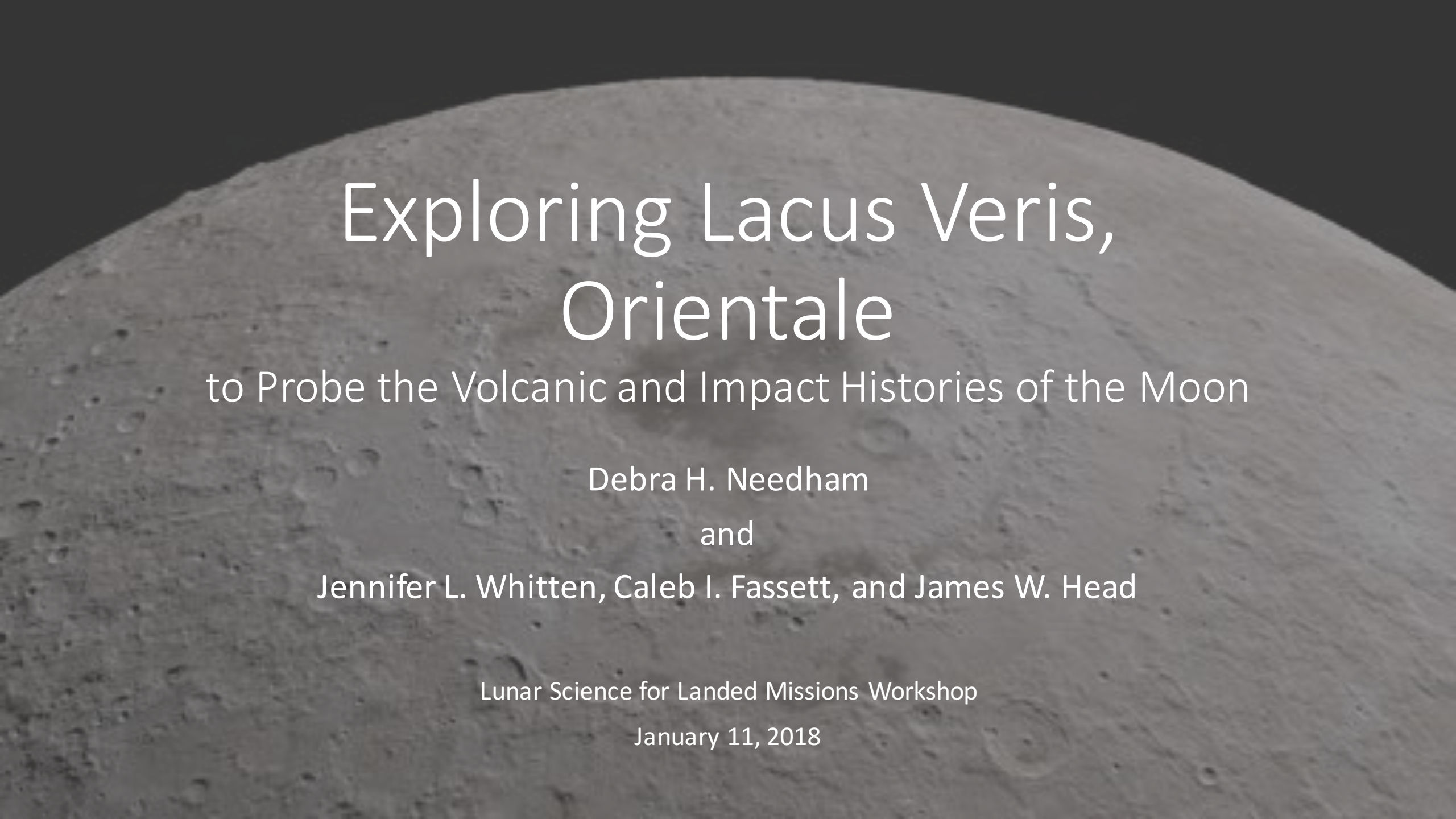

Exploring Lacus Veris, Orientale

to Probe the Volcanic and Impact Histories of the Moon

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and

Jennifer L. Whitten, Caleb I. Fassett, and James W. Head

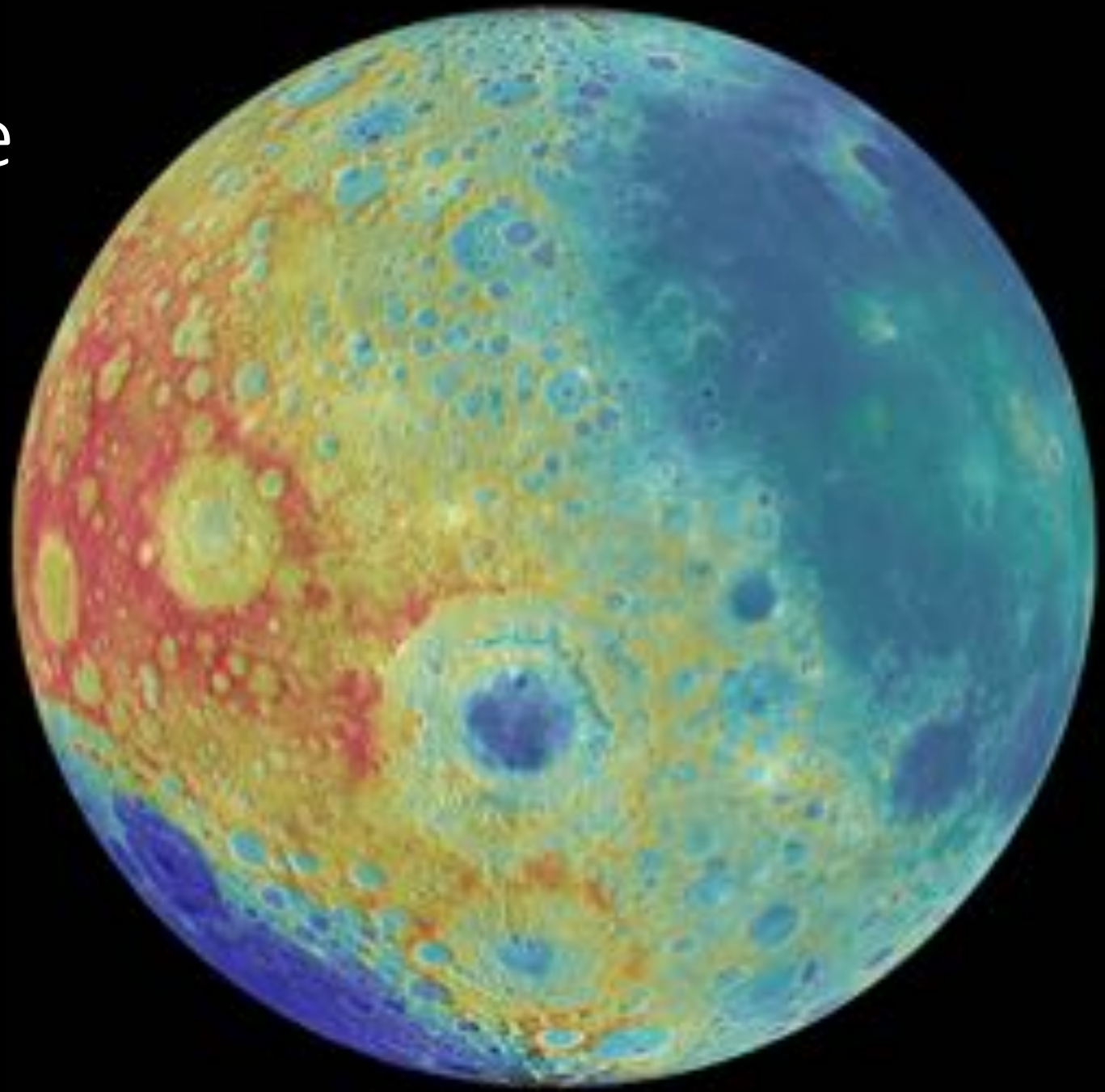
Lunar Science for Landed Missions Workshop

