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PROFILES OF SOME CRATERS FROM RANGER LUNAR PHOTOGRAPHS

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Profiles of large lunar craters have been well-known for a long time. In recent years, lunar spacecrafts made it possible for the first time to investigate the sizes and forms of small craters. First of lunar spacecrafts which transmitted thousands of high-resolution photographs of the lunar surface were Rangers VII, VIII and IX. Ranger VII was launched on July 28, 1964, and encountered the Moon on July 31 in the northern region of Mare Imbrium (impact point $\lambda = 21^{o}W$, $\beta = 11^{o}S$), later named Mare Cognitum; Ranger VII transmitted 4308 lunar photographs. Ranger VIII was launched on February 17, 1965, and encountered the Moon on February 20 in Mare Tranquillitatis (impact point $\lambda = 24^{o}E$, $\beta = 3\overset{\circ}{.}0$ N); this spacecraft transmitted 7137 lunar photographs. Last of these spacecrafts, Ranger IX, was launched on March 21, 1965, and encountered the Moon on March 24 in crater Alphonsus (impact point $\lambda = 2\overset{\circ}{.}5$ W, $\beta = 13\overset{\circ}{.}0$ S). Ranger IX transmitted 5814 photographs of lunar surface.

The Ranger spacecraft television system was composed of six cameras, divided into two separate channels designated F and P. The F channel contained two cameras, the A camera (f = 25 mm, f/1.0, field of view 25^{o}) and B camera (f = 76 mm, f/2.0, field of view $8\overset{\circ}{.}4$). The P channel contained four cameras, two with 76-mm, f/2.0 lenses (field $2\overset{\circ}{.}1$) and two with 25-mm, f/1.0 lenses (field

T a b l e 1

No.	U.T.	H_s	β_s	λ_s	β_c	λ_c
45	$13^h12^m30\overset{s}{.}17$	1682.48	$-4\overset{\circ}{.}15$	$-34\overset{\circ}{.}12$	$-13\overset{\circ}{.}01$	$-11\overset{\circ}{.}57$
107	13 17 47.60	1051.56	- 5.83	-30.77	-12.50	-14.17
178	13 23 51.11	271.25	- 9.01	-24.16	-11.23	-18.71
184	13 24 21.83	201.51	- 9.39	-23.35	-11.09	-19.18
186	13 24 32.07	178.10	- 9.53	-23.06	-11.04	-19.35
189	13 24 47.43	142.84	- 9.73	-22.62	-10.97	-19.60
192	13 25 02.79	107.39	- 9.95	-22.16	-10.89	-19.85
197	13 25 28.49	47.88	-10.32	-21.35	-10.75	-20.29

T a b l e 2

No.	U.T.	H_s	β_s	λ_s	β_c	λ_c
17	$9^h48^m29\overset{s}{.}389$	1004.71	$-3\overset{\circ}{.}55$	$+2\overset{\circ}{.}81$	$-3\overset{\circ}{.}00$	$+14\overset{\circ}{.}94$
20	9 49 20.589	910.14	- 3.17	+ 4.15	- 2.83	+15.98
23	9 50 06.668	824.90	- 2.81	+ 5.43	- 1.92	+16.90
37	9 52 40.268	540.40	- 1.38	+10.41	- 0.25	+19.60
48	9 53 57.067	398.51	- 0.51	+13.39	+ 0.54	+21.30
54	9 54 27.787	341.96	- 0.14	+14.70	+ 0.86	+21.84
59	9 54 53.387	294.96	+ 0.20	+15.85	+ 1.12	+22.27
72	9 55 59.947	173.54	+ 1.13	+19.09	+ 1.97	+23.33
80	9 56 40.907	99.57	+ 1.77	+21.30	+ 2.19	+23.91
83	9 56 56.267	72.02	+ 2.02	+22.18	+ 2.34	+24.12
85	9 57 06.507	53.72	+ 2.19	+22.78	+ 2.44	+24.25
87	9 57 16.747	35.47	+ 2.37	+23.39	+ 2.53	+24.38

