A DETAILED SPECTRAL REFLECTIVITY STUDY OF COPERNICUS AND ITS EJECTA

by

ERIC ROBIN WOLF
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Chairman, Departmental Committee
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Submitted to the Department of Earth and Planetary Sciences on June 4, 1970 in partial fulfillment of the requirement for the degree of Master of Science.

ABSTRACT

An observational study was performed to determine relative spectral reflectivity differences (0.4-1.1 microns) in the Copernicus region of the moon, as well as several other bright crater areas. A photoelectric filter photometer was used. Results suggest that: (1) spectral features do exist. (2) The spectral feature amplitude in the normalized relative spectral reflectivity curves for areas studied tends to decrease as distance of the areas from Copernicus increases. The general shape of the curve remains the same. This implies that the amount of Copernican material decreases as the distance of a spot from Copernicus increases. (3) The curves for areas on some Copernican rays have the same general shape as do the curves of areas in Copernicus. The amplitude of the spectral features for the ray area curves tends to be smaller than for areas in the crater, implying that the rays contain mare material as well as Copernican material. (4) There is no significant dependence of relative color at Copernicus on lunar phase angle. (5) The angular distribution of Copernican ejecta appears to be uniform. (6) Copernican ejecta has a relatively high albedo.

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Title: Assistant Professor of Planetary Physics

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INTRODUCTION

Purpose

An important means of studying the lunar surface is by determining the wavelength dependence (color) of the intensity of reflected solar radiation. By viewing the relative changes in this property over the lunar surface, it is possible to determine relative differences in the materials of the surface. Possible disparities could include differences in composition, particle size, particle shape, and particle packing configurations. Calibration of spectral differences can be accomplished by direct laboratory measurements and by study of lunar samples.

This work is the first known intensive spectral photometric observational study of Copernicus and its ejecta. There have been, however, many studies made of the color of areas on the moon. Two recent authors--Coyne (1963, 1965) and McCord (1968, 1969)--have found color variations, even within the maria. McCord observed some differences which were as high as 60%. A complete bibliography of such studies is presented by McCord (1968).

Definition

This study is concerned only with the relative differences in the reflected lunar spectrum. This simplifies the measurement and data reduction techniques. The quantity of interest--the normalized relative spectral reflectivity--is given by:

$$D(\lambda) = \frac{I_x(\lambda)/I_x(.53\mu)}{I_s(\lambda)/I_s(.53\mu)} \quad .$$

$I_x(\lambda)$ is the intensity of a lunar area at a given wavelength; $I_x(.53\mu)$ is the intensity of this spot at .53 microns. $I_s(\lambda)$ and $I_s(.53\mu)$ are the corresponding intensities of the standard spot.

By taking ratios of the intensity of light reflected from a given spot to that from a standard spot (taken at nearly the same time), multiplicative atmospheric effects (i.e. extinction) on the measurements are eliminated. The ratio process also compensates for changes in sensitivity, gain, and settings of the instruments.

This relative spectral reflectivity is normalized to .53 microns. The normalization is essential, since albedo variations on the moon are much greater than color variations. If this normalization were not made, a bright area (high albedo) would appear to have much greater relief in its spectral reflectivity curve than a dark area (low albedo). Albedo, then, rather than color, would be the major factor in determining apparent spectral reflectivity differences.

OBSERVATIONS

Instrumentation

A single-beam photometer mounted on the Mt. Wilson 24-inch telescope was used to make measurements. A set of thirteen narrow band interference filters was used to measure the spectral intensity within a spectral range of 0.4 to 1.1 microns. During the July-August, 1969 lunation, only the first eleven filters were used, extending over a spectral range of 0.4 to 1.0 microns. The effective wavelengths and spectral widths of these filters are tabulated in table 1. The filters were mounted on a slotted wheel which rotated automatically between integrations.

The detector used was an ITT photomultiplier tube with an S-1 surface. The tube was used in a pulse-counting mode.

The lunar guiding is facilitated on the 24-inch telescope by variable tracking rates. This can control the north-south and east-west motion of the telescope so that the telescope will stay on a point on the moon to first order in the moon's orbital motion. Manual guiding, though, is still necessary.

Table 1

FILTER CHARACTERISTICS

Filter	Effective Wavelength λ_{eff} (microns)	Passband $\Delta\lambda$ (microns)
1	.402	.03
2	.467	.03
3	.532	.03
4	.598	.03
5	.633	.03
6	.699	.03
7	.765	.03
8	.855	.05
9	.906	.05
10	.948	.05
11	1.002	.05
12	1.053	.05
13	1.101	.05

The effective wavelengths have been calculated considering the spectral characteristics of the following:

1. solar energy distribution
2. average lunar reflectivity
3. terrestrial atmospheric transmission (1 atm)
4. telescope optics (aluminum mirrors)
5. filter transmission
6. photocathode sensitivity

Method of Measurement

The spots observed were circular areas with diameters of about 8 km on the lunar surface (sub-earth point). About 25 spots in and around the lunar crater Copernicus were studied. These points included areas within the crater floor, the walls (or inside slopes), throwout around the crater, crater rays, and the peak in the center of Copernicus. (Fig. 1 and Table 2) The measured spectral intensity curve was then divided by the intensity curve of a standard spot in Mare Imbrium. The standard spot was chosen because: (1) it is located in a compositionally and topographically homogeneous area. Thus the measurements are not extremely sensitive to small guiding errors at the standard spot. (2) It is approximately at the same selenographic longitude as most of the other spots observed. Thus lighting conditions would be similar. (3) It is relatively near Copernicus--and thus saves time in moving the telescope between it and the crater. (4) It is in the field of view of several clear landmarks, which makes it easy to position the aperture very precisely.

Each point was observed with the entire filter set, while automatically printing the intensity, the

SELENOGRAPHIC COORDINATES OF LUNAR AREAS

Spot	λ	ϕ
5	20.0	9.7
1	22.0	9.6
17	20.1	12.2
33	20.7	11.2
36	27.5	6.3
35	19.6	11.1
14	19.2	9.7
10	20.1	9.0
12	20.7	9.7
7	20.4	10.1
9	20.1	8.4
34	20.1	8.1
2	20.5	10.7
18	20.1	7.2
20	18.9	20.6
11	21.3	9.6
21	16.7	25.4
25	19.5	20.6
15	18.9	9.5
24	20.8	11.5
8	20.0	10.2
22	21.7	8.2
23	18.2	9.5
13	21.1	8.8
MS11	-16.1	19.5
BR1	-16.8	19.4
BR2	-17.8	22.3
BR3	-19.0	25.0
MC	-15.8	16.2
MN	-15.9	16.6
T1	11.5	-43.2
T6	10.5	-43.6
T11	12.1	-43.0

Table 2

time, and the run number on paper tape. The standard area in Mare Imbrium was observed at least once every fifteen to twenty minutes. Several runs were made between observations of the standard spot. The effect of making standard runs no longer than about ten minutes before or after any other run is to eliminate variable extinction error due to atmospheric effects which have a time scale greater than ten minutes. Higher-frequency effects can't be thus eliminated, but, due to the number of samples of most spots, are eliminated in the data reduction.

Each spot was observed several times on a given night. In almost all cases each spot was observed on more than one night. As a check, in the data reduction the standard spot runs were normalized to 0.53 microns and divided by each other. This exposes any runs in which measurement error occurred. In all but a very few cases this produced a flat curve to within about 1%.

The filter scan started at the first filter in the filter wheel (0.40 microns) and proceeded around the wheel. After a full revolution of the filter wheel, a second observation was made with the first filter to check for guiding error. Observations were repeated if the first and last counts did not agree to within about 1%.

