THE SECONDARY CRATER HERRINGBONE PATTERN, V. R. Oberbeck and R. H. Morrison, NASA-Ames Research Center, Moffett Field, CA 94035.

The lunar surface herringbone pattern is associated with many lunar secondary craters. The herringbone pattern is important because it may reveal the conditions of formation of the secondary craters, and this may, in turn, reveal information about the formation of the parent craters. Identification of secondary craters based on the presence of the herringbone pattern is also important to those interested in distinguishing isolated secondary craters from primary craters. In addition, identification of such isolated craters may demonstrate long range transport of exotic components to local mare material of a different composition.

The herringbone pattern has been observed on the Apollo metric and panoramic photographs and selected Lunar Orbiter photographs. The features are described in this paper and compared to the features produced in the laboratory under conditions of velocity and impact angle that would have been necessary to form lunar secondary craters. The results are used to infer the conditions of formation of certain lunar secondary craters and to identify secondary impact craters not obviously related to any given parent crater.

The lunar herringbone pattern has been described in association with lunar secondary craters surrounding Copernicus Crater[1,2]. It consists of sets of separate and intersecting V shaped ridges that radiate from the point of overlap of adjacent secondary craters. Typically, the bisector of the V shaped ridge is nearly parallel with the radial to the parent crater. The points of the Vs usually point to the parent crater. When found in close proximity to one another they form the herringbone pattern. V shaped ridges have been observed in the ejecta blankets of Copernicus, Kepler, Aristarcus, Timocaris Tycho, Lambert, and others. In all cases the V shaped ridges radiate from secondary craters or secondary crater chains. This suggests that the herringbone pattern is associated directly with formation of secondary craters.

A series of laboratory impact experiments were performed in this study to determine whether the pattern could be produced in association with simultaneous production of impact craters. For these experiments two projectiles were launched into a quartz sand target under conditions of impact velocity and angle that would have been required to produce many of the lunar secondary craters. Impact variables evaluated included: impact angle, impact velocity, relative size of the projectiles, relative time of impact, and azimuth of the flight line, all of which are important secondary cratering variables. In all experiments, a ridge formed between the craters, provided that material was still being ejected from the first crater when the second impact occurred. However, the included angle of this ridge was the same as for the components of the lunar herringbone pattern only for those craters produced by projectiles impacting at angles greater than 70° from the normal to the target surface. Under these conditions the ridge was very similar to the components of the lunar herringbone pattern. Observed changes in orientation of V shaped ridges of laboratory crater pairs caused by changes in azimuth of the crater pairs relative to flight line resembled similar

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characteristics of lunar secondary craters. These and other similarities suggest that the lunar herringbone pattern is produced as a result of collision of material ejected from two adjacent impact craters formed at nearly the same time. This conclusion is supported by observation of high speed motion pictures of growth of the craters produced near one another at the same time. Material ejected from one crater collides with that ejected from the other and a zone of collision products forms and is deposited in the target surface. The hypothesis is further supported by an idealized mathematical model of the simultaneous production of two craters by normal impact of two projectiles. In this model, the equations of motion of particles ejected from two growing craters are used in conjunction with the equations of conservation of momentum to calculate the x, y coordinates of the particles after impact. Results of the model calculation show a concentration of impact points in a zone between the craters and perpendicular to the axis of symmetry of the craters. Thus, the ridges associated with both lunar secondary craters and laboratory craters are produced as a result of changes in the x component of velocity of material ejected from one crater and colliding with material ejected from the other crater.

In summary, the herringbone pattern can be explained as forming from the interaction of material ejected from adjacent secondary craters forming at nearly the same time. Thus, many of the secondary craters that are associated with this pattern have been formed by impact of material, and the impact angle measured from the local normal was probably greater than 70°. Many crater chains not obviously associated with parent primary craters can now be identified as secondary impact craters from the presence of V shaped ridges. Moreover, discovery of these secondary craters at great distances from any possible parent crater suggests widespread mixing of lunar surface material. Some crater chains that are considered to be of volcanic origin may actually be secondary impact craters. For example, well developed ridges have been observed to radiate from the point of crater overlap of adjacent craters in the Davy Crater chain.

REFERENCES

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