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Temporal Changes in the Cerberus Region of Mars: Mariner 9 and Viking Comparisons

ANDREW L. CHAIKIN, TED A. MAXWELL, AND FAROUK EL-BAZ

Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington, D.C. 20560

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As is seen from comparisons of Mariner 9 images obtained in 1972 and Viking Orbiter 1 images obtained in 1978, several changes have occurred in the Cerberus region of Mars. Changes in the boundary of the low albedo feature resulted in an increase of the total area of Cerberus by slightly more than 1%, although the southwestern boundary had shifted as much as 90 km. Relative darkening of Cerberus has resulted in a more uniform tone, and is accompanied by the disappearance of dark filamentary markings. Although several bright streaks within Cerberus changed in length, neither lengthening nor shortening of the streaks predominated. However, changes in streak direction indicate a clockwise rotation of mean streak azimuth between 1972 and 1978. These changes in the outline and appearance of Cerberus can best be explained by eolian redistribution and removal of bright material during major dust storms. Volcanic flow fronts which show through the albedo feature indicate that the contrast between Cerberus and the surrounding light plains is not due to a difference in lithology, but to the distribution of surficial deposits. Because of local topographic influences on the regional atmospheric circulation patterns, it is probable that Cerberus will retain a similar appearance and location.

INTRODUCTION

The Cerberus region of Mars, centered at 12°N, 205°W, contains abundant evidence of wind erosion and deposition characteristic of the present-day Martian climate. The Cerberus albedo feature is one of the classical dark regions of Mars named by G. Schiaparelli from observations in the late 1800s, and forms the southern boundary of the bright feature called Elysium. As seen in Earth-based telescopic photographs, Cerberus consists of a faint dark area extending approximately 1000 km east-northeast from the equator to a slightly darker area known as Trivium Charontis (see map by Schiaparelli; reproduced in Mutch *et al.*, 1976, p. 10). Although Earth-based photographs show extensive changes of dark markings within the hemisphere containing Cerberus and Syrtis Major, these changes have not permanently affected the location of Cerberus, which appears similarly placed in photographs taken from 1907 until 1954 (Slipher, 1962, Plate XXXV). In this paper we survey changes in the appearance and outline of Cerberus over the 6 years between the acquisition of Mariner 9 and Viking images, as well as analyze wind streaks contained within the albedo feature.

As noted by Thomas and Veverka (1979), absolute comparisons of the photometric characteristics of Mariner 9 and Viking images are limited by such factors as different emission and incidence angles, atmospheric opacity, and filters (Mariner 9 images were limited to a clear filter). However, sufficient coverage of the Cerberus region exists so that comparisons can be made of both large- and small-scale albedo variations which are most distinct in Viking frames taken with the clear and red filters. Consistent with the planet-wide low contrast in the near-UV wavelengths (Soderblom *et al.*, 1978), images of Cerberus with the violet filter show very little of the

