



### The Long Sinuous Rille System in Northern Oceanus Procellarum and its Relation to the Chang'e-5 Returned Samples

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### Chang'e-5, ~1731 g of lunar samples





#### **Chang'e-5 Landing Site**



20°E 40°E 60°E 80°E 100°E 120°E 140°E 160°E 180° 60°W 40°W 20°W ٥°  $\otimes$ Chang'e-5 ۱°0 Mare Imbrium Oceanus procellarum 20°N 10°N 10°1 10°S 10°S -20°S -20°S 30°S -30°S 40°S 40°S 50°S 60°S 100°W 80°W 60°W 40°W 20°W 0° 20°E 40°E 60°E 80°E 100°E 120°E 140°E 160°E 180° 180° 160°W 130°W 11:13 PM, Dec. 01, 2020, ~1731 g of surface and subsurface samples 43.06 N, 51.92 W (Wang et al. 2021)

Northern Oceanus Procellarum



#### **Young Mare Basalt**

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(Che et al., 2021, Science; Li Q. L., et al., 2021, Nature)







- ✤ Length: ~566 km
- Average width: ~840 m
- ✤ Average depth: ~76 m
- ✤ Regional slope: ~-0.008
- Rima Sharp is the "LONGEST" sinuous rille on the Moon (Hurwitz et al., 2013)
   Rima Sharp = Rima Sharp + Rima Mairan

No observable eruption source vents (i.e., fissures, cones, domes, dikes) for Em4/P58, except for Rima Sharp

#### **Rima** Prinz

- (Hurwitz et al., 2012, JGR)
- Length: ~87 km
- Average width: ~1,100 m
- Average depth: ~170 m
- Magma volume: ~50-250 km<sup>3</sup> (physical volcanology model)

CE-5 mare basalts volume: 1,450-2,350 km<sup>3</sup>, ~ 1900 km<sup>3</sup> in average (Qian et al., 2021, EPSL)

Are the lava forming CE-5 mare basalts coming from Rima Sharp + Rima Mairan eruption?









#### **Complex Sinuous Rille System**





Complex Sinuous Rille System = Rima Sharp + Rima Mairan + Rima Louville + Rima Harpalus







- One elongated source vent (NV)
- Rima Harpalus formed earlier than Rima Sharp
- Small sinuous rille formed earlier than Rima Sharp



FIG







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- Rima Sharp originates outside Em4/P58
- No clear evidence of materials from Rima Sharp (No overflow? The overflowed lavas have the same composition with the surrounding mare basalts? If so, 1) Rima Sharp doesn't provide mare basalt materials, but their compositions are identical by coincidence; or 2) Rima Sharp does provide all the mare basalt materials, therefore their compositions are the same naturally)





#### **Rima Mairan**





- Two elongated source vents, SV1 and SV2
- SV3 and SV4 don't have rims, which is more likely to be depressions not impact craters
- SV3 and SV4 are ponds of lavas controlled by wrinkle ridges





#### **Rima Mairan**





Intermediate-Ti materials surround Rima Mairan in the upper and middle segment (black arrows), may overflowed from Rima Mairan
 The bedrock before the formation of Em4/P58 has low-Ti abundance (white arrow), extending to the Gruithuisen region





#### **Formation Sequence**

















#### **Evidence: Rima Mairan enters Rima Sharp**









#### **Evidence: Rima Mairan enters Rima Sharp**







#### **Evidence: Lava pond & inner features**





Lava pond & inner features within Rima Sharp were produced by Rima Mairan entering Rima Sharp





#### **Evidence: Lava pond & inner features**



Figure Location (black box)

(high resolution data not available)

Lava pond & inner features within Rima Sharp were produced by Rima Mairan entering Rima Sharp





#### **Evidence: Lava pond & inner features**



Figure Location (black box)

NAC DEM (high resolution data not available)

Lava pond & inner features within Rima Sharp were produced by Rima Mairan entering Rima Sharp





#### **Evidence: Inner features**



Lava pond & inner features within Rima Sharp were produced by Rima Mairan entering Rima Sharp





#### **Evidence: Inner features**









#### **Evidence: Magnetic signature**

ND



#### Evidence

Magnetic signature based on Kaguya and Lunar Prospector measurements at altitudes of 10-45 km

a. DEM of Em4/P58 unit b. Digital orthophoto map c. Magnetic field inclination on P58 surface d. Crustal magnetic field of P58 and lava boundary

Green line: boundary of high and low magnetic field
Red square: lava source vents

Hu, T., et al., 2021. Magnetic Signature of Basalts in the Chang'e-5 Sample Region: Implications for the Earth Sp. Sci. Open Arch. DOI: 10.1002/essoa