January 11, 2018

Geology of Orientale

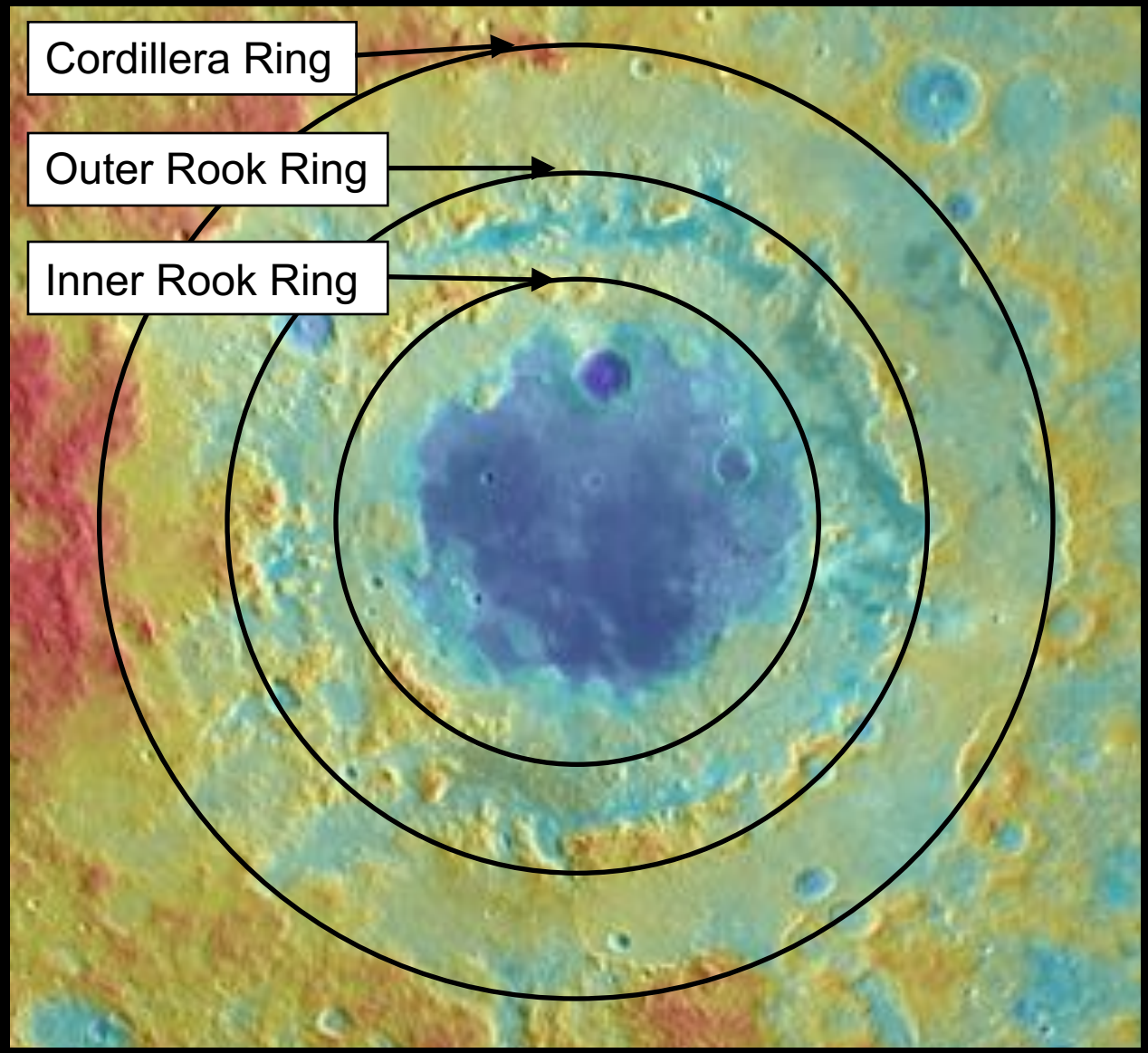
- Youngest of large lunar basins.
  - Formed ~3.68 Ga. (*Whitten et al.*, 2011)
  - End of the basin-forming epoch.

- Located on the transition of from thin to thick lunar crust.



Geology of Orientale

- Orientale has
  - Three concentric rings (multi-ring basin)

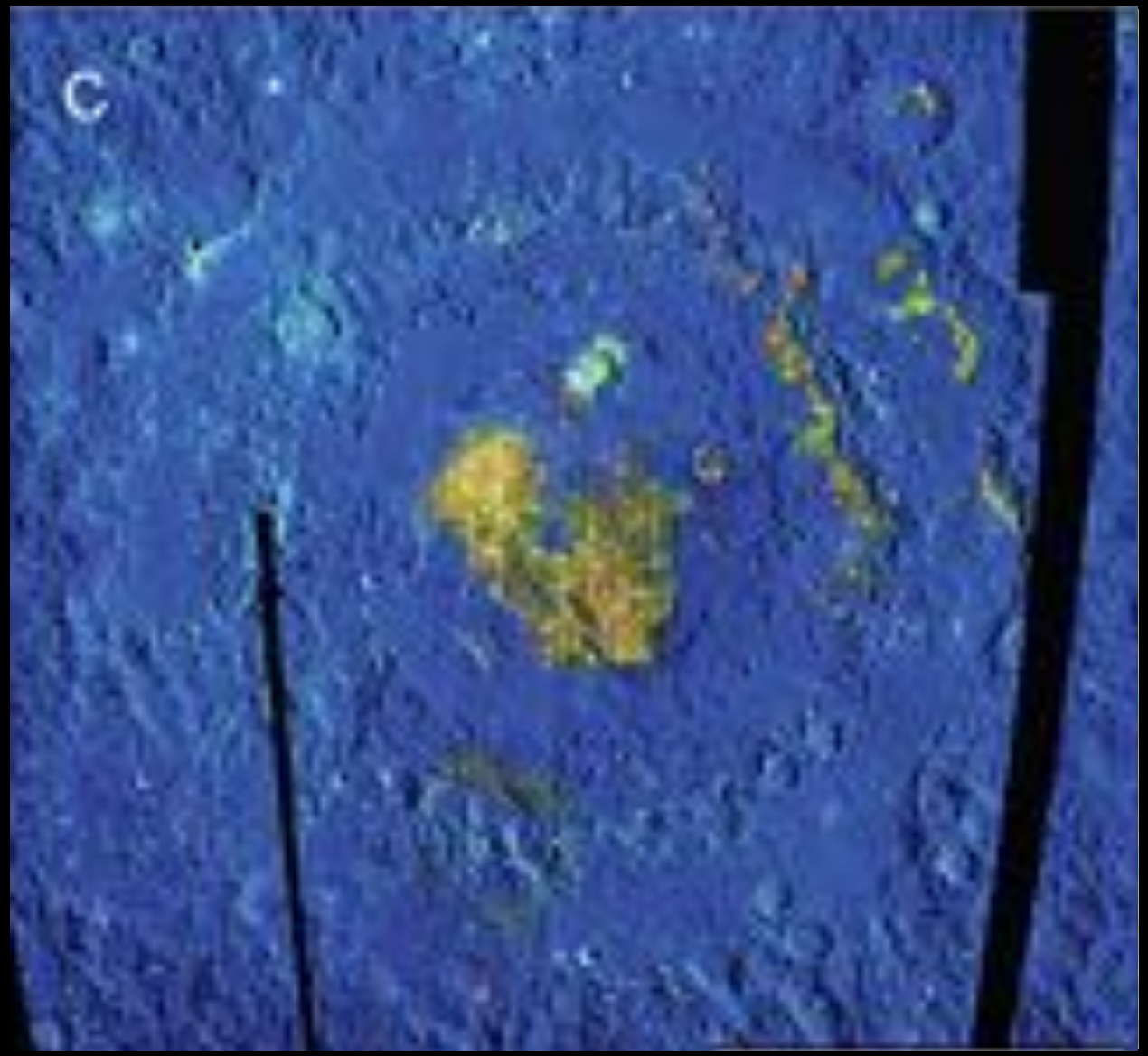


LROC WAC image, WAC GLD DEM;

Geology of Orientale

- Orientale has
  - Three concentric rings (multi-ring basin)
  - 23 mare ponds in addition to the central Mare Orientale.

