*Photogrammetric and Visual Compilation of Lunar Charts**

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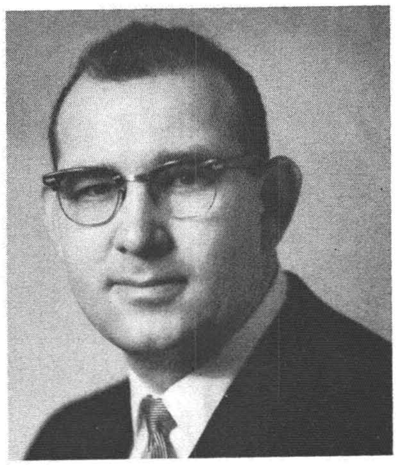
Introduction

ONE of the problems encountered in Lunar Cartography is photo identification of such features as small craterlets, low pressure ridges and surface features obscured by intense shadows on the Moon. During the past year the Aeronautical Chart and Information Center has minimized some of these problems by establishing a full-time Lunar Observation Office at Lowell Observatory, Flagstaff, Arizona. Visual telescopic observations have now become a vital part of our Cartographic Program and are the primary subject of this paper.

Lowell Observation Section

Late in 1960, arrangements were made to use the 24-inch Lowell Refractor at Flagstaff, Arizona for visual observations to support the Lunar Charting Program. At first, observers traveled from St. Louis to Flagstaff for only a few days each month to observe a chart area. This proved unsatisfactory because cloudy weather or poor observing conditions would occasionally preclude useful results.

In September 1961, the permanent Observation Section was established in order to make continuous observations well in advance of the time that charts were to be published. The Lowell Observatory was selected because it enjoys a great deal of fair weather particularly at night, and atmospheric turbulence is relatively low compared with other observatory locations in the country. The Observatory is located on the eastern edge of a mesa that runs north and south at an elevation of 7,250 feet. The mesa is covered with large pine trees and is in the shelter of the 12,000 foot San Francisco peaks just north of Flagstaff. These environmental factors are responsible for the abundance of clear weather and steady atmosphere enjoyed by this location.



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Observational Equipment

The 24-inch refractor was made famous by the observations of markings on Mars made by Dr. Percival Lowell and Dr. E. C. Slipher. It is still housed in the original wooden dome which is now about 65 years old. The telescope is considered to have excellent optics with an F/16 objective lens. The lens is corrected for the visual region of the spectrum, which is roughly between 5,000 and 6,200 angstroms. The visual resolution is approximately one-tenth of a second of arc, which means that one can visually observe a Lunar crater of less than 600 feet in diameter provided atmospheric conditions are very steady and transparent. The telescope is equipped for both visual and photographic observations so that visual work may be supplemented with photography.

The supplementary photography is obtained through the use of a motion picture

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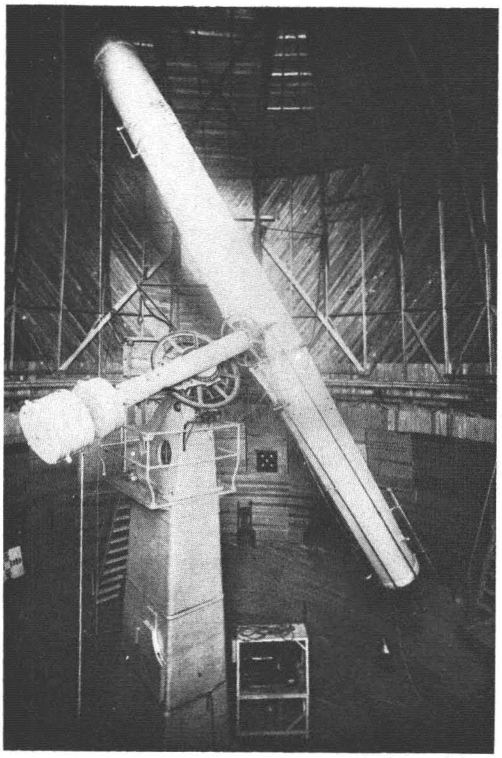

FIG. 1. The 24 inch Lowell refracting telescope at Flagstaff, Arizona.

camera. The eyepiece and camera are arranged as one unit with reflex prisms diverting the optical beam to the eyepiece. The observer changes from visual to photographic observing by pulling a plunger to retract the first prism allowing the beam to fall unreflected on the film placed in the focal-plane of the objective lens.

The second reflection to the eyepiece is introduced to erect the image which was inverted by the first. Also, this allows the second prism to be rotated about the optical axis so that the observer may assume a comfortable observing posture. There is no noticeable loss of visual resolution caused by the second reflection.

