N72-18445

TM-72-2015-2

TECHNICAL MEMORANDUM

LUNAR SURFACE EVA PHOTOGRAPHY OF HADLEY RILLE— CONTRAST AS A CONSTRAINT

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TITLE- Lunar Surface EVA Photography of Hadley Rille -- Contrast as a Constraint

TM-72-2015-2

DATE- February 1, 1972

FILING CASE NO(S)- 340

AUTHOR(S)- H. W. Radin

FILING SUBJECT(S)-
(ASSIGNED BY AUTHOR(S)-

ABSTRACT

Prior to the Apollo 15 flight, preliminary plans for lunar surface EVA photography of Hadley Rille were examined from the standpoint of expected photographic contrast. Considerable variation in contrast was predicted, resulting in suggestions for specific targets either to be emphasized or ignored at various EVA photo stations. Apollo 15 surface EVA photography appears to have highly satisfactory contrast, generally confirming the predictions. The general technique can be applied to Apollo 16 and 17 photography.

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TECHNICAL MEMORANDUM

I. INTRODUCTION

An important objective of lunar surface EVA's I and II on Apollo 15 was close-up photography of Hadley Rille. The contrast of the pictures (and hence their quality) was expected to vary considerably with the relative position of an EVA station and a particular target; hence, photo contrast became a consideration in selection of both stations and targets. This memorandum discusses the selection of EVA stations to optimize the contrast of certain targets, and then turns the problem around to select the best targets from the stations finally chosen.

II. RILLE AND LIGHTING GEOMETRY -- GENERAL DISCUSSION

Hadley Rille is essentially a V-shaped ditch about 300-450 meters deep, with wall slopes averaging about 26° above the local horizontal. Its rim was believed to contain nearly vertical ledge-like portions displaying highly interesting rock outcroppings (confirmed by the EVA photography). These ledges were high priority areas for photographs.

The general geological characteristics of most parts of the rille were expected to be essentially the same; thus, a fair amount of flexibility appeared to exist in the selection of the actual target areas to be photographed.

For EVA I, during the period set aside for photography of the rille, the sun elevation was calculated to be about 20° and the sun azimuth about -10° (10° south of due east). This led to a few obvious conclusions:

1. Most of the eastern slope of the rille and much of the bottom of the western slope would be dark during EVA I.
2. Very good contrast could be expected for the portion of the rille southwest of the elbow (east of Bridge Crater), where the rille is oriented roughly east-west and the sunlight would be expected to just graze the northern slope.
3. Relatively poor contrast could be expected for the curved portion of the elbow, where the sun would strike the western slope nearly along its normal.
4. Modest contrast could be expected for the straight portion of the rille north of the elbow, where the relative azimuth of the sun would be about 45°, but (it turned out) only for a restricted range of camera positions.

For EVA III, the sun elevation would be about 38° and the sun azimuth about -22°. We concluded that:

1. Although the sun would be high enough in the sky to illuminate the eastern slope, the astronauts would be to the east of it, and thus unable to see it. They would also be too far away from the southern wall of the rille, opposite Bridge Crater.
2. The long, straight-line portion of the rille would have grazing sunlight, and thus very good contrast.

Thus, the major straight-line portion of the rille most easily observable on each EVA would have grazing sunlight, indicating a reasonable choice of EVA station locations. Unfortunately, it was unavoidable that this choice also precluded photography of the eastern and southern slopes of the rille.

III. PHOTO CONTRAST -- DETAILED DISCUSSION

A. Analysis

A general vector solution for the photometric angles g and α was obtained (Appendix A) and applied to the case of Hadley Rille. Appendix B contains a short computer program, using MATH, which solves these equations for g and α for the Apollo 15 Hadley Rille case. These results were then used in R. A. Troester's FORTRAN program to obtain predicted photometric contrast. The rest of this discussion will draw upon the results of these analyses.

B. Contrast, and a Rule of Thumb

The definition of contrast employed in the above analysis is arbitrary, but it has a long history -- it is the brightness contrast of a 10° slope relative to a fixed datum. Using this definition, we may decide subjectively that a contrast of 0.1 is approximately the boundary between poor and fair contrast. This corresponds roughly to the contrast seen in a vertical photograph of a mare area taken from lunar orbit, with a sun elevation of 45°. We may point out in passing that the sum $g+\alpha$ correlates fairly well with photometric contrast, over a wide range of values of the angles: thus, a contrast of 0.1 corresponds to $g+\alpha = 45°$, a contrast of 0.25 to $g+\alpha = 60°$, and a contrast of 0.5 to $g+\alpha = 75°$ (see Figures 1-3). This rule of thumb is useful for rough calculations of anticipated contrast. Vertical orbital photography (α=o) thus yields a contrast of 0.25 for a sun elevation of about 30° ($g = 60°$), and a contrast of 0.5 for a sun elevation of about 15° ($g = 75°$). These can be considered rough boundaries for fair-to-good and good-to-very good contrast, respectively.

C. Photo Contrast for EVA I Stations

The computer program in the Appendix has yielded a wide variety of data, but we shall discuss here only a few cases. In particular, we shall consider only the contrast of the vertical cliff near the rim of Hadley Rille.

If we consider an EVA I target point on the rim of the western slope of the rille, just north of the elbow, we may find the range of camera positions for which reasonable photographs would be obtainable. Such a point on the vertical face of the cliff has a normal whose declination is 90° and whose azimuth is 35°. If we choose a contrast of 0.1 as our lower limit, we may find the range of camera azimuths, subtended at the target, for which the target contrast exceeds this value. This range is plotted in Figure 4.

Notice from the Figure that there are two separate regions marked. The northern region was not relevant, since the astronauts were nowhere near this area during EVA I; also, during EVA III, the lighting changed and these conditions no longer applied. We may point out here, for information only, that this case corresponds to a region on the photometric function where the angle α is negative -- the contrast would be fair, the brightness would be low, and the astronaut would have the sun in his eyes.

The eastern region would result in fair contrast also, about 0.15 at best, but it did not contain any of the EVA stations. The best photography of this target point would have been obtained, approximately, from a spot on a line joining it with the landing site, suggesting that the astronaut should have driven along this line to the eastern rim, photographed the western rim, and then proceeded to station 1. The contrast which would have been obtained on a photograph taken from station 1 would have been about 0.05, or less than 1/3 as good.

Continuing around the elbow, we discover that for points on the western rim for which the rille normal azimuth is 0°, or -30°, there were no camera positions yielding a contrast as high as 0.1. A target point having a rille normal azimuth of -60° would be photographed from a wide range of camera azimuths at a contrast greater than 0.1 (see Figure 5). Stations 2 and 3 were expected to yield a contrast of about 0.17, which is about the best obtainable for this target point.

A target point on the northern rim of the east-west portion of the rille, just east of Bridge Crater, would have very good contrast (see Figure 6), greater than 0.5 from stations 2 or 3.

D. Photo Contrast for EVA III Stations

During EVA III the astronauts were scheduled to be near a kink in the rille having two distinct straight-line portions, one having a normal azimuth of about 35° and the other about 0°. The 35° azimuth portion is directly opposite station 9, and could be photographed from a wide range of camera positions. Station 9 would give very good contrast, greater than 0.5 (Figure 7).

The 0° azimuth portion (Figure 8) again yielded two optimum areas for camera location; as in Figure 4, the eastern region yielded better contrast (about 0.15 at station 9), greater brightness, and no glare.

E. Photo Contrast for EVA's I and III -- Target Selection

If we now regard the EVA stations as fixed, we may ask where the astronaut should point his camera for best photo contrast. Arrows are drawn in Figures 9-14 indicating a number of directions in which the astronaut would wish to take pictures, from each of six EVA stations; the small numbers near the arrows give the predicted photo contrast for the target points at the tips of the arrowheads. Thus, we concluded that station 1 would be a very poor place from which to take pictures (Figure 9); that stations 2 and 3 would yield fair to very good photographs of the lower part of the rille elbow near Bridge Crater (Figures 10 and 11); that stations 9 and 10 would yield very good pictures of the straight-line portion of the rille north of the elbow and south of the kink (Figures 12 and 13); that only station 11 would yield very good pictures of the straight portion north of the kink (Figure 14); and that no pictures better than fair would be obtained of the kink itself (Figures 12, 13 and 14).

IV. RESULTS AND CONCLUSIONS

Assumed regular geometry and geological uniformity of Hadley Rille made lunar surface EVA rille photography both more and less difficult than photography of most targets. The geological uniformity suggested that almost any portion of the rille would be satisfactory as a photo target; the regular geometry placed restrictions on the lighting contrast obtainable in some regions, and hence constrained the locations of targets and EVA stations.

In particular, the portions of the rille oriented close to a north-south direction were expected to yield poor photographs, while good to very good photographs were expected of other portions. Five of the six EVA stations (Nos. 2, 3, 9, 10, and 11) were expected to yield at least some very good pictures, while the sixth (No. 1) was expected to yield poor results. Station 1 was lated relocated for other reasons, and eliminated from the photographic plan.

Figures 15-18 are typical 500 mm photos obtained during the Apollo 15 EVA. Figure 15 shows the region of Hadley rille southwest of the elbow and east of Bridge Crater (predicted contrast shown in Figure 10). The contrast of this photo is near the lower end of the range predicted for this area, due to two factors: the direction of the rille is somewhat north of the approximate east-west orientation assumed for the portion near Bridge Crater, and the northern wall of the rille as shown in the picture does not have the pronounced ledge which was anticipated. Both of these factors influence the resulting contrast fairly strongly.

Figure 16 shows the west wall of the kink in the rille, as photographed from station 9a; the contrast is fair, as predicted in Figure 12. Figures 17 and 18 show parts of the rille north of the elbow, as photographed from station 9a; both have very good contrast, as predicted in Figure 12.

Acknowledgments

R. A. Troester's prior work and current helpfulness are gratefully acknowledged.

2015-HWR-ams H. W. Radin

Attachments

APPENDIX A

DERIVATION OF PHOTOMETRIC ANGLES

The relative brightness of points on the moon may be determined by use of the lunar photometric function, in terms of the phase angle g and luminance longitude α (defined below). Referring to Figure AI-1, let us first define three unit vectors originating at an arbitrary photographic target point on a wall of Hadley Rille: $\hat{c}$ is the unit vector to the camera, $\hat{s}$ is the unit vector to the sun, and $\hat{n}$ is the unit normal to the lunar surface at the target point.

The phase angle g is defined as the angle between the light source and the observer, subtended at the target; in this case, g is obtained from the vector equation

$$\cos g = \hat{s} \cdot \hat{c} \quad . \tag{1}$$

The luminance longitude is defined as the angle between the projection of the unit normal $\hat{n}$ into the phase plane, and the unit vector $\hat{c}$ to the observer. Let us first define a unit vector $\hat{p}$ which is perpendicular to the phase plane at the target point: Since $\hat{s}$ and $\hat{c}$ both lie in the phase plane, $\hat{s} \times \hat{c}$ is perpendicular to the plane, and thus

$$\hat{p} = \frac{\vec{p}}{p} = \frac{\hat{s} \times \hat{c}}{|\hat{s} \times \hat{c}|} = \frac{\hat{s} \times \hat{c}}{\sin g} \quad . \tag{2}$$

Then the projection of $\hat{n}$ which is perpendicular to the phase plane is given by $(\hat{n} \cdot \hat{p})\hat{p}$, and the projection $\vec{M}$ parallel to the phase plane is

$$\vec{M} = \hat{n} - (\hat{n} \cdot \hat{p})\hat{p} \quad . \tag{3}$$

Combining (2) and (3), we have

$$\begin{aligned} \vec{M} &= \hat{n} - \frac{\hat{n} \cdot \hat{s} \times \hat{c}}{\sin g} \, \hat{p} \\ &= \hat{n} - \left(\frac{\hat{n} \cdot \hat{s} \times \hat{c}}{\sin^2 g} \right) \hat{s} \times \hat{c} \quad . \end{aligned} \tag{4}$$

Then the luminance longitude α may be defined from

$$\cos \alpha = \frac{\hat{c} \cdot \vec{M}}{M} \quad . \tag{5}$$

Using (4),

$$\cos \alpha = \frac{1}{M} \left[\hat{c} \cdot \hat{n} - \frac{\hat{n} \cdot \hat{s} \times \hat{c}}{\sin^2 g} \, \hat{c} \cdot \hat{s} \times \hat{c} \right] \quad .$$

