APPLICATION OF PHOTOMETRIC ANALYSES FOR INTERPRETATION OF MARS-MARINER VI AND VII IMAGERY

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SECTION 1

INTRODUCTION AND SUMMARY

This is the final report under Contract NASW-2222 sponsored by the Planetary Geology Program at NASA Headquarter (Code SL). The objective of this program was to investigate and illustrate the application of radiometric analyses in the interpretation of Mariner VI and VII imagery. We felt that the following types of problems could be addressed using this imagery:

(1) Evaluation of local reflectivity changes,

(2) Augmentation of geologic mapping,

(3) Discrimination of atmospheric phenomena, and

(4) Investigation of polar cap structure.

The use of conventional radiometric techniques requires the ability to convert sensor response into surface radiance, that is radiometric calibration of the Mariner TV systems. In order to interpret the surface radiance, knowledge of the bi-directional reflectivity function and the atmospheric effects (if any) are required. To circumvent the requirement that these functions, i.e., the radiometric response and bi-directional reflectivity, be known with a high degree of accuracy an interpretation technique based upon reflectivity ratios was employed during this study. Alternate near encounter frames from the wide angle Mariner cameras were taken through different spectral filters (red, green or blue). Consequently, the overlap between successive frames show the same area of the martian surface in two spectral bands. We call these areas the bi-band coverage areas.

A comprehensive review of previous and subsequent efforts to the present study was made and is included in this report. In performing this survey it was obvious to us that the terminology and definitions employed in discussing radiometric investigations (both inter-planetary and earth-based) is quite divergent and confusing to the reader. This lack of precision makes the comparison of results difficult. Consequently the next section of this report proposes a radiometric model which incorporates the definitions and terms used in both astronomy and electro-optics.

As noted above, the interpretation of radiometric data can require knowledge of the bi-directional reflectivity or photometric function. Consequently in Section 2 we have reviewed the definition of this function and discuss several parametric models for its representation. We also have included the parametric values obtained by several authors in fitting observed radiometric data to the functional representations for Mars.

Section 3 reviews some of the radiometric analysis techniques employed in geology. The development of topographic information including crater distribution functions and topographic profiles, the use of global reflectivity in defining geologic units and in establishing surface composition and the interpretation of local reflectivity differences are discussed.

Our analysis on Mariner VI and VII imagery to interpret local variations in reflectivity by using reflectivity ratios is presented in Section 4. We identify the areas where bi-band spectral data is available and present specific data in support of the interpretation methodology used. The results of our analysis show that light and dark markings interior to crater floors observed in Mariner frames 6N11 and 6N13 acquired through green and red filters respectively are caused by differences between particle sizes between the dark and light areas. Based upon laboratory spectral reflectivity data the most likely size groups for the particles in the two areas is consistent with that proposed by others. Global reflectivity differences between dark and light areas obtained by other authors support larger particle size differences. Based upon our data and that provided by other authors, we concluded that the most likely composition of this local area is limonite stained pyroxene, the latter being a basic silicate common in meteorites. Despite the evidence for basaltic flows on Mars, olivine which is associated with such flows was ruled out as a major constituent in this area based upon its relatively high normal reflectivity.

The application of reflectivity ratio analysis to geologic mapping and the study of atmospheric phenomena was inhibited by the limited amount of data available. It was anticipated that the Mariner IX mission would provide a wealth of bi-band coverage areas on the martian surface and analysis of this data was anticipated. Unfortunately the filter wheel became inoperative on Revolution 118 subsequent to the subsiding of the global martian dust storm. As a consequence, no significant bi-band coverage area of the martian surface was obtained during the Mariner IX mission and this portion of the study was deleted.

SECTION 2

THE RADIOMETRIC MODEL

While the primary objective of this study was not the development of basic radiometric (or photometric) principles or techniques but their application to planetology, an understanding of these principles had to be achieved in order to assess the efforts of related research. Unfortunately, the historical development of radiometric science in astronomy and in electro-optics has not had complete commonality--leading to a diversity of definitions and structure that can be confusing to the engineer not versed in both disciplines. This can result in the misinterpretation of the data presented in other research efforts. Nicodemus (1967) has noted:

> "Radiometry and particularly its overshadowing subdivision, photometry, are embarrassed by diversity in nomenclature. Careful attention to the definitions of all radiometric terms, symbols, and units both by authors and readers is needed to avoid confusion and misunderstanding."

In this section of our report we present a proposed radiometric model and provide definitions that include concepts from both astronomical and electro-optical radiometry as a basis for standardization in this and future efforts in terrestial geology as well as planetology.

An important distinction is made depending on the spectral response of the detector in radiometry. Terms such as luminance, illuminance and brightness are used in photometry where the detector has a spectral passband equal to that of the eye (photopic response). Although this is quite precise the prefix "photo" is frequently used when this is <u>not</u> the case.

An example in astronomy and planetology is the definition of "photometric function" which can be measured over a narrow visible or IR spectral band and is rarely measured with a photopic response. The model and terminology presented below is based upon a summary of radiometry (Nicodemus, 1967).

The geometry of the incident and reflected light from a planar surface (in the x-y plane) is shown in Figure 1. Reflectance of an opaque surface is a function of the influx direction through angles θ_i and ϕ_i and the efflux direction through angles θ_r and ϕ_r. The basic quantity

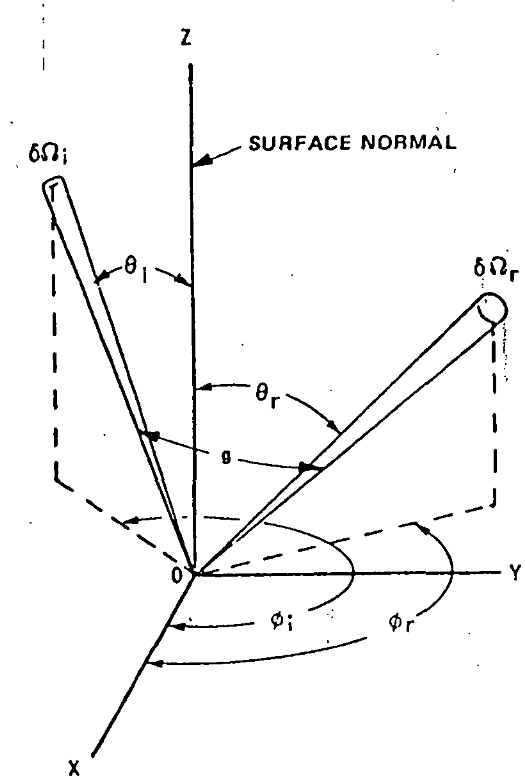

Figure 1. RADIOMETRIC MODEL GEOMETRY

is the spectral radiance, $N_\lambda(\theta_i,\phi_i,\theta_r,\phi_r)$, emanating from the surface and is expressed in units watts/$m^2\cdot sr\cdot\mu m$. The wavelength dependence is removed by integrating over the bandwidth of the incident light and the spectral response of the detector. The explicit dependence on wavelength is suppressed below with the understanding that the terms imply a particular bandpass.

The reflectance (dimensionless) of the surface is defined as the ratio of the reflected radiant power to the incident radiant power

$$\rho \equiv \frac{P_r}{P_i} = \frac{\int N_r(\theta_r,\phi_r)\,d\Omega'_r}{\int N_i(\theta_i,\phi_i)\,d\Omega'_i} = \frac{\int N_r(\theta_r,\phi_r)\,d\Omega'_r}{H_i(\theta_i,\phi_i)} \tag{1}$$

where the projected solid angle $d\Omega' = \sin\theta\cos\theta\, d\theta d\phi$. Both the incident radiance N_i and the reflected radiance N_r are functions of their respective direction angles (θ,ϕ). The reflectance of the surface as defined above can change as the receiver geometry is changed. Clearly we do not generally want to adopt such a definition. An exception occurs when the detector measures all of the reflected radiation, i.e., that reflected into the hemisphere, in which case we obtain the diffuse reflectivity or the Bond albedo discussed below.*

The reflecting properties of the surface are more appropriately described by the bidirectional reflectance function defined by

*The term reflectivity implies decimal fraction while reflectance is expressed in percent. For historical interest we note that the Bond albedo was introduced in 1861.

$$\rho'(\theta_i,\phi_i,\theta_r,\phi_r) \equiv \frac{N_r(\theta_r,\phi_r)}{H_i(\theta_i,\phi_i)} \tag{2}$$

where $H_i(\theta_i,\phi_i)$ is the incident irradiance in watts/m^2. Note that ρ' has dimensions of steradians^{-1}. Combining equations (1) and (2) the diffuse reflectivity (or Bond albedo) is given by:

$$\rho_d = \frac{\int_h \rho'(\theta_i,\phi_i,\theta_r,\phi_r) H_i(\theta_i,\phi_i)\, d\Omega'_r}{H_i(\theta_i,\phi_i)} = \int_h \rho'(\theta_i,\phi_i,\theta_r,\phi_r)\, d\Omega'_r \tag{3}$$

where "h" signifies integration over the hemisphere. For a perfectly diffuse (Lambertian) surface ρ' is independent of receiver coordinates and

$$\rho_d = \rho' \int_h d\Omega'_r = \pi \rho' \tag{4}$$

The normal reflectivity (or <u>normal albedo</u>), ρ_o, is the value of the bidirectional reflectance function when $\theta_i = \theta_r = 0$ and the influx and efflux directions are both normal to the surface:

$$\rho_o = \frac{N_r(0,0)}{H_i(0,0)} \tag{5}$$

In practice the normal albedo can be computed by measuring the radiance of the center of the planet (or the sub-earth point) near opposition and calculating H_i.

If we normalize the bidirectional reflectance to 1.0 at zero influx and efflux zenith angles Equation (2) becomes:

$$\rho'(\theta_i,\phi_i,\theta_r,\phi_r) = \rho_o \Phi(\theta_i,\phi_i,\theta_r,\phi_r) \qquad (6)$$

where Φ is the normalized function. In planetology and astronomy Φ is referred to as the <u>photometric function</u> even though it can be measured over non-photopic spectral bandpasses. In radiometric terms it is the normalized bidirectional reflectivity. The diffuse reflectivity (Bond albedo) can now be expressed in terms of the normal albedo, namely

$$\rho_d = \rho_o \int_h \Phi(\theta_i,\phi_i,\theta_r,\phi_r)\, d\Omega'_r \qquad (7)$$

where the integral is referred to as the phase integral.

Retroreflectivity (or <u>geometric albedo</u>) is the value of the bidirectional reflectivity when the influx and efflux angles are equal (zero phase angle), but not necessarily zero themselves, namely

$$\rho_r(\theta) = \rho_o \Phi(\theta,\phi,\theta,\phi) \qquad (8)$$

Note that the normal reflectivity is a special case of the retroreflectivity. The geometric albedo accounts for the variation in apparent brightness across a planetary disk near opposition. Because the lunar disk appears to be uniform, i.e. no limb darkening, its retroreflectivity is constant and equal to its normal reflectivity. This is not true for the martian disk where limb darkening effects have been observed. Frequently the terms normal albedo and geometric albedo are used interchangeably leading to some confusion. The average reflectivity of a planetary disk near opposition is an area weighted average of its retroreflectivity or geometric albedo but is sometimes identified as the geometric albedo of the planet.

In many situations the bidirectional reflectivity, Eq. (2), is not a function of the four angles $(\theta_i, \phi_i, \theta_r, \phi_r)$ but only three (θ_i, θ_r, g) where g is the phase angle shown in Figure 1.* This allows the bidirectional reflectivity to be written as:

$$\rho'(\theta_i, \theta_r, g) = \frac{N_r(\theta_r, g)}{H_i(\theta_i)} = \rho_o \, \Phi(\theta_i, \theta_r, g) \qquad (9)$$

This simplification is a consequence of <u>assumed</u> symmetry properties of the material, e.g. that the reflectivity is independent of a rotation about its normal. Although most radiometric ("photometric") studies of planetary surfaces accept this assumption it may not always be valid--for example if wind blown dust were to have a preferential deposition $\Phi(\theta_i, \theta_r, g)$ could be ambiguous.

Finally using the more conventional notation, $\theta_i = i$ and $\theta_r = \epsilon$, the component of radiance due to a planetary surface is given by the expression:

$$N(i, \epsilon, g, \lambda) = S(i, \lambda)\, t(\epsilon, \lambda)\, \rho_o(\lambda)\, \Phi(i, \epsilon, g, \lambda) \qquad (10)$$

where $S(i,\lambda)$ is the irradiance on the surface at wavelength λ and $t(\epsilon,\lambda)$ is the

*Note that $|\theta_i - \theta_r| \leq g \leq \theta_i + \theta_r$

loss factor due to the transmissivity of the optical path. Note that in the presence of a significant atmosphere S will include both solar and sky components and that the apparent radiance of the planet will include an atmospheric component as well as a surficial component. For the moon, Mercury and Mars (except during dust storms) the surficial component dominates the observed radiance.

Unfortunately one of the other ambiguities in the definition of radiometric terms is that factors of π "come-and-go". Some authors may have a factor of $1/\pi$ multiplying the right side of Eq. (10). This factor originates because of a difference in the definition of photometric units between the English and metric systems. To further complicate the situation, a similar difference does not formally exist for radiometric units although many authors impose such conditions in order to use operationally measured reflectivities. The English units were developed to facilitate the operational measurement of reflectivity such that a perfectly reflecting diffuse (Lambertian) surface has a bidirection reflectivity of unity. The English unit of luminance (ft-Lambert) has been rationalized by a factor of π in addition to the conversion factor from m^2 to ft^2. Consequently the luminous bidirectional reflectivity, Eq. (2), is increased by π, viz: $\rho' = \pi N_R/H_i$ and the diffuse reflectivity, Eq. (4), becomes $\rho_d = \rho'$ (i.e. the bidirectional reflectivity of a Lambertian surface is numerically equal to its diffuse reflectivity) and the factor of $1/\pi$ enters Eq. (10). Note also that $N_r(\theta_r, \phi_r)$ is constant for a Lambertian surface and the definition based upon the ratio of reflected to incident power, Eq. (1) also becomes $\rho = \pi N_r/H_i$ and the two definitions of luminous reflectivity are identical for Lambertian surfaces. Operationally we frequently measure the bidirectional reflectivity of a material by comparing the received power to that received from a Lambertian standard (with $\rho_d \simeq 1.0$) at the same orientation, the value obtained is governed by the alternate definition discussed here and the multiplying factors discussed above apply.

SECTION 3

BIDIRECTIONAL REFLECTIVITY (PHOTOMETRIC) FUNCTION

It is clear from the results of the previous section that some knowledge of the bidirectional reflectivity characteristics of the surficial materials on a planet are required in order to interpret the radiance measured by either an imaging system or a radiometer. Even if a planetary surface were composed of a single type of material with a well defined particle size regime, the radiance of the planetary surface will vary due to geometrical considerations alone. Both the normal reflectivity and the normalized bidirectional reflectivity (photometric) function can change due to compositional differences on the planetary surface. Consequently, it becomes a matter of removing the geometrical dependence of the radiance to arrive at an "albedo" which contains information about the composition of the surface. One approach is to use Eq. (10) to convert the observed radiance into the normal albedo. This requires knowledge of the normalized bidirectional reflectivity or photometric function. The normal albedo differences subsequently derived can be due to chemical or mineralogical differences, particle size differences or a combination of these effects. A primary objective of this study was to determine whether observed albedo differences (dark and light markings) in Mariner VI and VII photography of the Martian surface were due to chemical effects or particle size differences. However the analyses methodology did not require the computation of the normal albedo or reflectivity.

If we assume that there are no chemical or composition differences then the photometric function or normalized bidirectional reflectivity can be derived from measurements of the radiance of the surface at different illumination and viewing conditions. The measured data is fit to an analytic model for the photometric function. The most frequently used functional representation for surface radiance is the Minnaert equation (Minnaert, 1941). This equation is a parametric expression developed to obey the Helmholtz reciprocity law -- the bidirectional reflectivity is invariant upon reversability of the incident and emission angles, namely

$$\rho'(i,\epsilon,g) = \rho'(\epsilon,i,g) \tag{11}$$

The resulting parametric equation has the form

$$N(i,\epsilon,g,\lambda) = N_p(g,\lambda)\,(\cos i)^{k(g,\lambda)}(\cos\epsilon)^{k(g,\lambda)-1} \tag{12}$$

where the exponential parameter, k, is a function of both the phase angle and wavelength and can be thought of as a limb darkening parameter. The moon, which has no limb darkening effect, has a value of k=0.5 at zero phase while a Lambertian surface would have a value of k=1.0. The Minnaert law is frequently written with the symbol "B" in place of the symbol "N" which we have employed. The former implies the brightness of the surface in contrast to the radiance and consequently in keeping with the discussion in Section 3 we have avoided its use here. The term $N_p(g,\lambda)$, frequently written as "B_o" can be a function of phase angle without violating the reciprocity requirement since it does not depend on the incident or emission angle. At zero phase note that N_p is equal to the radiance obtained at normal incidence and normal emission, namely $N_p(0,\lambda)=N_r(0,0)=H_o(\lambda)\rho_o$ where H_o is the irradiance at normal incidence. This is required so that Eq. (12) has the correct limit at $i = \epsilon = 0$. The Minnaert equation is frequently used in a modified form obtained by implicitly dividing both sides by $H_o(\lambda)$. In this case the value of the parameter N_p or B_o at zero phase angle is the normal reflectivity or albedo. If we assume that N_p is not a function of the phase angle, then $N_p \equiv H_o(\lambda)\rho_o$ for the reasons given above. Some authors make this assumption without noting that it may not be justified.

Comparing Eq. (12) to Eq. (10) and assuming that the loss due to the atmosphere is negligible, the photometric function described by the Minnaert equation is

$$\Phi(i,\epsilon,\xi,\lambda) = \frac{N_p(\xi,\lambda)}{H_o(\lambda)\,\rho_o(\lambda)} (\cos i)^{k(\xi,\lambda)-1} (\cos \epsilon)^{k(\xi,\lambda)-1} \quad (13a)$$

Equating the photometric function and the Minnaert equation, the practice of some authors, is somewhat imprecise and misleading. If N_p is not a function of the phase angle the photometric function becomes

$$\Phi(i,\epsilon,\xi,\lambda) = (\cos i)^{k(\xi,\lambda)-1} (\cos \epsilon)^{k(\xi,\lambda)-1} \quad (13b)$$

The Far Encounter photography obtained during the Mariner VI and VII missions has been employed to estimate the parameters N_p,k in Equations (12) and (13) (Young, 1971). The video signal was converted to reflectivity using available calibration data such that the value of N_p/H_o at zero phase would be the normal reflectivity (albedo), ρ_o, if it could have been estimated. Log-log plots of $N \cos \epsilon$ versus $\cos i \cos \epsilon$ called "Minnaert plots" were constructed to estimate N_p/H_o and k. Since these photographs were obtained with the long focal length TV camera and occurred at limited phase angles, $\sim 23^o \pm 2^o$ this evaluation did not include the variation of N_p/H_o or k with phase angle or wavelength. The results obtained from each of the missions are summarized in the table below. The variation of k from place to place on Mars was attributed to a variation in composition and supported the hypothesis that the Martian surface is more than a two-component system.

Table 1

Minnaert Parameters from Mariner VI and VII Imagery

Region	West Longitude, deg.	Latitude, deg.	k_6	k_7	$\frac{N_{p6}}{H_o}$ Ster^{-1}	$\frac{N_{p7}}{H_o}$ Ster^{-1}
Ophir	68	-8	0.63	0.71	0.146	0.131
Center of Elysium	213	+12	0.56	0.55	0.144	0.132
Aeolis	213	0	0.61	0.68	0.133	0.133
Center of Syrtis Major	290	+5	0.46	0.48	0.093	0.071
Solis Lacus	90	-40	0.66	0.60	0.117	0.093

Earth-based observations of the radiance of Mars have also been employed to estimate the parameter k (Binder, 1972). Unfortunately Earth-based observations are constrained in that measurements cannot be made of the Martian surface at phase angles greater than 40° due to ephemeris considerations. The results of these measurements show a slightly higher value of k at a 23° phase angle, namely $k \approx 0.8$. These data were measured at a wavelength of 0.60 μm. The differences between these two measurements of k are most likely the result of the differences in the spectral bandpass of the sensors. This study also evaluated the variation of k with wavelength with the resulting dependence at approximately 10° phase angle.

$$k(10^\circ, \lambda) = 0.91 - .16/\lambda \quad (14)$$

Since the spectral passband of the B camera varies from 0.48μm to approximately 0.65 μm (Danielson, 1971) the value of the k parameter according to Eq. (14) corrected for the phase angle difference would vary from 0.74 to 0.84, still somewhat higher than the Mariner derived values. We note, however, that Binder arbitrarily assumed that k at zero phase angle was 0.5 (no limb darkening effect).

A more recent evaluation of the Minnaert coefficients derived from observations on the Mariner IX imagery (Thorpe, 1973) resulted in values presented in Table 2 as a function of phase angle at an effective wavelength of 0.56 μm. In this case also the value of N_p at zero phase would be the normal reflectivity. Note that the results presented in the table clearly indicate that N_p is dependent on the phase angle. If we fit results of

Table 2

Minnaert Parameters from Mariner IX Imagery

Phase (deg)	20	30	40	50	60	70	80
N_g	0.166±0.02	0.156±0.30	0.145±0.03	0.14±0.02	0.132±0.03	0.129±0.03	0.135±0.04
k	0.70 ±0.01	0.73 ±0.06	0.77 ±0.03	0.80±0.02	0.84 ±0.05	0.87 ±0.04	0.91 ±0.05

Thorpe for the variation of k with phase angle with a linear equation we find that

$$k(g) = 0.63 + 0.0035\ g \qquad (15)$$

since $k(0) > 0.5$ this indicates a limb darkening effect on Mars.

