Proceedings of the Third Lunar Science Conference
(Supplement 3, *Geochimica et Cosmochimica Acta*)
Vol. 3, pp. 2681–2687
The M.I.T. Press, 1972

An explanation of transient lunar phenomena from studies of static and fluidized lunar dust layers

G. F. J. GARLICK, G. A. STEIGMANN, and W. E. LAMB
Department of Physics, University of Hull, England

and

J. E. GEAKE
Department of Physics, University of Manchester Institute of Science and Technology,
Manchester, England

Abstract—Transient lunar phenomena (TLP's) such as brightening, color changes or obscuration of surface detail have been reported by many terrestrial observers. Explanations based on luminescence emission from the surface or from electrical discharges in gases venting through the surface fail for sunlit surfaces because the intensities would be many orders of magnitude lower than those needed for terrestrial observation. Experiments here reported show that when lunar dust layers lose their cohesion by suitable vibration, the albedo rises in sufficient magnitude to explain at least some of the TLP's observed within fully sunlit areas. The effect is very dependent on viewing angle but not on angle of incident sunlight. Dust flows associated with moonquakes etc. could produce such effects. Threshold conditions for dust fluidization and flow have been determined. Albedo changes are also accompanied by changes in the degree of polarization of reflected light from the layers. It is also shown that the albedo of dust layers is independent of temperature over a wide range including the lunar surface night-day extrema. In all experiments effects of postmission adsorption of gases can be found but can be eliminated by vacuum heat treatment.

INTRODUCTION

OVER THE PAST TWO CENTURIES there have been many reports by observers of transient lunar phenomena (TLP's) in the form of brightenings, color changes, and temporary obscuration of surface details in the sunlit area of the moon and also of glows in the dark lunar areas. More than 700 such reports have been catalogued (Middlehurst *et al.*, 1968; Moore, 1971) and their degree of authenticity estimated. In the latest list by Moore (1971) we find that most of the hundred or so events for which durations were given lasted less than or about one hour. Some were of a few minutes' duration only. There is also some evidence of correlation of more recent events with lunar perigee. In a recent paper (Nash and Greer, 1970) explanations of lunar events based on luminescence from the sunlit surface have been shown to be invalid because the efficiency of luminescence in lunar soils as measured in the laboratory is much too low to give observable effects to be seen from the earth. These low efficiencies were confirmed by other workers (Blair and Edgington, 1970; Geake *et al.*, 1970). A similar objection can be made to Mills' (1970) suggestion that luminescence due to electrical discharges in gases venting through the lunar surface might be observed terrestrially at least in sunlit areas when these occur. However, his own experiments on gas venting and soil fluidization have a bearing on the work reported below. Any

1972LPSC....3.2681G

observation of lunar surface brightening in sunlit areas requires a contrast of about 10% or more for the TLP to be visible; this corresponds to an increase in light flux from the surface of about 10^{-2} w/cm^{-2}. It therefore occurred to us that the most obvious source of such an increment would be an increase in reflected sunlight due to a rise in albedo and that such an increase might be expected if dust flow occurred which involved temporary loss of cohesion between grains and removal of the strong optical shadowing effects of the normal "fairy castle" structure of the dust of the lunar regolith. Such flows would be most likely during moonquakes which cause gas venting, dust falling down slopes, and in electrostatic repulsion effects (Gold, 1972; Criswell, 1972) and should show some degree of correlation with lunar perigee. It is already well known that reflectance of light from the lunar surface is highly directional, being mainly back along the direction of incidence. This arises from the pileup and shadowing effects of the strong intergrain cohesion. Fluidization of the layers should remove the normal structure and in so doing raise the albedo toward that of terrestrial free-flowing dusts. We therefore constructed a system, described below, in which a dust layer can be vibrated so that cohesion is removed and the consequent change in albedo measured for various angles of incidence of light and of diffuse reflectance. The diffuse reflection spectra for static and fluid states were also measured.

In the recent Third Lunar Science Conference, Lloyd and Head (1972) reported anomalously higher albedos for the crater floor of Aristarchus under earthshine conditions and relative to the albedo of surrounding maria. In considering this report it seemed to us that the one parameter that would be very different for normal moonlight from that under earthshine conditions would be the surface temperature. We therefore included in our studies measurements of the albedo of various lunar dust samples over a temperature range from 77° to 473°K, this range including the lunar temperature extrema.