The integration time was chosen long enough such that the purely statistical counting fluctuations ($\sqrt{N}/N$, where N is the photon count) would be less than a 1% effect.

DISCUSSION OF SURFACE-SCATTERED RADIATION

The lunar radiation observed in the 0.4 to 1.1 micron range is almost entirely reflected solar radiation. There is some controversy concerning the existence of temporally varying visible emission on the moon. (McCord, 1967; Ney, Woolf, and Collins, 1966) However, it is generally agreed that such radiation, were it to exist, would be much less intense than the visible reflected solar radiation.

The reflected spectrum of a material gives information about the atomic, molecular, and crystal structure of that material. By studying the relative reflectivity instead of the absolute reflectivity, relative differences between areas on the lunar surface become apparent. Definite information about the composition or physical properties is not determined.

That there are definite differences in spectral reflectivity between different areas on the moon has been demonstrated by several investigators (see introduction). These differences could conceivably be caused by compositional differences or by variations in the macrostructure of the lunar surface materials.

Laboratory studies have been made (Adams and Filice, 1967; Adams, 1967) of the relationship between spectral reflectivity and the physical properties of the materials studied. Such parameters as particle size, particle packing, and angle of illumination were varied for a given sample, using several different types of rocks. Composition and particle size were found to be the most important parameters as far as the spectral curves are concerned.

Decreasing the average size of particles makes them less opaque. Light scattered from a material (down to a certain grain size) has undergone more internal reflections than if it were scattered from a larger-grained surface of the same composition. This effect not only increases the albedo, since more light is scattered from the surface, but also increases the size of the spectral features of the reflectivity curve. To see this, consider the scattered light as composed of two components: one which has been scattered by the top-most surface layer, i.e. no penetration of grains; and one which has penetrated one or more grains and is then reflected back. The first component contains little spectral information, while the second one has had imposed more strongly upon it the spectral characteristics of the material. Clearly the second component will be larger in the case in which there are more internal reflections, i.e. when the grain size is smaller, and thus more structure is seen when the particle size is decreased. If the grain size is too small, however, little spectral information is contained in the reflected light spectrum because the path length through the grains--and thus between surface reflections--is short. Therefore much of the backscattered radiation will have passed only a short distance through the grains.

More importantly, and with greater certainty, compositional information can be deduced from spectral reflectivity. Adams and Filice (1967), after a study of laboratory data and lunar data, determined that the lunar surface could not be composed of crystalline acidic rocks or glassy rocks, but might be basic rock (e.g. basalts). Only basic rocks could produce the observed minima in the absolute spectral reflectivity curves at 1 micron. (Adams, 1967)

It is believed by most authors (including the present author) that lunar spectral reflectivity differences are due mainly to compositional differences. (McCord, 1968)

DATA AND INTERPRETATIONS

The quantities of interest are the normalized relative spectral reflectivities of the various lunar areas observed. Most areas were measured enough times so that averaged spectral curves could be plotted, with error bars representing the standard deviation of the average. The number of samples used in calculating the average curves varied from three to twelve, while most were in a range of from five to eight. The averaged curves with error bars, as well as curves of spots for which not enough data exists to determine error bars, are reproduced in Appendix I. These measurements span a lunar phase angle range of about 20 to 110 degrees. (see Table 3)

Phase Angle

McCord (1968) observed a 2-3% increase in color contrast as the lunar phase angle increased from 0 to 90 degrees. The sizes of spectral features in the normalized relative spectral reflectivity curves in this study are greater than a few percent, so that such a small phase effect would not be expected to be very noticeable. This is indeed the case, as no systematic changes in the spectra with phase angle were seen.

Spot	Date (UT)
5	8/3,4,5,29,30,31/69 9/1
1	8/4,5,29 9/1
17	9/1
33	8/30 9/1,3
36	8/30,31 9/1
35	9/3
14	8/4,5
10	8/3,5
12	8/3,4,5
7	8/3,4,5
9	8/3,5
34	9/1,3
2	8/4,5
18	8/3,5 9/1,3
20	8/29,30,31 9/1
11	8/5 9/3
21	8/29,30,31 9/1
25	8/29,30,31 9/1

Phase Angles of Center of Moon	
Date	Degrees
8/3/69	63
8/4	75
8/5	87
8/29	23
8/30	35
8/31	47
9/1	59
9/2	71
9/3	83
9/4	95
9/5	107

Table 3. Dates and approximate lunar phase angles of observations of some lunar areas.

Compositional Mixing

Inspection of the relative reflectivity curves for areas in Copernicus and along its rays reveals that, while the size of the spectral features varies greatly, the general curve shape is the same.

This could be indicative of compositional mixing differences. To understand this, we must consider the components of the light reflected from a spot on the lunar surface. One component is light which is scattered by material which is compositionally similar to the standard spot, denoted by I_1. The other is light scattered from material which is not similar to the standard spot material, denoted by I_2. The total intensity is the sum of these two components. Now when the intensity is divided by that of the standard spot (I_s), the result is:

$$I/I_s = I_1/I_s + I_2/I_s \ .$$

The first function on the right of the equality (I_1/I_s) gives a flat spectrum, since it is the ratio of two similar spectra. The second function (I_2/I_s), when plotted against wavelength, gives the relative spectral reflectivity curve of two different types of materials. Thus by measuring the relative spectral reflectivity of a spot, we not only determine whether the two areas are similar or different, but, by determining the amount of structure in the curves, we can determine qualitatively the relative amounts of different materials, weighted by their albedos. This effect is seen to be quite large when one examines the spectra of spots in Copernicus and the Copernican rays, and is believed by this author to be the major reason for differences in the size of features.in the relative spectral reflectivity curves of the areas studied.

We shall refer to the material which gives the normalized relative spectral reflectivity curves of areas in and around Copernicus their characteristic structure as "Copernican material". Thus, the size of the features of these similarly-shaped curves is a measure of the amount of Copernican material in an area. The larger the features, the more Copernican material (and the less "standard Imbrium" material) is present--relative to the total amount of reflecting material.

Curve Structure

As can be viewed in Appendix I, all of the "Copernican" normalized relative reflectivity curves rise monotonically over a range of 0.40 to 0.63 microns. There is, in each of them, a feature in the form of a relative rise at about 0.47 microns. (This may be due to a rise in the reflectivity of the Copernican spots, a dip in the reflectivity of the standard spot, or a combination of both.) There is a broad dip in the curves from about .63 to .76 microns, after which the curve becomes flatter until about .90 microns. The maximum value of relative reflectivity is reached between .76 and .85 microns. After about .90 microns, the relative reflectivity drops off rather sharply, reaching a minimum at around 1.05 microns. There is a dip at around .95 microns, which varies in size from spot to spot. The curve starts to rise again after the 1.05 micron minimum.

The size of spectral features is what differentiates one curve from another. It is therefore useful to determine quantitative parameters which characterize a given curve. A parameter--Amplitude of Spectral Features--was determined by measuring the height of the curve maximum relative to the height at .47 microns. It is tabulated for different spots as a percentage. (Table 4)

Amplitude and Distance

The Amplitude of Spectral Features of the Copernican curves was investigated as a function of the distance of the spots from the center of Copernicus. The results are seen in Figure 3. It was found that

Spot	D(km)	Amplitude(%)	Description
5	0	25	central peak
1	63	20	outside crater--west
17	77	20	outside--north
35	52	20	rim of crater
12	23	20	floor of crater
33	52	15-20	rim
14	23	15-20	floor
10	17	15-20	floor
7	20	15-20	floor
9	37	15-20	floor-wall
36	252	15	ray--near Hortensius
34	46	15	rim
2	40	10-15	wall
18	74	10	outside--south
20	350	10	ray
11	40	10	wall
21	504	7	ray
25	350	4	mare adjacent to ray

Table 4. Distance from the center of Copernicus, Amplitude of Spectral Features, and Description of "Copernican" spots.

the Amplitude of the curves of spots located on the floor of Copernicus lies between 15 and 20 percent. This same parameter lies between 10 and 20 percent on the crater walls.

