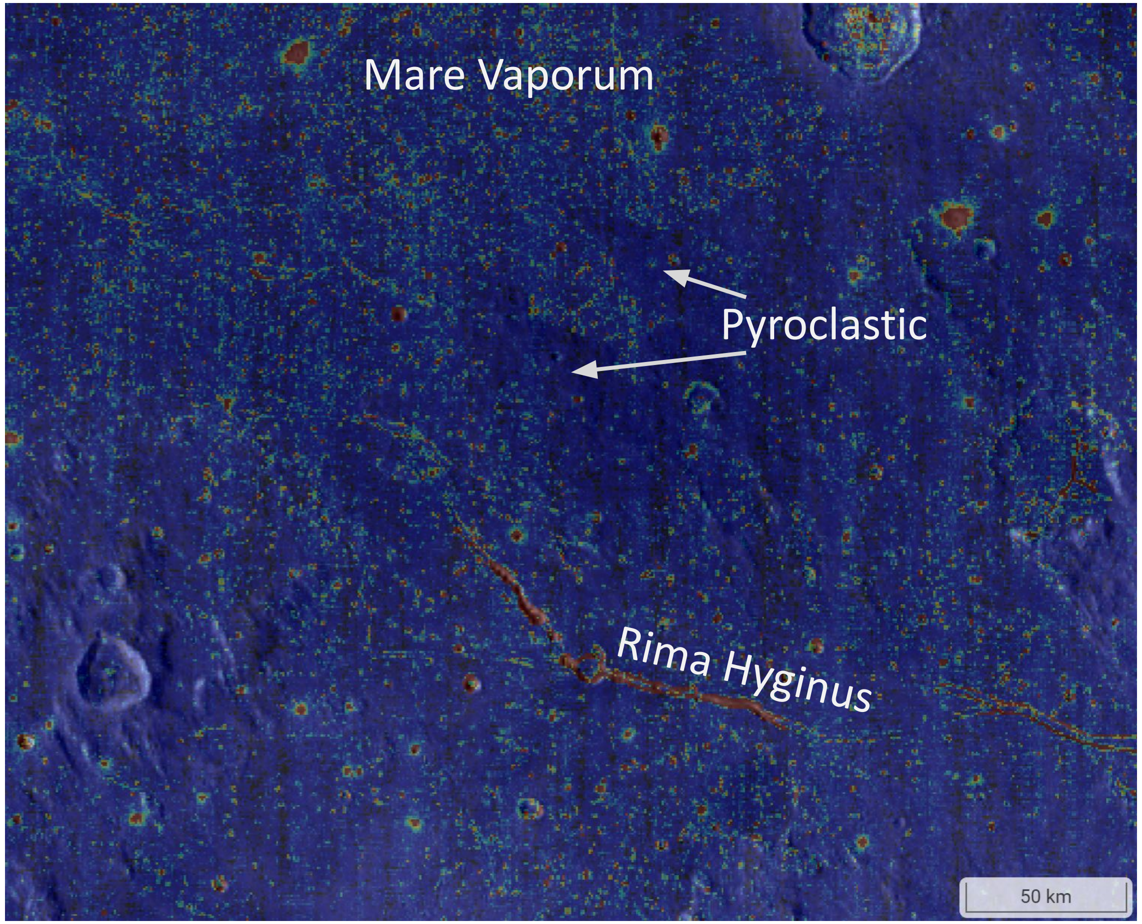
G: Normalized minimum temperature

B: Normalized maximum temperature




Williams, et al., 2021

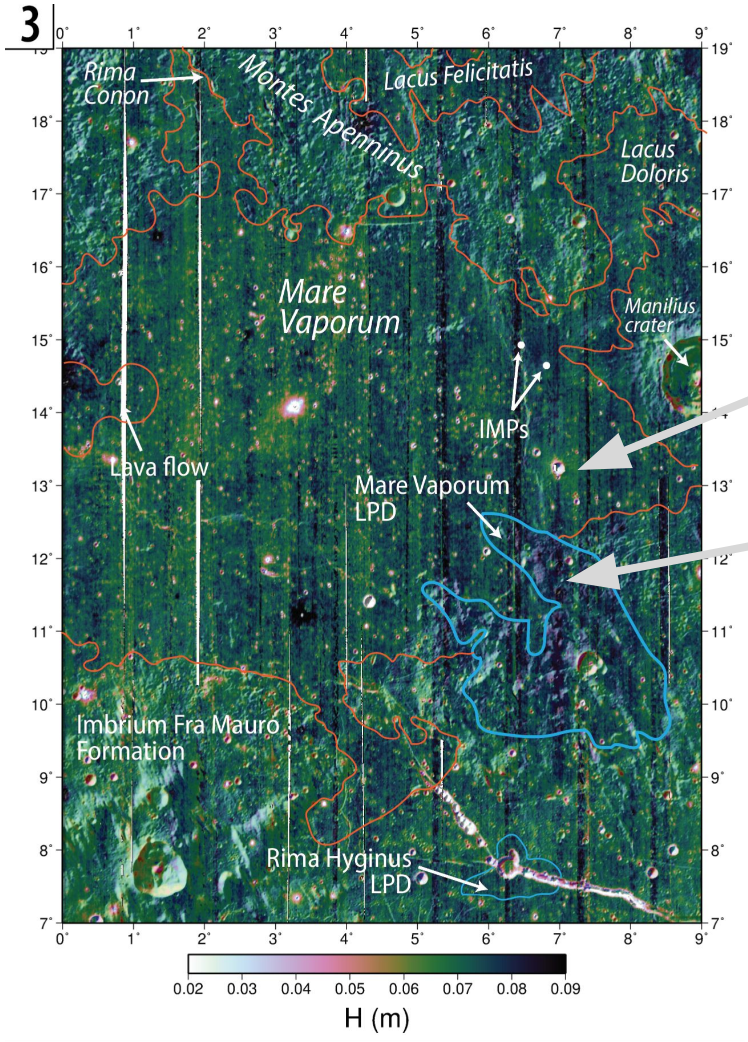
# Variability in daytime maximum temperatures and minimum nighttime temperatures can be used to derive thermophysical properties




Powell et al., 2023 via LROC Quickmap

Rock abundance is defined as the fractional area within an observation occupied by rocks that are larger than a defined size (~1-2 m in this map).

# Variability in daytime maximum temperatures and minimum nighttime temperatures can be used to derive thermophysical properties




A column of lunar regolith is assumed to increase in density and conductivity with depth. The regolith density with depth can be modeled and characterized as a free parameter known as the H-parameter.

Lower H-parameter values indicate a higher density in the upper ~10 cm.

Higher H-parameter values indicate a lower density regolith (”fluffier”) in the upper ~10 cm

Note differences here between mare (mostly center) and highland (Montes Apenninus and Imbrium Fra Mauro Formation). Regolith can vary greatly between terrains, with age, and with formation history (pyroclastic vs. effusive volcanism)

# DUST LIFTING AND REGOLITH PROPERTIES

Lunar regolith has unique physical and chemical properties that makes the lunar surface a challenging exploration environment

- Glassy, silicate-rich
- Sharp
- Electrostatic
- Insulating

The "lunar hay fever", as Apollo 17 astronaut Jack Schmitt described it, created symptoms in all 12 people who have stepped on the Moon.


An artist rendering of an astronaut working on the lunar surface during a future Artemis mission.
Credits: NASA

