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Phobos: Photometry and Origin of Dark Markings on Crater Floors

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Abstract

Viking Orbiter 1 close encounter pictures of Phobos reveal unusual dark patches on the floors of many craters. Photometry of these features indicates that they have a similar normal reflectance but a phase coefficient 30% larger than the average surface. These facts suggest that the "dark" material has a similar composition but a much rougher texture than the average surface of Phobos. By analogy with terrestrial impact, explosion and laboratory craters, the dark patches are interpreted as impact generated melt pools which remain visible on Phobos due to the low value of g and consequent small amount of fallback ejecta and slumping. Since blanketing by ejecta from subsequent impacts and micrometeoroid erosion should eventually obliterate such features, they should be more conspicuous in the fresher craters. Similar features should be visible on small asteroids and other low g bodies. However, they are not prominent on the surface of Deimos-- possibly because most of the craters imaged at high resolution on the outer satellite appear to have been blanketed by several meters of fine-grained material.

During February 1977, Viking Orbiter 1 made a series of close flybys of the inner Martian satellite, Phobos, passing within about 100 km at its closest approach. Conspicuous in many of the high resolution images obtained are dark patches on the floors of many craters. Since the average reflectance of Phobos is very low ($\sim$6%); Veverka, 1977), the apparent occurrence of an even darker material is of great interest, especially since ultra-dark material with an albedo of only 2 -3 % has been reported in the asteroid belt (Morrison, 1977) and in the outer solar system (Cruikshank, 1977).

In this letter we show that the apparently dark material on Phobos is only prominent at large phase angles and from its photometric properties we conclude that it represents areas of unusually rough texture whose reflectance near zero phase is similar to that of the mean surface ($\sim$6% in the visible), but whose phase curve is much steeper. Typically, we find that the contrast of such areas is less than 10% near zero phase but approaches 100% near phase angles of 90 degrees. We propose that these intricately textured deposits represent patches of vesicular impact melt (Goguen et al., 1978).

Figure 1 shows part of a Viking Orbiter 1 image of Phobos taken from a range of 286 km at a phase angle of 83 degrees.

Dark albedo markings are visible on the floors of some of the large craters such as A and B. By constructing brightness profiles across these markings (Fig. 2) we can determine the brightness ratio of a particular dark marking relative to its surroundings. For example, from Figure 2 we estimate brightness ratios (at 83° phase angle) of 0.23 and 0.35 for features A and B, respectively. (These brightness ratios correspond to the effective wavelength of the Viking CLEAR filter, or approximately 0.55 μm). Fortunately, we have images of features A and B at different phase angles and therefore can study the typical phase angle dependence of the brightness ratio. The results, for three different dark features on four different images, are plotted in Figure 3.

At phase angles $\alpha \lesssim 40^{\circ}$ there is close agreement among the points for different regions. A linear fit to the phase dependence of these points (dashed line, Fig. 3) indicates that the average normal reflectance of this material (i. e., the brightness ratio at $\alpha = 0^{\circ}$) is within 10% of that of the average surface material of Phobos. However, at $\alpha \lesssim 40^{\circ}$ the dark material has a phase coefficient (Veverka, 1977) 0.007 mag/deg (or about 30%) steeper than that of the mean surface. According to Noland and Veverka (1977) the intrinsic phase coefficient of the average surface material on Phobos is 0.020 mag/deg. The similar normal reflectance, but much larger phase coefficient of the dark material, is explained best in terms of a texture difference--the dark material appears to have a more rugged surface texture than does the average surface. The dark material appears darker at large phase angles because its rougher surface produces more shadows. This interpretation is consistent with the behavior of the points in Figure 3 at phase angles larger than 40°, where the points generally fall below the extrapolation of the dashed line. In Figure 4 we demonstrate that this fall-off of the brightness ratio at large phase angles is consistent with the predictions of simple models of macroscopic surface roughness. In this case we have used the very simple model of Veverka (1970) in which the effects of surface roughness are simulated by covering the surface with parabolic holes of a specified depth/diameter ratio (d/D). The observed behavior is matched best by a model with deep holes having d/D $\gtrsim \frac{1}{2}$. Such a pitted surface would be approximated by a vesicular material. Although the behavior at large phase angles is consistent with that expected for a pitted, vesicular surface, we note that this interpretation of the photometry is not unique. A qualitatively similar effect would result from positive roughness elements (Schoenberg, 1925) such as concentrations of coarse particles or boulders.

