No. 6 LUNAR GLOBE PHOTOGRAPHY

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THIS paper is a description of the methods employed in removing the foreshortening from photographic lunar observations. Particular attention is paid to these methods as they apply to the production of the *Rectified Lunar Atlas*, a forthcoming publication of the Lunar and Planetary Laboratory.

When a spherical body is viewed from a point in space, surface detail on the hemisphere visible to the observer suffers varying degrees of foreshortening in that the viewing angle with respect to the normal increases as one goes toward the limb. As a result, half the area of the visible hemisphere is foreshortened at least 50%. If we consider the Moon, whose surface approximates a sphere, half the area visible at any one time has such an observational limit placed upon it, and the additional areas made available to observation through librations are those regions at the limb where the foreshortening is almost complete.

The ideal solution to this problem would be to make photographs of lunar features from a rocket in a circumlunar orbit from a point directly overhead. Meanwhile, one may use existing data, putting it into a more easily interpretable form by projection of the photograph on a surface approximating the shape of the feature from which the data were originally taken. After this, there are numerous means of recording the non-foreshortened or *rectified* material for use by the observer.

For the Moon, a surface which approximates to the original shape from which data have been taken is a hemisphere. Therefore, the first step in preparation for a change in the point of observation is that of projecting a plane image onto a hemispherical screen. This idea is not new, and our efforts represent only a link in the chain of lunar observers who have used this method for removing foreshortening from their photographs.

To record the material projected on the globe, one has two alternatives. One may coat the spherical surface with a photosensitive emulsion or deform a plate to a spherical shape and record the information directly by projection (Wright 1935), or else one may coat the spherical projection surface with a non-gloss white paint, form an image at the surface, and rephotograph it with a separate optical system from a point of view of the observer's choice. Each of these methods has its own merits. In the first case, one has the advantage of a high degree of geometrical accuracy weighed against the difficulties encountered in coating the surface with emulsion, recording information from light striking the emulsion at angles up to grazing incidence, and making use of the information after it is recorded. In the second case, one has less geometrical precision in the recording stage in that only one point on the globe will be viewed in a line normal to the surface and if the area photographed covers an appreciable area with respect to the radius of the globe, then some new foreshortening effects will arise. The advantages of using this method lie in the freedom one has in choosing magnification and angle of aspect and in the ease in which the photographs obtained may be reproduced.

The work at the Lunar and Planetary Laboratory has been based on the second method, and the rest of this paper is concerned with the equipment used and with a description of current programs.

The first applications were experimental and made at the beginning of the fall of 1958 at the Yerkes Observatory. Tests and improvements were made by Messrs. D. W. G. Arthur and E. A. Whitaker. A three ft. wooden hemisphere was constructed by a pattern maker; this was later replaced by a cast aluminum hemisphere when the wooden globe proved somewhat variable with time, causing local irregularities. The equipment was transferred to the University of Arizona in September, 1960. It consists of three basic parts, the projector, the hemispherical screen, called the "globe," and the camera for rephotographing. The original plate material to which this process has been applied consists of selected photographs from the collections of the Lick, McDonald, Mount Wilson and Yerkes observatories. The criteria used for selection include overall definition and resolution, the position of the terminator, and the libration of the Moon at the time the plate was taken.

The projector was built along an aluminum beam and each unit in the system was built so as to be movable along this beam, fastened in place in their respective positions with screw-type pressure clamps. The forward unit is the projection lens, an achromatic doublet telescope objective of 2.15 meters focal length. The aperture of the lens is 12 cm, but it was stopped down to 5cm for a greater depth of focus at the globe. The positive transparencies used for projection are mounted in a plate carrier which can be rotated 360°. Those positives on glass plates are mounted alone, while those on film are sandwiched between two pieces of plane glass for stability.

