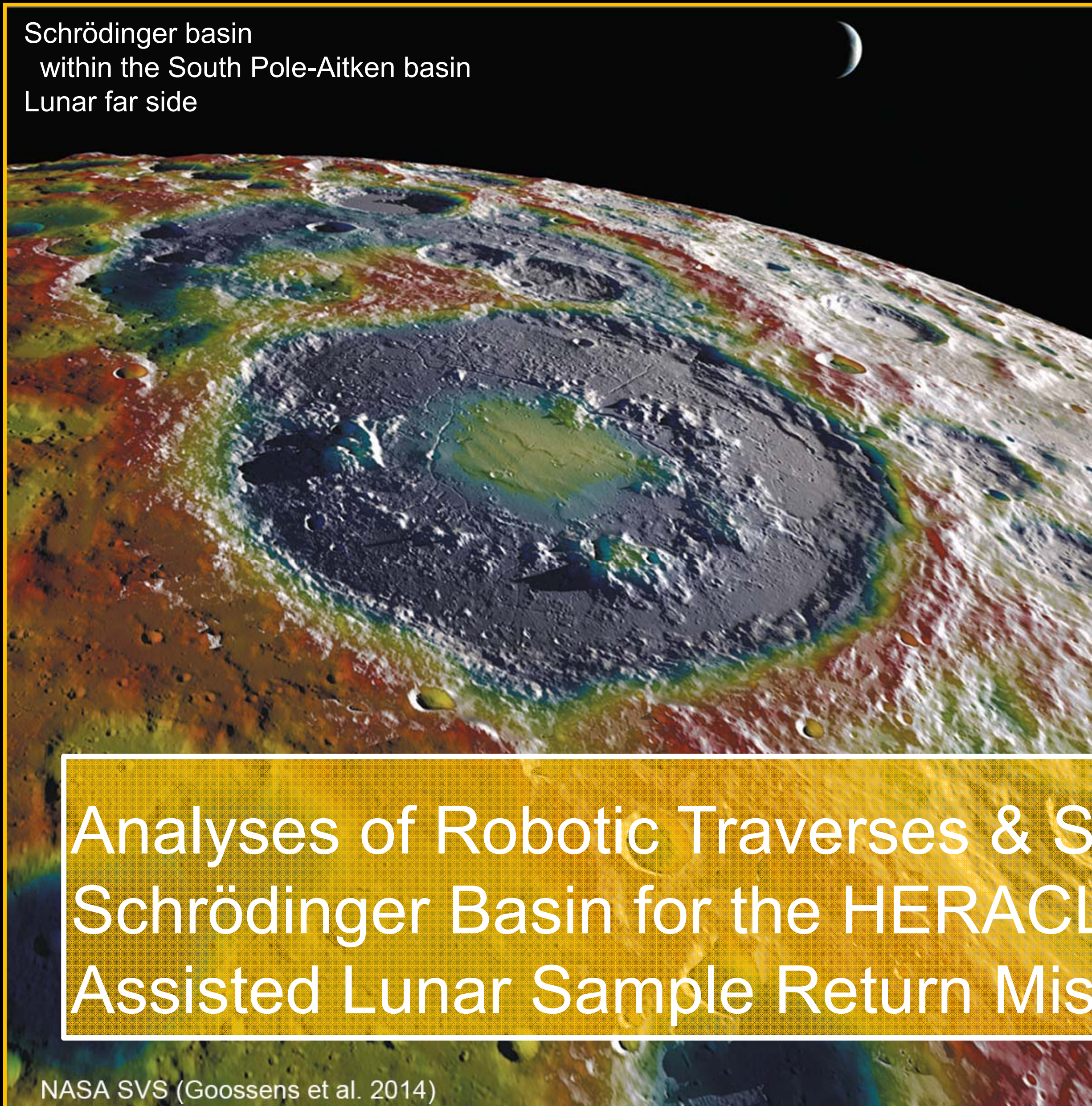
David A. Kring

CENTER FOR LUNAR SCIENCE AND EXPLORATION

vitally impacting the future – today

Analyses of Robotic Traverses & Sample Sites in the Schrödinger Basin for the HERACLES Human-Assisted Lunar Sample Return Mission Concept



NASA SVS (Goossens et al. 2014)

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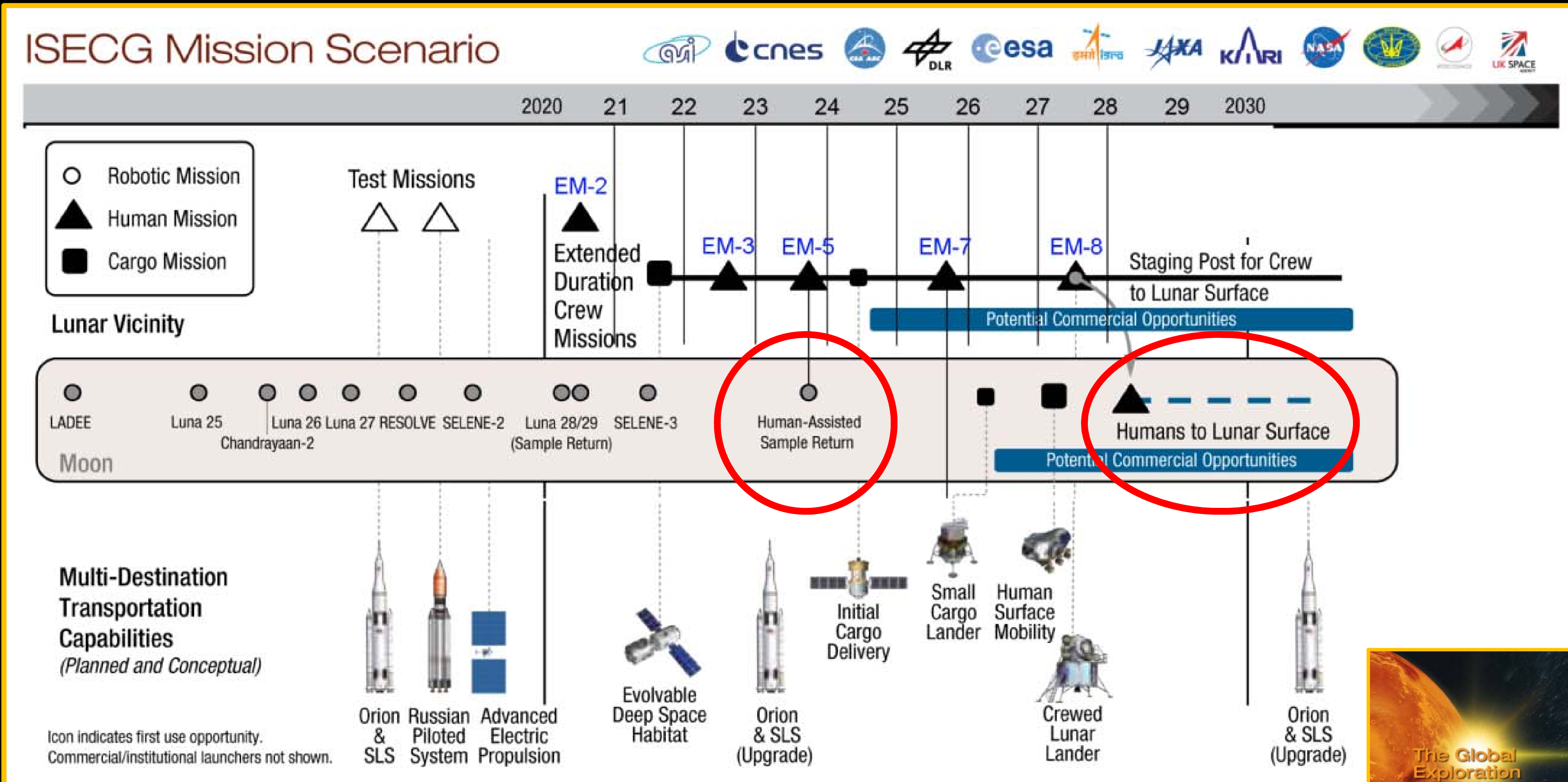
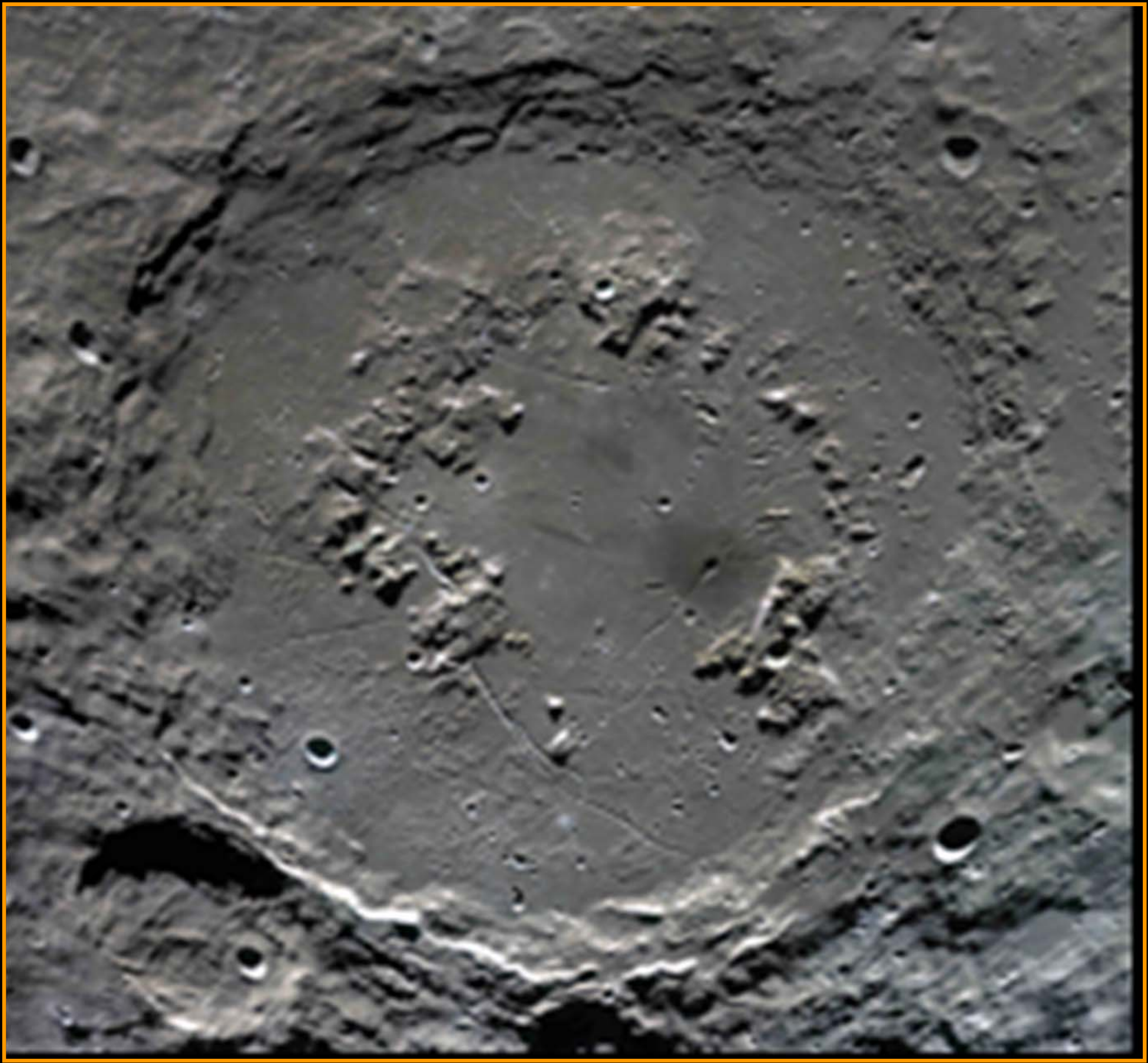
University of New Brunswick
Christian Venturino
University of Buffalo
Debra Hurwitz Needham
Goddard Space Flight Center
Kurt Klaus
The Boeing Company

EXPLORATION – IN PARALLEL WITH ORION & SLS VEHICLE DEVELOPMENT



Detail of illustration from the GER (2013) with small modifications.
Because the human missions could involve NASA's Orion vehicle and ESA's service module, notional Exploration Mission numbers have been added.

HERACLES TRAVERSE STUDIES



HERACLES

The opportunity:

3 landing sites with sample return capability

1 rover – deployed at the first landing site, traverses basin, collecting additional samples, before returning them sequentially to additional landers and ascent vehicles

