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Variable Features on Mars. VI. An Unusual Crater Streak in Mesogaea

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An unusual, prominent dark streak located in Mesogaea (near 8° N, 191° W) is described. Its appearance is unlike that of most dark streaks on Mars, many of which have ragged outlines, are variable on short time-scales, and are presumed to be erosional. The Mesogaea streak has a tapered, smooth outline, and no changes within it were observed. We suggest that this streak is depositional and that the low-albedo material originated within the associated crater itself. The source area is identified with a compact, low-albedo region on the crater floor. Two possible origins for the dark material are suggested: (1) deflation from a recently exposed, relatively unconsolidated subsurface deposit, and (2) production of ash by a volcanic vent.

1. Introduction

Mariner 9 photography revealed that crater-associated streaks are common albedo features in many areas of Mars (Sagan *et al.*, 1972, Paper I). These streaks are evidently aeolian, being produced by the transport of dust and sand by winds. Several mechanisms for the production of crater streaks can be suggested, including the deflation of sand or dust from crater floors (Sagan *et al.*, 1972, 1973). Since on Mars both bright and dark wind-transportable material is encountered (evidenced by bright dust clouds and low-albedo dune fields, respectively), a category of dark tails, produced by the deflation of dark sand or dust from craters, could exist. The source of dark material could be wind-accumulated deposits, or locally produced particulates of low-albedo material such as dark volcanic ash. In this paper we discuss one of the most prominent crater streaks found on Mars by Mariner 9, and present evidence that it probably falls into the latter subgroup. Examples of dark streaks which probably fall into the former subgroup are easier to find and are discussed first in the following section.

2. Dark Crater Streaks Produced by Deflation

From a statistical study of dark crater splotches and dark crater streaks at high southern altitudes, Arvidson (1974) suggested that many dark splotches in these regions probably result from the trapping of dark sand on the leeward sides of crater floors. He noted that craters with both dark splotches and dark streaks usually are shallow and lack raised rims; he explained this observation in terms of ponded dark sands that are easily blown over crater walls producing downwind streaks. It is unlikely that all crater splotches and dark streaks, even at high southern latitudes, fall into this category. For example, some splotches may be produced by wind erosion of a layer of bright dust from an underlying dark substrate (Sagan *et al.*, 1972; Greeley *et al.*, 1974; Veverka *et al.*, 1974).

Figure 1 shows examples of craters with both dark splotches and dark streaks. In some cases the likely explanation of these albedo features is probably the deflation of dark sand or dust which has accumulated within the crater. Generally these craters