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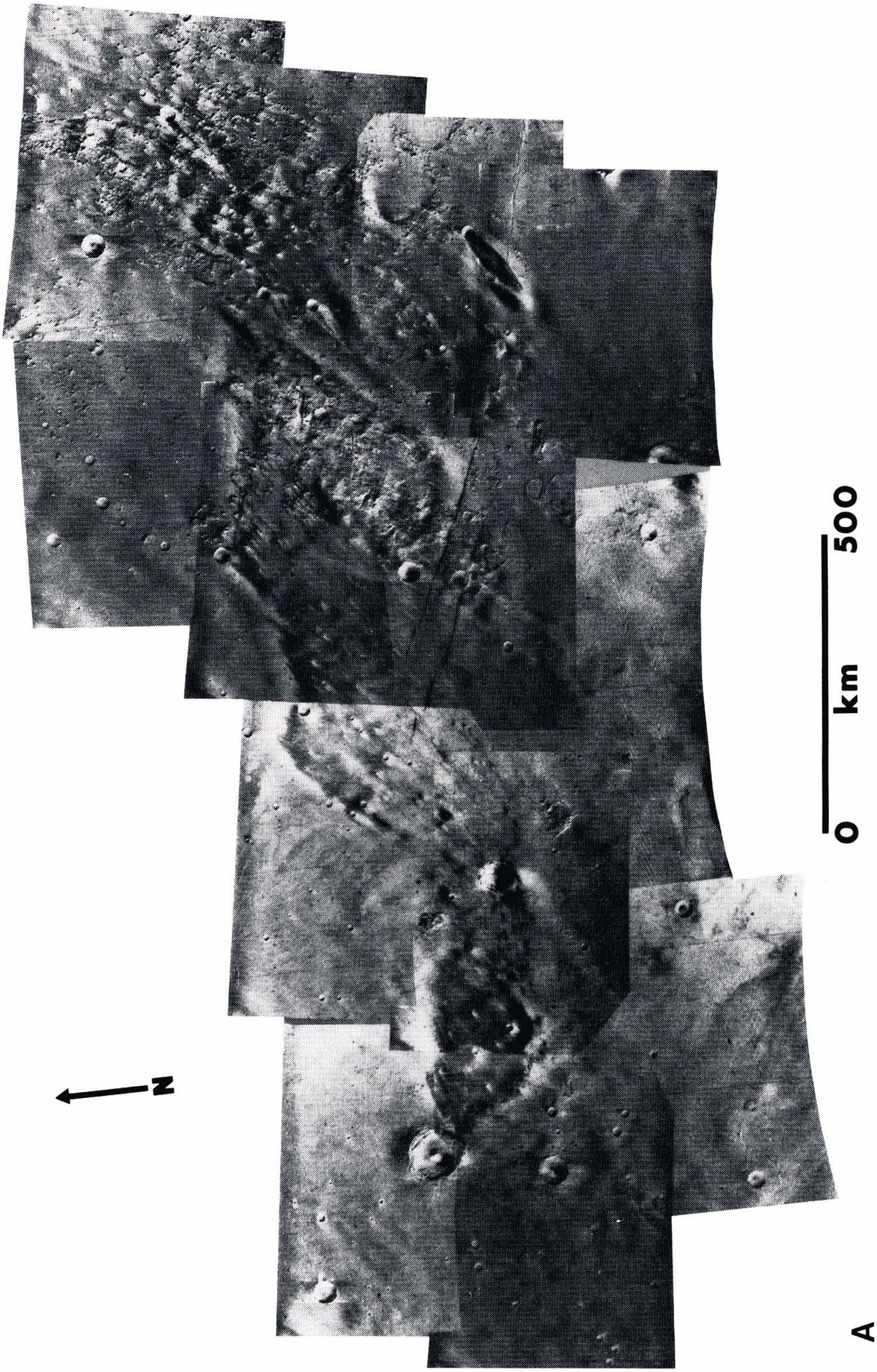
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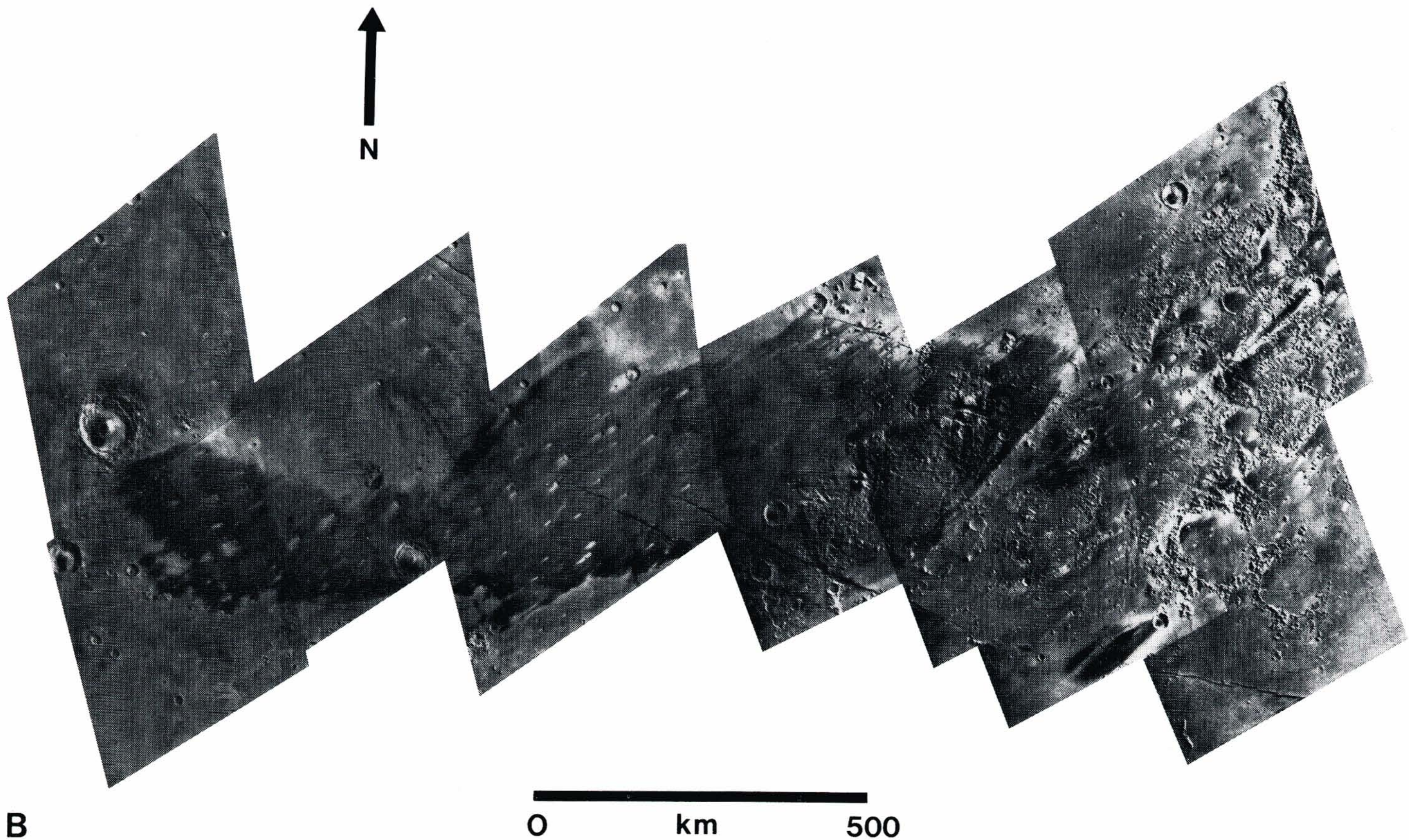

