PHOTOMETRIC CALIBRATION REPORT
- APOLLO 16 GONOMON S/N 1002
U.S. Geological Survey
January 1972
PHOTOMETRIC CALIBRATION REPORT

APOLLO 16 Gnomon #1002

by

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January 1972
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INTRODUCTION

The gnomon is a stadia rod mounted on a tripod. It is constructed so that the rod will align itself parallel to the local lunar gravity field, pointing essentially vertical. The gnomon rod, extending about 13 inches above the gimbal, has 10 painted gray steps ranging in absolute reflectance from 2.4% to 39%. Each gray band is .79 inches wide and the rod is .44 inches in diameter (Figure 1). The white band above the gray scales is 4.4 inches wide and the top .5 inch of the rod is painted black.

The Apollo 16 gnomon was photometrically calibrated at the Manned Spacecraft Center, Texas during December 2-3, 1971. The principal objective of the photometric calibrations is to permit the measurement of photometric properties of lunar materials.

Lunar surface photographs

Lunar surface photographs which include the gnomon have a vertical reference, a calibrated scale for determining the size of rock fragments, and an indication of camera orientation relative to solar position. The gray steps permit the determination of the relationship of scene luminance to film density, which allows photometric measurements of lunar materials to be extracted from film negatives. The photometric properties of lunar materials and rock types permit their recognition and delineation for geologic mapping at each landing site, and aid in correlation.
and extrapolation of geologic data from site to site across the lunar surface.

Method of Measurement

The reflectance from the gray steps on the gnomon rod was measured with a Gamma Scientific telephotometer model 2000. The gnomon was illuminated with a collimated xenon light which closely approximates the solar spectrum in the 400 to 700 nanometer range. The spectral sensitivity of the photomultiplier tube in the telephotometer also approximates the spectral sensitivity of the black and white lunar surface film. The reflectance from each gray step is measured by scanning across the rod diameter with 6-minute and 20-minute apertures and recording the photomultiplier output with a digital recorder. The 6-minute aperture covers an area of about 2 square mm on the gnomon.

The gray step reflectance is measured over the photometric geometry variations that will occur during the planned lunar surface photography. The light source is adjusted to simulate solar elevation angles of 11°, 22°, 34°. The telephotometer is positioned to simulate the camera view angles planned for down-sun and cross-sun photography which ranges over emission angles (e) of 15°, 20°, and 25° and at azimuth angles of 10° and 80° measured from the sun-line.

The photometric equipment is calibrated before each set of measurements and frequently rechecked during data acquisition. The reflectance measurements are expressed in absolute percentage.
reflectance based on measurements using a MgO reflectance standard. A freshly pressed MgO powder plaque is illuminated at an incident angle of 0 degrees and the reflectance measured at emission angle of 45° is adjusted to read 100 on the telephotometer.

Table of Measured Reflectance

The data from the 330 plotted graphs of integral reflectance contained in Appendix II have been consolidated into a table for more rapid determination of chart reflectance as a function of the illumination and camera viewing geometry. The illumination angle, \( i \), is equal to the solar elevation angle above the lunar surface providing the gnomon rod is aligned vertically. Any tilting of the rod caused by gnomon oscillation during photography requires an angular correction; the component of tilt toward sun is added to \( i \) values and the components of tilt away from the sun is subtracted from \( i \) values.

The viewing geometry consists of the azimuth angle (Az), defined as the angle in the horizontal plane between the camera pointing direction and the sun-line; and the emission angle (e) measured in the vertical plane between the camera pointing direction and the lunar horizontal. These angles are determined from study of the lunar surface pictures.

In the following table the measured reflectance is listed at various illuminating and viewing geometries. For intermediate values the reflectances have been plotted as graphs in Appendix II. Table I gives the step reflectance values at discrete incidence.
angles of 11°, 22°, and 34° for azimuths of 10° and 80° and emission angles of 15° and 20°, and 15°, 20°, and 25° respectively. The 6' apertures are given first followed by the 20' apertures. In all cases the 20' aperture values are lower because the larger gnomon area scanned integrates the dark and steep gradients of the illuminated gnomon step, reducing its signal correspondingly. This effect is more pronounced the greater the azimuth.