Measurements of the Minnaert coefficient k at a mean phase angle of 58° were also made during the initial portion of the Mariner IX mission while a dust storm covered Mars (Masursky et al, 1972). For these measurements k increased from 0.93 to 1.12 with increasing wavelength and indicate a nearly Lambertian surface (k=1.0). This result would be expected for an optically thick atmosphere composed of small particles ("dust").

A recent research effort has led to an alternative expression for the photometric function (Meador, 1975). Although more complex than the Minnaert law the Meador equation has the distinct advantage that its parameters can be related to the physical characteristics of the reflecting surface, e.g. particle size, single-particle albedo and compactness. The explicit functional form will not be presented here and the interested reader is referred to the cited reference for details. This expression has been compared to the three data sets previously used to derive the parameters for the Minnaert law as discussed above (Weaver, 1974). Based upon the fit of the Meador expression to the experimental observations and laboratory data on Colorado Basalt it was concluded that the mean intercenter spacing of adjacent particles is about 4/3 of the mean diameter. The mean diameter was concluded to be greater than 225 μm and not in conflict with other indications that the mean diameter of Martian surface particles is about 400 μm.

Regardless of which expression is used to represent the bidirectional reflectivity or photometric function in order to analyze the radiance of a planetary surface as measured by either an imaging system or a radiometer, the values of the influx or incident angle, i, the efflux or emission angle, ϵ, and the phase angle, g, must be determined. If the latitude and longitude of the sub-solar point are known (ϕ_{sz}, λ_{sz}) the incident angle at a point having latitude and longitude (ϕ, λ) is given by

$$\cos i = \sin\phi \sin\phi_{sz} + \cos\phi \cos\phi_{sz} \cos(\lambda - \lambda_{sz}) \tag{16}$$

The sub-solar point is the location on the planetary surface where the line from the center of the sun to the center of the planet intersects the surface. Similarly if the sub-spacecraft point is known (ϕ_{ss}, λ_{ss}) the emission angle can be determined by using

$$\cos\epsilon = \sin\phi \sin\phi_{ss} + \cos\phi \cos\phi_{ss} \cos(\lambda - \lambda_{ss}) \tag{17a}$$

As the spacecraft approaches the planet a (parallax) correction may be required. The emission angle, ϵ, given by Eq. (17a) is increased by δ.

$$\tan\delta = \sin\epsilon / (R_s/R - \cos\epsilon) \tag{17b}$$

where ϵ is the value determined from Eq. (17a), R_s is the distance from the spacecraft to the center of the planet and r is the radius of the planet. For the Mariner VI and VII imagery the values of R_s have been computed by Davis (1971) and $r \simeq 3385$km for Mars. For the Mariner VI and VII imagery $R_s/r = 2$-3 and the correction factor is significant. The locations of the sub-solar and sub-spacecraft paints are not as readily documented and must be determined from orbital data. If the azimuth angle between the incident and emission planes is known and equal to θ then the phase angle is given by

$$\cos g = \cos i \cos \epsilon + \sin i \sin \epsilon \cos \theta \tag{18}$$

The angle θ is the difference between the bearing of the sub-solar point, Z_{sz},

$$\cos |Z_{sz}| = \frac{\sin \phi_{sz} - \cos i \sin \phi}{\sin i \cos \phi} \tag{19a}$$

and the bearing of the sub-spacecraft point, Z_{ss},

$$\cos |Z_{ss}| = \frac{\sin \phi_{ss} - \cos \epsilon \sin \phi}{\sin \epsilon \cos \phi} \tag{19b}$$

The sign of Z_{sz} and Z_{ss} is determined by the value of the longitudes λ_{sz}, λ_{ss} with respect to λ.

SECTION 4

RADIOMETRIC APPLICATIONS IN GEOLOGY

In this section we discuss some of the applications of radiometry and the bidirectional reflectivity function in obtaining information about the geology of planets. No attempt has been made to make this discussion exhaustive but only representative of some of the applications available. The discussion has been divided into three categories which include (1) the influence of reflectivity on topographic information, (2) the use of reflectivity for global geology, and (3) the use of local changes in reflectivity in assessing compositional differences in surficial material.

4.1 Topographic Applications

Two examples where the reflectivity characteristics of a planetary surface influences topographic information include the use of imagery in crater distribution studies and the development of topographic profiles from photometrically corrected image data.

The effect of the finite resolution of an imaging sensor (e.g., Mariner television systems) upon the accuracy of distribution data is well known, namely as the diameter of the crater approaches the resolution limit of the imaging system the measured distribution falls below the actual distribution due to the inability to identify and measure the craters on the reconstructed imagery. The reflectivity characteristics of the planetary surface play a role in how rapidly the loss of information due to limited resolution occurs. This point is not necessarily appreciated by all investigators utilizing the imagery in obtaining their photogrammetric information. The resolution of an imaging system is most often quoted assuming that the object being imaged is high contrast (having extreme radiance values). As the contrast of the object decreases the resolution limit becomes poorer. That is, the inherent resolution limit of the imaging system is only achieved under illumination and viewing conditions where the objects under study have a reasonably high contrast. At high phase angles most surface features have associated shadows which enhance their contrast. Consequently, one would expect the information content of imagery acquired at large phase angles to be higher than that acquired at lower phase angles. As part of the development of quality evaluation techniques for Lunar Orbiter photography the author (Kinzly, 1967) developed an expression for information content in terms of a number of mission parameters including phase angle which was subsequently related to the minimum detectable crater diameter of Lunar Orbiter photography. The variation of the minimum crater diameter with respect to phase angle for this photography is shown in Figure 2. A 4:1 variation occurs as the phase angle changes from 0 to 90°. The change is most dramatic in the region from 60° to 90° emphasizing the value of large phase angle photography. More recently the importance of illumination conditions upon comparative planetary geology has been evaluated (Schultz, 1976). Comparative geology uses imagery from several planetary and lunar missions. It is noted, for example, that the information content of the Mariner IX imagery is comparable to the Mariner VI and VII imagery despite the smaller slant ranges involved on the former mission. The improved theoretical

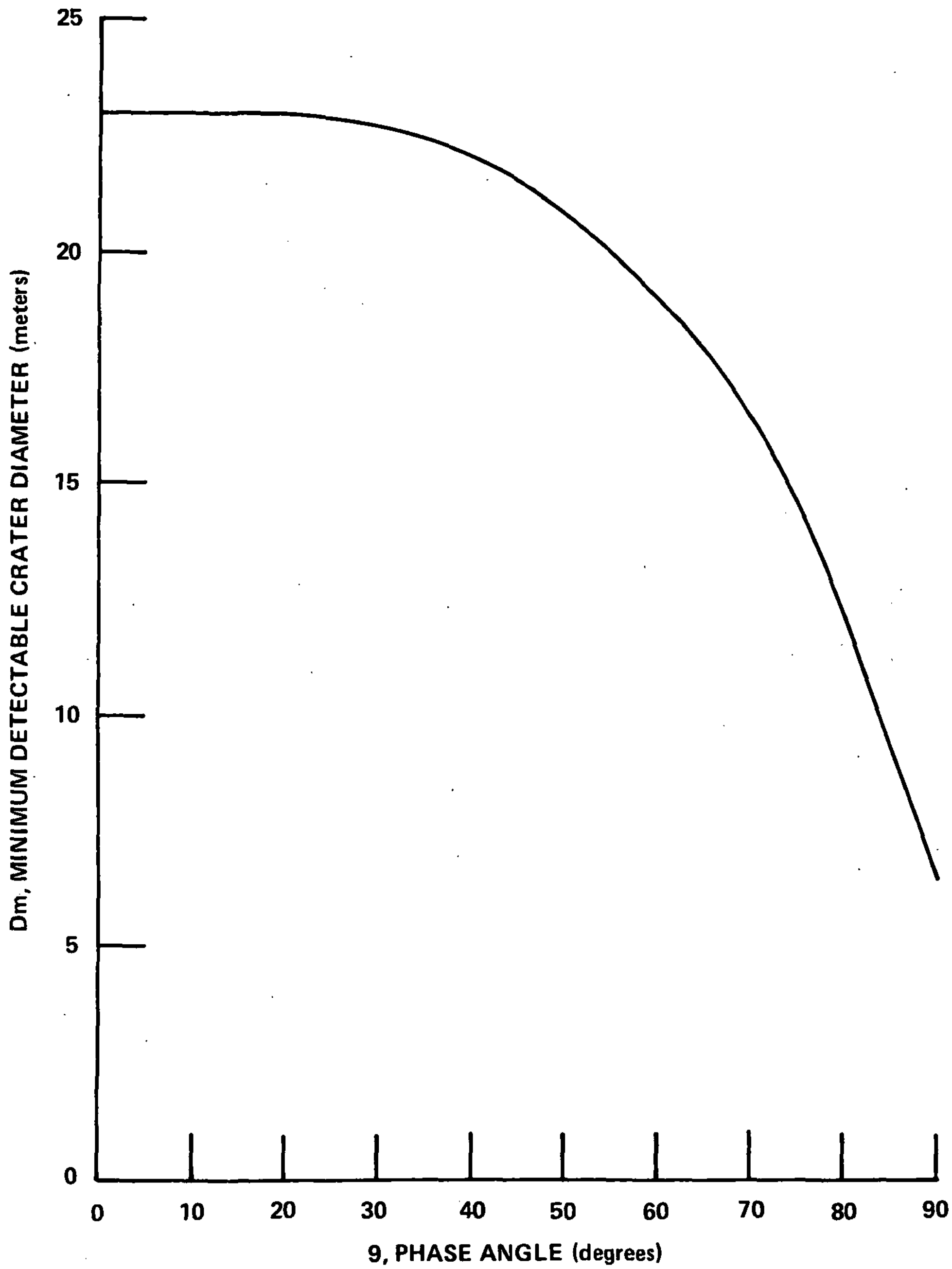

Figure 2 EFFECT OF PHASE ANGLE ON INFORMATION CONTENT OF NEAR VERTICAL LUNAR ORBITER PHOTOGRAPHY

resolution limit of the Mariner IX imagery is offset by the smaller phase angles at which the imagery was obtained. A comparison of TV and photographic imagery of the moon shows that image enhancement allows the TV image to approach the limiting resolution of 2.2 TV lines. However, the enhancement can distort topographic features which are on the order of several resolution elements.

Since the radiance of a point on a planetary surface depends upon the incident and emission angles measured with respect to the local surface normal, an accurate measure of surface radiance can be interpreted in terms of the surface orientation if the bidirectional reflectivity function for the surface is known. The conversion of surface radiance measured from an image into local slope and subsequently into a topographic profile has been termed "photoclinometry" and was applied to both Ranger (Rindfleisch, 1966) and Lunar Orbiter (Lambiotte, 1967) imagery. In the Lunar Orbiter application, the technique was used to derive relative surface roughness indices at potential Apollo landing sites. An evaluation of the quality of Lunar Orbiter imagery (Kinzly, 1968) showed that the medium resolution photographs of Missions I and II received excessive exposure and the image densities could not be reliably converted to surface radiance. The limitation that this placed on the application of photoclinometry was investigated (Gambell, 1968). More recently photoclinometry was used on Mariner IV imagery to produce depth/diameter data for martian craters (Cintala, 1976). Because of the nonlinear relationship between surface radiance and surface slope, the average radiance measured by an imaging system is not necessarily equivalent to the average slope of the surface -- both averaged over a resolution element. Consequently, the resolution of the imaging system can affect the accuracy of the profile information generated by photoclinometry. This analytical procedure, to the best of our knowledge, has nevery received widespread application beyond Lunar Orbiter.

4.2 Definition of Global Geology

As noted in Section 3, differences in the normal albedo of a planetary surface can be produced by chemical or mineralogical differences, particle size differences or a combination of these effects. Consequently, a geologist frequently makes use of the normal albedo of the surface as an aid in defining geologic units. This potential utilization led to the development of albedo maps of the moon (Pohn, 1970), Mars (Cutts, 1971 and de Vaucouleurs, 1973) and Mercury (Dzurisin, 1976). In addition to the fact that albedo boundaries can be coincident with the boundaries between different geological units, correlation between reflectivity of surficial materials has been noted to vary inversely with age on the lunar surface -- older and more heavily cratered areas having a higher reflectivity.

In addition to the production of albedo maps which are used in qualitative geologic evaluations, analysis of the reflectivity characteristics of the light and dark areas of a planet on the global scale have been used to draw inferences on the composition of surficial materials. Typical examples of these type of analyses have included those of Pollack and Sagan (1967) where it was concluded that the bright and dark areas of Mars appeared to have a very similar chemical composition with goethite, a major constituent of both areas. It was also suggested that both areas were covered by a fine powder and that the seasonal change in the reflectivity of the dark areas was produced by aeolian transport of material to and from the dark areas. The average diameter of the particles in the bright areas is estimated to be 50 μm while the dark areas were estimated to have particles ranging from 200 μm to 400 μm depending upon the period relative to the seasonal darkening. Based on visible polarimetry and IR radiometry they proposed limonite as a primary constituent of this powder.

A second example of global reflectivity analysis is that of Binder and Jones (1972). Observations were made using a ten channel spectroradiometer operating from 0.60 - 2.27 μm. They concluded that the measured spectro-reflectivity fell into two well-defined groups, mare and desert units, indicating that the martian surface consists of two types of materials. By comparison with laboratory data they proposed that both surface units contained lithic soils having a limonite stain and that the soils of the maria are richer in pyroxene, olivine, or both than the desert soils. This investigation, therefore, suggests that the differences between martian maria and deserts are due to composition and not due to differences in particle size as proposed by Pollack and Sagan.

A third example of global reflectivity investigations is the work of McCord and his associates (McCord and Adams, 1968; Adams and McCord, 1969; McCord and Westphal, 1971). These investigations involved spectroradiometric observation of Mars from 0.30 - 2.5 μm. Comparison of the resulting spectro-reflectivity curves to laboratory data led to the conclusion that oxidized basalts are a significant constituent of the martian surface. Evidence has been suggested for the existence of basaltic flows and mare on Mars, thereby supporting this hypothesis. It should be noted, however, that the Mariner IX imagery acquired after a martian dust storm contained numerous bright and dark areas produced by dynamic aeolian transport of material over the martian surface. These observations support the hypothesis by Pollack and Sagan that the seasonal changes in reflectivity are a result of a change in the average particle size. It is, of course, quite possible that both mechanisms play a role in the dynamic characteristics of the reflectivity of the martian surface.

4.3 Interpretation of Local Reflectivity Differences

The evaluation of local changes in planetary surface reflectivity requires the availability of radiometrically calibrated high resolution imagery. Consequently, the techniques available for such analyses are less developed although they parallel those used in evaluation of reflectivity changes on a global scale. The distinction that we make between global and localized analyses can be correlated directly with earth-based versus spacecraft observations of the planet. An example of the qualitative analyses of local reflectivity variations is the use of the radial bright ray patterns associated with some craters on the lunar surface in order to derive relative ages. Quantitative techniques are available as illustrated in this report to analyze the dark and light markings occurring in the Mariner VI and VII imagery.

As noted in the previous section, Young and Collins (1971) analyzed the Mariner VI and VII far encounter photographs to derive the parameters of the Minnaert photometric function for five regions of the martian surface. We consider this analysis to be global rather than local, however, since it only employed the far encounter pictures which have resolutions ranging from 10 - 100 km.

A method for evaluation of local changes in the reflectivity of soils employing radiometric analysis using conventional color aerial photography has been recently reported (Piech, 1974). The technique was developed to assist in terrestrial soil surveys by supplementing conventional land form analyses with reflectivity information extracted from color imagery. The cause of reflectivity variations in a soil unit are evaluated by computing the ratio of the reflectance in two spectral bands. Information on the relative soil moisture and texture characteristics is derived from the reflectivity ratios obtained from the imagery. In this case the aerial camera is employed as a radiometer. In addition to calibration, of the object-to-image radiometric response, the effects of the atmosphere must be removed from the imagery in the earth-based application. This is accomplished by radiometric analysis of standard scene objects such as shadow areas. If the darker soil element has a greater red-to-blue reflectivity ratio than the lighter soil element, the reflectivity variation is caused by differences in moisture content. If the darker soil element has a smaller ratio, the decrease in reflectivity is produced by an increase in the average particle size. Rather than computing the reflectivity ratios in two spectral bands the equivalent procedure of computing the ratio of the reflectivity of the darker unit to the lighter unit in each of the spectral bands selected can be used. If the ratio of the darker to lighter soil element at the longer wavelength (e.g. red) is less than the ratio at a shorter wavelength (e.g. blue) then the change in reflectivity can be attributed to a larger particle size for the darker element. Figure 3 shows laboratory data obtained in support of this analysis technique. The figure shows the ratio of the darker to lighter (i.e. wet to dry) soil elements for several terrestrial sands and varying amounts of moisture content. The reflectivity ratios were obtained from densitometer measurements of vertical photography (normal emission) obtained under ambient sunlight such that the incident angle and phase angle varied from 30° to 50°. Note that the ratio increases with wavelength supporting the interpretation of reflectivity ratios proposed above. In the case of reflectivity changes due to particle size variation, the ratio decreases with increasing wavelength. Additional experimental data is presented in the cited reference. This size-reflectivity change rule is not applicable to all types of minerals that could be constituents of soils. The reflectivity versus size effect has been investigated for likely martian surface materials (Salisbury, 1968) and is discussed further in Section 5.2.

The application of this analysis technique to adjacent light and dark surficial elements on the martian surface can be used to distinguish between a chemical cause for lower reflectivity, namely absorbed moisture or a physical cause due to varying particle size. Note that if the composition

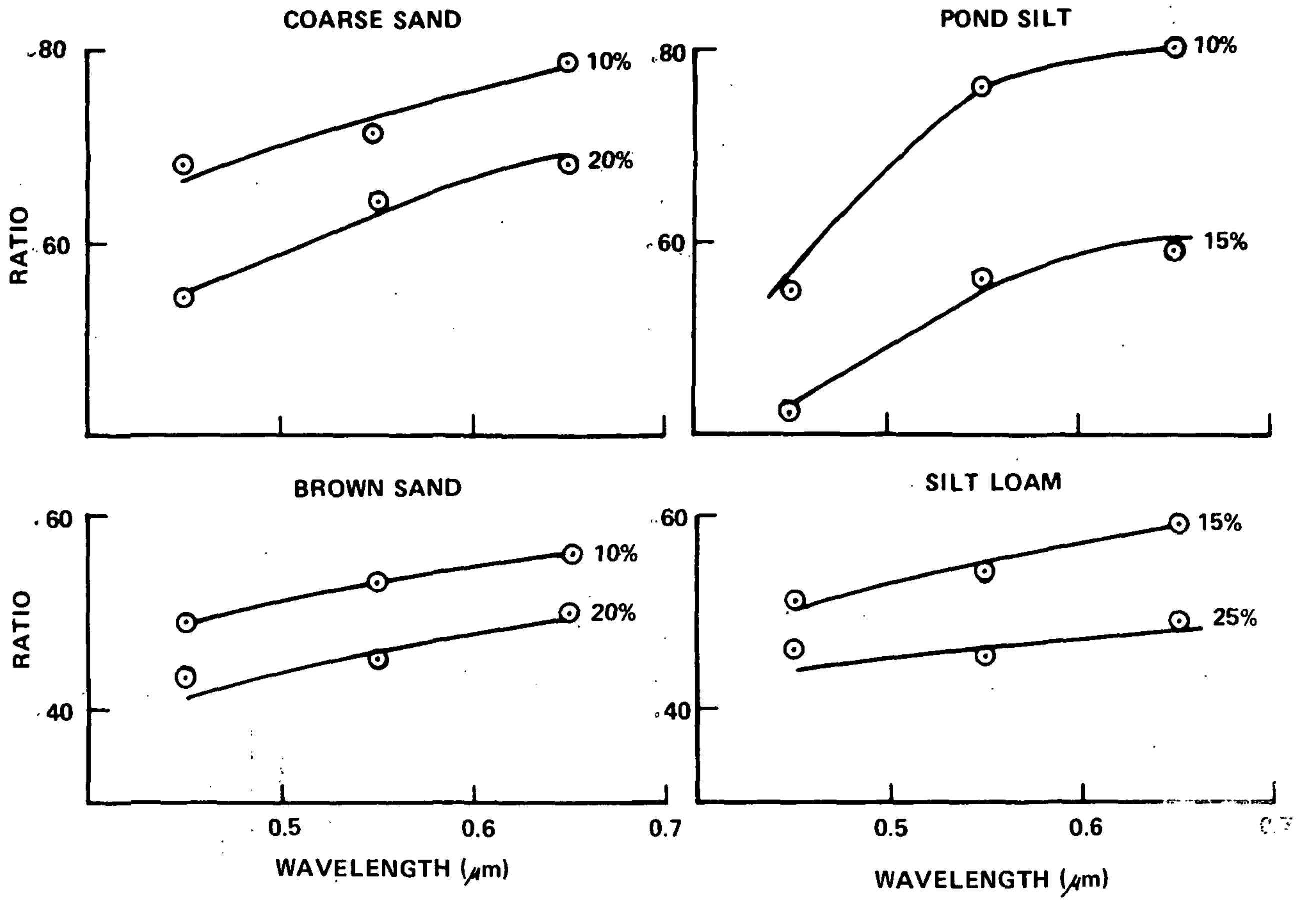

Figure 3 WET/DRY RATIOS DETERMINED PHOTOGRAPHICALLY FOR VARIOUS TERRESTRIAL SOILS AND MOISTURE CONTENTS BY WEIGHT

of the light and dark areas is assumed to be similar or if the bidirectional reflectivity is assumed constant, the ratio of the radiance of the dark to the light area is equal to the ratio of their reflectivities and no explicit correction for the bidirectional reflectivity or photometric function is required. This technique was applied to the analysis of adjacent light and dark areas occurring in the Mariner VI and VII imagery -- the results are presented in the next section of this report.