Since $\hat{c} \cdot \hat{s} \times \hat{c} = 0$, we have

$$\cos\alpha = \frac{\hat{c} \cdot \hat{n}}{M} \quad . \tag{6}$$

The problem thus becomes largely the calculation of the value of M. Let us define the three unit vectors we started with in terms of cartesian unit vectors:

$$\hat{s} = s_x\hat{i} + s_y\hat{j} + s_z\hat{k} \tag{7a}$$

$$\hat{c} = c_x\hat{i} + c_y\hat{j} + c_z\hat{k} \tag{7b}$$

$$\hat{n} = n_x\hat{i}\,\hat{} + n_y\hat{j} + n_z\hat{k} \tag{7c}$$

Then $\hat{s} \times \hat{c}$ is given by

$$\hat{s} \times \hat{c} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ s_x & s_y & s_z \\ c_x & c_y & c_z \end{vmatrix}$$

$$\begin{aligned} \hat{s} \times \hat{c} = {} & (s_y c_z - s_z c_y)\hat{i} + (s_z c_x - s_x c_z)\hat{j} \\ & + (s_x c_y - s_y c_x)\hat{k} \end{aligned} \tag{8}$$

This is more conveniently written

$$\hat{s} \times \hat{c} = a_x\hat{i} + a_y\hat{j} + a_z\hat{k} \qquad (9)$$

Then

$$\hat{n} \cdot \hat{s} \times \hat{c} = n_x a_x + n_y a_y + n_z a_z \qquad (10)$$

$$\frac{(\hat{n} \cdot \hat{s} \times \hat{c})(\hat{s} \times \hat{c})}{\sin^2 g} = \frac{n_x a_x + n_y a_y + n_z a_z}{\sin^2 g}(a_x\hat{i} + a_y\hat{j} + a_z\hat{k}) \qquad (11)$$

Defining, for convenience,

$$K = n_x a_x + n_y a_y + n_z a_z \qquad (12)$$

and using equation (4), we have

$$\vec{M} = (n_x - \frac{K}{\sin^2 g} a_x)\,\hat{i} + (n_y - \frac{K}{\sin^2 g} a_y)\,\hat{j} + (n_z - \frac{K}{\sin^2 g} a_z)\,\hat{k} \qquad (13)$$

Then

$$M = (M_x^2 + M_y^2 + M_z^2)^{1/2} \tag{14}$$

and

$$M = \left[(n_x - \frac{Ka_x}{\sin^2 g})^2 + (n_y - \frac{Ka_y}{\sin^2 g})^2 + (n_z - \frac{Ka_z}{\sin^2 g})^2 \right]^{1/2} \tag{15}$$

Finally, using (6),

$$\cos \alpha = \frac{n_x c_x + n_y c_y + n_z c_z}{\left[(n_x - \frac{Ka_x}{\sin^2 g})^2 + (n_y - \frac{Ka_y}{\sin^2 g})^2 + (n_z - \frac{Ka_z}{\sin^2 g})^2 \right]^{1/2}} \tag{16}$$

It is more convenient for the problem at hand to evaluate $\cos \alpha$ in terms of angles. Let us define the unit vector components, therefore, as follows:

$$s_x = \sin \phi_s \cos \theta_s \tag{17a}$$

$$s_y = \sin \phi_s \sin \theta_s \tag{17b}$$

$$s_z = \cos \phi_s \tag{17c}$$

$$c_x = \sin \phi_c \cos \theta_c \tag{18a}$$

$$c_y = \sin \phi_c \sin \theta_c \tag{18b}$$

$$c_z = \cos \phi_c \tag{18c}$$

$$n_x = \sin \phi_n \cos \theta_n \tag{19a}$$

$$n_y = \sin \phi_n \sin \theta_n \tag{19b}$$

$$n_z = \cos \phi_n \tag{19c}$$

The angles ϕ above are the polar declination angles of the unit vectors from the z axis (parallel to the lunar radius), and the angles θ are azimuth angles in the plane of the mean lunar surface, measured counterclockwise from due east.

In terms of the above angles, and using (9) and (1), we have

$$a_x = \sin \phi_s \sin \theta_s \cos \phi_c - \sin \phi_c \sin \theta_c \cos \phi_s \tag{20a}$$

$$a_y = \cos \phi_s \sin \phi_c \cos \theta_c - \sin \phi_s \cos \theta_s \cos \phi_c \tag{20b}$$

$$a_z = \sin \phi_s \cos \theta_s \sin \phi_c \sin \theta_c - \sin \phi_s \sin \theta_s \sin \phi_c \cos \theta_c \quad (20c)$$

and

$$\cos g = \sin \phi_s \cos \theta_s \sin \phi_c \cos \theta_c + \sin \phi_s \sin \theta_s \sin \phi_c \sin \theta_c + \cos \phi_s \cos \phi_c \quad (21)$$

Similarly, we may obtain an expression for $\cos \alpha$ in these terms by combining equations (16), (18), (19), (20), and (21). This exercise is left to the reader.

A comment is in order about the algebraic sign of α. The usual convention for the photometric function defines α as positive when the vector to the observer or camera is above the vector to the sun, and both are on the same side of the local surface normal as projected into the phase plane. These conditions are shown in Figure AI-2.

It is clear from the figure that the condition for positive α is met when the algebraic sign of $\hat{s} \times \hat{c}$ is the same as that of $\hat{c} \times \hat{m}$, and that α is negative otherwise. This condition in turn will obtain when $(\hat{s} \times \hat{c}) \cdot (\hat{c} \times \hat{m})$ is positive. In summary:

$$\alpha = +, \ \mathrm{sgn}\ (\hat{s} \times \hat{c}) = \mathrm{sgn}\ (\hat{c} \times \hat{m}), \ (\hat{s} \times \hat{c}) \cdot (\hat{c} \times \hat{m}) = +$$

$$\alpha = -, \ \mathrm{sgn}\ (\hat{s} \times \hat{c}) \neq \mathrm{sgn}\ (\hat{c} \times \hat{m}), \ (\hat{s} \times \hat{c}) \cdot (\hat{c} \times \hat{m}) = -$$

APPENDIX B

COMPUTER SOLUTION FOR g, α, AND CONTRAST

The solutions in Appendix A are easy to obtain, but formidable in extent. Accordingly, a simple computer program was developed to solve them, using MATH. This appears below, with the following definitions:

$$P(1) = \phi_s \qquad T(1) = \theta_s$$

$$P(2) = \phi_c \qquad T(2) = \theta_c$$

$$P(3) = \phi_n \qquad T(3) = \theta_n$$

$$V(1,1) = \sin P(1) \cos T(1) = \sin \phi_s \cos \theta_s = s_x$$

$$V(1,2) = \sin P(1) \sin T(1) = \sin \phi_s \sin \theta_s = s_y$$

$$V(1,3) = \cos P(1) = \cos \phi_s = s_z$$

and similarly for the vectors $\hat{c}$ and $\hat{n}$.

Also,

$$A(1) = a_x$$

$$A(2) = a_y$$

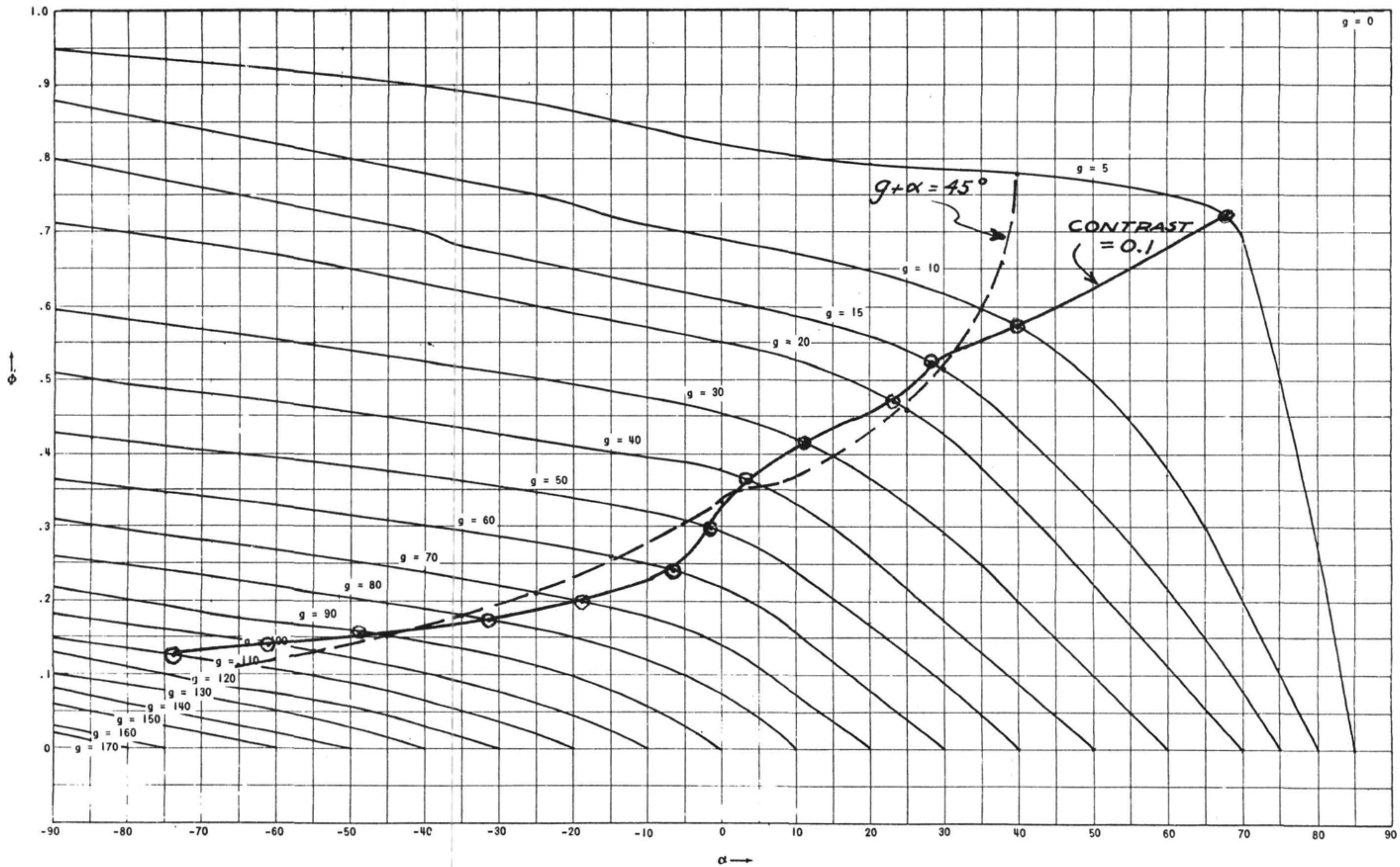
$$A(3) = a_z$$

and

$$Q = \cos g \quad , \quad x = g$$

$$R = \cos \alpha \quad , \quad y = \alpha$$

The results are saved and used as data input to R. A. Troester's Fortran program, which looks up tabulated values of the photometric function, interpolates between them, and calculates brightness and contrast (see Table AII-1).