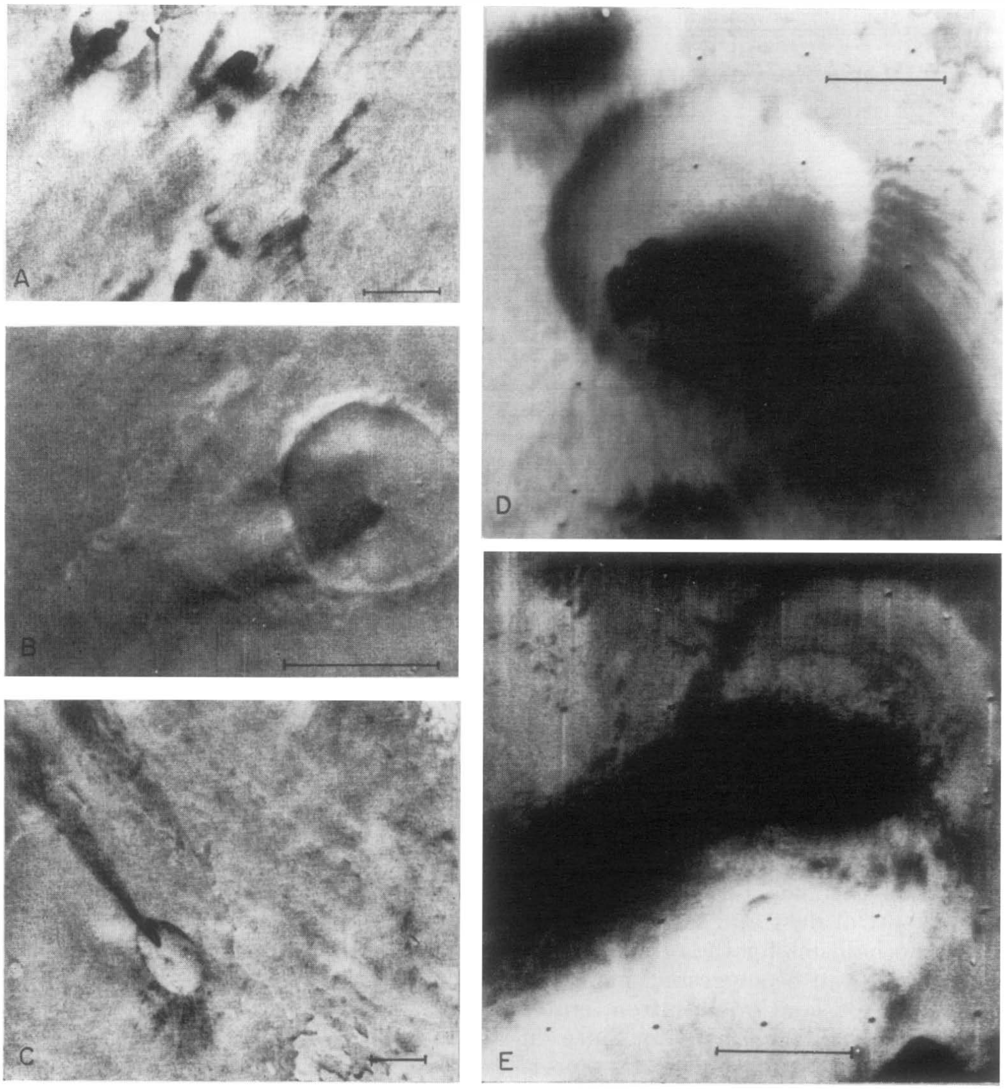

Fig. 1. Examples of dark streaks emanating from dark splotches on crater floors: (A) Orbit 149 (DAS 06928813); (61°S, 347°W). (B) Orbit 123 (DAS 05994663); (53°S, 109°W). (C) Orbit 149 (DAS 06928533); (64°S, 346°W). (D) Orbit 179 (DAS 08008353); (60°S, 234°W). (E) Orbit 138 (DAS 06533803); (60°S, 233°W). The scale bars represent 10 km.

appear to have low to nonexistent ramparts. In these instances there are no compelling reasons to believe that the deflated dark material originated with the crater itself. It is possible that under average wind conditions such craters act as efficient traps for wind-transported material; only unusually strong winds can deflate this accumulated material, producing dark streaks (Sagan *et al.*, 1972, 1973).

A related method of producing a depositional dark streak would obtain if there were a source of low-albedo material within the crater itself, such as a recently exposed, unconsolidated deposit, or even a volcanic vent. In either case, low-albedo material derived from the source area could be deposited downwind forming a streak.

3. The Mesogaea Crater Streak: Observations

Perhaps the best example of a dark crater streak that may have been produced by the deflation of low-albedo material originating within the crater itself is shown in Figs. 2–4.

The area lies in the Mesogaea region (8°N, 191°W), just east of Cerberus—the dark marking which trends northeast–southwest and marks the southeastern edge of the volcanic plateau Elysium. A local prevailing wind direction is indicated by numerous crater streaks trending southwest. Most of these streaks are bright and fairly short, 10–20km long. Dark crater tails are unusual in this region but those that do occur indicate a similar wind direction. The classical albedo marking Cerberus appears to owe its existence to these winds since it seems to consist of deposits of dark windblown material over which short bright crater tails are superposed.

The dark crater tail studied in this paper is unusual both for this area and for Mars as a whole. It is true that there is one crater in the downwind direction with a somewhat similar dark streak (Fig. 2), but unfortunately, no Mariner 9 imagery adequate to allow a meaningful analysis of this particular crater exists.

The principal crater streak (Fig. 3) extends some 120km downwind (southwest) from a crater about 25km in diameter. About 60km downwind from the crater rim, the streak interacts with a smaller crater (~ 18km). The maximum width of the streak is about 30km.

High-resolution photographs of various portions of the streak are shown in Fig. 4. A number of significant points emerge from a careful study of this and the previous figure:

(a) The streak originates within the 25km crater.
(b) There is an intense dark area on the floor of this crater.
(c) The darkness of the crater streak is nonuniform.
(d) An asymmetric bright streak is seen in the lee of the 18km crater; similar streaks occur behind a number of positive relief features within the main streak.

We now discuss some of these features in more detail. Within the principal dark streak there are numerous small hills (Figs. 4c, 4d). The smallest clearly visible is about 1km wide. Each has a bright streak in its lee extending 10–20km. The largest hill within the dark streak (about 5km wide) has a downwind bright streak about 30km long.

A much larger downwind bright streak occurs behind the 18km crater (Fig. 4b). Note that this crater has very low (eroded?) ramparts and a very shallow and smooth floor. Part of the northeast rampart is missing, and a low-albedo area, similar to the main streak, extends onto the crater floor through this gap.

By far the most significant aspect of this dark streak is its apparent source within the large crater: a very intense dark spot, about 5km in diameter (Fig. 4a). Figure 5 shows two versions of the same picture, each processed to emphasize different details. In Fig. 5a the streak outside the crater ramparts is emphasized at the expense of albedo detail on the crater floor. The reverse procedure is adopted in Fig. 5b, where the dark spot is most prominent.

Photometrically, the contrast between the dark streak and the brighter surroundings is variable and averages about 10%. Nowhere outside the crater does it exceed 15%. The very dark spot on the crater floor is considerably darker than any part of the downwind streak, the contrast being about 25%. The edge of the streak is not abrupt, and contrary to the appearance on some photographs, the streak is not bordered by a bright edge.

The following features must be explained:

(a) the very dark round spot at the head of the streak,
(b) the apparent funneling of dark material through the breach in the

