Behavior of Water in Vacuum: Implications for "Lunar Rivers"

We were intrigued by the novel suggestion by Lingenfelter *et al.* (*1*) that sinuous rilles on the lunar surface could be produced by aqueous erosion under an ice blanket. We attempted to model this process in a laboratory vacuum chamber. In doing so, we were not attempting to quantitatively scale a river system in the small volume available to us, a feat which is virtually impossible. We were attempting to model a class of feature (stream channels), and to compare this feature in air and in vacuum. In a case such as this, there is some justification in considering the laboratory stream itself as a small system, rather than a scale model of a large prototype (*2*). This method does not involve a questionable attempt to quantitatively extrapolate the many factors affecting stream flow to very small size, but does reproduce the morphology of natural features on a small scale. The degree to which the results that we obtained on this small scale may be directly applied to lunar surface features is debatable, but we believe that the results are as intriguing as the hypothesis advanced by Lingenfelter *et al.*, and valuable for the insight they provide into the behavior of water in vacuum.

The experiments were carried out in a vacuum chamber which was large enough to admit a tray 30 by 42.5 cm, containing a layer of crushed rock. Our crushed rock "soils" ranged from a 0-to 125-μ powder to a 2- to 4-mm gravel, with several attempts at gradations and layering. Most of the experiments used a soil consisting of particles less than 500 μ in diameter, with the major proportion of the particles less than 125 μ in diameter. Depth of the sample over the water inlet was varied from 0 to 5 cm. Changes in particle size and depth of soil layer did not result in any significant change in the effects noted. Water was introduced at the upper end of the tray at rates from a few milliliters to 800 ml/min. Most experiments used a flow of 300 ml/min. At the lowest rate, water froze in the inlet tube. At the high rate, a stream of water was sprayed vertically; it froze on the chamber window, and prevented observation of the experiment in progress. Between these two extremes of flow rate, water behaved as described below, with a higher flow rate simply accelerating the process. During the vacuum runs, the chamber pressure was maintained below the triple point of water (at about 1 torr), utilizing a 425-liter/min mechanical pump and a 2000-cm^2 liquid nitrogen cold trap. This pressure could be maintained, despite the flow of water into the chamber, primarily because of the cold trap, which has a high pumping speed for water vapor.

In air we were able to produce miniature stream channels similar to those carved by terrestrial streams (Fig. 1A). At low angles of tray inclination, the model stream produced a braided channel pattern. As the inclination increased, the number of channels decreased, and the depth to which they were incised increased. At no time did we produce a meandering channel with meanders of regular amplitude and frequency, although channels were typically sinuous. The fact that our small stream did not meander is not considered important to a comparison of channel formation in air and in vacuum, because meanders do not appear to be a function of material transport (*3*).

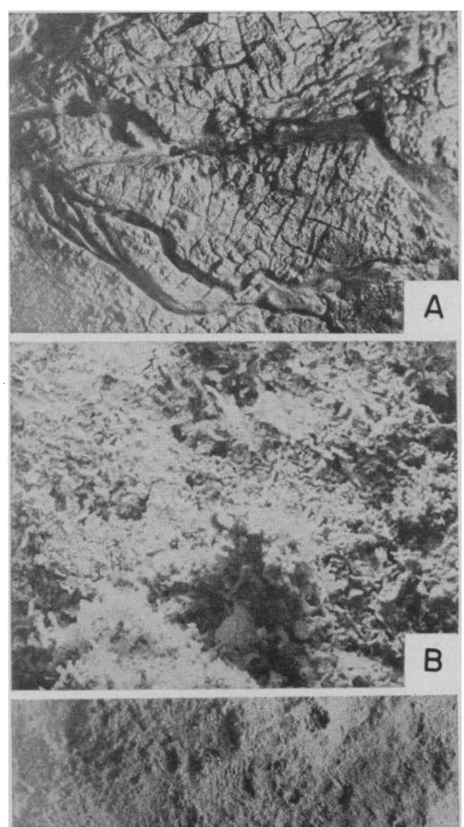

Fig. 1. When water is released on a soil surface in air, small stream channels are produced (A). In vacuum, a dendritic ice mass is formed (B). After the ice is sublimed away a hummocky surface remains (C).

During the vacuum tests, water was admitted to the model tray below or on the soil surface. The water boiled explosively as it was admitted, throwing soil and ice particles the full 50-cm length of the test chamber. This action continued for only a few seconds at any flow rate, until a frothy dendritic mass of ice accumulated, temporarily capping off the water source (Fig. 1B). Water continued to flow under the ice, as predicted by Lingenfelter *et al.* (*1*), but it did not necessarily flow downhill. Instead, it percolated through the soil following the greatest pressure gradient, breaking through to the surface first in one place and then in another. Each time it broke through explosively, entraining soil particles in the first rush of water vapor, which was followed by formation of a dendritic ice plug.

At the end of a run, an ice layer typically covered the entire sample tray. This ice, which contained about 10 percent soil particles by volume, was then sublimed away. Although there had been some downslope movement of the soil, which increased with increasing angle of inclination, no stream channels were ever developed. On the contrary, the soil surface invariably displayed a hummocky appearance (Fig. 1C).

These results show that ice will readily form in a vacuum to a sufficient thickness to allow liquid water to exist beneath it, as predicted by Lingenfelter *et al.* The model streams produced in vacuum did not, however, erode rille-like channels.

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References

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19 February 1969