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LUNAR RILLES – A CATALOG AND METHOD OF CLASSIFICATION

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LUNAR RILLES - A CATALOG AND METHOD OF CLASSIFICATION

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ABSTRACT

A representative sample of lunar rilles observed on Lunar Orbiter IV and V photographs is presented. A method of classification of rilles is described which will provide a means of quantitatively grouping rilles of similar planemetric shape. The method is based on a finite Fourier approximation of the edge of the rille. It provides an adequate approximation to all planemetric characteristics of the rille except rille recurvature.

INTRODUCTION

Lunar rilles have been subjectively classified as sinuous, normal, straight, arcuate, and branching. While there seems to be general agreement for the origin of many rilles, the origin of sinuous rilles has always been a subject of considerable controversy. The diversity of theories proposed for the production of sinuous rilles includes: surface and subsurface erosion by flowing water, erosion by ash flows, lava channel formation, lava tube collapse, magma intrusion followed by collapse, gas venting along subsurface fractures and intersection of fracture patterns. The great diversity in theories may indicate real differences in shape and origin of different sinuous rilles. If so, the subjective definition of sinuous rilles is much too general. Alternatively, all sinuous rilles may be similar in shape which might favor a single theory for all sinuous rilles. It is clear, therefore, that an objective classification of lunar rilles in general and sinuous rilles in particular is required if the origin of rilles is to be studied on a quantitative basis.

The purpose of this paper is to present a catalog of a representative group of lunar rilles and a brief description of a quantitative method of rille classification. The catalog will be used to obtain a subjective classification of lunar rilles from workers actively engaged in lunar studies. The subjective classification can then be compared to the results of an independent quantitative classification. In this way, we can determine which rilles are considered by most workers to be sinuous and determine their structural features quantitatively. In addition, the quantitative results might be used to further differentiate sinuous rilles into other subclasses.

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FINITE FOURIER APPROXIMATIONS OF LUNAR RILLES

If one end of a lunar rille is connected to the other by a straight line, this base line can be considered the X axis of a Cartesian coordinate system. The course of either bank of the rille can be considered mathematically as $F(X)$. In this case, $F(X)$ is usually an irregular single-valued function over most of the rille length. Most single-valued functions can be represented by the Fourier series if an adequate number of harmonics is considered. However, rilles often recurve upon themselves and in this interval of X there is more than one value of $F(X)$ and the simple Fourier series does not define the function. In general, this interval is small compared to total rille length so that the discontinuity has small effect on the spectral components of the rille and the method is suitable for defining a rille quantitatively.

Data for analysis of a rille is obtained by measuring discrete values of $F(X_r)$ at $N+1$ equally spaced points along the base line, ℓ, of a given rille. Thus, the rille is represented by the data function $F(X_r)$ where $X_r = r\ell/N$, $r = 0,1,\ldots, N$ and $F(0) = 0$. This data function can be approximated by any given set of harmonics $n \leq N$ at each of the $N+1$ points by the finite Fourier series:

$$F_n(X_r) = \sum_{k=1}^{n} B_k \frac{\sin X_r k\pi}{\ell} ; \quad n = 1,2,\ldots,N$$

The Fourier coefficients, B_k, are determined by least-squares estimates:

$$B_k = \frac{2}{n} \sum_{r=1}^{N} F(X_r) \frac{\sin X_r k\pi}{\ell}$$

When $n = N$ the Fourier approximation, $F_N(X_r)$, is equal to the empirical representation of the rille at each of the data points. When $1 \leq n < N$ error in fit is estimated by:

$$E(n) = \sum_{x=o}^{N} \frac{[F_N(X_r) - F_n(X_r)]^2}{N + 1}$$

The method used to estimate the least number of harmonics n that provide an adequate fit was to compare the percent reduction in error resulting from an increase in the number of harmonics with the reduction in error that resulted from a preceding increase in the number of harmonics; that is, comparisons of the type:

$$[E(n)-E(n+\Delta)/E(n)] \times 100$$

were computed for $n = \Delta, 2\Delta, 3\Delta, \ldots$ until the percent reduction was less than 1. These calculations were also analyzed with regard to the average amplitude of each rille.

EXAMPLES OF SPECTRAL COMPONENTS OF LUNAR RILLES

The method of Fourier analysis of rilles is ideally suited for an objective classification of lunar rilles because it can define quantitatively all planimetric features of rille shape except recurvature. A modification of the simple Fourier analysis is being developed to allow for the description of recurvature. The degree of approximation of a given rille by different sets of harmonics of the Fourier series is shown graphically in figure 1. Approximations to the rille at the top of the figure result from the fewest number of harmonics. As higher order harmonics are included, the calculated values of F(X) more nearly approximate rille 22 of the catalog shown at the bottom of the figure. Inspection of figure 1 shows that approximation of the rille using the first 109 harmonics is very accurate.

There is a wide range in pattern of harmonics associated with lunar rilles. It is this variation of values of Fourier coefficients and variation in significance of harmonic order that suggests that rilles can be classified using this technique. Figure 2 shows the amplitudes of B_k of the three rilles (rilles 4, 12, and 22 of the rille catalog). Amplitudes of B_k are plotted as a function of harmonic order. The wavelength of the first harmonic is twice the rille baseline length, the wavelength of the second harmonic is equal to the baseline length, and so on. The number of harmonics with significant amplitudes that are required to define each of the rilles is quite different, as are the amplitudes. While rilles 4 and 22 are characterized by a small number of harmonics, rille 12 is adequately described only by a complex spectral pattern that indicates the importance of higher order harmonics. The wide range in patterns of spectral components indicates that lunar rilles can be easily classified using Fourier analysis.

RILLE CATALOG

Lunar Orbiter photographs were examined for rilles shown at resolutions suitable for analysis. Most of the photographs in the catalog are taken from LO IV, although some are from LO V. The rille catalog is in two parts. The first section (rilles 1-91) shows *simple rilles* (those that usually contain no tributaries; however, some contain one or two branches or tributaries). They are obviously isolated rilles that are not part of a rille system. The second section (rilles 1001-1029) shows *complex rille* systems. These sometimes occur completely within craters and they are characterized by many intersecting or branching sections of rilles.

Each plate of the catalog shows one or more rilles or rille systems and the latitude and longitude of the center of each. Each rille is numbered, rille branches are lettered, named rilles are labelled, and a scale is given on each photograph.

Although the catalog was produced primarily as a working document for a quantitative analysis of lunar rilles, it may also be useful as a reference for investigators making other quantitative and qualitative studies of rilles.

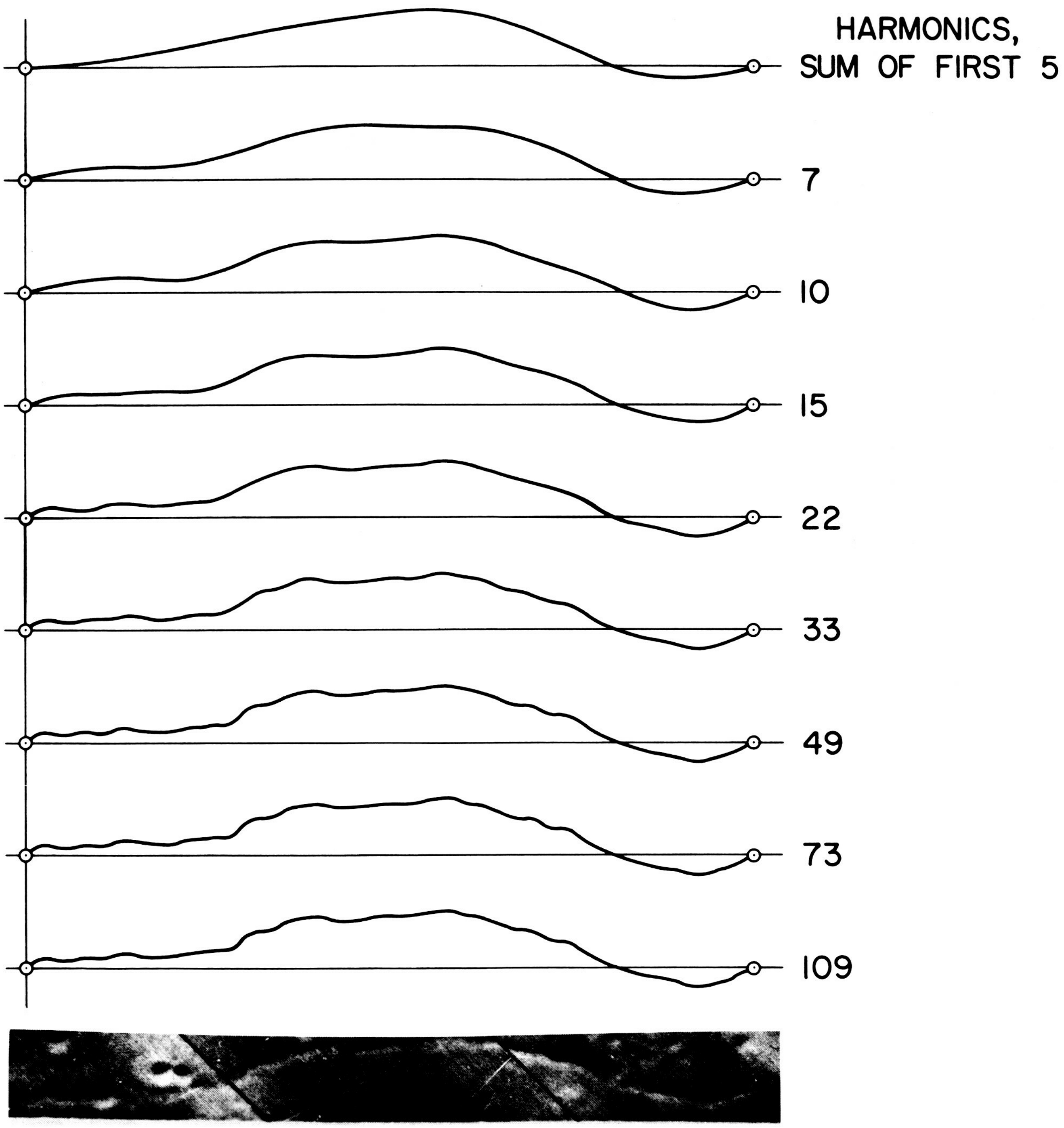


Figure 1.

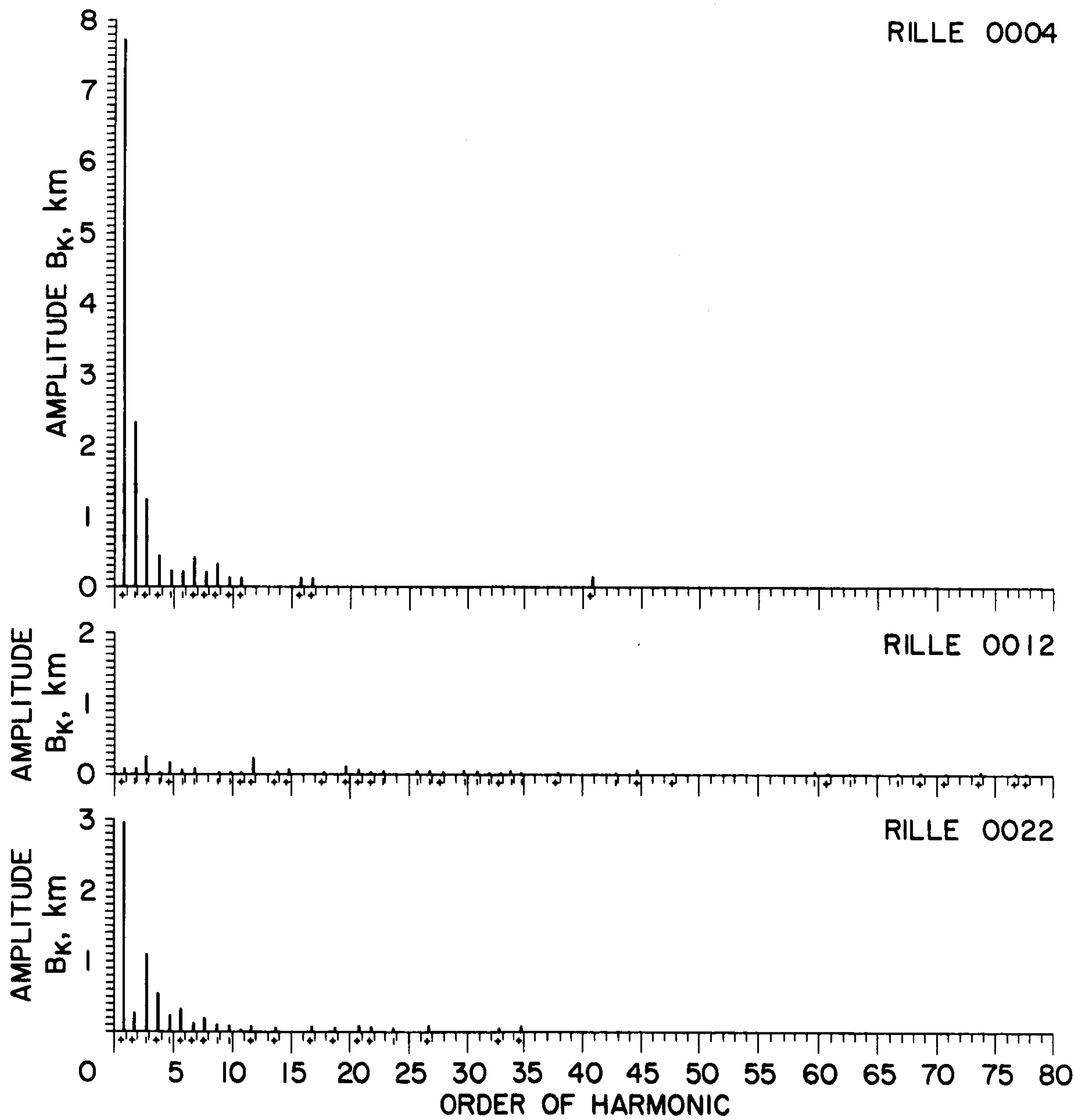
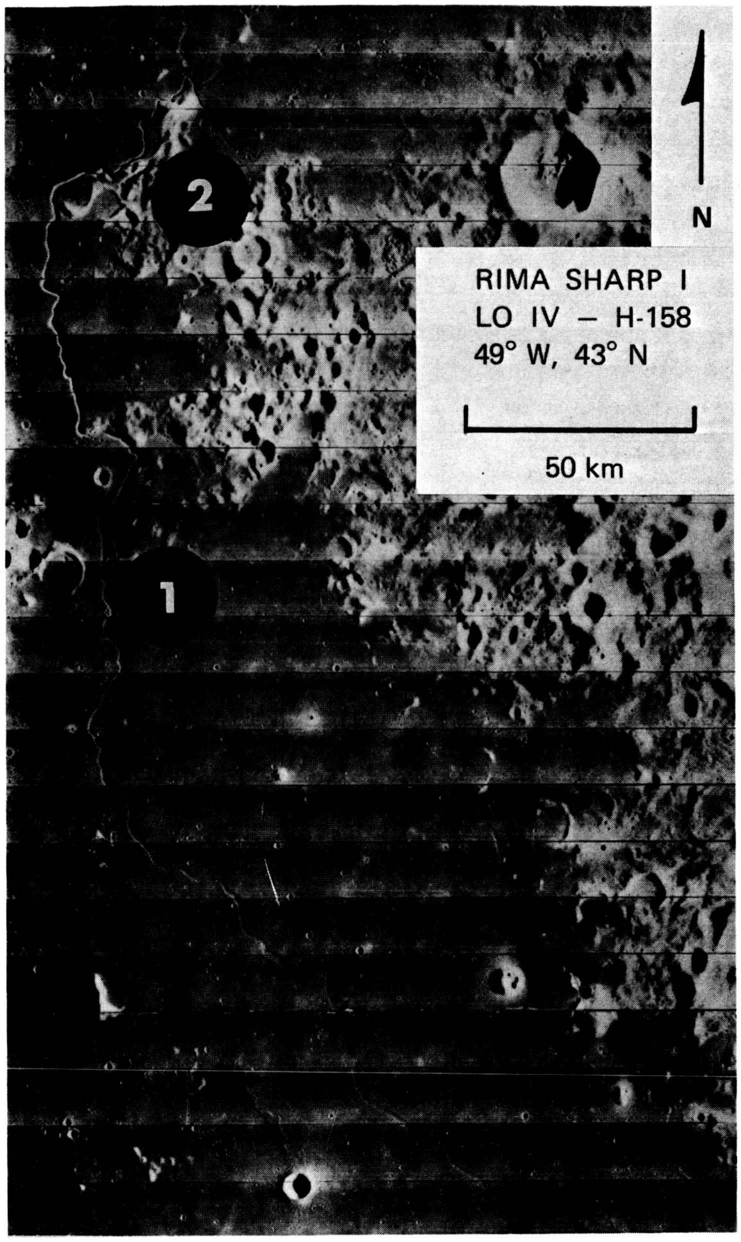
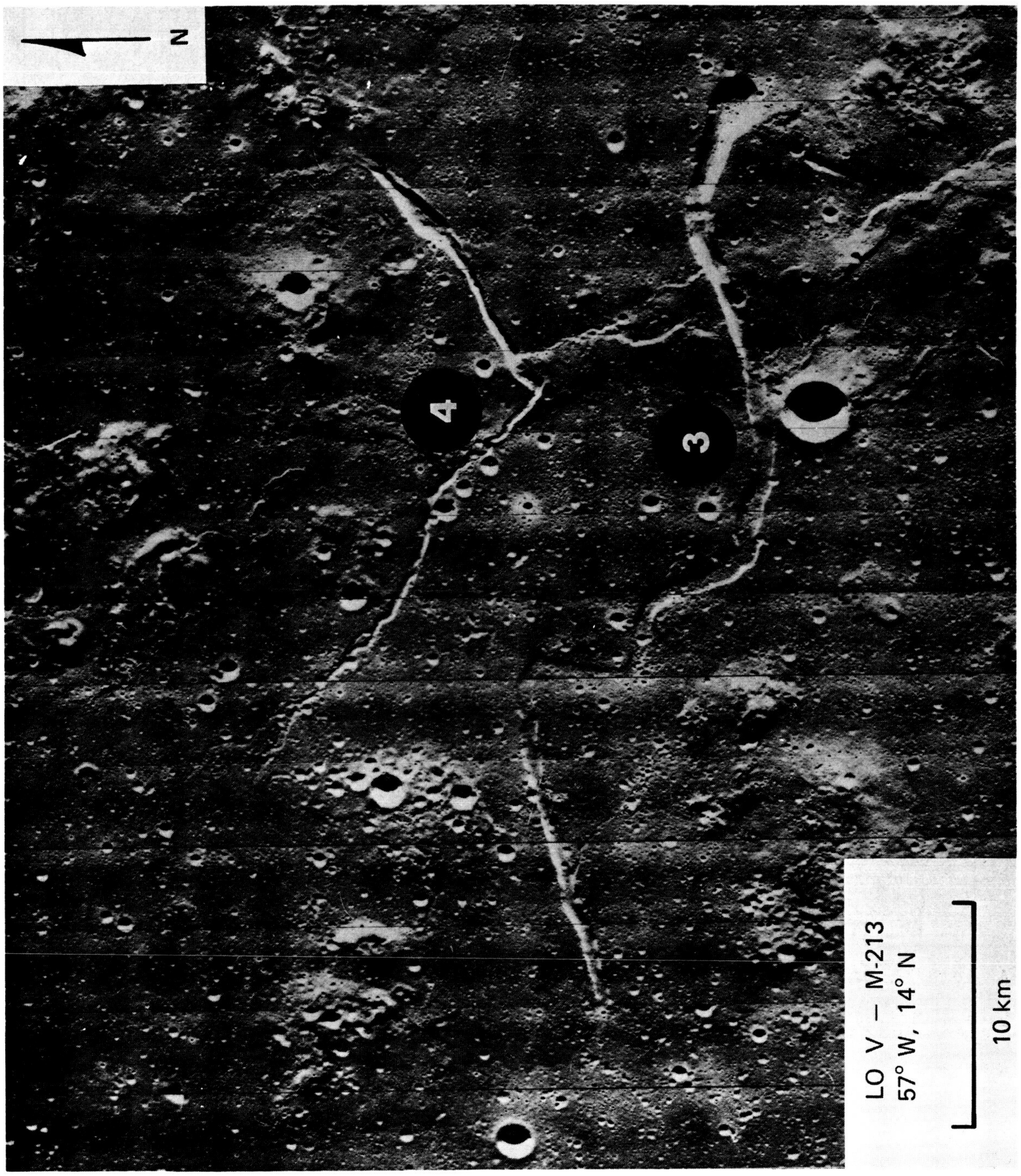

RILLE 0004
AMPLITUDE B_K, km
8
7
6
5
4
3
2
1
0
RILLE 0012
AMPLITUDE B_K, km
2
1
0
RILLE 0022
AMPLITUDE B_K, km
3
2
1
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
ORDER OF HARMONIC

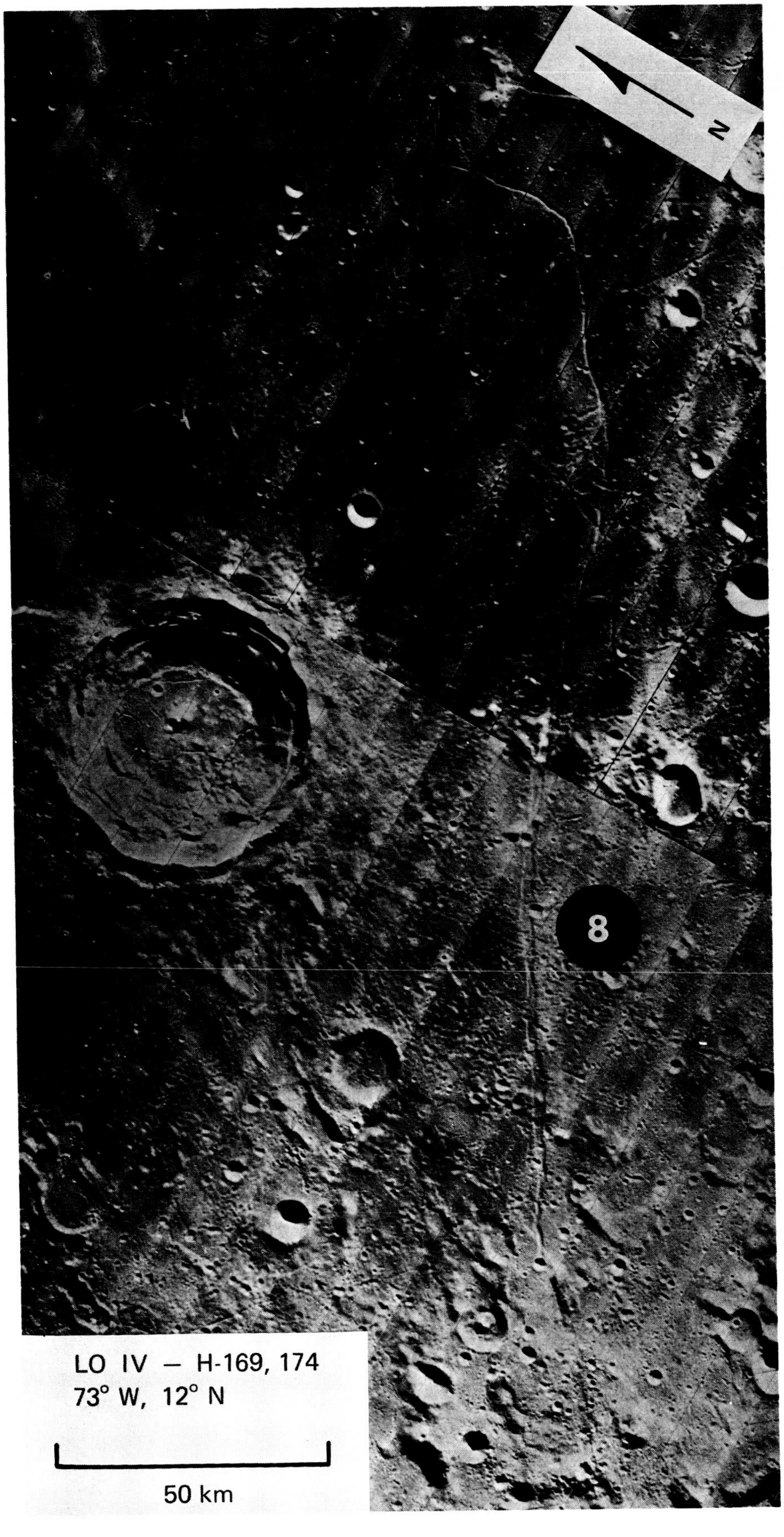
Figure 2.

