THE MOON FROM *LUNA* 9

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THE Russian probe *Luna* 9 was reported to have landed at the selenographic position $\lambda = 64°\ 22'$ W., $\beta = 7°\ 8'$ N. (astronautical convention). This places it 70 km north-east of the rim of the well-known 64-km diameter structure, Cavalerius, on the border of Oceanus Procellarum. The touchdown appears to have been on a bright, slightly elevated area within a few kilometres of a group of hills known, from Earth-based studies, to mark out the arc of a partial ring some 100 km in diameter. When *Luna* 9 landed, this whole region was in darkness; morning broke on the scene about an Earth-day later and picture transmission commenced soon afterwards. As a consequence of the Sun being only a few degrees above the horizon, even small obstacles cast long shadows; contrast was high and detail sized appreciably less than 1 cm was recorded in the near field of each photograph.

Blocks of rock 1 ft. or so in diameter and depressions are not uncommon and, at smaller sizes, the terrain is extremely rough. In the highly successful *Ranger* experiments carried out by the United States, 1 ft. was about the best resolution attained by the last photographs of each series; yet, even at this resolution, positive topography, such as blocks of rocks, was rare and virtually all the easily identifiable topography in the *Ranger* photography was negative. *Rangers* 7, 8 and 9 impacted in mare-type country, and the greater proximity of the touchdown point of *Luna* 9 to lunarite hills may be thought to explain the increased numbers of rock blocks per unit of surface. However, one clear—perhaps the most important—explanation of the difference between the American and Russian pictures is that ground resolution attained by *Luna* 9 is better by two orders of magnitude than that of any of the *Ranger* cameras.

The difference is not simply a function of the respective camera-to-ground distances and the lens characteristics; on the Moon the amount of detail recorded on photographs is critically dependent on the altitude (A) of the Sun and, while the first pictures from *Luna* 9 were taken with $A = 7°$, the later pictures of the three *Ranger* series were taken with $A = \sim 20°$, $\sim 15°$ and $\sim 10°$, respectively.

Thus the terrain would necessarily appear smoother on the *Ranger* photographs. Although some astronomers argued that the *Ranger* programme supported the 'deep-dust' theory, it was known that, in order to satisfy the Moon's peculiar light-scattering properties, the surface must in fact be highly porous. Elementary visual[1], photographic[2] and millimetric[3] observations combined had argued convincingly against an appreciable dust cover. Furthermore, evidence from the *Ranger* photographs themselves has been used[4] to demonstrate that apparent smoothness on the photographs may not be real. We believe that the greater part of the Moon will show a roughness comparable with that shown by *Luna* 9. For the first time there would seem to be complete proof that this part of the Moon does not have an appreciable cover of unsintered dust.

The first pictures from *Luna* 9 reveal a remarkable array of detail down to half a centimetre in size. *A* (Fig. 1) is apparently one of the petal-shaped covers that dropped away from the camera housing after touchdown. *B* is the sunrise shadow of the rock *C*, which itself is very pitted and may be as porous—possibly with a bulk density as low as 0·5 g/c.c.—as the surrounding terrain. It is a rounded rock about 15 cm in diameter, some 2 m from the camera. *D* is a second, rounded rock-block much larger than *C*. We have used two methods to estimate its size. First, the apparent roughness of the terrain between *C* and *D* changes by a factor of 10, so, assuming the average size of irregularities is constant over this distance, unit apparent transverse length at *D* is actually ten times the same unit at *C* and the distance from the camera to *D* is ten times the distance from the camera to *C*, quoted as 2 m. Thus the distance to *D* is about 20 m. This, and a second method based on the fact that the apparent (foreshortened) width of the shadow of *D* is a monotonic function of distance from the camera and the height of the camera above the ground, yield results compatible to within a factor of 2 on the assumption that the terrain is flat: the estimated diameter of block *D* is ~ 1 m. Many other blocks of rock or boulders may be seen in Fig. 1. The closest appear to be rounded and to be buried by only a small fraction of their diameters.

