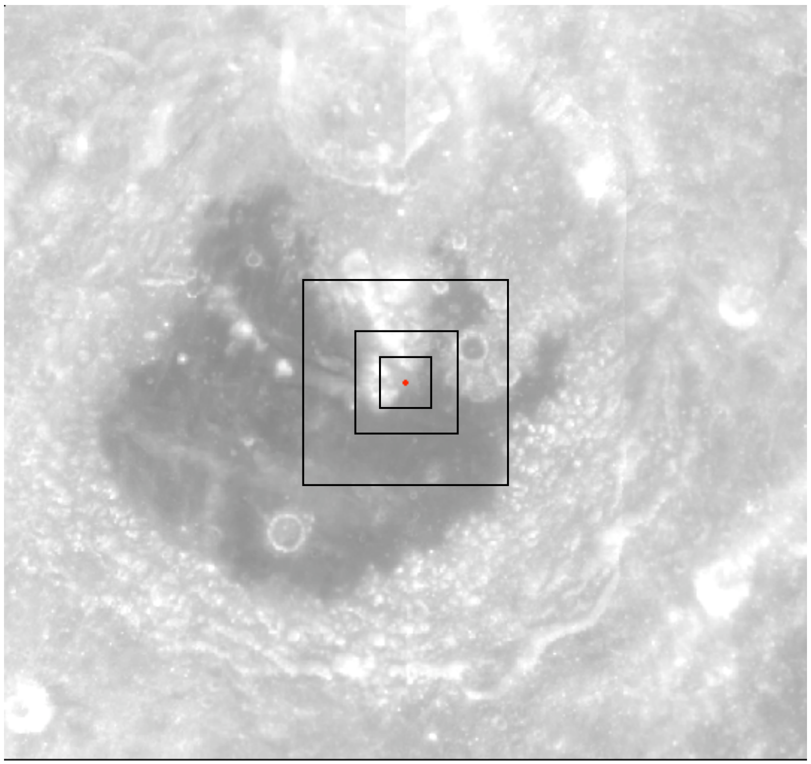
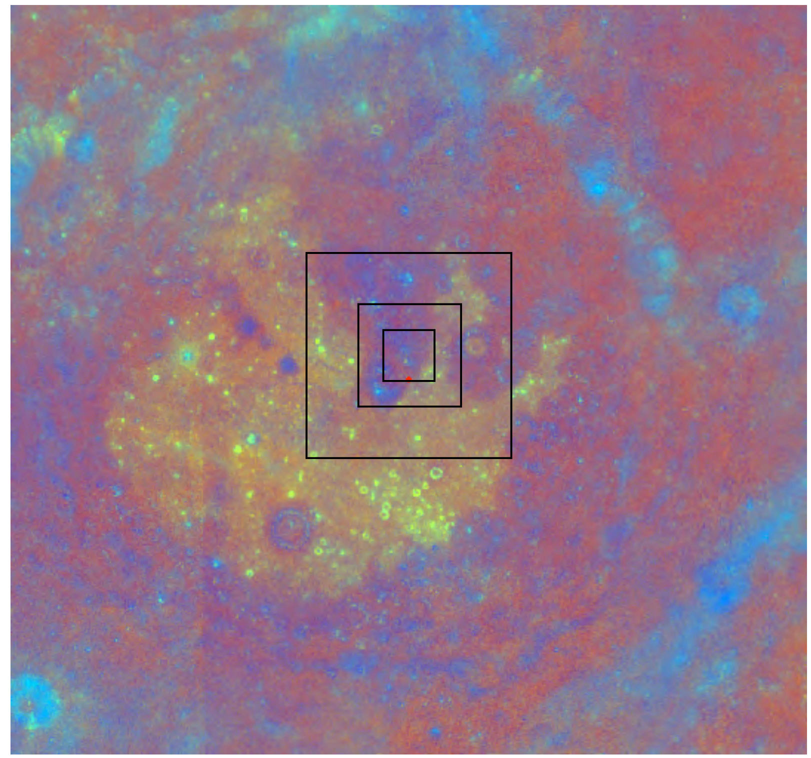
NASA Constellation Program Office Regions of Interest on the Moon:

An update for the 2009 Annual Meeting of the Lunar Exploration and Analysis Group





John E. Gruener

Lunar Surface Systems Project Office

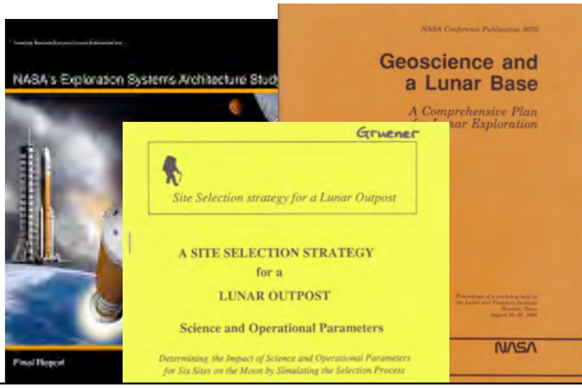
NASA Johnson Space Center

Constellation Program Office
Regions of Interest on the Moon

- **The regions of interest identified by the Constellation Program Office (CxP):**
  - Illustrate the diversity of scientific and resource opportunities, and geographic terrains and locations
  - As a set, they form a representative basis for scientific exploration, resource development, and mission operations

- **The CxP regions of interest <u>DO NOT</u> represent the initial step in a site selection process for future human missions to the Moon**

CxP NAC Targets, ROIs and Products



Geoscience and a Lunar Base Workshop – 1988
Site Selection Strategy for a Lunar Outpost – 1990
Exploration Systems Architecture Study (ESAS) - 2005

- **Leveraged heavily on past site selection work and recent Clementine and Lunar Prospector missions to the Moon**
  - Consideration of scientific, resource utilization, and operational merits and desire to span lunar terrain types
  - CxP corrected & refined coordinates, organized into 50 sites grouped into two "tiers" (based on LROC PI recommendation) – 12/08
  - Prepared CxP Target Catalog for eventual transfer to LRO – 1/09, example entries to follow

Customers:

Data / Products:	**Altair/ALHAT**	**Surface Systems**
Photo-mosaics & Digital Elevation Models	♦ Accurate *representative* site data for lander design and terrain relative navigation (TRN) & hazard avoidance system development. ♦ If targets are actual landing sites, pin-point landing accuracy through TRN ♦ Relevant ROI ~5 km radius	♦ Accurate *representative* site data for trafficability assessments and mobility system designs. ♦ Relevant ROI ~ 10 km radius
Hazard Assessments	♦ Accurate *representative* lander-scale boulders, craters, slopes distributions for lander design and hazard avoidance system development. ♦ If targets are actual landing sites, pin-point landing site designation. ♦ Relevant ROI ~5 km radius	♦ Statistical representation of surface mobility obstacles/hazards. ♦ If targets are actual landing sites, detailed operational traverse planning. ♦ Relevant ROI ~ 10 km radius

CxP Target Priority Strategy

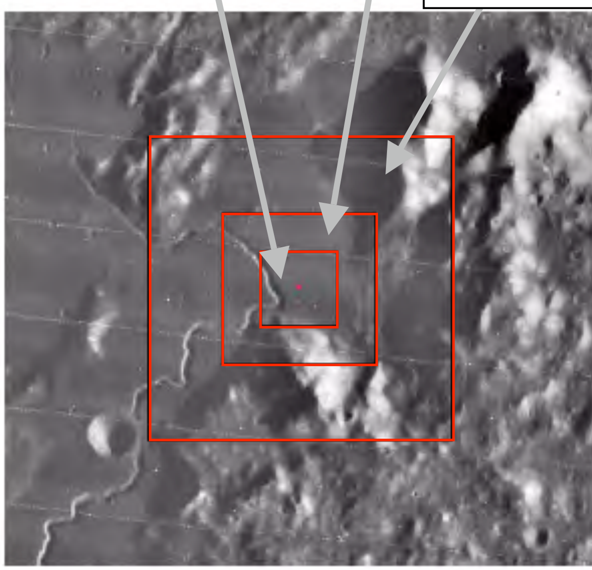
- CxP targets (50 total) are divided into two “tiers” of 25 each in event of mutual interference
- Region of Interest and observations necessary for specific data products prioritized to maximize total data return
- Targeting updates – simple process, but acquisition becomes harder as mission progresses (interference, lack of time)
- CxP target coverage will extend into SMD mission – transition/frozen orbit imaging possibilities

Priority 1: 10x10 km All Targets with “full observations*”

Priority 2: Other LROC Level 1 measurement requirements

Priority 3: 20x20 km All Targets “best effort” full observations + other Co-I or LRO science

Priority 4: 40x40 km All Targets “best effort*” nadir mosaics + outside science requests



***The full set of observations include:**

1. Monoscopic image mosaic
2. Geometric stereo images
   Two observations
   One nadir, one at 20° off nadir (requires s/c slew)
   Solar incidence angle 50-68° off vertical if possible
3. Photometric stereo images
   Four observations with different solar incidence & azimuth angles
   All nadir
4. Hazards
   Two Sets
   One at solar incidence angle of 66-72° off vertical, one near 80° off vertical

Actual number of images required will depend on specific orbit groundtracks, lighting, interference etc. and could be substantially more.

LEAG LROC SAT
January-April 2009

- Chair, Paul G. Lucey, U. Hawaii

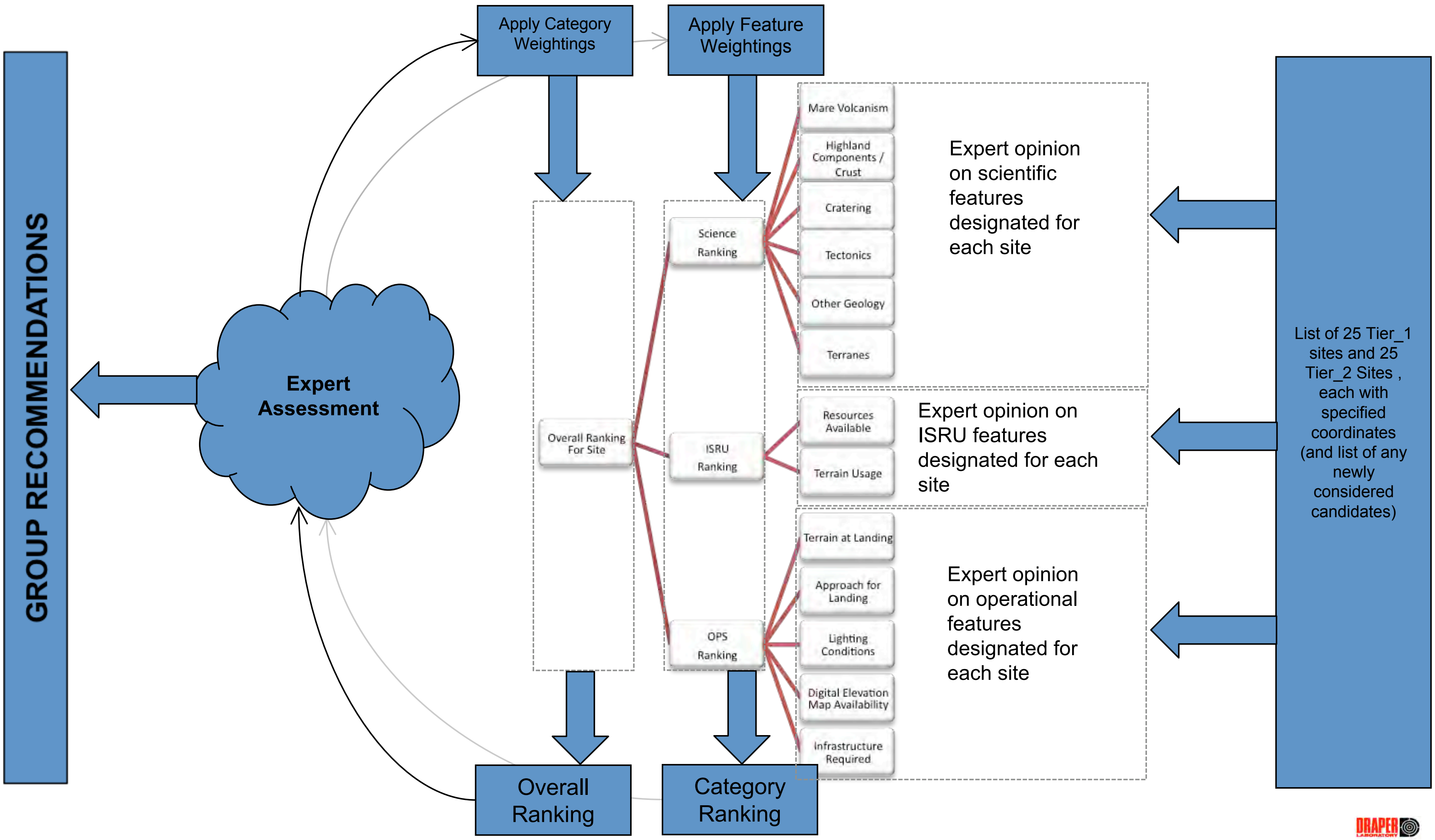
- Science Subgroup
  - Jeffrey Gillis-Davis, U. Hawaii
  - B. Ray Hawke, U. Hawaii

- ISRU Subgroup
  - Larry Taylor, U. Tenn, Knoxville
  - Mike Duke, At-large lunar scientist

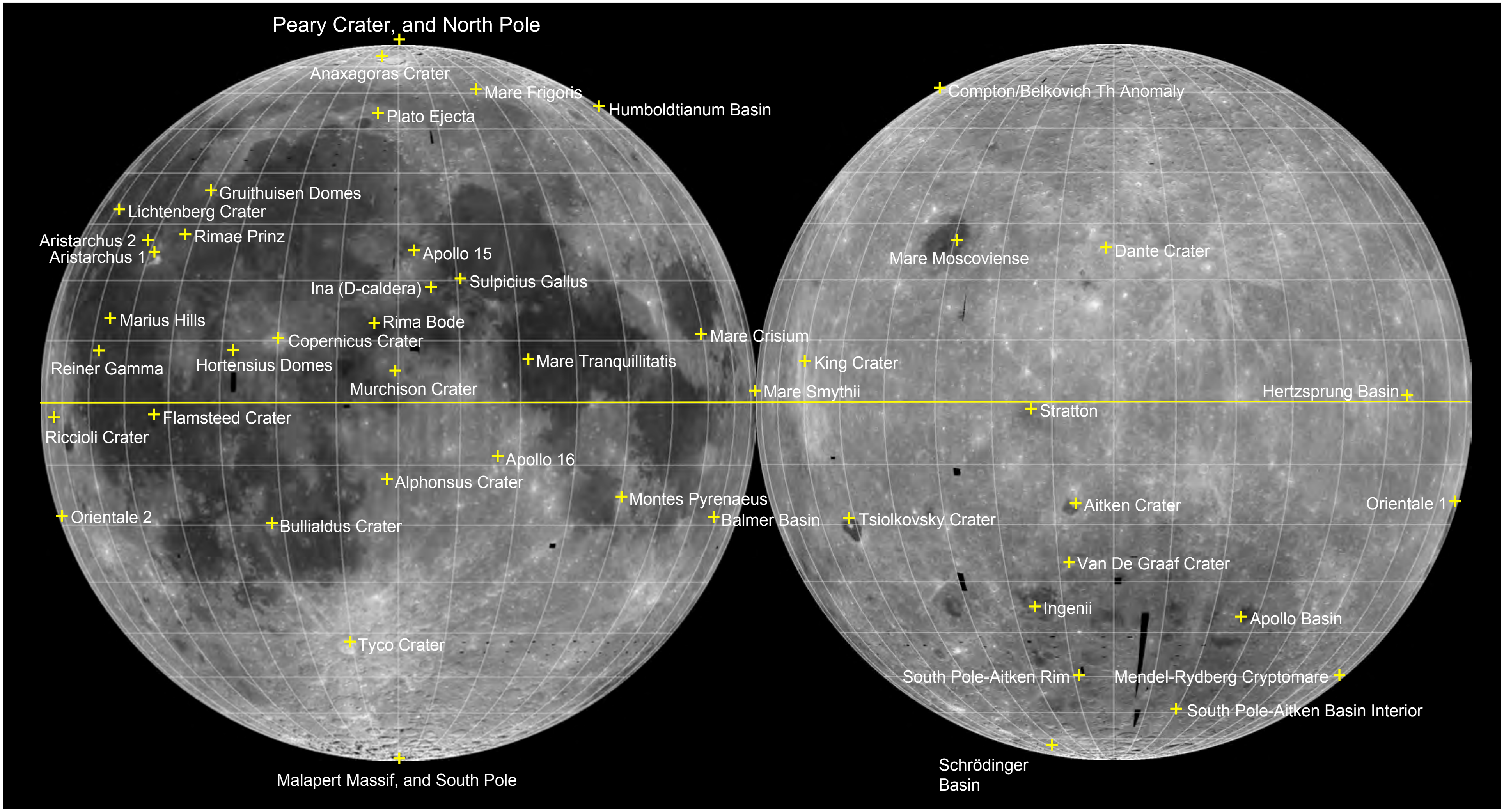
- Operations Subgroup
  - Tye Brady, Draper Lab
  - Todd Mosher, Sierra Nevada Corporation

- Observers
  - Mike Wargo, NASA
  - Steve Mackwell, LPI
  - Clive Neal, LEAG

LEAG LROC SAT
Comparison Methodology Overview (Illustrated)