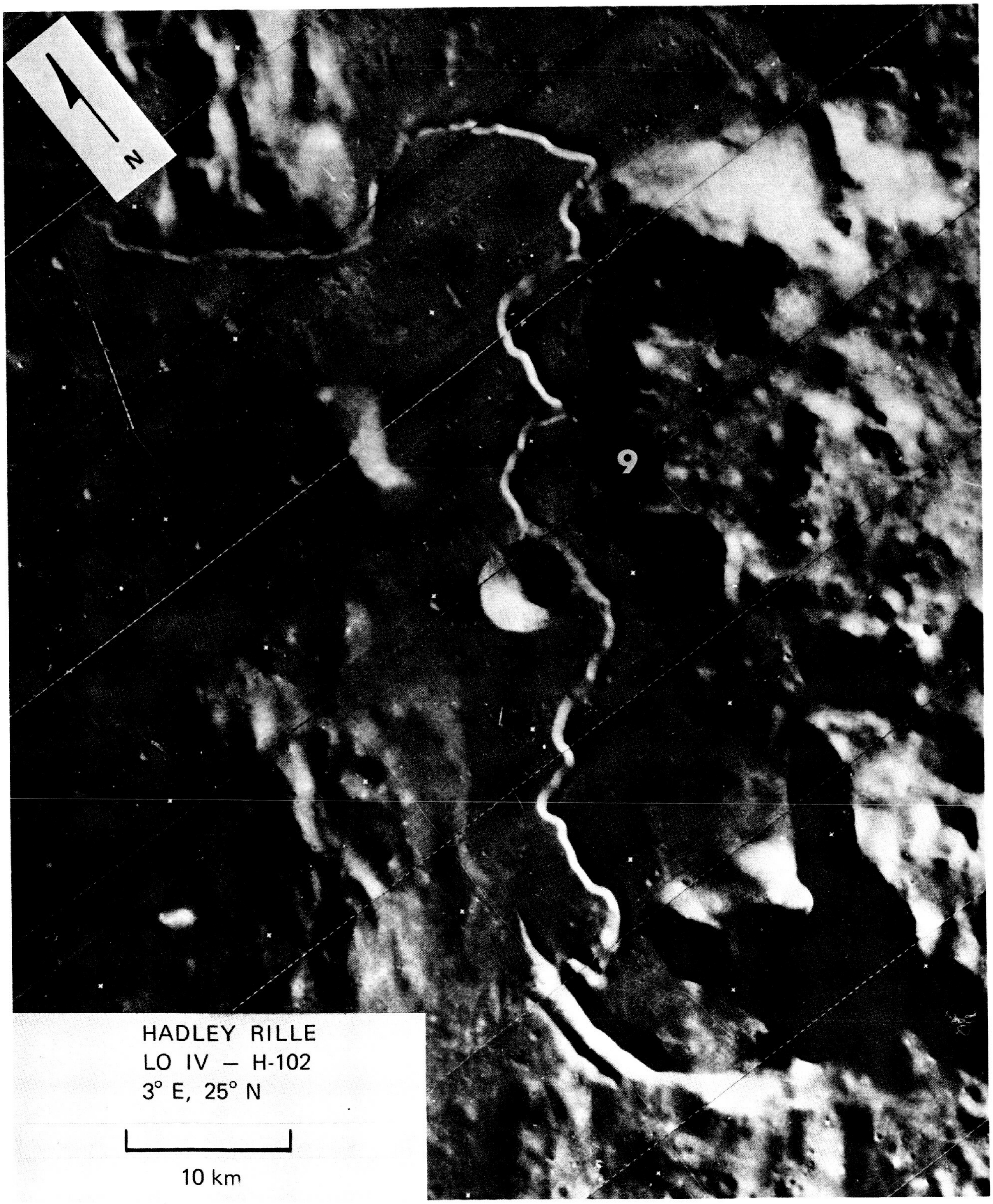


2
1
N
RIMA SHARP I
LO IV – H-158
49° W, 43° N
50 km

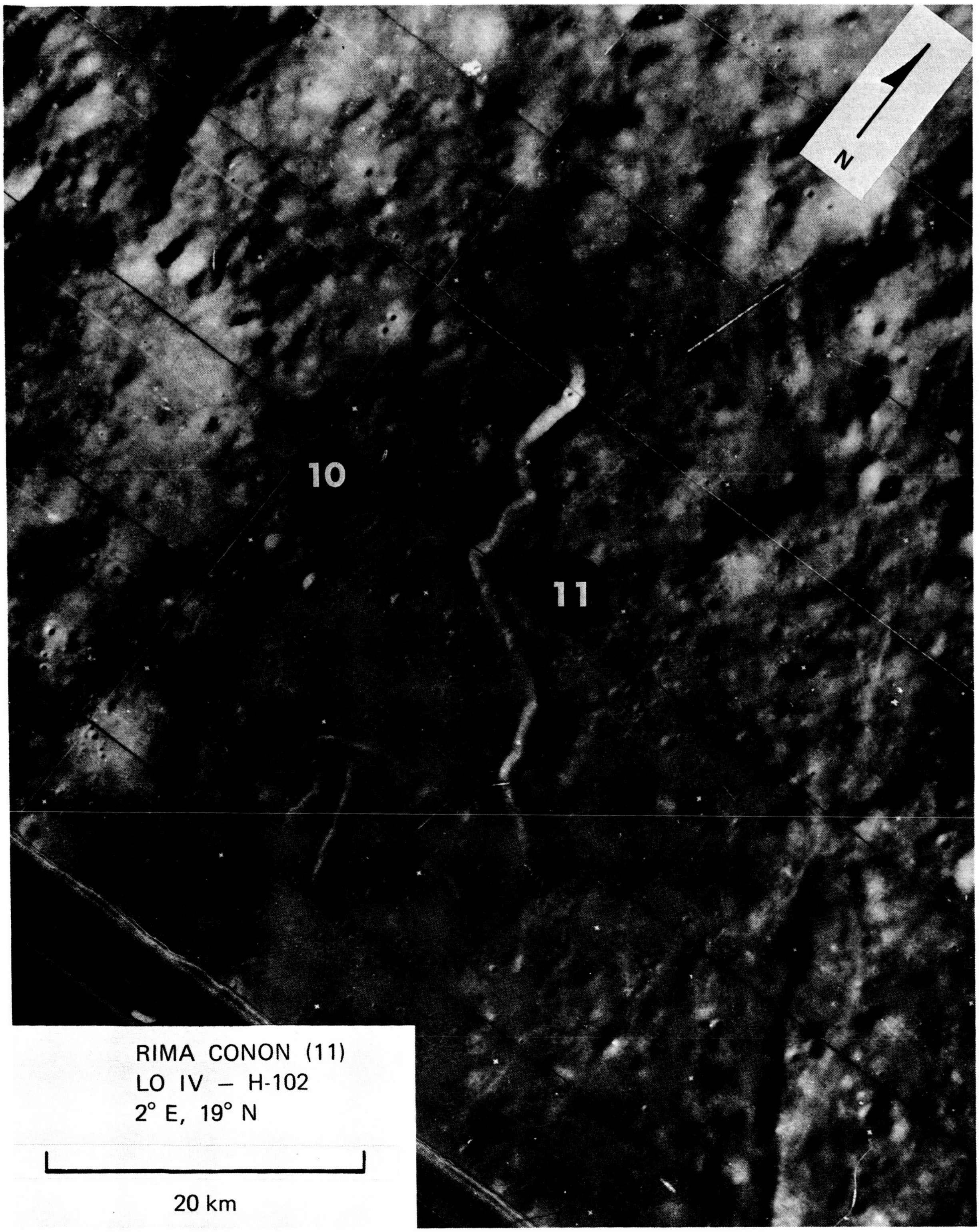

N
4
3
LO V – M-213
57° W, 14° N
10 km


LO V — M-190
43° W, 27° N
10 km
N
5
6
7


N
8
LO IV — H-169, 174
73° W, 12° N
50 km

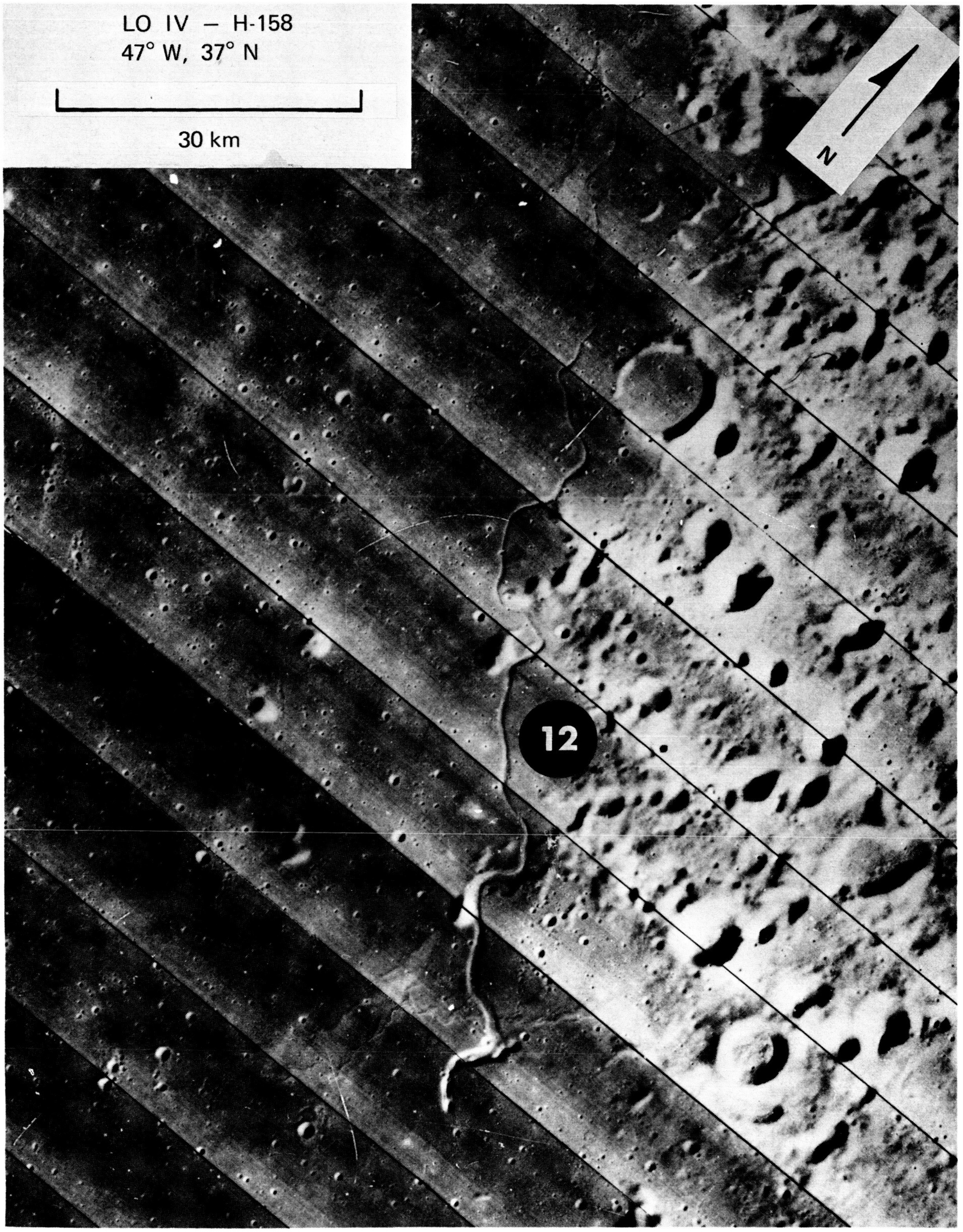


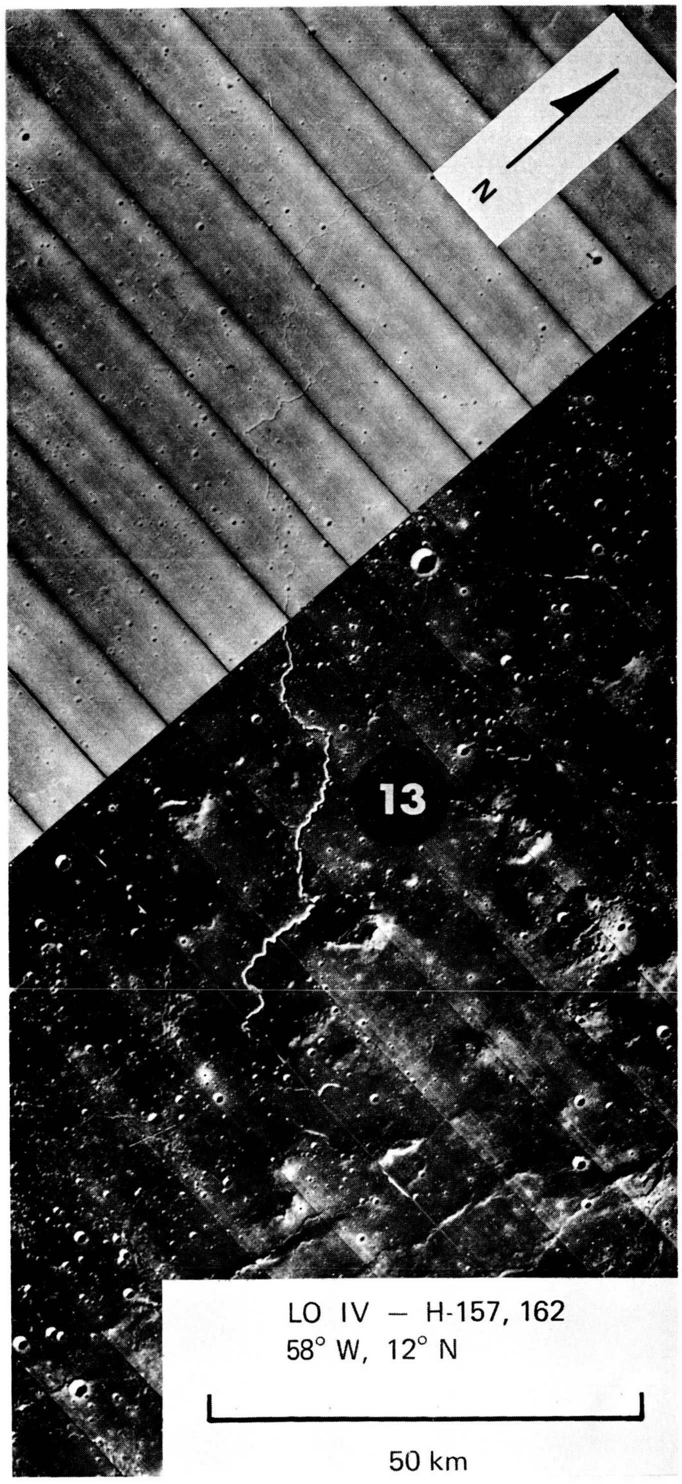
HADLEY RILLE
LO IV – H-102
3° E, 25° N

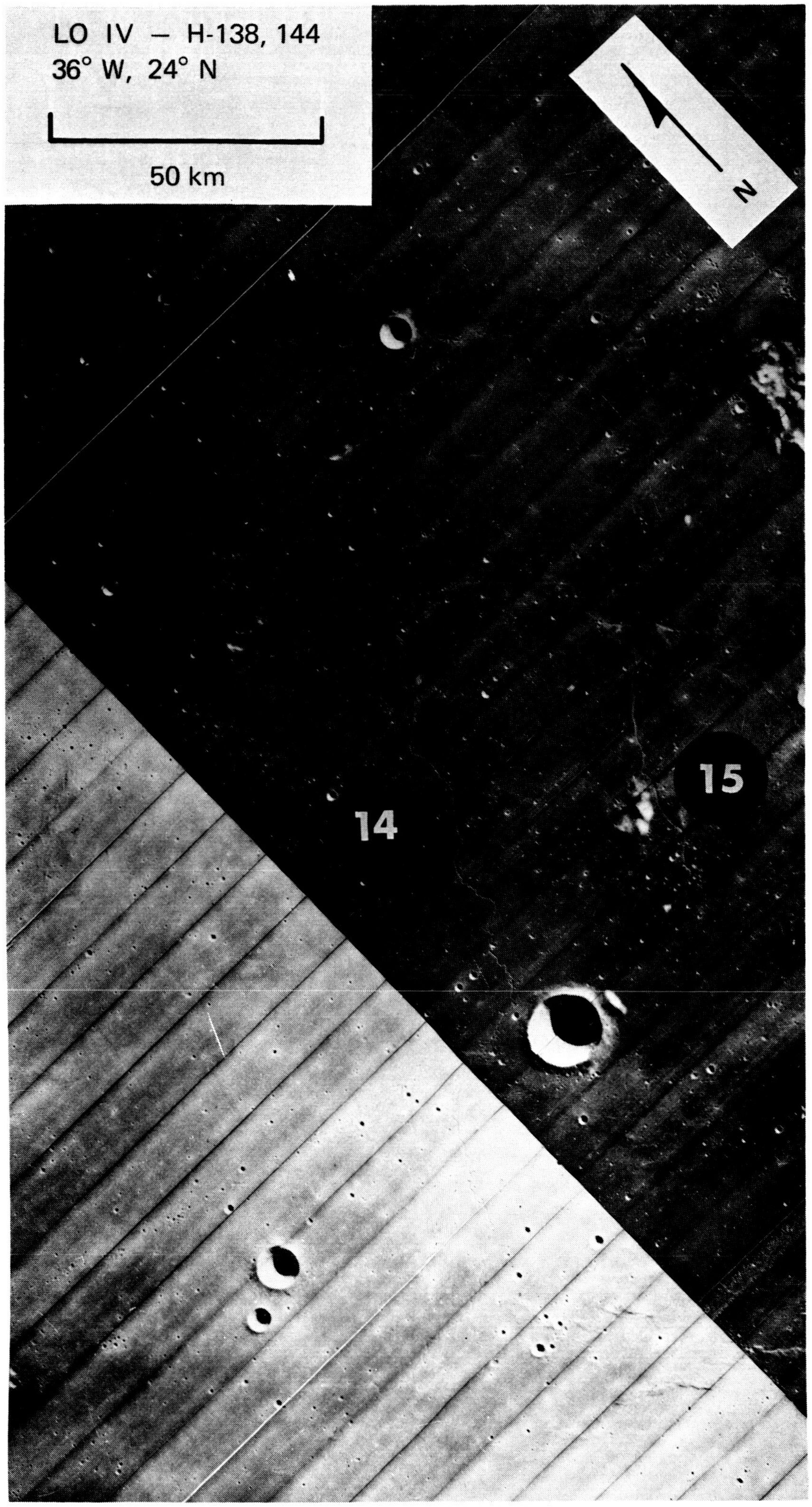


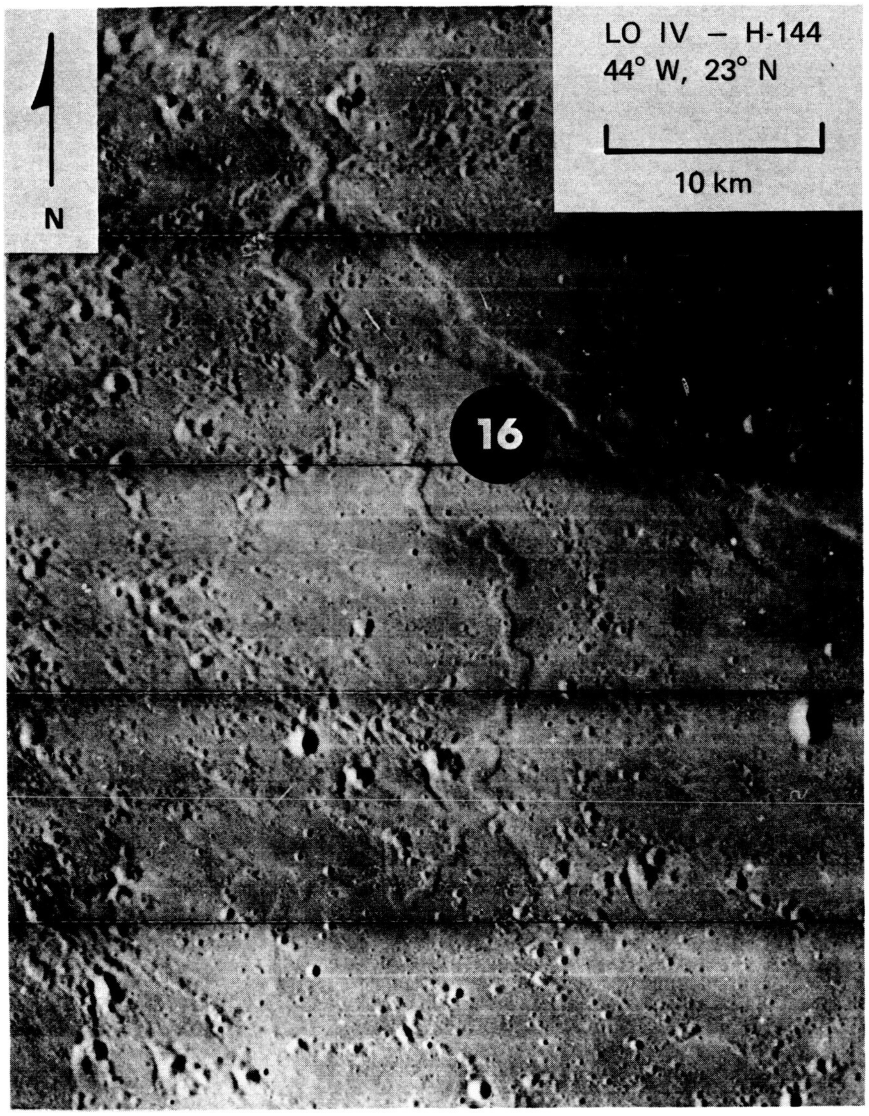
RIMA CONON (11)
LO IV – H-102
2° E, 19° N