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g = 5
g = 10
g = 15
g = 20
g = 30
g = 40
g = 50
g = 60
g = 70
g = 80
g = 90
g = 100
g = 110
g = 120
g = 130
g = 140
g = 150
g = 160
g = 170
g+α = 45°
CONTRAST = 0.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
φ
-90
-80
-70
-60
-50
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-30
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-10
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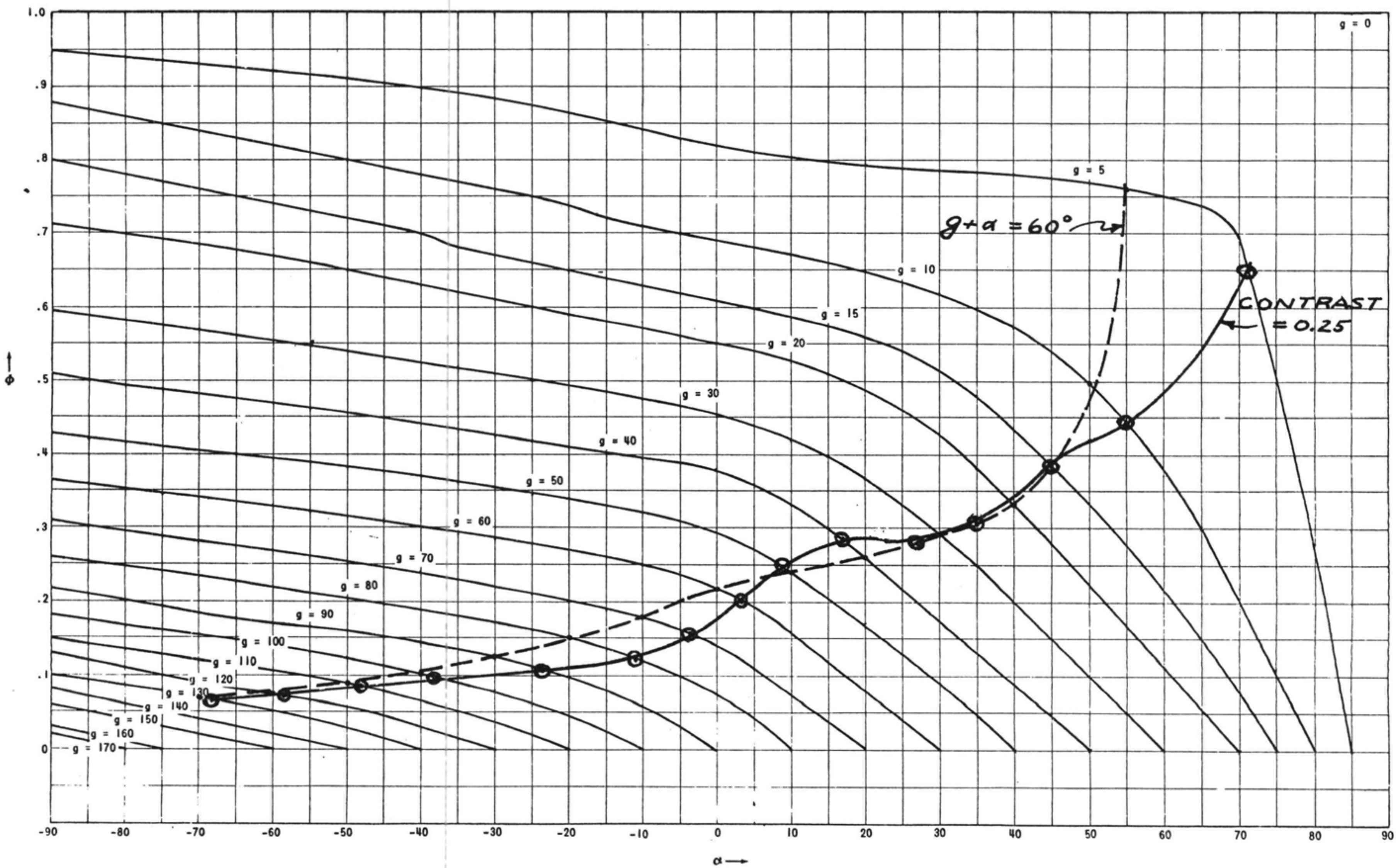
α

Figure 1



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g = 5
g = 10
g = 15
g = 20
g = 30
g = 40
g = 50
g = 60
g = 70
g = 80
g = 90
g = 100
g = 110
g = 120
g = 130
g = 140
g = 150
g = 160
g = 170
g + a = 60°
CONTRAST = 0.25
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
φ
-90
-80
-70
-60
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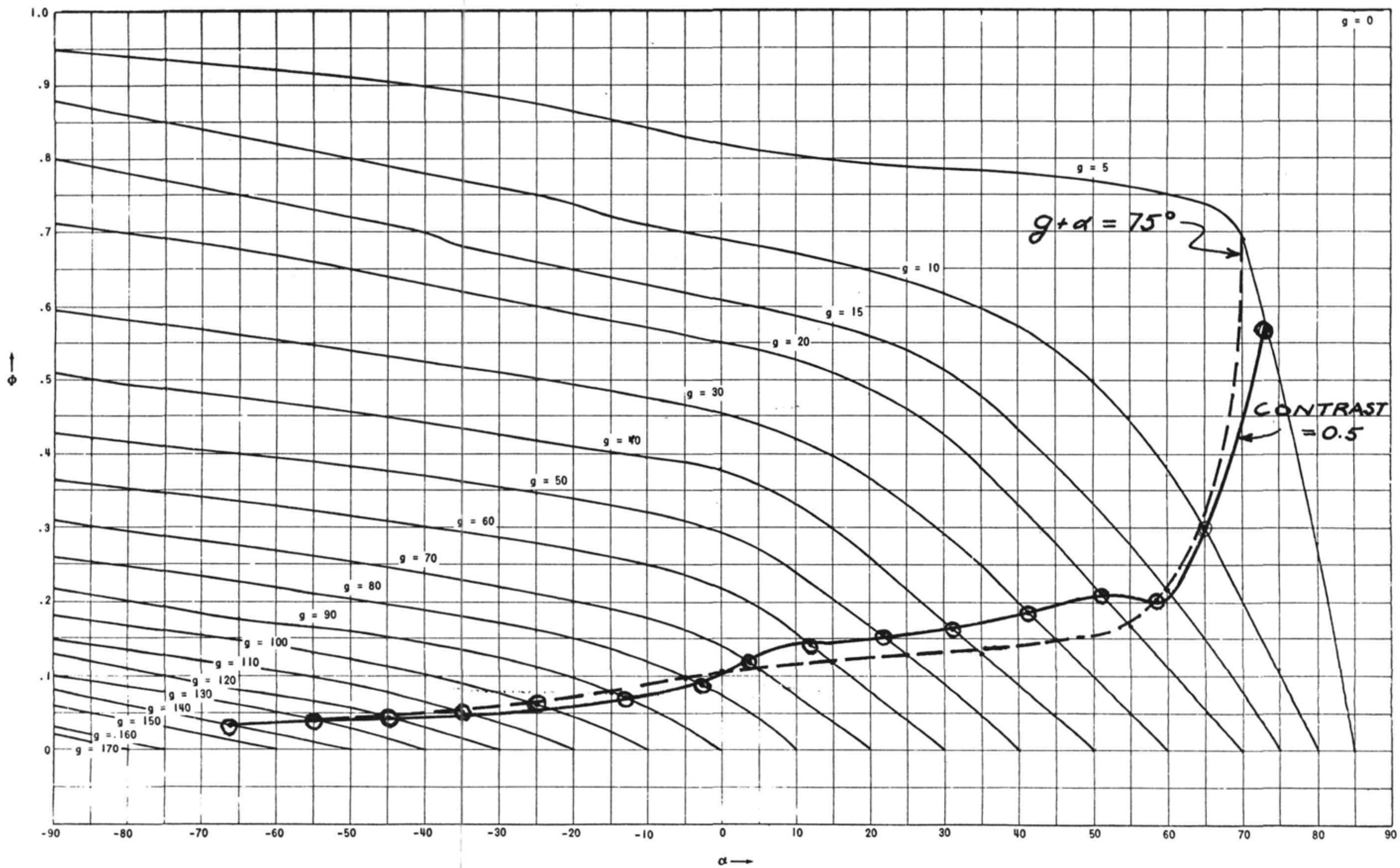
Figure 2



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g = 15
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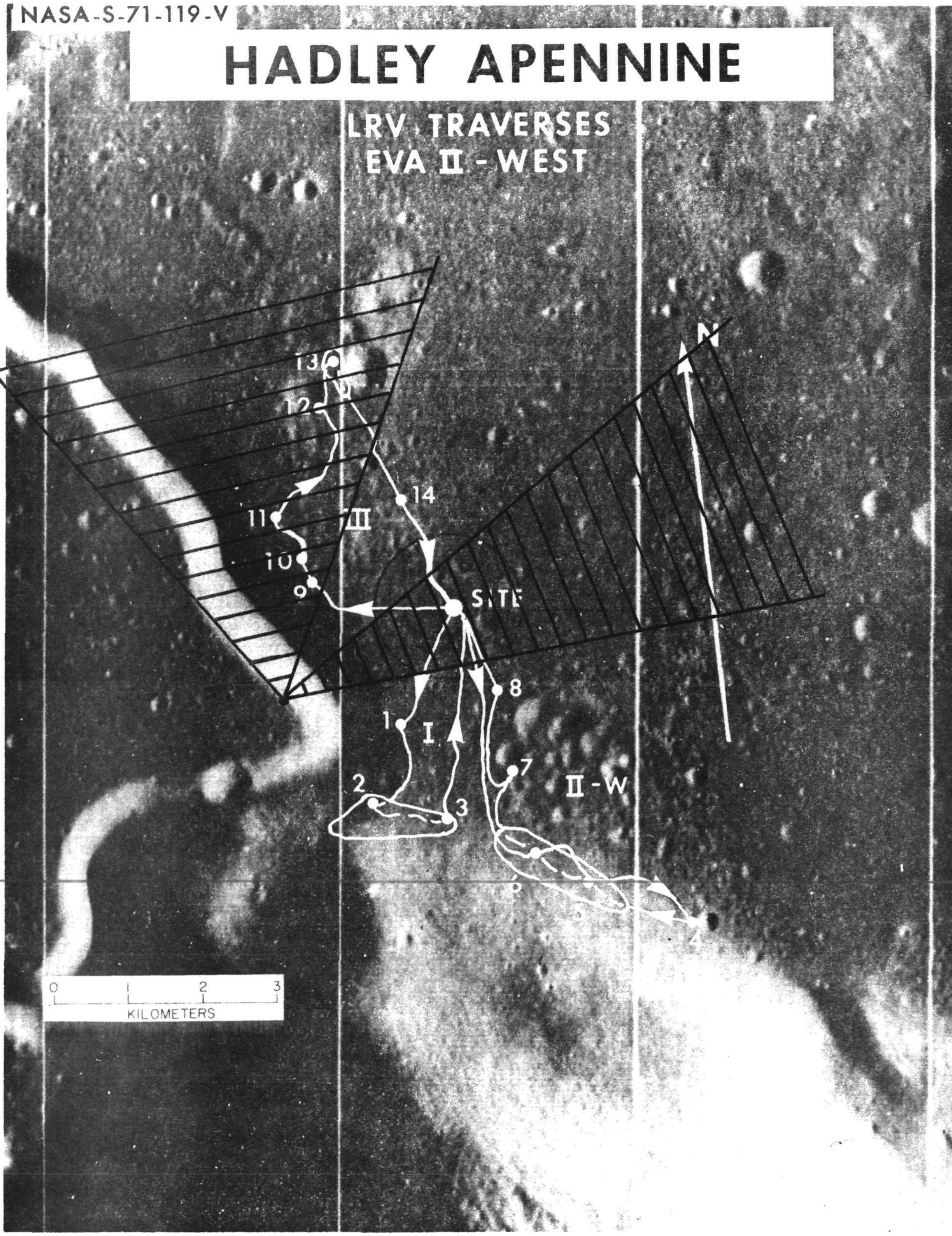
g = 50
g = 60
g = 70
g = 80
g = 90
g = 100
g = 110
g = 120
g = 130
g = 140
g = 150
g = .160
g = 170
g+α = 75°
CONTRAST = 0.5
Φ
α

Figure 3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HADLEY APENNINE
LRV TRAVERSES
EVA II - WEST
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KILOMETERS

Figure 4

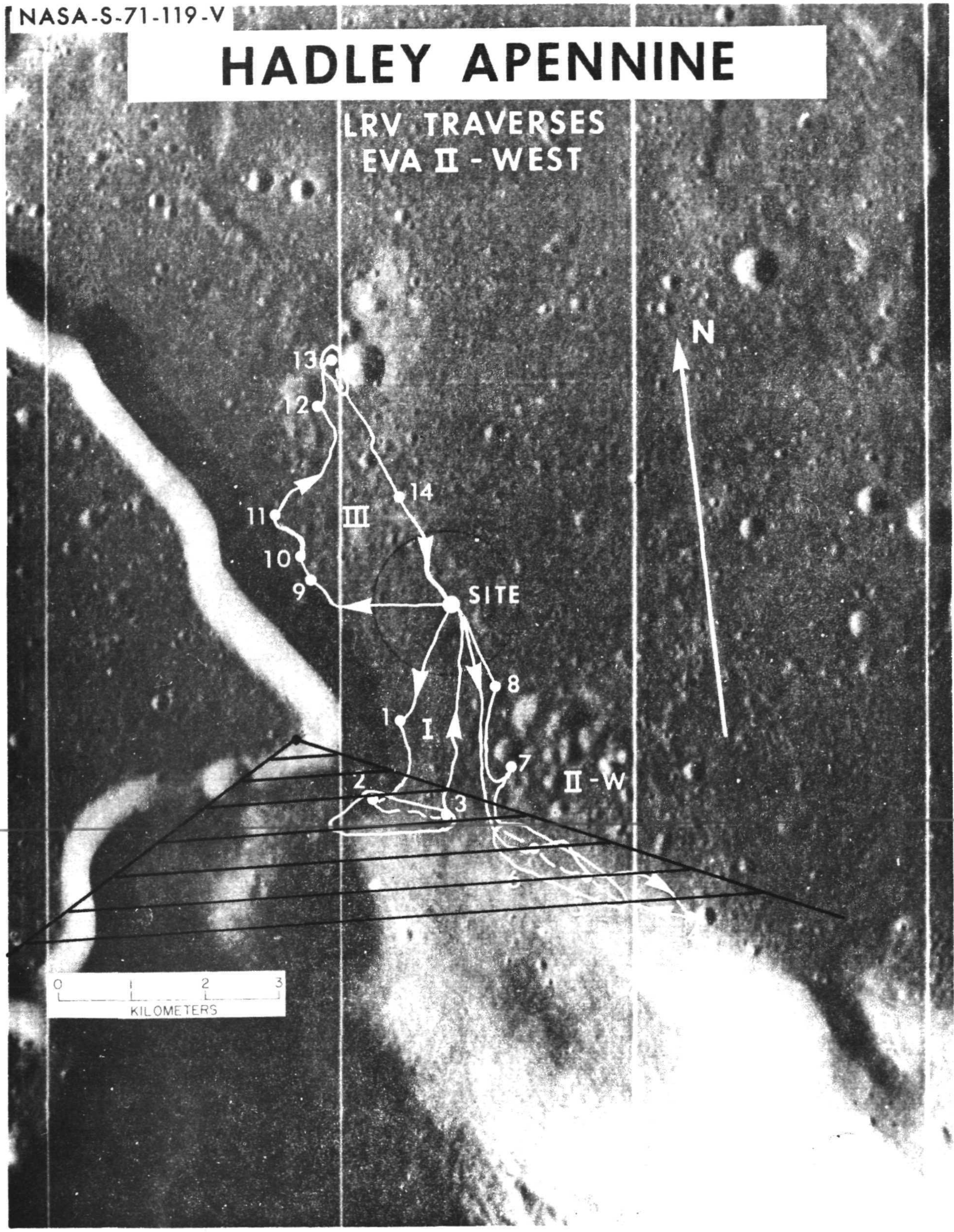
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Figure 5

