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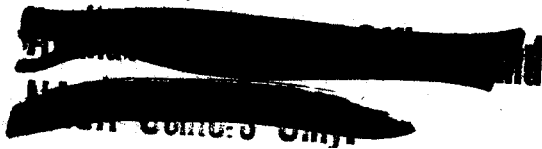
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THE IMPLICATIONS OF THE RANGER MOON PICTURES\*\*

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[REDACTED]

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Prior to the Ranger pictures the information about the small-scale structure of the lunar surface had been limited to that obtainable by telescope and radar observations. Earthbound telescope observations had given information down to a scale of about one kilometer, and had clearly shown that craters existed in all stages of "freshness." Craters that would be judged old by the criterion of overlap by others, were generally seen to be smoother, less high for a given diameter, and often had a rather smooth interior. Young craters had apparently sharp rims and steep, rugged features. From the consistency of this effect it had been concluded that an erosion process was active that continuously degraded the features much as erosion does on earth. This posed the question of a mechanism for transportation in the absence of agencies that erode on earth. The required rates are of course very low compared with terrestrial ones; one micron per year removal from high ground and deposition on low would suffice to create the observed effects in all of geologic time. This could still lead to deposits four kilometers deep. It is very difficult to judge such very slight processes in unusual conditions. However no processes could be envisioned that would transport large pieces of rock except the impact explosions. Those, however, convert much material into fine powder, and even with their action one could not contemplate a large fraction of the deposit on low ground being in any other state than dust. However the rates that could be ascribed to this process are too low in view of the number of small craters seen, and an additional process is required. Several processes can be suggested that may be effective in transporting material downhill, but only if it is in finely divided form. This was the origin of the suggestion that rock-dust was the major constituent of the lunar surface, and that low regions had accumulations of it down to the depth of the original

features, judged in some cases two or three kilometers deep.

The fact that deposits of dust may be kilometers deep must not be taken to mean that the material maintains the consistency of a fine powder at great depths, no more than it does on the earth. Sediments originally made of fine particles may be in various stages of cementation. The agencies causing cementation of sediments on earth are mostly different from those that could be active on the moon. There vacuum welding may be very important especially for particles that are pressed together for such long periods of time that solid state diffusion is a significant effect. Close to the surface, effects of sputtering and of evaporation and condensation can also assist in cementing grains together. The discussion of the mechanical properties of such sediments is clearly very important for future moon exploration, and measurements of these must receive a high priority in future moon missions. But it is important to keep separate the discussion of the origin of the material and its present mechanical properties -- a point which has been confused in the literature and in popular writings where it was often implied that if the low ground is filled with dust sediment then it will be loose and soft to some great depth. This is no more a direct implication there than it would be in the Mississippi basin. Nevertheless, such an origin raises the question of the bearing strength of the surface for exploration purposes, while an igneous origin would have implied almost inevitably an adequate strength.

Erosion and a sedimentary origin for the mare material was also implied by a different observation. It could be seen that almost without exception craters that fell partly on highland and partly on mare ground had the mare portion much more heavily eroded, and often it

had disappeared altogether. From this it had been concluded that mare material was generally more susceptible to erosion, and therefore that, most likely, it was not as solid a material as much or all of the highlands. One is there concerned with thicknesses of up to three kilometers, and the argument is independent of thin layers that may influence the radio, thermal or optical surface properties.

On a much smaller scale the radar evidence had demonstrated that the lunar ground was remarkably smooth on the scale of the wavelengths used when these were longer than about three centimeters (1,2). For shorter wavelengths the radar scatter assumed the character appropriate to a rough surface, demonstrating that irregularities of that size cover most of the surface. At 70 cm wavelength, where the most detailed observations were made, the majority of the ground appears smooth and the proportion of ground covered with irregularities on that scale has been estimated, by an argument that involved certain additional but plausible assumptions, as approximately five per cent (3).

This had implied something other than solid rock on a depth scale of at least a few meters, for it seemed inconceivable that such a smooth rock surface could be generated or maintained in the presence of primary and secondary bombardment with meteorites. Again erosion had been invoked to smooth over all the small impact craters except the most recent ones. Uneroded craters larger than about one meter across and rough enough to scatter diffusely would need to occupy about five per cent of the ground, on the assumption that no other types of rough features are common.