20 km

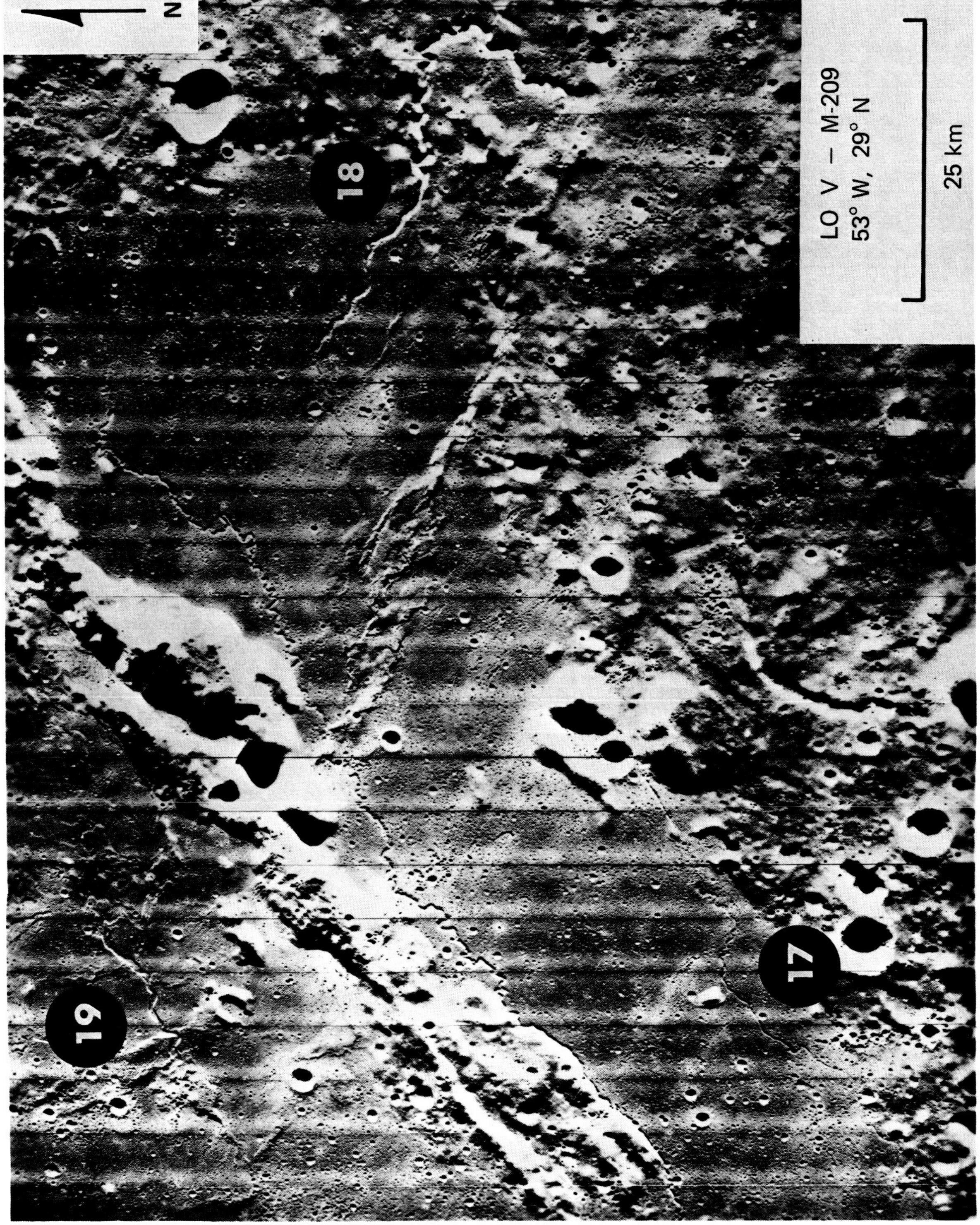

LO IV – H-158
47° W, 37° N
30 km
N
12

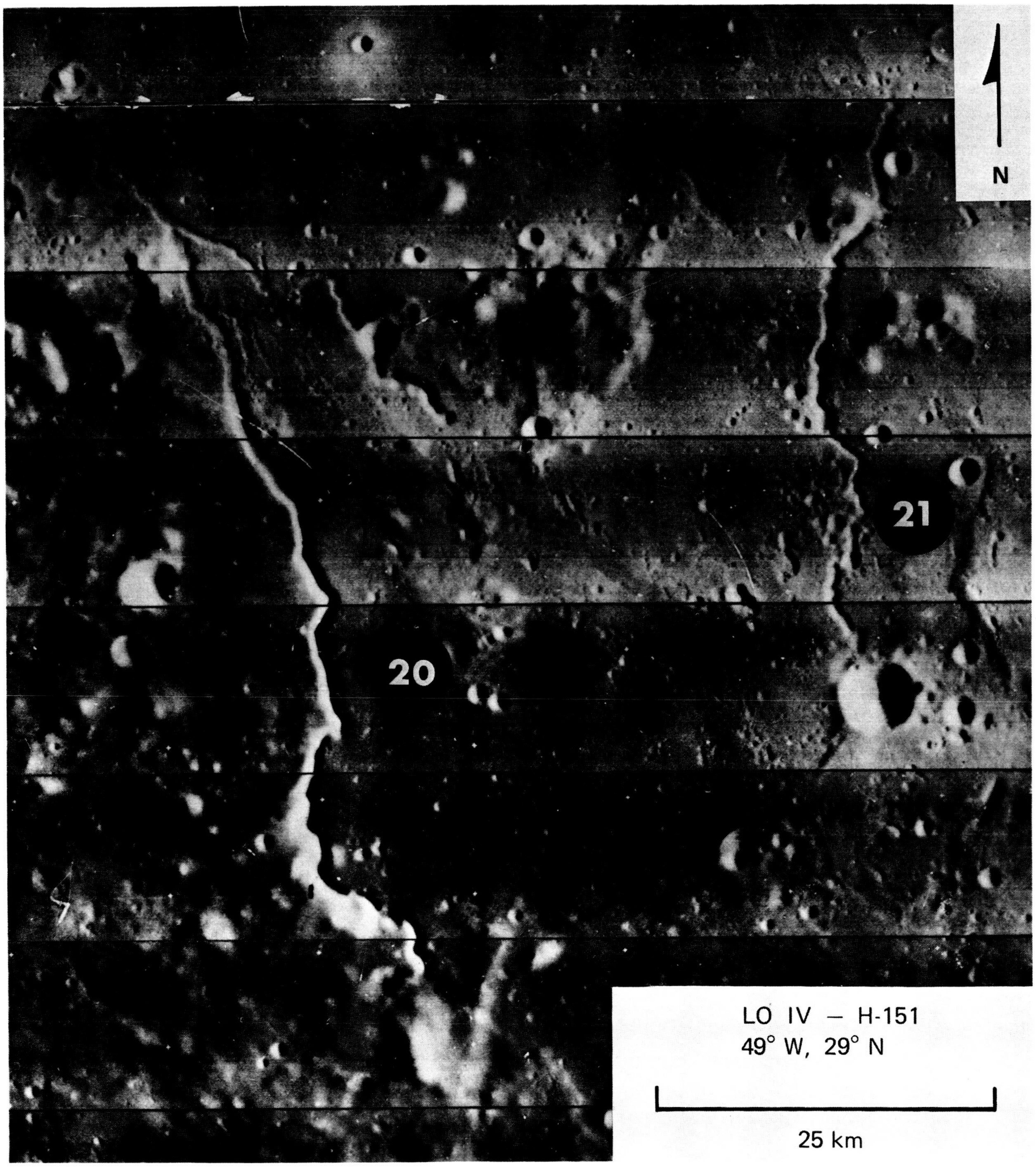

N
13
LO IV — H-157, 162
58° W, 12° N
50 km

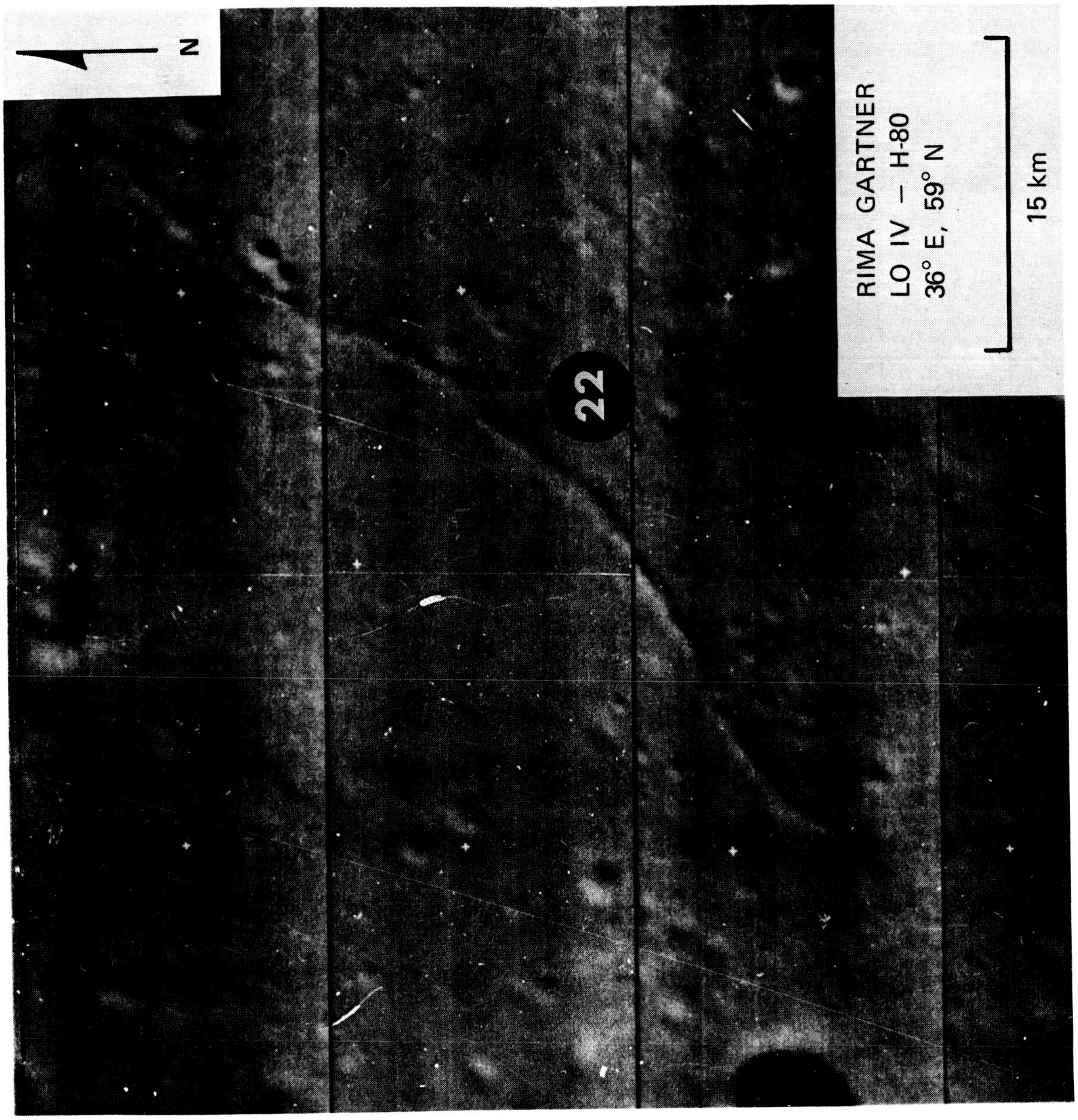

LO IV – H-138, 144
36° W, 24° N
50 km
N
14
15

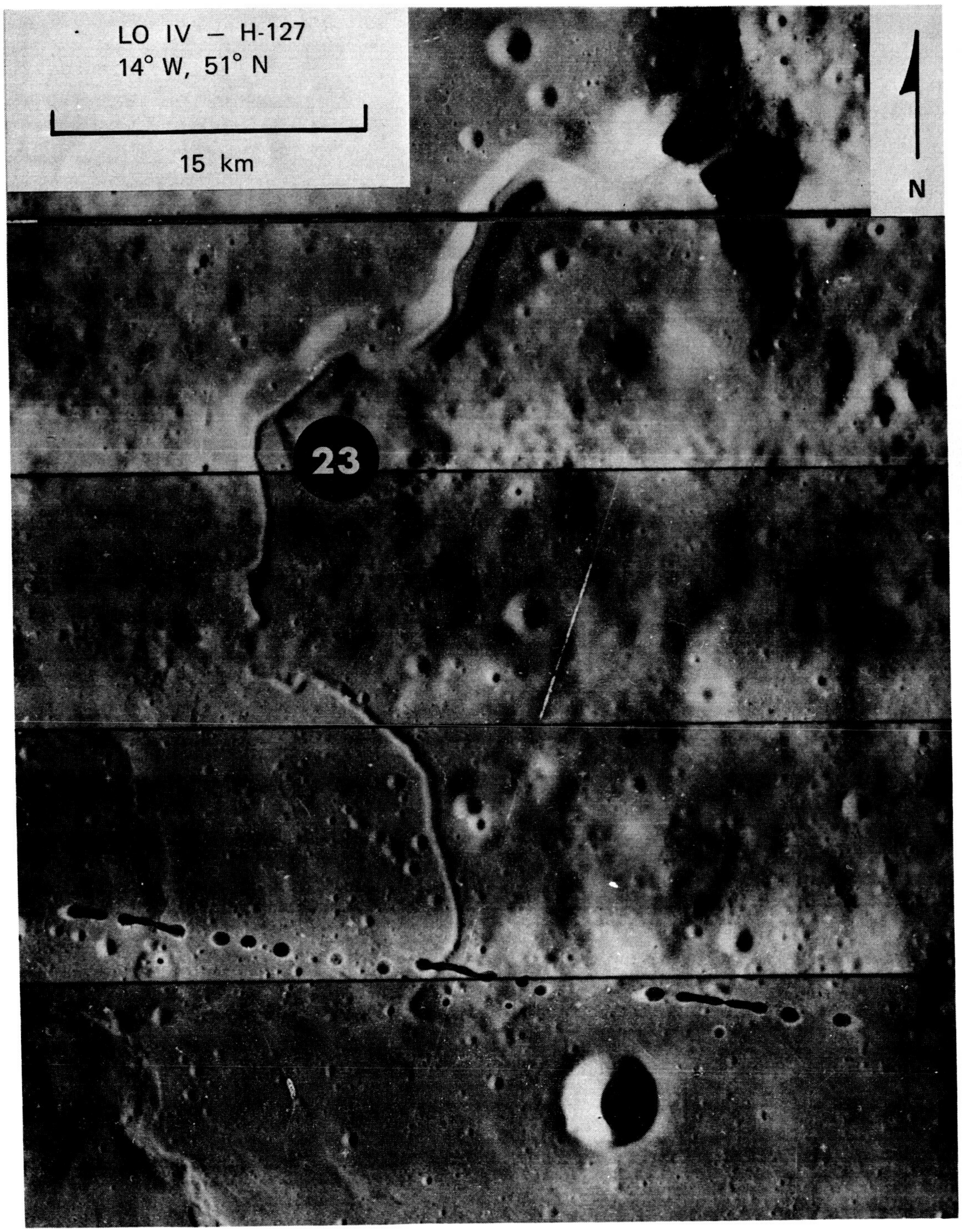


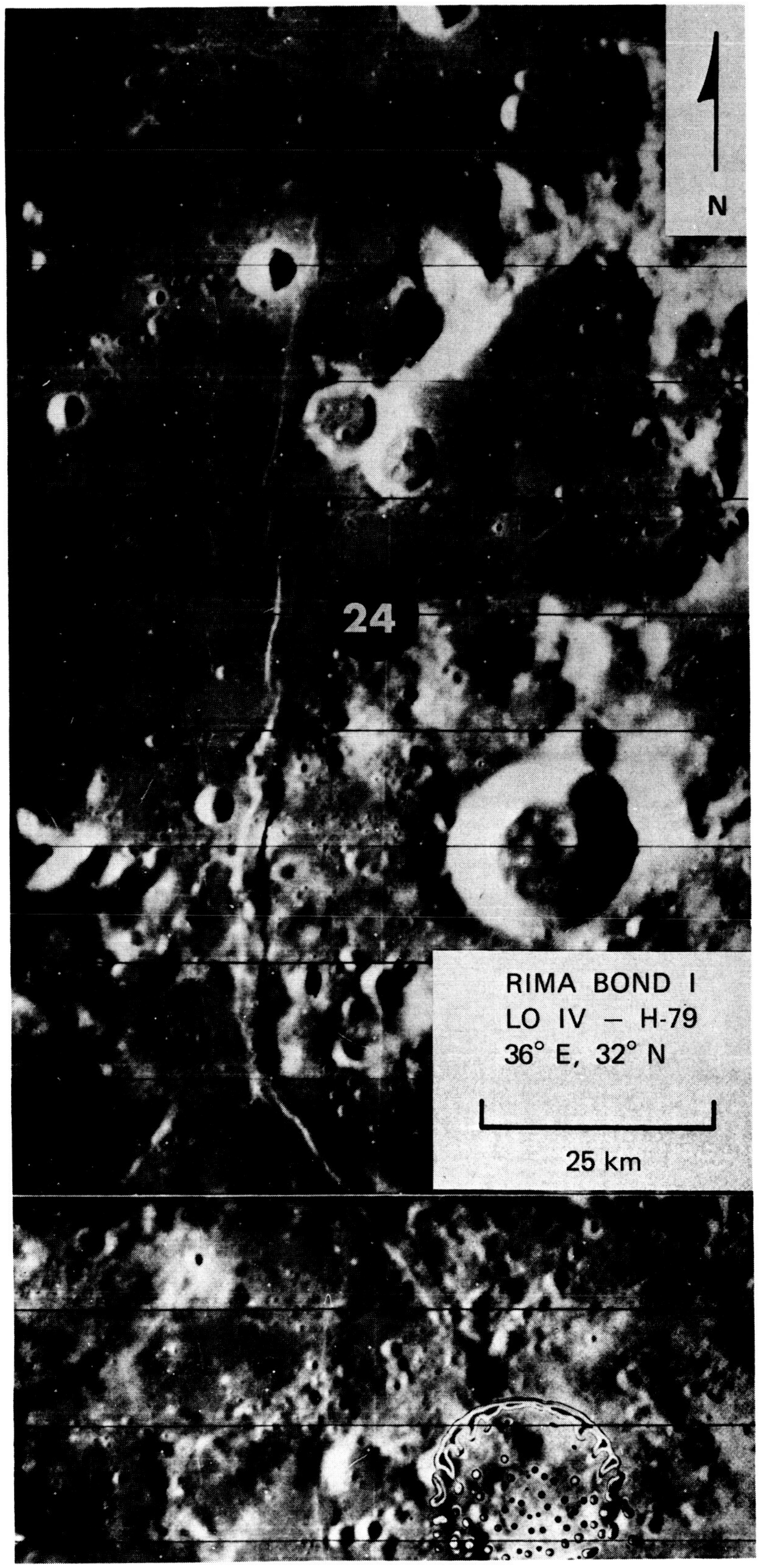
LO IV – H-144
44° W, 23° N
10 km
N
16

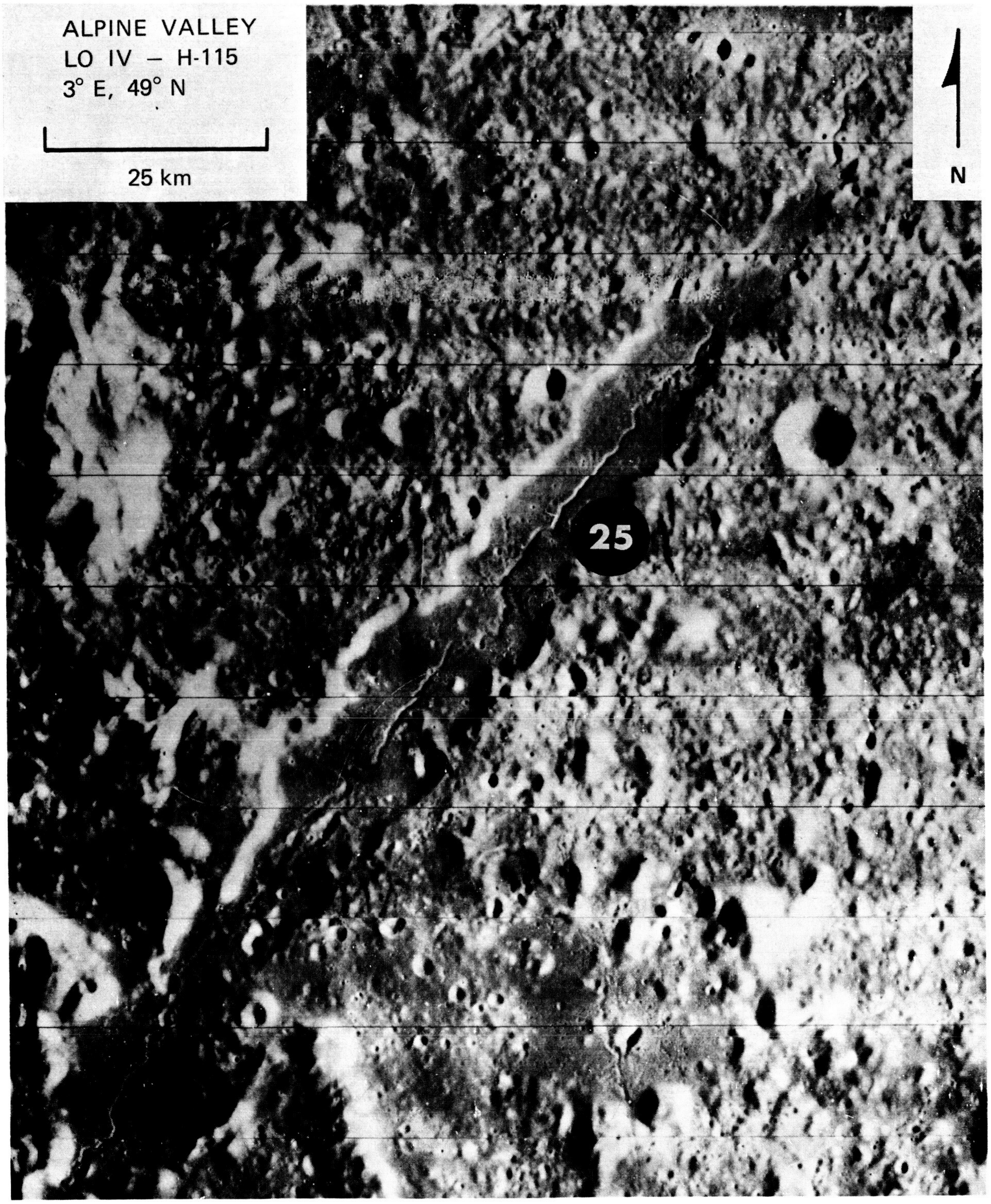

N
18
19
17
LO V – M-209
53° W, 29° N
25 km

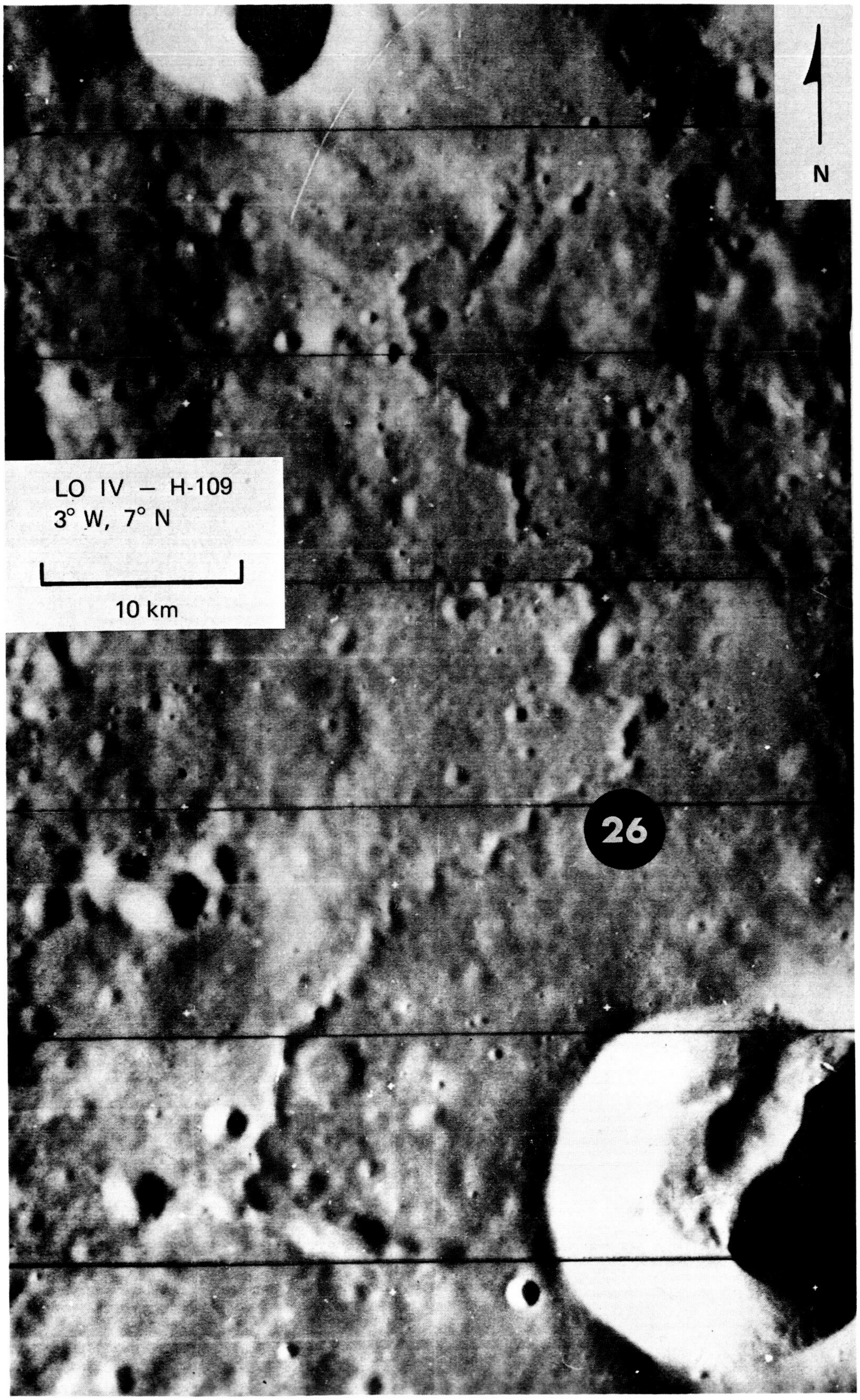

N
21
20
LO IV – H-151
49° W, 29° N
25 km

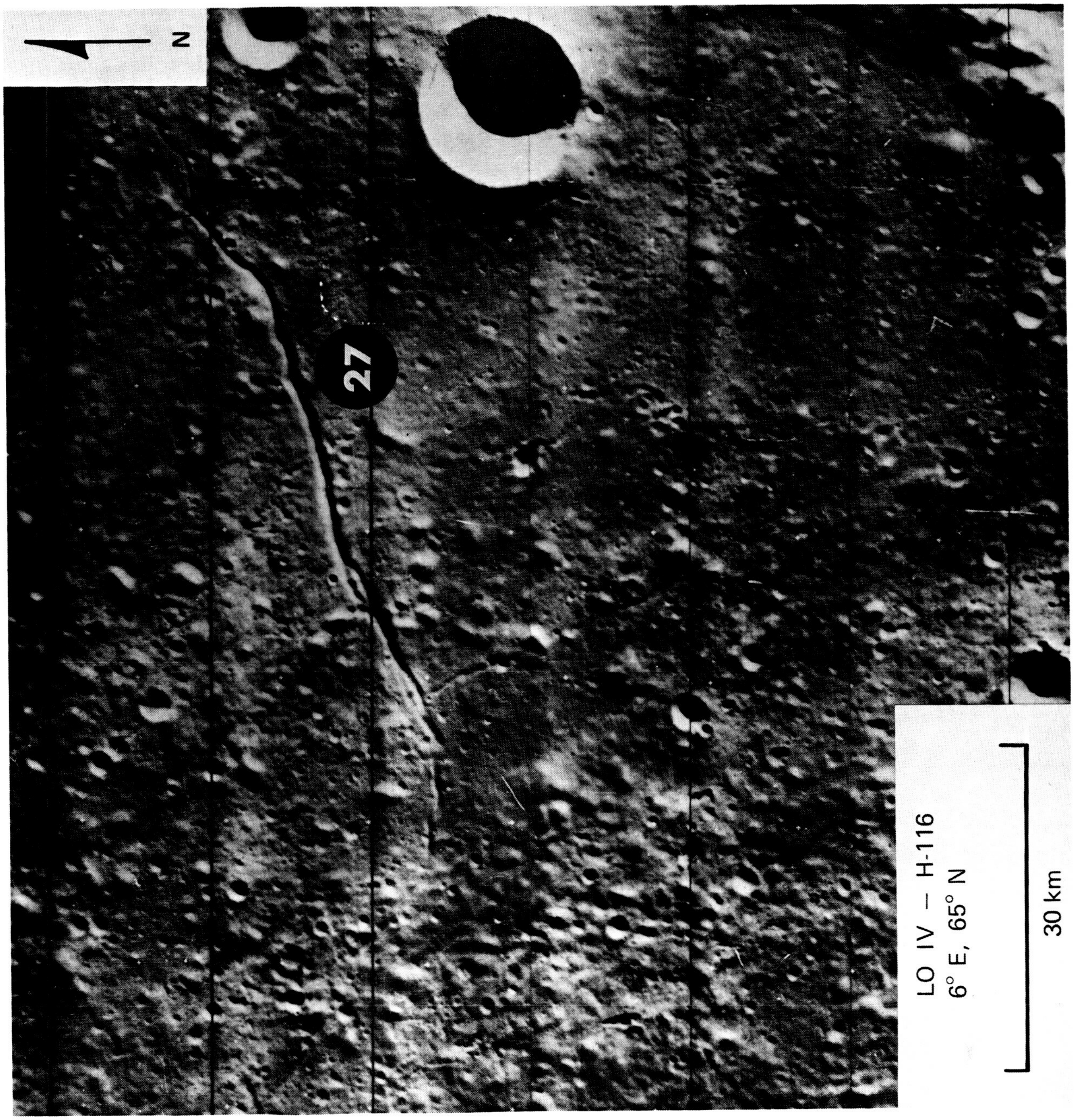

N
22
RIMA GARTNER
LO IV — H-80
36° E, 59° N
15 km

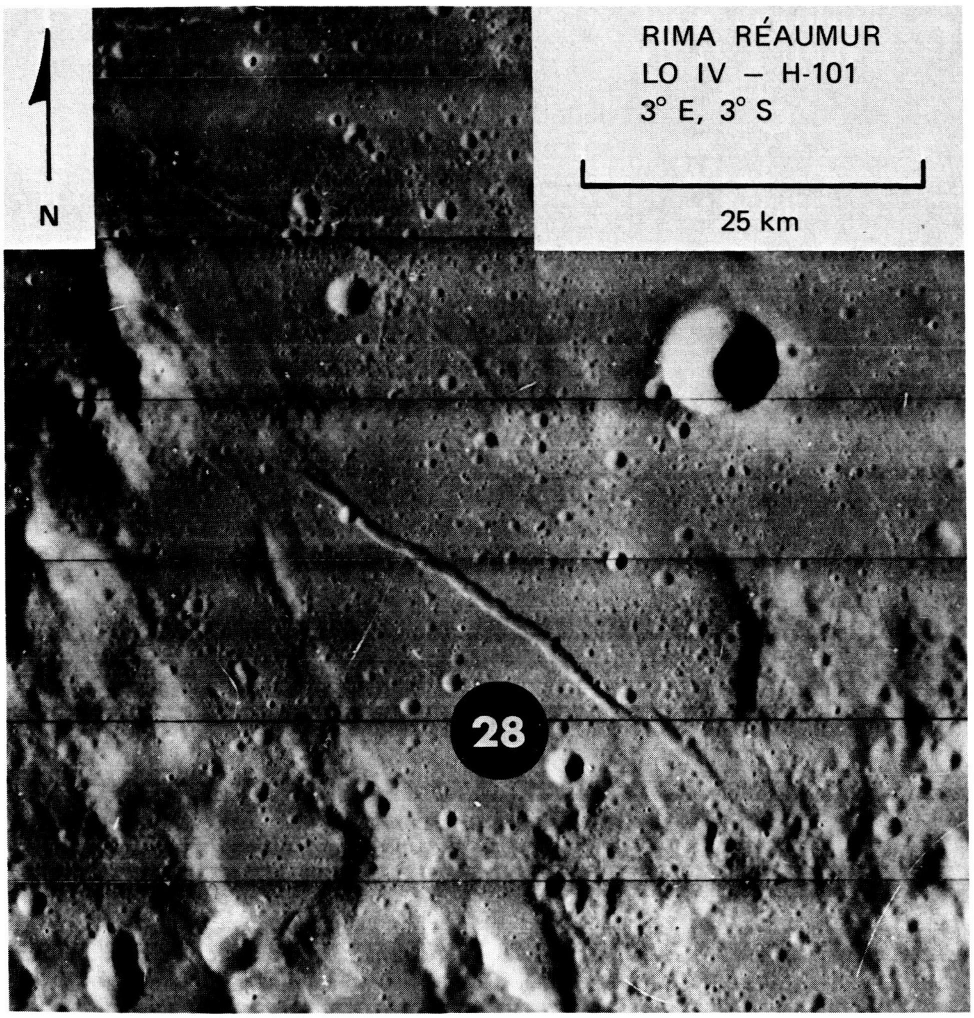

LO IV — H-127
14° W, 51° N
15 km
N
23

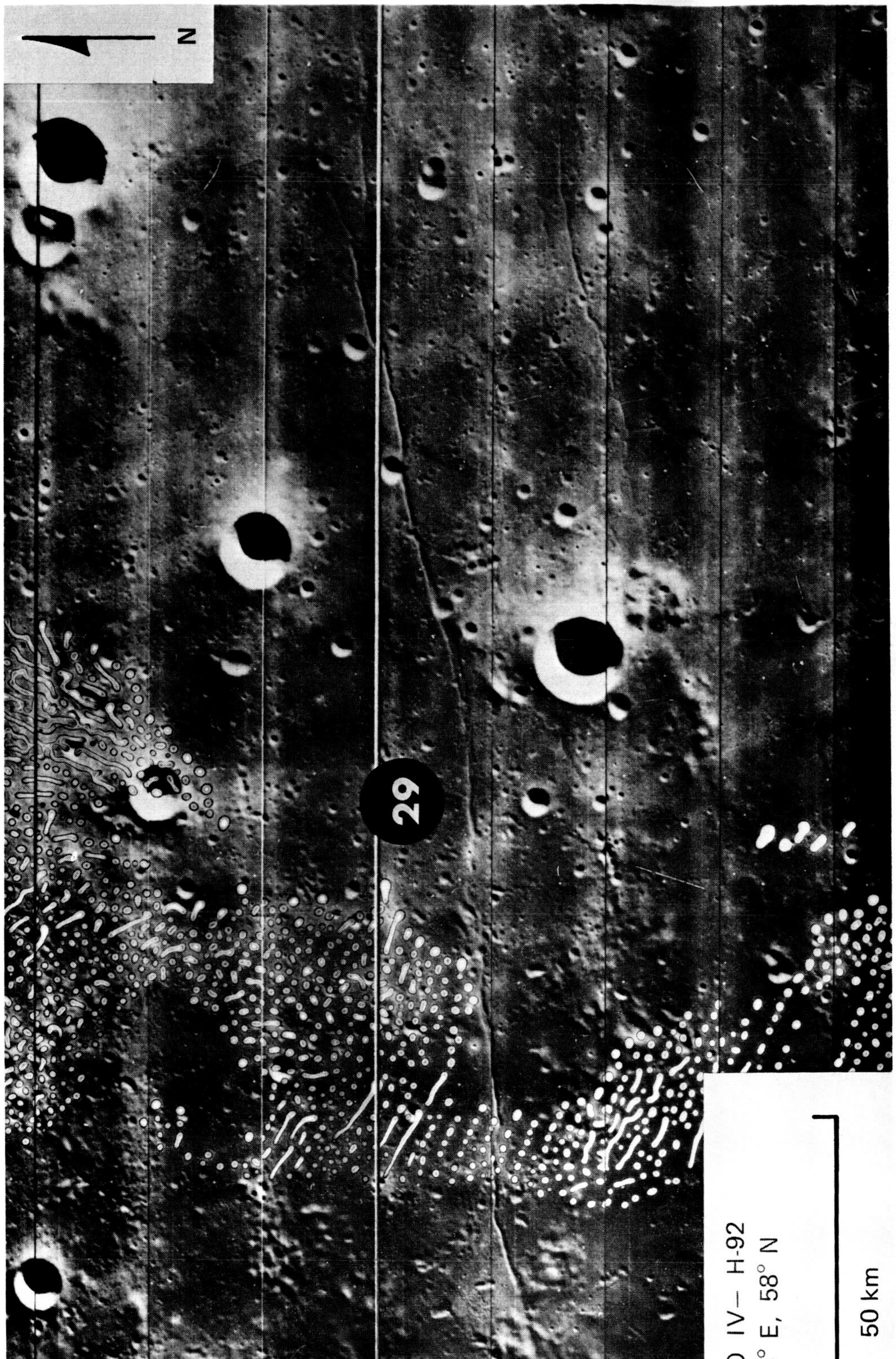

N
24
RIMA BOND I