T a b l e 3

No.	U.T.	H_s	β_s	λ_s	β_c	λ_c
27	$14^h02^m16\overset{s}{.}062$	832.42	$-11\overset{\circ}{.}32$	$-11\overset{\circ}{.}49$	$-11\overset{\circ}{.}75$	$-0\overset{\circ}{.}48$
42	14 04 24.062	549.56	-11.75	- 9.05	-12.12	- 0.88
53	14 05 20.382	422.00	-11.98	- 7.77	-12.29	- 1.14
65	14 06 21.822	280.41	-12.24	- 6.18	-12.48	- 1.50
76	14 07 18.142	148.18	-12.51	- 4.51	-12.65	- 1.87
80	14 07 38.622	99.47	-12.62	- 3.84	-12.72	- 2.03
87	14 08 14.462	13.39	-12.81	- 2.58	-12.82	- 2.32

Ranger VII

No.	R	I	F	E	E-W	N-S	D
45	1963.47	76°5	34°1	45°0	80.9	68.9	10°8
107	1250.56	74.0	34.0	42.7	50.2	43.7	10.2
178	330.86	69.5	34.1	37.9	12.7	11.4	8.7
184	246.54	69.0	34.1	37.5	9.4	8.5	8.6
186	218.12	68.8	34.1	37.3	8.3	7.5	8.6
189	175.20	68.6	34.1	37.0	6.7	6.1	8.5
192	131.96	68.3	34.1	36.8	5.0	4.6	8.4
197	59.02	68.0	34.1	36.3	2.3	2.1	8.4

Ranger VIII

No.	R	I	F	E	E-W	N-S	D
17	1105.14	65°3	34°0	31°4	42.28	36.95	-2°0
20	1011.75	66.3	34.0	32.4	39.11	33.88	-2.2
23	926.55	67.3	34.0	33.4	36.16	31.07	-2.5
37	633.74	70.3	34.0	36.6	25.60	21.39	-3.4
48	480.11	71.8	34.0	38.1	19.73	16.27	-4.0
54	416.97	72.3	34.0	38.7	17.26	14.15	-4.2
59	363.50	72.8	34.0	39.1	15.13	12.36	-4.4
72	220.53	73.8	34.0	40.3	9.31	7.53	-4.9
80	129.22	74.4	34.0	40.9	5.50	4.42	-5.2
83	94.26	74.7	34.0	41.2	4.02	3.23	-5.3
85	70.72	74.8	34.0	41.3	3.02	2.42	-5.3
87	46.97	74.9	34.0	41.5	2.01	1.61	-5.4

Ranger IX

No.	R	I	F	E	E-W	N-S	D
27	922.37	81°4	50°0	31°4	35.04	30.39	21°7
42	615.90	81.1	50.0	31.1	23.28	20.31	21.9
53	475.44	80.8	50.0	30.8	17.91	15.68	21.9
65	317.81	80.5	50.0	30.5	11.91	10.49	22.0
76	169.06	80.1	50.0	30.1	6.31	5.58	22.1
80	113.79	80.0	50.0	29.9	4.24	3.76	22.1
87	15.39	79.7	50.0	29.7	0.57	0.51	22.1

6°.3). The camera reference axes were oriented so that the fields of view of different cameras overlapped.

The Ranger photographs were published by National Aeronautics and Space Administration in atlases "Ranger Photographs of the Moon" in printed edition /1/. The pictures of the Ranger missions have been also published as photographs prepared from the original negatives /2/. These photographs (camera-"B" pictures) were used for the present investigation of the profiles of lunar craters. The resolution of the first photographs (largest distance of the spacecraft from the Moon) is equal to or better than that of the best pictures of the Moon taken with Earth-based telescopes, the resolution of the last photographs (shortly before impact) is about 30-60 cm.

