EVOLUTION OF THE LUNAR SURFACE: THE MAJOR QUESTIONS REMAINING,
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At the end of the Apollo program we have not yet a firm decision about the major processes that formed the surface of the moon. The two points of view are:

(1) That it is a surface generated by local magma differentiation, lava flows, and a moderate amount of subsequent grinding up by impacts.

(2) That it is a surface as left by the impacts and accretion of dust that formed the moon, with a moderate amount of melting occasioned by major impacts.

Most of the geological discussion has assumed (1), and restricted itself to the fitting of detail into that general picture. The evidence in favor is firstly the presence of the large maria, interpreted already long ago as huge lava flows. This belief was strengthened by the information that the bulk of the lunar surface material has a composition similar to basalt. Nevertheless, the overall information is greatly at variance with that point of view. The major evidence against this is derived from the following observations:

(a) The dust that covers all the known surface to an unknown depth is not simply derived from the crystalline rocks found in each locality. Its age since last molten, according to radioactive dating methods, is older and not younger than the crystalline rocks. Detailed chemical differences exist between crystalline rocks and dust in each region, that make clear that the dust is not merely a thin overlay derived from the local grinding up of rocks that were assumed to be general at a depth of a few meters.

(b) The seismic evidence proves the absence of any large structural units of rock in the first few kilometers of depth over most of the moon. It is compatible with a deep layer of the same dust that covers the surface, compacted gradually with depth. It has been claimed to be also compatible with heavily broken up bedrock at a shallow depth; but the long wave radar observations show that no large quantities of broken rock are present in any region, highland or lowland, at depths less than approximately 100 meters. Indeed, any rough interface to a substance of greater density than the surface soil would have been detected. (A rather smooth interface would be admissable for the radar evidence, but would then conflict with the seismic data. A rock surface which is smooth on top, but shattered into small fragments nevertheless, might be admissable, but no process can be envisioned that would generate such a material.) Observations have dis appointed those who hoped to see exposed rock layers. Not even on steep slopes or in craters has there been unequivocal evidence of bedrock. Some layering has been seen, but it may represent sedimentary layers of different compaction, strength or composition. No crystalline rocks have been found as part of a large system frozen in situ.

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(c) The back of the moon shows highland type of ground almost exclusively. Its appearance is quite compatible with being merely the ground left over by the multiple bombardment that formed the moon. Had we seen that face first, we would probably not have considered it necessary to invoke any large scale melting in its evolution. While circumstances can be discussed that would sharply differentiate between the external treatment received by the front and the back, such as the electrical effects in the earth's magnetotail, no major thermal or gravitational influences can be invoked to cause such a remarkable difference in the distribution of molten rock.

(d) All evidence concerning the temperature of the interior of the moon that can be gained from the observations of the external gravity field, and the response to externally impressed magnetic fields, suggests that it is rather cool. Very high permanent rigidity and low electrical conductivity are not readily reconciled with a model in which, at an earlier epoch, most of the body of the moon was molten; yet that is required if the high surface radioactivity that is observed were to be derived from a differentiation process combing out the Uranium and Thorium and transporting it to the surface.

(e) The investigations of the physical and chemical nature of the soil samples, from surface and subsurface cores, shows sharp layering. Meteoritic infall, grinding and mixing must therefore be of secondary importance only compared with a surface process in which material is deposited without mixing. All steep slopes show a characteristic surface pattern that seems to be related to a downhill transportation mechanism which again is dominant over meteoritic stirring.

Perhaps related is the observation of excessive surface exposure of most of the lunar soil. The cosmic ray track densities seen in most lunar soil exceed present day bombardment rates by solar flare particles for 5×10^9 years, if the irradiated layer is more than 1 meter deep. Yet many samples must be material brought close to the surface by some nearby impact, having previously been at some depth. The samples obtained are therefore representative of a layer much more than 1 meter deep. But it is not just the total tracks that seem excessive, but also the fact that few samples lack cosmic ray tracks, while this should be common if the dust were derived from bulk material on the moon, and only exposed there whenever impacts had brought it close to the surface. Impregnation with gases and other surface exposure and modification effects all point towards a steady, long surface exposure of most grains that seems incompatible with the statistical mixing effects expected on the lunar surface.

One can discuss all these observations in terms of the cold accumulation theory of the surface. One has then to suppose that the building material for the moon was already largely differentiated in processes on bodies that preceeded the present ones, and that perhaps as diverse a supply of materials existed as we now find in the meteorites. The type of material available

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for the last phase of growth would then have been one which was similar to, but not quite identical with, the present day Eucrites. Major impacts would always produce regional chemical differences by exposing and scattering material from some depth belonging to an earlier phase of accumulation, while the small particles falling in will tend to make uniform layers. The crystalline scattered rocks now found can then be understood as the product of the melting by major impacts, such as those that caused the maria, dug up and re-distributed by smaller subsequent impacts. Compositional differences with the soil are the representative of the initial layering. The nuclear age of the rocks then represents the age of the last major impacts, and quite possibly the period of formation of the moon. The greater age of the soil, as well as its space exposure effects may relate to the period between its formation on an earlier body and its acquisition by the moon; even a brief interval in orbit will suffice for the space exposure effects, considering the enormously greater surface area then exposed; and the infall velocity onto the lunar surface may well be low enough for no heating to obliterate the tracks or destroy other exposure effects.

In such a discussion the main body of the moon can always have been cool enough to have maintained the stresses associated with its observed mass distribution. Mascons would be a natural consequence of the major impacts that cause basins of compacted rather than porous ground, if low basins get filled by a surface transportation process of the dust. The flat maria, the obvious erosion features of the highlands, the layering observed in the soil, the patterns seen on all slopes, would all have to be attributed to such a process which seems to have taken place much more on the front than on the back of the moon. These features bear no marks of gaseous or liquid transportation effects (except for the sinuous rills) and are attributable to electrostatic effects.

The absence of water in the soil can only be understood as due to a general absence of water in the interior of the moon, if the soil were derived from lunar magma. If it is infallen material, however, water or steam may escape from the interior now and at all times in the past, without hydrating the soil except in very localized regions. The escape of water seems to have been observed, and also the sinuous rills can best be understood in terms of subterranean flows of water.