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IMPLICATIONS OF THE LUNA 9 PICTURES

The successful experimentation with Luna 9 resulted in an interesting set of panoramic lunar surface pictures of high quality. The definition appears to be close to 1 millimeter for the nearest ground and the illumination and range of gray scale is good enough to allow the detailed surface shapes to be seen. Owing to an unpredicted movement that took place some hours after the landing, views from different positions are available from which a stereoscopic picture can be constructed. Despite the clarity of this visual information, it seems to be impossible to make any definitive judgment concerning the mechanical properties or the processes responsible for the formations seen there.

Many observers made the rapid judgment that the ground looked like solidified lava and all the many holes were bubbles and pores caused by foaming and degassing during solidification. There are, however, grave difficulties with this point of view connected with a discussion of the rate of destruction by meteoritic infall, and of the optical, thermal, and radar properties of the surface. Also, the conclusion loses its force when it is realized that the appearance of a pulverized rock surface subjected to bombardment

becomes almost indistinguishable from that of the Luna 9 pictures.

We have prepared such surfaces out of dry commercial cement powder (average particle size $\sim$ 1 micron) mixed with powdered dyes to give a close approximation to the actual reflectivity of the lunar ground. All that is necessary is to throw powder at similar powder until the statistical nature is no longer changed by such further treatment. The adhesion of any very fine rock powder is quite enough to maintain the steep or even vertical slopes on a small scale and even substantial protuberances can be constructed by compaction of the powder (we noted in experiments with small charges of high explosive that such compaction frequently occurs in the ejected material from a crater, leaving protuberances standing after the explosion, that are nevertheless too friable to be picked up by hand).

The smaller the grain size of a powder the more cohesive it tends to become. For this reason the appearance shown in the Luna 9 pictures would rule out a sand as this would fail to maintain the steep slopes. It does not, however, rule out fine powders of particle size less than 10 or 20 microns, of almost any mineral.

It has sometimes been thought that the discussion of a dust layer covering the lunar surface would imply an exceedingly

mobile, easily flowing material, with perhaps flow channels being visible on the surface, or a material of exceedingly low bearing capacity. Neither of these conclusions follow, as the present authors have pointed out on many previous occasions.[1] The discussion of rock dust concerns the process of formation of the present surface by the deposition of small particles, the destruction by impact, or the downhill movement of the fine debris. There has been no acceptable theory concerning the binding between the particles that may have developed, or the degree of compaction that they may have suffered. Without that knowledge the mechanical properties of a surface derived as a dust can cover a very wide range, and that possible range has not been diminished much even with the success of three Rangers and of Luna 9.

It had been clear for several years through the radar data that the moon's surface was completely rough on a scale of a few centimeters. This had been pointed out by several authors[3,4,1] and the roughness now seen is thus in no way a surpise. It had been described that the ground must be only gently undulating when investigated on a scale of 10 cm. or larger, but exceedingly rough when investigated on a smaller scale. The most likely

type of roughness seemed that caused by impacts of primary, secondary or tertiary kind leading to densely overlapping little craters. That now seems a perfectly good description of what is in fact seen.

The vesicular lava hypothesis for the detailed appearance of the ground would require that external bombardment had not even destroyed features on a scale of centimeters. Estimates, on the other hand, of the primary and secondary bombardment would however imply no more than a few tens of thousands of years before these features would be completely obliterated. The solidification of the lava on the other hand cannot reasonably be thought of as being less than several hundred million years ago. Meteoritic infall would have had to have been many orders of magnitude less than it is now.

This argument is not avoided by supposing, as some authors do, that meteoritic infall removes more material of the moon than it brings in. Even if each incoming particle were to liberate and throw back into space more than its own mass there is no doubt that a very much larger quantity of material would be shattered and moved. At any time a surface would be seen which has been worked over by meteoritic infall to some substantial depth and at

any rate several centimeters. The fine structure of the ground that is seen can then not be the original porosity of freezing lava even if the ground were basically made of lava.

The radar evidence concerning the difference in the radio properties of the young and old craters clearly requires that the ground has been plowed over by external agencies to such a depth as to be effective at 70-cm. radio wavelength. That depth is thought to be several meters. The evidence is very clear-cut that each young crater is a much stronger radar scatterer than old craters of comparable diameter. Unless it were thought that the process of generation of craters had completely changed its nature between all the old craters and the small number of young ones, one would have to suppose that an external action had made the ground smoother and more radar absorbent in the course of time. The destruction and plowing over by meteorites would seem a perfectly satisfactory explanation for that. In that case, however, all but the youngest craters have been worked over to a depth of at least several meters. No original lava appearance could then be preserved.

