very little of the radiation would be coming from the uppermost part of the cloud in which the vast majority of the solar radiation is absorbed. Thus very little of the emergent infrared would be representative of a source function which was at all effected by temperature changes due to a change-of-state.

4) If freezing were to be locally triggered at the passage into shadow, the entropy would increase and the system would not return to its original state on the return of sunlight. The ammonia ice would remain ice and would merely cool down to a reasonable equilibrium temperature. There is no elongated trail of enhanced infrared radiation, observed to follow the shadow as it passes across the Jovian atmosphere, on those occasions when the phenomenon is observed to take place. Yet the entire shadow passes in about 15 minutes. A highly improbable cooling curve is thus required of the ammonia ice.

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"Dust" on the Moon

In 1955 Gold (*1*) discussed many features of the moon's surface, suggesting that the maria are not composed of lava flows (pumice or basalt) but are filled with dust produced by erosion processes and transported from mountainous areas over the surface of the moon by a "fluidization" process. Gold's suggestion has been discussed by many scientists and in the press, and in many instances his ideas have been misrepresented. (I am not entirely without sin in this respect.) In particular, it is generally assumed that Gold suggested that great depths of fluid dust filled the maria and that space ships would sink out of sight in these fluid seas. In fairness to an eminent and very intelligent colleague, critics of Gold should read his paper. Briefly, three points are important in this connection: (i) the origin of the dust, (ii) the method of transport, and (iii) the physical strength of the pool of dust.

Gold suggested that the finely divided material was produced by the actions of electromagnetic and particle radiation on the surface rocks and by collisions of micrometeorites; he presented what appeared (and still appear to me) to be cogent arguments against lava flows. He assumed that this dust had flowed from mountainous regions to the lower areas by a fluidization of a thin surface layer by various physical processes, and that this process has filled the maria to great depths. He did not, however, suggest that the deep layers of dust have low physical strength. He stated:

> There appear to be some very steep slopes in the filler material. In particular there are the small rills which possess very steep sides. This is not contrary to the known behaviour of dust. At a depth of more than a few metres the compaction under the overlying weight would suffice to convert the material effectively into a solid; in the absence of an atmosphere grains stick together with intermolecular forces with even less compaction than is necessary when atmospheric molecules intervene. If the material can be regarded as resistant to internal flow but possessing a thin fluidized surface layer, then the filling up of steep holes or gaps would proceed at a speed limited by the fluidization process, but the steep sides would persist until the filling up is complete. It is not a requirement that such rills should survive for a great length of time; Baldwin speaks of them as the youngest features on the Moon, yet has to add that some appear partly "filled with lava." These rills are to be thought of within the framework of the present interpretations as the small signs of the small isostatic adjustments that keep occurring as the maria fill up with dust and the highlands are denuded; and these rills are in turn comparatively quickly filled in. Their distribution mainly around the edges of the great maria is entirely in accord with this interpretation.

My own ideas regarding the maria were greatly influenced by Gold's, even though I disagreed with certain features of his arguments (*2*). I did not and do not now believe that the maria were filled by erosion from mountainous areas, but rather that the great collisions were dominant in the production of fragmented material. This belief does not exclude the possibility that Gold's fluidization process for a thin surface layer has been effective to some degree, but it is that the great collisions were much more effective in distributing the fragmented material over the surface.

In my criticism and extension of Gold's ideas I specifically mentioned evidence from the circular walled plain near Flamsteed, within which Surveyor 1 landed; I pointed out that this nearly buried large crater is not distorted in a manner to be expected if a great lava flow had moved over Oceanus Procellarum from some one direction. Moreover, the crater Prinz is filled with what appears to be fragmented material covering one wall and sloping smoothly down the interior and outer ramparts in a way that one hardly expects to result from liquid or *dust* flow—but that might be expected from unequal settling of fragmented material from a temporary atmosphere. Other craters suggest similar conclusions.

One argument of Gold appears to be especially convincing: that the many partially filled craters in mountainous areas and the many smooth areas between them could hardly result from separate lava pipes coming from deep in the lunar interior. But erosion from the surrounding mountains (as Gold suggests) or the falling of fragmented material from above (as I prefer to believe) constitute reasonable mechanisms for producing some of the smooth interiors of craters. There are some troublesome points: Wargentin is filled to the brim with smooth material that may possibly have fallen from above, or indeed it may have been filled by a lava flow; but the fill could hardly have been supplied by erosion of the rim material. Moreover, the flow of dust to the maria should have left some indication of paths by which dust moved from mountains to maria.

The idea that the lunar surface consists of fragmented material, the cosmic-ray ages of meteorites, the curious types of mixtures of fragmented materials in these objects, and their so-called polymict character led to the suggestion that stone meteorites may come from the moon (*3*). This suggestion has not been generally accepted but recently has been discussed seriously by some.