100 to 300 km traverse capability

HERACLES TRAVERSE STUDIES

HERACLES

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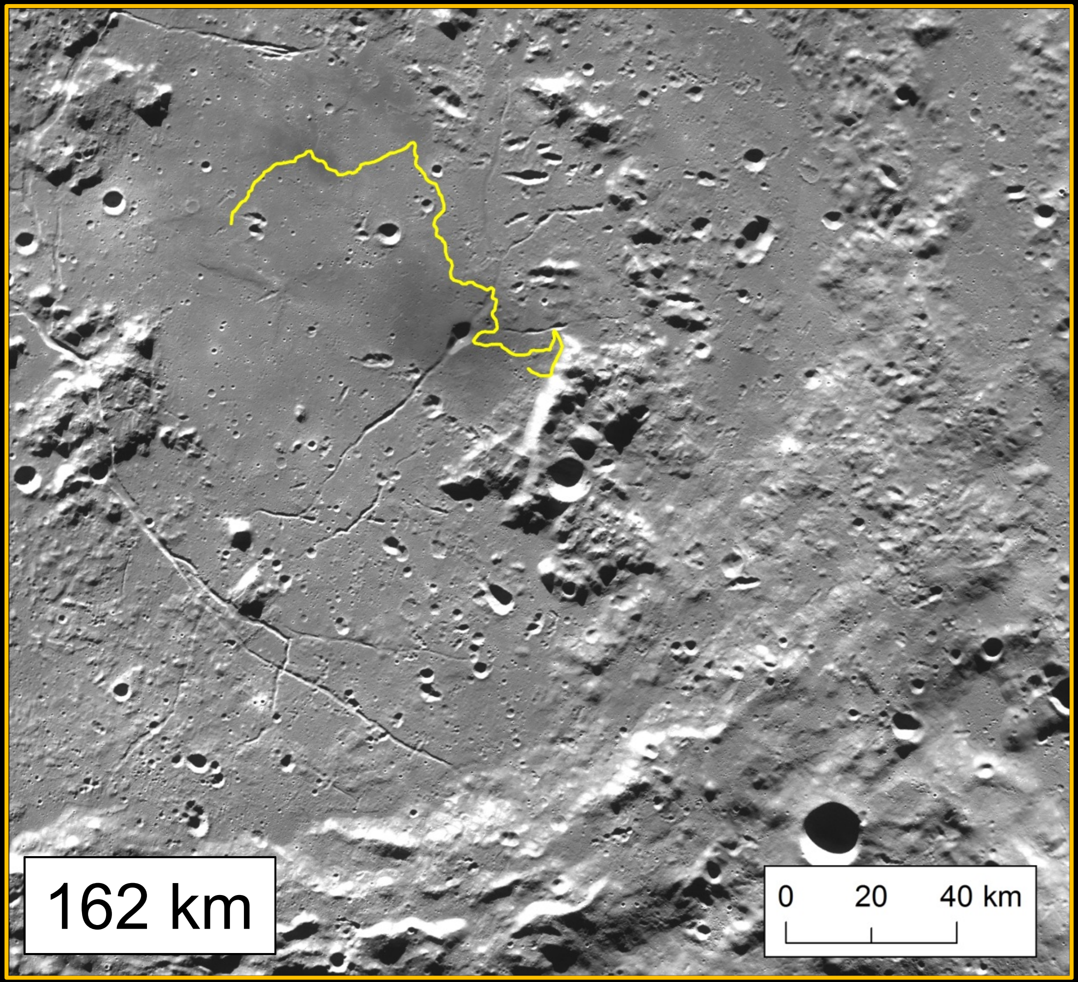
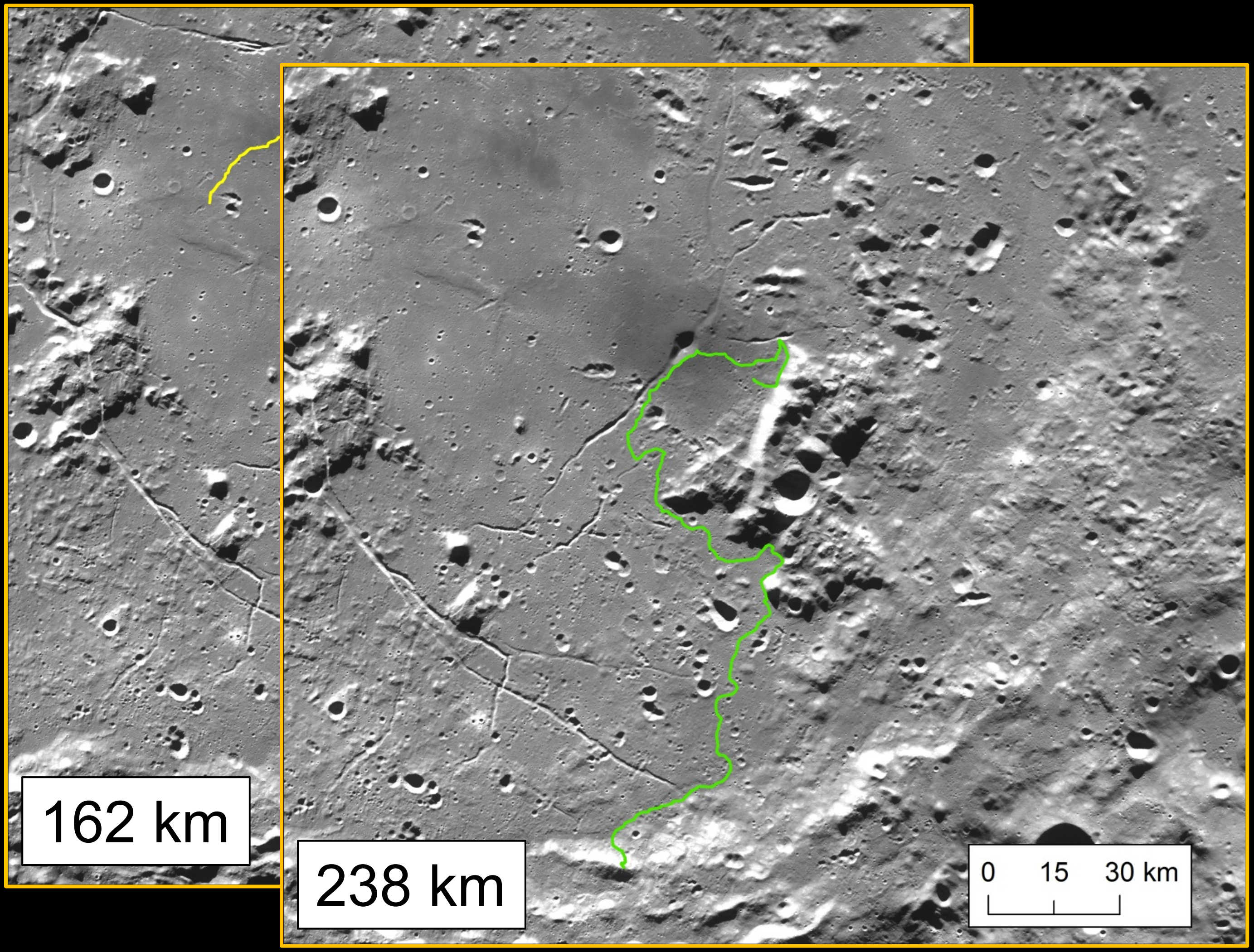
100 to 300 km traverse capability

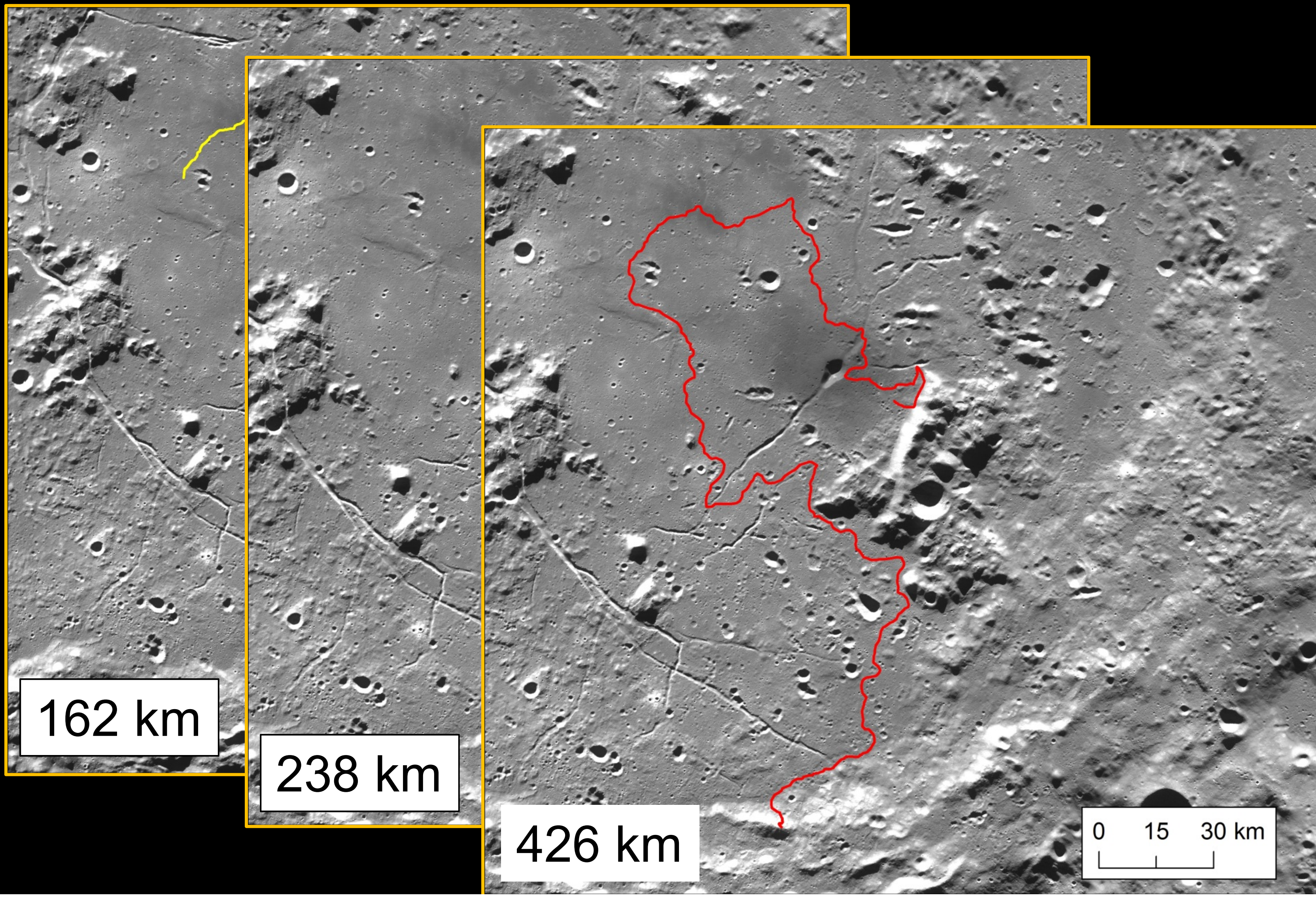
HERACLES TRAVERSE STUDIES: Three notional traverses



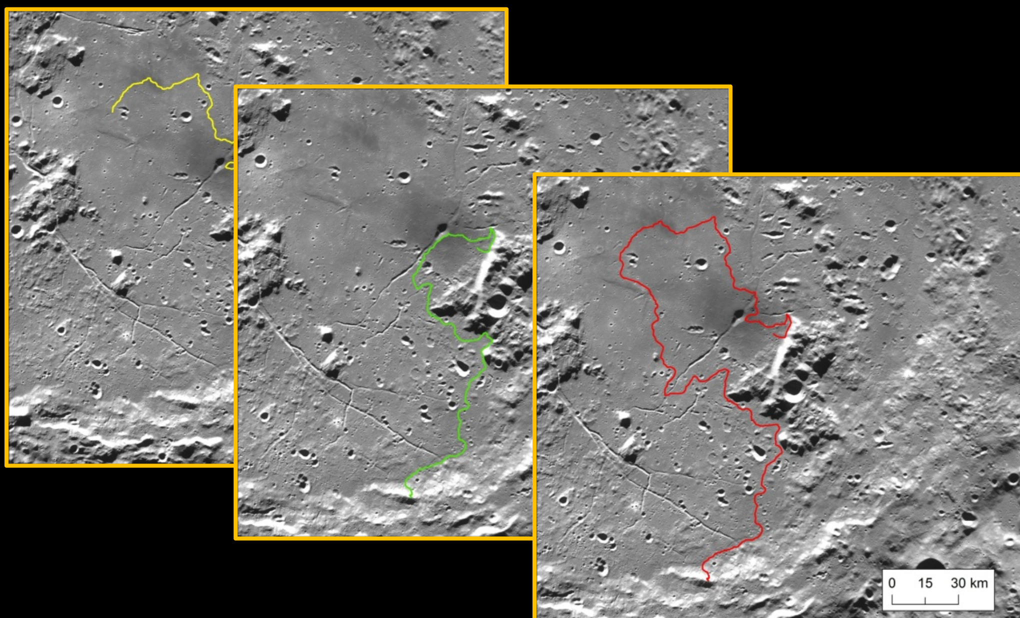
HERACLES TRAVERSE STUDIES: Three notional traverses



HERACLES TRAVERSE STUDIES: Three notional traverses



HERACLES TRAVERSE STUDIES: Three notional traverses



Schrödinger Basin
w/i the South Pole-Aitken Basin

Previously identified as one of the highest-priority landing sites

HERACLES

The notional traverses were based on detailed studies of Schrödinger basin by

O'Sullivan et al. (GSA SP 2011)
Mest (GSA SP 2011)
Bunte et al. (GSA SP 2011)
Kramer et al. (Icarus 2013)
Kumar et al. (JGR 2013)
Burns et al. (ASR 2013)
Pratt et al. (IAC 2014)
Potts et al. (ASR 2015)
Hurwitz & Kring (EPSL 2015)
Kumar et al. (2015-submitted)
Kring et al. (2015a-submitted)
Kring et al. (2015b-submitted)

Using M^3 data, LOLA data, and LROC data.

HERACLES TRAVERSE STUDIES

Delivered
29 May 2015

Delivered
30 July 2015

David A. Kring

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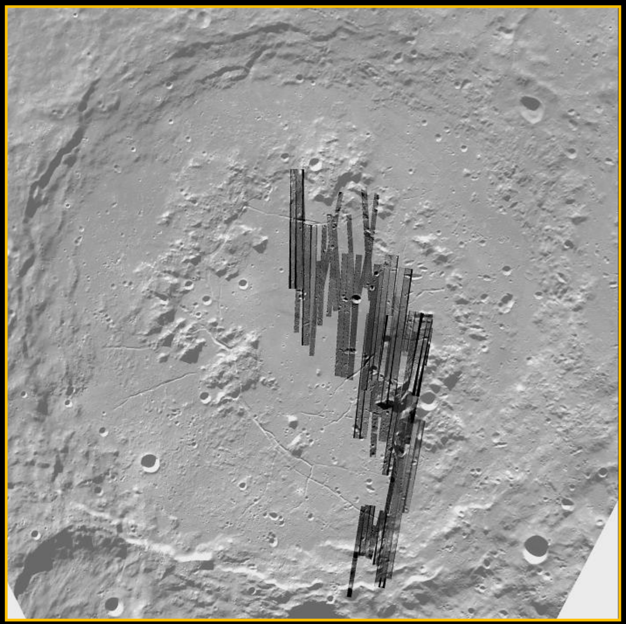
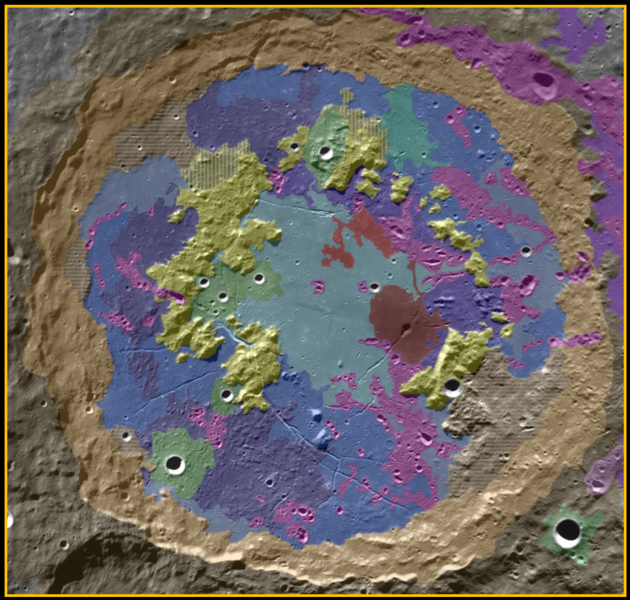
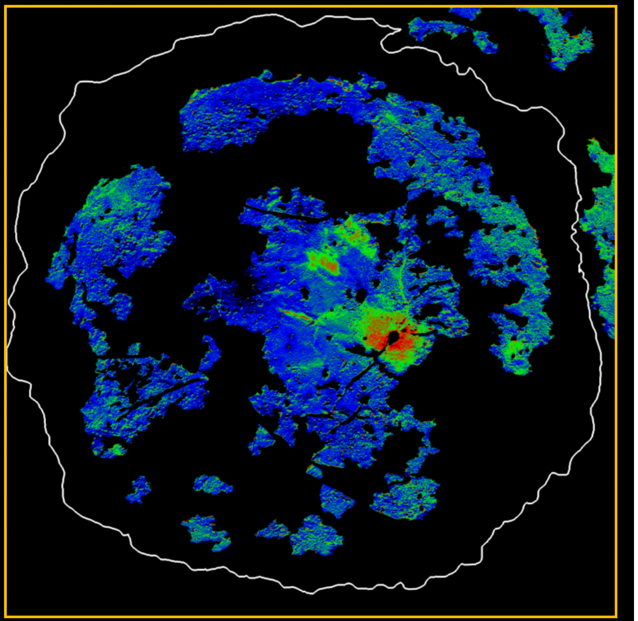
TRAVERSE PLANNING DATA INPUT







