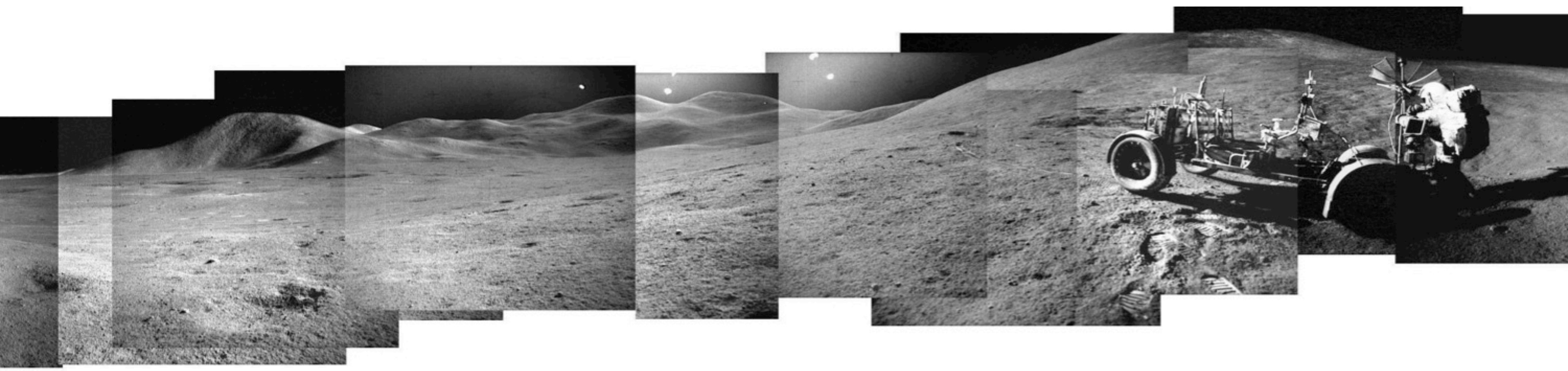
Elucidating the History of the Moon's Surface

High Spatial Resolution $^{40}Ar/^{39}Ar$ Geochronology of Multigenerational Lunar Impact Melt Rocks



School of Earth and Space Exploration
Arizona State University

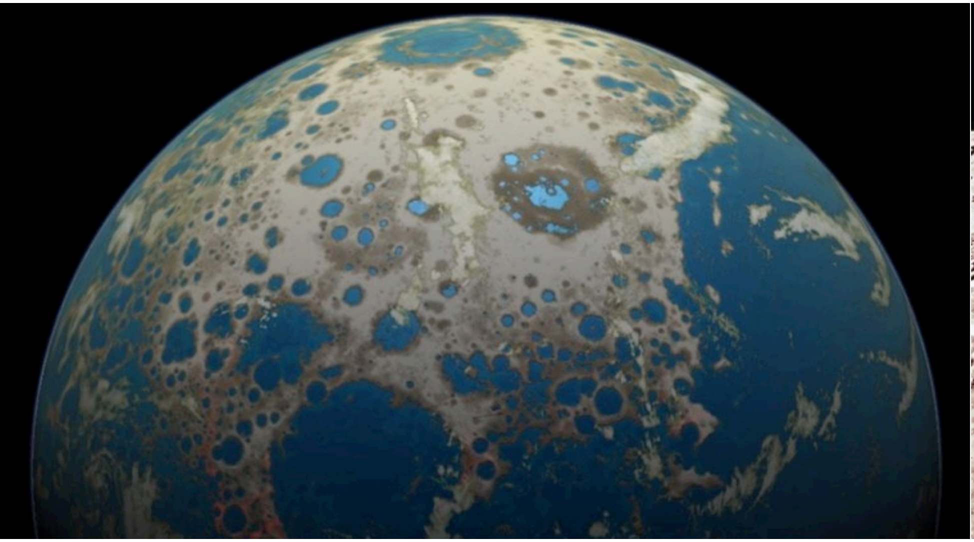
Hayden Miller

SESE Colloquium

March 17th, 2021

Why study the moon?

- Moon is an unique archive of early Solar System history



Artistic rendering of Hadean Earth (credit: Simone Marchi)

Heavily cratered lunar surface (credit: NASA)

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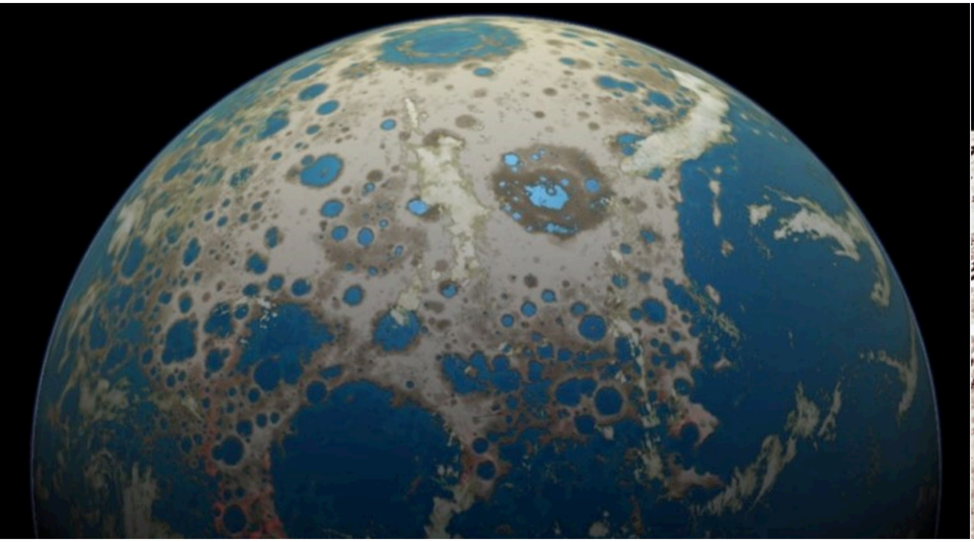

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Heavily cratered lunar surface (credit: NASA)

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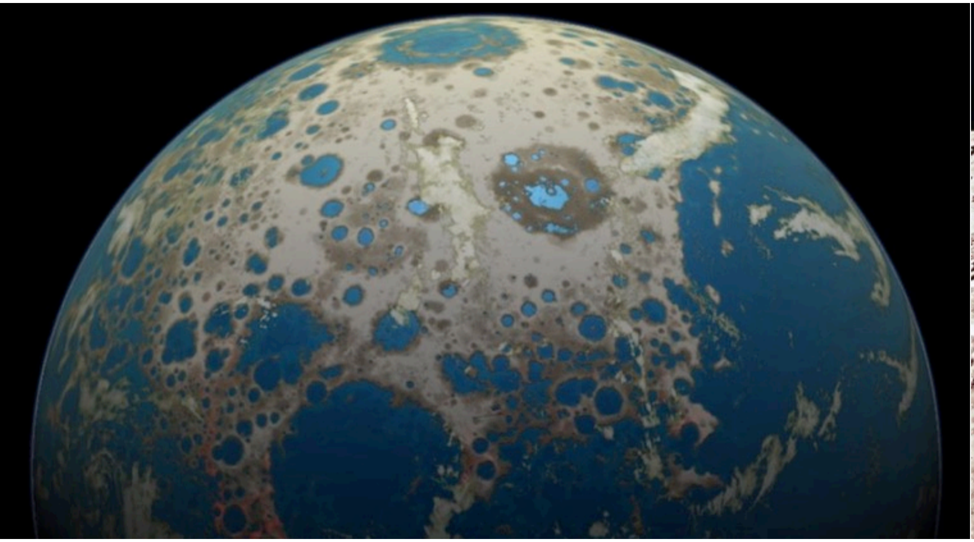
  - Implications for emergence of life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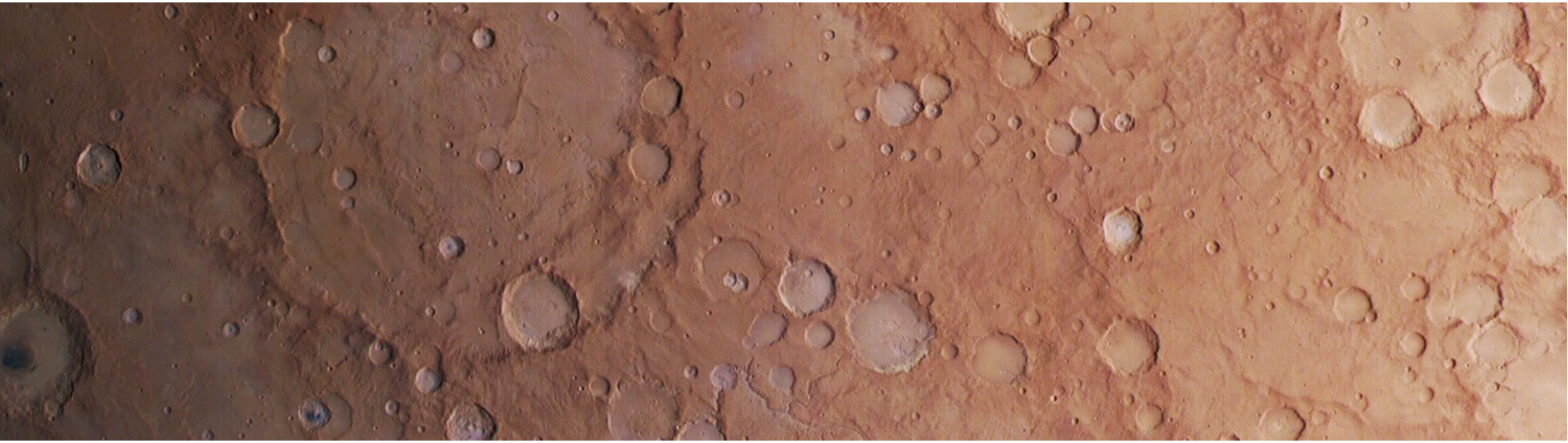
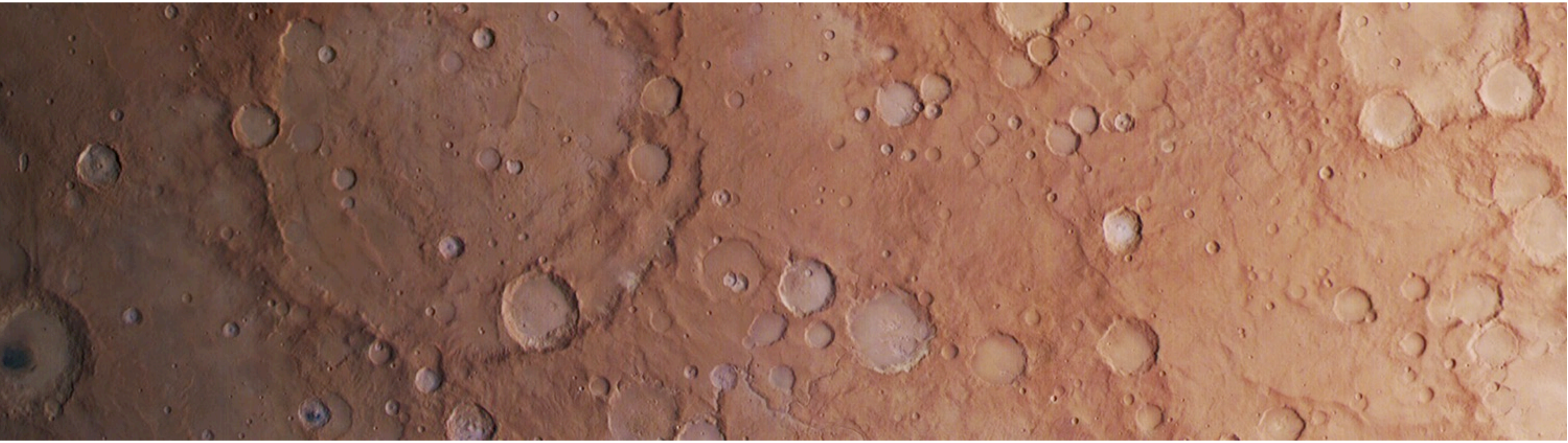
- Lunar history can be extrapolated to other solid surfaces in Solar System



Martian surface (credit: European Space Agency)

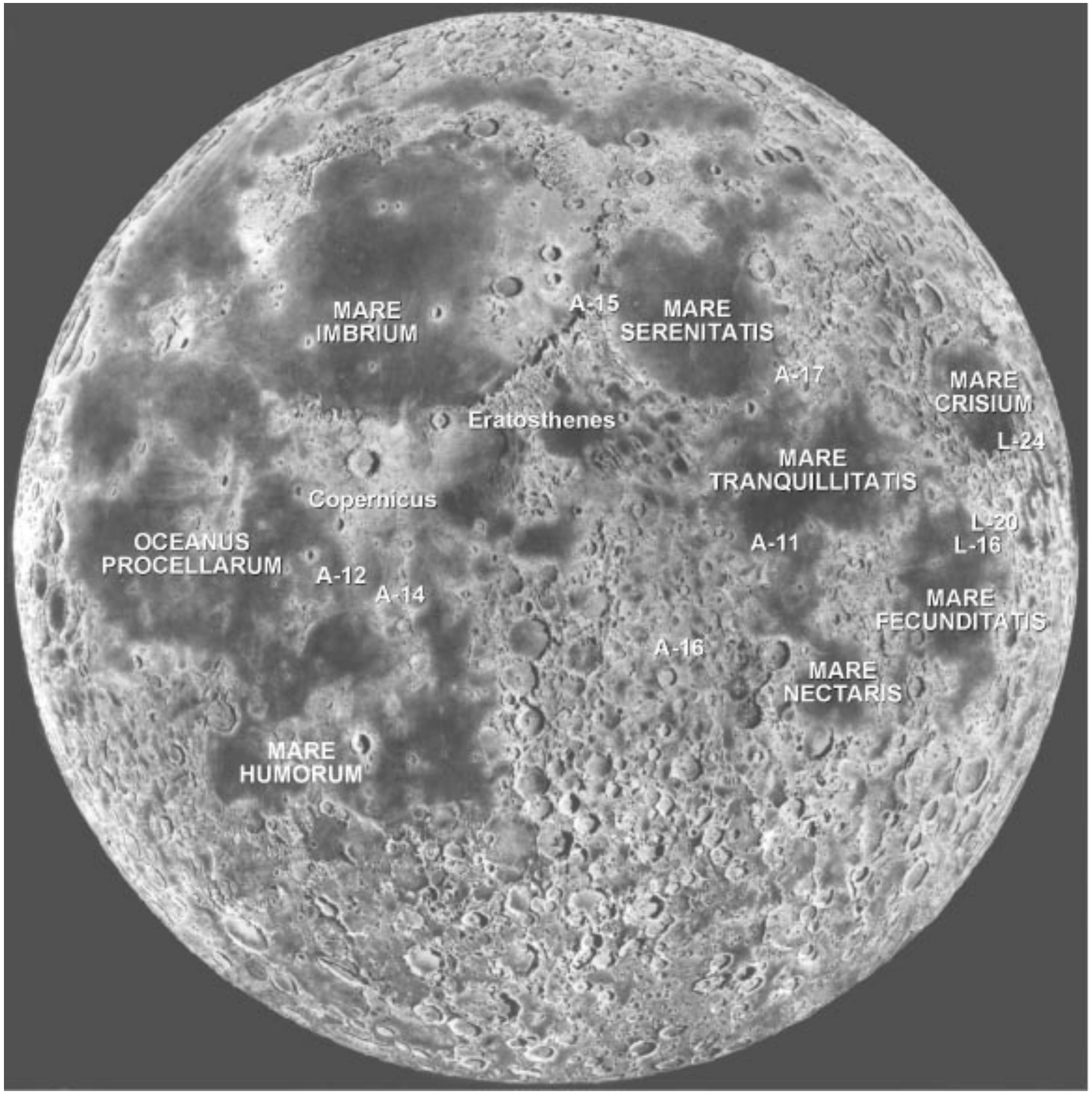
Why study the moon?