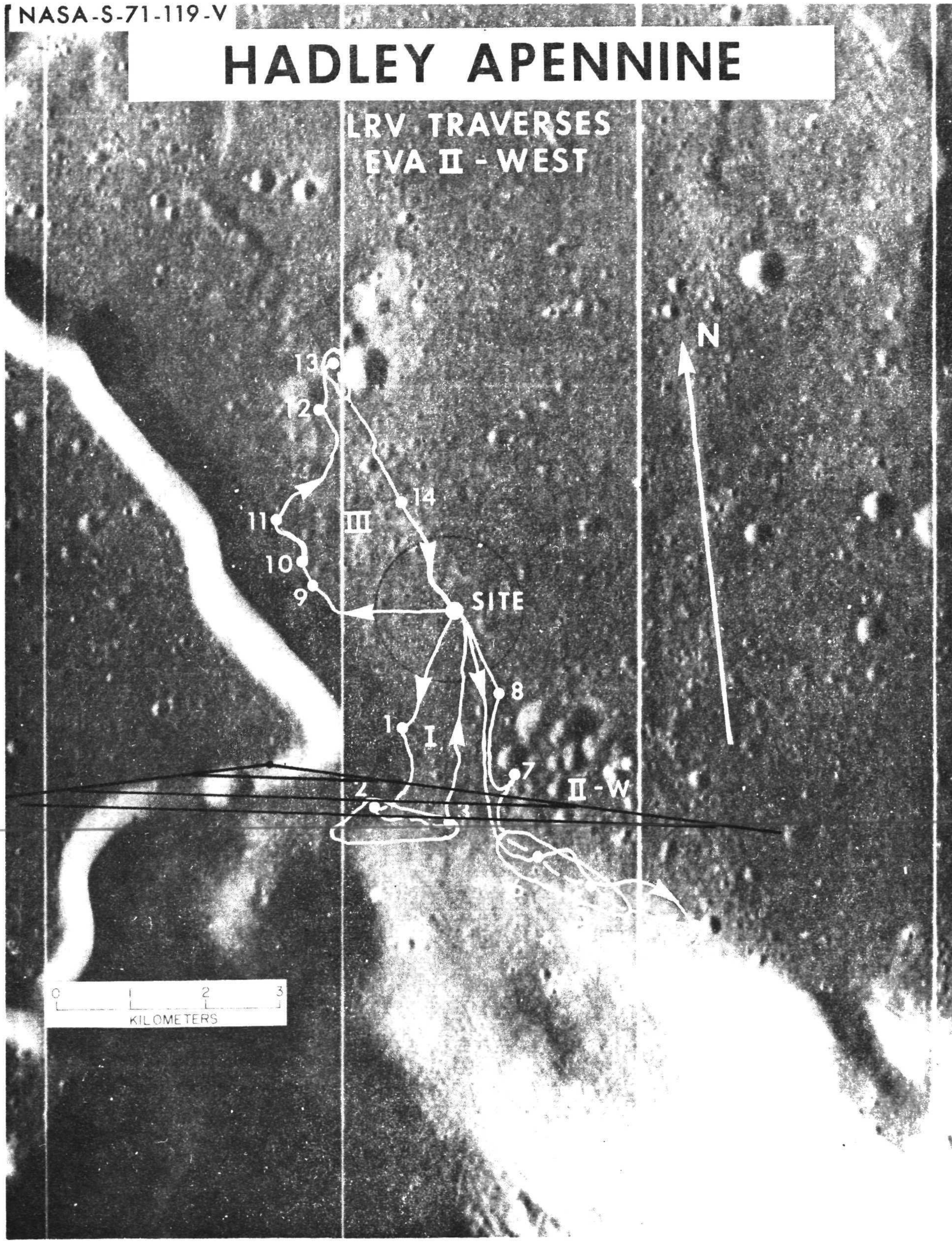

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Figure 6

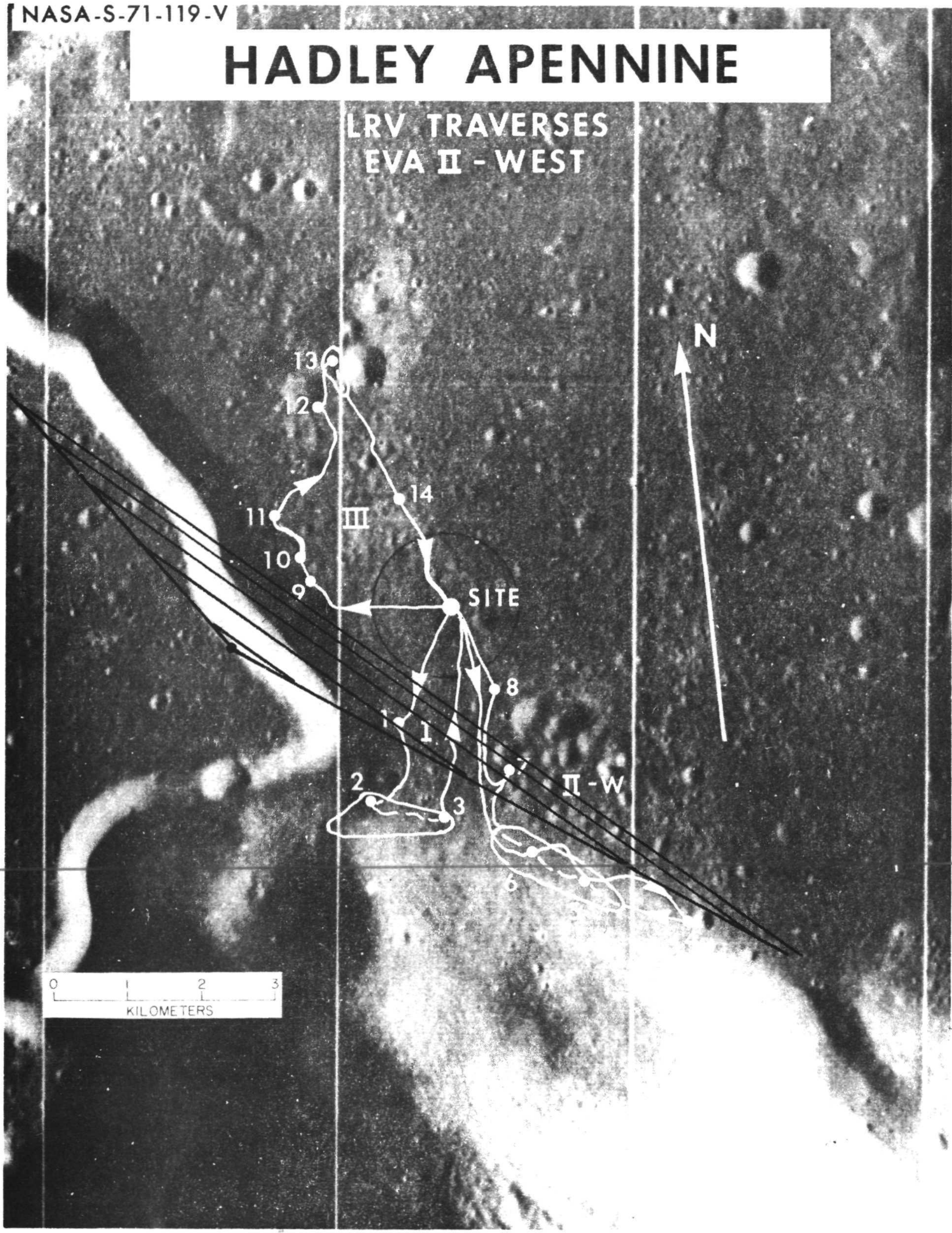
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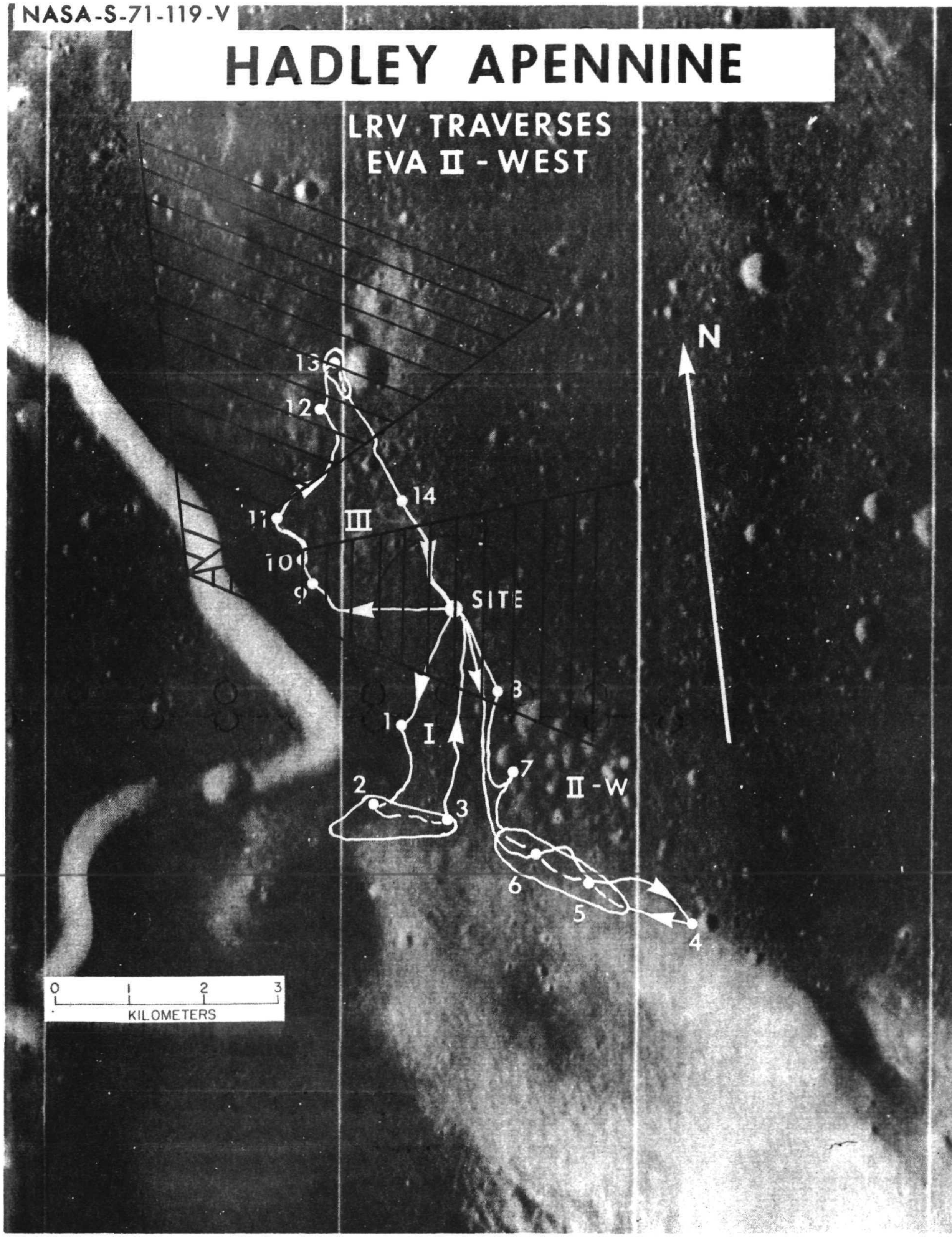
Figure 7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LRV TRAVERSES
EVA II - WEST
N
13
12
14
11
III
10
9
SITE
8
1
I
7
2
3
II-W
6
5
4
0
1
2
3
KILOMETERS