A conceivable mechanism responsible for this decrease in Amplitude on the walls is the slumping and sliding of rock. This would expose the underlying rock, which would not be as strongly (if at all) shocked as the material on the crater floor. Indeed, the rock on the walls of Meteor Crater, Arizona is the original underlying material. (Shoemaker, 1962). It would be expected, however, that there is shocked rock on the Copernican walls, present in the terraces.

The size of the spectral features of areas far from Copernicus is less than that of areas close to the crater. There are, however, exceptions to this trend, as is seen in Fig. 3. It is not possible to tell if a definite correlation exists, but it would appear that the amount of "Copernican" material decreases in general as the distance from Copernicus increases. This conclusion is a result of the abovementioned interpretation of amplitude differences in the relative reflectivity curves.

Angular Distribution of Ejecta

In order to determine the angular distribution of Copernican material, directional plots of Amplitude vs. distance from the center of Copernicus were made. The surface plane was divided into three sectors, and an Amplitude vs. Distance plot was constructed for each sector. Although there are fewer spots in some sectors than in others, the same apparent distribution is found in all sectors. This suggests that the angular distribution of Copernican material is uniform (to within the limits of the measurements). This agrees with recent studies of impact cratering. (Gault, Shoemaker, and Moore, 1963)

Albedo

Spots which are brighter than the surrounding areas have larger-sized relative reflectivity features than do their neighboring areas. This is clearly illustrated in the spectra of Spots 1 and 20. Spot 1 is a bright area outside of Copernicus about 60 kilometers west of the central peak. The bright area is roughly circular, about the size of the aperture used. Its spectral curve is among the largest-featured of those studied. (Amplitude is greater than 20%) Spot 20 is on a bright ray of Copernicus, about 350 kilometers north of the crater. The size of spectral reflectivity features of this spot (Amplitude is 10%) is greater than that of a neighboring mare spot--Spot

25 (Amplitude is 4%). This would imply that what is called Copernican material has a relatively high albedo.

Rays

Spots were observed on and adjacent to a long ray extending north from Copernicus. (See map, Fig. 4) The normalized relative spectral reflectivity curves of the spots on the ray show larger Copernican features than do those adjacent to it (Appendix I, curves of Spots 20, 21, 25), which means that there is a relatively larger amount of Copernican-like material exposed on the ray than on the mare surface. The size of the spectral features on the ray curve (e.g. Spot 20) is still significantly less than that of spots in the crater. This would imply that the ray contains both Copernican-type material and material similar to the material at Spot 0.

The crater rays have been interpreted as being a layer of coarsely crushed rock ejected from the primary crater. (Shoemaker, 1962) Within the rays are many bright secondary craters, formed by the impact of ejecta from the primary crater. Thus, light scattered from a ray contains components scattered from: a) primary crater material; and b) secondary craters and their ejecta. Ranger VII and VIII photographs show that only a small fraction of the area of a ray is covered with secondary craters. The albedo of the rays is uniform. This means that most of the light reflected from a ray is reflected from primary crater material (i.e. material ejected from Copernicus in the case discussed here).

The observation of a mixture of Copernican and mare (standard) material on the rays (i.e. size of spectral features intermediate between Copernicus and Spot 0) implies either (1) that the Copernican material is a thin layer, and the mare regolith material is "showing through"; or (2) mare material different from the surface mare material was turned up when the Copernican ejecta was deposited.

The normalized relative reflectivity spectrum of Spot 36--a ray area near the crater Hortensius--is seen to have a Copernican shape. (Amplitude is greater than 15%. See Appendix I) This area is bright, and contains both Copernican ray material and throwout from Hortensius. These factors, and the fact that Spot 36 is very close to Hortensius (and thus the mare would probably be covered with a relatively thick blanket of Hortensius ejecta), mean that it is unlikely that very much mare-regolith material (which might be similar in composition to Spot 0) was observed. This is also suggested by the relatively large size of the features in the normalized relative reflectivity spectrum of Spot 36. The fact that the shape of the curve is

Copernican implies that the material in the Hortensius area has a sizeable component which is similar in composition to the material in Copernicus. Whether the spectral characteristics of Copernican-type material is indigenous to an area on the lunar surface or a property of shocked rock can only be determined by studying other areas containing impact-shocked rocks. A less intensive study was made of such areas.

Non-Copernican Areas

Spots were observed in Mare Serenitatis, Menelaus, Tycho, and along the prominent north-south ray across Mare Serenitatis (referred to in this study as Bessel Ray, due to its proximity to the crater Bessel). Their normalized relative spectral reflectivity curves appear in Appendix I. (See maps, Figs. 5 and 6)

The spot observed in Mare Serenitatis (Spot MS11) has a sharp dip at 0.95 microns in its reflectivity spectrum relative to Spot 0, then rises. The dips of the Bessel Ray Spots--BR1, BR2, and BR3--are structured similarly to the MS11 dip.

The similarity of the curves implies that a major constituent of the ray is mare material, similar to Spot MS11. This is consistent with the interpretation that the underlying mare material is "showing through" or turned up.

The curves of Menelaus--Menelaus Center (MC) and Menelaus North (MN)--also show a sharp dip at .95 microns. These dips drop more precipitously and rise less steeply than the MS11 dip.

The Tycho spots--Tycho 1 (T1), Tycho 6 (T6), and Tycho 11 (T11)--display a distinctive feature. Between .90 and .95 microns the curves dip sharply. They then level off. Between 1.02 and 1.05 microns, there is a gradual rise, which becomes steep after 1.05 microns. The dip structure of these non-Copernican areas is illustrated in Fig. 7.

The spectral reflectivity of a spot relative to any standard could reveal, among other things, the relative amount of non-standard material at that area. In order to determine the amount of non-Mare Serenitatis material in Bessel Ray and Menelaus, normalized spectral reflectivity curves of these areas were made relative to Spot MS11. It is seen in Appendix I that the curves of Tycho relative to MS11 have a very strong 1.05 micron dip, as well as a sharp maximum at about .90 microns. The Bessel Ray curves relative to MS11 do not show these strong features, but are similar to the Menelaus curves.

The non-mare component of the ray, then, is largely Menelaus-like material. This would imply that Bessel Ray may have originated from Menelaus. In any case, it does not seem to be compositionally similar to Tycho.

The normalized reflectivity curve shapes of Menelaus relative to Spot MS11 are surprisingly similar to those of Copernicus relative to Spot 0. (Appendix I) The major difference is that there is no 1.05-micron dip in the Menelaus curves. (Also, the curves relative to MS11 start downward a few microns before .90.) The Bessel Ray curves (again relative to MS11) show the same shape as the Menelaus curves, but have smaller features. They are quite similar to the spectral reflectivity curves of Copernican ray spots relative to Spot 0. (See Spot 21 vs. Spot 0 and BR2 vs. MS11 in Appendix I)

These surprising results, were they to be more than coincidental, would suggest that the reflectivity spectrum of material in craters is transformed, perhaps through impact-shocking*, from the original spectrum (represented by the mare spectrum) in a systematic manner. Another possibility is that the material under the mare surface differs systematically in composition from the surface. This "under material" is found both

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* The floor of a primary impact crater contains impact-shocked material. The rays of such a crater also contain such material. The term "shocked" refers to material which has been quasi-melted by the impact-shock process and re-solidified.

in the crater and outside the crater, in the form of ejecta. These possibilities should be investigated by observing rays, primary craters, and their surrounding areas over many parts of the moon.

