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DIFFERENCES BETWEEN PROPOSED APOLLO SITES

Far Infrared Emissivity Evidence

June 9, 1969

Bellcomm, Inc.

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Far Infrared Emissivity Evidence

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ABSTRACT

Infrared emissivity comparison spectra of nine areas on the lunar surface, each 40 km in diameter, indicate that the majority of the lunar surface, including the five prime Apollo sites, has a constant Si:O ratio so far as present infrared techniques are able to detect. However, an anomaly in the 8 - 9μ region of the emissivity spectrum of the crater Plato is interpreted as evidence of significantly different Si:O ratio in the mineral assemblage exposed on that surface.

PREFACE

This paper represents the far-infrared portion of a multispectral study of the prime Apollo sites carried out at Mount Wilson between June and October 1968. Complimentary measurements were made in the visible and near infrared wavelength regions by T. B. McCord, T. V. Johnson, and H. H. Kieffer. B. C. Murray had overall responsibility for the synthesis of the findings. A combined report on all phases of the study will be published elsewhere.

DIFFERENCES BETWEEN PROPOSED APOLLO SITES

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INTRODUCTION

A search was made for differences in spectral emissivity, in the 8-13μ region, between the five prime Apollo lunar landing sites and other selected points on the lunar surface. The observations were made on the Mt. Wilson 24 inch telescope using equipment and methods described by Goetz (1968) and Goetz and Westphal (1967). No large scale differences were found. However, emissivity differences described previously by Goetz (1968) at other lunar localities were verified.

METHOD

Ratios of two different emission spectra acquired sequentially, are formed. A least-squares fit of a second order polynomial to the ratio is made in order to remove the effect of different surface temperatures and long term atmospheric transmission variations. A percentage difference between the polynomial and the quotient, called a "residual", is formed. The residual has the form

$$r(\lambda) = \frac{\varepsilon_1(\lambda) - \varepsilon_2(\lambda)}{\varepsilon_2(\lambda)} A(\lambda) \tag{1}$$

where $\varepsilon_1(\lambda)$ and $\varepsilon_2(\lambda)$ are the respective spectral emissivities of each point on the lunar surface and $A(\lambda)$ is the short period atmospheric transmission variation not removed by the ratioing process. The $A(\lambda)$ arises because the atmospheric transmission has temporal variations which do not "cancel" when the ratio of two emission spectra is formed. A weighted average of a number of sets of residuals of the same pair of points is formed to reduce the effect of $A(\lambda)$. Since emissivities of the lunar surface approach unity the averaged value of the residual approaches

$$\overline{r(\lambda)} \simeq \varepsilon_1(\lambda) - \varepsilon_2(\lambda) \tag{2}$$

EQUIPMENT

An Ebert-Fastie type spectrometer coupled with a mercury doped germanium detector was used in conjunction with a two beam photometer. Wavelength resolution averaged .08μ. A 27 arc second entrance diaphragm was used. Output was digitized for ease of data reduction.

OBSERVATIONS

Lunar spectra were obtained during the months of June through October, 1968. Lunar positions observed along with the number of spectra taken are listed in Table I. Unfortunately, at most times data had to be collected during periods of large southerly declination. The resulting high air mass numbers, coupled with unusually humid observing conditions, resulted in a large number of spectra being rejected.

RESULTS

Figure 1 shows the residual spectral differences of three Apollo sites, IIP6 (Tranquillitatis), IIP8 (Sinus Medii) and IIIP11 (Procellarum), used as comparison standards in this study. Deviations from zero correspond to spectral emissivity differences between the sites. Comparison spectra of each site with respect to itself are included to define confidence limits. Ideally these residuals should be zero throughout the spectrum. Deviations from zero arise when atmospheric transmission variations are not completely removed by averaging. The transmission in the 9-10μ region is strongly governed by the atmospheric ozone absorption band. It is generally not possible to remove entirely the effects of this band by averaging. In the difference spectra, no deviation is found that does not correspond to a probable atmospheric fluctuation as evidenced in the confidence spectra.