The following sets of photographs were used for the present study: Ranger VII photo numbers 45, 107, 178, 184, 186, 189, 192 and 197; Ranger VIII photo numbers 17, 20, 23, 37, 48, 54, 59, 72, 80, 83, 85 and 87 and Ranger IX photo numbers 27, 42, 53, 65, 76, 80 and 87. Tables 1, 2 and 3 contain the following data for each photograph: the number, the Universal Time of the exposure, the altitude (H_s in kms), and the selenocentric latitude (β_s) and longitude (λ_s) of the spacecraft, the selenocentric latitude (β_c) and longitude (λ_c) of the central reticle of the photographs, the distance from the spacecraft to the surface point covered by central reticle (R), the incidence[1] (I), phase[2] (F) and emission[3] (E) angles, the scale (E-W and N-S, in kms) and the deviation (D) between true and grid north (referring to the central reticle). These parameters were taken from /1/ and were used for the determination of the true sizes of craters.

Some craters, chiefly of regular forms, were measured in each photograph and their profiles were determined using the well-known shadow technique. The measuring was made by means of a coordinate comparator and 10 - 40 cross-sections (E-W) of each crater were

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1) Angle between the local surface normal and the direction of illumination.

2) Angle between the illumination direction and the camera axis.

3) Angle between the local surface normal and the camera axis.

measured in the sense east rim - border of the shadow - west rim. The step between the individual cross-sections was 0.25 or 0.5 mm. In this way the rectangular coordinates x, y of the points of the rims and of the border of the shadow were obtained. Fig. 1 (left) shows crater Guericke C as an example (Ranger VII, photograph No. 107).

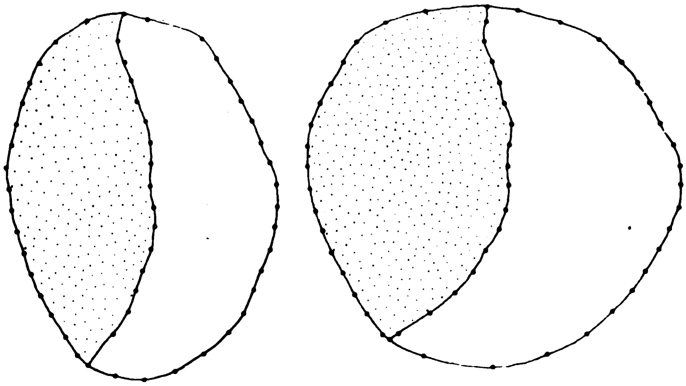

Fig. 1. Measured (left) and corrected (right) form of the crater Guericke C (Ranger VII, photograph No. 107).

Naturally, the forms of the craters in the photographs must be corrected for the foreshortening due to projection. The corrected coordinates x', y' of the points of the rims and of the border of the shadow may be obtained using the following relations

$$x' = x \cos D \sec E - y \sin D \sec E$$
$$y' = x \sin D + y \cos D$$

where E is the emission angle and D the deviation (north). The corrected form of crater Guericke C is shown in Fig. 1 (right).The depth δ' of the crater at a given point is

$$\delta' = \Delta x' \operatorname{cotg} I$$

where $\Delta x'$ means the length between the rim of the centre and the border of the shadow and I the incidence angle. The diameters of the measured craters were relatively small and therefore the curvature of the lunar surface may be neglected.

The diameter (or the depth) of the craters may simply be expressed in kilometres using the "scale". Of course, this is possible in such cases only if the crater is present in the square defined by the reticles which are situated immediately to the west and to the north of the central reticle. If the measured crater is outside this square, the rectangular coordinates of the other reticles may be transformed into the selenographic latitude and longitude using the values of Tabs. 1 - 3. These selenographic coordinates may be also simply determined from the Ranger Lunar Charts /3/. Let us denote the selenographic coordinates of the reticles of a square as λ_i and β_i . The rectangular coordinates x_i, y_i (in kms) of these reticles are

$$x_i = r \cos\beta_i \sin\lambda_i$$
$$y_i = r \sin\beta_i$$

and the "scale" (in kms) is

$$E\text{-}W = r \cos \Delta\beta_i \sin \Delta\lambda_i$$
$$N\text{-}S = r \sin \Delta\beta_i$$

where r means the Moon's radius ($r = 1736.67$).

