INDEPENDENT SELENOCENTRIC SYSTEM OF COORDINATES BY LARGE-SCALE STAR-CALIBRATED LUNAR PHOTOGRAPHY

SH. T. HABIBULLIN and N. G. RISVANOV
Department of Astronomy, University of Kazan, U.S.S.R.

(Received 27 July, 1983)

Abstract. The selenocentric coordinates of 263 craters and one mountain are given. The scale and orientation of the selenocentric coordinates system is determined by star-calibrated lunar photographs obtained with the long-focus horizontal telescope. The origin of the system is defined by the theory of the motion of the Moon. The physical libration is taken into account for the reduction of the coordinates system to the principal axes of the lunar inertia. The reference stars coordinates are reduced to the FK4 system. The position of the lunar mass centre is determined by LURE-2 theory, the rotation parameters are taken from the Migus tables (Migus, 1980).

1. Introduction

For a long time the lunar photographic observations have been carried out at the Kazan University with the horizontal long-focus telescope. These observations are used for the solution of certain lunar problems. The elaboration of methods for obtaining large-scale star-calibrated lunar photographs was stimulated by the wish to avoid the insufficiencies typical for previous lunar study methods based on the photograph measurements made with long-focus telescopes of large apertures. In these works the distinctive particularity is a plate constants definition with respect to the lunar points with known selenocentric coordinates. This calibration of lunar photographs was subject to the systematic errors to the coordinates of the measured points on the lunar surface (Schimerman *et al.*, 1973). The reduction method with reference to the stars surrounding the Moon provides a calibration independence of astrophotography from previous selenocentric systems. It determines an absolute barycentric coordinates system referred to the principal directions of the axes of lunar inertia with an accuracy of the errors of measurement, of the theory of lunar motion, the rotation, and of the coordinates of the reference stars.

2. Observational Material

The method of taking large-scale star-calibrated lunar photographs by means of the horizontal telescope ($F = 8000$ mm, $D = 200$ mm) on separate plates is based on the photography of the Moon and stars on two separate plates (Bistrov and Risvanov, 1973; Habibullin *et al.*, 1974). The lunar plate is located in front of the star plate 3 mm closer to the objective. At the time of exposure, the lunar plates moves in regard to fixed stars

Earth, Moon, and Planets **30** (1984) 1–19. 0167–9295/84/0301–0001$02.85.

plate with velocity of the lunar image relative to stars images in focal plane of the telescope. The diurnal rotation of the celestial sphere is compensated by a precise rotation of the coelostat mirror. In order to establish a connection between the lunar and stars plates, one prints simultaneously marks at four points of both plates. The location of mutual location of the points of reference is found separately with the aid of the star and reference point photography.

To obtain a qualitative observational material a special scientific mountain expedition was organized in the Ordubad district of the Nakhichevan Autonomous Republic. The observations were carried out in 1970–1975. The stars were photographed on the ZU-2 plates, and the Moon on the FU-5 plates. The first plates were treated with D-19 developer; the second, with fine-grained D-25 developer. The exposure times – depending on the phase of Moon and its zenith distance – oscillated between 15 to 180 s. The number of the stars was several dozens on some photographs; and were seldom completely absent. On the whole, more than 950 pairs of star-calibrated photographs have been secured.

The astro-climatic conditions of the place of observation are characterized by the following data. The average size of the atmospheric seeing discs was $1''$–$2''$ – i.e., comparable with the photographic angular resolution of the horizontal telescope of $p_f = 0''.95$; the resolution of photographic emulsion about 70 lines per millimetre; and diffraction limit of the aperture $0''.56$. The resolution of FU-5 photographic emulsion was much higher: if equal to 200 lines per millimetre, then $p_f = 0''.70$. This corresponds to 1.3 km on the lunar surface at its mean distance from the Earth. Thus on average quality photographs the craters of diameter 1–2 km can be distinguished; and this was confirmed by actual examination of the photographs.

In the choice of the photographs for measurements the first priority was given to the quality of reference points, of details on the lunar surface, to the number of control stars and the distribution of observations in libration and phases of the Moon. In Table I the information has been collected on 52 pairs of photographs selected for the treatment. The table gives, successively, the running number, number of observation on the telescope, epoch (year), date and month, observation moment (UT), exposure (Δt), quantity of lunar disc lighting part (E), total estimate of photographs quality by images of point marks, stars, craters (k) (1, satisfactory; 2, good; 3, perfect), quantity of stars, choosing as reference (n).

Both stellar and lunar photographs have been measured on a semi-automatic "Ascorecord" apparatus. The settings were carried out for the centre of crater photographic image, symmetrically to the crater walls.

3. Selenocentric Construction of the System by Stars Arrangement

The coordinates of the selected reference points fixed by special stars define the matrix of the transformation of the measured coordinates system on the lunar plate – x', y' – into the system of measured coordinates on the star plate – x, y – of the form