Constellation Program Office Regions of Interest



Constellation LRO NAC Targets

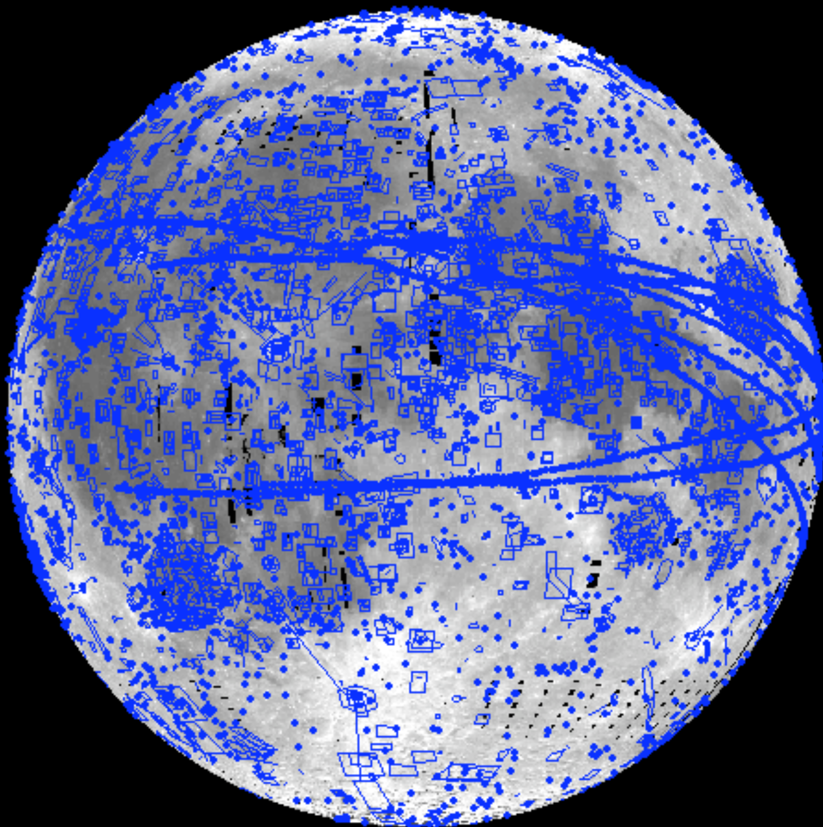
Tier 1

Code	Name	Long	Lat
ATK	Aitken Crater	173.48	-16.76
ALP	Alphonsus Crater	-2.16	-12.56
ANX	Anaxagoras Crater	-9.30	73.48
A15	Apollo 15	3.66	26.08
A16	Apollo 16	15.47	-9.00
APB	Apollo Basin	-153.72	-37.05
AR1	Aristarchus 1	-48.95	24.56
AR2	Aristarchus 2	-52.40	27.70
BUL	Bullialdus Crater	-22.50	-20.70
COP	Copernicus Crater	-20.01	9.85
GRT	Gruithuisen Domes	-40.14	36.03
HTZ	Hertzsprung	-125.56	0.09
KNG	King Crater	119.91	6.39
MAL	Malapert Massif	-2.93	-85.99
CRS	Mare Crisium	58.84	10.68
MUR	Murchison Crater	-0.42	4.74
NPO	North Pole	76.19	89.60
OR1	Orientale 1	-95.38	-26.20
PRY	Peary Crater	30.00	88.50
RMB	Rima Bode	-3.80	12.90
SPO	South Pole	-130.00	-89.30
SPA	South Pole-Aitken Basin Interior	-159.94	-60.00
STR	Stratton	166.88	-2.08
SPG	Sulpicius Gallus	10.37	19.87
TYC	Tycho Crater	-11.20	-42.99

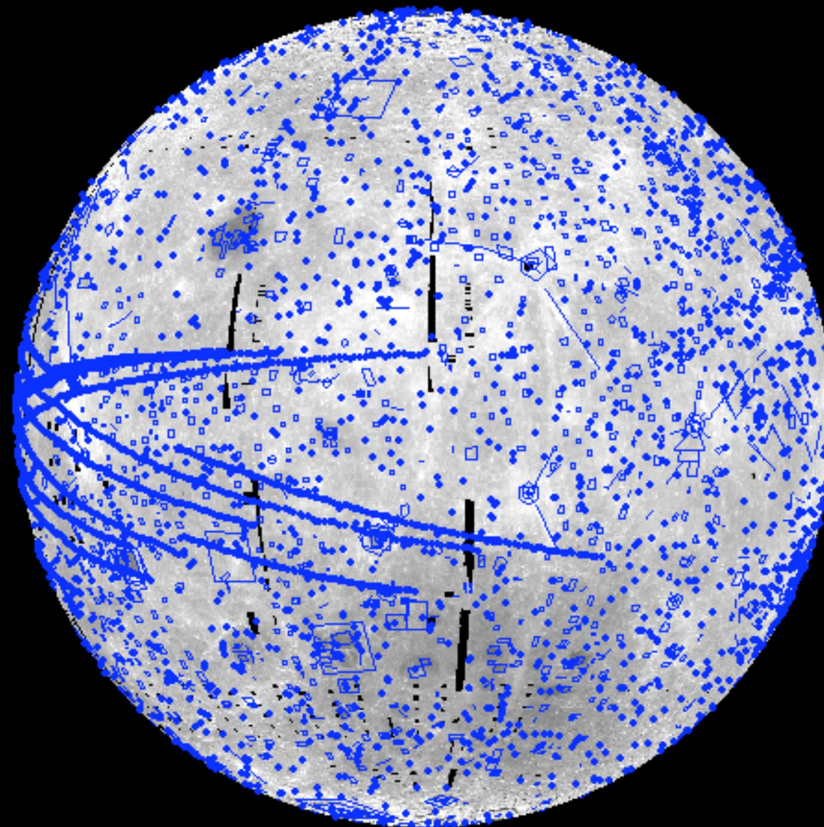
Tier 2

Code	Name	Long	Lat
BAL	Balmer Basin	69.82	-18.69
CMP	Compton/Belkovich Th Anomaly	99.45	61.11
DAN	Dante Crater	177.70	26.14
FLM	Flamsteed Crater	-43.22	-2.45
HRT	Hortensius Domes	-27.67	7.48
HUM	Humboldtianum Basin	77.14	54.54
INA	Ina ('D-caldera')	5.29	18.65
ING	Ingenii	164.42	-35.48
LCT	Lichtenberg Crater	-67.23	31.65
FRG	Mare Frigoris	26.10	59.80
MOS	Mare Moscoviense	150.47	26.19
SMT	Mare Smythii	85.33	2.15
TRN	Mare Tranquillitatis	22.06	6.93
MAR	Marius Hills	-55.80	13.58
MEN	Mendel-Rydberg Cryptomare	-93.07	-51.14
PYR	Montes Pyrenaeus	40.81	-15.91
OR2	Orientale 2	-87.91	-18.04
PLT	Plato Ejecta	-5.21	53.37
RNG	Reiner Gamma	-58.56	7.53
RIC	Riccioli Crater	-74.28	-3.04
RMP	Rimae Prinz	-41.72	27.41
SCH	Schrödinger	138.77	-75.40
SPR	South Pole-Aitken Rim	170.92	-51.00
TSK	Tsiolkovsky Crater	128.51	-19.35
VDG	Van De Graaf Crater	172.08	-26.92

LROC Master List of targets as of Nov. 10, 2009
(16, 056 targets)



Nearside



Farside

LEAG Workshop on Sustaining Lunar Exploration

- **Purpose and Scope:**
  - Learning from history is important for ensuring that a sustainable and long-term lunar return is possible
  - The Apollo program was not sustainable
  - Focus on the sustainability theme of the LEAG-coordinated Lunar Exploration Roadmap

- **The remainder of this presentation will discuss those Cx regions of interest that support sustainability on the Moon:**
  - Resources
  - Long-term habitation

Sustainability on the Moon
A historical perspective

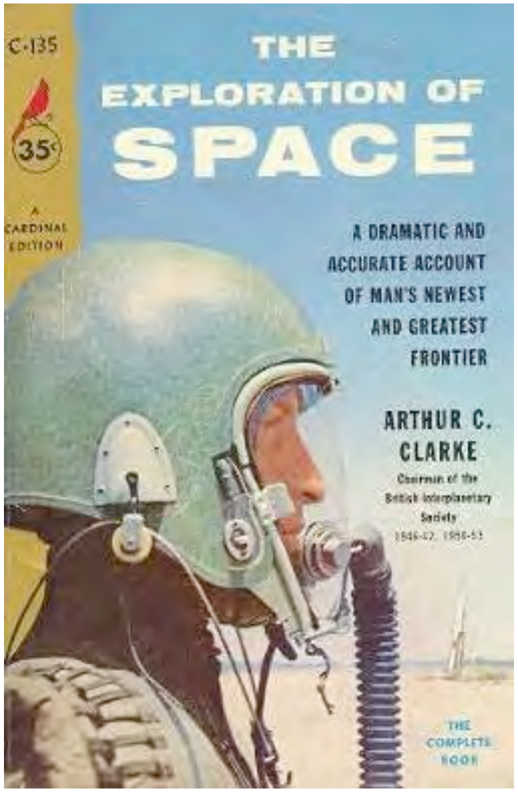
“The human race is remarkably fortunate in having so near at hand a full-sized world with which to experiment: before we aim at the planets, we will have had a chance of perfecting our astronautical techniques on our own satellite. . .the conquest of the Moon will be the necessary and inevitable prelude to remoter and still more ambitious projects.”

“The crossing of interplanetary space, though a technical problem which will challenge all Man’s ingenuity and resources, is not an end in itself but merely a beginning. There is no point in going to the planets unless we do something when we get there.”

“Today we can no more predict what use mankind may make of the Moon than could Columbus have imagined the future of the continent he had discovered.”

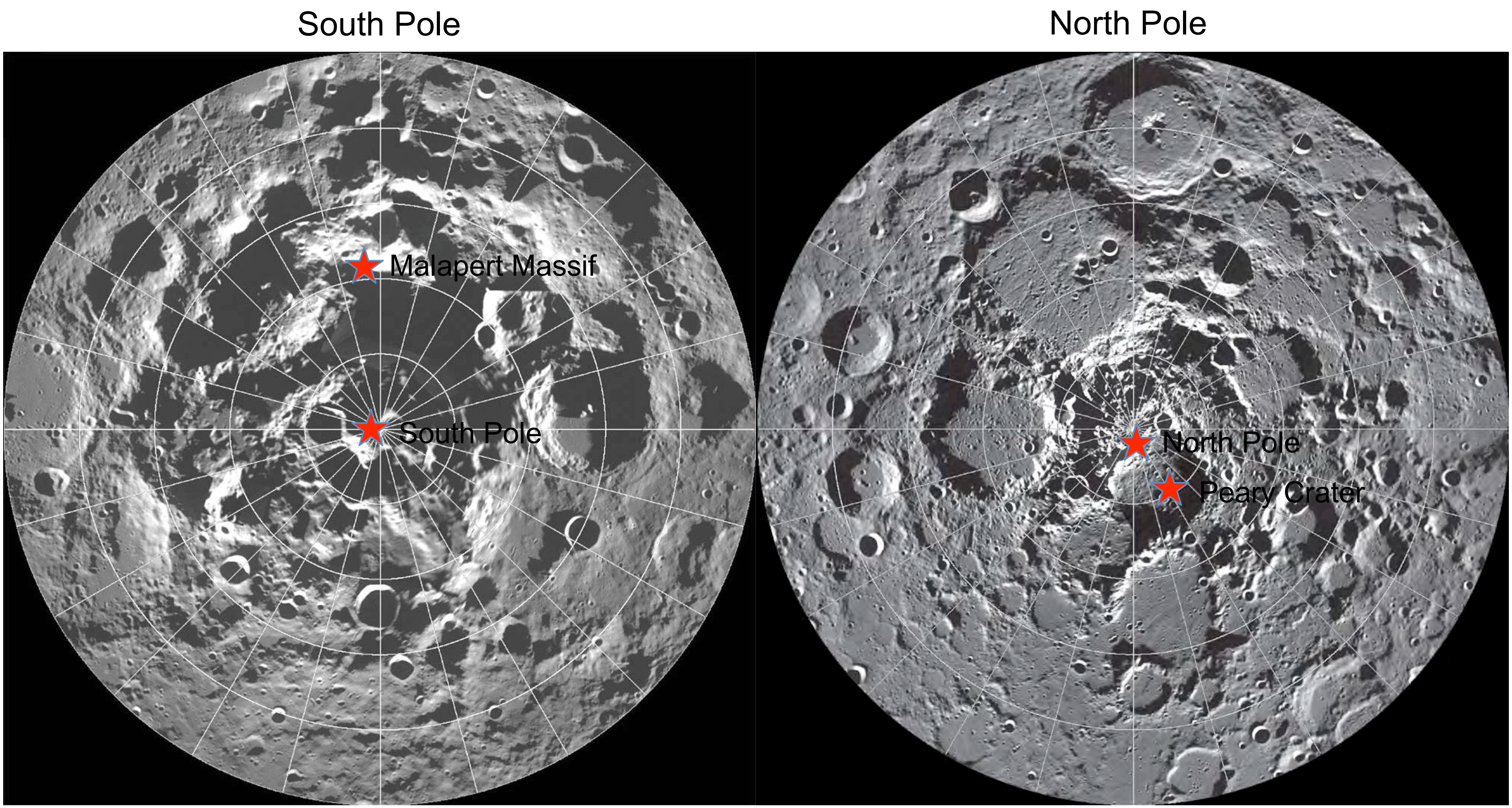
“The first lunar explorers will probably be mainly interested in the mineral resources of their new world, and upon these its future will very largely depend.”

“For a considerable time all flights to the Moon would be directed to the same spot, so that material and stores could be accumulated where they would be most effective. There would be no scattering of resources over the Moon’s twelve million square miles of surface.”

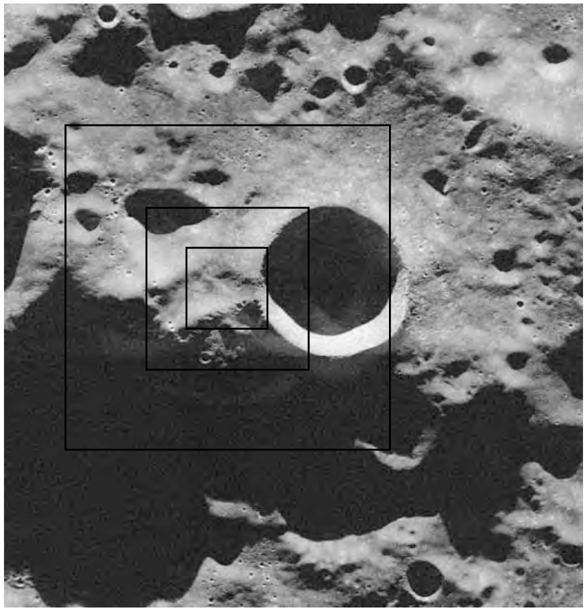


(1951)

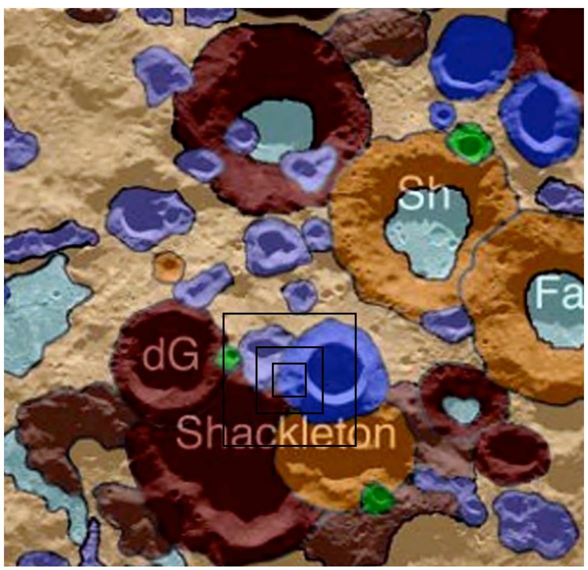
Constellation Polar Regions of Interest



from Paul Spudis, Clementine mosaics



Radar image from Margot et al., Science 284, 1658-1660 (1999)



Geologic map from Spudis et al., (2008)

South Pole

Location (longitude, latitude): -130, -89.3 (best estimate, see image to left)

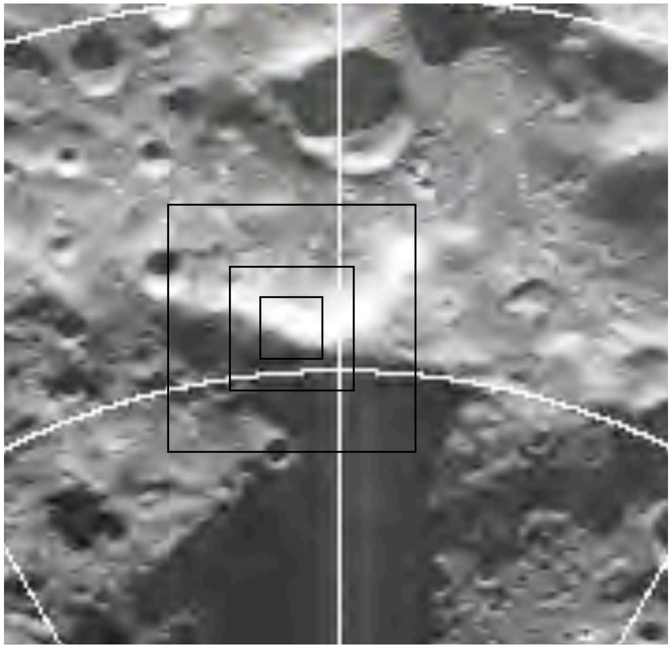
Scientific Rationale:
South Pole-Aiken (SPA) basin geology
Polar volatiles
Impact process (e.g., Shackleton and other craters)

Resource Potential:
Highlands regolith
Enhanced hydrogen in permanently shadowed polar craters (water ice?)
Sunlight

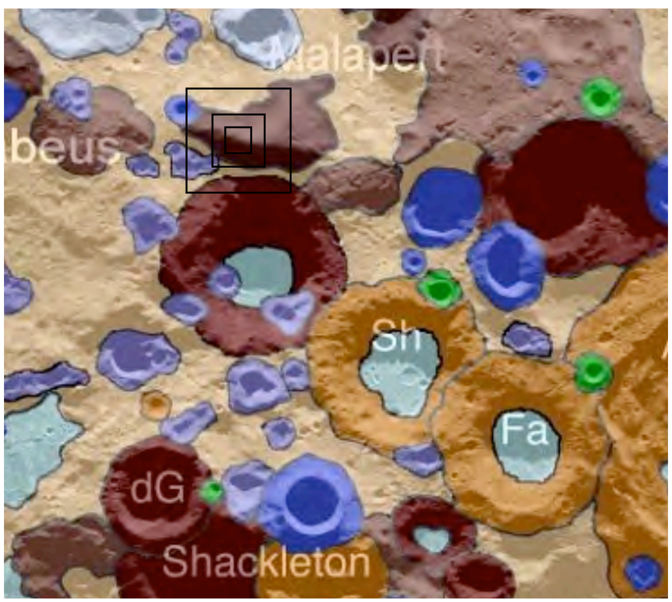
Operational Perspective:
Highlands terrain
Polar location
Areas of permanent shadow
Points of near-continuous sunlight

NASA References:
Exploration Systems Architecture Study (2005)
Geoscience and a Lunar Base (1990)

Other References:
Spudis et al., GRL, 35, L14201, doi:10.1029/2008GL034468.
Bussey et al., GRL, 26, no.9, 1187-1190 (1999)



Radar image from Margot et al., Science 284, 1658-1660 (1999)



Geologic map from Spudis et al., (2008)

Malapert Massif

Location (longitude, latitude): -2.93, -85.99 (best estimate, see image to left)

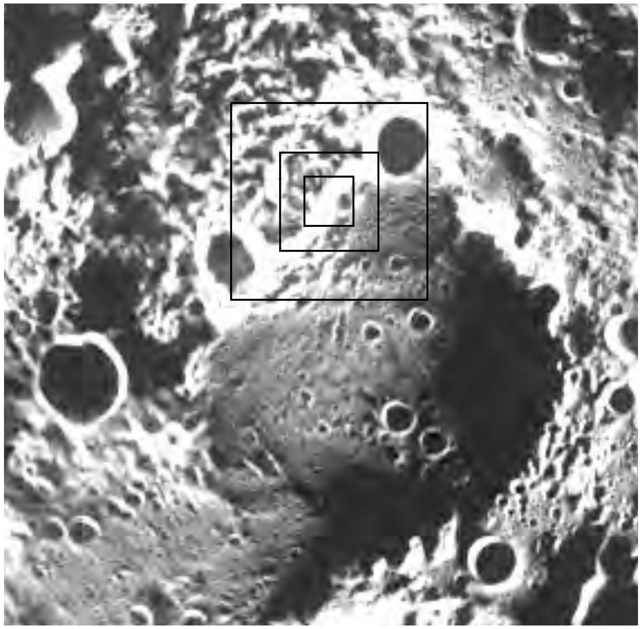
Scientific Rationale:
South Pole-Aitken (SPA) basin rim?
Basin geology
Observatories