A simplified procedure for determining the reflectance from the gray steps of the gnomon is outlined as follows:

1. Determine the illumination (i), emission (e), and azimuth angles (Az).

2. Proceed to table I and determine the reflectance value for appropriate gray steps using a linear interpolation for intermediate angles.
Phase angle values used in Apollo 16 Gnomon Calibration Procedures

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<thead>
<tr>
<th>Values of $i$ and $\epsilon$ from horizontal</th>
<th>Azimuth $10^\circ$</th>
<th>$80^\circ$</th>
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<td>$i = 34^\circ$  $\epsilon = 25^\circ$</td>
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<td>68.1°</td>
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Table I
Gray step reflectance at given i and Az angles and $\varepsilon$ varies from 15° to 20° to 25° with 6° aperture

Apollo 16 Gnomon S/N 1002

<table>
<thead>
<tr>
<th>Step</th>
<th>$i = 11°$</th>
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<td>38.0</td>
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*Bad Data
R = Rerun
Table I - Cont.

Gray step reflectance at given i and Az angles as \( \epsilon \) from 15° to 20° with 20° aperture

**Apollo 16**

### \( i = 11° \)

<table>
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### \( i = 34° \)

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</table>
Appendix 1

Calibration Procedure
Calibration Procedures

Apollo Gnomon

USGS-AG-16

Approved by: Henry E. Holt

January 1972
Calibration Procedures for Apollo Gnomon

1. Purpose--The required steps for measuring the goniophotometric properties of the gray scale on the gnomon are established in this procedure.

2. Scope--This procedure describes the instrumentation necessary to perform the goniophotometric details, the sequential steps to be followed, and describes the instrumentation necessary to perform the calibrations.

3. Responsibilities--The measurements will be conducted by U. S. Geological Survey personnel associated with the Lunar Geology Experiment or by personnel designated by them. The following personnel will conduct the calibration.

   A. Test conductor
   B. Equipment operators (2)
   C. Recorder

The Test Conductor is responsible for insuring the gnomon is adequately calibrated. Unforeseen complications caused by gnomon condition, facility conditions, equipment malfunctions, or other factors may require additions or deletions to the calibration procedures. The Test Conductor has the authority to make deletions or additions, repeat steps, and to calibrate instruments at any time during the procedure in order to insure adequate calibration of the gnomon.

4. Equipment--The following items are required to perform the measurements:

   A. Model 2000 and 2400 Gamma Scientific Photometer
   B. Magnesium oxide standard
C. Collimated xenon light source and power supply
D. Two geared head tripods for supporting the xenon light source and the photometer
E. Inclinometer capable of measuring to $\pm \frac{1}{2}^\circ$ of slope
F. Rotating platform for supporting gnomon with azimuth readout
G. Polaroid camera (film pack) or other cameras to record instrument setup and photograph gnomon
H. Chart recorder and/or digital voltmeter and printer
I. Autocollimating mirror
J. Flight qualified gnomon gimbal mounted
K. A luminance standard, such as the Gamma Scientific Model 220, is desirable but not required

5. Procedure

5.1 Gray scale calibration

Step

1. Set up xenon light source and 2000 photometer on tripods about 4' - 6' (feet) from planned gnomon position with 10$^\circ$ azimuth angle between the instrument or as close as to 10$^\circ$ as feasible as shown in Figure 1. The distance may have to be adjusted so that the desired $i$ and $\varepsilon$ may be obtained. Turn on photometer and insure photometer can view gnomon at $\varepsilon = 15^\circ$, 20$^\circ$ and 25$^\circ$.