- Lunar history can be extrapolated to other solid surfaces in Solar System
  - Lunar chronology ties crater size frequency distributions to radiometric time

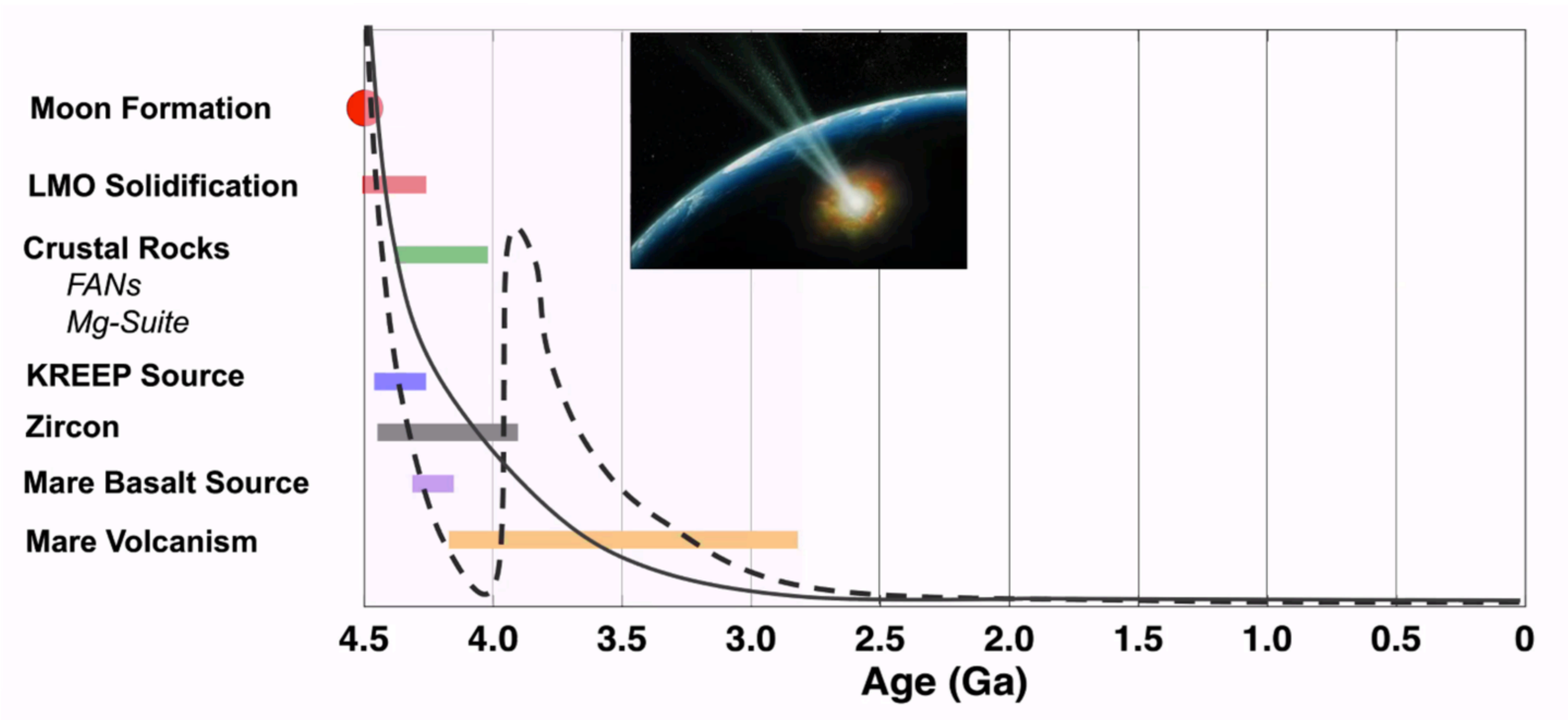


Martian surface (credit: European Space Agency)

The lunar surface



Lunar chronology



Credit: NASA

Argon geochronology

- ^{40}K ($t_{1/2}$ = 1.25 Ga) → ^{40}Ca and ^{40}Ar
- Neutron irradiation produces ^{39}Ar from ^{40}K
- $^{40}Ar/^{39}Ar$ measured in unknown and compared to neutron fluence age monitor

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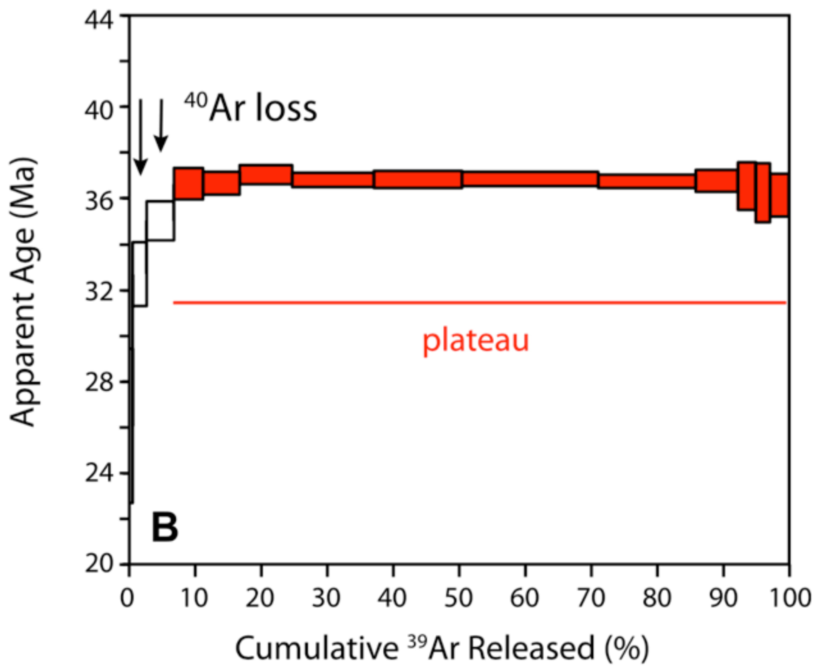

Schaen et al., 2020

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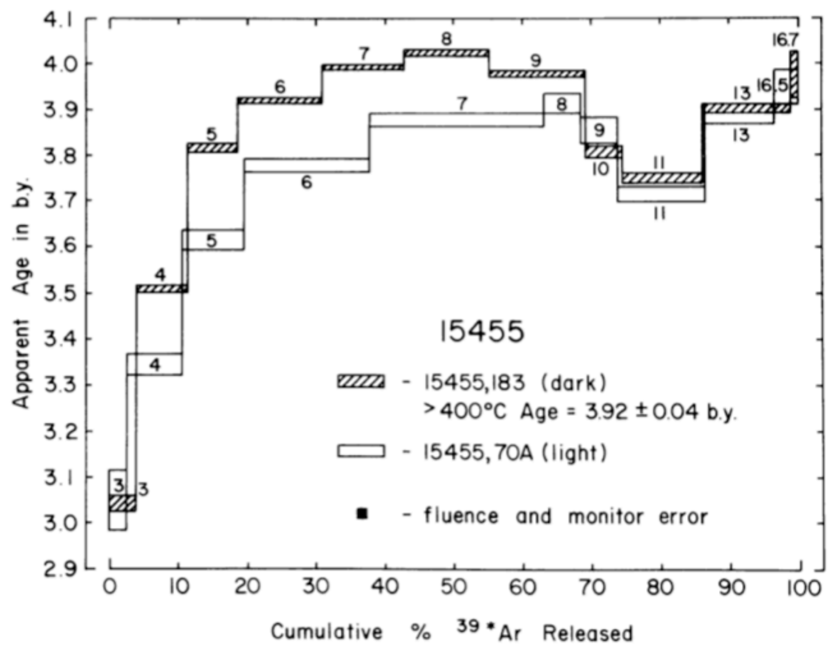

Alexander and Kahl, 1974

The UVLAMP $^{40}Ar/^{39}Ar$ method

- UV laser ablation microprobe (UVLAMP) analyses permit high-spatial resolution geochronologic investigations
  - Particularly useful for multi-generational materials
  - 193 nm wavelength, produces no collateral heating outside of ablation pit
  - Ancient nature of lunar materials require only tens of nanograms of ablated material
  - Sample targeting done in petrographic context

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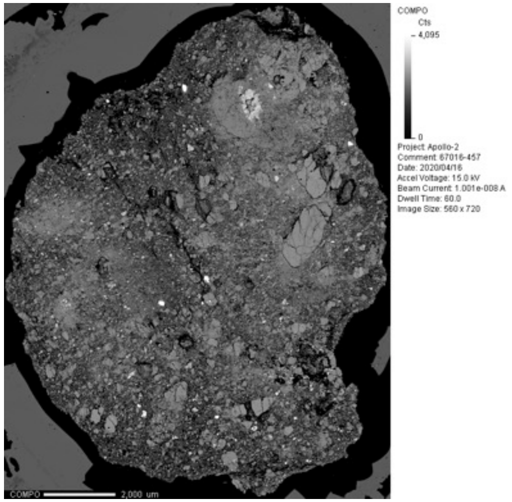

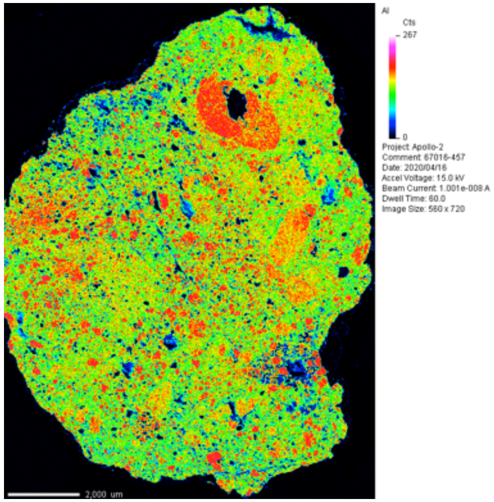

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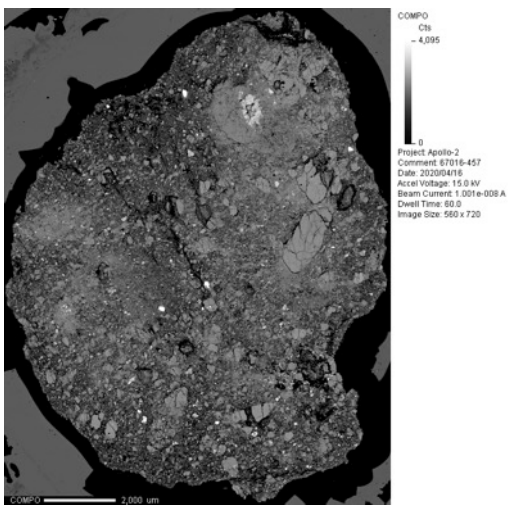