FIG. 1. Mariner 9 (A) and Viking 1 (B) mosaics of the Cerberus albedo feature, centered at 12°N, 205°W in the Elysium Quadrangle. Images for the Mariner 9 mosaic taken in February 1972, and those for the Viking 1 mosaic were taken in March and April 1978.

classical low-albedo marking. Further details of image processing can be found in Thorpe (1973, 1976).

Previous studies of Martian eolian surface patterns have concentrated primarily on the appearance (and disappearance) of crater-related streaks and splotches (Arvidson, 1974; Cutts and Smith, 1973; Greeley *et al.,* 1978; Sagan *et al.,* 1972, 1973; Thomas and Veverka, 1979; Veverka, 1975, 1976) rather than movement of large albedo features such as Cerberus. Consequently, the documentation of changes of one of the classical Martian albedo features fills an important gap in the understanding of the eolian regime. We will first present evidence for large-scale albedo variations and movement of Cerberus, followed by the results of investigations of crater- and knob-related streaks. Finally, models for the eolian origin of large- and small-scale albedo variations will be considered with respect to the Grand size and composition of surface materials.

GEOLOGIC SETTING

Cerberus is located in the Elysium quadrangle of Mars and consists of a dark zone, which is elongate in an E–W direction, measuring 1330 × 410 km at its maximum dimensions (Fig. 1). It lies 650 km to the southeast of Elysium Mons, and is bordered on the east by knobby, cratered terrain. On the basis of Mariner 9 A Frames, Scott and Allingham (1976) mapped Cerberus as a "streaked-plains" unit (Fig. 2) consisting of lava flow units with abundant wind streaks. Crater densities for the streaked plains indicate that it is the oldest plains unit in the quadrangle.

Surrounding the dark-streaked plains of Cerberus are three additional plains units interpreted to be varying mixtures of volcanic and eolian deposits. The rolling-plains unit, which occurs to the north and south of Cerberus was mapped as lava flows, some of which may have come from Elysium Mons and Albor Tholus. The rolling plains were described by Scott and Allingham (1976) as being modified by eolian deposits, and crater densities in that unit are lower than in the streaked plains of Cerberus. Additional plains units were interpreted as eolian deposits of variable thickness. The low crater density of the smooth plains unit to the southeast of Cerberus (Fig. 2) suggests that it is the youngest plains unit in the quadrangle (Scott and Allingham, 1976).

CHANGES IN CERBERUS: 1972–1978

Changes in Outline

The Mariner 9 and Viking 1 images of Cerberus are separated by more than 6 years. Most of the Mariner 9 coverage was taken in February (aerocentric longitude, $L_s = 66°$), June ($L_s = 138°$), and August ($L_s = 159°$) of 1972. The Viking 1 images used here were taken in March ($L_s = 142°$) and April ($L_s = 160°$) of 1978. Comparison of the Mariner and Viking images indicates that Cerberus became more distinct between 1972 and 1978, and darkening of large areas within the feature gave it a more uniform tone.

The outline of Cerberus in 1978 differs from that of 1972 in several places (Fig. 3). As a result of these changes, the total area of Cerberus increased approximately 4000 km^2 out of a total area of about 350,000 km^2, or by about 1.2%. Most of the increase in the area of Cerberus was at the expense of the bright plains surrounding the western portion of the feature. The western portion of Cerberus increased by 16%, whereas the eastern portion decreased by approximately 9%.