Thermal data similarly require that the youngest craters differ from all the others in being made of more compact material.

Exactly the same arguments apply except that the total depth effectively tested by thermal measurements is much less.

The Mechanical Properties Tested by Luna 9

Some limits on the mechanical properties of the lunar soil can be placed by the successful operation of Luna 9 and certain remarkable mechanical properties seem to be indicated. Firstly, the bearing strength was certainly enough to support the two-foot diameter sphere weighing 220 lbs., and thus approximately 40 lbs. on the moon. The depth of sinkage is not known and unless other information is available the pictures would not have revealed a sinkage of as much as six inches. The static bearing load is then little over one-tenth of a p.s.i. which is a low figure even for uncompacted soils.

Initially some observers surmised that much more was implied, namely that the present resting place of Luna 9 was also the place at which it first impacted. This however seems quite unlikely. The mode of landing of Luna 9, one of ejecting the instrumented spherical package from a bus which executed the landing maneuver, was clearly a mode that allowed a much larger horizontal component of velocity than vertical for the final impact. Since it is harder

to cancel with precision the horizontal components of velocity than the vertical, one assumes that this freedom will have been utilized and that the sphere in fact hit the surface initially at a glancing angle. For the velocities involved it would then skip, even on the lightest and fluffiest soils one might envisage (indeed it would also skip on water). It would then roll and finally come to rest, no doubt having an internal weight distribution that favors approximately the correct attitude. Its four petals that then opened will have helped to erect the package prior to its function. In this mode of landing the impact loading may have been large at first impact, but would not lead to digging in in any kind of soil. The final resting place after skipping and rolling would bear no more than the static weight. This is a method of landing an instrumented package which avoids many of the difficulties of other types of landing maneuver, and which is particularly appropriate to a ground of unknown bearing capacity.

During the first day and between two picture-taking sequences, the package seems to have shifted so that the point of origin of the pictures was displaced by several inches. This is a very remarkable fact. There is even an indication of a second smaller movement also. From first reports it does not appear that the experimenters wish to attribute this to any internal activity or

shifting of weights. If a passive object were thrown in a rocky desert anywhere on the earth it would be exceedingly unlikely that in the absence of wind or water it would move some hours after landing. No processes could be envisioned that have time constants of hours and that have a reasonable probability of occurring. Earthquakes are an exceedingly unlikely explanation, for if the moon had such violence of earthquakes occurring as to make this event probable it would no doubt have shown many other visible effects in historically observed times. Thermal distortions of either the ground or the package are so small that one would have to suppose the package to have come to rest in an exceedingly delicately poised position. One would guess that this would not occur once in a hundred throws on a terrestrial surface even if one subjected the package to the temperature range experienced on the moon between light and dark. Yet, if this is the first information we have concerning mechanical properties of the lunar surface we must clearly avoid forcing the explanation towards very unlikely occurrences in order to preserve terrestrial type surfaces. Rather, we must wonder whether the lunar surface is of a kind that makes this kind of event probable.

Plastic deformation time constants in any kind of rock material are many orders of magnitude longer. No significant deformation can be envisioned that would take a matter of hours to occur and then trigger off a larger amplitude movement. The only exception to that that we can now suggest would be time constants in the nature of those of an hourglass. If the lunar ground underneath Luna 9, and perhaps underneath most areas, had lots of hollow spaces, such as those that would be produced by all the many secondary impacts at moderate speeds, then it is conceivable that the additional loading may cause many such cavities to cave in. The time constants of caving in may then be given, just as in the case of an hourglass, by the many small particles that have to fall in sequence before a major structural change is made. If the addition of a new weight on the surface opens up a few new cracks in a very porous structure of not very firmly cemented small particles, then little collapses and landslides may appear until eventually the structural properties are so changed that a major collapse takes place.

The Luna 9 pictures clearly show a great many small holes. It is not clear whether some of these holes go deeply into the ground. A powder consisting of particles that have substantial cohesion would have the property that projectiles at rifle bullet

speeds would easily make deep internal channels. The bombardment which is secondary to the larger meteoritic impacts will be of that nature, and the lunar ground may well be in the equilibrium configuration which is obtained by tunneling and collapse caused by primary and secondary impacts. That equilibrium may contain at any time a lot of features that are not far from collapse; under the circumstances, the movement of Luna 9 would be a probable event.