<u>LROC images:</u>
NAC (0.5 m/px)
- 76 – 90% coverage

WAC (100 m/px)
- 100% coverage

<u>LOLA maps:</u>
DEM/Slope (100 m/px)
- 100% coverage

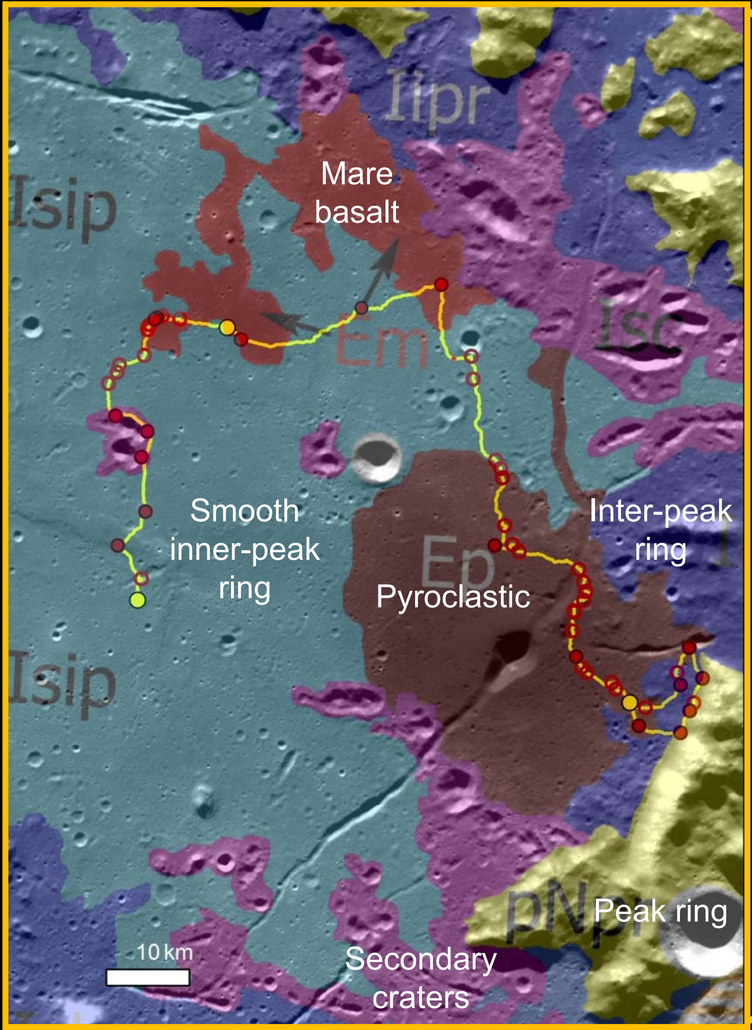
Clementine M^3 (Moon Mineralogy Mapper) spectra (70 - 140 m spatial resolution)

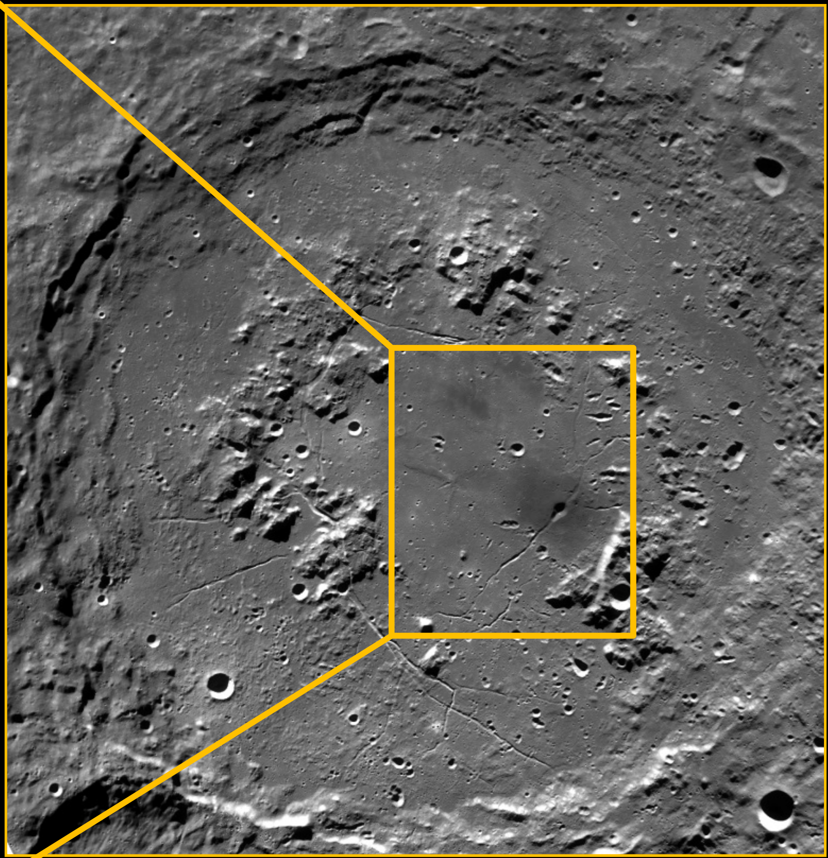
Geological map (Kramer et al., 2013)

FeO abundance map from Clementine spectral data (100 m/px)

(Kramer et al., 2013; Lucey et al., 2000)

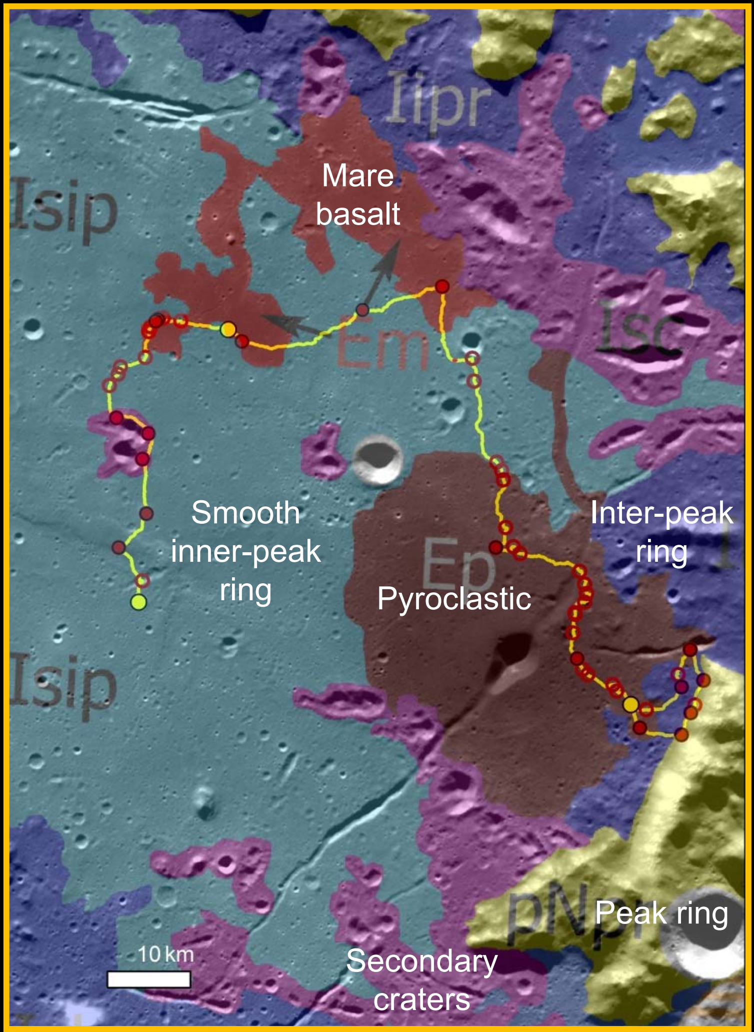
SHORTEST DISTANCE TRAVERSE





Basin diameter ~320 km

SHORTEST DISTANCE TRAVERSE



Traverse length: ~207 km
(Notional traverse extended by 45 km)

Total duration: 13 months (large margin)

- ~100 days at stations
- ~198 days traversing

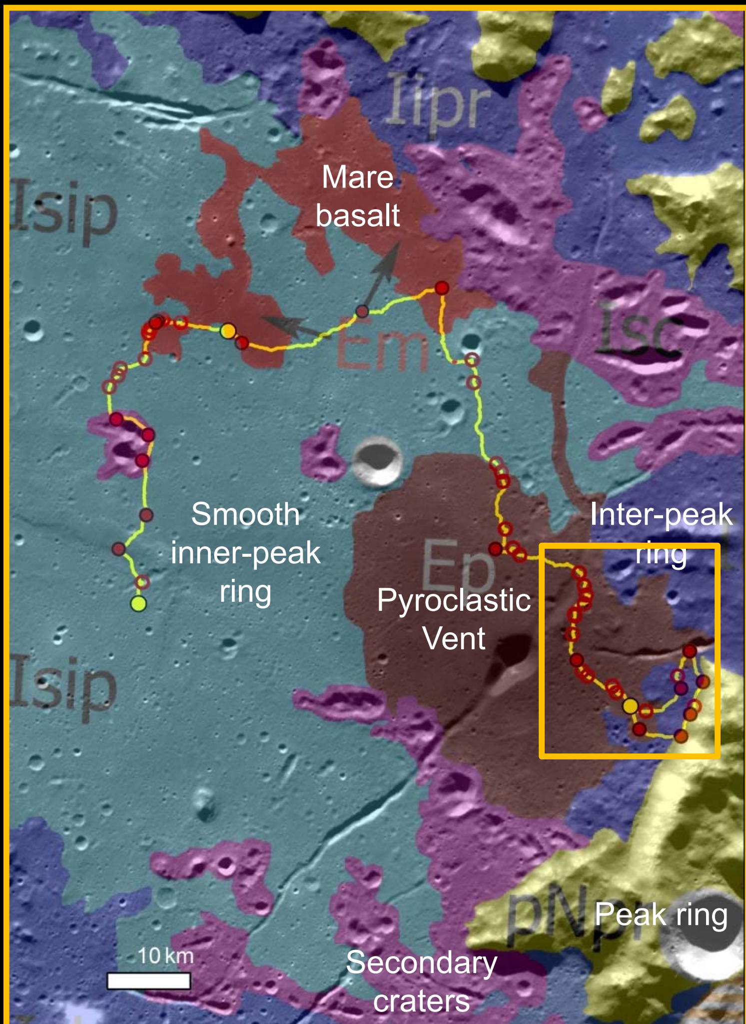
Traverses 6 geologic terrains

3 lander sites (yellow circles)

50 stations selected for imaging and *in-situ* analysis (red circles)

18 of the 50 stations are sampling sites (filled red circles)