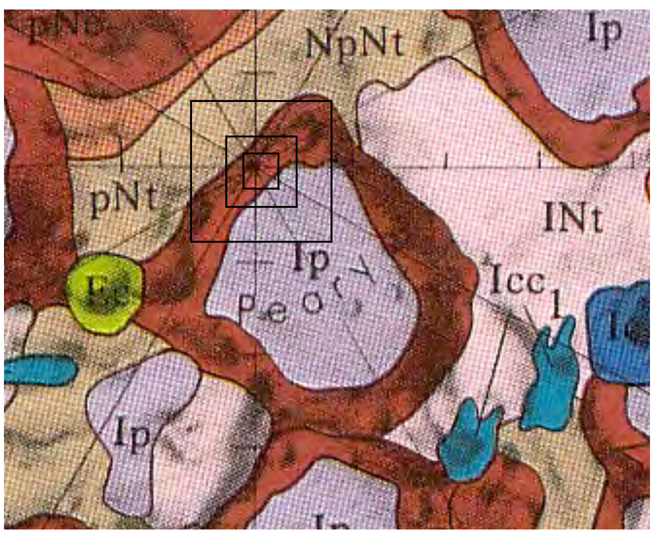
Resource Potential:
Near-continuous sunlight (continuous?)
Direct-to-Earth communication

Operational Perspective:
Highlands terrain (e.g., massif)
Polar location

NASA References:

Other References:
Spudis et al., GRL, 35, L14201, doi:10.1029/2008GL034468





(Clementine uvvis color ratio image not available)

North Pole

Location (longitude, latitude): 76.19, 89.60 (best estimate, see image to left)

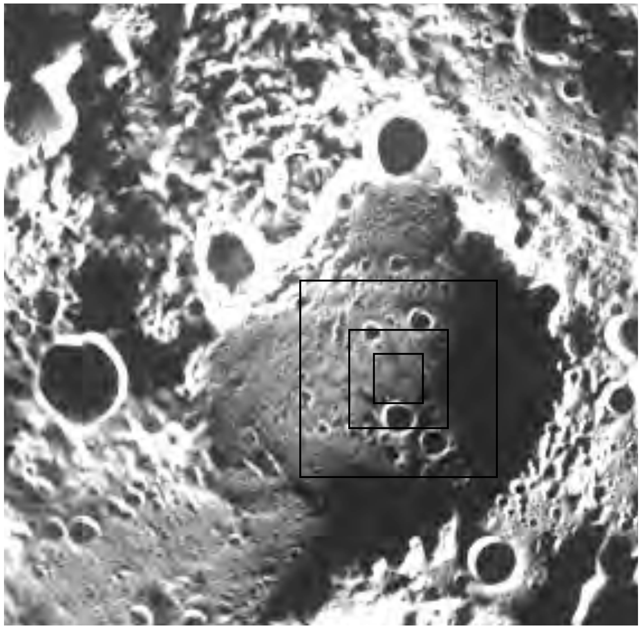
Scientific Rationale:
Polar volatiles
Impact process (e.g., heavily cratered highlands)
Distal Imbrium ejecta

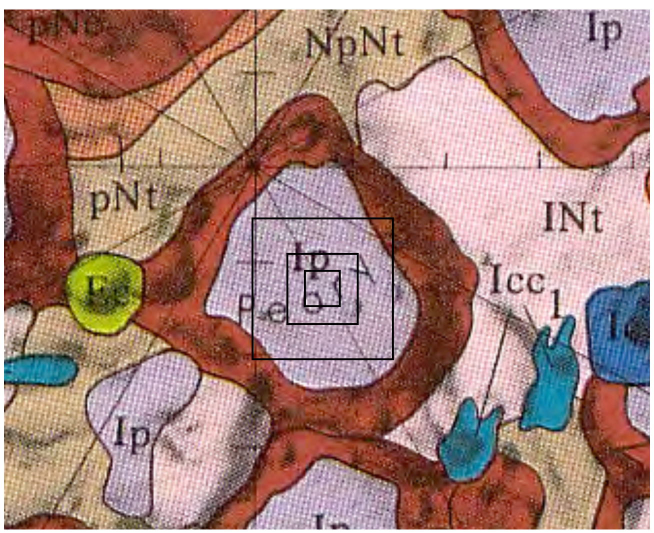
Resource Potential:
Highlands regolith
Enhanced hydrogen in nearby permanently shadowed polar craters (water ice?)
Sunlight

Operational Perspective:
Highlands terrain
Polar location
Nearby areas of permanent shadow
Points of near-continuous sunlight

NASA References:
Exploration Systems Architecture Study (2005)
Geoscience and a Lunar Base (1990)

Other References:





(Clementine uvvis color ratio image not available)

Peary Crater

Location (longitude, latitude): 30.00, 88.50

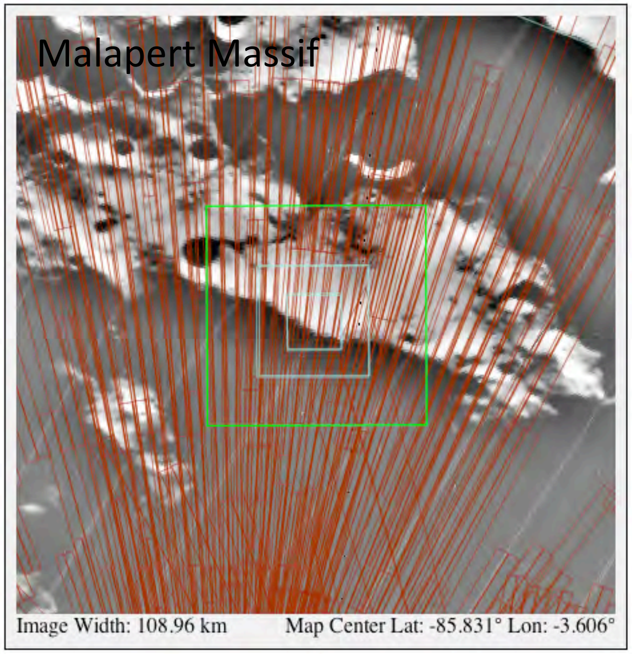
Scientific Rationale:
Polar volatiles
Impact process

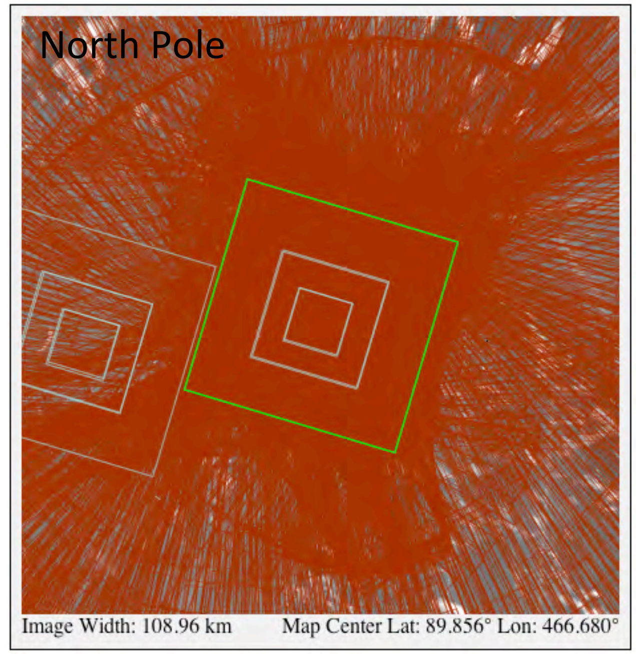
Resource Potential:
Highlands regolith
Enhanced hydrogen in permanently shadowed polar craters (water ice?)

Operational Perspective:
Highlands terrain
Polar location
Areas of permanent shadow

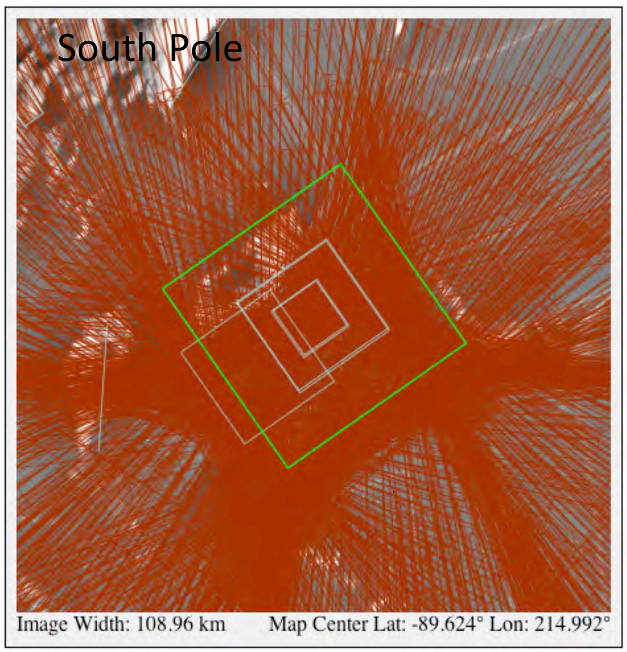
NASA References:
Exploration Systems Architecture Study (2005)
Geoscience and a Lunar Base (1990)

LROC NAC Coverage of Constellation Polar Regions of Interest (as of November 10, 2009)

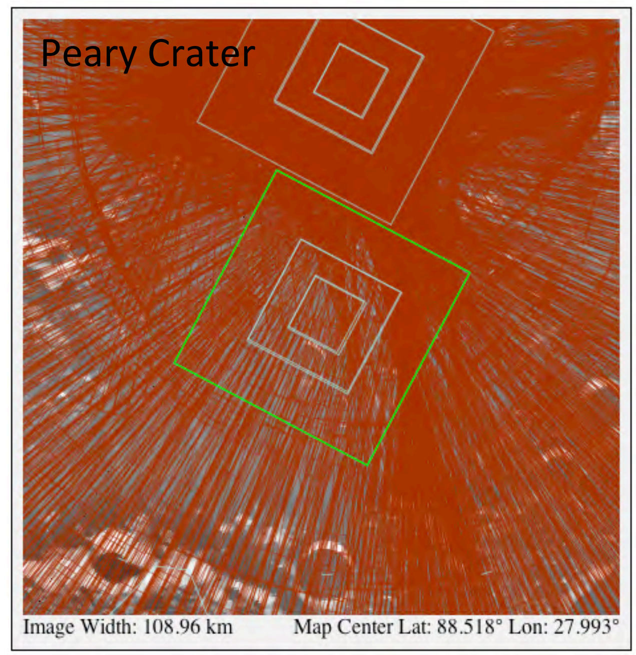




- **Potential resources:**
  - Sunlight
  - H_2 in permanent shadow
  - H_20 and solar wind H_2 in lunar regolith
  - O_2 and Al in lunar regolith
  - Regolith as construction material

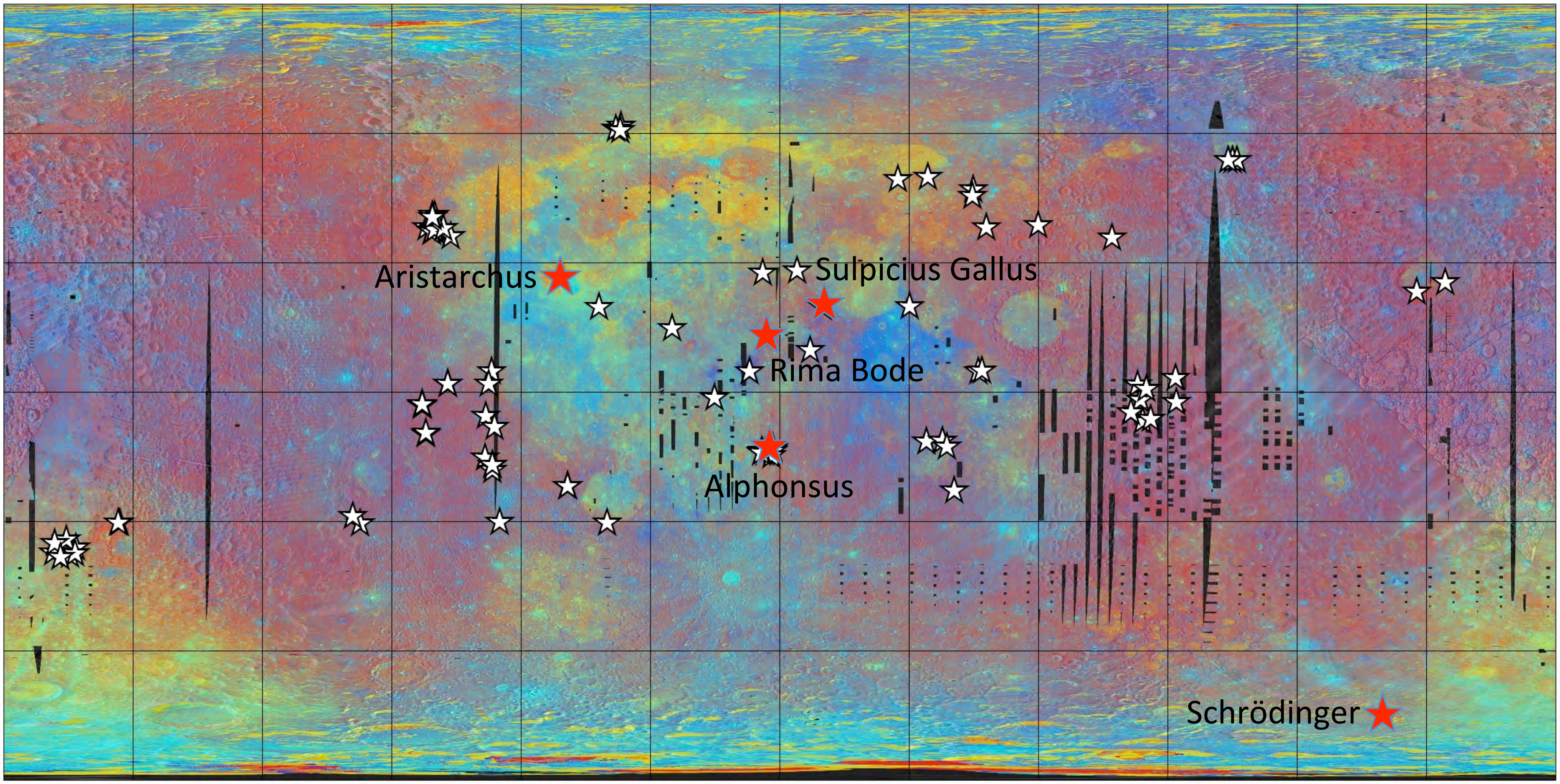


- **See presentations from earlier in the workshop for further details**

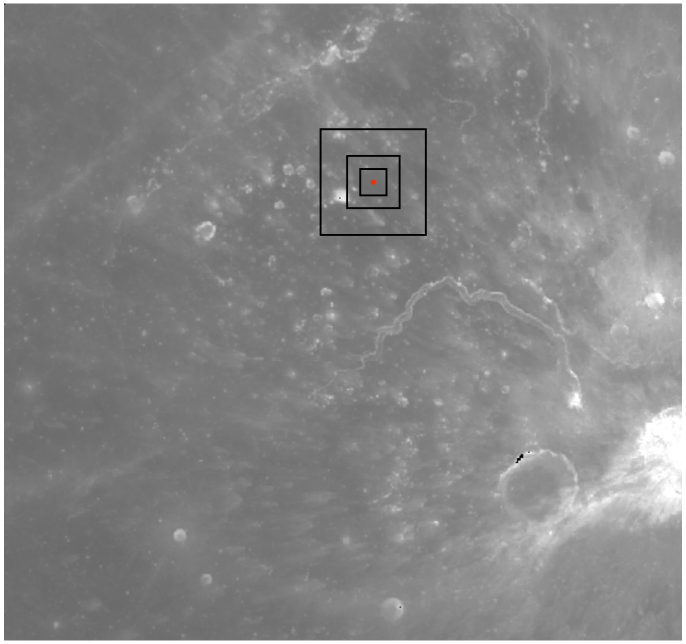


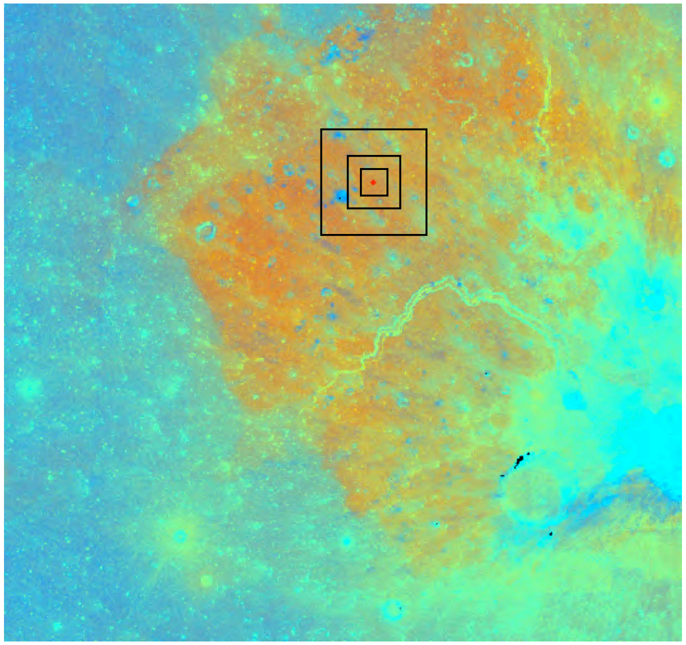
Location of pyroclastic deposits on the Moon