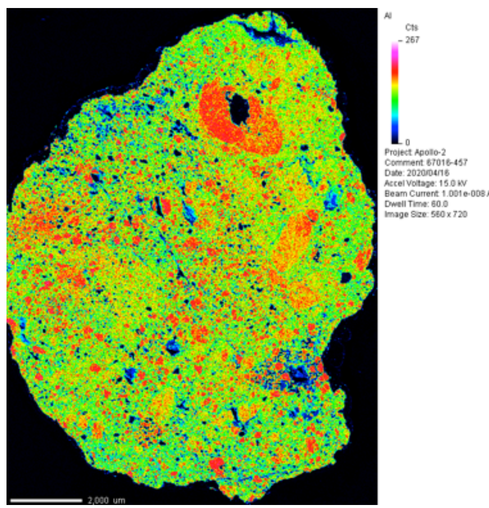

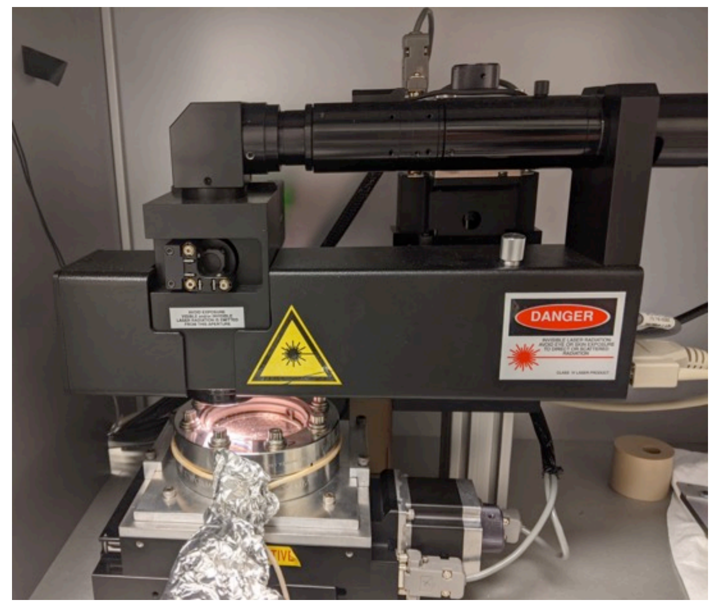

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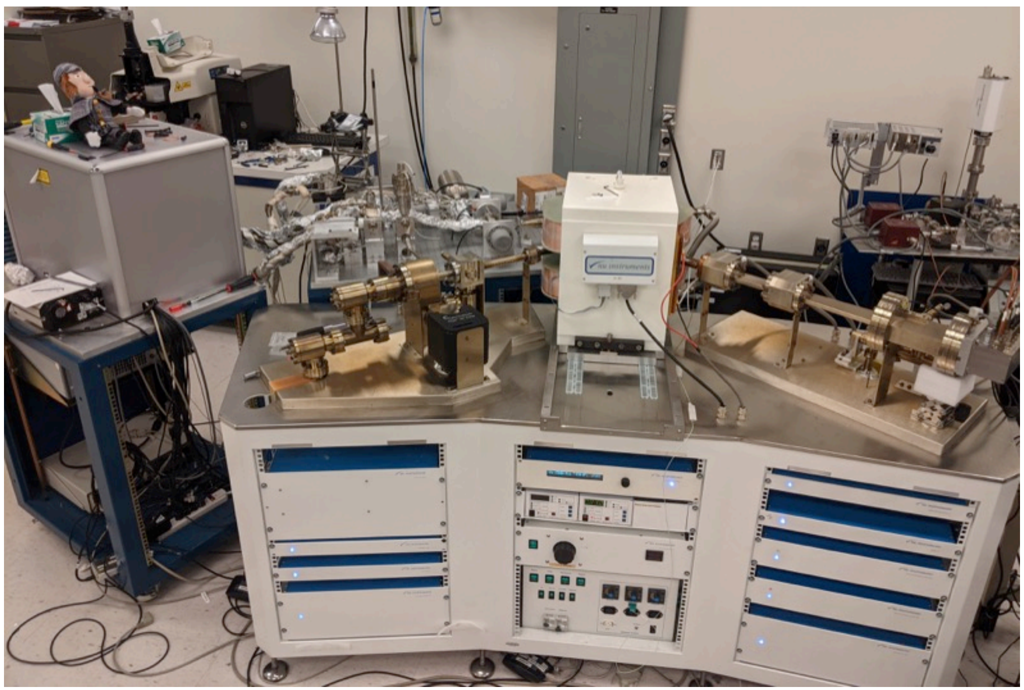
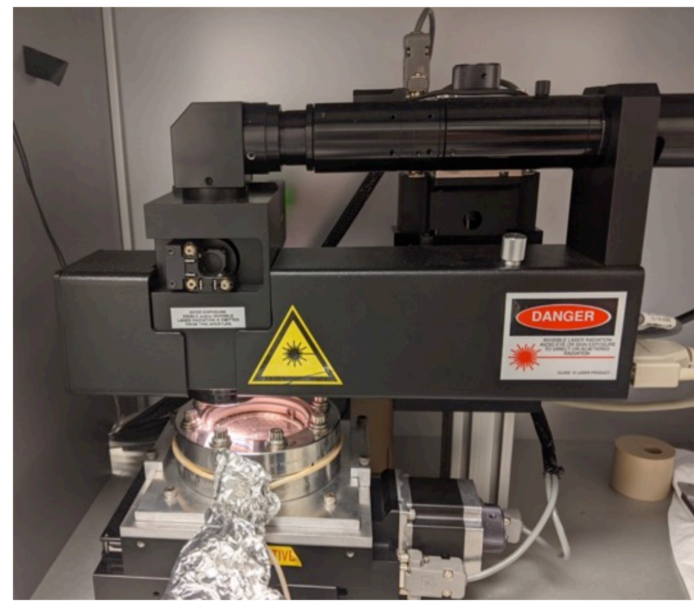
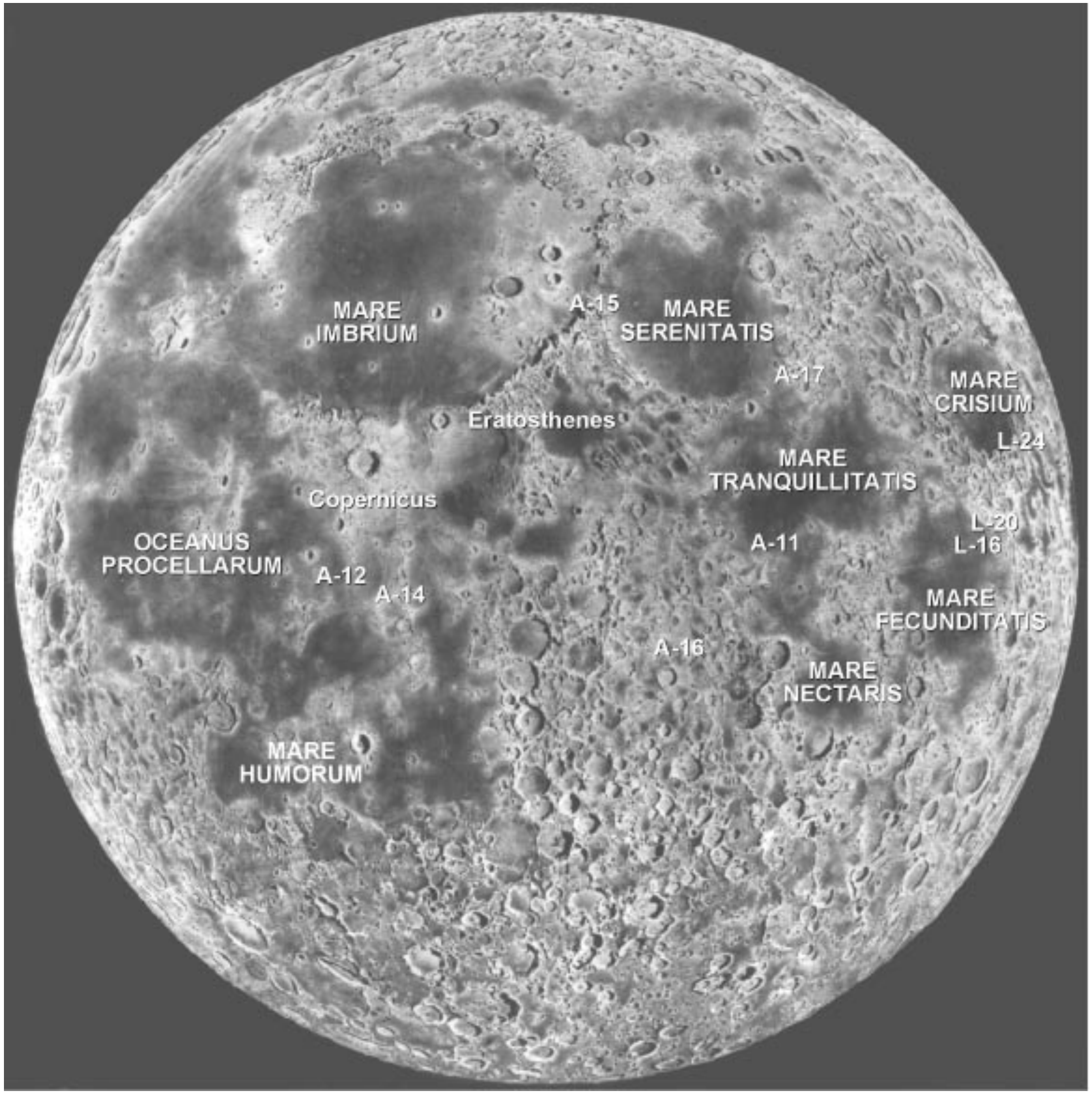
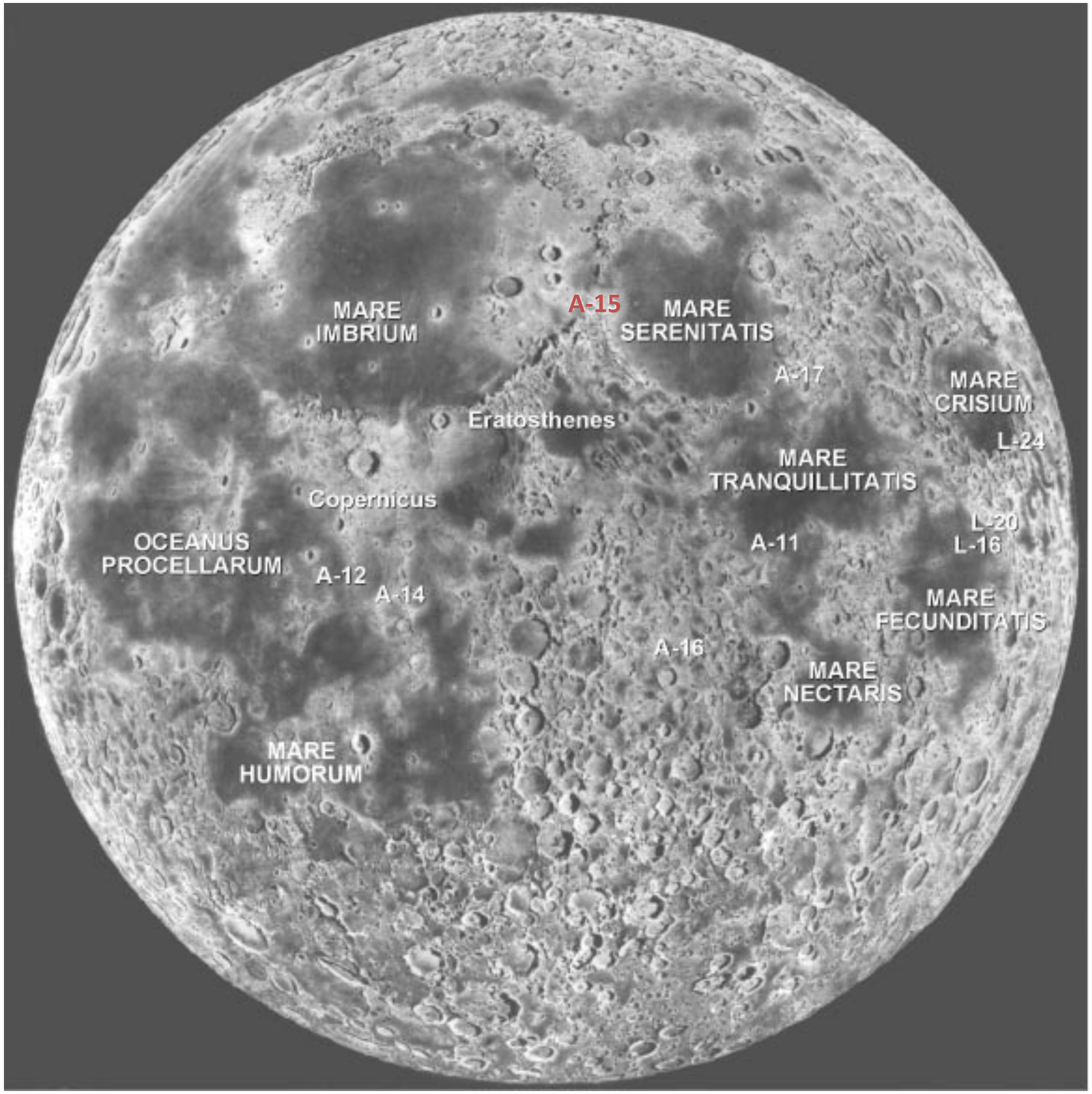





MARE IMBRIUM
A-15
MARE SERENITATIS
A-17
MARE CRISIUM
Eratosthenes
L-24
MARE TRANQUILLITATIS
Copernicus
L-20
OCEANUS PROCELLARUM
A-11
L-16
A-12
A-14
MARE FECUNDITATIS
A-16
MARE NECTARIS
MARE HUMORUM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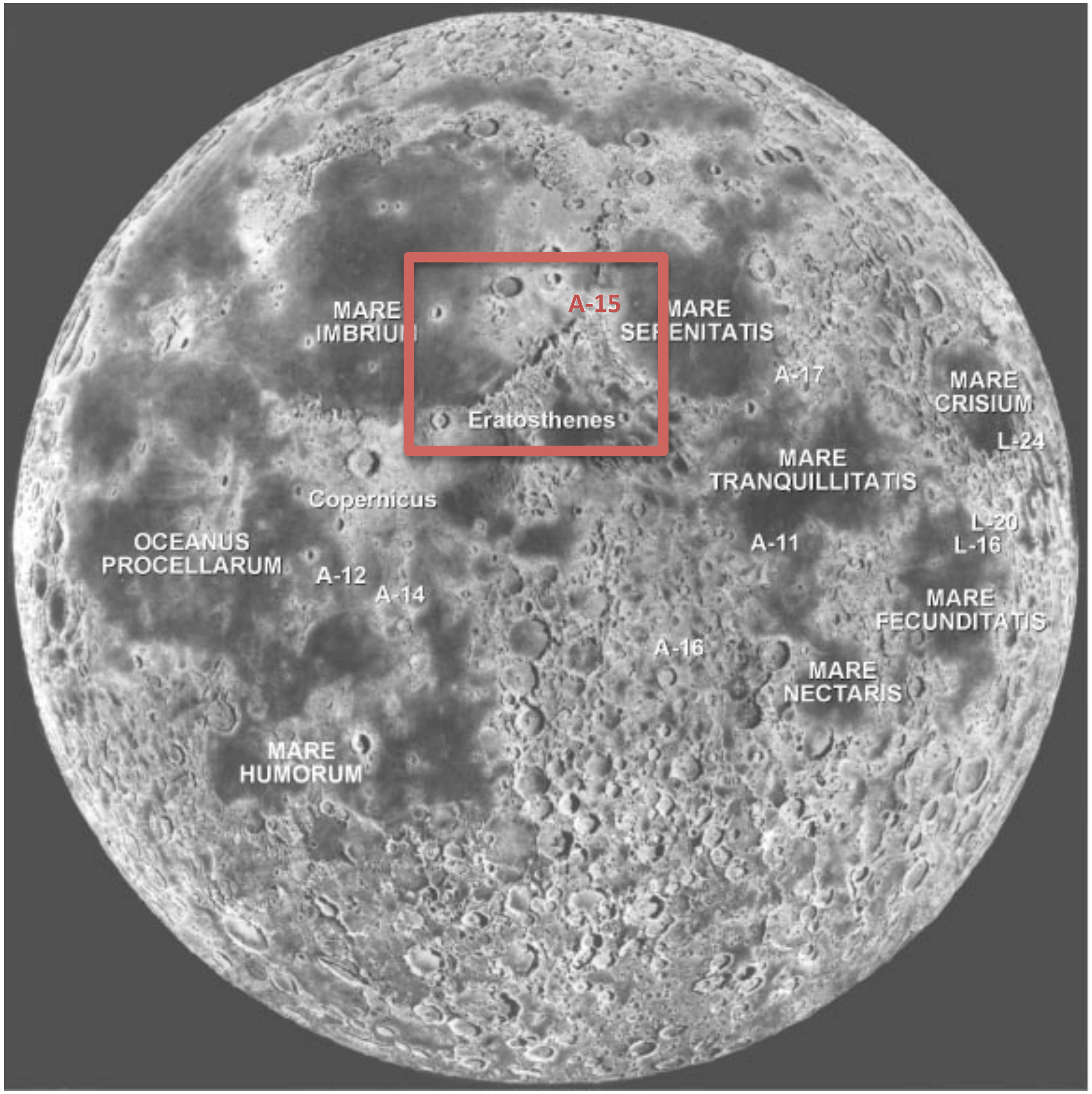
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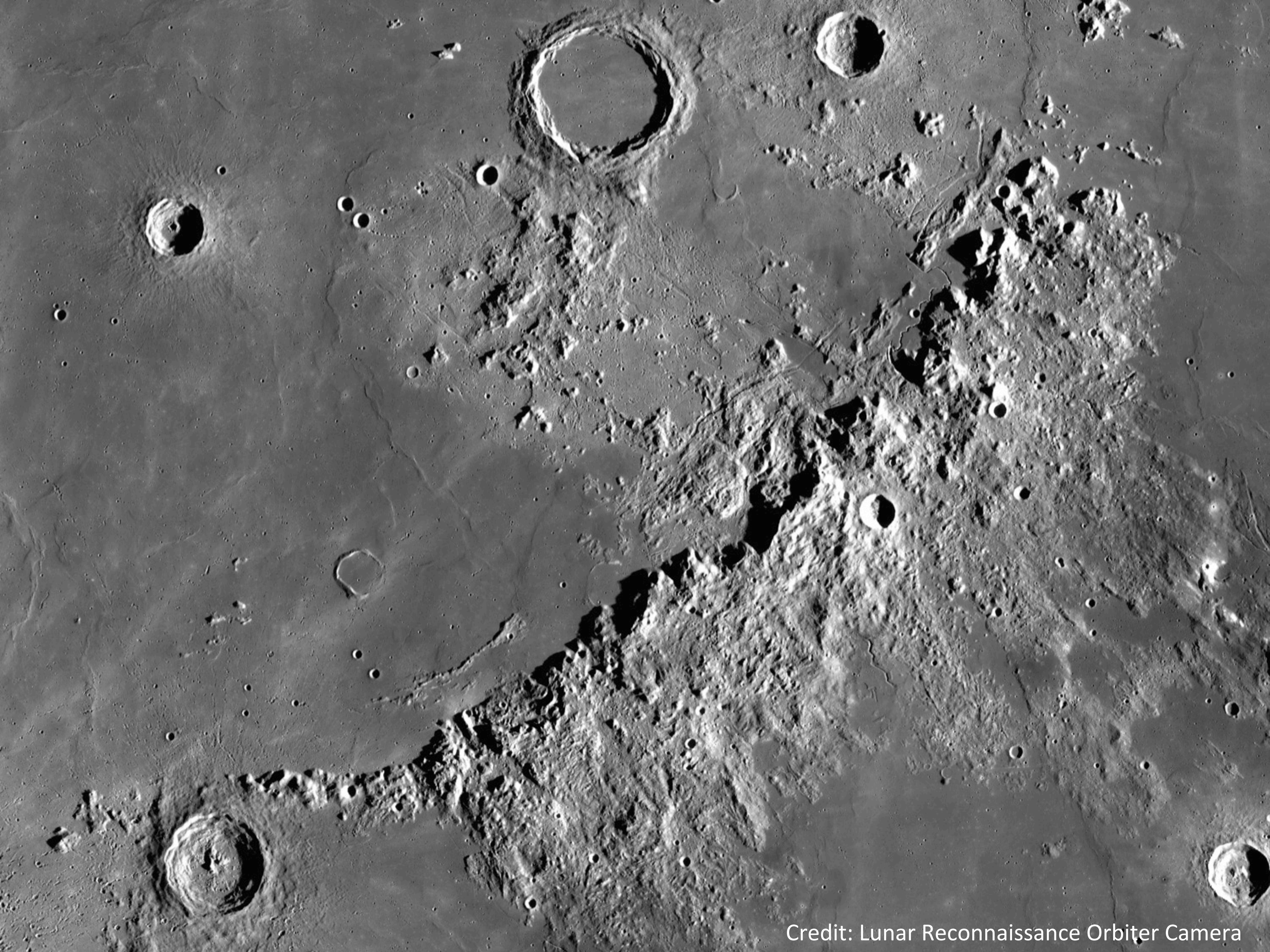
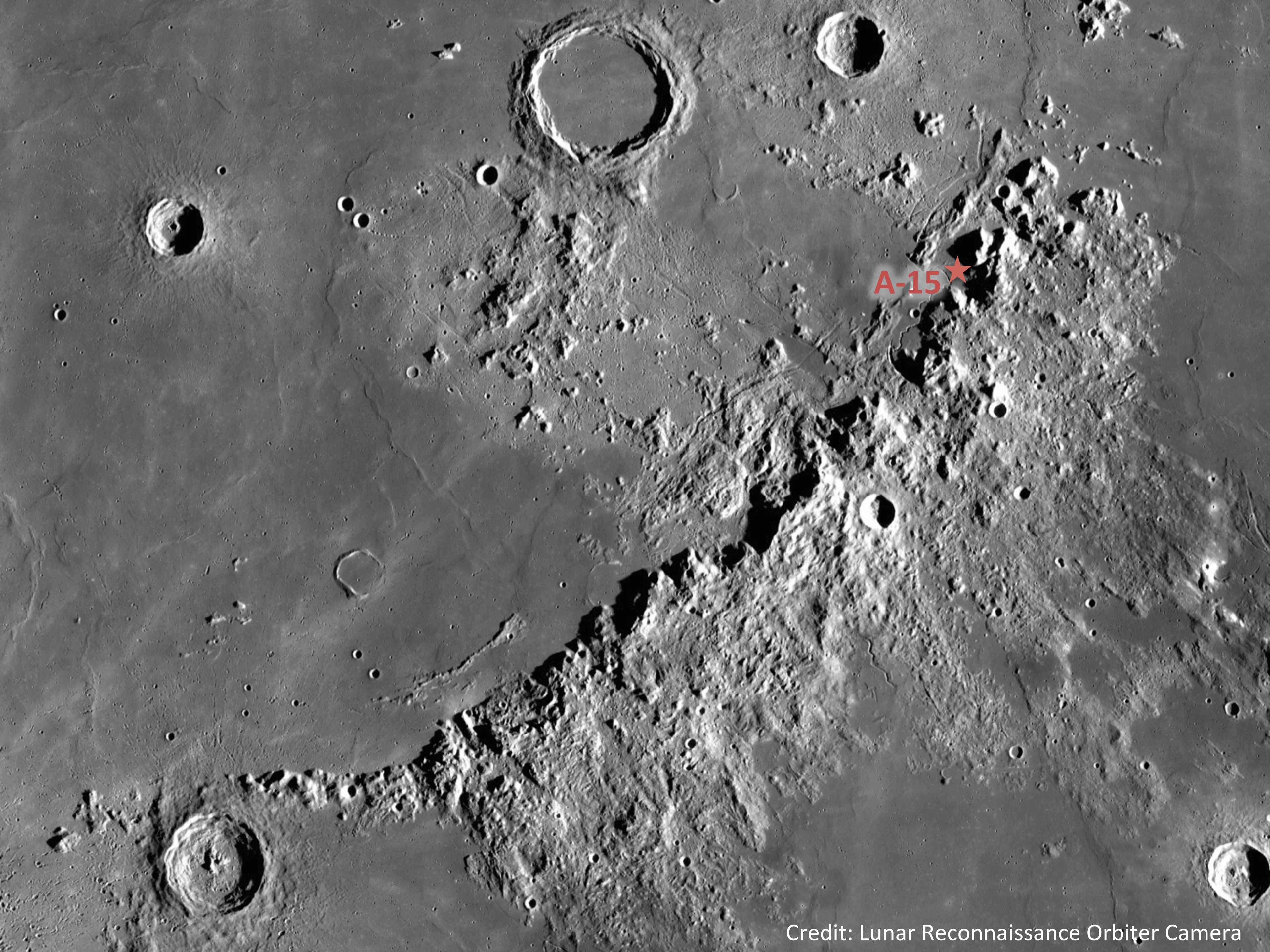

