THE LONG SINUOUS RILLE SYSTEM IN NORTHERN OCEANUS PROCELLARUM AND ITS RELATION TO THE CHANG'E-5 RETURNED SAMPLES. Yuqi Qian[1,2], Long Xiao[1*], James W. Head[2*], and Lionel Wilson[3], [1]Planetary Science Institute, China University of Geosciences, Wuhan, 430074, China (longxiao@cug.edu.cn), [2]Department of Earth, Environmental, and Planetary Sciences, Brown University, Providence. 02912, USA (James_Head@brown.edu), [3]Lancaster Environment Centre, Lancaster University, Lancaster, LA1 4YQ, UK

Introduction: China's Chang'e-5 (CE-5) mission recently returned samples from a young intermediate-Ti mare unit (Em4/P58, ~2.0 Ga) [1, 2] in Northern Oceanus Procellarum. Rima Sharp, previously mapped as the longest lunar sinuous rille, is the most prominent volcanic feature associated with the landing region [3]. Our analysis shows that Rima Sharp is not a single rille, but instead is composed of two separate rilles (Rima Sharp, originating from the North Vent, and Rima Mairan from the South Vent), meeting at ~40.40°N, 48.38°W. Rima Mairan and associated lavas (southeast of Em4/P58), embay and are slightly younger than Rima Sharp. Rille formation is largely influenced by pre-existing topography (earlier mare surface, proto-wrinkle ridges, highlands); rilles and deposits experienced post-formation deformation (wrinkle ridges, mare subsidence). CE-5 samples probably originate mainly from Rima Sharp's source vent, which was modelled in detail in [10] companied with this work.

Sinuous Rilles: Sinuous rilles are elongated, meandering channels that occur primarily in the lunar maria, and often begin at circular, elongated, or arcuate depressions interpreted to be source vents, often with associated pyroclastic deposits [4]. Rima Sharp associated with the CE-5 landing site was originally regarded as one single rille and is the longest on the Moon [5]. However, our detailed geomorphologic investigations show that Rima Sharp is actually composed of four independent rilles, that is, Rima Mairan, Rima Sharp, Rima Harpalus, and Rima Louville (Fig. 1). Three independent source vents have been recognized to the north, northwest, and south of Em4/P58, labeled as North Vent (NV), Northwest Vent (NWV), and South Vent (SV), respectively.

Rima Mairan. Rima Mairan originates from SV close to the silica-rich Mairan domes (Fig. 1). SV is composed of four circular depressions, that is, SV1, SV2, SV3, and SV4. SV1 (~560 m-wide, ~255 m-deep) and SV2 (~740 m-wide, ~265 m-deep) form a linear depression (~3,190 m-long, SE-NW); and SV3 (900 m-wide and 265 m-deep) and SV4 (740 m-wide and 144 m-deep) form another linear vent (SW-NE). SV1/SV2 are located outside Em4/P58, while SV3/SV4 are inside. SV3/SV4 appear more disrupted while SV1/SV2 are contiguous. Both SV3 and SV4 are rimless, indicating that they are not impact features. The western edges of SV3/SV4 are in the center of the rille channel, lower than the mare surface but higher than the rille floor. Rima Mairan generally follows the regional slopes in a northwest direction (Fig. 1). High-Ti materials (~6–16 km-wide) are distributed in strips ~6–16 km-wide on both western and eastern sides of Rima Mairan close to the source vents (hashed box, Fig. 1) and overlie the Imbrian-aged low-Ti mare basalts. Rima Mairan has a length of ~150 km, an average width of ~490 m, and a depth of ~46 m, before meeting Rima Sharp.

Rima Sharp. Rima Sharp originates from NV to the northwest of Sharp B crater (Fig. 1). NV is an ~320 m-deep, ~950 m-wide, and ~3,050 m-long elongated vent (NW-SE), which is ~14 m deeper than the Rima Sharp rille floor. An ~8,900 m NE-SW linear depression is located southeast of NV, but is not directly connected to NV. The trend of Rima Sharp generally follows regional slopes, first west, then south across a highland valley near Louville DA crater, then to the center of Em4/P58 (Fig. 1). No lava flows with compositions different from the young basalts are observed associated with the rille channel (Fig. 1), indicating either that lavas from the rille are coincidently the same as Em4/P58, or that Em4/P58 consists of products of the rille eruption. Rima Sharp has a length of ~320 km, an average width of ~920 m, and depth of ~70 m, before meeting Rima Mairan.

Relation between Sinuous Rilles and CE-5 Returned Samples: Based on our reanalysis of the Rima Sharp/Mairan source vents, rille characteristics and stratigraphic relationships, and their relationship to Em4/P58, we call on the paradigm of basaltic magma ascent and eruption outlined by [6] to reconstruct their emplacement (Figs 2c–2f). Following the short-lived Phase 1 as the dike reached the surface, Phase 2 involved a high-volume-flux Hawaiian eruptive phase as the magma degassed, forming a hemispherical pyroclastic fountain and attendant lava pond, the scale of which was dictated by the magma volatile content [7]. The initial high-flux stages of the eruption of both Rima Sharp and Rima Mairan (Phase 1) are likely to have involved the emplacement of sheet flows, rapidly flooding the surrounding topography. Phases 2 and 3 are predicted to involve the channelization of flow activity as the flow margins cooled, and the thermo-mechanical erosion of the rilles during the persistent and longer duration period of flow, with the rilles transporting lava to their distal ends until the termination of the eruption and solidification of the deposits. Source vent depths suggest eruption durations of 100–200 days [8]. Because of the smaller size of Rima Mairan, its less extensive surrounding deposits, and its stratigraphic and age relationships, we interpreted the Rima Mairan eruption to have involved a much smaller total volume than Rima Sharp, and to have occurred after the emplacement and solidification of Rima Sharp and the majority of Em4/P58.