This interpretation of the occurrence can of course not be taken as more than a possibility. The lunar surface may be unusual in ways that we have not yet thought of. While we may dismiss any one explanation of the phenomenon of the movements of Luna 9, we should not at this stage ignor an occurrence which constitutes one of the few pieces of information we have concerning the mechanical properties of the lunar surface.

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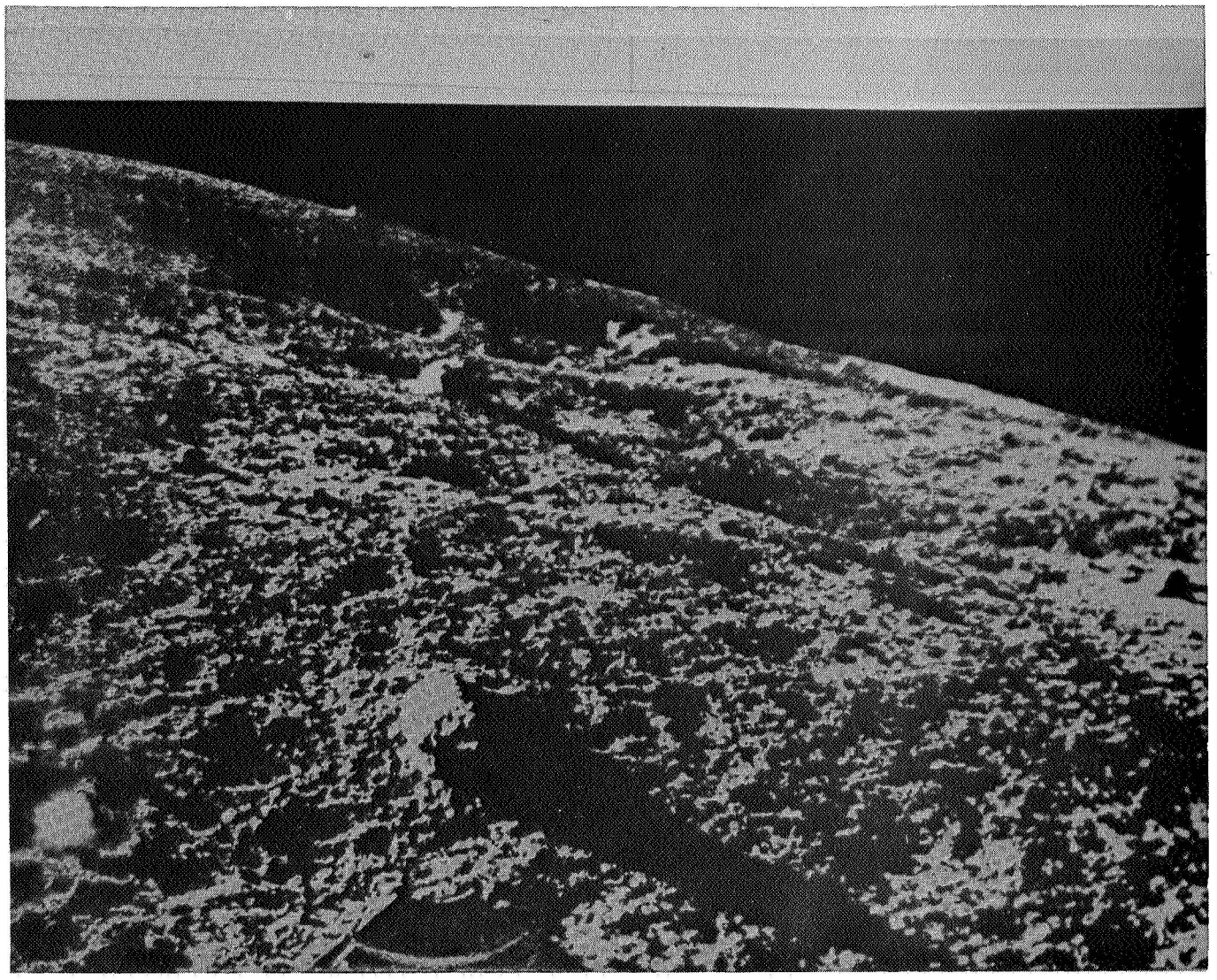