For illumination, there are three units, the lamphouse, the heat filter, and the condenser lens, all of which are mounted separately along the beam. At first a conventional bulb of 500 watt output was used. This was later replaced by a new type of bulb having the same light output from a filament of area less than 0.5 cm^2, producing a much more intense cone of light through the system. The heat generated by this bulb required the addition to the lamphouse of a forced-air cooling system and a heat-absorption filter was placed between the lamphouse and the condenser to prevent undue amounts of heat reaching the film. The condenser is a single-element plano-convex lens of 9 inches aperture with a focal length of 12 inches. A supplementary spherical reflector is used behind the projection bulb to superimpose an image of the filament in the gaps between the filament elements wherever such gaps occur and thereby create as compact a source of light as possible.

Since the original plates used have different scales, the projection distance has to be varied to make the lunar image fill the 36-inch globe. For this variation, the globe was mounted on wheels and has a freedom of motion along the optical axis of the system of some 15 feet. For greater distance changes, four piers were built at intervals of 12 feet on center, and the projector itself can be moved to rest on any adjacent pair of these piers. Therefore, the total range of projector to globe distances ranges from 25 to 66 feet (8-20 meters), with continuous variation between. The projection distance for the lunar image as photographed at any given observatory depends not only on the scale of the particular telescope but also on the Earth-Moon distance at the time the photograph was made. For plates taken at the observatories concerned with the Moon at its mean distance, the projection distances are shown in the accompanying table.

Telescope	Plate Scale (sec/mm)	Projection Distance	
		ft.	meters
Lick 36"	12.1	49.2	15.0
Yerkes 40"	10.7	44.3	13.5
McDonald 82" (Cassegrain focus)	7.4	32.9	10.0
Mount Wilson 100" (Cassegrain focus)	5.0	24.6	7.5

Since the projection characteristics of the Mount Wilson plates are at the limits of our optical arrangement and cause a steeper cone of projection than is desired because of the nearness to the globe, these are reduced in scale to about that of the McDonald plates. Therefore, the closest projection distance actually used is about 32 feet (10 meters), and the maximum geometrical distortion introduced by using this boundary distance is only of the order of 4 per cent.

The aluminum from which the globe was made was cast as a hemisphere of 36 inch diameter, 1 inch thick; then the outer surface was turned and polished to the desired precision. The face was thereupon painted with six coats of flat white paint, the upper coats being an unpigmented automobile primer paint having extremely fine grain characteristics.

There are three problems associated with the alignment of each specific transparency on the globe. These are scale, positioning of the image on the globe, and focus. Of these, the focus is most easily controlled; however, since the depth of sharp focus is only about 10 inches for the closer projection distances, this has to be watched. On the Yerkes and Lick plates, where the entire lunar image is on a single plate, the control of scale and position are not difficult since at least 180° of limb can be aligned with the edge of the globe. With the McDonald and Mount Wilson photographs, the presence of little or no limb on the original plates makes necessary the measurements of arc distances along the rectified