2. Set rotating platform to proper height (20") above the floor. Place the magnesium oxide standard normal to the optic axis of the xenon light in the position that the gnomon will occupy (use autocollimating mirror).
Figure 1. Generalized GSE setup to begin gray scale measurement.
3. After adequate warm up time on the photometer zero the dark current, and use internal calibration of 2000 photometer to check operation. Set up, zero, and check operation of chart recorder and/or digital voltmeter and printer.

4. Check collimation of light and flatness of illumination over the MgO standard at $i = 11^\circ$ and $\epsilon = 15^\circ$.

5. Adjust the 2000 photometer with neutral density filters and sensitivity gain such that the meter reads 108.2 foot lamberts with 6' (minute) aperture. Check operation of chart recorder and/or digital voltmeter and insure scale readout is matched (or linear) to the photometer scale readings. Adjust if necessary and record reading of MgO on chart recorder and/or digital voltmeter.

6. Remove MgO target and set up gnomon or revolving platform. Gnomon will be handled only by the legs with gloves. Never touch the painted surfaces. Set platform so leg with the photometric chart is pointing toward light source.

7. Position the xenon light source to illuminate the white area of the gnomon about 1 cm above the top gray step at an incident angle of $11^\circ$ measured in the vertical plane above the horizontal.

8. Position the photometer so the optic axis intersects the center of the white areas about 1 cm above the top gray step at an emission angle of $15^\circ$ measured in the vertical plane above the horizontal. Check that the phase angle is essentially $10^\circ$ ($\pm 1^\circ$) or as close as feasible. Insure
photometer aperture set to 6'.

9. Take measurement of reflected light across gnomon rod while recording the reflectance.

10. Adjust light source and photometer optic axes to the center of the top gray step at \( i = 11^\circ \) and \( \varepsilon = 15^\circ \). All \( i \) and \( \varepsilon \) angles are measured in the vertical plane above the horizontal unless otherwise directed. Measure reflectance across gray step at the center of gray step.

11. Adjust the light source and photometer optic axes sequentially in the center of each of the following gray steps at \( i = 11^\circ \) and \( \varepsilon = 15^\circ \), and repeat step 10 at each gray step in succession:

   11.1 2nd gray step
   11.2 3rd gray step
   11.3 4th gray step
   11.4 5th gray step
   11.5 6th gray step
   11.6 7th gray step
   11.7 8th gray step
   11.8 9th gray step
   11.9 10th gray step

12. Repeat measurements in steps 10 and 11 at 20' aperture (nearly covers diameter of rod). Check MgO value before and after measurements.

13. Adjust the light source and photometer optic axes to the gnomon at \( i = 11^\circ \) and \( \varepsilon = 20^\circ \). Insure the azimuth angle
is $10^\circ$ in the horizontal plane. Set MgO value at 108.2
and record with 6' aperture. Position photometer so
gnomon is in focus. Record the value of the MgO and adjust
as needed. Record reflectance across the white area about
1 cm above the top gray step.

14. Adjust light source and photometer optic axes to the center
of the top gray step at $i = 11^\circ$ and $e = 20^\circ$. Measure
reflectance across center of gray step with 6' aperture.

15. Adjust light source and photometer optic axes sequentially
in the center of each of the following grays steps at
$i = 11^\circ$ and $e = 20^\circ$, and repeat procedures in step 14 at
each gray step in succession:

15.1 2nd gray step
15.2 3rd gray step
15.3 4th gray step
15.4 5th gray step
15.5 6th gray step
15.6 7th gray step
15.7 8th gray step
15.8 9th gray step
15.9 10th gray step

16. Repeat measurements at 20' aperture.

17. Adjust the light source and photometer optic axes to the
gnomon at $i = 22^\circ$ and $e = 15^\circ$. Insure the azimuth is
$10^\circ$ in the horizontal plane. Set MgO value at 107.4 and
record. Record reflectance across the white area about 1 cm above top gray step with 6' aperture.

18. Adjust light source and photometer optic axes to the center of the top gray step at $i = 22^\circ$ and $\epsilon = 15^\circ$. Measure reflectance across center of gray step with 6' aperture.