Credit: Lunar Reconnaissance Orbiter Camera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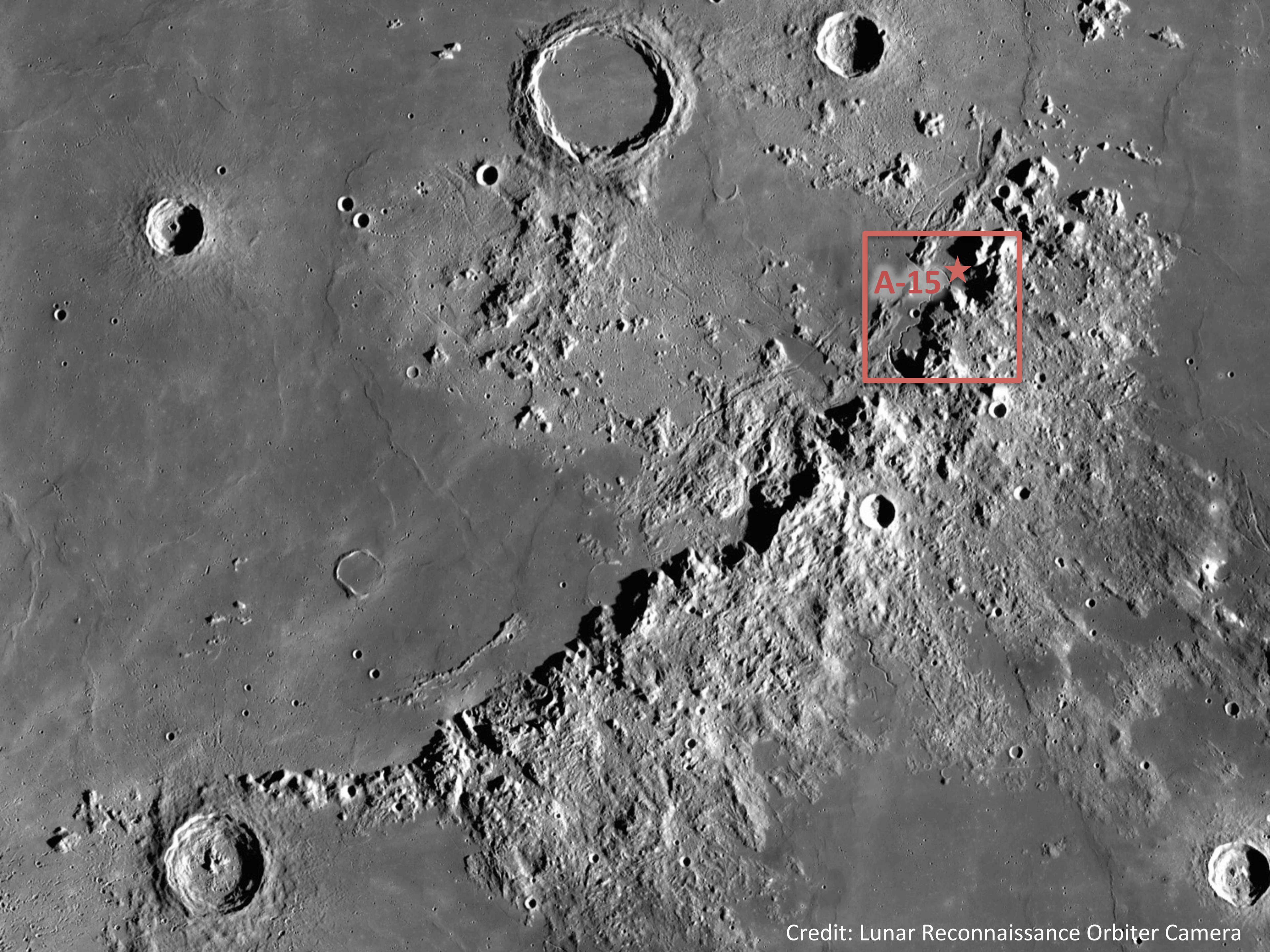
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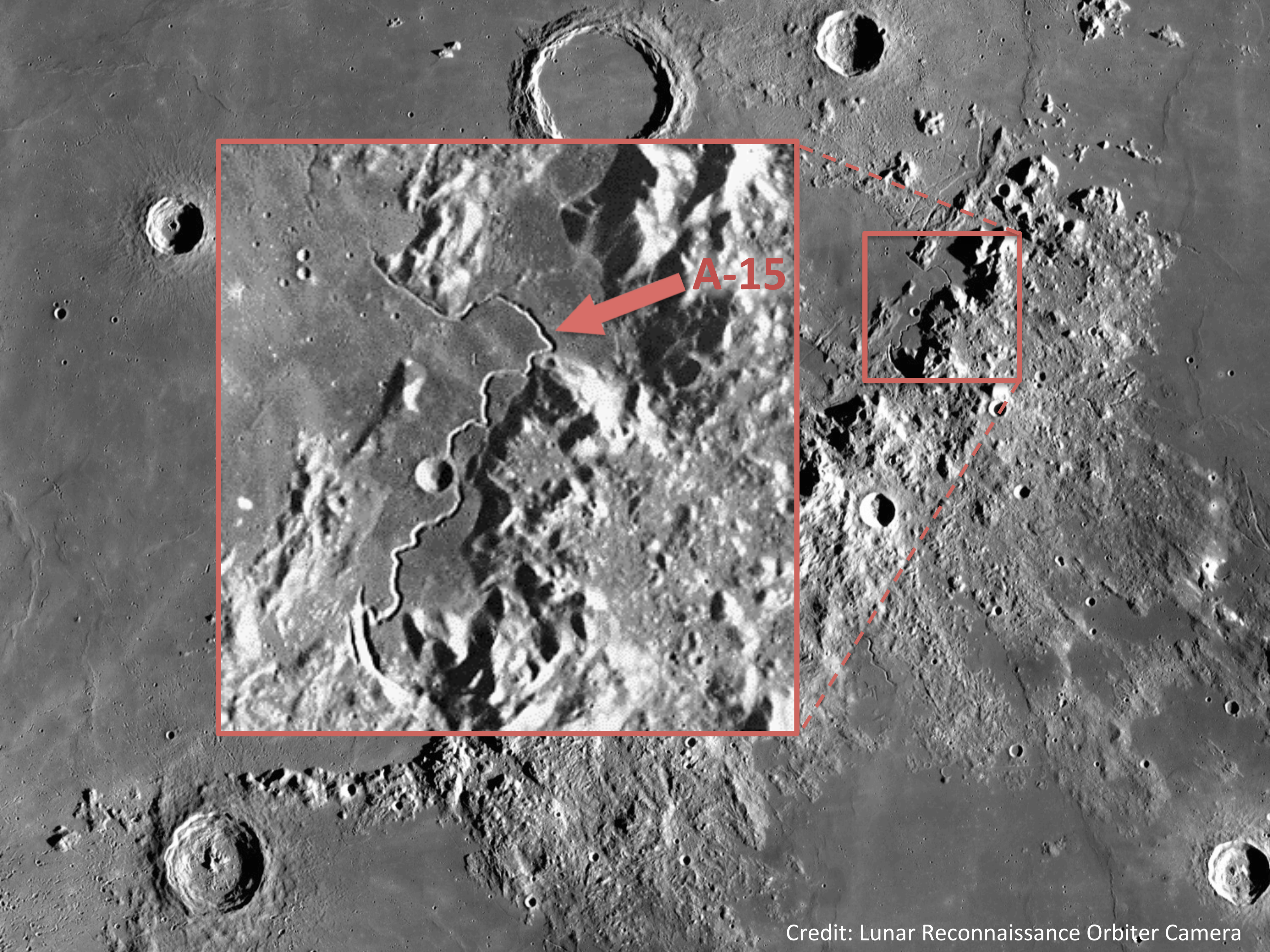

