campinae all the available species, *Celerio lineata* Fabr., *C. euphorbiae* Linn., and *Xylophanes tersa* Linn., showed positive responses. Acoustic responses were lacking in Sphinginae (six species), Smerinthinae (three species), and Macroglossinae (two day-flying species). Out of five species of Philampelinae tested only *Erinnyis obscura* Fabr. showed a response which required, however, sound intensities higher than those eliciting responses in choerocampine moths.

The functional significance of this species distribution is not clear. The habit of feeding on nectar while hovering with extended tongue is common to many diurnal and crepuscular sphingids, and might be expected to expose these otherwise swift fliers to attacks from birds or bats. Yet no obvious correlation could be found between this habit and tongue length and the possession of an auditory sense. Body size offers no answer; the choerocampine sphingids examined are intermediate in body size, many other sphingids being larger and many smaller. Comparative studies of the biology and behavior of adult sphingid moths may throw some light on the matter.

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7. The following were most helpful in supplying living moths and pupae: Robert Barth, University of Texas; Herndon Agee, U.S.D.A. Cotton Insects Laboratory, Florence, South Carolina; Judith Meyers, Archbold Biological Station, Lake Placid, Florida; Peter Belton and Peter Harris, Entomological Research Institute, Belleville, Ontario. This work was supported by an NIH research career award and by research grant AI-00947 to K.D.R. Some of the equipment used was purchased under an AFOSR grant.

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Ranger VIII and Gravity Scaling of Lunar Craters

Most investigators agree with Baldwin (*1*) on the location of the crater produced by the impact of Ranger VIII, but several points regarding the predicted size of the crater and its morphology need clarification. Baldwin suggests (i) that the size of the crater can be compared with craters produced by explosives detonated at scaled depths ($H/W^{\frac{1}{3}}$; H being the depth in feet, and W being the weight in pounds of the TNT equivalent) of burial between 0.10 and 0.25 ft/lb$^{\frac{1}{3}}$, and (ii) that the diameter of the crater should be 1.569 times larger than its terrestrial counterpart. It is doubtful that either of these suggestions is correct because Ranger VIII hit the lunar surface with an oblique trajectory, and data on cratering show corrections for the acceleration of gravity at the lunar surface are less than 1.569. In addition, the choice for the Ranger VIII impact crater shown by Baldwin is strengthened by the fact that it meets two requirements, namely, the distribution of ejecta around the crater is asymmetrical and the crater itself is oval.

The conditions of impact of Ranger VIII are similar to those of missiles at White Sands, New Mexico. In both cases, comparable trajectories are involved. Ranger VIII hit the lunar surface at 2.653 km/sec and an angle of 41.6° from the local horizontal (*2*). Some missiles at White Sands impact alluvium, lake beds, and fixed dunes with velocities near 2.6 km/sec and angles of impact of 42° to 58°. Thus, there are experimental data on impacts with natural materials for comparison with the crater produced by the impact of Ranger VIII.

The sizes of craters produced by missiles with oblique trajectories impacting at sufficiently high velocities are comparable to the sizes of craters produced by chemical explosives with small-scaled depths of burial when the kinetic energy of the missile is the same as the TNT (trinitrotoluene)-equivalent energy release of the explosive (*3*). Uncertainties in the direct correlation between impact craters and explosive craters arise, however, when the impact craters are produced by projectiles with oblique trajectories. Additional uncertainties arise from variations in crater size that are dependent on projectile velocity and target properties. In Fig. 1, diameters of missile impact craters in natural materials, measured from rim crest to rim crest, are compared with the kinetic energies of "inert" missiles impacting at oblique angles. Extrapolation of the data with "cube root" scaling (diameter proportional to the cube root of the kinetic energy) indicates the diameter of a crater produced by the impact of Ranger VIII on Earth should be between 7.0 and 12.5 m across but probably near 9.5 m. If gravity scaling (diameter proportional to the fourth root of kinetic energy) were used, the minimum predicted diameters would be about 6 to 11.5 m.

Since the acceleration of gravity at the lunar surface is about one-sixth of that at the earth's surface, these diameters might differ. The maximum correction for diameters of craters that are hemispherical or of other dimensions with fixed ratios is 1.569. We may compute

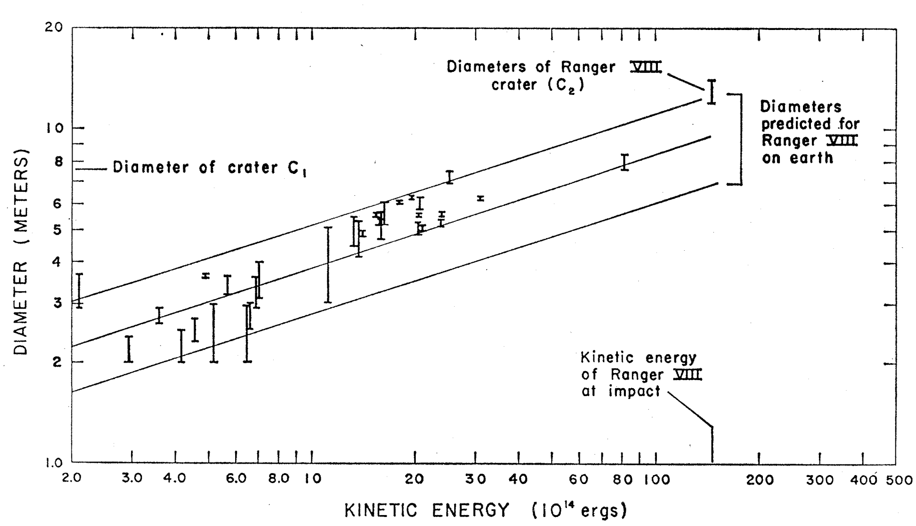

Fig. 1. Comparison between diameters of craters produced by missile impacts and diameter of crater produced by Ranger VIII. Missiles impacted at angles between 42.3° and 58° from the horizontal; Ranger VIII impacted at 41.6°.

