Lunar Rivers or Coalesced Chain Craters?

Lingenfelter, Peale, and Schubert (*1*) have proposed an ingenious mechanism whereby riverlike features on the lunar surface may be "eroded by water under vacuum conditions, since an overburden of ice can provide the pressure required to maintain the liquid phase." They were led to devise this hypothesis because of "the obvious similarities in appearance between the rills and terrestrial river channels." However, it is our opinion, based on experience with terrestrial rivers, that the differences between lunar channels and terrestrial rivers are significant. If we consider only the examples cited by these authors, Rima Prinz I, Rima Prinz II (*1*, Fig. 1), and the sinuous channel in Schroeter's Valley (*1*, Fig. 2), the morphologic peculiarities of these features suggest an internal rather that a surficial origin.

Rima Prinz I appears to originate in a small crater on the north flank of the eroded Prinz Crater. It follows a crescentic course to the west paralleling the structure of the crater. This course is unusual, but perhaps it can be explained by the irregularities of the Prinz ejecta blanket. When the rill crosses the 3000-m contour (*2*), it makes a very sharp, 120° turn to the north. From this point it follows a path essentially parallel to the regional contours. However, a fluid flowing on the lunar surface would have continued to move toward the west (down-slope).

Rima Prinz II follows a generally similar path, but in addition it crosses a lunar ridge (*1*, Fig. 1). Terrestrial rivers develop courses across ridges and mountains when they are superimposed on a resistant stratum from above, or when an obstruction rises very slowly across their paths. Both mechanisms involve long spans of time and large volumes of water. Neither would seem to be available for the development of the lunar channels.

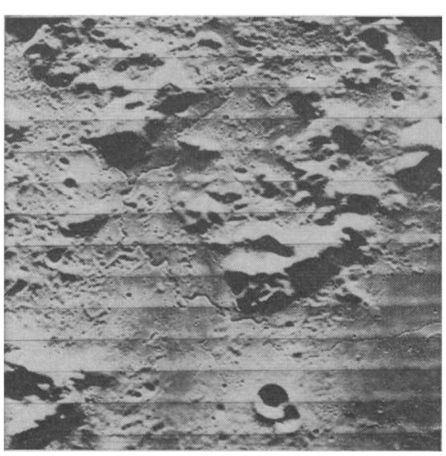

Fig. 1. This NASA photograph shows the sinuous rill, Rima Plato II (Lunar Orbiter V, site V-31, M-129). Two tributaries join to form the main channel, which at this scale resembles a terrestrial river channel. The larger of the two craters in the lower right of the photograph is about 9 km in diameter.

Schroeter's Valley is apparently controlled by a regional fracture pattern. Nevertheless, confined within this complex graben is a highly sinuous channel that superficially looks very much like that of a sinuous river (*1*, Fig. 2). This channel originates in or near the Cobra's Head north of the crater Herodotus, and, like a terrestrial river in a major structural valley, it follows a course established by the regional structural pattern. A peculiar feature of this channel is that at the westernmost limit of Schroeter's Valley it passes through the wall of the graben in a deep canyon and through at least two lunar ridges before disappearing in the Oceanus Procellarum. This is not the course that would be taken by water moving over the lunar surface.

If we assume that the location of contours on the lunar astronautical charts is reasonably accurate, other channel-like features on the lunar surface also seem to ignore both the regional slope and local irregularities. For example, the Marius Rill is an impressive example of a riverlike feature which originates near Marius C Crater (Keppler region LAC-57); however, it too crosses lunar ridges and behaves as no water-eroded channel could.

Moreover, the "pseudo-meanders" associated with lunar channels do not resemble the meander pattern of terrestrial rivers. For example, the irregularity of the Prinz channels is in places deceptively like terrestrial meanders, but the meanderlike scars are semicircular in form and could represent coalescing crater rims. The channel in Schroeter's Valley tends to follow closely the base of the steep valley walls. It appears first at the base of the northeast wall, then shifts to the base of the south wall. Along a brightly illuminated part of the south wall only half of the channel is visible. No evidence of major mass movement on this steep wall is present, but on the high-resolution imagery (*1*, Fig. 2) semicircular segments of the channel pattern are visible; this suggests strongly that at least part of the meander pattern is composed of coalescing craters.