SHORTEST DISTANCE TRAVERSE: Vicinity of Landing Site 1



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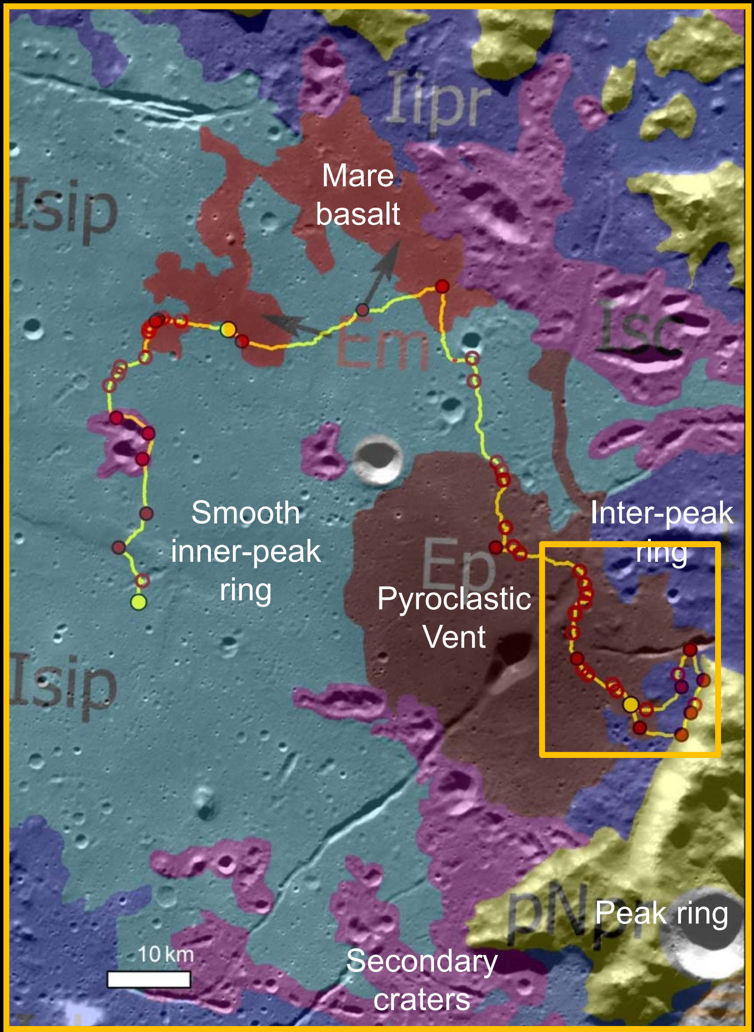
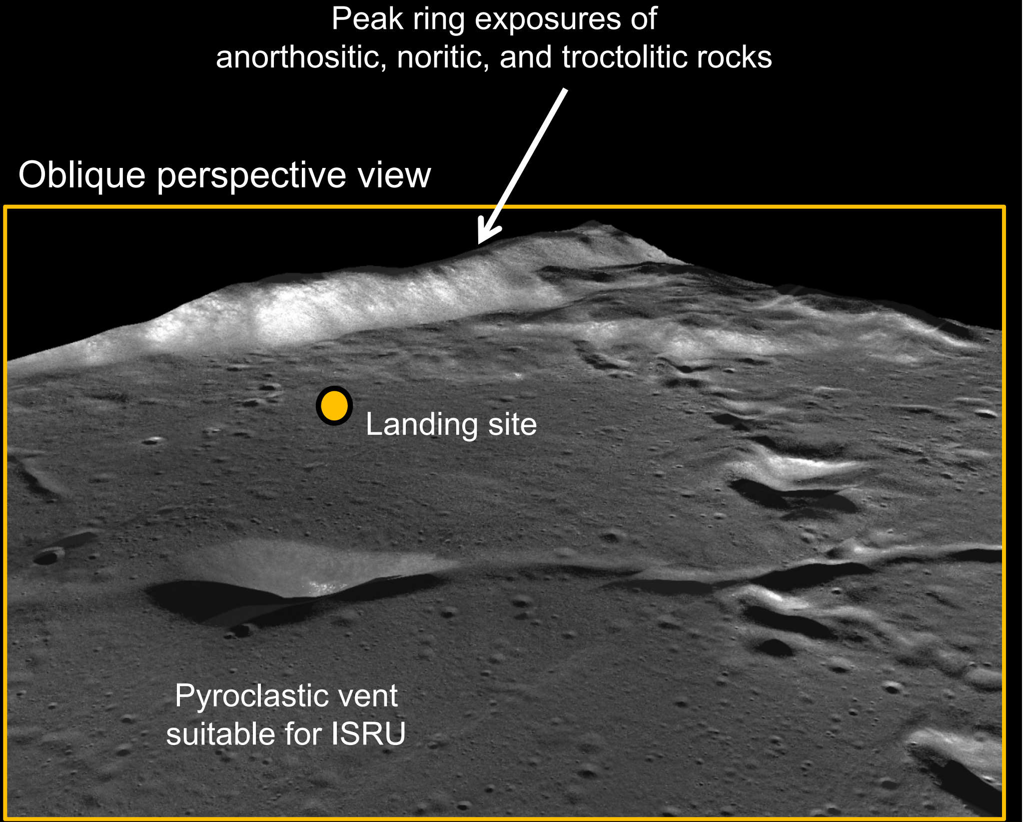
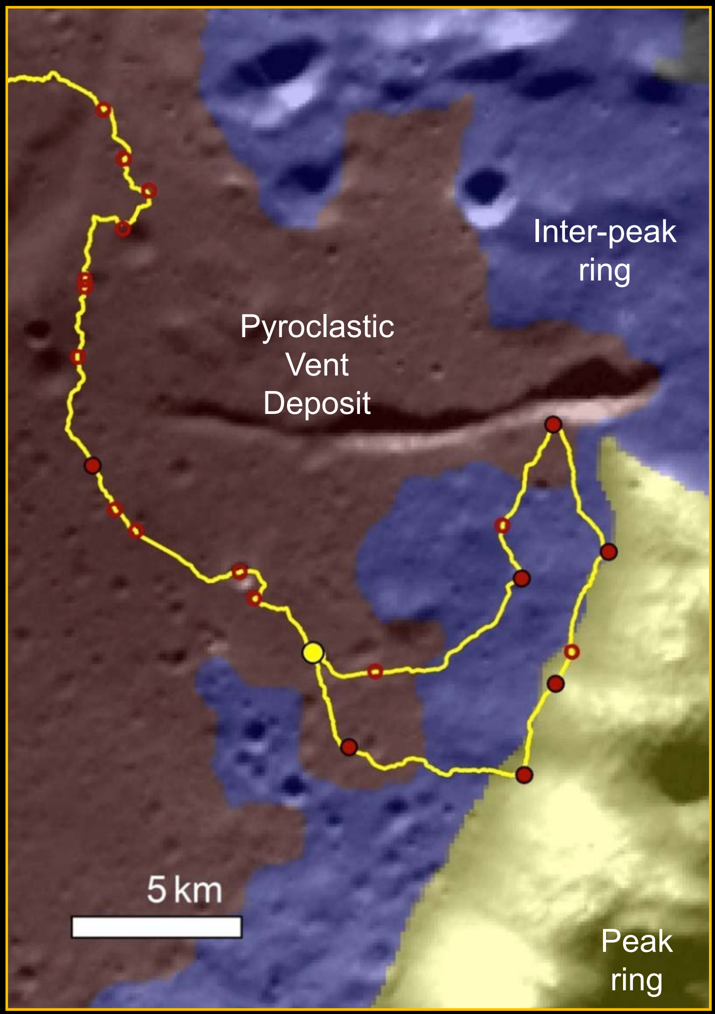


Oblique perspective view



A video flyover of this site is available at
http://www.lpi.usra.edu/lunar/lunar_flyovers/schrodinger/

SHORTEST DISTANCE TRAVERSE: Vicinity of Landing Site 1



Traverse length: ~35 km

9 stations selected for *in-situ* analysis and imaging (red circles)

6 of the 9 stations identified as sampling sites (filled red circles)

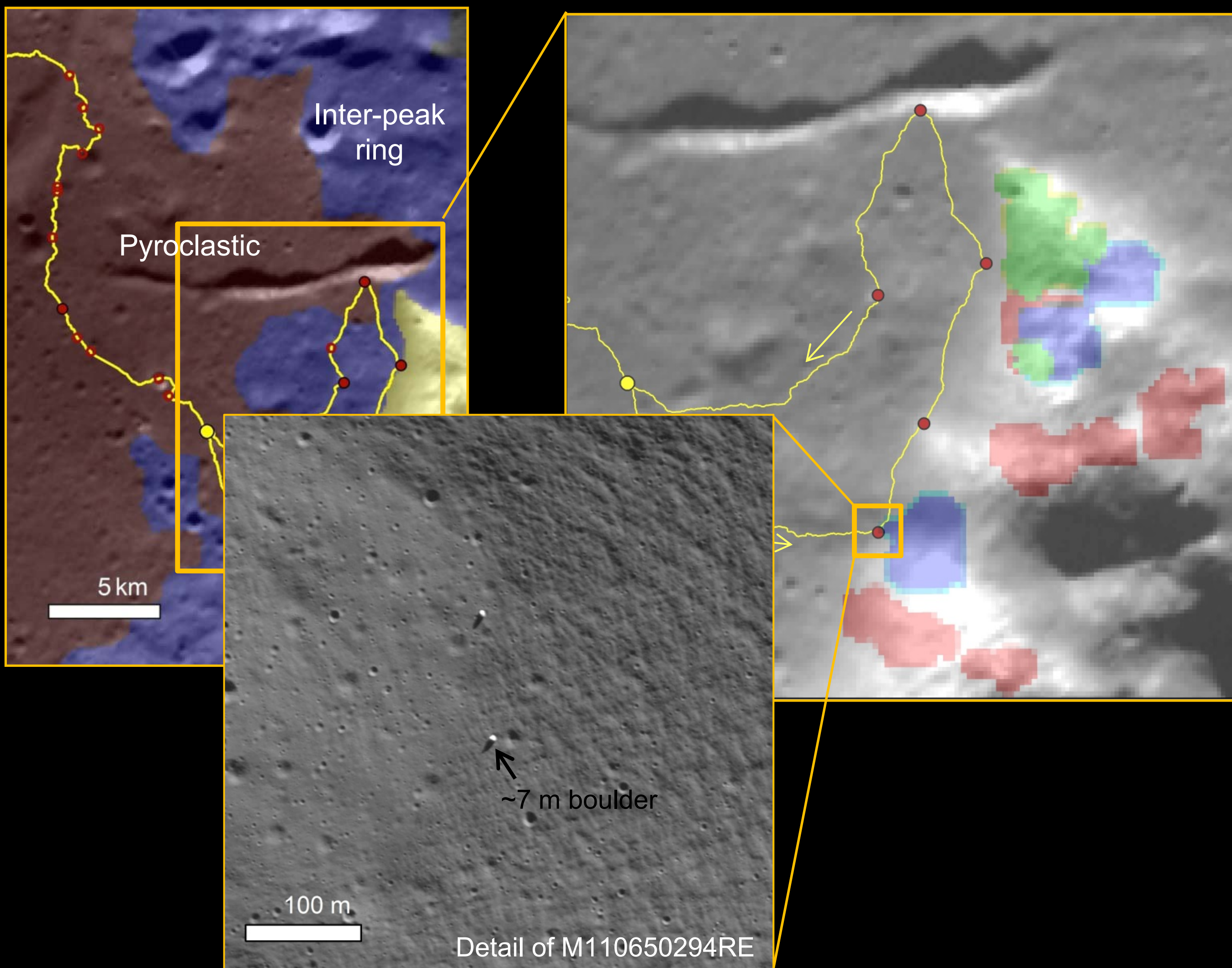
Sampling:
(based on CAPTEM, 2007, requirements)

- Peak ring material: 1.5 kg
- Fracture material: 1.0 kg
- Pyroclastic material: 2.0 kg
- Impact melt breccia: 5.0 kg
  (Inter-peak ring)

Total sample mass: 9.5 kg

Based on detailed Potts et al. (2015) study

SHORTEST DISTANCE TRAVERSE: Vicinity of Landing Site 1



Location:

Base of the peak ring

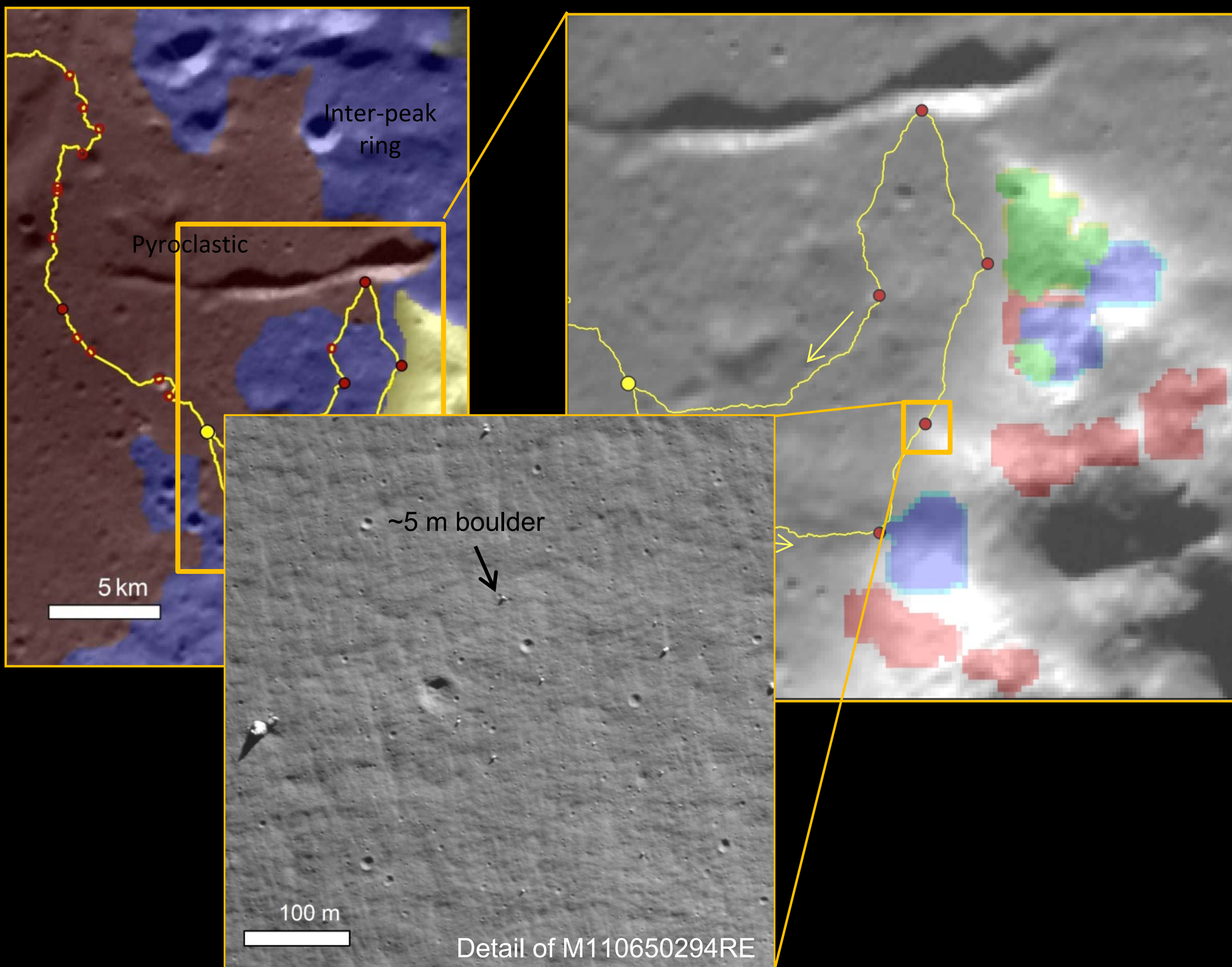
Boulder: D ~7 m

Associated boulder track to anorthositic source (M^3 data)

Sample:

500 g hand specimen from boulder

SHORTEST DISTANCE TRAVERSE: Vicinity of Landing Site 1



Location:

Base of the peak ring

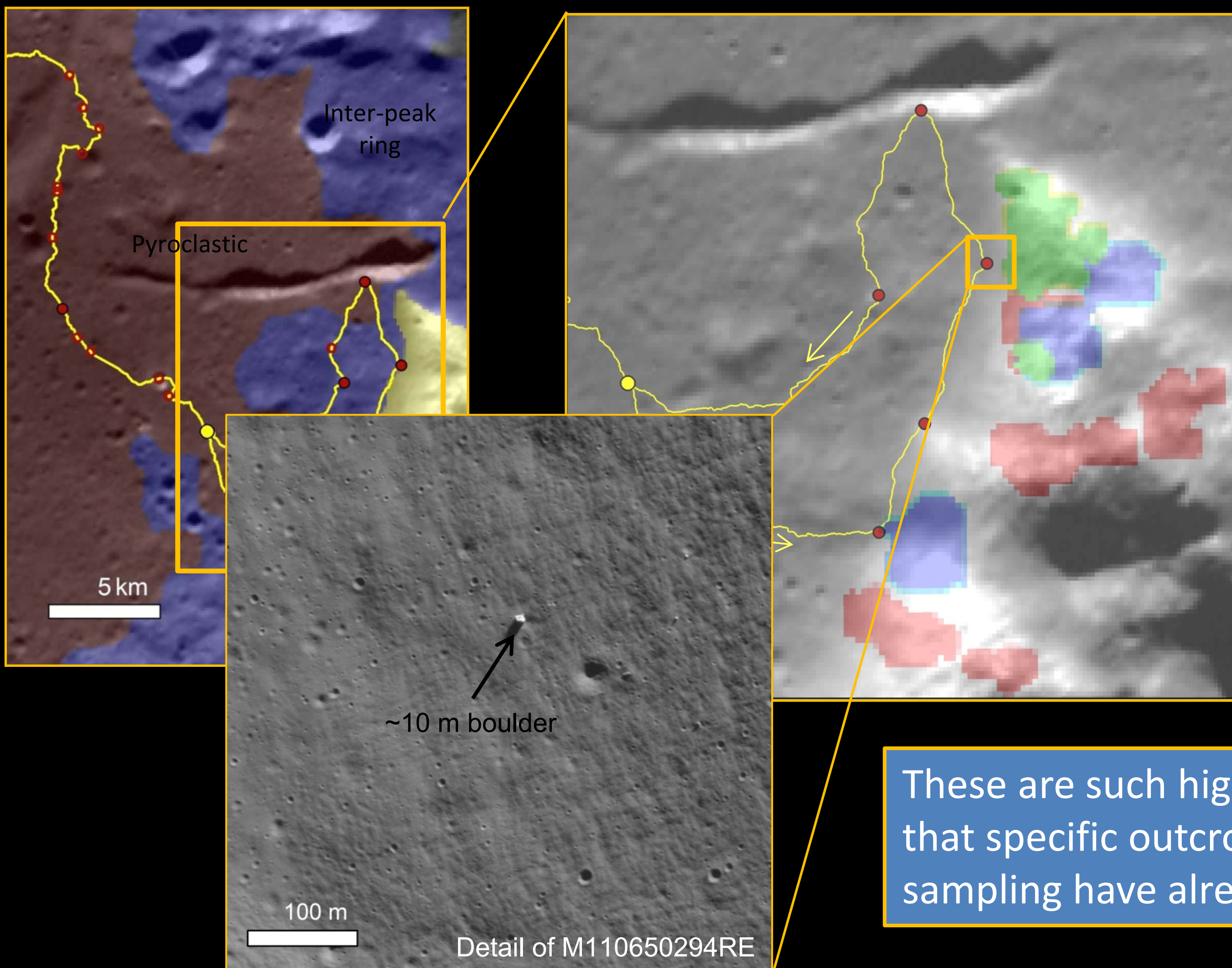
Boulder: D ~5 m

Associated boulder track to opx-bearing source (M^3 data)

Sample:

500 g hand specimen from boulder

SHORTEST DISTANCE TRAVERSE: Vicinity of Landing Site 1



Location:

Base of the peak ring

Boulder: D ~10 m

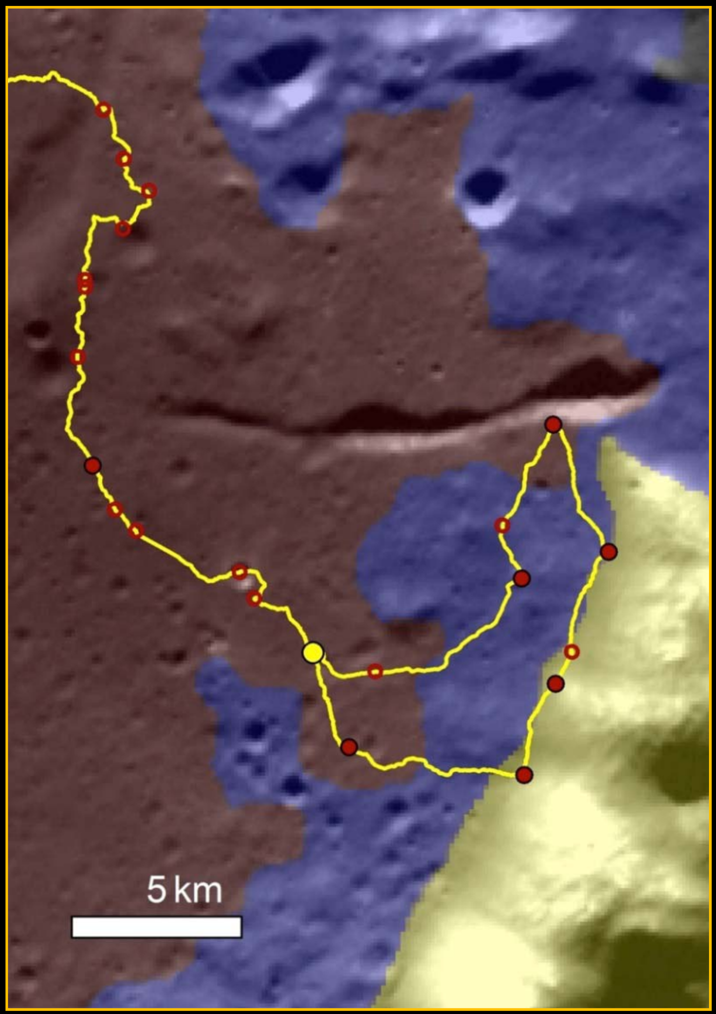
Associated boulder track to olivine-bearing source (M^3 data)

Sample:

500 g hand specimen from boulder

These are such high-fidelity traverse studies that specific outcrops and boulders for sampling have already been identified.

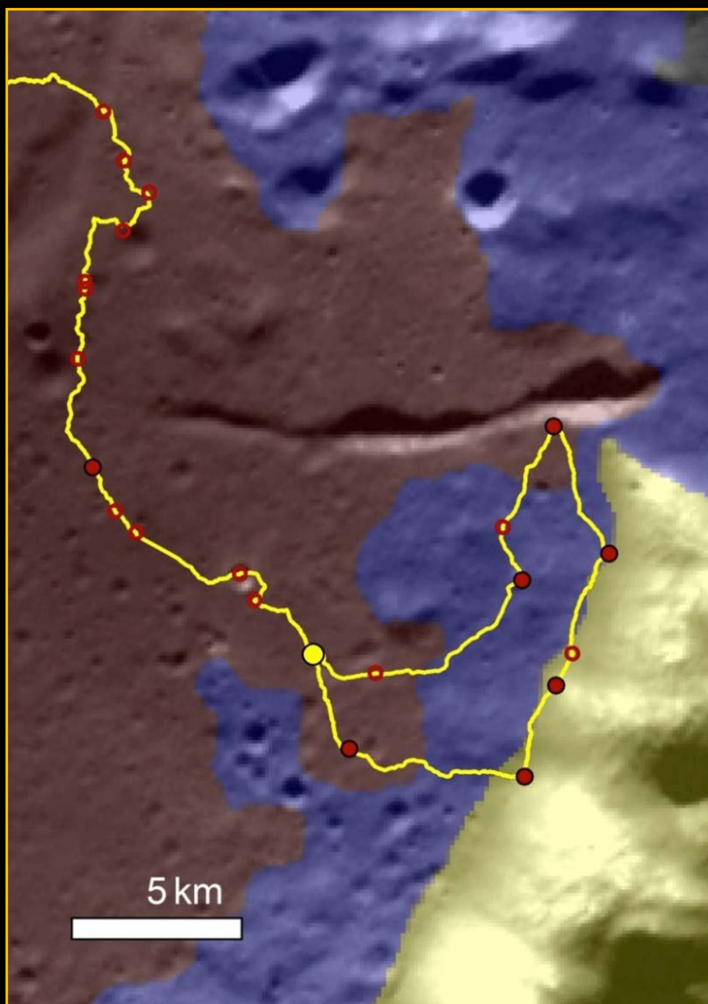
SHORTEST DISTANCE TRAVERSE: Vicinity of Landing Site 1



Mission narrative

1. Sample pyroclastic vent & potentially exposures in nearby fracture
   - ◊ The first samples of pyroclastic vent sample from the far side
   - ◊ ISRU-relevant glass
   - ◊ ISRU-relevant volatiles
   - ◊ Tests models of thermal & magmatic evolution of lunar interior
   - ◊ Tests models of volatile transport and deposition

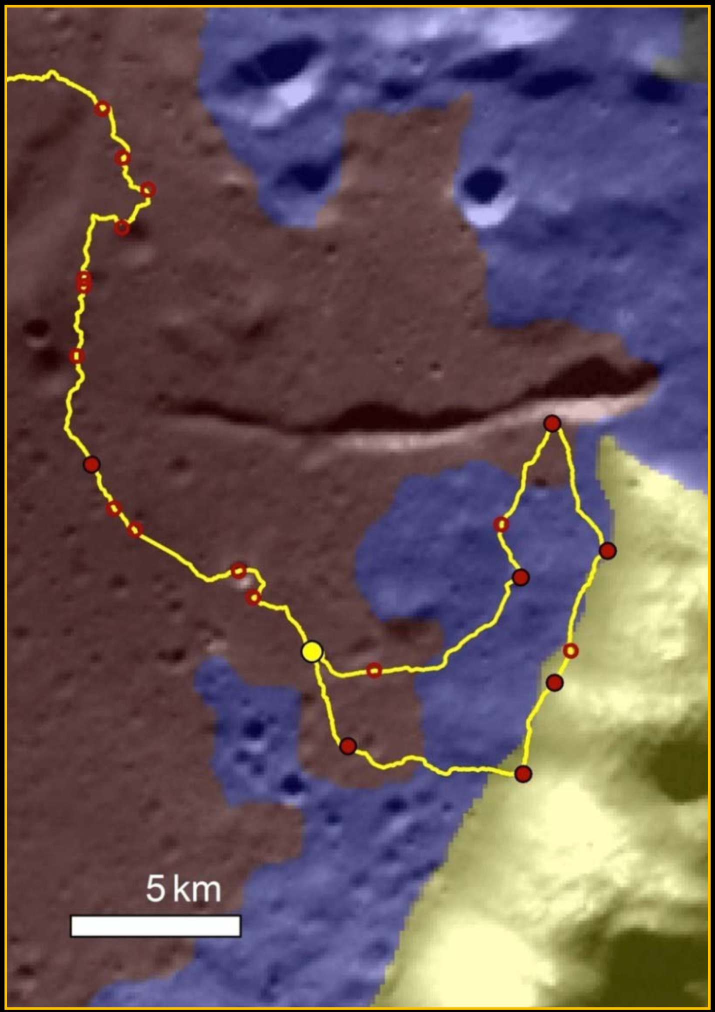
SHORTEST DISTANCE TRAVERSE: Vicinity of Landing Site 1



Mission narrative

2. Sample Schrödinger impact breccias
   - ◊ Determine age of near-final basin-forming impact on Moon
   - ◊ Clasts of excavated crustal components (including – potentially – SPA impact melt)
   - ◊ Schrödinger impact melt – if present – provides chemical average of melted crust
   - ◊ That sample may contain chemical fingerprint of impacting asteroid or comet
   - ◊ Tests models of inner solar system bombardment
   - ◊ Will tell us if life on Earth began after the basin-forming epoch or whether it emerged in the midst of the basin-forming epoch.

SHORTEST DISTANCE TRAVERSE: Vicinity of Landing Site 1

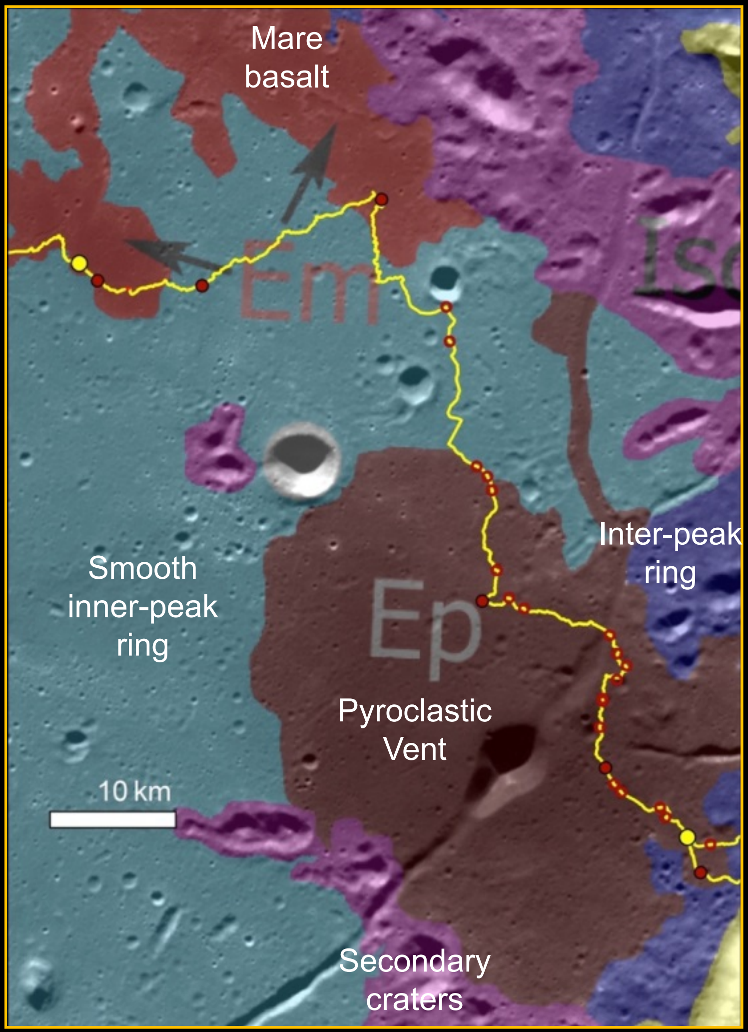


Mission narrative

3. Samples of noritic, anorthositic, and olivine-bearing lithologies in the uplifted peak ring

- ◊ Provides the first outcrop samples of lunar crustal lithologies anywhere on the Moon and, thus, will provide geologic context for subsurface relationships of pristine lithologies
- ◊ Will include samples from the lower crust (and potentially upper mantle)
- ◊ Tests models of planetary differentiation, including the lunar magma ocean hypothesis, and cause(s) of crustal dichotomy
- ◊ Tests models of peak-ring formation (complementing on-going studies of the buried dinosaur-killing Chicxulub Crater on Earth)

SHORTEST DISTANCE TRAVERSE: En route to Landing Site 2



Traverse length: ~112 km

24 stations selected for *in-situ* analysis and imaging (red circles)