Figure 8

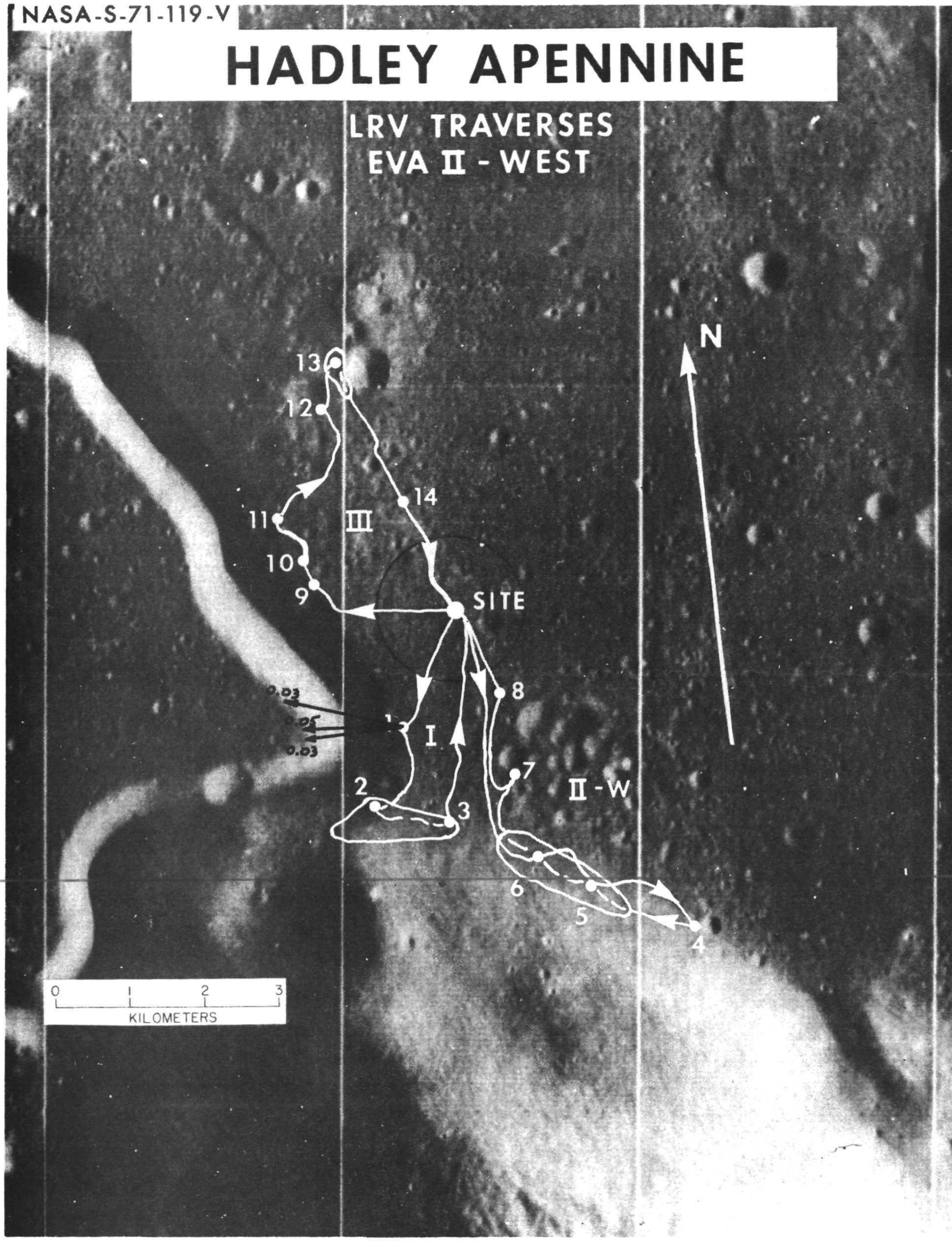

NASA-S-71-119-V
HADLEY APENNINE
LRV TRAVERSES
EVA II - WEST
N
13
12
14
11
III
10
9
SITE
8
0.03
0.05
0.03
I
7
II-W
2
3
6
5
4
0
1
2
3
KILOMETERS

Figure 9

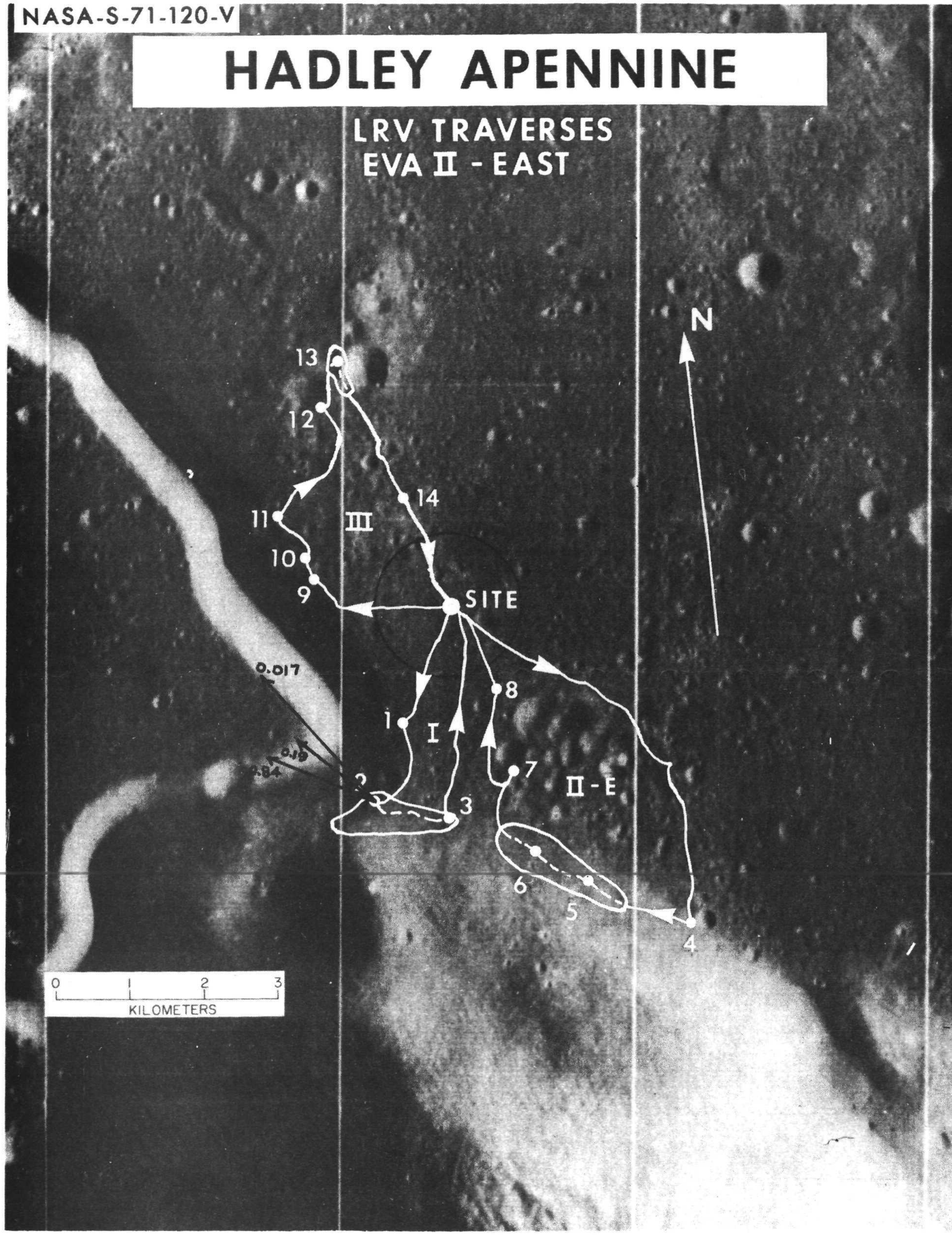

NASA-S-71-120-V
HADLEY APENNINE
LRV TRAVERSES
EVA II - EAST
N
13
12
14
11
III
10
9
SITE
0.017
1
I
8
7
0.19
0.84
2
3
II - E
6
5
4
0 1 2 3
KILOMETERS

Figure 10

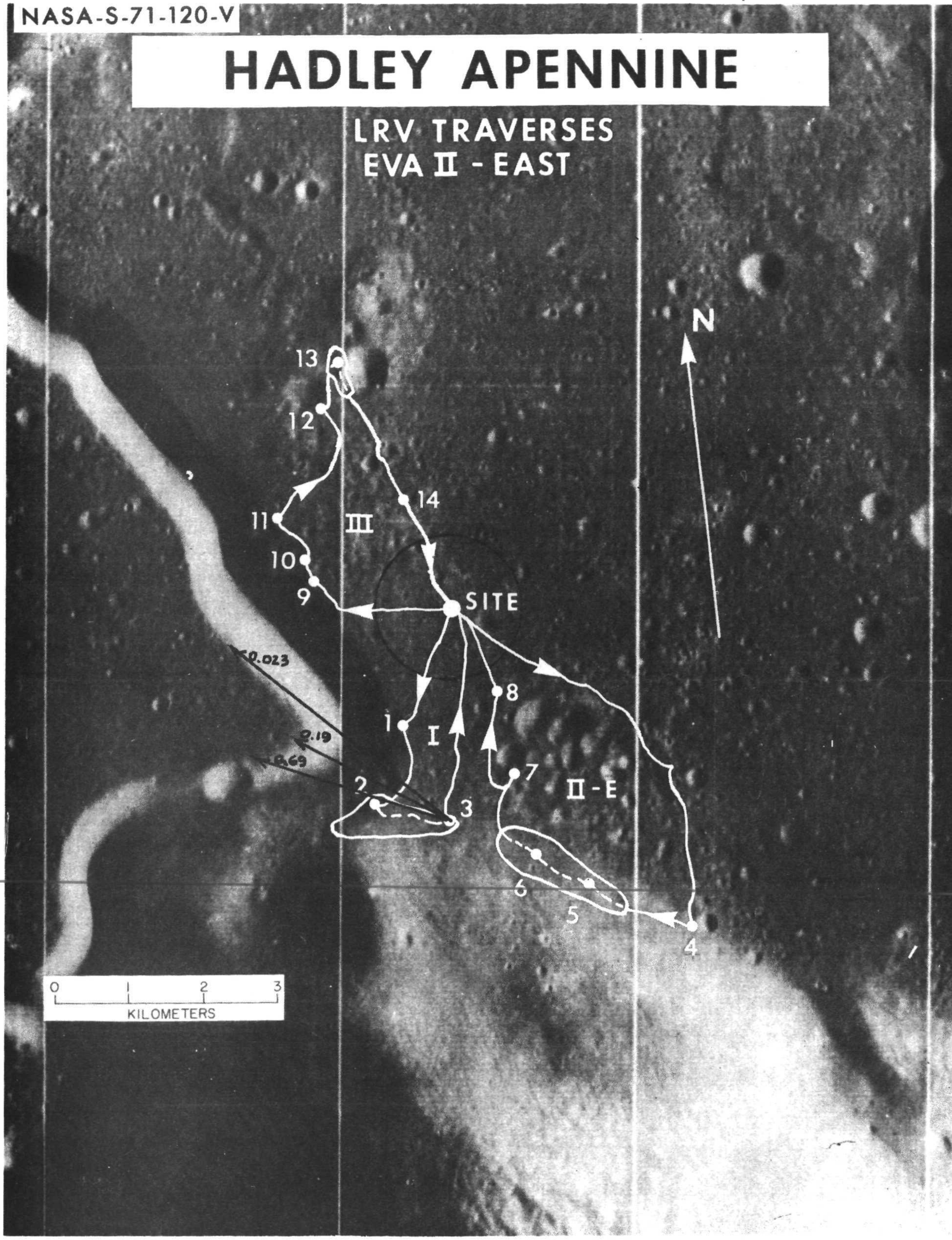

NASA-S-71-120-V
HADLEY APENNINE
LRV TRAVERSES
EVA II - EAST
N
13
12
14
11
III
10
9
SITE
0.023
8
1
I
0.19
0.69
7
II-E
2
3
6
5
4
0 1 2 3
KILOMETERS

