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Color and Feature Changes at Mars Viking Lander Site

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Analysis of three component color pictures taken by the Viking lander camera on Mars has established color differences for the background material, the rocks and spots on the rocks. Changes in the location of greenish rock patches and ground patterns have been observed over time. A combination of wind movement of dust and dirt dropped by sampler arm operations could have produced the slight changes in pattern and position. However, the observed patches, patterns and changes could also be attributable to biological activity. Analysis of six component color data on the same scene confirms the observations including the greenish color of the rock patches.

1. Color and Feature Changes on Mars

Color images transmitted by the Viking 1 spacecraft on Mars have been examined for temporal changes as part of an effort to aid interpretation of the Labeled Release (LR) life detection experiment (Levin & Straat, 1976, 1977*a*, *b*) performed on that mission.

The Viking cameras have six spectrally narrow band detectors, three in the visible and three in the near infrared. The use of all six channels has been shown (Huck *et al.*, 1977) to provide the most accurate color rendition. Because many of the images in our study had not been taken in six channels, three component color reconstruction was used. The three components correspond approximately to *Blue, Green,* and *Red*. The color reconstruction of these images was performed in a "radiometric" sense, meaning that the components were each linearly amplified to effect an equal average sensitivity over the spectral bandpass. Therefore, the reconstructed triplet, while possessing the same general color characteristics, is not intended to be an exact photometric reproduction of the actual sense as perceived by a human observer.

PLATE I. (a) Enlarged portion of radiometric color picture of Viking lander site 1, taken sol 1. Viking Picture 12A006/001. (b) Same view taken sol 302 showing changes on rocks and ground surface. Viking Picture 12Dl25/302.

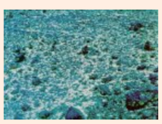


PLATE II. Areas registering in hue DN range 68-69 are given in green against blue field background. Green color coincides with Mars dust cover at Viking I site. Viking Picture 12A006/001.

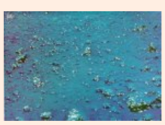


PLATE III. Hue DN range 65-66 given in green against blue field image. Green color coincides with Mars rocks at Viking I site. Viking Picture 12A006/001.

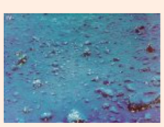


PLATE IV. Hue DN range 63-64 in green against a blue field background. Green color indicates separate color for spots on rocks. Viking Picture 12A006/001.

PLATE V. (a) Radiometric color picture of Delta Rock area taken on sol 1 of Viking 1 site showing rock-spot color on ground. Viking Picture 12A006/001. (b) Same view taken sol 302 showing intensified spot color on rocks and absence of spot color on ground. Viking Picture 12D125/302.

PLATE VI. Hue analysis in DN range 0-65 of Viking 1 site picture taken on sol 45. Trench where dig had occurred shows no underlying rock-spot-colored material. Response of unshadowed part of stripe on Patch Rock is seen. Viking Picture 12B125/045.

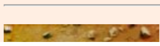


PLATE VII. Radiometric color split image composite of portions of scenes taken sol 1 (top) and sol 302 (bottom) demonstrating rocks have not moved and showing ground color change. Viking Pictures 12A006/001 and 12D125/302.

PLATE VIII. Lichen-bearing rocks and bark amid synthetic rocks in simulated Mars scene at JPL, taken from same position as Viking test lander camera with a single lens reflex camera and Kodachrome film.

PLATE IX. Radiometric color picture of lichen-bearing rocks and bark taken by JPL Viking test lander camera and processed as Mars pictures. Comparison with Plate VIII demonstrates difficulty in distinguishing color, contrast and shape of lichen colonies after Viking processing.

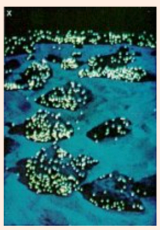


PLATE X. Hue analysis in DN range 0-60 of lichen-bearing material among synthetic Mars rocks. Compare to Plate VIII for location of lichen.