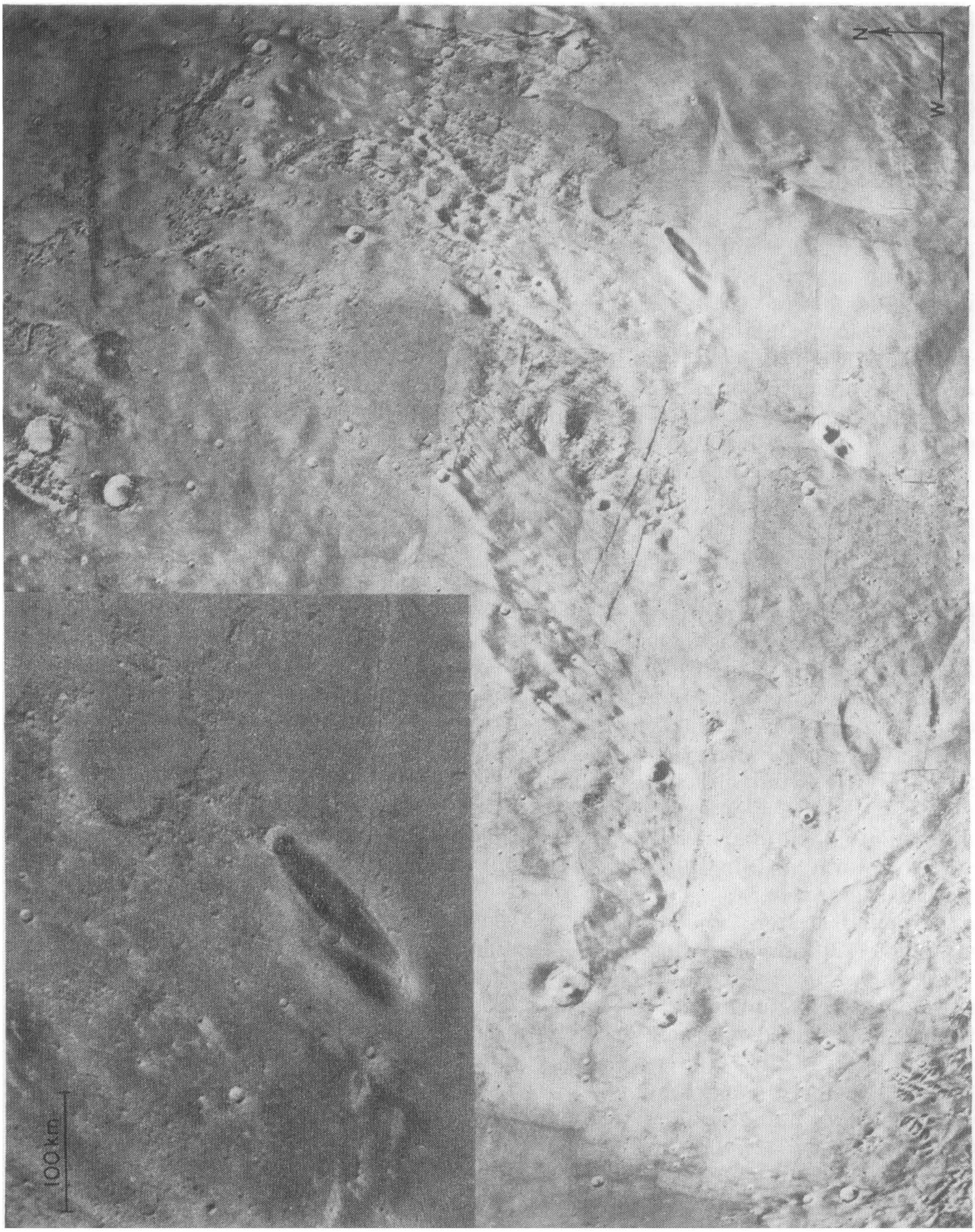

FIG. 2. Photomosaic of the Cerberus/Mesogaea region. Cerberus is the dark elongated albedo feature near the center of the photomosaic. The crater streak studied in this paper is shown at larger scale in the inset. The streak is about 150km long and 30km wide and trends southwest. There are numerous bright wind streaks in the area all trending in the same direction. (Inset: Orbit 175; DAS 07866638; IPL Roll 6150: 150540.)

