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

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New Orleans
Dec 13-17, 2021
Chang’-e-5, ~1731 g of lunar samples

- Sampler A
- Sampler B
- Panoramic Camera
- Landing Camera
- Drill
- Sealing and Packaging System
- Lunar Penetrating Radar
- Lunar Mineralogical Spectrometer
- Nearfield Cameras

- ~1480 g scoop sample
- ~251 g drill sample
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**

**Intermediate-Ti mare basalts**
(Qian et al., 2021, EPSL)

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

Youngest dated (~2.0 Ga) lunar mare basalts
(Che et al., 2021, Science; Li Q. L., et al., 2021, Nature)
Rima Sharp

- 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

- Length: ~87 km
- Average width: ~1,100 m
- Average depth: ~170 m
- Magma volume: ~50-250 km³ (physical volcanology model)

CE-5 mare basalts volume:
1,450-2,350 km³, ~1900 km³ in average (Qian et al., 2021, EPSL)

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

Rima Prinz (Hurwitz et al., 2012, JGR)
- Length: ~87 km
- Average width: ~1,100 m
- Average depth: ~170 m

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

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

(Qian et al., 2021, GRL)
- One elongated source vent (NV)
- Rima Harpalus formed earlier than Rima Sharp
- Small sinuous rille formed earlier than Rima Sharp

(Qian et al., 2021, GRL)
Rima Sharp

TC Morning Map

Clementine TiO2

MI False Color Ratio Map

(Qian et al., 2021, GRL)
- 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)

(Qian et al., 2021, GRL)
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.

(Qian et al., 2021, GRL)
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.

(Qian et al., 2021, GRL)
Formation Sequence

(Qian et al., 2021, GRL)
Evidence

(Qian et al., 2020, Icarus)

(Qian et al., 2021, GRL)
Evidence: Rima Mairan enters Rima Sharp

(Qian et al., 2021, GRL)
Evidence: Rima Mairan enters Rima Sharp

(Qian et al., 2021, GRL)
Evidence: Lava pond & inner features within Rima Sharp were produced by Rima Mairan entering Rima Sharp (Qian et al., 2021, GRL)
Lava pond & inner features within Rima Sharp were produced by Rima Mairan entering Rima Sharp

(Qian et al., 2021, GRL)
Evidence: Lava pond & inner features

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

(Qian et al., 2021, GRL)
Lava pond & inner features within Rima Sharp were produced by Rima Mairan entering Rima Sharp

(Qian et al., 2021, GRL)
Evidence: Inner features

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

(Qian et al., 2021, GRL)
Evidence: Magnetic signature

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 Lunar Dynamo. Earth Sp. Sci. Open Arch. DOI: 10.1002/essoar.10507737.1
Youngest Dated Lunar Mare Basalt

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

Xiaochao Che, Alexander Nemchin, Dunyi Liu, Tao Long, Chen Wang, Marc D. Norman, Katherine H. Joy, Romain Tarte, James Head, Bradley Jolliff, Joshua F. Snape, Clive R. Neal, Martin J. Whitehouse, Carolyn Crow, Gretchen Benedix, Fred Jourdan, Zhiqing Yang, Chun Yang, Jianhui Liu, Shiwen Xie, Zemin Bao, Runlong Fan, Dapeng Li, Zengsheng Li, Stuart G. Webb

2 basalt fragments
(1963±57 Ma; 2011±51 Ma only Zi-rich minerals)
Two billion-year-old volcanism on the Moon from Chang’E-5 basalts

Qiu Li Li, Qin Zhou, Yu Liu, Zhongyang Xiao, Yangting Lin, Jin-Hua Li, Hong Xia Ma, Guo-Qiang Tang, Shun Guo, Xu Tang, Jiang Yan Yuan, Jiao Li, Fu-Tuan Wu, Ziyuan Ouyang, Chunchai Li & Xiao-Hua Li

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47 basalt fragments (2030±4 Ma)

