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A series of maps of optical characteristics of the lunar surface*

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PHOTOMETRIC MAP OF THE VISIBLE HEMISPHERE OF THE MOON

The map is compiled from a photograph of the moon obtained by V. A. Ezerskaya on the 160 mm refractor of the Astronomical Observatory of Khar'kov University before the lunar eclipse of October 6, 1949. The photograph was made at a phase angle of $-1.5°$ in a system close to photovisual ($\lambda_e = 0.55\ \mu$) with an angular resolution of about 3". The map has an oblique positive outward perspective projection. The orientation of the coordinate grid is very close to direct (normal). The coordinates of the projection pole are: $\lambda = 0°.0$, $\beta = 1°.4$ N. The image of the visible hemisphere of the moon has the shape of a circle on the map bounded by the meridians 87°E and 87°W and by the parallels 88°N and 86°S.

The original photograph was treated photometrically by the method of equidensitometry. The calibration of the equidensites was conducted by the method of photometric profiles with an accuracy of 3% (N. N. Evsyukov, Astron. Vestn., 7, 65, 1973). The absolute tying in was carried out on the basis of the Khar'kov Photometric Catalog (V. A. Fedorets, Uch. Zap. Khar'kovsk. Gos. Univ., 42, 49, 1952) which was standardized earlier using N. N. Sytinskaya's catalog (Astron. Zh., 30, 295, 1953). V. A. Ezerskaya, L. F. Kapanina, and I. I. Latynina took part in the standardization. The error in matching the coordinate grid with the system of equidensities is determined by the linear resolution of the latter and, according to the author's data, is 1.5 mm in the scale of the map, which corresponds to 7.5 km (15') on the moon's surface at the center of the disk, increasing correspondingly toward the edges.

On the map is shown the distribution over the lunar disk of the surface brightness at full moon (B stilb) and of the normal albedo (ρ) in the visible region of the spectrum, which are related by the well-known equation B stilb = $(\rho/\pi)E_{\odot}$, where $E_{\odot} = 13.6$ phot is the illumination from the sun at the distance of the earth and moon (1 AU). These elements are represented by a system of isolines (equidensites) with layered coloration. The entire albedo range (from < 7.0 to > 19.8%) is divided into 22 steps having a size ($\rho_{n+1}-\rho_n$) of from 0.2 to 1.3% and averaging 0.6%. The dark regions ($\rho < 9\%$) are divided by albedo in more detail; for them the average step is 0.4% while for the lighter regions it is 0.7%. Such a distribution made it possible to show the brightness structure of the maria which otherwise (with the same step size for the dark and light regions) would not have been reflected in the map.

The map provides rich reference material on the photometric properties of the visible hemisphere of the moon in the visible region of the spectrum. It is the result of a series of works of many years on the photometric study of the moon conducted at the Astronomical Observatory of Khar'kov University. The thematic content of the map is executed at a high scientific level and can only be compared with one of the published photmetric maps – with the Photographic-Photoelectric Map of the Normal Albedo of the Moon (H. A. Phon, R. L. Wildey, and G. E. Sulton, U. S. Geol. Survey Prof. Paper 599-E). However, the albedo of the mare regions is protrayed in less detail on the latter. The color layout on the U. S. Geological Survey map is more appropriate (gray tones are used for the maria).

Among the drawbacks of both maps must be included their use of the perspective outward positive projection. The sole advantage of this projection is that it represents the moon as it is seen from the earth. The scale in this projection decreases rapidly toward the edges: at 60° the longitudes and latitudes are decreased twofold and at 80° fivefold. This leads to the distorted conveyance of the ratios of areas in different regions. The distortions of directions are also considerable in the projection used, being 40° at 60° longitude and latitude and 100° at 80° longitude and latitude. In our view it is preferable to use for such maps the Lambert azimuthal equal-area projection, in which the distortions of directions do not exceed 40° and distortions of areas are entirely absent.

The color layout of the map made it possible to represent rather well the separation of the maria and continents by albedo. A blue–green range, generally darker, corresponds to the maria and a yellow–red range to the continents. The largest craters on the mare surface and the bright rays are brought out. On the whole, however, the color layout of the map appears to be insufficiently thought out. The color scale of the layered coloring of the isolines extends from a blue color for the darkest regions to brown for the lightest regions. The intermediate colors are sky-blue, green, yellow, orange, and red. Each of the colors has three shades, from dark to light, which disrupts the smoothness of the image, creating "jumps" between colors in the perception of the map. The systems of bright rays on the continents are represented least successfully in this respect. A brown color is used for them which creates the impression of dark patches, i.e., the direct opposite of the phenomenon portrayed.