We propose that the deposits of texturally rough, and possibly vesicular, material on the floors of craters on Phobos, could be impact melt.

During high velocity impact cratering a large quantity of energy is released, some of which is expended in melting the target material. The melted and recrystallized rock, referred to as "impact melt" is similar in composition but often different in texture from the target material. According to Dence (1971), "...the melt rocks and glasses in shock-metamorphosed structures show greater similarity to the composition of adjacent country rocks than to each other." Dence, Short (1965) and Stoffler et al. (1975) all report vesicular glass as a common constituent of impact melt.

Figure 5 is a cross-section of Brent crater on the Canadian shield adapted from Dence (1968). At the bottom of the "primary crater" or "ejecta void" is a small pool of impact melt which is overlain by nearly a kilometer of fallback ejecta and sediments. Similar melt pools are found in nuclear explosion craters (Short, 1965). Short (1966) also points out that "shock-lithification" welds unconsolidated fragments together to form larger rocks. In either case, it is clear that the texture of the target material can be radically altered by the cratering event.

Since the melt pool forms at the bottom of the ejecta void during the early stages of crater formation it can remain visible only if fallback ejecta, slumping and sedimentary infilling are negligible--as is likely to be the case on an object such as Phobos for which g is extremely small. Ejecta should be spread over large distances compared to the crater size or escape completely. Such extended, thin ejecta blankets, if they occur, will result in some infilling of previously existing craters. This effect combined with surface erosion by micro-meteoroid impacts should eventually obliterate the dark markings. Therefore, dark crater deposits, if indeed they are impact melt, should be most conspicuous in the freshest craters. Similar features should be visible on small asteroids and other low g bodies.

Two other possible explanations for the dark markings should be mentioned:

a) the markings are due to the presence of a sub-surface unit of texturally coarse material exposed by the cratering events. We consider this possibility unlikely since we would expect the exposures of this unit to be concordant in depth, at least locally, which does not appear to be the case.

b) the markings may be due to accumulations of coarse debris on the floors of craters. This debris could be derived locally from crater walls or as ejecta from other cratering events. We consider the preferential accumulation of such materials on the floors of craters to be inefficient on Phobos since such processes involve gravity. In any case, according to this view, it is the older craters on Phobos which should show the more conspicuous markings (since they have accumulated more coarse material on their floors). On the other hand, the impact melt hypothesis which we favor predicts that the younger craters should exhibit dark patches better, since micrometeoroid erosion and blanketing by ejecta from other impacts will eventually obliterate the contrast between the impact melt and its surroundings. Available evidence supports the impact melt hypothesis: the dark markings are more conspicuous in fresher-looking less degraded craters.

There is no evidence that the dark markings are distributed non-uniformly on the surface of Phobos. Essentially, they are seen wherever adequate high resolution Viking coverage of craters exists on the satellite (Figure 6). Analogous markings have not been found on Deimos, possibly because most of the craters imaged at high resolution on the surface of the outer satellite appear to have been blanketed by several meters of fine-grained material having many of the characteristics of ejecta (Duxbury and Veverka, 1978; Thomas, 1978).

Acknowledgement

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References

Cruikshank, D.P., Radii and albedos of four Trojan asteroids and Jovian satellites 6 and 7, Icarus, 30, 224-230, 1977.

Dence, M.R., Shock zoning at Canadian craters: Petrography and structural implications, in Shock Metamorphism of Natural Materials, edited by B.M. French and N.M. Short, pp. 169-174, Mono, Baltimore, Md., 1968.

Duxbury, T. and Veverka, J., Deimos encounter by Viking: Imaging results. Science, in press, 1978.

Goguen, J., Veverka, J., Thomas, P. and Duxbury, T., Phobos: Photometry and origin of dark markings on crater floors. (Abstract) Reports of Planetary Geology Program, 1977-78, NASA Tech. Mem. 79729, 36-37, 1978.

Morrison, D., Diameters of minor planets, Sky and Telescope, 53, 181-83, 1977.

Noland, M., and Veverka, J., The photometric functions of Phobos and Deimos. III. Surface photometry of Phobos, Icarus, 30, 212-223, 1977.

Schoenberg, E., Investigations concerning theories of the illumination of the Moon based on photometric measurements. Acta Soc. Scien. Fennicea, 50, No. 9, 1925.

Short, N.M., A comparison of features characteristic of nuclear explosion craters and astroblemes, Ann. N.Y. Acad. Sci., 123, 573-616, 1965.