This finding and the observation that the vehicle did not penetrate to any great extent indicate that the surface has an appreciable bearing strength. From calculations based on possible ejecta from a supposed impact crater photographed by *Ranger* 9, G. P. Kuiper[5] estimated a crushing strength of > 1 kg cm^{-2} and this appears to be consistent with what is known of the *Luna* 9 landing vehicle.

It is unlikely that a spherical rock mass is an extrusive or the eroded top of an underlying rock mass. Rather, it appears that the blocks have been deposited on the surface. A cluster of blocks may be seen at *E*. They cannot be meteorites; even at the minimum velocity of 2·4 km sec^{-1} they would have penetrated some distance and scooped out impact craters explosively, breaking up in the process. Furthermore, it is unlikely that the blocks are ejecta from a primary impact crater, since the velocities of the secondary particles would still be of the order of 1 km sec^{-1} and, at these velocities, the blocks would probably break up on impact. Now towards the skyline in Fig. 1 there is a crater-like depression *DA* estimated by us to be of the order of 10 or 20 m in diameter. Could it be that this is a secondary impact crater—either of meteoritic or volcanic origin—and that the blocks were jettisoned as tertiary objects at low velocity? On another picture a similar-sized depression occurs a short distance away. Undoubtedly, these two objects would have been interpreted on *Ranger* photography as depressions without raised rims. Such depressions are generally regarded to be collapse craters. The *Luna* 9 pictures do not show clearly whether the rounded rims of these craters are raised above the surrounding terrain—which is hummocky—or not. If the depressions are due to collapse, then it would seem that the blocks strewn around outside could be volcanic bombs tossed out during mild eruptive phases. A similar distribution of particles can be seen around certain terrestrial volcanic centres[6–8].

There appear to be some sub-parallel features *FF* running across Fig. 1. The fact that there is more than