LO IV – H-79
36° E, 32° N
25 km

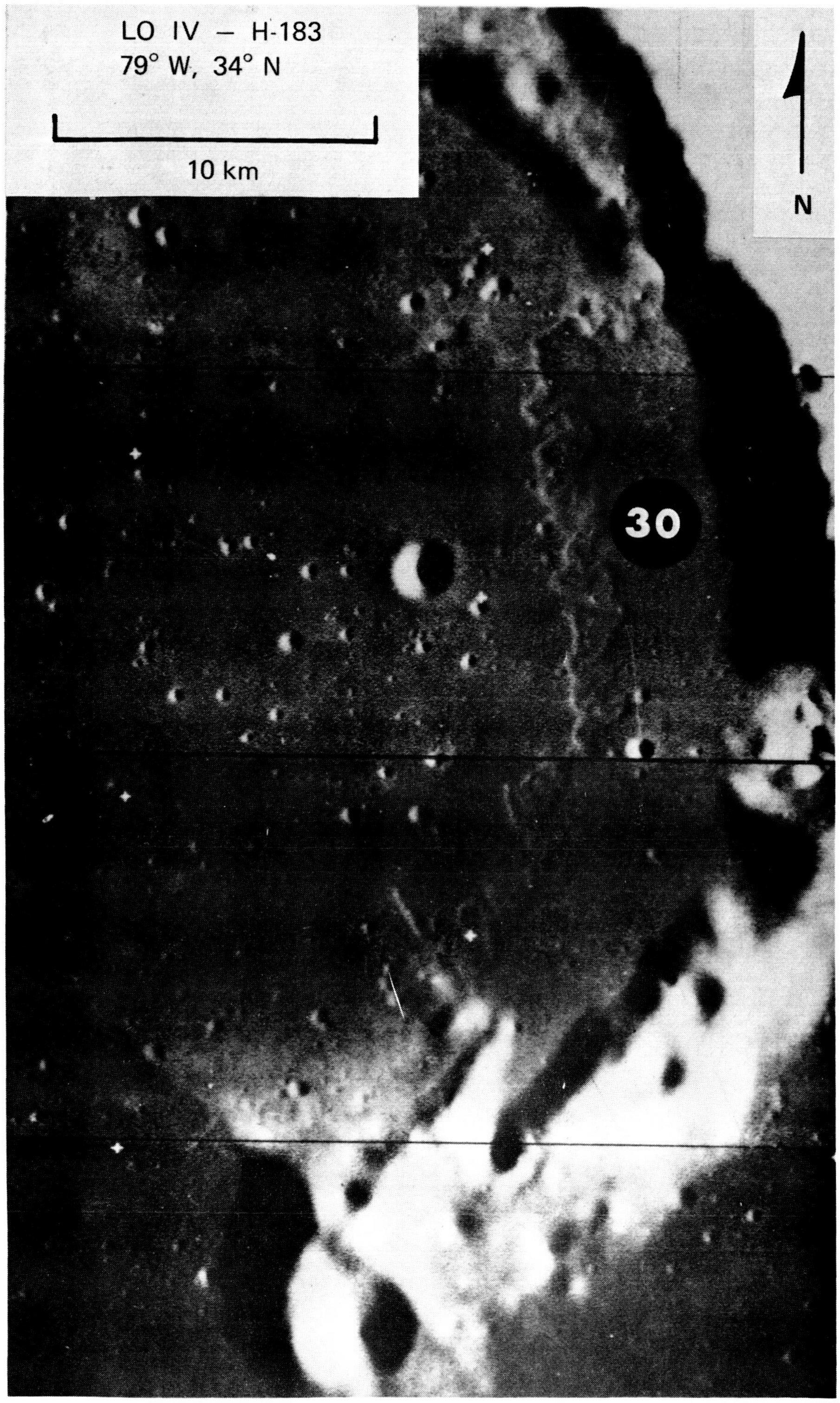

ALPINE VALLEY
LO IV – H-115
3° E, 49° N
25 km
N
25

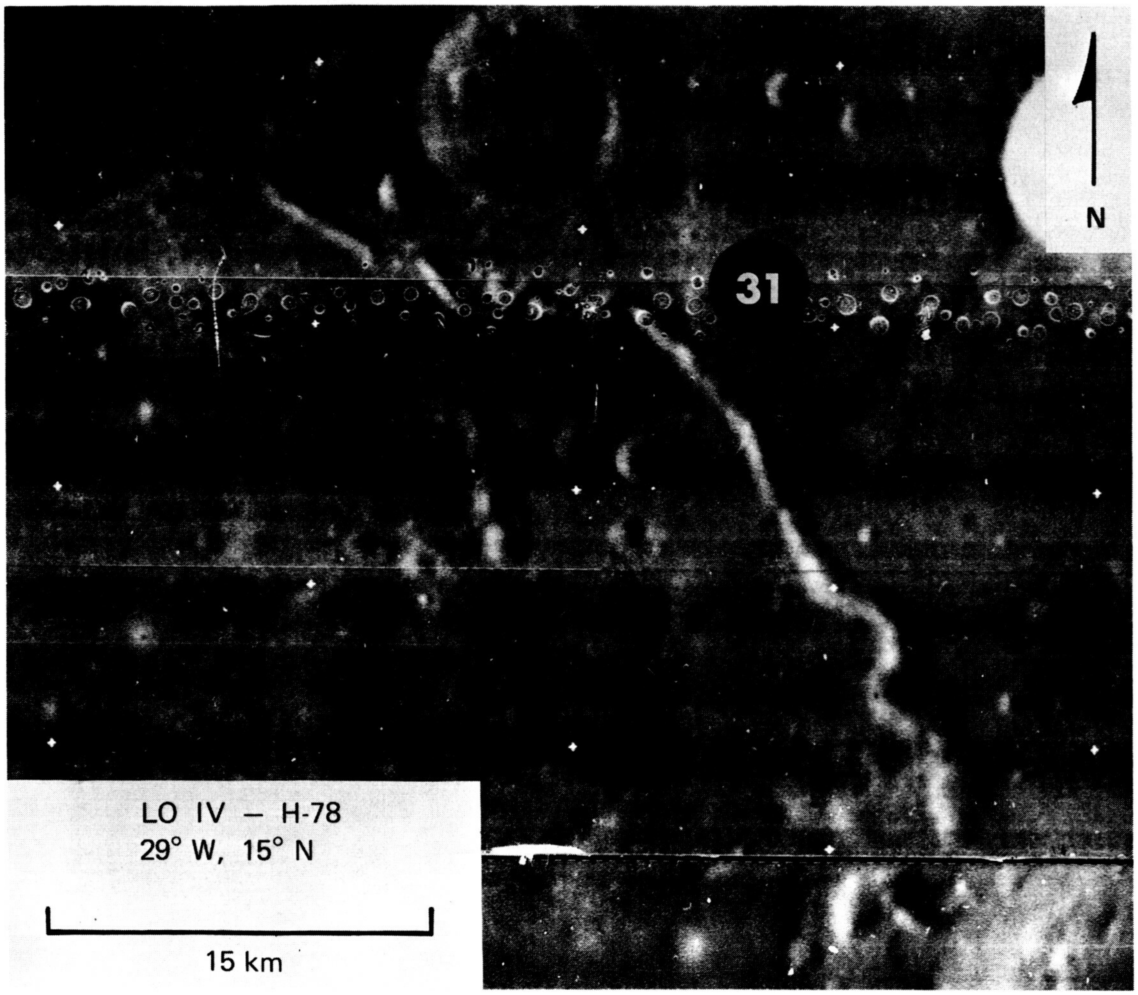

N
LO IV – H-109
3° W, 7° N
10 km
26

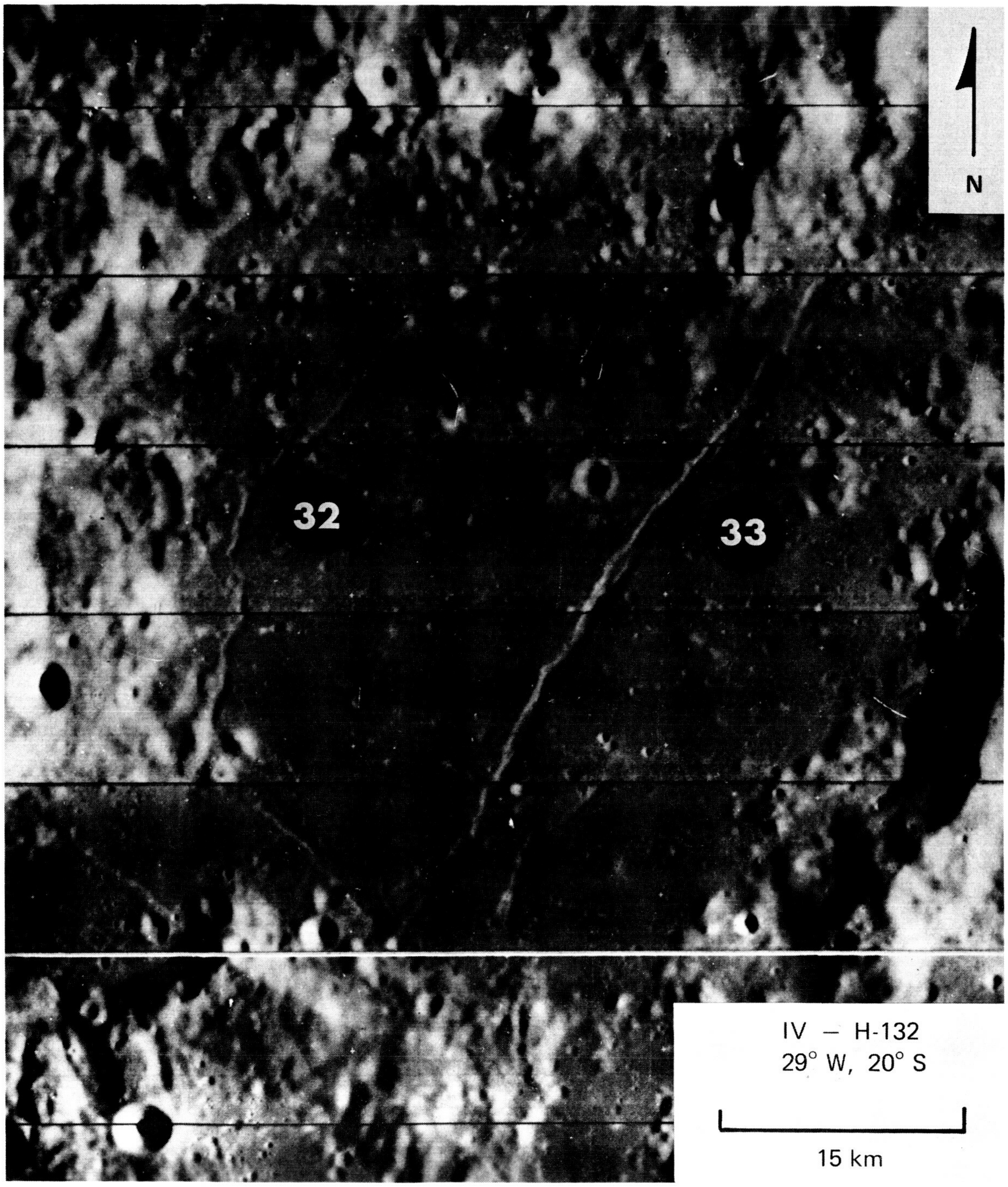

N
27
LO IV — H-116
6° E, 65° N
30 km


RIMA RÉAUMUR
LO IV – H-101
3° E, 3° S
25 km
N
28

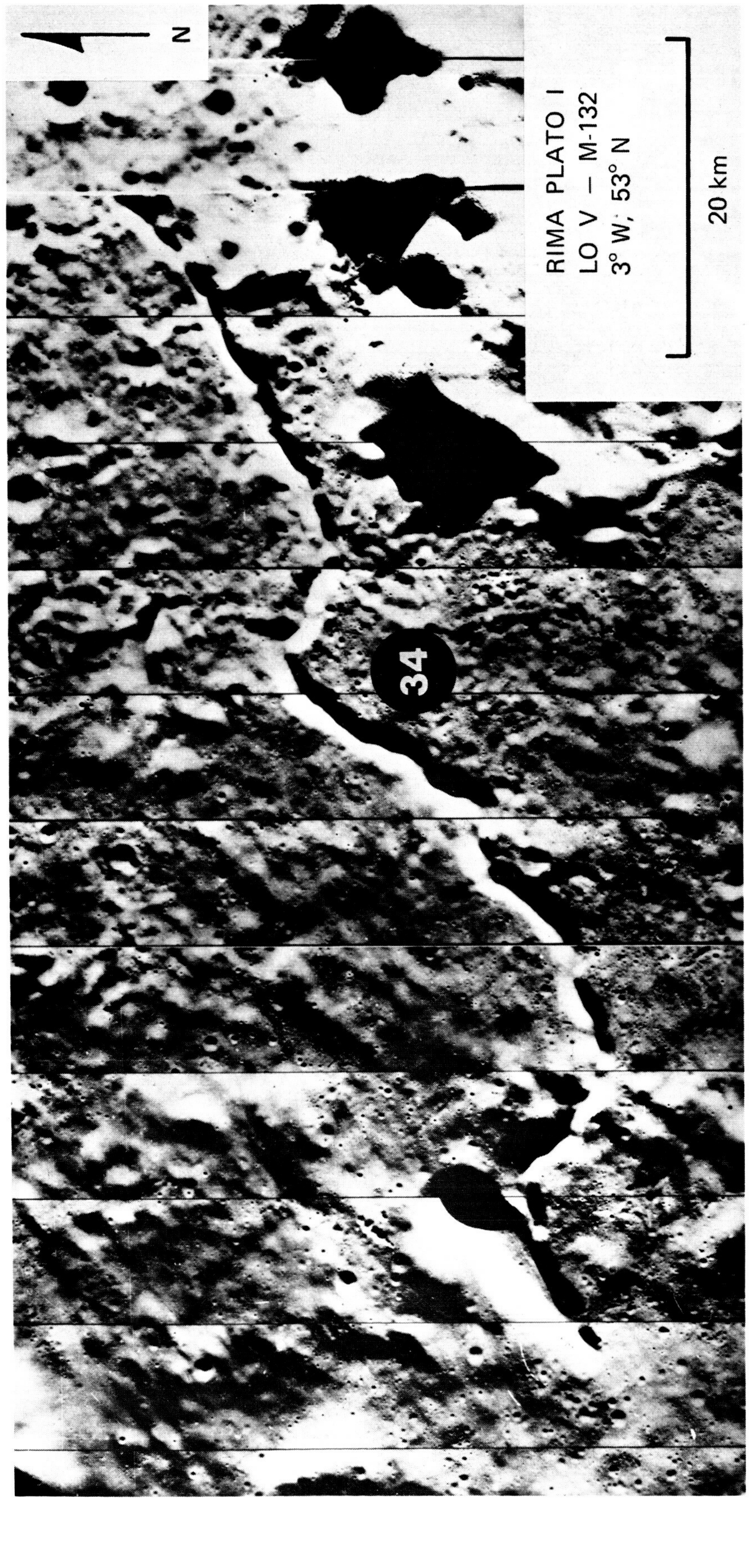

N
29
LO IV— H-92
24° E, 58° N
50 km

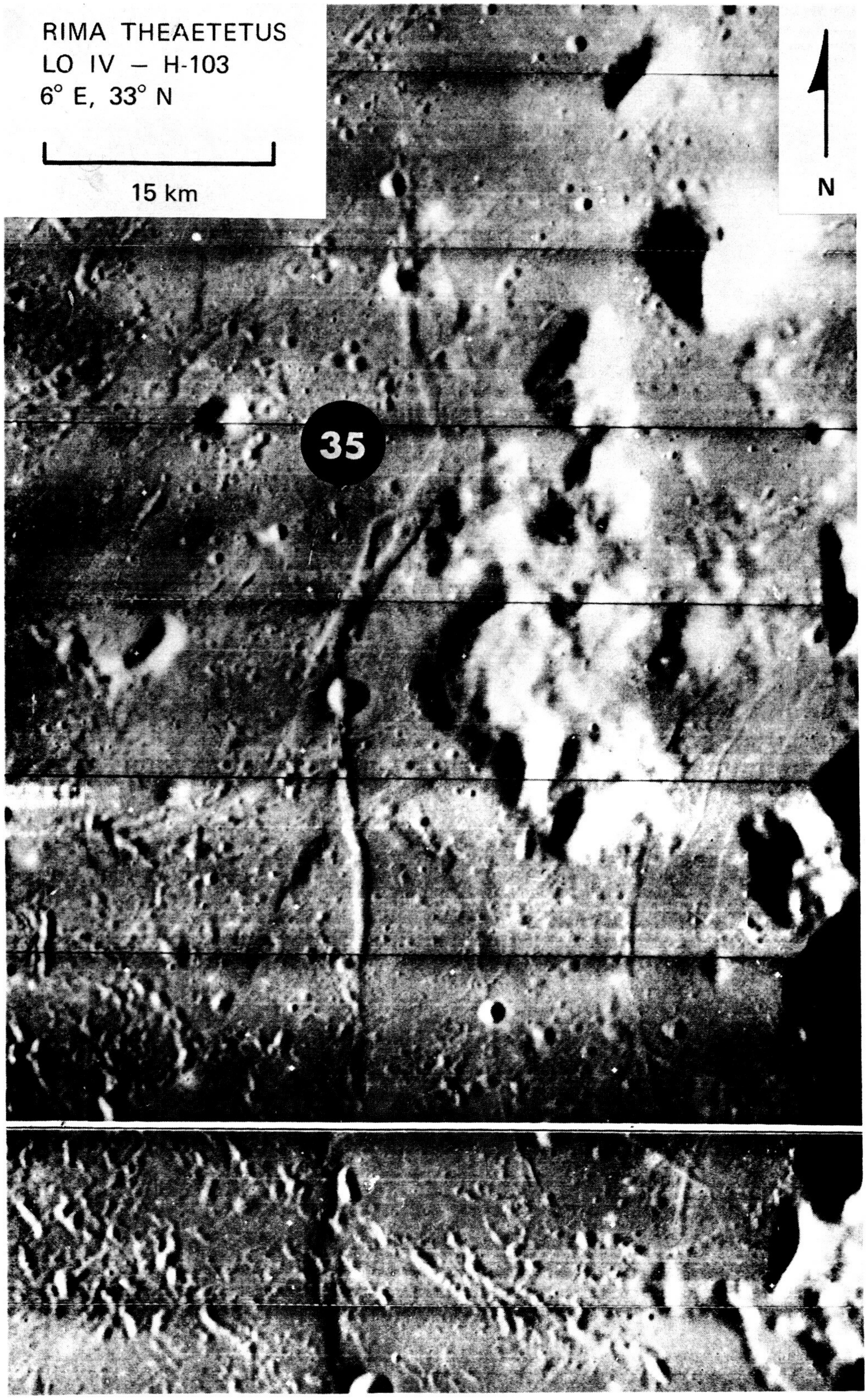

LO IV – H-183
79° W, 34° N
10 km
N
30

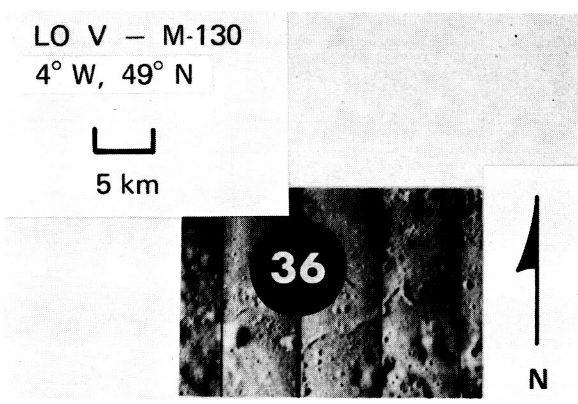

31
N
LO IV – H-78
29° W, 15° N
15 km

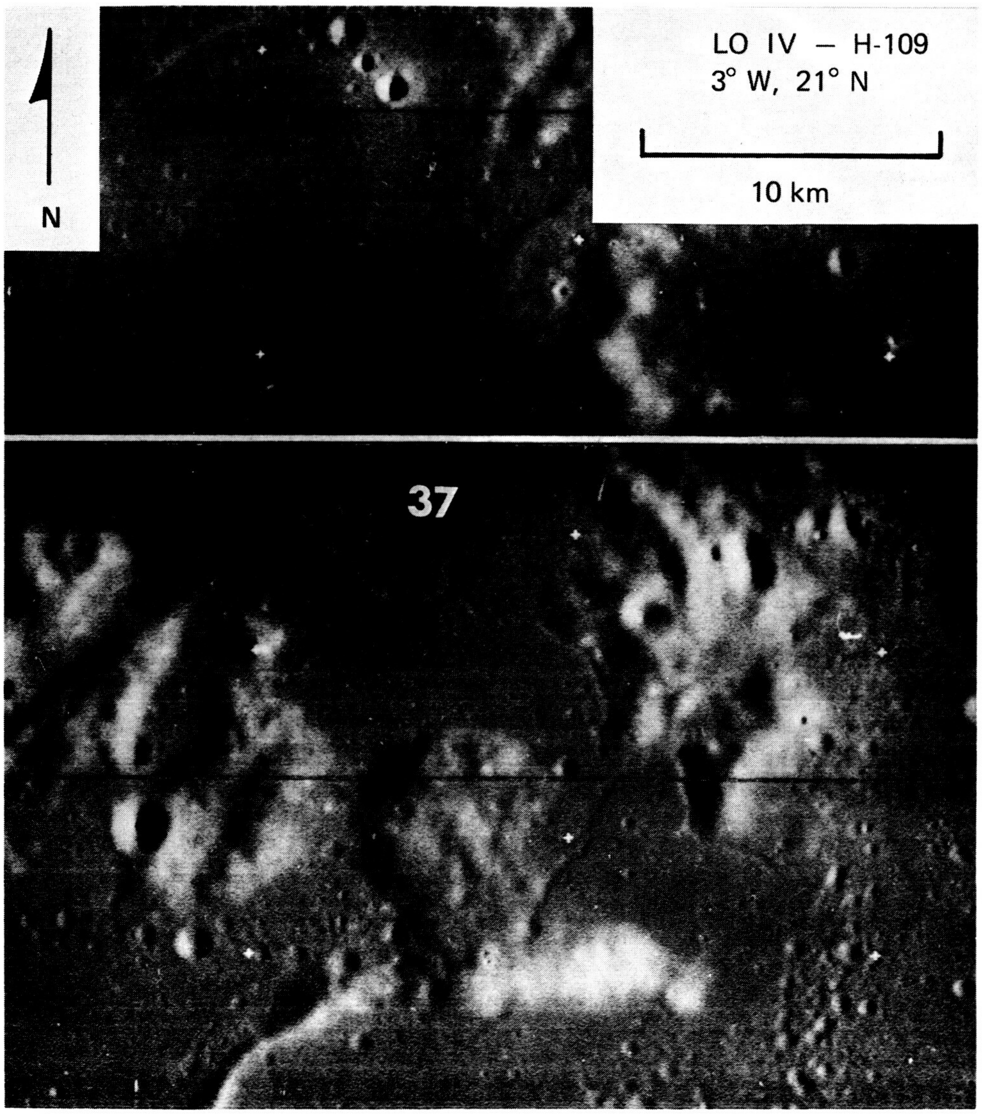


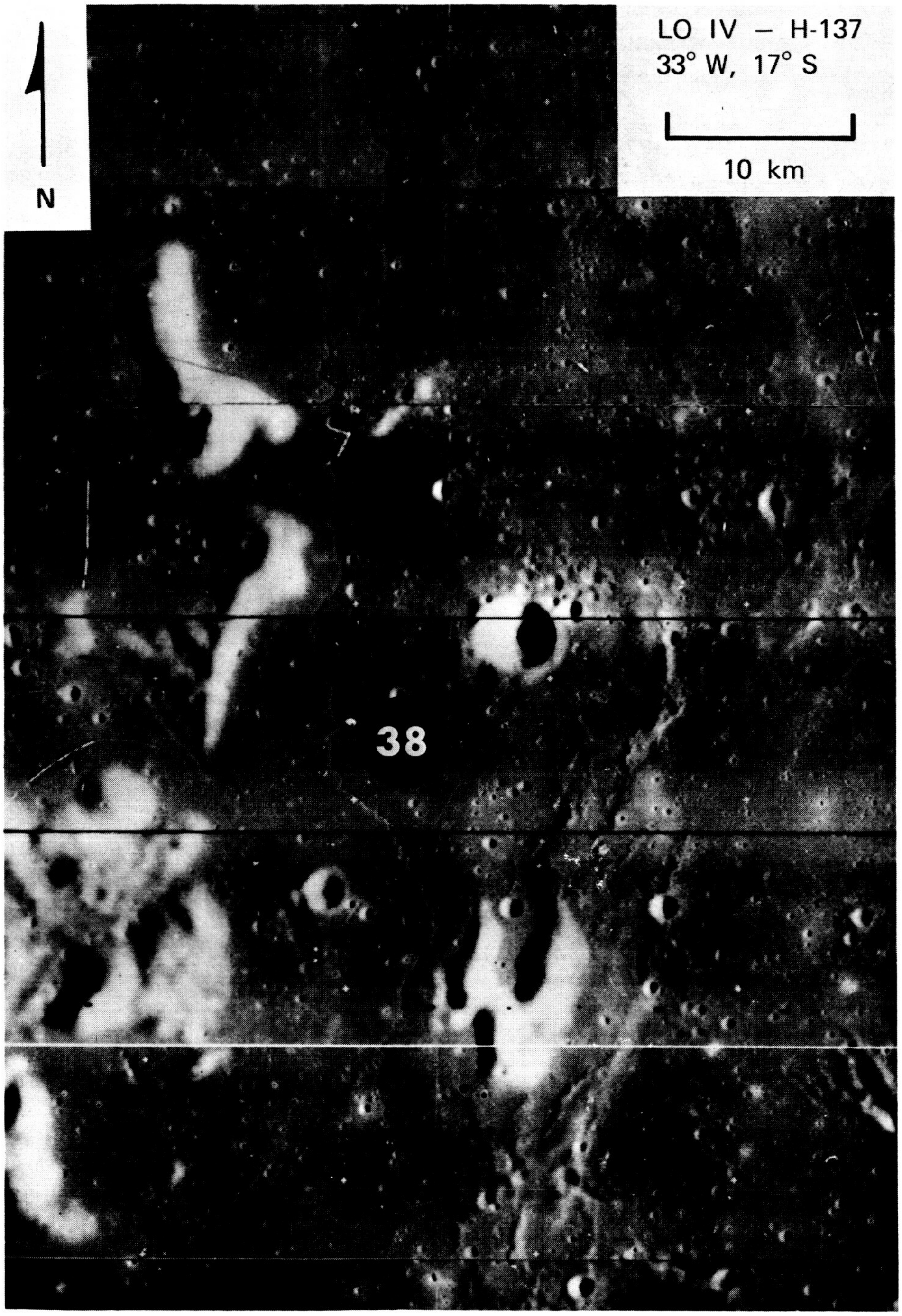
N
32
33
IV – H-132
29° W, 20° S
15 km

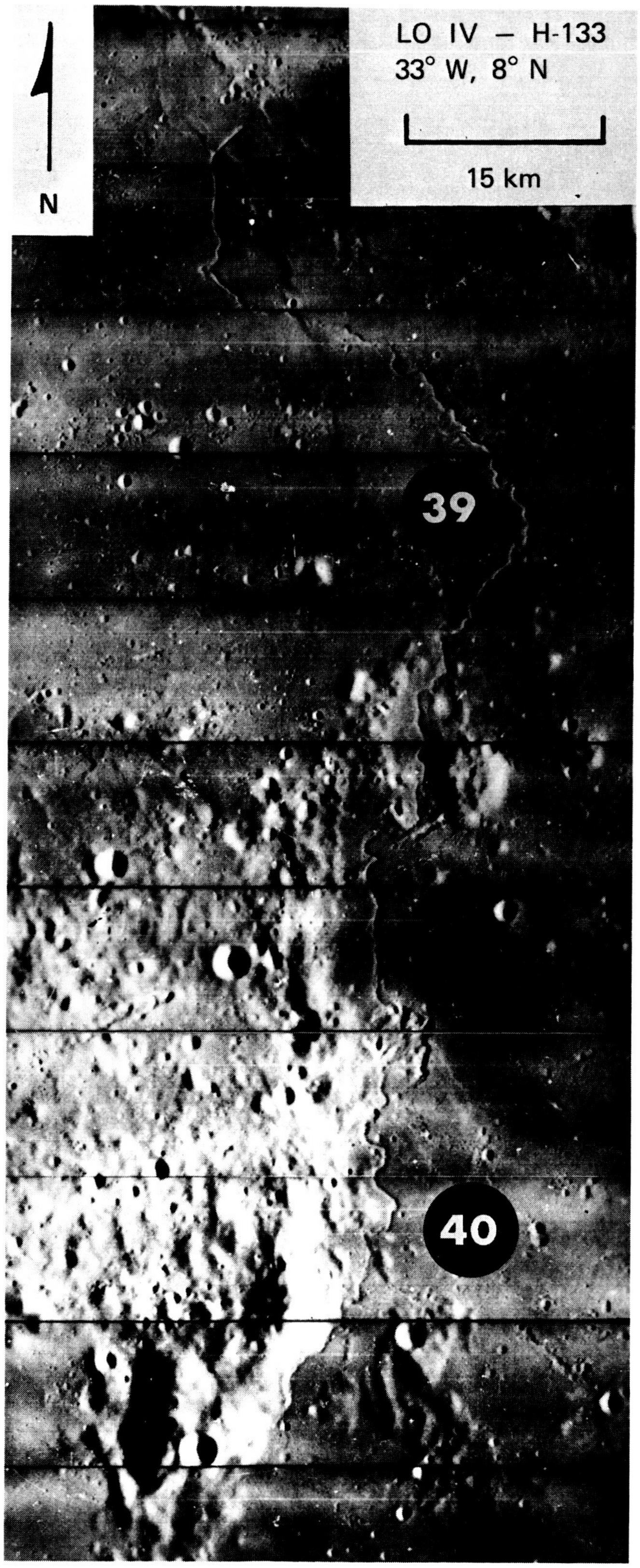

N
RIMA PLATO I
LO V — M-132
3° W; 53° N
20 km
34