The writer measured cross-sections of 71 different craters, 30 in Ranger VII photographs, 17 in Ranger VIII photographs and 24 in Ranger IX photographs. Some of the craters were measured in different photographs for the purpose of determining the measuring errors. Altogether 88 individual craters were measured, 40 of which in Ranger VII photographs, 20 in Ranger VIII photographs and 28 in Ranger IX photographs. Tables 4, 5 and 6 contain the following data for each measured crater: current number of the crater (No.), number of Ranger photographs (Ph.), number of Ranger Lunar Chart (RLC), name of the crater, selenographic longitude (λ) and latitude (β), measured diameter (Δ, in kms) of the crater and its depth (δ, in metres). Mean error of Δ , which was determined using 13 identical craters measured on 2 - 4 different photographs, is $\pm$ 5.0%, mean error of δ is $\pm$3.7%. Fig. 2 shows the profiles of an anonymous crater (Table 6, No. 9; $\lambda = -1^\circ 55'$, $\beta = -12^\circ 20'$) measured in three Ranger IX photographs (Nos. 53, 65 and 76). Figs. 3, 4 and 5 contain the profiles of individual craters, reduced to a uniform diameter.

The investigation of crater profiles showed that most of the craters considered, especially those of smaller sizes, are very nearly of a paraboloidal form. Smaller lunar craters are very similar to known terrestrial meteorite craters or to aritificial explosive craters. It may be concluded that a volcanic origin for the mentioned lunar craters seems improbable.

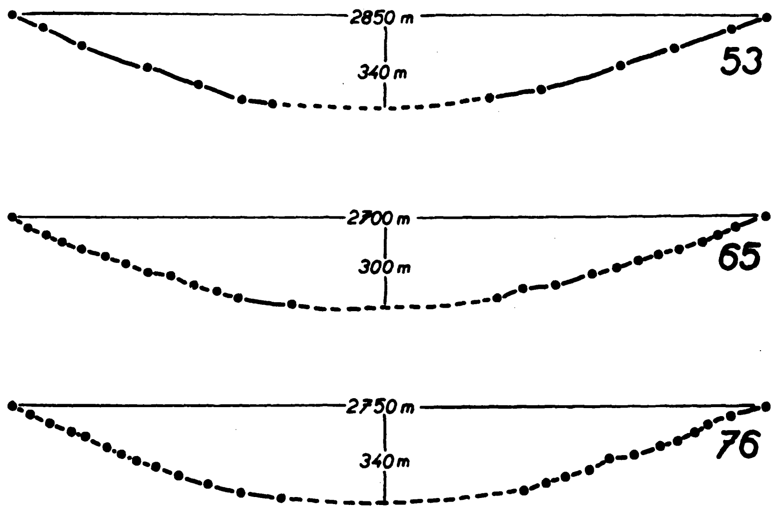

Fig. 2. Profiles of an anonymous crater (Table 6, No. 9) measured in three different Ranger IX photographs (Nos. 53, 65, 76).

The logarithmic diameter-depth relationship ($D = \log \Delta$, $d = \log \delta$) of the measured craters is shown in Fig. 6.