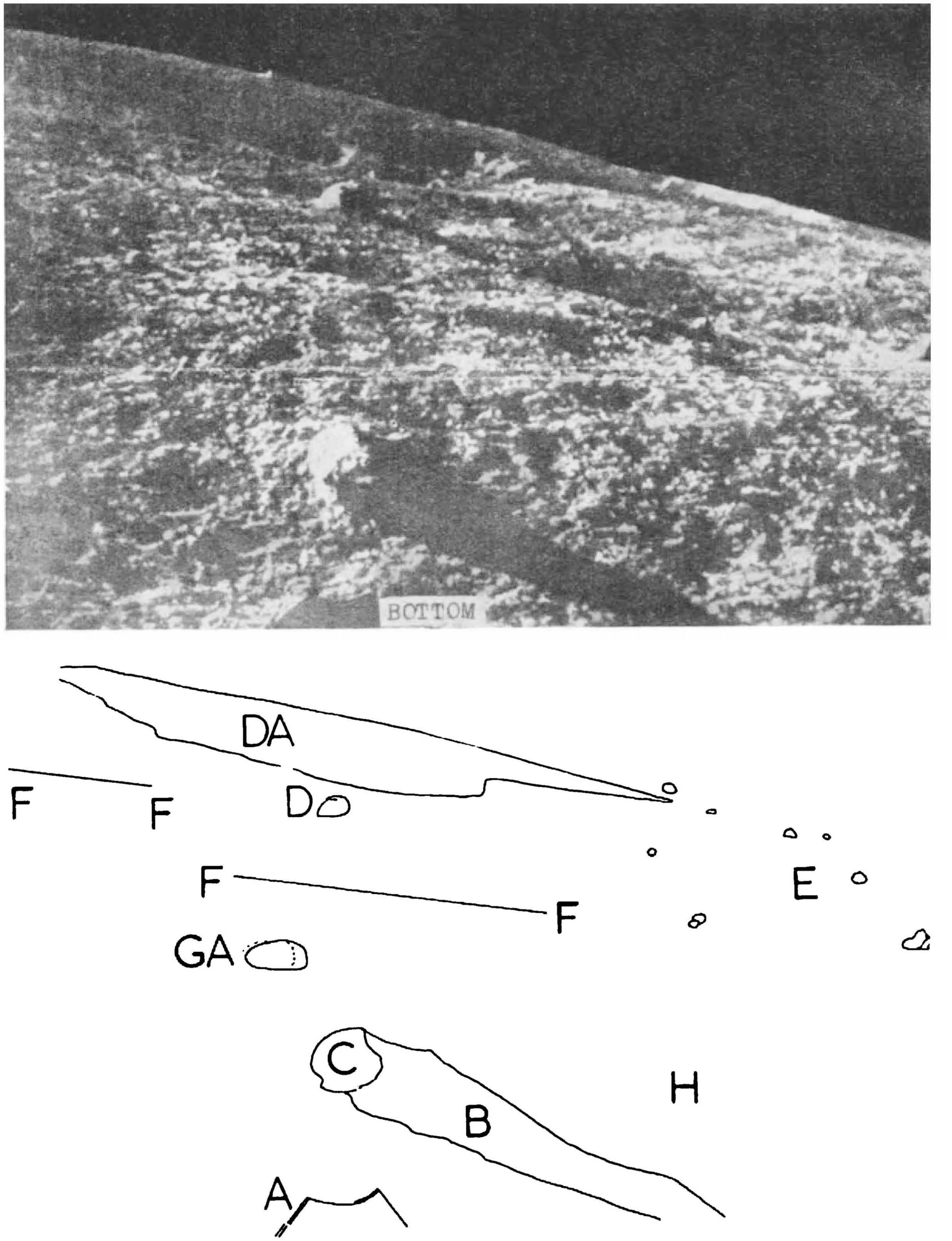

Fig. 1. *Luna* 9 photograph received from the U.S.S.R., February 4, 1966. This shows the closest view yet taken of the lunar surface. (Associated Press picture issued by the Official Soviet News Agency, Tass.) Bottom, key (see text)

one apparent lineament and that the terrain appears to change character across the lineaments suggests that they are real. These markings could be flow lines on, or fronts of, a lava flow; or they could be part of a concentric fracture system related to impact. Because of the similarity of the terrain to a lava terrain we prefer the former interpretation.

The skyline is reported to be only 1·5 km away. It undulates, like all the terrain, gently; slopes on a metre scale being of the order of 4°, excepting those of crater walls such as *GA* which have slopes steeper than 13°. Such craters may be primary or secondary impact craters. Secondary craters may be produced by the throw-out from a primary impact site or they may be produced when blocks hurled from an explosive volcanic eruption dig into the surface materials.

A whole plethora of steep-sided irregularities are, however, found on the centimetre scale. At this scale (*H* in Fig. 1) the lunar surface bears a remarkable similarity to the scoriaceous surface of an aa (Hawaii) type of lava flow, but we recognize that the irregularities might equally well have been sculptured by meteoritic churning. In any event, solar sputtering must have played a part in shaping the sub-centimetric irregularities and the shortwave and corpuscular radiation from the Sun must, in addition, have darkened the rocks from their original lighter tone.

It is well known that the lunar surface has reflexion properties unlike those of any terrestrial materials. These unusual properties are well illustrated by the graph in Fig. 2. The figure shows the brightness of marial material as a function of angle of observation for a given constant angle of incidence (in this case 30°), and is constructed by reducing the lunation brightness curves of many points to the curve of mean albedo; data have been derived from measurements by Fedoretz[9] and Bennett[10]. It seems that the observation that the Moon's surface (in both maria and highland areas) scatters a large fraction of the incident light back in the direction of incidence can only be explained satisfactorily by assuming that the surface is very rough and, in particular, that individual holes or pores are interconnected.