- Lacus Veris, the largest pond, is nested between:
  - Outer Rook Ring
    - Excavated lunar crust
  - Maunder Formation
    - Primary Orientale ejecta



Moon Mineralogy Mapper color composite, highlighting mafic mineral absorptions (R 1.0 μm; G 2.0 μm; B, 1489 nm), from *Whitten et al.*, 2011.

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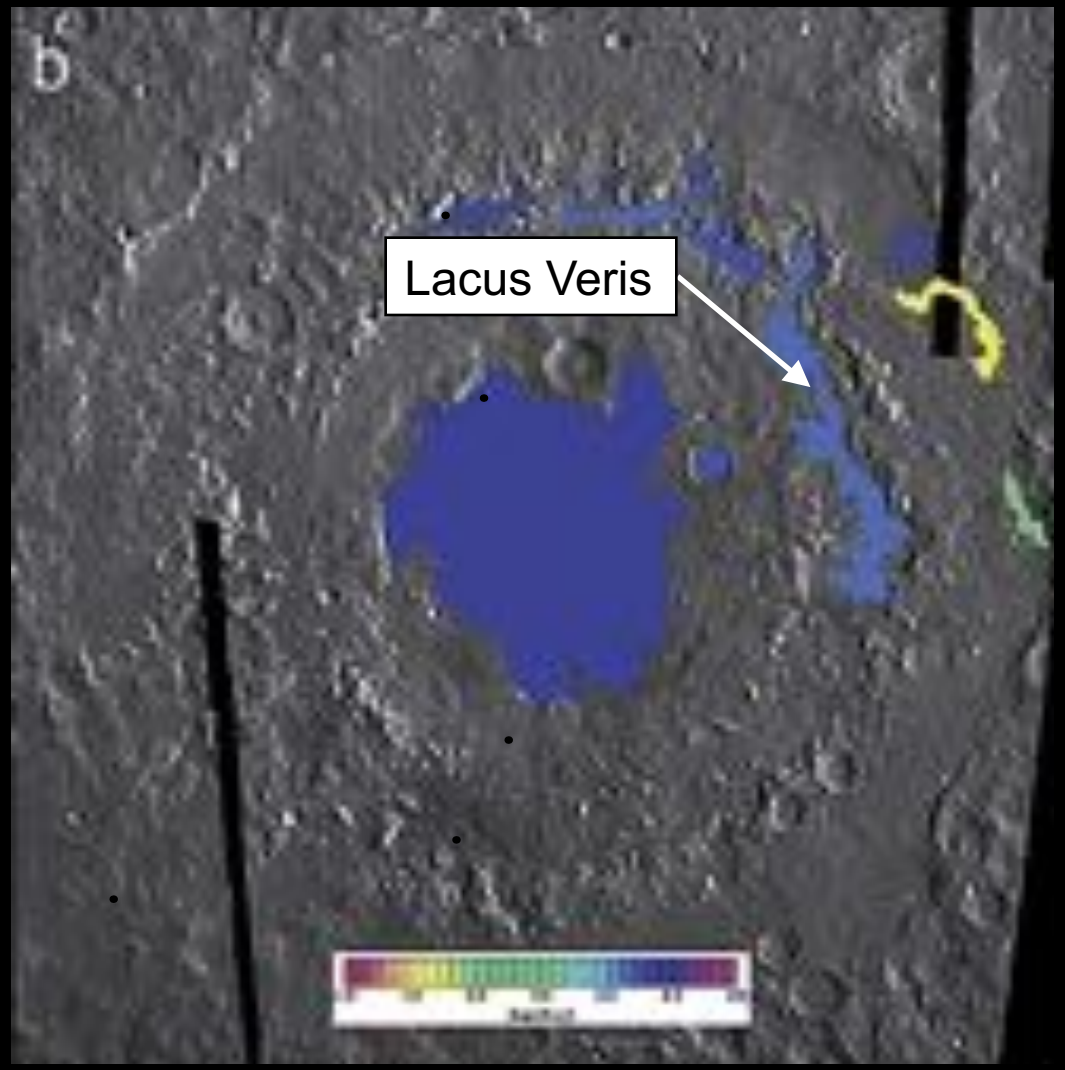


Mare pond ages within Orientale, from *Whitten et al.*, 2011.

Proposed Landing Sites

Selected because of proximity to a variety of geologic units within Orientale, including the mare, the melt sheet (Maunder Formation), and the basin ring materials.

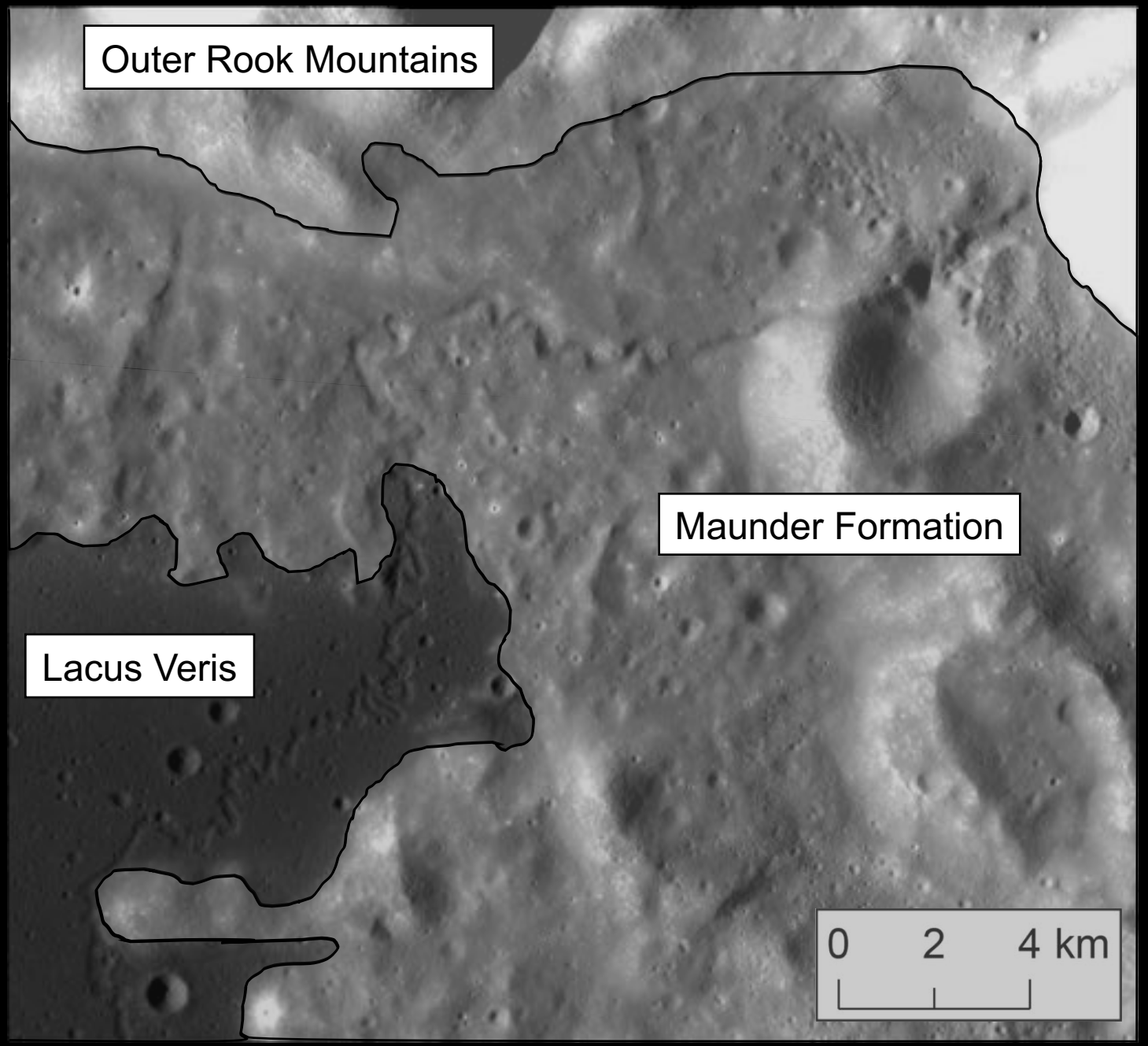
Western Orientale: Later this session (*Whitten et al.,*) between the Inner and Outer Rook Mountains