PLATE XI. (a) Saturation analysis in 0-60 DN range (0-24 % saturation) of sol 1 picture of Patch Rock. Viking Picture 12A006/001. (b) Saturation analysis in 0-60 DN range (0-24 % saturation) of sol 302 picture of Patch Rock showing change corresponding to shift in position of patch (compare to Plate I). Viking Picture 12D125/302.

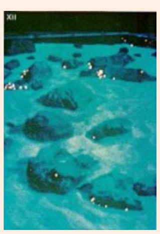


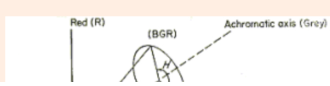
PLATE XII. Saturation analysis in 0-30 DN range (0-12 % saturation) of lichen-bearing materials shown in Plate VIII.

Plate I(a) is a portion of the first color picture taken on Mars by Viking 1. Some portion of the rocks and ground surface are perceived as green relative to the surrounding area. While this color is *perceived* as green, and is so called in this paper, the actual colors on Mars remain somewhat indeterminate. Thus, the Mars landscape was reported (NASA P-17164, July 1976) to be mostly "orange-red". More recently (Huck *et al.*, 1977), a six channel spectrophotometric analysis of the Viking lander camera data found the surface of the planet predominantly "moderate yellowish brown" with variations including "moderate olive brown".

Plate I(b), taken 301 sols (Martian days) later, shows a change in pattern and location of a green patch down the middle of the rock (herein called "Patch Rock") on the left side of the picture. Taken by the same camera, the three channel data were processed identically, thereby eliminating data processing as a possible cause of the differences between the two images.

Extensive digging and sifting operations by the spacecraft surface sampler arm occurred during the interval between the two pictures [note the trenches in Plate I(b)] and probably spread dust on the rock, thus accounting for the diminution of the green area on the right side of the Patch Rock. However, the apparent increase in the green area on the left side of the rock is not as readily explained.

In an attempt to establish quantitatively whether or not the spots on the rocks were of a color differing from that of the rocks, software programs developed at the Image Processing Laboratory (Huck, McCall, Patterson & Taylor, 1975) for the ERTS/LANDSAT projects were invoked. This software is designed for the purpose of color enhancement and feature discrimination (Goetz, Billingsley & Gillespie, 1975) and involves the transformation of the blue, green and red (BGR) components into a more useful set of hue, saturation and intensity (*HSI*) components.



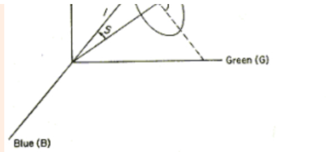


FIG. 1. Idealized BGR-*HSI* co-ordinate transformation.

The transformation of blue, green and red to hue, saturation and intensity is performed by a rotation of axes from the assumed orthogonal system BGR to a new orthogonal system *HSI* as shown in Fig. I. In practice, one first rotates the BGR co-ordinates into an *xyz* system such that *y* coincides with the achromatic axis:

$$\begin{Bmatrix} x \\ y \\ z \end{Bmatrix} = \begin{Bmatrix} \frac{1}{\sqrt{3}} & \frac{\sqrt{2}}{\sqrt{3}} & 0 \\ -\frac{\sqrt{2}}{\sqrt{3}} & \frac{1}{\sqrt{3}} & 0 \\ 0 & 0 & 1 \end{Bmatrix} \begin{Bmatrix} \frac{1}{\sqrt{2}} & 0 & \frac{1}{\sqrt{2}} \\ 0 & 1 & 0 \\ -\frac{1}{\sqrt{2}} & 0 & \frac{1}{\sqrt{2}} \end{Bmatrix} \begin{Bmatrix} B \\ G \\ R \end{Bmatrix}.$$

The values of *H*, *S*, *I* can then be computed as:

$$H = \tan^{-1}\left(-\frac{\sqrt{z}}{\sqrt{x}}\right)$$

$$S = \cos^{-1}\left(\frac{\sqrt{y}}{\sqrt{x+y+z}}\right)\Big/\Phi_m(H)$$

$$I = (x+y+z)/I_m(H,S),$$

where Φ_m (*H*) is the maximum colatitude permitted at a given hue and, $I_m(H, S)$ is the maximum intensity permitted at a given hue and co-latitude. The scaling factors Φ_m and I_m are necessary in order to represent *S* and *I* as percentages of full scale, and not to allow the computation of BGR values which do not fall inside the color cube. If this were not enforced, negative intensities would be produced, as well as values above the available digital range.