Figure 2 shows the IIP13 Apollo site as well as spectra of several points outside the Apollo zone. For the sake of brevity the confidence spectra are not shown. IIP13 exhibits no significant difference from the other Apollo sites. Aristarchus, shown by detailed Orbiter photography to be one of the freshest large impact features on the visible portion of the lunar surface, does not exhibit any important differences with respect to IIP13 nor, by figure 1, to any of the other sites. This result has important bearing on the relationship between infrared and color anomalies. Aristarchus exhibits one of the strongest blue anomalies recorded on the lunar surface (McCord, 1969). The point Mare Humorum 2 is located on a linear thermal anomaly reported by Hunt et. al. (1968). Unfortunately only one good pair of spectra was available. However, no obvious spectral differences are present.

Plato/Copernicus exhibits the same anomalous deviation in the 8.2-9μ region as reported by Goetz (1968). Plato/IIP6 shows similar behavior, reinforcing the argument that the origin of the anomalous spectral emissivity behavior is in fact in Plato.

INTERPRETATION

Previous work (Goetz, 1968) has shown that a wide range of lunar features including maria, highlands, and bright ray craters, exhibit little or no differences in spectral emissivity in the 8-13μ wavelength region. Therefore, it is not surprising that no significant differences are found between Apollo landing sites, in spite of differences in apparent age shown by crater counts and regolith thickness (Oberbeck and Quaide, 1969). Regolith thickness has been shown to be approximately the same for the sites IIP2, IIP6, and IIP13. However, IIP8 exhibits a significantly thicker and IIIP11 a thinner surface layer.

The thermal emissivity of a surface is governed by composition and texture. When the particle size or roughness of the surface is large compared to the emitted radiation, emission from silicates in the 8-13μ region is characterized by high reflection features called reststrahlen bands produced by Si-O lattice stretching vibrations. The location of these reststrahlen bands is diagnostic of the silicon to oxygen ratio and associated coordination number in the mineral (Launer, 1952). These bands are most readily detected in polished or very coarsely ground samples. With decreasing particle size or roughness these spectral emission features become generally subdued. If the particle size is decreased to below 50 microns virtually all reststrahlen features disappear.

When the particle size is of the order of the emitted radiation wavelength, new features arise because of scattering effects (Conel, 1969). One prominent feature is an emissivity maximum at or near the principal Christiansen frequency, the frequency of maximum transmission as measured in powder films. Laboratory spectra exhibit a peak to trough signal difference of about 3%.

The observation that the emission signatures of the Apollo sites are similar can therefore be interpreted in three ways: (1) The regions are compositionally* homogeneous (averaged over a 40 km area) and the textural variations are not sufficient to significantly

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*Compositionally homogeneous here means principally homogeneous in Si:O ratio. For example, variation in pyroxene type between sites, but no significant variation in Si:O coordination number, probably would not produce an observable change in the emission signatures.

modify the emission spectra; or (2) the areas are compositionally heterogeneous and the particle sizes are small enough to subdue any reststrahlen bands and not so small as to induce Christiansen features; or (3) some surface alteration has produced a "skin" which obscures the emission features of the bulk compositions.

The second hypothesis meets with difficulty in view of the fact that our extrapolation of Surveyor I, III, V, and VI data indicates that greater than 80% of the particles composing the surface are smaller than 50μ. If the areas are quite compositionally dissimilar and the observed form of the particle size distribution continues into the range of a few microns, Christiansen features arise. The most acceptable hypothesis is, then, that the Apollo sites are compositionally similar or possess surface alterations producing "skins" which are compositionally similar.

The behavior of the difference spectra of Plato versus IIP6 and Copernicus in the 8-9μ region, shown in Figure 2, is identical to that shown by Goetz (1968). Plato is the only point measured in either study which showed consistent spectral differences. The fact that the emission signature of Plato differs from the Apollo sites can be accounted for in several ways. First, if Plato is compositionally different and the overall texture of the sites is coarse enough so that reststrahlen bands were dominant in the emission signature, one would conclude that the Apollo sites had a significant content of free quartz. The content of free quartz would probably be significantly higher than indicated by the observed spectral variation because texture undoubtedly subdues these features to some extent. This conclusion is not compatible with evidence from the Surveyor alpha scattering experiments which indicate that areas in the region of the Apollo sites do not contain significant amounts of quartz.