Short, N.M., Shock lithification of unconsolidated rock materials, Science, 154, 382-284, 1966.

Stoffler, D. Gault, D.E., Wedekind, J., and Polkowski, G., Experimental hypervelocity impact into quartz sand: Distribution and shock metamorphism of ejecta, J.Geophys. Res., 80, 4062-4077, 1975.

Thomas, P. The Morphology of Phobosand Deimos. Ph.D. Thesis. Cornell University, Ithaca, N.Y. (also Cornell CRSR Report No. 693), 1978.

Tolson, R.H., Duxbury, T.C., Born, G.H., Christensen, E.J. Diehl, R.E., Farless, D., Hildebrand, C.E., Mitchell, R.T., Molko, P.M., Morabito, L.A., Palluconi, F.D., Reichert R.J., R.J. Toraji, H., Veverka, J., Neugebauer, G., and Findlay, J.T., Viking first encounter of Phobos: Preliminary results, Science, 199, 61-64, 1978.

Veverka, J., Photometric and polarimetric studes of minor planets and satellites Ph.D., Thesis, Harvard University, Cambridge, MA, 1970.

Veverka, J., Photometry of satellite surfaces in Planetary Satellites (J. Burn, ed.) University of Arizona Press, 1977.

Figure Captions

Figure 1. A portion of Picture Number 248A05 taken by Viking Orbiter 1 with the clear filter ($\lambda = 0.55\ \mu m$) from a range of 286 km and 83° phase angle. Note the conspicuous patches of dark material on the floors of many craters (e.g., A and B). A 1 km scale bar is shown.

Figure 2. Sum of DN's for a 3 pixel wide scan along the lines through craters A and B in Figure 1. The numbers with arrows give the brightness ratio of the dark to average surface. The brightness of the average surface close to the dark marking and viewed from a similar geometry is shown as unity.

Figure 3. Relative phase curve showing the ratio of brightness of the dark and average materials as a function of the phase angle. Different symbols depict different dark features and arrows indicate that the point is an upper limit due to smearing of the image. The dashed line represents a linear phase function fit through points with $\alpha < 40°$.

Figure 4. Same as Figure 3, except including the results of a model of surface roughness parameterized by the depth/diameter (d/D) ratio of parabolic craters (see text).

Figure 5. Simplified cross-section of Brent Crater on the Canadian shield adapted from Dence (1968). Note the melt pool at the bottom of the "ejecta void".

Figure 6. Sketch map of Phobos showing locations of dark markings visible in Viking images.