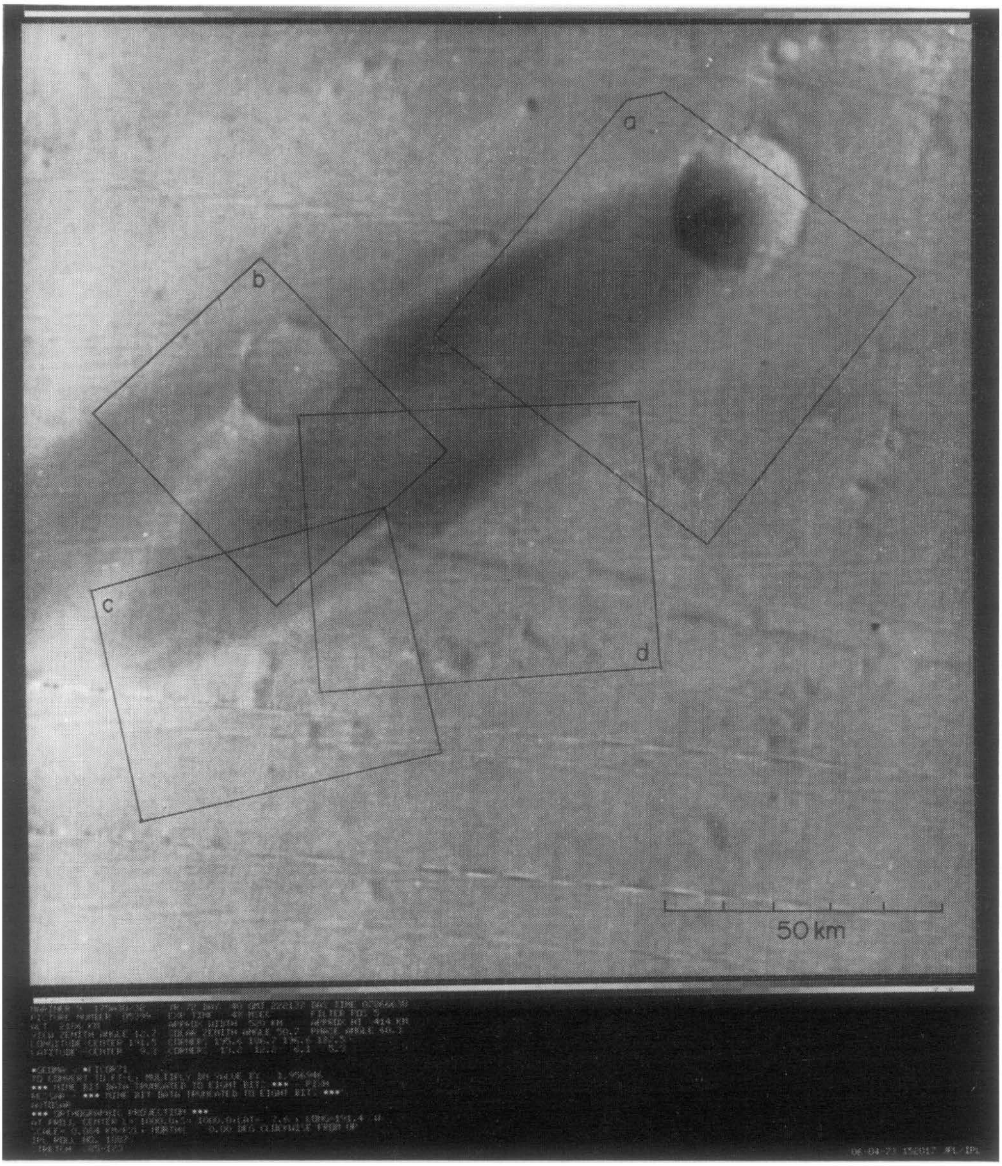

FIG. 3. Expanded portion of Mariner 9 picture: DAS 07866638 (Orbit 175), showing the approximate footprints of the high-resolution frames shown in Fig. 4. (IPL Roll 1887, 152017.)

ramparts of the downwind (18km) crater,

(c) the bright streaks behind the 18km crater and behind the several small hills.

4. THE MESOGAEA CRATER STREAK: INTERPRETATION

The range of alternative explanations for this dark streak can be divided into two broad categories: (a) The streak is produced by wind erosion of bright material. (b) The streak is produced by wind deposition of dark material.

(a) *Erosional Hypothesis*

According to this hypothesis winds are accelerated behind the crater and an overlying cover of bright material is removed. There is no compelling reason for rejecting