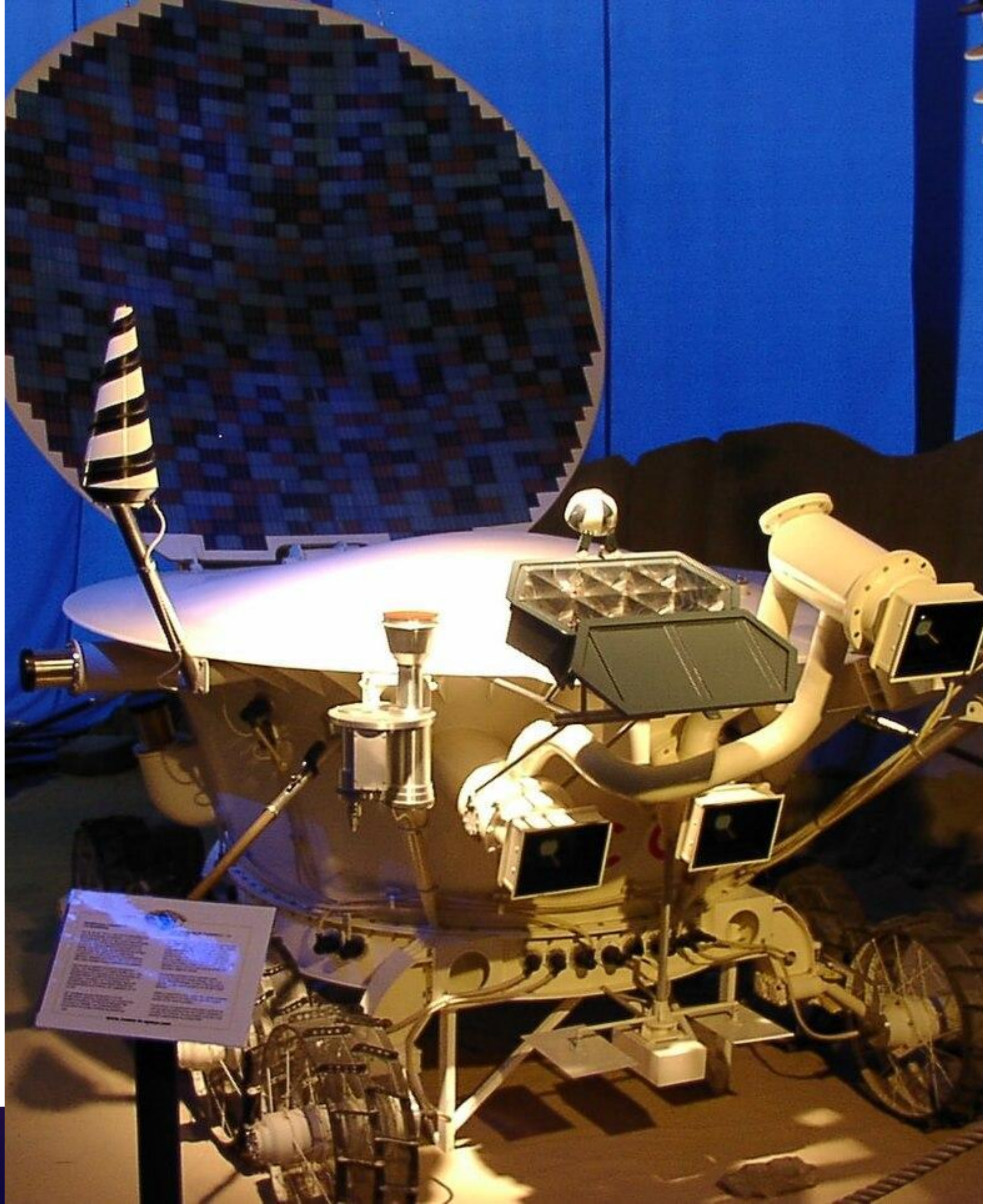
# CASE STUDY: LUNOKHOD-2

Power was supplied by a solar panel, which would charge the batteries when opened.

