Scaling Law of Impact Fragmentation and Coagulation

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Impact fragmentation and coagulation of solid bodies are important processes in planetary formation. These processes must have significantly affected the formation times and subsequent evolution of terrestrial planets. We briefly review the experimental data obtained by Nagoya University high-velocity gun in the velocity range of 100 to 2000 m/sec: these include the data of impact fragmentation and coagulation of basalt, ice, and metals. The experimental data are reasonably well described using by the "late-stage effective energy" introduced by Mizutani et al.(1). The "late-stage effective energy" is defined by the following equation:

$$I = P_o L_p{}^3$$

where P_o is the maximum pressure generated at the impact point, and L_p is the size of the projectile. The other useful non-dimensional parameters to describe several characteristics of impact phenomena are (3):

$$P_I = P_o L_p{}^3 / Y_t L_t{}^3$$

and

$$P_{II} = P_o / Y_i$$

where Y_i is the strength of target material (i=t) or projectile (i=p) and L_t is the target size.

The size of the maximum fragment M_{max}, and the size distribution of fragments are expressed using P_I as follows:

$$M_{max} / M_t = C_0 P_I{}^{-1}$$

and

$$N(>m) = A\ m^{-b}, \qquad b = C_i + a_i \log (P_I)$$

where N(>m) is the cumulative nunber of fragments, and A, a, b, and C_i are constants.

The velocity of a fragment ejected from an antipodal point is also related to P_I (2);

$$v_{eject} / v^* = C_5 P_I$$

where $v^* = Y / {}_t C_t$, which is the normalizing velocity and C_5 is a constant.

The above relations seem to hold for all brittle materials Ductile materials like metals, however, behave differently from brittle materials. As shown shematically in Fig. 1, coagulation of projectile and target was observed only at metal-metal collision in a limitted range of P_{II} values of the projectile and target. Since the P_{II} value corresponds to the strain of the material at the impact point, the experimental data indicate that both the target and projectile should be sufficiently strained to be coagulated. The region of coagulation diminishes with decreasing temperature. In the case of metallic iron, the coagulation region disappears at the temperature of T = 170 K which corresponds to the temperature of ductile-brittle transition. Thus the direct coagulation of a projectile and a target requires a rather special condition. Probably a more dominant coagulation mode in a planetary formation process will be a gravity assisted coagulation. When P_{II}'s of the both projectile and target are large enough to destroy both of them, but the P_I is low enough to secure the ejection velocities of fragments lower than the escape velocity, coagulation of two bodies is realized. Numerical simulation of planetary formation must take into account of various impact phenomena on the basis of the proper scaling laws.

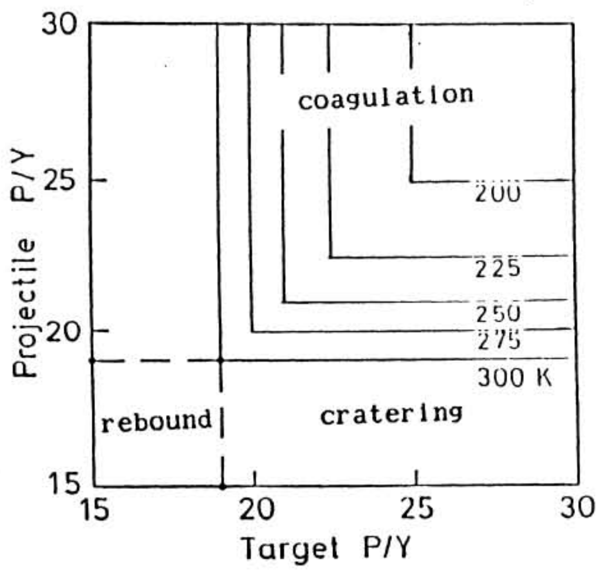

Fig.1 Temperature variation of accretion region of metals.

References

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