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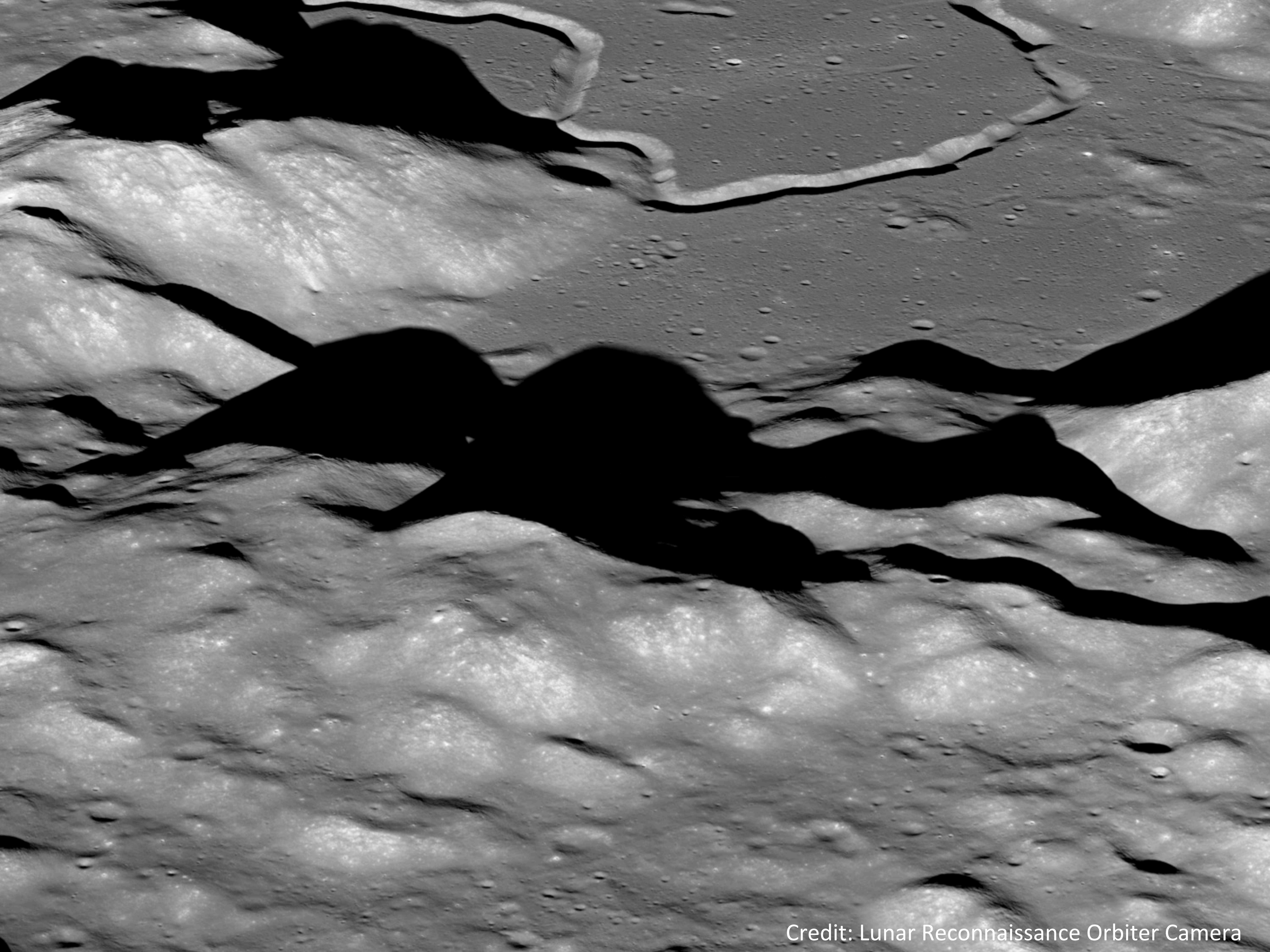
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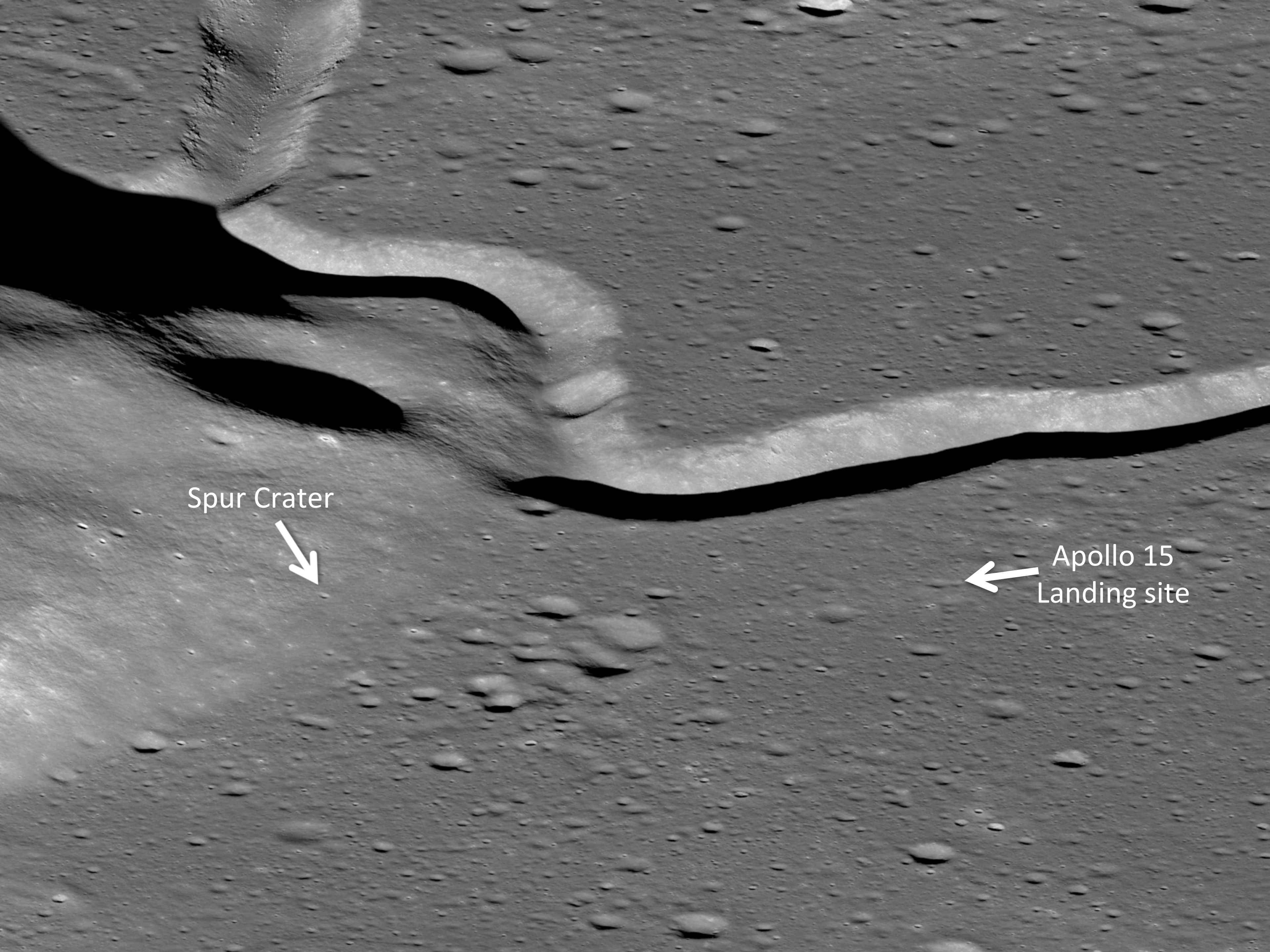
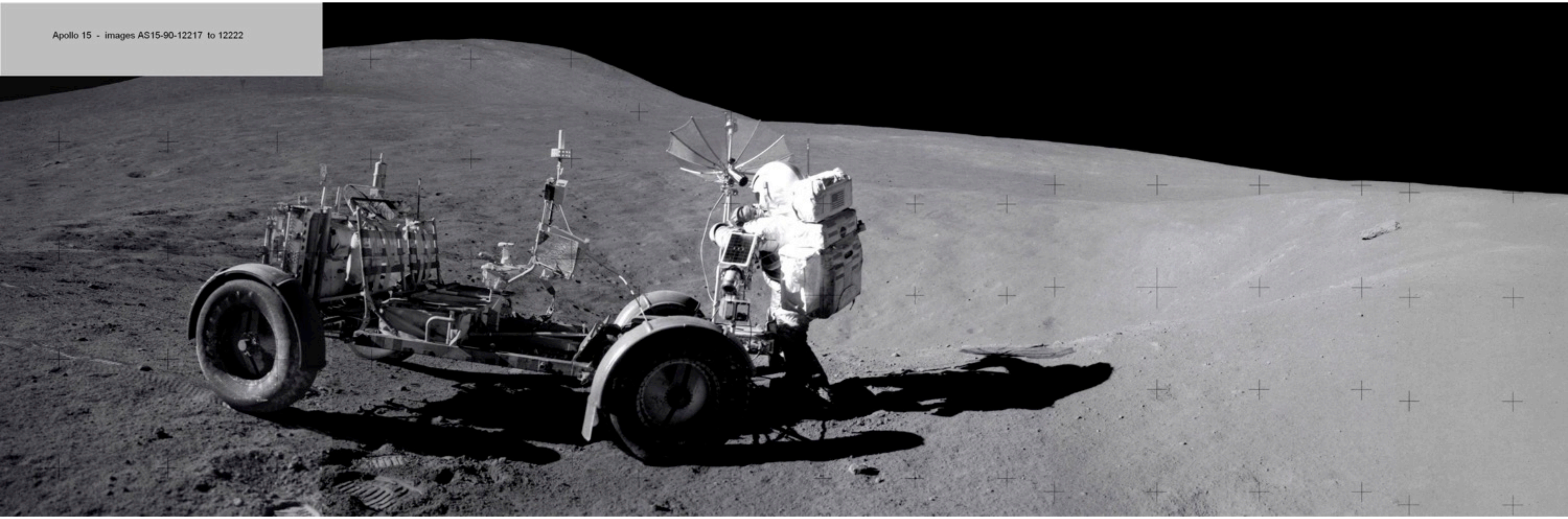

Spur Crater
Apollo 15
Landing site

Spur Crater – 15455 and 15445



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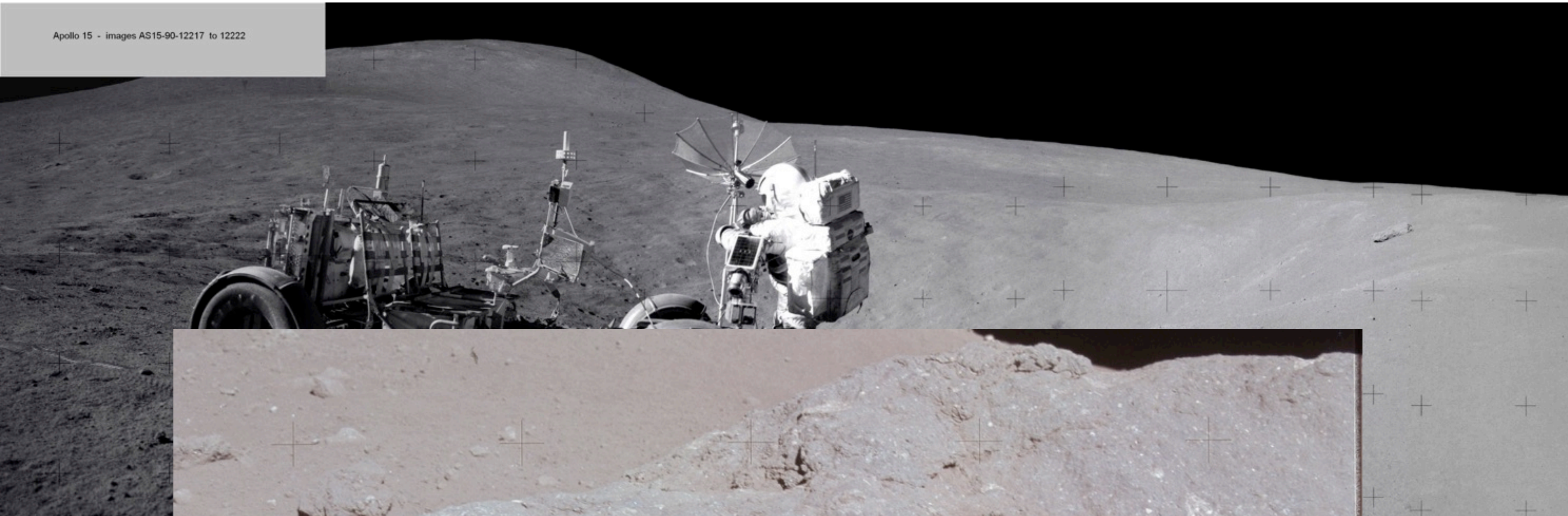
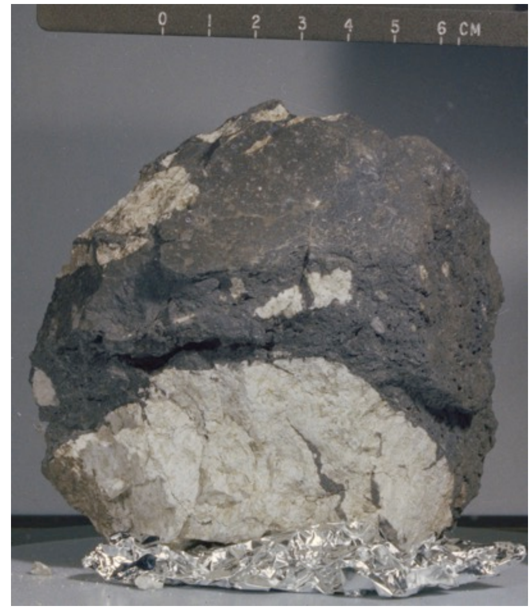


The Apollo 15 ‘white an black’ rocks

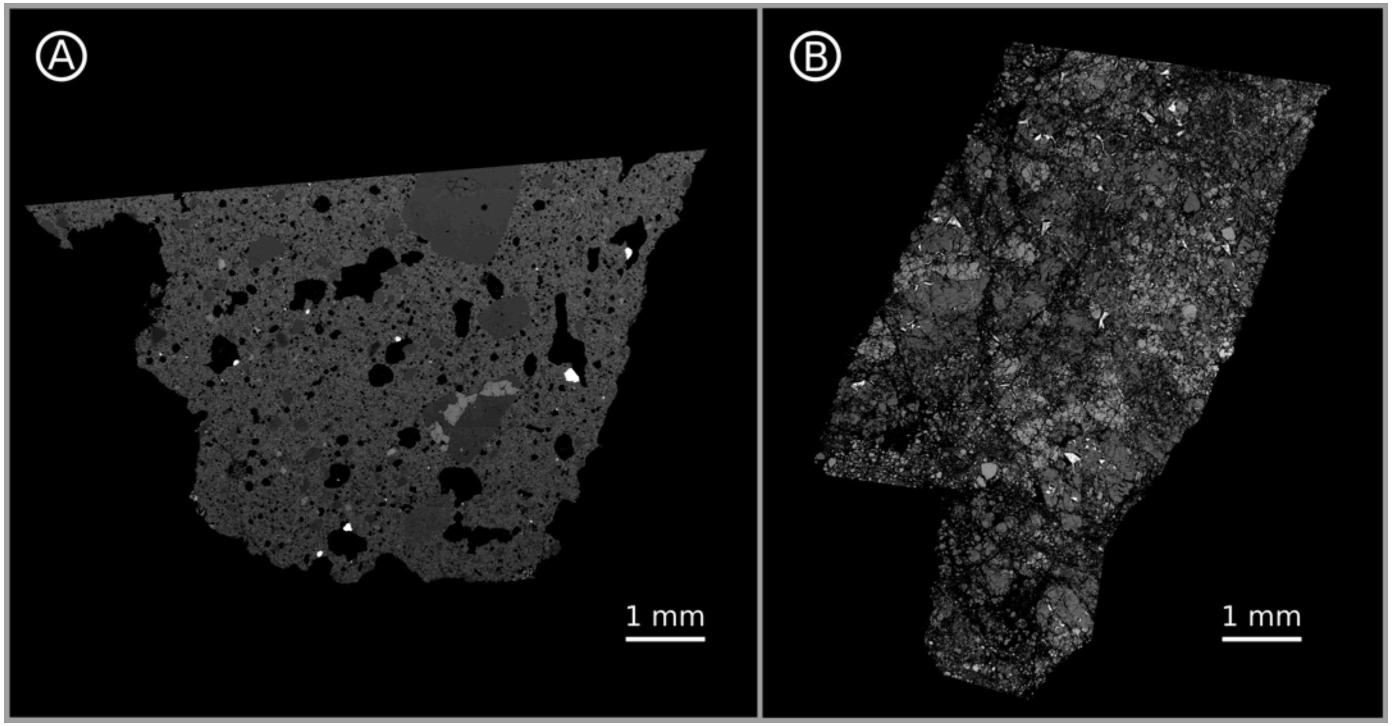
15445



15455

- Macroscopic fragments of plutonic rock hosted within a fragment-laden impact melt breccia
- The two samples are geochemically and petrographically linked