19. Adjust light source and photometer optic axes sequentially in the center of each of the following gray steps at $i = 22^\circ$ and $\epsilon = 15^\circ$, and repeat procedures in step 18 at each gray step in succession:

   19.1 2nd gray step
   19.2 3rd gray step
   19.3 4th gray step
   19.4 5th gray step
   19.5 6th gray step
   19.6 7th gray step
   19.7 8th gray step
   19.8 9th gray step
   19.9 10th gray step

20. Repeat measurements at 20' aperture.

21. Adjust the light source and photometer optic axes to the gnomon at $i = 22^\circ$ and $\epsilon = 20^\circ$. Insure the azimuth angle and record. Record reflectance across the white area about 1 cm above top gray step with 6' aperture.

22. Adjust light source and photometer optic axes to the center of the top gray step at $i = 22^\circ$ and $\epsilon = 20^\circ$. Measure reflectance across center of gray step with 6' aperture.
23. Adjust light source and photometer optic axes sequentially in the center of each of the following gray steps at $i = 22^\circ$ and $e = 20^\circ$, and repeat procedures in step 22 at each gray step in succession:

23.1 2nd gray step
23.2 3rd gray step
23.3 4th gray step
23.4 5th gray step
23.5 6th gray step
23.6 7th gray step
23.7 8th gray step
23.8 9th gray step
23.9 10th gray step

24. Repeat measurements at 20' aperture.

25. Adjust the light source and photometer optic axes to the gnomon at $i = 34^\circ$ and $e = 20^\circ$. Insure the azimuth angle is 10° in the horizontal plane. Set MgO value at 107.2 and record. Position the photometer so gnomon is in focus. Record the value of the MgO and adjust as needed. Record reflectance across the white area about 1 cm above top gray step.

26. Adjust light source and photometer optic axes to the center of the top gray step at $i = 34^\circ$ and $e = 20^\circ$. Measure reflectance across center of gray step with 6' aperture.

27. Adjust light source and photometer optic axes sequentially in the center of each of the following gray steps at $i = 34^\circ$
and $\epsilon = 20^\circ$, and repeat procedures in step 26.

27.1 2nd gray step  
27.2 3rd gray step  
27.3 4th gray step  
27.4 5th gray step  
27.5 6th gray step  
27.6 7th gray step  
27.7 8th gray step  
27.8 9th gray step  
27.9 10th gray step

28. Repeat measurements at 20' aperture.

29. Adjust the light source and photometer optic axes to the gnomon at $i = 34^\circ$ and $\epsilon = 15^\circ$. Insure the azimuth angle is 10° in the horizontal plane. Set Mg0 value at 106.5 and record. Record reflectance across the white area about 1 cm above top gray step. Adjust light source and photometer optic axes to the center of the top gray step at $i = 34^\circ$ and $\epsilon = 15^\circ$. Measure reflectance across center of gray step with 6' aperture.

30. Adjust light source and photometer optic axes sequentially in the center of each of the following gray steps at $i = 34^\circ$ and $\epsilon = 15^\circ$, and measure reflectance across step.

30.1 2nd gray step  
30.2 3rd gray step  
30.3 4th gray step  
30.4 5th gray step
30.5 6th gray step  
30.6 7th gray step  
30.7 8th gray step  
30.8 9th gray step  
30.9 10th gray step  

31. Repeat measurements with 20' aperture.

32. Adjust light source and photometer optic axes to the gnomon at $i = 22^\circ$ and $e = 15^\circ$. Insure the azimuth angle is $10^\circ$. Set Mg0 value to 107.4 with 6' aperture and record. Move telephotometer to azimuth angle of $80^\circ$. Measure Mg0 if possible (should be about 85.2). Position the xenon light source to illuminate the white area of the gnomon about 1 cm above top gray step at incident angle of $22^\circ$.

