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16. The planning and coordination of the mission operations that have made possible the successful operation of this experiment would have been impossible without the devoted and capable attention of A. Castro, whose engineering skills, moreover, are in large part responsible for the construction and excellent performance of the x-ray instrument. W. Kelliher's contributions to these activities and to the general oversight of the instrument building process were also indispensable. Data reduction by C. D. Rowe and R. P. Christian, analysis of imagery and sampler problems by J. L. Gooding, temperature analysis by R. A. Wall, calibration calculations by P. H. Evans and R. Weldon, laboratory studies of R. Moore, and the cheerful secretarial skills of L. Nash are all gratefully acknowledged. This work was supported by NASA (Viking Program) grants NAS 1-11855, NAS 1-11858, L-9717, and NAS 1-9000.

2 September 1976

Viking Magnetic Properties Investigation: Preliminary Results

Abstract. *Three permanent magnet arrays are aboard the Viking lander. By sol 35, one array, fixed on a photometric reference test chart on top of the lander, has clearly attracted magnetic particles from airborne dust; two other magnet arrays, one strong and one weak, incorporated in the backhoe of the surface sampler, have both extracted considerable magnetic mineral from the surface as a result of nine insertions associated with sample acquisition. The loose martian surface material around the landing site is judged to contain 3 to 7 percent highly magnetic mineral which, pending spectrophotometric study, is thought to be mainly magnetite.*

This investigation (*1*) is designed to detect magnetic particles, and their composition and abundance if present, in the martian surface material around the Viking landing sites. The experiment is simple, employing a series of permanent magnet arrays that are either inserted directly into the surface material or passively exposed to windblown particles. The magnets are periodically viewed with the lander imaging system, the resulting pictures being the primary data on which conclusions are based. A 4× magnifying mirror will eventually be employed to enhance particle resolution. Plans also call for the eventual use of a magnet cleaning brush to allow for more controlled experiments.

Magnet arrays. The shape and dimensions of the samarium cobalt permanent magnets (*1*) are illustrated in Fig. 1. The center and ring magnets are magnetized parallel to their axes, but in opposite directions.

One of these annular arrays is mounted on the central photometric reference test chart (RTC) (*2*) atop the lander, the other two being incorporated in the backhoe of the surface sampler. These latter (Fig. 2) are fitted so that where the surface of one array is approximately 0.5 mm from the surface, the adjacent array is sunk 3 mm below, which provides two levels of attractive force. The weak array on one side of the backhoe is the strong array on the other, and vice versa. The effective magnetic field and field gradient at the surface of a strong array (including the magnet on the photometric target) are 2500 gauss and 10,000 gauss/cm; for a weak array these values are 700 gauss and 3000 gauss/cm, respectively. The magnetic attractive force provided by the strong and weak magnet arrays is in the approximate ratio 12 : 1.

The images of the magnets which had been taken at the time of writing are listed in Table 1. The results are summarized and interpreted below.

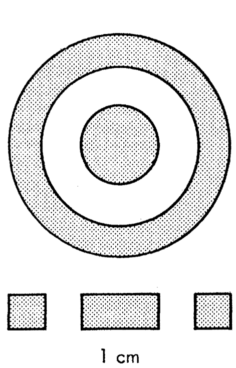
Reference test chart magnet. Survey mode images (lower resolution) of this magnet were received immediately after touchdown and again on sol 3 (Table 1). In both there is evidence of material adhering to the magnet. On sol 15 and again on sol 31, high-resolution images of the RTC magnet revealed an unmistakable bull's-eye pattern, indicating a significant and substantially increased amount of material on the magnet array (Fig. 3).

Three possible sources of these magnetic particles are (i) dust elevated into the atmosphere by the rocket exhausts on landing, (ii) dust generated in connection with sample acquisition and delivery, and (iii) dust particles normally suspended in the atmosphere.

The pink sky on Mars is attributed to the presence of reddish dust particles of the order of 1 μm in diameter (*3*) and in an amount equivalent to about ten particles per cubic centimeter (*4*). Such particles, if of hematite or goethite, would be attracted to the RTC magnet. We have calculated that a wind of 5 m/sec blowing such atmosphere over the magnets could in 15 days result in a layer on the magnets 10 μm thick if the extraction efficiency is assumed to be 5 percent. If the layer were to grow thicker than 100 μm a strong wind (>20 m/sec) might tend to remove such particles. We await data that will indicate whether or not there is a correlation between periods of calm or high wind and changes in the amount (or color) of particles adhering to the RTC magnet. Such a correlation would confirm the atmosphere as a source of at least some of the particles.

