The Exotic Materials at the Chang’e-5 Landing Site

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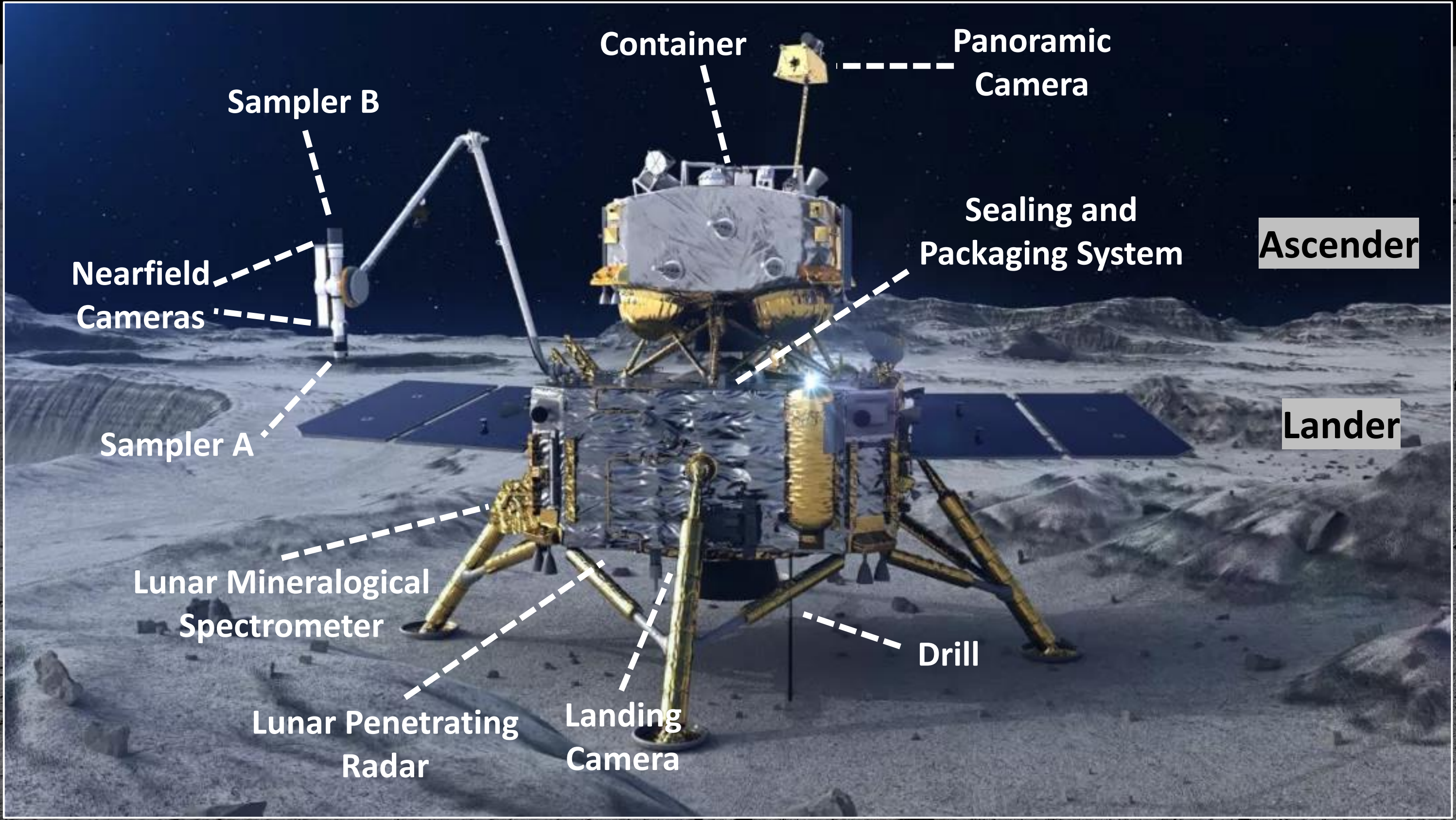
EPSC2021
September 13-24, 2021

Chang'e-5

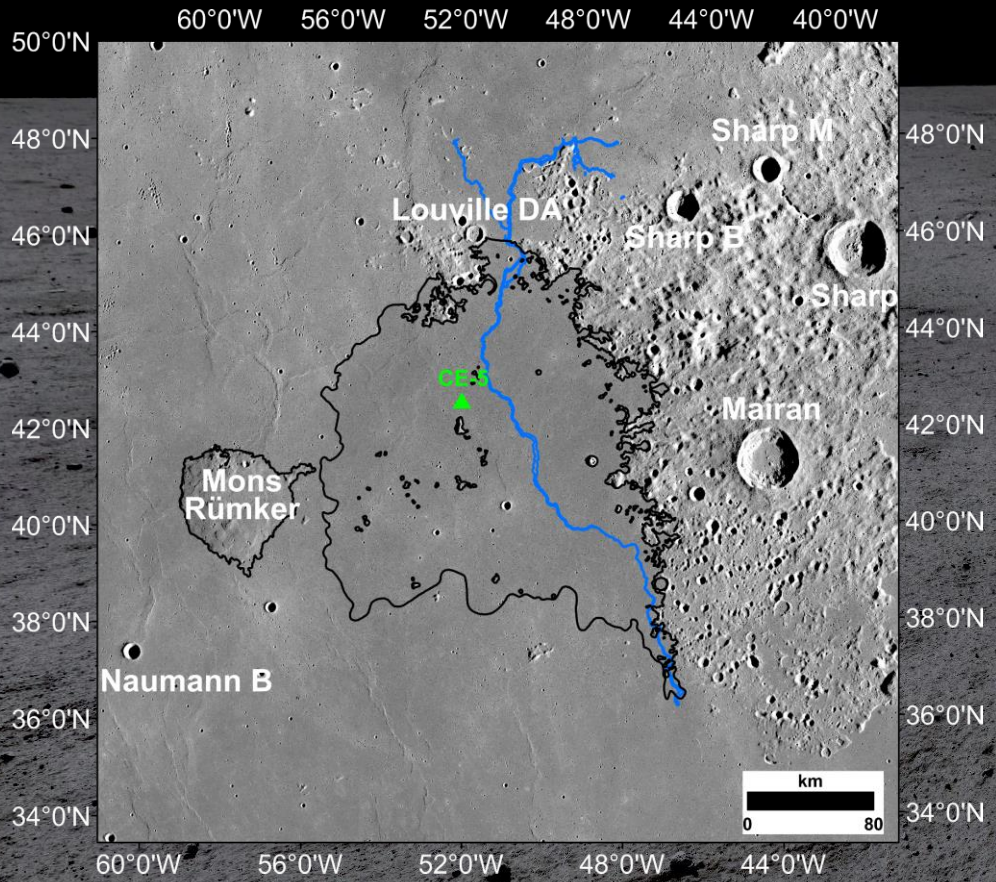



Sampler A

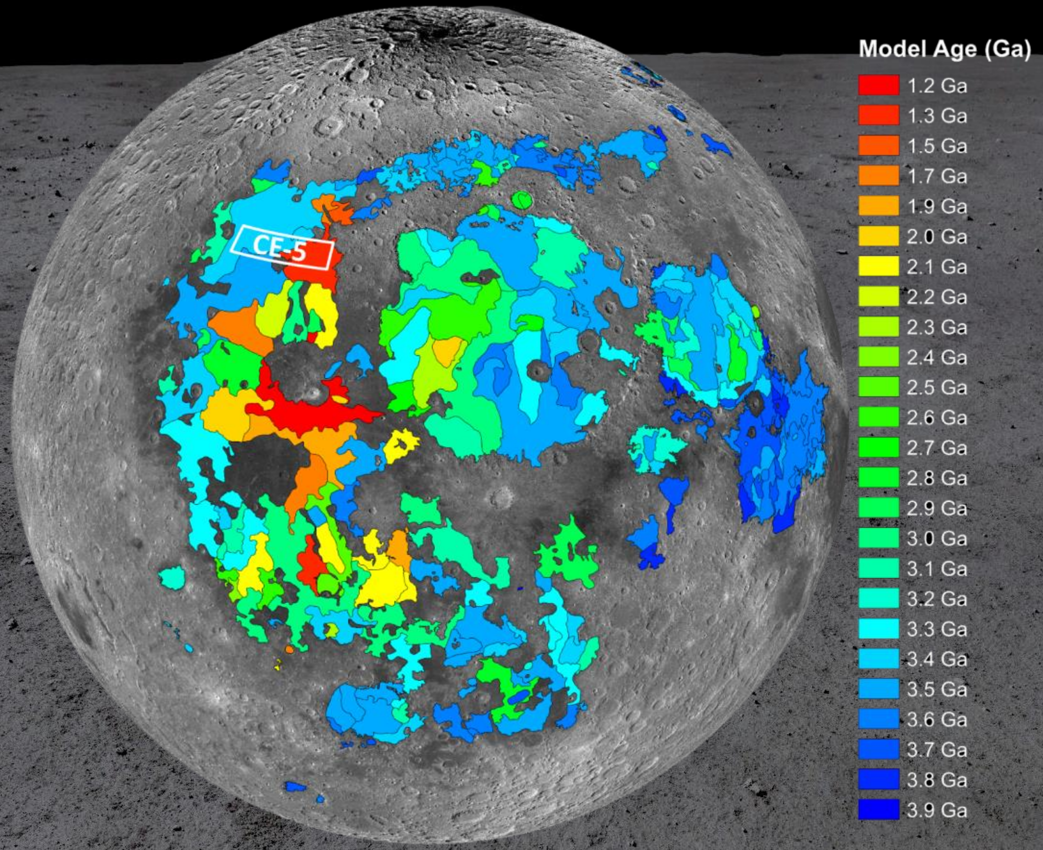

Sampler B

1,731 g of lunar samples were taken back

Young Mare Basalts



Eratosthenian-aged (~1.7 Ga, CSFD) intermediate-Ti mare basalts (Qian et al., 2021, EPSL)