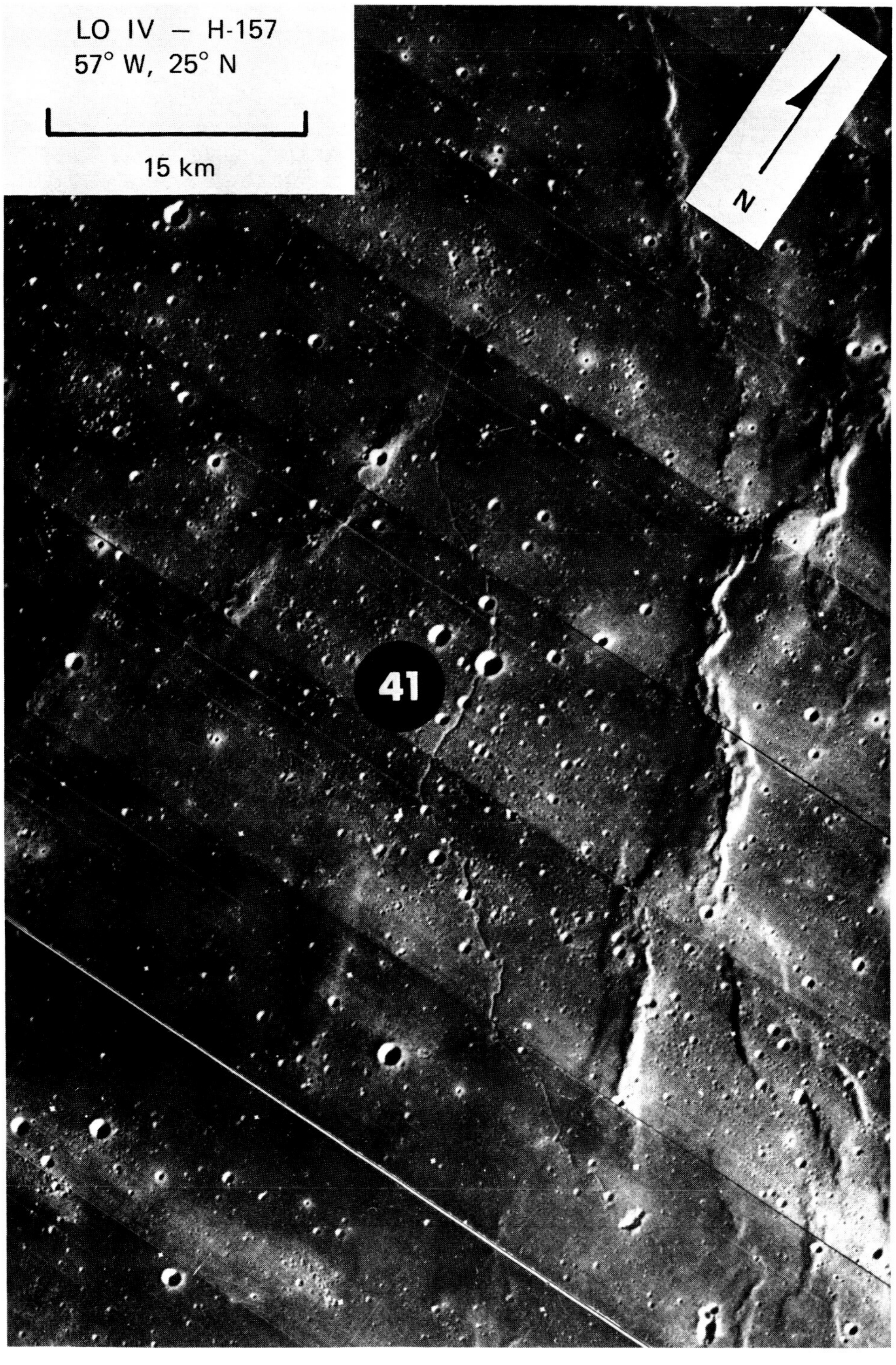

RIMA THEAETETUS
LO IV – H-103
6° E, 33° N
15 km
N
35

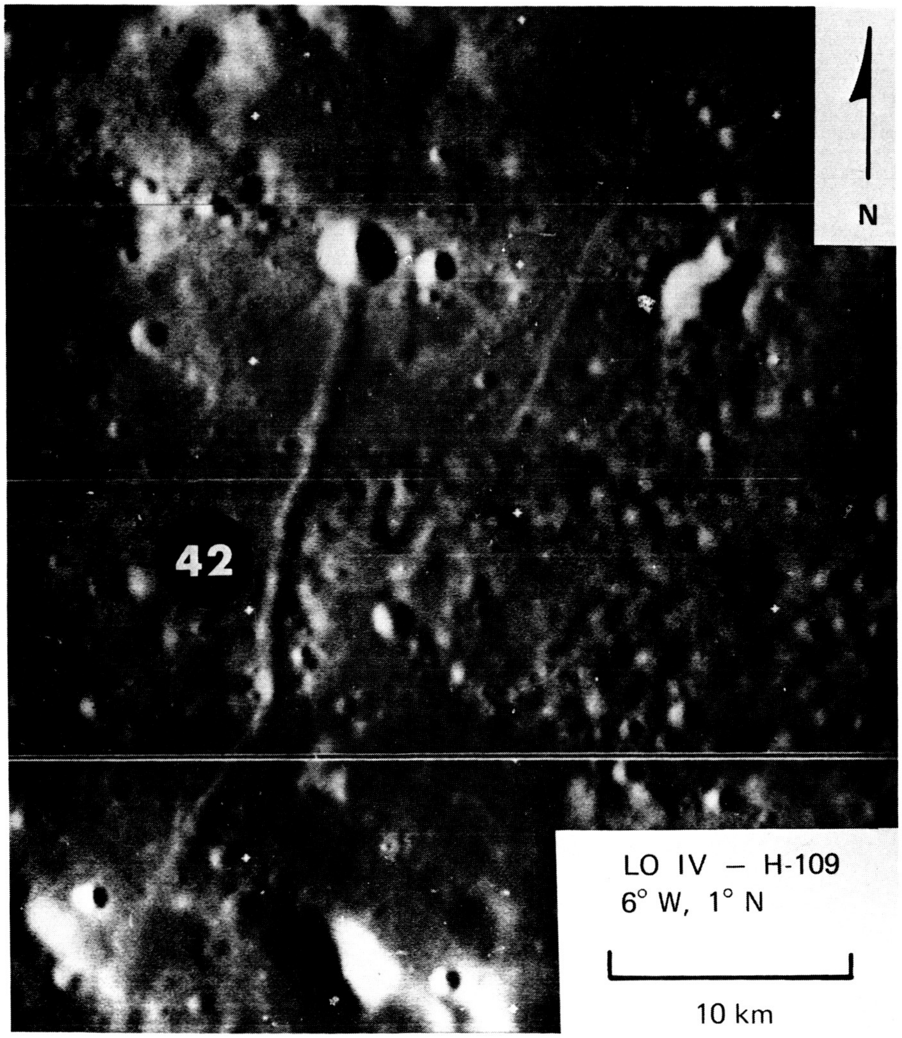

LO V – M-130
4° W, 49° N
5 km
36
N


N
LO IV – H-109
3° W, 21° N
10 km
37

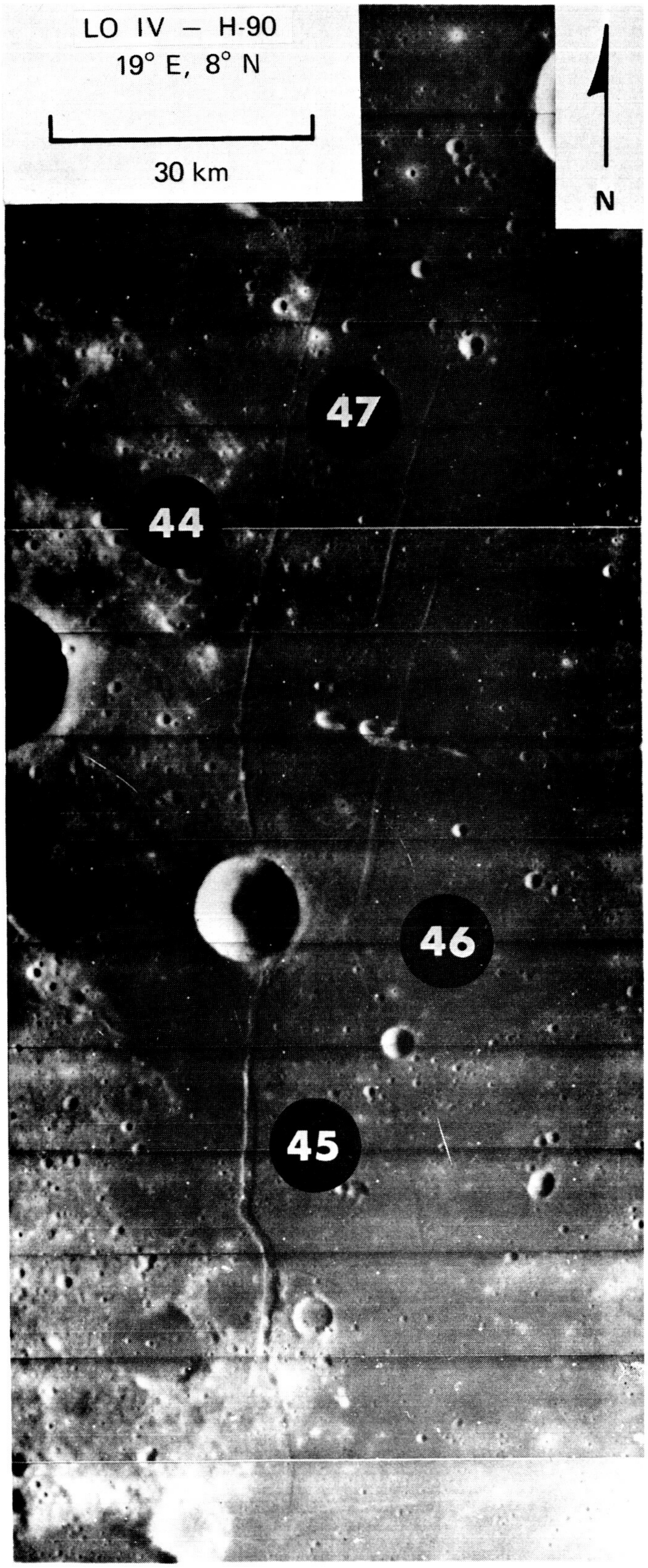

LO IV – H-137
33° W, 17° S
10 km
N
38

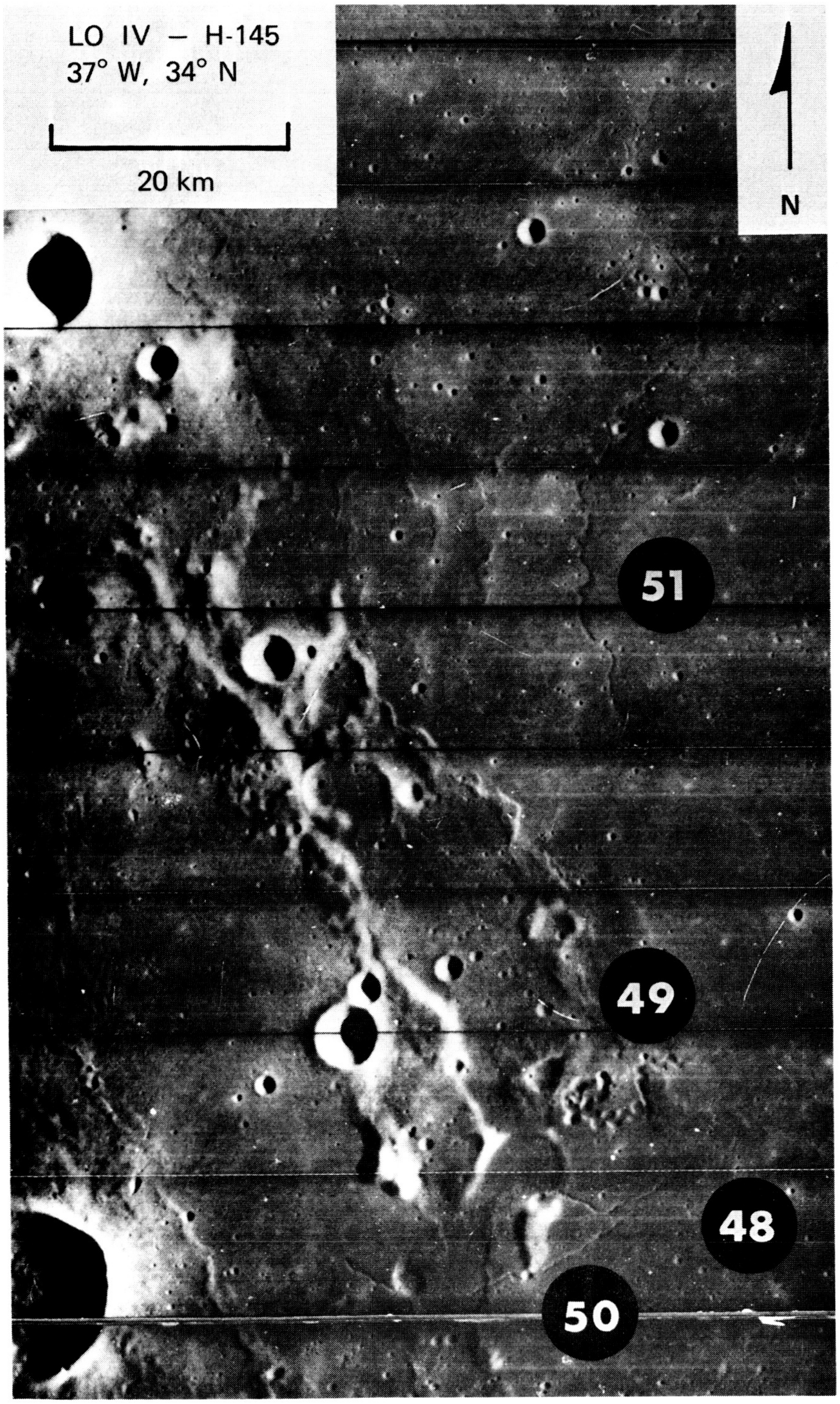

LO IV – H-133
33° W, 8° N
15 km
N
39
40

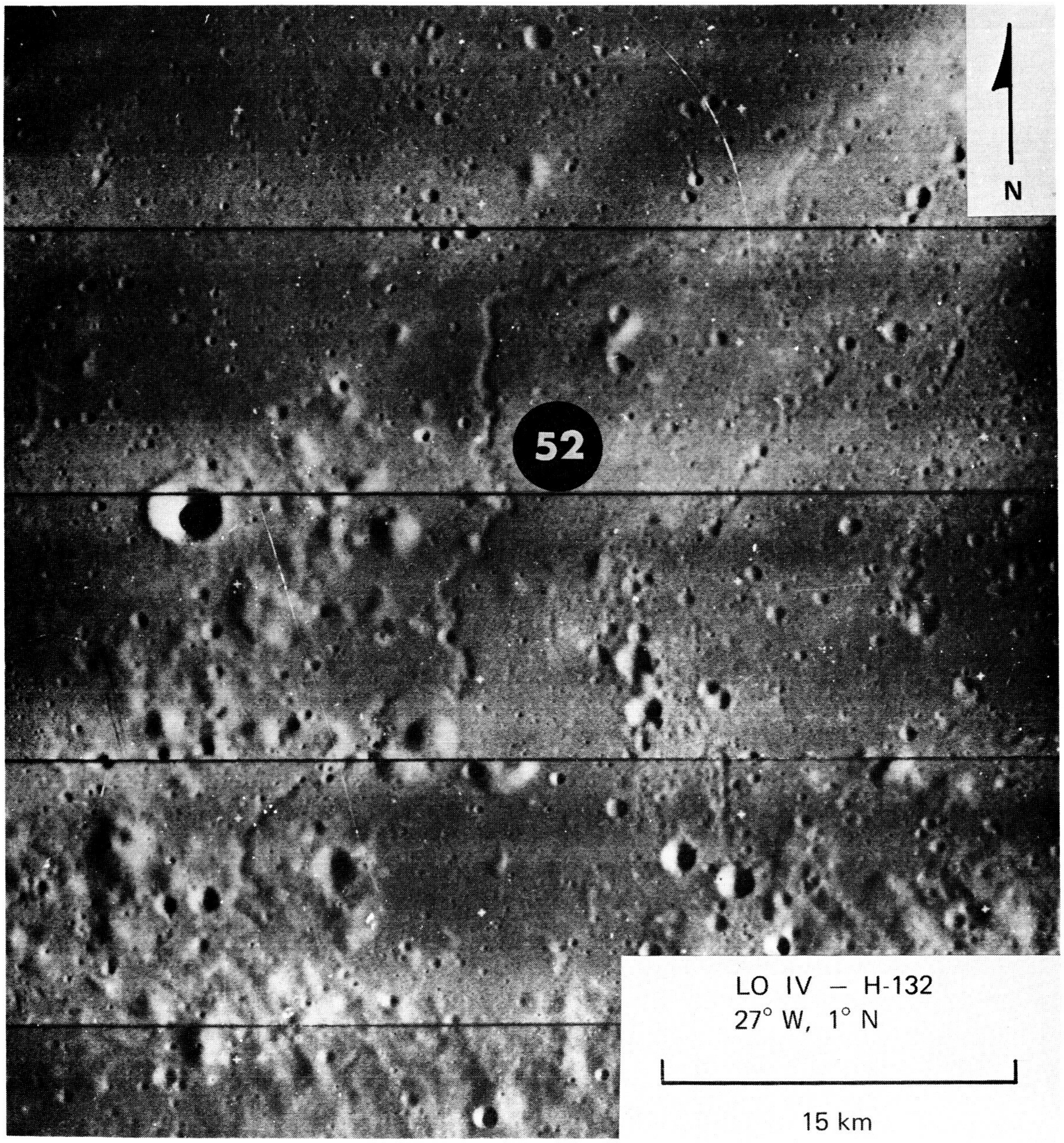

LO IV – H-157
57° W, 25° N
15 km
N
41

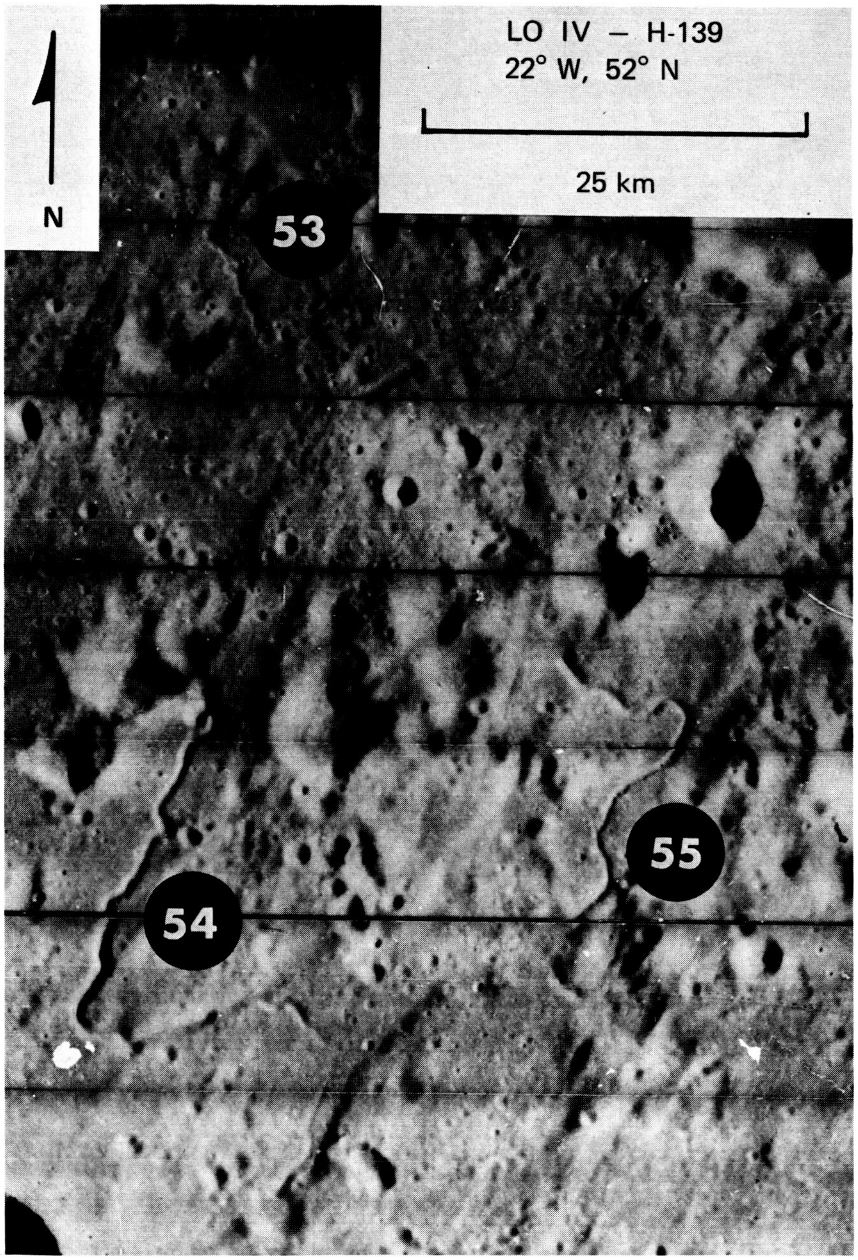

N
42
LO IV – H-109
6° W, 1° N
10 km

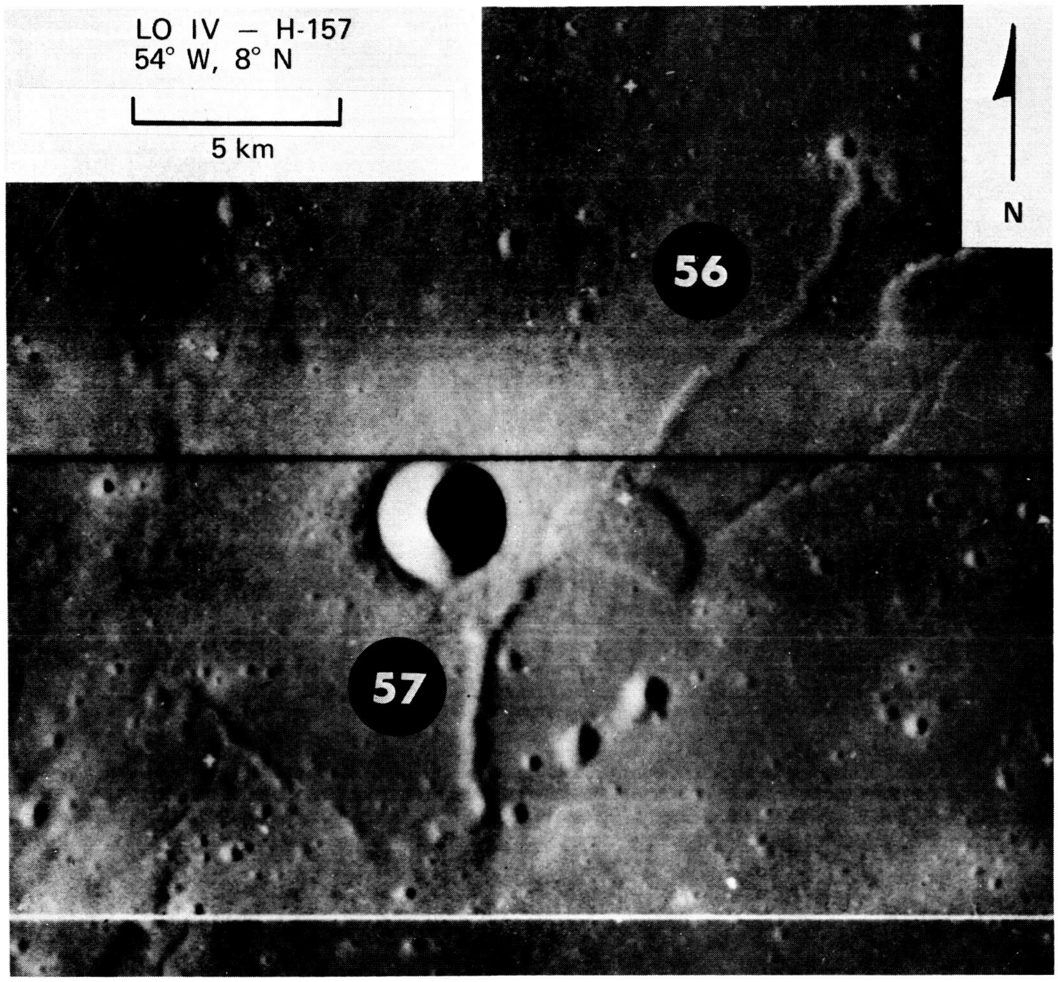

LO V – M-166
31° W, 13° N
15 km
N
43

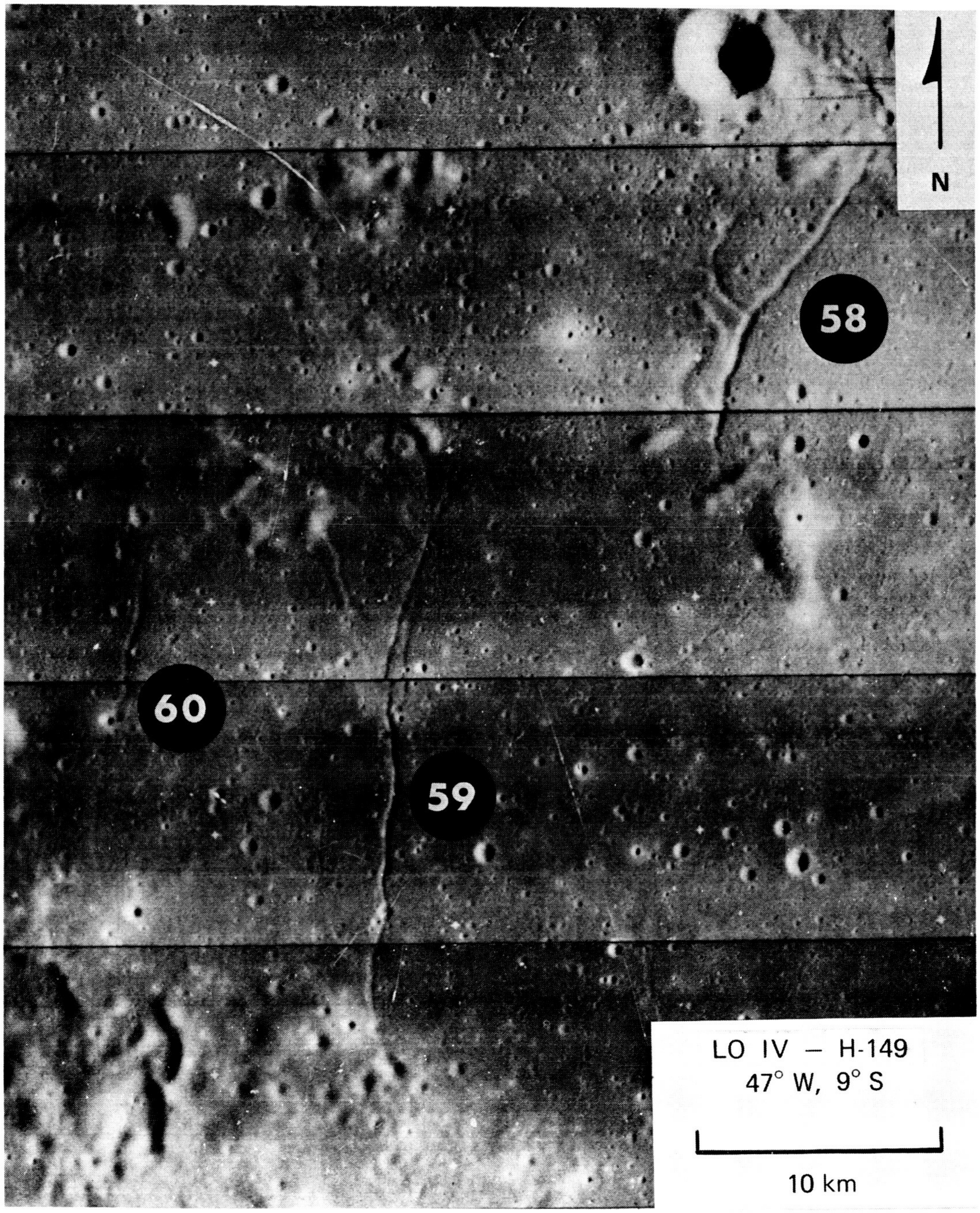

LO IV – H-90
19° E, 8° N
30 km
N
47
44
46
45

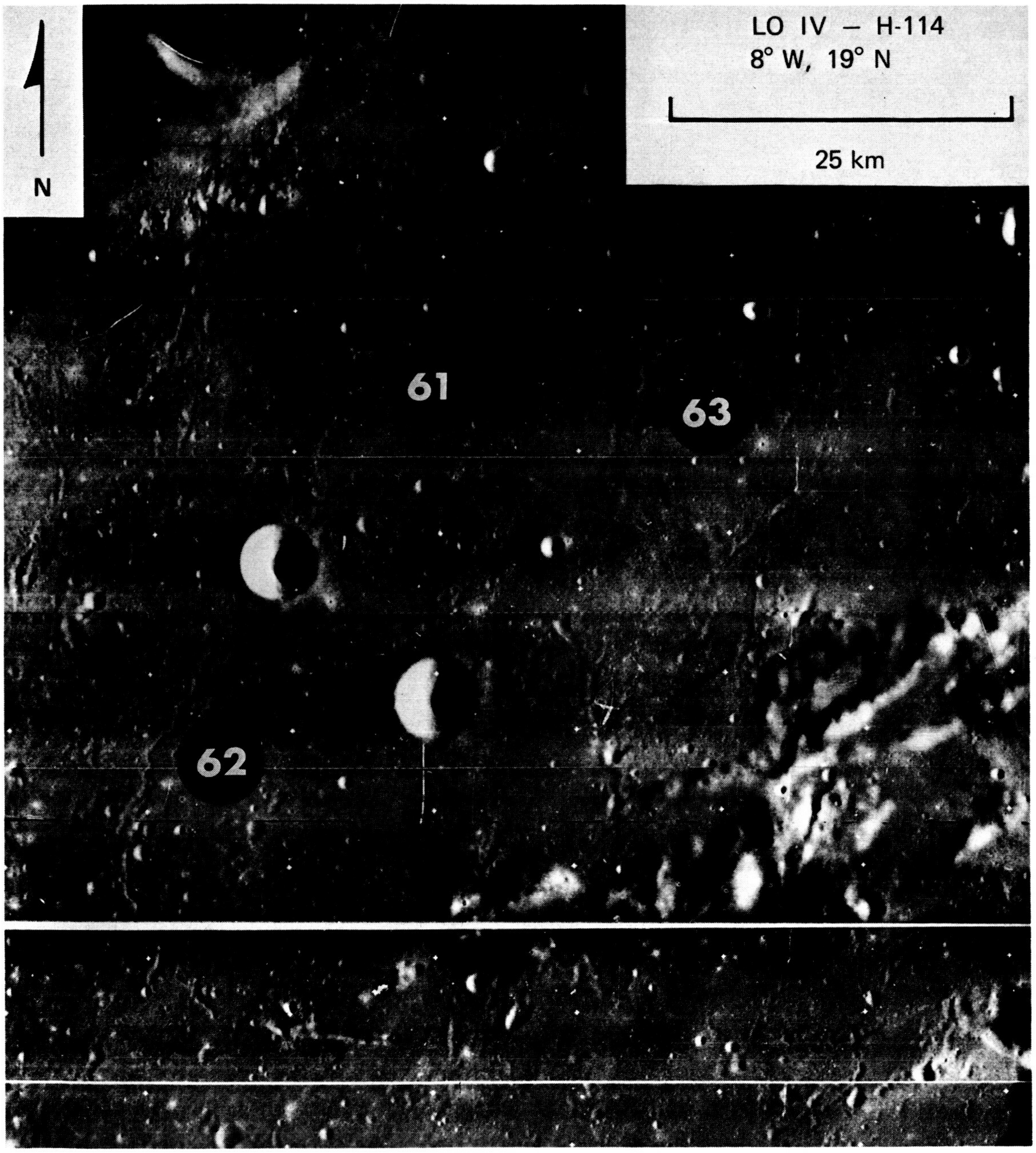

LO IV – H-145
37° W, 34° N
20 km
N
51
49
48
50