Figure 1. A small portion of the surface of Oceanus Procellarum as photographed by Luna 9. The "rock" in the foreground is probably about 6 feet away and is about 6 inches in diameter. As judged by stereoscopic viewing, the horizon appears to be the rim of a crater and is probably not more than one or two hundred feet away. (Courtesty Tass)

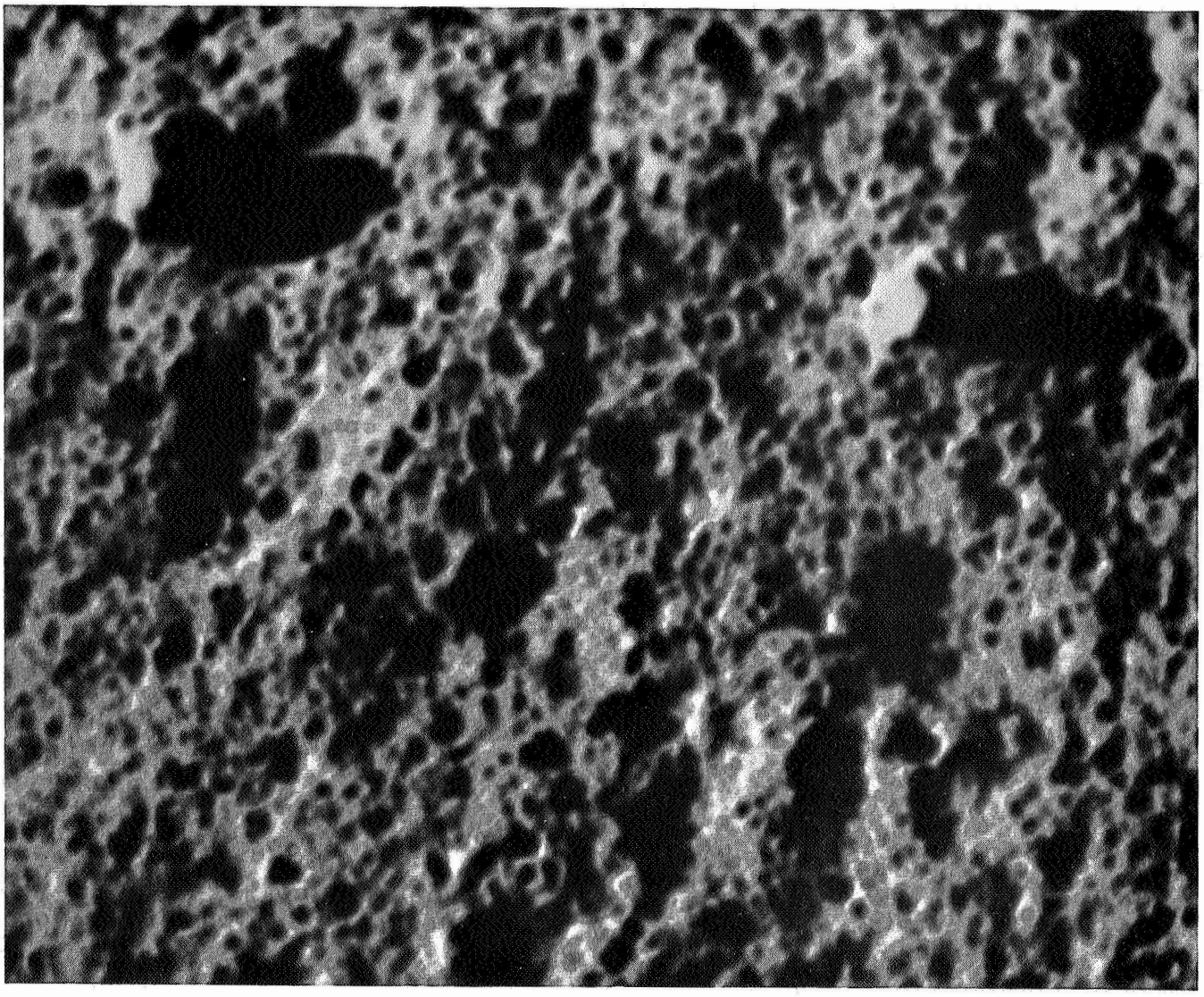

Figure 2. A surface of dust in the laboratory. The picture shows an area about 2 feet by 3 feet and should be compared with the foreground of Figure 1. The material is dry, commercial Portland cement powder. The surface features were formed by throwing handfulls of cement powder at the surface to simulate the action of meteorite ejecta impacts on the lunar surface. The "rocks" are clumps of powder about 3 inches in diameter. The photograph has been taken using low lighting and is defocussed and printed with high contrast in order to simulate to a certain extent the conditions of Figure 1.