SECTION 5

ANALYSIS OF MARINER VI AND VII IMAGERY

This section of our report documents analyses carried out on Mariner VI and VII imagery to interpret local variations in reflectivity by using reflectivity ratios derived from the imagery. Darkening of the martian surficial material can be produced by chemical effects such as absorbed water, by changes in the particle size or by changes in the composition of the surface material. Identification of the presence of significant amounts of moisture in the martian soil is important to the assessment of life forms on Mars while the assessment of relative particle size differences is important to the evaluation of dynamic aeolian processes. Alternate near encounter frames from the wide angle Mariner cameras were taken through different spectral filters (red, green or blue) and the overlap between successive frames show the same area of the martian surface in two spectral bands. These regions of overlap provide an opportunity to use reflectivity ratio analysis techniques in the study of martian planetology. In this section we (1) identify the areas where bi-band spectral data is available, (2) present additional data in support of the interpretation of the reflectivity ratios beyond that identified previously in Section 4.3, (3) describe the tools developed to compute the reflectivity ratios from digital data supplied by the Image Processing Laboratory at JPL and (4) present the results of the analysis of adjacent light and dark areas occurring in the Mariner photography.

5.1 Mariner VI and VII Multi-Spectral Image Data

The objective of this investigation was to illustrate the utility of radiometric analysis, particularly reflectivity ratios, to planetology in general and the study of Mars in particular. We planned to use TV image data obtained from the Mariner VI, VII and IX missions. Mariner VI and VII were fly-by missions that had a variety of experiments including a dual TV imaging system (Danielson, 1971). One TV sensor employed a short focal length lens (~50mm) while the second sensor employed a long focal length lens (~500mm) and were termed the "wide angle" and "narrow angle" cameras respectively. Since the imagery was obtained during fly-bys the resolution (~2.2 TV lines) changed from image to image. For the imagery utilized it was approximately 2-4 km for Mariner VI and 4-5 km for Mariner VII. The wide angle camera contained a filter wheel with four spectral filters. The spectral transmission of the filters incorporated into Mariner VI and VII are shown in Figure 4. Alternate near encounter frames from the wide angle Mariner cameras overlapped such that the same area of the martian surface was taken through two different spectral filters. The initial step in the research effort was the identification of those areas where bi-band coverage was available. Reflectivity ratios computed within these areas could be used for geologic mapping, discrimination of atmospheric phenomena, obtaining information about polar cap structure and obtaining information about the cause of local variations in the reflectivity of the martian surficial material.

Six areas of bi-band coverage were identified from the Mariner VI mission and six areas of bi-band coverage from the Mariner VII mission.

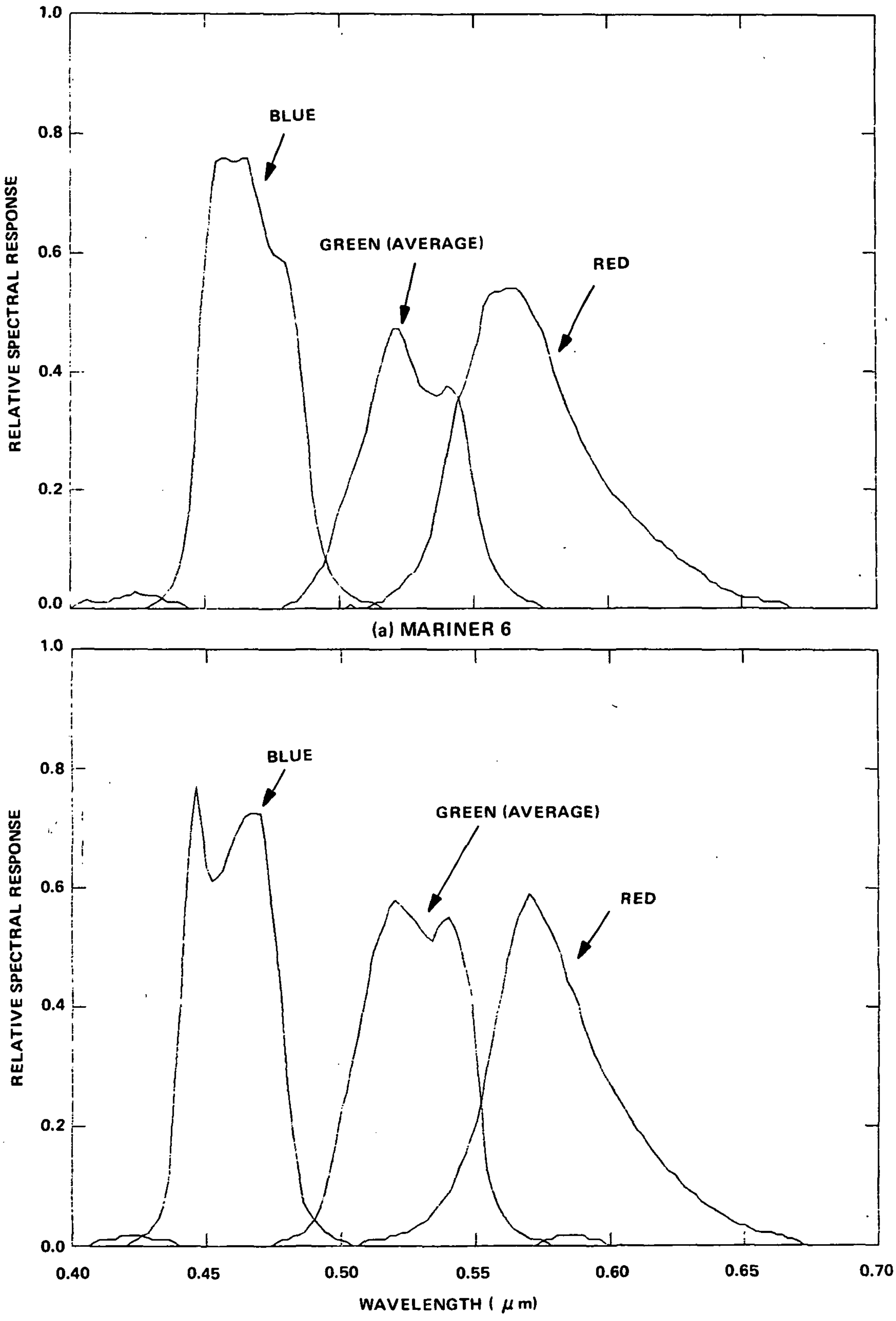

Figure 4 SPECTRAL TRANSMISSION OF MARINER VI AND VII WIDE ANGLE CAMERAS

Table 3 summarizes these areas which are designated by the mission number followed by a letter code A through G. This table identifies the location of each of these areas and the frame numbers and spectral filters of each of the overlapping photographs. Figure 5 shows the location of each of the bi-band coverage areas on the 1971 Shaded Relief Map of Mars.

A number of potential bi-band coverage areas were eliminated from consideration. These included the two areas of overlap between 7N5, 7N7 and 7N9. These photographs were obtained at a highly oblique angle and had lower resolution thau the subsequent near encounter frames. Consequently the radiometrically corrected digital imagery was not requested from JPL. In retrospect this is somewhat unfortunate since these photographs included some of the areas in Meridiani Sinus coincident with areas 6B and 6C previously selected. In addition, the overlap area between frames 7N29 and 7N31 were deleted from consideration because of their proximity to the terminator which yields a lower quality due to the low exposure level on the vidicon. One area of overlapping coverage among frames 7N15, 7N17 and 7N19 actually had tri-band coverage. This is a small area in the South Polar Cap located at 72°S - 80°S, 332°W - 348°W. Although no specific analysis was undertaken over this area, several features appear that might be caused by atmospheric phemonena. Figures 6 through 9 show the Mariner VI bi-band coverage areas on enhanced versions of the imagery transformed to othographic projections. Figures 10 through 13 show the bi-band coverage areas of Mariner VII on similar projections. Digital tapes containing TV image data for each frame identified in Table 3 were obtained from Mr. A. Collins at the

Table 3a

Mariner Bi-band Coverage Areas
Mariner VI

DESIGNATION	REGION	LOCATION	FRAME NO.	SPECTRAL BANDS	OVERLAP (APPROX.)	PHASE ANGLE	GEOLOGIC UNIT*	PRINCIPAL MAPPING QUADRANGLE(S)
6A	Aurorae Sinus - Margaritifer Sinus	$2^{\circ}N - 19^{\circ}S$, $280^{\circ}W - 47^{\circ}W$	6N5, 6N7	Red, Green 1	40%	51°	cu, h	Margaritifer Sinus
6B	Thymiamata	$11^{\circ}N - 13^{\circ}S$, $2^{\circ}W - 15^{\circ}W$	6N9, 6N11	Blue, Green 2	40%	51°	cu	Oxia Palus - Margaritifer Sinus
6C	North Meridiani Sinus & West Edom	$7^{\circ}N - 10^{\circ}S$ $352^{\circ}W - 30^{\circ}W$	6N11, 6N13	Green 2, Red	30%	51°	cu	Sabaeus Sinus
6D	Margaritifer Sinus and East	$9^{\circ}S - 23^{\circ}S$, $13^{\circ}W - 23^{\circ}W$	6N15, 6N17	Green 1, Blue	25%	80°	cu	Margaritifer Sinus
6E	Margaritifer Sinus and East	$13^{\circ}S - 21^{\circ}S$, $1^{\circ}W - 6^{\circ}W$	6N17, 6N19	Blue, Green 2	25%	80°	cu	Margaritifer Sinus
6F	Sabaeus Sinus and West	$12^{\circ}S - 21^{\circ}S$, $350^{\circ}W - 353^{\circ}W$	6N19, 6N21	Green 2, Red	25%	80°	cu	Sabaeus Sinus
6G	Sabaeus Sinus and West	$11^{\circ}S - 20^{\circ}S$ $338^{\circ}W - 341^{\circ}W$	6N21, 6N23	Red, Green 1	25%	80°	cu	Sabaeus Sinus

*List of Units (after Carr, 1973)

h: Chaotic Deposits
cu: Cratered Deposits, Undivided

Table 3b

Mariner Bi-band Coverage Areas
Mariner VII

DESIGNATION	REGION	LOCATION	FRAME NO.	SPECTRAL BANDS	OVERLAP (APPROX.)	PHASE ANGLE	GEOLOGIC UNIT*	PRINCIPAL MAPPING QUADRANGLE(S)
7A	Edge Polar Cap	50°S - 70°S, 2°W - 56°W	7N11, 7N13	Green 2,Red	50°	35°	cm,cu,ps	Argyre
7B	Polar Cap	57°S - 79°S, 342°W - 56°W	7N13, 7N15	Green 2,Red	50°	35°	cm,cu	Argyre - Mare Australe
7C	Polar Cap	64°S - 86°S 322°W - 26°W	7N15, 7N17	Red,Green 1	50°	35°	?	Mare Australe
7D	Polar Cap	68°S - 88°S 292°W - 4°W	7N17, 7N19	Green 1,Blue	50°	35°	?	Mare Australe
7E	Noachis - Hellas	29°S - 44°S 322°W -342°W	7N23, 7N25	Green 1,Blue	25%	80°	cu	Noachis
7F	Boundary Hellespontus Hellas Boundary	38°S - 48°S 311°W -322°W	7N25, 7N27	Blue,Green 2	15%	80°	cu,m,ps	Noachis - Hellas
7G	Hellas Floor	40°S - 45°S 295°W -303°W	7N27, 7N29	Green 2,Red	small	80°	ps	Hellas

*List of Units (after Carr, 1973)

cm: Cratered Deposits, Mantled
cu: Cratered Deposits, Undivided
ps: Sparsely Cratered Plains
m: Mountainous Deposits