Summary

It has been seen that the amplitude of features of normalized relative spectral reflectivity curves seems to decrease with distance from Copernicus. This is interpreted as a decrease in Copernican material with distance from Copernicus. Much of this material appears to be ejecta from the crater. However, more areas away from the crater must be studied to confirm this trend.

A result which should be further investigated is the decreased size (from crater spot features) of features of the spectral reflectivity curves of crater rays relative to surrounding maria, implying that a large amount of underlying mare material may be contained in them. The shape of these curves suggests that a component of the ray material is compositionally similar to nearby craters. This may give clues as to the crater of origin of rays.

No significant lunar phase angle effect has been found in the reflectivities of Copernican spots.

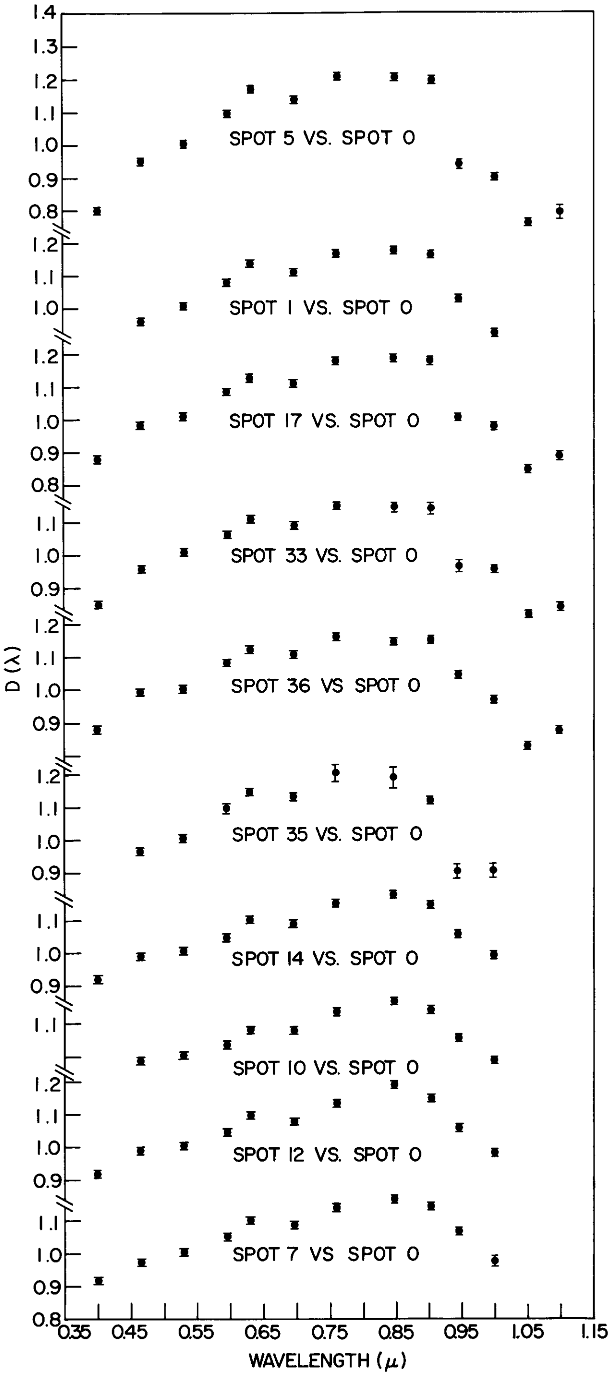
The normalized spectral reflectivity curves of Copernicus and Copernican rays relative to Spot 0 are similar in shape to those of Menelaus and Bessel Ray relative to Spot MS11. The possibility of a systematic change in spectral properties of certain rocks due to impact cratering is suggested by this observation, and should be investigated.

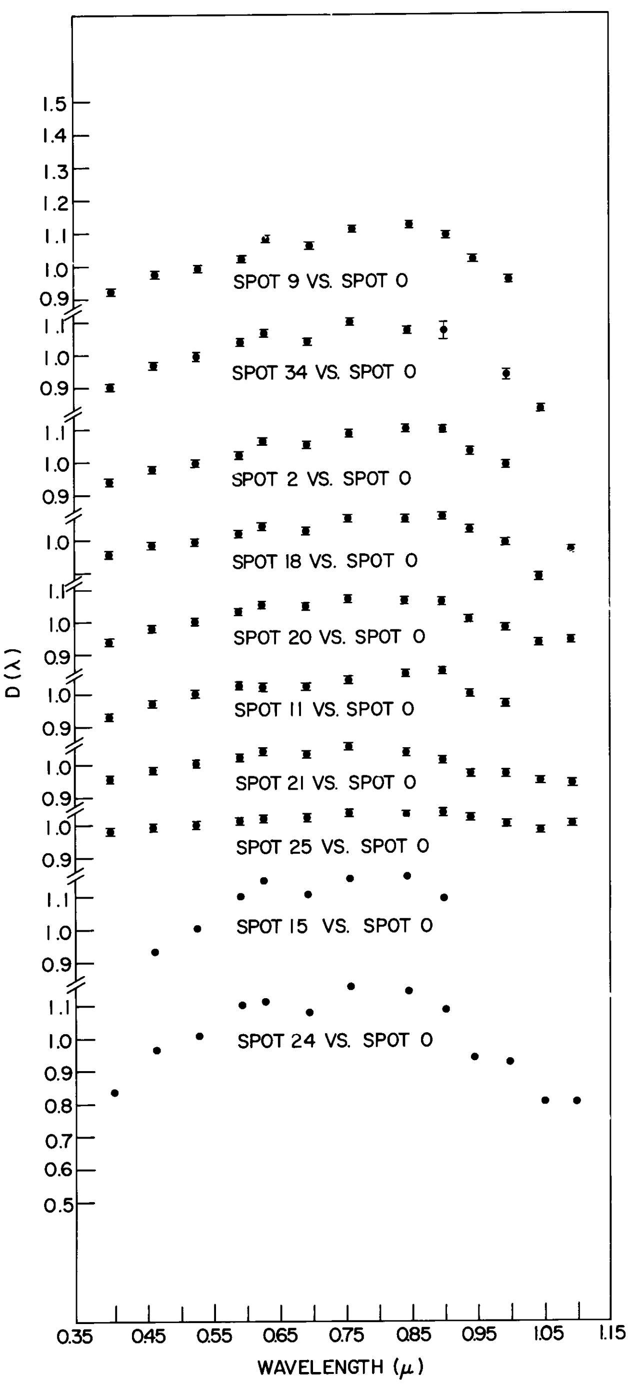
The distribution of ejecta from Copernicus seems to be angularly uniform.