The Apollo 15 ‘white an black’ rocks



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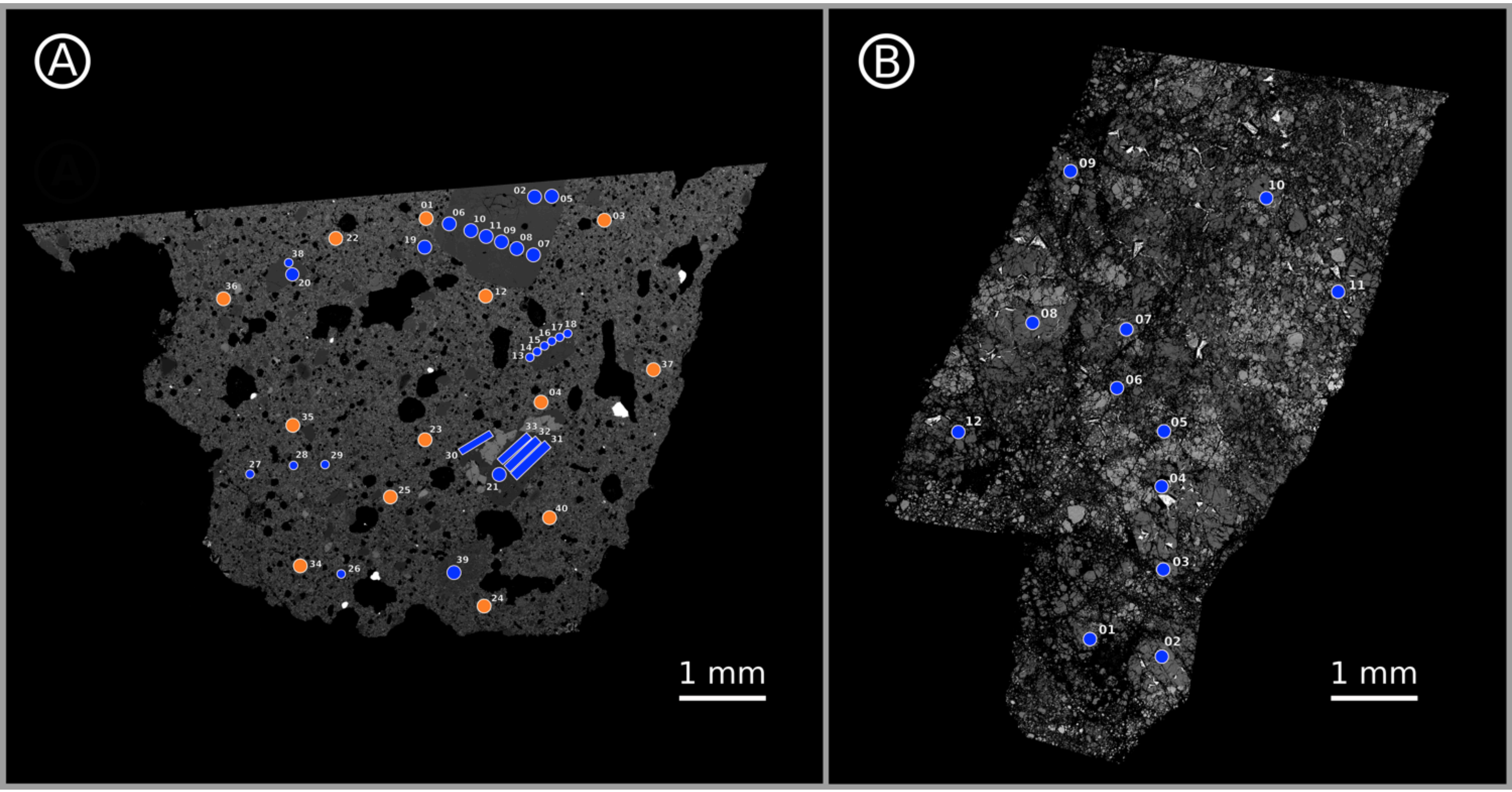
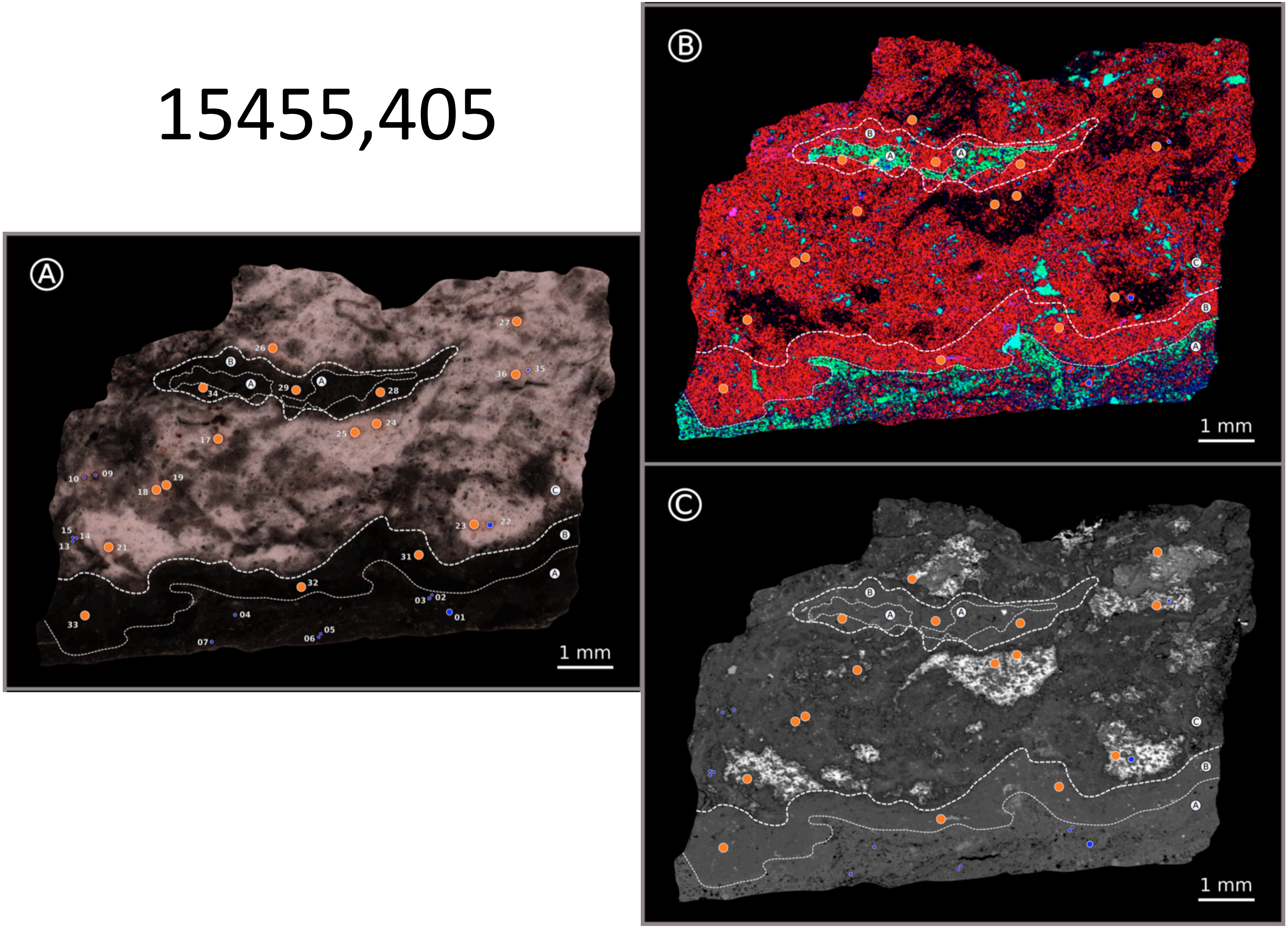
15455,383 and 15455,386



15455,405



A
B
C
1 mm
1 mm
1 mm
26
27
34
29
28
36
35
17
25
24
10
09
18
19
15
14
13
21
23
22
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03
02
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01
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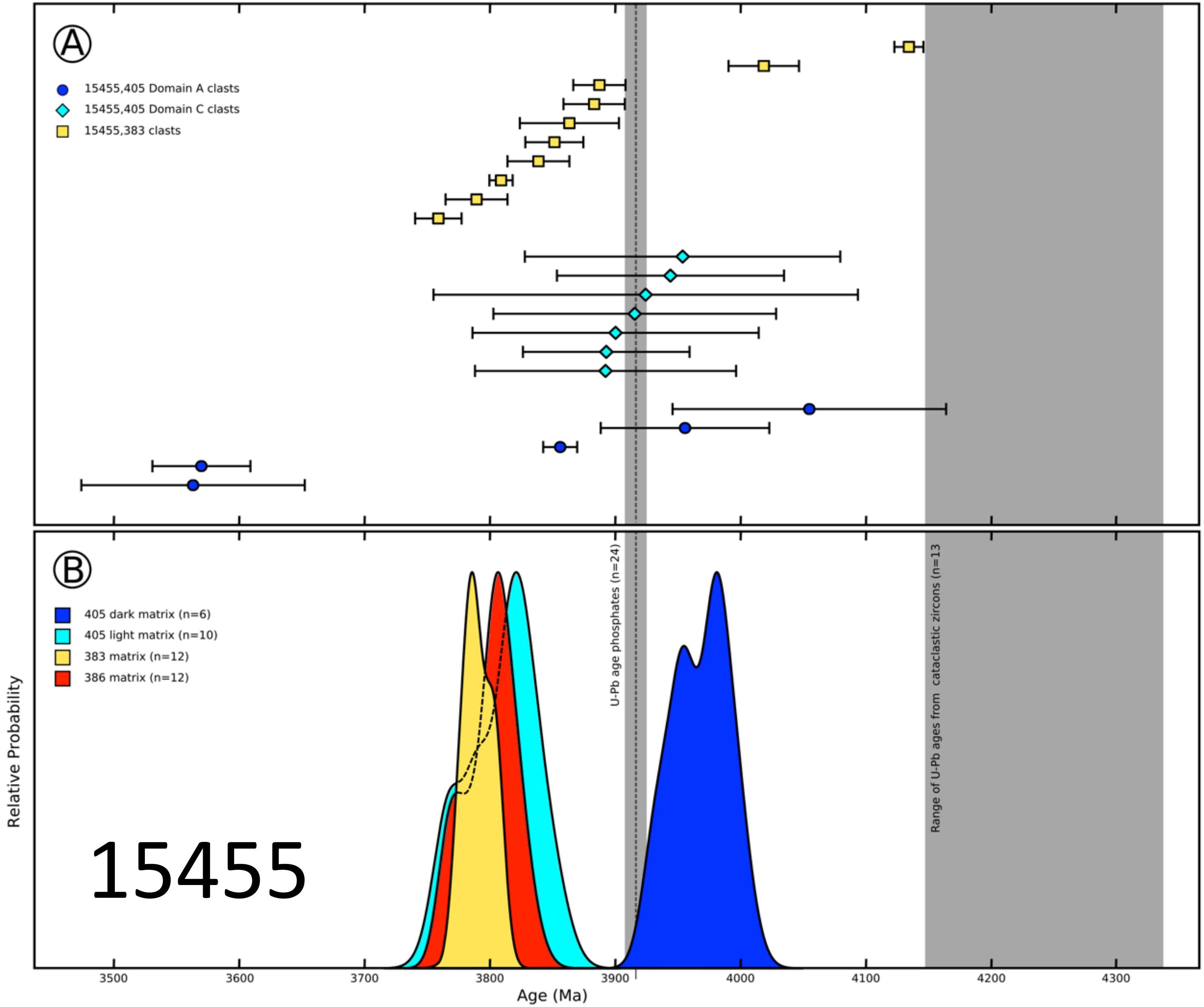
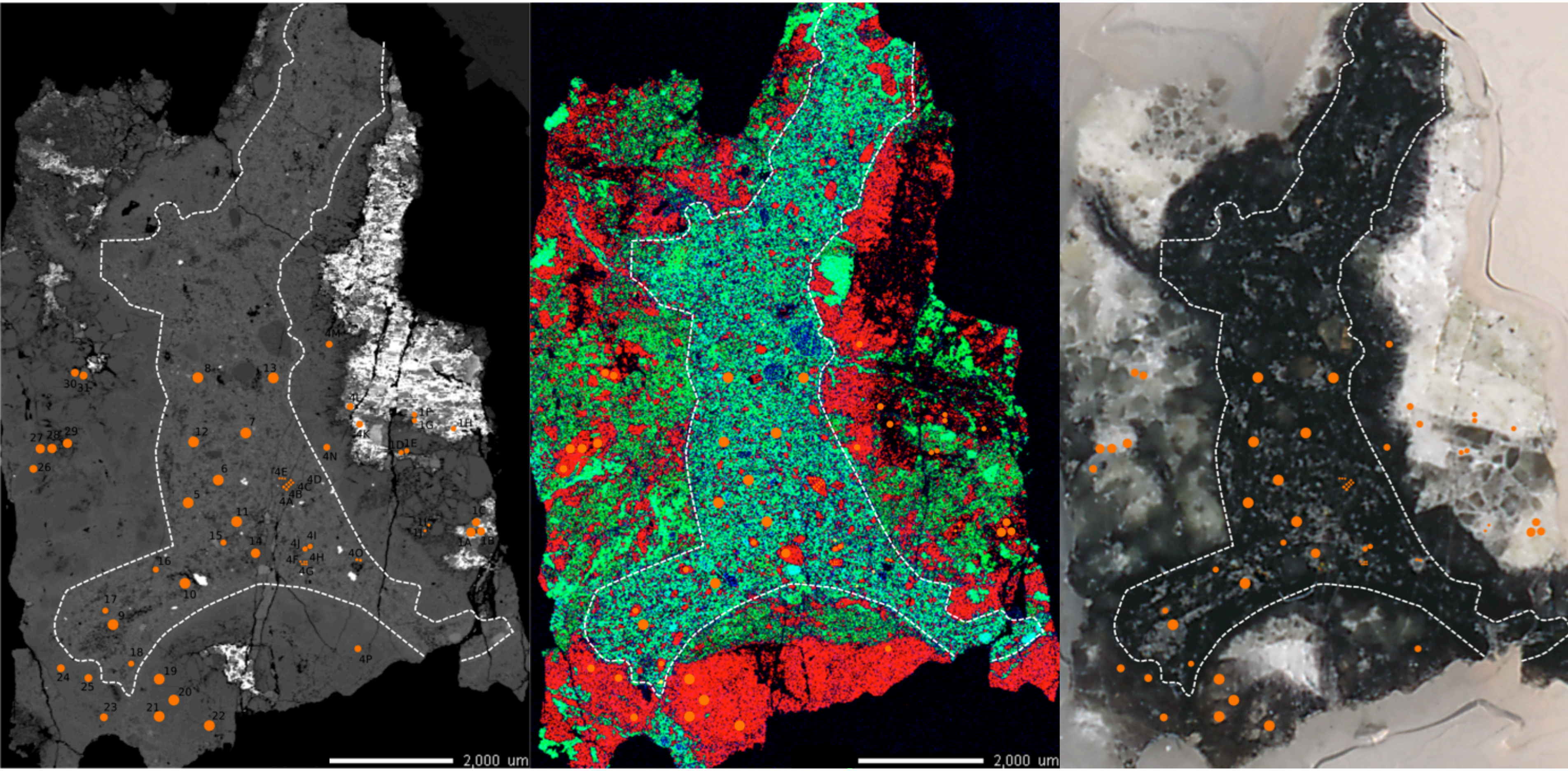
06
05