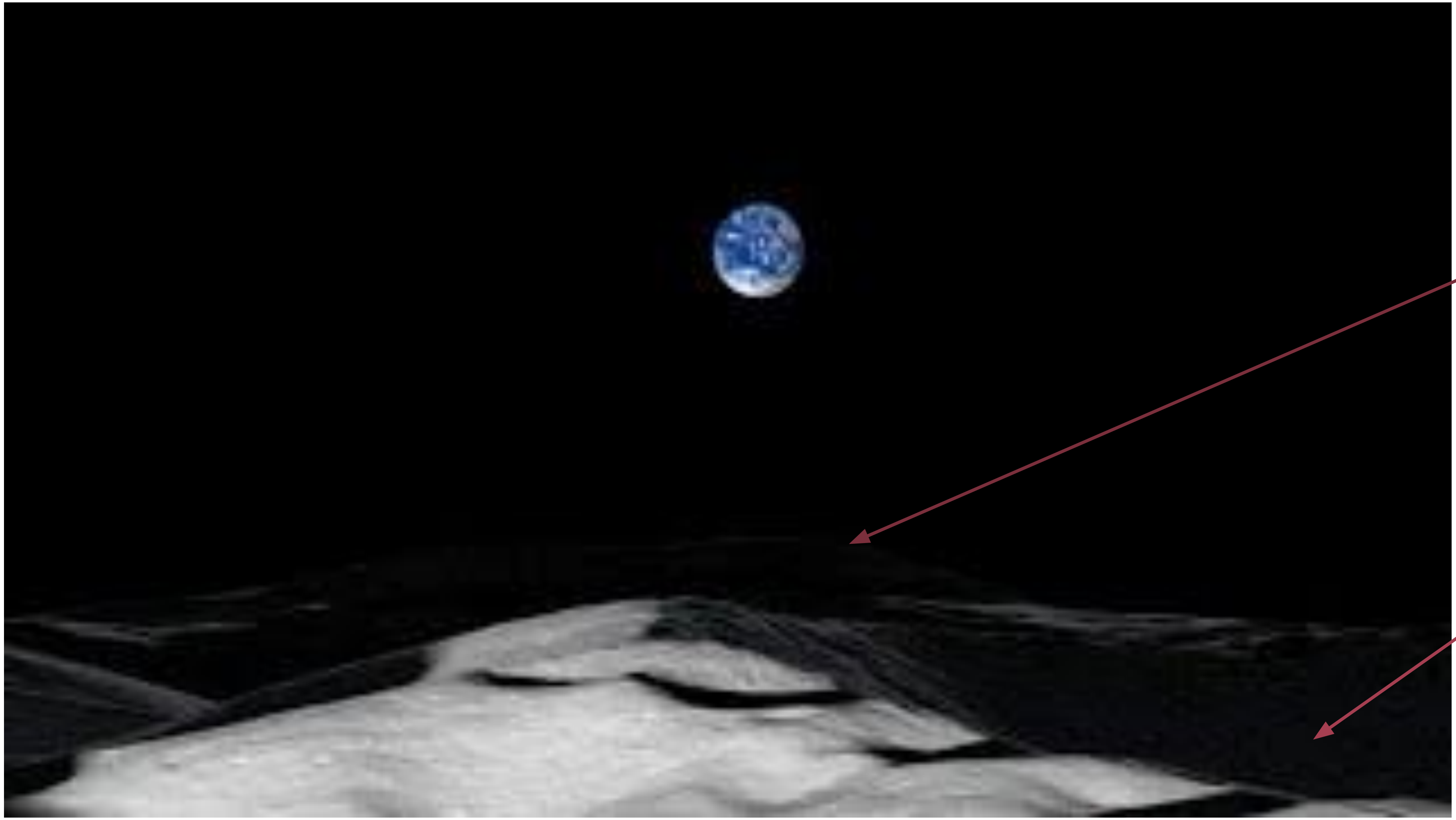
A polonium-210 radioisotope heater unit was used to keep the rover warm during the long lunar nights.