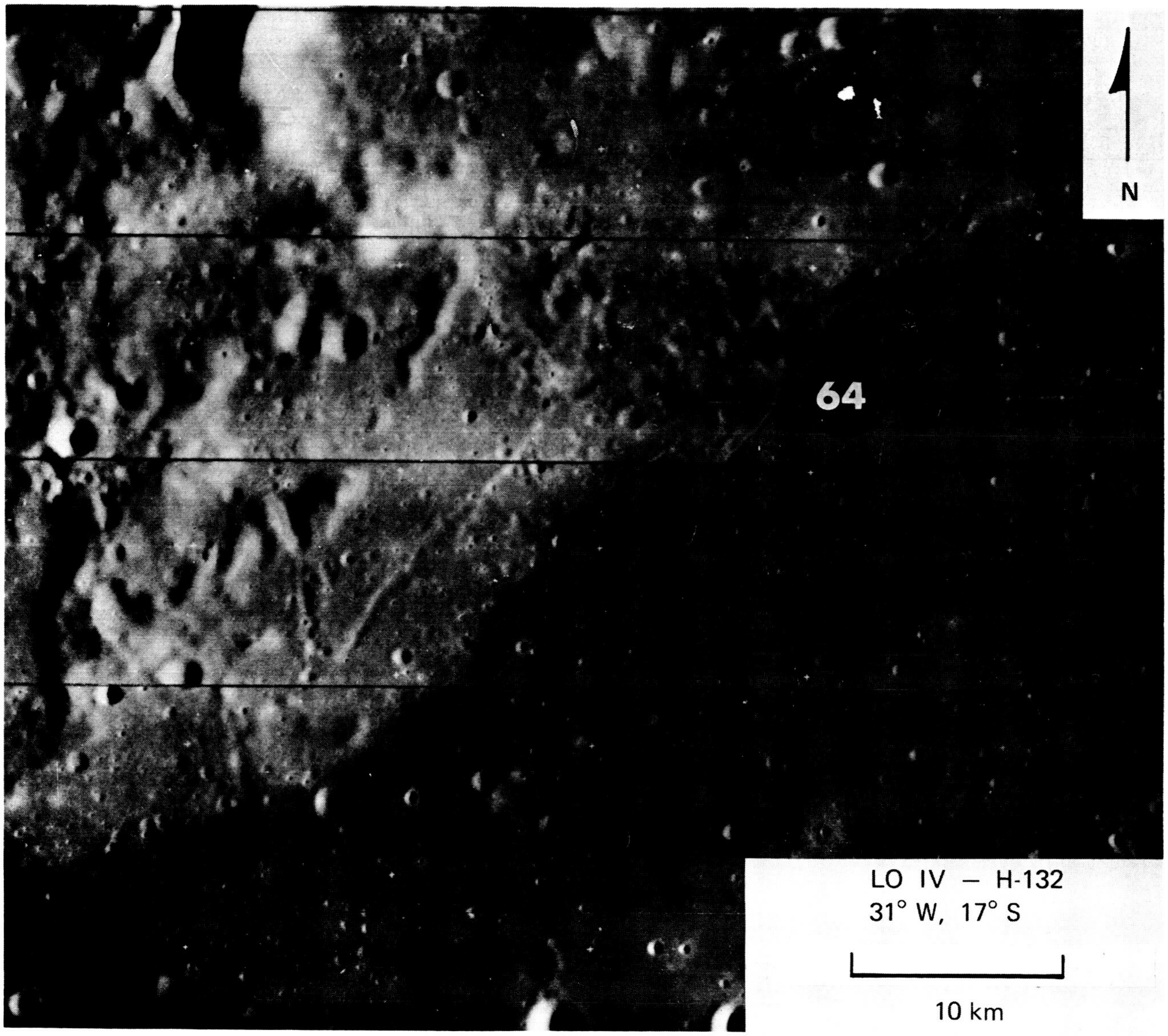

N
52
LO IV – H-132
27° W, 1° N
15 km

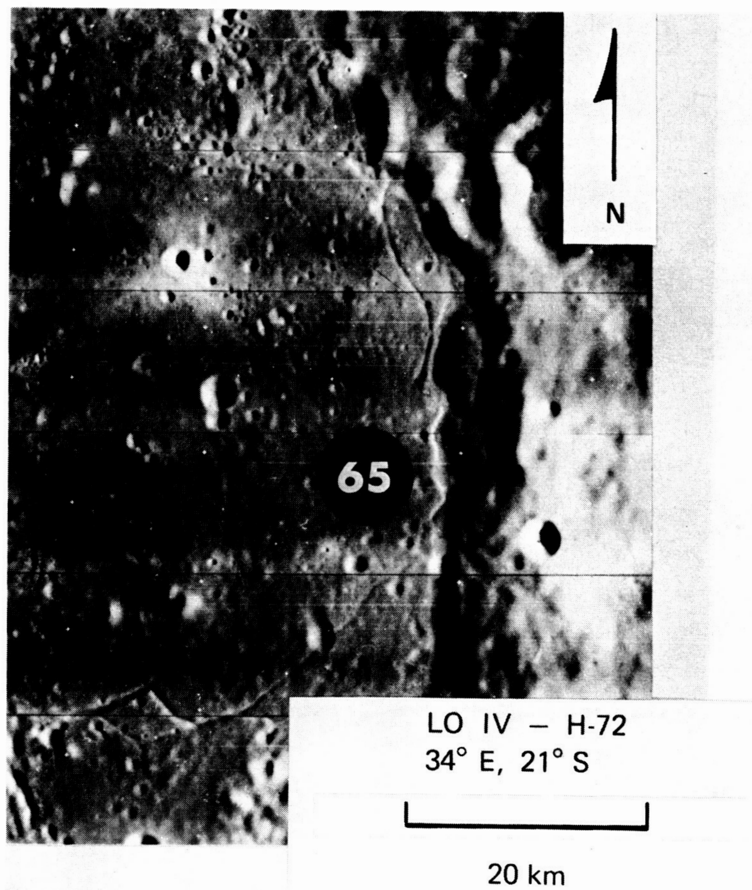

LO IV – H-139
22° W, 52° N
25 km
N
53
54
55

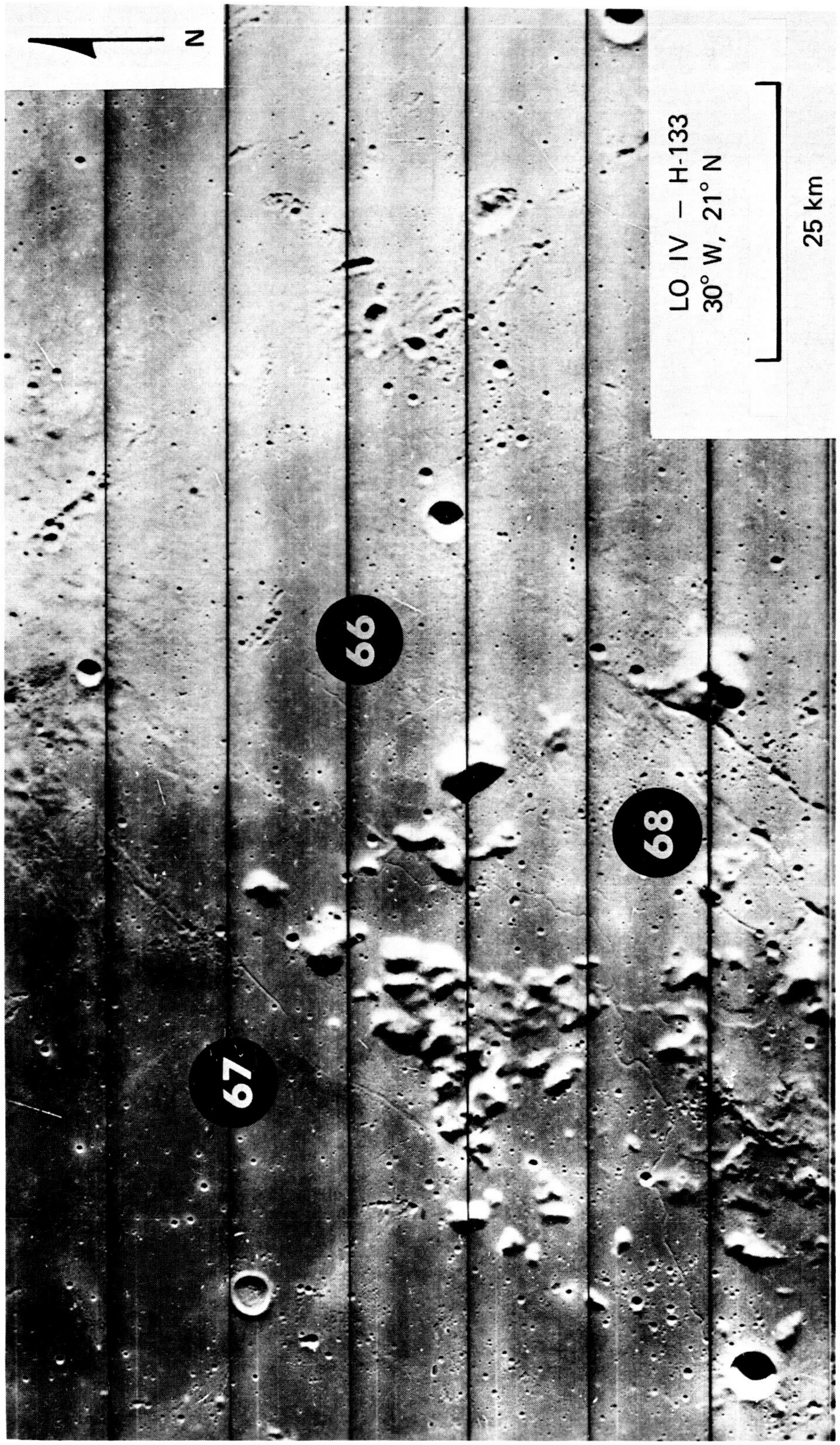

LO IV – H-157
54° W, 8° N
5 km
N
56
57

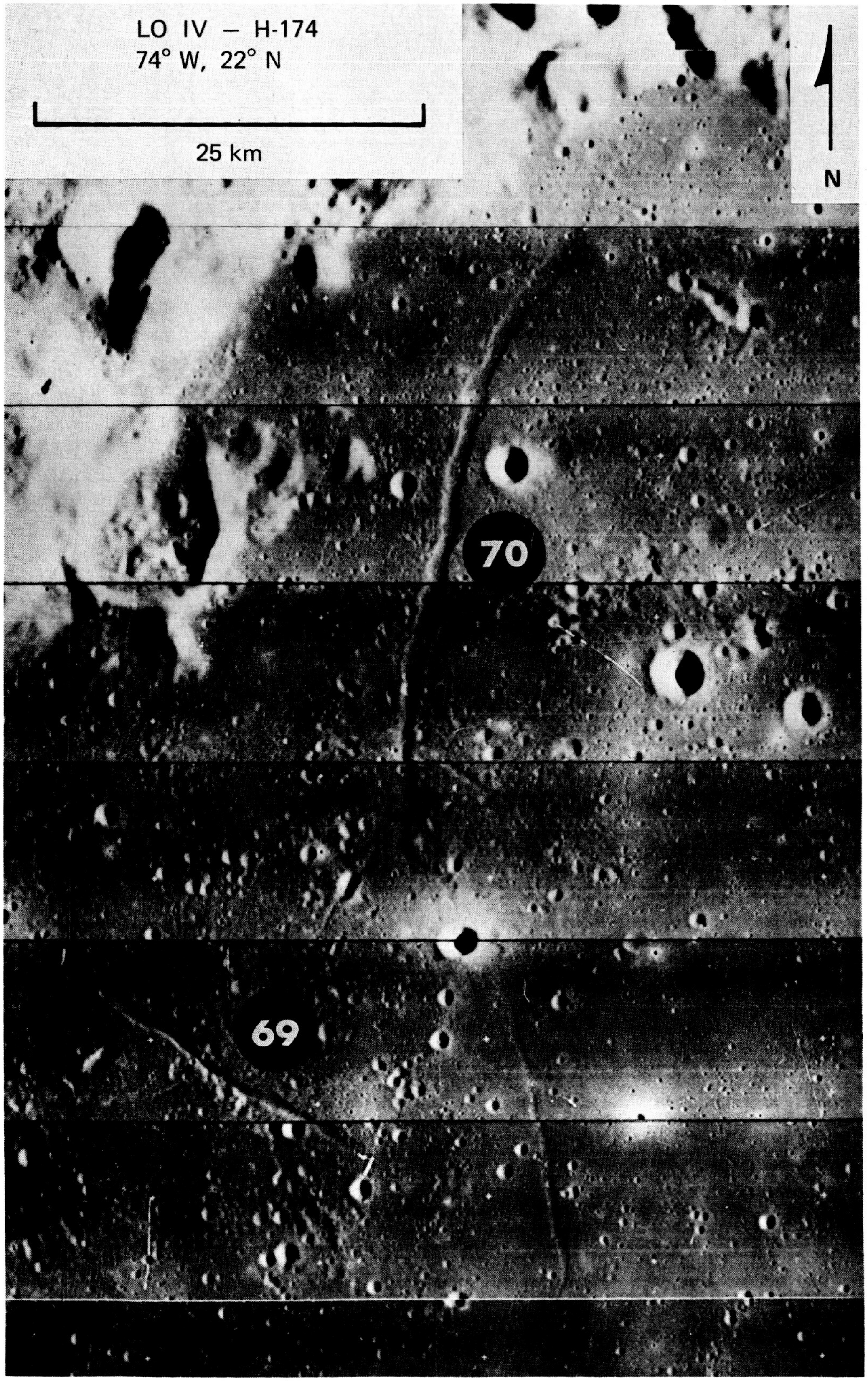

N
58
60
59
LO IV – H-149
47° W, 9° S
10 km

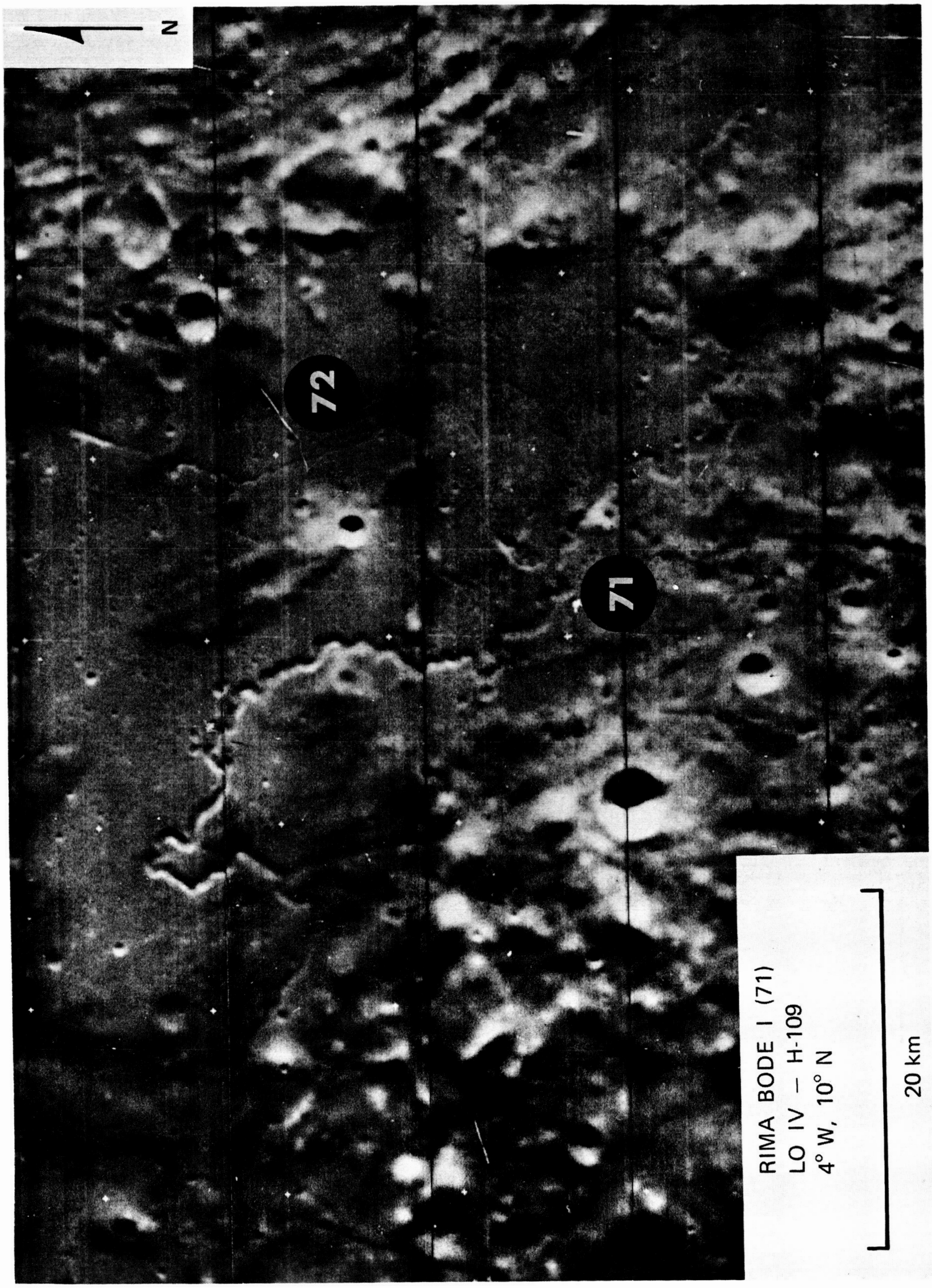

LO IV – H-114
8° W, 19° N
25 km
N
61
63
62


N
64
LO IV — H-132
31° W, 17° S
10 km


N
65
LO IV — H-72
34° E, 21° S
20 km

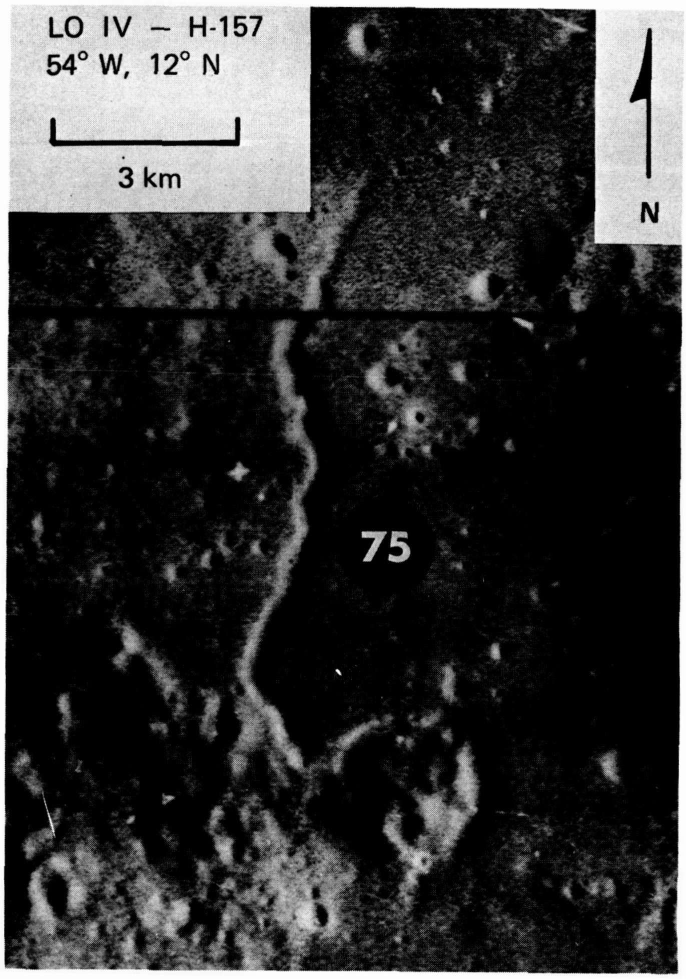

N
LO IV – H-133
30° W, 21° N
25 km
66
67
68

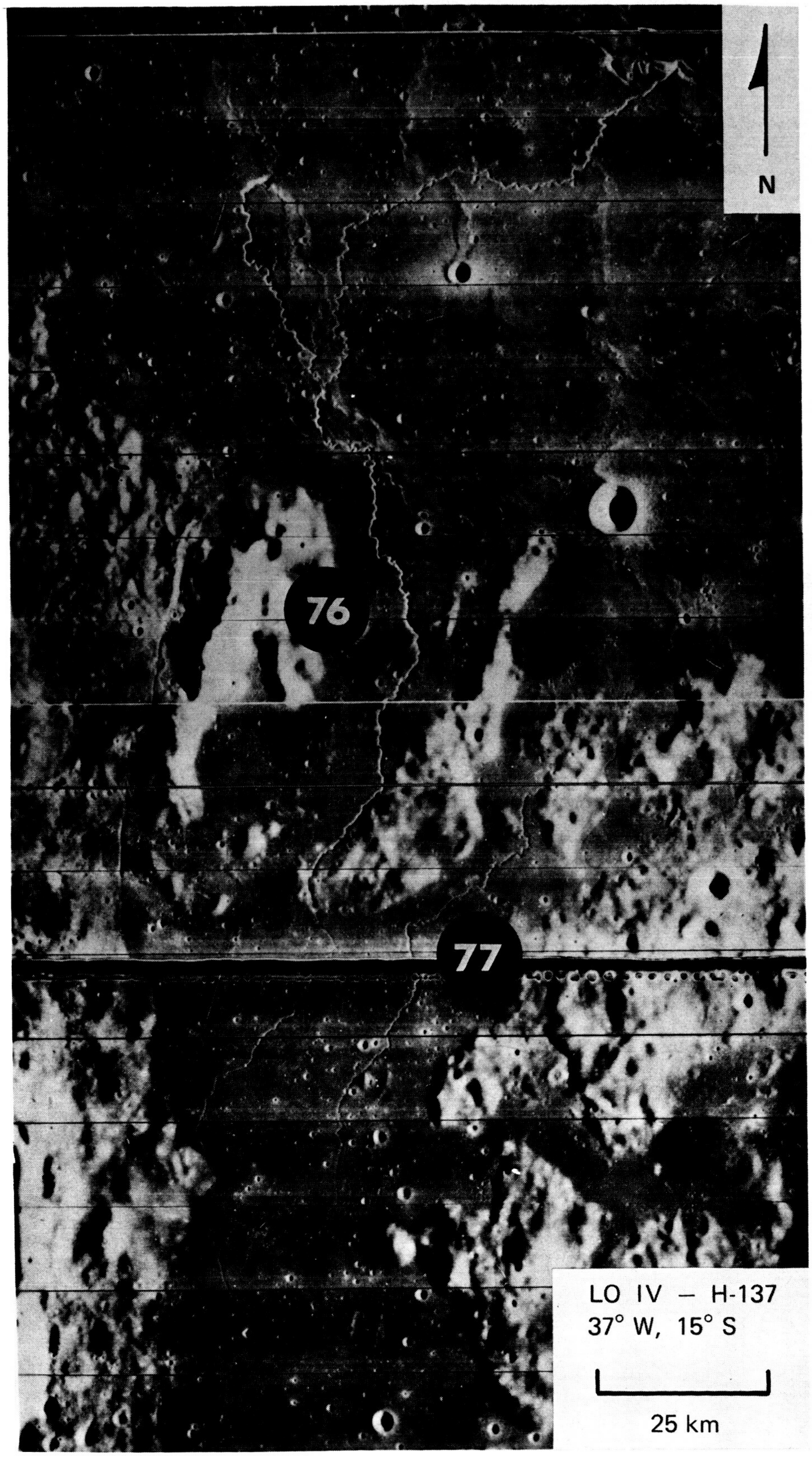

LO IV – H-174
74° W, 22° N
25 km
N
70
69

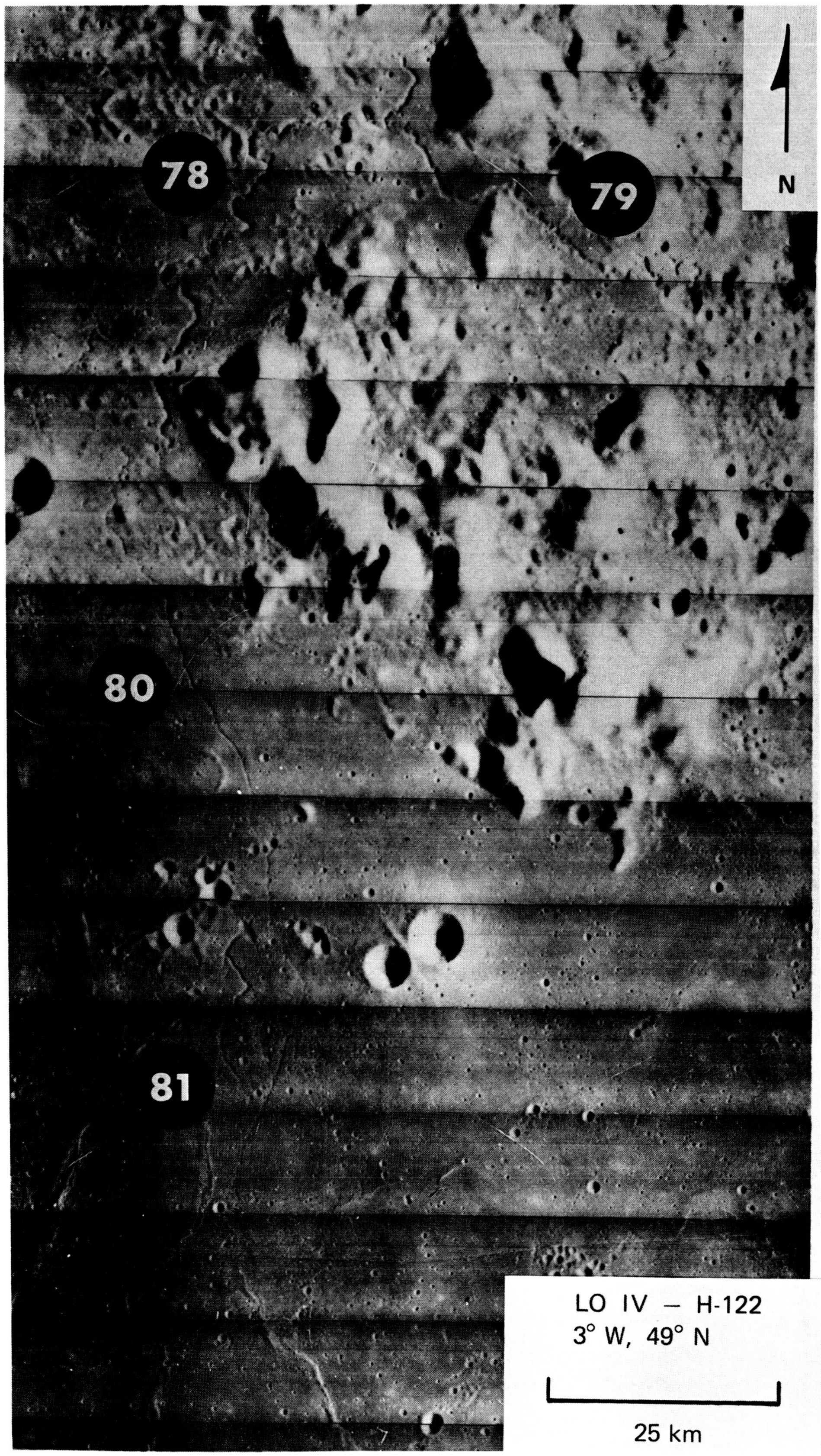


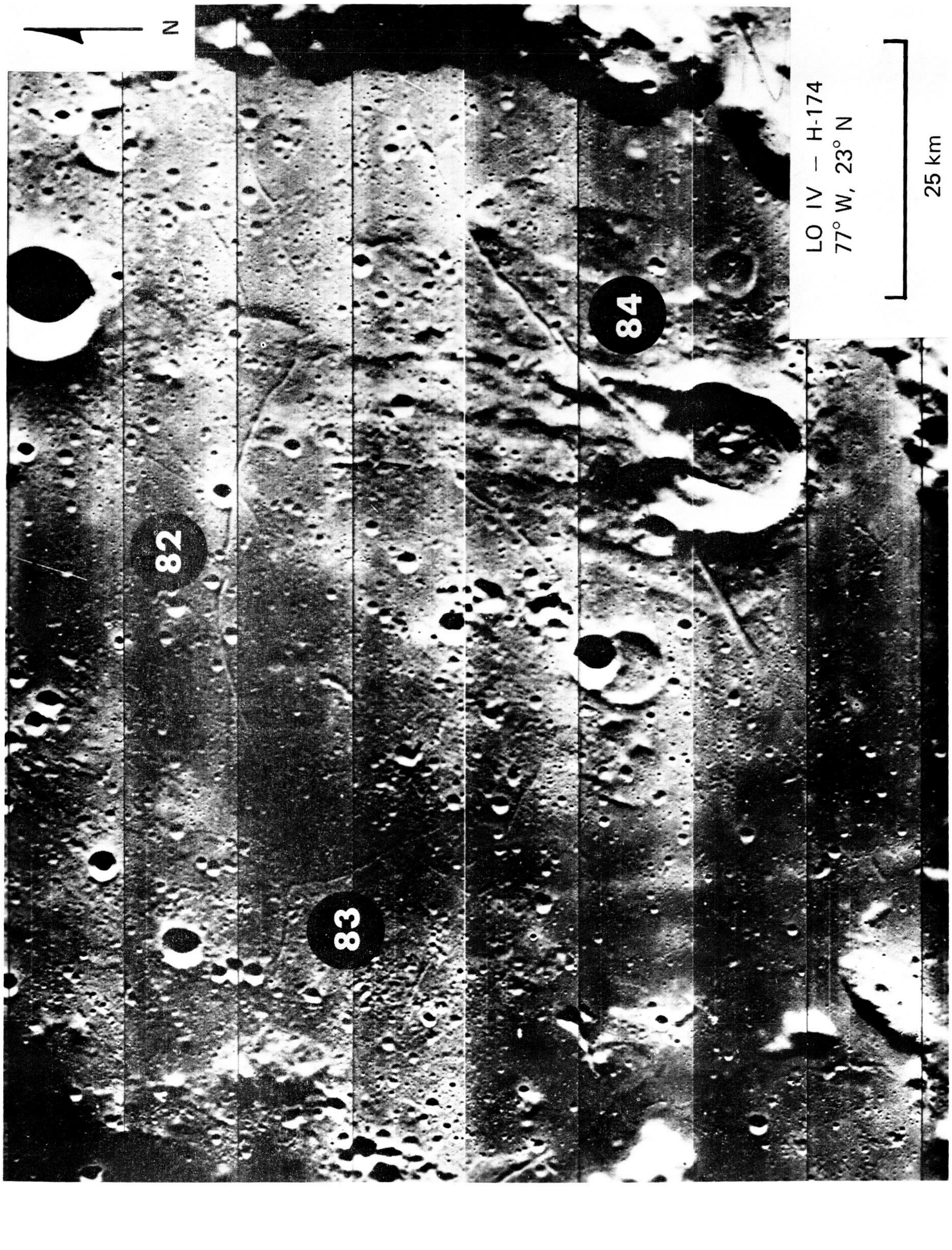
RIMA BODE I (71)
LO IV — H-109
4° W, 10° N