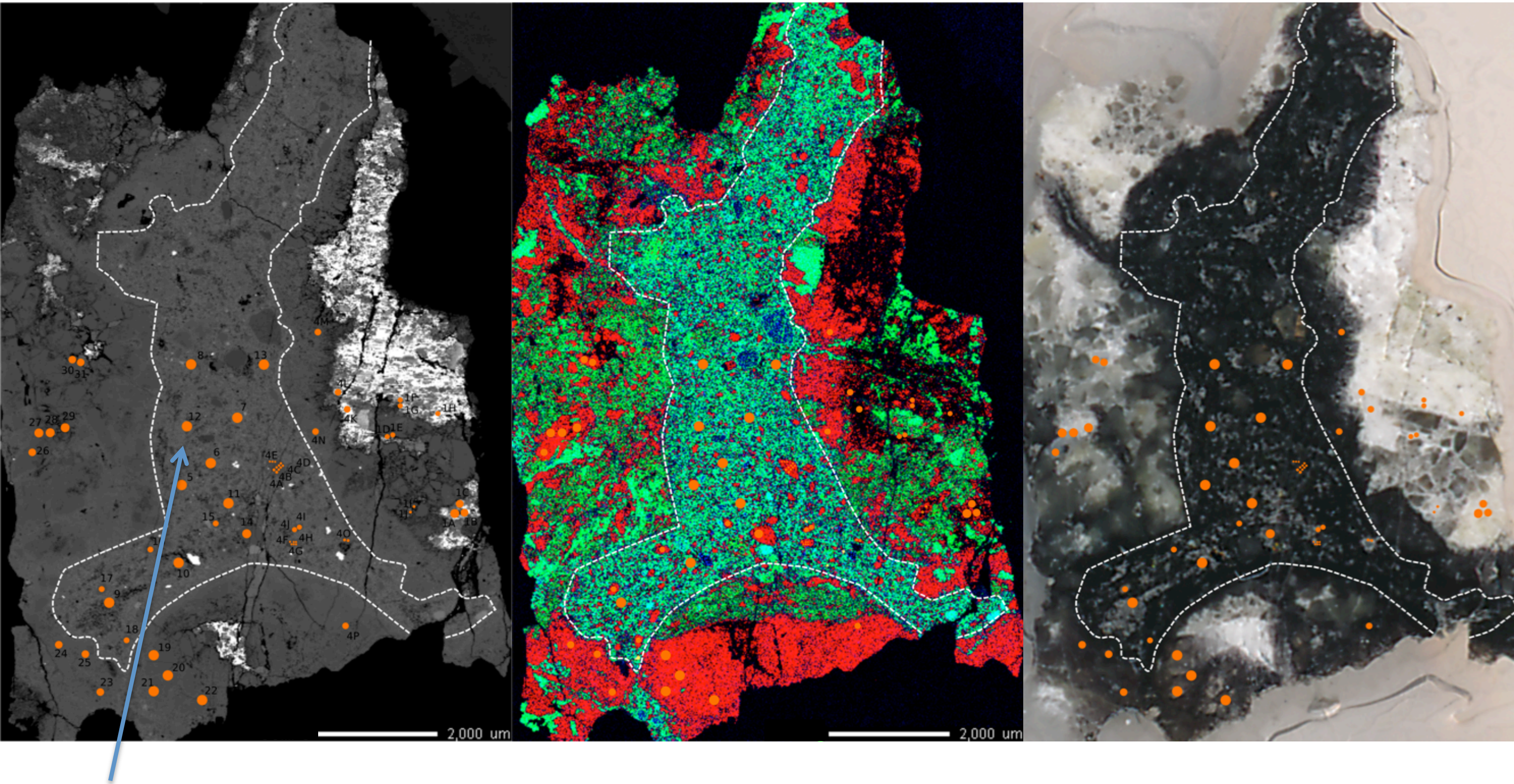


A
15455,405 Domain A clasts
15455,405 Domain C clasts
15455,383 clasts
B
405 dark matrix (n=6)
405 light matrix (n=10)
383 matrix (n=12)
386 matrix (n=12)
U-Pb age phosphates (n=24)
Range of U-Pb ages from cataclastic zircons (n=13
Relative Probability
15455
3500
3600
3700
3800
3900
4000
4100
4200
4300
Age (Ma)

15445

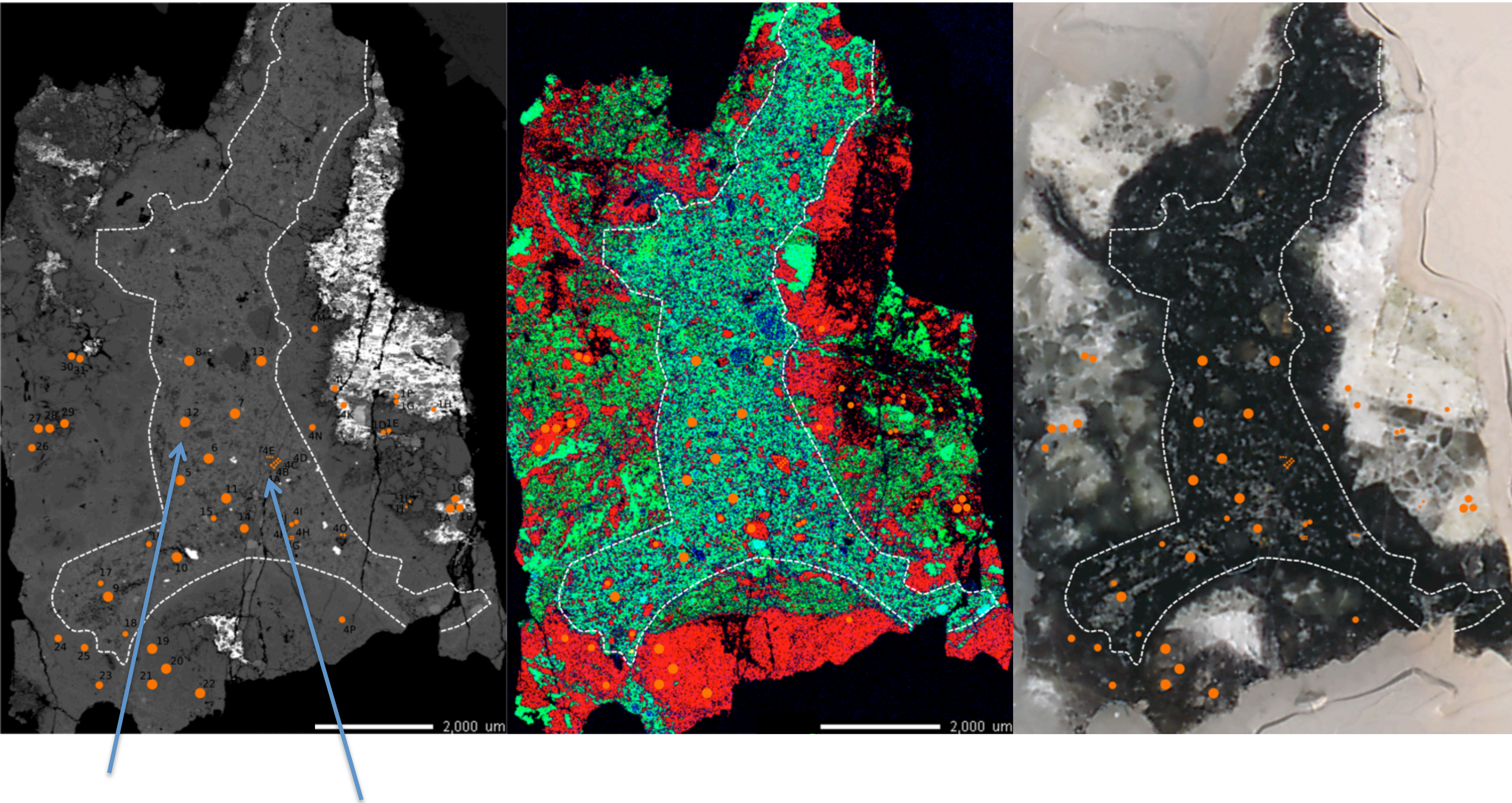


15445



3668 ± 33 Ma
(n=8)

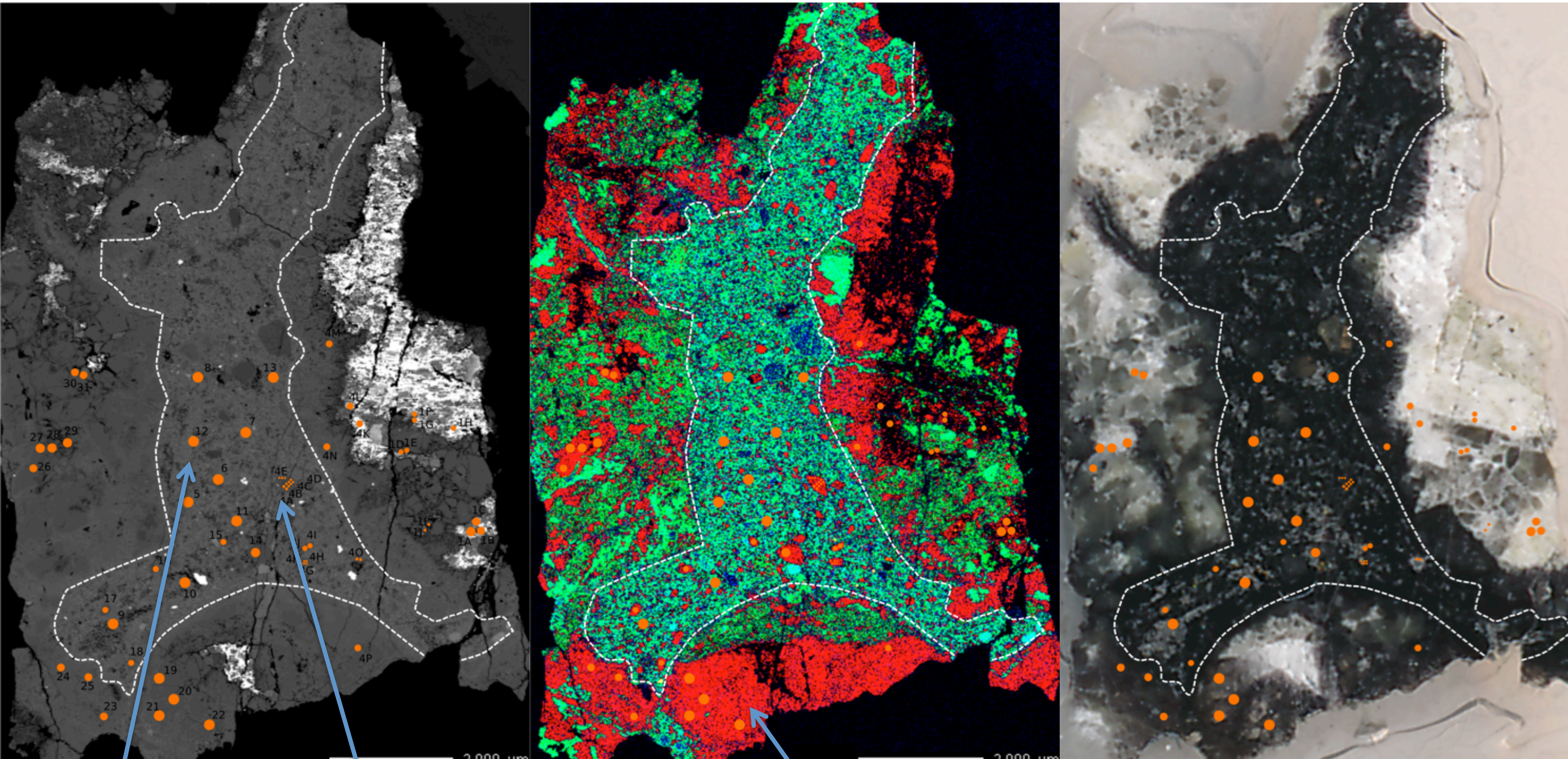
15445



3668 ± 33 Ma
(n=8)

3654 ± 86 Ma
to 4078 ± 43 Ma

15445

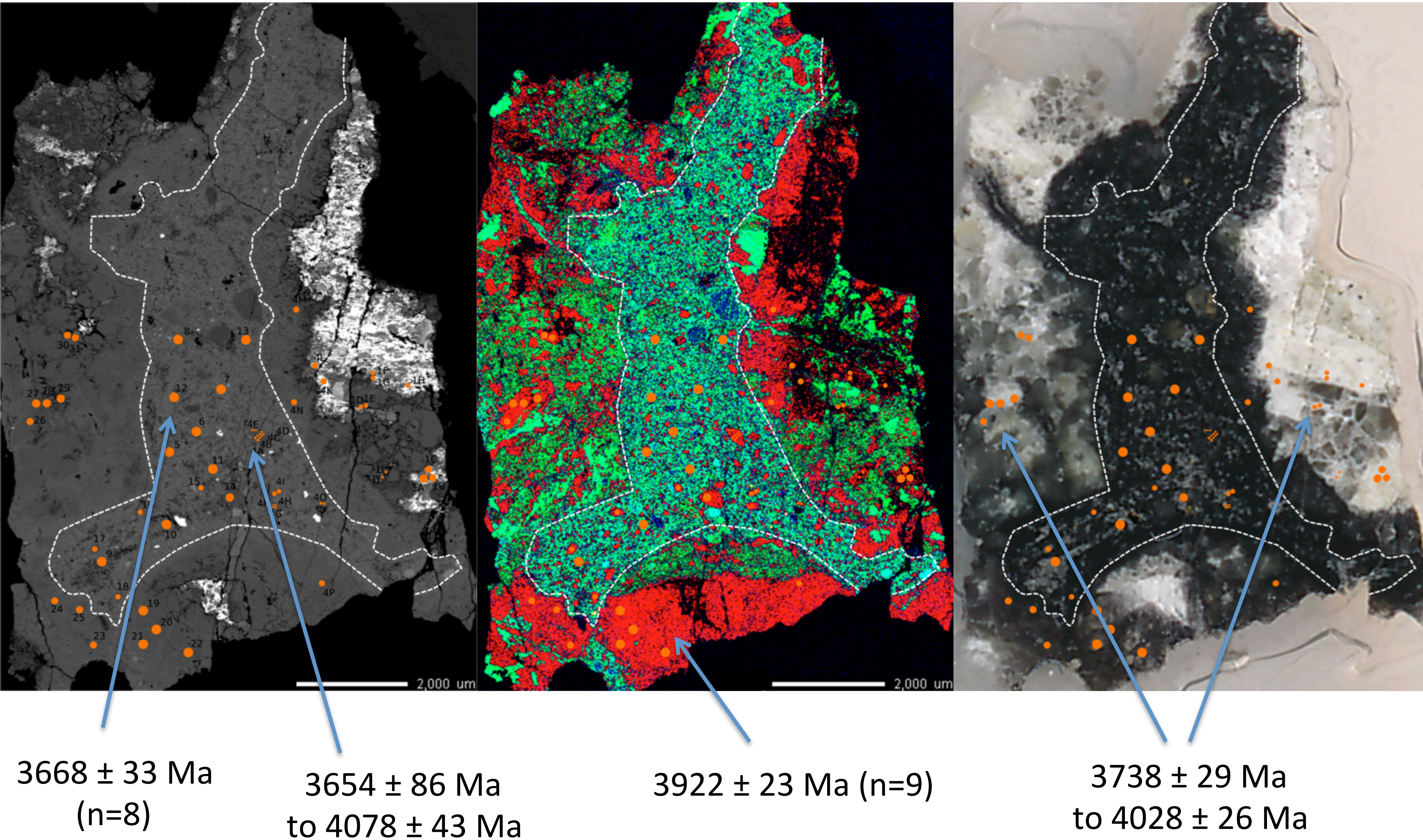


3668 ± 33 Ma
(n=8)

3654 ± 86 Ma
to 4078 ± 43 Ma

3922 ± 23 Ma (n=9)

