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Session scientifique II

NATURE ET STRUCTURE DU SOL LUNAIRE

1. *Radiometric and photometric mapping of the Moon through a lunation*

R. W. Shortill, J. M. Saari

Measurements

Mapping of the illuminated lunar disk has been accomplished simultaneously at two wavelengths for more than 20 phases of the Moon. Isothermal and isophotic contours are produced which can be related to visible surface features. The specific goals of the program are:

(1) To investigate the radiometric properties of the lunar surface.
(2) To provide more photometric information taken photo-electrically.
(3) To investigate the relationship between albedo and surface temperature.
(4) To follow the temperature curves of specific areas of interest such as rayed craters.
(5) To search for areas which are thermally anomalous under illumination. A photomultiplier was used for measuring the reflected light, its peak response chosen to be 4450 Å corresponding to that used by Rougier in his measurements of the light curve for the illuminated disk as a function of phase. The photometric data from each complete scanning can be integrated and normalized to his curve. A mercury doped germanium photodetector, cooled to liquid hydrogen temperature, was used with a 10–12 micron filter and calibrated with black bodies at known temperatures. Corrections for atmospheric transmission can be made using ground and balloon-sonde meteorological data.

Both detectors had a spatial resolution of 8″ of arc and were placed at the Newtonian focus of the Mount Wilson 60-inch telescope. The Moon was scanned at 530″ of arc per second of time with a separation between scan lines equal to the aperture diameter; therefore the entire lunar disk was covered, a full Moon requiring about 240 scan lines.

It took a half hour or less to perform a scan program, depending on the phase of the Moon and the orientation of the scanning device. The signals were recorded in analog form on magnetic tape for subsequent data reduction by an IBM 7094 computer, giving position versus brightness temperature and light intensity to a scale such that $\frac{3}{8}$ inch is equal to 8″ of arc. Four or five pairs of contours have been reduced. It will require about a year to process and construct all the isothermal and isophotic charts.

Thermal anomalies

While the above measurements were being made, it was possible to make some infra-red measurements on the dark side of the Moon with minor modifications to the equipment. Thermal anomalies were found on the rayed craters Proclus and Strabo, in agreement with

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previous work during eclipses by the Boeing, Flagstaff, and Harvard groups, and on the dark side by the Cal Tech Group. In addition, are found positive anomalies not associated with rayed craters:

(1) About 140 km, east of Plinius;

(2) East of Arago in the sea of Tranquility;

(3) Over the Hyginus Rille.

There appear to be negative anomalies on the illuminated disk of the Moon which are not obviously the result of albedo or local geometry. One, amounting to 5°K, has been observed on the edge of Mare Imbrium situated about one-third the distance from Copernicus to Aristarchus within several clays of local sunset; at full Moon it seems to disappear. The temperature history chiring a lunation of this region (and others) will be studied closely as more of the data are reduced.

Surface roughness and thermal anomalies

The thermal anomalies have been interpreted as being due to a thinner dust layer. An alternative interpretation in terms of enchanced roughness in the vicinity of rayed craters is being studied. So far a rather simplified model consisting of a flat surface interspersed with cavities has been considered; under illumination, with the albedo assumed to be zero, the entire surface comes to a uniform temperature. During an eclipse, when the solar radiation is suddenly removed, the cavities cannot cool as rapidly as the flat areas. An infra-red detector pointed to the area will see a composite surface of warmer and cooler areas, resulting in an apparent brightness temperature higher than the environs. Topographical profiles calculated for a range of temperature differences between rayed craters and their environs using V-shaped trenches for the cavities appear to give a reasonable scale of roughness for these features. The enchanced radar returns observed from several rayed craters are compatible with this theory.

The additional parameters offered by this theory can be used to resolve the discrepancy that has appeared to exist between eclipse and lunation cooling of the general lunar surface. The calculations revealed a smoother surface than necessary to explain the rayed crater anomalies. In addition, the scale of this roughness may well be on a smaller scale and could result from the continuing bombardment of the lunar surface by micrometeorites.

Work on most sophisticated models for this theory is underway.

2. *Lunar research at Harvard College Observatory*

H. C. Ingrao, D. H. Menzel

We have discussed the principle of operation of the radiation pyrometer for lunar work developed at Harvard College Observatory ('Radiation pyrometer for lunar observations'. *Scientific Report* no. 4, NASA Grant NsG 64–60). We have stressed the problem of locating the projection of the resolution element on the lunar surface when working with high spatial resolution. The pyrometer has two channels, infra-red and visual-photographic, operated by a mirror chopper. The chopping frequency can be continuously varied from 10 cycles per second to 70 cycles per second with the choice of frequency depending upon the scanning rate.