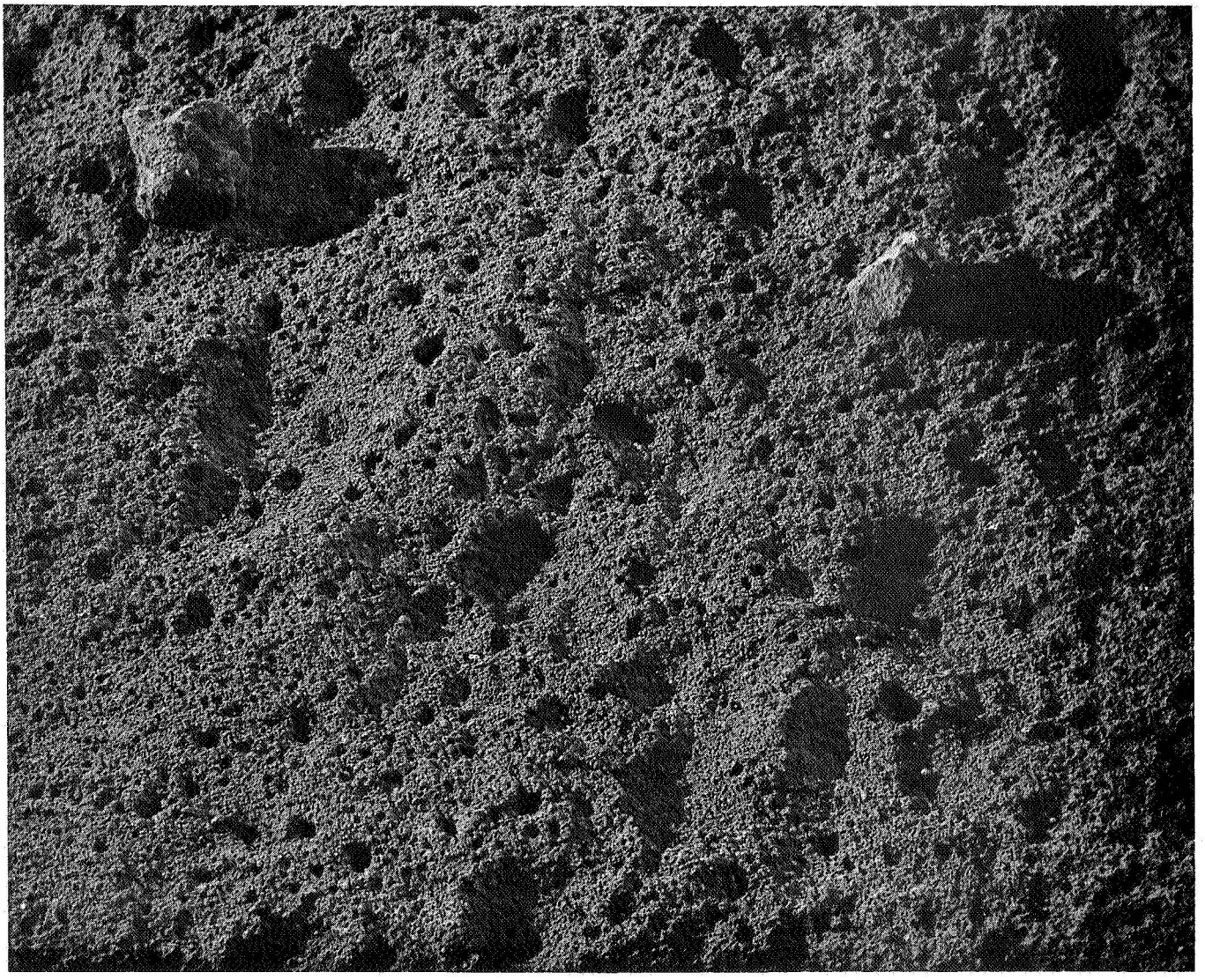

Figure 3. The same surface as Figure 2 except with smaller contrast, improved resolution and lighting. Even in these circumstances it would be extremely difficult to identify the material wihtout additional information. For example, the material might easily be mistaken for vesicular lava.