The isolines on the map are not signed, which is explained by the double numbering (for albedo and brightness), although the map would be more convenient to use in the presence of signing of the isolines. Names are given on the map for all the maria and the largest craters most prominent in brightness (Grimaldi, Aristarchus, Kepler, Copernicus, Ptolomaeus, Tycho, Langrenus). The placing of a larger number of named craters on the map would undoubtedly have made it more convenient to use, since the elements of a general selenographic base are missing from it and the tying in of the contents to specific objects of relief must be done only with the help of the coordinate grid. The accuracy of the location of details relative to the coordinate grid for the present map lies within the limits of the measurement errors on the map, i.e., work can be carried out without any coordinate corrections.

The distribution of the moon's surface brightness is accurately reflected selenographically on the map and the typical outlines of the continent and mare regions are conveyed. Such complex objects from a cartographic point of view as systems of bright rays are also reflected. The map is accompanied by a text, located on the same sheet, in which the method of obtaining the system of equidensites is explained briefly and yet comprehensively and data are given on the time of observation, accuracy characteristics, etc.

The map reviewed is one of the first such maps in lunar cartography. It is compiled entirely from native materials using thoroughly verified data. This map will undoubtedly be useful to a wide circle of scientists and specialists engaged in studies of the moon, as rich factual material for reference purposes, and for analysis together with the data of other studies conducted both by terrestrial and by space methods.

ALBEDO MAP OF THE VISIBLE HEMISPHERE OF THE MOON

A photograph of the moon obtained by V. N. Dudinov on the AZT-8 70 cm reflector of the Astronomical Observatory of Khar'kov University was used to compile the albedo map. The photograph was made at a phase angle of 2°.0 in the red part of the spectrum ($\lambda_e = 0.62\ \mu$) with an angular resolution of 1".5. The map is constructed in an oblique positive outward perspective projection (the coordinates of the projection pole corresponding to the coordinates of the center of the lunar disk at the given libration are $\lambda = 4°.6$ W, $\beta = 3°.2$ N). The map has the shape of a circle. The territory depicted is located between 82°E and 90°W in longitude and between 89°N and 83°S in latitude.

The photograph was treated by the method of equidensitometry for the construction of the map. The calibration and absolute tying in of the equidensites were done by the same method as for the Photometric Map of the Visible Hemisphere of the Moon. In this allowance was made for the spectral dependence of the albedo and its differences for different regions of the moon in accordance with Younkin's data [R. Younkin, Astron. J., 75, No. 7, 831 (1970)]. The accuracy of the calibration is ~1% for the maria and ~2% for the continents. The dispersion of the albedo values for an individual detail as determined by comparison with the Photometric Map is 5% according to the author's data.

The Albedo Map of the Visible Hemisphere of the moon represents the distribution over the disk of the normal albedo ρ in the red region of the spectrum. This is shown with the help of isolines and layered coloring. The scale contains 25 steps from < 7.1% to > 23.2%. For the darkest sections ($\rho < 9\%$) the size of the scale step is 0.2%. This size gradually increases from 0.3 to 3.0% with an increase in the albedo of the sections. The division of the dark sections in more detail than on the Photometric Map made it possible to show the structure of the albedo of the maria in the same detail (with respect to the size of the areas with different albedo) as for the continents. The latter are shown on the Albedo Map with greater detail than on the Photometric Map. The main reason for this is the higher resolution of the photograph which served as the original material for the Albedo Map.

The richest reference material on the albedo in the red region of the spectrum, in which the moon, as is known, displays the greatest brightness, is presented in the map. We know of no other such maps prepared for the entire hemisphere of the moon and at such a high level on the part of their thematic content. Neither the Photometric Map, nor the Atlas of Isophots and Isotherms of Saari and Shorthill, nor the Photographic-Photoelectric Map of the Normal Albedo of the Moon of the U. S. Geological Survey gives such a simultaneously thorough, detailed, complete, and clear picture of the albedo distribution (although each of the works mentioned has certain advantages in individual aspects over the map being reviewed).

