EMPLACEMENT OF LUNAR CRATER DEPOSITS; V. R. Oberbeck, NASA-Ames Research Center, Moffett Field, Calif., 94035, and R. H. Morrison, LFE Corp., Richmond, Calif. 94804.

Laboratory impact studies have provided the basis for theoretical models of ejection, deposition of ejecta, erosion of pre-existing terrain, and for the origin of crater and basin deposits (1). For example, calculations indicate as much as 75% of the formation at the Apollo 14 site may be local material, not Imbrium ejecta; and model results explain the major structural features of the Fra Mauro Formation (2). Until now, no detailed study has related the major topographic elements of lunar crater deposits to secondary craters. The purpose of this paper is to describe the topography of parts of the continuous deposits of the lunar craters Delisle and Diophantus, to use ballistic models to calculate the percentages of local material in the crater deposits, and to calculate the percentages of local material if the craters had been formed on Earth. The model results adjusted for terrestrial gravity are compared with recently published drill core results from the Ries Crater deposits (3) as an independent check of the model.

Delisle and Diophantus, 25 km and 17 km in diameter, respectively, (formed in the basalt lava flows of Mare Imbrium) are relatively unmodified by post-formation degradational processes and are large enough that topographic variations within the continuous deposits are easily resolved on the 1:25,000 scale topographic maps produced from Apollo panoramic photographs. The map areas are well inside the mapped boundaries where pre-existing craters were obliterated. For each crater the surface of the continuous deposits in many places intersects the level of the pre-existing terrain well inside the continuous deposits. In each map area, many depressions form part of a pattern of concentric and radial chains of secondary craters. Profiles taken along great circles connecting the center of each parent crater and the secondaries show that generally the most developed rims face the parent crater. In the case of Delisle, two secondary crater chains formed so close together, in echelon, that their uprange rims form a dune concentric to Delisle that is a major topographic feature of the continuous deposit. Other secondaries in the deposits of Delisle and Diophantus have V-shaped ridges, and well-developed flows project from the points of intersection of the members of other crater chains. Results suggest that major positive relief forms of the deposits were produced by secondary cratering, and that secondary cratering is a major process acting during emplacement of the deposits.

Although significant thicknesses of deposits must have been necessary to obliterate pre-existing craters, the deposits were emplaced in such a manner that their upper surfaces are in many places still at or below the original level of the regional mare surface. Uniform secondary cratering action must have stripped significant thicknesses of mare lava and regolith before the debris surge material was emplaced. Enhancement of uprange rims of secondaries within the continuous deposits are evidence that most secondaries were produced at any given range before the debris surge material (primary crater ejecta and ejecta of secondaries formed nearer the primary crater) was deposited and that secondary crater ejecta momentarily blocked the debris surge to produce the dunes. If the secondaries had formed at any given range after the debris surge had arrived, the uprange rims of secondaries would

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have been less well developed than the downrange rims as for craters produced in the laboratory by low angle impact. Since the secondaries formed entirely in local material, it is possible to calculate the amount of secondary ejecta in the continuous deposits of lunar craters.

Scaling equations combined with the classical ballistic range equation as described in (4) were used to calculate the percentage of secondary ejecta in the continuous deposits and secondary crater fields of Delisle and Diophantus. Preliminary results, plotted as a function of distance from the center of each crater in Fig. 1, indicate secondary cratering has mixed large amounts of local material into the deposits of Delisle and Diophantus. To test the result we used the same observed secondary craters of Delisle and Diophantus to calculate the expected secondary ejecta in the deposits of the two primary craters if they had formed on Earth. The ejection velocities and sizes of the fragments that produced the lunar secondary craters were calculated respectively by using the classical ballistics range equation and the equation

$$d_M = 1.67\ (D_r^{1.134}/\cos^{0.378}\theta_o)_M\ (\sin 2\theta_o/R_s)^{1/3},$$

where d_M is the diameter of the fragment, D_r is the diameter of the secondary crater, θ_o is the ejection angle of the fragment making the crater, and R_s is the range of the projectile's flight. The classical solutions to the equations of motion for material in ballistic trajectories were then used to calculate the impact velocities and angles of the ejecta fragments had the primary craters formed on Earth and ejected these fragments. These values were then substituted into the following equation, derived after the manner given in (4), but using terrestrial gravity:

$$\mu_E = 4.73\ d_E^{-0.354} V_{fE}^{1.764} \cos\theta_{fE},\ \text{where } d_E = d_M,\ \text{and } V_{fE} \text{ and } \theta_{fE}$$

are the impact velocity and angle, respectively, calculated for each fragment size from the classical solutions.