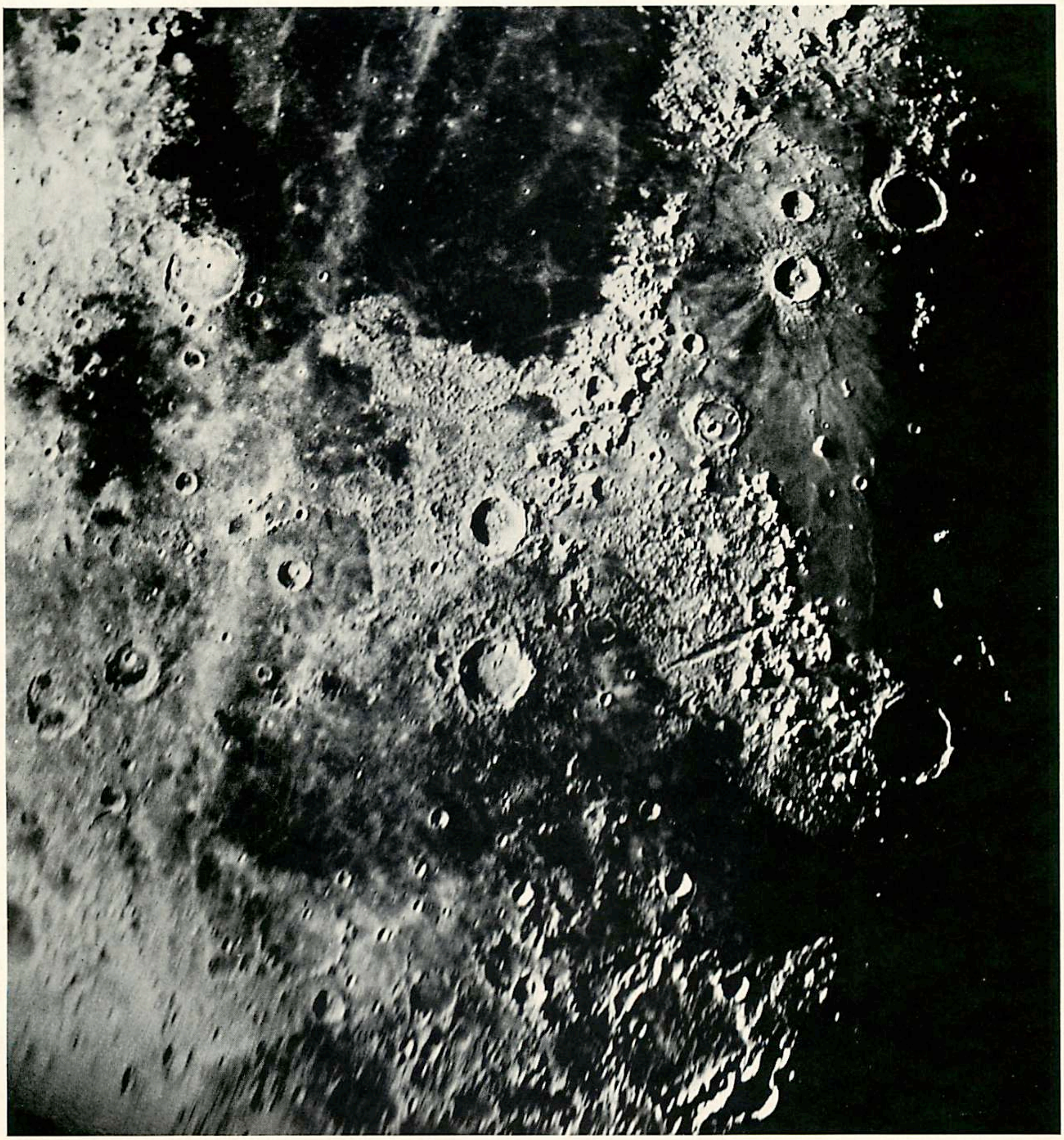

Plate 6.1. Sunrise: Area 7.

Plate 6.2. High Illumination: Area 7.