TABLE I

Observation used for construction of catalogue

	N	Epoch	UT	Δt	*E*	*K*	*n*
1.	4	1970 20.09	$00^h.16^m$	60^s	0.74	2	9
2.	31	15.10	18 .55	30	0.99	2	7
3.	44	13.11	20 .25	30	0.99	3	18
4.	45	13.11	20 .38	30	0.99	3	15
5.	46	13.11	20 .55	30	0.99	3	13
6.	65	1971 8.02	19 .35	15	0.97	1	12
7.	67	8.02	20 .09	20	0.97	1	9
8.	76	11.02	22 .27	20	0.98	2	7
9.	91	11.04	20 .49	25	0.99	1	4
10.	92	11.04	21 .14	30	0.99	1	4
11.	138	8.07	20 .20	60	1.00	2	13
12.	161	1.09	17 .12	55	0.84	2	20
13.	176	5.09	20 .54	25	0.99	2	8
14.	180	7.09	22 .05	35	0.87	2	11
15.	185	3.10	18 .51	35	0.98	2	11
16.	188	5.10	20 .50	30	0.97	2	9
17.	194	5.11	21 .56	35	0.88	2	17
18.	195	5.11	22 .10	30	0.88	2	13
19.	197	6.11	22 .43	45	0.79	2	14
20.	202	2.12	20 .51	20	0.99	2	6
21.	207	1972 26.03	19 .45	50	0.92	2	13
22.	208	26.03	20 .05	50	0.92	2	11
23.	210	31.03	21 .31	70	0.96	2	8
24.	240	28.06	21 .22	70	0.96	1	16
25.	241	28.06	21 .31	70	0.96	1	16
26.	247	29.06	21 .50	70	0.90	2	14
27.	258	1972 3.07	00 .06	110	0.63	3	5
28.	254	3.07	00 .15	110	0.63	2	7
29.	261	22.07	18 .36	103	0.87	2	10
30.	267	23.07	18 .39	92	0.93	1	9
31.	268	23.07	18 .49	97	0.93	1	9
32.	273	24.07	19 .30	68	0.97	2	14
33.	274	24.07	19 .40	75	0.97	2	9
34.	284	1.08	23 .48	102	0.54	1	7
35.	285	1.08	23 .58	102	0.54	1	6
36.	303	21.08	18 .18	92	0.83	1	16
37.	304	21.08	18 .29	85	0.83	2	17
38.	307	22.08	17 .34	68	0.95	1	9
39.	356	27.08	21 .34	60	0.87	3	8
40.	357	27.08	21 .44	56	0.87	3	9
41.	358	28.08	21 .07	68	0.79	2	6
42.	359	28.08	21 .14	68	0.79	2	8
43.	406	16.08	17 .16	92	0.76	1	13
44.	407	17.08	17 .05	56	0.85	2	10
45.	433	1973 18.01	18 .28	15	1.00	3	11
46.	458	9.06	17 .13	25	0.68	1	6
47.	468	16.06	21 .13	32	0.99	2	10
48.	478	14.07	19 .20	39	1.00	2	13
49.	501	20.07	23 .42	20	0.73	2	6
50.	526	18.08	22 .22	68	0.76	2	14
51.	542	9.09	18 .19	68	0.91	2	7
52.	547	1973 10.09	19 .13	42	0.96	2	8

$$\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \end{pmatrix} \begin{pmatrix} x' \\ y' \\ 1 \end{pmatrix}. \tag{1}$$

If a, b, c, d, e, f are constants of the star plate defined by the reference stars and x_k, y_k are the measured coordinates of the craters with reference to the star plate, its standard coordinates follow from the formula

$$\begin{pmatrix} X_k \\ Y_k \end{pmatrix} = \begin{pmatrix} a & b & c \\ d & e & f \end{pmatrix} \begin{pmatrix} x_k \\ y_k \\ 1 \end{pmatrix}. \tag{2}$$

From the values X_k, Y_k the spherical equatorial crater coordinates α'_k, δ'_k are computed in the usual way. They will be apparent, topocentric ones.

Furthermore, we denote a selenocentric rectangular coordinates sytem by ξ, η, ζ, whose ξ-axis is directed to Mare Crisium, η-axis is directed along the Moon's axis of rotation to its north pole; ζ-axis, to the direction to the Earth; and U, V, W represent a selenocentric rectangular system coordinates, with U and V axes in the plane of projection. The U-axis is in the direction of increasing right ascension, while the V-axis coincides with the declination circle projection and is directed to the celestial pole; and the W-axis is directed to the observer. The transformation from the first to the second system of coordinates can be expressed as

$$\begin{pmatrix} U \\ V \\ W \end{pmatrix} = \begin{pmatrix} A_{22} & A_{32} & A_{12} \\ A_{23} & A_{33} & A_{13} \\ A_{21} & A_{31} & A_{11} \end{pmatrix} \begin{pmatrix} \xi \\ \eta \\ \zeta \end{pmatrix}. \tag{3}$$

The crater coordinates U_{obs} and V_{obs} are found from the observations. On the other hand, U_c and V_c can be computed from the ξ_c, η_c, and ζ_c coordinates taken from a catalogue. The differences

$$\Delta U = U_{\text{obs}} - U_c, \qquad \Delta V = V_{\text{obs}} - V_c, \tag{4}$$

allow to determine the corrections $\Delta\xi$, $\Delta\eta$, and $\Delta\zeta$ to the adopted values of ξ_c, η_c, and ζ_c from the equations of condition of the form

$$\begin{aligned} A_{22}\Delta\xi + A_{32}\Delta\eta + A_{12}\Delta\zeta &= \Delta U, \\ A_{23}\Delta\xi + A_{33}\Delta\eta + A_{13}\Delta\zeta &= \Delta V. \end{aligned} \tag{5}$$

The values of U_{obs} and V_{obs} are defined by the coordinates of the observed craters and ephemeris topocentric coordinates of the Moon $\alpha'_{☾}$, $\delta'_{☾}$. First, we find the projected coordinates

$$\bar{U}_{\text{obs}} = \frac{\cos\delta'_k \sin(\alpha'_k - \alpha'_{☾})}{\sin\delta'_k \cos\delta'_{☾} + \cos\delta'_k \sin\delta'_{☾} \cos(\alpha'_k - \alpha'_{☾})},$$

$$\bar{V}_{\text{obs}} = \frac{\sin \delta_k' \cos \delta_☾' - \cos \delta_k' \sin \delta_☾' \cos (\alpha_k' - \alpha_☾')}{\sin \delta_k' \cos \delta_☾' + \cos \delta_k' \sin \delta_☾' \cos (\alpha_k' - \alpha_☾')}; \tag{6}$$

and then a transformation is carried out to their orthographic projections

$$\begin{aligned} U_{\text{obs}} &= \bar{U}_{\text{obs}}(1 - W_c \sin R_☾'), \\ V_{\text{obs}} &= \bar{V}_{\text{obs}}(1 - W_c \sin R_☾'), \end{aligned} \tag{7}$$

where W_c is found from Equation (3); where $R_☾'$ stands for the topocentric ephemeris lunar radius.