33. Position the photometer optic axes to the white area about 1 cm above the top gray step at an emission angle of $15^\circ$. Insure photometer is set with 6' aperture and the azimuth angle is $80^\circ$. Record reflectance across the rod. This reading is the standard for all $80^\circ$ azimuth measurements. (If Mg0 can not be used.)

34. Adjust light source and photometer optic axes to the center of top gray step and measure reflectance with 6' and 20' apertures.

35. Adjust light source and photometer optic axes sequentially to each of the gray steps at $i = 22^\circ$ and $e = 15^\circ$, and measure reflectance with 6' and 20' apertures.
36. Adjust the light source and photometer optic axes to the white area about 1 cm above the top gray step at $i = 22^\circ$ and $e = 20^\circ$. Insure the azimuth angle is $80^\circ$. Record the reflectance across the white area, (if MgO can be used, set MgO value accordingly).

37. Adjust light source and photometer optic axes to the top gray step at $i = 22^\circ$ and $e = 20^\circ$. Measure reflectance across top gray step with 6' and 20' apertures.

38. Adjust light source and photometer optic axes sequentially to each of the gray steps at $i = 22^\circ$ and $e = 20^\circ$, and measure reflectance with 6' and 20' apertures.

39. Adjust the light source and photometer optic axes to the white area about 1 cm above the top gray step at $i = 22^\circ$ and $e = 25^\circ$. Insure the azimuth angle is $80^\circ$. Record reflectance across the white area, (if MgO can be used, set MgO value accordingly).

40. Adjust light source and photometer optic axes to the top gray step at $i = 22^\circ$ and $e = 25^\circ$. Measure reflectance across gray step.

41. Adjust light source and photometer optic axes sequentially to each of the gray steps at $i = 22^\circ$ and $e = 25^\circ$, and measure reflectance with 6' aperture.

42. Adjust the light source and photometer optic axes to the white area about 1 cm above the top gray step at $i = 11^\circ$ and $e = 25^\circ$. Insure the azimuth angle is $80^\circ$. Record
the reflectance across the white area 1 cm above the top gray step and adjust as needed.

43. Adjust light source and photometer optic axes to the top gray step at $i = 11^\circ$ and $\varepsilon = 25^\circ$. Measure reflectance across gray step with 6' aperture.

44. Adjust light source and photometer optic axes sequentially to each of the gray steps at $i = 11^\circ$ and $\varepsilon = 25^\circ$, and measure reflectance with 6' aperture.

45. Adjust the light source and photometer optic axes to the white area about 1 cm above the top gray step at $i = 11^\circ$ and $\varepsilon = 20^\circ$. Insure the azimuth angle is $80^\circ$. Record reflectance across the white area and adjust as needed.

46. Adjust light source and photometer optic axes to the top gray step at $i = 11^\circ$ and $\varepsilon = 20^\circ$. Measure reflectance across gray step with 6' and 20' apertures.

47. Adjust light source and photometer optic axes sequentially to each of the gray steps at $i = 11^\circ$ and $\varepsilon = 20^\circ$ and measure reflectance with 6' and 20' apertures.

48. Adjust the light source and photometer optic axes to the white area about 1 cm above the top gray step at $i = 11^\circ$ and $\varepsilon = 15^\circ$. Insure the azimuth angle is $80^\circ$. Record the reflectance across the white area.

49. Adjust light source and photometer optic axes to the top gray step at $i = 11^\circ$ and $\varepsilon = 15^\circ$. Measure reflectance across top gray step with 6' and 20' apertures.
50. Adjust light source and photometer optic axes sequentially to each of the gray steps at $i = 11^\circ$ and $\varepsilon = 15^\circ$, and measure reflectance with 6' and 20' apertures.

51. Adjust the light source and photometer optic axes to the white area about 1 cm above the top gray step at $i = 34^\circ$ and $\varepsilon = 15^\circ$. Insure the azimuth angle is $80^\circ$. Record the reflectance across the white area.

52. Adjust light source and photometer optic axes to the top gray step at $i = 34^\circ$ and $\varepsilon = 15^\circ$. Measure reflectance across top gray step with 6' and 20' apertures.