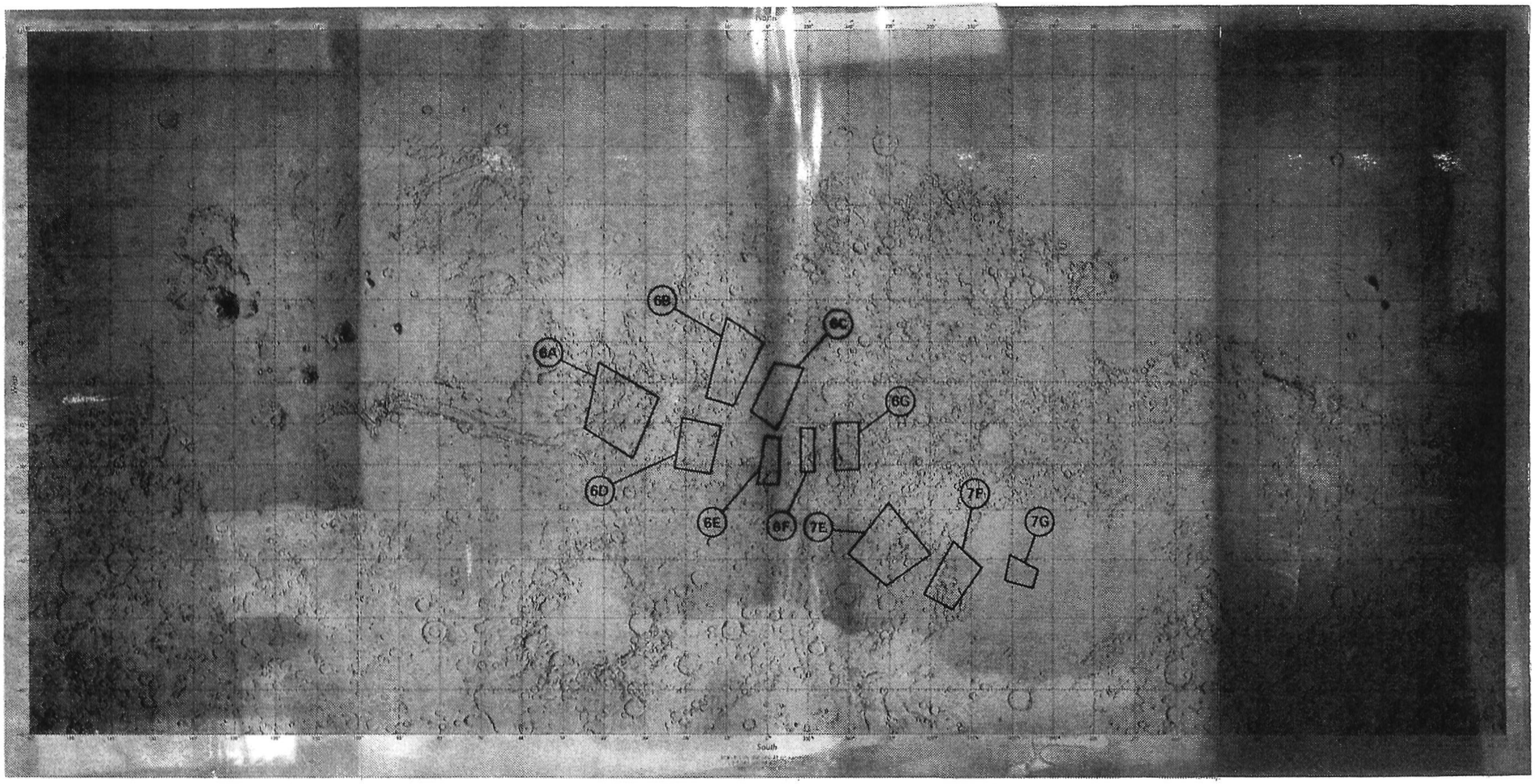

Figure 5 BI-BAND COVERAGE AREAS ON MARS

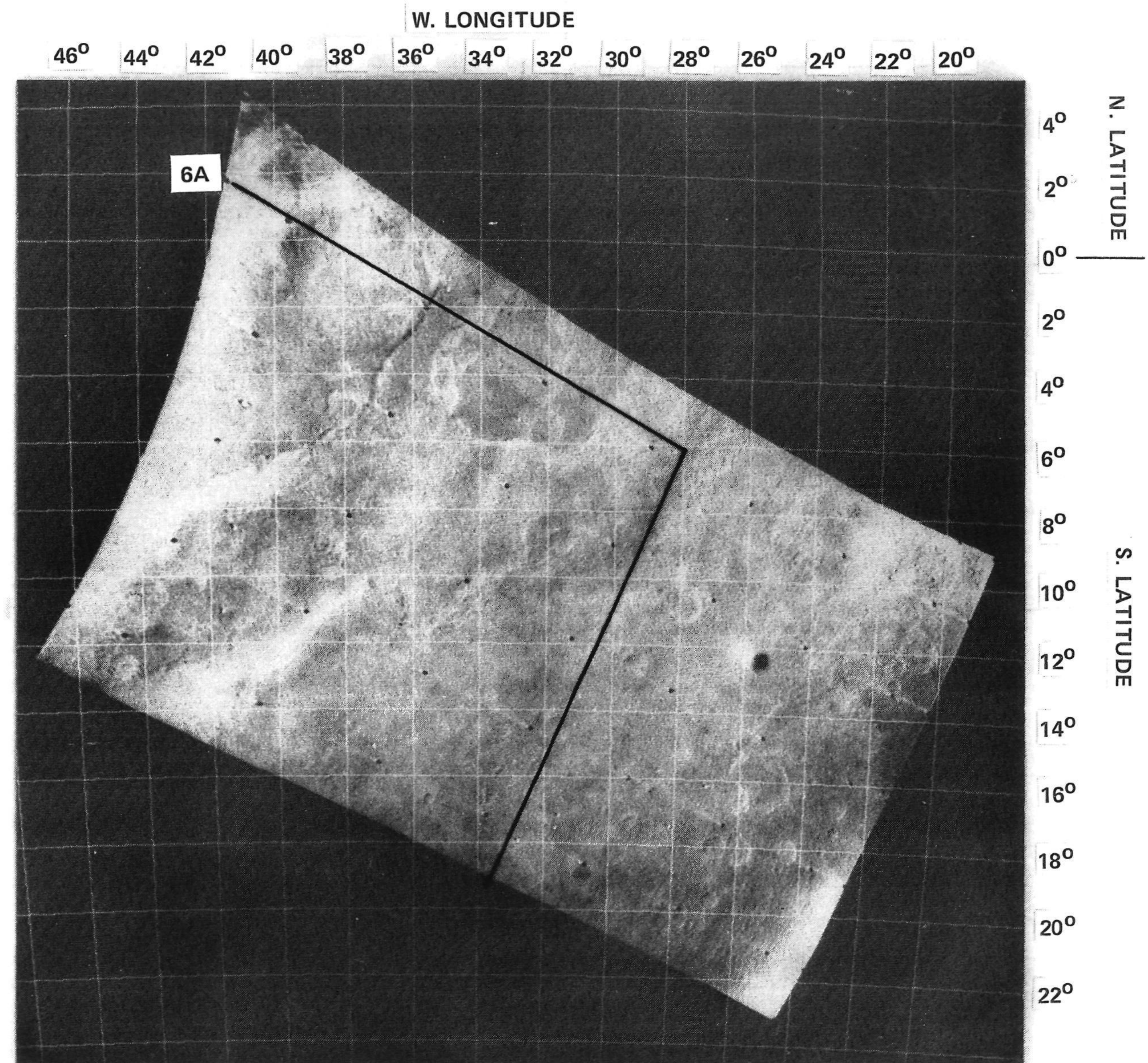

Figure 6 BI-BAND AREA 6A SHOWN ON ORTHOGRAPHIC PROJECTION OF FRAME 6N7

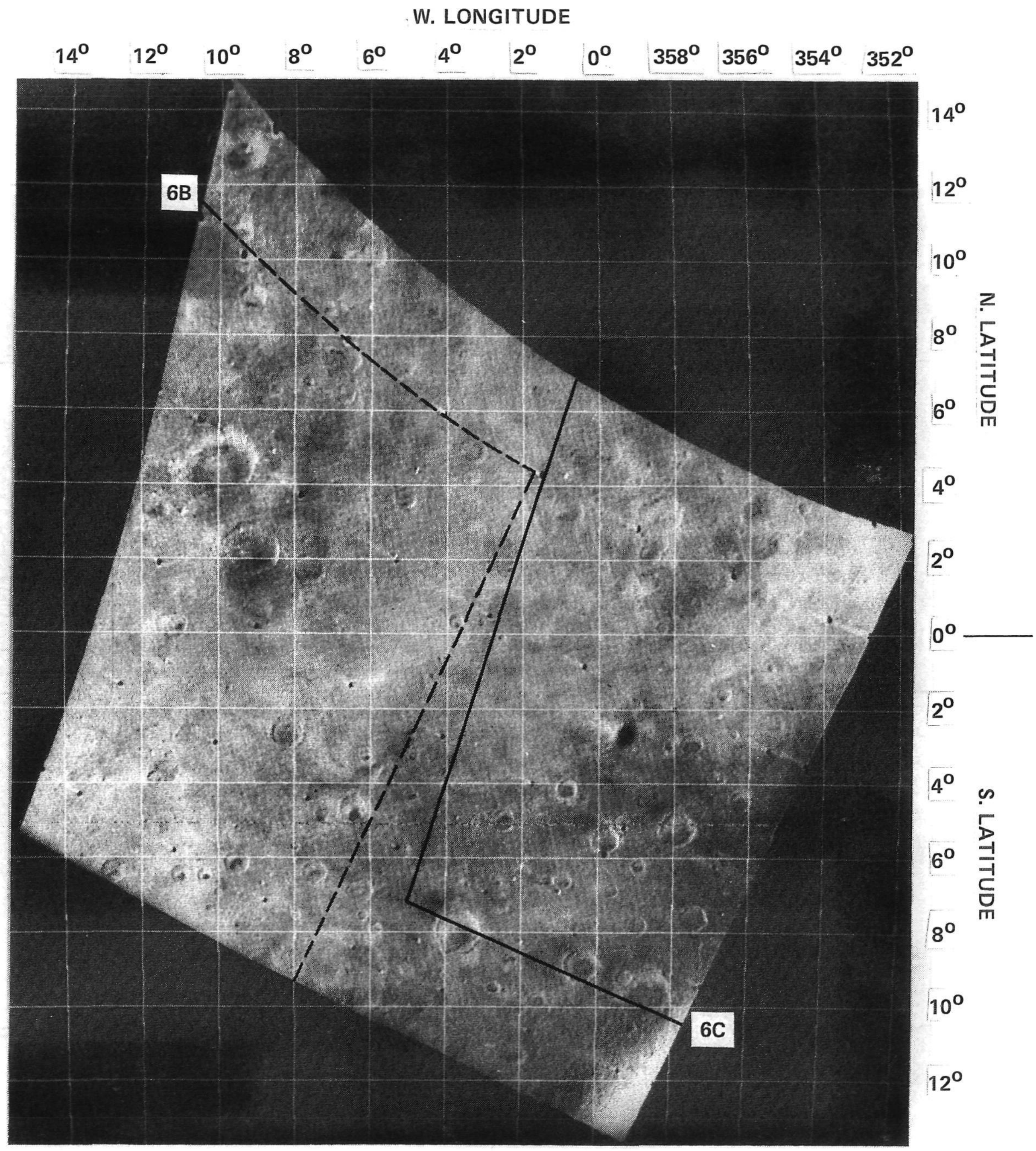

Figure 7 BI-BAND AREAS 6B AND 6C SHOWN ON ORTHOGRAPHIC PROJECTION OF FRAME 6N11

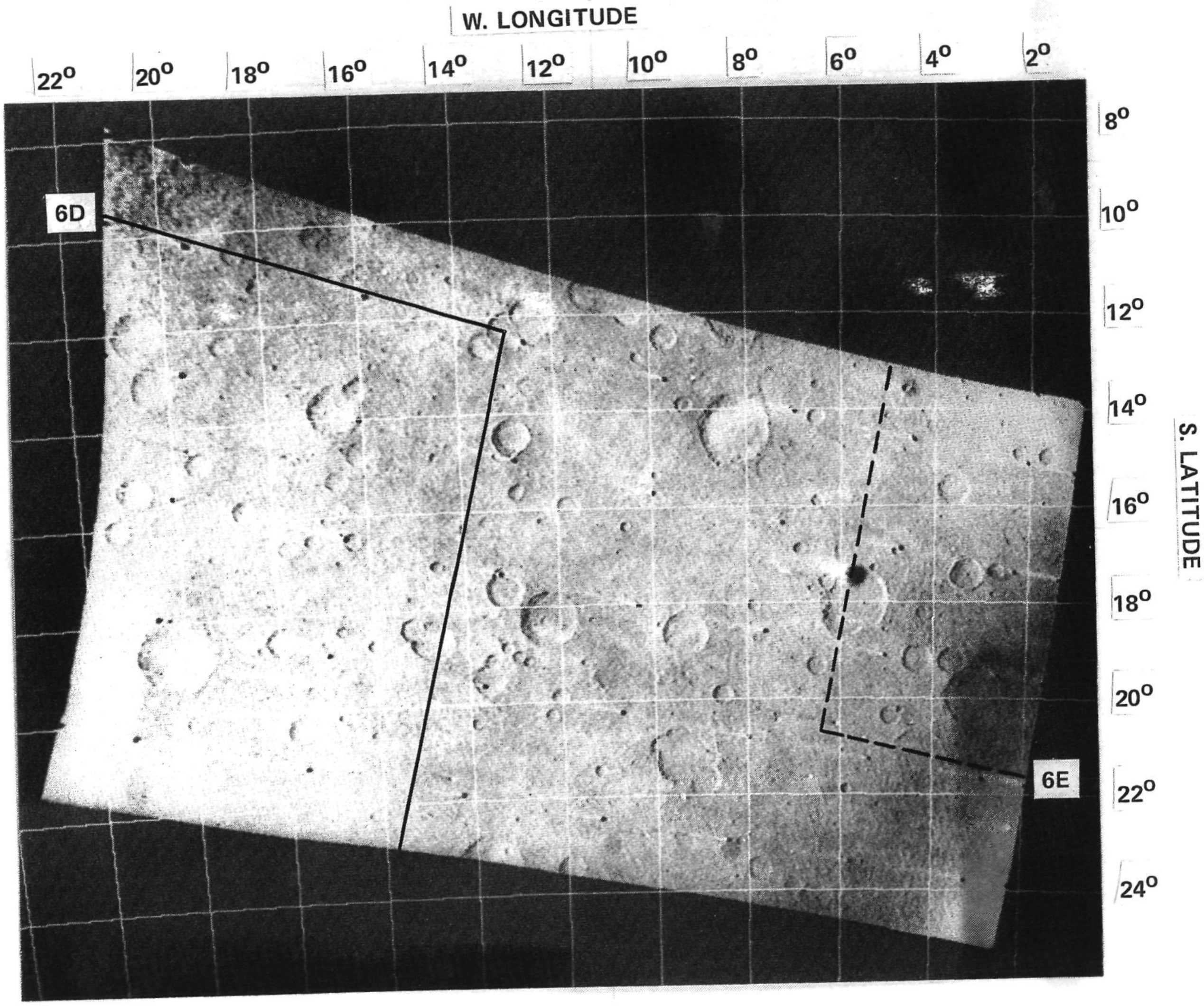

Figure 8 BI-BAND AREAS 6D AND 6E SHOWN ON ORTHOGRAPHIC PROJECTION OF FRAME 6N17

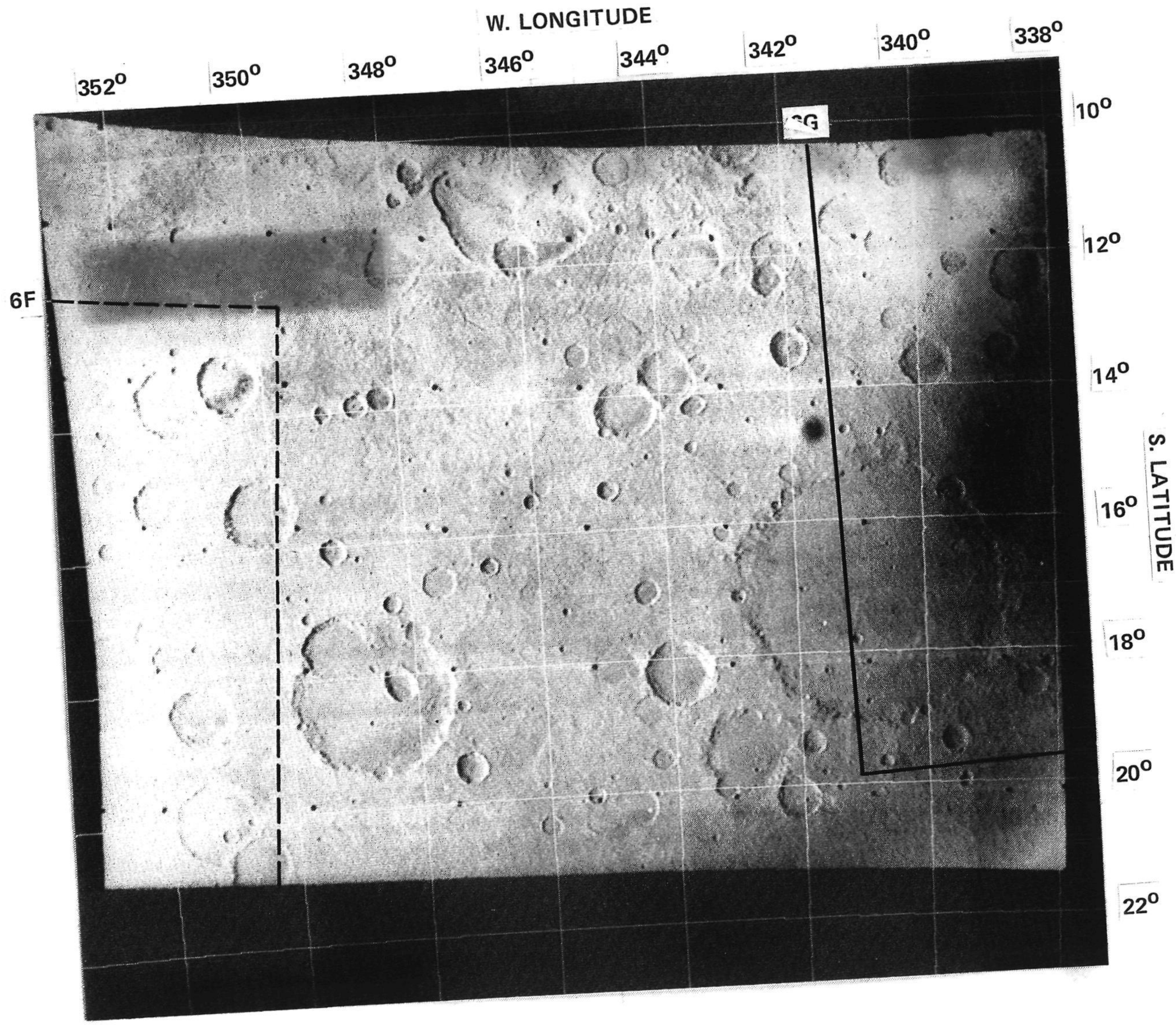

Figure 9 BI-BAND AREA 6F AND 6G SHOWN ON ORTHOGRAPHIC PROJECTION OF FRAME 6N21

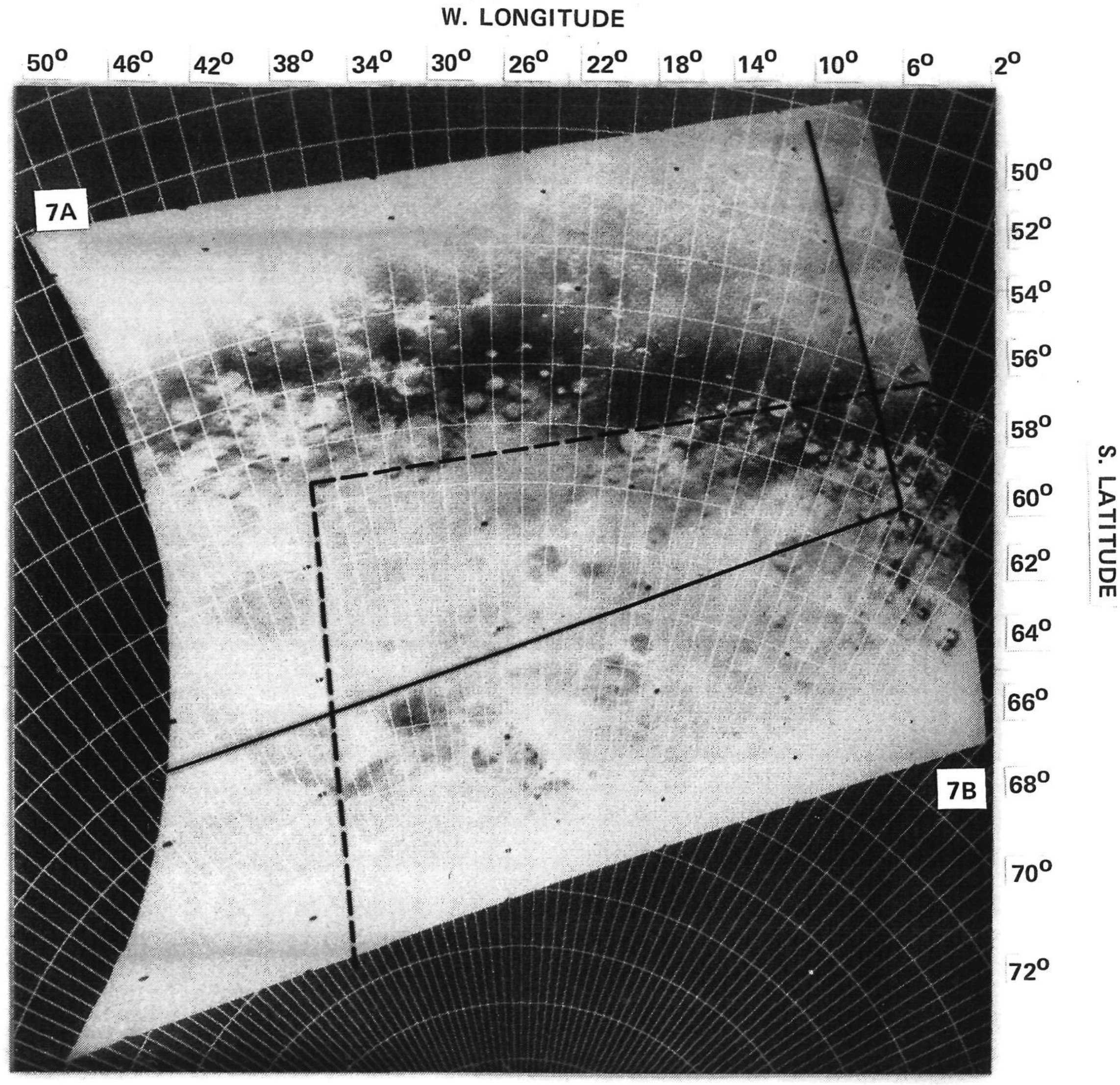

Figure 10 BI-BAND AREAS 7A AND 7B SHOWN ON ORTHOGRAPHIC PROJECTION OF FRAME 7N13

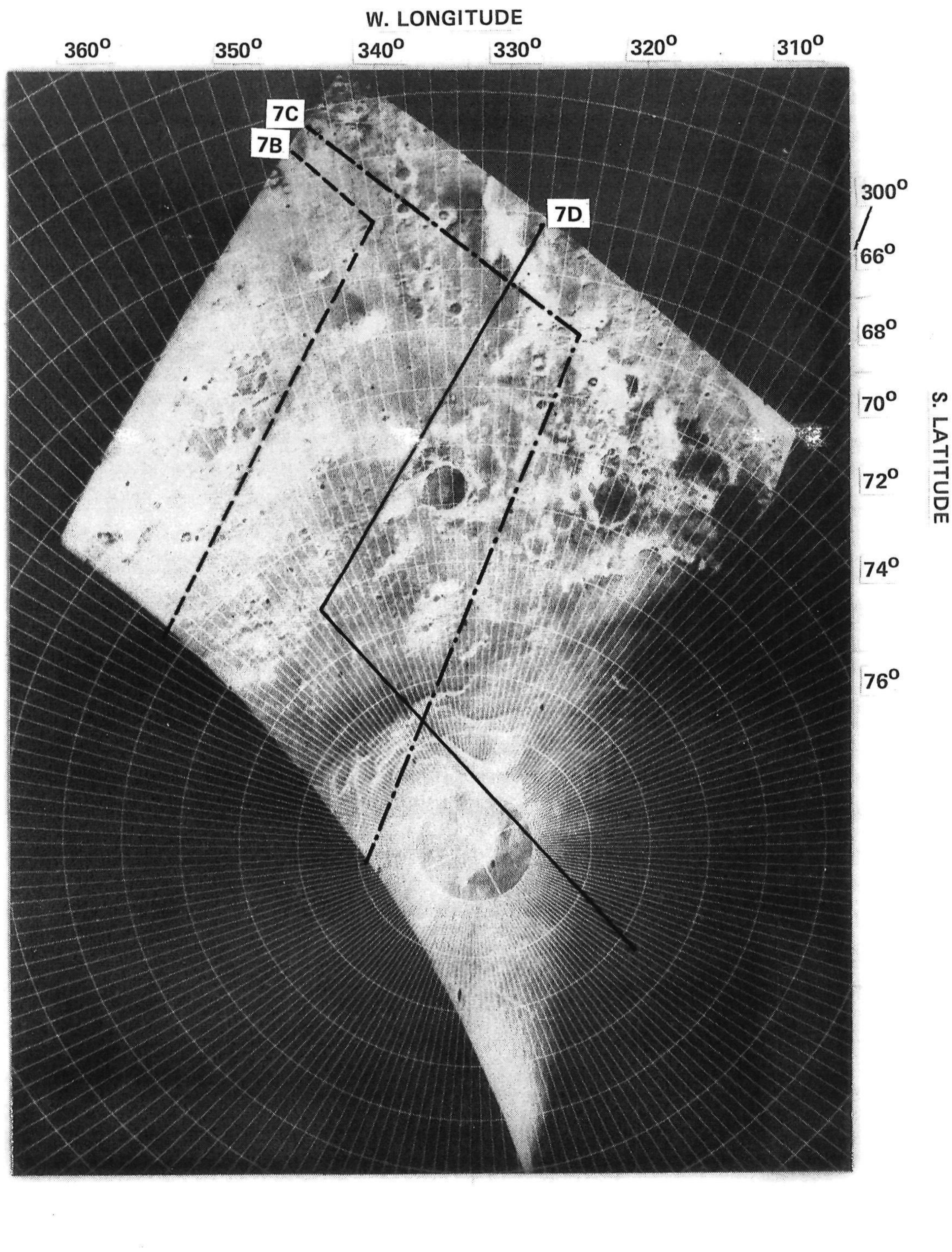

Figure 11 BI-BAND AREAS 7B, 7C AND 7D SHOWN ON ORTHOGRAPHIC PROJECTION OF FRAME 7N17

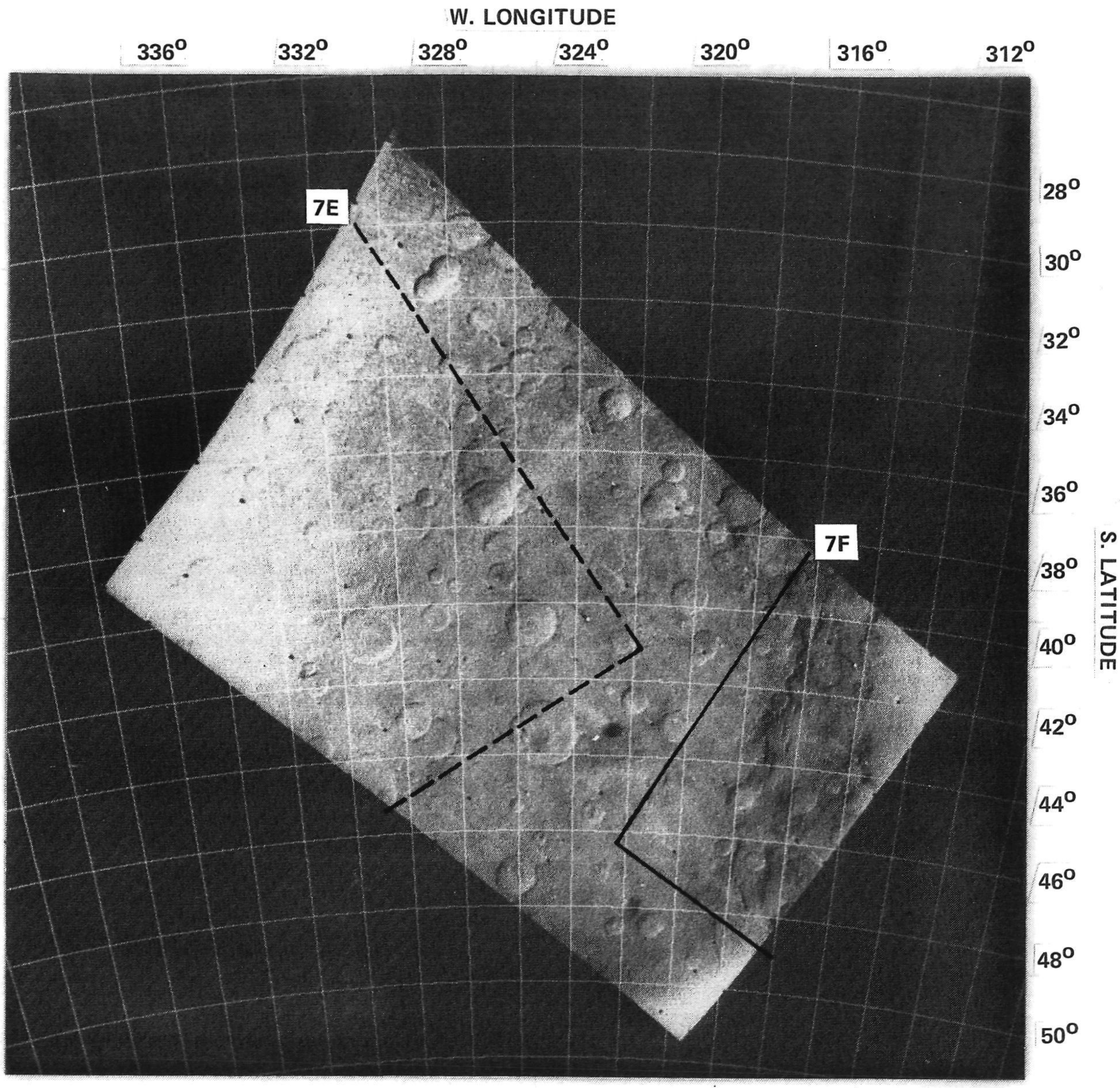

Figure 12 BI-BAND AREAS 7E AND 7F SHOWN ON ORTHOGRAPHIC PROJECTION OF FRAME 7N25

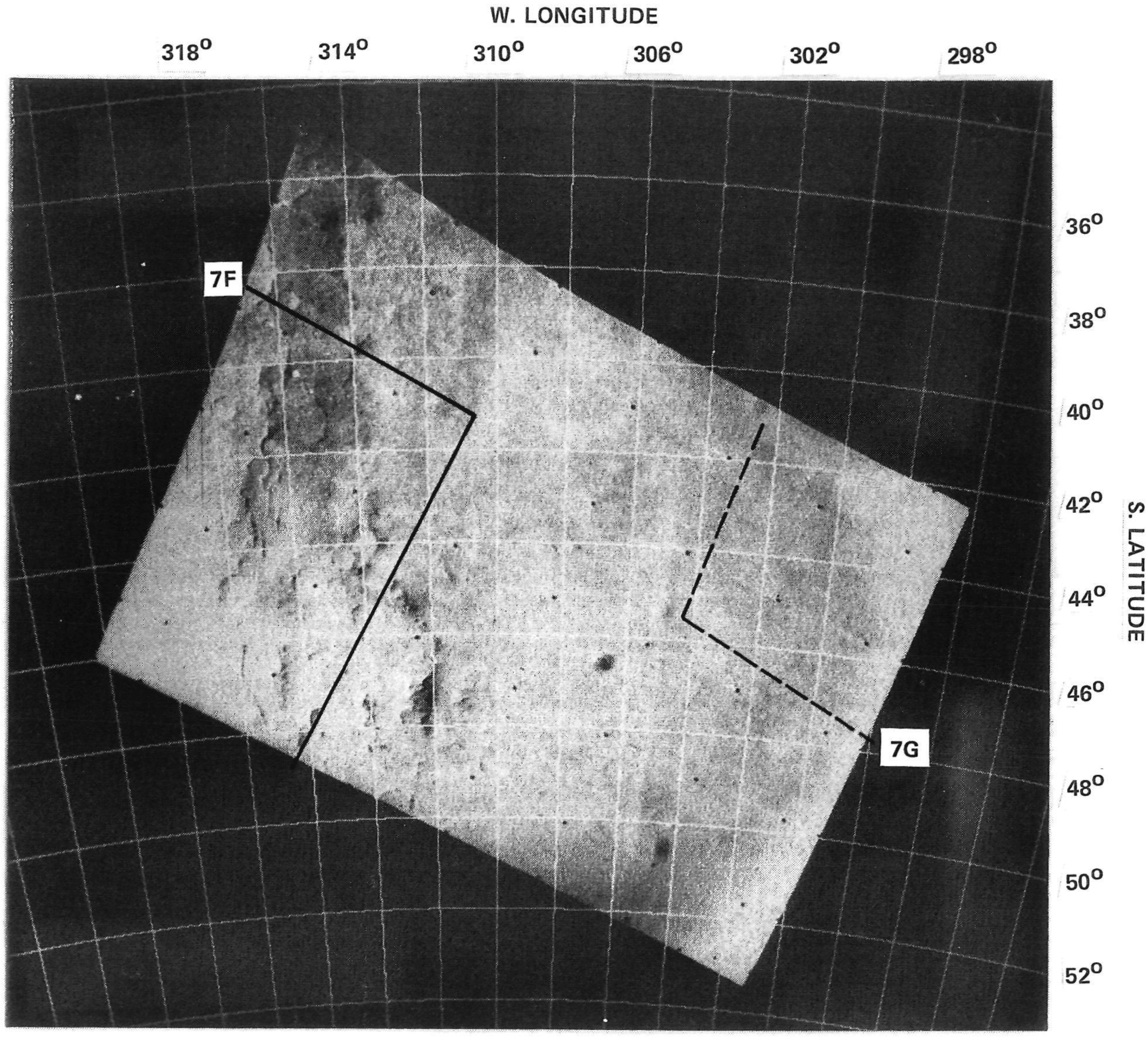

Figure 13 BI-BAND AREAS 7F AND 7G SHOWN ON ORTHOGRAPHIC PROJECTION OF FRAME 7N27

Jet Propulsion Laboratory. The data obtained was the LMICOR version which was produced by the Image Processing Laboratory at JPL by correcting the raw TV data for radiometric distortion introduced by the TV systems. The corrected data represents the surface bidirectional reflectivity multiplied by a factor of 6.0 in order to optimally utilize an 8-bit format.

The area that received the most detailed analysis was 6C. This area has light and dark markings on crater floors which were evaluated to determine whether this variation is caused by absorbed water or by changes in particle size. The method employed uses the reflectivity ratios in the manner discussed in Section 4.3. Section 5.2 contains additional data on the relationship between particle size and reflectivity that supports our analysis of these markings. The results of the analysis itself are contained in Section 5.4.

5.2 Reflectivity - Particle Size Effect

A size-reflectivity change rule was described in Section 4.3 that has been utilized in terrestrial soil surveys. This rule indicated that the reflectivity ratio of the dark-to-light soil element should decrease with increasing wavelength if a change in particle size was responsible for the change in reflectivity.

The proposal that limonite be a major constituent of the martian surface led Salisbury and Hunt (1968) to conduct a study of the spectral behavior of likely martian surface materials. They classified potential materials by their change in reflectivity as a function of particle size. The class of transparent materials, which includes silicate minerals, show a increase in reflectivity with a decrease in particle size as assumed in the development of the size-reflectivity change rule referenced above. Opaque material, particularly metal sulfides, showing a decrease in reflectivity with decreasing particle size. A third class of materials which Salisbury and Hunt term "trans-opaque" exhibits a decrease in reflectivity in the opaque portion of the visible spectrum and an increase in reflectivity in the transparent portion of their visible spectrum. That is, the spectral reflectivity curve for one particle size will cross that for a different particle size leading to a reversal in reflectivity between the two particle sizes within the visible spectrum. This behavior is exhibited by several ferric oxides such as limonite, goethite and hematite that are likely candidates for existence on the martian surface. As Salisbury and Hunt point out, light and dark markings on the martian surface composed of high concentrations of these types of materials should exhibit a contrast reversal at some point in the visual spectral region. That is, the light markings should become dark and the dark markings become light as the radiometric or image data increase in wavelength. Since such a reversal has not been observed Salisbury and Hunt concluded that the hypothesis that the martian soil consists in a large part of limonite and that the reflectivity differences are due to particle size changes are incompatible. As an alternative they propose that the most likely soil is one composed of silicates lightly stained or coated with ferric oxides. In terms of the present evaluation of the Mariner imagery the dark-to-light reflectivity ratio could increase with wavelength between the blue and green images and subsequently decrease with wavelength between the green and red images if a significant amount of the trans-opaque type materials composed the elements under evaluation and the change in particle size was the principal cause for the change in reflectivity. Our analysis concentrated on the local reflectivity changes occurring in bi-band coverage area 6C involving overlapping green and red imagery.

To further support our analyses using the reflectivity ratio, the ratios for typical martian materials were evaluated over the spectral responses of the Mariner VI and Mariner VII wide angle cameras presented earlier in Figure 4. Hunt and Salisbury (1970, 1971) have obtained a number of spectral reflectivity curves for various rocks and minerals as part of a laboratory study of spectroscopic remote sensing techniques. We selected typical candidates from the published data for silicate minerals (1970) and oxides and hydroxides (1971). The spectral reflectivity for each of the minerals selected is shown in Figure 14 (although measurements were made at IR wavelengths this data was not of interest here). The reflectivity data were obtained near normal incidence and emission angles at a phase angle of 15° and referenced to a Lambertian surface with a diffuse reflectivity near 1.0. Generally the data were obtained for four different particle size regions allowing six different ratios of the reflectivity of larger-to-smaller particle sizes to be obtained. For materials whose reflectivity increases with decreasing particle size this ratio is equivalent to that of the darker-to-lighter soil elements. The six different ratios obtained are identified in Table 4 using the letter symbol A through F.