The excellent Ranger pictures have completely confirmed these points. Firstly, it is striking that in the entire interval of size

or resolution from 1000 ft. -- the best visual telescope resolution -- to 3 ft., the highest Ranger resolution, there is no widespread new type of feature to be seen. Round craters seem still the predominant surface irregularity. There is nothing that could be regarded as signs of lava flow; there are no boulder fields or rock surfaces of angular shapes except in very small areas. The ground is not covered with cracks or faults as occurs on all rock surfaces on the earth. By comparison with any terrestrial rock desert the ground is very featureless. A sand desert would provide a better approximation except that rounded crater shapes are substituted for the usual shapes that result from wind and water erosion. A few features other than craters are seen -- gentle ridges and some unevenness on the nearly flat ground -- but though very interesting these features are certainly very minor in the sense of the area covered by them. Since there is no new type of widespread feature that might have invalidated the interpretation of the radar results, it is clear that the pictures with a definition of a few feet and the interpretations placed on the 70 cm radar measurements had to be in close agreement. This is indeed the case, and the excellence of the agreement will increase the reliance on radar data in future. Most of the ground is seen to be smooth or possessing only very rounded craters that would not diffuse 70 cm waves. A few per cent of the ground is covered with sharp-edged steep sided craters that certainly will diffuse 70 cm waves. The differentiation into two types of ground rather than a continuous spectrum of irregularity had been suggested by the radar observation of signal strength versus range, which showed an abrupt change of gradient. One can now see that this is indeed merely the differentiation seen on high definition pictures between "new" craters

and all the rest.

The Ranger pictures leave no doubt that erosion is a major effect in shaping the surface. No effect could be suggested that would make the great number of shallow and gently rounded crater profiles other than starting with steep, sharp-edged craters like the "new" ones seen and letting erosion degrade them. For craters a few meters or tens of meters across the erosion process must be very fast compared with the geological time scale, if the same process is to have had the discernable effects on craters tens of kilometers in size in the age of the moon. Erosion rates of the order of one micron per year, as needed for the explanation of the large features, would destroy a ten meter crater that is initially three meters deep in about three million years. Assuming that the erosion rate shows up when all gradients have become low, such a crater would still remain visible for longer, but as a shallow one with rounded profile.

It is not our present purpose to discuss possible mechanisms for erosion, but only to discuss the evidence for its occurrence. However, since one is not inclined to accept even the strongest evidence when it points towards an inconceivable occurrence, it should be mentioned that we can see no reason to discard the suggestion of dust transportation downhill by the combined action of micrometeorites liberating particles from their surface adhesion, and electrostatic effects opposing their immediate return to the surface, thus making for a tendency to glide for some way and greatly enhancing the effective downhill creeps beyond that which mere statistics of repeated random scattering would achieve (4).

It appears then that a few per cent, perhaps five, of the moon's

surface has been covered with craters larger than one meter in, say, three million years. From this one may derive an order of magnitude of meteoritic infall rate, but not without an assumption regarding the surface structure and thus of the size of meteorite required for the formation of a given size crater. In a loosely cemented dust surface of much less than the compact density, craters will be much larger for a given meteorite size than they would be in solid rock. This difference will be largest for very small craters where structural strength rather than gravity determines the size, while for very large craters the difference will reduce to that resulting from the density factor alone.

The fact that crater formation proceeds more readily than in solid rock is also displayed by the appearance of the multitude of small secondary craters seen on the Ranger pictures. There it is certain that impact speeds are low, well below lunar orbital speed. Nevertheless the great majority of these are also circular or only slightly deformed. This must mean that the energy liberated even at speeds of less than one kilometer per second is still enough to excavate a crater that is very large compared to the projectile. In rock or any firm material this would not be the case, and the craters would mostly appear as imprints of the shapes of the projectiles or scars torn by them. In softer materials the effects of any liberation of gas at impact would be more significant. One may obtain more information on this by attempting to create the same general appearance as lunar secondary craters by means of various projectiles shot into different terrestrial surfaces.

The Ranger pictures thus appear to show mostly a uniform, fine-grained material of low structural strength near the surface and in the first few meters depth. They show no hint of any transition to a dif-



ferent material below, such as a change in the appearance of deeper craters or an occasional outcrop of something looking like rock. It is therefore most likely that one is seeing the same type of material at all the depths excavated by the craters, but very probably in progressively greater compaction and cementation at the greater depths.

The Ranger pictures have clearly strengthened the case for dust as the main constituent of the lunar lowlands by not showing any rock formations. There is no case for discussion of a two-layer model. What structural strength can be attributed to dust sedimentation at various depths cannot be judged very well until impact probe experiments have been carried out; but without any clear signs of firm rock the pictures must lead to more concern about sinkage on impact or dust blowing in rocket exhausts in future operations on the lunar surface.

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