MODELLING OF LUNAR ACCRETION IN A CIRCUMTERRESTRIAL DISK;
William K. Hartmann and Dominique Spaute, Planetary Science Institute, Tucson, Arizona 85719

We have begun modelling collisional accretion processes in circumplanetary debris disks. The project is relevant generally to collisional processes in disks of unspecified origin around any planet (such as might be created by collisional breakup of satellites in cases like Phobos or Mimas). However, we focus here on a swarm of debris around primordial Earth. A chaotic swarm is created in a "stage 1" of unspecified nature (we imagine that such a swarm could result from impact of a giant planetesimal, as in the impact-trigger model of lunar origin). We then use a numerical simulation model based on that developed by Spaute et al. (1985, Icarus 64, 139), to follow accretional processes occuring simultaneously at different distances from Earth. The model involves particles of uniform size (or two specified sizes) and various specified mechanical properties. This program is a modeification of Spaute's 1983 dissertation (Toulouse) inspired by the numerical model of accretion developed at PSI (described by Greenberg et al., 1978, Icarus 35, 1). The PSI model, in contrast, followed bodies of many varied sizes but at a fixed distance from the primary.

We point out that collisional evolution is extremely fast in a circumplanetary disk, relative to that in the solar nebula. For example, consider a set of particles of fixed mass and eccentricity. One lunar mass of such particles is placed in a circumterrestrial nebula with radius a few earth-radii; and 0.1 solar mass of such particles is placed for comparison for circum-solar nebula with radii a few tens of A.U. If materials and velocities were adjusted so that the accretion efficiency were the same in both cases (i.e. the fraction of collisions that result in mass gain), we find that the equivalent mass change that requires 10^7 years in the solar nebula will occur in only about a month in the circumterrestrial nebula!

This suggests that once conditions evolve to the point were collision velocities are low enough to permit accretion in the circumterrestrial disk, accretional growth can be very rapid, on a timescale months or years.

Under what conditions we accretion occur? We are still examining a number of the physical parameters in the program, but based on our numerical simulations to date we can sketch some aspects of accretional growth that are of at least qualitative interest. We assume that eccentricities, inclinations, and collisional velocities are relatively high at the outset of "stage 2," which marks the beginning of collisional evolution after the disk is created in "stage 1." Generally, the typical material properties (weak rocky particles) we find that fragmentation ensures during this phase: the particles are grinding each other apart. This leads to very efficient energy loss and velocity damping, which we interpret as equivalent to the rapid collapse of the high-inclination initial swarm into a flat disk.

MODELLING OF LUNAR ACCRETION
Hartmann, W.K. and Spaute, D.

Examining further collisional evolution in the disk, we find that the rate of collisional evolution is generally higher in the inner parts of the disk, because the particles' relative velocities are highest here. If particles start with such high relative velocities that they shatter, there will simply be energy loss and disk flattening until the velocities are low enough to permit accretion in the more flattened disk outside Roche's limit. We have even studied cases where, at time $t = 0$ on a given run, accretion is operating at the (slower-colliding) outer edge of the disk, but fragmentation is occurring on the inner edge of this region. Our models to date suggest that due to the shorter evolution timescale on the inner edge, velocities drop there, accretion can begin, and the planetesimals can grow faster on the inner edge than on the outer edge, eventually overtaking the latter in terms of size. For this reason, we suspect that in an extended disk of sufficient mass, the largest moonlets will appear first in the innermost parts of the disk. We note also that the disk is likely to be strongly concentrated toward the Earth (at least if created by a giant impact on the Earth), enhancing this effect.

In terms of lunar origin, we may ignore moonlets growing inside the synchronously orbiting zone of the disk, because once a moonlet in that region grows large enough to induce tidal interactions, it will spiral inward and be lost to the system. Therefore, the important moonlets to consider are those that grow beyond the synchronous point. From the work described above, we suggest that the first large moonlet in this region capable of experiencing tidal evolution will appear just beyond the synchronous point. If such a body appears, it should begin to spiral outward, sweeping up the rest of the material.

We are continuing to use and improve the numerical modelling program in an attempt to improve our understanding of circumplanetary collisional evolution. The scenario we have derived to date, based on a number of quantitative calculations with the existing accretion program, suggests a plausible outline for lunar formation. In "stage 1" a swarm of debris is created. Probably this is a dynamically chaotic swarm with overlapping orbits of high i and e, produced by a giant impact; however, other origins for the swarm could be pre-supposed. In "stage 2" this swarm collapses into a thin disk, velocities are rapidly damped, and accretion of particles (particles condensed from cooling gaseous ejecta, or entrained particles?) begins. This lunar accretion is very fast relative to standard models of planet accretion. Some early moonlets may grow inside the synchronous zone and crash onto Earth, but the first large moonlet of interest grows just outside the synchronous zone, spirals outward, and efficiently sweeps up the rest of the disk, creating the present moon.

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