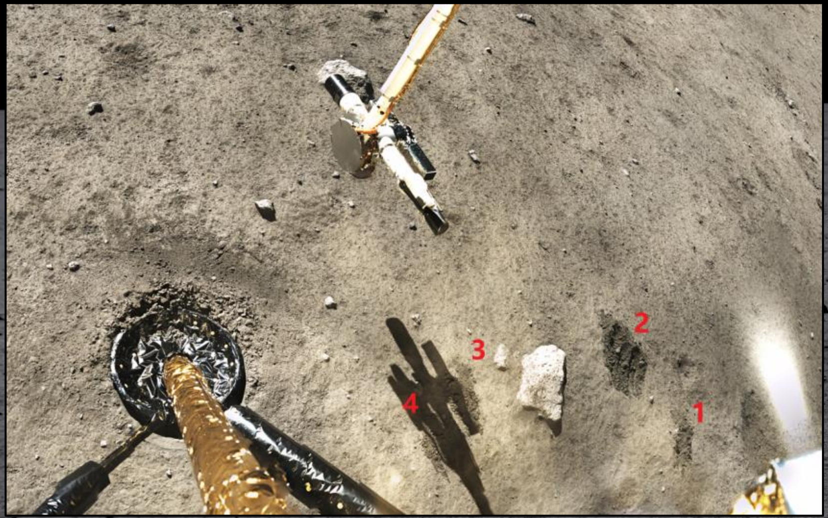


Lunar mare basalt age map (Hiesinger et al., 2011, JGR)

~2.03 Ga !!!

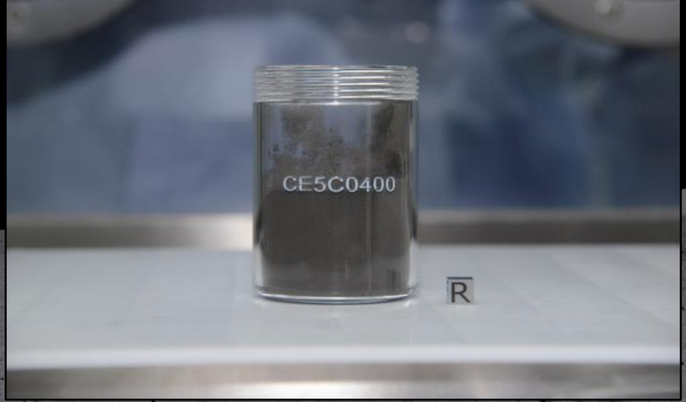
Li, Q.-L., et al. Timing of the latest volcanism on the Moon from Chang'E-5 basalts. Submitted to Nature 271 (2021).

Chang’e-5 Sample

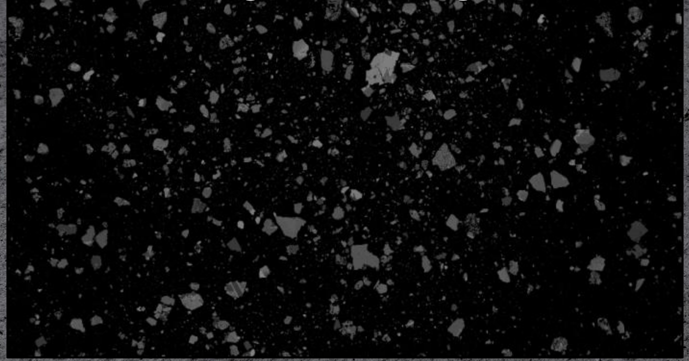


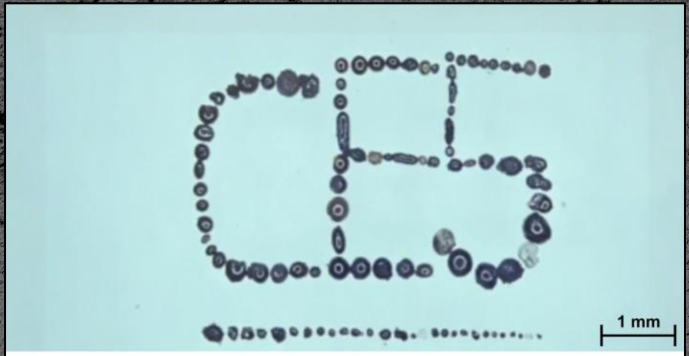
(CNSA/CLEP/GRAS)