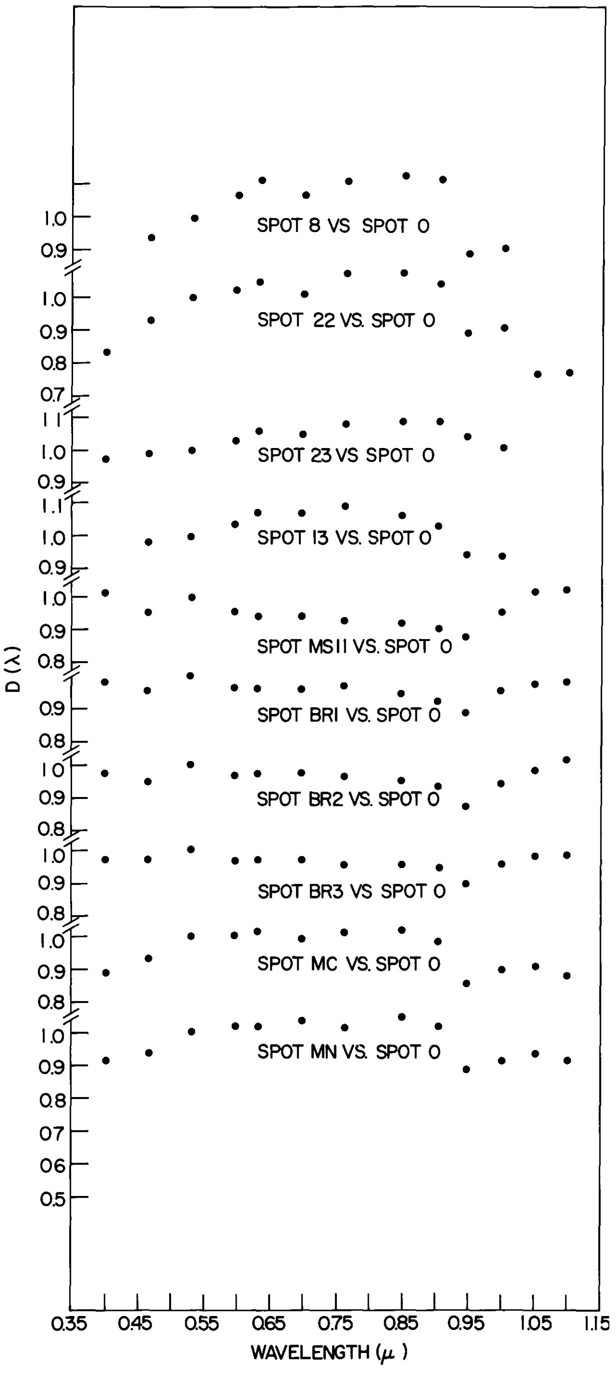
APPENDIX I

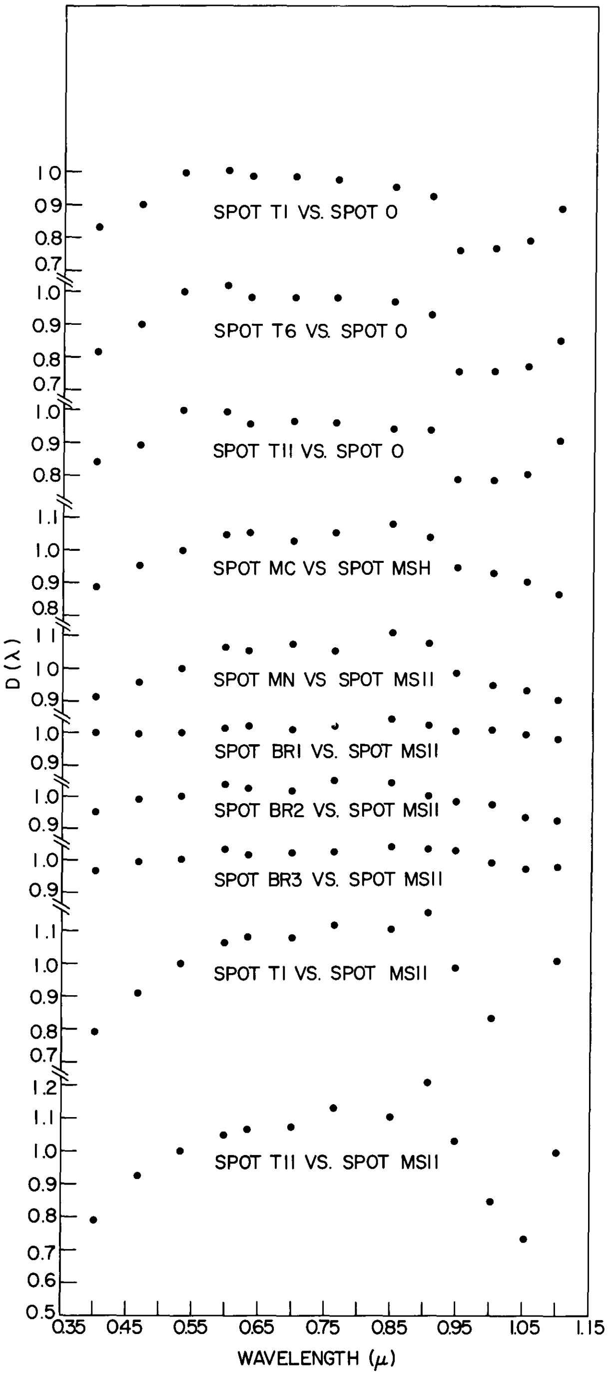
(Data)

(Note: Copernican area spots are those with just a number, e.g. 5, 36. Non-Copernican spots have a number and a letter, or just a letter, e.g. BR2, MC)


D (λ)
SPOT 5 VS. SPOT 0
SPOT 1 VS. SPOT 0
SPOT 17 VS. SPOT 0
SPOT 33 VS. SPOT 0
SPOT 36 VS SPOT 0
SPOT 35 VS. SPOT 0
SPOT 14 VS. SPOT 0
SPOT 10 VS. SPOT 0
SPOT 12 VS. SPOT 0
SPOT 7 VS SPOT 0
0.35 0.45 0.55 0.65 0.75 0.85 0.95 1.05 1.15
WAVELENGTH (μ)


D (λ)
SPOT 9 VS. SPOT 0
SPOT 34 VS. SPOT 0
SPOT 2 VS. SPOT 0
SPOT 18 VS. SPOT 0
SPOT 20 VS. SPOT 0
SPOT 11 VS. SPOT 0
SPOT 21 VS. SPOT 0
SPOT 25 VS. SPOT 0
SPOT 15 VS. SPOT 0
SPOT 24 VS. SPOT 0
0.35 0.45 0.55 0.65 0.75 0.85 0.95 1.05 1.15
WAVELENGTH (μ)


SPOT 8 VS SPOT 0
SPOT 22 VS. SPOT 0
SPOT 23 VS SPOT 0
SPOT 13 VS. SPOT 0
SPOT MS11 VS. SPOT 0
SPOT BR1 VS. SPOT 0
SPOT BR2 VS. SPOT 0
SPOT BR3 VS SPOT 0
SPOT MC VS. SPOT 0
SPOT MN VS. SPOT 0
D (λ)
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.35
0.45
0.55
0.65
0.75
0.85
0.95
1.05
1.15
WAVELENGTH (μ)


SPOT T1 VS. SPOT 0
SPOT T6 VS. SPOT 0
SPOT T11 VS. SPOT 0
SPOT MC VS SPOT MSH
SPOT MN VS SPOT MS11
SPOT BR1 VS. SPOT MS11
SPOT BR2 VS. SPOT MS11
SPOT BR3 VS. SPOT MS11
SPOT T1 VS. SPOT MS11
SPOT T11 VS. SPOT MS11
D (λ)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.35
0.45
0.55
0.65
0.75
0.85
0.95
1.05
1.15
WAVELENGTH (μ)

APPENDIX II

(Figures)

(Note: There is no Figure 2, due to an intentional omission.)