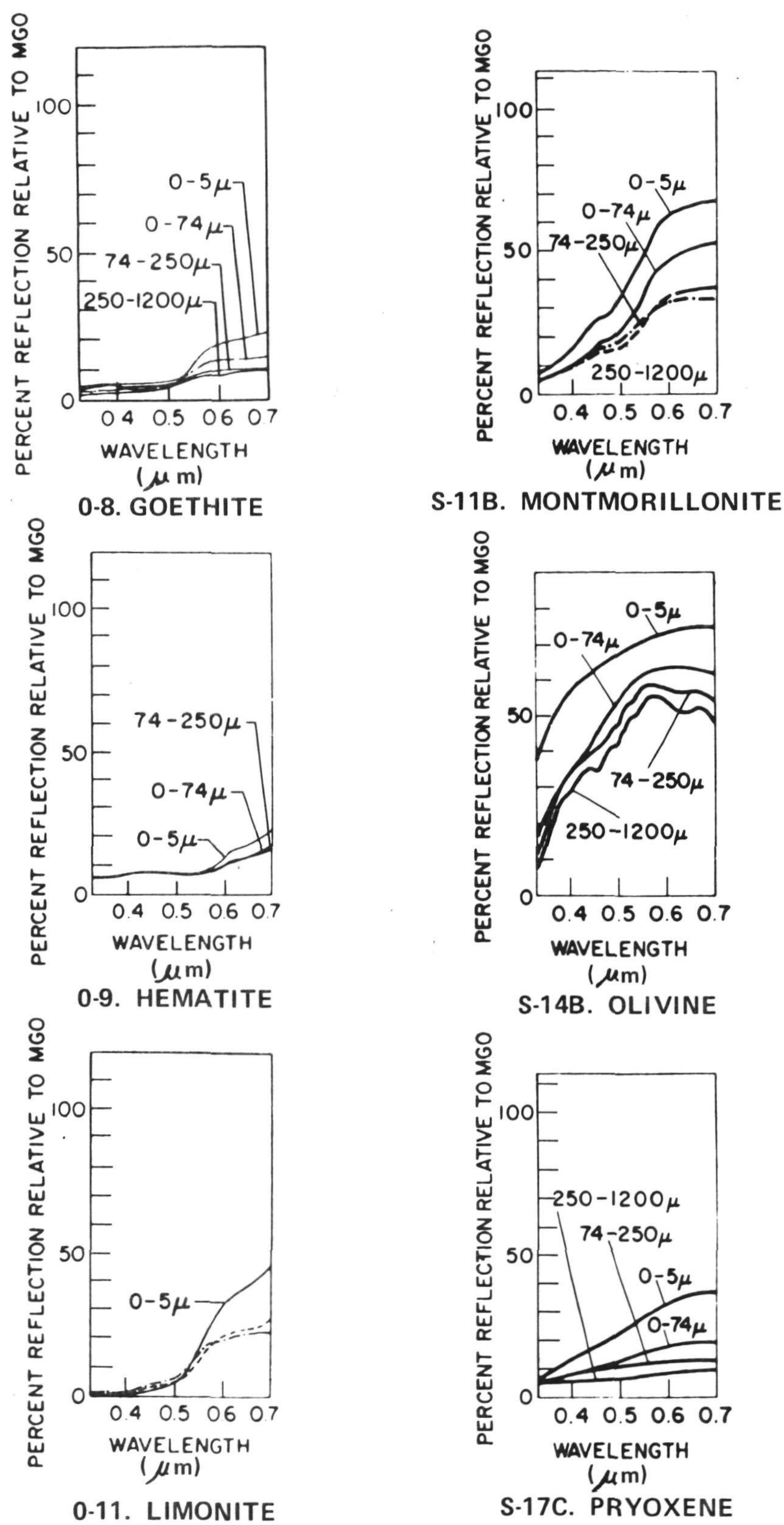

Figure 14 SPECTRAL REFLECTIVITY FOR TYPICAL MARTIAN MINERALS AS A FUNCTION OF PARTICLE SIZE

Table 4

Large-to-Small Particle Index

Symbol	Particle Size Ratio
A	250-1200 μm/0-5 μm
B	250-1200 μm/0-74 μm
C	250-1200 μm/74-250 μm
D	74-250 μm/0-5 μm
E	74-250 μm/0-74 μm
F	0-74 μm/0-5 μm

From the silicate minerals olivine and pyroxene were selected based upon the analysis of Binder and Jones (1972). Montmorillonite was arbitrarily added as the third selection from the silicate minerals. Limonite was selected from the ferric oxides since it has been proposed as a major constituent by Pollack and Sagan (1967) and as a stain on silicates by Binder and Jones (1972) and Salisbury and Hunt (1968). Pollack and Sagan proposed goethite as a major constituent of the martian surface and consequently this was also selected by the oxide group. Finally, Hematite was added as a third ferric oxide--a logical addition to those already selected. Table 5 presents the average reflectivity of these minerals within the Mariner VI and VII spectral bands. As the table shows, the reflectivity increases with decreasing particle size in all cases except for the smallest particle size group of goethite in the green band (and presumably the blue band) and for all of the particle size groups measured in the case of limonite for both the blue and green spectral bands. Consequently, the ratio of the larger-to-smaller particle size groups obtained from this data are equivalent to the ratio of the darker-to-lighter surface elements except for the cases cited.

Table 5

Average Reflectivity of Potential
Martian Materials Within the Mariner Spectral Bands

Mineral	Size Range	Mariner VI			Mariner VII		
		Blue	Green	Red	Blue	Green	Red
0-8 Goethite	250-1200 μm	.048	.064	.083	.049	.064	.085
	74- 250 μm	.039	.065	.089	.037	.066	.092
	0- 74 μm	.060	.080	.116	.059	.081	.121
	0- 5 μm	?	.078	.152	?	.079	.162
0-9 Hematite	74- 250 μm	.072	.068	.082	.072	.068	.087
	0- 74 μm	.080	.075	.089	.081	.075	.093
	0- 5 μm	.081	.080	.103	.081	.080	.110
0-11 Limonite	250-1200 μm	.054	.104	.174	.053	.106	.182
	0- 74 μm	.040	.088	.164	.040	.089	.177
	0- 5 μm	.030	.097	.228	.029	.099	.250
S-11B Mont-morillonite	250-1200 μm	.144	.201	.292	.143	.203	.306
	74- 250 μm	.166	.227	.290	.162	.229	.298
	0- 74 μm	.186	.276	.404	.182	.279	.422
	0- 5 μm	.270	.407	.547	.265	.411	.568
S-14B Olivine	250-1200 μm	.373	.478	.536	.365	.481	.539
	74- 250 μm	.427	.530	.577	.418	.533	.578
	0- 74 μm	.473	.573	.617	.459	.576	.620
	0- 5 μm	.637	.681	.713	.631	.682	.718
S-17C Pyroxene	250-1200 μm	.058	.066	.077	.057	.066	.079
	74- 250 μm	.098	.113	.120	.096	.114	.121
	0- 74 μm	.108	.137	.162	.105	.138	.165
	0- 5 μm	.193	.254	.305	.188	.256	.312

Figure 15 shows the reflectivity ratios determined for the ferric oxide samples and the Mariner VI spectral response functions. The ratios were plotted at the effective focal length for each of the spectral filters as specified by Danielson (1971). Figure 16 is the corresponding plot for the silicate samples. The results obtained in the case of Mariner VII are similar to the reflectivity ratios shown here. We would expect that the ratios would approach unity as the particle size differences between the two groups being ratioed decreases. In addition, the rate of change of the ratio with respect to wavelength should decrease as the particle size differences decrease, i.e., the slope of the curve becomes less. If we compare the progression of curves for cases A to B to C we would expect that these phenomena would be apparent in Figures 15 and 16. Except for the cases where a reversal in the change of reflectivity with particle size occurs, this phenomena is exhibited for all of the minerals evaluated. A similar trend is exhibited in going from the curves with index D to the curves of index E. We can infer from these results that information about the relative difference in particle sizes can be obtained by examining the level and slope of the reflectivity ratio versus wavelength curve. The difference between the ratio from the green to the red band is presented in Table 6. In this table a positive number indicates a decrease in the ratio as the wavelength is increased as expected from the size-reflectivity change rule stated previously. Note that most of the changes are positive (i.e., show a decrease with increasing wavelength) except for olivine which shows an increase in the ratio for all cases. If we eliminate this sample from consideration the average value of the change which is also presented in the table is greatest for the A ratio which has

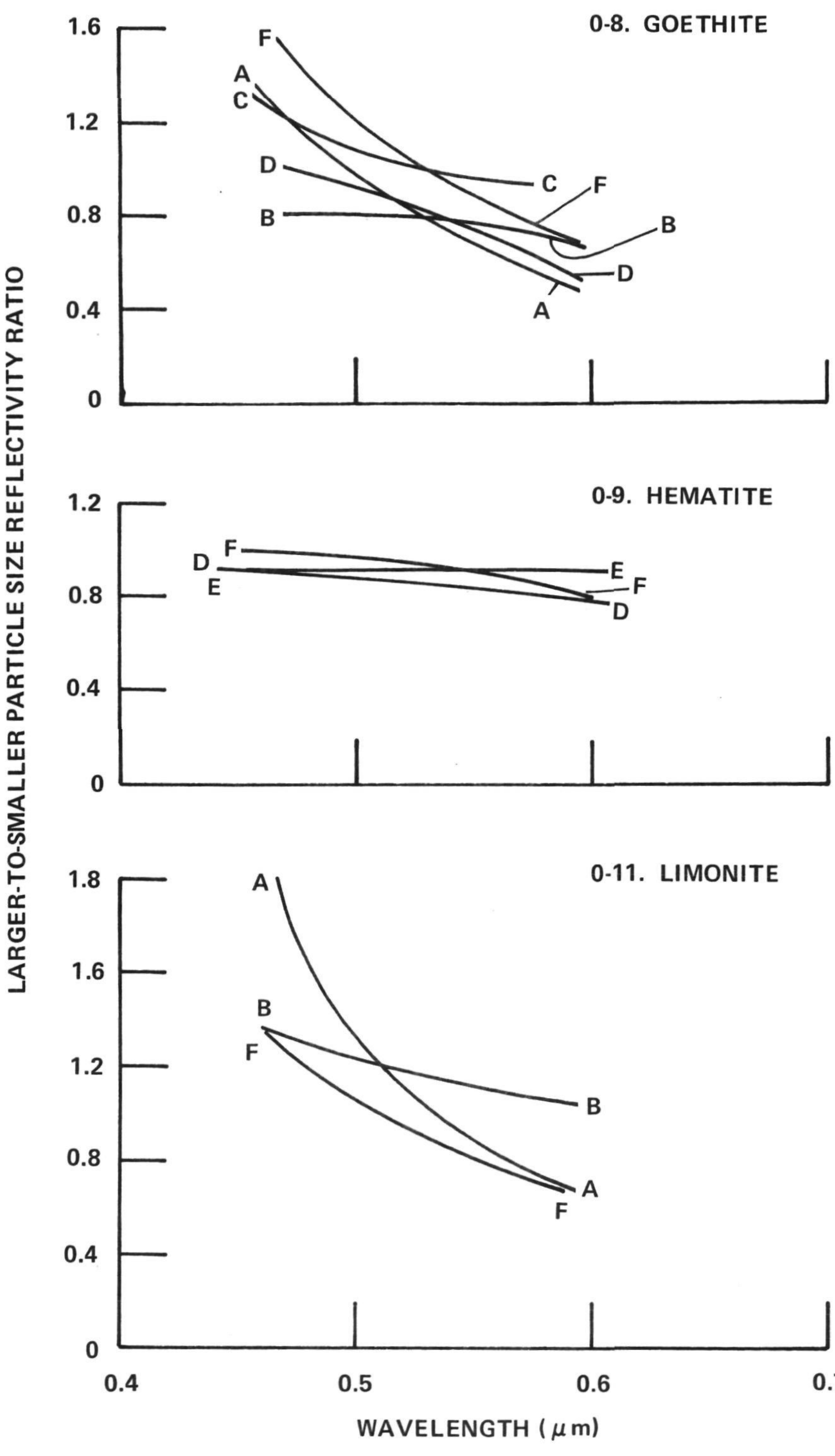

Figure 15 REFLECTIVITY RATIOS FOR SELECTED OXIDES AND VARIOUS PARTICLE SIZE GROUPS

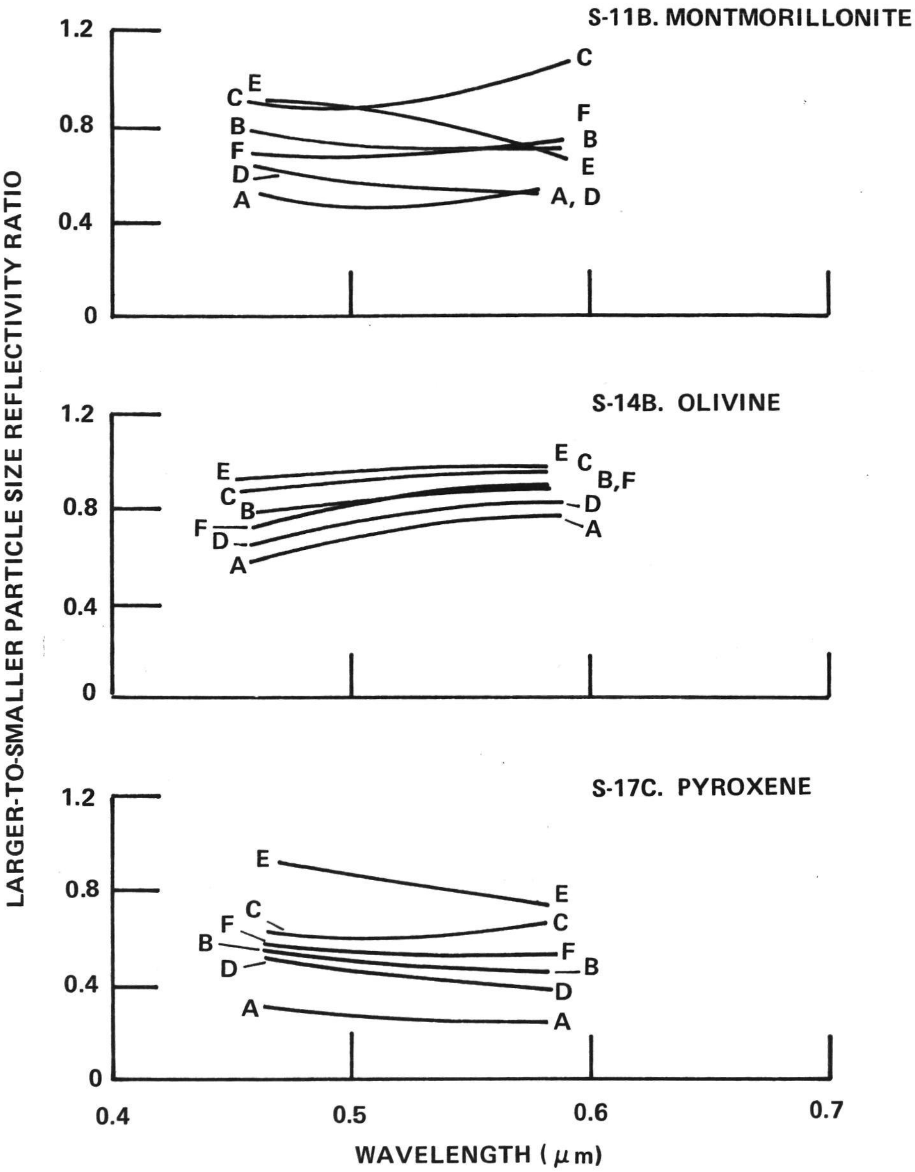

Figure 16 REFLECTIVITY RATIOS FOR SELECTED SILICATES AND VARIOUS PARTICLE SIZE GROUPS

Table 6

Green-to-Red Decrease in the Reflectivity Ratio

Index	0-8 Goethite	0-9 Hematite	0-11 Limonite	S-11B Montmorillonite	S-14B Olivine	S-17C Pyroxene	Average (w/o Olivine)
A	.27	-	.31	-.04	-.03	.01	.14
B	.08	-	.12	.01	-.04	.00	.05
C	.05	-	-	-.11	-.05	-.06	-.04
D	.24	.05	-	.03	-.02	.05	.09
E	.04	-.01	-	.10	-.03	.08	.05
F	.30	.08	.19	-.06	-.03	.01	.10

the largest particle size differences and least (negative) for the C ratio where the particle size differences are not as great. Consequently, we conclude that the slope of the reflectivity ratio versus wavelength curve indeed does contain information about the relative particle size of the materials producing the light and dark markings.