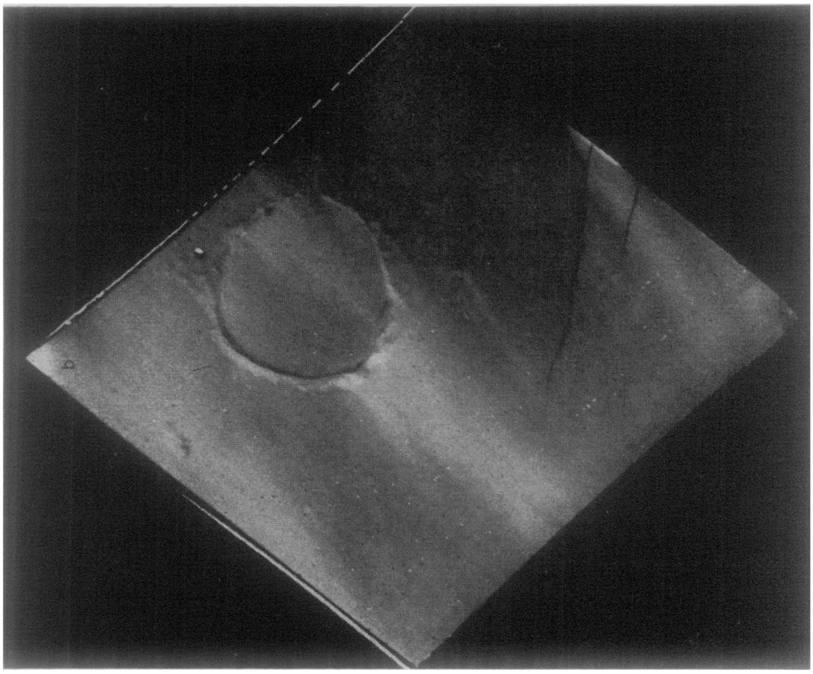

FIG. 4b

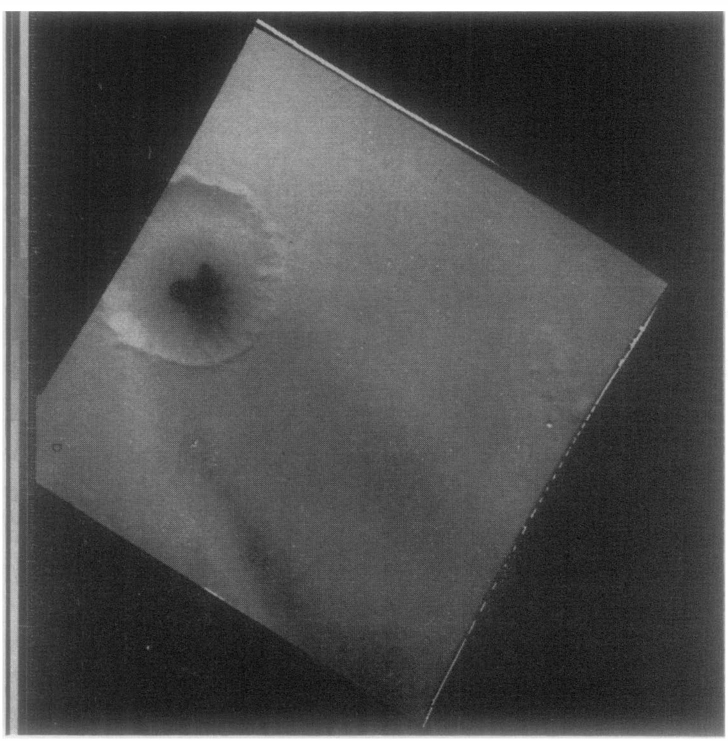

FIG. 4a

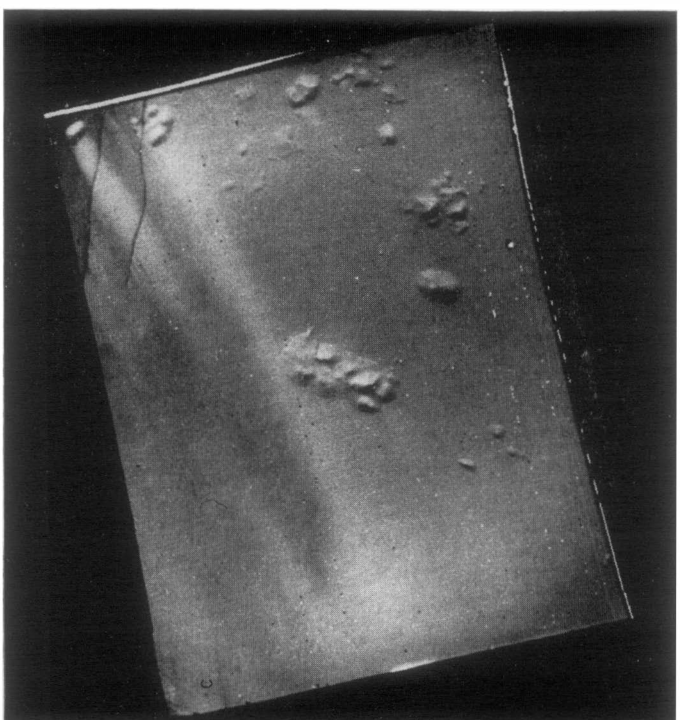

FIG. 4c

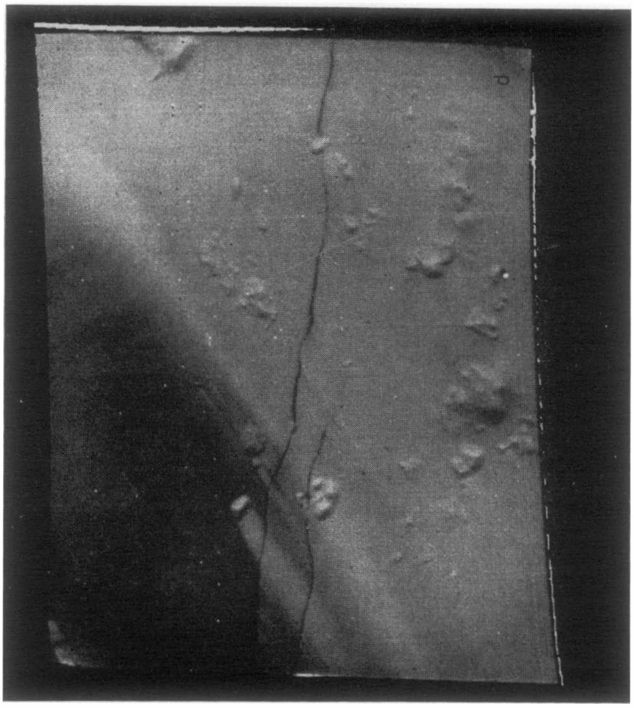

FIG. 4d

FIG. 4. High-resolution (B-camera) coverage of the area: (A) Orbit 450 (DAS 12326691); IPL Roll 1887: 235056. (B) Orbit 214 (DAS 09269129); IPL Roll 1887: 222424. (C) Orbit 450 (DAS) 12326481); IPL Roll 1887: 225257. (D) Orbit 450 (DAS 12326551); IPL Roll 1887: 231757. Approximate footprints are shown in Fig. 3.