VISUAL OBSERVATIONS

Visual observations of the Moon are normally made along and up to approximately 30 degrees in front of the terminator. In this illuminated portion, the shadows are optimum for detail interpretation. Along the terminator, the very low and gentle relief features, such as Maria Ridges and valleys, will show up prominently. Craters, small prominences, and rilles can easily be interpreted from 5 to 15 degrees in front of the terminator. The very large or steep craters or mountains may be best interpreted when the sun angle is between 15 and 30 degrees. Even higher illuminations can be important in seeing some crater floors and the fine details of crater rays.

The visual work is often severely handicapped by seeing conditions. Seeing is the term used to describe the image motion caused by atmospheric turbulence. It seems that there is always some motion in a telescopic image because the atmosphere is never entirely without turbulence. The quality of the telescopic image is judged on a scale from 0 to 10, with 0 being a useless image that cannot be focused and 10 the perfect image. No. 10 seeing is the condition that never seems to occur. When Dr. Lowell and Dr. Slipher observed the fine markings on Mars, the seeing was rated as No. 8 and occasionally No. 9, but never No. 10. No. 5 or 6 seeing is considered very good, and we are happy when these conditions exist even one-fourth of the time. 0 to 4 comprise the seeing range for the majority of the time. Zero seeing can occur on a night that is perfectly clear or transparent. To the unaided eye, the image of the Moon may be extremely sharp and crisp, yet in the telescope even large craters such as Copernicus cannot be brought into focus.

There are times when the effect of atmospheric turbulence can be minimized by using a smaller aperture. Mediocre seeing conditions become worse with a larger aperture telescope. If the air cells caused by turbulence, which act as lens themselves, are smaller than the telescope aperture, their effect is longer lasting as they move in front of the objective. By using an aperture that is smaller or no larger than the air cells, the seeing is affected by only one cell at a time.

The 24-inch refractor is fitted with an iris diaphragm in front of the objective lens which permits aperture stops from 24 inches down to 6 inches. Normally, we find that mediocre seeing conditions can be optimized between 12 and 18 inch aperture. There are many times, however, that even a 6 inch aperture may not help, and the only thing that can be hoped for is that seeing conditions will improve during the night.

The magnifying power of the eyepiece is just as important in optimizing the effect of seeing as the size of the aperture. We use the zoom eyepiece which has a range of focal-lengths from 21 millimeters to 8 millimeters. On the 24-inch refractor, this amounts to a magnifying power range from about 428 to 1,050. We normally use a magnifying power of 500, and only on rare occasions has use

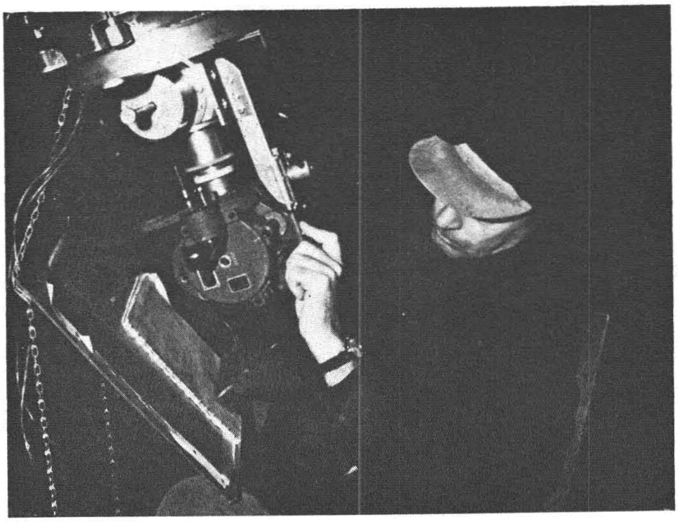

FIG. 2. The 35 mm. motion picture camera used on the 14 inch Lowell refractor.

been made of powers in excess of 800. The zoom eyepiece is very convenient in that the optimum magnifying powers can be found by merely turning a knurled ring.

The visual observer attempts to record his observations at the telescope by drawing sketches of the features he sees or by making notes or annotations on a photograph of the region. We normally annotate Lunar Atlas photographs. During mediocre seeing this is a task that may go rather slowly because the observer must concentrate on a single feature and wait for the moments of steadiness to occur. When these moments occur every few seconds, the observer can make steady progress. But when the image becomes very steady with only slow pulsations or swimming motion, the amount of small, fine details that can be seen at one time will usually overwhelm him to the point that he can do nothing but stare in amazement. At times like this, the camera is a most valuable tool.