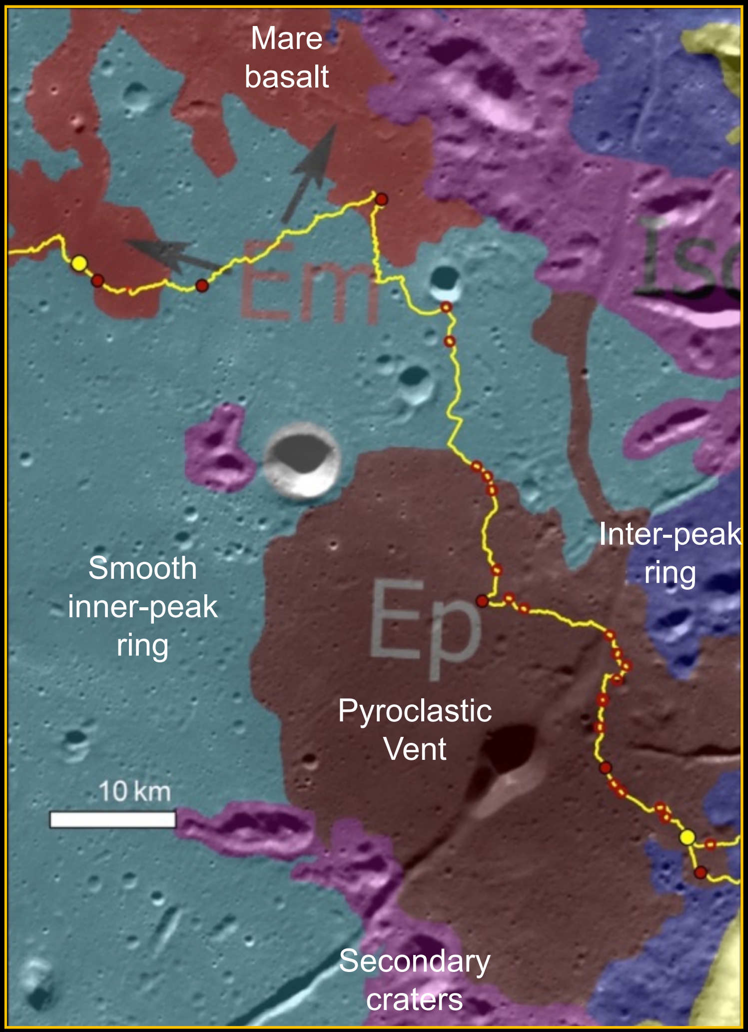
5 of the 24 stations are sampling sites (filled red circles)

Sampling:
(based on CAPTEM, 2007, requirements)

- Pyroclastic material: 4.0 kg
- Mare basalt: 1.0 kg
- Impact melt breccia: 5.0 kg
  (Smooth inner-peak ring)

Total sample mass: 10 kg

SHORTEST DISTANCE TRAVERSE: En route to Landing Site 2



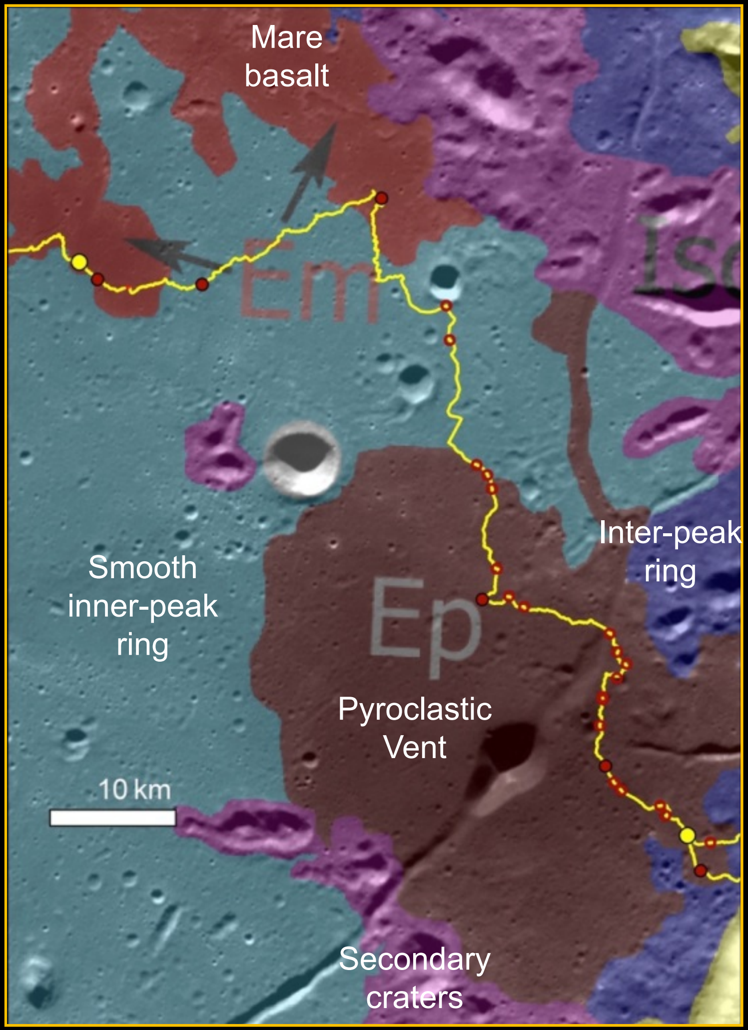
Mission narrative

4. Will obtain additional samples of pyroclastic vent deposits

5. Samples of rough (clast-rich) and smooth (melt-rich) Schrödinger impact fill*
   - ◊ This will be the first time we have explored the top of an impact melt sheet on the Moon
   - ◊ May greatly enhance our ability to interpret Apollo samples of potential basin-origin

* Sampling options: collect regolith on top of impact fill or, better, collect rocks excavated from underlying bedrock by fresh craters.

SHORTEST DISTANCE TRAVERSE: En route to Landing Site 2



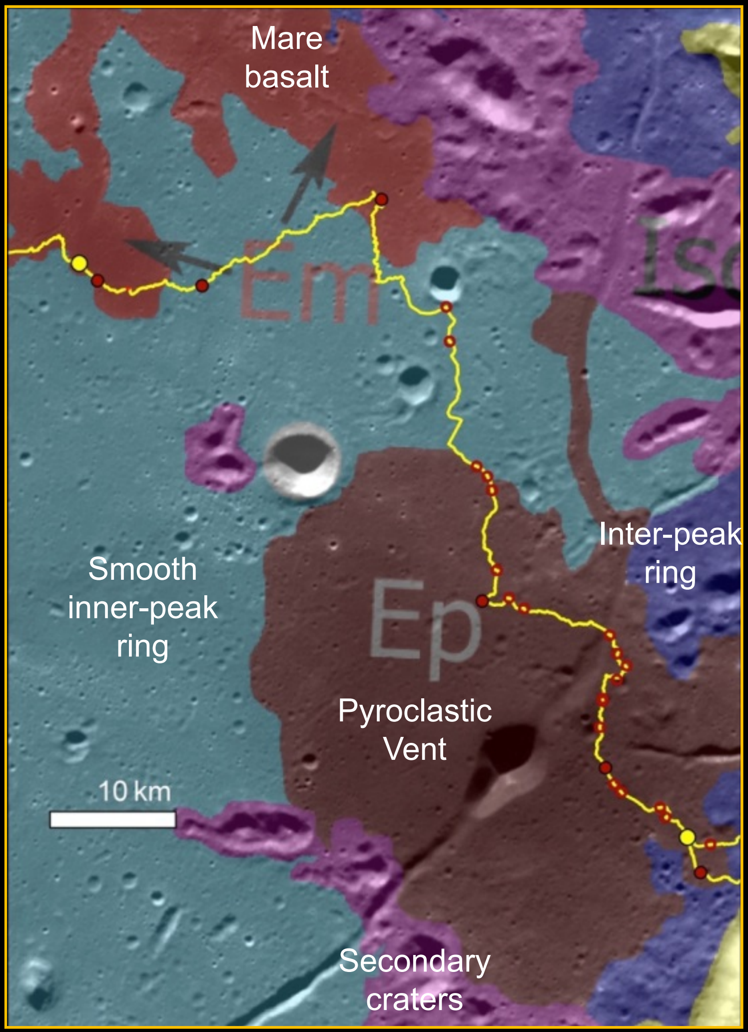
Mission narrative

5. Samples of rough (clast-rich) and smooth (melt-rich) Schrödinger impact fill

(continued)

◊ Will provide age of Schrödinger basin impact, helping to define the end of the basin-forming epoch on the Moon
◊ Comparing and contrasting these samples with the impactites found near the first landing site will greatly enhance the collective findings of how basins form
◊ Sampling the melt at different locations will allow geologists to resolve uncertainties about impact melt mixing (e.g., the degree of homogeneity) which currently limits the usefulness of Apollo samples.

SHORTEST DISTANCE TRAVERSE: En route to Landing Site 2



Mission narrative

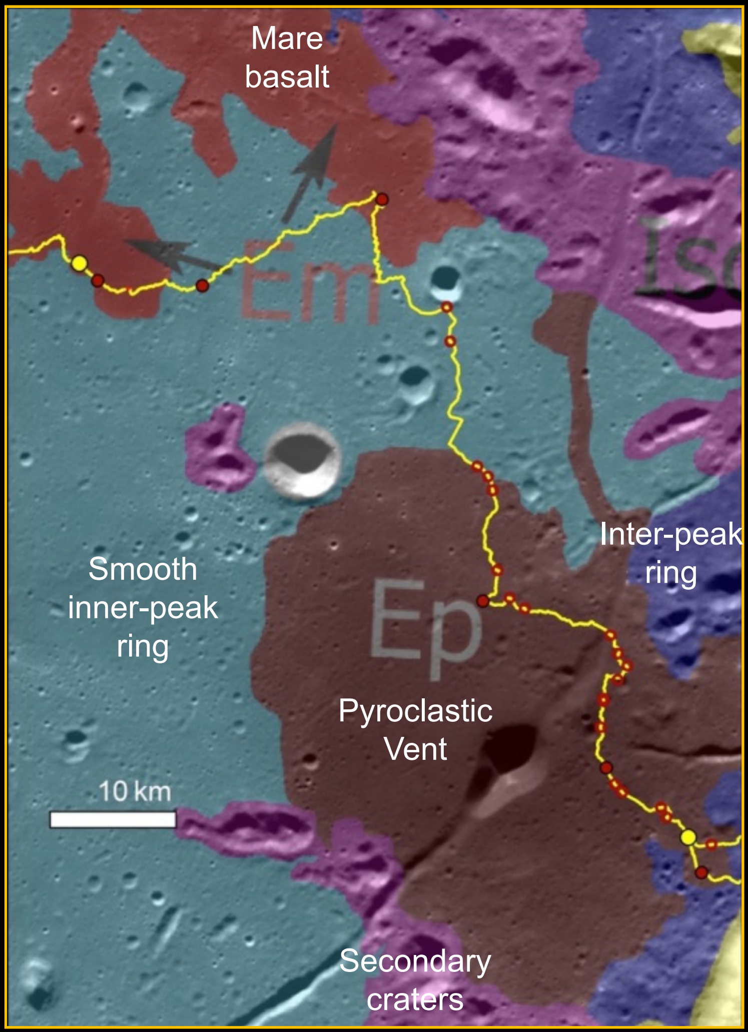
5. Samples of rough (clast-rich) and smooth (melt-rich) Schrödinger impact fill

(continued)

◊ Sampling the melt ejected by fresh crater will allow geologists to determine if melt sheets chemically differentiate.

◊ Determining the age of a fresh crater will also help calibrate the recent impact flux to the Earth-Moon system.

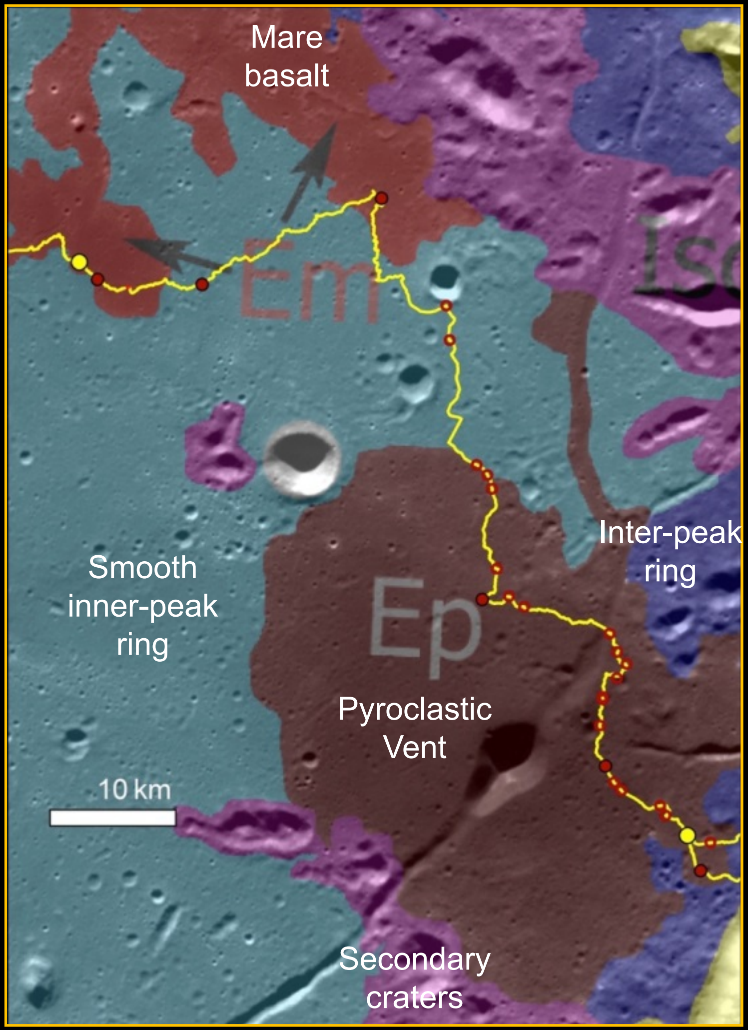
SHORTEST DISTANCE TRAVERSE: En route to Landing Site 2



Mission narrative

6. Samples of mare deposit
   - ◊ This will be the first farside mare sample collected with known geologic context (cf., lunar meteorites)
   - ◊ Provides a measure of the thermal and magmatic evolution of the Moon
   - ◊ Will help refine the calibration of Ti-maps and, thus, estimates of the ISRU potential of Ti-bearing basalts on the Moon.
   - ◊ Possibly produced at a different time than the pyroclastic vent.
   - ◊ Possibly produced from a different depth in the lunar mantle than the pyroclastic vent.

