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THE ORIGIN OF THE GROOVES ON PHOBOS

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The characteristic surface features of the inner Martian satellite Phobos are impact craters and long, linear depressions, here called grooves. The grooves have been explained as surface manifestations of deep-seated fractures, but there has been a divergence of opinion as to the cause of the fracturing. Soter and Harris[1] have attributed the fracturing to tidal stresses induced by Mars; Pollack and Burns[2] have suggested fracturing by drag forces during the hypothetical capture of the satellite by Mars; Veverka et al[3] have attributed the fracturing to a large, nearly catastrophic cratering event. In this note we present new data on the grooves which tend to support the cratering hypothesis and appear to rule out the tidal mechanism.

While it was known[4] from the Mariner 9 images obtained in 1971-72 that the surface of Phobos is heavily cratered, the discovery of the grooves by the Viking Orbiters came as a surprise. An effective resolution of ≲70 meters is needed to see grooves well, whereas the best resolution achieved by Mariner 9 was ≳ 200 meters. Sufficient Viking Orbiter imagery has now been obtained to map the surface distribution of grooves, study their morphology, and to date them by means of the density of superimposed impact craters.

Figure 1 is a map of the distribution of grooves on Phobos. For reference we have sketched in the outline of the largest topographic feature on Phobos — the 10 km crater Stickney. The region west of Stickney, between longitudes 70° and 160°W has been imaged at resolutions of only ≳150 meters, whereas imagery with a resolution of ≲50 meters exists for the remainder of the satellite. Thus no significance should be attached to the apparent low density of grooves west of Stickney evident in Figure 1.

The striking pattern in Figure 1 is that the grooves emanate from all sides of Stickney and run continuously towards a region near 270°W where they die out. This area, although not exactly 180° away from the center of Stickney, is in fact antipodal to the crater when one considers the actual three-dimensional shape of Phobos. (Phobos[5] is approximately a triaxial ellipsoid with principal axes 27 x 21 x 19 km across; the longest axis coincides with the 0°- 180° longitude direction).

The remarkable pattern of grooves seen in Figure 1 strongly suggests that the formation of Stickney and of the grooves were intimately related events. This idea is supported by the typical morphology of the grooves. Individual grooves are best developed in the neighborhood of Stickney and taper out near longitude 270°. Most grooves are between 100 and 200 meters wide and 10 to 20 meters deep, with concave-up cross-profiles. The largest grooves, 700 meters wide and 90 meters deep are near Stickney. Only near the antipodal point near longitude 270° are the grooves consistently less than 100 meters in width.

The grooves have a more complex morphology than that expected of simple fractures. They commonly have a beaded or pitted appearance due to subtle depressions along their lengths. Some grooves, especially between longitudes 170° and 220°W have wide irregularly bounded segments of hummocky topography, some of which appear to rise above the surrounding surface. Some straight-walled groove segments appear to have subtle, slightly raised rims. Thus the morphology of the grooves is not that of simple fractures or of fault blocks. The grooves almost certainly represent some response of the Phobos regolith to deeper fractures, and it is probable that the formation of the grooves involved a variety of processes of which deep-seated fracturing was dominant. Attempts to elucidate some of these processes are underway.[6] Whatever the modifying processes, the grooves appear to be closely related to the formation of Stickney.

The orientations of most grooves are consistent with the concept of planar fractures cutting through much of Phobos. One prominent set of groove planes is nearly parallel to the equatorial plane of Phobos. A second is roughly perpendicular to the sub-Mars direction, while a third is intermediate between the first two, with southern hemisphere normals on the Mars side of Phobos. While the grooves are not radial to the rim of Stickney, the major planes defined by the grooves are roughly perpendicular to the plane of the crater's rim.

The age of the grooves can be estimated from the density of superimposed impact craters (Fig. 2). In Figure 3 we compare the density of impact craters within the grooves with the average value for all of Phobos. Also shown for comparison is an extrapolation of the crater density curve for the lunar uplands.[7] Within the error bars, we consider the density of impact craters averaged over Phobos to be equal to the extrapolated value for the lunar uplands, and the density within the grooves to be at least half this value. On this basis the absolute age of the grooves can be estimated using the techniques of Hartmann.[8] A crater production rate for Mars twice that of the Moon, scaled to the g on Phobos ($g \approx 0.5$ cm/sec^2; crater diameters scaled as $g^{-0.12}$)[9] gives an age in excess of 3.4 billion years for the grooves. Extreme values of fluxes and of gravity scaling exponents must be used to yield ages less than 10^9 years.