SUPPLEMENTARY PHOTOGRAPHY

We use the motion picture camera to increase the chances of getting an image of fine

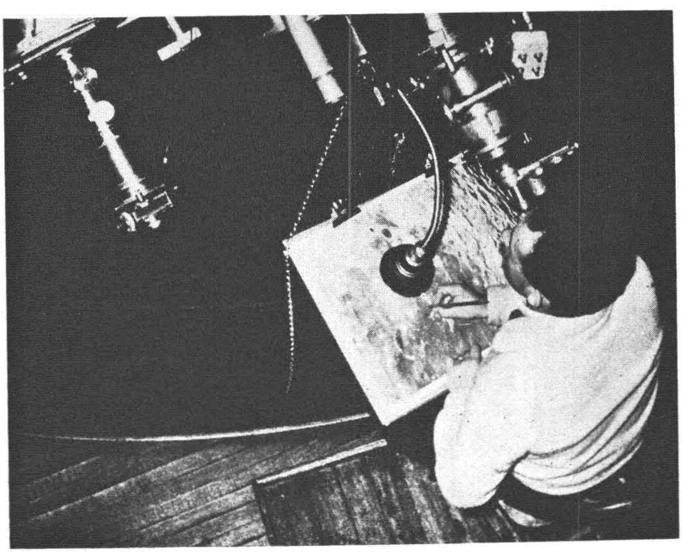

FIG. 3. Recording visual observations at the telescope. The photographic Lunar Atlas is the base on which annotations are made.

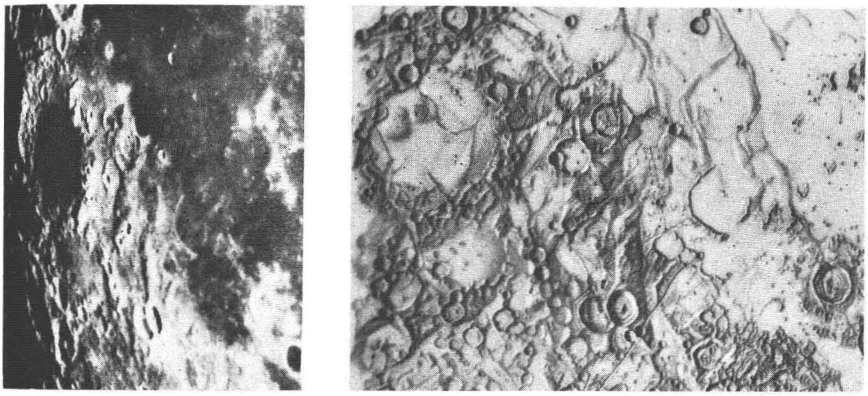

FIG. 4. The abundance of details added to the chart as a result of visual observation is apparent in this comparison of the chart with the atlas photograph.

details. The camera is not able to capture the details with all the sharpness and clarity that can be seen by the observer even during moments of great steadiness because of the ever-present small residual motion. However, even a slight image of the small features is a great help to the observer because having clearly seen them with the telescope, he can readily interpret the photograph. By running the camera for a few seconds to obtain a burst of several frames, the odds are favorable that some of the frames will record sharp images during a steady moment. The speed of the camera is important to catch the moments of steadiness. We have had occasions when a film speed of 16 frames per second, during what seemed to be a good seeing, yielded a slightly blurred image, while 24 frames per second exposed immediately after, recorded several sharp images. At other times, only 8 frames per second has been fast enough to catch the steady moments.

The observer must learn to judge from experience which camera speed to use. Of course, the camera speed is limited by the speed of the film emulsion which, in turn, is limited by the telescope and the phase of the Moon. As yet, we have not decided which film emulsions will be optimum for standard use on the 24-inch refractor. Our aim is to select a group of emulsions to be used at various phases angles which can be run at camera speed between 8 and 24 frames per second so that maximum detail can be captured during moments of best seeing.