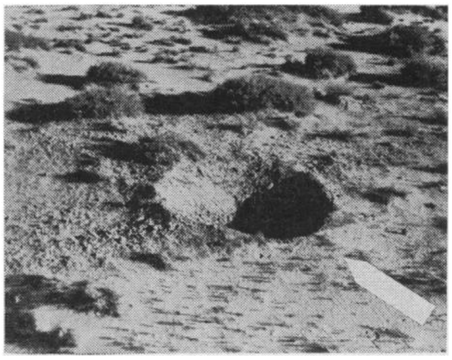

Fig. 2. Asymmetrical distribution of ejecta from crater produced by missile impact. Crater is about 6 m across. Missile impacted at about 45° from horizontal. Arrow indicates trace of path of missile. [Photograph courtesy of U.S. Army]

this correction by considering the work required to make the crater against gravity on the earth and then on the moon, and by assuming that for both the earth and moon a fixed amount of energy is lost irreversibly from heating, fragmentation, and ejection of debris. However, if the strength of the materials is important or irreversible energy losses are higher for the lunar materials, the correction of 1.569 is too high. The data of Moraski and Teal (*4*) on small craters in sand produced by explosives in low-acceleration fields indicate that lunar explosive craters in sandlike material with small scaled depths of burial should be about 1.25 to 1.40 times larger than their terrestrial counterparts. According to the experimental data, the diameters of a crater made by impact of Ranger VIII might then be as large as 17.5 m, but probably nearer 11.8 to 13.3 m.

Data on craters produced by missile impacts also show that the ejecta deposited around craters produced by missiles with angles of impact near 45° are bilaterally symmetrical about the plane of the trajectory (Fig. 2). During crater formation, the bulk of the ejected debris is deposited at right angles to the plane of the trajectory and in the general direction of the missile path. A lesser amount of debris is deposited "up" trajectory. Such ejecta blankets with bilateral symmetry are found around craters produced by missiles impacting at angles near 45° with velocities of 4.5 km/sec and less.

Lunar Orbiter II photograph H-70 shows two craters, C_1 and C_2, near the impact of Ranger VIII (*1*, fig. 1). Curiously, both craters lie on the trace of the path of Ranger VIII, and both have ejecta patterns consistent with the trajectory of Ranger VIII and data on missile impact craters. The smaller crater (C_1) is nearly circular and measures about 7.6 m across; the larger one measures about 13 m across, but its diameter at right angles to the trace of the path of Ranger VIII is slightly larger than that parallel to it. Such a crater shape would be expected to result from the impact of a suitably oriented elongate projectile such as Ranger VIII. Although both craters lie on the trace of the trajectory, the larger crater C_2 lies on the extrapolated traces of the reticles of the P cameras on the lunar orbiter photographs.

Thus, the larger crater, C_2, is apparently the crater produced by Ranger VIII when it hit the moon because (i) it is found at the appropriate place, (ii) it has the correct elements of symmetry both in crater shape and ejecta distribution, and (iii) its size is in agreement with the data on missile impacts combined with the experimental results on cratering in low acceleration fields obtained by Moraski and Teal (*4*).

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Moore's comment presents corroborating evidence not available to me at the publication time of my note (*1*) on the same subject.

Moore reports that tests at White Sands showed that inert missiles impacting in alluvium, lake beds, and fixed dunes would produce craters with bilateral symmetry of form and ejecta, much like that found for the C_2 crater of Ranger VIII.

His extrapolation of the data with cube-root scaling indicates that the diameter of a crater produced by the impact of Ranger VIII on earth (in alluvium, and elsewhere) should be between 7.0 and 12.5 m but probably near 9.5 m. If gravity scaling (or fourth-root) were applicable, the minimum predicted diameters would be about 6 to 11.5 m. Presumably the most probable value would be about 8.5 m for this case.

Craters produced by chemical explosives differ in various ways from low-velocity impact craters, but, until recently, data on the latter were not available (*2*). The most probable diameter of the Ranger VIII crater, if it had been produced on earth, was found to be 7.45 m (*1, 3*). This came from interpolations from chemical-charge craters at a scaled depth of burst of 0.10. The scaling exponent was experimentally determined to be 1/3.3 at this crater size.

Thus low-velocity impacts are apparently somewhat more efficient at producing craters than are equivalent TNT explosions at the proper depths. Consequently Ranger VIII would have produced a slightly larger crater on the earth than my calculated one. This also means that, based on the suggested similarity in cohesiveness in lunar and terrestrial soils, the Ranger VIII C_2 crater should have been slightly larger than the observed 13 m, if gravity scaling were fully effective.

From this new information, several possibilities may be listed. (i) The lunar soils are more cohesive than those I tested on earth; or (ii) gravity scaling is not fully effective, as Moore suggests, based on data from Moraski and Teal (*4*); or (iii) because of some peculiar characteristic of the actual impact of Ranger VIII, the resulting crater is smaller than would be expected; such variations are common, both in impact and in explosive craters. With only one example to work with, we cannot distinguish among the possibilities.

The important point made by Moore is that if we compare the Ranger VIII crater on the moon with new information on similar impact craters on the earth, the lunar crater is found to be larger than it would have been on earth, and therefore the reduced lunar gravity has affected the diameter of the Ranger VIII crater by an amount which lies between a factor of perhaps 1.38 and the theoretical limit of 1.569. This confirmation and improvement of the earlier results is encouraging.

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