For this study, the hue and saturation components of the color image were examined for variations independent of the local scene intensity, thereby allowing the discrimination of subtle hue (color) and saturation (grayness) deviations. Digitally, the hue range extends from 0 to 255, with green at 0, red at 85, and blue at 170. The saturation range of 0 to 255 represents 0 to 100% color respectively. In the figures utilizing the HSI components, the hue is shown in green, the saturation in red, and the intensity in blue.

Use of the hue capability revealed that, although the entire hue response obtained on Mars lies within a relatively narrow range of data-numbers (DN), the different hues are not randomly distributed. The "reddest" material is the pervasive overlying dust. This material registers within the DN range of 68 to 69, as seen in Plate II. The color corresponds to the "yellowish-brown" recently reported (Huck *et al.,* 1977) for the Mars surface as opposed to the red color first reported (Mutch *et al.,* 1976). As the hue is probed more toward the green end of the scale, the dust response drops out and the rocks begin to appear. At lander site 1, this cross-over occurs at approximately a hue of 66 to 67 DN. Continuing down the hue scale, the study revealed that the basic color of (or on) the rocks corresponds to a DN range of 65 to 66, Plate III, while spots on the rocks appear in the range of 63 to 64 DN as seen in Plate IV. This color analysis thus determined that the finely divided surface material at the Viking 1 lander site is of a narrow, uniform color. The rocks are also of a narrow, uniform color but of a color distinct from that of the dust. Finally, spots do exist on the rocks and are differently colored from the rocks themselves. Only a few DN's separate the colors of the fine surface material, the rocks and the spots. However, the consistency of the separations demonstrated by the great many pixels comprising each object makes the small differences significant. This evidence thus establishes color differences among classes of objects on Mars.

A saturation analysis of Plate I(a) showed a linear feature responding at saturation DN 64 on the top of Patch Rock. Forty-five sols later, the saturation response of this feature had changed to DN 67. This is supporting evidence that some changes on Patch Rock occurred sometime prior to sol 46.

Examination of color images of the area around the triangular rock (herein called "Delta Rock") discloses another phenomenon of interest. Plate V(a), taken on sol 1, shows some material approaching the color of the spots on the rock scattered in a faint pattern on the surface of the ground. Plate V(b), taken on sol 302, shows that rock spots and color patterns have undergone changes with respect to the sol 1 picture. Although the spot color is more prominent on the rocks, the similarly colored material previously present on the ground surface is gone.

No evidence was found that the greenish rock or surface color on the ground occurs below the surface. This is shown by a hue analysis in the 0 to 65 DN range of a picture made on sol 45 (Plate VI) where the sides and bottom of the trenches dug during the interval do not respond to the same DN hue range as the rock spots. In fact, the color of the trenches is indistinguishable from the color of the surface material comprising the background of the scene.

In saturation analysis, Plate V(a) revealed the greenish colored ground surface area to be less saturated in color than the other portions of the ground. An image of the same scene taken at approximately the same sunangle 45 sols later showed that both the saturation difference and the greenish pattern on the ground were gone.

The most straightforward scenario explaining the observed phenomena would be as follows:

> The colored spot of Patch Rock is a dustfree area showing the mineral of the rock. Erosion from the mineral formed the colored pattern on the ground. Sometime after Plate I(a) was obtained, winds removed the ground pattern and bared a larger portion of the rock. Subsequent to this event, the sampler arm dropped surface dust onto the right side of the rock. Plate I(b) was then obtained making it appear that the greenish spot had changed position and showing that the ground pattern had been removed.