(★ = Constellation Program region of interest)



from Lisa Gaddis, USGS Lunar Pyroclastic Volcanism Project





Aristarchus 2

Location (longitude, latitude): -52.40, 27.70

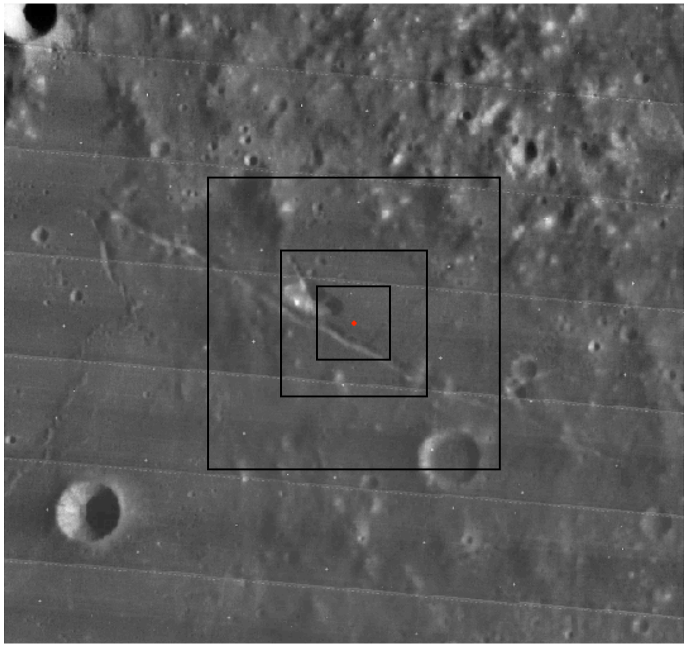
Scientific Rationale:
Pyroclastic materials
Nearby volcanic features

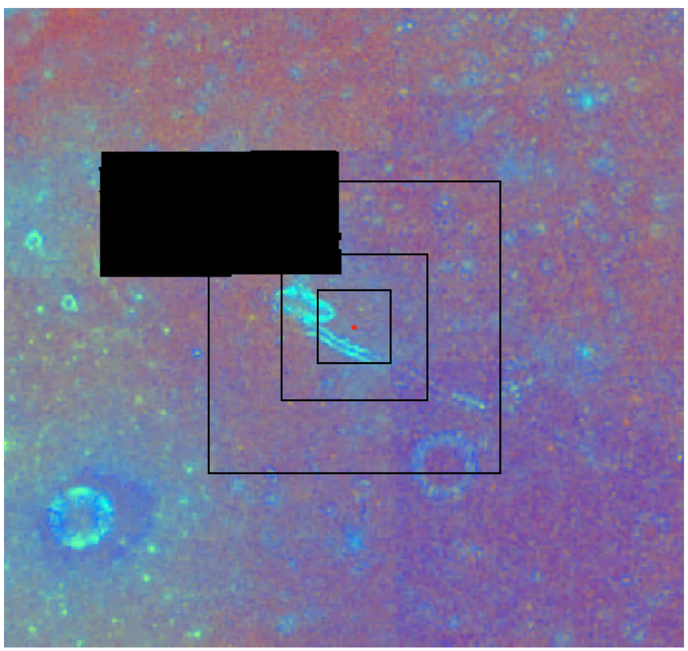
Resource Potential:
Pyroclastic materials

Operational Perspective:
Pyroclastic covered surface
Near side location

NASA References:
Exploration Systems Architecture Study (2005)
A Site Selection Strategy for a Lunar Outpost (1990)
Geoscience and a Lunar Base (1990)

Other References:





Rima Bode

Location (longitude, latitude): -3.80, 12.90

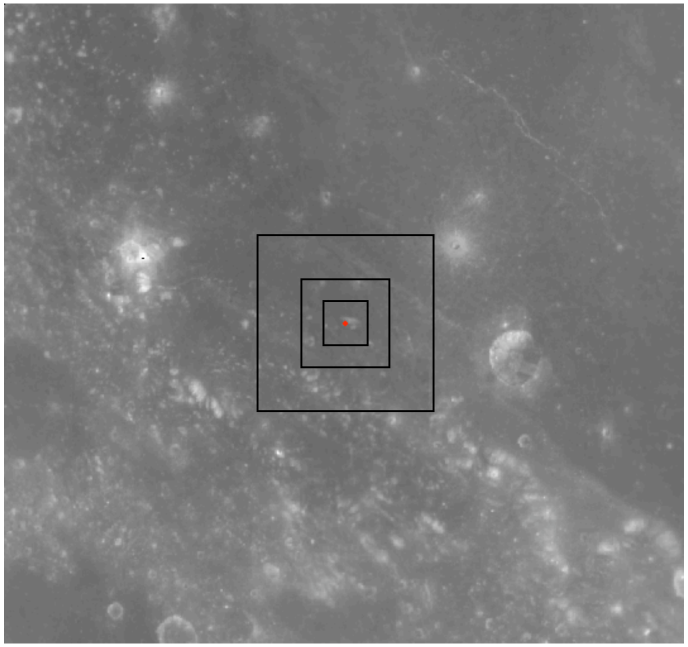
Scientific Rationale:
High-Ti pryroclastic material
Mantle xenoliths

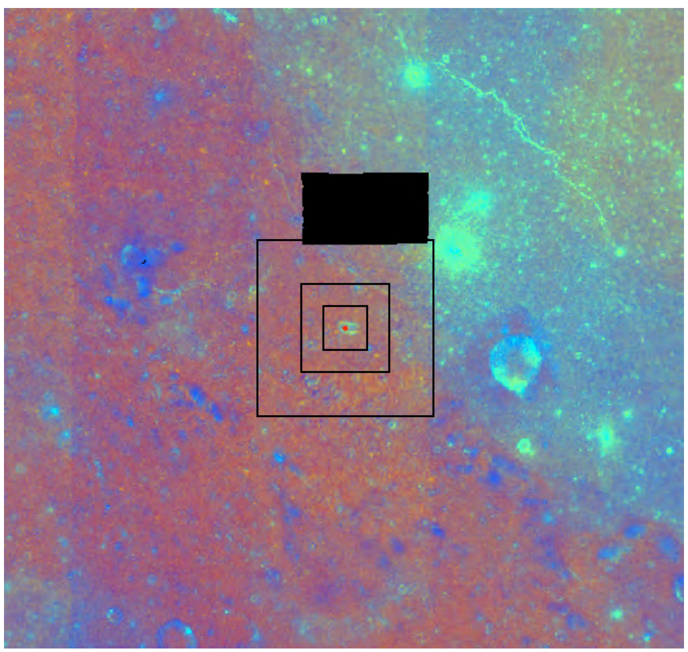
Resource Potential:
High-Ti pyroclastic material

Operational Perspective:
Pyroclastic covered surface
Highlands terrain
Near side location

NASA References:
Exploration Systems Architecture Study (2005)
Geoscience and a Lunar Base (1990)

Other References:





Sulpicius Gallus

Location (longitude, latitude): 10.37, 19.87

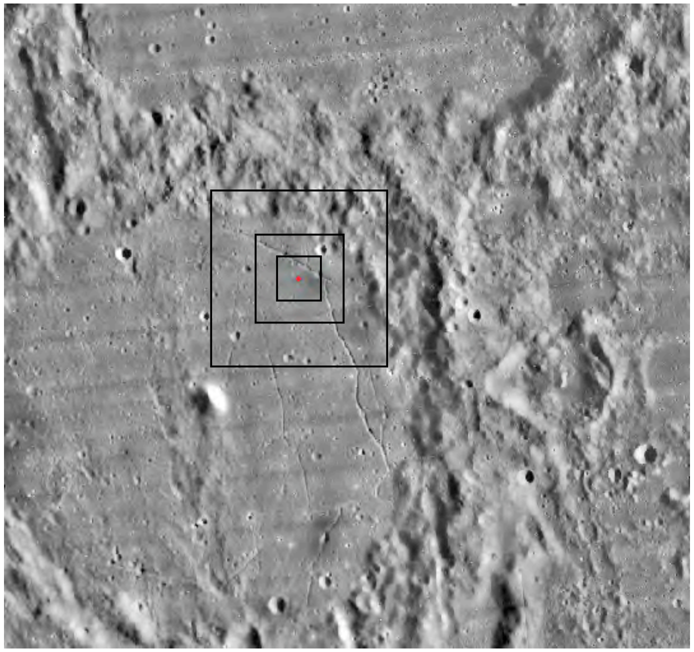
Scientific Rationale:
Dark mantling material, pyroclastics
Mantle xenoliths

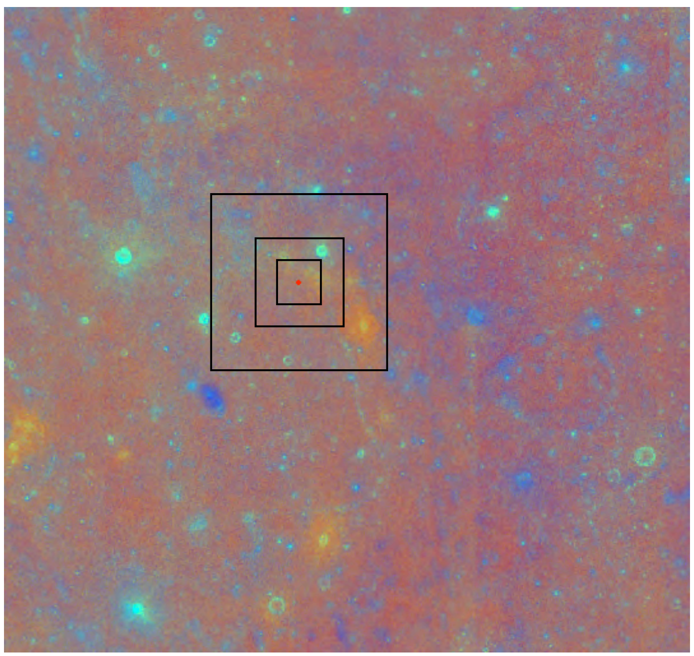
Resource Potential:
Pyroclastic deposits

Operational Perspective:
Smooth pyroclastic covered surface
Mare terrain
Near side location

NASA References:
Geoscience and a Lunar Base (1990)

Other References:
Lucchitta and Schmitt, 5th Lunar Conference (1974)





Alphonsus Crater

Location (longitude, latitude): -2.16, -12.56

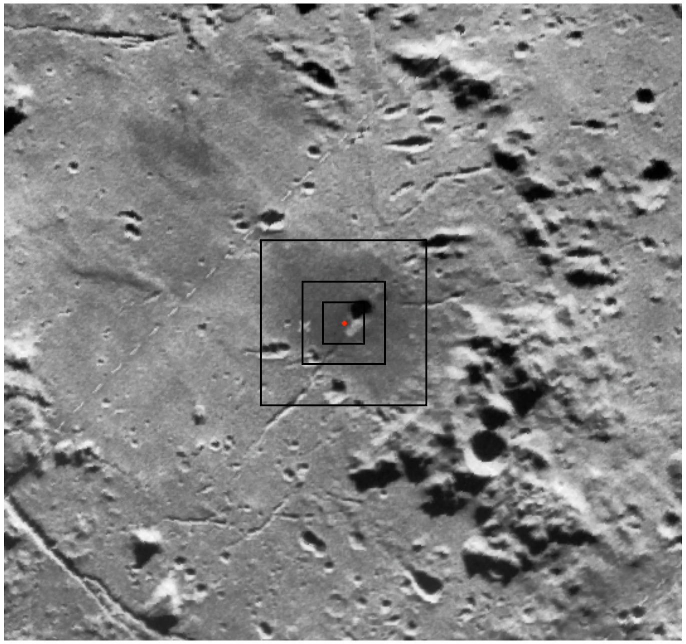
Scientific Rationale:
Pryoclastic vents and materials
Lunar transient events
Alphonsus crater rim massifs
Ranger 9 impact site

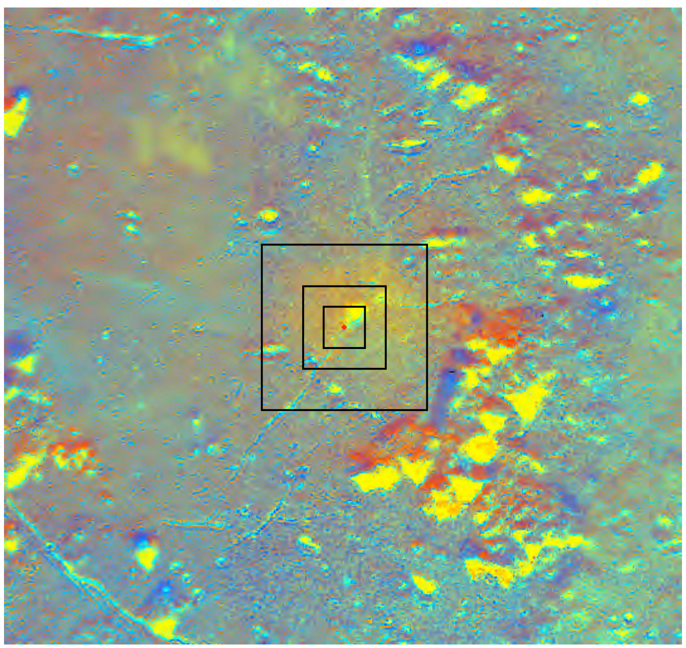
Resource Potential:
Highlands regolith
Pyroclastic materials

Operational Perspective:
Highlands terrain
Pyroclastic covered surface
Surface fracture

NASA References:
Optimizing Science and Exploration Working Group (OSEWG) Sortie Surface Scenario Workshop (2008)
Geoscience and a Lunar Base (1990)

Other References:





Schrödinger

Location (longitude, latitude): 138.77, -75.40

Scientific Rationale:
Pyroclastic materials
Mantle xenoliths
Schrödinger basin impact melts and breccias

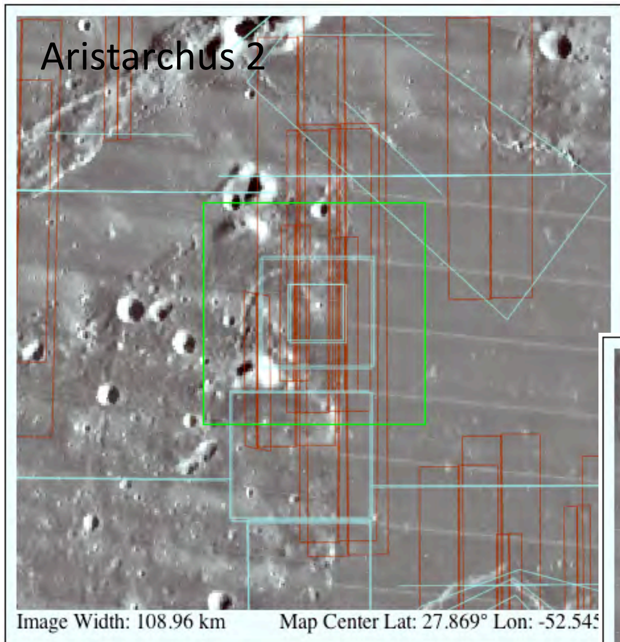
Resource Potential:
Pyroclastic materials

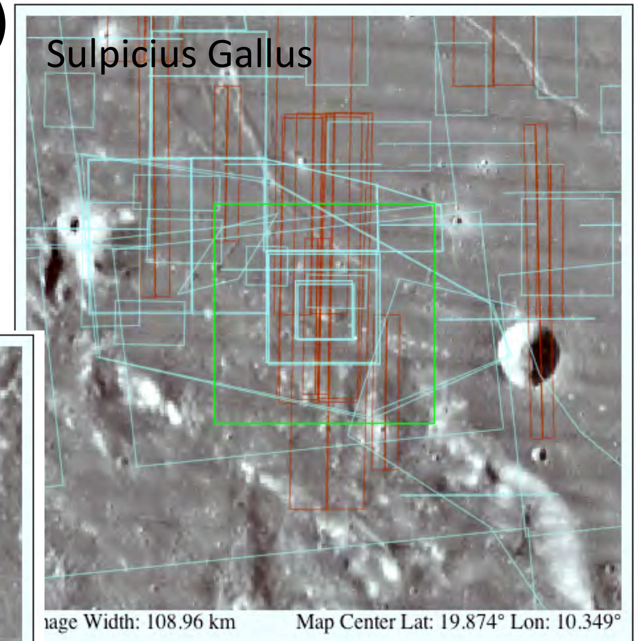
Operational Perspective:
Pyroclastic covered surface
Far side location

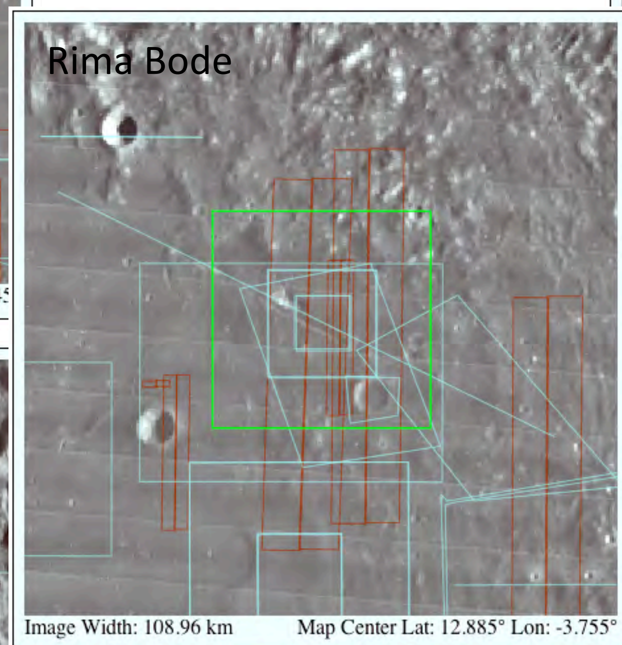
NASA References:
Geoscience and a Lunar Base (1990)

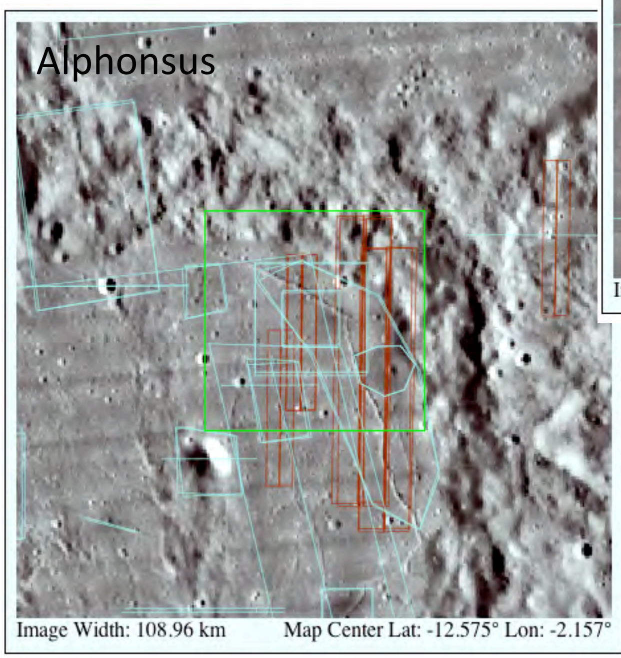
Other References:
E.M. Shoemaker et al. (1994), Science Vol. 266, 1851-1854.

