LETTERS TO THE EDITORS

ASTRONOMY and ASTROPHYSICS

Volcanoes on the Moon

For some time, opinion on the origin of the Moon's craters has been hardening in favour of the meteoric theory and against the volcanic. The recent observation of volcanic activity by Dr. Kozyrev has, in some quarters, produced a reaction in favour of the volcanic origin. I would like to suggest that this reaction is unnecessary.

Whatever is the origin of the craters it is possible that they may be filled with dust to considerable depths. The thermal conductivity of dust, in a good vacuum, and under a low gravitational pull, is likely to be extremely low, owing to the small areas of actual contact between the particles. It may be supposed that this area of true contact between adjacent particles depends only on the force between the two particles and on the yield-strength of the material composing them. In a thick layer of dust, the force between particles of given size will increase linearly with depth from the surface and hence so will the area of true contact. Suppose the mean density is ρ gm. cm.$^{-3}$. Then at depth h cm. the pressure is ρgh dynes/sq.cm. If the compressive yield-strength of the material is s dynes/sq.cm., the contact-areas in each column of particles will be only $\rho gh/s$ of the cross-sectional area of the column.

The effect of this on the conductivity will depend on the shapes of the particles before deformation. If we use the drastic simplification of supposing the particle contacts to be derived from pyramidal points crushed on to plane surfaces, we find that the effective conductivity k_e is given approximately by $2k\sqrt{\rho gh/s}$ when the quantity $\rho gh/s$ is small, k being the thermal conductivity of the solid material. If we suppose the material forming the dust to be a fairly hard rock (Mohs' scale 6 or Vickers' hardness 700 kgm./mm.^{2}) with thermal conductivity 5×10^{-3} cal. cm.$^{-1}$ deg. C.$^{-1}$, and take g to be 160 cm. sec.$^{-2}$, this gives a value of k_e of about $7 \times 10^{-7}\sqrt{h}$. At 100 m. in the case considered, the conductivity might be around 1/70 of the bulk value or, at 1 m., 1/700 of the bulk value. Owing to the multiplicity of reflecting surfaces, the contribution of radiation can be neglected, and gas conduction, important in more familiar circumstances, is zero.

In such conditions the importance of the Moon's natural radioactivity may be high, although, owing to the Moon's small size, it has usually been thought less important than that of the Earth. Suppose that this is equivalent to 2 parts per million of uranium—appreciably less than the equivalent total activity of the Earth's crust. An isolated piece of such material will then show a temperature rise in the region of 8 deg. C. per million years. Since the conductivity of hot rock is fairly high, the interior of the Moon is likely to have reached an equilibrium temperature some time ago. In equilibrium conditions the heat flux reaching the surface must be the whole of that produced in the interior. This will give about 260 calories per year per cm.^{2} or $8{\cdot}4 \times 10^{-6}$ cal./sec./cm.^{2}. Then if T is the difference between the temperature at depth h and the mean surface temperature :

$$\delta T = \frac{8{\cdot}4 \times 10^{-6}\,\delta h}{7 \times 10^{-7}\sqrt{h}} \text{ deg. C.}$$

$$\text{so } T = 24\sqrt{h} \text{ deg. C.}$$

At 1-m. depth this is already 240° C. It will reach the softening point of, for example, basalt at about 25 m. depth if we neglect changes in properties with temperature. In other words, dust could not lie indefinitely over large areas to depths of more than about 25 m. With a thickness of only a few metres, conduction to the sides of a crater kilometres across will be as important as conduction through the dust. Even if the craters were not formed by volcanic action, however, the mere filling of the larger ones with dust would provide, in time, for volcanic activity in the centres.

It is unlikely that enough material would be involved in any one eruption to cause the ejection of major quantities of liquid or solid. The very low mechanical pressure of the dust would seem rather to encourage frequent small local instabilities due to high-temperature release of gases. These instabilities would result in periodic liberation of puffs of hot gas and dust just as the slow liberation of marsh gas leads to occasional bursts of mud and gas from the bottom of a stagnant pond. 'Frequent' here means many times per million years. The phenomenon would therefore appear analogous to boiling with bumping rather than to volcanic action on the Earth's surface, and would produce just the kind of phenomenon which has been observed. It is not so likely that it could be responsible for the central peaks which are often observed in the larger craters.

I am indebted to Mr. F. R. Stewart of this Department for pointing out that, if this picture of events is even approximately true, a large and fairly accessible source of power should be available to the establishments which will doubtless be set up on the Moon in due course.

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Changes in the Inclination of Satellite Orbits to the Equator

In a recent article[1], we gave some details of changes in the orbital inclination of *Sputnik* 2 (1957β) and suggested that these changes might be caused by the rotation of the atmosphere. Bosanquet has presented an analysis[2] which supports this view, giving fair agreement with the observed changes. We have now completed a more thorough investigation, taking into account the spread of atmospheric resistance around perigee.

If the atmosphere is assumed to rotate with the same angular velocity as the Earth, and the drag force acts along the direction of motion of the satellite relative to the air, the change, Δi, in orbital inclination i is given by :