The changes in the outline of Cerberus involved a displacement of the 1972 boundary in a south or southwest direction, with the most pronounced change along the southwestern edge. The maximum displacement, measured parallel to the NW–SE direction of bright wind streaks is 90 km. The northeast boundary, characterized by knobby terrain, and the downwind edges of coalescing knob streaks also changed no-

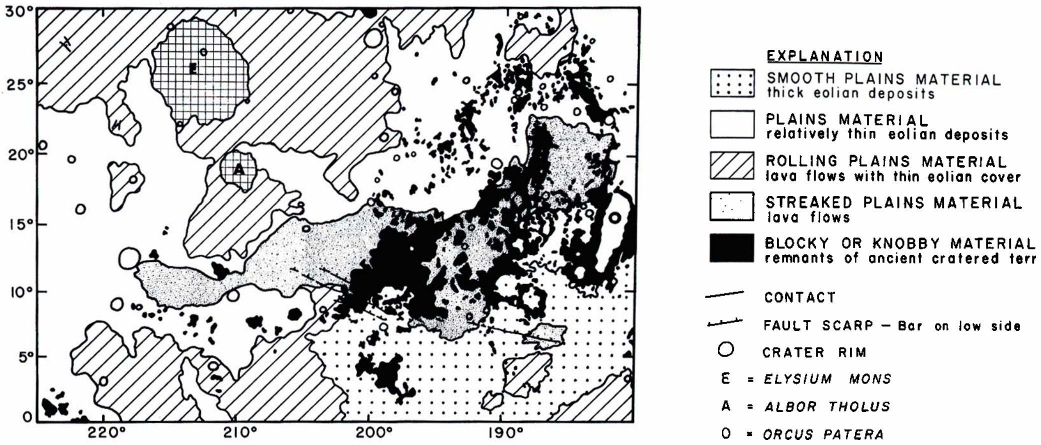

FIG. 2. Geologic sketch map of the Elysium Quadrangle, based on the geologic map by Scott and Allingham (1976). The Cerberus albedo feature is mapped as "streaked plains," one of the stratigraphically oldest units.

ticeably. Because of southward motion of the boundary from 1972 to 1978, some knob streaks are no longer completely delineated.

Some areas of Cerberus changed little in the time between Mariner 9 and Viking 1 coverage. Along the northern edge of the central portion of Cerberus, for example, there were only slight changes in the boundary (Fig. 3).

Wind Streaks

A few scattered dark-toned streaks were present on the windward (NE) side of craters in Cerberus during 1972; by 1978 these dark streaks had disappeared. However, bright streaks in Cerberus are similar in both 1972 and 1978 images, although some changes in streak length and orientation have occurred. Thomas and Veverka (1979) noted that bright streaks in Cerberus were generally 10% longer than they were in 1972, although many remained unchanged. For this study, measurements of streak length were made for 17 crater streaks and 15 knob streaks whose outlines were distinct in both Mariner and Viking images. Streak lengths were measured from the

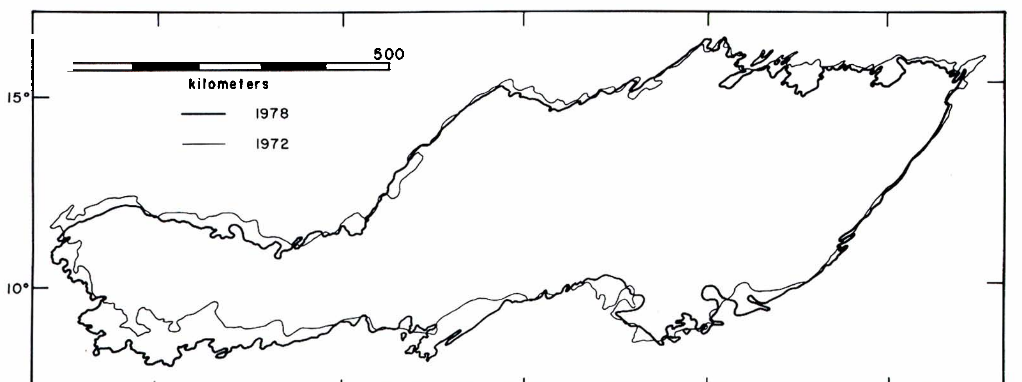

FIG. 3. Outline map of Cerberus showing changes between 1972 and 1978. The boundary in the southwest portion of Cerberus has shifted as much as 90 km to the southwest while areas along the north-central boundary remained relatively stable.

downwind edge of the crater or knob to the tip of the streak. If the streak had a ragged downwind edge, an "average length" was taken (this being necessarily a subjective measurement). Comparison of these streak lengths indicates that many streaks showed a 5- to 15-km change in length, but neither lengthening nor shortening of the streaks predominated.

In addition to the numerous crater-related streaks within Cerberus, bright streaks also occur to the southwest of irregularly shaped knobs that appear to protrude through the plains material. A comparison of several crater and knob streaks was made using the streak length (L) vs crater or knob diameter (D) as measured from Viking images. The knob widths were measured perpendicular to the streak direction, so that the maximum component of the knob width acting as a barrier to the wind flow was taken. As shown in Fig. 4, both crater- and knob-related streaks occur in the same general size range, suggesting that craters and knobs behave approximately the same in the wind flow (El-Baz and Maxwell, 1980).