CE5C0400: Regolith



CE5C0300YJFM001 BSE: regolith, including different fragments





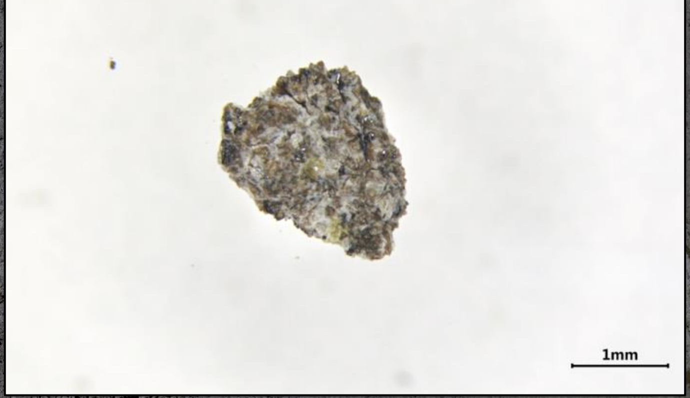
Chang'e-5 Regolith Glasses

Credit: Xinhua Net

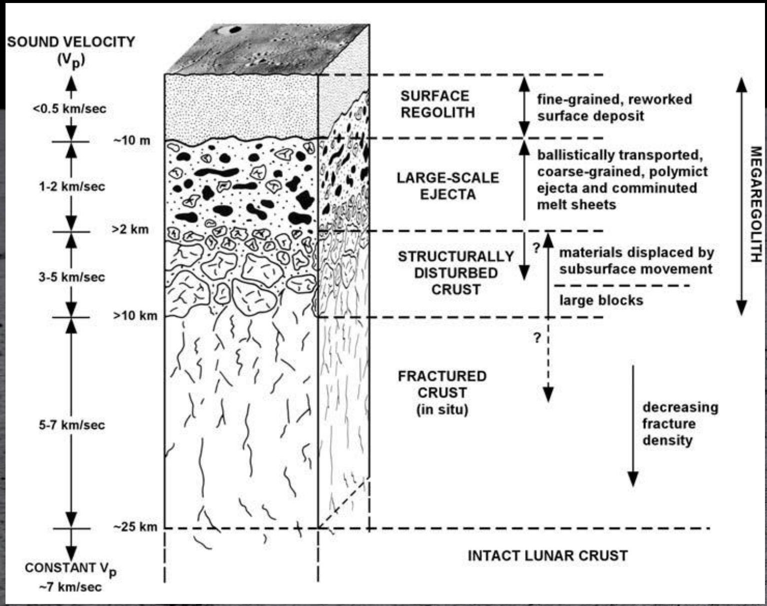
CE5C0800YJYX034: Agglutinate

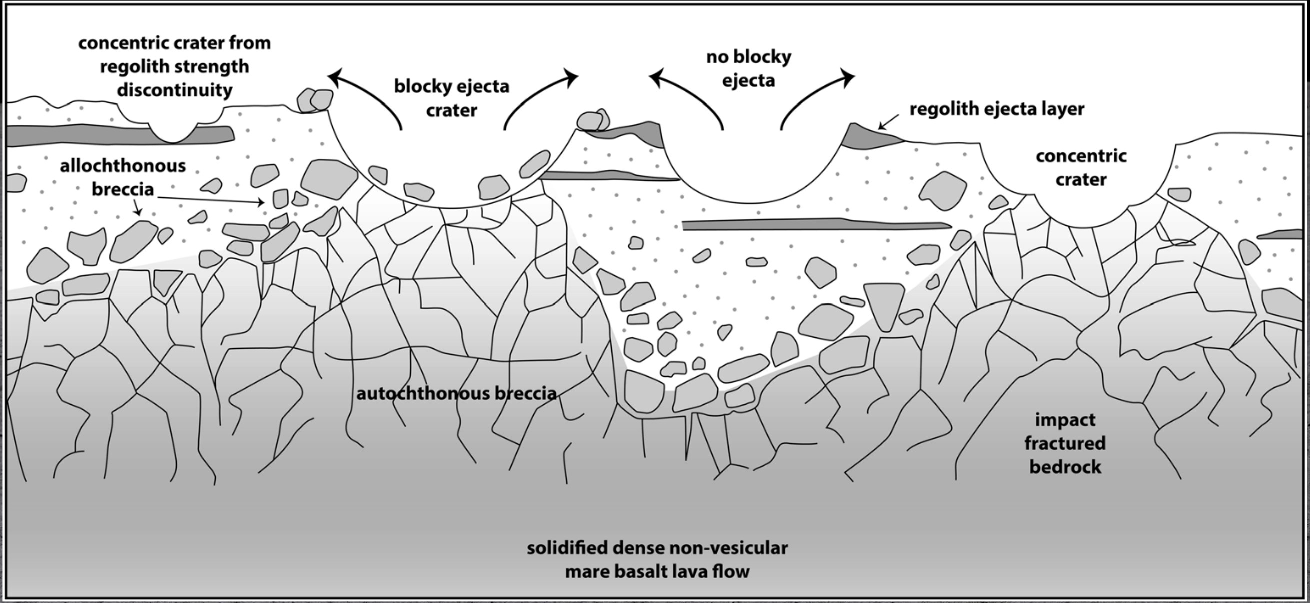
CE5C0000YJYX070GP: Breccia

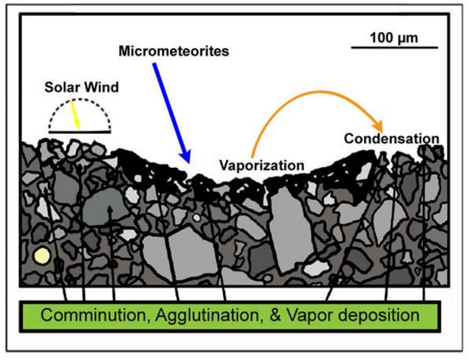
CE5C0000YJYX041GP: Basalt



Formation of Lunar Regolith







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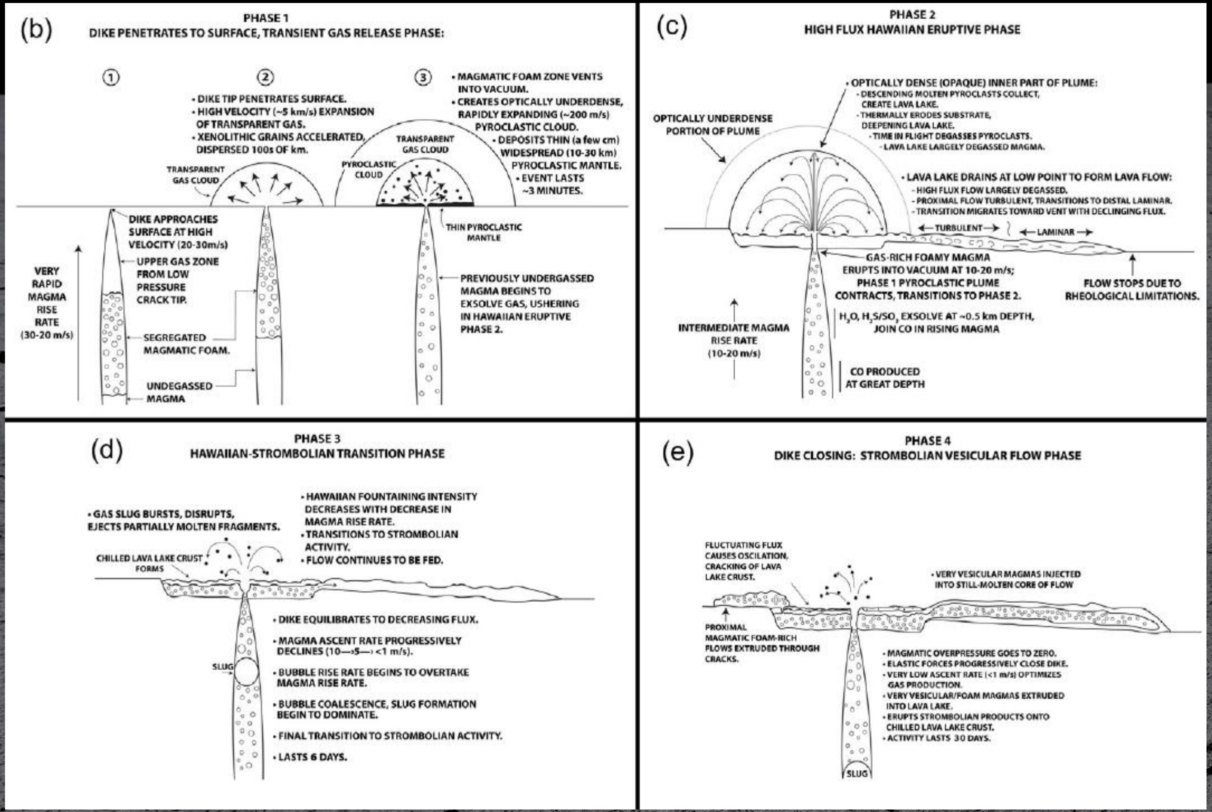
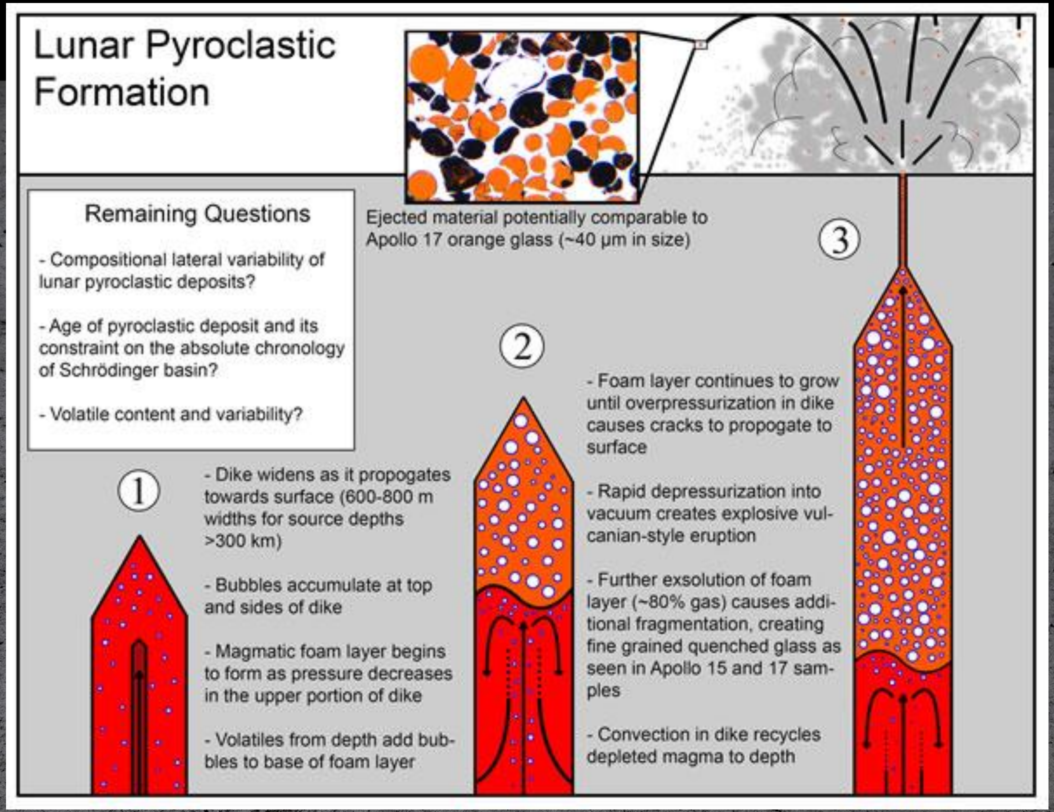
(Heiken et al. 1991; Hiesinger & Head, 2006)

- CE-5 Sample
  - Local Material
    - Young Mare Basalt (~2.0 Ga)
    - Local Impact Ejecta
    - → Major
  - Exotic Material
    - Distant Impact Ejecta
    - Meteoritical Component
    - Nonmare material (Silica-rich component & Highland Materials)
    - Volcanic Beads
    - → Minor

Exotic material: Volcanic Beads

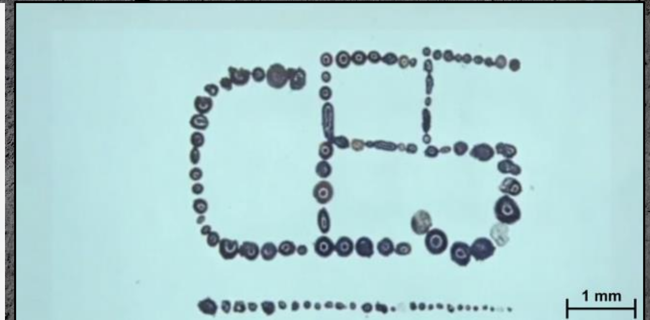


The four phases of the development of a typical long-duration eruption on the Moon (Morgan et al., 2021)