The particles on the RTC magnet on sol 0 must have been raised into the atmosphere by the retrorocket exhaust when the spacecraft landed. The increase in the amount adhering as seen on sol 15 (in particular) and sol 31, however, can be correlated with sample acquisition and delivery on sols 8, 14, 22, and 31. Because the material sampled is now known to contain a significant fraction of highly magnetic particles (as discussed below), dust raised by the surface sampler is considered to be the principal source of the particles on the RTC magnet.

The particles on this magnet are below



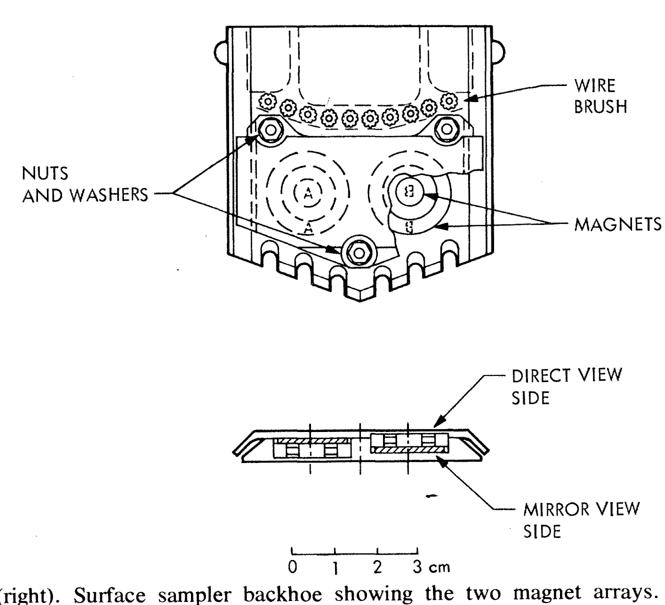


Fig. 1 (left). Viking magnet array. When mounted the magnets are completely covered by a magnesium metal plate, 0.5 mm thick over a strong array and 3.0 mm thick over a weak array. Fig. 2 (right). Surface sampler backhoe showing the two magnet arrays. Although normally standing perpendicular to the sampler axis, the backhoe is spring-hinged so that it can fold back when the sampler advances into the surface.

resolution of the imaging system (~1 mm at this range). Because of the absence of any sign of a shadow cast by the magnetic particles in the sol 15 image taken at low sun elevation (15°) (Fig. 3), we calculate that the magnetic particle layer must be thinner than about 250 μm.

Backhoe magnet arrays. In the sol 8 images which happened to include the collector head, the backhoe was either shadowed and too distant or too near and out of focus for confident interpretation of the image. Much clearer, high-resolution direct view images of the back of the backhoe were obtained on sols 20, 24, 31, and 34 (Fig. 4). The sol 20 image was obtained after a total of six insertions into the surface but before the vibration of the surface sampler that results from delivery of the sample to any one of the analytical instruments. This sol 20 image shows a substantial amount of material held by the magnets, together with particles adhering elsewhere on the collector head. Later backhoe images, taken in each case after delivery of samples and the associated vibration, reveal a conspicuous concentration of magnetic particles in the characteristic bull's-eye pattern on both weak and strong magnets. The large amount of particles on the weak magnet is particularly noteworthy; comparison with terrestrial material suggests that a relatively pure, highly magnetic mineral phase is involved. Quantitative estimates of the concentration of magnetic particles in the surface material are hindered by the lack of clear backhoe pictures before sol 20, by which time six soil acquisitions had been performed and the magnets were approaching saturation. The amount adhering to the weak magnet, in particular, seems to have increased between the sixth and ninth acquisitions, but clearly the magnets were nearing saturation and there was very little difference between weak and strong magnets. On the basis of laboratory tests using flight-type magnet arrays and terrestrial materials, we judge that the concentration of highly magnetic particles in the surface material is 3 to 7 percent. More precise estimates must await cleaning of the backhoe with the cleaning brush added to the lander for this purpose, followed by systematic imaging after successive insertions. This experiment is proposed for the extended mission.