Another source of the mare material was suggested in 1964 (*4*): the flow of finely divided gas-laden solids from the lunar interior, resulting from the great collisions that produced the maria.

It was suggested that this material was of primitive solar composition but became mixed with the materials of the surface and of the colliding objects. Terrestrial "ash flows" of great magnitude, related to volcanic processes, are well known, although the chemical composition is very acidic—similar to that of granite and quite different from that suggested for the lunar "ash flows."

Rangers VII, VIII, and IX gave marked indication of the presence of fragmented material of considerable depth—some tens of meters or more (*5, 6*). Indications of considerable cavities below the surface, considerably larger than those observed in lava fields, suggest the presence of partially compacted solids below, or possibly cavities caused by evaporation of water. The recent interesting and objective report (*7*) on Surveyor 1 presents conclusive evidence of the existence of a fragmented-conglomerate deposit, about 1 m in depth, in the walled plain in which Flamsteed lies. Combining the evidence we may conclude that some tens of meters of fragmented material *probably* covers the smooth great areas of the moon and that this layer *may* extend to the floors of the maria depressions. It is also possible and perhaps probable that limited lava flows produced by melted material from the great collisions (*5*), or more-terrestrial-type lava flows, also are present.

The Surveyor 1 and Luna 9 pictures also show great blocks, some with most intriguing shapes, scattered about the surface; and the Luna 9 pictures are reported to have shown small pedestals with a cap material on top and interpreted to mean that lunar material is being lost to space. Suggested compositions of the massive objects (that I have heard) range from the very fragile rock produced by explosions ("instant rock"), through tektite material, massive igneous rocks, and pumice, to metallic iron-nickel. (The iron-nickel is my suggestion, but I also think of pumice.) It is evident that pictures of strange material in a strange environment do not lead to unique deductions as to composition.

However, erosion studies lead one to suspect that some material very resistant to erosion, such as iron-nickel, may be responsible for the "toadstool" structures observed by Luna 9; it also might help one to understand the preservation of some objects lying on the lunar surface for long periods (*8*). That some iron-nickel should be scattered about the lunar surface is not an unreasonable postulate. On the other hand, the other suggestions may have merit. Even conglomerated fragmental material may have great strength—as is observed in many chondritic meteorites, for example. Even rather fragile meteorites do arrive at Earth's surface!

Surveyor 1 showed that the strength of the surface is low—about 5 lb/in.^{2} (0.33 atm, 300 g/cm^2). This strength, completely unknown before Surveyor 1, is not unreasonable for fragmented material in high vacuum—as was first pointed out by Gold. The landing pads crushed into the lunar surface and turned up much darker material than that on the undisturbed surface. The material has a crumbly appearance, perhaps like certain soils. It reminds me, naturally, of the Orgueil meteorite, since I suggested such an origin for this type of meteorite (see *4*). The dark color may result from carbonaceous material such as that found in the carbonaceous chondrites. But neither my eyes nor those of men having other ideas are equipped with miraculous lenses that enable us to analyze this material chemically, from pictures of strange objects in a strange environment, when minerals cannot be identified.

Only general statements regarding the γ-ray spectrum of the moon from Luna 10 observations have been made by Soviet scientists; definite conclusions must await the detailed scientific report. However, after discussion of the data with Soviet scientists, colleagues have reported to me that the potassium, uranium, and thorium contents are low; detection of these elements may be marginal; uranium and thorium were not detected, the potassium concentration is on the low side of basalt or possibly similar to that of ultrabasic rocks (not like that of granite or tektites), and no difference in potassium concentrations between maria and terrae was detected.

The cautious reports and lack of definite numerical data in these reports suggest marginal values. This suggestion indicates much less differentiation by lava-flow processes than is true for Earth, and argues against the assumption that the maria are lava flows of the terrestrial type. Always one must expect that smaller planetary objects such as the moon are subjected to more-limited volcanic activity than large objects such as Earth, unless some special source of heat is present or other special conditions obtain; this has been my contention since my first publication on the subject (*9*). I have been prejudiced in this matter for I have hoped that the moon would be interesting. If lava flows cover the moon as they cover Earth, all the early history has been lost just as on Earth.

Ten years ago I said (*2*):

> This dust hypothesis of Gold, if it stands up to critical study, is to me the most important suggestion in regard to the moon's surface which has been made since the outstanding study of Gilbert in 1893. However, I do not agree with Gold in regard to the source of the dust . . . .

I believe that the great collisions must have produced much fragmented material and that this would become distributed in some wide but unpredictable pattern on the moon's surface. Also, lunar ash flows induced by the great collisions may have contributed to this material, and of course collisions of objects, large and small, with the surface have mixed up the surface materials. Gold's hypothesis in all its details can hardly be regarded as having "stood up"; but apparently it is partly true and that is all one can reasonably expect of theoretical predictions in this field. His ideas have influenced my own thinking and should have been more seriously considered by others, even though complete agreement was withheld.

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