Eastern Orientale: This Study along the Outer Rook Mountains

LROC WAC

Lacus Veris Site

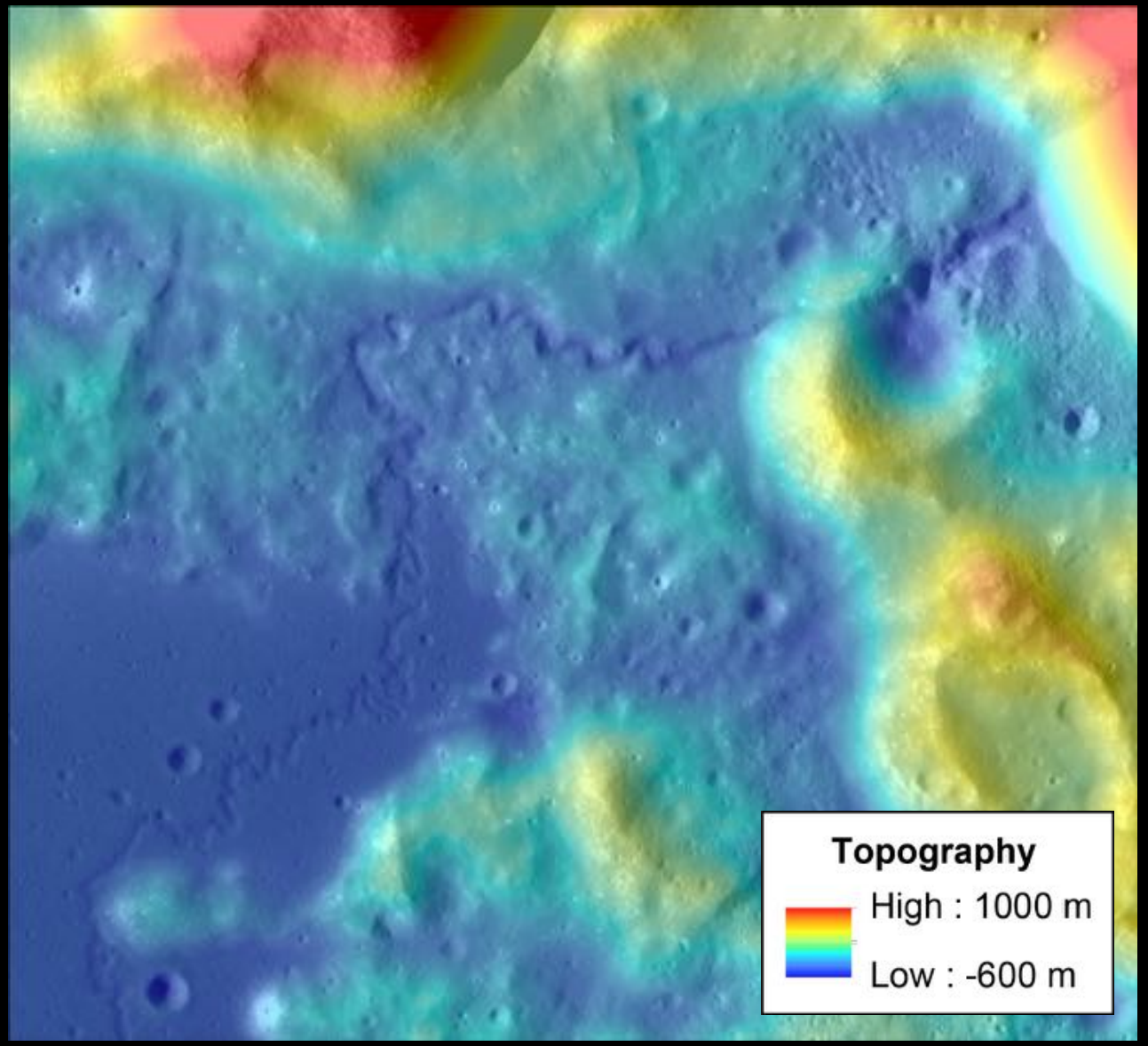
- Access to samples from
  - Outer Rook Mountains
    - Excavated lunar crust
  - Maunder Formation
    - Primary Orientale ejecta
  - Lacus Veris Mare Basalt Pond
  - Sinuous Rille



Kaguya Terrain Camera TC_EVE_02_S12E273S15E276SC.

Science Objectives and Traverse at Lacus Veris

- Science Objectives:
  1. Determine composition and age of volcanic activity, investigate sinuous rille formation.
     a) Addresses Goals 5, 7 of NRC, 2007.
  2. Determine composition and age of Maunder Formation impact melt.
     a) Addresses Goals 1, 3, 6, 7.
  3. Determine composition and depth of origin of Outer Rook Mountains.
     a) Addresses Goals 1, 3, 6.