Discussion. Potential candidates for the highly magnetic mineral or minerals present in the surface material are metallic iron, Fe (or NiFe); magnetite, Fe_3O_4 (or titaniferous magnetite); pyrrhotite, approximately $Fe_{0.9}S$; and maghemite, γFe_2O_3. Minerals of lower susceptibility such as hematite, αFe_2O_3; ilmenite, $FeTiO_3$; and goethite and lepidocrocite, $FeO \cdot OH$, can be excluded because

Table 1. Magnet images received, sols 0 to 35. The image reference number consists of, first, the camera event number, and, second, the roll and frame number, the frame number of the best image being given. Survey refers to low-resolution camera mode; HR, high-resolution camera mode. Direct view is view of the back surface of backhoe.

Sol	Image reference No.	RTC magnet	Backhoe magnets	Comments
0	12A002/00 F1001/24	Survey, shade		
3	11A018/003 F1005/13	Survey, shade		
5	11A032/005 F1007/5		HR, shade	Direct view before sampling
7	12A054/007 F1012/19		HR, sun	Direct view before sampling
8	11A060/008 F1012/42		HR, shade	Long-range direct view after fourth sample acquisition
8	12A061/008 F1012/46		Survey, shade	Backhoe over inorganic analysis sample receiver after fifth sample acquisition, out of focus
15	12A101/015 F1020/6	HR, sun		
17	11A105/017 F1023/2		Survey, shade	Long-range direct view after a sixth sample acquisition
19	12A110/019 F1026/33	HR, shade		
19	12A112/019 F1026/49		HR, shade	Direct view, slightly out of focus
20	11A118/020 F1027/66		HR, sun and shade	Direct view, strong magnet in sun
24	12A140/024 F1031/23		HR, sun	Direct view after sample delivery
26	12A145/026 F1033/2	Survey, shade		
27	12A160/027 F1034/68	Color, sun		First color image
28	12A171/028 F1035/56	Color, infrared, survey, sun		
31	12A247/031 F1038/65	Color, infrared, sun		
31	12A242/031 F1038/41	HR, sun		
31	12A252/031 F1039/4		HR, sun	Direct view after seventh sample acquisition
34	12B034/034 F1041/57	Color, infrared, survey, sun		
34	11B019/034 F1041/82 11B020/034 F1041/87		HR, sun	Direct view images after eighth and ninth sample acquisitions

they could not possibly adhere to the weak backhoe magnet in the amount observed. None of the potential minerals can be excluded unequivocally on the basis of data currently available. Color and infrared imaging of the backhoe will be taken on sol 40, and it is hoped that these will help identification of the minerals.

The magnetic particles adhering are likely to be very fine-grained ($< 100\ \mu$m) (*5*), which favors their being monomineralic. We believe that small particles of metallic iron are unlikely to survive in the relatively oxidizing martian surface environment. The vapor pressure of sulfur above pyrrhotite, especially the magnetic variety ($Fe_{\sim 0.9}S$), is thought to be sufficiently high (*6*) that it would probably have been detected after the 500°C heating for organic analysis (*7*). This, however, does not exclude the possible presence of more iron-rich, nonmagnetic pyrrhotite or troilite. The most likely mineral candidates, in our opinion, are magnetite and maghemite. Maghemite is produced in the weathering cycle leading to red lateritic soil in Hawaii (*8*), but in the pure state it tends to be yellowish brown to reddish. Ideally magnetite is also unstable in the martian atmosphere, but could survive metastably in the cold environment, as it does on Earth.