The pyrometer can take different detectors and electronics, the change takes only seconds. The detector we use at present is an immersed germanium thermistor bolometer, 0·1 mm × 0·1 mm in size. The noise level with a 4 second post-detection time constant is 5×10^{-11} watts peak to peak. We have the choice of two band pass filters, $8\mu - 14\mu$ or $8{\cdot}3\mu - 9{\cdot}2\mu$.

The pyrometer has well calibrated reference and calibration black bodies. The output is recorded in analog form, but an analog digital converter is under construction.

The visual-photographic channel subtends a field of view of 7·0′ × 4·5′ and has in the center a cross hair that indicates the equivalent position of the detector. The accuracy in locating the resolution element on the Moon could be of the order of ± 1·5″.

The infra-red signal, timing marks (WWV) and picture frame marks are simultaneously recorded on the same three channel paper chart. The conversation of the observer and the operator of the electronics, timing marks (WWV) and event marks are recorded on magnetic tape.

At the end of 1963 and during 1964 the scannings of the Moon were secured at different observing sites.

The total lunar eclipse of 1963 December 30 was observed by Hector C. Ingrao and Andrew T. Young from the Dominion Astrophysical Observatory, Victoria (Canada), using the radiation pyrometer attached to the 72-inch reflector at the Newtonian focus. Because weather conditions were generally poor, we reduced only the data gathered during intervals of good weather. The following table gives the results:

Name of crater	Approximate size (sec of arc)	Observation time (U.T.)	Temperature anomaly ΔT (°C)
Aristarchus	20	$8^h\,56^m\,30^s$	7°C ± 5°C (warmer*)
Censorinus	3	$8^h\,09^m\,55^s$	12°C ± 5°C (cooler*)
Dionysius	9·5	$8^h\,18^m\,43^s$	7°C ± 1°C ,,
Fracastorius A	8·5	$8^h\,25^m\,37^s$	7°C ± 2°C ,,
Proclus	15	$7^h\,48^m\,30^s$ (?)	10°C ,,
Pytheas	11	—	?

* than the background.

The size of the resolution element during the measurements at the Dominion Astrophysical Observatory were 8″ × 8″.

The lunar eclipse of 1964 June 24/25 was observed by Hector C. Ingrao and Andrew T. Young from the Radcliffe Observatory in Pretoria (Republic of South Africa), using our radiation pyrometer attached to the 74-inch reflector at the Newtonian focus.

Before commencing the lunar measurements we allowed the detector to be scanned by Alpha Scorpii in order to determine the responsivity profile of the detector and its position with respect to the reticle. The reticle then enables us to determine the locations of the resolution element on the lunar disk.

In the early part of the night, prior to the eclipse, scans were made of Aristarchus, Censorinus, Dionysius, Proclus and Menelaus. After the beginning of the eclipse scans were made across the entire Moon in an east to west direction through the center of the disk. The scans passed north of Censorinus and south of Dionysius. From the scans we will construct cooling curves for areas of the Moon at all distances from the center of the disk.

During totality, because of the darkness of the eclipse (it was not as dark as the eclipse of 1963 December 30) our photographic system was unable to locate the position of the resolution element on the lunar disk; however, we took pictures of the limb at the entrance and exit of the scanning with stars in the background.

During totality we secured scans showing temperature anomalies (hotter on cooler background) in different areas and we are confident that on the basis of the few photographic data and extrapolation from the scanning mode of the telescope, we will be able to identify the position of the scans. The data is in the process of reduction.

Before, during, and after an eclipse the South African Weather Bureau launched meteorological balloons to measure the total amount of precipitable water. The lowest value was 2·5 mm.

An isothermal map of the Proclus region included between selenographic latitude parallels $+8°$ and $+20°$ and selenographic longitude circles $+38°$ and $+60°$ has been made. The region was scanned with the pyrometer at the Newtonian focus of the 61-inch Weyth reflector of Harvard College Observatory when the Moon was 14·5 days old.

The results were reduced and the isotherms plotted by Harold Boeschenstein, Jr. The temperature increments between isotherms range from $\Delta T = 0{\cdot}7°C$ to $\Delta T = 0{\cdot}9°C$. The accuracy in the location of the resolution is in the order of ± 6 seconds of arc. The isotherms suggest that the observed temperature gradients depend more on the slope and surface structure than on the visual albedo.

A mosaic photograph composed of prints made from the identification negatives taken with the pyrometer camera was made, and 1040 points representing fixed power level intervals were plotted on it. The isotherms were drawn through points of equal power level (Fig. 5).