The Albedo Map portrays the system of bright rays more minutely than the Photometric Map and their internal structure in albedo is shown in more detail. The albedo distribution in the maria is conveyed with the greatest detail of any available map, which allowed the author of the map, after its analysis, to establish the eccentric brightness structure of the circular maria and the chaotic structure of the maria of irregular shape [N. N. Evsyukov, Astron. Zh., 49, 1088 (1972)].

The projection of the map being reviewed is analogous to the projection of the Photometric Map, so all that was said above concerning the properties of the image in this projection is also valid for the Albedo Map.

The drawbacks of the color layout mentioned for the Photometric Map also pertain to the Albedo Map which is laid out similarly. The choice of the color step between the continents and the maria is less fortunate in the latter, as a result of which the boundaries of the maria are less well expressed than on the Photometric map. The absence of signing of the isolines must be recognized as an essential drawback of the layout. The "mute" isolines make reading of the map difficult, and orientation can only be obtained from the coloring of the intervals between isolines. This is not very easy, especially since in some parts of the map several steps of the scale are combined into one and given a color corresponding to a narrower albedo range according to the legend.

Any elements of general selenographic content are absent from the map. Only the names of the maria are entered. Considering that the albedo is shown on this map in rather great detail the names of the craters most prominent in albedo should have been carried. This would have considerably facilitated work with the map.

The coordinate grid was calculated for the given libration and superposed on the system of equidensites. The absence on the map of elements of a general selenographic base, as well as the inaccuracy apparently tolerated in the calculation of the grid, led to the fact that the identification of objects is difficult, especially in the outer zones. The coordinate grid has the following drawbacks (determined by tying in the characteristic albedo contours to specific objects of relief). The meridians in the northern hemisphere should be closer to the central meridian of the map and in the southern hemisphere closer to the edges of the map (i.e., the grid in the form given on the map corresponds to less libration in latitude than is required for its correspondence to the system of isolines). The displacement of the meridians at longitudes of 50-60° is about 1° at the equator, 2° at 20°S, and 3° at 40°S, at a longitude of 70° it is 2-3° in the equatorial region, and at a longitude of 80° it is 4-5° in the same region. Thus, the indicated correction must be introduced in identifying the albedo contours with surface objects.

In its thematic content the Albedo Map fully corresponds to a scale of 1:5,000,000 (with the exception of the outer zones where because of the peculiarities of the observation of the moon from the earth the isolines delineate regions of much greater size than in the central part of the disk in conversion to the scale of 1:5,000,000). The map under consideration is the most detailed of the existing maps of the albedo of the moon's visible hemisphere. Its factual data provide rich reference material for making comparisons with the data of direct studies of the moon using space stations. This map can serve as a basis for regional division into zones and for compiling other maps (geological maps, maps of bright rays, etc.).

An explanatory test of small size placed on the map aptly supplements it. It should be emphasized that the map is compiled entirely from native materials.

COLOR MAP OF THE VISIBLE HEMISPHERE OF THE MOON

Two photographs of the moon served as the original material for the map: the one used to compile the Albedo Map ($\lambda_e = 0.62\ \mu$) and another obtained at the same time in the region of $\lambda_e = 0.38\ \mu$. Thus the projection, coverage of territory, and coordinate grid are analogous on the Color Map and the Albedo Map.

The distribution of sections of different color on the visible hemisphere of the moon is shown on the map with an indication of the quantitative data. A color index of the type $C = \rho(0.62\ \mu)/\rho(0.38\ \mu)$ is chosen as the color characteristic, where ρ is the normal albedo. Consequently, the name Color Map is arbitrary to some extent since the map conveys the difference in spectral reflectivity of the lunar surface and could also be called a spectrophotometric or spectrozonal map. The distribution of color over the lunar disk is obtained by the method of color-contrast photography proposed by Zwicky (F. Zwicky, Astron. J., 58, 237-238, 1953) and first used for the moon by Whitaker (E. Whitaker, in: Ranger VII JPL-NASA Tachn. Rep. 32,700, 1965). The photography was obtained by combining the "red" positive ($\lambda_e = 0.62\ \mu$) with the "ultraviolet" nagative ($\lambda_e = 0.38\ \mu$) with equality of the slopes of the characteristic curves. The latter made it possible to exclude the surface albedo and obtain a picture of the distribution of the color index. Three such images obtained from two pairs of negatives were treated by the method of equidensitometry and the three systems of equidensites obtained were averaged. The entire color range was divided by isolines (equidensites) into 33 parts. Since the color differences for neighboring parts lie at the limit of detection the colorimetric tying in was conducted over one interval, i.e., values of the color index were obtained for 16 isolines.