The coordinates U_c, V_c, and W_c were computed by the formula (3) according to the ξ_c, η_c, and ζ_c coordinates values taken from "The Tucson Selenodetic Triangulation" (Arthur and Bates, 1968). The A_{ij} matrix elements are defined from expressions

$$\begin{aligned} \begin{pmatrix} A_{11} \\ A_{12} \\ A_{13} \end{pmatrix} &= \begin{pmatrix} 1 & 0 & 0 \\ 0 & -\sin C & \cos C \\ 0 & -\cos C & -\sin C \end{pmatrix} \begin{pmatrix} \cos b & \cos l \\ \sin b & \cos l \\ & \sin l \end{pmatrix}, \\ \begin{pmatrix} A_{21} \\ A_{22} \\ A_{23} \end{pmatrix} &= \begin{pmatrix} 1 & 0 & 0 \\ 0 & -\sin C & -\cos C \\ 0 & -\cos C & \sin C \end{pmatrix} \begin{pmatrix} \cos b & \sin l \\ \sin b & \sin l \\ & \cos l \end{pmatrix}, \\ \begin{pmatrix} A_{31} \\ A_{32} \\ A_{33} \end{pmatrix} &= \begin{pmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{pmatrix} \begin{pmatrix} \cos C & \cos b \\ \sin C & \cos b \\ & \sin b \end{pmatrix}, \end{aligned} \tag{8}$$

where l, b, and C signify, respectively, the optical libration in longitude, latitude and position angle at the place of observations, and corrected for the physical librations.

The latter have been published in *National Astronomical Ephemeris*; but the lunar ephemeris for $j = 2$ does not correspond to the accuracy of the present methods of observation, as its errors can exceed $0''.5$. At present a number of new more precise lunar ephemerides has been created, which are based on the numerical as well as analytical theories of the Moon's motion. By reduction of the observations of the lunar coordinates we defined $\alpha_☾'$, $\delta_☾'$, and $\pi_☾'$ by the numerical LURE-2 theory. The physical libration components were computed by the analytic libration tables of Migus (1980). For the lunar photographs with positive declination the star coordinates were taken from the AGK3 Catalogue. For negative declination the positions of the reference stars were defined by observations of corresponding southern sky areas on the astrograph Zeiss 400/2000 of Zelentchuk high-altitude station of Kasan University in the system of the catalogue Perth, 1970 (Høg and van der Heide, 1976).

The solution of the equations of condition (5) has been carried out by the least-squares method. We noted that, in our case, the terms on their right-hand sides depend functionally on the same arguments. Therefore, in the solution by least-squares method the generalized weight matrix (Arthur, 1965) was used. As a result, the solution of normal equations furnished the corrections $\Delta\xi$, $\Delta\eta$, and $\Delta\zeta$ and its errors; and the desired coordinates values of the craters were computed from the formulae

$$\xi = \xi_c + \Delta\xi, \quad \eta = \eta_c + \Delta\eta, \quad \zeta = \zeta_c + \Delta\zeta. \tag{9}$$

These final coordinate values included in catalogue are barycentric ones, related to the principal axes of inertia.* The coordinates ξ and η refer to crater centres and the third coordinate ζ refers to the mean level of craters walls.

4. Description of the Catalogue

To construct the catalogue we included 66 craters of the Moutsoulas' list (Moutsoulas, 1975) and the list of 200 craters proposed by Gurstein and Slovokhotova (1971). The choice of these craters as control points on the earthside is well-founded on the basis of a number of works (Weimer, 1973; Gurstein and Slovokhotova, 1971; Gavrilov, 1973) and it is confirmed by the resolution of the XV General Assembly of the IAU (Moutsoulas, 1975). In the west half of the visible lunar side – in zones investigated by spacecraft Apollo 15 (Schimerman, 1976) – a number of smaller craters was chosen to establish agreement of the coordinates system of the visible and far side of the Moon. Furthermore, for an analysis of the accuracy of heliometric observations 32 more craters of the Mamakov (1979) catalogue were included. 264 objects were chosen as result of the examination of these lists – 263 craters and one mountain. The three craters have diameters of more than 15 km, 26 craters are smaller than 5 km; the other are between 5 and 15 km. The number of selected craters defines the mean density of distribution on the lunar surface – not less than one crater per area $10° \times 10°$.

Table II gives the independent barycentric coordinates of 264 objects on the lunar surface. The structure of the Catalogue is as follows: in the first and second columns the ordinal numbers and object numbers by Blagg and Muller (1935) are given. In the next three columns we give the rectangular selenocentric coordinates of the objects expressed in terms of the adopted mean lunar radius of 1738.1 km. The next three columns give the selenographic coordinates – λ, β and ΔH – the absolute altitude of the respective object above the sphere radius, 1730 km. In the last column we indicate the list from which the object is taken. Thus the Moutsoulas list is denoted by *M*; the Gurstein and Slovokhotova one, by *G*; the Mamakov catalogue, by *K*, and the smaller 30 craters which we selected are designed by *A*. In the second line the errors of rectangular coordinates are given, which are expressed by the lunar radius quota 10^{-5}, also the absolute altitude, in km. When an object is absent in the B and M list, it has been assigned a number from the "*Consolidated Catalogue of Selenographic Positions*" (Arthur, 1962). In the latter case the numbers are given to five digits. The objects N 76, B and M 1404 is a separate mountain (Mons Undest), the object N 91, 24425A is a crater of 0.9 km diameter, but not a light spot as indicated in Arthur's *Consolidated Catalogue*.

* When one speaks of the principal axes of inertia, the model of the rigid Moon, based on the physical libration theory, is implied.

TABLE II

The catalogue of the independent selenocentric coordinates of 264 objects

N	B and M	ξ	η	ζ	λ	β	ΔH	Catalogue
1	987	0.05514	0.90643	0.41622	7°.546	65°.122	4.69	M
		± 16	± 16	± 156			± 1.12	
2	895	07143	40028	91323	4 .472	23 .604	7.51	G
		13	13	117			1.84	
3	897A	07279	46558	87963	4 .730	27 .811	4.45	G
		20	20	177			2.71	
4	834	08917	03055	99550	5 .119	1 751	8.01	M
		18	17	63			1.09	
5	966	09766	77217	62379	8 .878	50 .696	3.66	G
		15	15	136			1.44	
6	932	09982	66631	73635	7 .720	41..882	4.76	G
		25	25	229			2.97	
7	965	11245	78160	60923	10 .458	51 .598	3.52	M
		12	12	119			1.25	
8	606	18873	33563	92104	11 .580	19 .646	5.12	M
		10	11	89			1.40	
9	689A	20016	92334	32173	31 .888	67 .688	4.73	G
		22	22	189			1.17	
10	685A	21039	90527	36377	30 .043	65 .099	4.71	G
		32	31	261			2.16	
11	689B	21973	92464	30472	35 .795	67 .888	4.23	G
		30	29	262			1.50	
12	792	22010	84443	48303	24 .497	57 .847	3.60	G
		23	27	251			1.93	
13	727	23856	71708	65326	20 .061	45 .877	6.24	K
		17	18	158			1.78	
14	561	25837	06901	96327	15 .015	3 .958	7.61	M
		9	8	74			1.24	
15	619	28407	36962	88279	17 .837	21 .730	5.20	M
		10	9	88			1.35	
16	672A	29165	85217	42798	34 .273	58 .711	4.25	G
		19	19	168			1.30	
17	573	31252	13547	93921	18 .405	7 .793	6.48	G
		14	13	135			2.19	
18	552	32023	01686	94659	18 .690	0 .966	7.11	G
		12	12	111			1.83	
19	622	32447	41799	84665	20 .969	24 .750	5.33	G
		14	13	131			1.95	
20	645A	32777	66517	66793	26 .138	41 .798	4.64	G
		14	14	138			1.57	
21	645	33325	67847	65264	27 .050	42 .795	5.78	G
		31	32	305			3.53	
22	491	34100	54707	76186	24 .112	33 .242	4.61	M
		10	9	87			1.16	