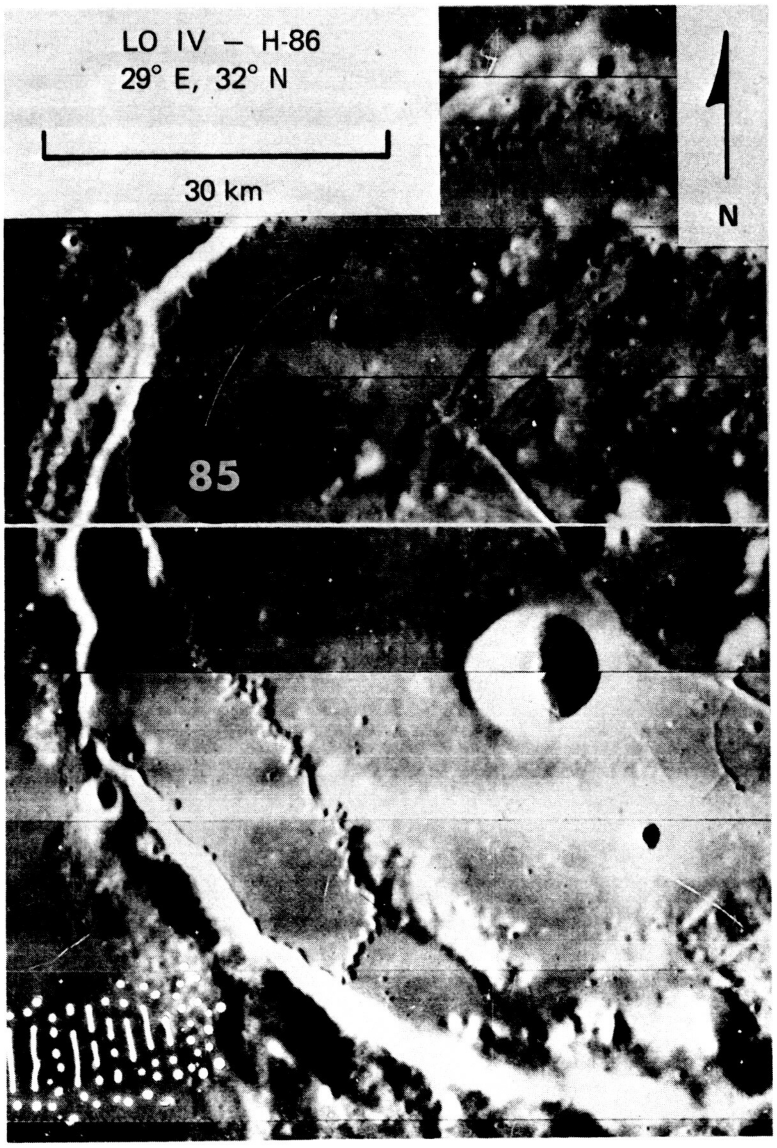

73
74
N
LO IV – H-139
33° W, 29° N
25 km

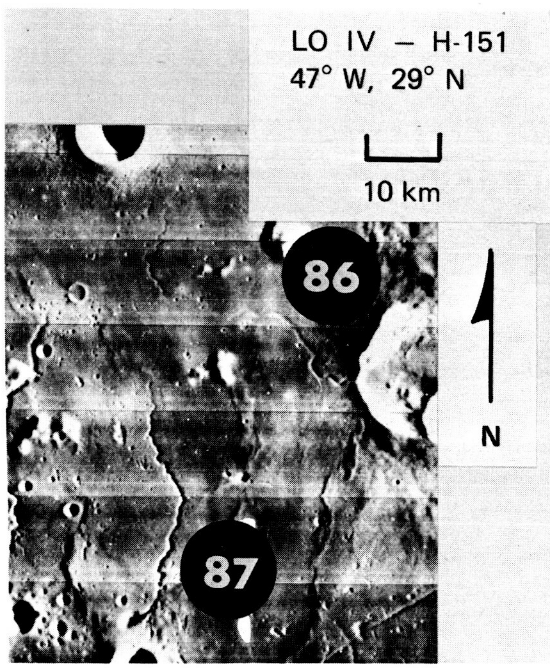

LO IV – H-157
54° W, 12° N
3 km
N
75

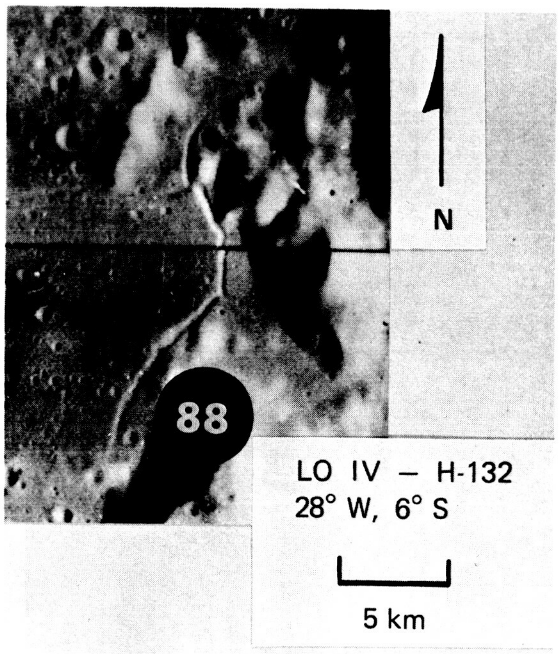

N
76
77
LO IV – H-137
37° W, 15° S
25 km

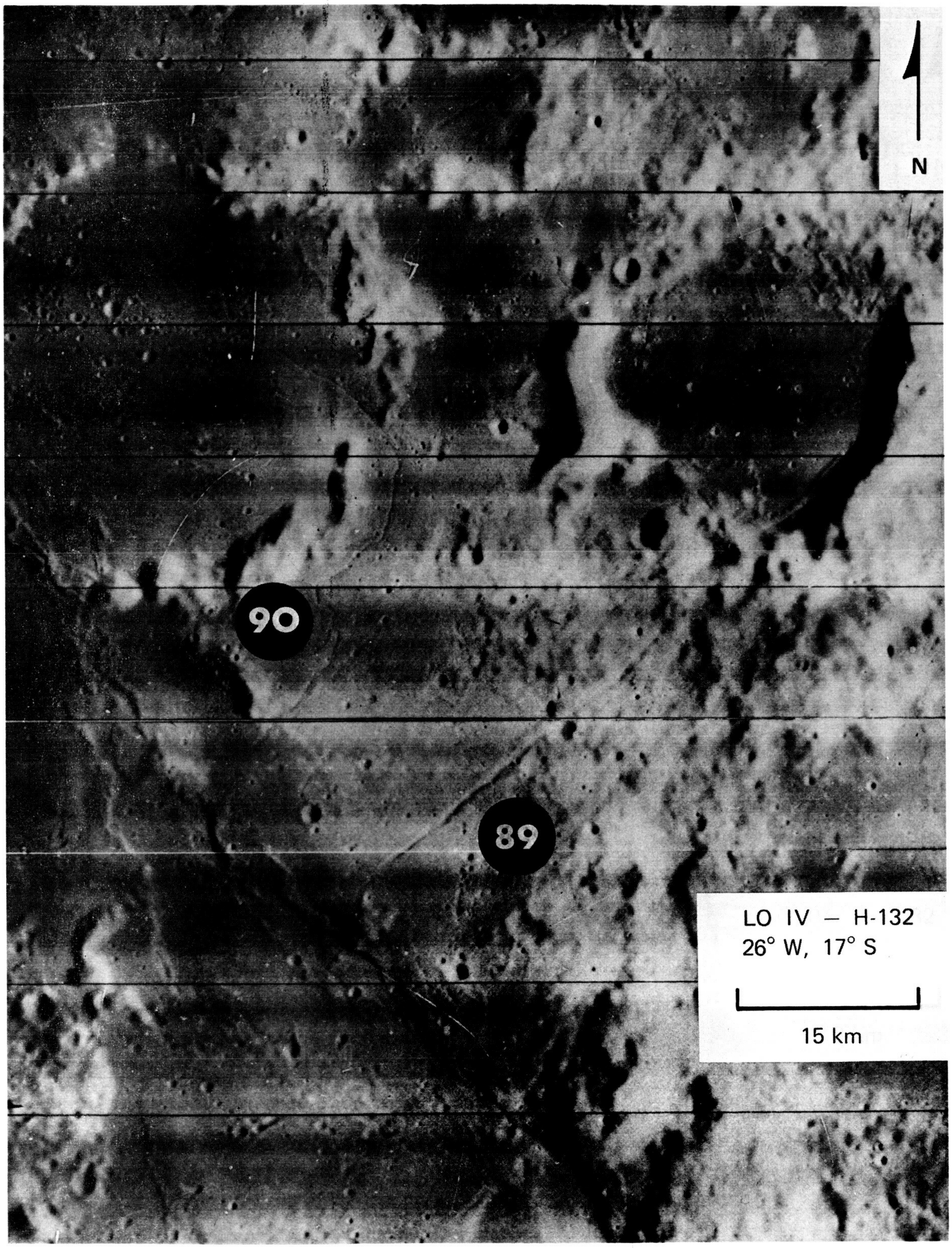

78
79
N
80
81
LO IV – H-122
3° W, 49° N
25 km


N
82
83
84
LO IV — H-174
77° W, 23° N
25 km


LO IV – H-86
29° E, 32° N
30 km
N
85

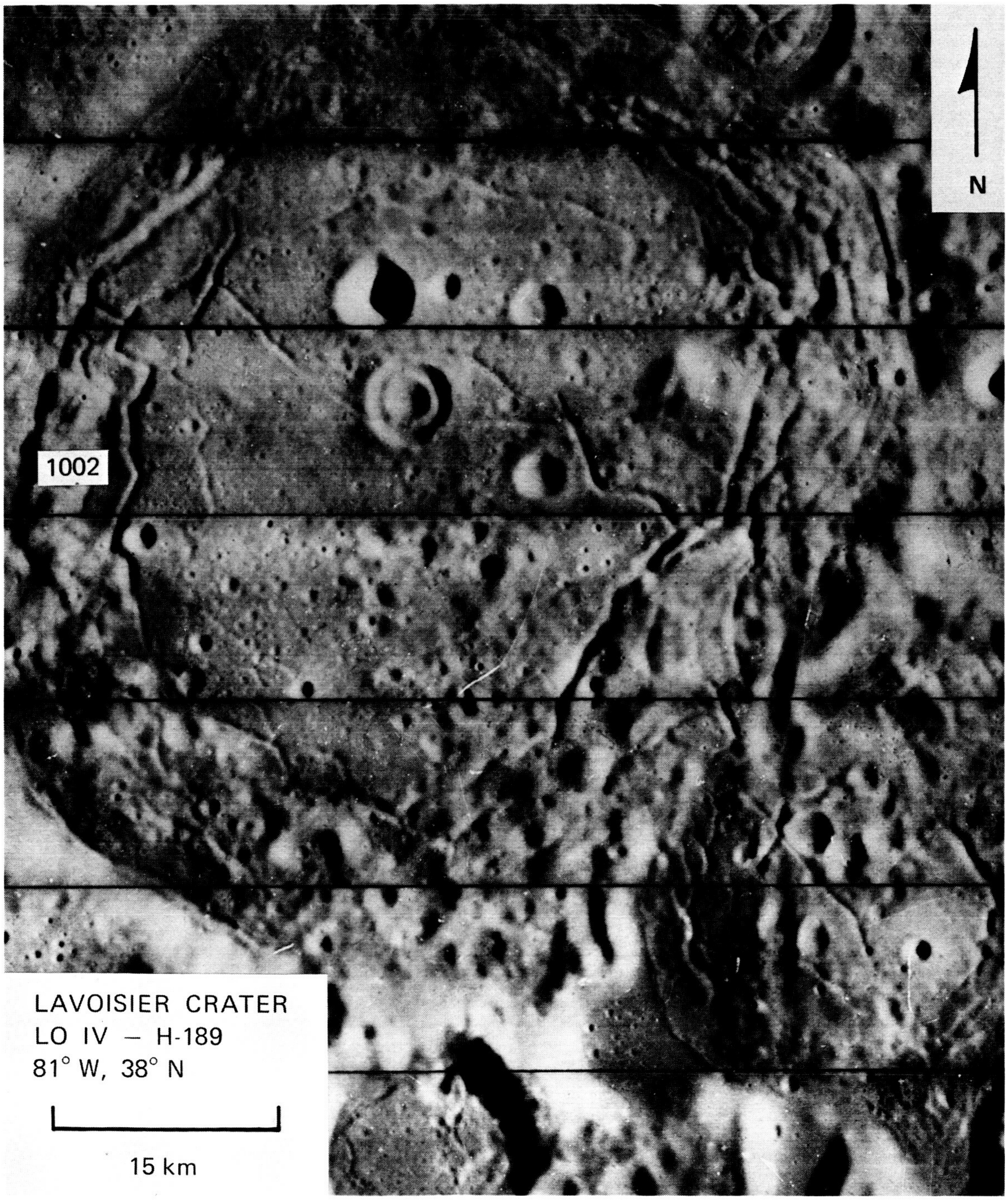

LO IV – H-151
47° W, 29° N
10 km
86
87
N

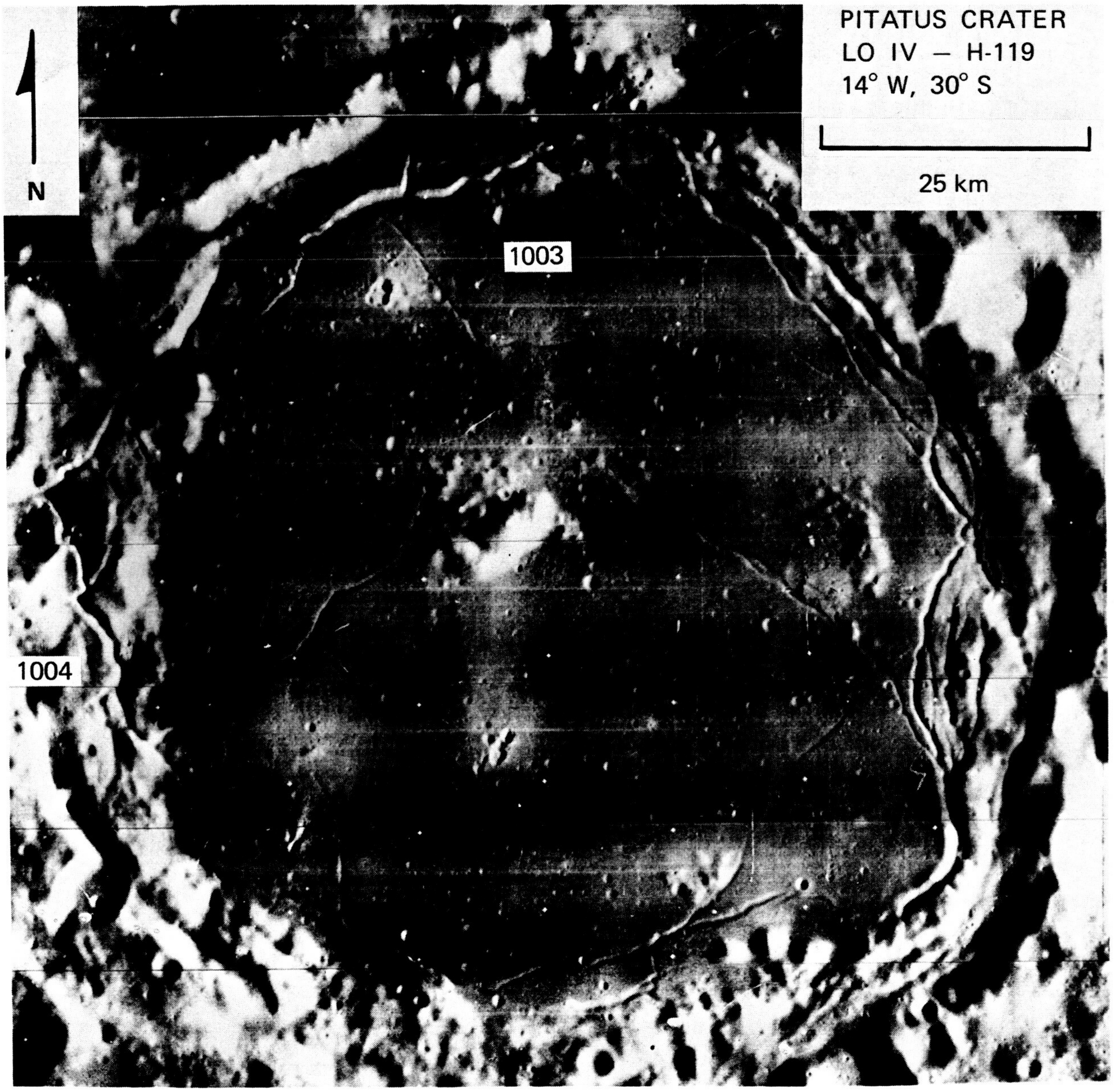

N
88
LO IV – H-132
28° W, 6° S
5 km

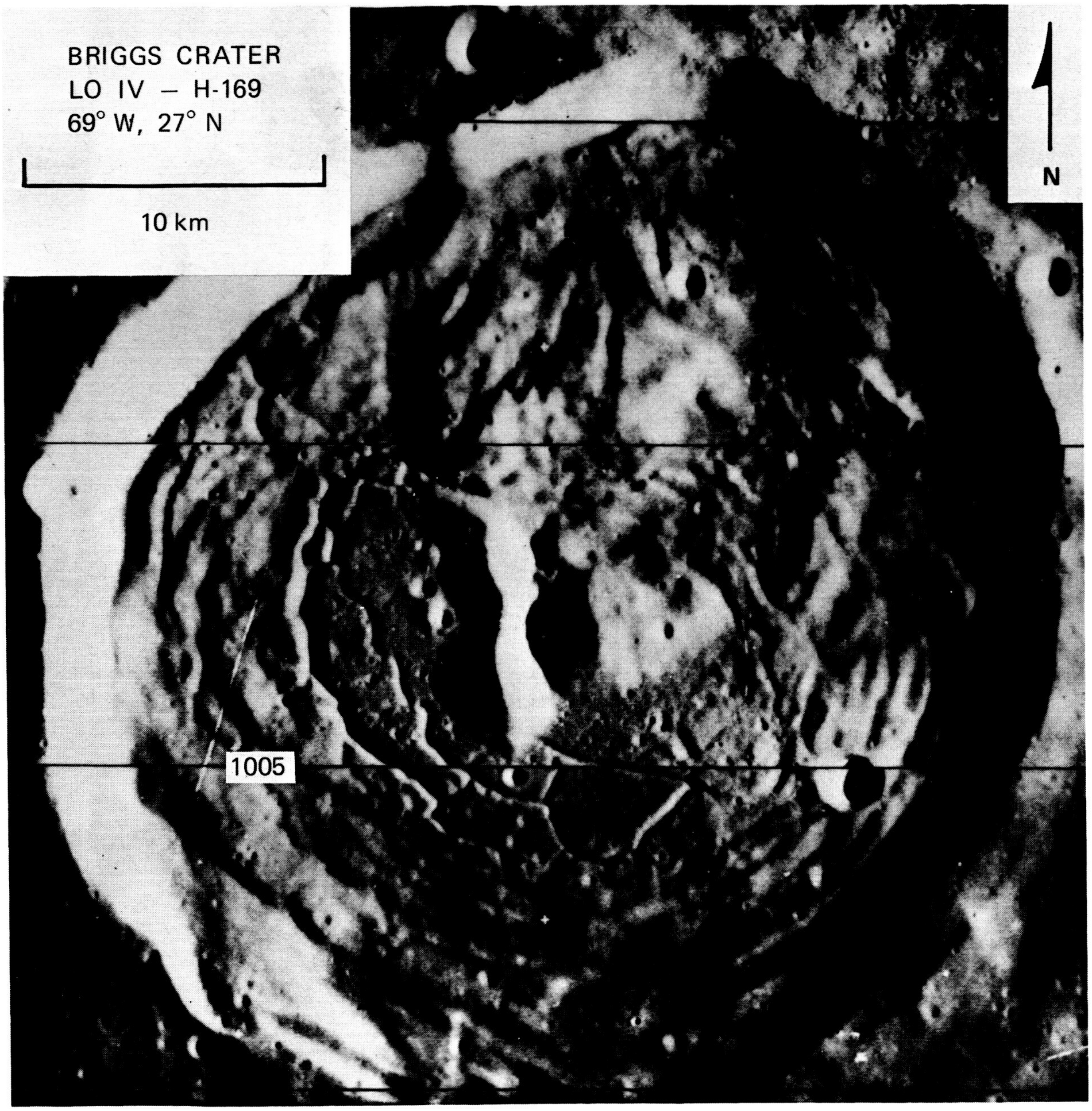

N
90
89
LO IV – H-132
26° W, 17° S
15 km

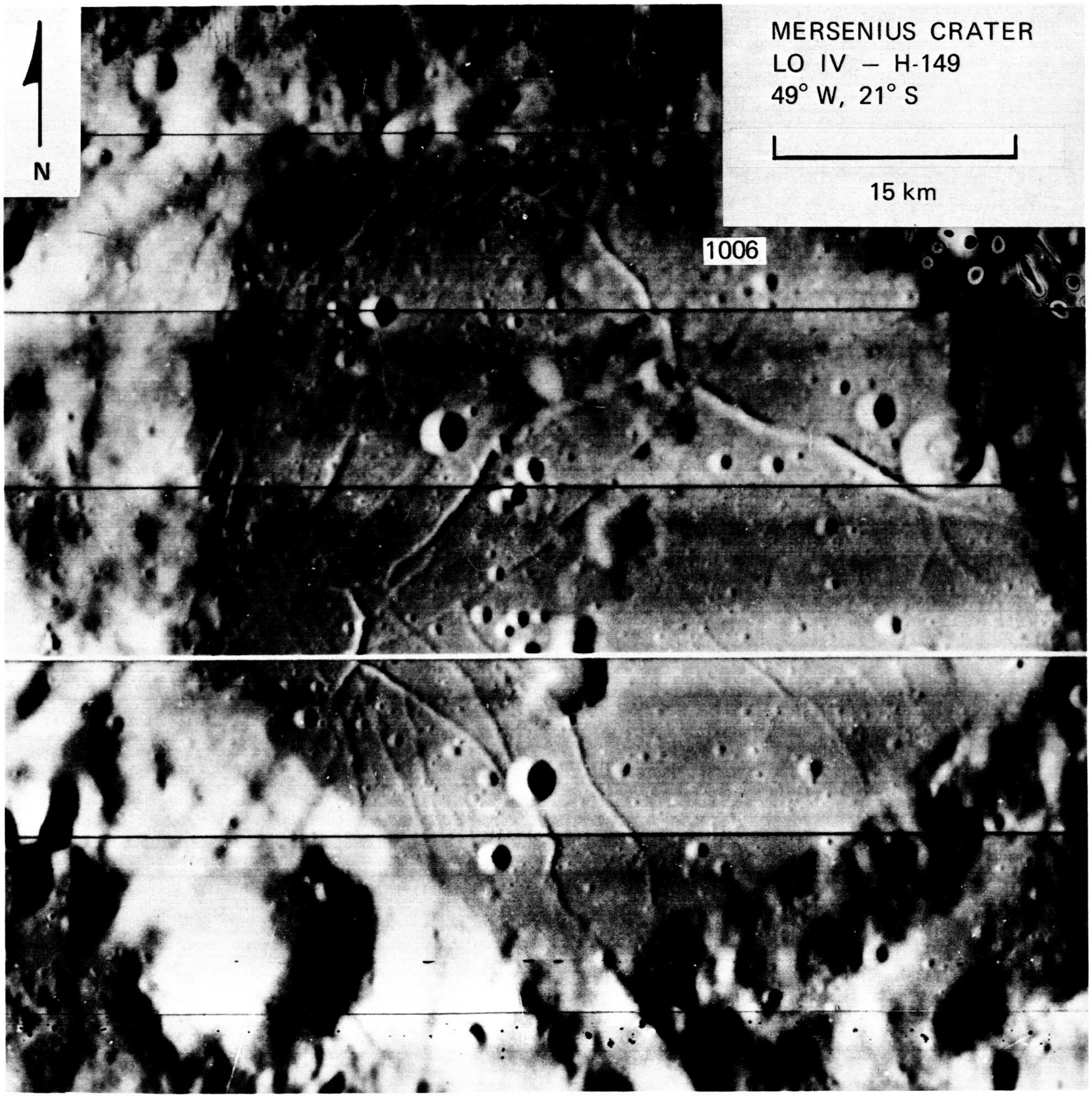

N
91
LO IV – H-158
53° W, 29° N
15 km

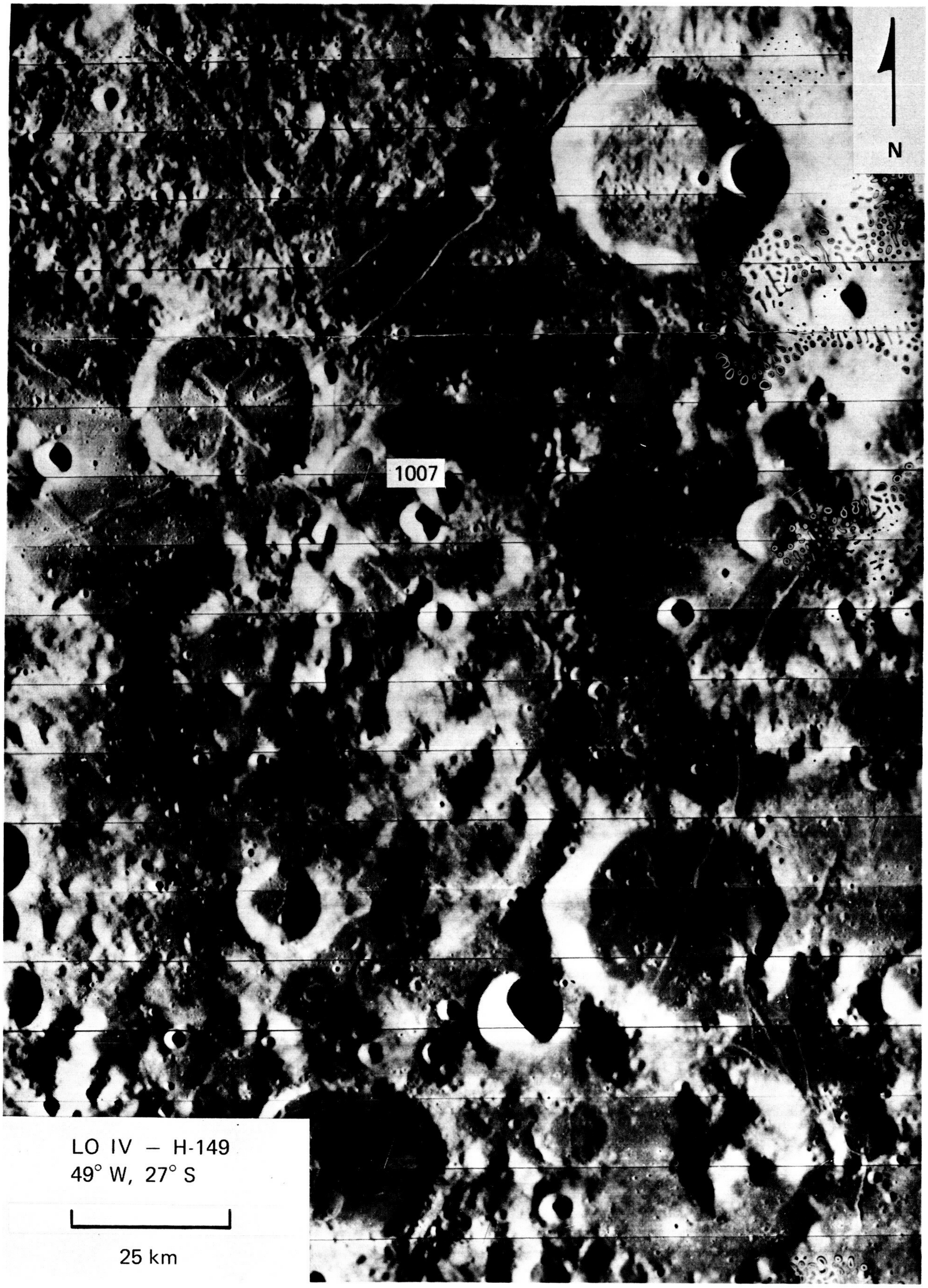

N
1001
LO IV – H-149
44° W, 27° S
15 km

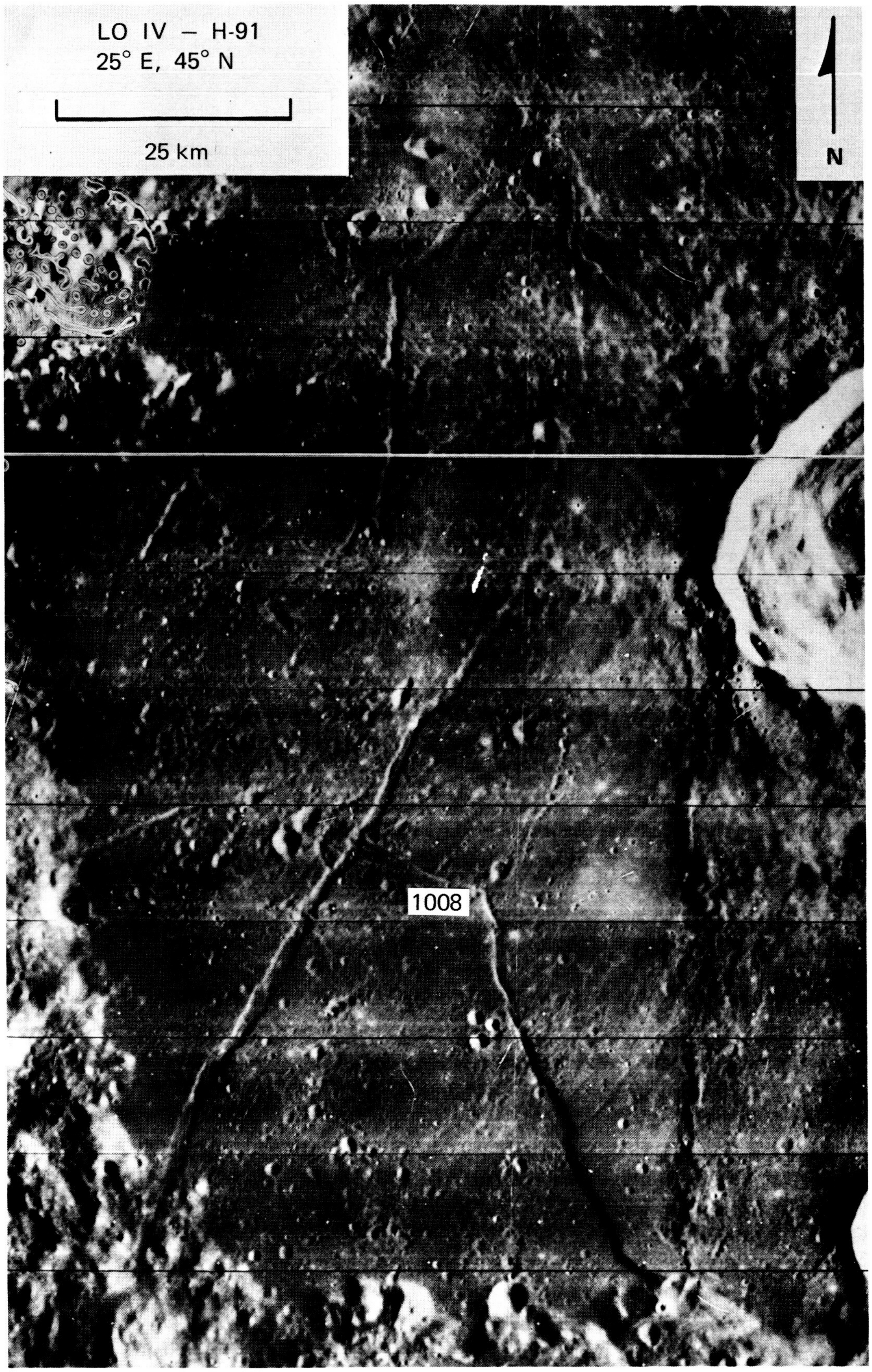

N
1002
LAVOISIER CRATER
LO IV – H-189
81° W, 38° N
15 km

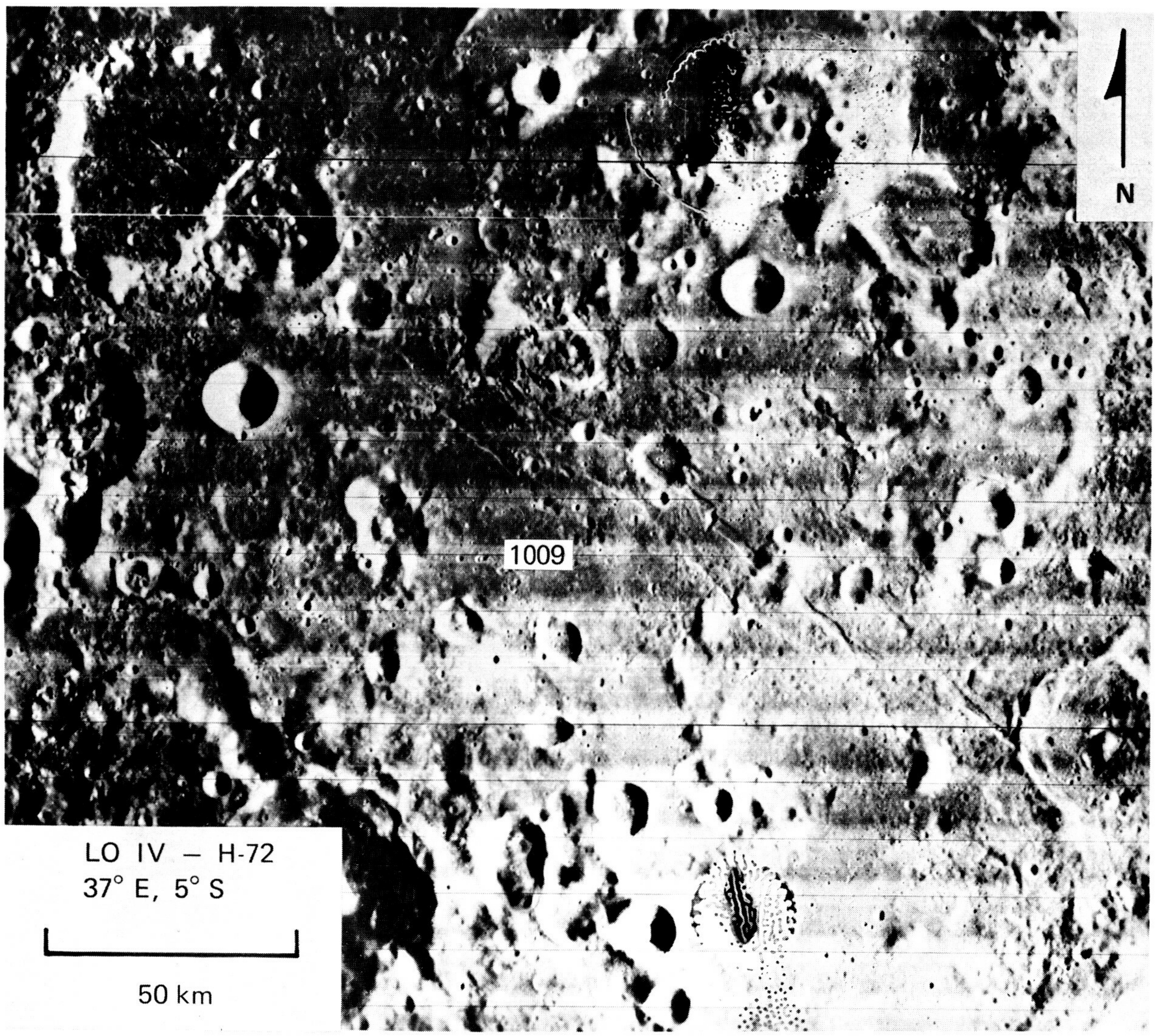

PITATUS CRATER
LO IV – H-119
14° W, 30° S
25 km
N
1003
1004

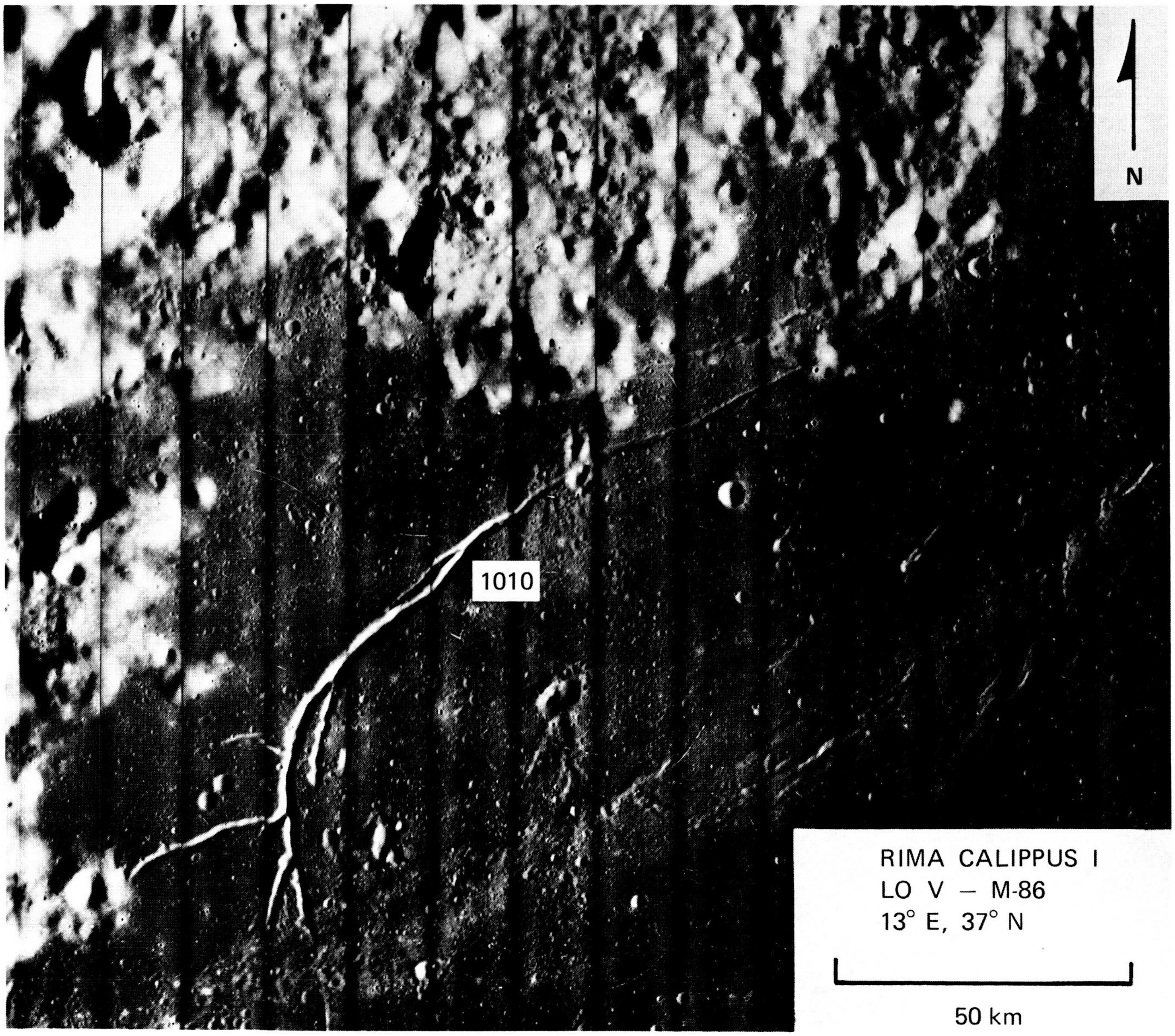

BRIGGS CRATER
LO IV – H-169
69° W, 27° N
10 km
N
1005


N
MERSENIUS CRATER
LO IV – H-149
49° W, 21° S
15 km
1006

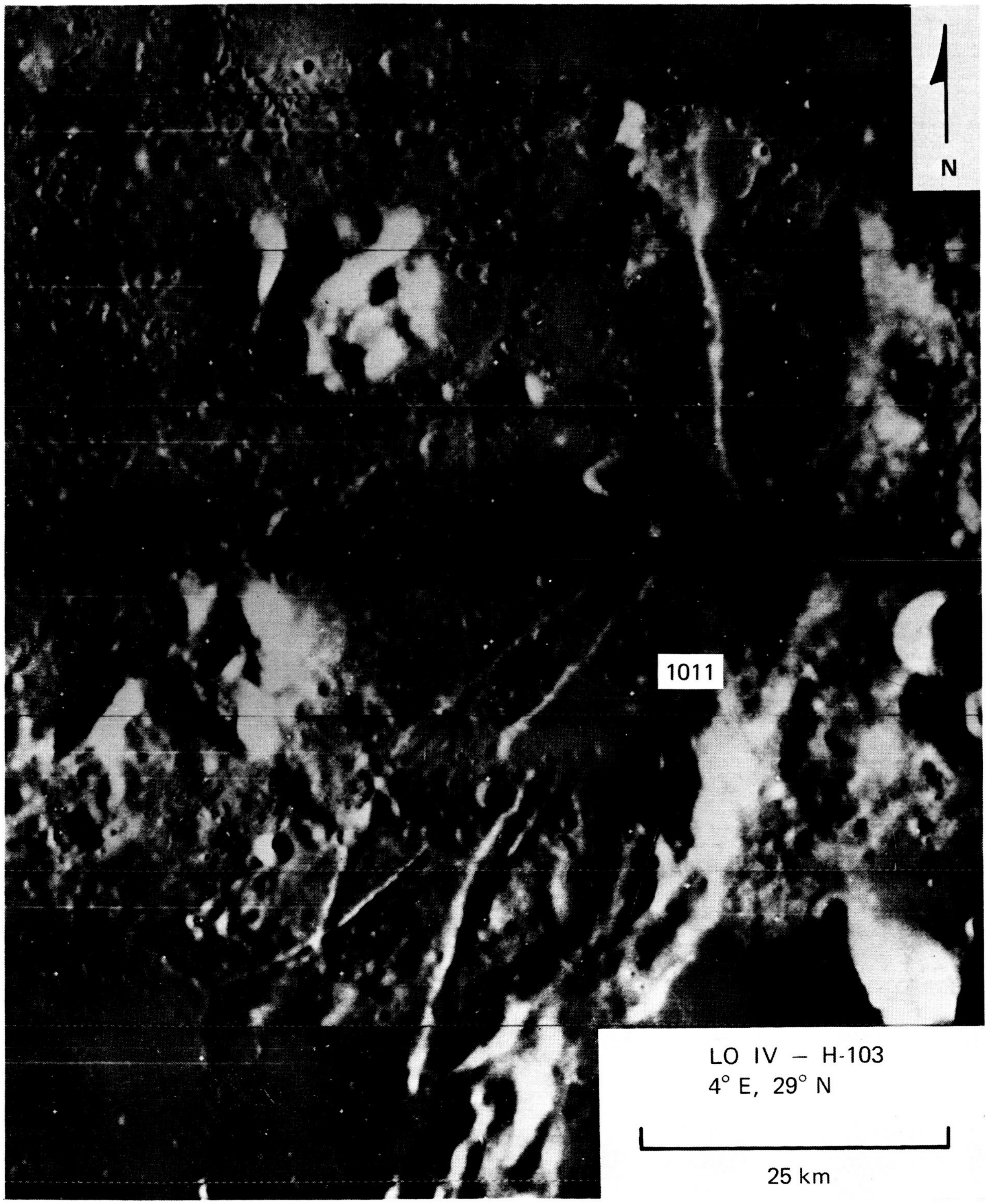

N
1007
LO IV – H-149
49° W, 27° S
25 km

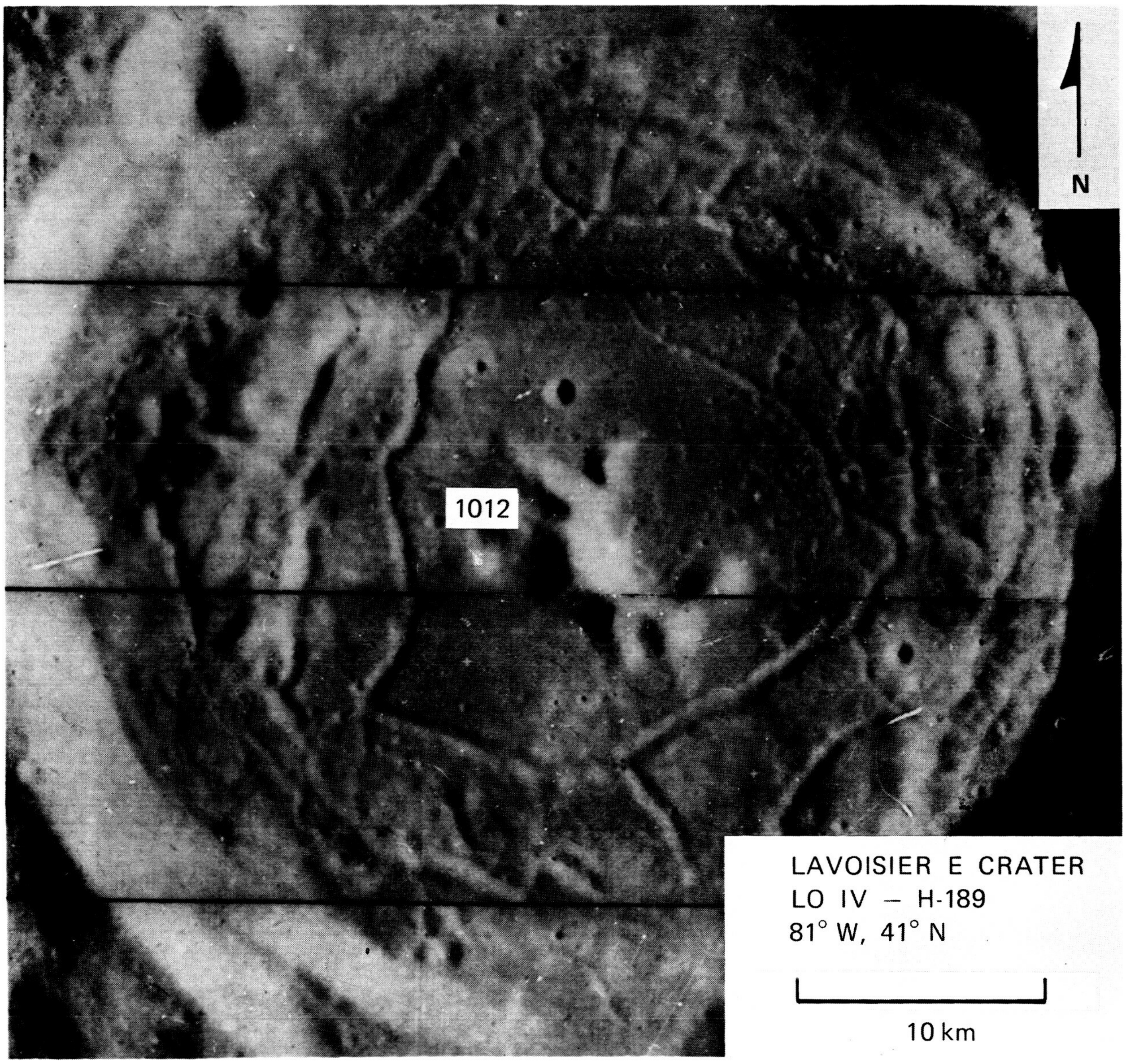

LO IV – H-91
25° E, 45° N
25 km
N
1008

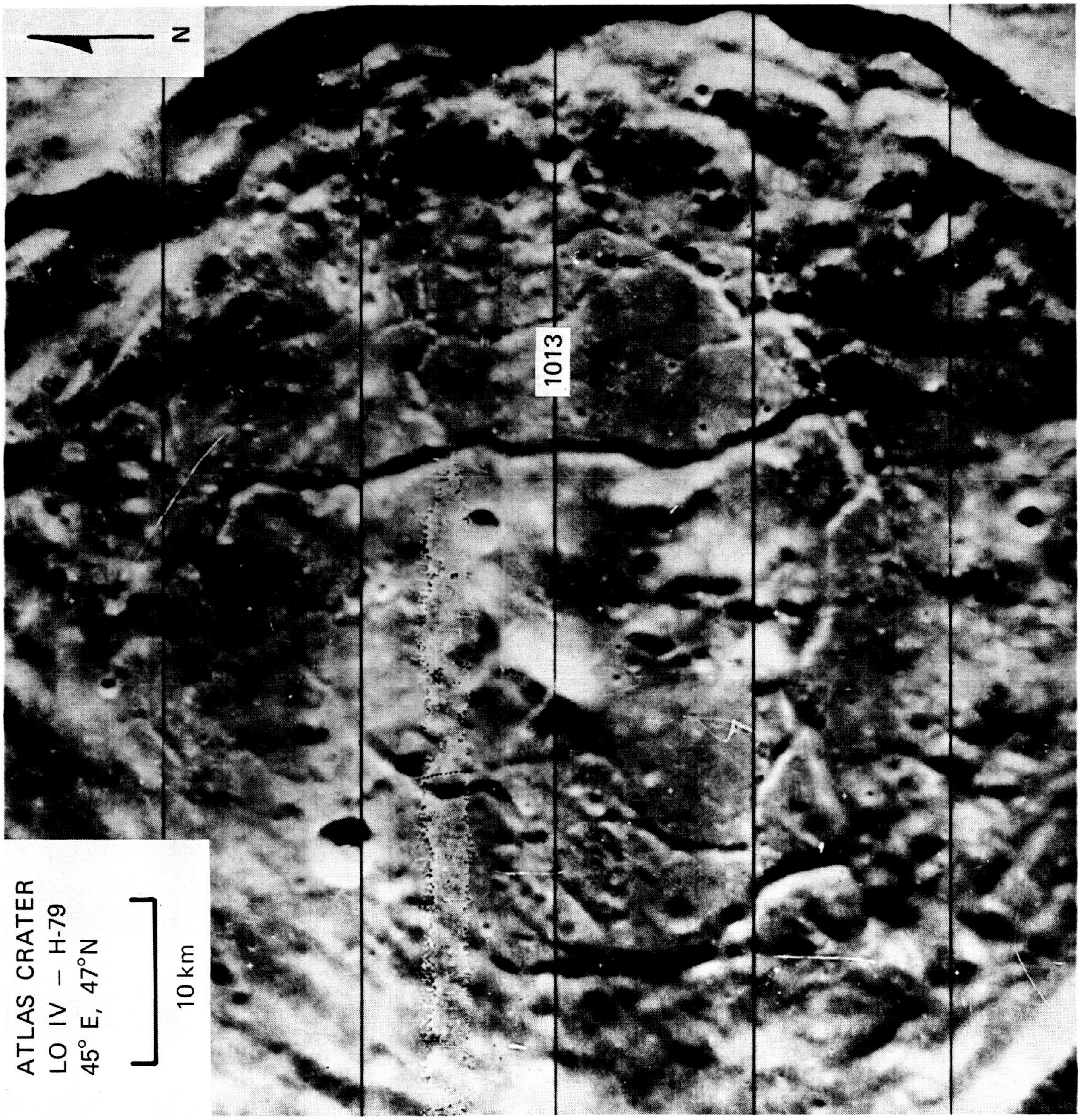

N
1009
LO IV – H-72
37° E, 5° S
50 km

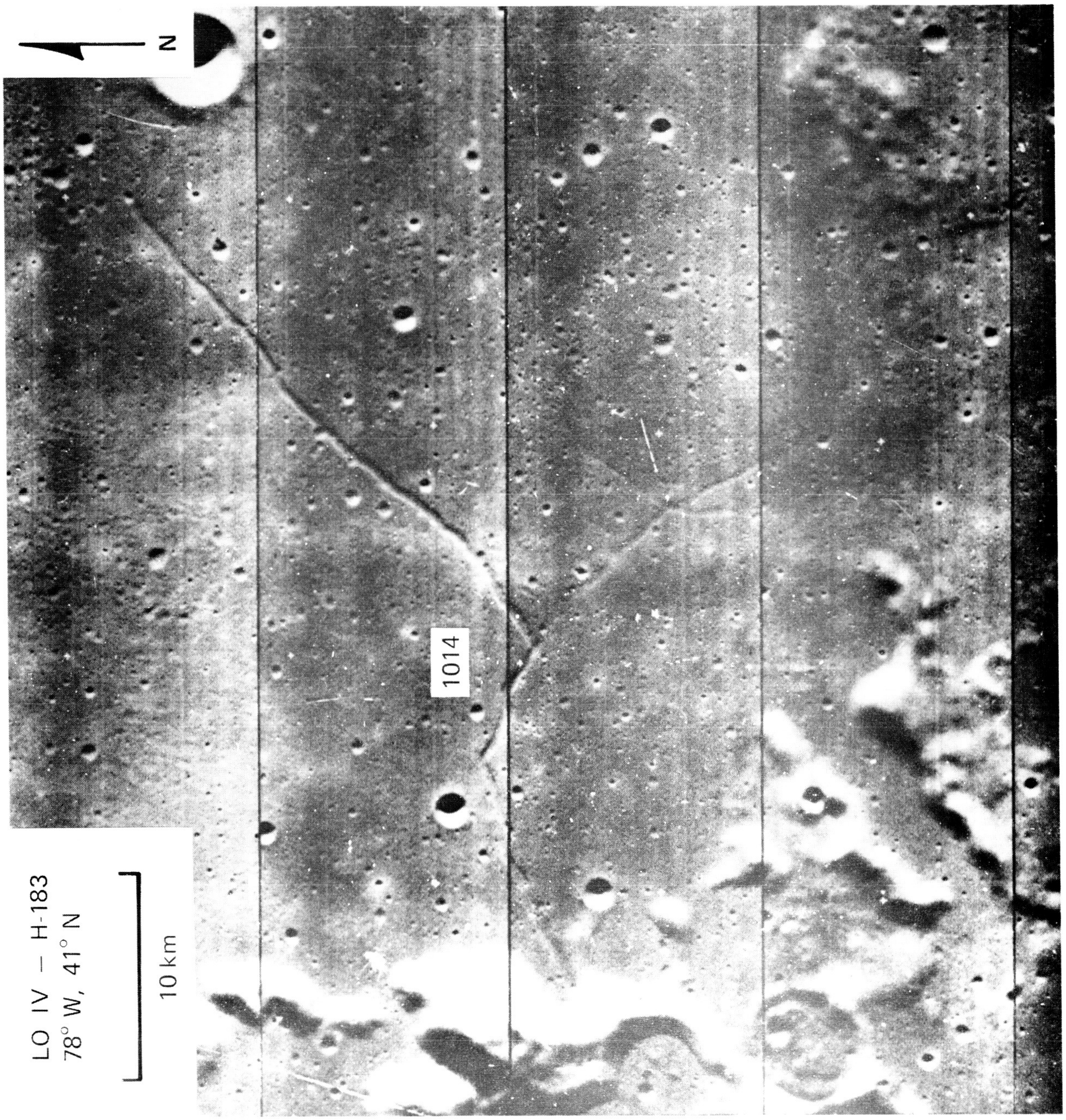


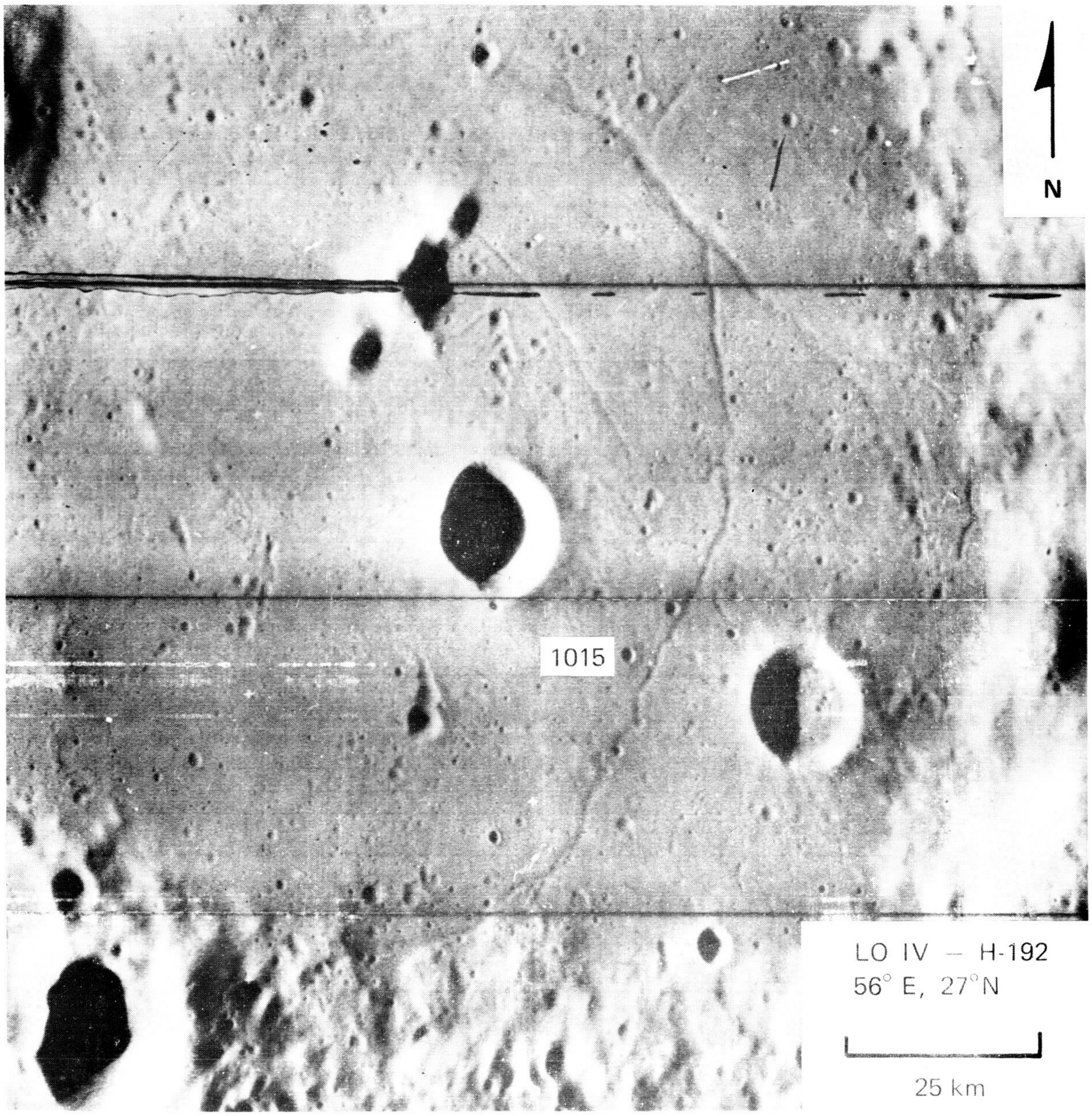
RIMA CALIPPUS I
LO V – M-86
13° E, 37° N