Figure 11

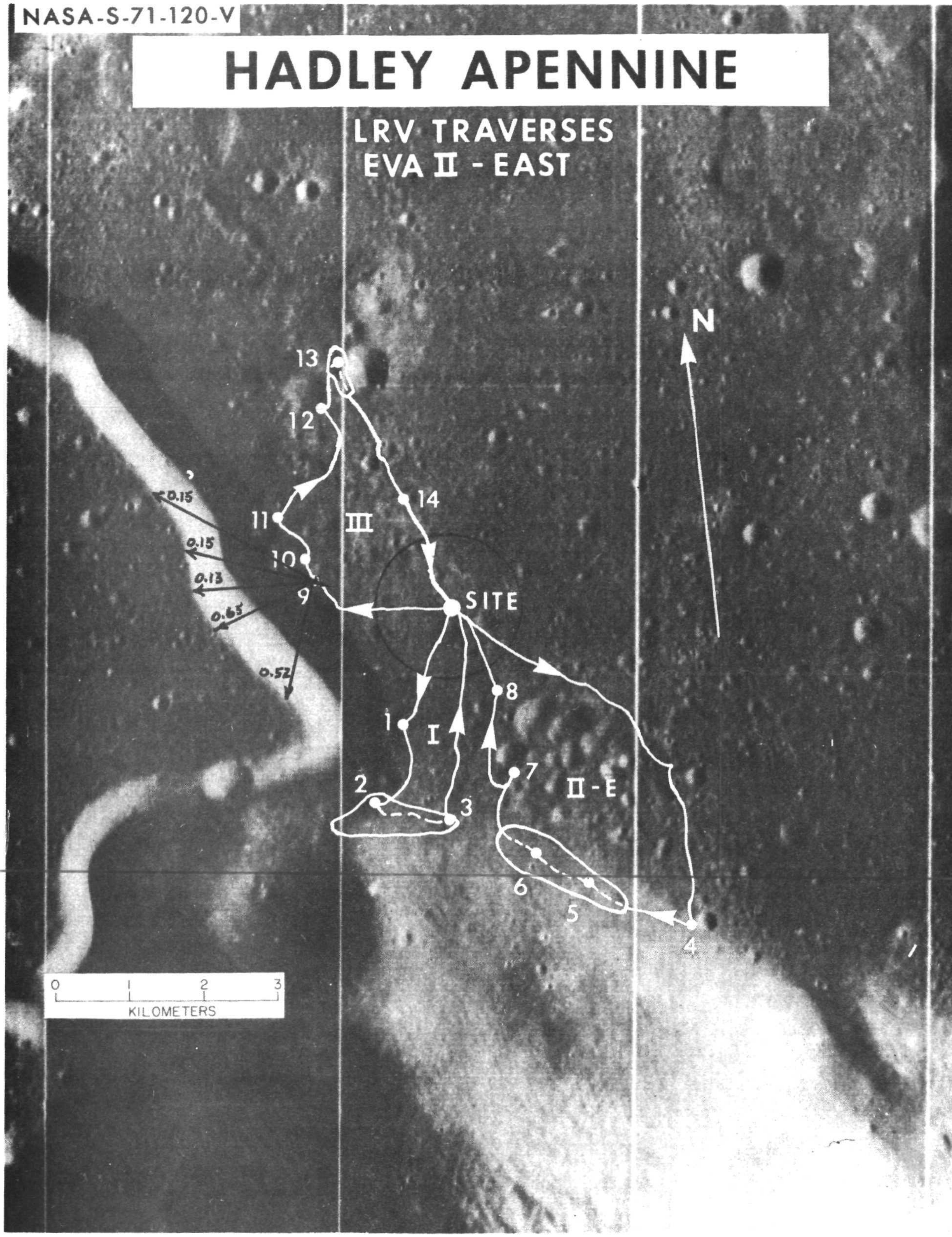

NASA-S-71-120-V
HADLEY APENNINE
LRV TRAVERSES
EVA II - EAST
N
13
12
14
11
III
10
9
SITE
1
I
8
2
3
7
II-E
6
5
4
0.15
0.15
0.13
0.65
0.52
0 1 2 3
KILOMETERS

Figure 12

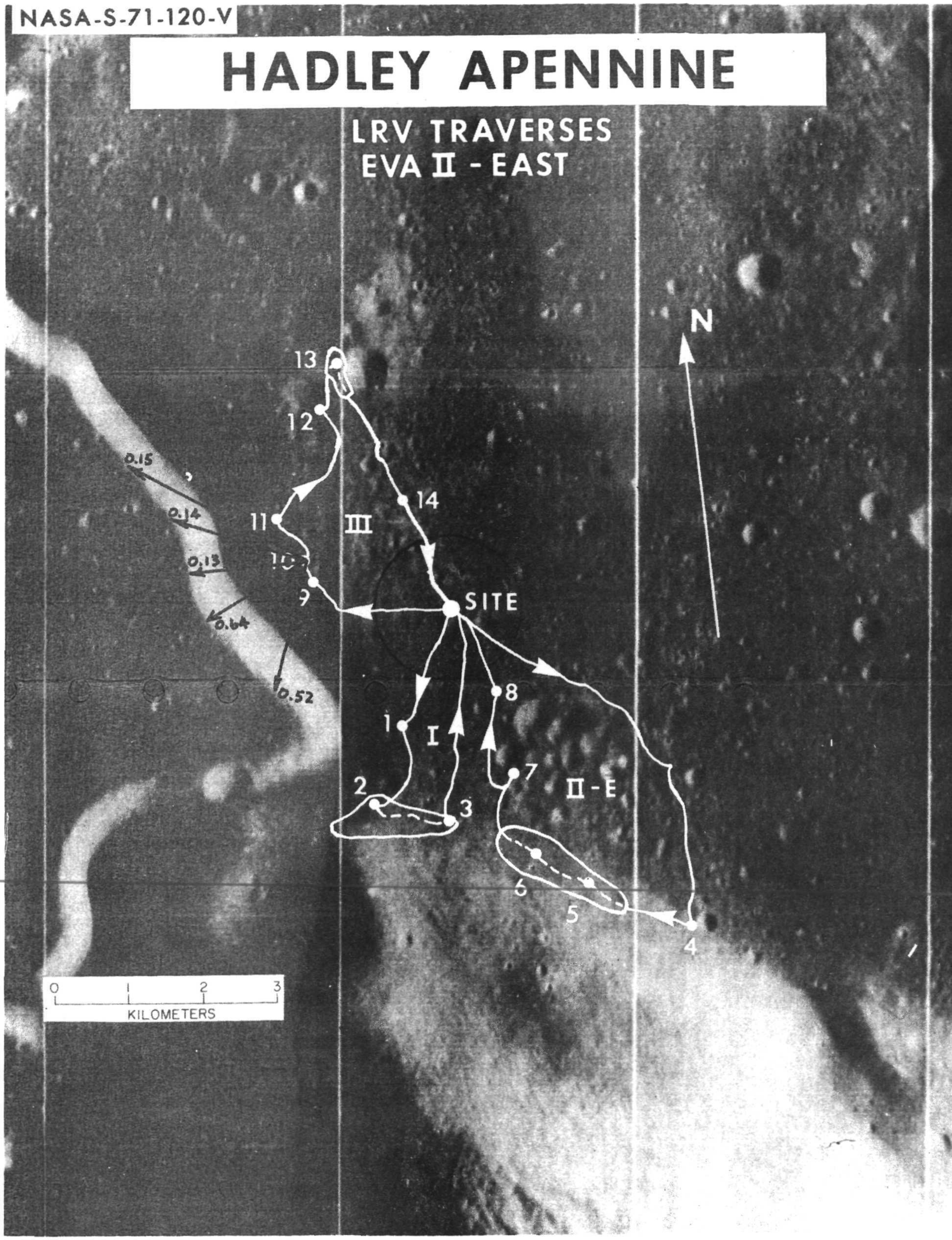

NASA-S-71-120-V
HADLEY APENNINE
LRV TRAVERSES
EVA II - EAST
N
SITE
I
II - E
III
1
2
3
4
5
6
7
8
9
11
12
13
14
0.15
0.14
0.13
0.64
0.52
0 1 2 3
KILOMETERS

Figure 13

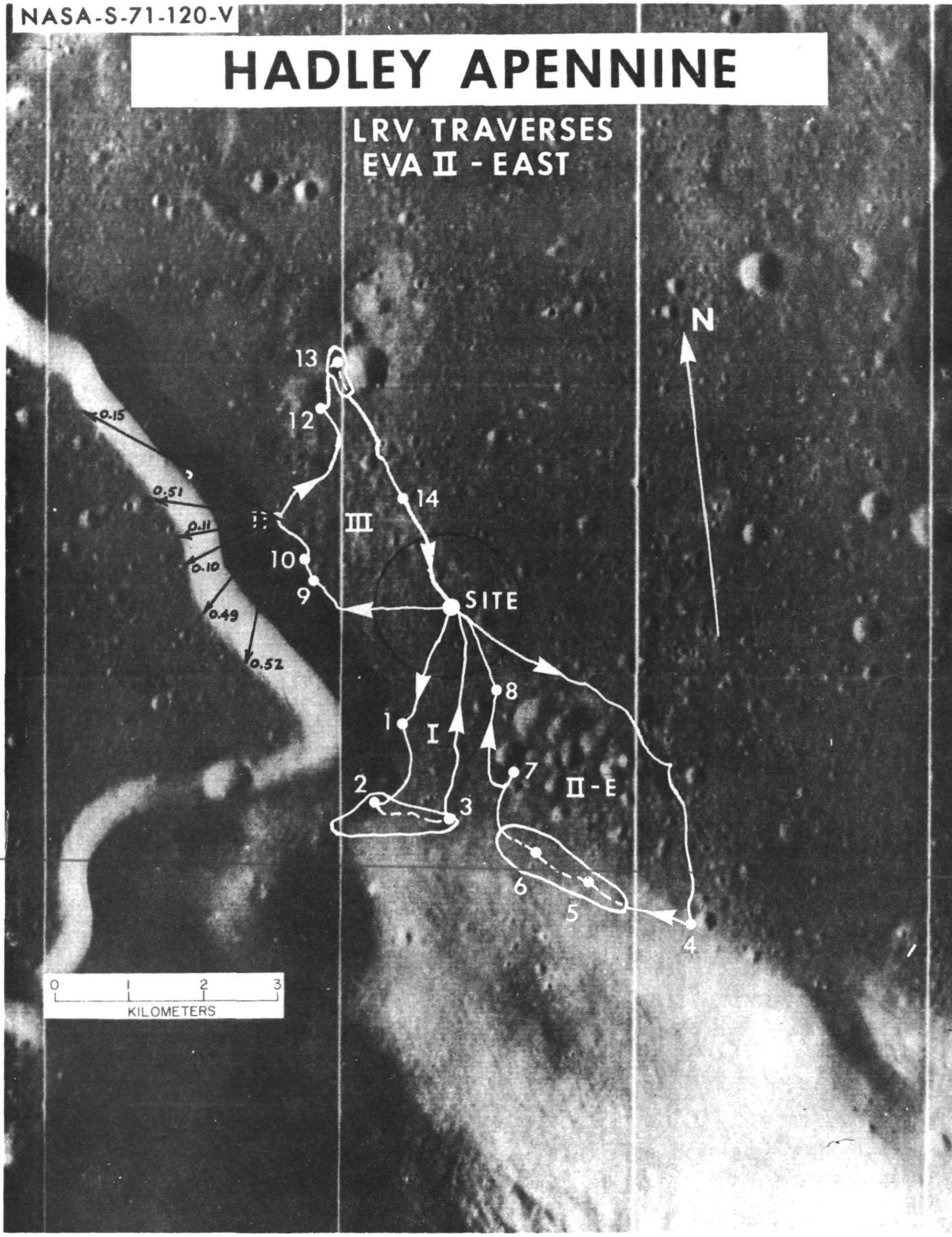

NASA-S-71-120-V
HADLEY APENNINE
LRV TRAVERSES
EVA II - EAST
N
13
12
14
III
10
9
SITE
0.15
0.51
0.11
0.10
0.49
0.52
8
1
I
7
II-E
2
3
6
5
4
0 1 2 3
KILOMETERS