5.3 Evaluation of the Light and Dark Markings Associated with Craters

Bi-band coverage area 6C contained several craters with light and dark markings located interior to the crater on their floor. Several of these craters were chosen for subsequent analysis of the reflectivity ratio of these markings from frames 6N11 and 6N13. The craters selected are shown in Figure 17. The light and dark markings were located by sample and line number and subsequently retrieved from the LMICOR images contained on digital tape supplied by JPL. Software programs were developed to retrieve this data over a rectangular area specified by the initial and final sample and line number. A description of this software is presented in the appendix to this report. Table 7 contains the average reflectivity and subsequent ratio for each of the selected dark and light markings in the red and green spectral bands.

These data are not the only source of reflectivity ratios of dark-to-light markings on the martina surface. Dollfus measured the dark-to-light area contrasts in several wavelength bands. These data were employed by Pollack and Sagan (1967) and were extracted for comparison to our results. These results are presented in Table 8. Other studies utilizing reflectivity

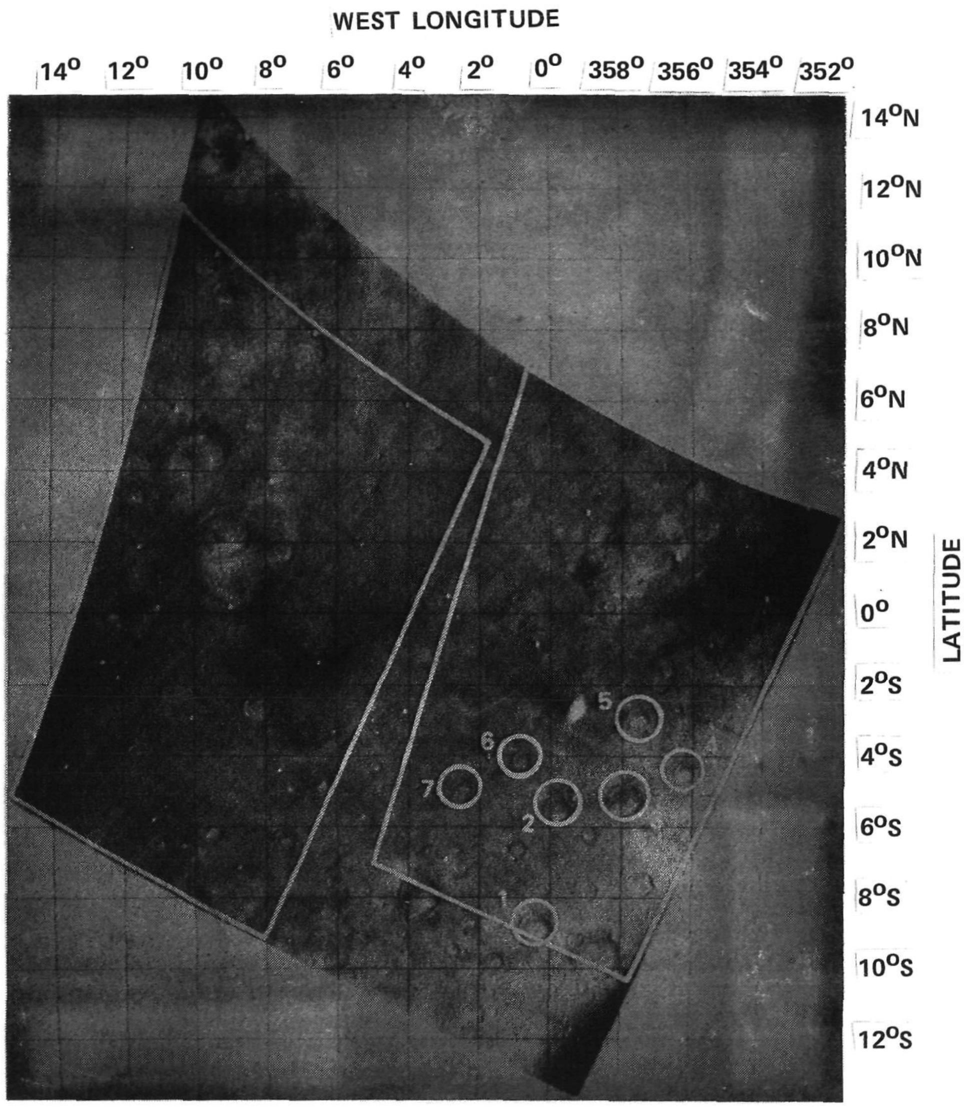

Figure 17 CRATERS ANALYZED IN BI-BAND COVERAGE AREA 6C

Table 7

Reflectivity and Reflectivity Ratio of Crater Markings

Target	6N11-Green (.53 μm)			6N13-Red (.58 μm)		
	Dark	Light	Ratio	Dark	Light	Ratio
1 - Crater	.0588	.0602	.977	.0742	.0879	.844
2 - Crater	.0583	.0633	.921	.0708	.0843	.840
3 - Crater	.0592	.0640	.925	.0658	.0816	.806
4 - Crater	.0604	.0632	.956	.0668	.0754	.886
5 - Crater	.0598	.0641	.933	.0665	.0767	.867
6 - Crater	.0603	.0651	.926	.0717	.0806	.890
7 - Crater	.0599	.0638	.939	.0734	.0764	.961
Average	.0595	.0634	.940	.0699	.0804	.871
σ	.0009	.0015	.020	.0035	.0046	.049

Δ = Green-to-Red Change = .07

Table 8

Normal Reflectivity and Dark-to-Light Reflectivity Ratios Derived from Dollfus Contrast Data

λ (μm)	Dark Areas	Bright Areas	Ratio
.45	.065	.071	.92
.50	.098	.120	.82
.55	.120	.164	.73
.60	.139	.210	.66
.65	.150	.250	.60

Δ = Effective Green-to-Red Change = .09

ratios were conducted by McCord (1969) and by Cutts (1971). McCord studied selected dark and bright regions primarily the Arabia-Syrtus Major pair at 21 narrow spectral passbands in the visible spectrum. From his results, McCord concluded that the bright regions are much redder than the dark regions, that is the ratio of the reflectivity of the dark-to-light regions in the red region is greater than the blue region. According to the size-reflectivity change rule, this would indicate that particle size effects are probably responsible for the differences between the bright and dark martian regions. Cutts subsequently employed the McCord data to augment his evaluation which was obtained using the late far encounter images obtained during the Mariner VII mission. Cutts evaluated nine different regional areas ranging from high to low reflectivity. The reflectivity ratio for dark-to-light areas for selected data presented by Cutts is contained in Table 9. The first three ratios were selected to represent that of the darkest-to-lightest features. The second two ratios were selected because they represent moderately dark-to-light features. Note that the value of the reflectivity ratio is closer to one for the second group than the first group and that the change or average slope of the reflectivity ratio curve is less for the second group compared to the first group. The third group contains two cases, the first being the ratio between two relatively dark features and the second being the ratio between two relatively light features. Note in this case that the reflectivity ratios are much closer to unity and that the average slope is less than either of the two preceeding groups.

Table 9

Dark-to-Light Reflectivity Ratios Derived from Selected Cutts/McCord Data Within Mariner Spectral Bands

	Description	Blue (.47μm)	Green (.53μm)	Red (.58μm)	(Green-to-Red)
I	Syrtis Major/Arabia*	.87	.77	.65	.12
	Margaritifer Sinus/Moab	.83	.73	.59	.14
	Meridiani Sinus/Moab	.84	.75	.65	.10
II	Deucalionis Regio/Moab	.97	.95	.93	.02
	Thymiamata/Moab	.92	.87	.80	.07
III	Meridiani Sinus/Sabaeus Sinus	.95	.94	.90	.04
	Edom/Moab	1.01	1.00	.97	.03

*After Cutts

All three data sources were plotted for comparison to the Mariner VI crater markings in Figures 18 and 19. Figure 18 shows that the crater markings show a change in ratio which indicates that particle size differences are responsible for the change in reflectivity (the ratio decreases with increasing wavelength). Furthermore, comparison of the Mariner results to that of Cutts and McCord indicates that the Mariner ratios represent more moderate changes in particle size than that due to the extreme reflectivity changes. The change in reflectivity ratio from green-to-red of 0.07 is compatible with those in Group II in Table 9 and is consistent with the changes obtained in Section 4.2 for particle size groups B and E. A similar result is exhibited in Figure 19 when compared with the Dollfus ratios. The Dollfus results appear to represent a larger change in reflectivity than that due to the crater markings. The

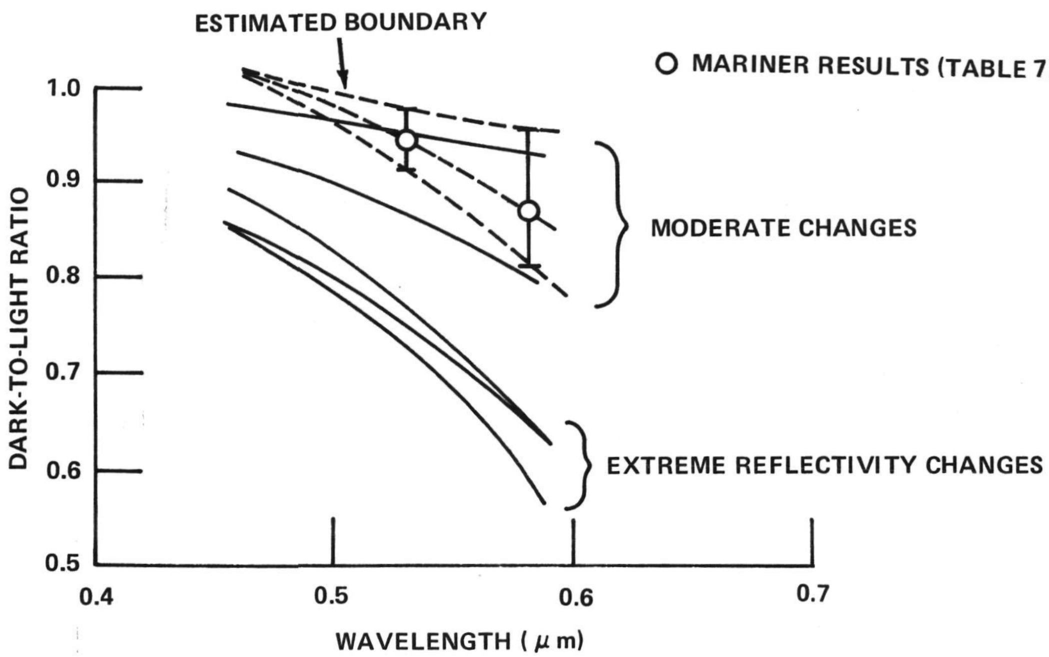

Figure 18 COMPARISON OF MARINER REFLECTIVITY RATIOS TO THOSE OF CUTTS AND McCORD

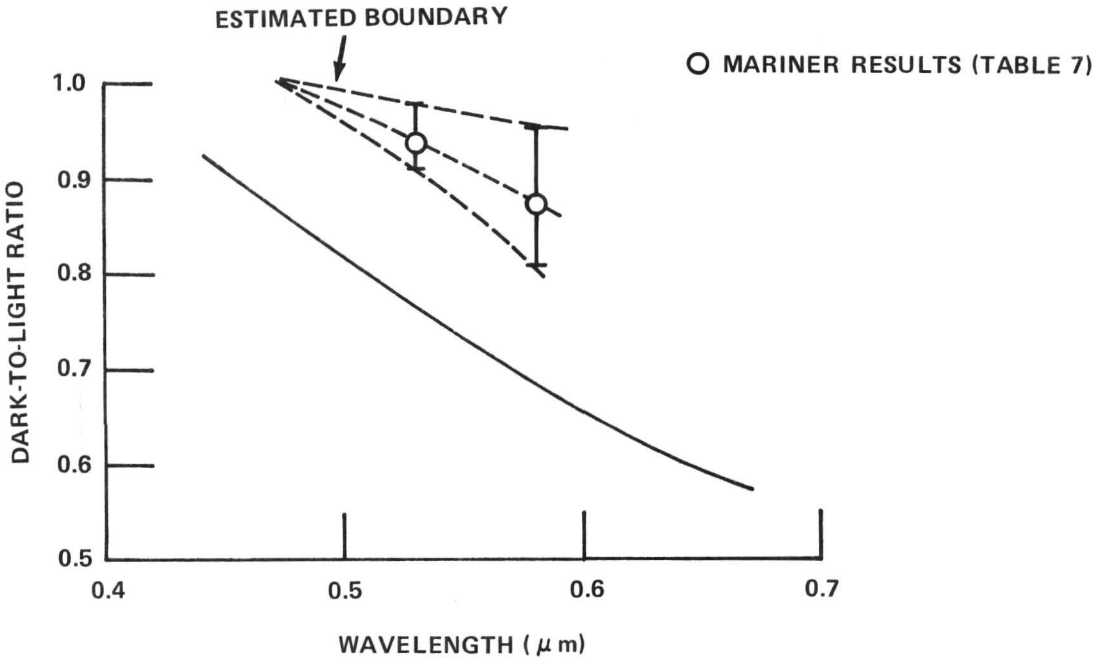

Figure 19 COMPARISON OF MARINER RATIO TO THOSE OF DOLLFUS

Group I data of Cutts and McCord (Table 9) and that of Dollfus (Table 8) are consistent with size Groups A and D in Section 4.2. Note that the size ranges represented by Groups B and E are compatible with the postulated mean particle sizes for the light and dark areas offered by Pollack and Sagan (1967).

If we compare the reflectivity presented in Table 5 to an extrapolation of the Minnaert parameter N_g obtained by Thorpe (Table 2) we find that the normal reflectivity of olivine appears to be a factor of 2-3 greater than the average normal albedo. Consequently, limonite stained olivine is not considered to be a likely candidate as a major constituent on this local area. Limonite stained pyroxene appears to be the best candidate based upon the data obtained during the course of this effort. Of course this conclusion must be somewhat tenuous since a number of mineral compositions could yield the results obtained.

5.4 Mariner IX Imagery and Other Related Data

We had hoped to continue the present effort using Mariner IX image data obtained through multiple spectral filters. It was anticipated that a large number of multi-spectral coverages would be available. Unfortunately, the filter wheel mechanism became inoperative during Revolution 118 and only a very limited amount of multi-spectral data was obtained. For the subsequent portion of the Mariner mission image data was obtained using the orange polarizing filter contained in the fifth filter wheel position. During the initial part of the mission the martian surface was obscured by a dust storm and consequently no useful image data of surface features were obtained in this part of the mission when the filter wheel was operative. Mariner IX did confirm that dynamic aeolian processes play a significant role in the reflectivity variations on the martian surface and that a significant number of these variations are caused by changes in particle size.

An analysis of the light and dark markings present in the Mariner IX imagery obtained subsequent to the subsiding of the dust storm was made by Arvidson (1974). As a result of his analysis he found that "dark splotched craters in regions with bright streaks usually have upwind bright patches, suggesting that these features formed by dumping of bright dust over crater rims ... ". This characteristic pattern minus the bright streaks downwind of the craters are identical to those that we have analyzed. Furthermore, they have a North to South orientation consistent with the direction of the wind pattern observed subsequent to the dust storm through analysis of the wind-blown streaks. In addition, a sequence of wind tunnel experiments have been carried out by Greeley and his associates (1974). The results of these experiments have generated light and dark markings similar to those observed during our effort and have further demonstrated that some of the dark markings occur from wind erosion and that some of the light markings are depositional in nature. The reader is also referred to a comparison of Mariner VI and VII imagery and Mariner IX imagery which includes the bi-band coverage area we analyzed for a qualitative assessment of effect of the dust storm on local reflectivity variations (Ververka, 1974).

Though it was intended to demonstrate the use of reflectivity ratios as an aid to geologic mapping, the lack of availability of Mariner IX imagery greatly degraded this objective. The Mariner VI and VII imagery within the bi-band coverage areas occurred over a limited number of geologic units and the detailed geologic maps for the Quadrangles containing these areas had not as yet been produced. It was also intended to obtain information about the martian atmosphere through radiometric measurements of the shadows associated with geological features, especially bowl-shaped craters. Although a number of shadows were identified in the narrow field of view imagery from Mariner VI, in particular Frame 6N22, the lack of available shadows is a direct result of the large diameter/depth ratios observed for Mars compared to Mercury and the Moon (Cintala, 1976). The diameter to depth ratio for craters near 10 km in diameter is approximately 8 times larger while for craters near 100 km in diameter it is approximately 3 times larger. The lack of Mariner IX bi-band image data further inhibited the evaluation of atmospheric phenomena.

SECTION 6

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APPENDIX

ANALYSIS SOFTWARE

This appendix describes three items of analysis software which were prepared during the course of this study. The principal software package consisted of the main program written in Fortran language and an associated subroutine, EPIC, written in Assembly language. Listings of the main program and subroutines programs are included in Figures A-1 and A-2 respectively. The purpose of this program is to retrieve a rectangular array of reflectance data from digital tapes of Mariner imagery provided by JPL and compute the mean, standard deviation, minimum and maximum of the reflectivities in the array. The data required is retrieved from the digital tapes using the Subroutine FPIC and subsequently analyzed by the main program whose listing is included in Figure A-1. In addition to computing the basic statistics, this main program also has the option of computing a histogram of the reflectivity values in the specified array.