- On May 9 (one month before EOM declared), the rover's open lid touched a crater wall and became covered with dust. When the lid was closed, this dust was dumped on to the radiators.
- The following day, May 10, controllers saw the internal temperature of Lunokhod-2 climb as it was unable to cool itself, eventually rendering the rover inoperable.
- On May 11, signal from the rover was lost.

*"We put on this radiator the best insulator—lunar soil," Basilevsky laments.*



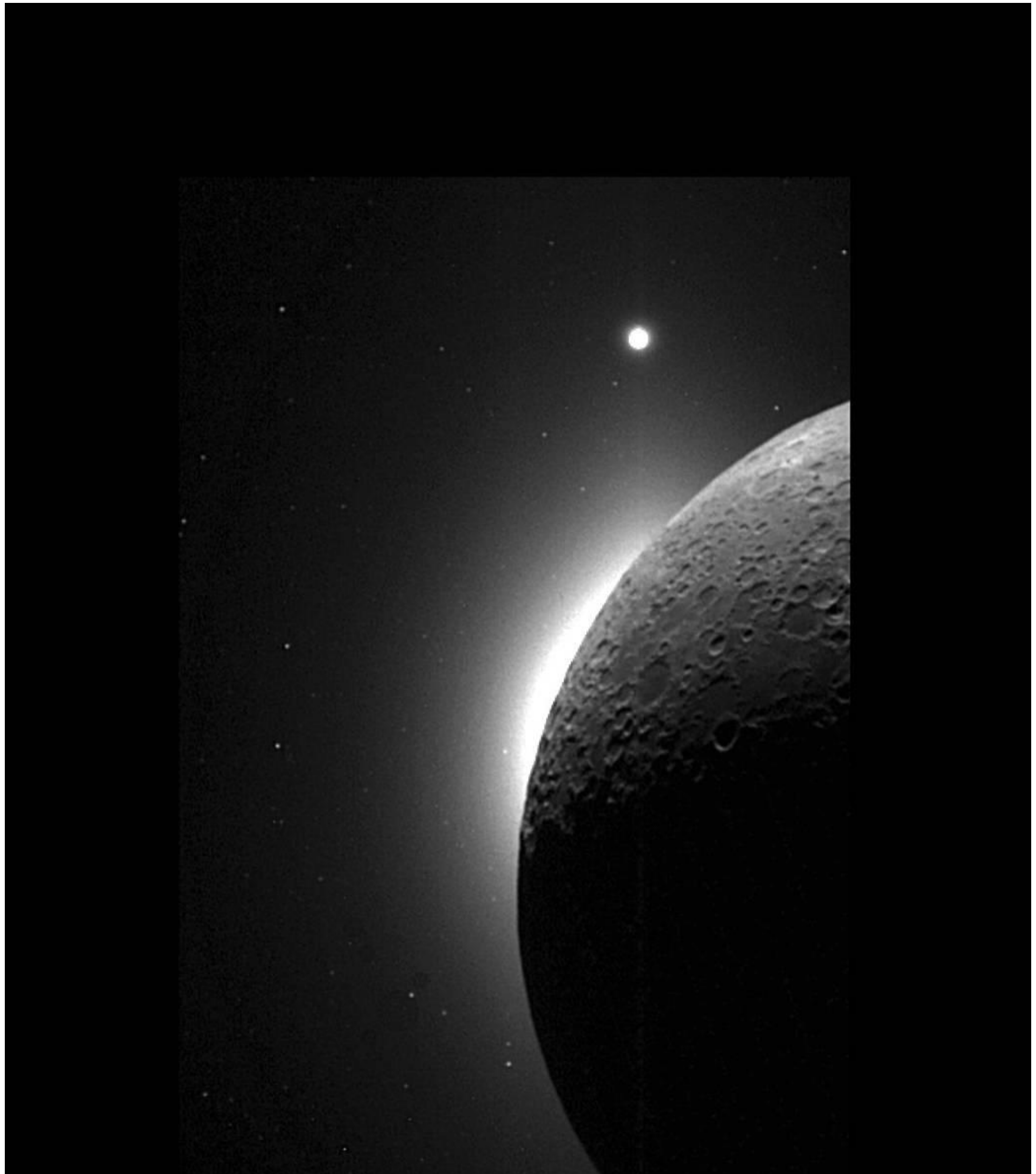
# LIGHTING AND THE HORIZON




Earth, Sun from Moon's South Pole (youtube.com)

# YOU’RE GLOWING!

- Sorry, no glorious sunsets on the Moon like we get on Earth or Mars
- Instead, sunsets through dust particles in the thin lunar exosphere produce a “lunar horizon glow”
- Charged dust can levitate above the surface, creating “fairy castle structures” on the surface or lofting it tens of kilometers above the surface.
- This dust cloud forward scatters light, creating the lunar horizon glow. Electrostatic charging is thought to eject tens of millions more particles than micrometeoroid impacts. The term "Moon fountain" has been used to describe this effect.



In this picture from the Clementine startrackers, the Moon is seen illuminated solely by light reflected from the Earth (Earthshine). The bright glow on the lunar horizon is caused by light from the solar corona; the Sun is just behind the lunar limb.
Credit: JPL/NASA/USGS

# A LITTLE PERSPECTIVE

- Because the Moon is smaller than Earth, its horizon will look shorter and closer.
- To someone standing on a level Earth surface, the horizon is about 3 miles away on a clear day.
- On the Moon, the horizon will be only about 1.5 miles away. Depending on the local terrain, this could present some potential engineering differences with line of sight, body curvature considerations, and navigation.
- The lack of atmosphere will also alter our depth and height perception, making it nearly impossible to tell how far away something is

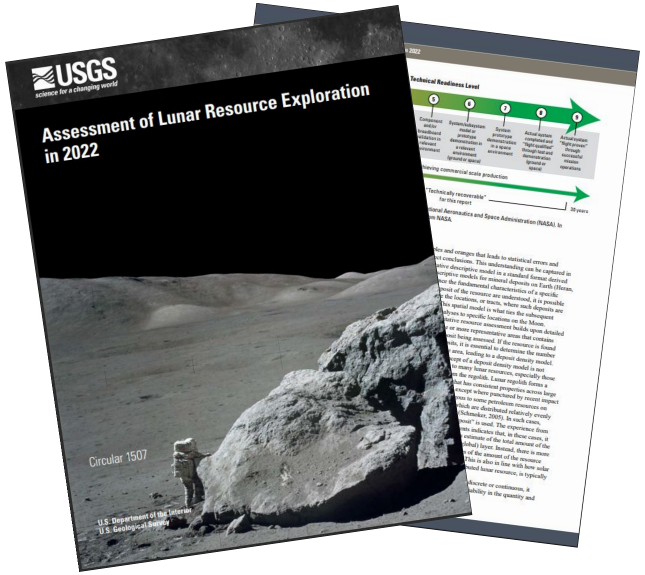
*Earthrise, Apollo 11. Credit: NASA*

# THANK YOU

Lori Pigue
lpigue@usgs.gov

US Geological Survey
Astrogeology Science Center

USGS Assessment of Lunar Resources in 2022
Circular 1507





*Earthrise, Apollo 11. Credit: NASA*