Figure 14

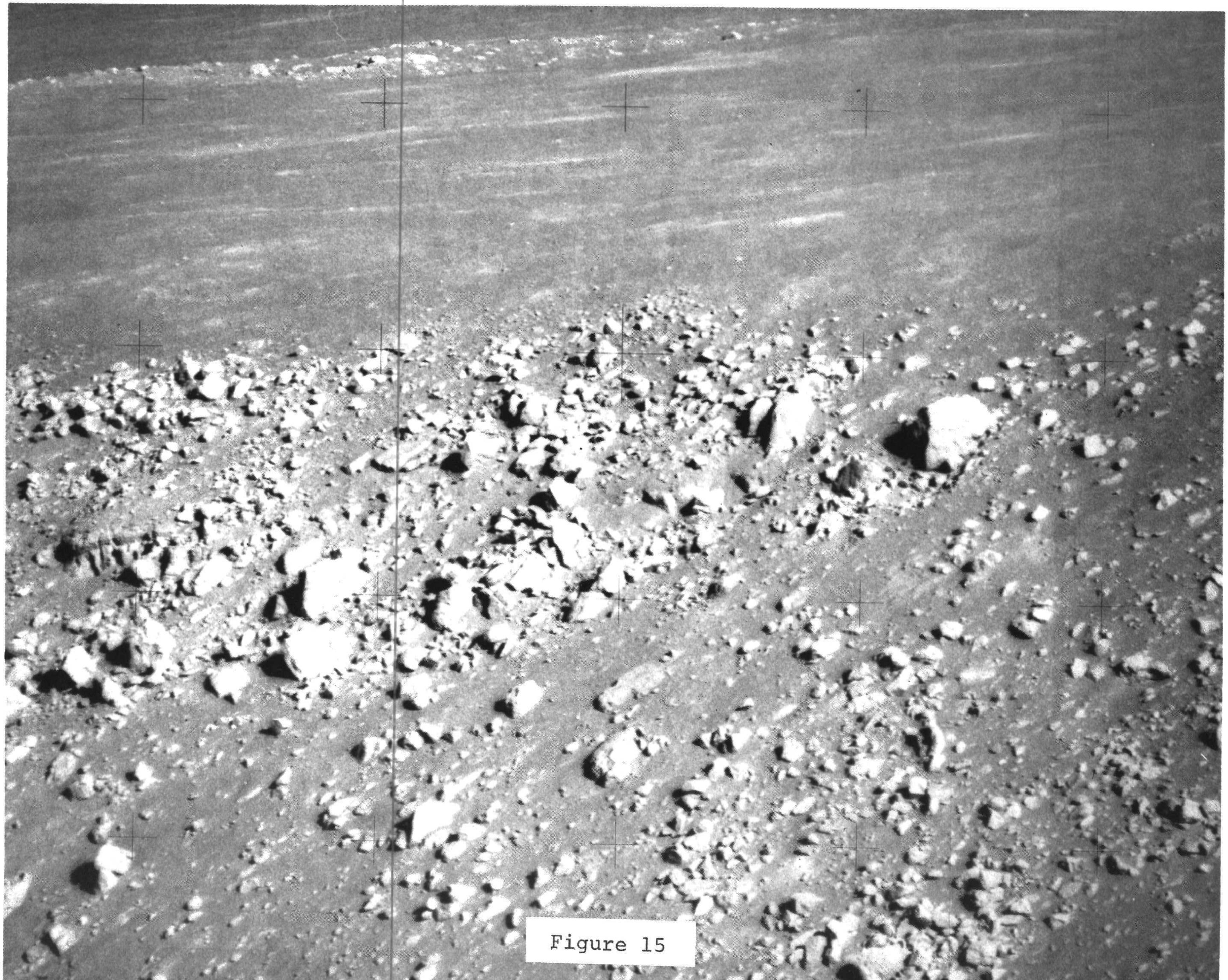


Figure 15

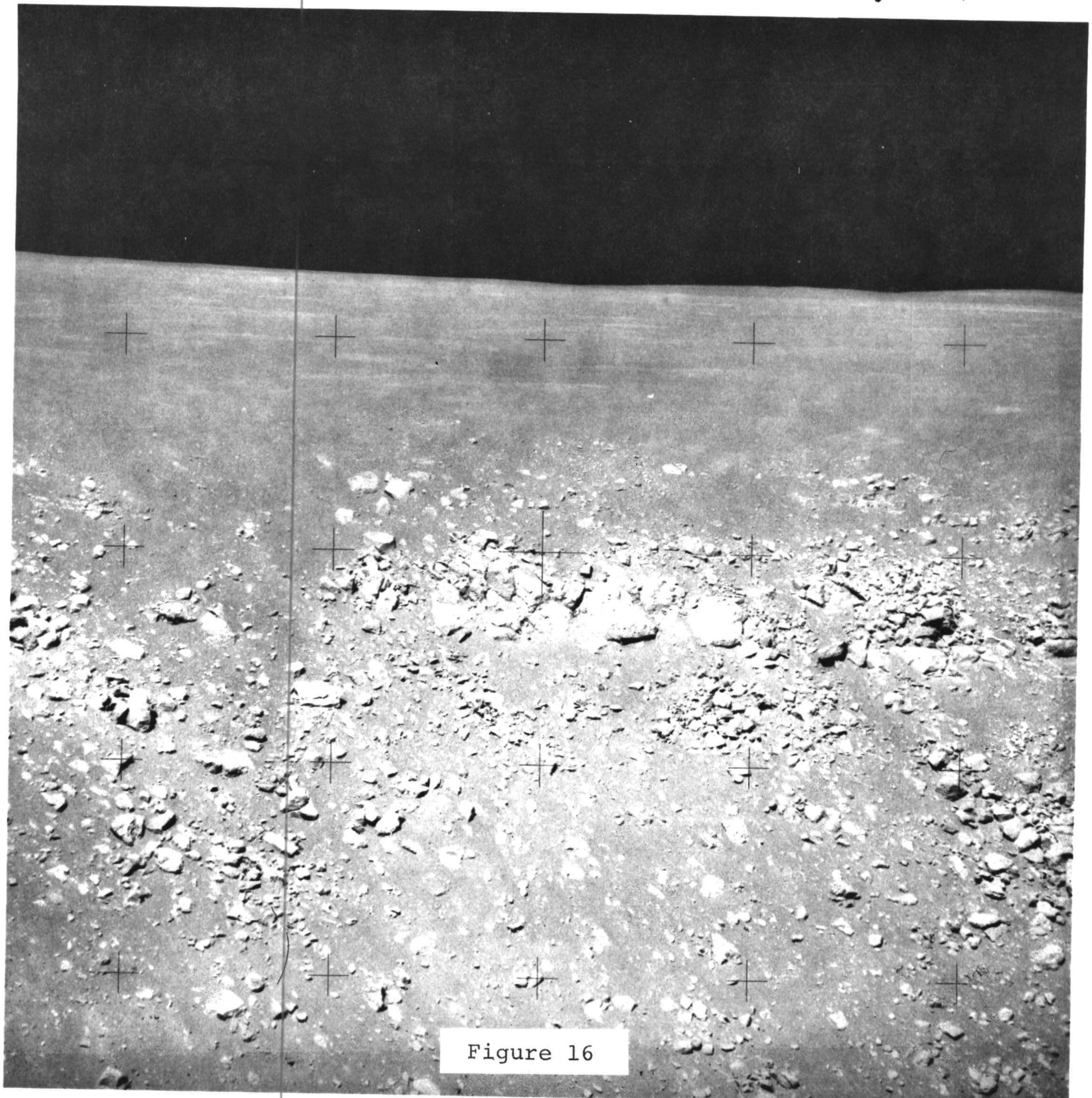


Figure 16

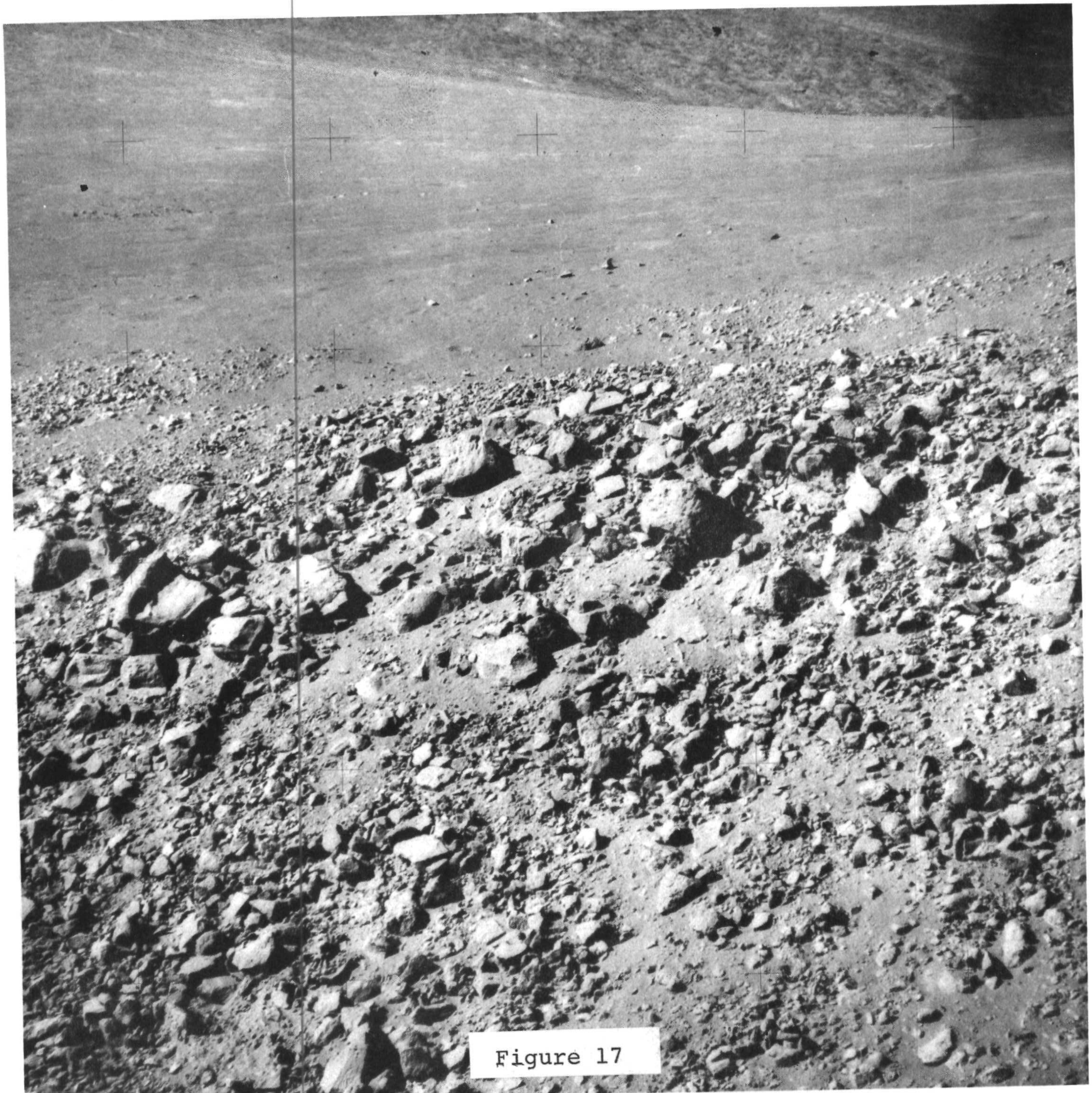


Figure 17

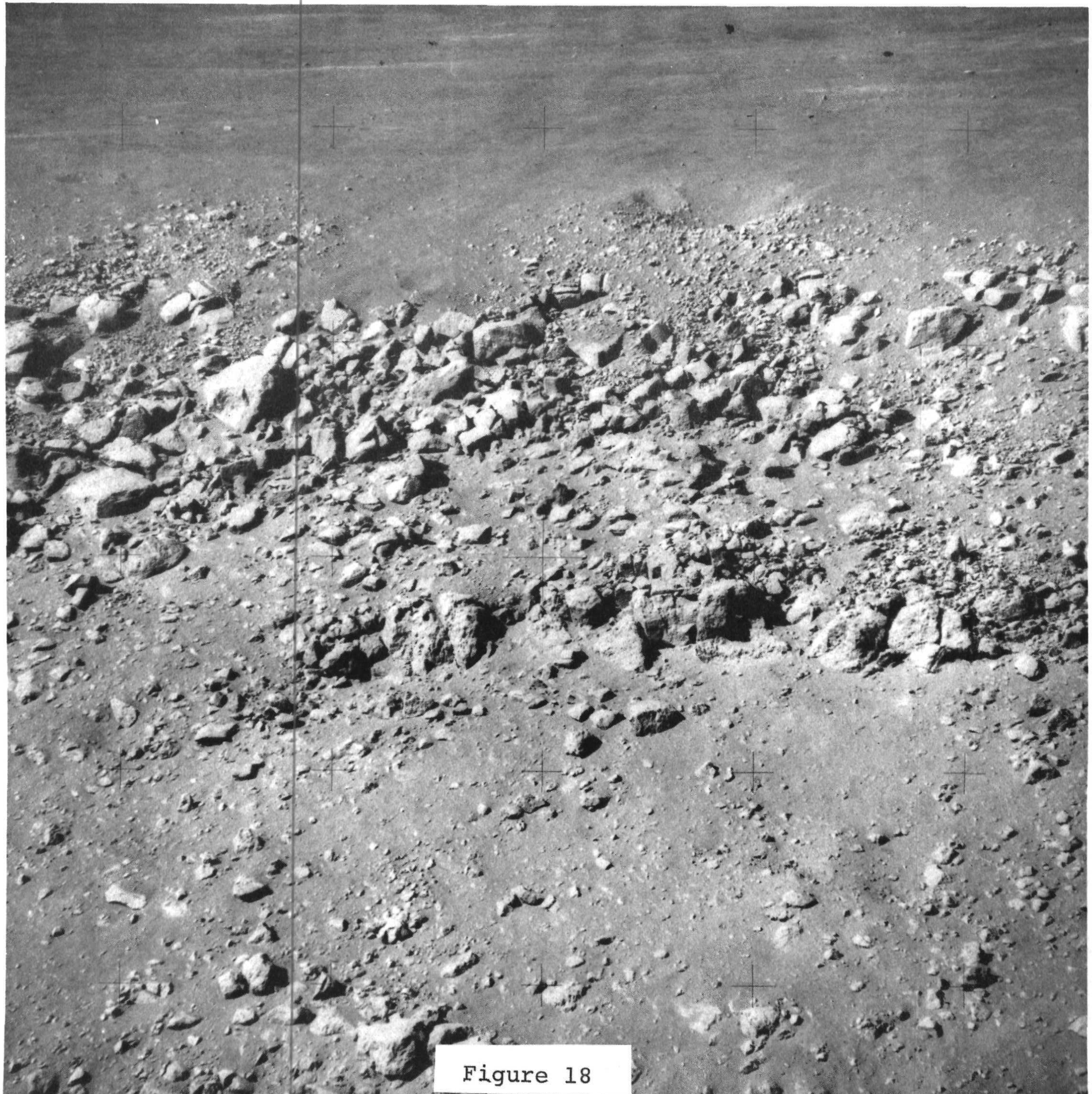


Figure 18

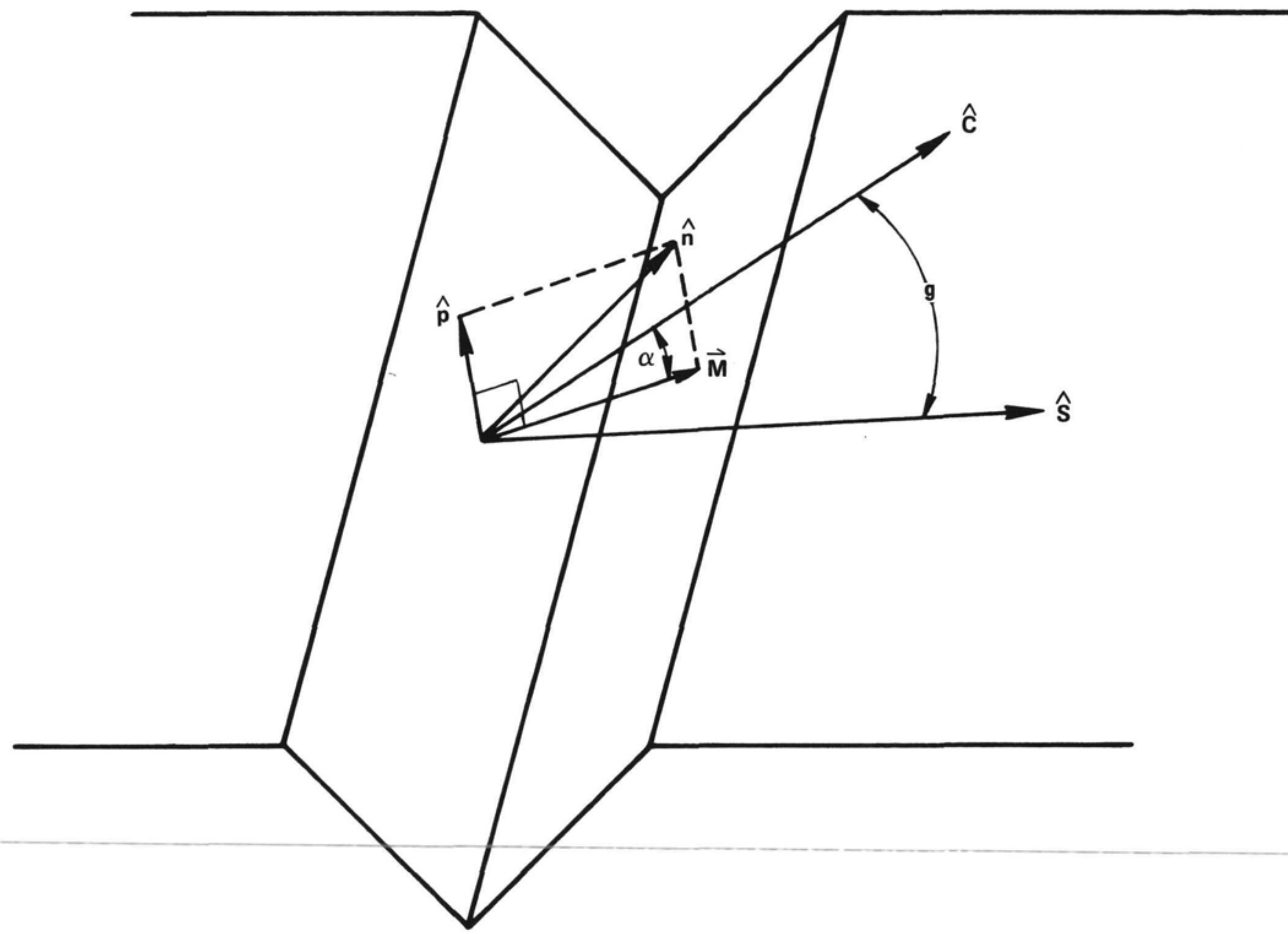
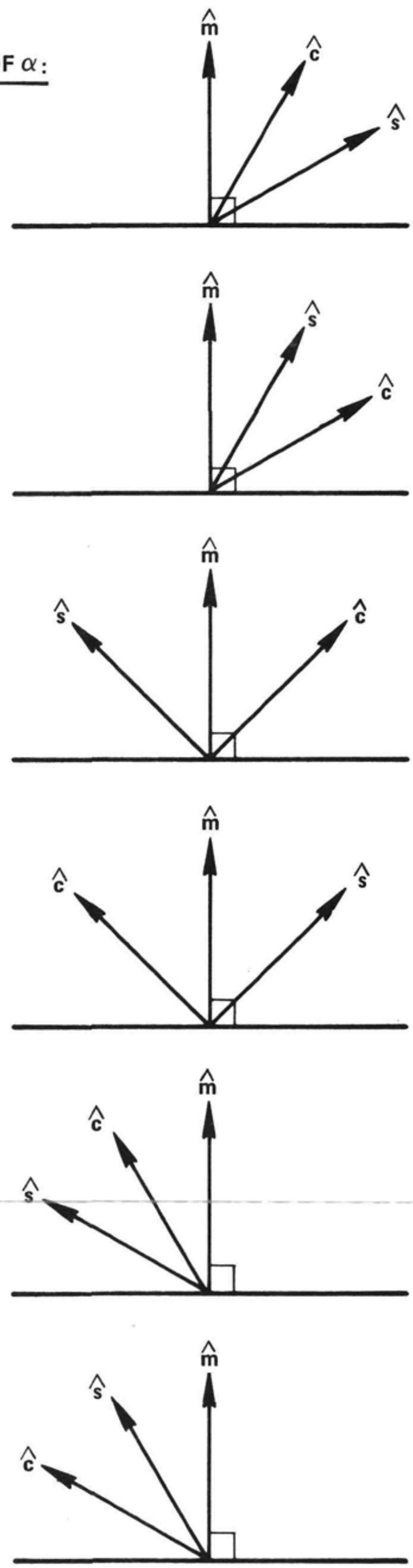


FIGURE AI-1 - GEOMETRY OF PHASE PLANE

SIGN OF α:



SIGN OF α			
+	$\hat{s} \times \hat{c} = +$	$\hat{c} \times \hat{m} = +$	$\hat{s} \times \hat{m} = +$
−	$\hat{s} \times \hat{c} = -$	$\hat{c} \times \hat{m} = +$	$\hat{s} \times \hat{m} = +$
−	$\hat{s} \times \hat{c} = -$	$\hat{c} \times \hat{m} = +$	$\hat{s} \times \hat{m} = -$
−	$\hat{s} \times \hat{c} = +$	$\hat{c} \times \hat{m} = -$	$\hat{s} \times \hat{m} +$
+	$\hat{s} \times \hat{c} = -$	$\hat{c} \times \hat{m} = -$	$\hat{s} \times \hat{m} -$
−	$\hat{s} \times \hat{c} = +$	$\hat{c} \times \hat{m} = -$	$\hat{s} \times \hat{m} = -$

$\alpha = +$ WHEN SGN $(\hat{s} \times \hat{c})$ = SGN $(\hat{c} \times \hat{m})$

$\alpha = -$ OTHERWISE

FIGURE AI-2 - DETERMINATION OF SIGN OF α

Table AII-1

```
1.10    USE FILE PHOTO.
1.31    SET P(2) = N(7).
1.32    SET T(2) = N(8).
1.33    SET P(3) = N(10).
1.4     SET P(1) = 52.
1.43    SET T(1) = -22.
1.45    SET T(3) = N(9).
1.5     DO PART 4 FOR I = 1(1)3.
1.9     TO PART 2.

2.23    SET A(1) = V(1,2)*V(2,3) - V(1,3)*V(2,2).
2.24    SET A(2) = V(1,3)*V(2,1) - V(1,1)*V(2,3).
