PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

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Phil. Trans. R. Soc. Lond. A 1977 **285**, 325-329
doi: 10.1098/rsta.1977.0072

Phil. Trans. R. Soc. Lond. A. **285**, 325–329 (1977) [325]
Printed in Great Britain

Lunar surface movements – the evidence and the causes

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A review is made of the various kinds and sources of evidence for motion or disturbance of lunar surface dust. This evidence ranges from the terrestrial reporting of transient lunar phenomena to Apollo Mission evidence such as anomalous alpha particle activity over certain areas such as Aristarchus and Grimaldi craters and the occurrence of horizon glow due to dust suspensions at the lunar sunset terminator. Moonquakes of the deep seated kind are relatively unlikely to cause surface dust motion but shallower quakes and those of thermal origin may correlate with dust movement and consequently with terrestrially observed transients, e.g. just after lunar sunrise. Anomalous alpha particle activity and non-equilibrium of daughter product with parent indicate spasmodic gas evolution at sites like Aristarchus where there is evidence of unusual albedo levels also suggestive of surface motion. Future study of transients will be facilitated by monitoring the degree of polarization of moonlight in its variation across the lunar terrain and its marked sensitivity to dust disturbance.

1. Introduction

The so-called *transient lunar phenomena* (t.l.p.) have been reported by terrestrial observers for more than two centuries and have a wide range of authenticity as regards existence at all, location, duration and appearance. Catalogues and analyses have been provided by various workers (Middlehurst & Burley 1966; Middlehurst & Moore 1967; Moore, Middlehurst, Burley & Walther 1968; Moore 1971; Cameron 1972). Whatever the level of scepticism about the occurrence of such events the question arises as to what kind of transient surface process on the Moon would be visible from the Earth? It was recognized by more than one of the above workers that to be seen from earth events would have to have an incremental brightness of the same order as that of the sunlit lunar surface. For this reason it is easy to show that luminescence and gas discharges would not provide this level of emission but would be many orders of magnitude too small (Nash & Greer 1970).

In our own work on lunar dust samples we were able to show that fluidization or disturbance of the dust layers sufficient to break the intergrain cohesion caused a rise in diffuse reflectivity of the layer more than sufficient to give the necessary contrast to the surrounding, undisturbed surface (Garlick, Steigmann, Lamb & Geake 1972). Thus there arises the idea of associating t.l.p. with dust movements or disturbances of durations from minutes to days. It should be noted that the usual duration of t.l.p. reported is of *ca.* 20 min. In the present paper we bring together the evidence from different sources and types of experiment for such dust disturbance or for possible causes of the same. We will stress the temporal and spatial distributions of effects with a view to possible correlations with t.l.p. It is important to do this because we have now a sensitive means of detecting dust reflexion changes or rather the marked changes in degree of polarization of the reflected light caused by dust motion or fluidization (Garlick, Steigmann & Lamb 1973/74). Thus lunar activity may continue to be monitored from the Earth and also from orbiting satellites.

We consider the following areas of investigation in relation to dust motion:

(*a*) Lunar seismic activity and its effects at the regolith surface.

(*b*) Effects at specific locations:

  (i) unusual earthshine albedos in the Aristarchus crater and region;
  (ii) temporal and spatial anomalies in the alpha particle count and polonium-radon ratios;
  (iii) lunar slope stability and soil mechanics;
  (iv) the horizon glow effect at sunset terminator locations; correlative evidence from the returned parts of Surveyor III.

(*c*) Polarization imaging system for surveys of lunar and other planetary terrains in relation to transient events.

2. Evidence for and possible causes of lunar dust disturbances

(*a*) *Lunar seismic activity*

The work of relevance here is that of the University of Texas group (e.g. Latham *et al.* 1973). Three main types of lunar quake activity are of interest:

(i) Deep seated events with epicentres at 800–1000 km depth. These show no marked correlation with the spatial distribution of transient lunar phenomena. It is unlikely that from the quoted quake energies the resultant displacement energies at the surface would be sufficient to cause rupture of intergrain cohesion and dust flow. These deep quakes do show a strong correlation with lunar tidal periods of first and higher orders (Latham *et al.* 1973). We may compare with this the slight correlation of t.l.p. with lunar perigee (Cameron 1972).

(ii) Lunar quakes are detected which arise from thermal effects at relatively short distances from the seismic stations. Their frequency is high at one or two days after lunar sunrise. Here there is a possibility of t.l.p. having some association as the t.l.p. correlation with lunar sunrise is the strongest found by Cameron (1972). The most likely cause of transient events would be the gas venting of the regolith with rise in temperature. Evidence for this comes from the alpha particle activity measurements discussed later in §2*b*(ii). Thermal strain release in boulders etc. might cause transient dust flow if the location was on a slope of high angle (see subsection *b*(iii) below).

(iii) A third type of seismic activity is the relatively infrequent lunar quake at a relatively shallow depth reported by Lammlein (this volume) and which Middlehurst has indicated, may show correlation with t.l.p. located around certain mare rims, for example (Middlehurst, this volume). These shallower quakes have energies which suggest they could give larger wave amplitudes at the surface of the regolith than deep seated Moon quakes.

To summarize there are some aspects of lunar seismic activity which could cause dust disturbance, directly or indirectly, and thus give rise to reflexion changes visible from the Earth.