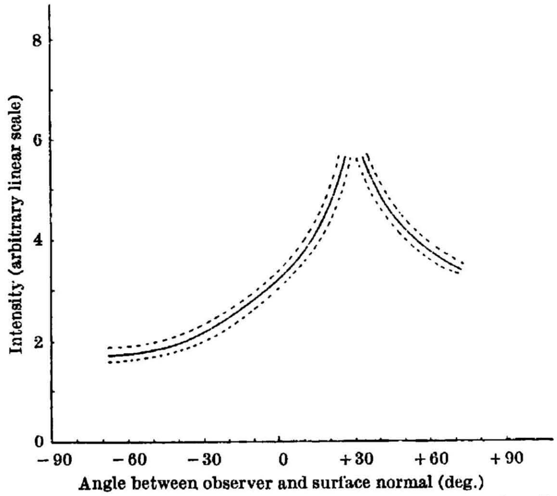

Fig. 2. Scattering diagram for maria with angle of incidence of sunlight = 30 degrees. The dashed lines indicate the limits of probable error

We have attempted to explain these features on the assumption that at least some parts of the lunar surface consist of lava flows. If this is so it will be appreciated that the lava reaching the surface encounters not an atmosphere as in the case of the Earth, but a high vacuum, and as a result any release of entrapped gas is likely to cause a higher degree of vesicularity than in the corresponding terrestrial case. Following Dobar *et al.*[11], we have, therefore, rapidly evacuated the atmosphere from vessels containing molten igneous rocks and examined the resulting solids after cooling to room temperature. In all cases a highly vesicular material is found consisting of interconnected vesicles from 0·1 to 2 or 3 cm in diameter. Such material, when darkened by solar radiation, is consistent in appearance with the terrain so far resolved in the Russian photographs, and our material also reproduces the observed lunar photometric properties. It is not yet possible to decide to what extent the surface has been broken up by meteoritic impacts and re-sintered by the solar bombardment; photographs taken with a resolution of less than 1 mm will be needed to resolve such questions. There is, however, strong evidence based on polarimetric observations[12] that the irregularities photographed by *Luna* 9 will be found to be peppered with darkened but individual grains that are certainly produced by micrometeorites.

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OBITUARIES

Sir Gordon Morgan Holmes, C.M.G., C.B.E., F.R.S.

Sir Gordon Morgan Holmes died at his home in Farnham, Surrey, on December 29, 1965. He was in his ninetieth year.

Holmes was born in Castlebellingham, Co. Louth, Ireland, in 1876. After gaining his M.D. with the gold medal of the year from Trinity College, Dublin, he was for a short period a resident medical officer at the Richmond Hospital in Dublin, but then turned to the study of the comparative anatomy of the nervous system and proceeded to the Anatomical Institute at Frankfurt, then directed by the famous neuro-anatomist, Ludwig Edinger, where Holmes also encountered another pioneer in the field, Carl Weigert.

During the two years that he remained at Frankfurt he produced work on the nervus acusticus, on the forebrain of the bird, and was given by Edinger the task of working out the residual anatomy of one of Goltz's 'dogs without forebrain'. So impressed was Edinger by his young student that he offered Holmes a position as his assistant, and this might well have determined Holmes's future place and order of study. However, he came to England and turned to neurological medicine, filling successively the roles of resident medical officer, pathologist, director of research and finally physician to the National Hospital, Queen Square, London, until his retirement during the Second World War.

From his first arrival at this well-known neurological hospital, which enjoyed an international reputation for research many years before it finally achieved university recognition after Holmes's retirement, his output of original work was continuous. It covered the anatomical and morbid anatomical investigation of the human nervous system and the manifestations of diseases of the nervous system over a wide range.

The study and analysis of cerebellar defect, due to disease or injury, began in 1904 when, with Grainger Stewart, he published the first adequate study of cerebellar tumours. Later, during the First World War, which he spent in France as neurological consultant to the British Forces, he amplified his analysis of cerebellar function by investigations on acute injuries from gunshot wounds. The final results of all his investigations on this subject were published in 1917 and 1922.