Assuming this relationship to be linear the following relations may be obtained for craters measured in different Ranger photographs:

Ranger VII: $D = 1.0348\ (\pm 0.0299)d + 0.7271\ (\pm 0.0771)$
Ranger VIII: $D = 0.8562\ (\pm 0.0311)d + 1.2269\ (\pm 0.0826)$
Ranger IX: $D = 1.0036\ (\pm 0.0148)d + 0.9844\ (\pm 0.0284)$

The differences may be due partly to observational errors, partly they may be caused by different properties of the lunar surface material in different regions on the Moon, where the craters were photographed. The diameter-depth relationship for all 71 measured craters is

$$D = 0.9327\ (\pm 0.0158)d + 1.0476(\pm 0.0378)$$

T a b l e   4

Ranger VII

No.	Ph.	RLC	Crater	λ	β	Δ	δ
1	45	13	Alpetragius B	$-6^{\circ}49'$	$-15^{\circ}05'$	12.2	1400
2	45	-	-	-10 30	-18 00	6.7	800
3	45	-	-	- 8 45	-19 39	6.5	850
4*	107	1	Guericke C	-11 32	-11 32	11.6	1570
5*	107	2	Guericke D	-14 37	-12 01	8.05	1000
6	107	1	Lassel H	-11 15	-14 32	3.9	580
7	107	1	Lassel J	-10 29	-14 48	3.5	430
8	107	2	Bonpland C	-17 30	-10 12	5.12	800
9	107	2	Guericke A	-17 17	-11 09	5.75	890
10	107	1	Guericke E	-12 03	-10 02	3.90	560
11	107	1	-	-12 42	-11 52	3.17	450
12	107	2	Opelt K	-17 06	-13 38	4.33	780
13	107	1	-	-12 48	-12 43	3.06	350
14	107	1	Guericke M	-12 27	-12 57	2.50	330
15*	107	2	Guericke G	-15 01	-14 02	5.20	720
16	107	2	Guericke P	-14 41	-15 05	3.95	610
17	107	2	Guericke KA	-13 33	-15 05	2.55	400
18	107	2	Guericke K	-13 16	-15 11	2.95	450
19*	178	2	-	-19 04	-11 13	1.70	173±
20*	184	2	Bonpland G	-18 46	-11 37	4.05	670±
21*	184	2	Bonpland R	-18 35	-10 43	2.50	410
22*	184	3	Bonpland HA	-19 48	-11 10	1.97	295±
23	192	3	Bonpland HH	-20 03	-10 39	1.41	228±
24	192	3	-	-20 01	-11 11	0.57	115±
25	192	3	-	-20 03	-11 02	0.66	80±
26	192	3	Bonpland HF	-20 05	-11 12	0.67	115±
27	192	3	-	-20 07	-11 04	0.58	80±
28	192	2	-	-19 45	-10 45	0.295	68±
29	192	3	-	-20 20	-10 43	0.31	47±
30	197	3	-	-20 04	-10 50	0.253	37±

*Measured also on photographs:
4 - Ph. No. 45
5 - Ph. No. 45
15 - Ph. No. 45
19 - Ph. Nos.184,186,189
20 - Ph. No. 178
21 - Ph. No. 178
22 - Ph. Nos. 186,192