Table II (continued)

N	B and M	ξ	η	ζ	λ	β	ΔH	Catalogue
23	661	0.36083 ± 23	0.77596 ± 23	0.51256 ± 251	35°.144	51°.068	3.78 ± 2.25	G
24	534A	38489 12	21773 12	89524 117	23 .264	12 .595	5.49 1.81	G
25	519	42223 7	29550 6	85550 57	26 .269	17 .210	5.90 0.86	M
26	458	43442 15	72344 16	53297 146	39 .183	46 .456	4.75 1.37	M
27	457	45247 24	70373 24	54405 227	39 .750	44 .842	4.59 2.19	G
28	409	45558 30	83187 29	30744 280	55 .987	56 .548	3.00 1.56	G
29	498	45639 16	58064 17	67111 153	34 .218	35 .581	4.47 1.78	G
30	270A	46188 11	31923 11	82566 106	29 .223	18 .646	5.45 1.52	G
31	244A	48210 13	03485 13	87386 128	28 .885	2 .000	5.73 1.95	G
32	385	50827 10	60261 10	61301 95	39 .664	37 .116	5.72 1.02	M
33	495A	50993 15	52387 14	67984 144	36 .872	31 .652	5.18 1.86	G
34	260	51604 10	15388 11	84147 88	31 .519	8 .864	6.41 1.88	M
35	308	53556 14	38374 14	74913 132	35 .561	22 .622	3.98 1.71	G
36	391	54572 26	65576 26	51815 224	46 .485	41 .069	4.89 2.00	G
37	275A	57882 14	24744 14	77586 137	36 .724	14 .340	6.56 1.85	G
38	397	58420 29	75509 29	29452 275	63 .248	49 .092	6.56 1.37	G
39	312	60362 12	54193 11	58220 115	46 .035	32 .871	5.49 1.16	M
40	182	60932 19	33465 20	71723 183	40 .349	19 .575	6.09 2.28	K
41	204	62477 23	29949 23	71930 211	40 .977	17 .450	5.86 2.67	K
42	325A	64245 21	51161 21	50852 205	48 .494	30 .811	6.11 2.02	G
43	178	68652 10	45747 9	56352 89	50 .620	27 .251	6.49 0.88	M
44	187	69104 25	38138 25	61214 252	48 .465	22 .446	6.10 2.05	G

Table II (continued)

N	B and M	ξ	η	ζ	λ	β	ΔH	Catalogue
45	206	0.69593	0.24525	0.67315	45°.953	14°.214	6.01	G
		± 13	± 14	± 124			± 1.49	
46	122	73501	45503	49862	55 .848	27 .127	4.55	G
		35	35	322			2.86	
47	165	74231	58410	32383	66 .431	35 .800	5.55	G
		21	21	202			1.20	
48	216	75709	12594	63879	49 .844	7 .246	5.58	M
		11	11	107			1.18	
49	106	78767	25116	55790	54 .690	14 .586	3.55	M
		14	14	127			1.23	
50	142	81442	49444	29804	69 .900	29 .689	5.13	G
		26	26	252			1.41	
51	69	83591	05723	54354	56.967	3 .285	5.89	G
		29	28	304			2.90	
52	19032	93236	02442	35720	69 .037	1 .401	5.91	G
		37	30	306			2.38	
53	1073	−02069	81960	56739	−2 .088	55 .288	2.97	G
		20	20	172			1.68	
54	1214	−02139	15650	98679	−1 .242	9 .010	6.98	M
		13	13	120			2.06	
55	1147	−02326	52362	84810	−1 .571	31 .682	2.87	G
		14	14	128			1.87	
56	1125	−04287	66681	74105	−3 .311	41 .934	4.29	G
		19	20	183			2.31	
57	1215	−05409	15200	98645	−3 .139	8 .747	7.32	K
		10	10	87			1.49	
58	1217	−08157	21195	97204	−4 .797	12 .259	5.00	G
		11	12	105			1.76	
59	1204	−08534	24222	96499	−5 .054	14 .038	5.64	G
		9	9	77			1.28	
60	1145	−09948	47000	87560	−6 .481	28 .073	5.92	M
		13	13	116			1.75	
61	1250	−13561	08310	98637	−7 .828	4 .771	6.55	G
		12	12	94			1.33	
62	1069	−16285	76086	62535	−14 .596	49 .658	5.04	G
		28	35	318			3.15	
63	1302	−16471	63844	74845	−12 .411	39 .797	3.68	G
		15	16	143			1.82	
64	1070	−18020	76158	61861	−16 .241	49 .768	3.88	G
		20	23	206			2.09	
65	1121	−18307	72404	66219	−15 .454	46 .503	4.84	M
		13	14	132			1.50	
66	1298	−18685	46664	86206	−12 .229	27 .880	4.45	A
		14	15	129			1.92	

Table II (continued)