(*b*) *Effects at specific locations*

(i) *Unusual earthshine albedos in Aristarchus and region*

During one of the orbits of the Apollo 15 Command Vehicle around the Moon photographs were taken of the surface illuminated by earthshine. Comparison of these photographs with those of the same region under sunshine conditions (Lloyd & Head 1972) showed that the earthshine albedo for a considerable area of the crater Aristarchus and its walls was many times the normal value for the sunlit crater. Comparisons for the adjacent mare areas showed no such anomaly. Unusual albedos have already been reported for Aristarchus under earthshine (Cameron 1972) as t.l.p. and it thus seems possible that the particular transit over the region happened to coincide with a transient crater surface disturbance. This surmisal should be considered in relation to the evidence below for spasmodic gas evolution from Aristarchus crater (*b* (ii)). However, there is another factor which cannot be neglected and that is the temperature difference of the lunar surface at night (temp. $\approx$ 100 K) from that during the day ($\approx$ 400 K). There could be a strong dependence of albedo for particular lunar dusts on the temperature. In previous work (Garlick *et al.* 1972), however, we have shown that there is no significant change in albedo of various lunar samples over the temperature range involved between lunar night and day. Thus the temperature plays little part. It is unfortunate that other photographs were not obtained during earlier or later orbits for the same area under earthshine.

(ii) *Temporal and spatial anomalies in alpha radioactivity*

Data from the alpha particle spectrometers aboard the Command and Service Modules of the Apollo 15 and 16 spacecraft (Bjorkholm, Golub & Gorenstein 1973; Gorenstein, Golub & Bjorkholm 1973) distinguish the count rates for ^{222}Rn and ^{210}Po as functions of location of the modules over the lunar surface. The radon counts represent the evolution of that gas out of the lunar surface while the polonium counts represent the amount of polonium deposited at the surface by decay of the radon. Increased activity was clearly evident over the areas of the craters Aristarchus and Grimaldi, over the rims of craters and at the sunrise terminator, or rather displaced from the latter by an equivalent of several hours following sunrise. In some records the polonium activity exceeded that expected for equilibrium with the radon at the location. This suggests that the processes involved in transport of radon to the surface are time varying. If the terrestrial ratio of radon to other gases evolving from the surface is assumed ($1:10^{14}$) then the activity level in Aristarchus, for example could indicate enough gas venting on a particular occasion to give dust levitation. The latter is relatively easy on the Moon, even compared to the dust levitation which one can sustain for hours when pumping on mineral powders in the laboratory. Correlation with post-sunrise times of the alpha activity is easily associated with the thermal detrapping of radon, literally frozen into the upper layers of the regolith at the low night temperatures.

(iii) *Lunar slope stability and soil mechanics*

The attempt to explain t.l.p. must include considerations of the possibility of lunar slope instability. Soil mechanics studies have shown that initiation of significant down slope movement of lunar soil, e.g. due to meteoric impact is unlikely unless the slope angle is greater than 48° (Houston, Moriwaki & Chang 1973). From examination of terrain photographs from various missions few slopes reach these angles.

(iv) *The horizon glow effect at the sunset terminator regions*

Pictures relayed back to Earth from Surveyor VII showed a horizon glow after local sunset brighter than the solar corona (Criswell 1972). Criswell has made a detailed analysis of the photographic data and has provided an explanation in terms of the disturbance of the lunar photoelectron sheath (Feuerbacher *et al.* 1972) which occurs when rocks on the surface are only half illuminated. Reference should be made to Criswell's paper for details but what emerges is that electric fields can result of the order of 500 V/cm capable of moving electronic charges and the finer grains to which they are attached. The tilling rate of this process is estimated to be more than an order of magnitude higher than that due to micrometeoroid impacts. Its effect is evident in the low density of microcraters around surface rocks in the dust layers and in the very high damage track density in the dust grains of less than 5 μm in size, evidence for a longer unshielded exposure at the surface caused by the photoelectric churning. As a possibly related topic the problems of explaining the dust distributions on the surfaces of the returned Surveyor III spacecraft should be noted (Carroll & Blair 1971). The dust deposits were selectively of finer grains (up to 4 μm on the surfaces well above ground level) and their directional density distribution suggests that they resulted from some lunar transport process rather than from the dust raising of the Lunar Module landing near.

Horizon glow effects emphasize the fact that dust motion is very sensitive to electrostatic configurations and these can temporarily give fields large enough for dust transport and consequent visual effects.

(*c*) *Polarization image system for future monitoring of dust motion*

We have shown previously (Garlick *et al.* 1973) that the degree of polarization of reflected light from lunar dust layers is increased considerably on dust fluidization. We have recently developed an imaging system which analyses and displays the degree of polarization in a viewed scene or surface independent of intensity variations in light reflected from the surface (Garlick *et al.* 1973/74). The system is capable of detecting differences of 0.1 % in degree of polarization across a scene and can be attached to a telescope or be satellite borne. Its relevance to the present discussion is that it could be used as a very sensitive monitoring display of any lunar transients at terrestrial stations.

3. CONCLUSIONS

There appears to be a possibility of correlation between temporal and topographical data of various kinds and the use of these relations to assess the lunar dust motion or disturbance at the surface of the lunar regolith. A technique now exists, namely polarization imaging by which monitoring of lunar transients can be effected without the strong subjectivity factor present in simple visual observations.

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