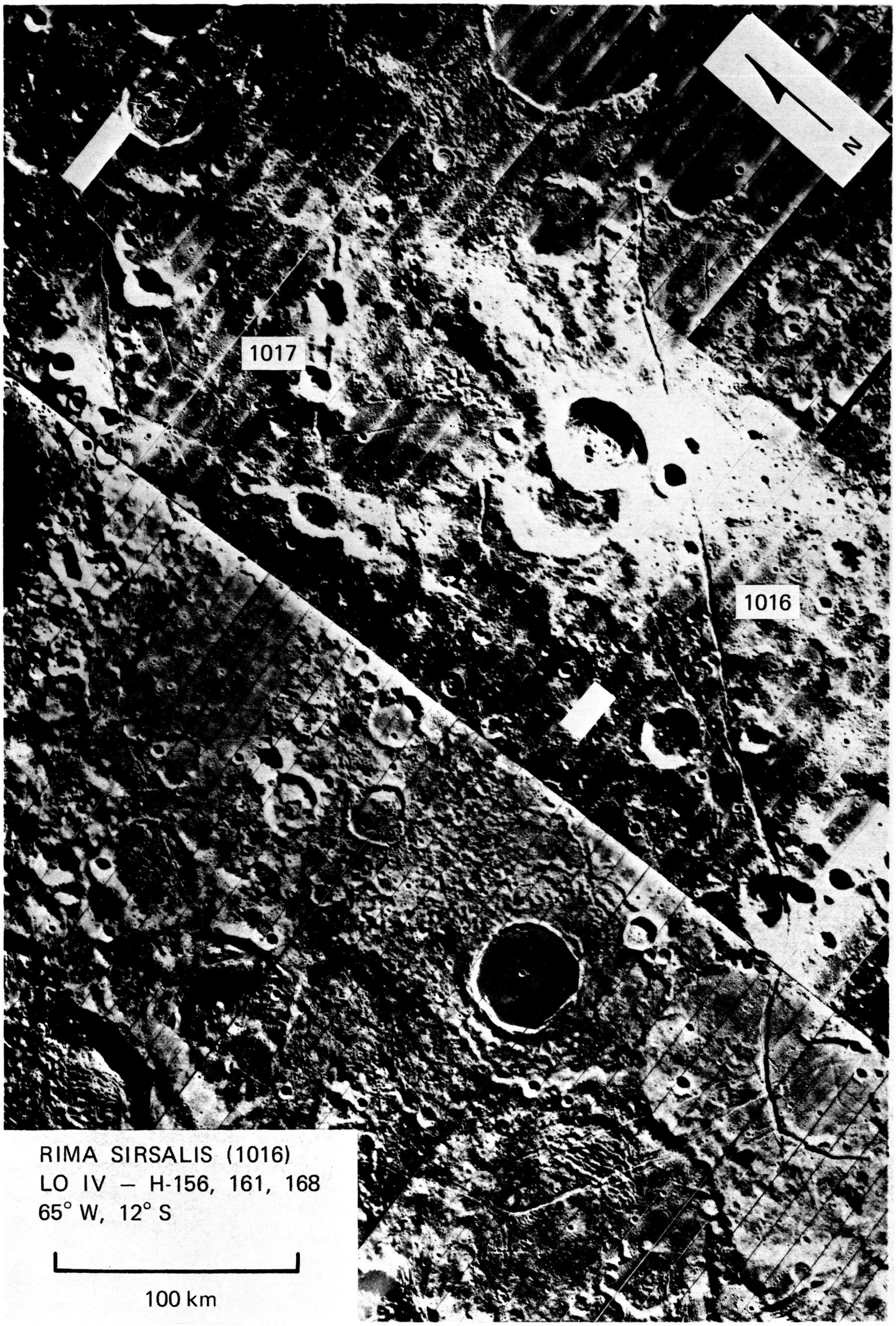

N
1011
LO IV – H-103
4° E, 29° N
25 km


N
1012
LAVOISIER E CRATER
LO IV – H-189
81° W, 41° N
10 km


N
1013
ATLAS CRATER
LO IV — H-79
45° E, 47°N
10 km

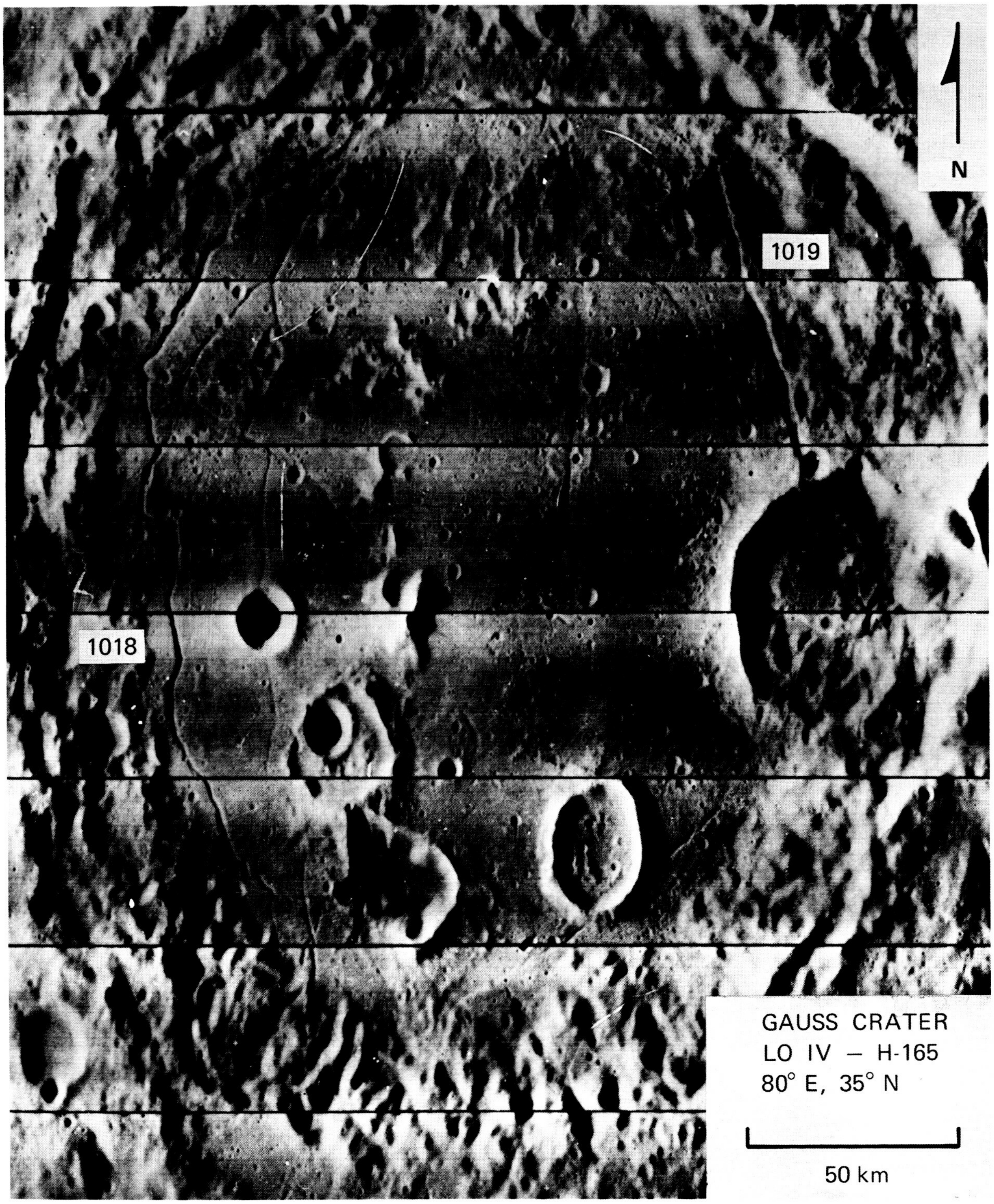

N
1014
LO IV — H-183
78° W, 41° N
10 km

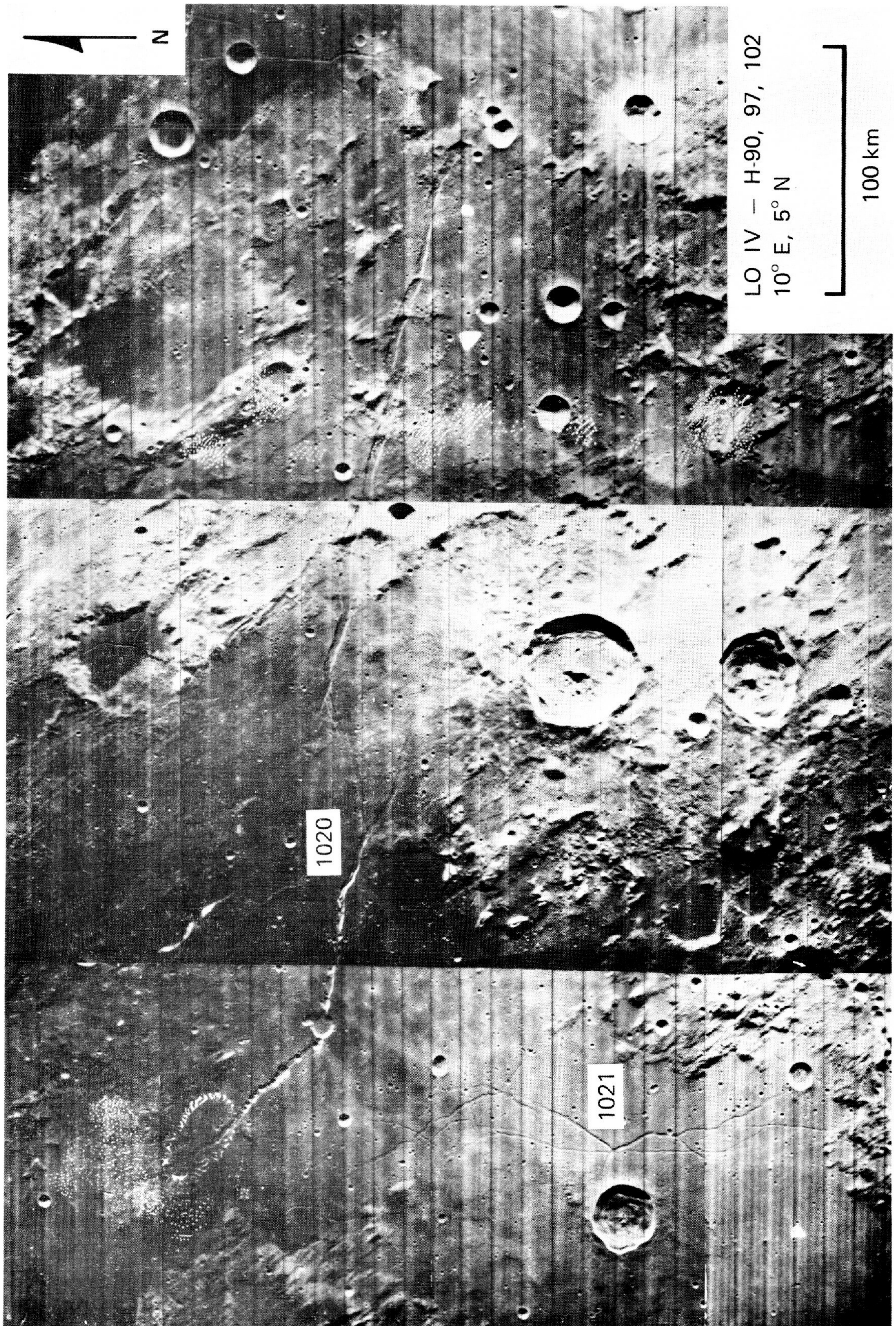

N
1015
LO IV — H-192
56° E, 27°N
25 km

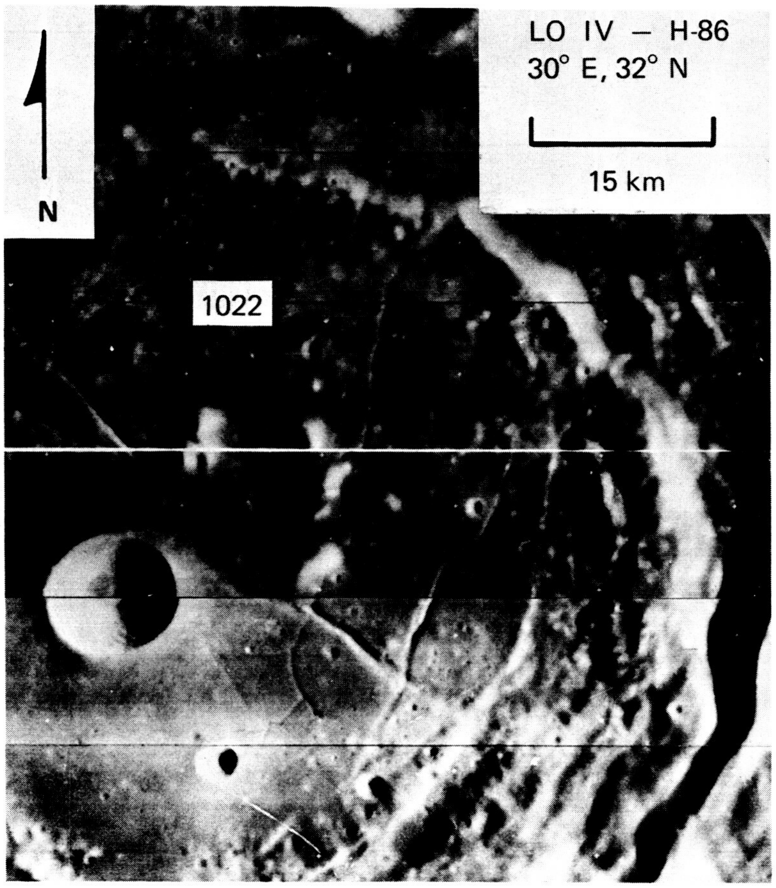


RIMA SIRSALIS (1016)
LO IV – H-156, 161, 168
65° W, 12° S

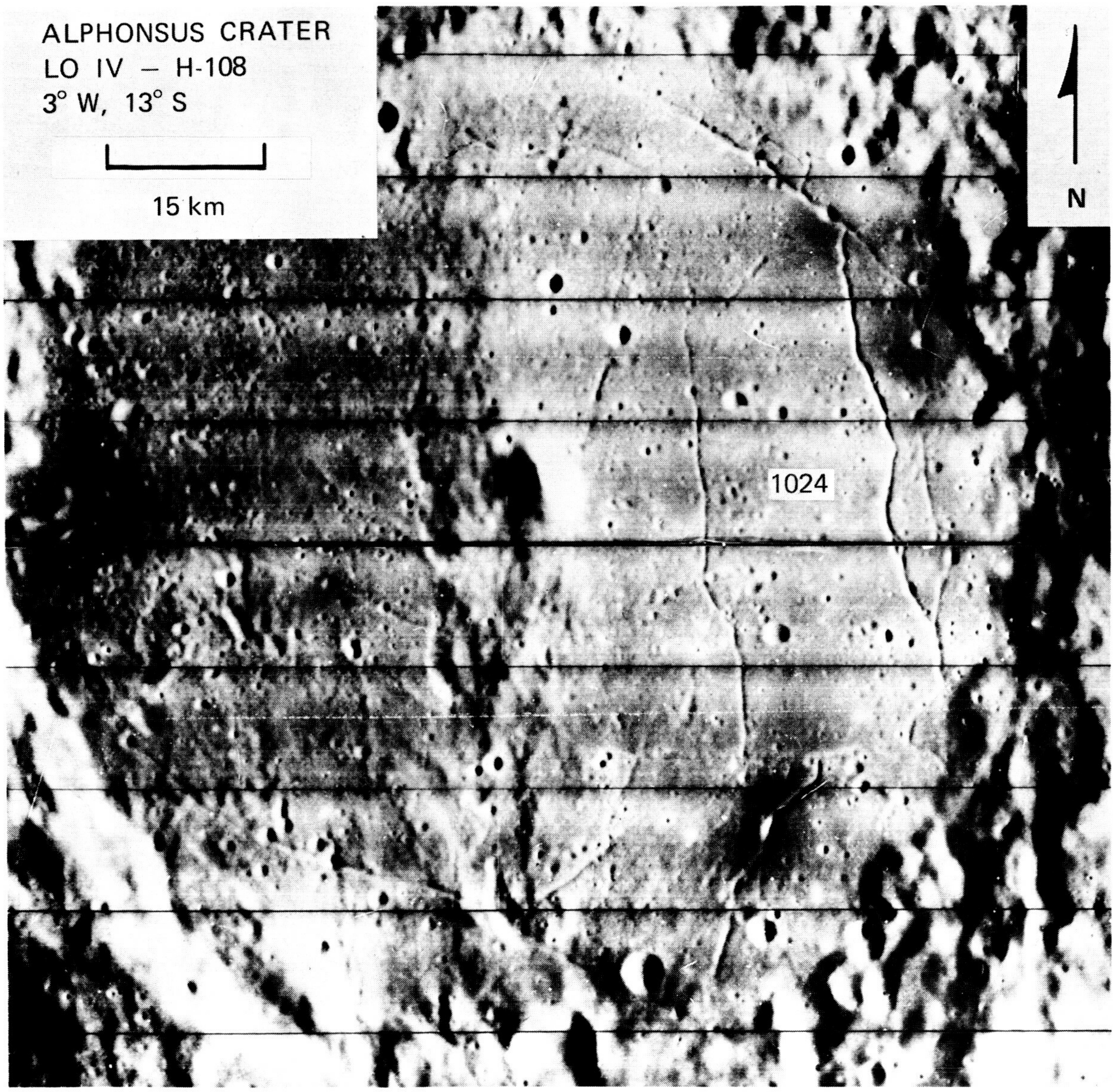
100 km

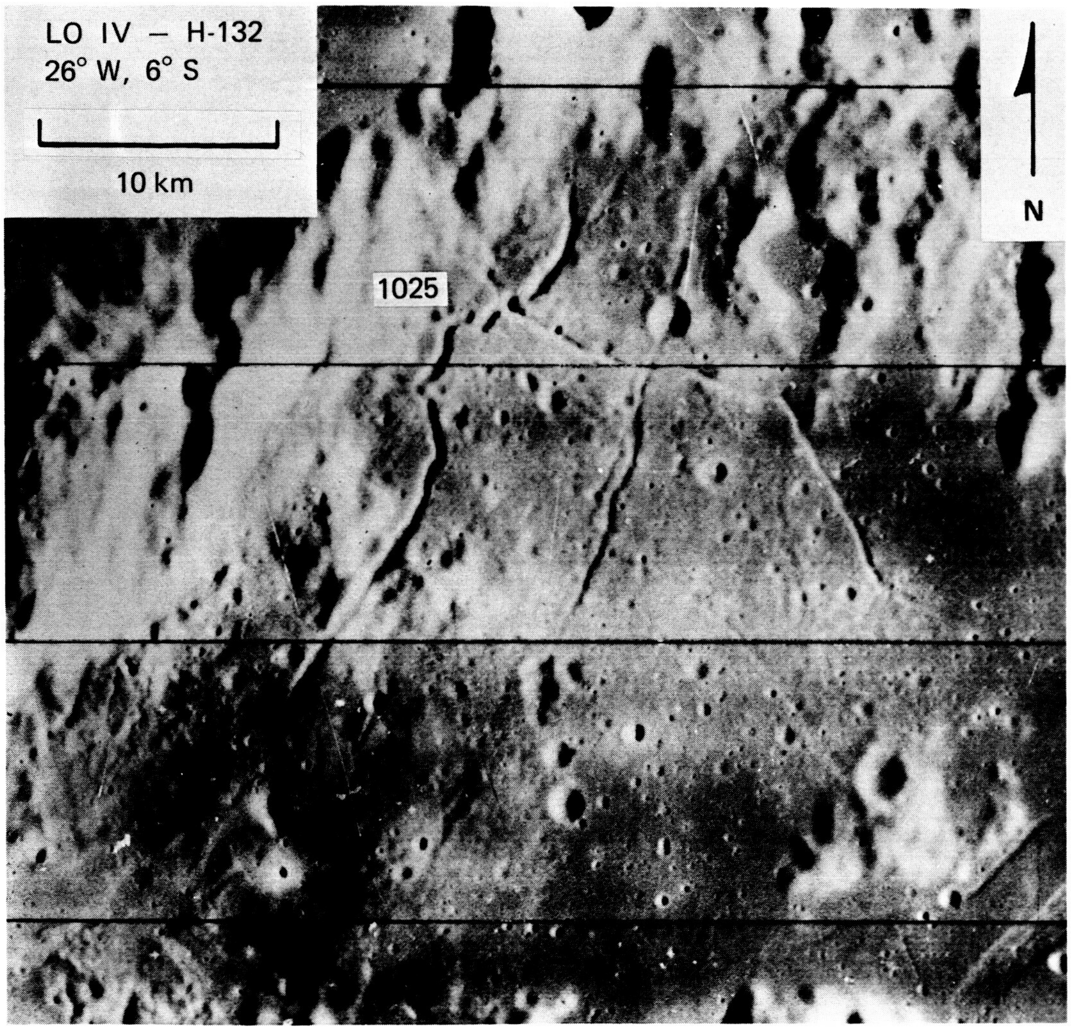

N
1019
1018
GAUSS CRATER
LO IV – H-165
80° E, 35° N
50 km

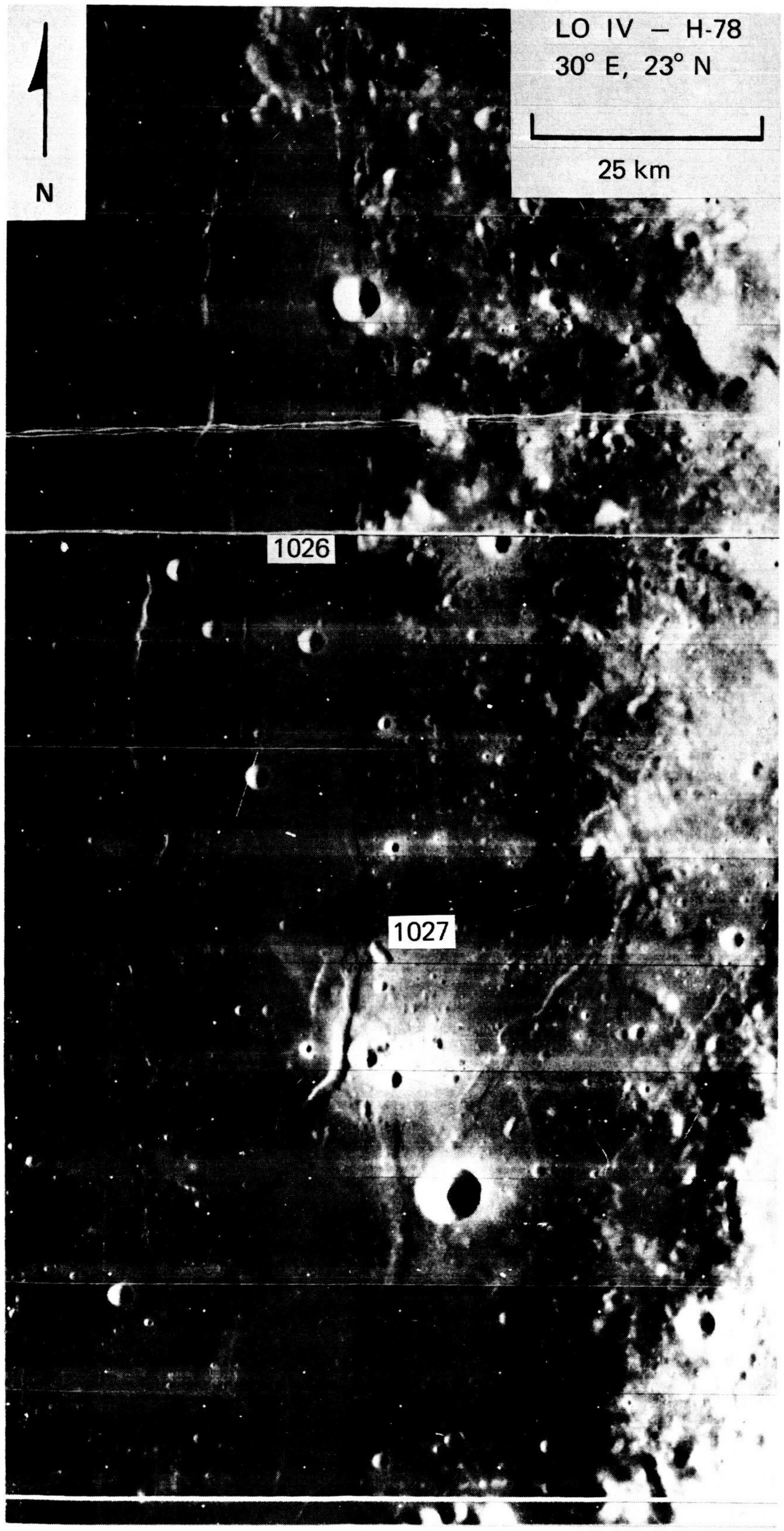

N
LO IV — H-90, 97, 102
10° E, 5° N
100 km
1020
1021


LO IV – H-86
30° E, 32° N
15 km
N
1022

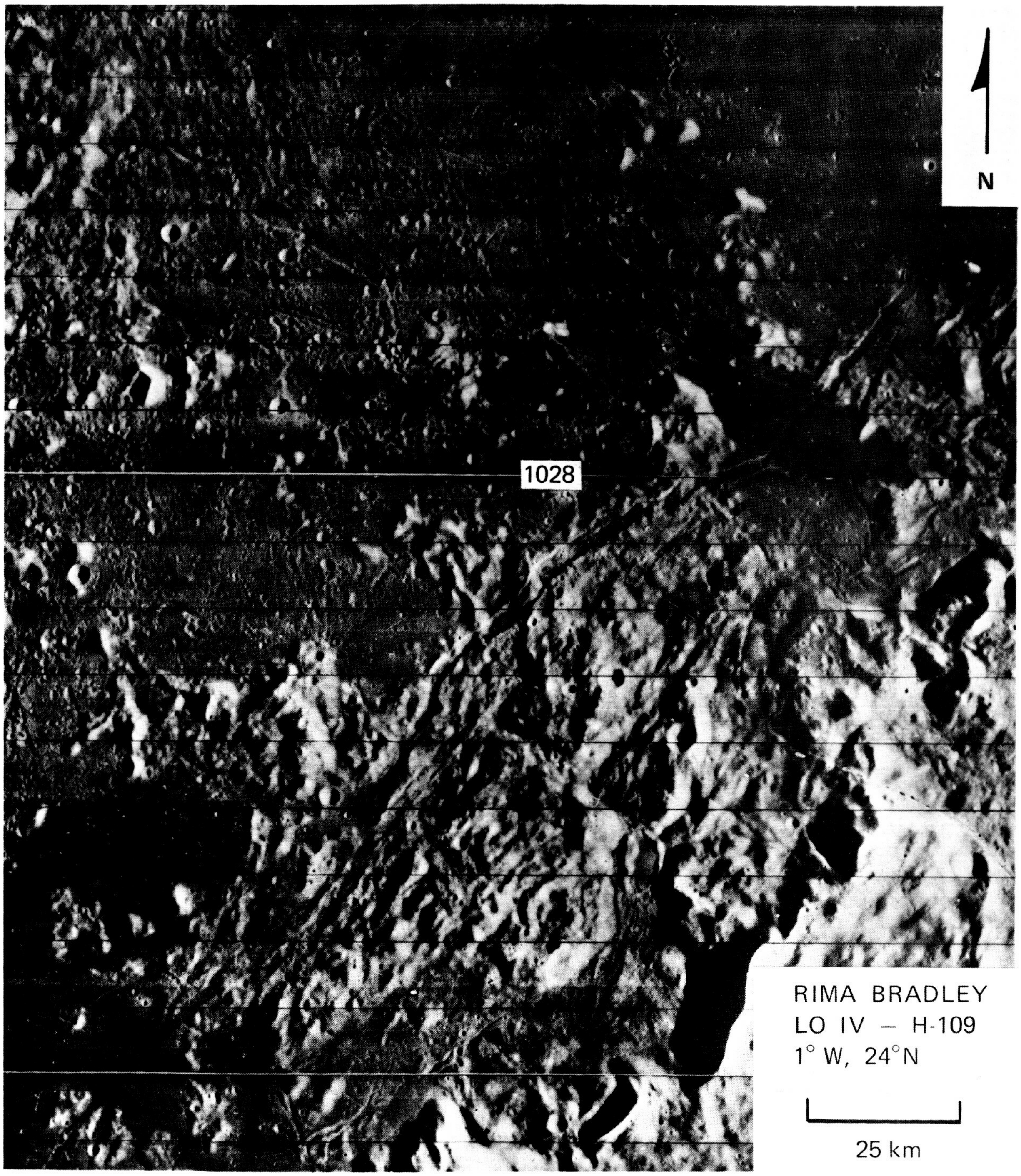

N
1023
LO IV — H-151
45° W, 27° N
25 km

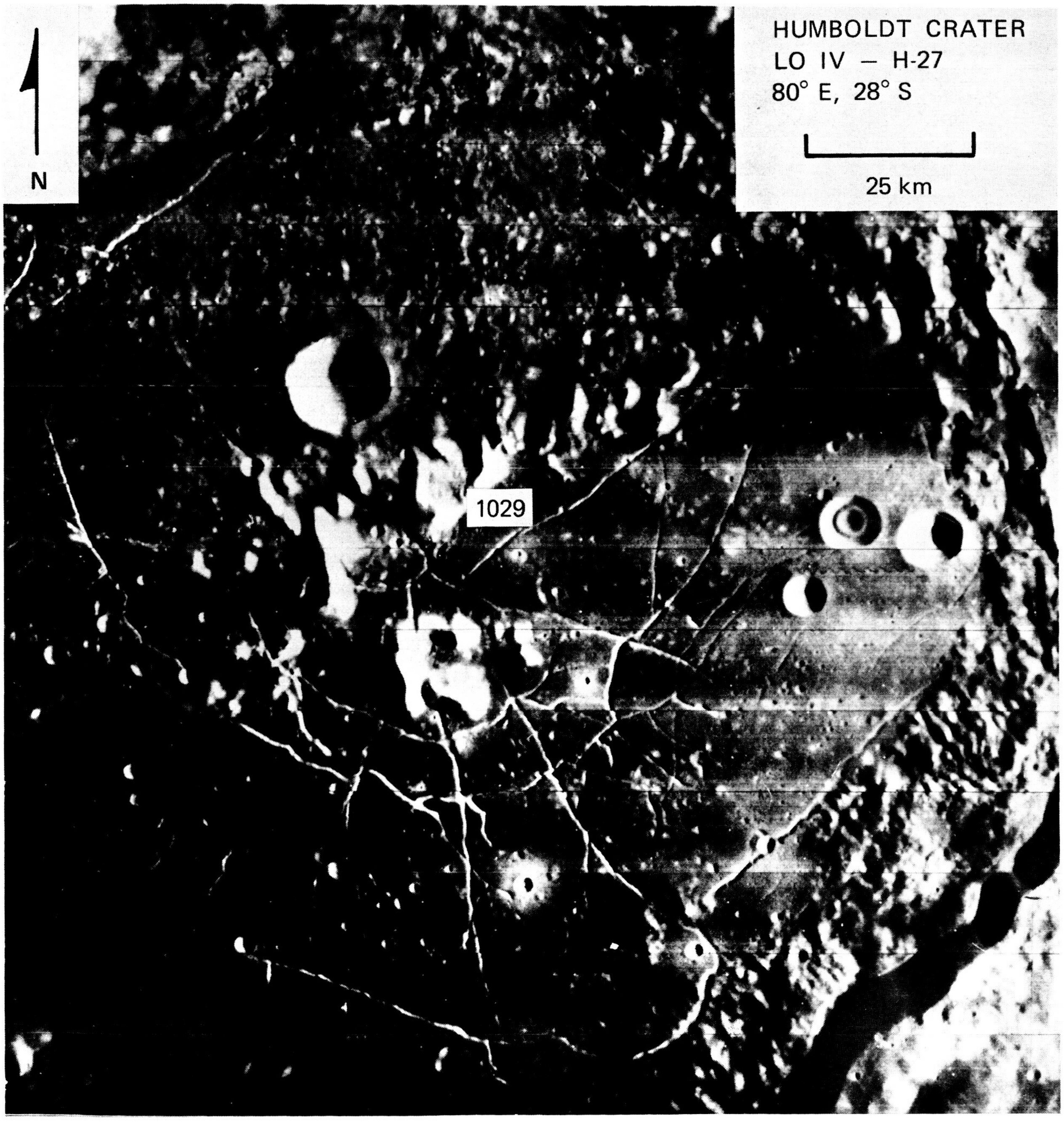

ALPHONSUS CRATER
LO IV – H-108
3° W, 13° S
15 km
N
1024


LO IV – H-132
26° W, 6° S
10 km
N
1025



N
LO IV – H-78
30° E, 23° N
25 km
1026
1027


N
1028
RIMA BRADLEY
LO IV – H-109
1° W, 24°N
25 km


HUMBOLDT CRATER
LO IV – H-27
80° E, 28° S
25 km
N
1029

ERRATA

NASA TM X-62,088

LUNAR RILLES - A CATALOG AND METHOD OF CLASSIFICATION

V. R. Oberbeck, Ronald Greeley, Robert B. Morgan,
and Michael J. Lovas

Ames Research Center

Page 2, first equation should read:

$$F_n(X_r) = \sum_{k=1}^{n} B_k \sin\left(\frac{X_r k\pi}{\ell}\right); \qquad n = 1,2,\ldots,N$$

Page 2, second equation should read:

$$B_k = \frac{2}{n} \sum_{r=1}^{N} F(X_r) \sin\left(\frac{X_r k\pi}{\ell}\right)$$