The old age of the grooves, their pattern on the surfaces, as well as their evident association with the crater Stickney are not consistent with the tidal hypothesis of Soter and Harris.[1] If Martian tides were the main cause of grooves, the grooves should be younger than 10^9 years since Phobos is presently spiraling into Mars on a timescale of 10^8 years.[10]

The fracturing of Phobos by drag forces during its hypothetical capture by Mars does not explain the evident association of grooves with the crater Stickney.

The old age of the grooves and their pattern on the surface of the satellite are best explained by third hypothesis according to which the grooves are modified surface expressions of deep seated fractures produced during the formation of Stickney. Available evidence suggests that Stickney is of comparable age to the grooves and Pollack et al[4] have calculated that the energy of impact that formed Stickney may have been within an order of magnitude of the binding energy of Phobos. It has recently been suggested[11-13] that Phobos is made of a mechanically weak material similar to that found in primitive carbonaceous chondrite meteorites.

Thus it seems quite plausible that a severe impact such as that responsible for the formation of Stickney could fracture much of the satellite.

According to our argument other small bodies in the Solar System made of similar mechanically weak material (some C-asteroids, for example[14]) may be expected to have similar patterns of grooves associated with the largest impact craters.

Acknowledgement

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FIGURE CAPTIONS

Figure 1: Sketch map of Phobos showing the location of the grooves and of the largest crater Stickney. Stippled areas are hummocky topography in grooves.

Figure 2: Part of Viking Orbiter Picture 246A06 showing impact craters within the grooves. The scale bar represents 1 km.

Figure 3: Surface density of impact craters within the grooves (points) compared with that on the rest of Phobox (dashed line) and on the lunar uplands (solid line). The lunar curve is extrapolated from Hartmann.[7] Within the accuracy of the data we consider the dashed and solid curves to be identical. The data points for the grooves fall into two groups since two sets of images of differing resolution were used.