N	B and M	ξ	η	ζ	λ	β	ΔH	Cata-logue
67	1328A	−0.20469	0.89995	0.37750	−28°.467	64°.491	3.15	G
		± 26	± 27	± 169			1.03	
68	1500	−20560	05804	97584	−11 .898	3 .331	6.28	G
		15	16	141			2.38	
69	1328	−21791	89204	38963	−29 .217	63 .414	3.77	G
		20	21	175			1.22	
70	1298A	−22286	41876	87842	−14 .236	24 .801	5.19	A
		10	10	92			1.40	
71	1394	−23145	54382	80432	−16 .054	33 .014	4.82	G
		17	18	160			2.18	
72	1292	−24067	41949	87324	−15 .408	24 .850	5.01	G
		13	14	118			1.74	
73	22749A	−24683	79365	55244	−24 .074	52 .678	4.62	M
		14	15	134			1.28	
74	1381	−26505	77332	57211	−24 .883	50 .802	4.40	K
		19	20	176			1.68	
75	1367	−27113	85440	43666	−31 .837	58 .970	3.03	G
		25	27	222			1.38	
76	1404	−28401	44559	84751	−18 .527	26 .497	5.92	A
		9	9	84			1.27	
77	1366	−29284	81392	49790	−30 .462	54 .637	4.73	K
		18	19	171			1.44	
78	1679	−29808	88412	35455	−40 .055	62 .349	4.82	G
		23	26	289			1.22	
79	1368B	−30753	79185	52327	−30 .443	52 .530	4.12	G
		24	25	218			1.90	
80	1392	−30767	50489	80465	−20 .924	30 .374	5.54	G
		13	14	125			1.72	
81	1498	−32240	01677	94552	−18 .828	0 .962	6.56	M
		11	11	104			1.72	
82	1315	−32711	69105	64069	−27 .047	43 .850	3.78	G
		17	18	153			1.64	
83	1390	−33970	55505	76105	−24 .171	33 .784	4.94	M
		17	18	158			2.02	
84	1399A	−34636	46401	81330	−23 .068	27 .695	5.26	A
		12	14	120			1.64	
85	1407	−34735	34880	86881	−21 .792	20 .444	5.62	A
		10	10	97			1.00	
86	1399	−34951	47687	80439	−23 .504	28 .539	5.14	A
		12	14	120			1.64	
87	1412	−35072	29338	88744	−21 .564	17 .090	5.17	M
		14	15	131			2.00	
88	23454	−35828	44487	81882	−23 .632	26 .462	5.28	A
		10	14	121			1.55	

Table II (continued)

N	B and M	ξ	η	ζ	λ	β	ΔH	Catalogue
89	1391	−0.36579	0.57866	0.72682	−26°.715	35°.419	5.42	G
		± 11	± 11	± 104			± 1.37	
90	1666	−40085	82446	39299	−45 .567	55 .750	3.62	G
		26	28	244			1.57	
91	24425A	−42471	45553	78038	−28 .556	27 .145	5.39	A
		19	23	159			2.15	
92	1418	−42907	21143	87713	−26 .067	12 .218	6.50	G
		13	13	118			1.79	
93	1604	−42939	60446	66810	−32 .729	37 .275	4.72	G
		12	14	122			1.36	
94	24346	−45122	36459	81133	−29 .081	21 .441	5.56	A
		7	8	66			0.90	
95	1635	−45660	73762	49353	−42 .733	47 .650	4.76	M
		13	14	126			1.09	
96	1522	−46742	11237	87549	−28 .097	6 .460	6.01	G
		17	18	164			2.50	
97	1591	−47005	48555	73489	−32 .604	29 .100	5.29	A
		9	10	76			0.94	
98	24395	−49393	35344	79284	−31 .922	20 .725	5.91	A
		9	11	76			1.02	
99	1529	−49620	17370	84879	−30 .311	10 .019	5.35	K
		13	14	121			1.79	
100	1589	−49924	46292	73066	−34 .344	27 .615	5.85	M
		13	13	123			1.56	
101	1591A	−50658	45815	72866	−34 .808	27 .305	5.90	A
		15	16	137			1.70	
102	1584	−50892	41696	75109	−34 .120	24 .682	5.48	A
		10	11	97			1.25	
103	1606	−50900	58304	63077	−38 .902	35 .729	5.39	G
		14	15	126			1.33	
104	1520	−51003	07609	85529	−30 .809	4 .369	5.87	G
		12	13	110			1.63	
105	1581B	−52285	35962	77113	−34 .139	21 .106	5.79	A
		14	15	136			1.82	
106	1539	−52410	16081	83465	−32 .126	9 .267	5.64	G
		11	12	103			1.46	
107	1590	−52849	46267	71033	−36 .649	27 .590	6.30	A
		13	16	142			1.66	
108	1613	−53915	65596	52514	−45 .754	41 .074	5.27	G
		21	22	182			1.60	
109	25732A	−53921	72663	42109	−52 .012	46 .724	4.67	G
		15	18	162			1.05	
110	1725	−54936	77183	31222	−60 .389	50 .694	3.75	G
		25	30	247			1.20	

Table II (continued)

N	B and M	ξ	η	ζ	λ	β	ΔH	Catalogue
111	25656	−0.55699 ± 9	0.66462 ± 10	0.49370 ± 87	−48°.446	41°.763	4.37 ± 0.71	G
112	1578	−56189 11	35603 11	74524 103	−37 .015	20 .922	6.24 1.33	M
113	1737	−57557 14	49783 17	64599 109	−41 .701	29 .916	4.99 1.33	G
114	1555	−58581 11	12392 12	79964 104	−36 .226	7.126	6.32 1.42	M
115	25592	−59208 15	52530 18	60864 149	−44 .210	31 .742	5.44 1.52	A
116	1580	−59258 17	36467 18	71684 170	−39 .579	21 .410	6.36 2.15	A
117	1581A	−59690 16	36219 16	71409 145	−39 .892	21 .264	5.84 1.83	A
118	1576	−62669 18	33797 19	70033 167	−41 .824	19 .780	5.86 2.00	G
119	1736	−62944 15	50859 17	58477 147	−47 .107	30 .624	5.33 1.47	A
120	1728	−64121 26	71802 27	26474 238	−67 .567	45 .986	5.33 1.48	G
121	1540	−64548 13	00585 14	76184 119	−40 .274	0 .336	5.56 1.59	G
122	1758	−65191 18	46833 19	59362 180	−47 .679	27 .976	5.23 1.84	A
123	26457	−65564 18	47383 17	58608 156	−48 .206	28 .316	6.24 1.66	A
124	1557	−65700 13	17400 14	73089 121	−41 .952	10 .040	4.74 1.52	G
125	1739	−66656 15	52622 17	52476 146	−51 .788	31 .811	5.12 1.25	G
126	1877	−69094 24	60739 27	38631 225	−60 .790	37 .499	4.23 1.41	G
127	1814	−70182 10	21761 11	67596 97	−46 .074	12 .589	5.36 1.13	M
128	1816	−71702 13	24126 14	65196 126	−47 .721	13 .979	5.81 1.42	G
129	1806	−73361 15	36652 16	56966 134	−52 .170	21 .555	5.52 1.29	M
130	1868	−75733 16	48365 18	43421 166	−60 .172	28 .988	4.62 1.29	A
131	27466	−76438 12	46521 14	44103 125	−60 .016	27 .796	3.93 0.97	A
132	1833	−77917 13	08933 14	61841 126	−51 .562	5 .132	5.95 1.36	M