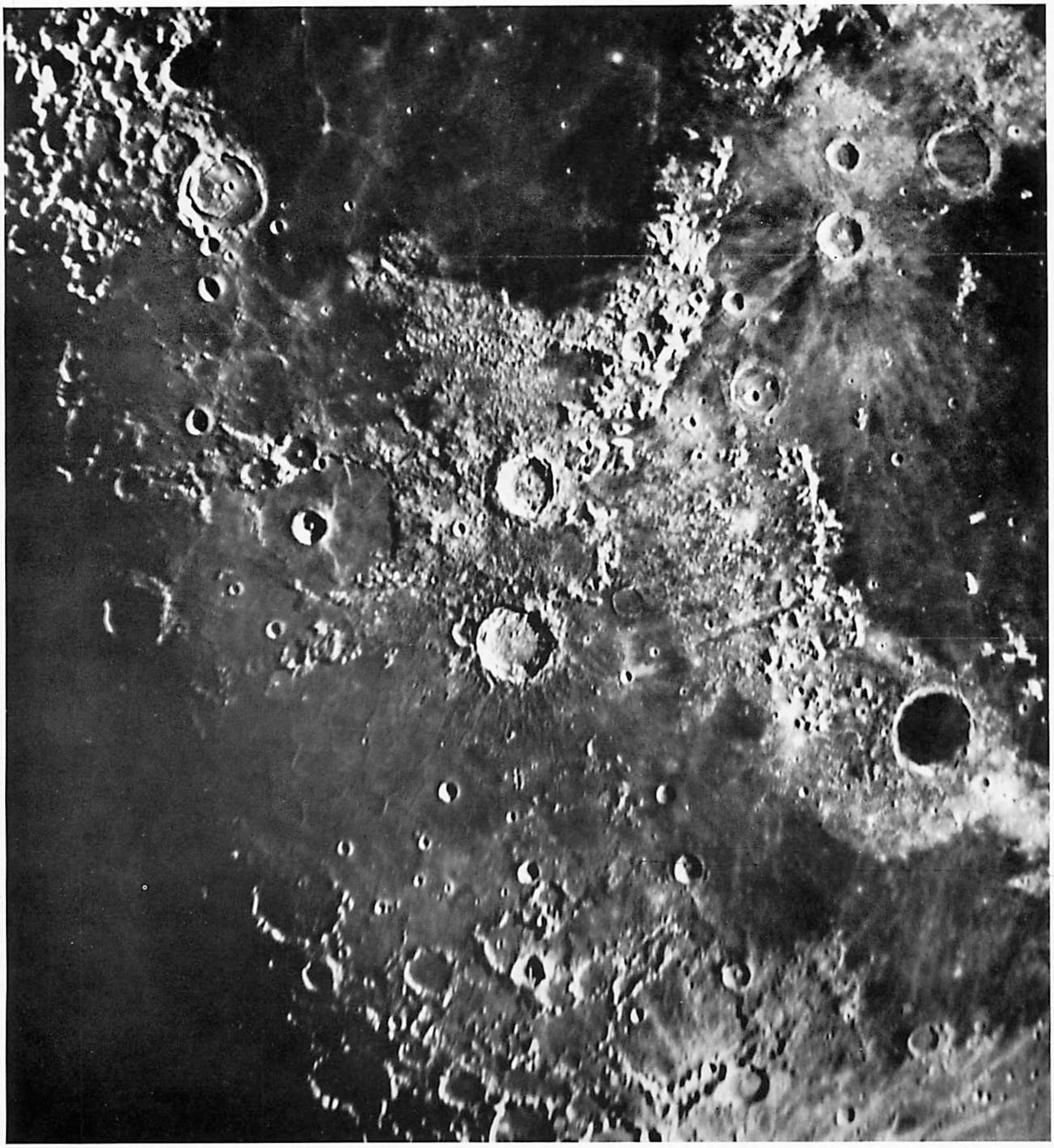

Plate 6.3. Sunset: Area 7.