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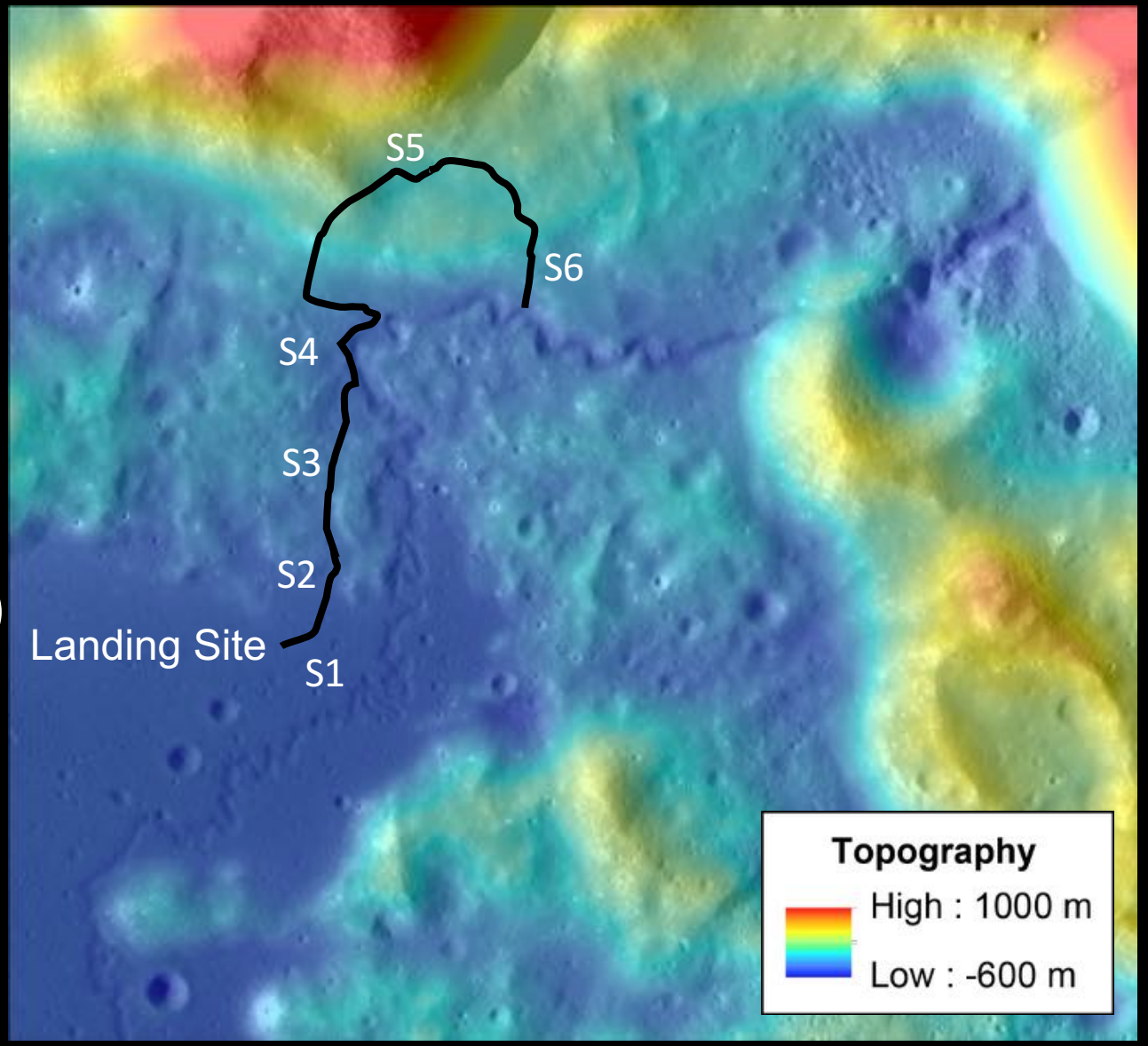
Science Objectives and Traverse at Lacus Veris

- Traverse: ~20 km
  - Station 1: Sample mare basalts (SO1)
  - Station 2: Investigate contact between mare basalt and MF (SO1, SO2)
  - Station 3: Sample MF impact melt (SO2)
  - Station 4: Investigate sinuous rille (SO1)
  - Station 5: Sample ORR boulders that slumped from outcrops above (SO3)
  - Station 6: Investigate contact between ORR and MF (SO2, SO3)



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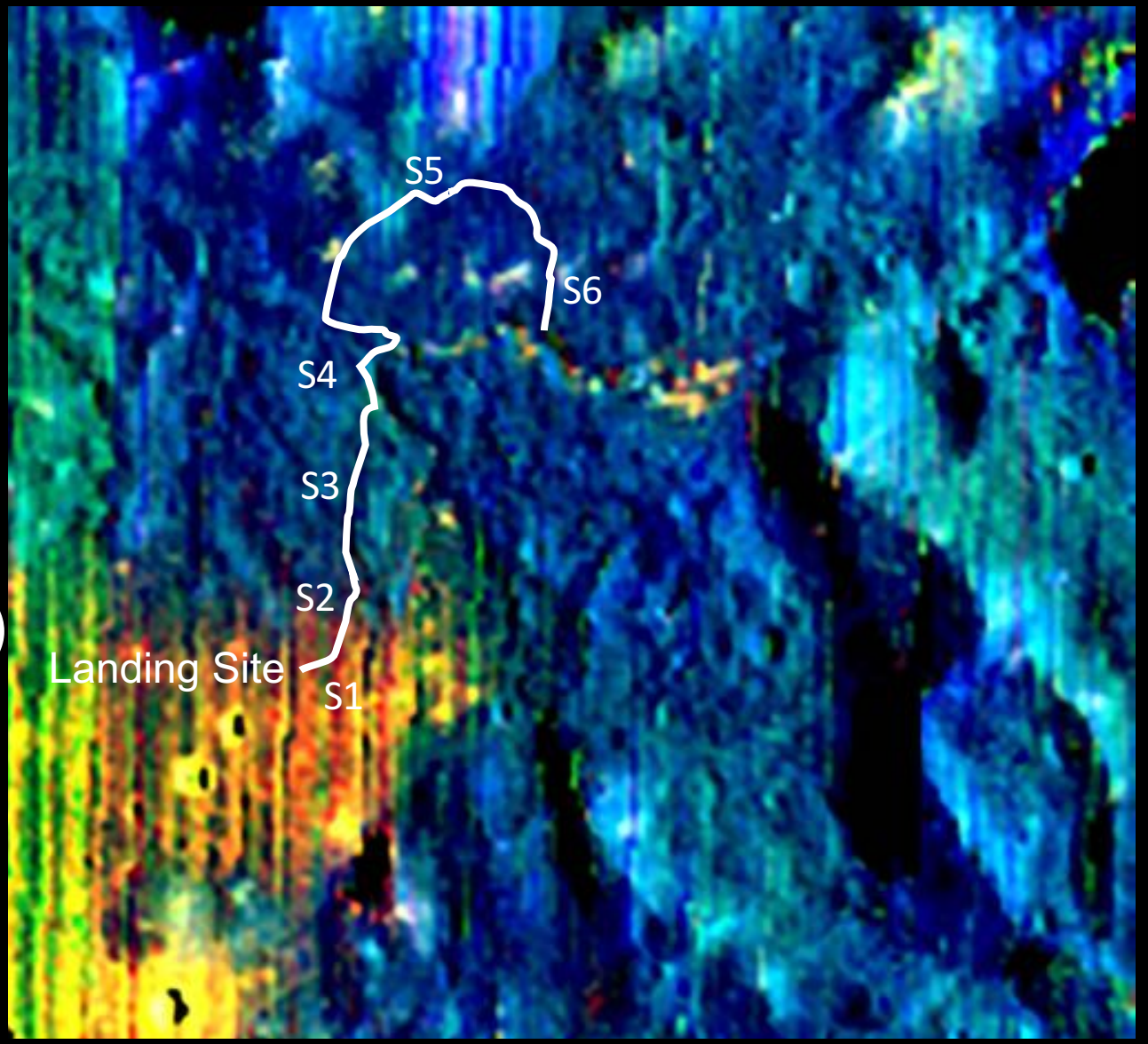

Moon Mineralogy Mapper color composite.