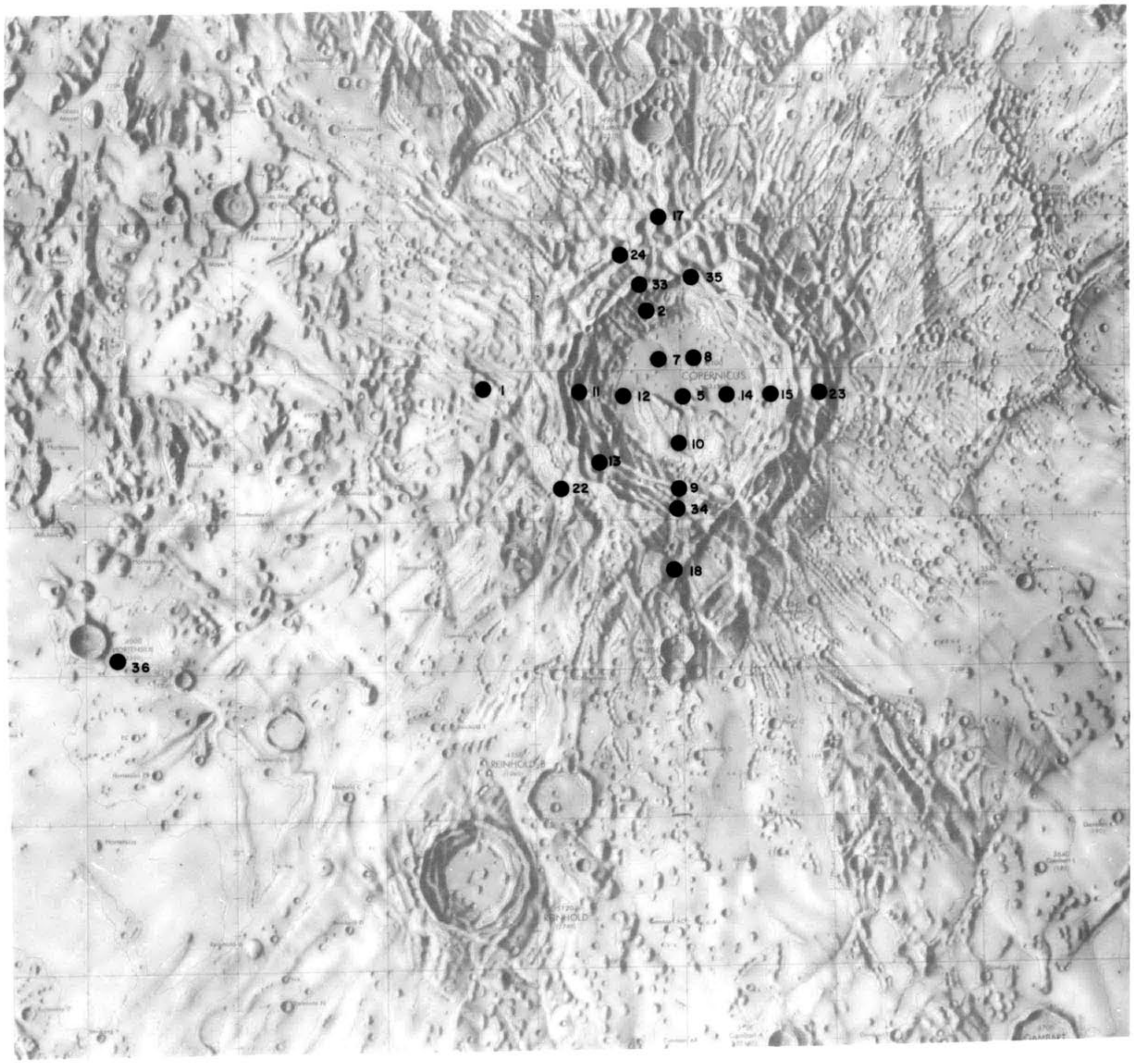


FIG. I COPERNICAN SPOTS

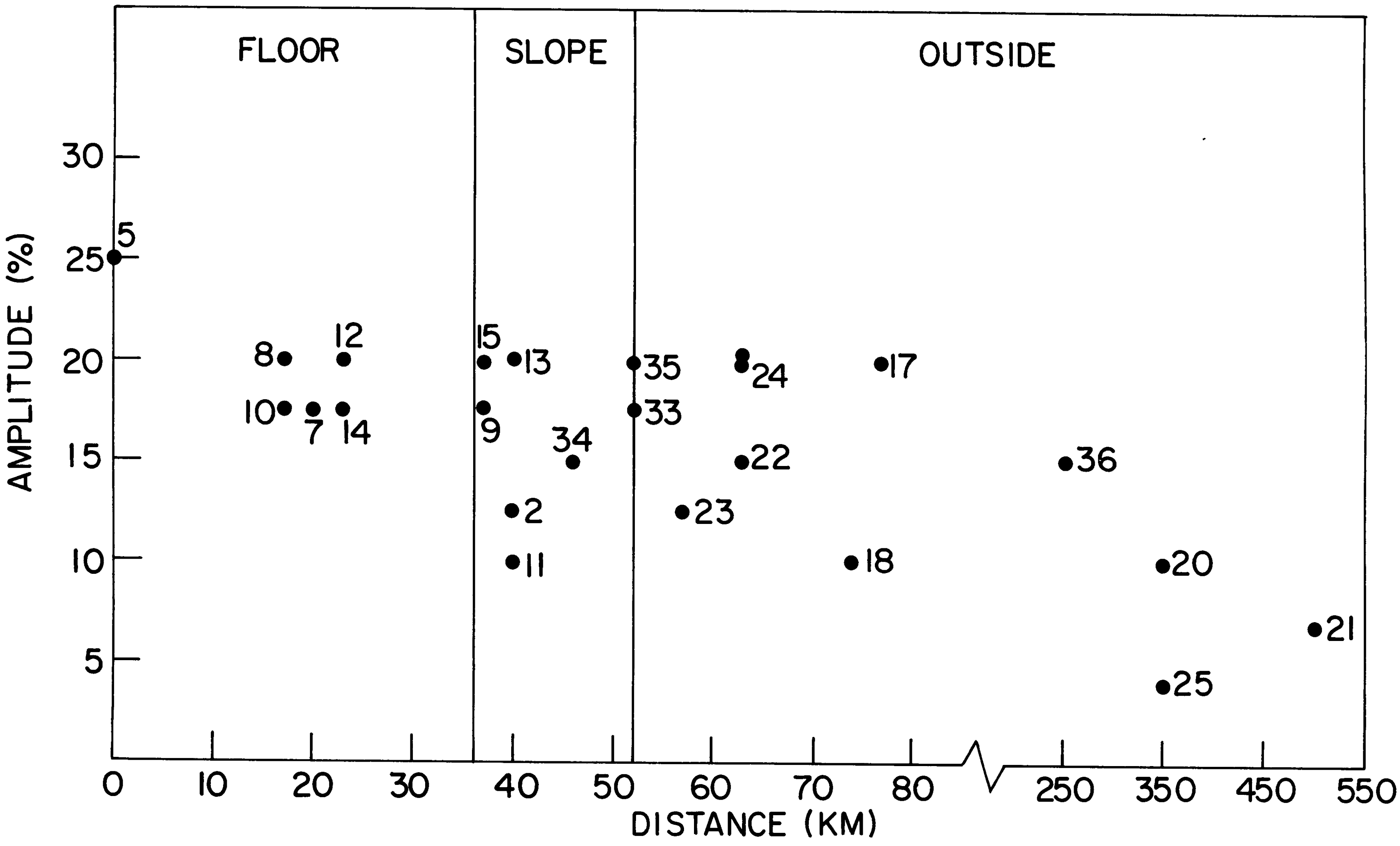


FIG. 3 AMPLITUDE OF SPECTRAL FEATURES