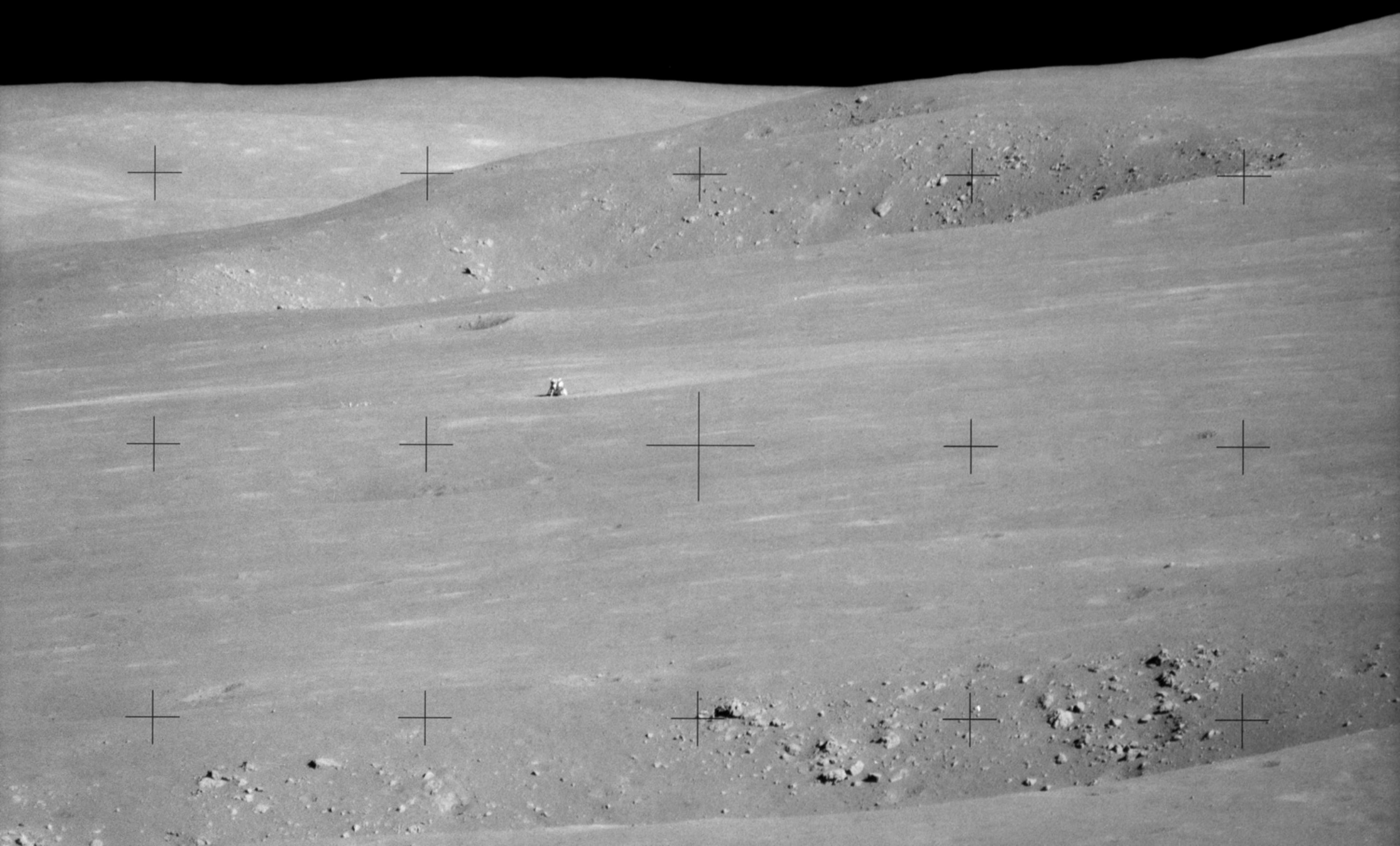
15445


2,000 um
2,000 um
3668 ± 33 Ma (n=8)
3654 ± 86 Ma to 4078 ± 43 Ma
3922 ± 23 Ma (n=9)
3738 ± 29 Ma to 4028 ± 26 Ma

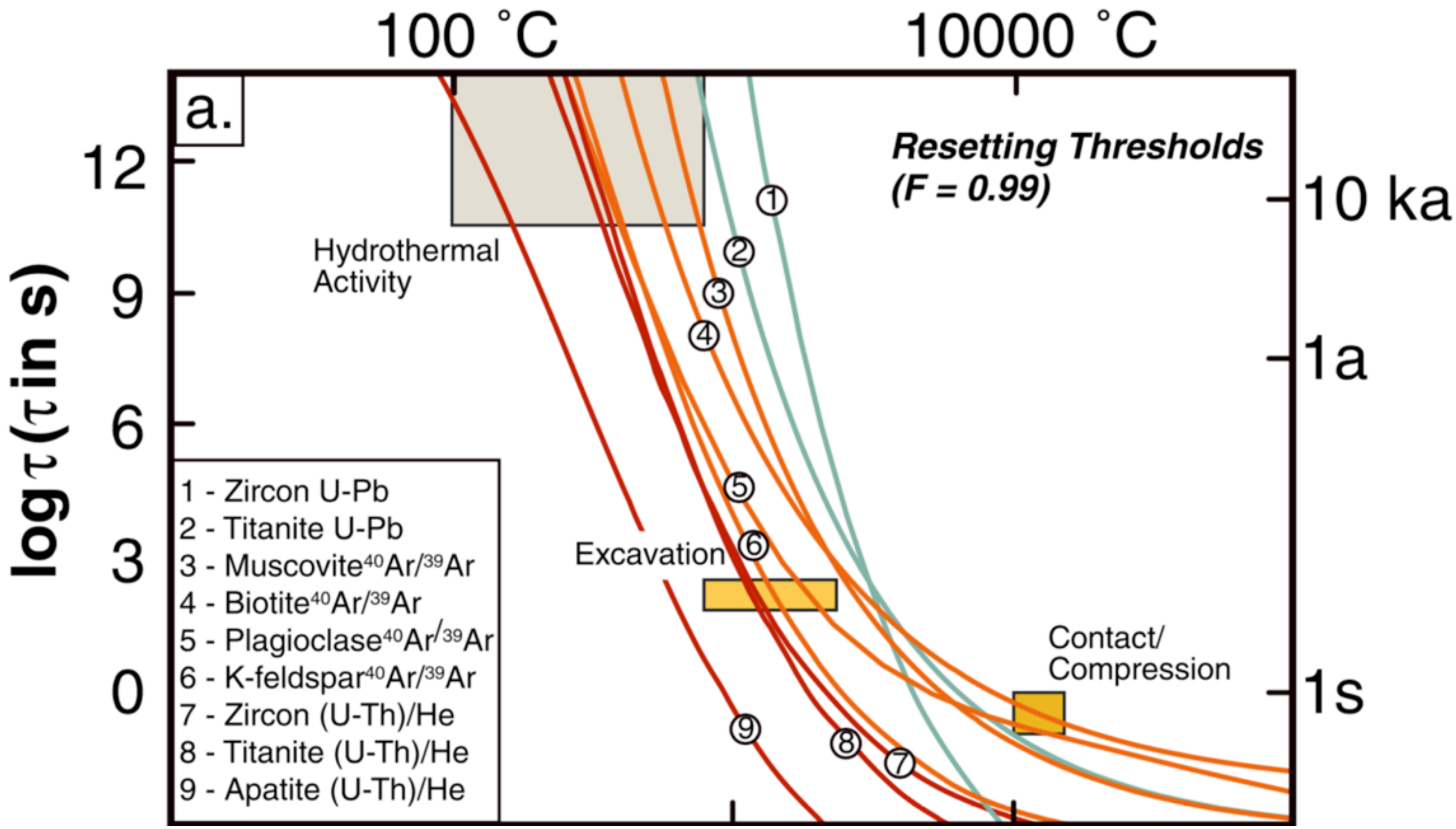
Conclusions

- High-spatial resolution UVLAMP $^{40}Ar/^{39}Ar$ analyses undertaken on the 'white and black' Apollo 15 samples
  - Protracted history of impact bombardment recorded spanning ca. 500 Ma
  - Impact melt generation in 15445 ca. 3670 Ma but ca. 3800 Ma in 15455
  - Despite geologic expectation, these samples may not record impact melt generation associated with the Imbrium basin forming impact
  - Powerful tool, especially when used as a complement to other high-precision chronometers such as U-Pb

Questions

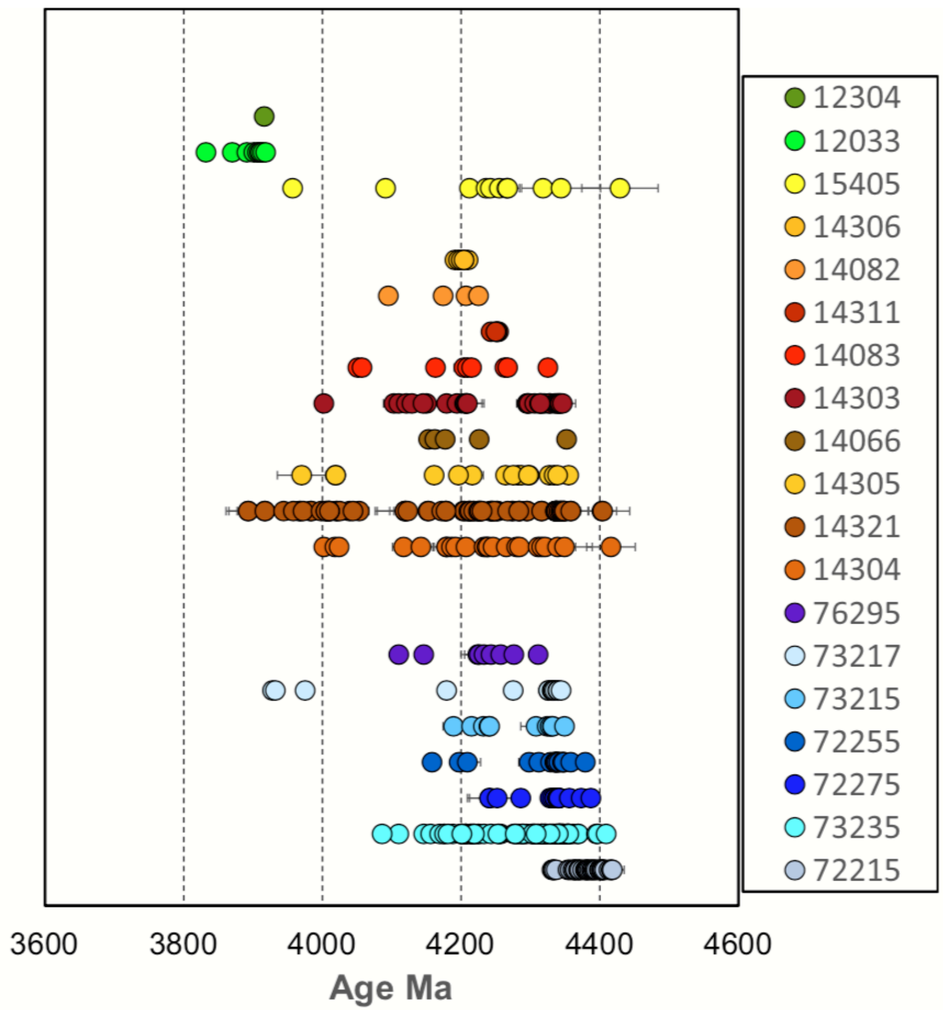


Interpreting lunar ages



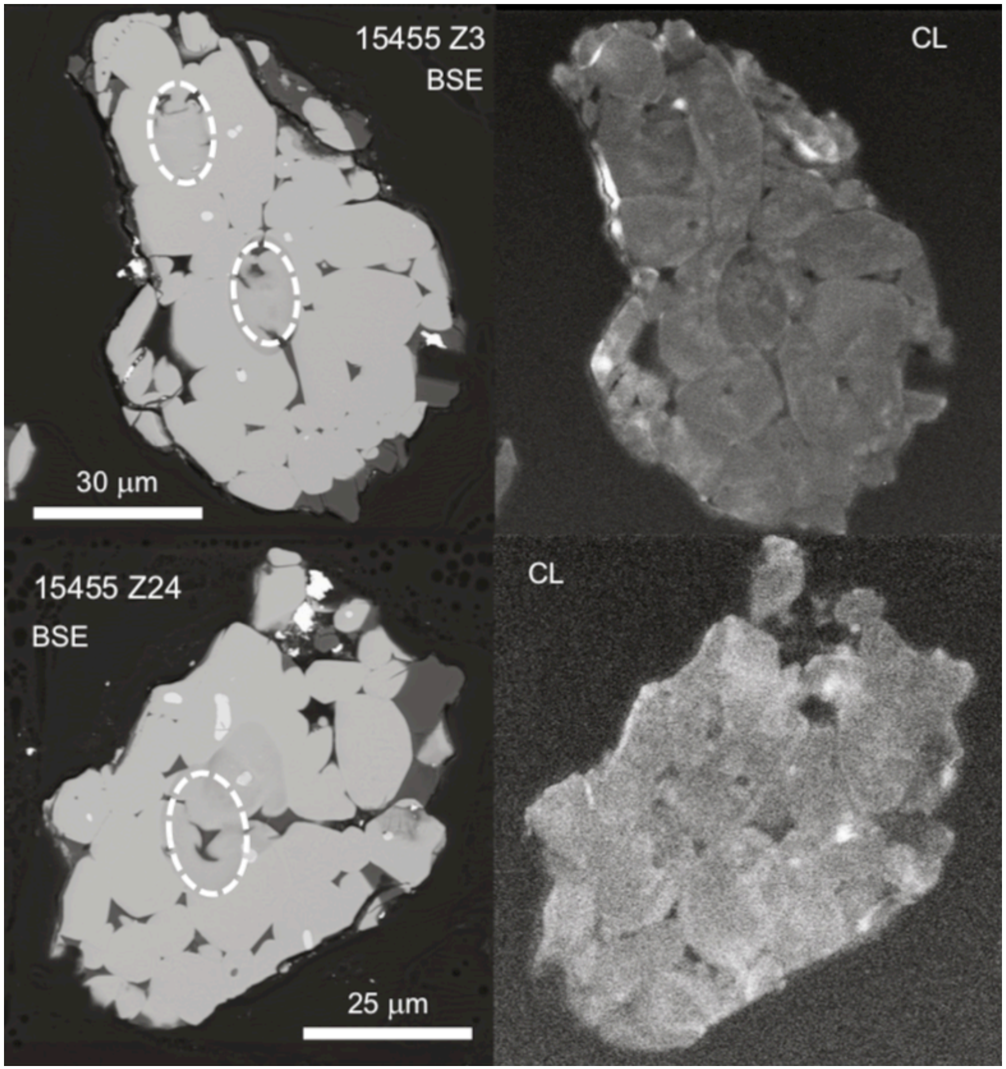
Young et al., 2013

Lunar zircon record

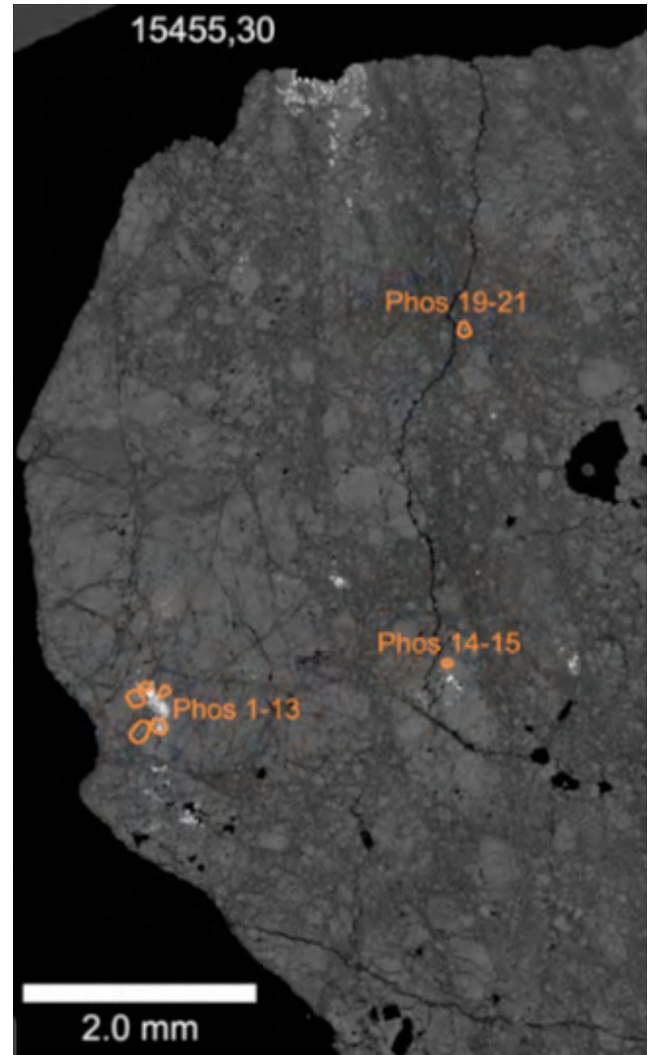


Borg et al., 2015

Zircons and phosphates from 15455



Crow et al., 2017



Nemchin et al., 2020