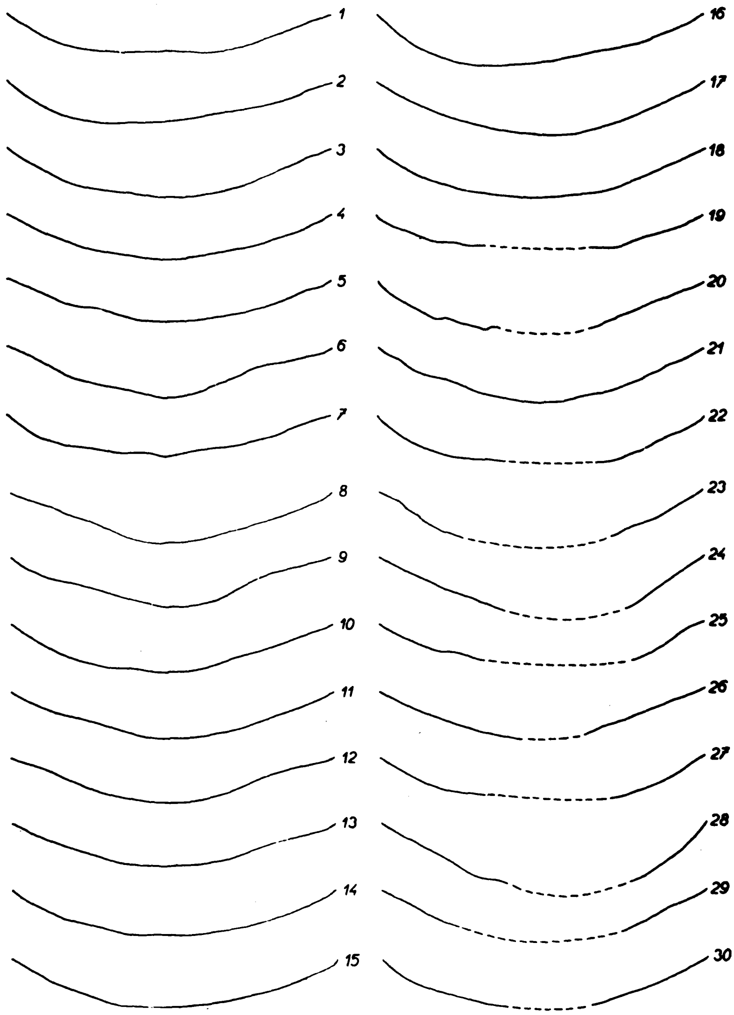

Fig. 3. Profiles of craters from Ranger VII photographs, reduced to a uniform diameter. Numbers correspond to the Nos. in Table 4, in which the true values of diameter and depth are given.

T a b l e 5

Ranger VIII

No.	Ph.	RLC	Crater	λ	β	Δ	δ
1*	17	6	Theon Senior C	$+14^{\circ}30'$	$-1^{\circ}23'$	5.80	1190
2	17	6	Taylor D	+15 43	- 5 20	7.90	1620
3	23	6	Theon Senior A	+15 25	- 0 11	4.74	1000±
4	23	6	Theon Senior	+15 27	- 0 47	17.1	2640±
5	23	6	Theon Junior	+15 50	- 2 23	17.0	>2100
6	37	6	Schmidt	+18 47	+ 1 00	12.6	2250
7*	37	7	Sabine AD	+20 37	+ 0 59	3.90	590
8	48	7	Hypatia E	+20 24	- 0 19	6.5	1000
9	54	7	Hypatia CB	+21 45	+ 0 08	2.36	345
10	59	7	Hypatia BA	+21 27	+ 1 02	1.82	260±
11	72	8	Sabine D	+23 39	+ 1 20	2.95	400
12*	80	9	Sabine DV	+23 59	+ 2 24	0.775	99
13	80	9	Sabine DY	+23 42	+ 2 10	0.765	76±
14	83	9	-	+23 58	+ 2 10	0.435	48
15	85	9	Sabine ED	+24 24	+ 2 24	1.15	106±
16	85	-	-	+24 32	+ 2 26	0.605	70±
17	87	9	Sabine EF	+24 19	+ 2 37	0.985	100

* Measured also on photographs:

1 - Ph. No. 20
7 - Ph. No. 48
12 - Ph. No. 83

This relation is in good agreement with the relationships D vs. d for other lunar craters /4/, for craters on Mars /5/ and for Earth's meteoritic and artificial explosive craters /6/. It is evident that these results are not only a contradiction of the meteoritic-impact theory of the origin of the measured lunar craters, but they are a valuable evidence for this theory.

This study has been supported in part by a grant from the Akademischer Austauschdienst, Bad Godesberg, Federal Republic of Germany. The measurements and preliminary reductions were made by the writer during his stay at the Hamburg Observatory. Special thanks of the author go to Professor H. Haffner for many helpful discussions and comments during the course of this paper.