A second possible explanation for the observed anomaly is that the composition is similar between Plato and the Apollo sites but the texture of Plato modifies the emission spectrum differently than does that of the Apollo sites. Surveyor data indicates that the small particle distributions are similar between sites even for "young" regions such as Tycho. Plato does not exhibit any macroscopic features which indicate a "young" surface, and its texture is most likely similar to that of the Apollo sites, barring any recent surface alteration. However, there is no evidence of recent activity in Plato as there is for example in Aristarchus and in the floor of Alphonsus, both of which do not exhibit spectral infrared anomalies.

The third and most likely possibility for the cause of the anomaly in Plato is that there is little textural variation between Plato and the Apollo sites, but that the Si:O ratio of Plato differs from that of the Apollo sites and the observed spectral feature in Plato is due to a differing Christiansen vibration frequency. This hypothesis is compatible with Surveyor data regarding particle size distribution, morphological evidence from the Orbiter photography, and does not require a high quartz content in the Apollo sites, since the observed spectral anomaly could arise from the presence or absence of a considerable variety of minerals, generally compatible with the alpha-scattering data.

SUMMARY AND CONCLUSION

In view of the preceding evaluation of the possible causes for the absence of spectral emissivity differences between the Apollo sites and for the anomaly existent in Plato, the most likely hypothesis is that the mineral assemblages are similar between Apollo sites within the sensitivity of the method, and that the mineral assemblage of Plato differs in some way from these assemblages. This difference might arise, for example, from different relative contents of pyroxenes, amphiboles, plagioclase feldspars or olivines or some variation not seen in terrestial rocks which have different Si:O ratios.

Finally we should note that our observations cannot rule out the ad hoc possibility that some unknown surface alteration or combination of alterations is present in Plato only, is present in the Apollo sites only, or is present in both.

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L. A. Soderblom

2015-AFHG-tla

Attachments
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Table I
Figures 1 and 2

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TABLE I

Date of Observation	Pair of Sites Compared	Number of Runs
6/9/68	IIP6 and IIP8	16
6/10/68	IIP6 and IIP8	24
6/11/68	Plato and Copernicus	22
6/12/68	IIIP11 and IIP8	22
6/13/68	Aristarchus and IIP11	24
7/9/68	IIP6 and IIIP11	22
7/10/68	IIP8 and IIIP11	16
8/11/68	IIIP11 and IIP13	12
9/4/68	IIP2 and IIP6	14
9/5/68	IIP2 and IIP6	12
9/6/68	IIP6 and IIP8	22
9/7/68	IIP6 and Plato	16
10/11/68	Mare Humorum 2 and IIP11	20

Site	Selenographic Position	
	Latitude	Longitude
IIP2	2°40'N	34°00'E
IIP6	0°45'N	23°37'E
IIP8	0°25'N	1°20'W
IIIP11	3°30'S	36°25'W
IIP13	1°50'N	41°50'W
Plato	9°30'W	52°00'N
Copernicus	20°20'W	9°30'N
Aristarchus	47°00'W	23°30'N
Mare Humorum 2	44°00'W	23°00'S