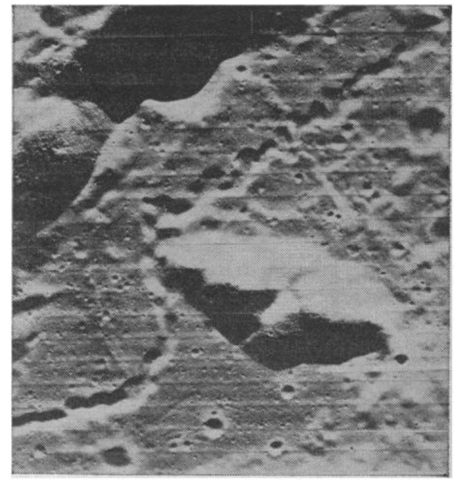

Fig. 2. This high-resolution NASA photograph of the right tributary shown in the upper center of Fig. 1 (Lunar Orbiter V, V-31, H-130) reveals that the channel is not continuous. It appears to have been formed by the coalescence of craters above a major fracture. The mountain to the right of the channel is about 11 km long.

Evidence for an internal origin of at least parts of some of the lunar channels is provided by the sinuous rill, Rima Plato II, which is located between the Alpine Valley and the Crater Plato (Fig. 1). Portions of this rill are very well defined, but the channel is not continuous and parts of it appear to be composed of coalescing craters that apparently result from the emission of gas along a fracture beneath the lunar regolith (Fig. 2).

In view of the morphologic peculiarities of the lunar channels, it seems unlikely that they could have formed entirely by surface erosion. Rather, we suggest that at least parts of some of the channels were formed by internal processes. The emission of gas along fractures, which control the courses of channels near Prinz Crater and in Schroeter's Valley, would have formed chains of circular and elongate craters, which upon coalescence could have become the lunar channels.

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References and Notes

1. R. E. Lingenfelter, S. J. Peale, G. Schubert, *Science* **161**, 266 (1968).
2. "Aristarchus Lunar Astronautical Chart 39" (Aeronautical Chart and Information Center, U.S. Air Force, St. Louis, Mo., Nov. 1963).
3. We thank Dr. H. Masursky for the assistance provided by the Branch of Astrogeologic Studies, U.S. Geological Survey, under National Aeronautics and Space Administration contract T663536.

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Because lunar sinuous rills look "deceptively like terrestrial meanders" and run "parallel to the regional slope," Schumm and Simons have cast aside our "ingenious mechanism" and have devised the pseudo-alternative that "parts of some of the channels" are the "coalescence of chain-crater systems." However, it is our opinion that the differences between lunar sinuous rills and coalesced chain craters are fundamental. If we consider only the examples cited by these authors, Rima Prinz I and II, the sinuous channel in Schroeter's Valley, Rima Marius, and Rima Plato II, it is obvious that their basic morphological characteristics (continuous and uniform meandering channels, mature meanders, goosenecks, distributary channels, and flood plains) cannot be imitated by coalesced chain craters. As can be seen in some straight rills, such as Hyginus, coalesced chain craters do not resemble sinuous rills nor should they be confused with them. Coalescence of craters produces depressions with irregular floors and opposing walls that are mirror images of each other, that is, like ( ), rather than the observed smooth floors and matching walls, that is, like ((, of the lunar sinuous rills.

Using the lunar astronautical charts, Schumm and Simons state that sinuous rills do not follow the local gradient and that Rima Marius and the rill at the end of Schroeter's Valley both cross ridges. However, the Lunar Orbiter photographs have shown that these charts are so inaccurate that they cannot be used as a basis for the study of sinuous rills. Even such large features as the Cobra's Head of Schroeter's Valley are grossly distorted on the charts. From a survey (*1*) of Lunar Orbiter IV photographs of about 130 sinuous rills, we find that, wherever it is possible to determine a gradient, the rills meander from higher to lower elevations. Lunar Astronautical Chart 39 shows a "ridge" crossing Rima Marius, whereas Lunar Orbiter IV photograph H150 reveals that this "ridge" is in fact two ridges offset by 10 km, which do not cross the rill but terminate on either side of it. Similarly the Schroeter's Valley rill does not cross any "ridges" but meanders between isolated hills (Lunar Orbiter IV photograph H157).