There is evidence for rising dust in the Martian atmosphere, caused by a dust storm in the southern hemisphere, beginning about 20 sols after the landing of Viking 1 and peaking sharply approximately 210 sols later. However, Arvidson *et al.* (1978) state that "wind velocities at both landing sites seem to have never been high enough to erode undisturbed materials." Thus, it is questionable whether winds could remove dust from the ground surface and rocks. A general subsidence in atmospheric dust occurred until approximately sol 310 (8 sols after the picture in Plate I(b) was taken). Settling occurs under quiescent conditions and is generally uniform. It has been estimated (Arvidson *et al.,* 1978) that a few microns of dust may have been uniformly deposited over the lander area during this subsidence. Settling thus seems inadequate to account for spot color disappearance on part of the rock and insufficient to cover the ground pattern. However, dust dropped from the sampler arm could have hidden part of the rock spot.

Close examination of Plates I and V with respect to the wind movement theory shows a large amount of detail and fine structure including pebbles and cracks on the surface of the planet. Features about 4 mm in size can be resolved at the distance of the Patch Rock, which is located approximately 2 m from the camera, and is about 15 cm long and 8 cm high. No subtle differences in the fine structure of the ground surface are visible in comparing the two figures although several additional pebbles appear around the trench area. The only obvious differences in the surface fine structure seem to be attributable to the lower sunangle in the second picture casting the lowlying features into greater relief. There is no obvious evidence for wind movement of surface material.

The fact that trenches were dug in the Delta Rock area led to the supposition that the rocks under study might have been moved by the sampler arm between sols 1 and 302 causing the observed change in the greener area of the rocks. To test this possibility, Plate VII was generated by the computer. The top half of the figure is taken from Plates I(a) and V(a) while the bottom half is from Plates I(b) and V(b). The two halves meet perfectly, establishing the fact that the rocks were not moved during the 301 day interval between the two pictures. The composite picture also shows the color change in the ground surface.

The possibility that the greenish color pattern differences are artifacts caused by viewing the same scene under different sunangles has been deemed unlikely (Jones, 1978, pers. comm.). The colored pattern on the ground surface is prominent in Plates I(a) and V(a) which was taken at high sunangle. In Plates I(b) and V(b), taken at lower sunangle, that pattern and color have disappeared although the greenish color on the rocks has intensified in the lower sunangle picture. This indicates the sunangle effect would have to enhance the greenish cast at higher sunangles while eliminating it on the ground. A similar problem would exist were the changes in rock spot and surface pattern color attributed to the observed increase in the hue of the Martian sky during the observation period.

during the observation period.

The greenish colored spots may be caused by refraction or reflection from similarly inclined facets of crystals in the rock. Were this the case, however, it seems likely that the effects would be random and not patterned.

Frost appeared on the Mars surface in later pictures from the more northerly Viking lander 2. The possibility existed that frost may have been responsible for the spots observed on the rocks. However, an analysis of the hue showed that frosted areas do not respond in the DN range of the rock spots.

Conceivably, a temporary discoloration of rocks and soil could have been caused by chemical or physical effects of the descent engine exhaust with the subsequently observed changes occurring as the normal state returned. Soil erosion movement of particles and small rocks, and impingement of exhaust ammonia attending the landing of the spacecraft, affected the vicinity including the Patch Rock area (Moore, Hutton, Scott, Spitzer & Shorthill, 1977).

Finally, the effects may result from some unknown artifact of the imaging system. The digital analysis of the color spectrum would seem more vulnerable to a possible artifact than would the full color picture. However, an imaging system artifact which would intensify the spot color on the rocks while, at the same time, removing it from the ground surface seems unlikely.

The above possibilities, taken singly or in some combination, could be the driving mechanism behind the observations. On the other hand, a biological process could explain the results. The observed phenomenon brings to mind moss, lichen, algae and other organisms on Earth which live in extreme environments creating visible pattern and color changes as they extend their growth or die. Endolithic blue-green algae have now been found (Friedmann & Ocampo, 1976) in Antarctic rocks which were previously reported (Horowitz, Cameron & Hubbard, 1972) to be void of indigenous life. More recently, fungi, algae and bacteria have been discovered (Friedmann & Ocampo, 1978) living several millimeters beneath limestone rock surfaces in the Antarctic dry valleys. Algae, fungi and lichen, as well as bacteria, have given positive responses in laboratory LR experiments.