Analysis of 67 bright crater streaks and 25 knob streaks indicates that the mean streak direction has rotated clockwise between 1972 and 1978. The mean azimuth for

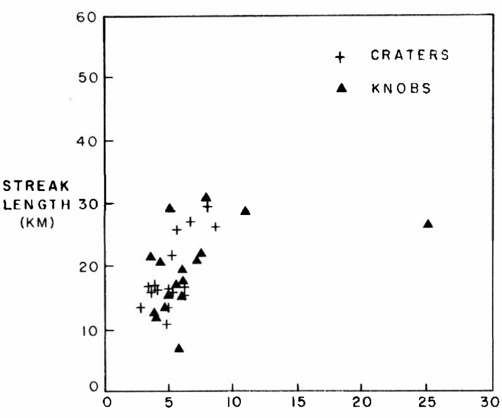

FIG. 4. Streak length versus crater diameter (and knob width) for bright wind streaks within Cerberus. Both craters and knobs produce similar scale streaks.

the crater streaks in 1972 was S 46°W, while in 1978 it was S 57°W. However, the mean azimuth of knob streaks, located at the northeastern edge of Cerberus, changed only 2°, from S 52°W to S 54°W (Fig. 5).

Dark Filamentary Markings

Thin, dark-toned lineations observed on Mariner 9 images of the Cerberus region were previously described by Veverka (1976), who used the term "dark filamentary markings." These lineations are only a few pixels wide (<400 m) on Mariner 9 B Frames, and were imaged in three locations in the Cerberus region; in the bright plains below the southwestern boundary, along the north-central boundary, and in the knobby terrain along the northeast boundary. The markings occur in greater number and density within Cerberus than outside Cerberus, and in many cases, the markings show a preferred orientation approximately parallel to that of nearby wind streaks.

As shown by images made later in the Mariner 9 mission, and by Viking images, these small filaments are not permanent features. Dark filaments that were present in the northeast part of Cerberus in February 1972 were no longer visible 6 months later, during which time the area had also become more uniformly dark. The Mariner 9 B Frames which document these changes differ in sun illumination angle by only 13° and in phase angle by 8°, so that it is unlikely that their disappearance is due to different viewing geometry. In a 1978 Viking image with a greater resolution (152 m/pixel) than the Mariner 9 image (180 m/pixel), the dark filaments are not present, although the larger-scale albedo patterns surrounding the filaments are still visible.

In 1972, dark filamentary markings were also present in the bright plains south of the southwest boundary of Cerberus. The Mariner 9 B Frames that show these markings (Fig. 6) were taken more than a month after the disappearance of filaments in northeast-

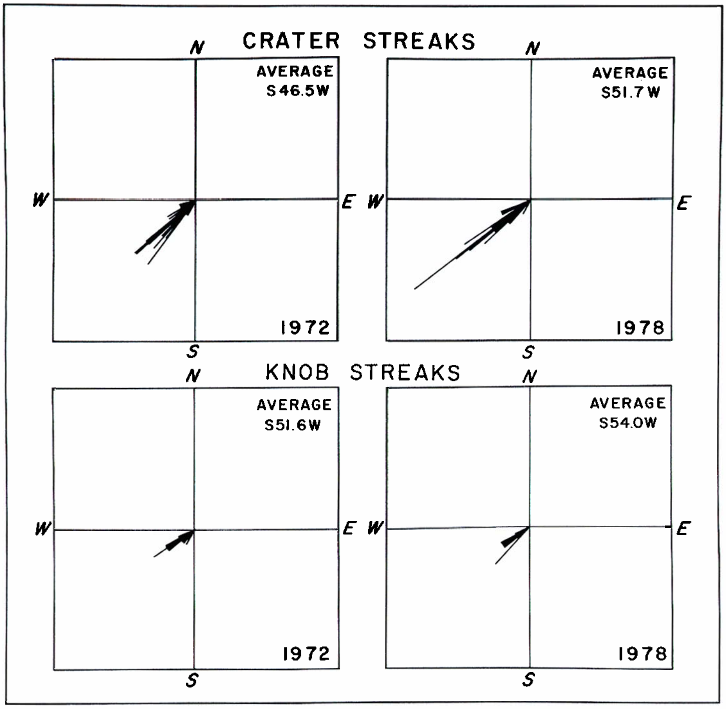

FIG. 5. Crater- and knob-streak orientation in Cerberus. Crater-streak direction shifted approximately 10° to the west between 1972 and 1978, during which time knob streaks in the northeastern part of Cerberus shifted approximately 2°.

ern Cerberus. As shown by Viking images, much of the area in the southwest where filaments were present in 1972 is now part of Cerberus itself, and dark filaments are no longer visible. Although their disappearance may be due to the slightly lower resolution of the Viking images (270 m/pixel), it is probable that the filaments have disappeared here in association with the general darkening of the area.

DISCUSSION

On the basis of observations of the outline of Cerberus and the behavior of streaks and small filamentary markings, these changes can best be explained by embayment of the dark surface by bright material in the north, and removal of bright material in the south to expose a dark substrate. This combination of erosion and deposition is similar to the model proposed for changes in dark areas by Kuiper (1957), and Pollack and Sagan (1967), who noted that the dark areas on Mars which exhibit secular change are "completely or almost completely surrounded by bright areas."