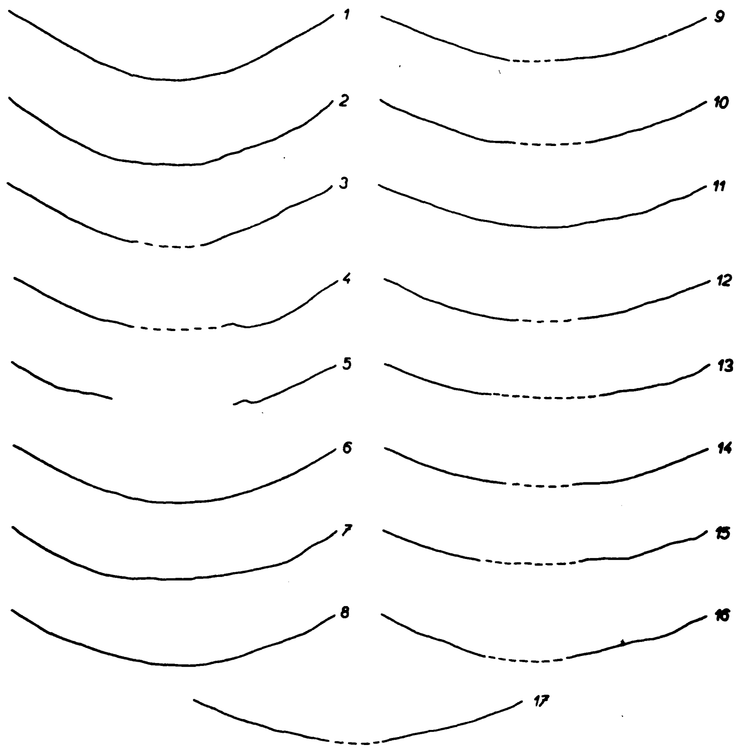

Fig. 4. Profiles of craters from Ranger VII photographs, reduced to a uniform diameter. Numbers correspond to the Nos. in Table 5, in which the true values of diameter and depth are given.

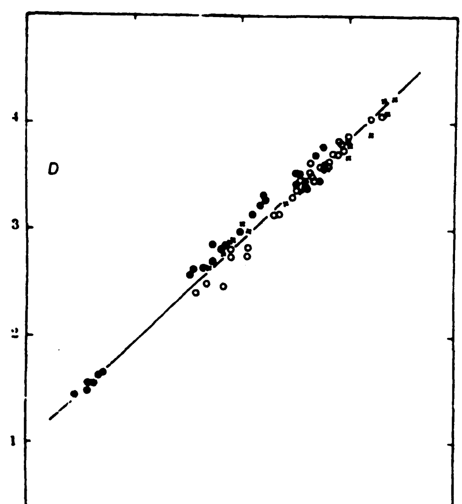

Fig. 6. Logarithmic diameter-depth relationship of craters measured in Ranger VII (open circles), Ranger VII (crosses) and Ranger IX (full circles) photographs. (Diameters and depths are given in metres.)

T a b l e 6

Ranger IX

No.	Ph.	RLC	Crater	λ	β	Δ	δ
1	27	13	Ptolemaeus Y	$+ 0^\circ 43'$	$- 9^\circ 18'$	6.1	590
2	27	13	Parrot W	+ 1 30	-13 07	5.01	590±
3	42	13	Ptolemaeus S	- 0 29	-10 32	3.50	350
4*	65	14	Alphonsus KB	- 0 44	-12 47	3.34	340
5	65	14	-	- 0 47	-12 27	3.43	>415
6	65	15	Alphonsus GD	- 2 02	-13 07	1.90	170
7	65	15	Alphonsus GE	- 1 50	-13 06	1.40	130
8	65	14	Alphonsus MA	- 1 18	-11 47	1.75	160
9*	65	14	-	- 1 55	-12 20	2.77	330±
10	76	14	Alphonsus KC	- 1 36	-12 51	2.12	260±
11*	76	15	-	- 1 51	-12 26	0.89	96
12	76	14	-	- 1 38	-12 12	0.39	34
13	76	14	-	- 1 36	-12 34	0.74	55
14	76	15	-	- 2 00	-12 55	0.67	69
15	80	15	-	- 1 59	-12 40	0.455	46
16	80	15	-	- 1 58	-12 42	0.51	56
17	80	15	-	- 2 00	-12 54	0.72	74
18	80	15	-	- 1 56	-12 49	0.43	37
19	87	16	-	- 2 20	-12 48	0.036	3.75
20	87	16	-	- 2 20	-12 47	0.036	4.35
21	87	16	-	- 2 18	-12 47	0.047	5.3
22	87	16	-	- 2 18	-12 48	0.045	4.8
23	87	16	-	- 2 19	-12 51	0.029	2.8
24	87	16	-	- 2 19	-12 51	0.032	3.7