Table II (continued)

N	B and M	ξ	η	ζ	λ	β	ΔH	Cata-logue
133	27485	−0.78491	0.45530	0.41682	−62°.030	27°.126	5.60	A
		± 17	± 18	± 154			1.12	
134	27297	−79386	27315	54029	−55 .761	15.879	5.26	G
		13	15	129			1.15	
135	27493	−79523	43488	41858	−62 .239	25 .823	5.24	A
		13	15	127			0.90	
136	1812	−81289	38967	42912	−62 .170	22 .973	5.30	G
		10	11	94			0.69	
137	1844	−87223	20248	44144	−63 .156	11 .702	5.20	M
		12	14	118			0.91	
138	1959	−92694	04892	37009	−68 .235	2 .806	6.87	G
		28	30	238			1.48	
139	1960	−93273	02247	35854	−68 .973	1 .288	7.28	G
		24	25	249			0.93	
140	3268	−00609	−90088	43122	−0 .809	−64 .419	5.98	G
		23	24	224			1.52	
141	2963	−01535	−14766	98787	−0 .890	−8 .500	6.30	G
		18	18	163			2.81	
142	3086	−02556	−38870	92100	−1 .590	−22 .874	8.08	G
		18	18	141			2.26	
143	3204	−05112	−75220	65484	−4 .464	−48 .872	5.71	G
		20	20	171			2.13	
144	3102	−05797	−48575	87134	−3 .806	−29 .085	6.84	G
		17	18	140			2.42	
145	3294	−07999	−92126	37939	−11 .906	−67 .175	7.28	G
		17	17	129			2.28	
146	3154	−08445	−63440	76799	−6 .275	−39 .389	7.60	M
		13	14	121			1.66	
147	2933	−09120	−05570	99371	−5 .244	−3 .195	7.12	M
		9	8	74			1.27	
148	3251D	−10417	−81779	56415	−10 .462	−54 .950	6.27	G
		15	15	191			1.50	
149	3212	−10722	−79345	59769	−10 .170	−52 .573	6.62	K
		15	16	138			1.50	
150	3028	−11633	−26033	95720	−6 .929	−15 .108	5.96	M
		21	21	190			2.18	
151	3063	−13875	−37981	91263	−8 .645	−22 .365	4.98	G
		15	15	136			2.18	
152	3292	−15354	−95154	26379	−30 .201	−72 .215	6.87	G
		26	30	267			1.53	
153	2748	−16284	−57517	80080	−11 .494	−35 .139	6.90	M
		15	14	129			1.80	
154	3237	−16429	−84792	49914	−18 .219	−58 .212	3.84	M
		14	15	138			1.29	

Table II (continued)

N	B and M	ξ	η	ζ	λ	β	ΔH	Cata-logue
155	2856	−0.19743	−0.20003	0.95852	−11°.639	−11°.552	6.14	M
		± 14	± 14	± 120			± 2.02	
156	2699A	−21906	−88812	40185	−28 .596	−62 .736	6.55	G
		20	22	181			1.45	
157	2726	−22256	−69730	68059	−18 .108	−44 .240	7.20	G
		20	20	182			1 96	
158	2922	−22966	−02430	97206	−13 .293	−1 .394	6.57	G
		13	13	118			2.00	
159	2694	−23373	−86877	43164	−28 .435	−60 .534	4.36	M
		18	19	185			1.53	
160	2716	−26226	−75463	59955	−23 .626	−49 .069	6.10	G
		36	35	277			2.92	
161	2778	−26854	−45570	84684	−17 .594	−27 .155	5.41	M
		16	18	160			2.41	
162	2677	−28808	−90763	30505	−43 .362	−65 .190	7.97	G
		22	27	201			1.58	
163	2818	−29447	−29264	90894	−17 .951	−17 .029	6.82	G
		12	13	114			1.82	
164	2763	−31114	−55325	77219	−21 .946	−33 .606	7.38	G
		20	20	186			2.56	
165	2629	−33782	−86169	37274	−42 .187	−59 .724	4.24	G
		25	28	237			1.53	
166	2898	−35675	−09508	92820	−21 .024	−5 .462	6.25	M
		8	8	71			1.15	
167	2589	−36613	−68418	62825	−30 .232	−43 .255	5.37	M
		13	13	124			1.41	
168	2614A	−37508	−73742	56022	−33 .803	−47 .565	6.63	G
		29	30	258			2.63	
169	2831	−38716	−25181	88609	−23 .602	−14 .596	6.75	G
		15	15	138			2.14	
170	2832	−42598	−24409	86955	−26 .100	−14 .149	5.63	M
		13	13	119			1.82	
171	2566	−42855	−57813	69245	−31 .753	−35 .372	5.82	G
		16	17	144			1.81	
172	2526	−43180	−43784	78695	−28 .754	−26 .002	5.87	G
		22	23	211			2.96	
173	2594	−43586	−68631	58071	−36 .890	−43 .386	6.57	M
		13	15	133			1.43	
174	34734	−43927	−74589	49975	−41 .315	−48 .266	7.28	G
		24	29	241			2.31	
175	2277A	−48665	−77999	39361	−51 .034	−51 .255	8.22	G
		27	32	200			2.50	
176	2462	−49464	−20400	84370	−30 .382	−11 .782	6.46	G
		14	15	131			1.94	

Table II (continued)