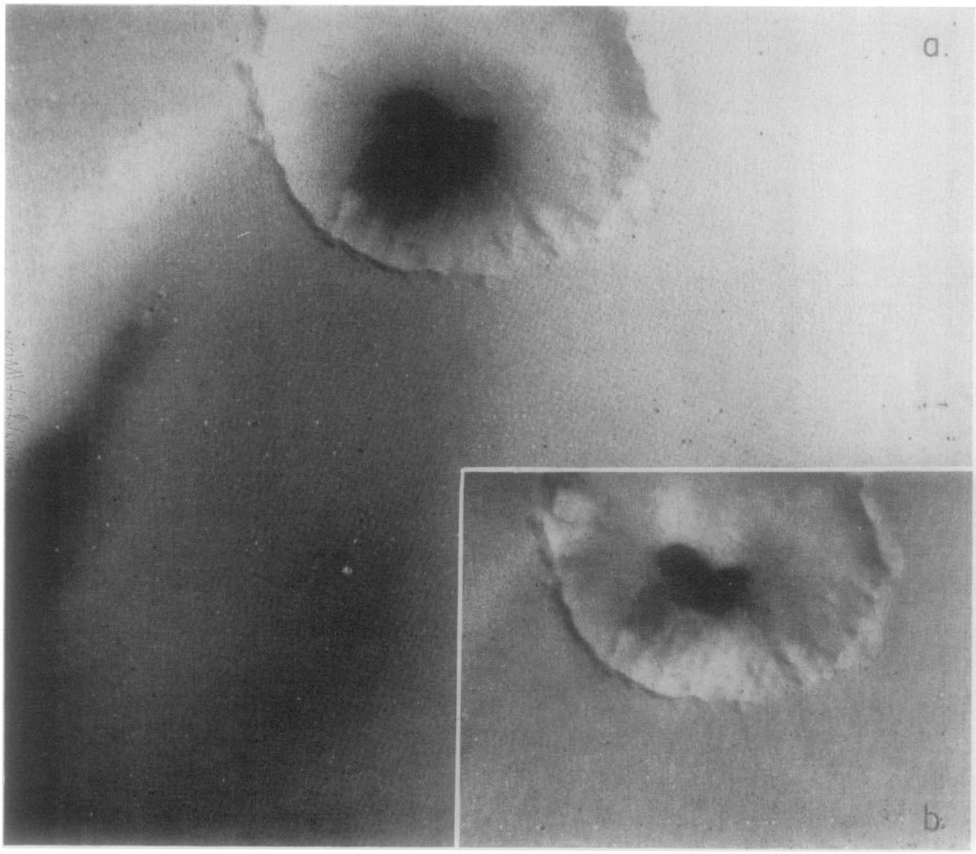

FIG. 5. Two versions of high-resolution frame DAS 12326691 (Orbit 450), processed to bring out the albedo detail within the main crater. Note the compact dark region, especially evident in version (b): (a) IPL 08-18-72 (150907). (b) IPL Roll 7247: 120046.

this hypothesis, but some circumstantial evidence argues against it: (i) Nearby craters, of comparable size and topography, do not have downwind dark streaks. (ii) The appearance of this dark streak is unlike that of most other dark crater streaks on Mars. Many of these, presumed to be erosional (Greeley *et al.*, 1974; Veverka, 1975) have very ragged outlines and are variable on short time scales (Sagan *et al.*, 1972). The Mesogaea streak has a tapered, smooth outline and no changes within it have been observed (Section 5, below).

(*b*) *Depositional Hypothesis*

According to this hypothesis the streak is produced by the deposition of dark windblown material downwind of the crater. This hypothesis may be subdivided into at least three subcategories:

(i) The dark material originates in a large dust cloud which covers the entire area. Deposition of dark dust occurs throughout the area. In most areas this material is later swept away by prevailing winds. Only where craters act as wind shadows does the low-albedo material remain. To be tenable, this version must also account for the bright streaks within the dark tail, and requires the additional speculation either that conditions were such that deposition was hindered in the lee of the positive relief features where we now see the bright streaks, or that subsequent erosion behind these hills was very efficient. Also, no satisfactory explanation of the dark spot within the main crater is provided.

(ii) The dark material is windblown material which once accumulated within the crater and which has since been deflated. This process has been proposed for the formation of other dark streaks on Mars (Sagan *et al.*, 1972) and Arvidson (1973) has presented statistical evidence for this mechanism. Possible examples of such streaks are shown in Fig. 1.

(iii) The dark material originates within the crater, and is distributed downwind.

Either explanation (ii) or (iii) can account for the presence of bright streaks behind the hills within the dark tail. What makes (iii) attractive is that the very dark intense, round spot within the main crater is a possible source for the low-albedo material. Therefore, we suggest that this particular crater streak is depositional and that the low-albedo material originates within the crater itself.

There are at least two ways in which this can come about: The source area may be a "deflation hollow," or it may be a volcanic vent. In the first case, the dark material would be deflated from a recently exposed, relatively unconsolidated subsurface deposit; in the second, dark volcanic ash has been produced within the crater.

Neither possibility can be rejected out of hand. Since the area of the dark streak is only about 100 times that of the suspected source, the depth of excavation necessary to produce the material now in the dark streak is not excessive; the streak deposit need not exceed 1 cm in thickness, so that an excavation of only 1 m in the source area would provide sufficient material.

If a volcanic vent is involved, it is probably much smaller than 5km across. In this case, the dark spot may represent an area of increased accumulation surrounding the vent. Viewed as a deposit of dark volcanic ash, this crater streak has some interesting analogies with terrestrial ash deposits.

Macdonald (1972) discusses a number of well-documented volcanic ash eruptions. For the 1912 Katmai eruption in Alaska, the total volume of ash produced is estimated at $25 km^3$. The ash deposit pattern (Macdonald, 1972, Fig. 7.5) was controlled by prevailing winds and is strongly elongated downwind. Even 100 miles from the source of the eruption, the ash accumulation is 30cm deep.

Eaton (1963) studied maps of 24 recent ash deposits and showed that the observed long axis of a given deposit is parallel to the prevailing regional wind direction. The deposits are strongly elongated downwind and reach a length of 240km. A typical example of an ash deposit, from the 1947 eruption of Hekla (Iceland), is shown in Fig. 6. Other, more extensive deposits of tephra associated with previous eruptions of this volcano are discussed by Lamb (1970). In a number of these, appreciable deposition occurred several hundred kilometers downwind from the vent.