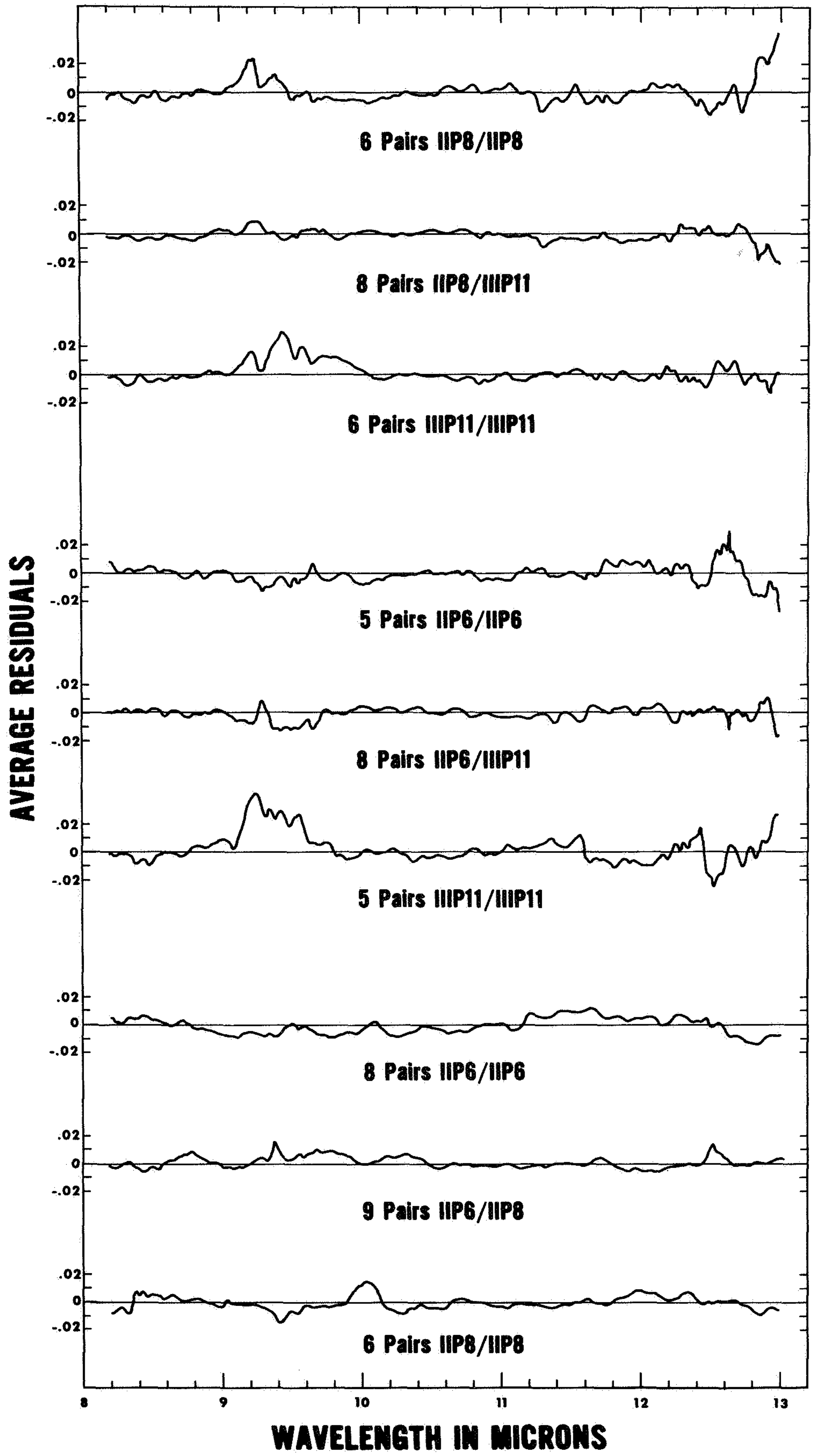
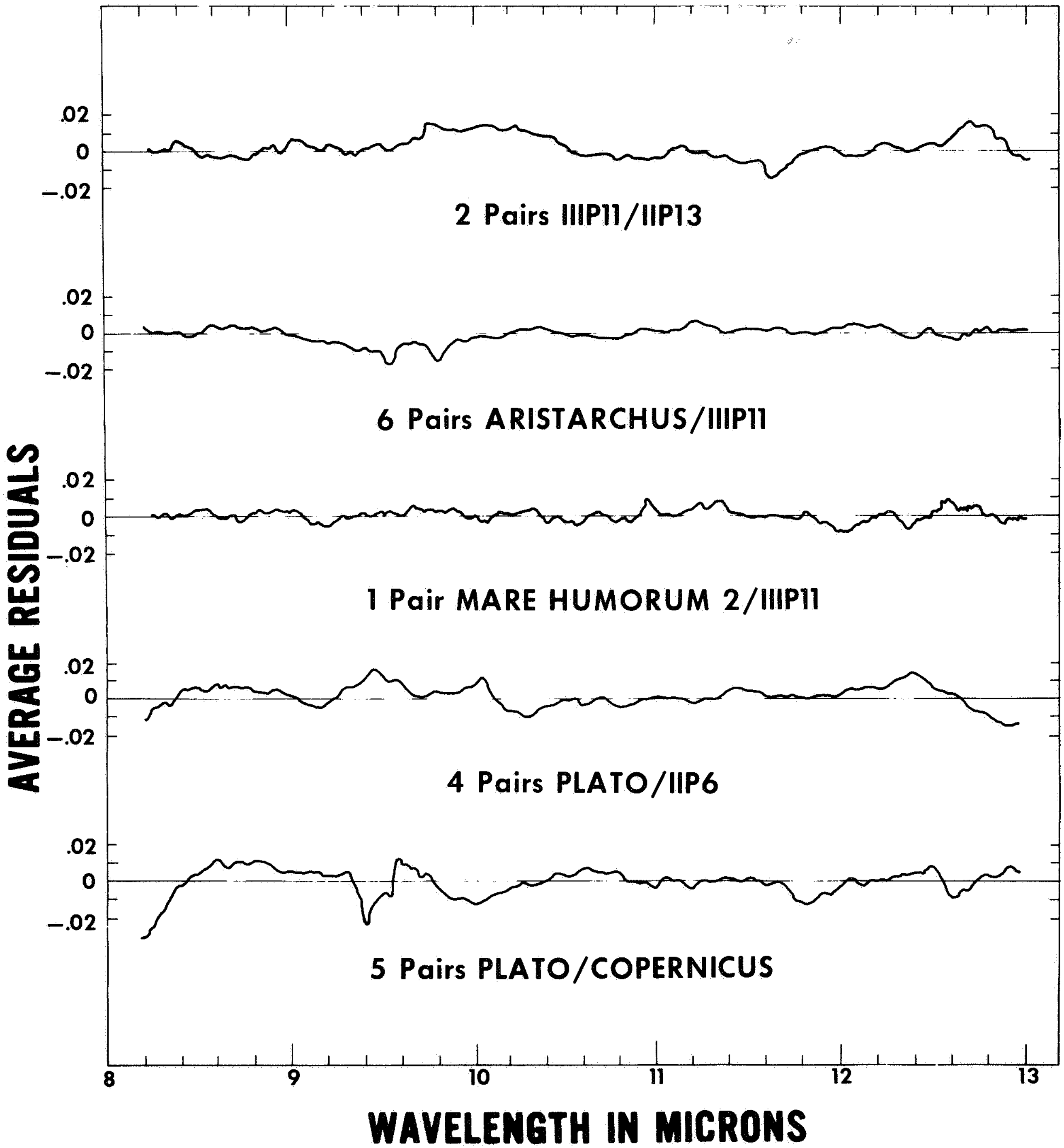

6 Pairs IIP8/IIP8
8 Pairs IIP8/IIIP11
6 Pairs IIIP11/IIIP11
5 Pairs IIP6/IIP6
8 Pairs IIP6/IIIP11
5 Pairs IIIP11/IIIP11
8 Pairs IIP6/IIP6
9 Pairs IIP6/IIP8
6 Pairs IIP8/IIP8
AVERAGE RESIDUALS
.02
0
-.02
8
9
10
11
12
13
WAVELENGTH IN MICRONS

Figure 1



.02
0
−.02
2 Pairs IIIP11/IIP13
.02
0
−.02
6 Pairs ARISTARCHUS/IIIP11
.02
0
−.02
1 Pair MARE HUMORUM 2/IIIP11
.02
0
−.02
4 Pairs PLATO/IIP6
.02
0
−.02
5 Pairs PLATO/COPERNICUS
AVERAGE RESIDUALS
8
9
10
11
12
13
WAVELENGTH IN MICRONS

Figure 2

Distribution List

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