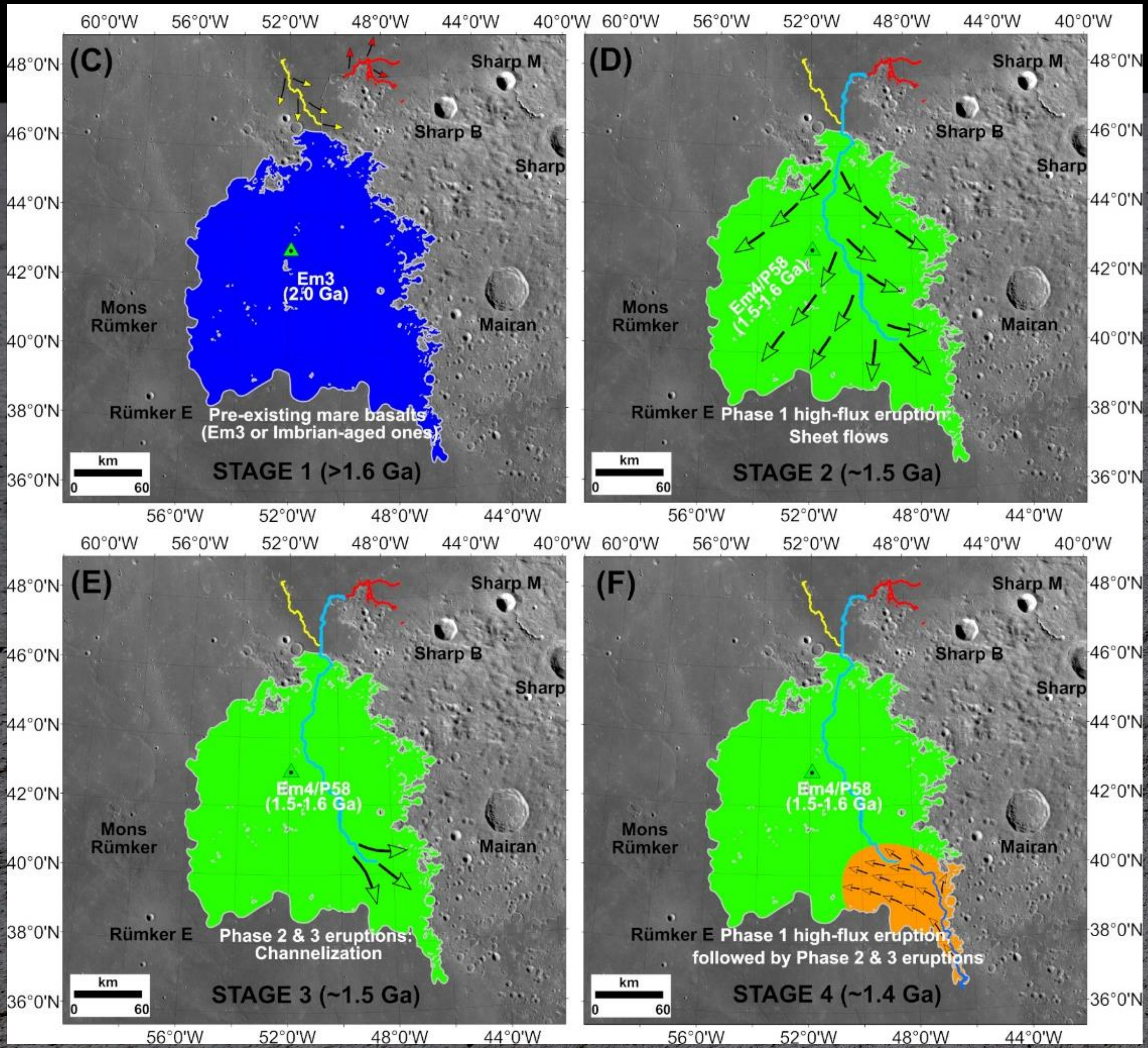


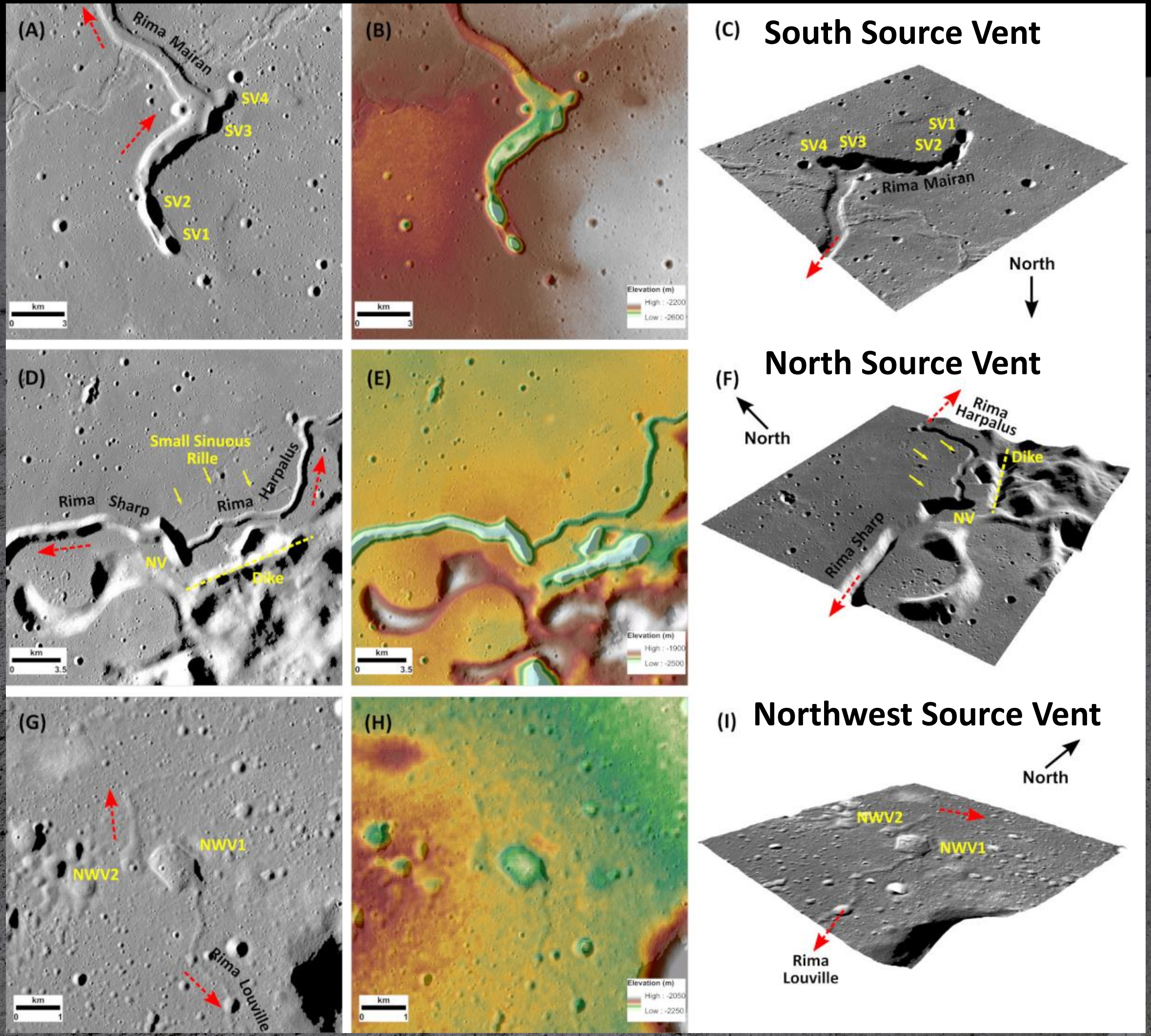
Lunar pyroclastic eruption © LPI

Glass Beads: Volcanic Beads, Impact Beads



Exotic material: Volcanic Beads

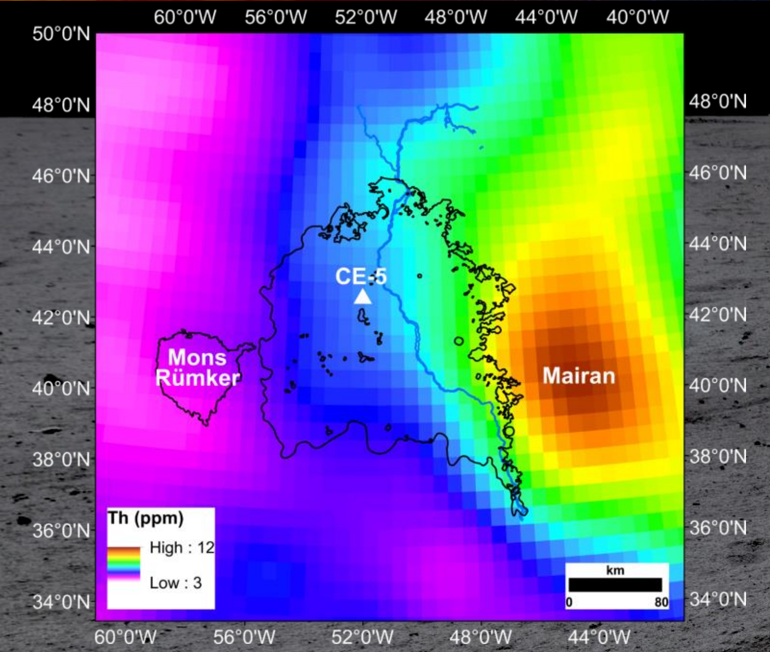


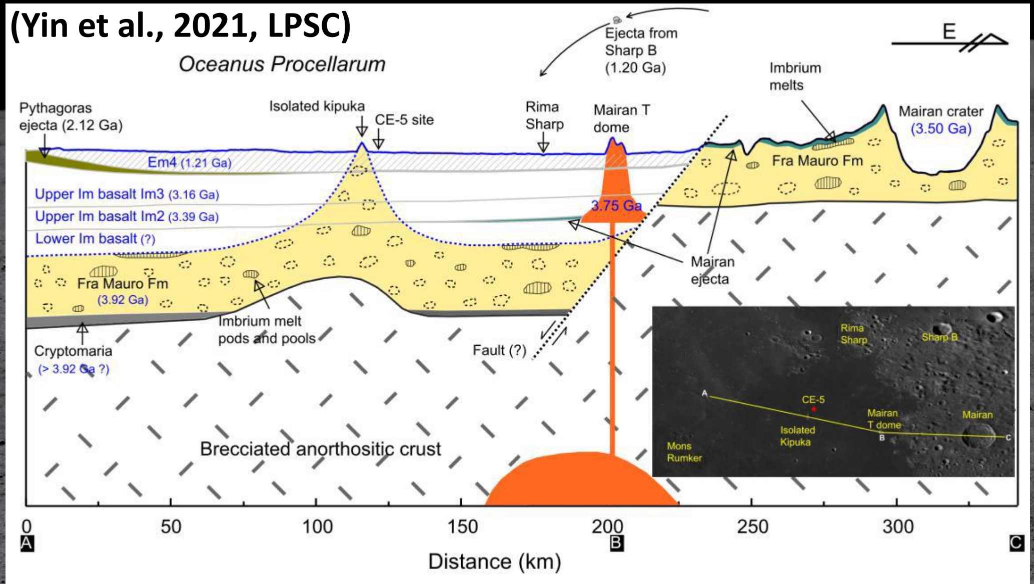


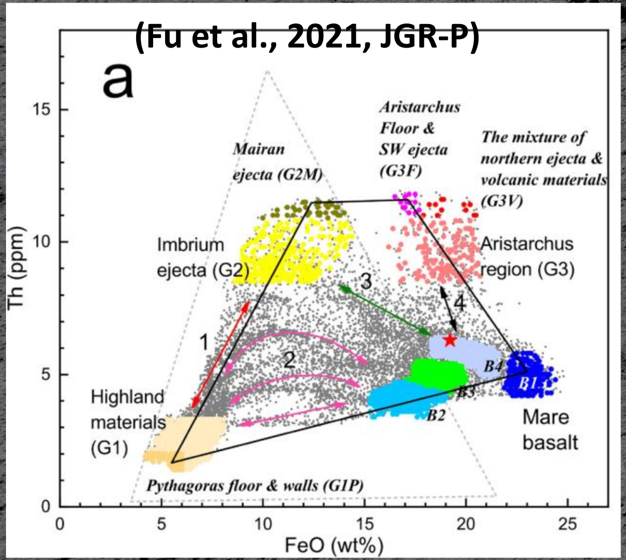
(Qian et al., 2021, GRL)

