HEATING DURING ASTEROIDAL COLLISIONS. II.

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At the 1990 LPSC (1) we reported preliminary results from our exploration of the heat deposition within the rock interiors of asteroidal bodies during collisions, using our three-dimensional smooth particle hydrodynamics (SPH) code, described in connection with our investigations of the Giant Impact theory of Moon formation (2,3,4), modified so that the smoothing lengths of the particles in the code were made variable. Our report was primarily concerned with the inadequacies in our treatment of wave propagation in the interiors of bodies when we used the ANEOS (ANalytical Equation Of State) representation for dunite. We had found that the large negative pressures allowed by the equation of state at low temperatures in all solid materials led to efficient transmission of waves throughout the interiors of our model asteroids, giving spurious heating effects.

Studies of pure materials under tension have shown that fracture tends to occur at negative pressures of about 5 kilobars. In our simulations we found that negative pressures of much greater magnitude than this were involved in the transmissions of the nearly elastic waves which we found propagating through the asteroidal interiors. We tried the experiment of taking 50 kilobars of negative pressure as a rupture condition, beyond which the material was treated as consisting of two phases: a gas at the saturation vapor pressure under the local thermodynamic conditions, which contributes what is normally a very small positive pressure, and lumps of solid material which do not contribute to the pressure but supply the additional mass required by the density. This procedure almost completely eliminated the elastic waves. From this we concluded that allowing any negative pressure at all was an unnecessary complication of the calculations and that we might as well assume that zero pressure was the threshold for rupture. We were encouraged in doing so by arguments that had been given to us by Jay Melosh and Tom Ahrens (in private communications) that impure materials would generally rupture under much weaker conditions than negative pressures of 5 kilobars. With this revised procedure we found that particles in the asteroidal interiors generally heated smoothly to a maximum temperature during a collision, and upon dispersal these maximum temperatures were usually retained except for very high tempeeratures where a considerable gas phase was present, whereupon some adiabatic cooling was evident. We make no provision for radiative cooling over the short time scales involved in these collisions.

As an initial set of problems we considered collisions between asteroids of 200 and 300 km radii with relative velocities at infinity of 5 km/sec. The mass of these asteroids is sufficiently small so that this velocity was increased only a few percent during the collision. The collision parameter (aim point) was varied; we examined central impacts, impacts with aim points half-way out along the radius of the larger body (deemed intermediate impacts here), and impacts with aim points tangent to the limb of the larger body (here somewhat inaccurately called grazing impacts). The initial temperature throughout both asteroids was set at 400 K. At this temperature the sound speed in our rock material, dunite, is 6.5 km/sec, making our collisions slightly subsonic. We placed 3000 particles in the larger asteroid and 2000 particles in the smaller one.

In all three cases we found that particles close to the point of initial contact in the collision received a great deal of heating, whereas particles on the far sides of the asteroids were hardly affected, being heated only a few tens of degrees, typically. So the rule is: a small number of particles are heated a lot, but a large number of particles are heated only slightly. There is much more heating in the central collision than in the grazing collision, with the intermediate collision producing, appropriately, intermediate results.

The figure shows a contour diagram of the heating that at first glance will be hard to interpret. This shows a cross section of the two asteroids in the grazing case just beginning their collision. Plotted here are the contours for the maximum temperatures reached by the particles during the future course of the collision, thus showing which parts of the central planes of the asteroids are heated by varying amounts. The outside profile of the asteroids is defined by the initial temperature of 400 K. Progressively away from this contour are contours of maximum temperatures of 500, 700, 1000, 1500, 2000, 3000, and 4000 K. The bright patch at the point of contact contains particles in the range 4000 to 5000 K.

These results indicate that asteroidal collisions at 5 km/sec produce a wide range of thermal effects. Near the point of initial contact most of the material will be vaporized. Regions heated to 1000–1500 K will experience metamorphism effects similar to those in equilibrated chondrites, and those heated to 1500–1800 K will experience extensive melting. Perhaps most interesting is the fate of the vaporized material; rapid adiabatic expansion will cause much of the material near the surface of the vapor cloud to condense as relatively unfractionated smoke-like particles, although because of the dimensions of the vapor cloud these particles may grow into the millimeter size range. Material nearer the center of the

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vapor cloud may condense as liquid droplets having a range of sizes; we would expect these to have low FeO and volatile metal contents. Some of these might reaccrete onto solid bodies and be difficult to distinguish from chondrules. It seems doubtful that temperatures could stay high long enough to produce the pronounced fractionation present in Ca-Al-rich refractory inclusions.

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