- Poikilitic
  - 2027±7 Ma
- Subophitic
  - 2030±6 Ma
- Equigranular
  - 2034±8 Ma
- Porphyritic
  - 2037±54 Ma

Zr-bearing minerals

Chang’E-5 Basalt

n = 159
MSWD = 0.6

Intercept = 0.12510 ± 0.00028
Age = 2.030 ± 4 Ma (95% conf.)
Rima Mairan: $1.4 \pm 0.2$ Ga
Rima Sharp: $1.9 \pm 0.3$ Ga
Rima Louville: $2.2 \pm 0.5$ 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

(Qian et al., 2021, GRL)
Evidence: Magnetic signature

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

(Xu & Qiao, 2022, A&A)
Volcanic History of Northern Oceanus Procellarum

| Geologic Era | Mare Materials | Rimker Plateau Materials | Dome Materials |
|--------------|----------------|-------------------------|---------------|
| Eratosthenian | Em4            | Em3                     | Em1           |
|               | Eml            | Eml                     | 1d            |
|               | 1m1            | 1m2                     | 1m3           |
|               | 1m2            | 1m3                     | 1d            |
|               | 1d             | 1m3                     | 1m2           |
|               |                |                         |               |
|               |                |                         |               |
|               |                |                         |               |
|               |                |                         |               |
|               |                |                         |               |

(Qian et al., 2021b, EPSL)

Basement: The basement of the Northern Oceanus Procellarum may be the basement complex of the Mesozoic orogenic belt. The basement rocks are characterized by their high degree of metamorphism and greenstone belts. The basement complex is composed of gneisses, schists, and metavolcanics.

Layer VII (Srubanian-Lower Low-Ti Mares): The basalts are characterized by their low Ti content, which suggests a mantle source enriched in incompatible elements.

Layer VI (Eratosthenian-Old-Medium-Ti Basalts): These basalts have intermediate Ti content, indicating a mixed mantle source.

Layer V (Eratosthenian-Medium-Ti Basalts): These basalts have medium Ti content, indicating a more enriched mantle source.

Layer IV (Eratosthenian-Moderate-Ti Basalts): These basalts have moderate Ti content, indicating a mixed mantle source.

Layer III (Eratosthenian-Rich-Ti Basalts): These basalts have high Ti content, indicating a more enriched mantle source.

Layer II (Eratosthenian-Old-Medium-Ti Basalts): These basalts have medium Ti content, indicating a mixed mantle source.

Layer I (Eratosthenian-Old-Medium-Ti Basalts): These basalts have medium Ti content, indicating a mixed mantle source.

(Qian et al., 2021a, EPSL)

Layer III (Regolith and Ejecta) - Layer VII (Low-Ti Basalts) - Layer VI (Moderate-Ti Basalts) - Layer V (Rich-Ti Basalts) - Layer IV (Regolith and Ejecta) - Layer III (Regolith and Ejecta)

Layer VII (Low-Ti Basalts): These basalts have low Ti content, indicating a depleted mantle source.

Layer VI (Moderate-Ti Basalts): These basalts have moderate Ti content, indicating a mixed mantle source.

Layer V (Rich-Ti Basalts): These basalts have high Ti content, indicating a more enriched mantle source.

Layer IV (Regolith and Ejecta): These materials are believed to be derived from the underlying basaltic crust.

Layer III (Regolith and Ejecta): These materials are believed to be derived from the underlying basaltic crust.

Layer II (Regolith and Ejecta): These materials are believed to be derived from the underlying basaltic crust.

Layer I (Regolith and Ejecta): These materials are believed to be derived from the underlying basaltic crust.

(Qian et al., 2018, JGR)

Layer IV (Regolith and Ejecta): These materials are believed to be derived from the underlying basaltic crust.

Layer III (Regolith and Ejecta): These materials are believed to be derived from the underlying basaltic crust.

Layer II (Regolith and Ejecta): These materials are believed to be derived from the underlying basaltic crust.

Layer I (Regolith and Ejecta): These materials are believed to be derived from the underlying basaltic crust.
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., 2021, GRL)