During preparations for the Viking landings, a Test Lander camera was assessed for its ability to detect plant life. Lichen-bearing rocks were scanned in bright daylight. Upon viewing the color images obtained, it was concluded (Brown, 1976, pers. comm.) that the lichen on rocks could not be discerned. We repeated this experiment in the Viking Science Test Laboratory using a test lander camera in the reconstructed Mars site at JPL. Green lichen on rocks and bark were arranged among the synthetic rocks on sand in the model landing site. The scene was illuminated by tungsten lamps (probably somewhat redder than Mars sunlight in contrast to the earlier tests with Earth sunlight which is less red than Mars sunlight). Plate VIII is reproduced from a slide taken by a camera held in front of the lander camera. The lichen-bearing materials are readily visible. Plate IX is a color version of the same scene as imaged by the lander camera. The lichen-bearing materials are more difficult to distinguish from the synthetic rocks in the lander image than in the camera image (Plate VIII). This is a result of the artificial lighting and the infrared sensitivity in the lander camera color filters, thus causing the lander camera to record the image differently than would be perceived by photographic film or the human eye. Another reason for the difference in color reproduction might be that the Viking lander camera averages color within a single, relatively large, pixel element.

An attempt was made to distinguish the lichen-bearing materials from the synthetic rocks by examining the test lander images in the *HSI* components. Plate X was obtained when the hue range of 0 to 60 DN was examined. The entire range of color frequency responses was next examined in two-DN increments. No apparent differences were detectable among the lichen, the lichen-bearing rocks, and the synthetic rocks. The failures of the Viking test camera in the past and in recent experiments to detect lichen against a rock background imply that the Viking lander imaging system, when only three color components are available, tends to see fewer color differences than does the eye.

Having found no apparent characteristic response in the hue analysis of the lichen images, the saturation components were probed for such differences. It was found that the rock spot-colored areas in the sol 1 and 302 pictures of Patch Rock were the first to register as saturation was examined from 0 to 100%. Plate XI presents those areas responding to 0 to 24% saturation. It is of interest to note that the low saturation patch has shifted in position during the interval between the two pictures, paralleling the apparent change in the greener area of the color images. A similar saturation study was performed on the image of the lichen-bearing rocks and bark (Plate VIII). The lichen were predominantly the first objects to appear when saturation was scanned from 0 to 100%. Plate XII shows the response obtained at the saturation range of 0 to 12 %. This low saturation response is similar to that produced by the spots on the Mars rocks although the initial response ranges are different.

Some six channel data on the scenes studied were available and were analyzed as a check on the accuracy of the images produced by the three channel color data. Two sets of six channel data studied consist of:

(1) image 12A006/001 (The sol 1 three channel color picture, portions of which are shown in this paper) plus three channel infrared image 12A033/005 which viewed the same scene 4 sols later,

(2) images 12A168/028 and 12A170/028, both taken on sol 28.

The six channel data on the first sextet revealed that the patch on Patch Rock, portions of the front of Delta Rock, and the pattern perceived as "greenish" on the nearby ground are significantly greener (ranging down to hue DN 32) than shown by the three channel data images reproduced above. Further, the six channel views enhance the contrast of the green areas against the background. Analysis of the second sextet showed those features to be less green than the first sextet but slightly greener than in the three channel images (Patch Rock responding in the hue DN range 55 to 60). The significant difference between the sol 1, 4 and the sol 28 sextets might be attributable to the four-day lapse between the images constituting the first sextet or may be the result of a real change of some type associated with the spacecraft landing. Saturation studies of the six channel data confirmed that the area lowest in color saturation was on the top of Patch Rock corresponding to that area shown in Plate XI(a). In six channels, the top of the rock responded on the 0-12 % saturation range, the same as did the lichen-bearing rock in Plate XII when imaged by three channel data from the test lander camera.

The analyses of the Viking images are continuing, and other color and pattern changes are being sought. It would be highly interesting to view the area exhibiting the changes discussed herein in intervals of exactly one Martian year for comparison under the identical sunangle. This might help resolve the possibility that the angle of incidence plays a role in the observed effects.

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