Movement of the northeast boundary of Cerberus most likely resulted from transportation of bright material during global dust storms, at least three of which have occurred between 1972 and 1978 (Briggs *et al.*, 1979). Transportation of bright material is consistent with spectral reflectance data which suggest that dust cloud material is mineralogically identical to the surface layer of other bright areas on Mars (McCord *et al.*, 1977). However, not all of the changes were in response to major dust storm activity. It took less than 6 months for the filaments in the northeast part of Cerberus to disappear after the 1971–1972 dust storm. The general darkening of this area which took place during this period suggests that the disappearance of the dark

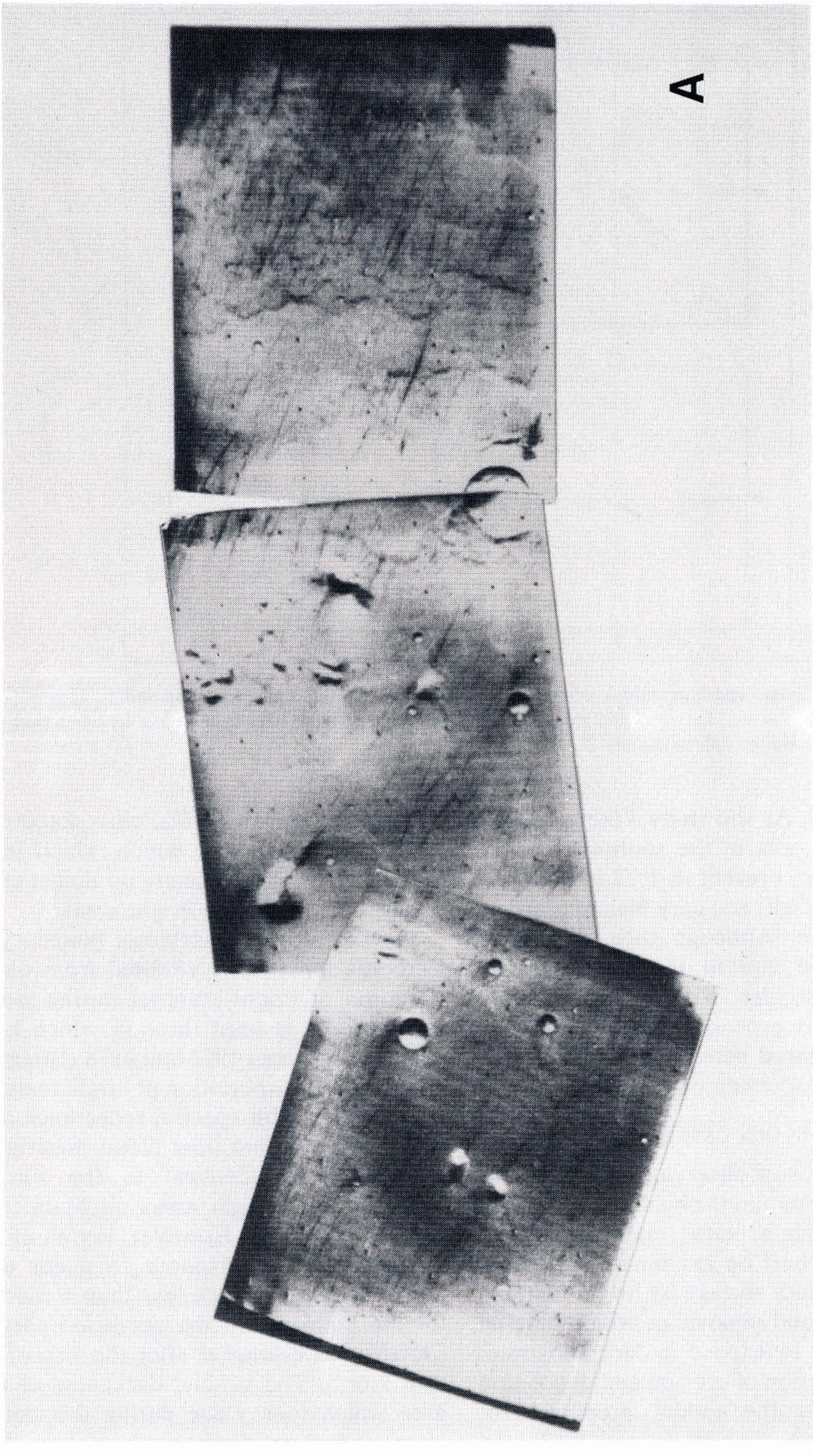

FIG. 6A. Mosaic of three Mariner 9 B Frames located 90 km south of Cerberus' 1972 southwestern boundary showing dark filamentary markings not aligned with the direction of nearby bright streaks. (DAS 12150957, 12150747, 12150817; clear filter).