Subroutine FPIC retrieves each element in a rectangular array located within the digital TV picture data for subsequent processing by the main program. The rectangular area of interest is defined by the following calling sequence:

CALL FPIC (NLS, NSS, NSE, NOL, ARRAY, NLA, NSA, RFAC) where:

NLS: is the line number within the picture where data retrieval begins

NSS: is the sample number within the line where data retrieval begins

```
              C     THIS PROGRAM CALCULATES THE STATISTICS OF A RECTANGULAR IMAGE ARRAY
              C     SUPPLIED BY SUBROUTINE FPIC.
              C
ISN 0002            DIMENSION R(25,25),IHIST(15)
ISN 0003            REAL*8 TARGID
ISN 0004            DATA IOPT/0/
ISN 0005          1 FORMAT(A8,50X,4I4,F4.0,I2)
ISN 0006          9 FORMAT(1H1)
ISN 0007         10 FORMAT(6X 'TARGET IDENTIFICATION= ',A8,'     INITIAL LINE NO.=',I4,
                   *'  INITIAL SAMPLE NO.=',I4,'  FINAL SAMPLE NO.=',I4,'  NO. OF LINE
                   *S=',I4 /// 13X 'PERCENT REFLECTANCE: MINIMUM=',F6.3,'  MAXIMUM=',
                   *F6.3,'  AVERAGE=',F6.3,'  STANDARD DEVIATION=',F8.5 ///
                   *13X 'HISTOGRAM: CLASS INTERVAL=',F6.3,// 16X 'CLASS NO.       ',
                   *15(I3,1X) / 16X 'NO. OF PIXELS   ',15(I3,1X) /  16X 'TOTAL NO. OF P
                   *IXELS=',I5 /////)
ISN 0008         11 FORMAT(6X 'TARGET IDENTIFICATION= ',A8,'     INITIAL LINE NO.=',I4,
                   *'  INITIAL SAMPLE NO.=',I4,'  FINAL SAMPLE NO.=',I4,'  NO. OF LINE
                   *S=',I4 /// 13X 'PERCENT REFLECTANCE: MINIMUM=',F6.3,'  MAXIMUM=',
                   *F6.3,'  AVERAGE=',F6.3,'  STANDARD DEVIATION=',F8.5 // 13X 'TOTAL
                   *NO. OF PIXELS=',I5 /////)
ISN 0009            ICASE=-1
ISN 0010            NLA=25
ISN 0011            NSA=25
ISN 0012         50 READ(5,1,END=100) TARGID,NLS,NSS,NSE,NOL,RFAC,IOPT
ISN 0013            ICASE=ICASE+1
              C
              C     OBTAIN REFLECTANCE DATA ARRAY 'R'
              C
ISN 0014            CALL FPIC(NLS,NSS,NSE,NOL,R,NLA,NSA,RFAC)
              C
              C     COMPUTE THE AVERAGE, STANDARD DEVIATION, MINIMUM AND MAXIMUM OF
              C     THE 'R' ARRAY
              C
ISN 0015            SUM=0.0
ISN 0016            SSQ=0.0
ISN 0017            RMIN=100.
ISN 0018            RMAX=0.0
ISN 0019            NOS=NSE-NSS+1
ISN 0020            NTOT=NOS*NOL
ISN 0021            DO 60 I=1,NOL
ISN 0022            DO 60 J=1,NOS
ISN 0023            RT=R(J,I)
ISN 0024            IF(RT.GE.RMIN) GO TO 55
ISN 0026            RMIN=RT
ISN 0027         55 IF(RT.LE.RMAX) GO TO 59
ISN 0029            RMAX=RT
ISN 0030         59 SUM=SUM+RT
ISN 0031         60 SSQ=SSQ+RT**2
ISN 0032            RAVE=SUM/FLOAT(NTOT)
ISN 0033            RSTD=SQRT((SSQ-FLOAT(NTOT)*RAVE**2)/FLOAT(NTOT-1))
ISN 0034            IF(IOPT.EQ.0)GO TO 80
              C
              C     COMPUTE HISTOGRAM
              C
ISN 0036            NI=RFAC*(RMAX-RMIN)/15.
ISN 0037            CINT=FLOAT(NI+1)/RFAC
ISN 0038            DO 65 I=1,15
ISN 0039         65 IHIST(I)=0
ISN 0040            DO 70 I=1,NOL
ISN 0041            DO 70 J=1,NOS
ISN 0042            N=(R(J,I)-RMIN)/CINT +1.0
ISN 0043         70 IHIST(N)=IHIST(N)+1
ISN 0044            IF(MOD(ICASE,4).EQ.0)WRITE(6,9)
ISN 0046            WRITE(6,10) TARGID,NLS,NSS,NSE,NOL,RMIN,RMAX,RAVE,RSTD,CINT,
                   *(I,I=1,15),(IHIST(I),I=1,15),NTOT
ISN 0047            GO TO 50
ISN 0048         80 IF(MOD(ICASE,4).EQ.0)WRITE(6,9)
ISN 0050            WRITE(6,11) TARGID,NLS,NSS,NSE,NOL,RMIN,RMAX,RAVE,RSTD,NTOT
ISN 0051            GO TO 50
ISN 0052        100 STOP
ISN 0053            END
```

Figure A-1 IMAGE STATISTICS MAIN PROGRAM LISTING

SYMBOL	INTERNAL STATEMENT NUMBERS											
I	0021	0023	0038	0039	0040	0042	0046	0046	0046	0046	0046	0046
J	0022	0023	0041	0042								
N	0042	0043	0043									
R	0002	0014	0023	0042								
NI	0036	0037										
RT	0023	0024	0026	0027	0029	0030	0031					
MOD	0044	0048										
NLA	0010	0014										
NLS	0012	0014	0046	0050								
NOL	0012	0014	0020	0021	0040	0046	0050					
NOS	0019	0020	0022	0041								
NSA	0011	0014										
NSE	0012	0014	0019	0046	0050							
NSS	0012	0014	0019	0046	0050							
SSQ	0016	0031	0031	0033								
SUM	0015	0030	0030	0032								
CINT	0037	0042	0046									
FPIC	0014											
IOPT	0004	0012	0034									
NTOT	0020	0032	0033	0033	0046	0050						
RAVE	0032	0033	0046	0050								
RFAC	0012	0014	0036	0037								
RMAX	0018	0027	0029	0036	0046	0050						
RMIN	0017	0024	0026	0036	0042	0046	0050					
RSTD	0033	0046	0050									
SQRT	0033											
FLOAT	0032	0033	0033	0037								
ICASE	0009	0013	0013	0044	0048							
IHIST	0002	0039	0043	0043	0046							
TARGID	0003	0012	0046	0050								

LABEL	DEFINED	REFERENCES	
1	0005	0012	
9	0006	0044	0048
10	0007	0046	
11	0008	0050	
50	0012	0047	0051
55	0027	0024	
59	0030	0027	
60	0031	0021	0022
65	0039	0038	
70	0043	0040	0041
80	0048	0034	
100	0052	0012	

LABEL	ADDR	LABEL	ADDR	LABEL	ADDR	LABEL	ADDR
50	000DF6	55	000ED8	59	000EE4	60	000EEE
65	000FFA	70	001054	80	001144	100	0011D4

STATISTICS   SOURCE STATEMENTS =   52 ,PROGRAM SIZE =   4608

Figure A-1 (Cont'd)

```
                                       1 * THIS SUBROUTINE WAS CREATED TO PROCESS THE MARS MARINER TV DATA . IT  00000100
                                       2 *          BASICALLY COPIES A TAPE FILE TO A DISK ON THE FIRST CALL NAD 00000200
                                       3 *          THEN ACCESSES THE DISK IN DIRECT MODE TO FIND SQUARES OF THE 00000300
                                       4 *          PICTURE AS REQUESTED BY THE CALLING PROGRAM                  00000400
                                       5            PRINT NOGEN                                                  00000500
000000                                 6 FPIC       CSECT                                                        00000600
                              00000    7            USING *,15                                                   00000700
                                       8            SAVE  (14,12),,FPIC_DON_SPARROW                              00000800
00001A 18ED                           14            LR    14,13          CHAIN THE SAVE AREAS                    00000900
00001C 41D0 F030              00030   15            LA    13,SAVE                                                00001000
000020 50DE 0008              00008   16            ST    13,8(14)                                               00001100
000024 50ED 0004              00004   17            ST    14,4(13)                                               00001200
000028 47F0 F58C              0058C   18            B     FPIC1                                                  00001300


                                      20            DROP  15                                                     00001500
                              00030   21            USING SAVE,13                                                00001600
000030                                22 SAVE       DS    9D                                                     00001700
                                      23 TDCB       DCB   DDNAME=TAPE,DSORG=PS,MACRF=(R),EODAD=EOT,SYNAD=TERR,  *00001800
                                                          BUFNO=0                                                00001900
                                      74 DDCB       DCB   DDNAME=DISK,DSORG=PS,MACRF=(WL),EODAD=EOD,SYNAD=DERR, *00002000
                                                          RECFM=F,BUFNO=0,DEVD=DA                                00002100
                                     125 DDCBI      DCB   DDNAME=DISK,DSORG=DA,MACRF=(RKC),EODAD=EODI,SYNAD=DERRI,*00002200
                                                          RECFM=F,OPTCD=E,LIMCT=1000,BUFNO=0                     00002300
000180                               174 KEY        DS    F                                                      00002400
000184                               175 BUFFER     DS    CL1000                                                 00002500
                              00001  176 TRUE       EQU   1                                                      00002600
                              00000  177 FALSE      EQU   0                                                      00002700
00056C 00                            178 ENDOFHDRS DC     AL1(FALSE)                                             00002800
000570                               179 TEMP       DS    D                                                      00002900
000578                               180 NUMBEROFLINESPERPICTURE DS F                                            00003000
00057C                               181 NUMBEROFSAMPLESPERLINE DS F                                             00003100
000580                               182 NOOFLABELRECORDS DS F                                                   00003200
C00584                               183 NUMBEROFRECORDSONTAPE DS F                                              00003300
000588 42000000                      184 FLOATPAT DC      X'42000000'                                            00003400


00058C                               186 FPIC1      DS    0H                                                     00003600
00058C 1881                          187            LR    8,1            SAVE THE PARM ADDRESS                   00003700
00058E 9501 D53C        0056C        188            CLI   ENDOFHDRS,TRUE       FIRST ENTRY ?                     00003800
000592 4780 D6FE              0072E  189            BE    FPIC2          NO - BRANCH                             00003900

                                     191            OPEN  (TDCB,(INPUT))       YES - OPEN THE INPUT TAPE         00004100
                              00000  197            USING IHADCB,1                                               00004200
0005A2 4110 D048              00078  198            LA    1,TDCB                                                 00004300
0005A6 9110 1030        00030        199            TM    DCBOFLGS,X'10'       WAS OPEN ALRIGHT ?                00004400
0005AA 47E0 D836              00866  200            BNO   TOERR          NO - BRANCH                             00004500

0005AE 4140 D0A0              000D0  202            LA    4,DDCB         YES - GET  THE @ OF THE DISK DCB        00004700
                                     203            DROP  1                                                      00004800

0005B2 1B22                          205            SR    2,2            CLEAR THE RECORD COUNTER REGISTER       00005000
0005B4 47F0 D596              005C6  206            B     READTAPE       START THE COPY                          00005100

0005B8                               208 COPYTODISK DS 0H                                                        00005300
                                     209            CHECK CDDECB         SEE IF DISK WRITE WAS ALRIGHT           00005400

0005C6                               215 READTAPE DS      0H                                                     00005600
0005C6 D703 D5A0 D5A0 005D0 005D0    216            XC    TDECB,TDECB    CLEAR THE DECB FOR A READ               00005700
                                     217            READ  TDECB,SF,TDCB,BUFFER+4,'S' READ A TAPE RECORD          00005800
0005EE 4122 0001              00001  230            LA    2,1(2)         COUNT THE RECORD                        00005900

0005F2 9501 D53C        0056C        232            CLI   ENDOFHDRS,TRUE       ARE WE IN THE DATA RECORDS ?      00006100
0005F6 4780 D624              00654  233            BE    DATARECORD     YES - BRANCH                            00006200

                                     235            CHECK TDECB          NO - SEE IF THE TAPE READ WAS ALRIGHT   00006400
000608 4110 D158              00188  240            LA    1,BUFFER+4     SET BASE FOR USING                      00006500
00060C 5920 D938              00968  241            C     2,=F'1'        IS THIS THE FIRST LABEL REOCRD ?        00006600
000610 4720 D600              00630  242            BH    NOT1STLABEL    NO - BRANCH                             00006700

                              00000  244            USING LABEL,1        YES - GET NS AND NL FOR THIS TAPE       00006900
000614 F273 D540 1020 00570 00020    245            PACK  TEMP,NL        CONVERT FROM EBCDIC TO BINARY           00007000
00061A 4F00 D540              00570  246            CVB   0,TEMP                                                 00007100
00061E 5000 D548              00578  247            ST    0,NUMBEROFLINESPERPICTURE                              00007200

000622 F273 D540 1024 00570 00024    249            PACK  TEMP,NS        REPEAT FOR NS                           00007400
000628 4F00 D540              00570  250            CVB   0,TEMP                                                 00007500
00062C 5000 D54C              0057C  251            ST    0,NUMBEROFSAMPLESPERLINE                               00007600
                                     252            DROP  1                                                      00007700

                                     254 * THE LAST LOGICAL LABEL RECORD HAS AN 'L' IN THE LAST BYTE -           00007900
                                     255 *          NO ADDITIONAL LABEL RECORDS WILL FOLLOW THIS ONE             00008000
000630                               256 NOT1STLABEL DS 0H                                                       00008100
000630 4100 0005              00005  257            LA    0,5                                                    00008200
```

Figure A-2 SUBROUTINE FPIC LISTING

```
000634                                 259 CHECKFORLASTLABEL DS OH                                                        00008400
                              00000    260          USING LABELREC,1                                                      00008500
000634 95D3 1047      00047            261          CLI   ENDOFLABELCHECK,C'L'      IS THIS THE LAST LABEL RECORD ? 00008600
000638 4780 D618              00648    262          BE    SETLASTLABELRECORD                                              00008700

00063C 4111 0048              00048    264          LA    1,72(1)          NO - BUMP INDEX                                00008900
000640 4600 D604              00634    265          BCT   0,CHECKFORLASTLABEL LOOK ALLL LABEL RECORDS IN BLOCK            00009000
000644 47F0 D596              005C6    266          B     READTAPE         GET NEXT LABEL RECORD                          00009100

000648                                 268 SETLASTLABELRECORD DS OH                                                       00009300
000648 9201 D53C      0056C            269          MVI   ENDOFHDRS,TRUE        YES - SET SWITCH                          00009400
00064C 5020 D550              00580    270          ST    2,NOOFLABELRECORDS  SAVE THE NUMBER OF LABEL RECORDS            00009500
000650 47F0 D596              005C6    271          B     READTAPE         CONTINUE                                       00009600
                                       272          DROP 1                                                                00009700

000654                                 274 DATARECORD DS  OH                                                              00009900
                                       275          CHECK TDECB            SEE IF TAPE READ WAS ALRIGHT                   00010000

                              00000    281          USING IHADCB,4                                                        00010200
000662 9110 4030      00030            282          TM    DCBOFLGS,X'10'        IS THE DISK DCB OPEN ?                    00010300
000666 4710 D656              00686    283          BO    DDCBO            YES - BRACNH                                   00010400

00066A 5800 D54C              0057C    285          L     0,NUMBEROFSAMPLESPERLINE NO - SET THE BLKSIZE                   00010600
00066E 4000 403E              0003E    286          STH   0,DCBBLKSI                                                      00010700

                                       288          OPEN  (DDCB,(OUTPUT))       OPEN THE DCB                              00010900
00067E 9110 4030      00030            294          TM    DCBOFLGS,X'10'        WAS THE OPEN ALRIGHT ?                    00011000
000682 47E0 D846              00876    295          BNO   DOERR            NO - BRANCH                                    00011100

000686                                 297 DDCBO    DS    OH                                                              00011300
                                       298 * THE KEY OF EACH RECORD IS THE RECORD NUMBER OR LINE NUMBER WHICH             00011400
                                       299 *        RANGES FROM 1 TO NUMBEROFLINESPERPICTURE                              00011500
000686 1802                            300          LR    0,2              COMPUTE THE KEY                                00011600
000688 5800 D550              00580    301          S     0,NOOFLABELRECORDS                                              00011700
00068C 5000 D154              00184    302          ST    0,BUFFER         SET THE KEY IN FRONT OF THE RECORD             00011800

000690 D703 D66C D66C 0069C 0069C      304          XC    CDDECB,CDDECB         CLEAR THE DECB FOR DISK WRITE             00012000
                                       305          WRITE CDDECB,SF,DDCB,BUFFER    WRITE THE RECORD TO DISK               00012100

0006BA 47FF D68E              006BE    319          B     *+4(15)          CHECK THE RETURN CODE FROM WRITE               00012300
0006BE 47F0 D588              005B8    320          B     COPYTODISK                                                      00012400
0006C2 47F0 D588              005B8    321          B     COPYTODISK                                                      00012500
0006C6 47F0 D588              005B8    322          B     COPYTODISK                                                      00012600

                                       324          ABEND 69,DUMP          WRITE WAS NO GOOD                              00012800
                                       332          DROP  4                                                               00012900

0006DA                                 334 EOT      DS    OH                                                              00013100
0006DA 0620                            335          BCTR  2,0                   (2) = NUMBER OF RECORDS ON TAPE           00013200
0006DC 5020 D554              00584    336          ST    2,NUMBEROFRECORDSONTAPE                                         00013300

0006E0 5820 D550              00580    338          S     2,NOOFLABELRECORDS  DOES IT CHECK WITH NL IN HEADER ?           00013500
0006E4 5920 D548              00578    339          C     2,NUMBEROFLINESPERPICTURE                                       00013600
0006E8 4780 D6CA              006FA    340          BE    TDOK             YES - BRANCH                                   00013700

                                       342          ABEND 169,DUMP                                                        00013900

0006FA                                 351 TDOK     DS    OH                                                              00014100
                                       352          CLOSE (TDCB,,DDCB)   CLOSE THE DCBS                                   00014200

00070A 4120 D0E8              00118    361          LA    2,DDCBI            SET DATA TO READ DISK                        00014400
                              00000    362          USING IHADCB,2                                                        00014500

00070E 5800 D54C              0057C    364          L     0,NUMBEROFSAMPLESPERLINE                                        00014700
000712 4000 2052              00052    365          STH   0,DCBLRECL                                                      00014800
000716 4000 203E              0003E    366          STH   0,DCBBLKSI                                                      00014900

                                       368          OPEN  (DDCBI,(INPUT))       READY DISK FOR INPUT MODE                 00015100

000726 9110 2030      00030            375          TM    DCBOFLGS,X'10'        WAS RE-OPEN ALRIGHT ?                     00015300
00072A 47E0 D856              00886    376          BNO   DOOERR           NO - BRANCH                                    00015400
                                       377          DROP  2                                                               00015500

                                       379 * WE END UP AT THIS POINT AFTER THE TAPE IS COPIED TO THE DISK ON THE          00015700
                                       380 *        FIRST CALL, OR IMMEDIATELY ON THE SECOND AND SUBSEQUENT CALLS         00015800
00072E                                 381 FPIC2    DS    OH                                                              00015900
                              00000    382          USING PARMLIST,8                                                      00016000
00072E 9825 8000              00000    383          LM    2,5,NLS          GET THE ADDRESSES OF THE PARMS                 00016100
000732 5822 0000              00000    384          L     2,0(2)                                                          00016200
000736 5833 0000              00000    385          L     3,0(3)                                                          00016300
00073A 5844 0000              00000    386          L     4,0(4)                                                          00016400
00073E 5855 0000              00000    387          L     5,0(5)                                                          00016500

000742 1222                            389          LTR   2,2              IS START LINE NUMBER POSITIVE ?                00016700
000744 4700 D986              00886    390          BNP   A269             NO - BRANCH                                    00016800

000748 1812                            392          LR    1,2                                                             00017000
00074A 1A15                            393          AR    1,5                                                             00017100
00074C 5910 D548              00578    394          C     1,NUMBEROFLINESPERPICTURE IS END LINE # IN PICTURE ?            00017200
000750 4720 D896              008C6    395          BH    A369             NO - BRANCH                                    00017300

000754 1233                            397          LTR   3,3              IS THE START SAMPLE POSITIVE ?                 00017500
000756 4700 D8A6              008D6    398          BNP   A469             NO - BRANCH                                    00017600

00075A 1934                            400          CR    3,4              IS START SAMPLE LESS THAN END SAMPLE ?         00017800
00075C 4780 D8B6              008E6    401          BNL   A569             NO - BRANCH                                    00017900

000760 5940 D54C              0057C    403          C     4,NUMBEROFSAMPLESPERLINE IS END SAMPLE ON A LINE ?              00018100
000764 4720 D8C6              008F6    404          BH    A669             NO - BRANCH                                    00018200
```

Figure A-2 (Cont'd)

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000768 1244                              406            LTR   4,4            IS END SAMPLE WITHIN A LINE ?                 00018400
00076A 47D0 D8D6                00906    407            BNP   A769           NO - BRANCH                                   00018500

00076E 1255                              409            LTR   5,5            IS THE NUMBER OF LINES IN SQUARE POSITIVE     00018700
000770 47D0 D8E6                00916    410            BNP   A869           NO - BRANCH                                   00018800

000774 5860 8014                00014    412            L     6,NLA          GET THE DIMENSIONS OF RECEIVING ARRAY         00019000
000778 5866 0000                00000    413            L     6,0(6)          # OF COLUMNS IN RECEIVING ARRAY              00019100
00077C 5870 8018                00018    414            L     7,NSA                                                        00019200
000780 5877 0000                00000    415            L     7,0(7)          # OF ROWS, E.G. ARRAY 'A' IS 'A(NSA,NLA)'    00019300

000784 1814                              417            LR    1,4                                                          00019500
000786 1813                              418            SR    1,3                                                          00019600
000788 4111 0001                00001    419            LA    1,1(1)          (1) IS THE NUMBER OF SAMPLES TO PUT IN A     00019700
                                         420 *                                    PUT IN A ROW OF 'A' ARRAY                00019800
00078C 1917                              421            CR    1,7            IS THE REQUEST FITTABLE IN ARRAY ROWS ?       00019900
00078E 4720 D8F6                00926    422            BH    A969           NO - BRANCH                                   00020000

000792 1956                              424            CR    5,6             IS REQUEST FITTABLE IN ARRAY COLUMNS ?       00020200
000794 4720 D906                00936    425            BH    A1069          NO - BRANCH                                   00020300

000798 5810 801C                0001C    427            L     1,RFAC         GET THE SCALE FACTOR                          00020500
00079C 7821 0000                00000    428            LE    2,0(1)                                                       00020600

0007A0 58C0 8010                00010    430            L     12,A                                                         00020800
0007A4 18A7                              431            LR    10,7                                                         00020900
0007A6 89A0 0002                00002    432            SLL   10,2           NSA*4 - SIZE OF ROW IN ARRAY                  00021000

0007AA 181A                              434            LR    1,10                                                         00021200
0007AC 0650                              435            BCTR  5,0                                                          00021300
0007AE 1C05                              436            MR    0,5                                                          00021400
0007B0 41B1 C000                00000    437            LA    11,0(1,12)     A + ((NSA-1)*4)*(NOL-1) - @ OF LAST ROW IN    00021500
                                         438 *                                     ARRAY TO SET FROM DATA                  00021600

0007B4 0630                              440            BCTR  3,0            READY (3) FOR LOOP AT SAMPLELOOP              00021800

0007B6 4160 0001                00001    442            LA    6,1            INCREMENT FOR SAMPLE LOOP                     00022000
0007BA 0640                              443            BCTR  4,0                                                          00022100
0007BC 4174 D154                00184    444            LA    7,BUFFER(4)    @ OF LAST SAMPLE IN REOCRD TO PROCESS         00022200

0007C0                                   446 LINELOOP   DS    0H                                                           00022400
0007C0 5020 D150                00180    447            ST    2,KEY           SET OF RECORD WE WANT TO READ                00022500