N	B and M	ξ	η	ζ	λ	β	ΔH	Catalogue
177	2355	−0.49652	−0.51816	0.69634	−35°.490	−31°.210	7.02	G
		± 11	± 12	± 101			± 1.28	
178	2483	−50944	−05242	85767	−30 .710	−3 .008	6.26	G
		14	15	135			2.04	
179	35629	−52250	−69583	49119	−46 .770	−44 .136	6.77	G
		30	31	313			2.79	
180	2425	−54427	−23030	80456	−34 .077	−13 .337	5.14	M
		11	10	96			1.35	
181	2419	−56048	−36815	74028	−37 .130	−21 .628	6.08	G
		12	14	118			1.57	
182	2338	−59897	−61492	51116	−49 .522	−37 .987	6.51	M
		12	13	112			1.03	
183	2457	−61180	−13105	77838	−38 .167	−7 .540	5.79	M
		16	18	157			2.16	
184	36535	−63238	−55439	54055	−49 .476	−33 .679	7.62	G
		27	29	260			2.44	
185	2306A	−64255	−68907	33406	−62 .531	−43 .576	7.48	G
		24	30	256			1.40	
186	2318	−64548	−65623	38918	−58 .913	−41 .044	7.01	G
		13	15	124			0.92	
187	2154	−65154	−41674	63245	−45 .852	−24 .653	6.50	G
		14	14	117			1.28	
188	2325A	−66139	−62498	41413	−57 .947	−38 .692	7.70	G
		13	15	129			1.03	
189	2444	−67558	−13561	72242	−43 .089	−7 .806	5.44	M
		19	22	251			2.38	
190	2151	−67710	−33814	65234	−46 .044	−19 .773	7.27	G
		9	11	101			1.20	
191	2445	−68807	−10322	71648	−43 .841	−5 .932	5.86	G
		15	17	143			1.81	
192	2157B	−69141	−32938	64156	−47 .142	−19 .250	6.48	G
		22	31	272			3.21	
193	37405	−70806	−45482	53873	−52 .734	−27 .077	6.74	G
		20	23	193			1.95	
194	2230	−70921	−63605	30355	−66 .829	−39 .501	7.83	G
		23	33	233			1.74	
195	2446	−71940	−09591	68616	−46 .355	−5 .510	5.96	G
		15	17	144			1.73	
196	2138A	−72191	−25579	64083	−48 .405	−14 .841	5.71	M
		13	14	126			1.43	
197	37359	−75412	−39515	52331	−55 .242	−23 .292	6.97	G
		24	26	226			2.06	
198	2222B	−79806	−49238	34657	−66 .526	−29 .506	7.62	G
		12	14	120			0.82	

Table II (continued)

N	B and M	ξ	η	ζ	λ	β	ΔH	Cata-logue
199	2047	−0.81640	−0.41544	0.40029	−63°.881	−24°.556	7.52	K
		± 13	± 14	± 123			±0.93	
200	2062	−83052	−35269	43277	−62 .477	−20 .636	9.36	M
		12	13	109			0.85	
201	2088	−84378	−23456	48092	−60 .318	−13 .578	6.60	G
		14	18	167			1.42	
202	1992	−84788	−09108	52035	−58 .462	−5 .231	6.32	M
		15	17	142			1.32	
203	1977	−88836	−01313	45544	−62 .857	−0 .754	5.31	G
		13	15	120			0.97	
204	3466	+00748	−59371	80437	+0 .533	−36 .430	7.71	G
		27	30	276			2.48	
205	3467	01044	−53729	84221	0 .710	−32 .534	6.46	G
		14	13	143			2.09	
206	3356	01619	−93104	36340	2 .550	−68 .659	7.38	G
		24	22	195			1.34	
207	3535	03450	−40067	91549	2.158	−23 .622	7.96	G
		17	17	147			2.38	
208	3386B	04362	−84179	53647	4 .648	−57 .405	6.64	G
		18	18	153			1.42	
209	3570	07282	−30277	94998	4 .383	−17 .629	7.61	G
		15	15	137			2.26	
210	3532A	07850	−41936	90322	4 .967	−24 .823	6.22	G
		21	21	186			1.59	
211	3366A	09165	−88368	45728	11 .333	−62 .177	6.71	G
		18	18	139			0.83	
212	3550	12622	−29263	94772	7 .586	−17 .018	7.87	M
		15	15	139			2.30	
213	3609	12734	−08728	98804	7 .344	−5 .007	8.14	G
		16	16	146			2.50	
214	3463	13383	−59484	79192	9 .592	−36 .525	7.13	G
		26	27	237			2.42	
215	3377	13893	−81396	56227	13 .880	−54 .566	6.34	M
		21	22	190			2.02	
216	3606	14105	−12849	98243	8 .170	−7 .376	9.49	M
		6	8	78			1.35	
217	3848	15406	−64710	74570	11 .672	−40 .359	6.83	G
		19	18	135			1.76	
218	3815	17690	−46753	86548	11 .552	−27 .890	7.20	M
		15	16	137			2.10	
219	3736	17785	−28242	94244	10 .687	−16 .408	7.74	G
		19	19	178			2.91	
220	3809A	19635	−50103	84209	13 .125	−30 .090	6.98	G
		18	18	158			2.31	

Table II (continued)