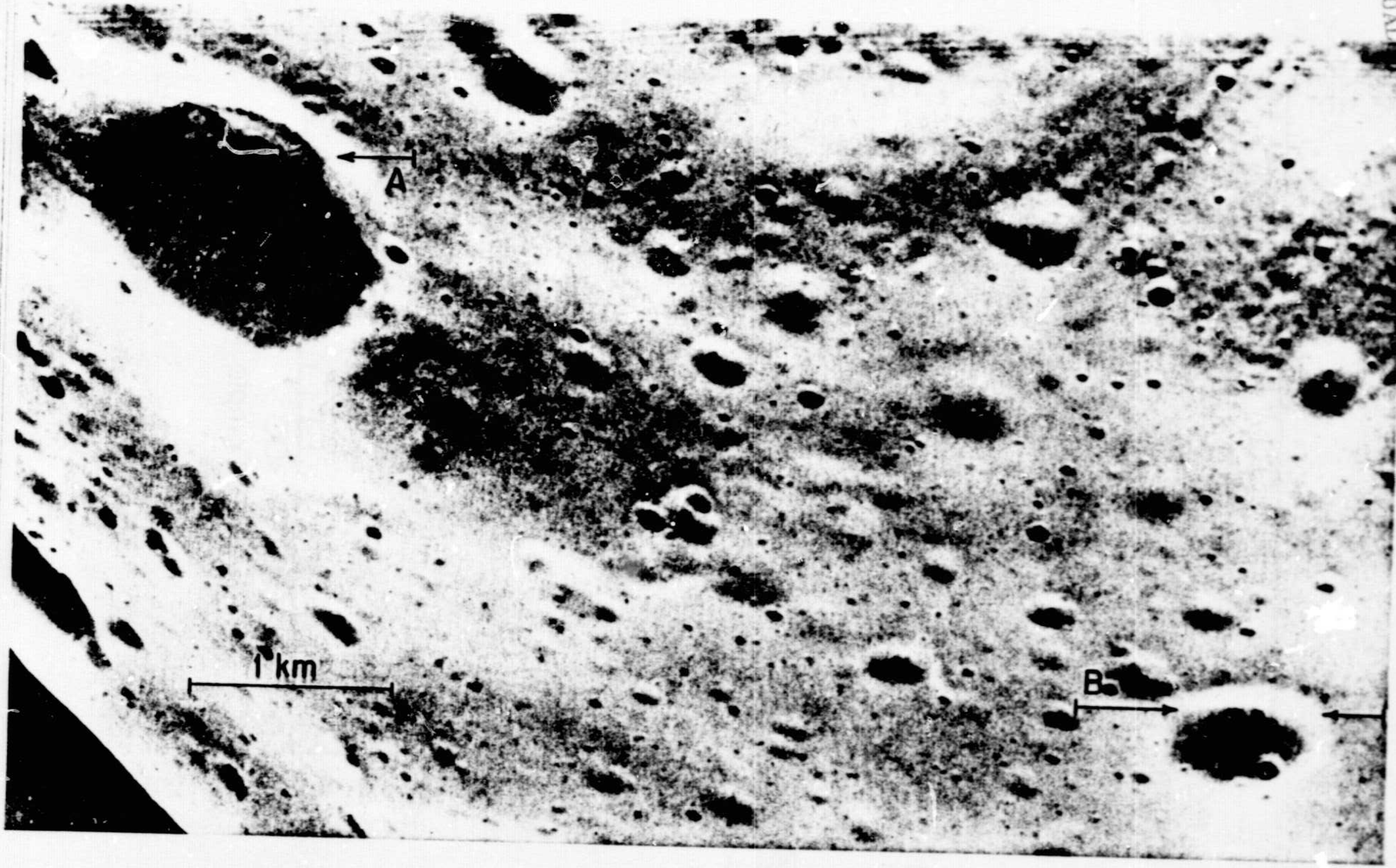


Fig. 1