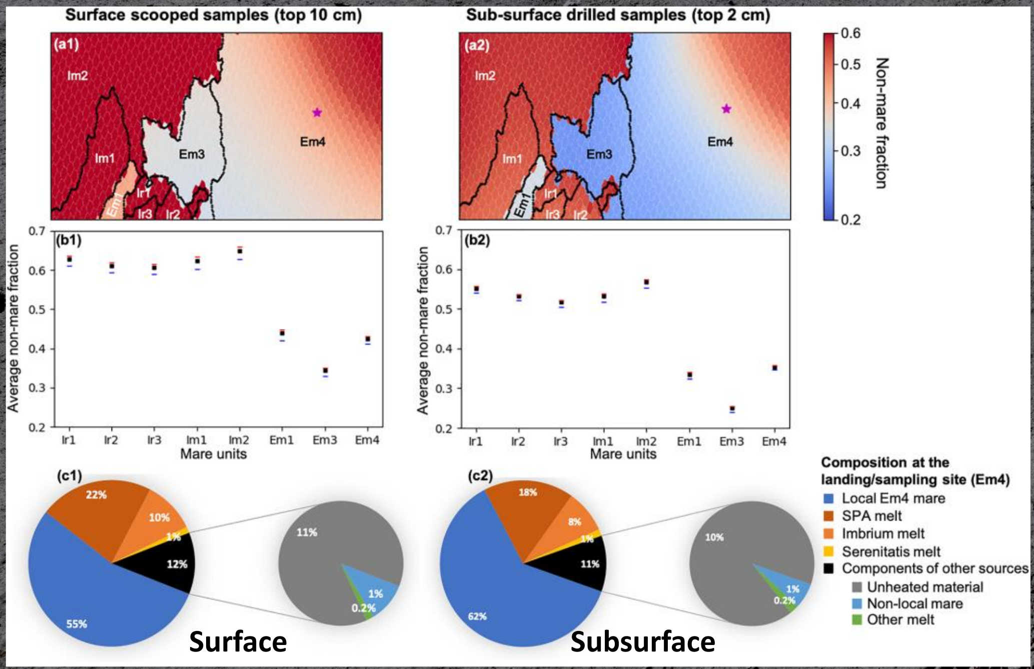
Volcanic beads may partially come from the source vents of Rima Sharp and Rima Mairan

Exotic material: Nonmare Material









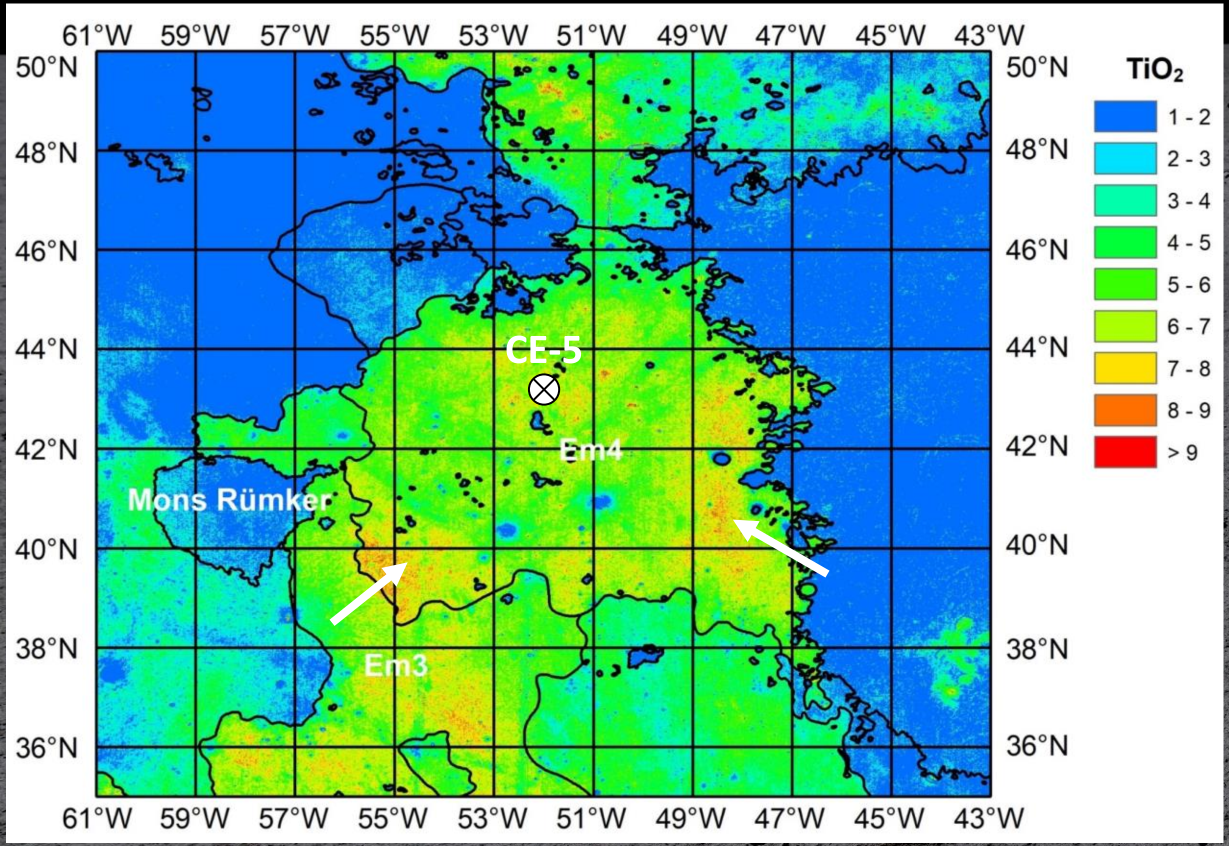
Fu et al., 2021, JGR-P & Yin et al., 2021, LPSC
Unmix 12 FeO-Th endmembers

- Aristarchus crater contributed highly evolved nonmare materials
- Rock fragments derived from Aristarchus ejecta are important for the interpretation of magmatic differentiation and non-mare volcanism
- Thorium is indigenous to basalts rather than impact mixing.

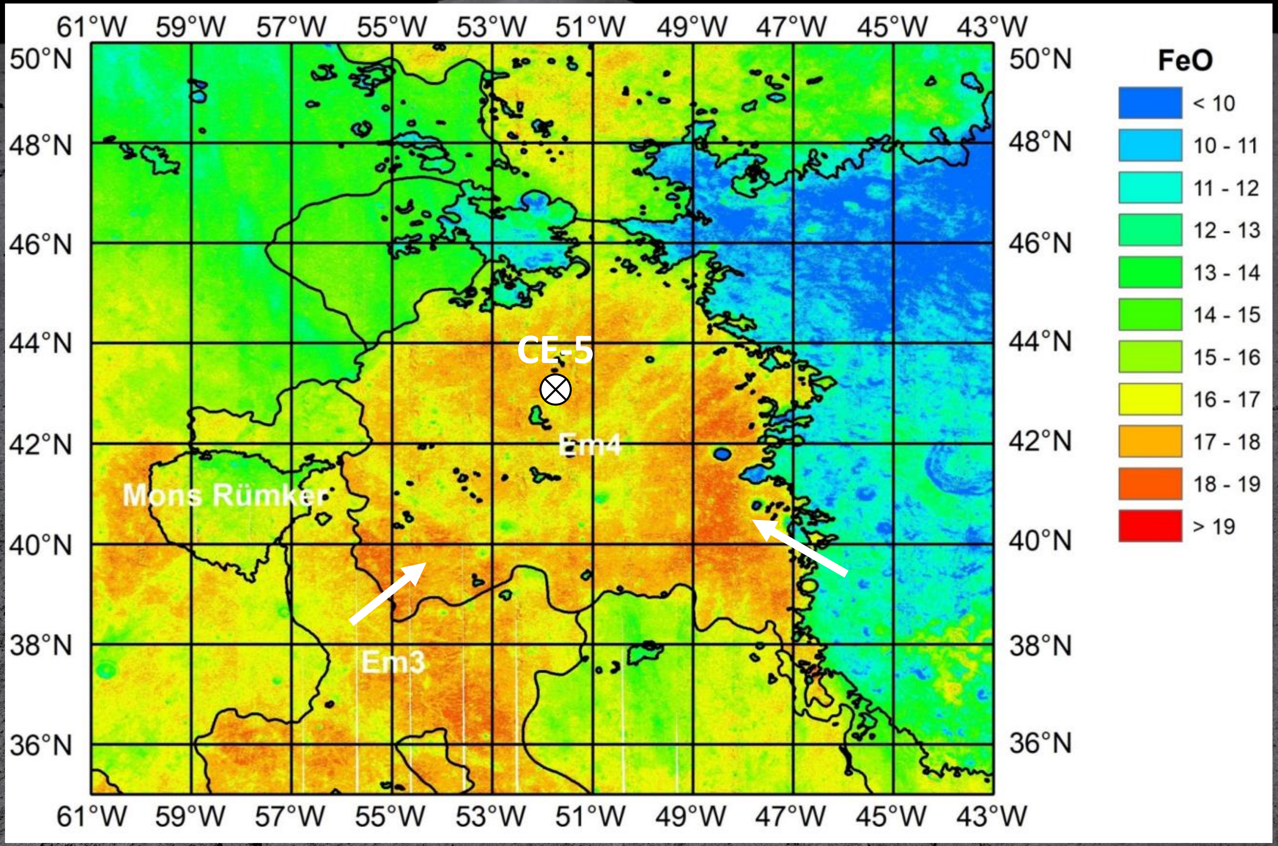
Liu et al., 2021, GRL
Spatially resolved numerical model

- ~60% local mare component
- ~40% nonmare component
- South Pole-Aitken (~20%), Imbrium (~10%), and Serenitatis (~1%)