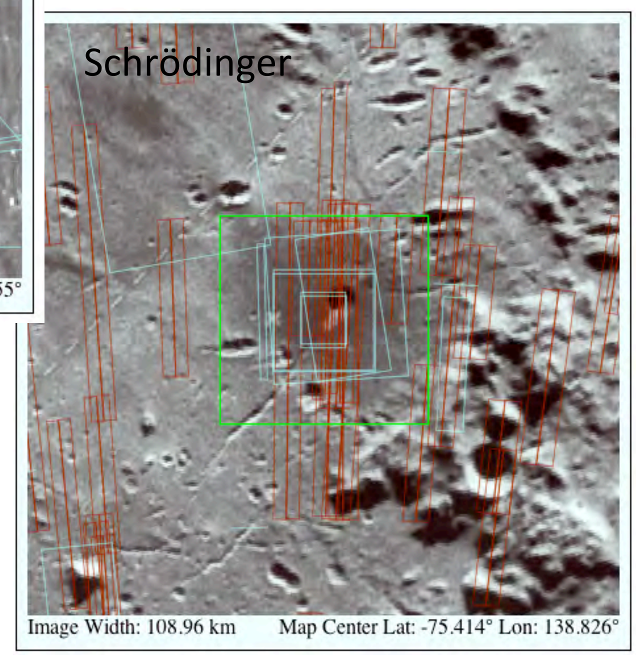
LROC NAC Coverage of Constellation Pyroclastic Regions of Interest (as of November 5, 2009)











Cx ROI: Aristarchus 2

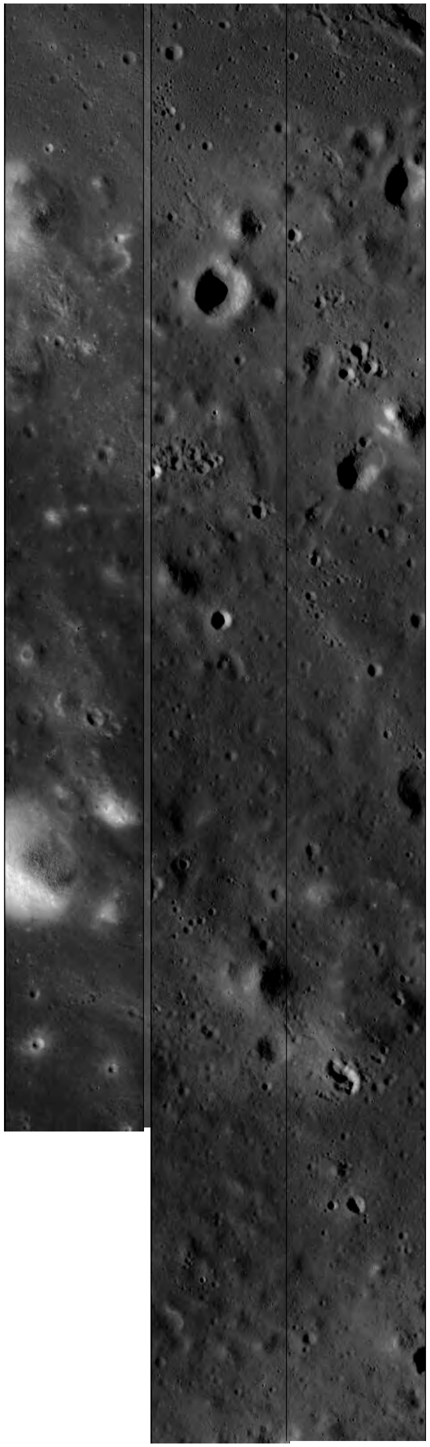
Simple Mosaic using NAC images: (left to right)

M104862583L

M104862583R

M102500639L

M102500639R



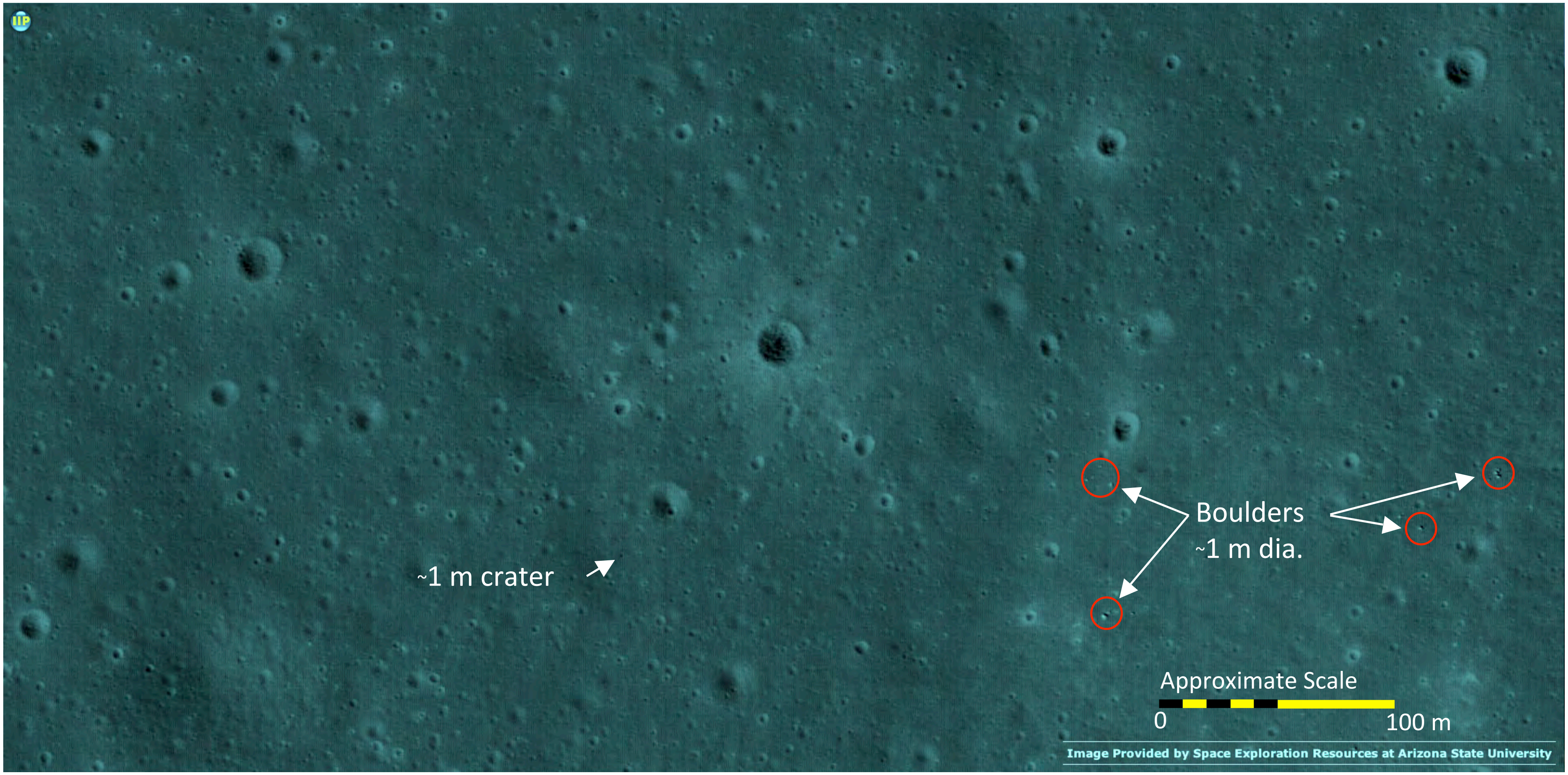
~10 km

Cx ROI: Aristarchus 2

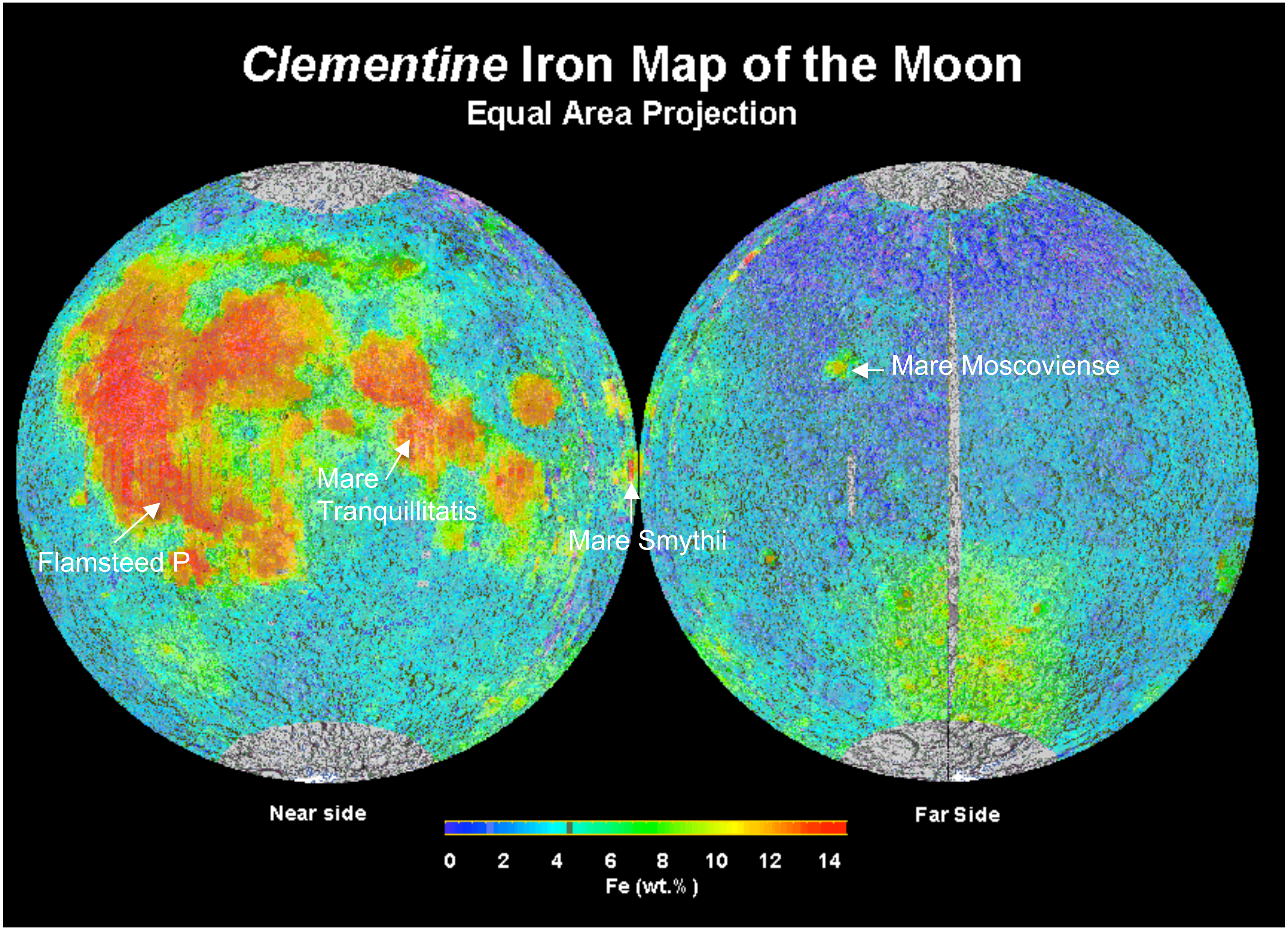
NAC Images: M111945148R

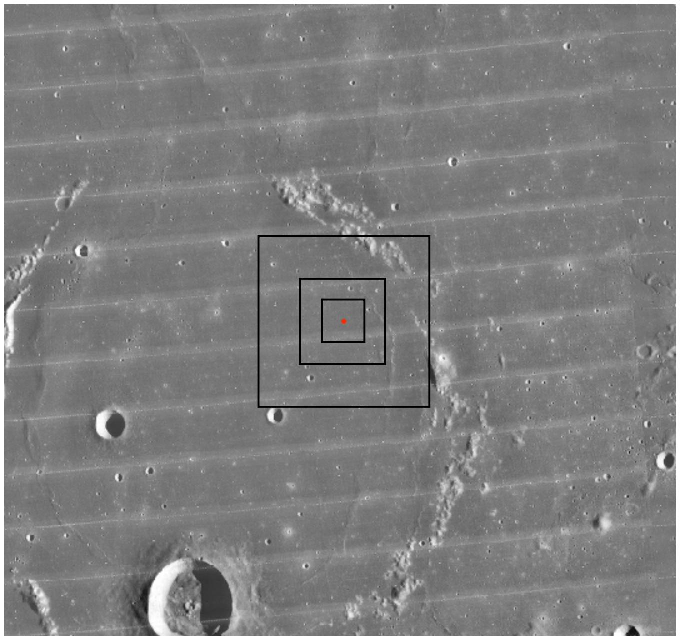
LRO Altitude: 47 km

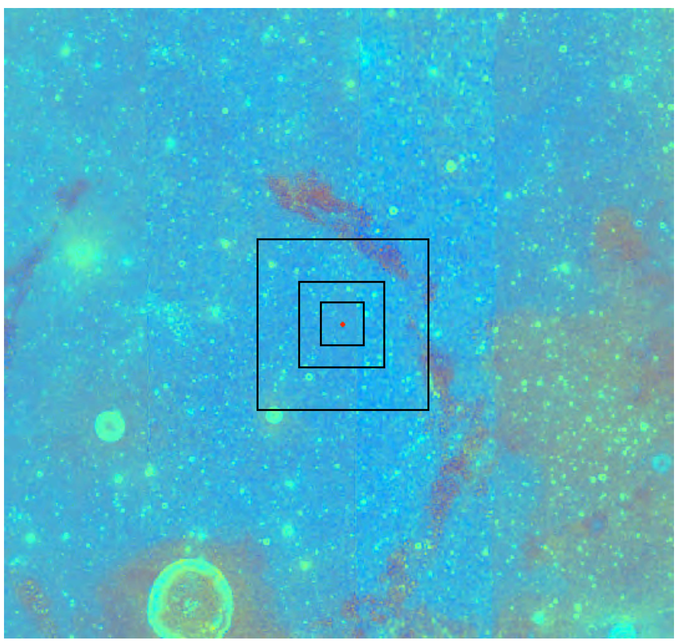
Resolution: 0.54 m/pixel



Constellation High-Fe or High-Ti Mare Regions of Interest







Flamsteed Crater

Location (longitude, latitude): -43.22, -2.45

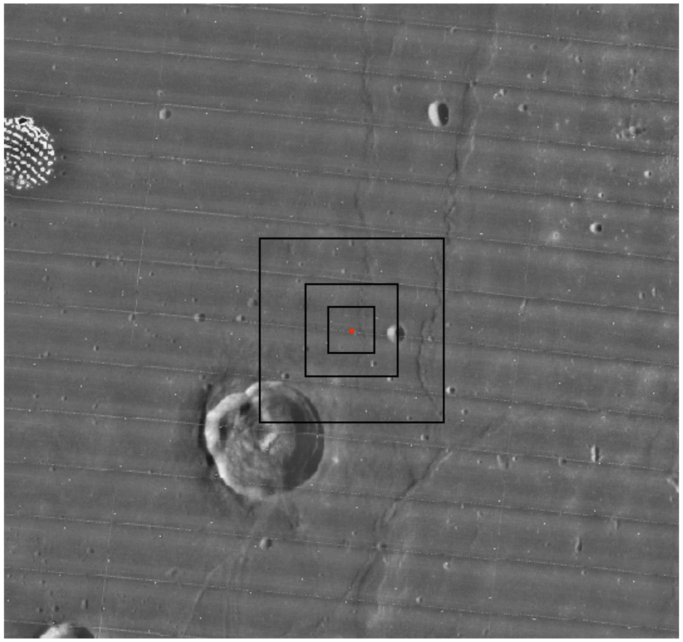
Scientific Rationale:
Surveyor 1 site
Young basaltic lavas (Eratosthenian–Copernican?)
Thin regolith
Nearby Flamsteed P crater ring

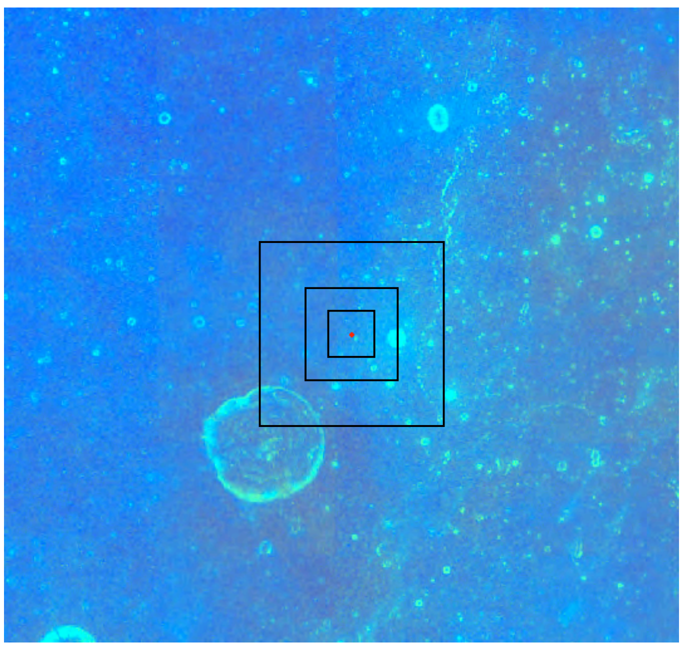
Resource Potential:
High-Ti basalts

Operational Perspective:
Mare terrain
Near side location

NASA References:
Exploration Systems Architecture Study (2005)
Geoscience and a Lunar Base (1990)

Other References:





Mare Tranquillitatis

Location (longitude, latitude): 22.06, 6.93

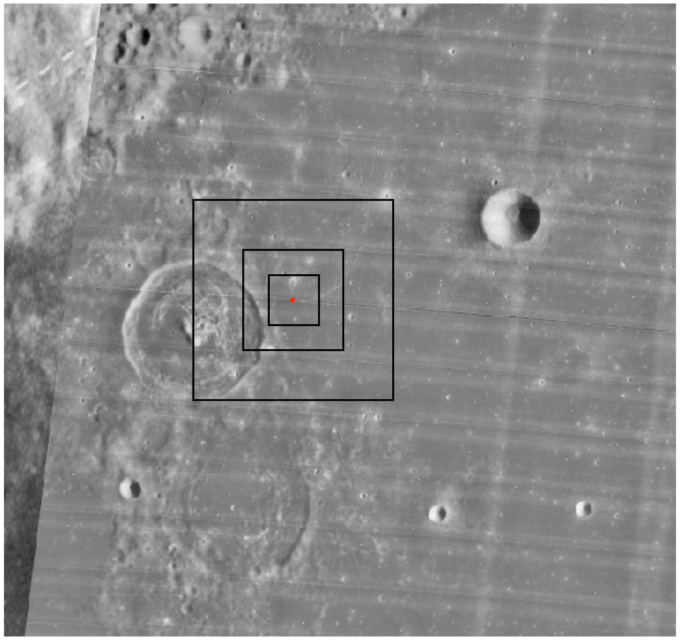
Scientific Rationale:
High-Ti basaltic lavas
Volcanic processes
Wrinkle ridges, low basaltic shields