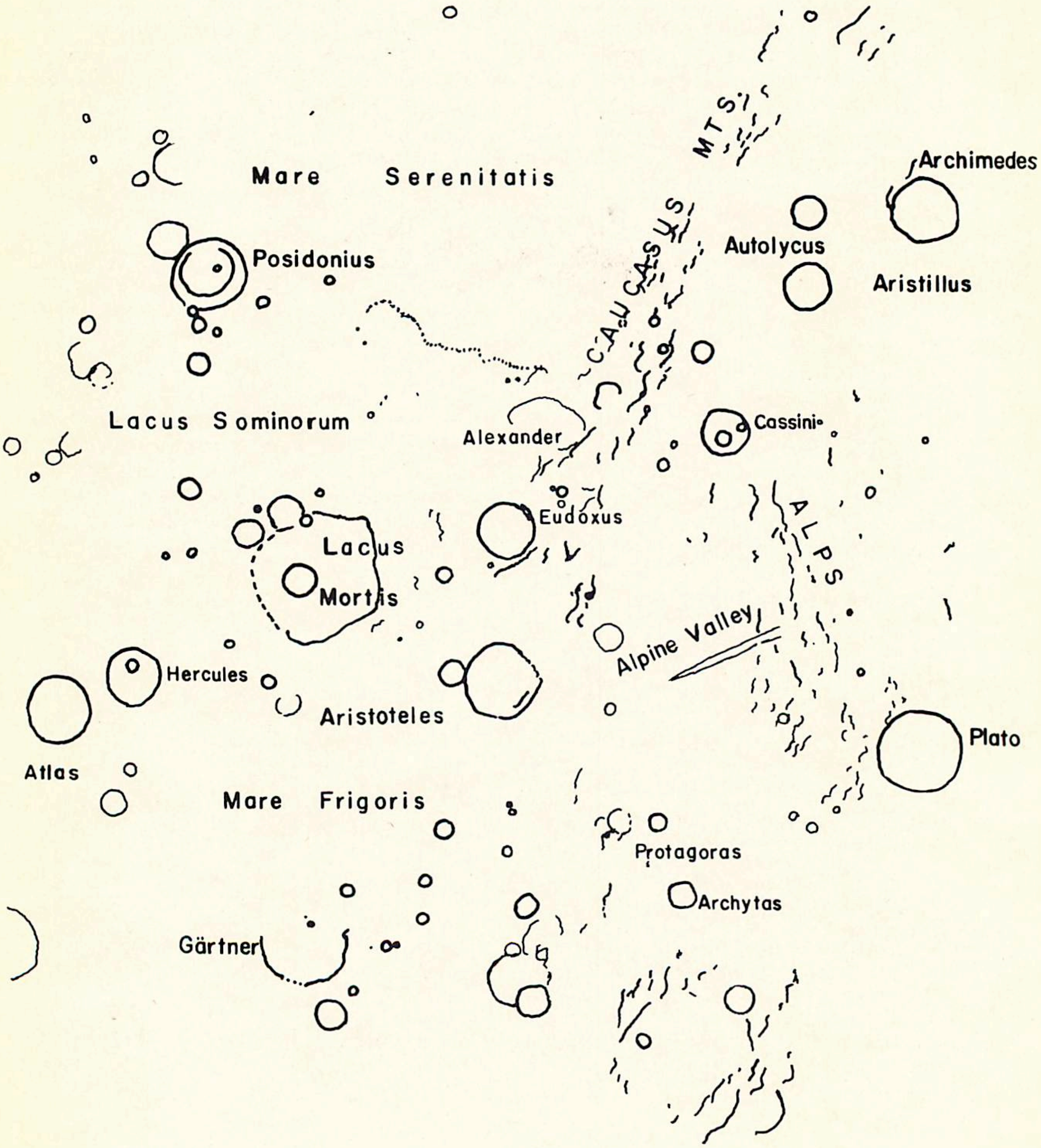

Plate 6.4. Nomenclature: Area 7.

image to check with actual relative positions on the moon. Since the transparency can be rotated in the projector carrier, the image can be positioned such that the area being photographed is centered on a horizontal line through the center of the globe on that side of the globe most accessible to the camera.

The camera found most useful in photographing the projected images is a press or view camera with built-in distortion controls and equipped with an auxiliary shutter. The film size is not a critical factor, but we have found 4″ x 5″ film satisfactory. In almost all cases, the limiting grain has been that of the original plates.

The focal length chosen yields adequate resolution at a distance from the globe which does not introduce much additional foreshortening—that is, at least several globe radii away. A 10¾ inch focal length anastigmatic process lens made by the Goerz Company was selected. This lens, used with a Wratten No. 8 filter and Eastman Royal Ortho film gives a very good image with an exposure at f/11 and averaging 15 to 20 seconds long.

The distortions introduced by the projection and the second photography are both given by the factor $(1-\cos\theta)$ in which θ is the angle comprised between the line connecting the projector (or camera) with the center of the globe and with the feature in question respectively. At the closest position of the projector to the globe, 32 feet, the maximum value of θ is $2^\circ 4'$; whereas for the camera, used at its normal distance from the globe the maximum value of θ is $5^\circ 10'$. The corresponding distortions for the two cases are 0.001 and 0.004 respectively, which are quite negligible. It is seen that the principal distortions in the second photography arises from the curvature of the globe itself, the numerical amount depending on the size of the field recorded. Figures 1 and 2 show the main features of the projection units and the geometry involved in the projection and rephotography.