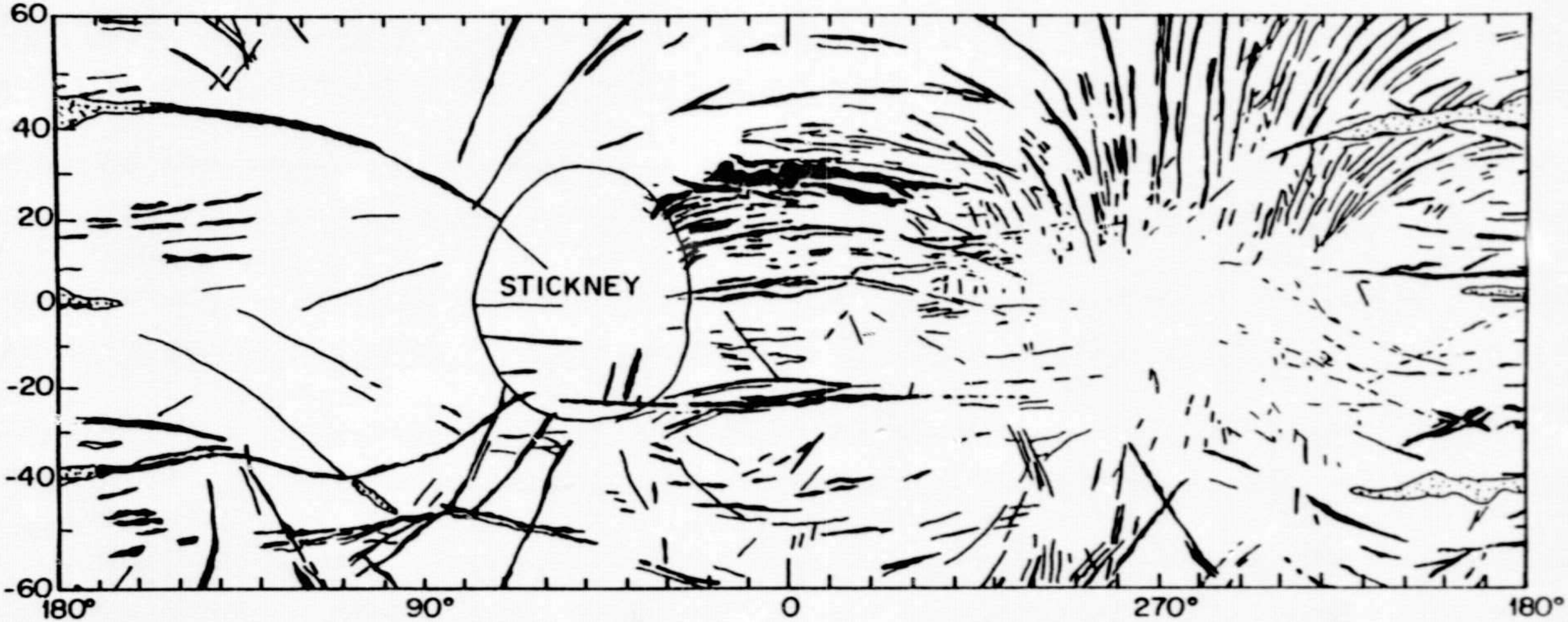

FIGURE 1a

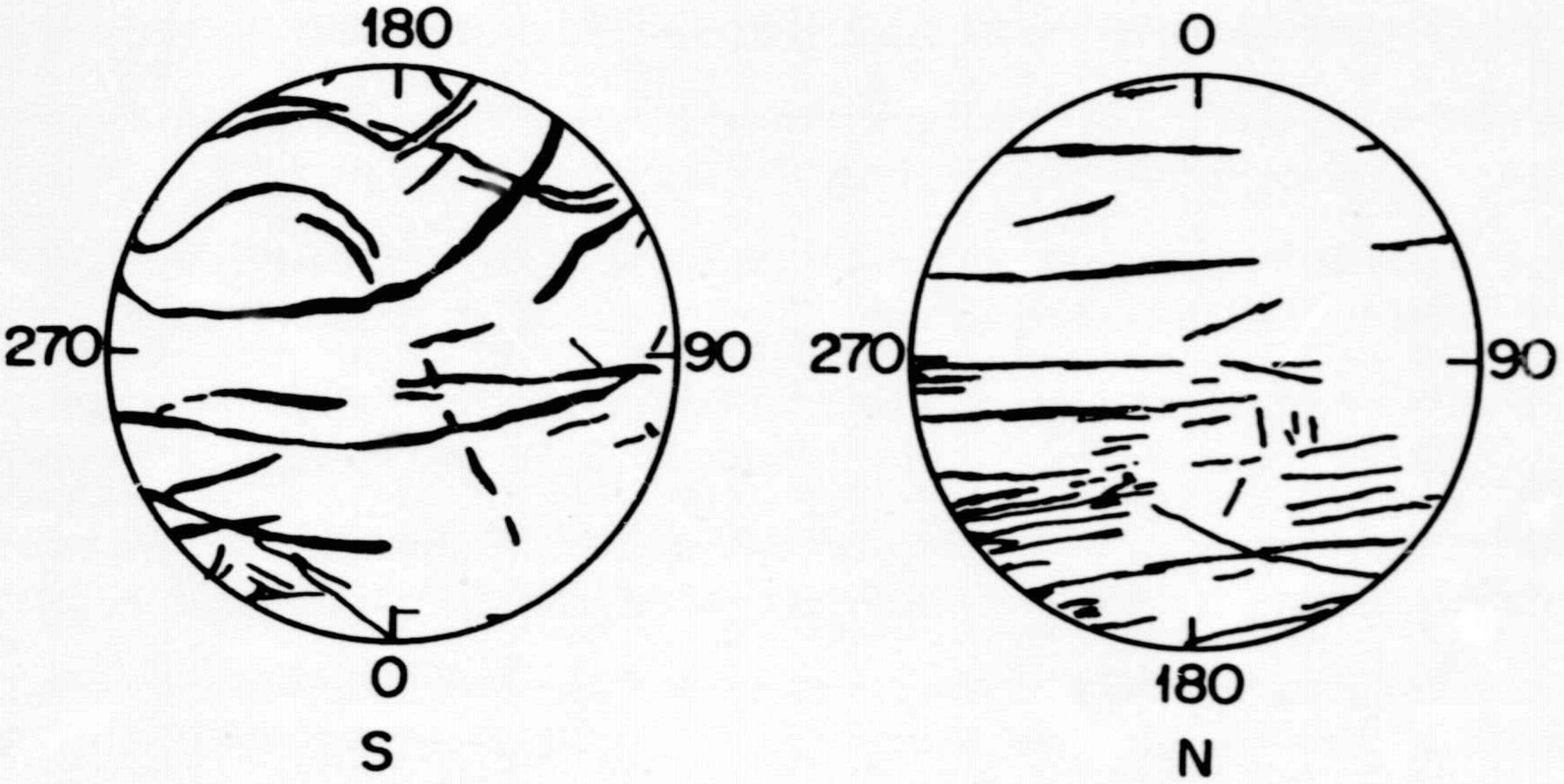

FIGURE 1b