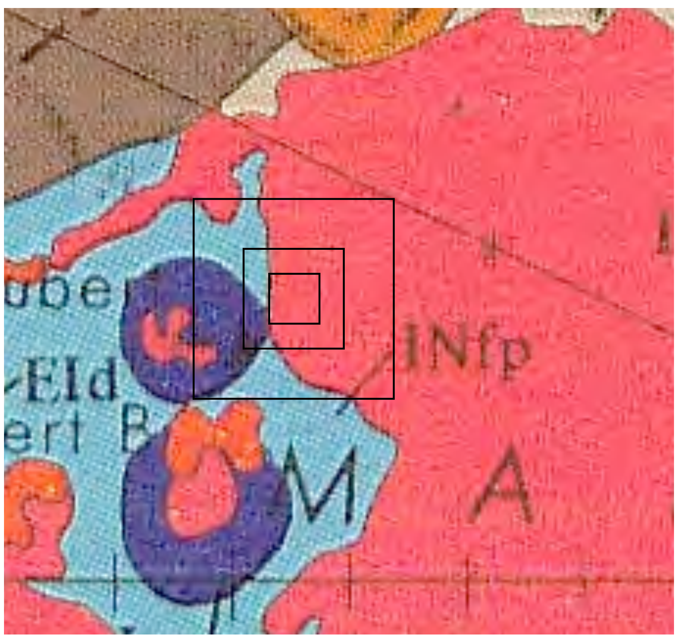
Resource Potential:
High-Ti mare regolith

Operational Perspective:
Mare terrain
Near side location

NASA References:
Exploration Systems Architecture Study (2005)

Other References:





(Clementine uvvis color ratio image not available)

Mare Smythii

Location (longitude, latitude): 85.33, 2.15

Scientific Rationale:
Young basaltic lavas
Nearby floor-fractured crater

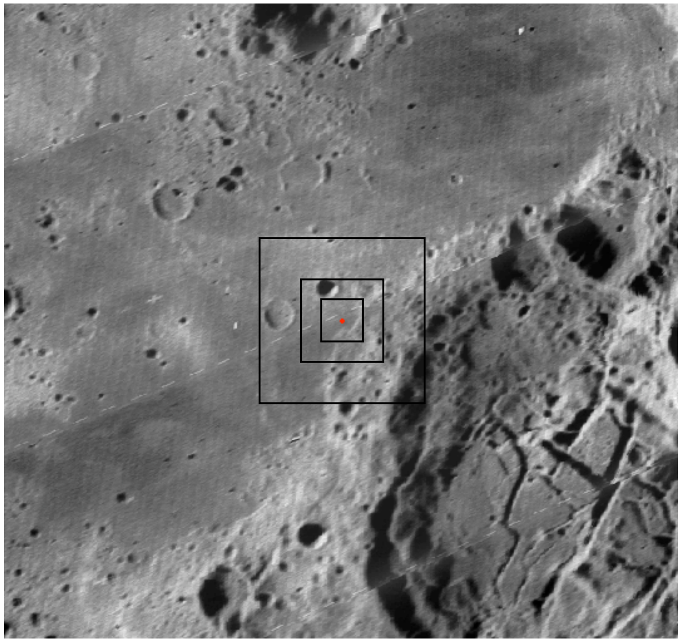
Resource Potential:
High-Fe mare regoilth

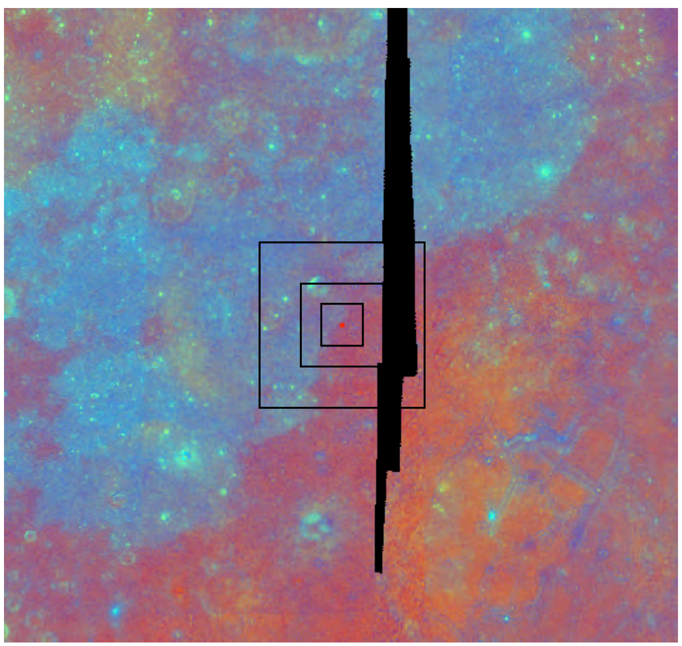
Operational Perspective:
Mare terrain
Limb location

NASA References:
Exploration Systems Architecture Study (2005)
A Site Selection Strategy for a Lunar Outpost (1990)

Other References:

Mare Moscoviense





Location (longitude, latitude): 150.47, 26.19

Scientific Rationale:
Mare age and composition (e.g., far side mare)
Basin geology (e.g., inner ring)

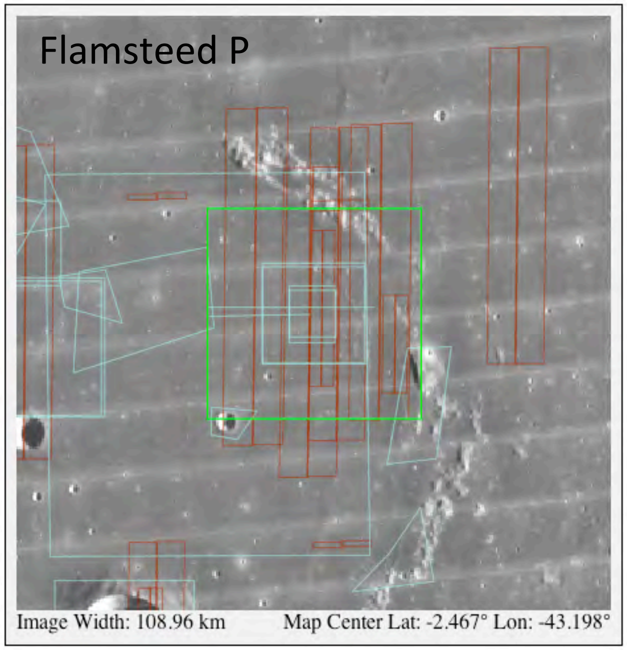
Resource Potential:
High-Ti mare regolith

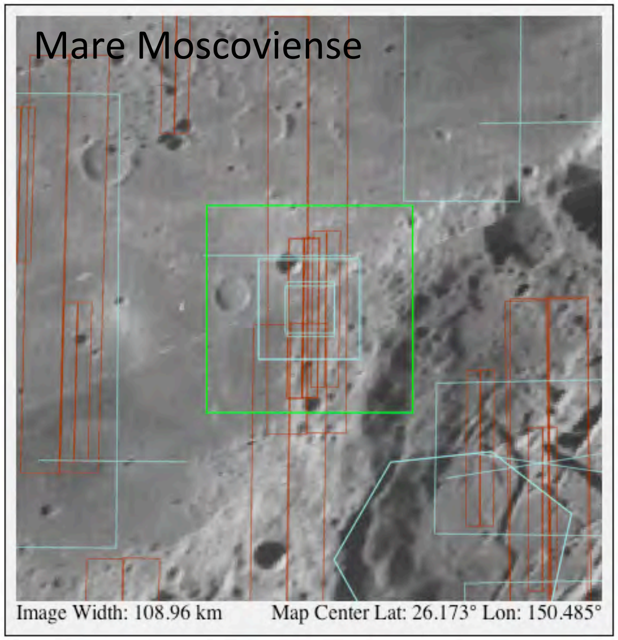
Operational Perspective:
Mare terrain
Highlands terrain
Far side location

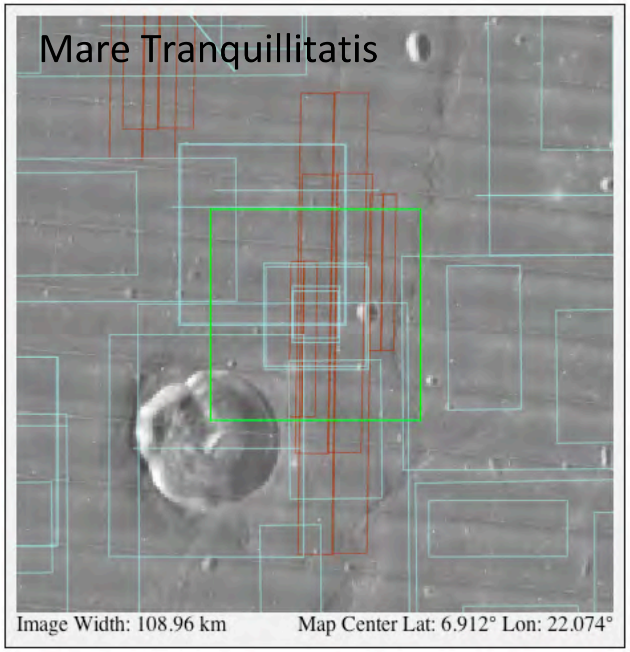
NASA References:
Geoscience and a Lunar Base (1990)

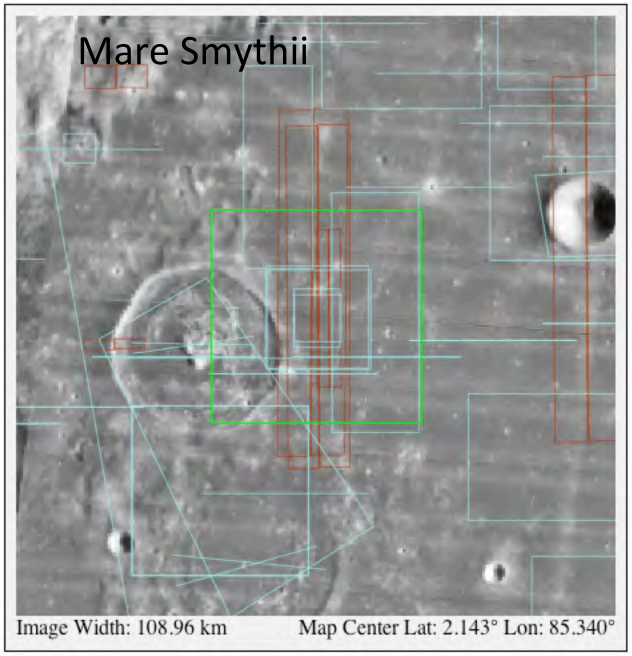
Other References:

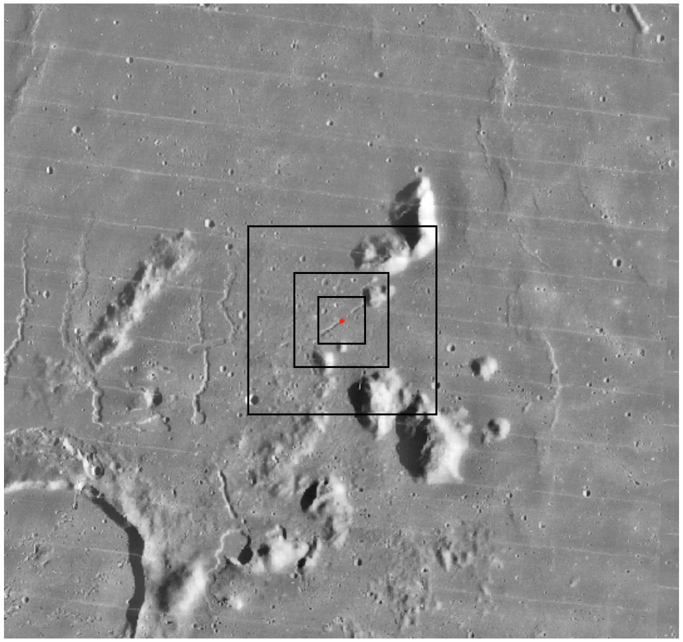
LROC NAC Coverage of Constellation High-Fe or High-Ti Mare Regions of Interest (as of November 6, 2009)

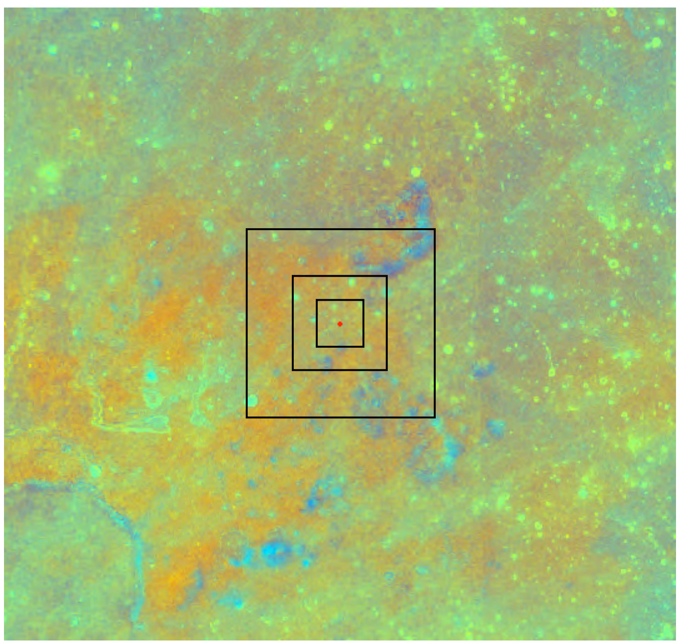












Rimae Prinz

Location (longitude, latitude): -41.72, 27.41

Scientific Rationale:
Rille
Possible lava tube
Nearby highlands massifs (Imbrium basin related)

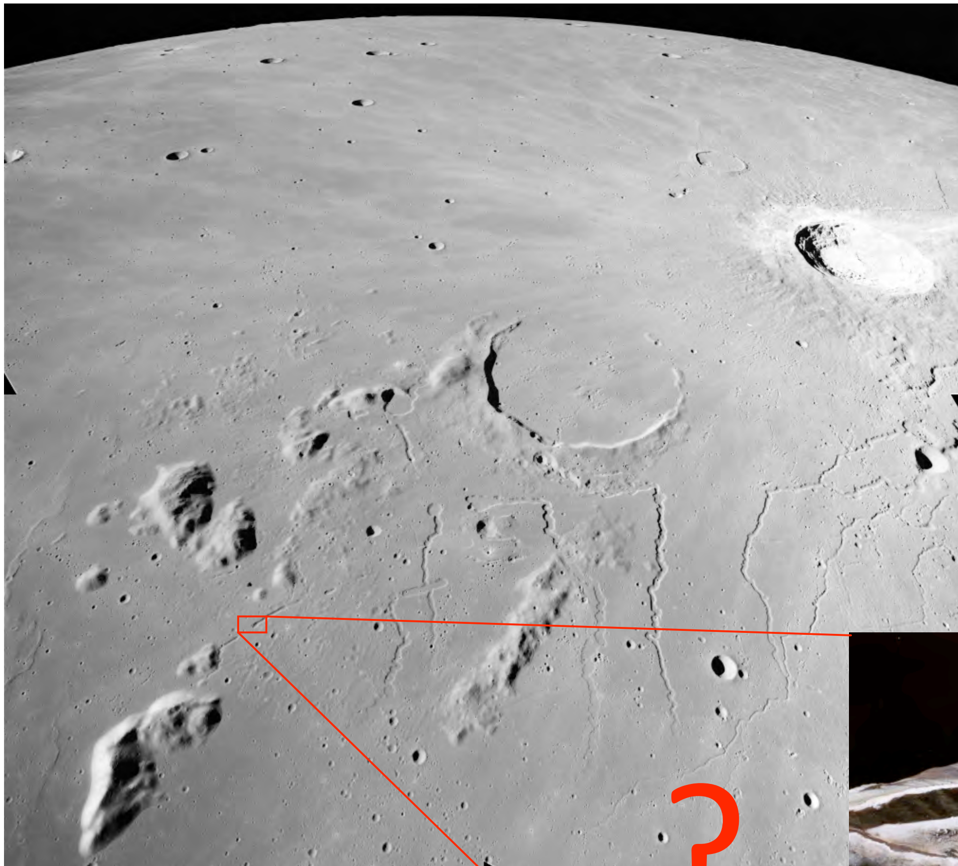
Resource Potential:
Mare regoilth

Operational Perspective:
Mare terrain
Sinuous rille (e.g., similar to Apollo 15 Hadley rille)
Near side location

NASA References:

Other References:
Hörz, Lunar Bases and Space Activities of the 21st Century (1985)