Exotic materials: Impact Ejecta



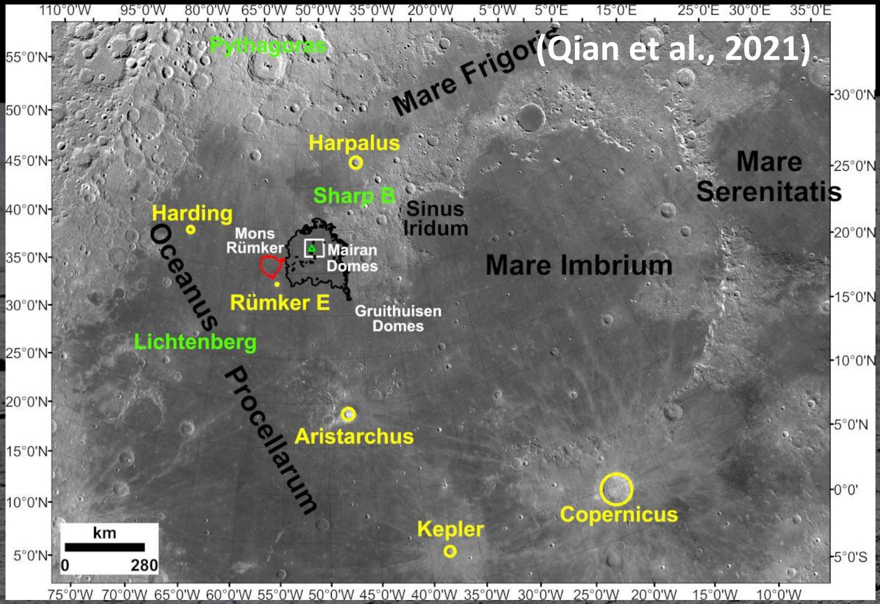
LROC WAC TiO_2 Abundance Map
(Sato et al., 2017)

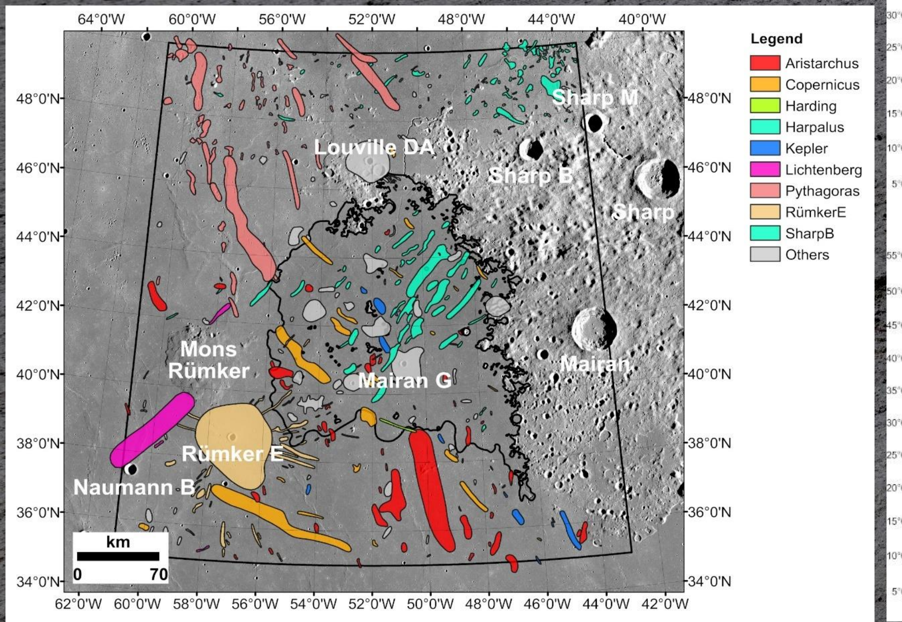


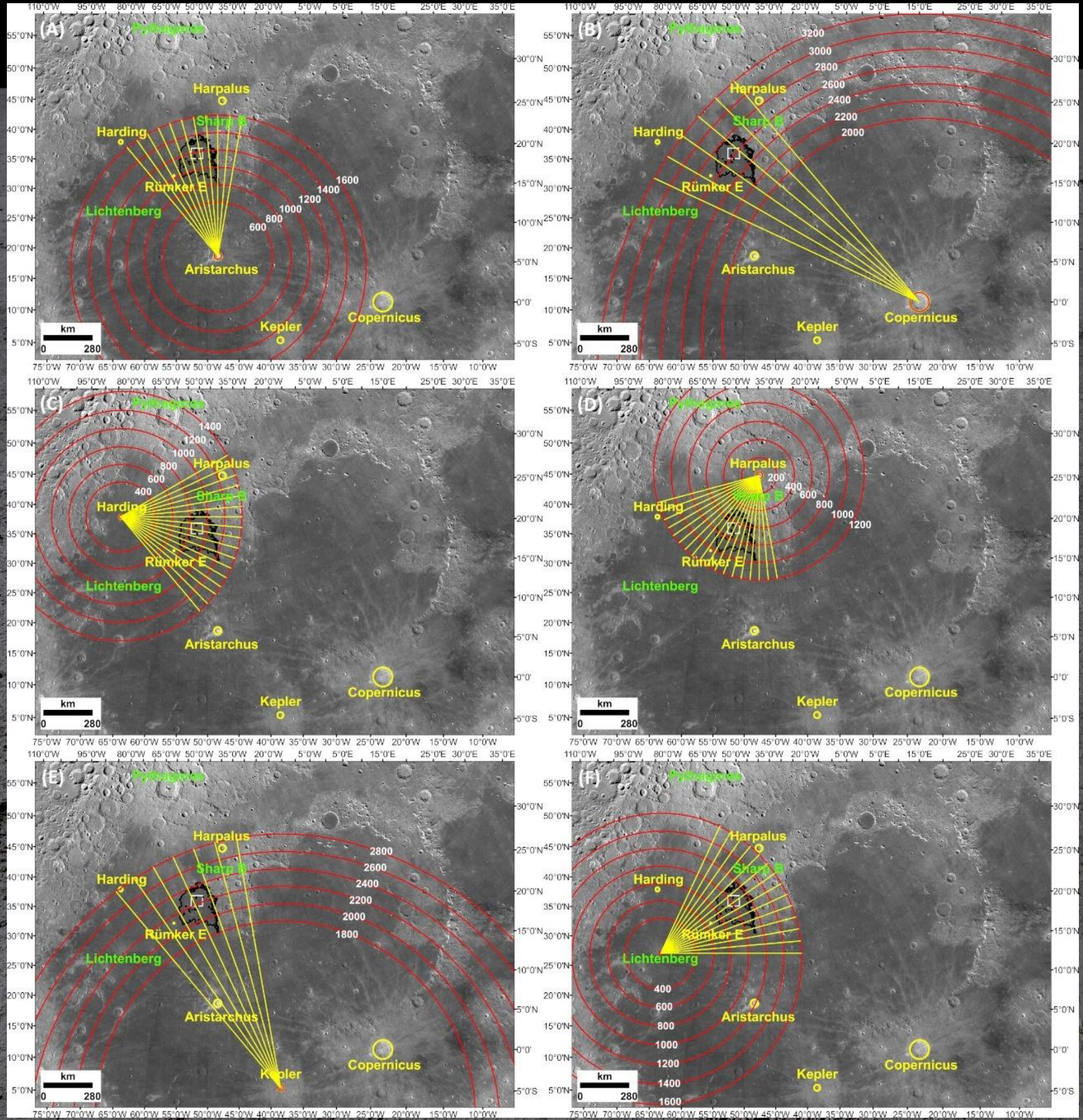
Kaguya MI FeO Abundance Map
(Lemelin et al., 2015)

Distant impact ejecta can be directly seen from the albedo and composition (TiO2, FeO) maps