0007C4 D703 D7A0 D7A0 007D0 007D0        449            XC    FDECB,FDECB    READY FOR FETCH READ                          00022700
                                         450            READ  FDECB,DK,DDCBI,BUFFER,'S',KEY,TEMP FETCH DATA FROM DISK      00022800
                                         464            CHECK FDECB          SEE IF THE READ WAS ALRIGHT ?                 00022900

000800 1B11                              470            SR    1,1            (1) IS INDEX TO ROW IN A ARRAY                00023100
000802 4143 D154                00184    471            LA    4,BUFFER(3)    (4) IS PTR TO DAZTA ITEM TO PROCESS           00023200

000806                                   473 SAMPLELOOP DS 0H                                                              00023400
000806 4304 0000                00000    474            IC    0,0(4)         GET THE DATA                                  00023500
00080A 4200 D559                00589    475            STC   0,FLOATPAT+1   FLOAT IT                                      00023600
00080E 7800 D558                00588    476            LE    0,FLOATPAT                                                   00023700
000812 3D02                              477            DER   0,2            SCALE IT                                      00023800
000814 7001 C000                00000    478            STE   0,0(1,12)      STORE IT IN 'A' ARRAY                         00023900
000818 4111 0004                00004    479            LA    1,4(1)         BUMP ROW PTR                                  00024000
00081C 8746 D7D6                00806    480            BXLE  4,6,SAMPLELOOP        FINISH THE ROW                         00024100

000820 4122 0001                00001    482            LA    2,1(2)         BUMP DESIRED RECORD KEY                       00024300
000824 87CA D790                007C0    483            BXLE  12,10,LINELOOP        PROCESS ALL LINES IN SQUARE            00024400


000828 58DD 0004                00004    485            L     13,4(13)                                                     00024600
                                         486            RETURN (14,12),RC=0 RETURN                                         00024700



000836                                   491 EOD        DS    0H                                                           00024900
                                         492            ABEND 1169,DUMP                                                    00025000

000846                                   501 DERR       DS    0H                                                           00025200
                                         502            ABEND 1269,DUMP                                                    00025300

000856                                   511 TERR       DS    0H                                                           00025500
                                         512            ABEND 1369,DUMP                                                    00025600

000866                                   521 TOERR      DS    0H                                                           00025800
                                         522            ABEND 1469,DUMP                                                    00025900

  LOC  OBJECT CODE    ADDR1 ADDR2  STMT   SOURCE STATEMENT                                  ASM H V 05 11.17 07/14/77

000876                                   531 DOERR      DS    0H                                                           00026100
                                         532            ABEND 1569,DUMP                                                    00026200

000886                                   541 DOOERR     DS    0H                                                           00026400
                                         542            ABEND 1669,DUMP                                                    00026500

000896                                   551 DERRI1     DS    0H                                                           00026700
                                         552            ABEND 1769,DUMP                                                    00026800

0008A6                                   561 DERRI2     DS    0H                                                           00027000
                                         562            ABEND 1869,DUMP                                                    00027100
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Figure A-2 (Cont'd)

```
0008B6                        571 A269       DS     0H                                  00027300
                              572            ABEND  269,DUMP                            00027400

0008C6                        581 A369       DS     0H                                  00027600
                              582            ABEND  369,DUMP                            00027700

0008D6                        591 A469       DS     0H                                  00027900
                              592            ABEND  469,DUMP                            00028000

0008E6                        601 A569       DS     0H                                  00028200
                              602            ABEND  569,DUMP                            00028300

0008F6                        611 A669       DS     0H                                  00028500
                              612            ABEND  669,DUMP                            00028600

000906                        621 A769       DS     0H                                  00028800
                              622            ABEND  769,DUMP                            00028900

000916                        631 A869       DS     0H                                  00029100
                              632            ABEND  869,DUMP                            00029200

000926                        641 A969       DS     0H                                  00029400
                              642            ABEND  969,DUMP                            00029500

000936                        651 A1069      DS     0H                                  00029700
                              652            ABEND  1069,DUMP                           00029800

000946                        661 EODI       DS     0H                                  00030000
                              662            ABEND  1969,DUMP                           00030100

000956                        671 DERRI      DS     0H                                  00030300
                              672            ABEND  2069,DUMP                           00030400

000000                        681 LABEL      DSECT                                      00030600
000000                        682            DS     32X                                 00030700
000020                        683 NL         DS     CL4                                 00030800
000024                        684 NS         DS     CL4                                 00030900
000028                        685            DS     32X                                 00031000

000000                        687 LABELREC DSECT                                        00031200
000000                        688            DS     71X                                 00031300
000047                        689 ENDOFLABELCHECK DS C                                  00031400

000000                        691 PARMLIST DSECT                                        00031600
000000                        692 NLS        DS     A                                   00031700
000004                        693 NSS        DS     A                                   00031800
000008                        694 NSE        DS     A                                   00031900
00000C                        695 NOL        DS     A                                   00032000
000010                        696 A          DS     A                                   00032100
000014                        697 NLA        DS     A                                   00032200
000018                        698 NSA        DS     A                                   00032300
00001C                        699 RFAC       DS     A                                   00032400

                              701            DCBD   DSORG=PS                            00032600
                              702+*,***   IHB069   DEVD NOT SPECIFIED-ALL ASSUMED       02-IHBER
                             1452            END                                        00032700
000968 00000001              1453                   =F'1'
```

CROSS REFERENCE

```
SYMBOL     LEN    VALUE     DEFN   REFERENCES

A          00004  000010    0696   0430
A1069      00002  000936    0651   0425
A269       00002  0008B6    0571   0390
A369       00002  0008C6    0581   0395
A469       00002  0008D6    0591   0398
A569       00002  0008E6    0601   0401
A669       00002  0008F6    0611   0404
A769       00002  000906    0621   0407
A869       00002  000916    0631   0410
A969       00002  000926    0641   0422
BUFFER     01000  000184    0175   0225  0240  0302  0313  0444  0458  0471
CDDECB     00004  00069C    0308   0210  0304  0304
CHECKFORLASTLABEL
           00002  000634    0259   0265
COPYTODISK
           00002  000588    0208   0320  0321  0322
DATARECORD
           00002  000654    0274   0233
DCBBIT0    00001  00000080  0714   0835  0851  0890  0908  0953  0963  0979  1020  1030  1042  1065  1096  1099  1101  1103
                                   1126  1129  1149  1154  1173  1210  1263  1286  1318  1322  1335  1430  1433  1443
DCBBIT1    00001  00000040  0715   0836  0852  0909  0917  0953  0963  0981  1021  1031  1044  1066  1069  1078  1096  1099
                                   1102  1103  1131  1149  1152  1154  1176  1177  1178  1213  1214  1263  1288  1324  1326
                                   1338  1382  1430  1435  1444
DCBBIT2    00001  00000020  0716   0837  0853  0910  0919  0963  0982  1022  1032  1045  1047  1048  1066  1068  1073  1079
                                   1096  1098  1105  1133  1156  1158  1181  1182  1183  1217  1218  1265  1291  1327  1343
                                   1385  1389  1430  1445
DCBBIT3    00001  00000010  0717   0801  0838  0854  0924  0966  0983  1023  1045  1048  1050  1066  1081  1106  1136  1156
                                   1160  1185  1186  1187  1221  1222  1265  1293  1295  1297  1329  1344  1395  1390  1430
DCBBIT4    00001  00000008  0718   0802  0855  0925  0969  0984  1024  1033  1082  1107  1137  1162  1168  1169  1190  1191
                                   1225  1226  1228  1229  1267  1300  1345  1385  1391
```

Figure A-2 (Cont'd)

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DCBBIT5   00001 00000004  0719   0804 0856 0927 0970 0984 1025 1034 1083 1110 1112 1139 1162 1165 1166 1169
                                 1194 1196 1197 1198 1232 1233 1234 1235 1267 1302 1305 1331 1347 1380
DCBBIT6   00001 00000002  0720   0806 0839 0857 0929 0971 0988 1026 1084 1086 1089 1110 1113 1140 1201 1202
                                 1203 1204 1238 1239 1240 1241 1308 1349
DCBBIT7   00001 00000001  0721   0808 0840 0933 0973 0989 1027 1084 1087 1089 1115 1144 1206 1207 1244 1245
                                 1247 1248 1333 1350 1392
DCBBLKSI  00002   00003E  1352   0286 0366
DCBFDAD   00008   000005  0735   0738
DCBLRECL  00002   000052  1414   0365
DCBOFLGS  00001   000030  1125   0199 0282 0294 0375
DCBSSID   00008   000000  0942   0945
DCBWTOID  00004   000000  0862   0877 0886
DDCB      00004   0000D0  0078   0202 0292 0312 0358
DDCBI     00004   000118  0130   0361 0372 0457 0462
DDCBO     00002   000686  0297   0283
DERR      00002   000846  0501   0111
DERRI     00002   000956  0671   0161
DOERR     00002   000876  0531   0295
DOOERR    00002   000986  0541   0376
ENDOFHDRS
          00001   00056C  0178   0188 0232 0269
ENDOFLABELCHECK
          00001   000047  0689   0261
EOD       00002   000836  0491   0096
EODI      00002   000946  0661   0146
EOT       00002   0006DA  0334   0045
FALSE     00001 00000000  0177   0178
FDECB     00004   0007D0  0453   0449 0449 0465
FLOATPAT  00004   000588  0184   0475 0476
FPIC1     00002   00058C  0186   0018
FPIC2     00002   00072E  0381   0189
IHADCB    00001 00000000  0712   0197 0281 0362 0760 0784 0812 0831 0861 0941 1002 1053 1122 1254 1271 1275
                                 1281 1370 1376 1400 1421
KEY       00004   000180  0174   0447 0460
LABEL     00001 00000000  0681   0244
LABELREC  00001 00000000  0687   0260
LINELOOP  00002   0007C0  0446   0483
NL        00004   000020  0683   0245
NLA       00004   000014  0697   0412
NLS       00004   000000  0692   0383
NOOFLABELRECORDS
          00004   000580  0182   0270 0301 0338
NOT1STLABEL
          00002   000630  0256   0242
NS        00004   000024  0684   0249
NSA       00004   000018  0698   0414
NUMBEROFLINESPERPICTURE
          00004   000578  0180   0247 0339 0394
NUMBEROFRECORDSONTAPE
          00004   000584  0183   0336
NUMBEROFSAMPLESPERLINE
          00004   00057C  0181   0251 0285 0364 0403
PARMLIST  00001 00000000  0691   0382
READTAPE  00002   0005C6  0215   0206 0266 0271
RFAC      00004   00001C  0699   0427
SAMPLELOOP
          00002   000806  0473   0480
SAVE      00008   000030  0022   0015 0021
SETLASTLABELRECORD
          00002   000648  0268   0262
TDCB      00004   000078  0027   0195 0198 0224 0356
TDECB     00004   0005D0  0220   0216 0216 0236 0276
TOOK      00002   0006FA  0351   0340
TEMP      00008   000570  0179   0245 0246 0249 0250 0461
TERR      00002   000856  0511   0060
TOERR     00002   000866  0521   0200
TRUE      00001 00000001  0176   0188 0232 0269
=F'1'     00004   000968  1453   0241

                         DIAGNOSTIC CROSS REFERENCE AND ASSEMBLER SUMMARY


 NO STATEMENTS FLAGGED IN THIS ASSEMBLY

OVERRIDING PARAMETERS-  LOAD
OPTIONS FOR THIS ASSEMBLY
 NODECK, OBJECT, LIST, XREF(SHORT), NORENT, NOTEST, BATCH, ALIGN, ESD, NORLD, LINECOUNT(55), FLAG(0), SYSPARM()
NO OVERRIDING DD NAMES

  327 CARDS FROM SYSIN      5496 CARDS FROM SYSLIB
  392 LINES OUTPUT            30 CARDS OUTPUT
```

Figure A-2 (Cont'd)

NSE: is the last sample within the line to be included in the retrieved data

NOL: is the number of consecutive lines for retrieval of data (including NLS)

These parameters define the rectangular area within the image.

ARRAY: is the array into which the retrieval data is put

NLA: is the second dimension of the array (the number of rows (lines) the array contains)

NSA: is the first dimension of the array (the number of columns (samples) the array contains)

These parameters define the array to receive the data.

RFAC: is a scale factor by which each sample is divided

Note: NLS, NSS, NSE, NOL, NLA, NSA are assumed to be INTEGER *4 arguments while ARRAY and RFAC are assumed to REAL *4 arguments and further, a previous statement:

DIMENSION ARRAY (NSA, NLA) is assumed to have been included in the program that uses FPIC, which is FORTRAN compatible.

The data to be manipulated by FPIC is assumed to reside on a tape defined by a DD card as follows:

```
//GO.TAPE DD DSN=name,DISP=OLD,UNIT=2400,
// VOL=SER=volser,DCB=(RECFM=U,BLKSIZE=1000)
// LABEL=(file #,SL,,IN)
```

As part of FPIC's operation, another DD card is required as follows:

```
//GO.DISK DD DSN=&&TEMP,DISP=NEW,UNIT=SYSDA,
// DCB =(DSØRG=DA,KEYLEN=4,SPACE =(TRK,(300,10))
```

The operation of FPIC is as follows:

1) The first call to the subroutine causes the data (not the label) records to be copied from the tape to the disk data set as a direct access file with the line number as the record key.

2) The required lines (records) are then read from the disk, the sample bytes are extracted, floated, scaled and stored in ARRAY.

Certain operational errors will cause user abends. These are listed below.

Abend	Reason
69	disk write rejected
169	no. of data records ≠ NL in header
269	start line number negative
369	requested number of lines > NL in header
469	start sample # negative
569	start sample # > end sample #
669	end sample # > NS in header
769	end sample # negative
869	number of lines in square (NOL) negative
969	(end sample # - start sample #)>NS in A array
1069	number of lines (NOL)> NL in A array
1169	EODAD on disk (write)
1269	disk I/O error (write)
1369	Tape I/O error
1469	unable to open tape data set dcb

1569	unable to open disk data set (write) dcb (write)
1669	unable to open disk data set dcb (read)
1969	end of dataon disk data set (read)
2069	I/O error on disk data set (read)

A program was written to compute the average spectral reflectance within a particular spectral band given the spectral reflectivity of the sample and the spectral transmission of the filter under consideration. Figure A-3 is a listing of this program which was written in Fortran language. Each of the steps in the program is clearly identified by comments and no further explanation is required. As utilized in the present study, FIL (1,J) through FIL (6,J) represent the six spectral transmissions for the blue, green, red filters of Mariner VI and Marinter VII respectively. RBAR represent the average spectral reflectivity of the sample in each of these spectral bands and the value of RATIO (1) and RATIO (2) are the red-to-blue and red-to-green reflectivity ratios for the Mariner VI spectral bands while RATIO (3) and RATIO (4) are the corresponding values for the Mariner VII spectral bands.

```
           C
           C ****************************************************************************
           C **                                                                       **
           C **   THIS PROGRAM COMPUTES THE AVERAGE SPECTRAL REFLECTANCE OF A SAMPLE  **
           C **   FOR SPECTRAL BANDS GIVEN THE SPECTRAL TRANSMISSION AND THE          **
           C **   SAMPLE REFLECTANCE.                                                 **
           C **                                                                       **
           C ****************************************************************************
           C
ISN 0002         DIMENSION FIL(6,151),R(151),SID(20),RBAR(6),RATIO(4)
ISN 0003       1 FORMAT(4(10X,F10.0))
ISN 0004       2 FORMAT(20A4)
ISN 0005       3 FORMAT(1H1,9X,20A4//15X 'AVERAGE REFLECTANCE'/ 20X 'BAND',2X,'1',
                *8X,'2',8X,'3',8X,'4',8X,'5',8X,'6'// 20X, 6F9.3 //15X 'REFLECTANCE
                * RATIOS', 10X, 4F8.3, 4(/))
ISN 0006       4 FORMAT(   10X,20A4//15X 'AVERAGE REFLECTANCE'/ 20X 'BAND',2X,'1',
                *8X,'2',8X,'3',8X,'4',8X,'5',8X,'6'// 20X, 6F9.3 //15X 'REFLECTANCE
                * RATIOS', 10X, 4F8.3, 4(/))
ISN 0007         CALL CLEAR(FIL(1,1),FIL(6,151))
           C
           C  ***************************************************************************
           C  *                                                                         *
           C  *  READ SPECTRAL TRANSMISSION DATA                                        *
           C  *                                                                         *
           C  ***************************************************************************
           C
ISN 0008         READ(5,1)  (FIL(1,J),J=2,151)
ISN 0009         READ(5,1)  (FIL(2,J),J=2,151)
ISN 0010         READ(5,1)  (FIL(3,J),J=2,151)
ISN 0011         READ(5,1)  (FIL(4,J),J=1,151)
ISN 0012         READ(5,1)  (FIL(5,J),J=1,151)
ISN 0013         READ(5,1)  (FIL(6,J),J=1,151)
           C
           C  ***************************************************************************
           C  *                                                                         *
           C  *  NORMALIZE SPECTRAL TRANSMISSION DATA                                   *
           C  *                                                                         *
           C  ***************************************************************************
           C
ISN 0014         DO 30 I=1,6
ISN 0015         S=0.0
ISN 0016         DO 22 J=1,151
ISN 0017      22 S=S+FIL(I,J)
ISN 0018         DO 24 J=1,151
ISN 0019      24 FIL(I,J)=FIL(I,J)/S
ISN 0020      30 CONTINUE
           C
           C  ***************************************************************************
           C  *                                                                         *
           C  *  READ SAMPLE SPECTRAL REFLECTANCE DATA                                  *
           C  *                                                                         *
           C  ***************************************************************************
           C
ISN 0021         ICASE=0
ISN 0022      40 READ(5,2,END=70) SID
ISN 0023         ICASE=ICASE+1
```

Figure A-3 AVERAGE REFLECTIVITY MAIN PROGRAM LISTING

```
ISN 0024            READ(5,1) R
               C
               C  **************************************************************************
               C  *                                                                        *
               C  *   DETERMINE AVERAGE SAMPLE REFLECTANCE FOR EACH SPECTRAL BAND          *
               C  *                                                                        *
               C  **************************************************************************
               C
ISN 0025            DO 50 I=1,6
ISN 0026            RBAR(I)=0.0
ISN 0027            DO 45 J=1,151
ISN 0028         45 RBAR(I)=RBAR(I)+R(J)*FIL(I,J)
ISN 0029         50 CONTINUE
               C
               C  **************************************************************************
               C  *                                                                        *
               C  *   COMPUTE RATIOS OF AVERAGE REFLECTANCES                               *
               C  *                                                                        *
               C  **************************************************************************
               C
ISN 0030            DO 55 N=1,4
ISN 0031         55 RATIO(N)=0.0
ISN 0032            IF(RBAR(1).GT.0.0) RATIO(1)=RBAR(3)/RBAR(1)
ISN 0034            IF(RBAR(2).GT.0.0) RATIO(2)=RBAR(3)/RBAR(2)
ISN 0036            IF(RBAR(4).GT.0.0) RATIO(3)=RBAR(6)/RBAR(4)
ISN 0038            IF(RBAR(5).GT.0.0) RATIO(4)=RBAR(6)/RBAR(5)
               C
               C  **************************************************************************
               C  *                                                                        *
               C  *   PRINT OUTPUT DATA AND RECYCLE TO PROCESS NEXT CASE, IF ANY.          *
               C  *                                                                        *
               C  **************************************************************************
               C
ISN 0040            IF(MOD(ICASE,5).NE.1) GO TO 60
ISN 0042            WRITE(6,3) (SID(K),K=1,20),(RBAR(I),I=1,6),(RATIO(N),N=1,4)
ISN 0043            GO TO 40
ISN 0044         60 WRITE(6,4) (SID(K),K=1,20),(RBAR(I),I=1,6),(RATIO(N),N=1,4)
ISN 0045            GO TO 40
               C
               C  **************************************************************************
               C  *                                                                        *
               C  *   TERMINATE EXECUTION                                                  *
               C  *                                                                        *
               C  **************************************************************************
               C
ISN 0046         70 STOP
ISN 0047            END
```

Figure A-3 (Cont'd)

LABEL	ADDR	LABEL	ADDR	LABEL	ADDR	LABEL	ADDR
22	001472	24	00149C	30	0014AA	40	0014C6
45	00153A	50	001550	55	00155E	60	001626
70	00167A						

*****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****

```
SYMBOL  INTERNAL STATEMENT NUMBERS
I       0014 0017 0019 0019 0025 0026 0028 0028 0028 0042 0042 0042 0044 0044
        0044
J       0008 0008 0008 0009 0009 0009 0010 0010 0010 0011 0011 0011 0012 0012
        0012 0013 0013 0013 0016 0017 0018 0019 0019 0027 0028 0028
K       0042 0042 0042 0044 0044 0044
N       0030 0031 0042 0042 0042 0044 0044 0044
R       0002 0024 0028
S       0015 0017 0017 0019
FIL     0002 0007 0007 0008 0009 0010 0011 0012 0013 0017 0019 0019 0028
MOD     0040
SID     0002 0022 0042 0044
RBAR    0002 0026 0028 0028 0032 0032 0032 0034 0034 0034 0036 0036 0036
        0038 0038 0038 0042 0044
CLEAR   0007
ICASE   0021 0023 0023 0040
RATIO   0002 0031 0032 0034 0036 0038 0042 0044
```

```
LABEL   DEFINED   REFERENCES
    1   0003      0008 0009 0010 0011 0012 0013 0024
    2   0004      0022
    3   0005      0042
    4   0006      0044
   22   0017      0016
   24   0019      0018
   30   0020      0014
   40   0022      0043 0045
   45   0028      0027
   50   0029      0025
   55   0031      0030
   60   0044      0040
   70   0046      0022
```

Figure A-3 (Cont'd)