EXPERIMENTAL EQUIPMENT AND PROCEDURES

A moving coil transducer unit was fitted with a shallow, flat-bottomed cup in which a lunar dust sample of about 10 to 20 mg cm^{-2} was arranged as a horizontal layer and subjected to vertical, simple harmonic oscillations of selected amplitude. After finding that observed effects were not sensitive to vibration frequency over the usual audio range, a frequency of 208 Hz was selected for the experiments. Fluidization occurred for amplitudes of about 0.005 mm, and for all but threshold measurements an amplitude of 0.007 mm was used. A tungsten light source with collimator system and a photomultiplier with collimating apertures were mounted on separate circles concentric with the sample layer surface so that angles of incidence and reflectance could be separately varied. The output of the photomultiplier was fed to a pen recorder. For diffuse reflection spectra measurements the system was moved to a spectrometer which had a range from 0.4 to 1.0 μ. To measure variations of albedo with temperature, dust samples were mounted in a vacuum cryostat. All samples were preheated for several hours in vacuo at 140° to 160°C to remove laboratory-occluded gases. This eliminated spurious albedo changes due to the presence of adsorbed gases and also restored the high degree of cohesion characteristic of the uncontaminated dust samples. To simulate lunar regolith conditions, the dust layers were roughened by "teasing" with a needle point until they showed the right kind of appearance under microscopic observation (see, e.g., Geake *et al.*, 1970). Thresholds for loss of intergrain cohesion were measured by visual and photoelectric observation as the vibration amplitude was slowly increased. The amplitude was precalibrated by observing the motion of the cup containing the sample through a microscope and recording the corresponding voltage across the transducer terminals with a digital voltmeter.

EXPERIMENTAL RESULTS

All lunar dust samples subjected to vertical vibrations showed a marked rise in albedo as soon as fluidization of the layers occurred, the effect being maintained until vibration was stopped. A full return to the previous low albedo values was not observed, but this was to be expected as the very random nature of the roughened surface is not restored under the very simple and highly directional disturbance in our system. The experiment is simply designed to show that dust fluidization can cause a marked rise in albedo sufficient to give an explanation of some TLP's. The albedo changes are very dependent on viewing angle, as shown by the selected data for an Apollo 14 sample in Fig. 1. A polar plot of reflectance before and during fluidization is presented for three different angles of incidence of light. No albedo change is observed in each case for reflection back along the incidence direction, but in each case the albedo change is a maximum at a viewing angle of about 20° to the surface. The variation of the reflection at 20° to the surface as a function of angle of incidence is given in Fig. 2 and is not very marked. The plots of Figs. 1 and 2 show that dust fluidization can yield rises in surface albedo of 50 to 100%.

Measurements of the diffuse reflection spectrum of a layer before and during fluidization show that the rise in albedo is the same at all wavelengths. This result may of course be peculiar to our experimental conditions, since dust flow and motion, e.g., due to gas venting on the lunar surface, will involve a wide dust grain-size distribution while in our experiments we had to use the sieved fines as provided.

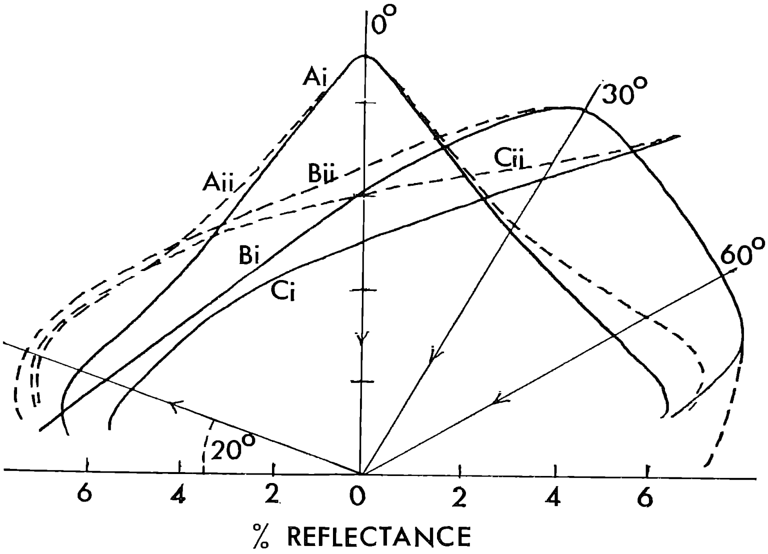

Fig. 1. Variation of lunar dust layer reflectance (sample 14259,56) with viewing angle for different angles of incident light and under static and fluidized conditions.