Observational Results

Contributions to Lunar Charting through the observational program have exceeded our original expectations. The first efforts were concentrated in the central regions of the Moon and are constantly being improved through successive observations. One of our early charts in the region of crater Kepler has enjoyed progressive improvement and is representative of the results achieved. Clues to the existence of fine detail are often found on the photographs only as a slight discoloration of the emulsion. Through the pursuit of these clues on the telescope, many small craterlets and small prominences have been added. Crater floors have been detailed—the formation resembling a hand in the crater Kepler is illustrative of this contribution. Many features appearing to be continuous ridges on the photographs resolve into individual peaks through the telescope. A majority of the rilles appearing on our charts have been added through observation. Domes to the east of crater Kepler have been detailed through progressive observations even though they are very indistinct. We have not only been able to pick up their shapes but also the

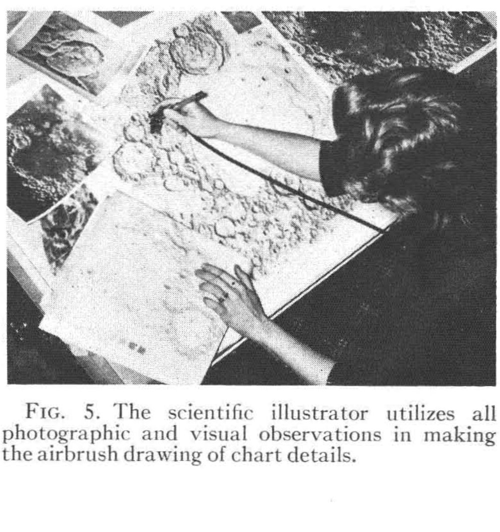

FIG. 5. The scientific illustrator utilizes all photographic and visual observations in making the airbrush drawing of chart details.

calderas on the domes. Variations in crater rims and pressure ridge patterns in the maria also represent a marked contribution.

Our efforts in the limb regions have been very fruitful. On the photographs, there are such large expanses compressed in such small areas, and perspective views of features predominating, that lesser features are lost to casual viewing. The same clues exist, however, and much valuable information has been gleaned from observations. Our efforts on the crater Grimaldi exemplifies these results. The floor appears fairly smooth in the photographs, yet the existence of planes of variable elevations, domes, small ridges and craterlets have been resolved and added to our chart.

Transforming Observational Data

The visual observations plus all the available photography are utilized by a scientific illustrator to make a final drawing of the chart detail. The control for the chart detail is obtained from the selenographic grid which has been applied over the Lunar Atlas Photographs. The selenographic grid for the Lunar Atlas was computed by Messieurs D. W. G. Arthur and E. A. Whitaker, associates of Dr. Gerard P. Kuiper. They evaluated all control measured by other selenographers and added several new measures of their own. The grid is considered the most accurate horizontal control available for the Moon.

The Atlas photography containing the orthographic grid is rectified to the desired chart projection. The rectification is accomplished through the use of spherical easels. The variable perspective projection, which is basically a large light collimator, is used in this process. It consists of a spherical mirror 30 inches in diameter and a projector placed off-axis in the focal-plane of the mirror. The projected light is reflected from the mirror in a parallel beam. Theoretically, infinite focus is achieved which permits projection on spherical easels. The rectified photographs are carefully mosaiced to the projection to provide the control base over which the Lunar features are drawn.

Drawing of the Lunar features is accomplished by means of an air brush with India ink on translucent plastic. The relief features and the background coloration showing the ray patterns are drawn separately. The features are shaded as though they are illuminated by a west-light source. However, this light source is idealized in that the altitude of the light is varied so that the angle of illumination nearly matches the slope angle of the feature. In this way, there are no cast shadows to cover up detail; yet the very low or shallow features receive sufficient shading to be clearly discernible.

The background coloration containing the ray systems are portrayed with varying tones of gray as they appear under full-moon illuminations. The tones on both the relief and coloration drawings are carefully controlled so that the relative prominence of features will be retained in printing. Also, the tones are carefully matched between charts to maintain continuity when adjacent sheets are put together.

The relief and coloration drawings are printed in two different colors so that the final product will clearly show all the Lunar features which can be seen and portrayed at 1–1,000,000 scale.

Conclusion

In conclusion, we would like to give due credit to the Astronomers both past and present who have thoroughly laid the groundwork for us to follow. Through the cooperative efforts of Dr. John Hall, Director of Lowell Observatory; Dr. Gerard Kuiper, Director, Lunar and Planetary Laboratory, University of Arizona; Professor Zdenek Kopal, Chairman, Astronomy Department, Manchester University, and other members of the Scientific Community, ACIC has completed a total of 5 charts in the LAC Series. Eight more are scheduled for completion this calendar year. In addition to Air Force usage these charts are being used by many elements of NASA in support of their Ranger and Apollo Programs. Cartographically recording what we can learn from ground based instruments is the main objective of our present program. Therefore, until such time as space technology advances and permits a closer look at the Moon, visual telescopic observations will continue to play a major role in Lunar Charting.