* Measured also on photographs: 4 - Ph. No.53; 9 - Ph. No. 53 and 76; 11 - Ph. No. 65

References

/1/ Ranger VII Photographs of the Moon. Part II: Camera "B" Series. NASA (1965).
Ranger VIII Photographs of the Moon. NASA (1966).
Ranger IX Photographs of the Moon. NASA (1966).

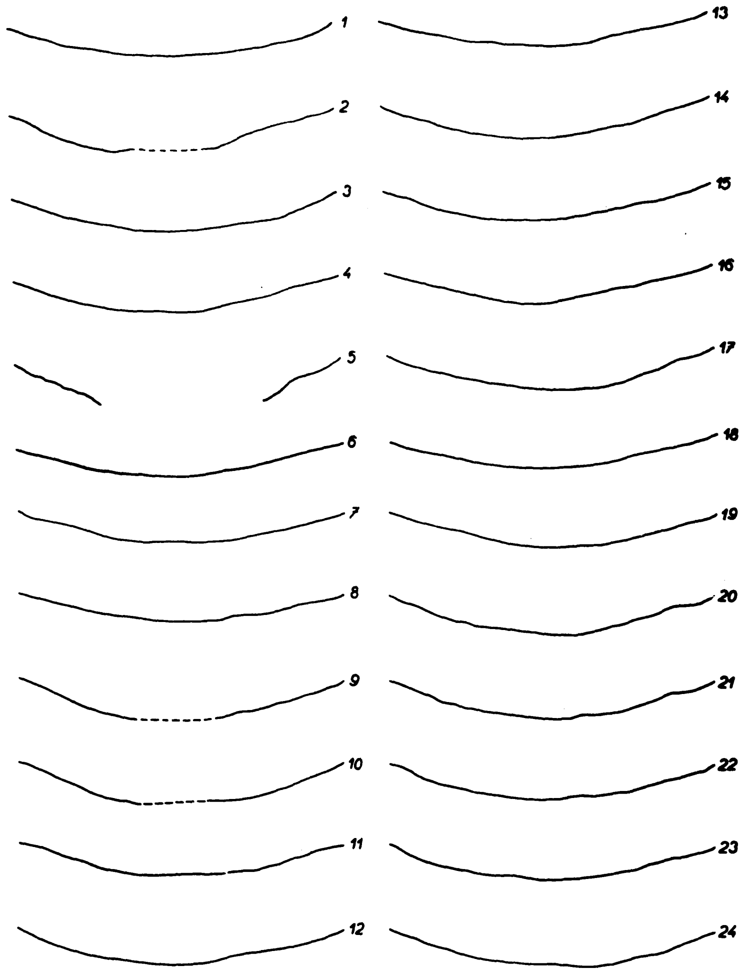

Fig. 5. Profiles of craters from Ranger IX photographs, reduced to a uniform diameter. Numbers correspond to the Nos. in Table 6, in which the true values of diameter and depth are given.

/2/ Ranger VII Photographs of the Moon. Part II: Camera "B" Series (Photographic Edition). JPL (1964).
Ranger VIII Photographs of the Moon (Photographic Edition). JPL (1965).
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