N	B and M	ξ	η	ζ	λ	β	ΔH	Catalogue
221	3722	0.24411	−0.18134	0.95342	14°.361	−10°.440	9.38	G
		± 24	± 24	± 218			± 2.61	
222	3791	25036	−39059	88598	15 .779	−22 .989	8.27	G
		19	19	179			2.76	
223	3865B	25238	−72745	63574	21 .652	−46 .763	5.53	G
		31	30	279			3.30	
224	3790	26433	−40658	87299	16 .846	−24 .025	5.75	G
		22	22	201			2.71	
225	3986	26491	−85701	43876	31 .122	−59 .119	5.63	G
		20	20	193			1.47	
226	4004	29466	−67469	67558	23 .565	−42 .470	6.76	M
		12	10	98			1.18	
227	3683	30786	−10636	94563	18 .033	−6 .105	8.36	M
		13	13	114			1.88	
228	4098	30966	−48112	81988	20 .691	−28 .766	7.72	M
		11	12	105			1.51	
229	4033A	32020	−56945	75517	22 .978	−34 .770	5.57	G
		18	19	169			2.30	
230	3936B	32400	−90228	28371	48 .792	−64 .485	7.73	G
		25	28	283			2.25	
231	3992	32615	−76966	54571	30 .865	−50 .443	5.09	G
		19	19	150			1.43	
232	4480	37558	−70709	59834	32 .116	−45 .026	7.26	G
		26	26	236			2.68	
233	4109	38751	−43133	81413	25 .454	−25 .566	7.25	G
		17	17	160			2.32	
234	3667	40841	−00978	91109	24 .145	−0 .561	5.48	K
		9	9	78			1.24	
235	3965B	41519	−81874	39516	46 .416	−55 .005	7.11	G
		26	25	209			1.56	
236	4220	41772	−18325	88818	25 .188	−10 .575	5.43	G
		20	20	185			2.96	
237	4158	42093	−29329	85832	26 .124	−17 .056	8.03	G
		13	13	125			1.86	
238	4156	42542	−32033	84611	26 .693	−18 .688	7.67	G
		15	16	153			2.25	
239	4227	43597	−04677	89731	25 .913	−2 .684	5.86	G
		15	15	140			2.17	
240	4064	46399	−60677	64521	35 .721	−37 .362	7.88	G
		19	20	202			1.74	
241	4488	46439	−72017	51204	42 .206	−46 .173	5.05	M
		16	19	152			1.39	
242	4083B	49787	−44007	74590	33 .722	−26 .138	6.27	G
		23	23	219			2.82	

Table II (continued)

N	B and M	ξ	η	ζ	λ	β	ΔH	Catalogue
243	4292	0.54063	−0.13952	0.82772	33°.151	−8°.033	5.38	G
		± 23	± 23	± 215			± 2.08	
244	4143	54363	−30704	77941	34 .896	−17 .906	5.75	M
		14	15	136			1.85	
245	4442A	55177	−61445	56302	44 .422	−37 .935	7.22	M
		20	20	183			1.83	
246	4286	55742	−07410	82646	33 .999	−4 .251	7.44	M
		13	13	118			1.70	
247	4503A	57601	−75771	30658	61 .975	−49 .266	8.02	G
		29	32	288			1.53	
248	45685	58560	−65759	47331	51 .053	−41 .132	7.56	G
		24	26	135			1.17	
249	4417A	58945	−48294	64731	42 .321	−28 .883	7.84	M
		18	18	164			1.87	
250	4385	60209	−41831	67904	41 .563	−24 .747	6.88	G
		14	13	134			1.05	
251	4241	60490	−05560	79233	37 .360	−3 .192	5.29	G
		11	11	96			0.70	
252	4417	60795	−54483	57744	46 .474	−33 .015	7.99	G
		15	16	111			0.74	
253	4320	61724	−19334	76055	39 .062	−11 .166	5.32	M
		10	11	95			0.91	
254	4363	63861	−29940	70739	42 .075	−17 .441	6.25	G
		20	20	191			2.61	
255	4607	66552	−52780	52452	51 .757	−31 918	5.15	K
		13	14	130			1.28	
256	4576	71423	−55292	42789	59 .075	−33 .588	7.17	G
		20	22	180			1.38	
257	4396	71672	−38521	57946	51 .045	22 683	6.24	M
		19	20	193			1.94	
258	4255	72860	−03500	68249	46 .872	−2 .008	6.26	M
		15	16	153			2.02	
259	4326	76284	−12081	63267	50 .329	−6 .950	5.32	G
		18	19	170			1.87	
260	4691	81155	−18001	55315	55 .722	−10 .386	5.48	G
		17	19	195			1.87	
261	48331	83707	−31703	44275	62 .124	−18 .510	5.69	G
		19	20	196			1.51	
262	4688	86160	−09788	49578	60 .082	−5 .623	6.14	M
		13	13	130			1.10	
263	4699B	88131	−27272	38138	66 .600	−15 .854	5.09	G
		22	22	215			1.43	
264	4706	88226	−21389	41586	64 .763	−12 .369	5.55	K
		12	12	119			0.86	

Acknowledgements

The authors are very much obliged to all persons who rendered assistance in this work; in particular, to F. A. Garaev, L. I. Rahimov, Z. K. Tutischkina, M. I. Kibardina, and E. M. Schukin. The authors gratefully acknowledge V. K. Abalakin and M. A. Fursenko who helped during the reduction of measurements.

References

Arthur, D. W. G.: 1962, *Commun. Lunar Planet. Lab.* **1**.

Arthur, D. W. G.: 1965, *Commun. Lunar Planet. Lab.* **4**, N62.

Arthur, D. W. G. and Bates, P.: 1968, *Commun. Lunar Planet. Lab.* **7**, N131.

Blagg, M. A. and Müller, K.: 1935, *Named Lunar Formations* **1**, 2. IAU, London.

Bistrov, N. F. and Risvanov, N. G.: 1973, *Trudi Kasanskoy Gorodskoy Astronomitsheskoy Observatorii* **39**, 156.

Gavrilov, I. V.: 1973, *The Moon* **8**, 511.

Gurstein, A. A. and Slovokhotova, N. P.: 1971, *The Moon* **3**, 266.

Habibullin, S. T., Risvanov, N. G., and Bistrov, N. F.: 1974, *The Moon* **11**, 12.

Høg, E. and van der Heide, J.: 1976, *Abhandl. aus der Hamb. Sternwarte*, p. 9.

Mamakov, A. S.: 1979, *The Moon and the Planets* **21**, 17.

Migus, A.: 1980, *The Moon and the Planets* **23**, 391.

Moutsoulas, M.: 1975, in *Space Research* XV, p. 65. Akad.-Verlag, Berlin.

Schimerman, L. A.: 1976, 'The Expanding Apollo Control System'. Appendix. Apollo 15 Crater Coordinates Relatable to Earth-based Telescopic System'. Defense Mapping Agency Aerospace Center. St. Lous, Missouri, U.S.A.

Schimerman, L. A., Cannel, W. D., and Meyer, D.: 1973, 'Relationship of Spacecraft and Earth-based Selenodetic System'. Defense Mapping Agency Aerospace Center, St. Louis, Missouri, U.S.A.

Weimer, Th.: 1973, 'Note sur l'elaboration et la structure de la Liste de Cratères Fondamentaux adoptés par l'U.A.I. à Sydney', Commission 17.