### **Youngest Dated Lunar Mare Basalt**

RESEARCH

(Che et al., 2021, Science)

#### LUNAR GEOLOGY

# Age and composition of young basalts on the Moon, measured from samples returned by Chang'e-5

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2 basalt fragments (1963±57 Ma; 2011±51 Ma only Zi-rich minerals)







### **Youngest Dated Lunar Mare Basalt**



47 basalt fragments (2030±4 Ma)





#### **Evidence: CSFD measurements**







Rima Mairan: 1.4±0.2 Ga

Rima Sharp: 1.9±0.3 Ga Rima Louville

Rima Louville:  $2.2\pm0.5$  Ga

CE-5 Sample Age: 2.0 Ga (Che et al., 2021, Science; Li Q. L., et al., 2021, Nature)

Sampled Chang'e-5 intermediate-Ti mare basalts represent the products of Rima Sharp eruptions





#### **Evidence: Magnetic signature**



Diamete



Diamete

(Xu & Qiao, 2022, A&A)

## **Volcanic History of Northern Oceanus Procellarum**





### Conclusion



Qian, Y., Xiao, L., Head, J.W., Wilson, L., 2021. The Long Sinuous Rille System in Northern Oceanus Procellarum and Its Relation to the Chang'e-5 Returned Samples. Geophys. Res. Lett. 48, e2021GL092663.

Pre-existing features, Post-formation deformation
 Origin of mare basalts: Chang'e-5 basalts represent the lava erupted from Rima Sharp, with an age of ~2.0 Ga
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(Qian et al., 2021b, EPSL)



Layer I-II (Regolith and Ejecta): Mixture of predominantly relatively immature in-situ component from impact modification of solidified young mare flows (Layer II), and exotic components (Layer I) from distant craters. Blue patches (ejecta) contain exotic materials (rays and secondary cluster deposits), primarily from Harpalaus, Copernicus, and Aristarchus craters, but still dominated by local materials (ray) 6%, Section 4.2) excavated by incoming secondaries. Regolith thickness is irregular, but up to ~7 m based on the crater morphology method (Qian et al., 2020). Characteristics of regolith are relatively immature compared to Apollo/Luna landing sites due to the young age (-1.6.1.7 Ga).

> Layers III-IV (Eratosthenian-aged Moderate-Ti Mare Basalts): Lava flows of the Eratosthenian-aged moderate-Ti mare basalts (Em4/P58, -1.6-1.7 Ga). Layer III mare basalts originated from the extensive sinuous rille system (Rima Sharp) enzytions. Rima Sharp has two major source vents, to the north and south of Em4/P58; the landing site is only ~15 km from Rima Sharp. Layer IV represents possible mare basalts of similar composition from now-buried dike and vent enzptions (Head & Wilson, 2017).

Layer V (Eratosthenian-aged Moderate-Ti Mare Basalts): Em3, the lowest unit of the moderate-Ti mare basalt sequence, with an age of ~2.0 Ga. It is exposed stratigraphically below Layers III-IV to the west of the landing site near Mons Rümker, and very likely underlying Layers III-IV in the landing site. The total thickness of Layers III-V is estimated at ~50 m based on crater excavation method (Qian et al., 2021).

Layers VI-VII (Paleo-Regolith and Paleo-Ejecta): Mixture of regolith in-situ components (gray, Layer VII) on the underlying Imbrian-aged low-Ti basalts, and exotic components from distant craters (light blue, Layer VI). Exotic materials are primarily ejecta from Sharp B and Pythargoras craters. Paleo-regolith layer has a thickness of ~10 m, assuming a regolith growth rate of ~5 mm/Myr (Horz & Cintala, 1997).

Layer VIII (Imbrian-aged Low-Ti Mare Basalts): Regional mare basaltic unit inferred to lie below the Eratosthenian-aged moderate-Ti mare basalts; stratigraphically equivalent to the Imbrian-aged Iow-Ti mare basalts (Im2/P10, ~3.4 Ga) occurring to the west of Em4/P58 (Clain et al., 2018). Low-Ti mare basalts may have a thickness of -900 m, based on mare thickness modeling using GRALL gravity data (Gong et al., 2016).

Basement: The basement of the Northern Oceanus Procellarum may be the basin ring system of the Imbrian basin (Scott & Eggleton, 1973); kipukas are the outcrops of the basement rock. Overlaying regolith, paleo-regolith, and mare basalts layers may contain the materials from Imbrium and Iridum, and rocks of the Procellarum KREEP Terrain-type crust by vertical and lateral mixing (Liu et al., 2021).

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