53. Adjust light source and photometer optic axes sequentially to each of the gray steps at $i = 34^\circ$ and $\varepsilon = 15^\circ$, and measure reflectance with 6' and 20' apertures.

54. Adjust the light source and photometer optic axes to the white area about 1 cm above the top gray step at $i = 34^\circ$ and $\varepsilon = 20^\circ$. Record reflectance across the white area and adjust as needed.

55. Adjust light source and photometer optic axes to the top gray step at $i = 34^\circ$ and $\varepsilon = 20^\circ$. Measure reflectance across gray step with 6' and 20' apertures.

56. Adjust light source and photometer optic axes sequentially to each of the gray steps at $i = 34^\circ$ and $\varepsilon = 20^\circ$ and measure reflectance with 6' and 20' apertures.

57. Adjust the light source and photometer optic axes to the white area about 1 cm above the top gray step at $i = 34^\circ$ and $\varepsilon = 25^\circ$. Insure the azimuth angle is $80^\circ$. Record
the reflectance across the white area 1 cm above the top gray step and adjust as needed.

58. Adjust light source and photometer optic axes to the top gray step at \( i = 34^\circ \) and \( \epsilon = 25^\circ \). Measure reflectance across gray step with 6' aperture.

59. Adjust light source and photometer optic axes sequentially to each of the gray steps at \( i = 34^\circ \) and \( \epsilon = 25^\circ \) and measure reflectance with 6' aperture.
Documentation

1. Take general pictures of instrument set up, personnel, and gnomon as record of calibration in color and black and white.

2. Take high resolution color and black and white pictures of the gnomon and photometric chart under full illumination to document condition of painted surfaces.

3. Photograph gnomon and photometric chart at 10° and 80° azimuth, 10 and 7' distances at proper height (4½ feet above gnomon plane) at \(i = 12°, 22°, \) and \(34°\) with flight cameras and flight film (same emulsion batch) with sensitometry record luminance of each step on chart and gnomon.
GSE Shutdown and Removal

1. Turn off xenon lamp and allow to cool.
2. Turn off DVM and DP.
3. Collect all data and package for hand carrying to Flagstaff, Arizona.
4. Carefully prepare gnomon for stowage keeping gloved hands off of the gray and color scales. Package the gnomon in its plastic tube. Return gnomon to quality control personnel or to the bond room.
5. Prepare GSE equipment for removal from test area.
6. Remove all GSE equipment from test area.
Appendix 2

Recorded Data

$E^* \cdot \text{APERTURE}$
Step #5

6° APER

I = 11°

A_2 = 90°

A_3 = 10°

R

25

15

20

30

20

A_1

15° 20° 25°

APOLLO 16 GALIMON 5/4/1002
Step #5

6 APER

I = 22°

A = 10°

A = 20°

A = 30°

A = 40°

APOLLO 10 CHROMAT MIX 100%
Step # 7

\( \theta = 15^\circ \)

\( \theta = 20^\circ \)

Apollo 16 Gnomon 5/21/1972
Step # 4 6° PER 2°2°

C = 15°

10 30 40 50

R1

10 30 40 60 80

Apollo 16 Gnomon 3/11/1972
Step # 8  6' APER  θ = 10°

E = 15°

E = 20°

Apollo 16 Cnomon 3/1/1972
Appendix 2

Recorded Data

20° APERTURE
Step #3  20 APER.  \[ I = 22^\circ \]

\[ \beta = 10^\circ \]

\[ H = 80^\circ \]

Apollo 16 Command S/1972
Step 29

\[ \alpha = 10^\circ \]

\[ \beta = 90^\circ \]

\[ I = 22^\circ \]

Apollo 16

[Signature]
Step # 1

I = 22°

E = 20°

E = 15°
Step # 3

\( \theta = 15^\circ \)

\( \gamma = 34^\circ \)

Apollo 16, Moon 3/4/1002