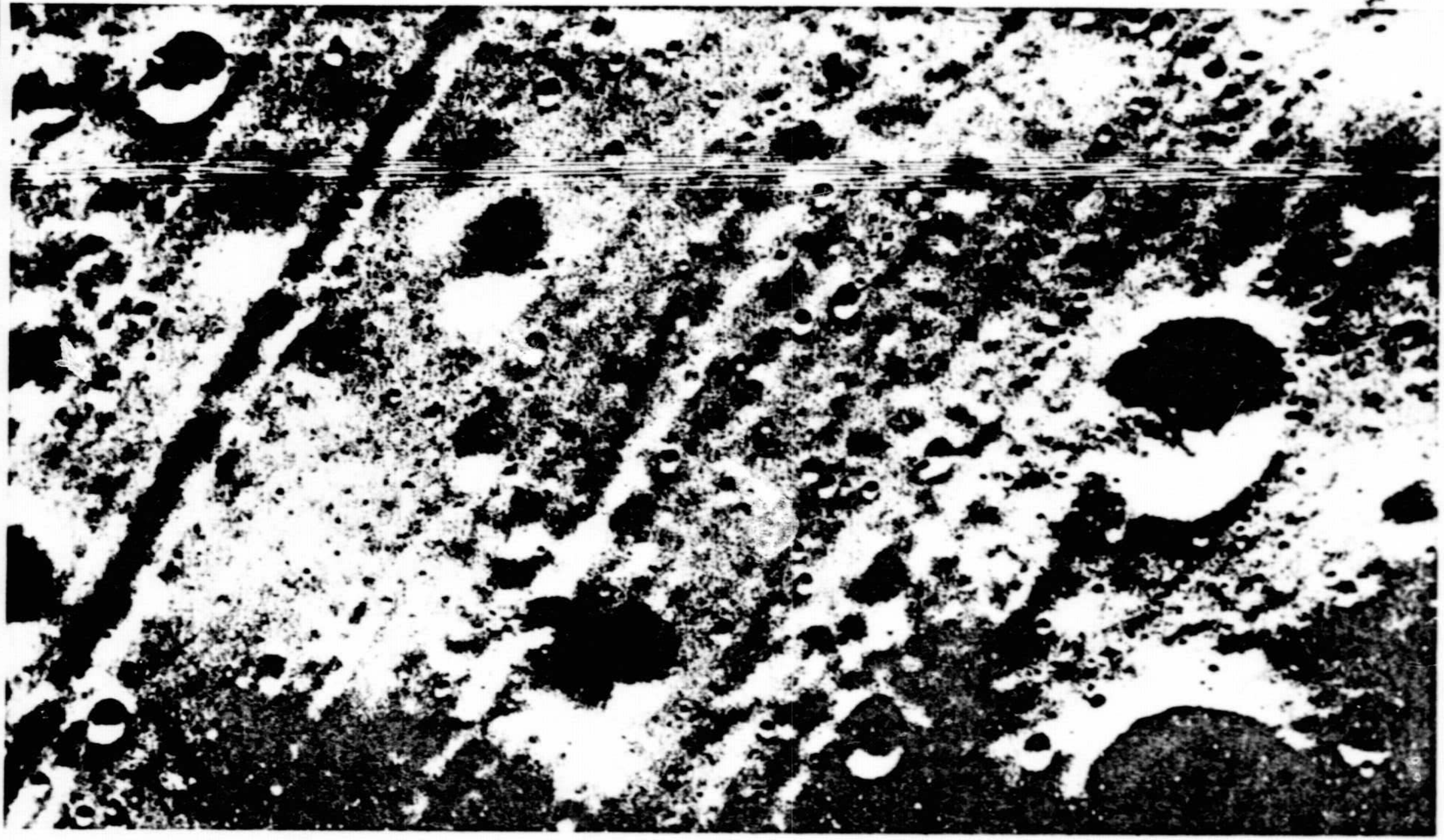

FIGURE 2

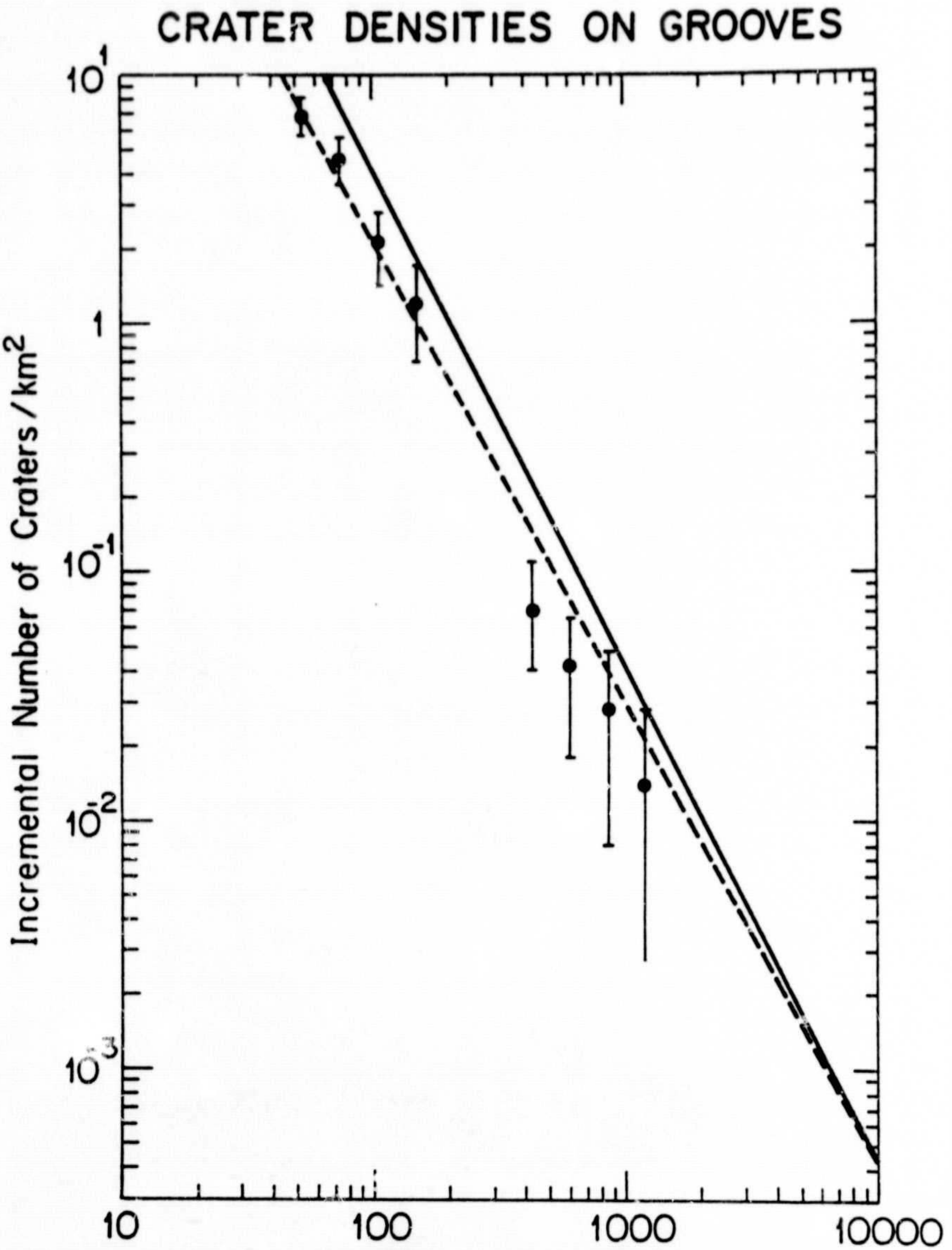
CRATER DENSITIES ON GROOVES
Incremental Number of Craters/km^2
10^1
1
10^{-1}
10^{-2}
10^{-3}
10
100
1000
10000
Diameter, meters

FIGURE 3