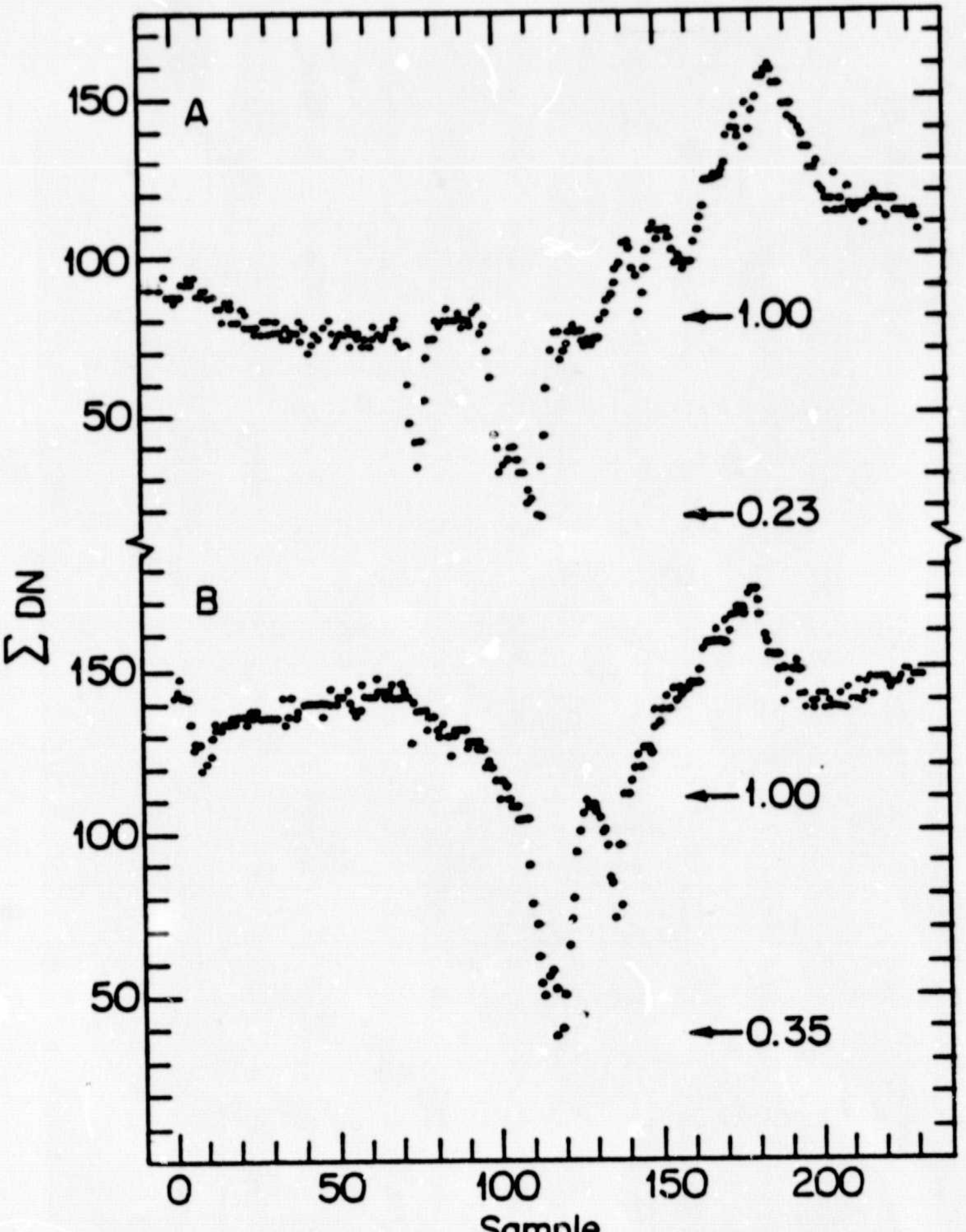
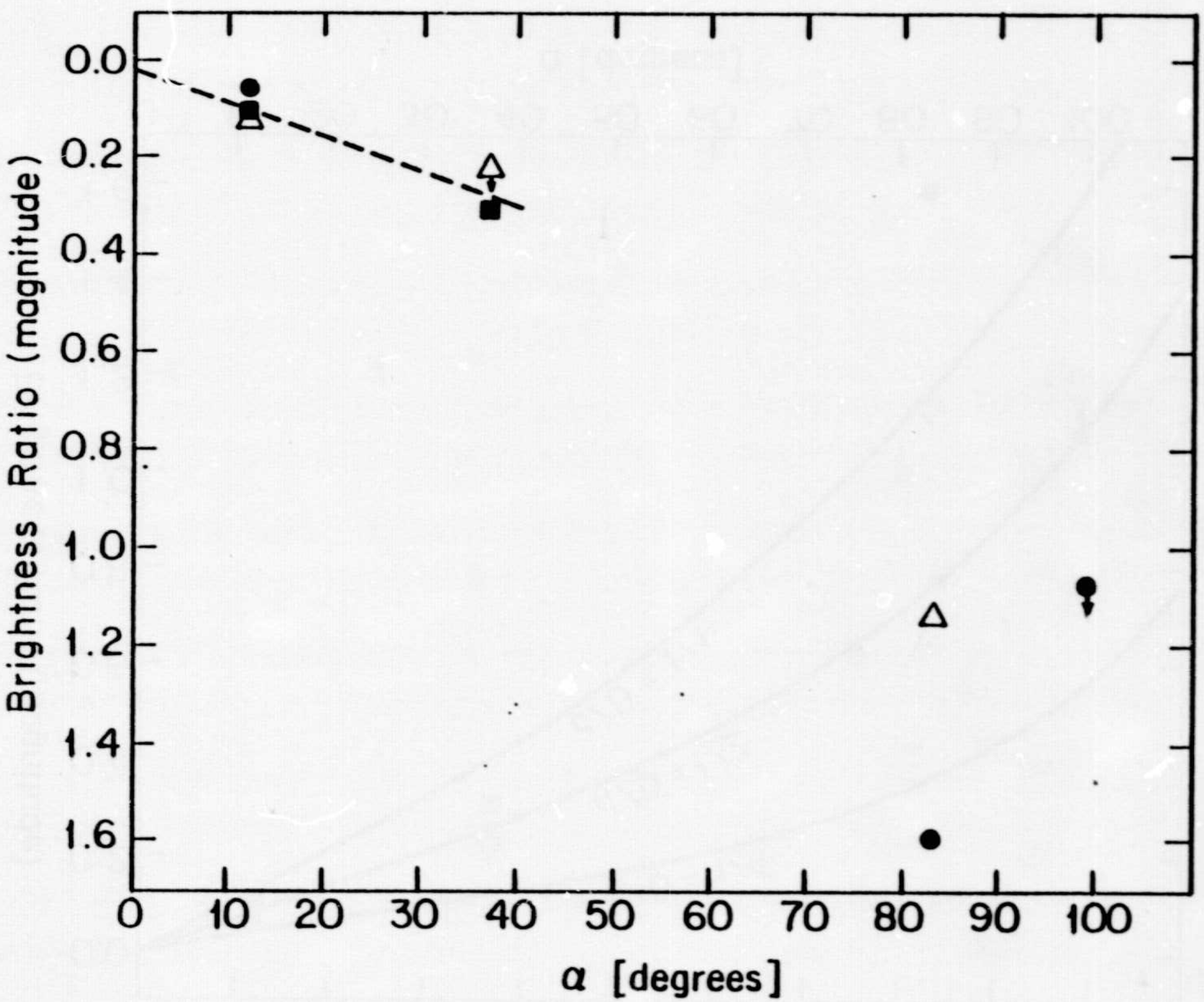