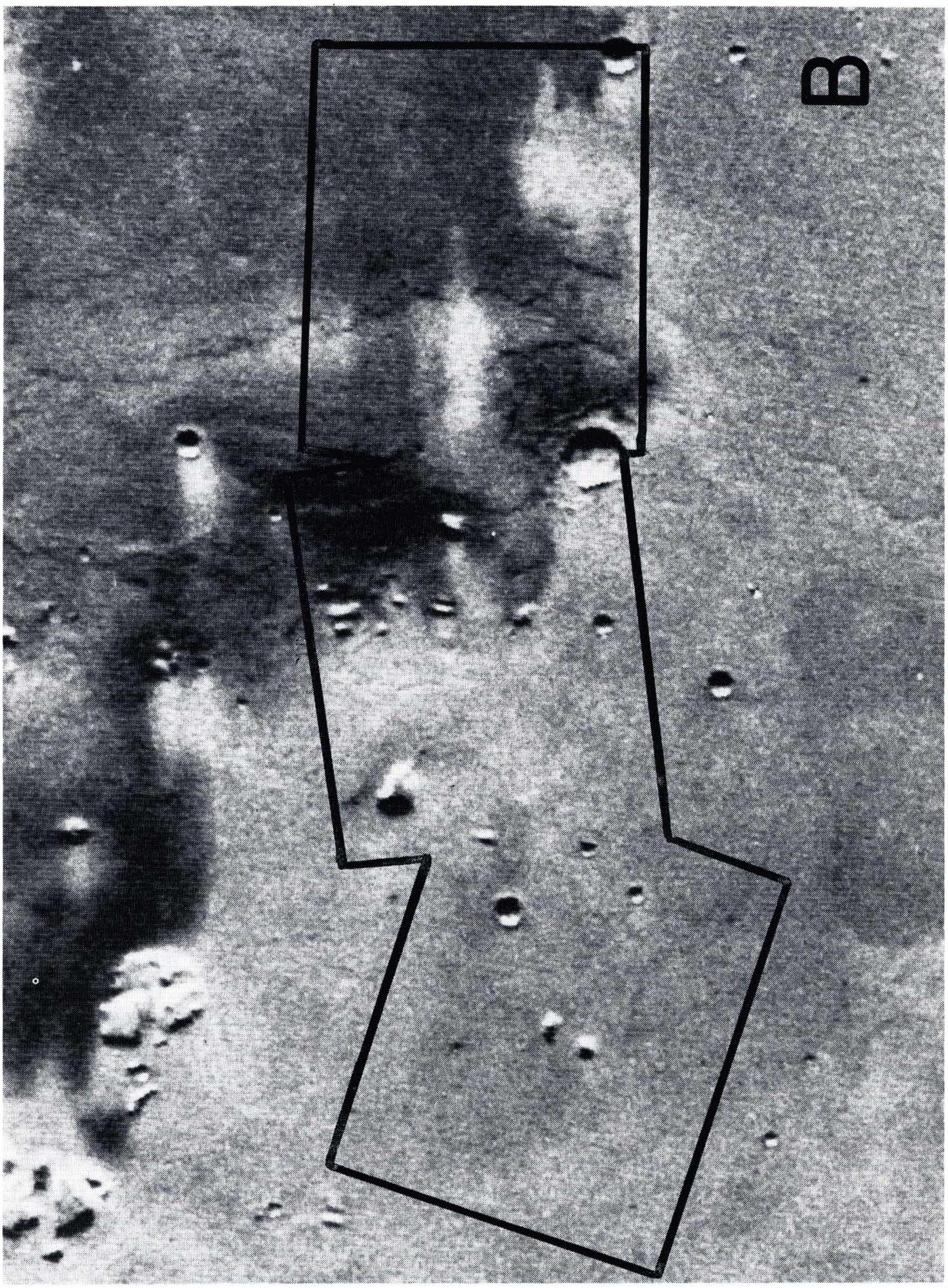

FIG. 6B. Viking image of the same area in 1978 showing overall darkening and displacement of the southern boundary of Cerberus (Viking 1 frame 631 A24; red filter).

filaments was caused by the removal of a thin layer of duststorm fallout. During the time just after the 1971 dust storm, preferential erosion of dust from joints (Veverka, 1976) could have produced the filaments. After 6 months, however, enough erosion would have occurred to remove the remaining dust as well, darkening the surface and making the filaments invisible.

An extreme upper limit on the thickness of the bright eolian cover surrounding Cerberus may be provided by volcanic flows which trace continuous paths across the feature. However, experimental evidence suggests that even a coating of bright dust a few microns thick could account for the fact that large areas of Cerberus were apparently swept clean of bright material in the 6 years between the Mariner and Viking coverage. In the western one-third of Cerberus alone, for example, an area in excess of 11,000 km^2 was stripped of its bright cover.