A(i) Incidence angle 0° to normal: static condition.
A(ii) Incidence angle 0° to normal: fluidized condition.
B(i) Incidence angle 30° to normal: static condition.
B(ii) Incidence angle 30° to normal: fluidized condition.
C(i) Incidence angle 60° to normal: static condition.
C(ii) Incidence angle 60° to normal: fluidized condition.
(Line at 20° to surface shows direction of maximum albedo change.)

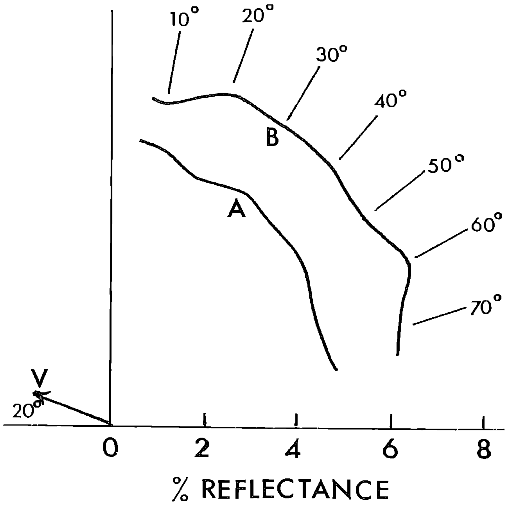

Fig. 2. Variation of lunar dust layer reflectance, observed at 20° to surface, with angle of incident light (sample 14259,56) A. Static condition, B. fluidized condition.

Table 1. Fluidization thresholds for lunar dust layers subjected to vertical vibrations.

Sample no.	Vibration amplitude ($\times 10^{-4}$ mm)		Max. acceleration of layer in msec^{-2}	
	Initial	After heat treatment	Initial	After heat treatment
10084,6	109 ± 10	119 ± 7	18.5 ± 1.7	20.2 ± 1.2
12032,39	110 ± 7	120 ± 4	18.7 ± 1.2	20.4 ± 0.7
12033,60	107 ± 5	114 ± 11	18.2 ± 0.8	19.4 ± 1.9
14163,51	102 ± 5	120 ± 7	17.3 ± 0.8	20.4 ± 1.2

Differential effects of different grain sizes on the spectral distribution would not be unexpected. Measurements of albedo over the temperature range 77° to 473°K showed that the albedo is independent of temperature over this range.

Finally, we have measured with the vibrator system the threshold amplitudes of vibration for breaking of cohesion between dust grains. The results are collected in Table 1, the maximum accelerations being calculated and inserted alongside the corresponding threshold amplitudes.

Discussion and Conclusions

It is evident that fluidization with consequent cohesion loss of lunar dust layers can cause a rise in albedo of a magnitude more than sufficient to satisfy the contrast requirements for terrestrial observation of such effects on sunlit lunar areas. The mass of dust needed to obtain the rise is of the order of 10 to 20 mg/cm^{-2} at the most. Only fluidization is needed without any resultant lateral flow of dust across the surface. Suggestions have been made by other workers (Pat, Hsieh, and O'Keefe, 1972) that processes such as gas venting may produce suspensions of dust which can persist for times comparable with those for many reported TLP's. In another case, Criswell (1972) suggests that dust suspensions might be created electrostatically by the excursion of photoelectrons from sunlit to dark areas across the terminator and that such suspensions could be an explanation of the "horizon" glow detected by the Surveyor 6 and 7 (soft-landing) spacecrafts just after lunar sunset. Intense light scattering relative to normal surface brightness is evident from the temporary dust clouds produced by the astronauts' boots as shown in several mission photographs. The removal of self shadowing of the dust-layer reflection by loss of intergrain cohesion has been shown to be critically dependent upon viewing angle; this places strong constraints on favorable viewing times for different sites on the lunar surface during the lunar phases, should dust disturbance be a cause of the TLP. To demonstrate this point we have used the data given in Fig. 1 to construct the polar diagrams of Fig. 3, which give the expected albedos, with and without fluidization of the dust layers for