Rimae Prinz



Apollo 15 metric frame M-2606

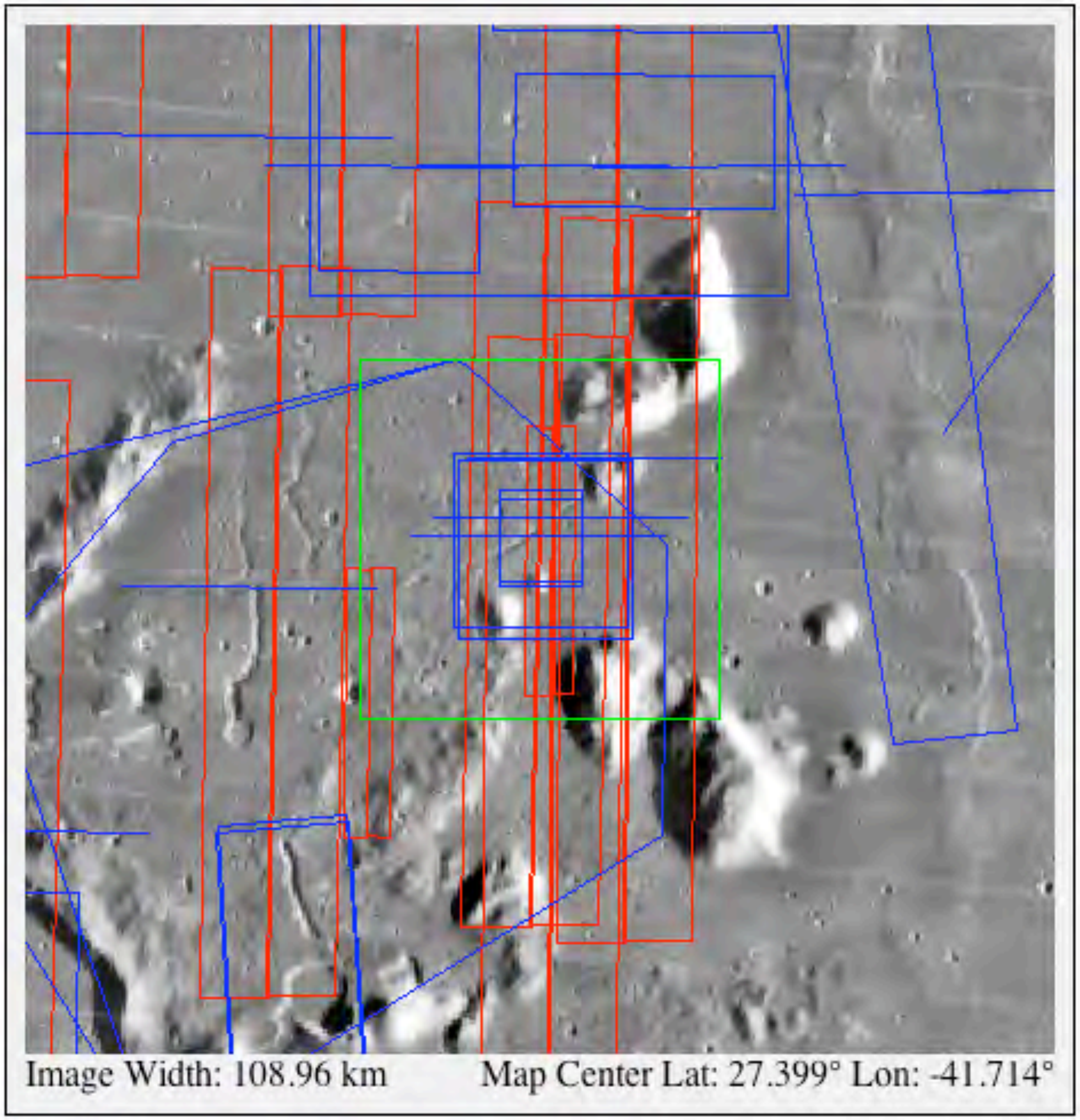
Understanding Volcanic Processes

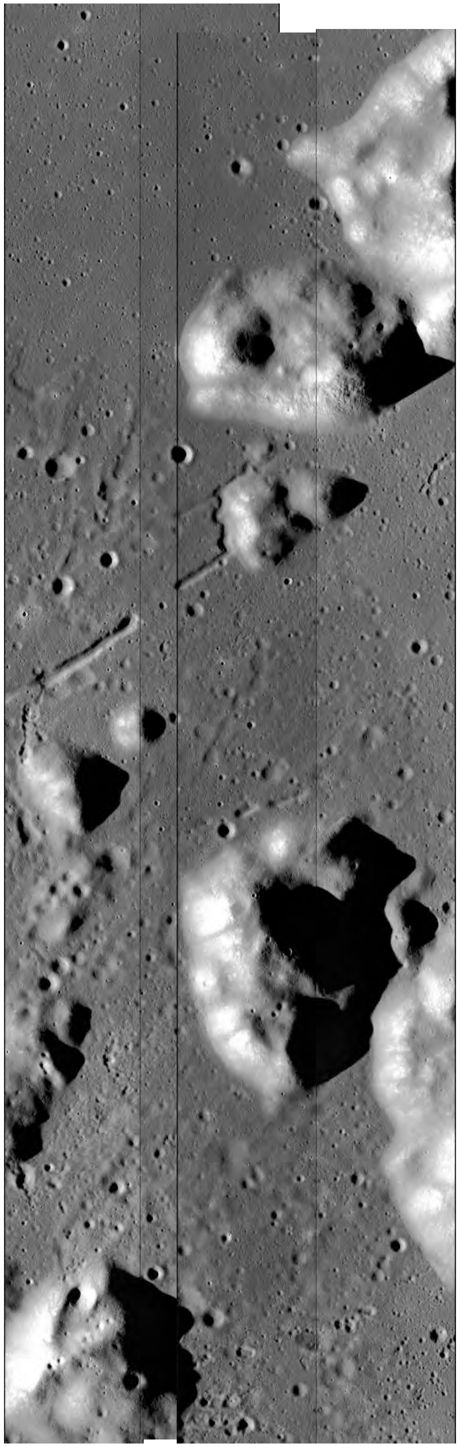
Determine how magma is generated and transported to the surface

Determine how lava flows are emplaced on the Moon

Artist concept of the discovery of a lunar lava tube

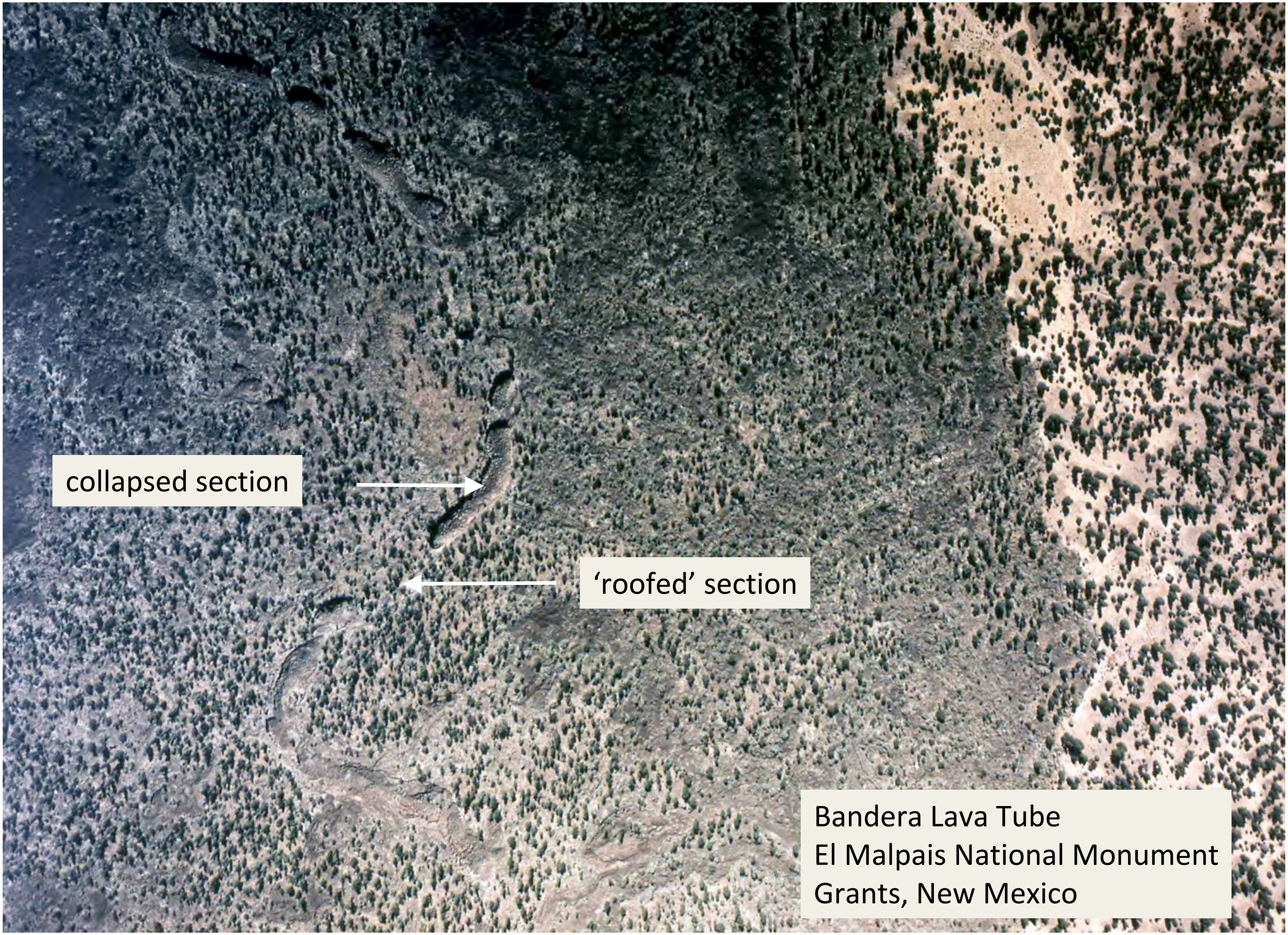
LROC NAC images acquired of Rimae Prinz region of interest
(as of 10-20-09)





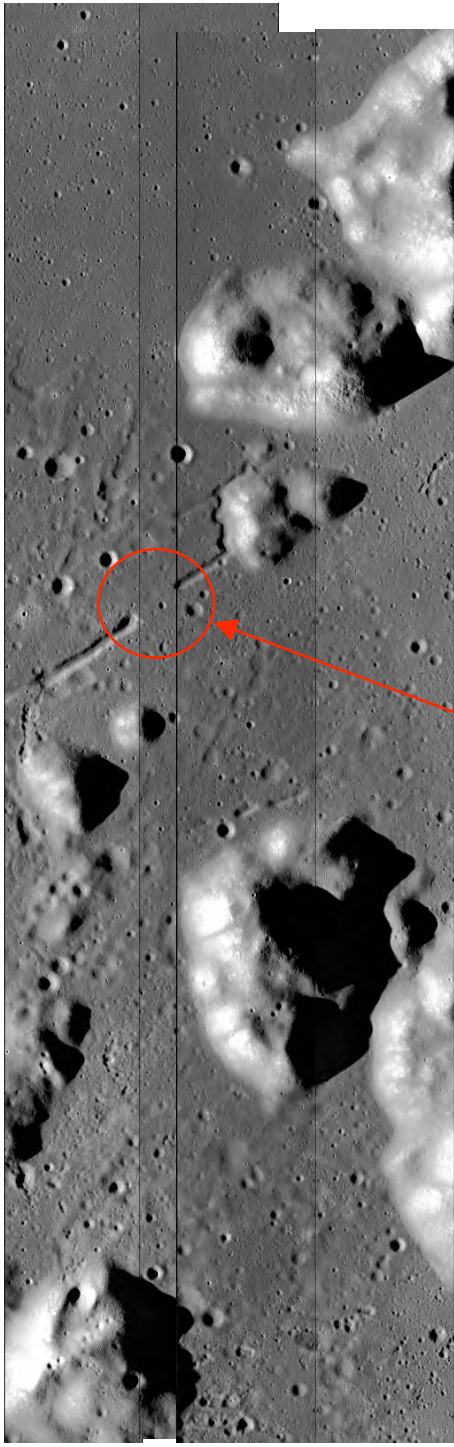
Simple Mosaic using NAC images: (left to right)
M102436231L
M102436231R
M102429075L
M102429075R

~10 km


collapsed section
'roofed' section
Bandera Lava Tube
El Malpais National Monument
Grants, New Mexico

opening into tube at end of collapse section
(courtesy of BLM)

opening into tube through a 'skylight'
(courtesy of NPS)



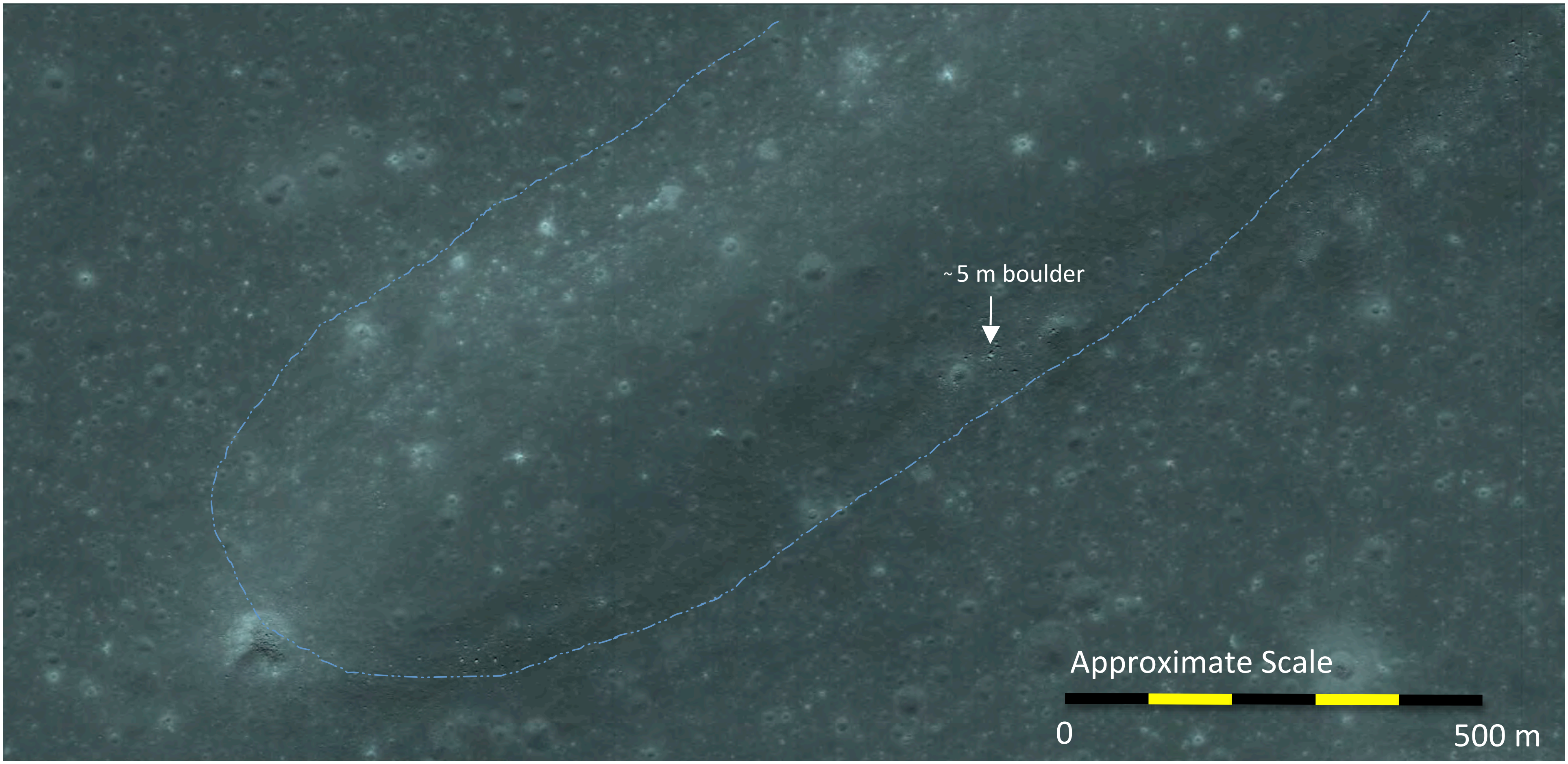
Simple Mosaic using NAC images: (left to right)
M102436231L
M102436231R
M102429075L
M102429075R

The next five slides will focus on this area

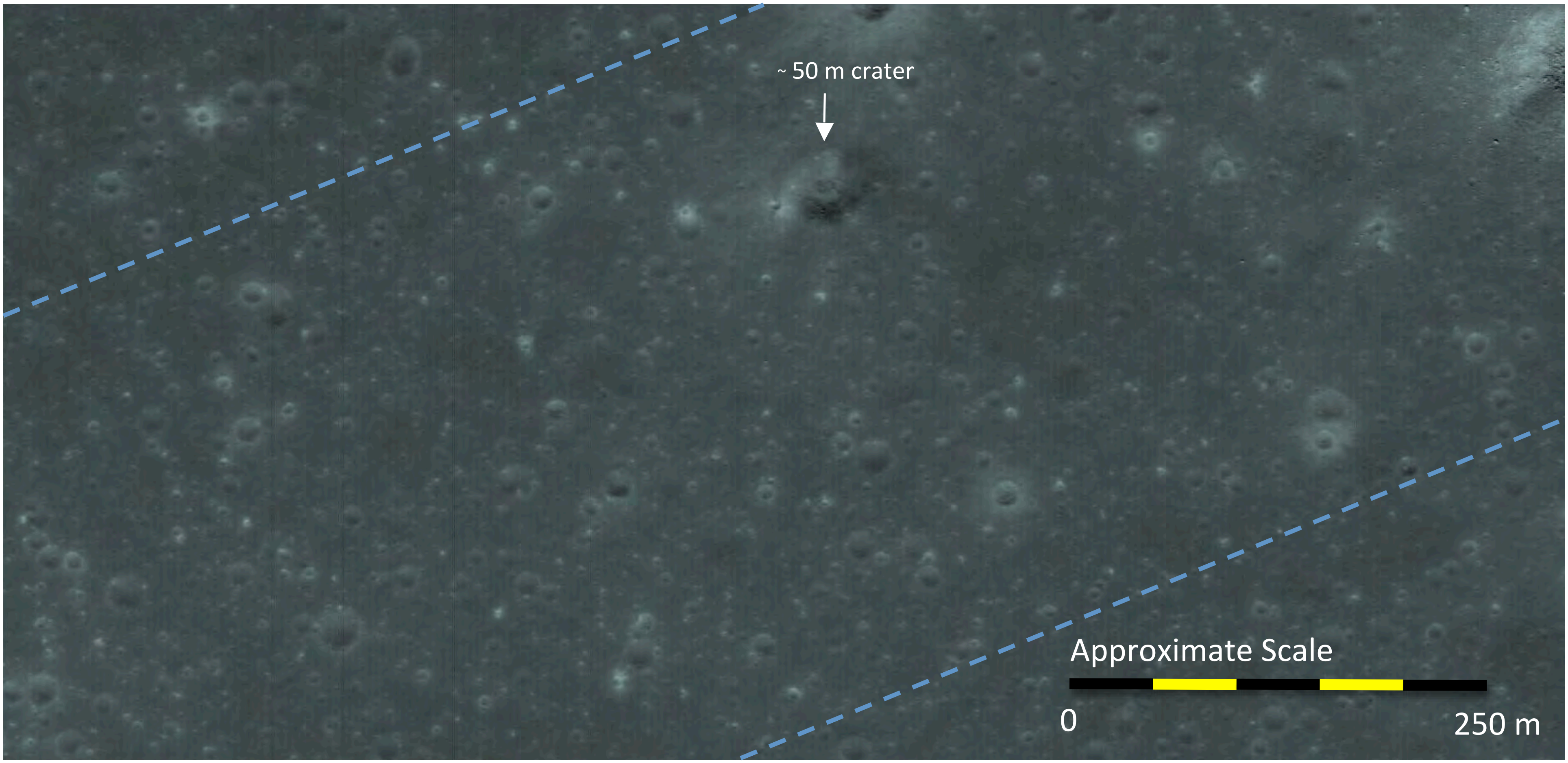
~10 km

NAC Image: M102436231R
LRO Altitude: 146.18 km
Resolution: 1.47 m/pixel

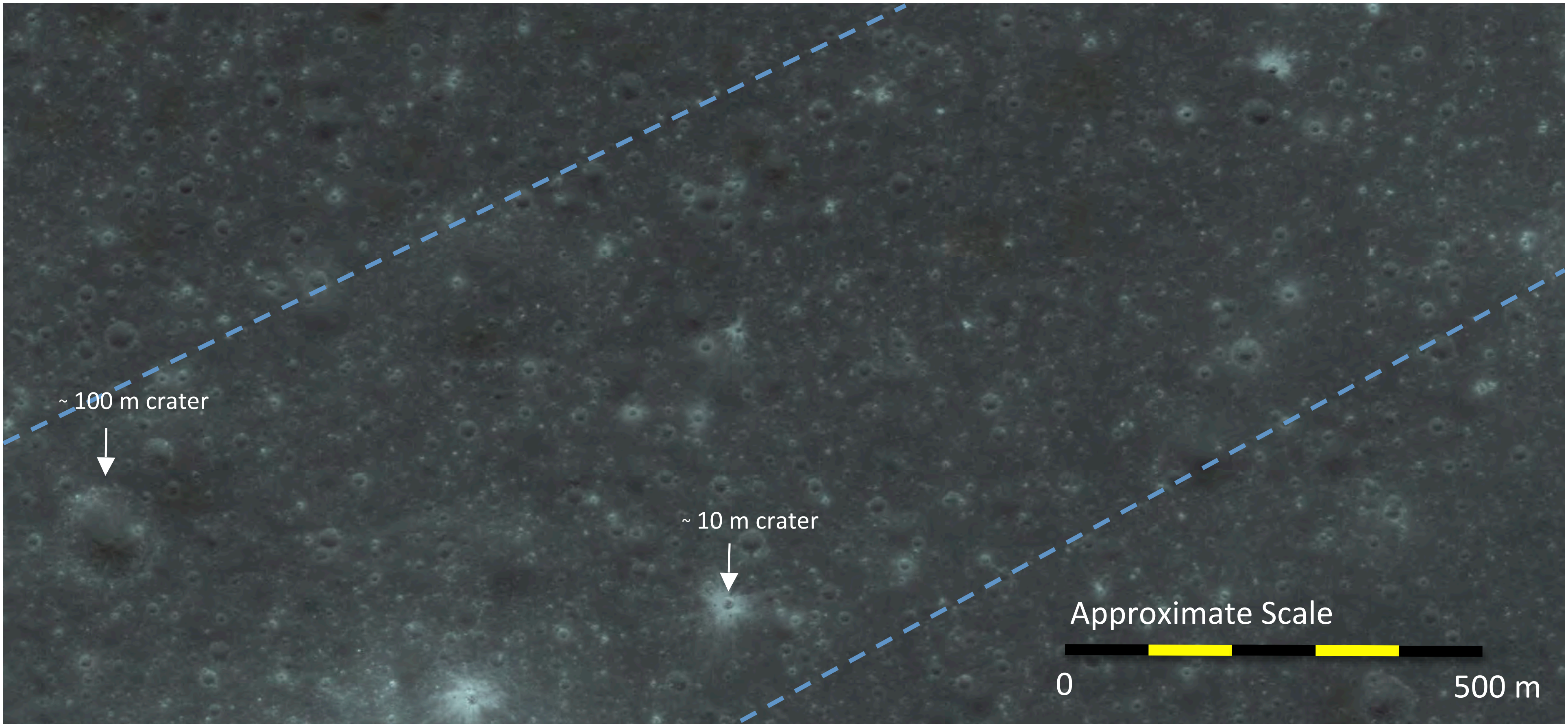
NAC Image: M109507800L
LRO Altitude: 50.52 km
Resolution: 0.53 m/pixel