Some additional clues as to the nature of the surface material within Cerberus are provided by the Viking Infrared Thermal Mapping (IRTM) experiment. Since thermal inertia depends on the conductivity of the surface [which in turn is related to particle size; Kieffer *et al.* (1977)], thermal inertia values can be used to deduce some information about possible particle sizes. Peterfreund and Kieffer (1977) found that Cerberus is located within a zone of relatively high thermal inertia, and Peterfreund (1980) noted that the bright streaks in the Cerberus region occur in an area with low albedo and high thermal inertia. However, the 2° bin size did not allow resolution of the individual streaks. Thermal inertia values within Cerberus reach maxima of 10 milli-inertias (10^{-3} cal cm^{-2} $sec^{-1/2}$ $°K^{-1}$) in several places [Plate 1d in Zimbelman and Kieffer (1979)]. For an average thermal inertia of 8, a thermally homogeneous deposit of about 0.6-mm-sized material a few centimeters in depth (Kieffer *et al.*, 1977, Fig. 10) could be responsible for the range of values reported for Cerberus. However, because of the regional setting of Cerberus at the edge of the Elysium volcanic region, and the presence of individual flows that can be traced through the feature, it is likely that the surface consists of a mixture of rock sizes; relatively large lag deposits originating from the volcanic flows, and some residual fine-grained eolian deposits, particularly in the lee of craters and knobs.

Changes in the appearance of both dark and bright wind streaks are similarly consistent with major erosional and depositional episodes at the times of dust storms. The direction of dust storm winds implied by these streaks is NE–SW, similar to the changes in the boundary of Cerberus. The edges of Cerberus that are oriented transverse to the inferred wind direction have changed the most, while the edges lying parallel to the wind direction have changed the least. In addition, the small dark streaks which are not present in Viking images of Cerberus may have been obscured by either deposition of bright material during dust storm activity, or removal of bright material from the surface adjacent to the dark streak. The latter possibility is supported by the change in the appearance of parts of Cerberus to a more uniformly dark tone between 1972 and 1978.

The general NE–SW orientation of the bright streaks within Cerberus is consistent with atmospheric circulation patterns for near-surface winds in the north equatorial region during southern hemisphere summer derived from the Mariner 9 infrared-spectroscopy date (Sagan *et al.*, 1973). However, this pattern is locally altered in the case of streaks adjacent to topographic features such as other craters. In particular, the knob streaks located at the northeastern edge of Cerberus experienced the least change in orientation between 1972 and 1978, possibly resulting from the topographic influence on near-surface winds imposed by the rugged terrain to the east. In addition, large-scale features (such as Elysium Mons) are probably important influences on regional atmospheric circulation (Veverka *et al.*, 1978). A combination of both regional and local topographic irregularities may thus explain the long-term stability of the Cerberus albedo feature.

CONCLUSIONS

Comparison of Mariner 9 and Viking images indicates that two major types of changes took place in the Cerberus albedo feature between 1972 and 1978:

(1) Changes in the outline of the feature resulted in an increase in the total area of Cerberus by about 1.2%. The most significant changes occurred in the southwestern region, where the boundary shifted as much as 90 km.

(2) Darkening of many areas within Cerberus resulted in the development of a more uniform dark tone. In places where dark filamentary markings were present in 1972, this darkening was accompanied by the disappearance of the filaments.

Both kinds of changes can be explained by eolian redistribution and removal of bright material during major dust storm activity.

Both crater and knob streaks in Cerberus occur within the same size range in a plot of streak length vs crater diameter (or knob width), suggesting that craters and knobs behave approximately the same way in the wind flow. Neither lengthening nor shortening of crater and knob streaks predominated between 1972 and 1978, further suggesting that individual crater or knob morphology may be more important than atmospheric circulation in determining whether deposition or deflation will occur at a particular streak.

The mean streak azimuth of crater streaks rotated 11° clockwise between 1972 and 1978, during which time the orientation of knob streaks at the northeastern edge of Cerberus rotated only 2°. The changes in length and orientation of the bright streaks could be the result of major dust storm activity or of more frequent eolian activity in the Cerberus region. Several craters within Cerberus had both bright streaks and dark streaks in 1972, with the dark streaks trending opposite to the NE–SW orientation of the bright streaks. The dark streaks, which resemble other dark streaks interpreted as erosional features, were absent in 1978, most likely resulting from eolian removal of bright dust around the streaks.

The darkening of volcanic flows which can be traced from the bright plains north of Cerberus into Cerberus itself is inconclusive evidence for the cause of Cerberus' dark appearance. Viking IRTM data does not resolve the ambiguity. Taken together, the IRTM data and spectral studies indicate that only a thin layer of bright dust surrounds Cerberus. This is consistent with the changes between 1972 and 1978, and suggests that more dark areas may be exposed with time, particularly as the albedo feature migrates to the south. However, topographic features such as Elysium Mons and the rugged terrain to the east of the feature may influence the regional atmospheric circulation pattern, helping the feature to maintain a similar appearance and location.

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