FINAL REPORT

NASA GRANT NGR 05-002-158

"LUNAR STUDIES"

From

THE CALIFORNIA INSTITUTE OF TECHNOLOGY

To

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

(NASA-CR-138774) LUNAR STUDIES (California Inst. of Tech.) 7 p HC $4.00 CSCL 03B
N74-27349
Unclas
G3/30 41917

Principal Investigators

Andrew P. Ingersoll

Justin J. Rennilson

June 18, 1974

8

LUNAR POLARIMETRY

Andrew P. Ingersoll, Investigator

Aims of the Research

The original goal of the research was to assess the feasibility of using polarization to classify large-scale features on the moon. It was proposed to build and test a system capable of measuring polarization by subtracting two film images taken through perpendicular Polaroid filters. The resulting difference-pictures, when contoured, might show boundaries which were otherwise invisible or difficult to recognize by ordinary imaging. The method is similar to colorimetry, where one subtracts two film images taken through filters of different colors. As shown by Soderblom (1970), color boundaries on the lunar surface often do not reflect the obvious morphological and albedo boundaries. Similarly, it was hoped that polarimetric images would reveal new boundaries not associated with morphology and albedo.

Theoretical Considerations

It is an empirical fact that most solid surfaces of geological interest show an inverse relation between percentage polarization and albedo (Dollfus, 1961; Gehrels et al., 1964; Ingersoll, 1971). We define $I_\perp$ and $I_\parallel$ as the intensities perpendicular and parallel, respectively, to the plane of scattering, which is the plane containing the sun, the observer and the point under observation. Percentage polarization δ is defined as

$$\delta = \frac{I_\perp - I_\parallel}{I_\perp + I_\parallel} \quad . \tag{1}$$

The denominator is the total scattered intensity, which is proportional to albedo. Thus

$$I_{\perp} + I_{\parallel} = A\, F_{\odot} \quad , \tag{2}$$

where $F_{\odot}$ is the incident solar flux and A is the albedo. Combining (1) and (2) we obtain

$$\delta = \frac{I_{\perp} - I_{\parallel}}{A\, F_{\odot}} \quad . \tag{3}$$

The solar flux $F_{\odot}$ is the same for all points on the lunar surface. Thus the empirical fact that $\delta \propto 1/A$, for surfaces of similar composition but different orientations or physical properties, implies that $I_{\perp} - I_{\parallel} \propto A\,\delta \approx$ constant for such surfaces. Any departure from the relation $I_{\perp} - I_{\parallel}$ = constant for the whole moon might be due either to violation of the relation $\delta \propto 1/A$ (e.g., $\delta \propto 1/A^{n}$ with $n \neq 1$) or to compositional variations across the lunar surface. It was hoped that a lunar image in which brightness is proportional to the intensity difference $I_{\perp} - I_{\parallel}$ might provide information on compositional variations.

Instrumentation and Observing

A camera which recorded two images of the same portion of the moon taken through perpendicular Polaroid filters was built and completed in early 1973. The images were recorded on adjacent frames of a piece of 35 mm film, and thus were subject to the same developing process. An electronically timed shutter controlled the exposure time with a reproducibility better than 1%. Spatial non-uniformities in the film and in the developing process were found to be less than 2% of the average grain density for a properly exposed photograph. Polaroid material HNP'B was found to have a transmission of less than 1% through crossed Polaroids compared with that through parallel Polaroids.

The spatial resolution of the film was seriously degraded in the differencing process: the effective "grain size" of the film increased by at least a factor of 10 in going from a simple image to a difference image. Thus the number of resolution elements across the 35 mm width of the film was between 100 and 200 depending on the film. Although this was a serious limitation, it did not prevent a reasonable assessment of the feasibility of the method.

Observations were taken during the summer of 1973 by Mr. Donald Sullivan, then a graduate student of planetary science at Caltech. The area around Mare Tranquillitatis and Mare Serenetatis was photographed at phase angles near 90° through visible and ultraviolet filters using the Mt. Wilson 24-inch telescope. This area of the moon was studied extensively by Soderblom (1970), who identified several boundaries within the maria using color differences of several percent. It was hoped that these boundaries might be more obvious in the polarimetric images, especially in the ultraviolet where percentage polarizations are largest.

The images were digitized, and difference-pictures were made using the film scanner and video film converter at the Image Processing Laboratory of the Jet Propulsion Laboratory.

Results and Conclusions

The resulting images, in which brightness is proportional to $I_\perp - I_\parallel$, showed clearly identifiable features. Invariably, however, the brightness of features on the difference pictures was inversely related to albedo. No boundaries were discovered that were not already discernable in ordinary photographs. Attempts to stretch the contrast of the difference pictures merely accentuated the importance of albedo markings. Thus the method did not provide any new information or a means of obtaining new information about the moon.