vs. DISTANCE FROM CENTER OF COPERNICUS

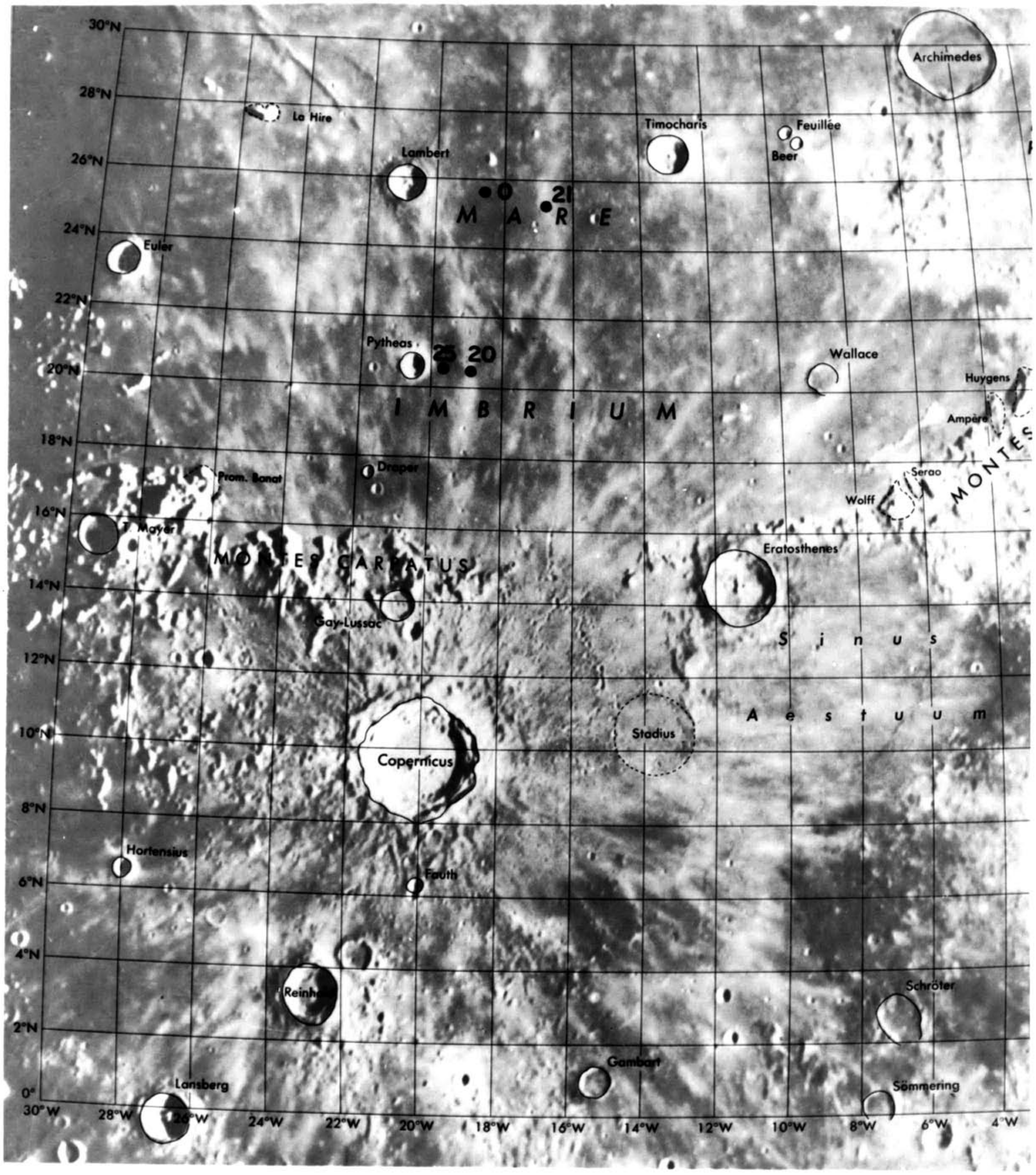


FIG. 4 LOCATION OF STANDARD SPOT AND RAY SPOTS WITH RESPECT TO COPERNICUS.