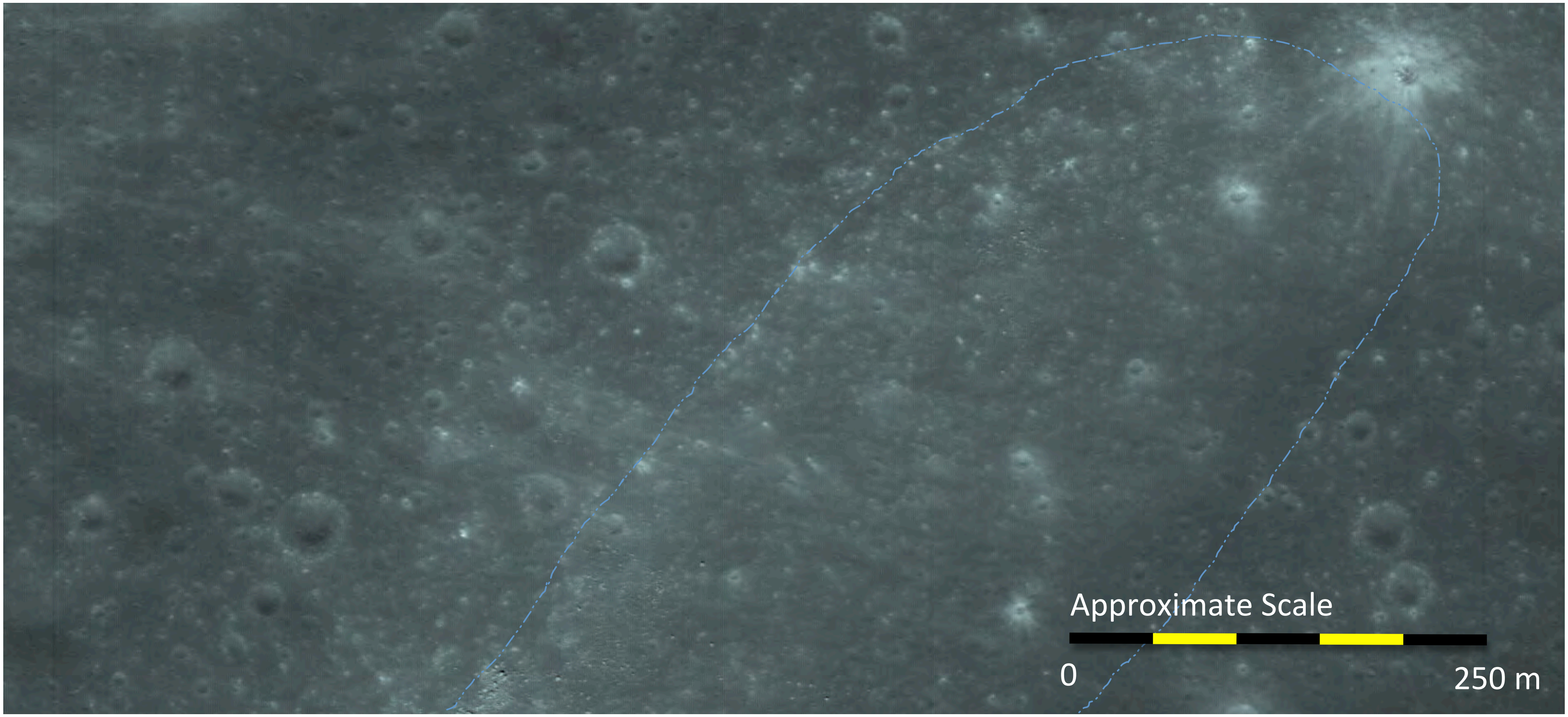
NAC Image: M109507800L
LRO Altitude: 50.52 km
Resolution: 0.53 m/pixel



NAC Image: M109507800R
LRO Altitude: 50.52 km
Resolution: 0.53 m/pixel



NAC Image: M109507800R
LRO Altitude: 50.52 km
Resolution: 0.53 m/pixel



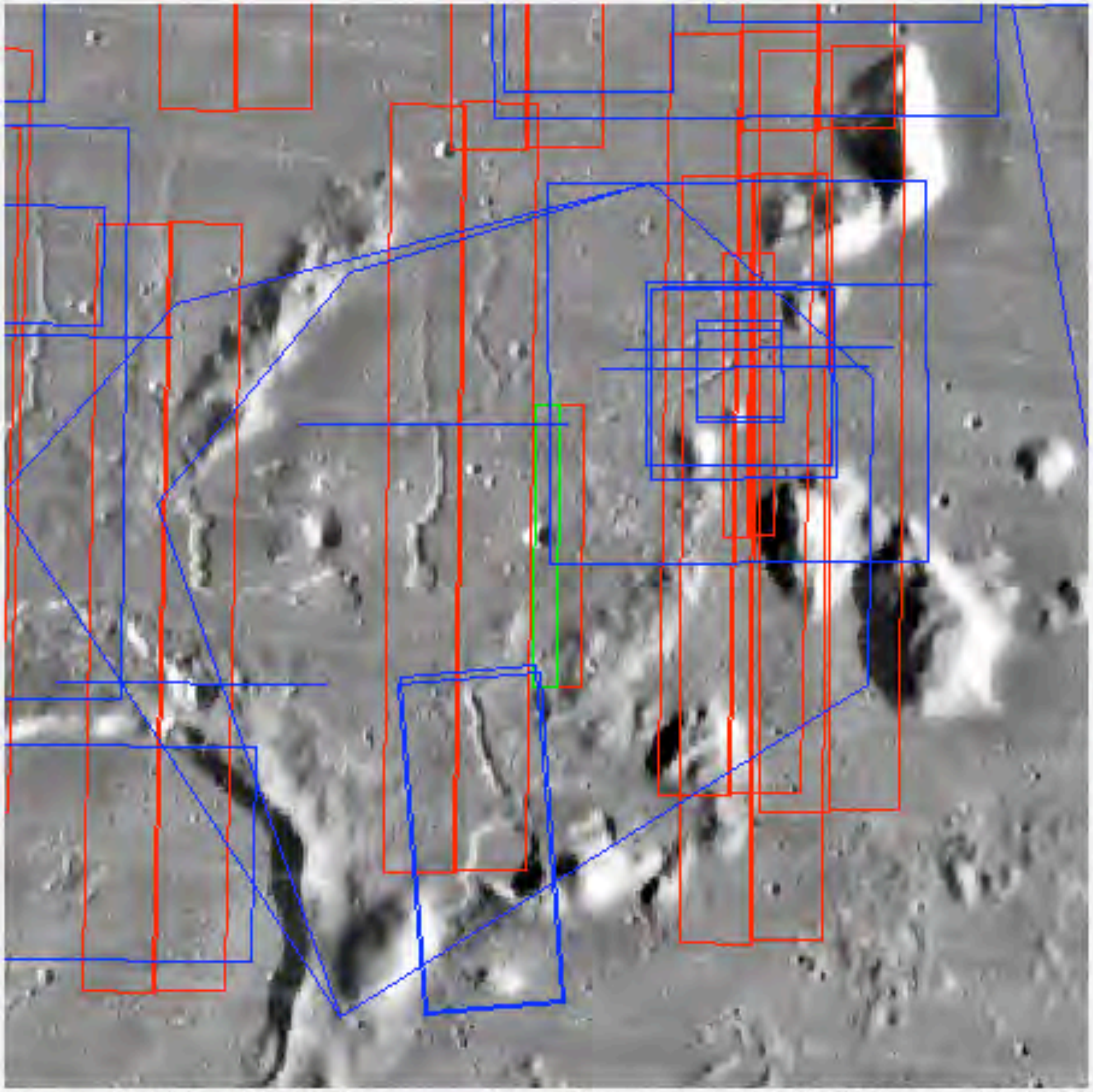
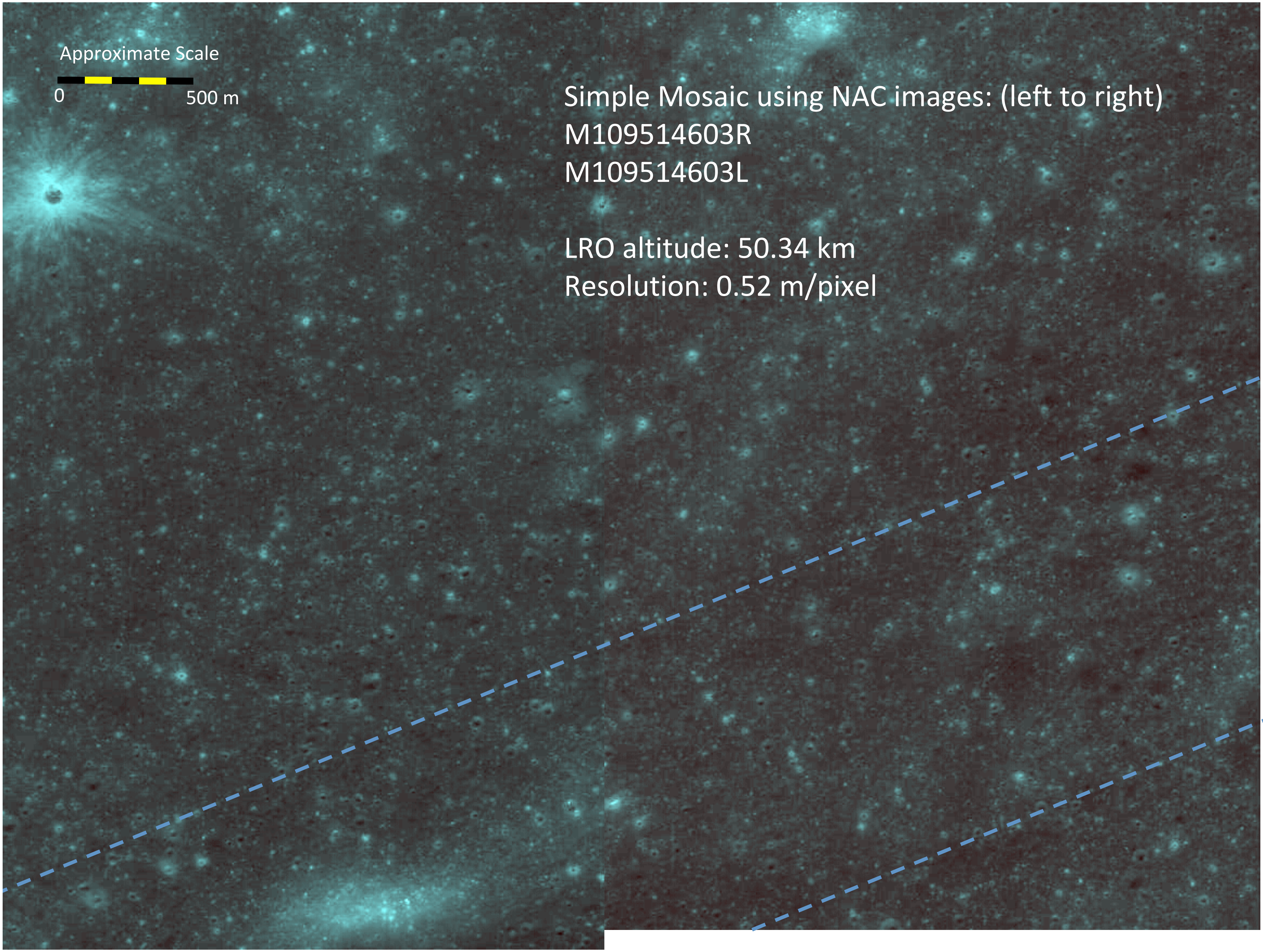
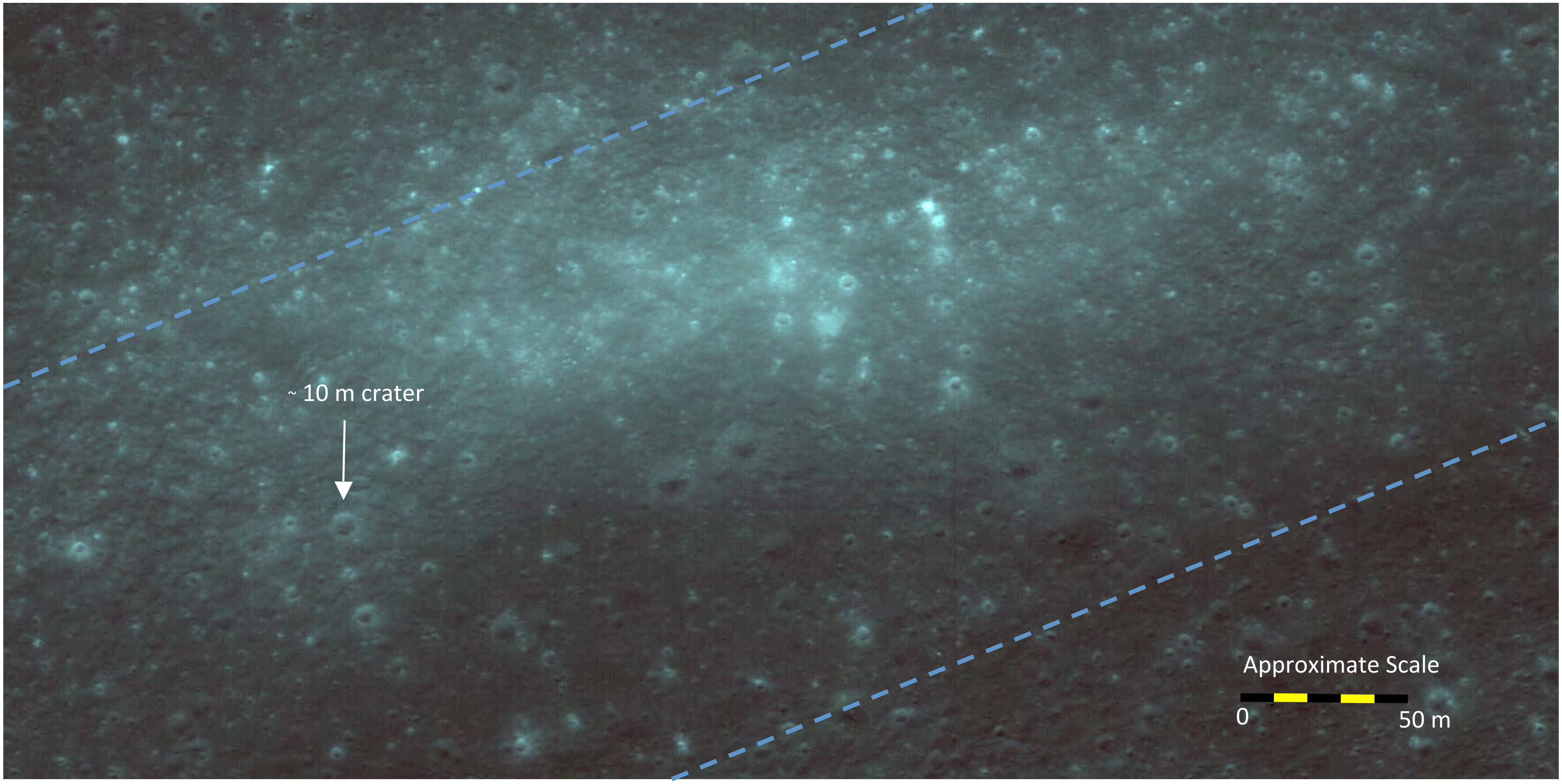


Image Width: 108.96 km Map Center Lat: 26.825° Lon: -42.428°


Approximate Scale
0
500 m
Simple Mosaic using NAC images: (left to right)
M109514603R
M109514603L
LRO altitude: 50.34 km
Resolution: 0.52 m/pixel

NAC Image: M109514603R
LRO Altitude: 50.34 km
Resolution: 0.52 m/pixel



Summary

- **In coordination with the LROC team and the lunar science community, NASA's Constellation program (CxP) has designated 50 regions of interest for LROC NAC imaging**
  - As a set, they Illustrate the diversity of the lunar surface, and form a representative basis for scientific exploration, resource development, and mission operations
  - The 50 CxP regions of interest are a subset of over 16,000 LROC targets
  - The CxP regions of interest are getting excellent quality images and consistent imaging from the LROC NAC
  - The CxP regions of interest DO NOT represent the initial step in a site selection process for future human missions to the Moon

- **Many of the CxP regions of interest support the sustainability theme of the LEAG-coordinated Lunar Exploration Roadmap**
  - Resources
  - Long-term habitation

- **Initial analysis has begun on the 50 CxP regions of interest**
  - Much of the Aristarchus 2 ROI appears to be relatively boulder free at 1-meter scale
  - There are no apparent openings into one of the lava tube candidates at the Rimae Prinz ROI