It is interesting to compare the pattern of deposition in the Mesogaea streak with that of terrestrial ash deposits discussed by Eaton (1963). The patterns (Fig. 6) are quite comparable, as are the amounts of material required. The Mesogaea streak covers an area of some 120×30km. Since 1 cm of this material is certainly optically thick, the amount of deposited material may be as little as $10^{-2} km^3$, which is quite

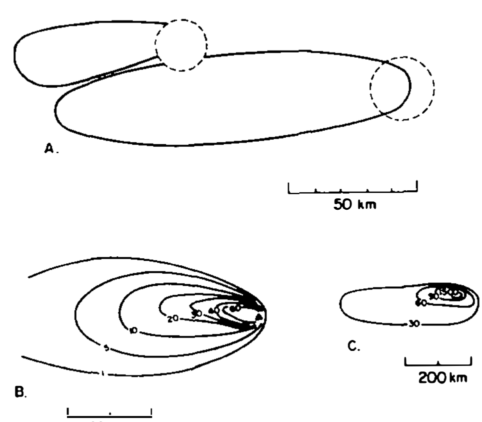

FIG. 6. Sketch comparison of the outline of the dark streak studied in this paper (A) with those of two terrestrial ash deposits (after Eaton, 1963): (B) Thickness map of the ash deposited after the March 29, 1947, eruption of Hekla volcano, Iceland. (C) Similar map for the Mt. Natazhat, Alaska eruption. The thickness is expressed in centimeters.

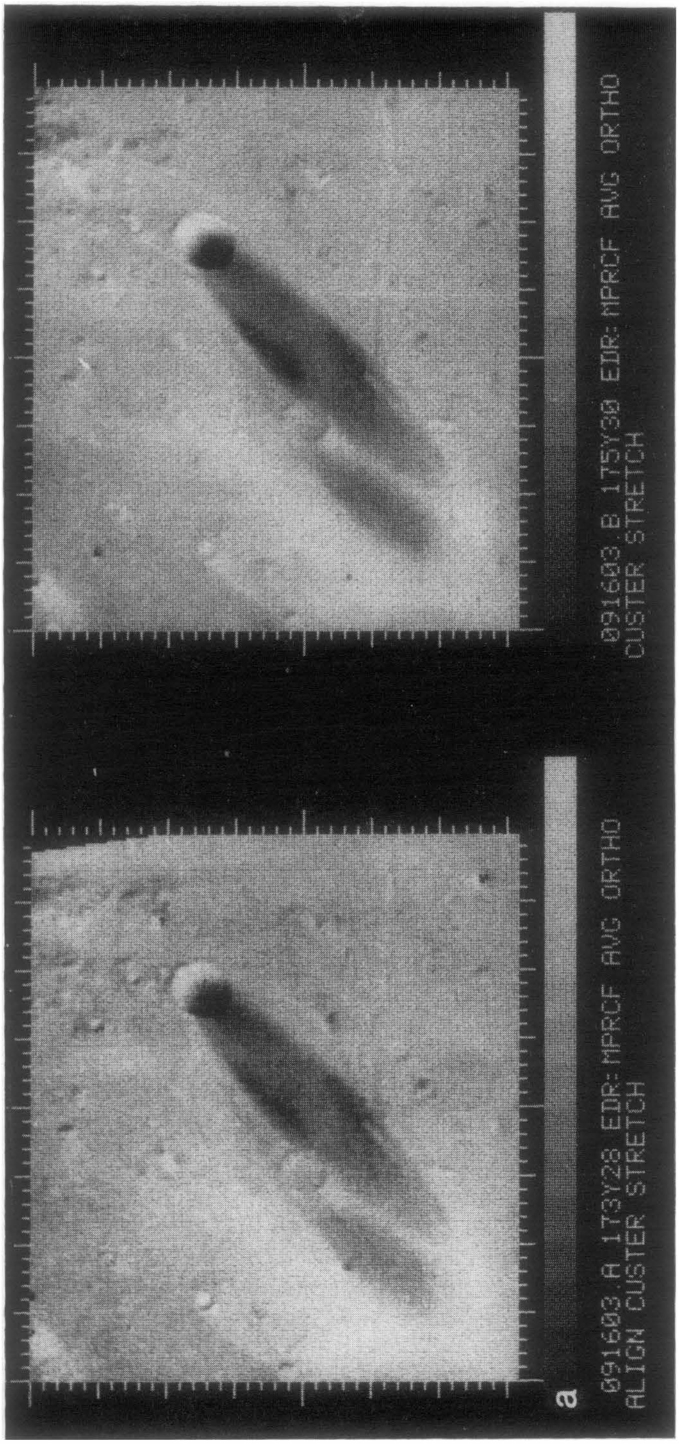
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FIG. 7a