Exotic materials: Impact Ejecta





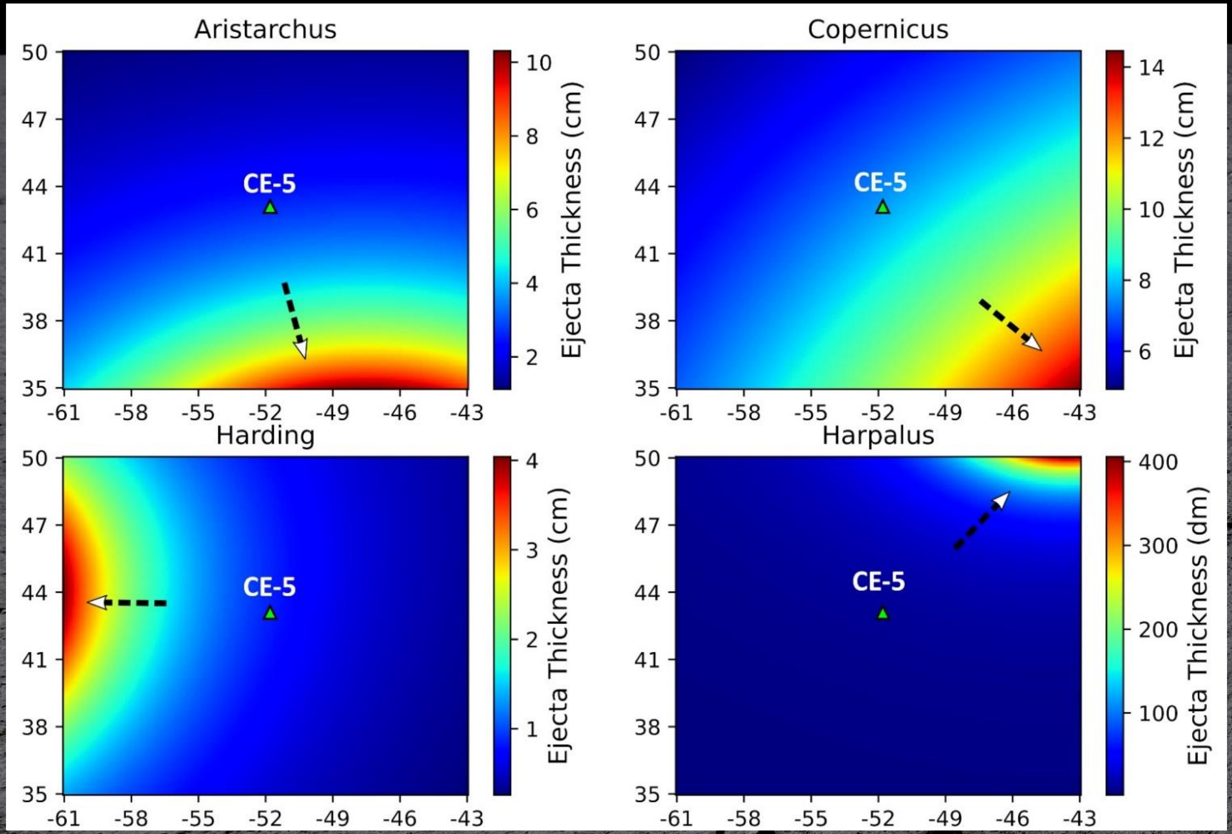


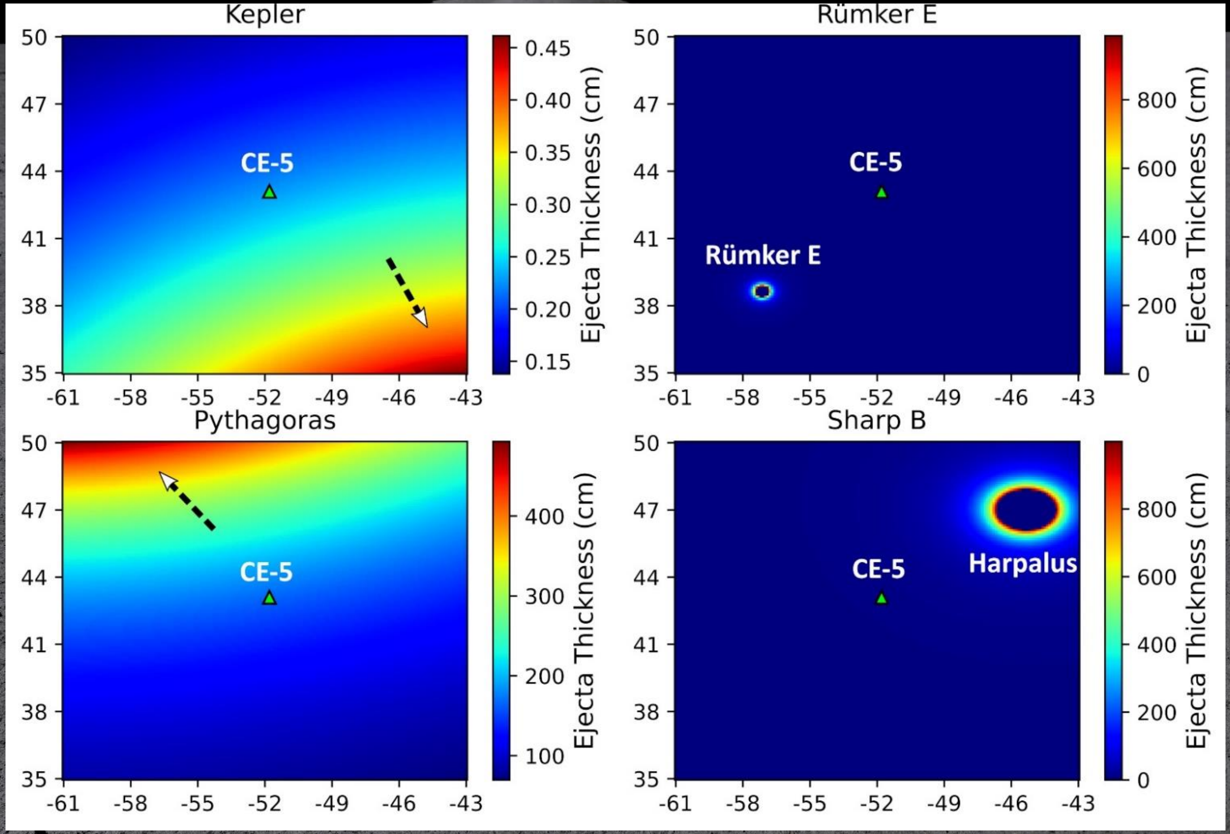
Tracing impact ejecta in Northern Oceanus Procellarum (Qian et al., 2021, EPSL)

(Qian et al., 2021, EPSL)

Exotic materials: Impact Ejecta

(Qian et al., 2021, EPSL)





Empirical power law model

$T = 3.95 * R^{0.399} * (r/R)^{-3}$

$\mu = 2.25 * 10^{-5} * r^{0.87}$

T: ejecta thickness

R: final crater radius

r: the distance to the crater center

Regolith Gardening Model (Costello et al., 2018)

$\Pi = 3.45 \times 10^{-5} t^{0.47}$

At least one overturn

Π: reworking depth in meters

t: is re-working time in years

>>>

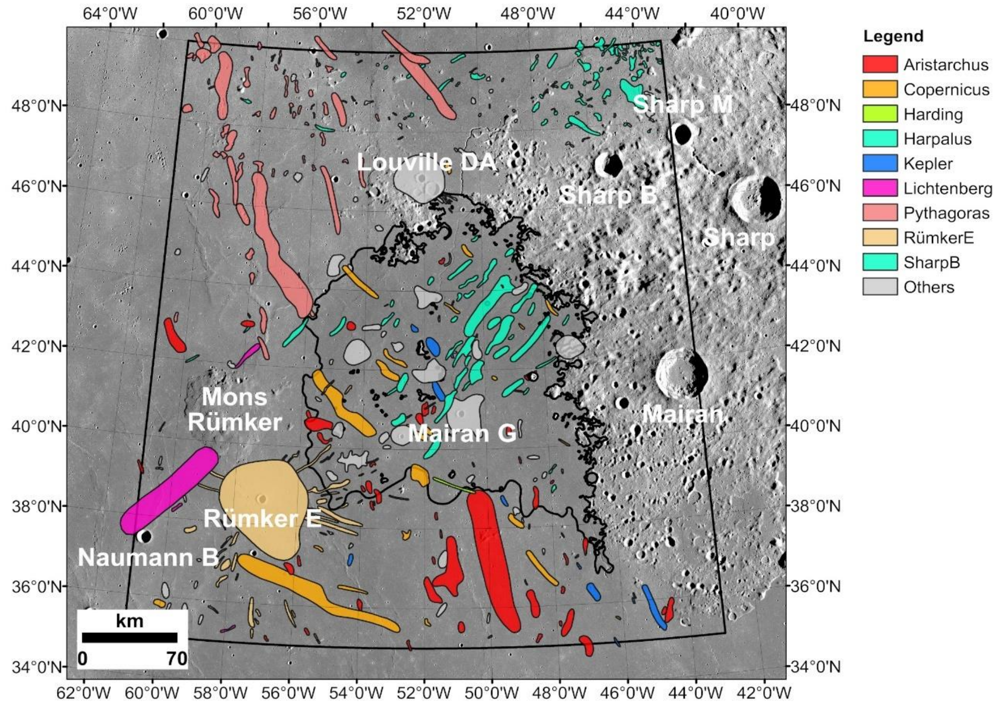
The top ~74 cm regolith of the CE-5 site is mixed up

Exotic materials: Impact Ejecta

Table 1
Main source craters and calculated ejecta thickness for Em4/P58.

	Diameter (km)	Longitude (°)	Latitude (°)	AMAs (Ga)	Total Ejecta Thickness (cm)[i]	Percentage in Regolith (%)[j]
Post-Em4/P58						
Rümker E	6.76	−57.14	38.64	/	0.1 (0.06)	0.08
Aristarchus	40.14	−47.49	23.74	280 Ma[a]	2.6 (0.8)	1.1
Kepler	30.12	−38.00	8.11	625-950 Ma[b]	0.2 (0.04)	0.05
Copernicus	94.30	−20.06	9.64	779 Ma[c] 796 Ma[d] 782 Ma[e]	7.6 (1.3)	1.8
Harding	23.04	−71.68	43.54	881 Ma[f]	0.8 (0.3)	0.4
Harpalus	39.77	−43.49	52.73	2.40 Ga[f,k] 3.50 Ga[g,k]	10.3 (4.2)	5.7
In total					21.6	9.1
Pre-Em4/P58						
Lichtenberg	19.53	−67.72	31.85	>1.68 Ga[h]	/	/
Sharp B	20.96	−45.34	47.00	1.15 Ga[f,k] 1.58 Ga[g,k]	5.6 (3.0)	/
Pythagoras	144.55	−62.98	63.68	2.68 Ga[f]	166.0 (46.4)	/

[a] Zanetti et al. (2017), [b] Koenig et al. (1977), [c] Hiesinger et al. (2012), [d] Iqbal et al. (2020), [e] Barra et al. (2006), [f] Xie et al. (2020), [g] THIS STUDY, [h] Hawke et al. (2004). [i] The total ejecta thickness equals the thickness of source crater ejecta (numbers in the brackets) and local materials excavated by the coming impact ejecta. [j] Contributions from each source craters to the top ~74 cm of lunar regolith (see Section 4.2). [k] We propose that directly counting Harpalus and Sharp B crater will produce unreliable AMAs (see Section 4.1).