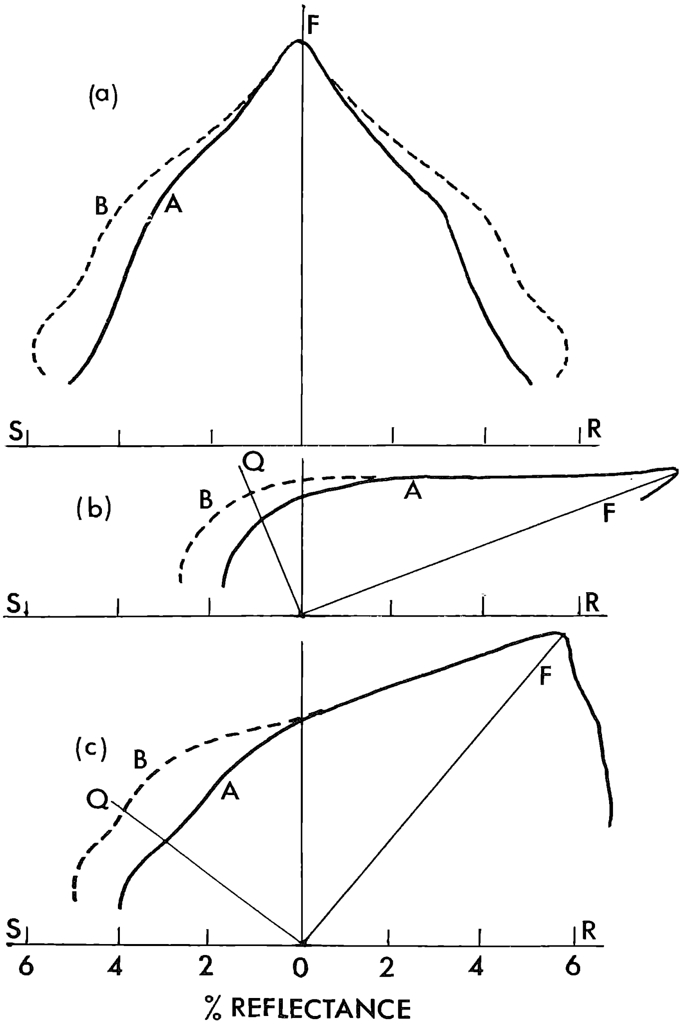

Fig. 3. Polar diagrams for change of lunar albedo with phase angle, with and without dust fluidization for different lunar surface sites. (a) Curves for sub-earth point. (b) Curves for sites of craters Hevelius (3°N, 67.5°W) and Grimaldi (5°S, 67.5°W). (c) Curves for site of crater Kepler (7.5°N, 37.5°W). A. static condition, B. fluidized condition, F. Full moon, R. Sunrise, S. Sunset, Q. Third quarter. (% reflectance contains the correction factor cos ε, where ε is the viewing angle relative to normal to lunar surface at site).

selected lunar sites, as functions of the phase angle (angle between incidence and viewing direction). For the subearth point, the best time for observation of TLP's due to soil disturbance is just after the first quarter or just before the third quarter. In other cases, e.g. for the sites of craters Hevelius, Grimaldi, and Kepler, the third quarter is the best time for observation.

Another optical effect that should change with fluidization is the degree of polarization of reflected light from the dust layer. We have designed a system to measure the polarization using the Lyot polarimeter from the Physics Department of the University of Manchester Institute of Science and Technology in combination with our vibrator system. Preliminary data show that the small negative polarization at small phase angles is slightly decreased on fluidization, but there is a large increase, sometimes of more than 100% in the positive degree of polarization at large phase angles. The general shape of the polarization curves follow those given by Dollfus *et al.* (1971), Geake *et al.* (1970), and others.

The albedo of lunar dust layers is independent of temperature over a range containing the lunar day and night extrema, which makes it unlikely that the differences in relative albedo for earthshine and moonlight conditions in the crater Aristarchus can be related to the large temperature difference. However, in making these experiments and those on thresholds for fluidization we have also shown that cohesion data and flow characteristics may be subject to terrestrial adsorption effects unless preheating and vacuum treatments are applied before measurements. The data also make it evident that soil mechanics studies should include dynamic conditions which may be very relevant to lunar surface slopes and stabilities involved in Apollo 16 and 17 missions.