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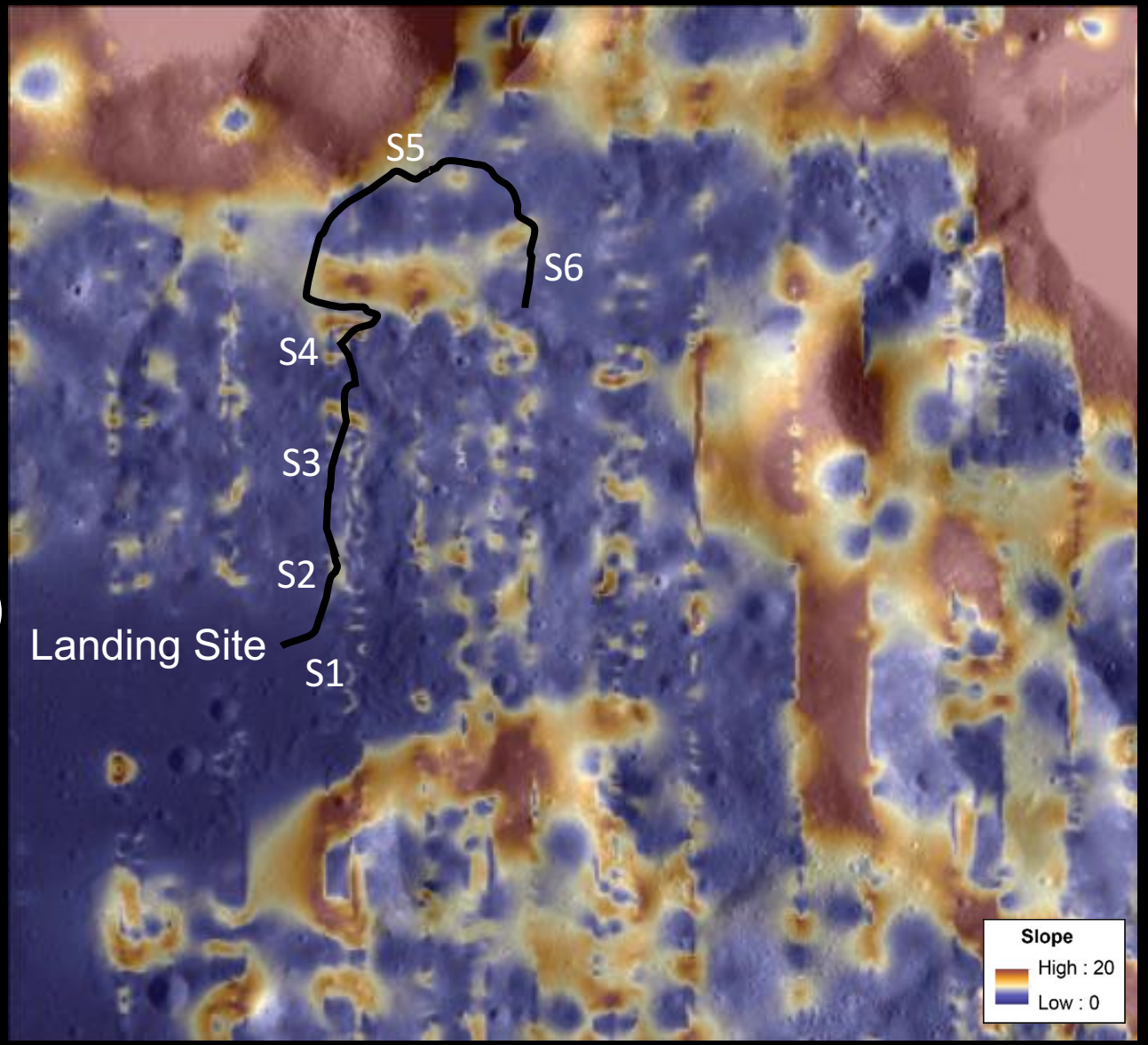

Kaguya Terrain Camera Slope Map.

Science Objectives and Traverse at Lacus Veris

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Science Objectives and Traverse at Lacus Veris

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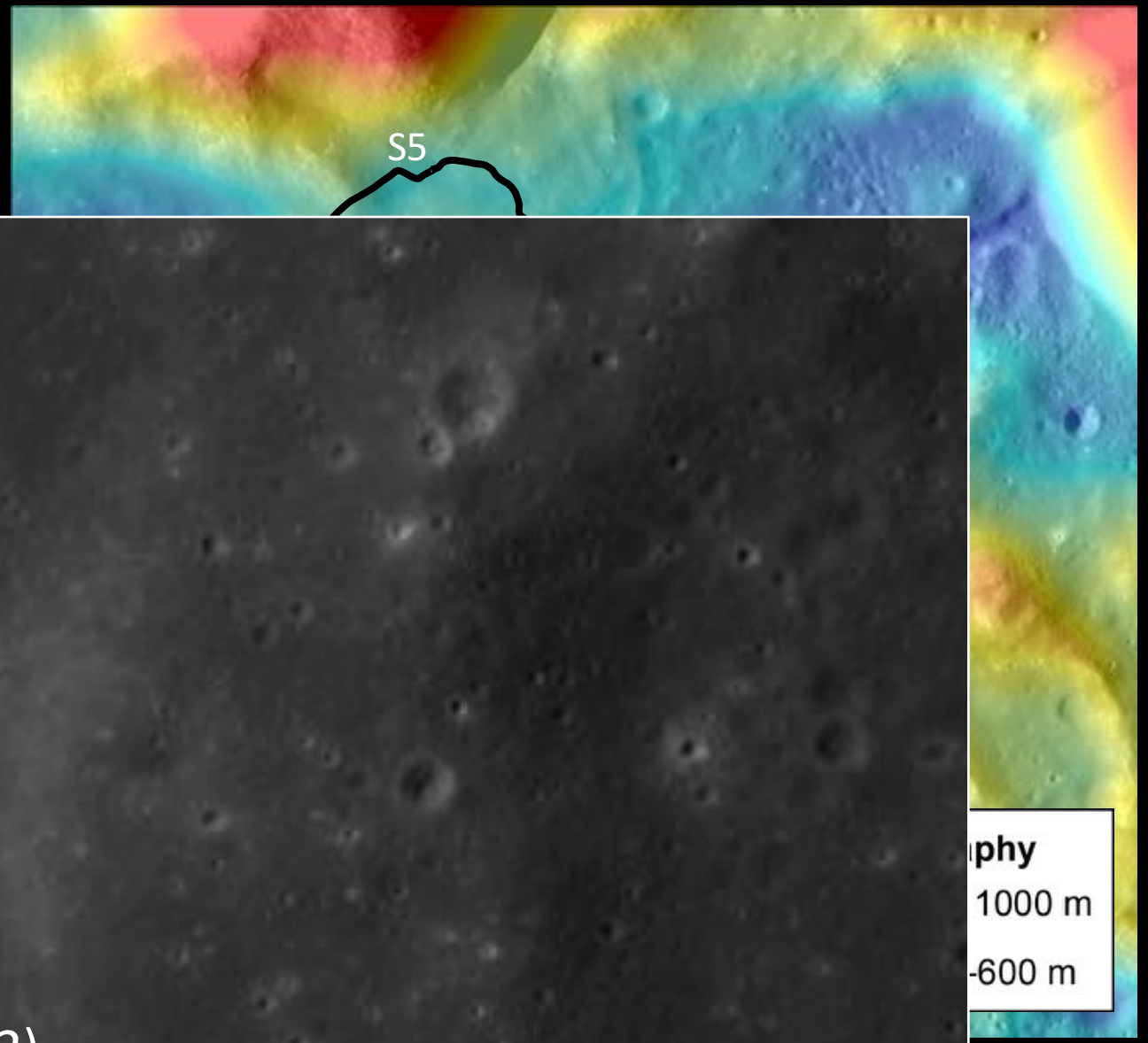
Science Objectives and Traverse at Lacus Veris



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Station 3: Sample MF impact melt (SO2)

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Science Objectives and Traverse at Lacus Veris

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LROC image M1160675618LE.