Despite the erroneous examples cited by Schumm and Simons, there is no reason to doubt that a channel eroded by surface water could not be subsequently uplifted. A possible example of this might be Rima Prinz II. Since its channel is deeper on the plains to either side of the ridge, the rill must either have been uplifted subsequent to its formation, or must have passed through a gap in the ridge depressed below the level of the surrounding plain.

Schumm and Simons' contention that the course of Rima Prinz I is "unusual" fails to recognize the fact that the course of this rill and of neighboring ones is partially controlled by a rather conspicuous regional fracture pattern, as are the courses of terrestrial rivers. Their statement that there has been no major mass movement on the walls of Schroeter's Valley is contradicted by the fact that "only half of the channel is visible." The only places where Rima Plato II appears discontinuous are those where the channel has been obliterated by obvious impact craters.

The very distinctive morphology of the lunar sinuous rills, particularly the mature meanders, goosenecks, distributary channels, flood plains, and other features similar to those of terrestrial rivers, requires that they be features of surface water erosion.

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27 March 1969

Hierarchical Structures

The portion of the summary of the Conference on Hierarchical Structures describing the "cosmic diagram" (*1*) contains the same error in Fig. 1, the caption, and the text.

In Fig. 1, the limit parallel to the Schwarzschild limit marked $m = Sr$ should be marked $m/r = Sm_p/a_0$. In the caption, the limit $m/r = S = 10^{39.4}$ should read, $m/r = Sm_p/a_0 = 10^{23.8}$ g/cm. In the text (p. 1229, right-hand column, line 17), the phrase "or at $m = Sr$" should be similarly changed.

The maximum observed gravitational potential for stars, galaxies, and clusters of galaxies appear to have closely the same value in the neighborhood of $10^{23.5}$ g/cm. In dimensionless terms—expressing mass in units of baryon mass m_p, and lengths in units of the Bohr radius a_0—the observed potential limit takes the value $ma_0/m_pr = 10^{39}$ or fS where f is a number of the order of unity. From the definitions, $S = e^2/Gm_pm_e$ and $a_0 = e^2/\alpha^2c^2m_e$, it follows that for the observed limit $Gm/c^2r = f\alpha^2$ compared to $GM/c^2r = 1/2$ for the Schwarzschild limit. The fine structure constant thus emerges from astronomical measurements, under the assumption that all dimensionless physical numbers of the order of 10^{39} are the same (*2*).

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2. P. A. M. Dirac, *Proc. Roy. Soc. London Ser. A* **165**, 199 (1938).

1 April 1969

Granitic Rock: Properties in situ

Simmons and Nur (*1*) have reported that laboratory measurements of sound velocity and electrical resistivity of granitic rocks yielded results that were inconsistent with certain measurements *in situ*. One possibility they offered to explain this inconsistency is that the rock *in situ* lacks the small, open cracks evident in the laboratory specimen. They conclude that "the absence of small, open cracks that close due to lithostatic pressure with depth in the earth's crust holds serious implications for geophysics." I do not wish to treat here the important question of whether cracks are present in rock *in situ* but simply to suggest that the conclusions reached by Simmons and Nur may be based on doubtful evidence. My principal objections to their comparison of measurements *in situ* and in the laboratory are as follows:

1) The lithology of the Matoy well is extremely complex (*2*), with wide variations in composition, grain size, and texture. It seems highly questionable to compare a measurement made *in situ* over a wide suite of rocks with laboratory measurements for a single rock or rock type. Although half the cuttings examined by Ham *et al.* (*2*) were described as diorite or diabase rather than granite, the velocity of these cuttings *in situ* was compared with the velocity of granites.

2) I have studied in detail the electrical log for the Phillips No. 1 Matoy well. It is very difficult to obtain the