Finally, we would re-emphasize that the reported effects of dust layer disturbance on albedo offer a particular contribution to explanations of lunar transients. They are relevant to TLP's occurring in the sunlit areas of the lunar surface and even within that group cannot account for the reported observations of spectral fine structure, suggestive of molecular species, by Kozyrev (1962, 1963) though, to be visible, the intensity of such emissions must have been associated with considerable local surface activity which would also engender albedo changes. Present data also do not give any explanation of the reddish coloration often reported by TLP observers. However, we have noted that our vibrator system and the sieved dust samples do not give a sufficiently close simulation of lunar surface conditions. It is worth noting that Greenacre (1965) refers to "sparkling" or "flowing" appearances of TLP's which might suggest possible surface motion. Such motion would also explain the temporary obscurations reported (Moore, 1971) if dust flow and even suspension were involved. Suffice it to say that the observational data on TLP's in sunlit lunar areas show a fair degree of correlation with the effects we have measured on lunar samples and their implications for surface motion.

REFERENCES

Blair I. M. and Edington J. A. (1970) Luminescence and thermoluminescence under 159 MeV proton bombardment of lunar material returned by Apollo 11. *Proc. Apollo 11 Lunar Sci. Conf., Geochim. Cosmochim. Acta* Suppl. 1, Vol. 3, pp. 2001–2012. Pergamon.

Criswell D. R. (1972) Horizon glow and motion of lunar dust (abstract). In *Lunar Science—III* (editor C. Watkins), p. 163, Lunar Science Institute Contr. No. 88.

Dollfus A., Geake J. E., and Titulaer C. (1971) Polarimetric properties of the lunar surface and its interpretation. Part III: Apollo 11 and Apollo 12 lunar samples. *Proc. Second Lunar Sci. Conf., Geochim. Cosmochim. Acta* Suppl. 2, Vol. 3, pp. 2285–2300. MIT Press.

Geake J. E., Dollfus A., Garlick G. F. J., Lamb W. E., Walker G., Steigmann G. A., and Titulaer C. (1970) Luminescence, electron paramagnetic resonance and optical properties of lunar material from Apollo 11. *Proc. Apollo 11 Lunar Sci. Conf., Geochim. Cosmochim. Acta* Suppl. 1, Vol. 3, pp. 2127–2147. Pergamon.

Gold T. (1972) The depth of the lunar dust layer (abstract). In *Lunar Science—III* (editor C. Watkins), pp. 321–322, Lunar Science Institute Contr. No. 88.

Greenacre J. C. (1965) The 1963 Aristarchus events. *Ann. N.Y. Acad. Sci.* **123,** 811.

Kozyrev N. A. (1962) Spectroscopic proofs for existence of volcanic processes on the moon. In *The Moon* (editors Z. Kopal and Z. K. Mikhailov), pp. 263–271, Academic Press.

Kozyrev N. A. (1963) Volcanic phenomena on the moon. *Nature* **198,** 979–980.

Lloyd D. D. and Head J. W. (1972) Earthshine and near terminator photography obtained on Apollo 15 (abstract). In *Lunar Science—III* (editor C. Watkins), pp. 489–490, Lunar Science Institute Contr. No. 88.

Middlehurst B., Burley J. M., Welther B. L., and Moore P. (1968) Chronological catalog of reported lunar events. NASA Tech. Report TR R-277.

Mills A. A. (1970) Transient lunar phenomena and electrical glow discharges. *Nature* **225,** 929–930.

Moore P. (1971) Extension of catalog of reported lunar events. *J. Brit. Astron. Assoc.* **81,** 365–390.

Nash D. B. and Greer R. T. (1970) Luminescence properties of Apollo 11 lunar samples and implication for solar excited luminescence. *Proc. Apollo 11 Lunar Sci. Conf., Geochim. Cosmochim. Acta* Suppl. 1, Vol. 3, pp. 2341–2450. Pergamon.

Pai S. I., Hsieh T., and O'Keefe J. A. (1972) Lunar ash flows: How they work (abstract). In *Lunar Science—III* (editor C. Watkins), pp. 593–595, Lunar Science Institute Contr. No. 88.