From the work which has been done so far by Hector C. Ingrao and Andrew T. Young, temperature anomalies have been observed in the following craters: Aristarchus, Censorinus, Dionysius, Fracastorius A, Lalande, Manilius, Menelaus, Proclus, Pytheas (?), Taquet.

Hector C. Ingrao reported that Andrew T. Young has written a 7094 FORTRAN computer program that traces accurately the path of a scanning line across the Moon using the data from the radiation pyrometer. The telescope may be moving at a uniform rate in either hour angle and declination, or if desired in both. The program accepts as input, data from the Ephemeris, the lunar orthogonal coordinates (ξ, η) of one or more points along the scan, and the time at which each point is scanned. It produces, as output, the following data for specified intervals during the scan: Orthogonal coordinates (ξ, η); the altitude of the Sun; the difference in azimuth of Earth and Sun; and the phase angle (angular separation of Earth and Sun). In each case, 'Earth' refers to the position of the observer, not the center of the Earth. The error in the computed quantities corresponds to less than 1 second of arc in the sky, or ·001 lunar radius; the accuracy of the results is in practice governed by the accuracy of the input coordinates and times.

3. *Lunar radar measurements at 70 cm*

G. H. Pettengill

Lunar radar measurements at 70 cm using the 300 m reflector of Cornell University in Puerto Rico have been initiated. In these observations the technique of range-Doppler mapping has been employed to achieve a lunar surface resolution of about 20 km by 40 km. So far, regions containing the craters Tycho, Kepler, Copernicus, Langrenus, and Theophilus have been examined. In all cases anomalously high surface reflectivity has been observed which corresponds well in position with the visual feature. Moreover, many smaller craters of dimensions substantially less than the resolution cell have also been observed. The technique appears to be particularly useful in locating regions which are unusually rough at the scale of the radio wavelength used. Polarization measurements imply that the scattering mechanism in these regions is predominantly due to a rough surface rather than merely a series of highly inclined smooth surfaces.

DISCUSSION

Shoemaker: Which is the orientation of the map?

Gold: L'orientation des pentes explique les différences des signaux reçus.

Pettengill: Not only the inclination of the 'pentes', but scattering, is due to the *roughness* of the surface at the scale of wavelength. The question of the 'pentes' goes along with function of libration.