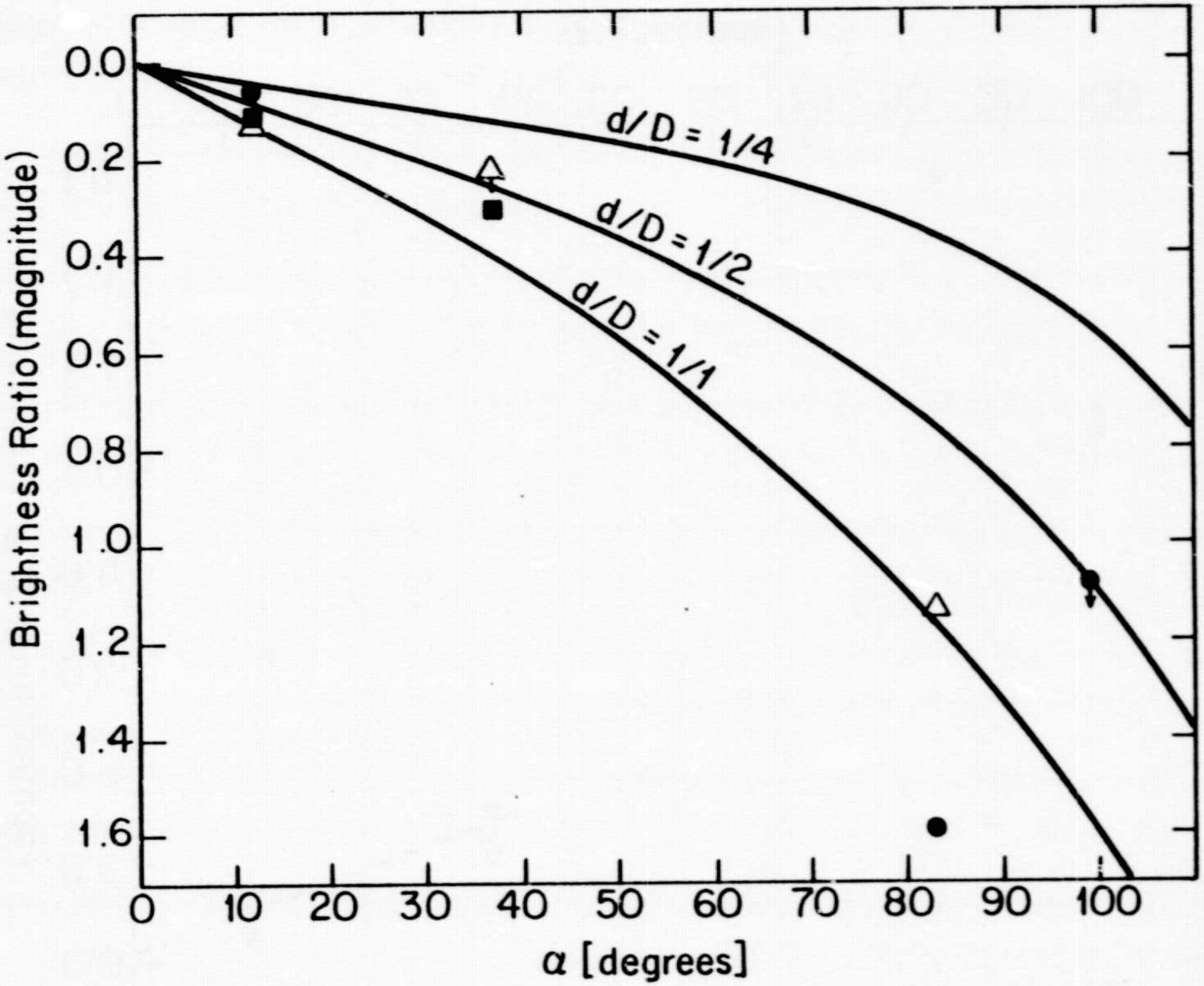