SHORTEST DISTANCE TRAVERSE: En route to Landing Site 2



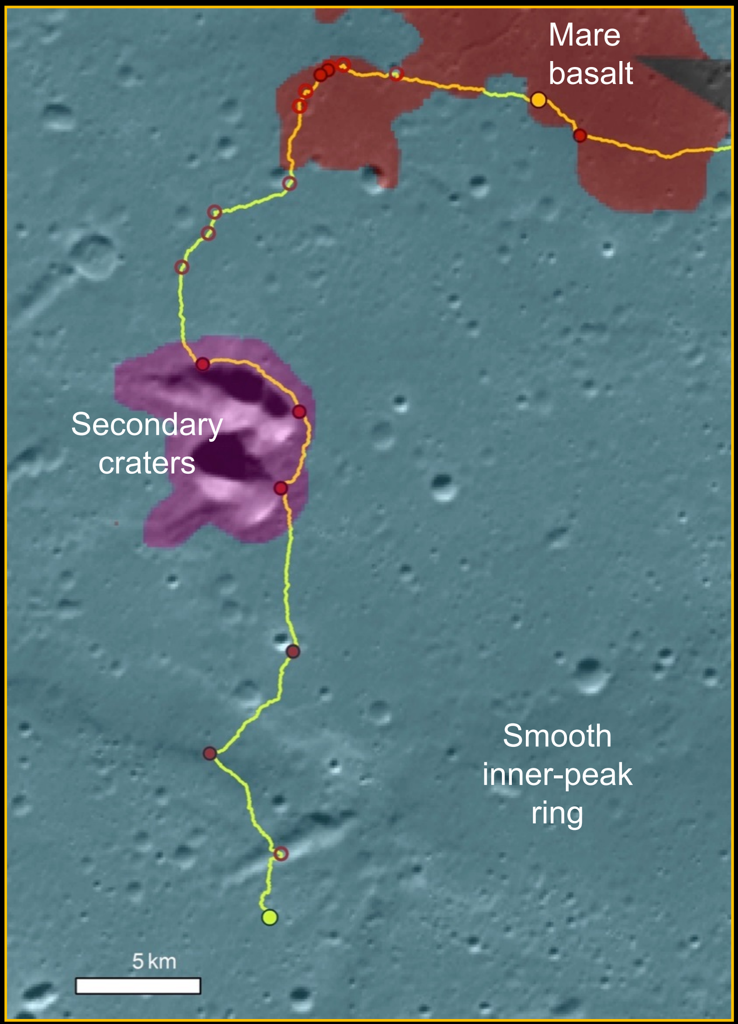
Mission narrative

6. Samples of mare deposit

(continued)

- ◊ Determining an age of the mare surface will help calibrate the crater counting chronology in the ~3.7 to 2.5 Ga interval.

SHORTEST DISTANCE TRAVERSE: En route to Landing Site 3



Traverse length: ~59 km

17 stations selected for *in-situ* analysis and imaging (red circles)

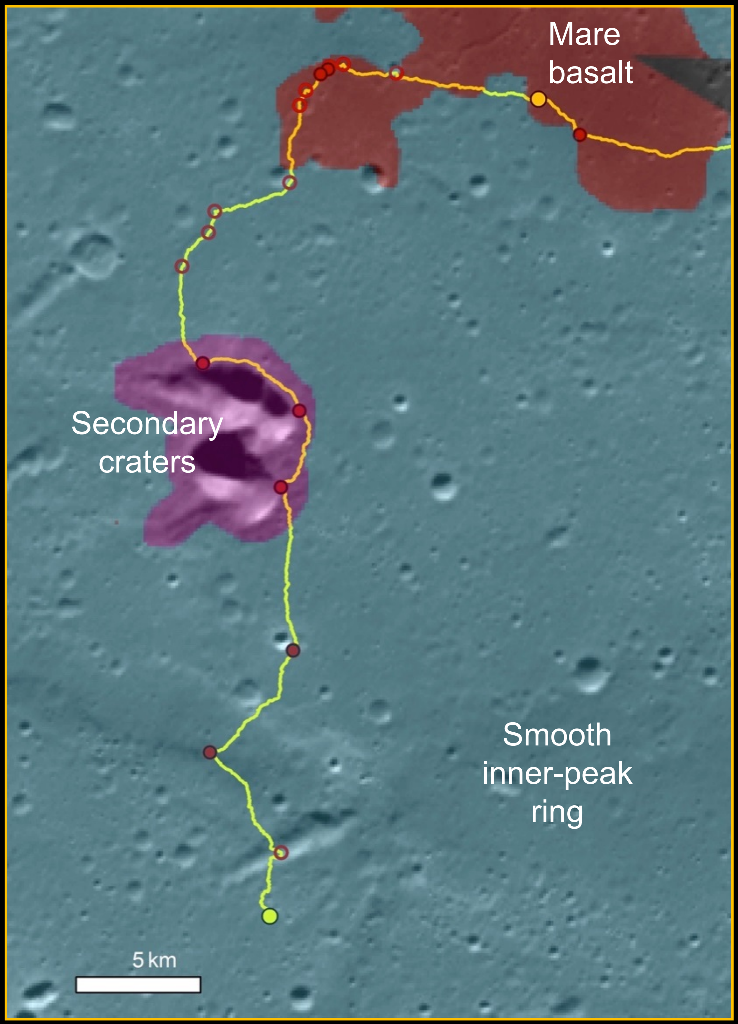
7 of the 17 stations are sampling sites (filled red circles)

Sampling:
(based on CAPTEM, 2007, requirements)

- Mare basalt: 1.0 kg
- Secondary crater: 1.0 kg
- Impact melt breccia: 5.0 kg
  (Smooth inner-peak ring)
- Iron-rich ridge: 2.0 kg

Total sample mass: 9 kg

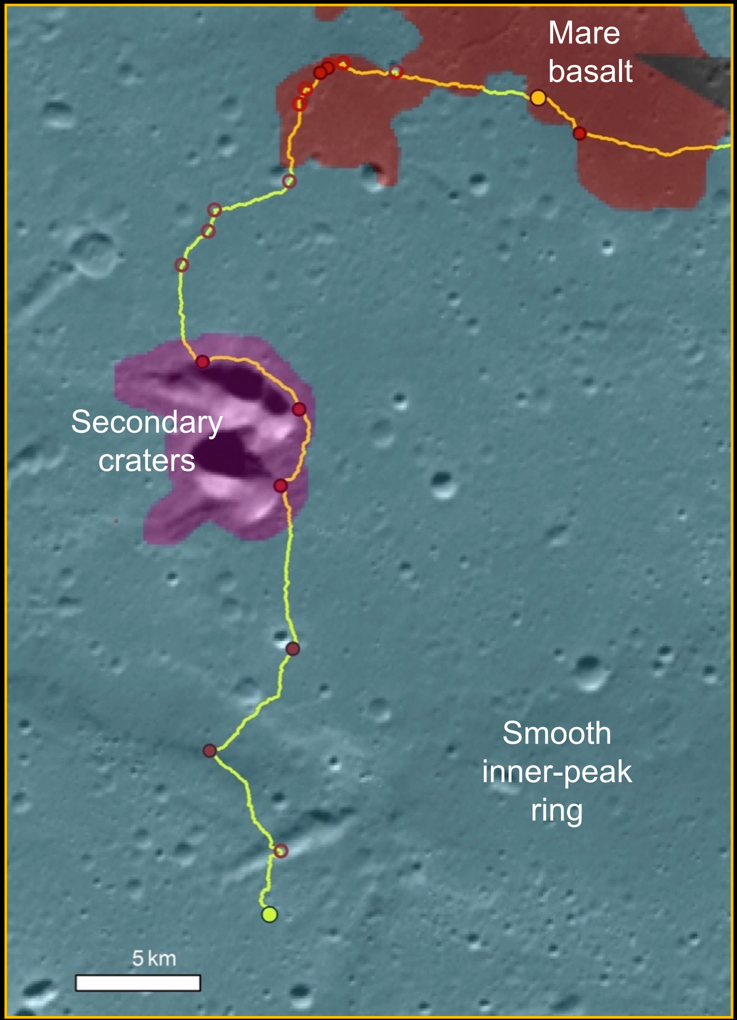
SHORTEST DISTANCE TRAVERSE: En route to Landing Site 3



Mission narrative

7. Samples of second mare deposit
   - ◊ This will refine estimates of either basaltic lava flow distribution (if same age) or the thermal evolution of subsurface magma sources (if a different age)
   - ◊ Samples collected in several locations may be from flows of different ages, compositions, and/or cooling rates

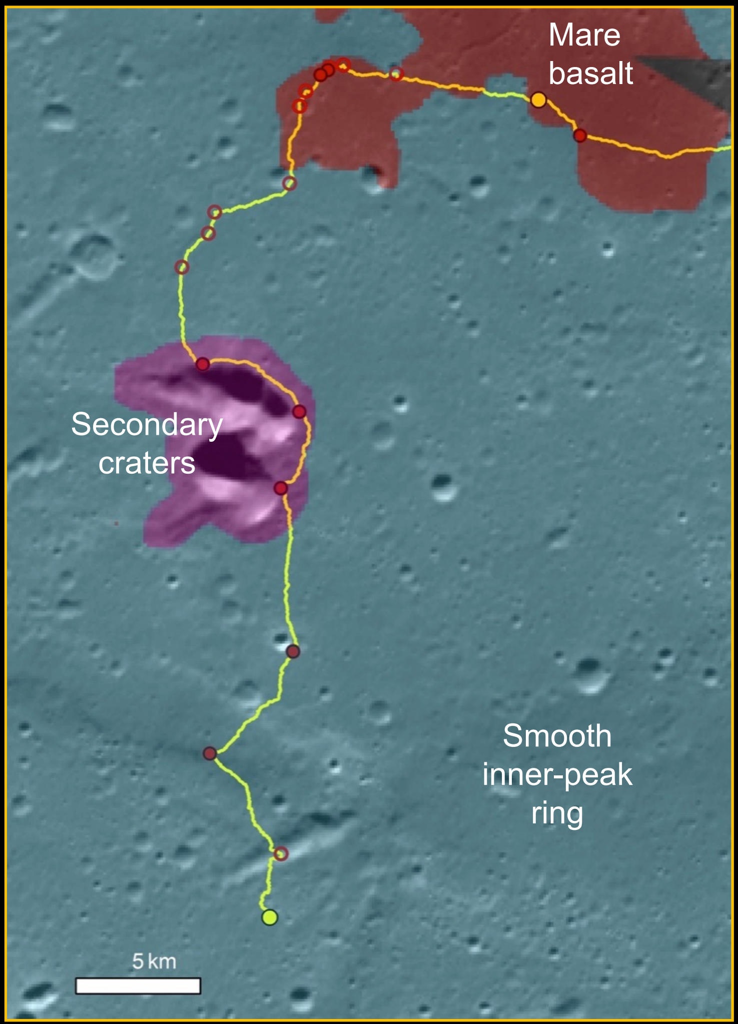
SHORTEST DISTANCE TRAVERSE: En route to Landing Site 3



Mission narrative

8. Samples of regolith
   - ◊ These will be the first farside regolith samples collected with known geologic context (cf., lunar meteorites)
   - ◊ Provides a measure of farside regolith production rates on melt sheets vs. that on highland and mare surfaces
   - ◊ Will help refine the calibration of Ar-Ar ages of regolith closure ages.

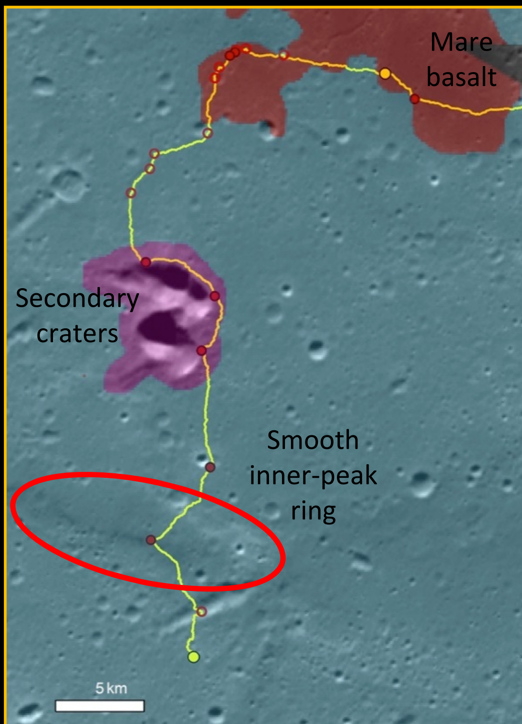
SHORTEST DISTANCE TRAVERSE: En route to Landing Site 3

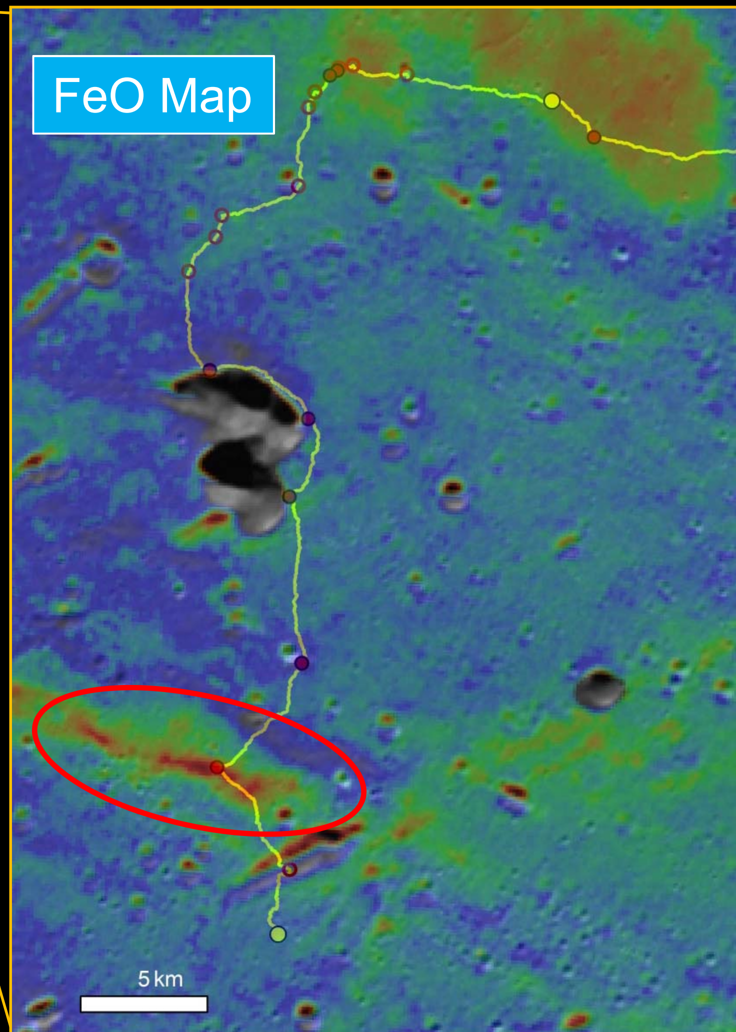


Mission narrative

9. Sample secondary crater deposit
   - ◊ Potentially produce samples of lunar crust from a distant location
   - ◊ Observations will provide a measure of a relatively low-velocity secondary cratering event and the debris ejected from it. This will help resolve scientific questions about impact cratering processes & help address the exploration hazards of secondary cratering events.