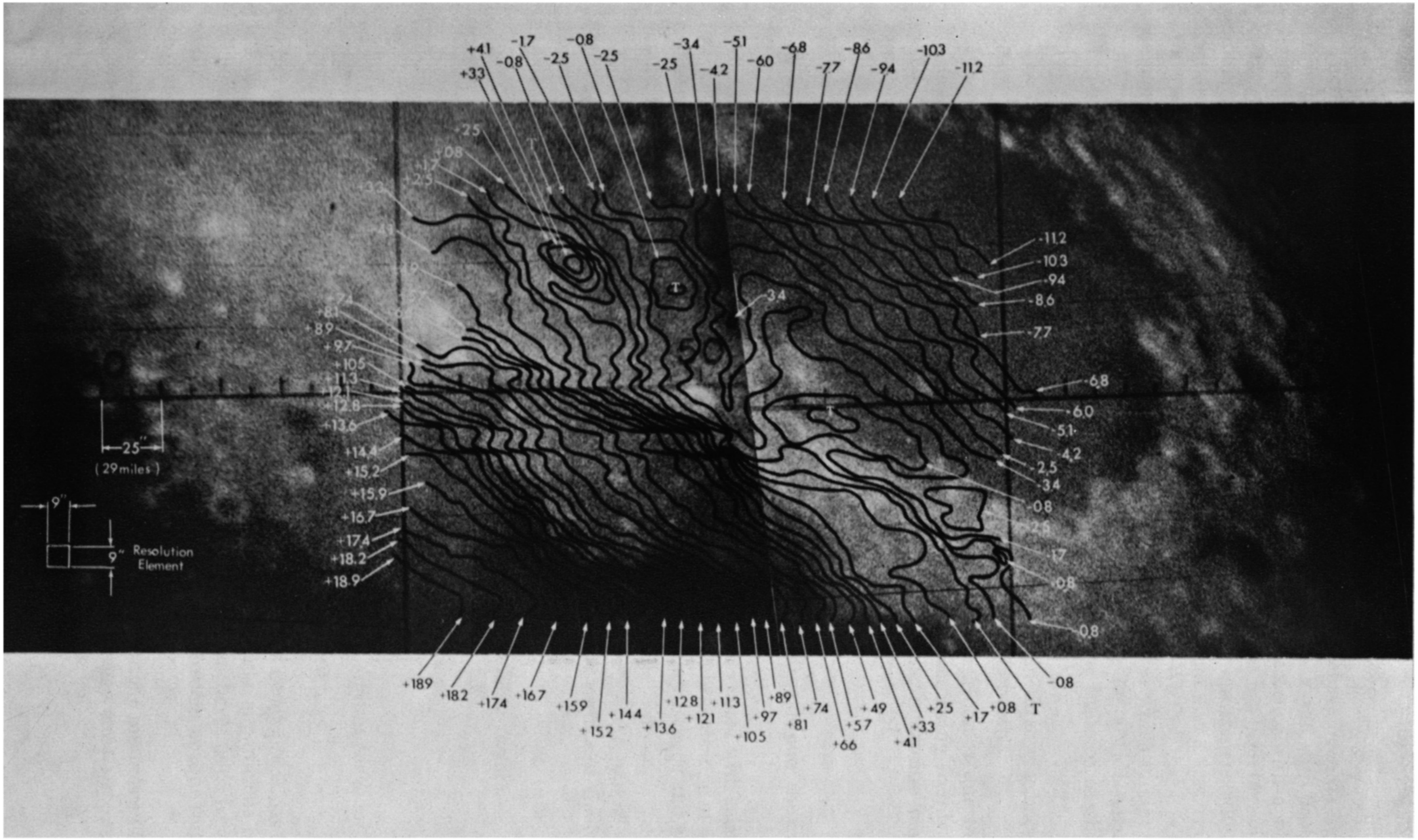

Fig. 5. An isothermal map of the Proclus region on a mosaic photograph composed of prints made from the identification negative taken with the pyrometer photographic camera. For this map 1040 points representing fixed power level intervals were reduced. The temperature increments between isotherms range from $\Delta T = 0{\cdot}7^{\circ}C$ to $\Delta T = 0{\cdot}9^{\circ}C$; the accuracy in the location of the resolution element is of the order of $\pm$ 6 seconds of arc. The Moon was 14·5 days old. The isotherms suggest that the observed temperature gradients depend more on the slope and surface structure than on the visual albedo.

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4. *Moon luminescence*

J. E. Geake, C. J. Derham, J. C. G. Walker

There is some evidence that the Moon is luminescent, and we have been trying to simulate this in the laboratory. We have bombarded dust samples with UV and with protons (usually about 40 keV), and have recorded the spectrum of any luminescence with a photo-electric spectrophotometer. A range of different types of stony meteorites has been investigated under proton excitation; they mostly luminesce negligibly or weakly, but the enstatite achondrites alone luminesce strongly, with an efficiency approaching 1 per cent and a spectrum consisting of a strong red peak at 6700 Å and a weaker blue peak at 4000 Å. We find that it is the enstatite component which luminesces, but that it is present in two states which luminesce predominantly red and blue respectively. The colour appears the same for a wide range of proton, electron and X-ray excitation; however, under UV excitation the emission is white and very feeble.

The meteorites studied under proton excitation seem to be in three efficiency groups, in narrow ranges around 1, 1/20 and 1/200 per cent with none in between.

It seems more likely that the observed luminescence of the Moon is due to potentially luminescent (but radiation damaged) regions of the lunar surface being freshly exposed by meteoritic or volcanic disturbances, than that it is due to the meteoritic material itself. Enstatite has been suggested earlier as a possible lunar surface material.

DISCUSSION

E. Öpik: Is luminescence or fluorescence of the surface of the Moon the result of the permanent solar wind only?

Z. Kopal: Luminescence in several spectral ranges have to be related with solar flares. The total brightness of full Moon is correlated with solar activity. The organization of a Committee between Commissions 16 and 10 for systematic study of lunar luminescence and solar activity should be particularly efficient.

T. Gold: Particles bombardment makes a luminescence of 10^{-6}. Above views are insoutenable because luminescence will occur also in the dark part of the surface of the Moon. A UV source of energy has to be involved.

5. *Effect of solar wind on optical properties of the lunar surface*

T. Gold

(No abstract received)

6. *Interprétation des propriétés polarimétriques de la lumière diffusée par le sol lunaire*

A. Dollfus

Les études polarimétriques entreprises jadis par B. Lyot, puis développées par l'auteur, sur la Lune et des échantillons terrestres avaient montré que la couche superficielle recouvrant le sol lunaire est constituée par une poudre formée de petits grains enchevétrés de facon complexe, et constitués par un matériau très absorbant, c'est-à-dire complètement opaque sous l'épaisseur de quelques longueurs d'ondes.