The projection equipment and procedures were developed for the purpose of carrying out systematic programs for the surface of the Moon, the first of which was the production of a Rectified Lunar Atlas. The purpose of this atlas is to present a series of high-quality photographs of the lunar surface as it would appear if viewed from a number of specific directions of observation other than the earthward direction. The visible lunar hemisphere was divided into 30 areas using selenographic latitude and longitude lines as boundaries. The equator, and 30° and 60° were chosen as the main latitude divisions. The

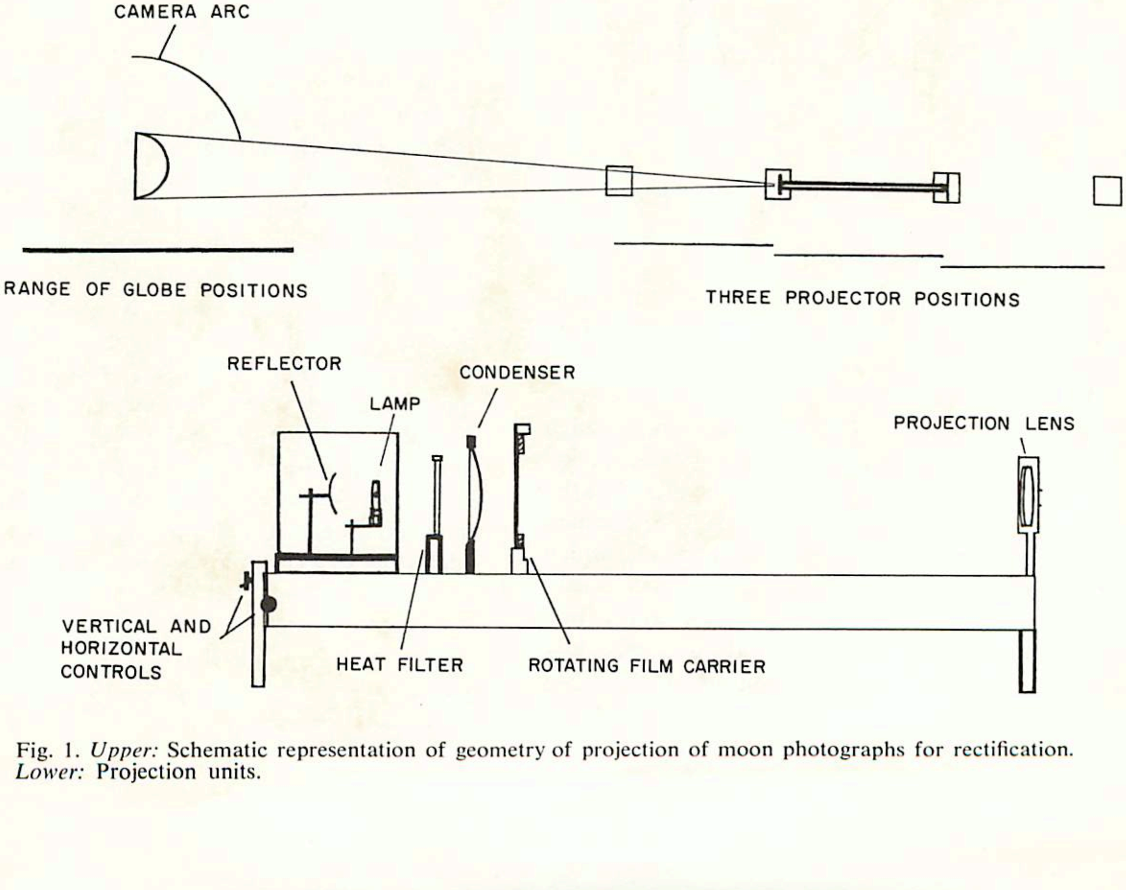

Fig. 1. *Upper:* Schematic representation of geometry of projection of moon photographs for rectification. *Lower:* Projection units.

two caps from 60° to the respective poles were divided into three wedge-shaped areas 60° in longitude. The remaining four belts were divided into six areas, each 30° of longitude.