Science Objectives and Traverse at Lacus Veris

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Measurements and Instruments Needed to Address Objectives

- Science Objectives:
  1. Determine composition and age of volcanic activity.
     - Measure bulk, trace element compositions of basalt.
     - Measure relative abundances of K/Ar, Rb/Sr, or U/Pb isotopes.

- Requires stereo camera and micro-imager for navigation and context images.
- Requires mini-XRF/XRD or mini-SEM.
- Requires KArLE, with LIBS (*Cohen et al.*, 2014), or equivalent.

Measurements and Instruments Needed to Address Objectives

- Science Objectives:
  2. Determine composition and age of Maunder Formation impact melt.
     - Measure bulk, trace element compositions of anorthosite-bearing impact melt.
     - Characterize shock features present in impact melt to constrain impact effects.
     - Measure relative abundances of K/Ar, Rb/Sr, or U/Pb isotopes.

  - Requires stereo camera and micro-imager for navigation, context images, and to search for shock features in anorthosite.
  - Requires mini-XRF/XRD or mini-SEM.
  - Requires KArLE, with LIBS (*Cohen et al.*, 2014), or equivalent for other geochronometers.

Measurements and Instruments Needed to Address Objectives

- Science Objectives:
  3. Determine composition and depth of origin of Outer Rook Mountains.
     - Measure bulk, trace element compositions of anorthositic rocks, particularly abundance of An.
     - Determine mineral suite present in ORR to determine depth of origin.
     - Characterize shock features present in anorthosite to constrain impact effects.

  - Requires stereo camera and micro-imager for navigation, context images, and to search for shock features in anorthosite.
  - Requires mini-XRF/XRD or mini-SEM.

Summary

Science Objective	NRC, 2007	Measurements	Instruments
1. Determine composition and age of volcanic activity, investigate sinuous rille formation	Goal 5 (volcanic history) Goal 7 (regolith formation)	- Bulk, trace element compositions of basalt. - Relative abundances of K/Ar or other.	- Mini-XRF/XRD or mini-SEM. - KArLE, with LIBS, or equivalent.
2. Determine composition and age of Maunder Formation impact melt.	Goal 1 (bombardment history) Goal 3 (diversity of crustal rocks) Goal 6 (impact processes) Goal 7	- Bulk, trace element compositions of basalt. - Relative abundances of K/Ar or other. - Shock features in impact melt.	- Mini-XRF/XRD or mini-SEM. - KArLE, with LIBS, or equivalent. - Micro-imager
3. Determine composition and depth of origin of Outer Rook Mountains	Goal 1 Goal 3 Goal 6	- Bulk, trace element compositions of basalt. - Mineral suite. - Shock features in impact melt.	- Mini-XRF/XRD or mini-SEM. - Micro-imager

- Additionally, a UVVIS spectrometer to assist in identifying samples for analysis.
- Will also need a robotic arm to retrieve samples and deliver to instrument deck, and a rock abrasion tool to remove regolith from sample sites.

Lacus Veris Site

- Access to samples from
  - Outer Rook Mountains
    - Excavated lunar crust
  - Maunder Formation
    - Primary Orientale ejecta
  - Lacus Veris Mare Basalt Pond
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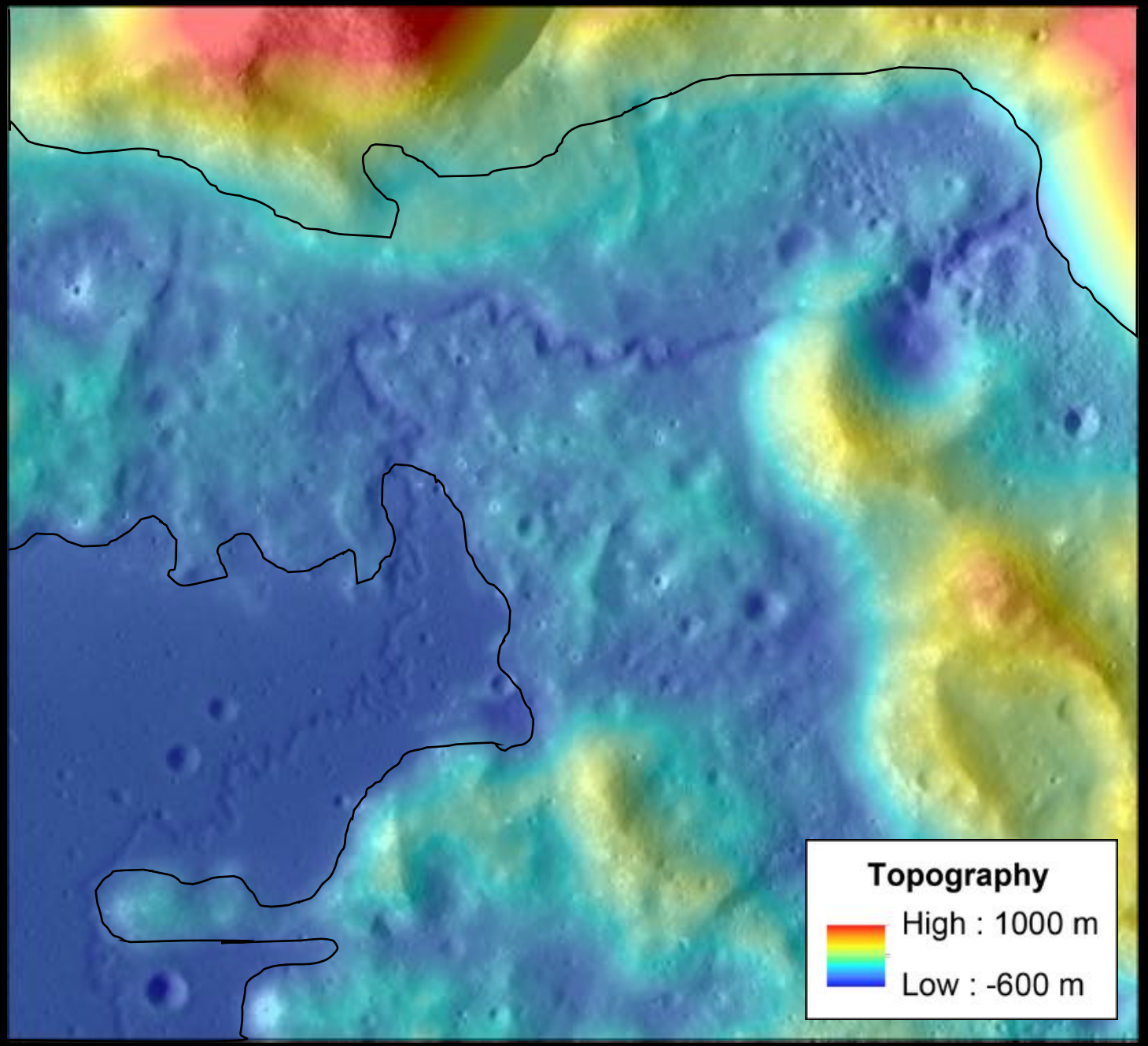

Kaguya Terrain Camera DTM.