A series of photometric profiles of the original photographs was constructed for the calibration of the map. The minimum color contrast distinguished is 1% according to the author's data. Younkin's data [R. Younkin, Astron. J., 75, No. 7, 831 (1970)] on the spectral dependence of the albedo for different regions of the moon were taken for the absolute tying in. The error in the standardization of the map by these data is 3% according to the estimate of the map's author.

The error in matching the coordinate grid with the system of equidensites is determined by the resolution of the latter. It equals 2 mm in the map scale, which corresponds to 10 km on the moon's surface at the center of the disk, and increases twofold toward the edges.

The distribution of the color index is shown with the help of isolines and layered coloring. The scale contains 17 steps from $C < 1.06$ to $C > 1.40$. The size of a scale step (i.e., the size of the color contrasts distinguished) is from 0.01 to 0.04 and averages 0.02. In addition, between the numbered isolines are plotted lines which it proved impossible to number (see above), and the entire scale contains 33 isolines.

The color Map is compiled from the same original materials as the Albedo Map, hence all that was said about the projection, accuracy of the coordinate grid, etc. of the latter is also true for the Color Map. Despite the inaccuracies of the grid indicated above, the issuing of two maps having the same base considerably simplifies the comparison of the thematic content between these maps.

The color layout of the Color Map is analogous to that of the two preceding maps. The scale runs from dark blue ($C < 1.06$) to red ($C > 1.40$) through light blue, green, yellow, and orange. However, such a layout is apt for the Color Map since the "bluer" regions are shown by the blue range while the "redder" regions are shown by shades of orange and red. In our view the excessively bright green and yellow tones, which portray on the map regions central in color characteristics, should have been toned down. Possibly a gray color with shades of blue and red would have been more successful for these regions and the "blue," "neutral," and "red" regions could have been shown clearly. To facilitate the reading of the map the values of the isolines should be given not only in the legend but on the map itself. The identification of objects would be considerably simplified by placing a larger number of crater names on the map.

This map is alone among the known maps in portraying the color differences of the lunar surface in such a large scale for the entire hemisphere, in being very detailed, and in characterizing the color differences quantitatively. There is not even anything to compare with the map under review, which has simultaneously a large coverage of territory and great detail, since there exist either detailed color maps of limited sections of the surface or rough diagrams encompassing only the mare regions out of the entire hemisphere. The factual data contained on it provide unique reference material, presented in a clear form and at the same time having rigorous metric properties.

An analysis of this map permitted its author to distinguish several regularities of the colorimetric structure of the lunar maria and properties of the statistical distribution of the color index over the lunar disk [N. N. Evsyukov, Astron. Zh., 50, 1274 (1973); Vest. Khar'kovsk. Univ., No. 99, Ser. Astron., Part 8, 26, 1973].

The maps reviewed and the initial conclusions obtained from their analysis show that photometry, and especially global photometry of the moon, provides much more information than is taken for granted. The use of the cartographic method of research for the study of the moon gave very fruitful results. This method is destined to play an important role in planetary studies since the complex analysis of different maps constructed by terrestrial methods permits the extrapolation of data obtained at separate points by direct explorations.

It must be emphasized that all three of the maps reviewed are compiled on native observational material obtained at the Astronomical Observatory of Khar'kov University which is one of the leading centers of planetary astronomy in the USSR. The oldest school of planetary and lunar photometry was based here and was headed for many years by N. P. Barabashov. The maps reviewed were compiled under his scientific guidance. The scientific and organizational cooperation of the Astronomical Observatory of Khar'kov University with the Institute of Space Studies, Academy of Sciences of the USSR played as essential role in the creation of these maps.

These maps have great scientific value and will undoubtedly find wide application in different areas of lunar research.

*Scale 1:5,000,000. Three sheets, 79 x 94 cm, multicolored. Astronomical Observatory of Khar'kov State University, Institute of Space Studies, Academy of Sciences of the USSR. Compiler N. N. Evsyukov. Scientific Editor N. P. Barabashov. Naukova Dumka, Kiev (1973). Printing of 1000 copies. (32 kop.)