It was decided that each of these areas be pictured in three illuminations; sunrise oblique, high illumination (local noon), and sunset oblique, giving a total of 90 area-illuminations to be covered in the survey. In choosing the original plates to be rectified and rephotographed, there were many cases in which there were several plates of high quality for a given area and illumination. All such plates were used, projection positives were made, and the process was carried through the stage of printing the rectified negatives before the final selections were made. In all, over 200 illuminations of the 30 fields were used in the production of the atlas plates. Of these, the sources were as follows:

Yerkes	93	Mount Wilson	39
McDonald	41	Lick	33

Since many of the originals had extremely high contrast, a printer was used in the production of some of the positive transparencies which reduced overall gradients while retaining local contrasts.

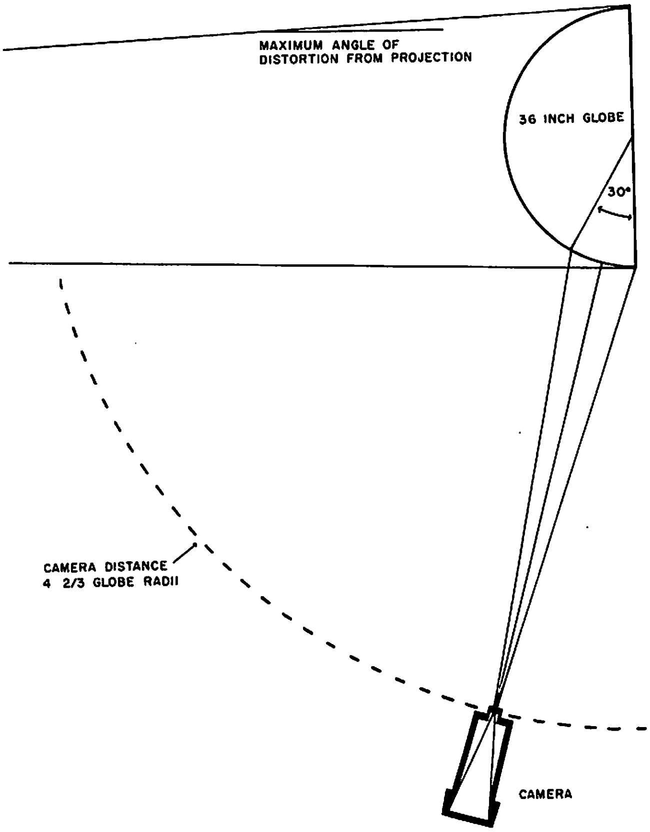

Fig. 2. Scheme of geometry of rephotography.

For each of the areas, the camera was directed normal to the center of the area at a distance of 5½ feet from the surface or 4⅔ radii from the center of the globe. The distortion introduced by so close an observation point is much less than that globe curvature for a field of 30 degrees. Yet the total foreshortening for the extreme case of a field corner, taking both effects into account, is only about 10 per cent. The respective contribution of the two effects are: field curvature, 7 per cent; and camera distance, 3 per cent. In order to gain another one per cent over this for the same size field, the camera would have to be removed to a distance of over twice as far from the globe. A sample set of photographs showing Area 7 of the *Rectified Lunar Atlas* on a reduced scale is given in Plates 6.1-6.3, an area centered approximately on the crater Eudoxus. In the *Atlas* each area will have a gridded sheet showing the principal surface features: in this publication the grid was omitted in the accompanying sheet because of the reduced scale. Plate 6.4 shows the more important named features of Area 7.

Beside the production of *Rectified Lunar Atlas*, there are other programs which lend themselves to treatment by globe photography. There are many lunar features which exhibit symmetry about a point and can better be analyzed and understood through a rephotographing with an aspect normal to that point. Currently, work is being done to study such features through these methods as well as to get an optimum point of view of large scale features such as the maria and ray systems. Another interesting application of this work is that of going beyond the limb of the globe-moon and looking back toward the earthward hemisphere in a kind of reverse foreshortening. In this way much has been done to aid in an understanding of the Soviet photographs of the far side of the Moon as they relate to previously known information (Comm. No. 13).

REFERENCE

Wright, F. E., 1935, *Carnegie Inst. of Washington Pub.* No. 501, p. 59.