Fig. 2



Brightness Ratio (magnitude)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
0
10
20
30
40
50
60
70
80
90
100
α [degrees]

Fig. 3



Brightness Ratio (magnitude)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
d/D = 1/4
d/D = 1/2
d/D = 1/1
0
10
20
30
40
50
60
70
80
90
100
α [degrees]

Fig. 4

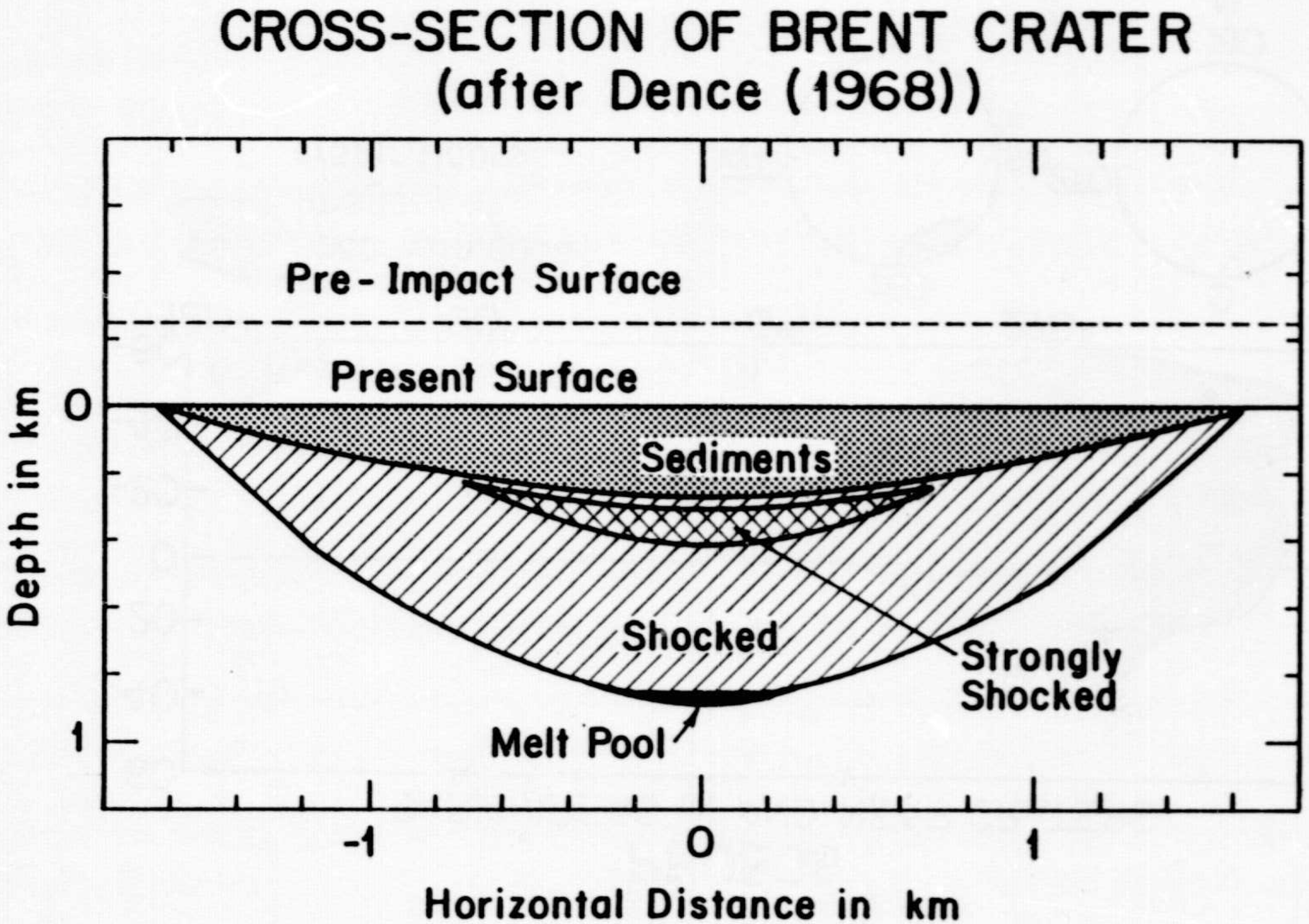

CROSS-SECTION OF BRENT CRATER
(after Dence (1968))
Pre-Impact Surface
Present Surface
Sediments
Shocked
Strongly Shocked
Melt Pool
Depth in km
0
1
-1
0
1
Horizontal Distance in km