De nouveaux échantillons minéraux broyés en fines poudres ont été mesurés à l'Observatoire de Meudon; ils ont été choisis en raison des différentes hypothèses émises récemment sur la composition du sol lunaire.

Des *tektites* d'Indochine, des échantillons du revètement intérieur bréchiforme du *Meteor Crater* de l'Arizona, des *Obsidiennes* basiques ou acides, des *Ignimbrites* donnent des poudres beaucoup trop claires, avec une polarisation trop faible et presque dépourvue de la branche initiale négative qui caractérise la surface lunaire.

Des météorites pierreuses *achondrites* pulvérisées se comportent de la même façon, ainsi que de nombreux échantillons de *chondrites*. Une seule météorite chondritique pulvérisée très sombre et très chargée en olivine (Karoonda) a donné une polarisation de la lumière se rapprochant de celle de la Lune.

Des *cendres volcaniques* sombres ou des *laves volcaniques* pulvérisées donnent des courbes de polarisation très semblables à celles de la Lune; des mélanges convenables de cendres de différents pouvoirs réflecteurs reproduisent convenablement les propriétés polarimétriques du sol lunaire en lumière jaune (comme Lyot l'avait déja indiqué), ainsi que leurs fortes variations selon l'éclat de la région lunaire. Cependant les variations de la polarisation avec la longueur d'onde ne sont pas toujours respectées.

Des poudres de minérais clairs soumises à un bombardement protonique intense ou prolongé s'assombrissent. Il pourrait en être de même à la surface de la Lune sous l'effet du vent solaire. En collaboration avec le Dr J. E. Geake, à Manchester, nous avons noirci un échantillon pulvérisé de météorite achondrite à enstatite (Khor Temiki), par un bombardement protonique de 8 heures, sous 60 keV, la densité de courant étant $2 \cdot 10^{-6}$ amp/cm^2. Les proportions de lumière polarisée relevée sur l'échantillon ainsi bombardé sont très différentes de celles de l'échantillon initial; elles deviennent semblables, sous tous les angles de vision,et à mieux que 1 millième, à celles observées sur les régions lunaires de pouvoir réflecteur 0·145. Les variations de la polarisation avec la longueur d'onde, entre 0·45 et 0·63 microns, deviennent également identiques à celles de la Lune. Cependant ce premier échantillon conservait un pouvoir réflecteur plus élevé que celui du sol lunaire de comparaison.

Comme il est possible que d'autres échantillons, en particulier parmi ceux mentionnés ci-dessus, donnent sous bombardements de protons des surfaces plus sombres, nous nous proposons de développer ces recherches.

D'autre part nous procédons à l'Observatoire de Meudon à l'étude polarimétrique de la Lune et d'échantillons minéraux dans l'infra-rouge jusqu'à 1·1 microns. Nous préparons un programme semblable pour l'ultra-violet jusqu'à 0·32 micron. Ces grandes extensions du domaine spectral de comparaison donneront des critères encore beaucoup plus précis pour la sélection des substances naturelles ou irradiées par protons capables de reproduire les propriétés photométriques et polarimétriques du sol lunaire.

7. *Electronic polarimetric images of the Moon*

V. P. Dzhapiashvili and L. V. Xanfomaliti

(1) Polarimetric observations of the Moon and planets have been carried out at the Abastumani Astrophysical Observatory (Georgia). The polarimetry is based on an electron polarimeter, the last model of which gives reading of degree of the plane of polarization, the angle and the stellar magnitude of the object (down to the $13^{m}.5$ using the 40-cm refractor). Interesting results have been obtained with this device.

(2) Since 1962, observations of polarimetric images of the Moon have been carried out with a special device—an electron polarovisor, which is a scanning polarimeter.

(3) Polarimetric observations of the Moon in different phases permitted the detection of a class of objects on the lunar surface similar in shape to circi and craters, but not always spatially identified with them. The nature of these objects (for which the conventional names 'polaro-

circi' and 'polaro-craters' are proposed) is perhaps connected with the history of the Moon and results from the strained state of hypothetical glass-like mass accumulations or from the gas emission on the Moon's surface.

(4) As early as 1960, the authors found that the polarimetry of the lunar surface near full Moon with the small polarimeter aperture ($1''\cdot5$) shows the existence of small objects (2·5 km) with very different physical properties.

(5) At the beginning of 1963 the second model of polarovisor was put in operation. With this device the effect of inversion of the polarization of seas and continents near full Moon was found.

(6) At present, the third model of electron polarovisor is under construction. This polarovisor will permit to improve the resolution of separate details on polarimetric images of the Moon.