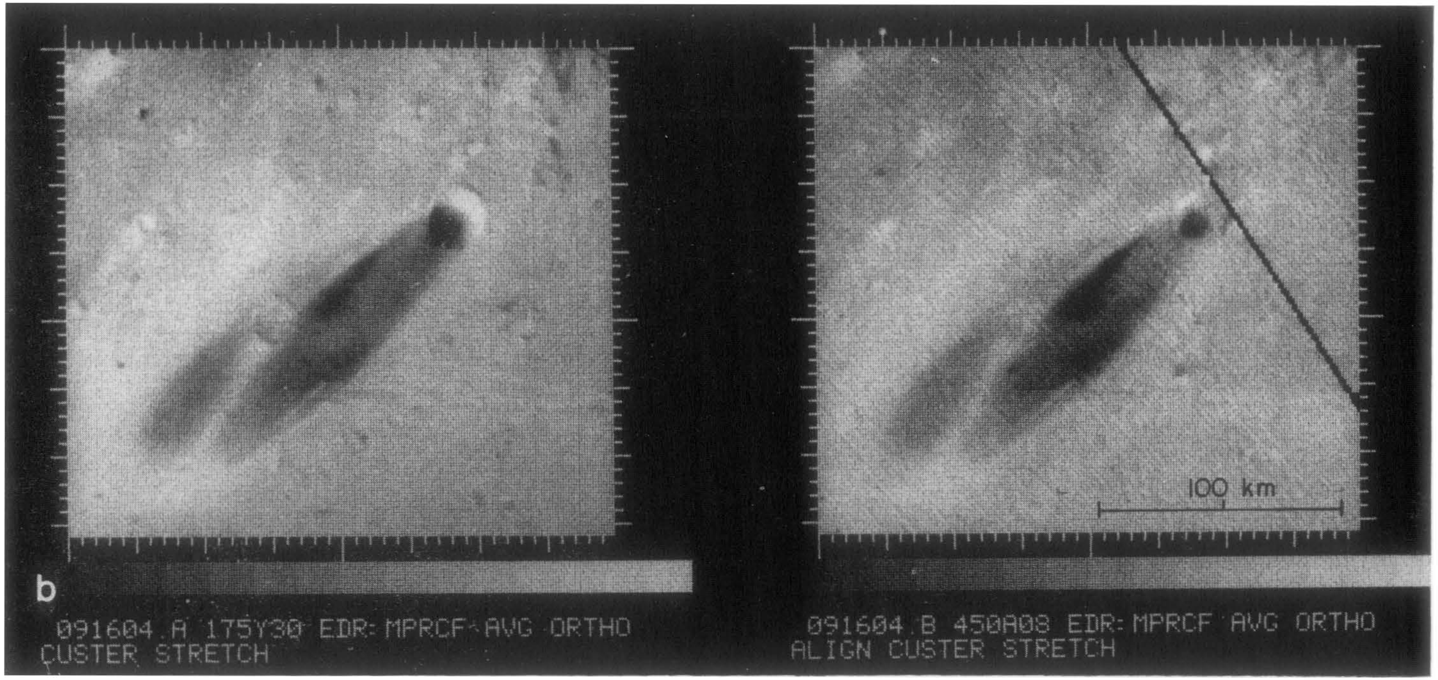

FIG. 7b

FIG. 7. Picture comparisons showing the appearance of the Mesogaea streak on three different dates: (a) *left*: Orbit 173 (DAS 7795093), 8 February, 1972; *right*: Orbit 175 (DAS 7866633), 9 February, 1972 (Stanford AI product STN 184-091603). (b) *left*: Orbit 175 (DAS 7866633), 9 February 1972; *right*: Orbit 450 (DAS 12326721), 25 June 1972 (Stanford AI product STN 184-091604). Note that the lighting and viewing conditions on Orbit 450 were significantly different from those obtaining on Orbits 173 and 175. Shown are picture comparisons provided by L. Quam of Stanford's Artificial Intelligence Laboratory.

comparable to the amounts involved in smaller terrestrial ash deposits (Macdonald, 1972).

Wind tunnel simulations also support explanations (ii) and (iii). In these simulations, fine particles were emitted from the crater floor (simulating a volcanic vent) and carried downwind from the crater and deposited. The resulting deposition pattern was plume shaped and closely similar to that of the Mesogaea streak (Greeley *et al.*, 1976). This pattern is quite different from that produced when there is no constant intracrater source (Greeley *et al.*, 1974).

5. Changes in the Mesogaea Streak

No satisfactory monitoring of this feature was performed during the Mariner 9 mission. There is no evidence for changes in any of the available data—a 1 day sequence of observations on Orbits 173 and 175 with photometric conditions almost identical (Fig. 7A) and a view 132 days later on Orbit 450 (Fig. 7B). On Orbit 450 the photometric angles are quite different from those on Orbits 173 and 175; this can be seen from the changes in the shadow patterns on the ramparts of the main crater. Also, transmission noise in this Extended Mission photograph is appreciable. Nevertheless, it is unlikely that any significant changes occurred during the 132 day interval between Orbits 175 and 450.

It is debatable whether this feature could be seen, or indeed, has been seen, by Earth-based observers. Thus no limit on its duration can be derived from these sources. However, had the marking been prominent in 1969, it might have shown up on the Mariners 6 and 7 far encounter photographs. A search through this material has proved negative and the possibility exists that the dark streak was less prominent in 1969 than at the time of Mariner 9. The development of this feature should be checked by the 1976 Viking orbiters.

6. Discussion

The Mesogaea dark streak provides the best example on Mars of a depositional streak in which the low-albedo material originates within the crater itself. Such features may be common on Mars, but may not always be easily identifiable.

If such features are common, they must play a significant role in determining the distribution of albedo patterns on the planet and the changes in these patterns, an idea very similar to McLaughlin's "volcanic–aeolian" explanation of Martian variable features (Veverka and Sagan, 1974).

We suggested two possible origins for the dark material—excavation by winds from an exposed subsurface deposit, or production by a volcanic vent. There appear to be no compelling arguments against either possibility, and the location of the crater on the periphery of the Elysium volcanic plateau lends some added plausibility to the second view.

Additional high-resolution imagery of the source area on future Mars missions is highly desirable.

Acknowledgment

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