Fig. 5

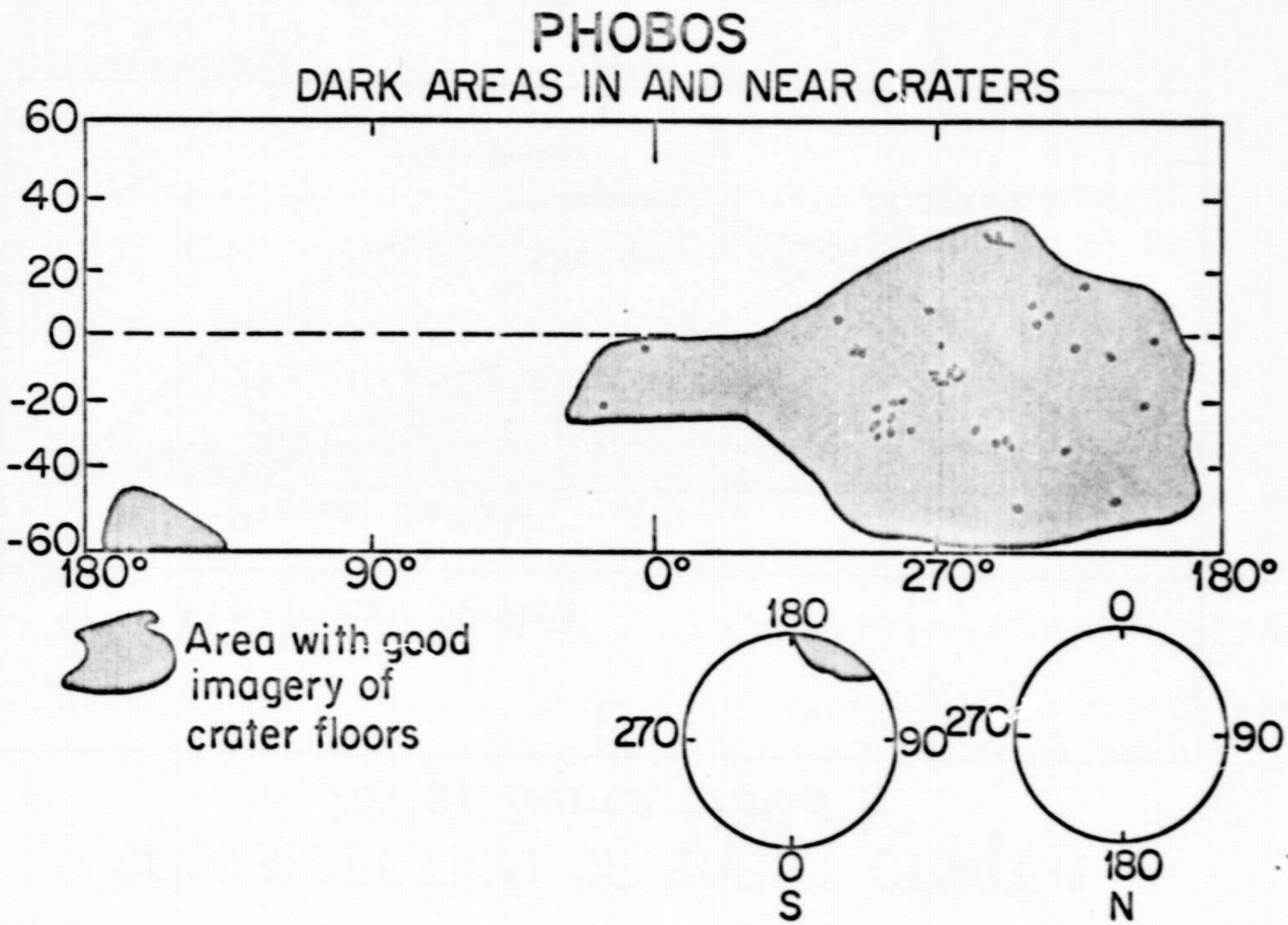

PHOBOS
DARK AREAS IN AND NEAR CRATERS
60
40
20
0
-20
-40
-60
180°
90°
0°
270°
180°
Area with good imagery of crater floors
180
270
90
0
S
0
270
90
180
N

Fig. 6