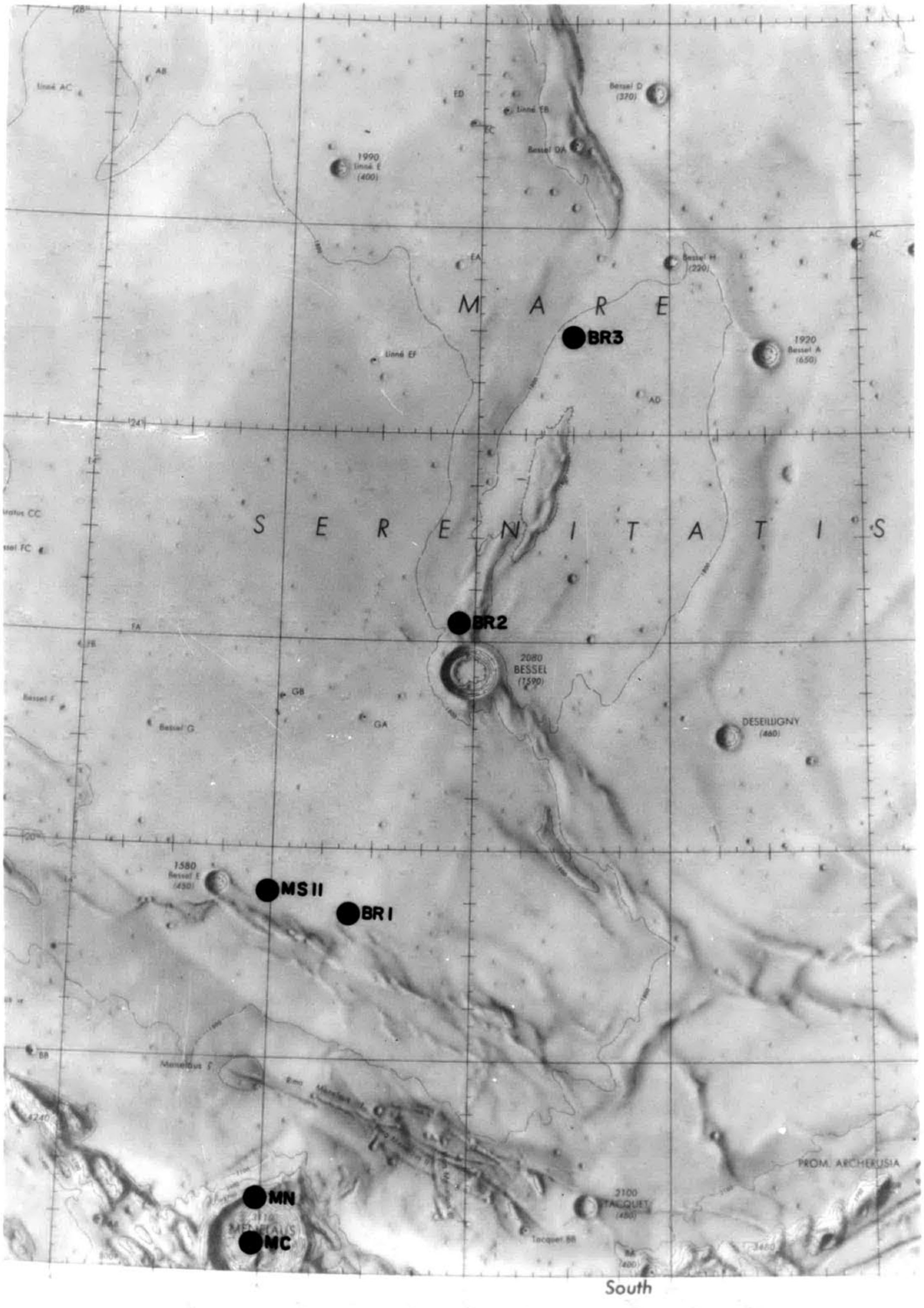


FIG. 5 SPOTS IN THE MARE SERENITATIS AREA

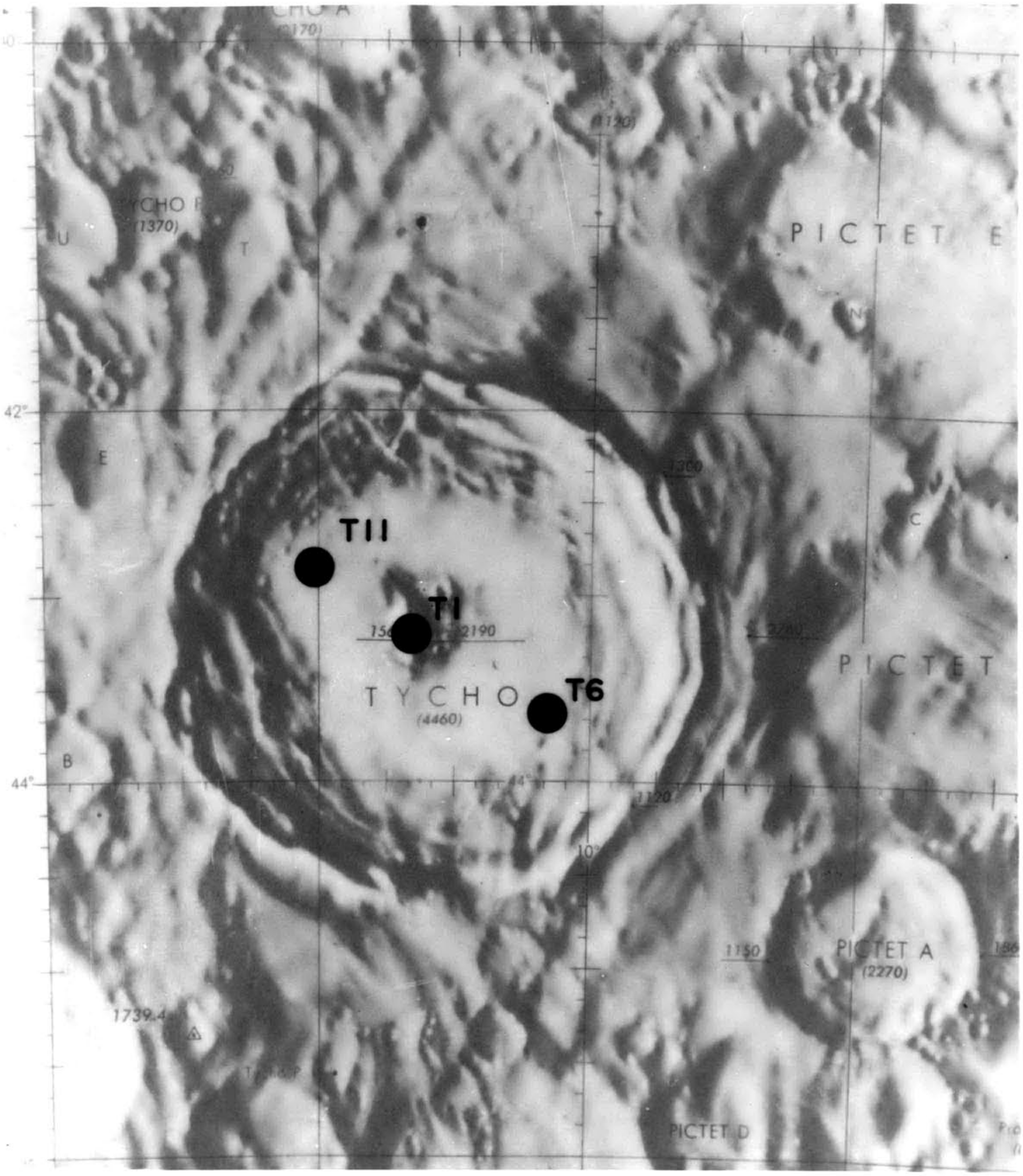


FIG. 6 TYCHO SPOTS

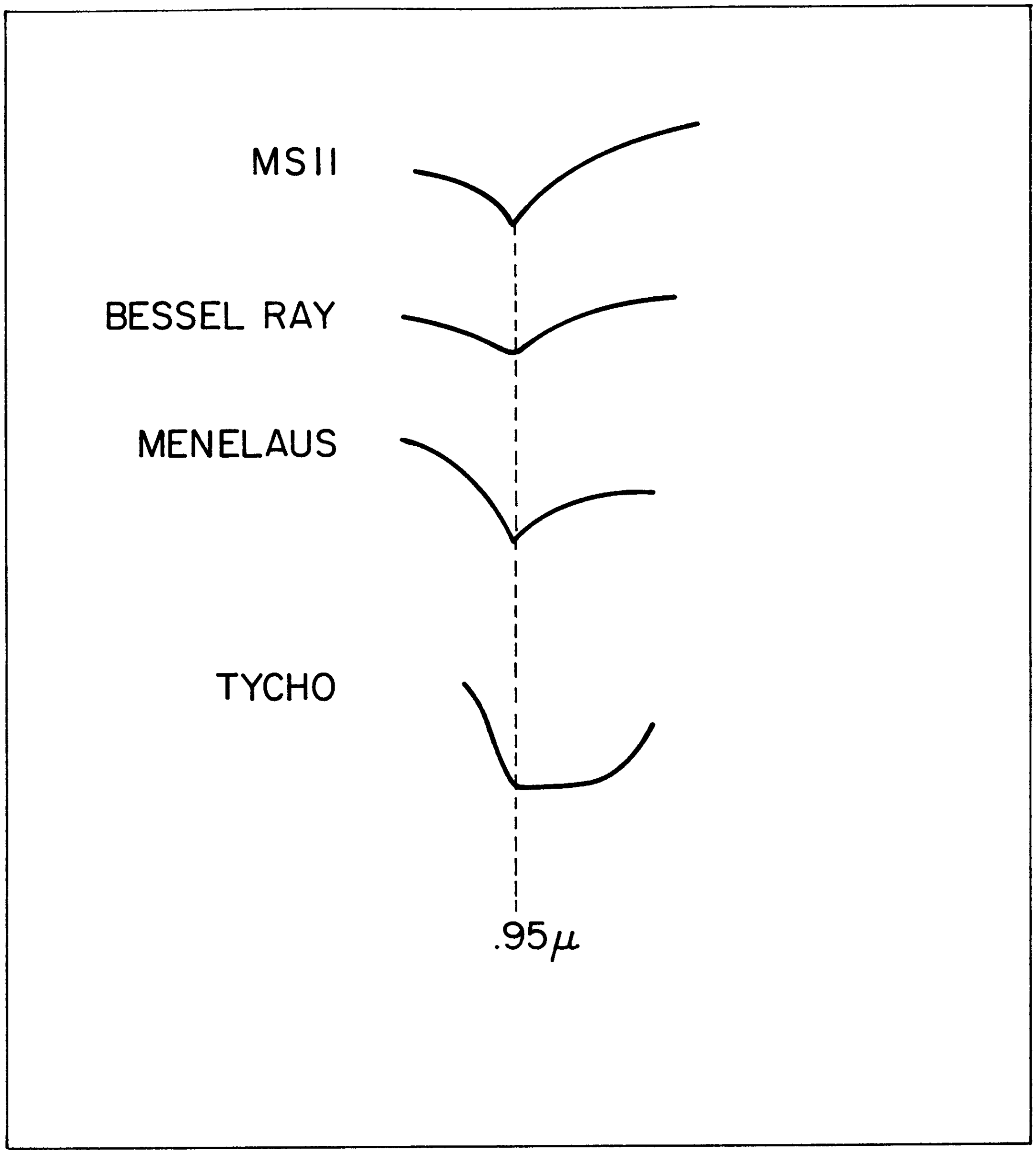


FIG. 7 SCHEMATIC DIP SHAPES OF NON-COPERNICAN SPOTS

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