These values of μ, converted to percentage values, are plotted in Fig. 2. They are compared to the measured percentages of local material (secondary ejecta) in the continuous deposits of the Ries Crater, which is about intermediate in size between Diophantus and Delisle. The general agreement of the results supports the validity of the model used in this paper to calculate the percentages of local material in lunar craters Delisle and Diophantus (Fig. 1).

References: (1) Oberbeck V. R. (1975) Rev. Geophys. Space Phys., 13, 337-362; (2) Morrison R. H. and Oberbeck V. R. (1975) Proc. Lunar Sci. Conf. 6th, p. 2503-2530; (3) Hörz F. (1978) Clast Population Studies in the Bunte Breccia Deposits, Ries Crater, Germany. Lunar Science IX; (4) Oberbeck V. R., Hörz F., Morrison R. H., Quaide W. L., and Gault D. E. (1975) The Moon, 12, 19-54.

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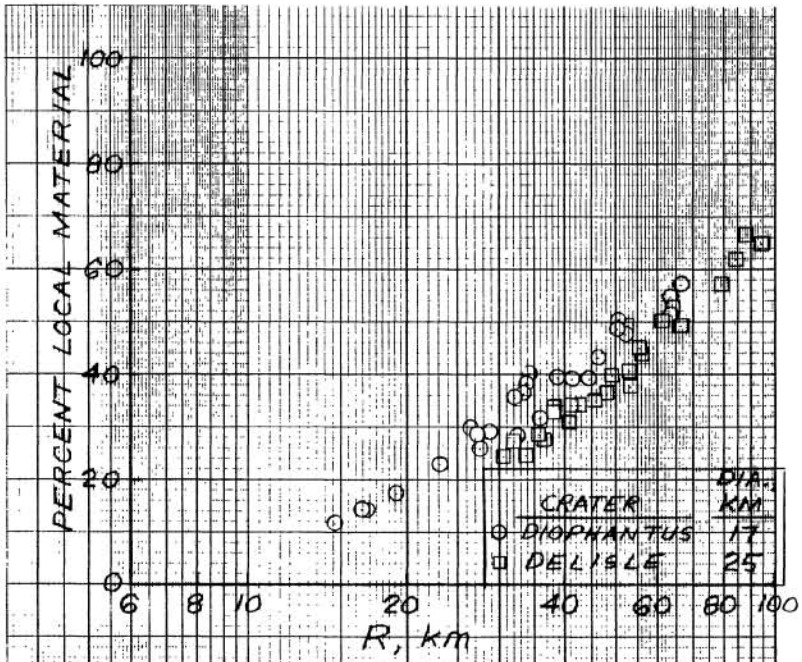

Figure 1. - Percent local material in lunar crater deposits.

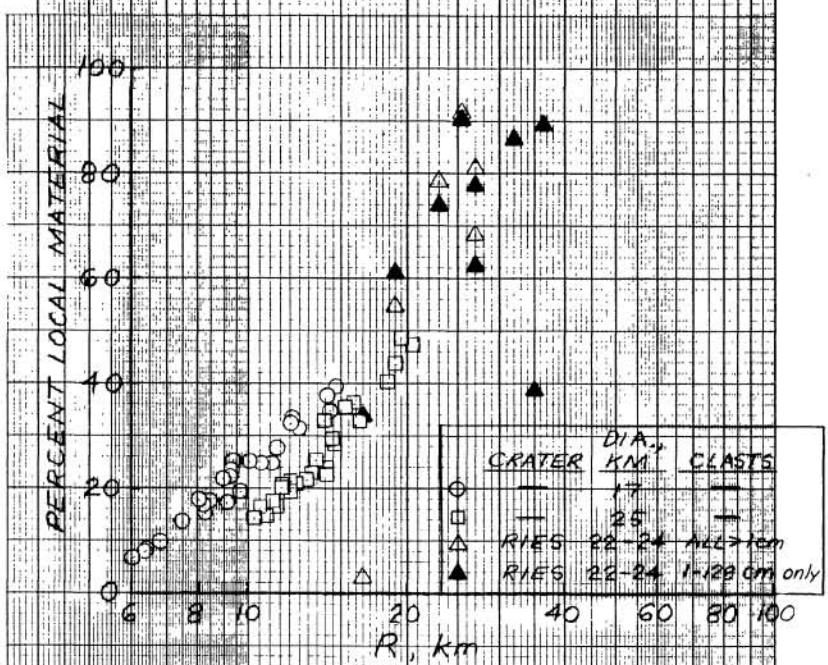

Figure 2. - Percent local material in terrestrial crater deposits.