Conclusion: According to our analysis, we found that Rima Sharp is characterized by source vents at its beginning and end and is actually composed of two main rilles. Rima Mairan postdates Rima Sharp, and flows into its southern end. Both source vents and rilles appear to be traversing and emptying into Em4/P58 and are thus likely to be the source of it. The CE-5 samples may represent the lavas from the source vent of Rima Sharp. Therefore, the formation of Rima Sharp is detailed modeled via physical volcanology methods, and presented in [10].

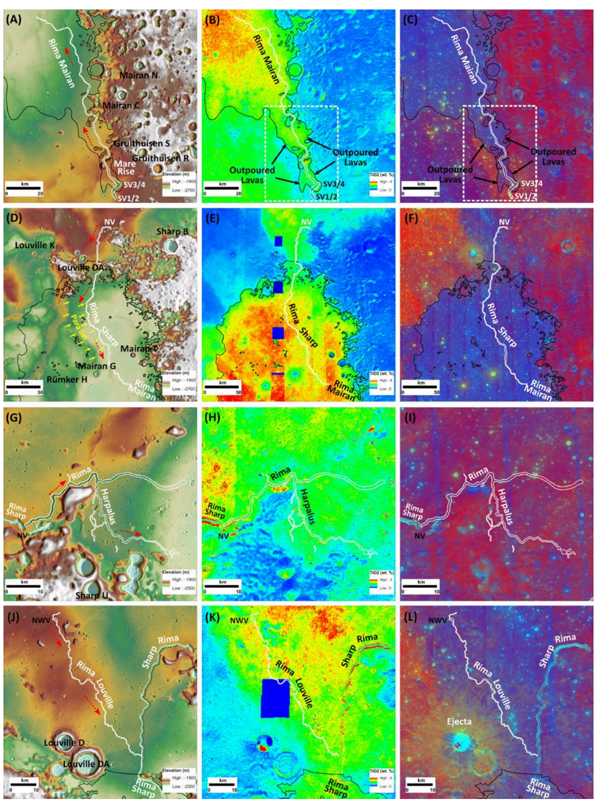

Figure 1. The elevation, TiO_2, and false-color maps of Rima Mairan (a–c), Rima Sharp (d–f), Rima Harpalus (g–i), and Rima Louville (j–l). The red arrows indicate the rille flow directions. The white-broken-line boxes indicate lavas outpoured from Rima Mairan, overlaying the low-Ti mare surface, maybe extending to the northwest of the outlined boxes.

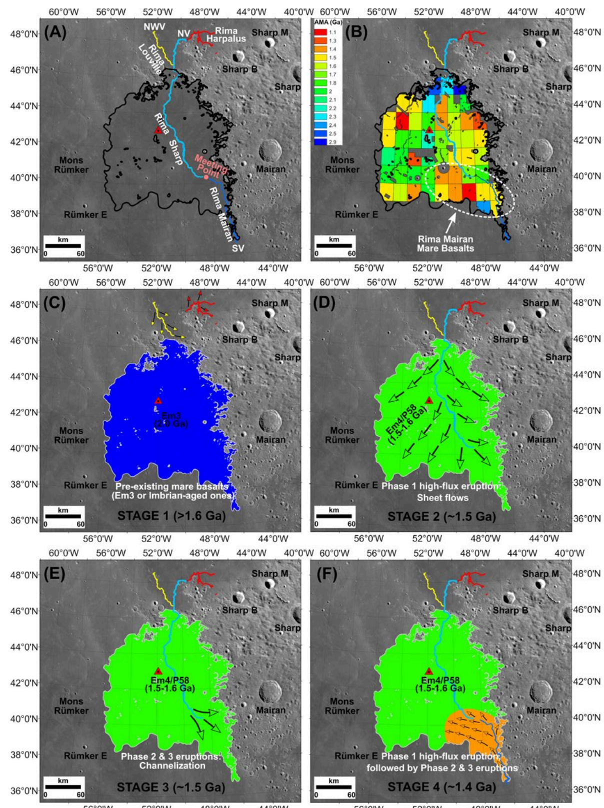

Figure 2. a) Sinuous rilles across Em4/P58 (black line) in Northern Oceanus Procellarum. The red triangle indicates the CE-5 landing site. (b) Absolute model ages of Em4/P58 [9]. (c–f) The geological evolution of Em4/P58. (c) Em3 or Imbrian-aged mare basalts covered the current Em4/ P58 mare region before its eruption. (d–e) Phase 1 high-flux eruption produced sheet flows, followed by Phase 2/3 channelization (green). (f) The eruption of Rima Mairan produced lavas covering the southeast of Em4/P58 (brown).

References: [1] Che X. et al. (2021) *Science, 374, 887-890*. [2] Li Q. et al. (2021) *Nature, 600*, 54-58. [3] Qian Y. et al. (2021) *Geophys. Res. Lett. 48*, e2021GL092663. [4] Head J. W., and Wilson L. (2017) *Icarus, 283*, 176-223. [5] Hurwitz D. M. et al. (2013) *Planet. Space Sci.* 79–80, 1–38. [6] Wilson L., and Head J. W. (2018) *Geophys. Res. Lett. 45*, 5852–5859. [7] Morgan C., et al., (2021) *J. Volcanol. Geotherm. Res. 413*, 107217. [8] Wilson L., and Head J. W. (2021) *52nd LPSC*, Abstract#1226. [9] Qian Y. et al. (2021) *Earth Planet. Sci. Lett. 555*, 116702. [10] Wilson L. (2022) *53rd LPSC*.