SHORTEST DISTANCE TRAVERSE: En route to Landing Site 3





Location:

Smooth inner-peak ring impact melt

FeO-rich ridge

Sample:

2 kg scoop of material near crater

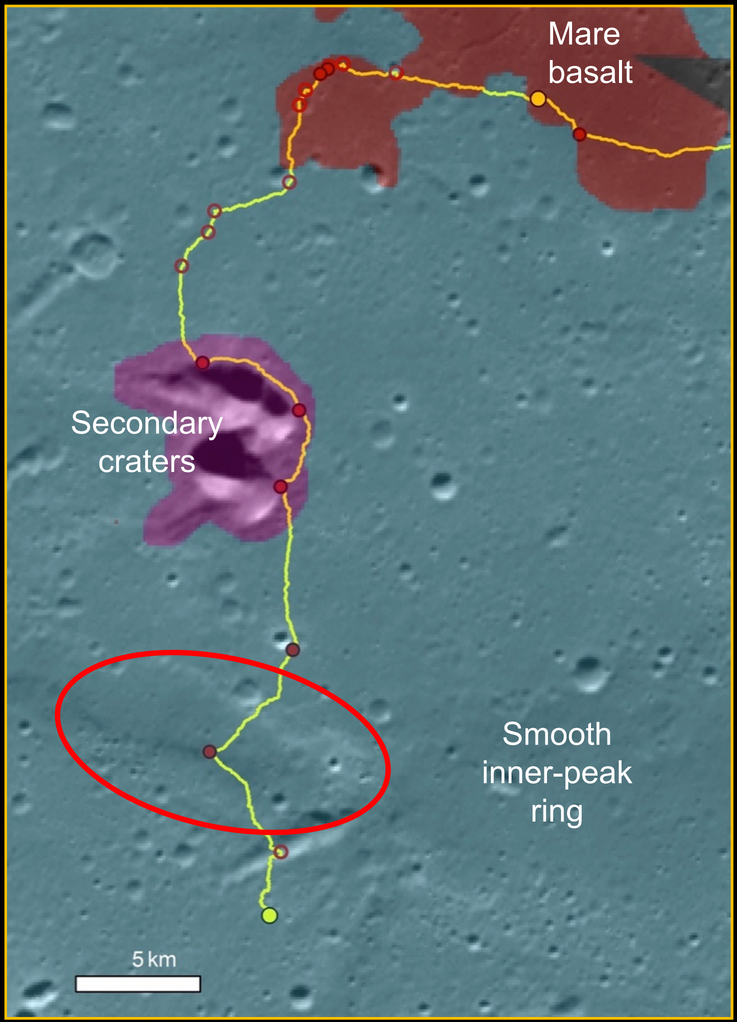
Objectives:

Processes controlling surface structure – dike or faulting?

Thermal and magmatic evolution

Compare with mare and pyroclastic units

SHORTEST DISTANCE TRAVERSE: En route to Landing Site 3



Mission narrative

10. Potentially a third mare deposit

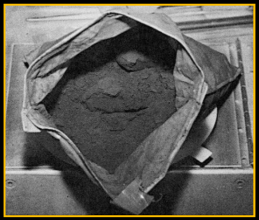
- ◊ This will refine estimates of either basaltic lava flow distribution (if same age) or the thermal evolution of subsurface magma sources (if a different age)
- ◊ Resolve origin of ridge – are these types of features created by a dike, a volcanic extrusion, or a fault?

SHORTEST DISTANCE TRAVERSE – Sample summary

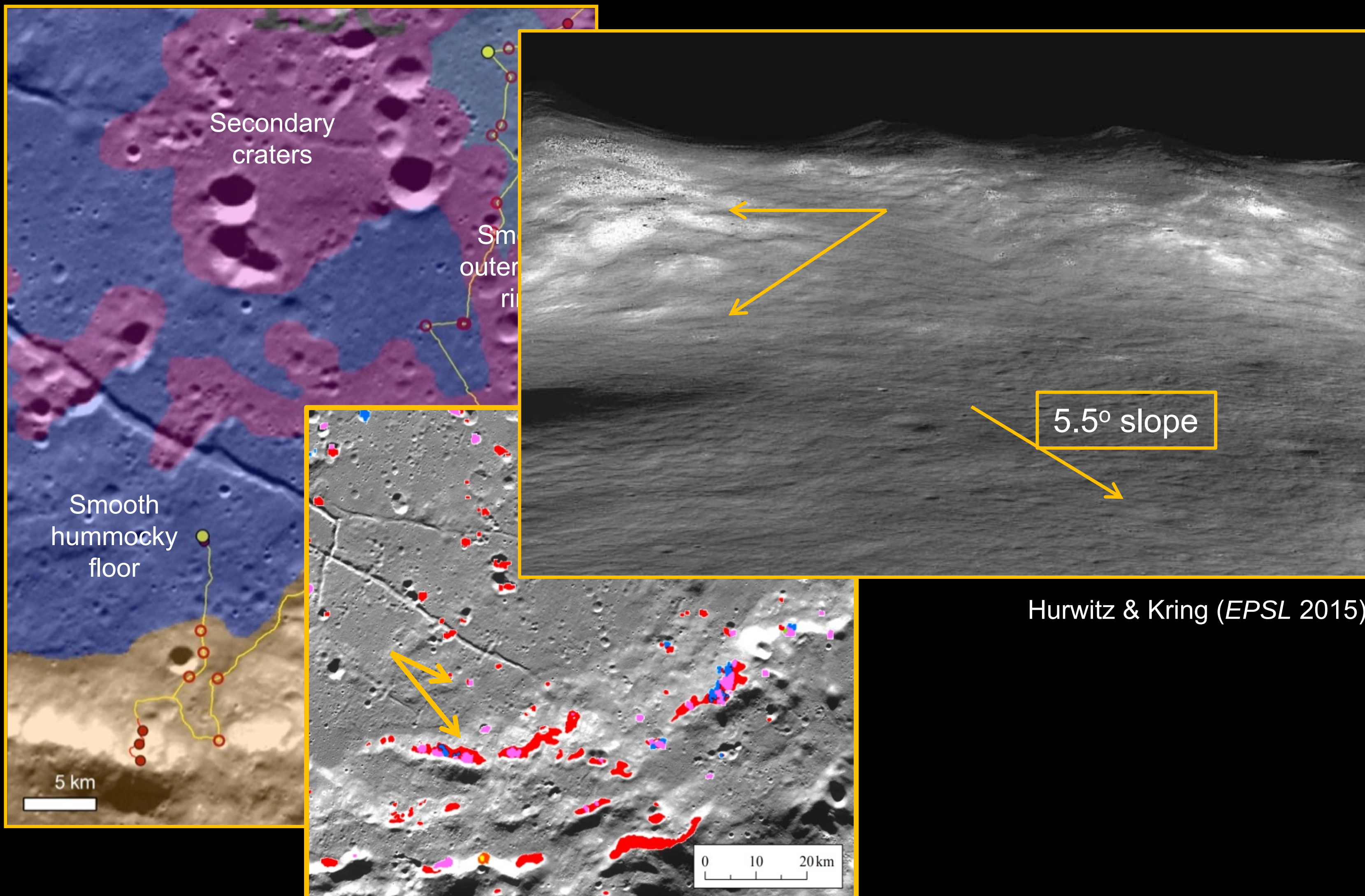
Applying CAPTEM (2007) recommendations, sample masses are estimated as:

Lithology	Stations	Mass (kg)
Pyroclastic material	S1, S14, S24	6.0
Fracture material	S6	1.0
Peak ring material	S2, S3, S5	1.5
Impact melt breccia	S8, S32, S48	15.0
Mare basalt	S31, S33, S37, S38	2.0
Secondary crater material	S45, S46, S47	1.0
FeO-rich ridge material	S49	2.0
	Total:	28.5

Landing site 1: Total mass with packaging: 10.5 kg
Landing site 2: Total mass with packaging: 11 kg
Landing site 3: Total mass with packaging: 10 kg



INTERMEDIATE DISTANCE TRAVERSE: En route to Landing Site 3



Hurwitz & Kring (*EPSL* 2015)

SHORTEST DISTANCE TRAVERSE: NRC (2007) OBJECTIVES ADDRESSED

NRC Concept/Goal	a	b	c	D	e
1: Bombardment history of the inner solar system	***Test cataclysm hypothesis***	***Age of South Pole-Aitken basin***	***Establish absolute chronology***	Recent impact flux	Secondary craters
2: Structure and composition of lunar interior	***Thickness/ variability of lunar crust***	***Stratification of mantle***	***Size, composition, state of core***	Thermal state of interior	N/A
3: Diversity of lunar crustal rocks	***Differentiation products***	***Age, distribution, origin of rocks***	Composition of lower crust	Complexity of lunar crust	Extent/structure of megaregolith
4: Lunar poles and volatiles	***State and distribution of volaties***	Source of volatiles	Transport, alteration, loss processes	Properties of polar regolith	Polar regolith and ancient solar environment
5: Lunar volcanism	Origin/variability of basalts	Age of mare basalts	Range/extent of pyroclastic deposits	Lunar volcanic flux	N/A
6: Impact processes	Melt sheet differentiation	Structure of multi-ring impact basins	Crater formation	Mixing of local and ejecta material	N/A
7: Regolith processes	Characterize ancient regolith	Physical properties of regolith	Regolith modification processes	Rare minerals in regolith	N/A

Addressed along traverse

Not addressed along traverse

May be addressed along traverse

David A. Kring

CENTER FOR LUNAR SCIENCE AND EXPLORATION

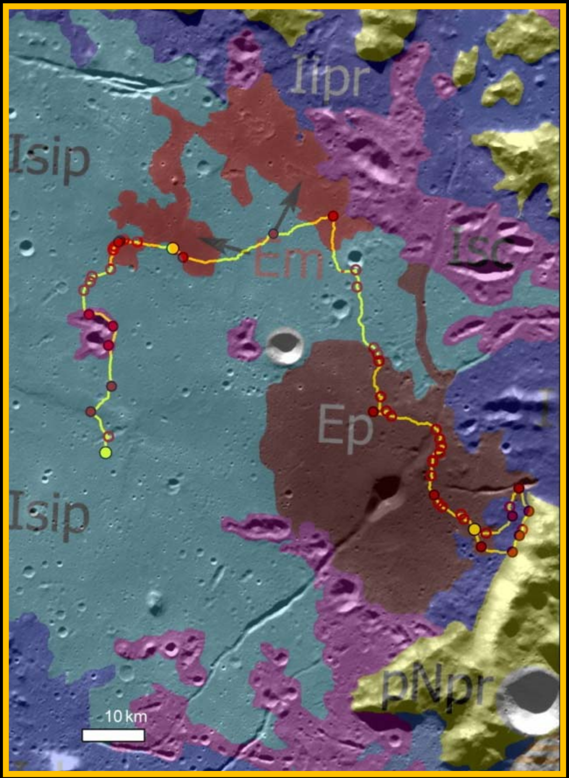
vitally impacting the future – today

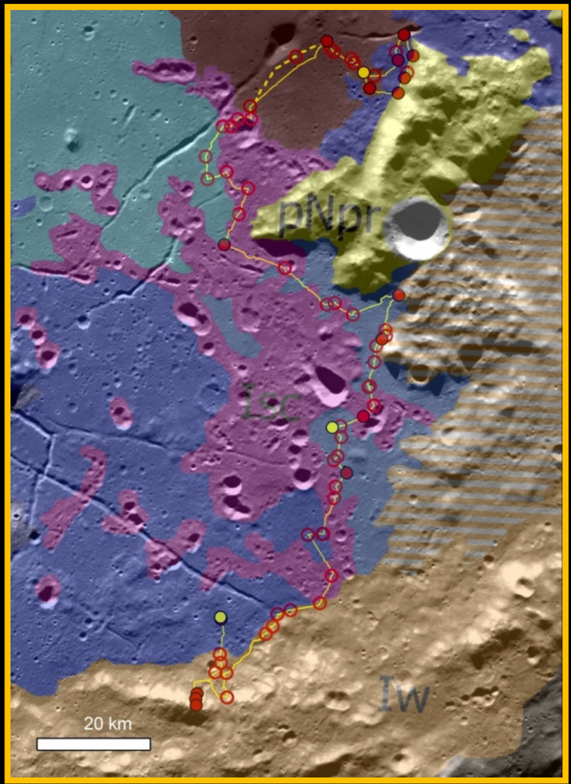
INTERMEDIATE DISTANCE TRAVERSE: NRC (2007) OBJECTIVES ADDRESSED

NRC Concept/Goal	a	b	c	D	e
1: Bombardment history of the inner solar system	***Test cataclysm hypothesis***	***Age of South Pole-Aitken basin***	***Establish absolute chronology***	Recent impact flux	Secondary craters
2: Structure and composition of lunar interior	***Thickness/ variability of lunar crust***	***Stratification of mantle***	***Size, composition, state of core***	Thermal state of interior	N/A
3: Diversity of lunar crustal rocks	***Differentiation products***	***Age, distribution, origin of rocks***	Composition of lower crust	Complexity of lunar crust	Extent/structure of megaregolith
4: Lunar poles and volatiles	***State and distribution of volatiles***	Source of volatiles	Transport, alteration, loss processes	Properties of polar regolith	Polar regolith and ancient solar environment
5: Lunar volcanism	Origin/variability of basalts	Age of mare basalts	Range/extent of pyroclastic deposits	Lunar volcanic flux	N/A
6: Impact processes	Melt sheet differentiation	Structure of multi-ring impact basins	Crater formation	Mixing of local and ejecta material	N/A
7: Regolith processes	Characterize ancient regolith	Physical properties of regolith	Regolith modification processes	Rare minerals in regolith	N/A

Addressed along traverse — Not addressed along traverse — May be addressed along traverse

CONCLUSIONS





HERACLES

The mission concept can address the highest lunar science priorities

The mission concept can address several ISRU issues that can help guide decisions about sustainable exploration options

Simply said – this would be an exciting opportunity that should appeal to (and involve) nearly every one interested in exploring the Moon.