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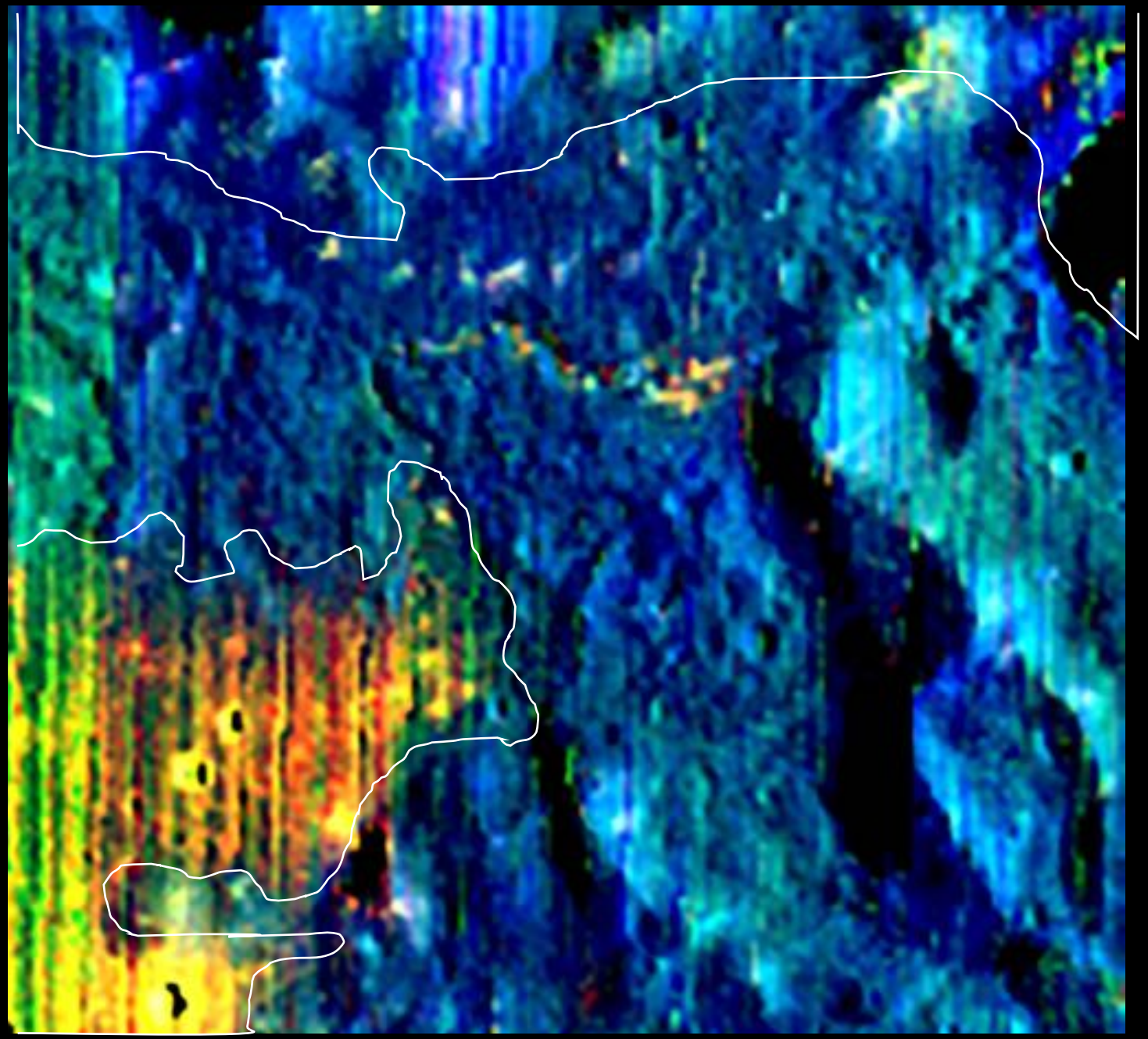

Moon Mineralogy Mapper color composite. Basalt is orange-yellow, fresh anorthosite is purple.

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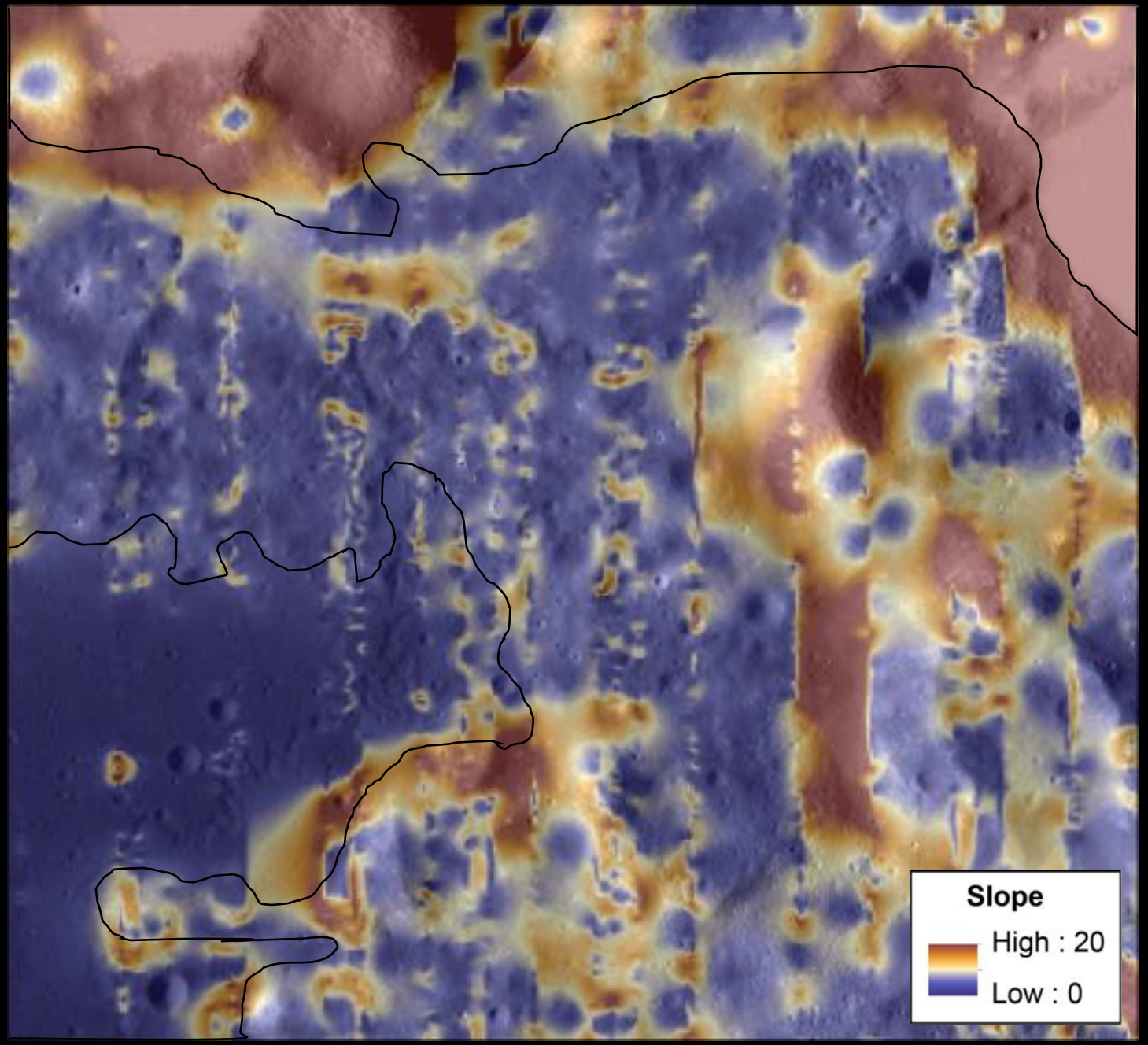

Kaguya Terrain Camera Slope Map.