2.25    SET A(3) = V(1,1)*V(2,2) - V(1,2)*V(2,1).
2.3     SET K = V(3,1)*A(1) + V(3,2)*A(2) + V(3,3)*A(3).
2.31    SET Q = V(1,1)*V(2,1) + V(1,2)*V(2,2) + V(1,3)*V(2,3).
2.315   TO PART 7 IF Q = 1.
2.32    SET U = V(2,1)*V(3,1) + V(2,2)*V(3,2) + V(2,3)*V(3,3).
2.33    SET B(1) = V(3,1) - (K*A(1))/(1-Q**2).
2.34    SET B(2) = V(3,2) - (K*A(2))/(1-Q**2).
2.35    SET B(3) = V(3,3) - (K*A(3))/(1-Q**2).
2.36    SET L = SQRT(B(1)**2+B(2)**2+B(3)**2).
2.41    SET B(4) = (B(1)/(L**2))*(Q*V(2,1) - V(1,1)).
2.42    SET B(5) = (B(2)/(L**2))*(Q*V(2,2) - V(1,2)).
2.43    SET B(6) = (B(3)/(L**2))*(Q*V(2,3) - V(1,3)).
2.6     SET R = U/L.
2.9     TO PART 3.

3.6     SET X = |ARG(Q,SQRT(1-Q**2))*180/3.14159|.
3.7     SET Y = |ARG(R,SQRT(1-R**2))*180/3.14159|*SGN(B(4)+B(5)+B(6))

3.75    SET J = J+1.
3.80    SET E(J) = N(7).
3.81    SET F(J) = N(8).
3.82    SET D(J) = N(9).
3.83    SET C(J) = N(10).
3.84    SET G(J) = X.
3.85    SET H(J) = Y.

4.01    SET P(I) = P(I)*(3.14159/180).
4.02    SET T(I) = T(I)*(3.14159/180).
4.03     SET V(I,1) = SIN(P(I))*COS(T(I)).
4.04    SET V(I,2) = SIN(P(I))*SIN(T(I)).
4.05    SET V(I,3) = COS(P(I)).

5.1     DO PART 8 FOR N(7) = 90.

6.1     DO PART 5 FOR N(9) = 35,0,-30,-60,-90.

7.1     SET X = 0.
7.2     SET Y = *****.
7.3     TO STEP 3.8.

8.1     DO PART 1 FOR N(8) = (-90+N(9))(5)(90+N(9)).

9.1     SET J = -251.
9.2     DO PART 6 FOR N(10) = 90.
9.3     SAVE H,G,F,E,D,C,J REPLACING FORD1.
```