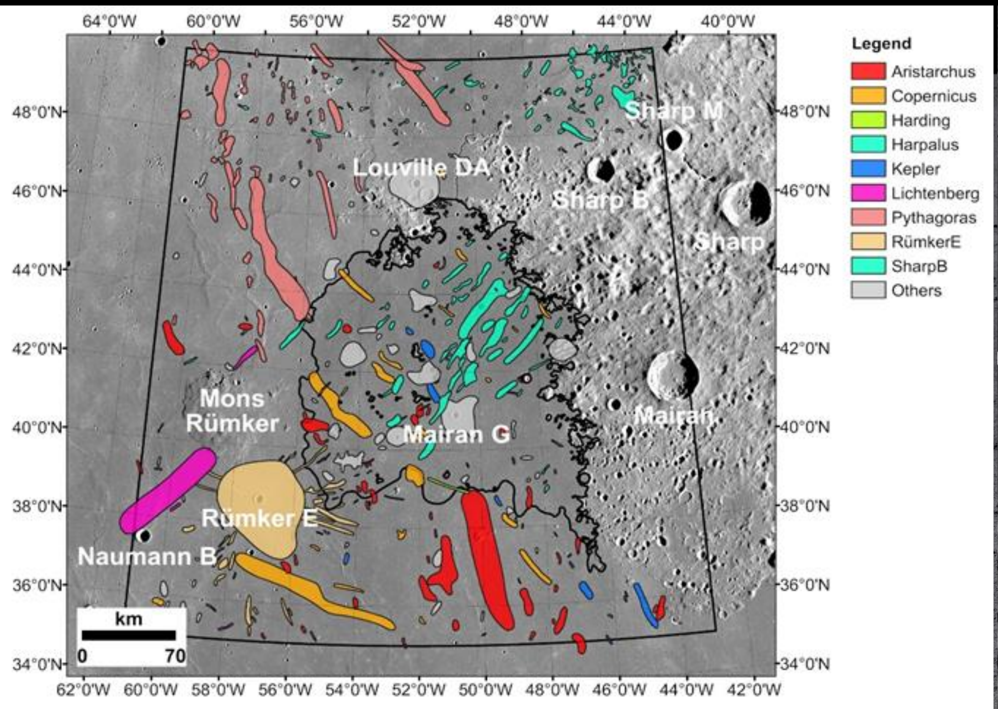
Percentage of ejecta from major source craters

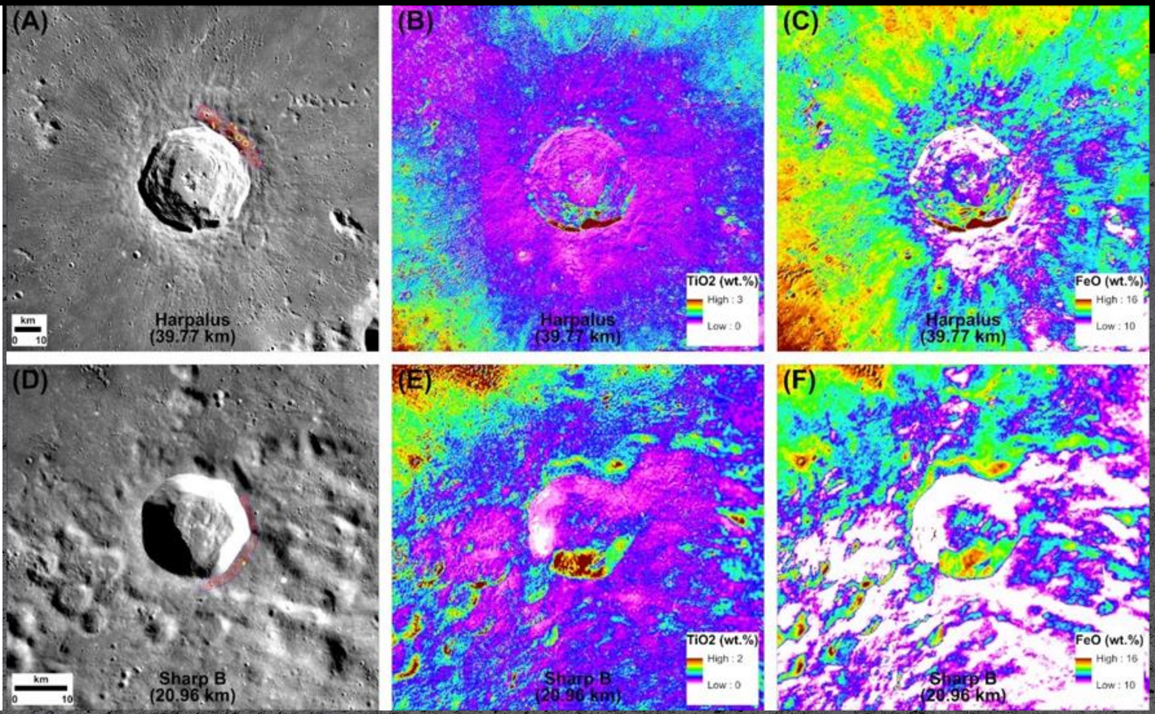
Match well with the ejecta tracing results

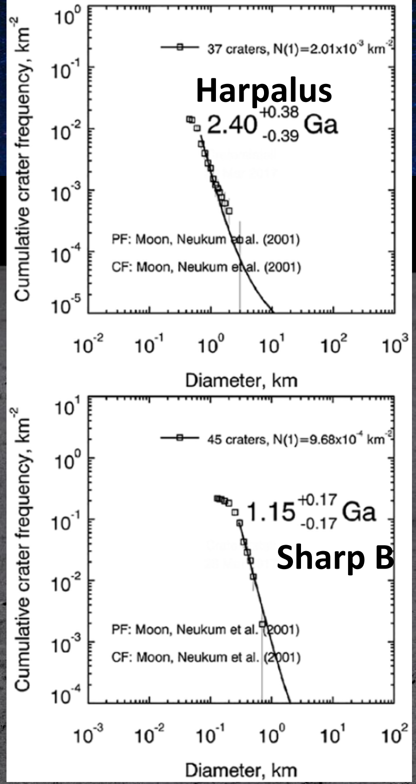
Materials may be contained in the CE-5 regolith

- Local material: mare basaltic regolith (~90 %)
- Exotic material: distal impact ejecta (~10 %), Harpalus (~6 %), Copernicus (~2 %) and Aristarchus (~1 %) crater. Similar to the results of Xie et al. (2020, JGR-P) based on basaltic sedimentation model

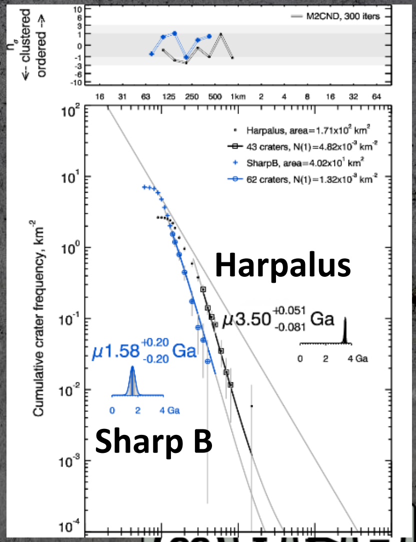
Exotic materials: Impact Ejecta







(Xie et al., 2020)



(Qian et al., 2021)

Dominated by the NE-SW ejecta, either from Harpalus or Sharp B crater or both of them

Xie et al., 2020, JGR-P; Jia et al., 2021, JGR-P: from Sharp B

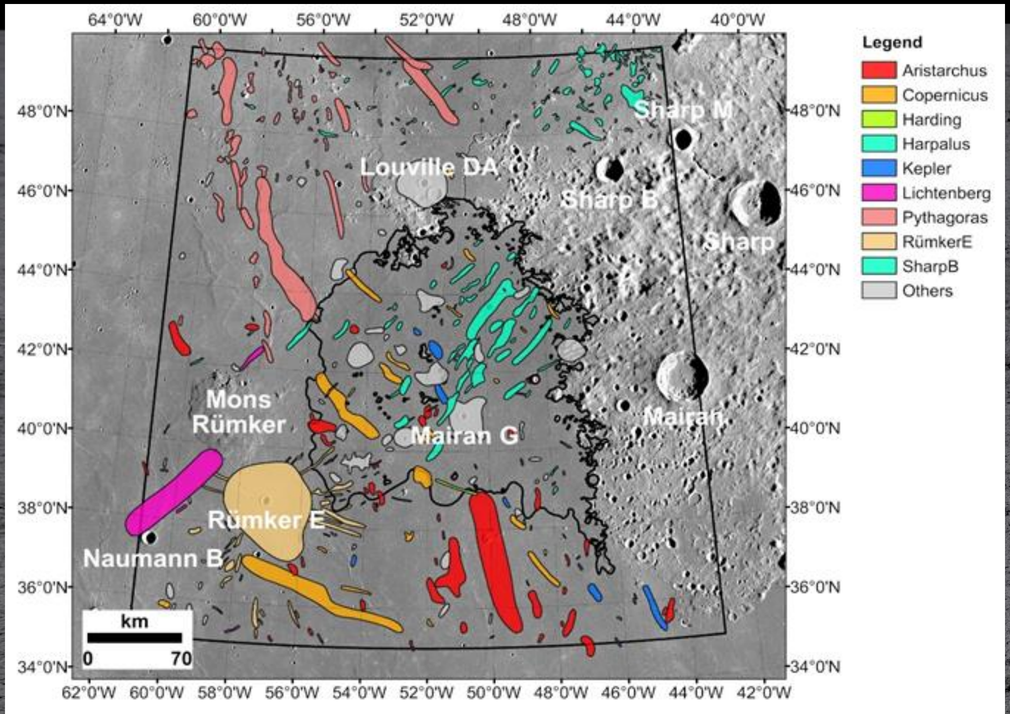
Qian et al., 2021, EPSL; Qiao et al., 2021, Icarus: from Harpalus

HOWEVER, HARPALUS IS MORPHOLOGICALLY MUCH YOUNGER THAN SHARP B CRATER, MAYBE BECAUSE DIRECTLY DATING THE CRATER EJECTA IN THIS CASE WOULD SUFFER:

Secondary craters, self-secondary craters, partially buried craters, abnormal degradation on a rough surface

THEREFORE, NOT RELIABLE. CRATER DATING ON THESE TWO CRATERS SHOULD BE DEALED WITH MORE CAUTIONS

Conclusion



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