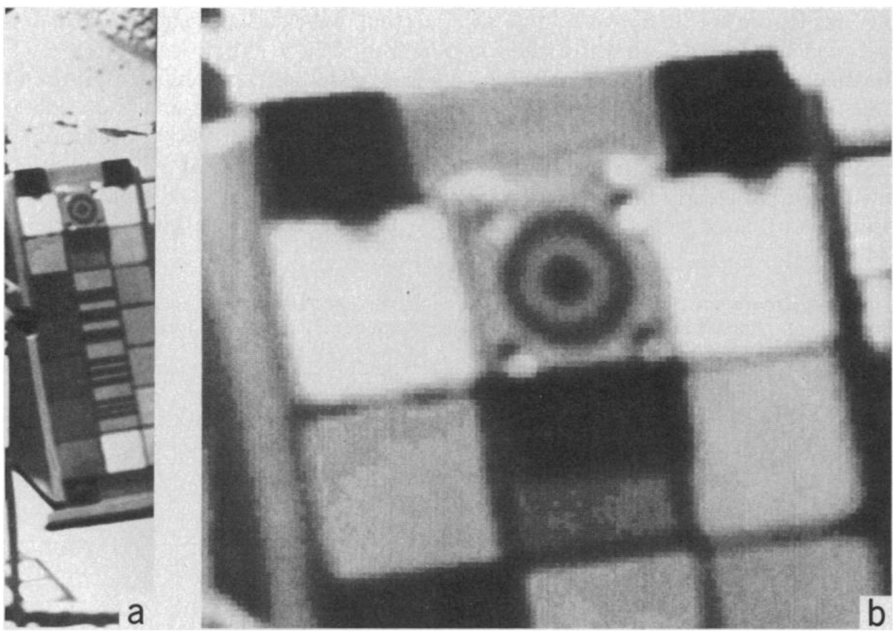


Fig. 3. (a) The center photometric reference test chart as seen on sol 31, with (b) an enlargement of the magnet array. The bull's-eye pattern is unambiguous evidence of adhering magnetic particles.

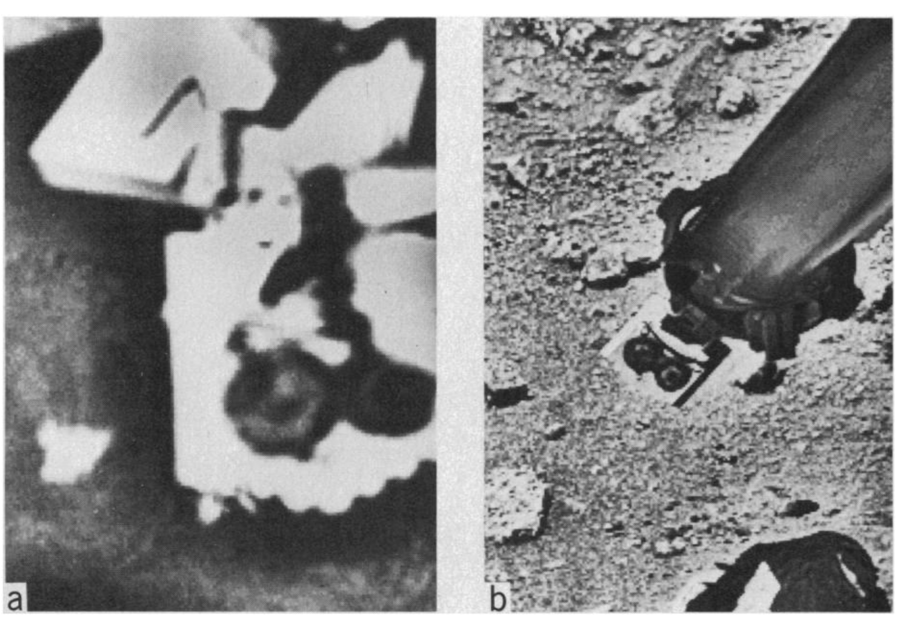


Fig. 4. The surface sampler backhoe as seen from the rear on (a) sol 31 and (b) sol 34. The dense bull's-eye concentration of dark magnetic particles on both magnets [particularly in (b)] is unmistakable. A slight, dark protrusion at about 5:00 o'clock on the left (stronger) magnet is thought to be the shadow cast by a ~2-mm particle.

Color and infrared images of the RTC magnet have been taken (those for the backhoe magnets are scheduled on sol 40, too late for this report); the magnetic particles appear reddish black. This could (i) be the color of the magnetic mineral phase; (ii) indicate that black particles have a red coating; or (iii) result from an overlay on black particles of reddish dust that mantles everything and may be concentrated on the magnet. A more definite interpretation of the mineralogy of the magnetic particles should be possible when the full spectrophotometric studies of the backhoe magnet are completed.

Provisionally, we believe a black mineral is the principal phase present, and that it is most likely magnetite. If this is correct, then it suggests that a significant fraction of the loose surface material sampled is mechanically weathered or disaggregated, relatively unoxidized rock-mineral debris.

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