The fact that albedo effects persisted in the difference pictures, with $I_\perp - I_\parallel$ inversely related to albedo, indicates a failure of the relation $\delta \propto 1/A$. Let us rewrite equation (3) with $\delta = C\,A^{-n}$, C being dependent on composition but independent of physical processes that could cause albedo differences. Thus we have

$$I_\perp - I_\parallel = F_\odot\, C\, A^{-n+1} \quad . \tag{4}$$

For n = 1, $I_\perp - I_\parallel$ would depend only on C and hence only on compositional differences unrelated to albedo differences. However, for $n > 1$, $I_\perp - I_\parallel$ would be inversely related to albedo, as observed. For n - 1 sufficiently large, changes in C from point to point on the lunar surface would be masked by changes in A, and the difference pictures would contain no more information than is available in an ordinary image of the moon. Apparently this is what happened. From a comparison of the contrast in the difference pictures to contrast in the ordinary images, we conclude that n - 1 is approximately 0.3, whence $n \approx 1.3$. This value of n is sufficiently different from 1 so that the effect of albedo variation from point to point is not suppressed by taking images in the quantity $I_\perp - I_\parallel$.

References

Dollfus, A. 1961, in Planets and Satellites, ed. G.P. Kuiper and B.M. Middlehurst (Chicago: University of Chicago press), chap. 9.

Gehrels, T., Coffeen, T., and Owings, D. 1964, Astron. J., 69, 826.

Ingersoll, A.P. 1971, Astrophys. J., 163, 121.

Soderblom, L.A. 1970, "The Distribution and Ages of Regional Lithologies in the Lunar Maria," Ph.D. thesis, California Institute of Technology.

LUNAR PHOTOGRAPHIC LIBRARY

Justin J. Rennilson, Investigator

History

The lunar portion of Caltech's Division of Geological and Planetary Sciences' Space Photographic Library was accomplished over almost a three year effort beginning November 1, 1970. The original objective of the portion was: to develop a system which allows easy access to selected lunar photographs from all space missions. To accomplish this objective through the following techniques:

1. Collect high quality positive film copies of all lunar related space missions together with their associated camera parameters.
2. To copy the positive film onto microfiche cards with the highest resolution and tonal scale possible.
3. To rapidly display these microfiche images through a system of indexing. The displayed image to be of such a magnification that the maximum photographic information stored on the microfiche card will be utilized.

The above lunar section objectives have to a large degree been met, even though portions of the photography were not copied onto microfiche.

Present Status of the Lunar Library

The lunar portion consists of the following equipment.

1. An Image Systems 201 card reader with COSATTI microfiche image format (maximum size 11.5 x 16.5 mm/per frame). Design and lens for conversion to a dual lens magnification system on 201 reader. The magnifications to be 20 x and 51 x.

2. Light sources and film holders for microfiche copying from 70 mm roll, 5" aerial metric and 5" x 48" panorama strips and 20 x 24-inch positive transparencies.

Lunar photography copied onto microfiche cards and stored in the Image Systems reader.

Invertory

Apollo 8 - 864 frames		
10 - 1311 "		
11 - 1359 "		
12 - 1575 "	7021 frames = 118 cards	
13 - 584 "		
14 - 1328 "		
Lunar Orbiter I - V	59 cards	

The above are microfiche card images copied under MSC direction.

The following were copied from positive film at Caltech. The duplicate set of negative microfiche cards was sent to NSSDC.

Apollo 15 - all 70mm and 5" Metric	113 cards	
16 - " " " " "	112 cards	
17 - " " " " "	121 cards	
Lunar Orbiter I	13 cards	
II	13 cards	
III	13 cards	65 cards estimated.
IV	13 cards	
V	13 cards	
Grand Total	588 cards	

Reader capacity 750 cards.

The Lunar orbiter is being recopied onto microfiche directly from 20 x 24-inch positive transparencies furnished on loan from NSSDC.

Associated Data

Indices presently exist for the MSC microfiche according to frame numbers. Indices of the Apollo 15, 16, and 17 frames exist at Caltech according to frame numbers. In addition, magnetic type records of the important camera and mission parameters exist for the Lunar Orbiter and Apollo 15 metric cameras. The associated microfiche call up codes and camera parameters can be arranged in a picture data file which, in combination with the Space Photographic Library's SPACEL computer program, will recall and display the lunar images from given parameter selection.

Not Completed

Several parts of the photography intended for microfiche retrieval were not accomplished because the positive film copies were not available to Caltech. These were: All Apollo 15, 16 and 17 panorama photography. Apollo 14 Hycon photography. Recopying of Apollos 8, 10-14 missions from direct transparencies. The index of camera parameters for the Apollo 16 & 17 missions is not yet available on magnetic tape. Thus a picture data file to be used in computer controlled retrieval has not been generated.

Conclusion

It should be recognized that although many of the original goals were accomplished during the grant, the Lunar portion of the Space Photographic Library is not complete. If in the future it is deemed important to complete the effort, all the necessary equipment and technical knowledge exists at Caltech to do so.