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VELOCITY DISTRIBUTION OF FRAGMENTS OF CATASTROPHIC IMPACTS

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ABSTRACT

Three dimensional velocities of fragments produced by laboratory impact experiments were measured for basalts and pyrophyllites. The velocity distribution of fragments obtained shows that the velocity range of the major fragments is rather narrow, at most within a factor of 3 and that no clear dependence of velocity on the fragment mass is observed. The NonDimensional Impact Stress (NDIS) defined by Mizutani et al. (1990) is found to be an appropriate scaling parameter to describe the overall fragment velocity as well as the antipodal velocity.

INTRODUCTION

Size distribution, velocity distribution, and energy partition of fragments produced by catastrophic collision are important for understanding process of planetary growth. The experimental data relevant to this problem, however, is not sufficient due to some experimental difficulties. Recently Nakamura and Fujiwara (1991) determined three dimensional velocities of some tens of fragments produced by a catastrophic impact experiments. Their result shows that the fragment velocities are proportional to $m^{-1/6}$, where m is the fragment mass. The present study reports results of our new impact experiments where the impact velocities are set to be lower than those in Nakamura and Fujiwara (1990).

EXPERIMENTAL METHODS

Impact experiments were performed by a single-stage powder gun at Nagoya University. Projectiles of cylindrical aluminums 1.0 cm in diameter and length were impacted to targets of cubic basalts and pyrophyllites. The experimental conditions are listed in Table 1.

Table 1. Experimental Conditions

	Material	Target v^* (m/s)	Mass (g)	Projectile Mass (g)	Impact Velocity (m/s)	Impact Energy (J)	NDIS	m_L/M_t	$\Sigma m/M_t$
# 1	Basalt	33.8	50.71	7.56	143	77.3	0.333	0.131	0.737
# 2	Basalt	33.8	139.8	7.59	140	74.4	0.119	0.825	0.940
# 3	Pyrophyllite	8.98	323.7	2.23	413	190.2	0.216	0.296	0.978
# 4	Pyrophyllite	8.98	339.1	2.25	653	479.7	0.344	0.141	0.809

v^*: chracteristic velocity of target material (see text), m_L: largest fragment mass, M_t: target mass, Σm: total mass of fragment whose velocity could be measured.

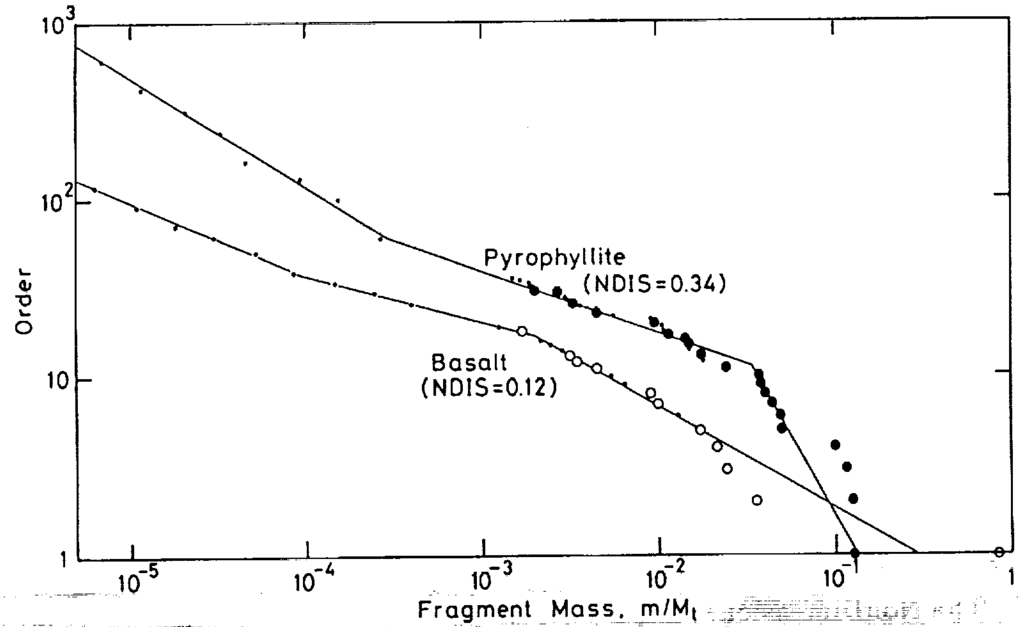

Fig. 1. The relation of the fragment mass normalized by the original target mass and the fragment order in size (= the cumulative number of fragments heavier than the mass). The large marks indicate fragments whose velocities could be measured.

Motions of fragments were recorded by a high-speed motion camera in 1500 to 3000 frame/sec. Four mirrors were set in front of the lens in order to obtain the stereographic picture of the fragment motions. Three dimensional position of fragments were obtained from the stereographic picture for each frame of the motion pictures and the velocity of fragment were determined by the least-squares fitting of the position-time data. The estimated error of the velocity determination is within 17 % of the determined velocity. Fragments containing more than 97.5 % of the mass of the target were recovered after the experiment and the mass of each fragment larger than 4 mm was measured to determine the size distribution of the fragments.

RESULTS

Figure 1 shows size distributions of fragments obtained in the present two experiments. As described in our earlier papers (Takagi *et al.*, 1984; Mizutani *et al.*, 1990), the size distribution curves are divided into three regimes. The large marks in the figure indicate fragments whose velocities could be measured. Almost all the velocities of fragments in the regime I were measured. The total mass of fragments whose velocities could be measured is 74 to 98 percent of the initial target mass.

Figure 2 shows the velocity of each fragment as a function of its mass. In this figure, fragment velocities are normalized by the characteristic velocity of the target material (Mizutani *et al.*, 1990), $v^* = Y/C_0\rho$, where Y, C_0, and ρ are the strength, bulk sound velocity, and density of the target, respectively. Fragment masses are also normalized by the original target mass, M_t.

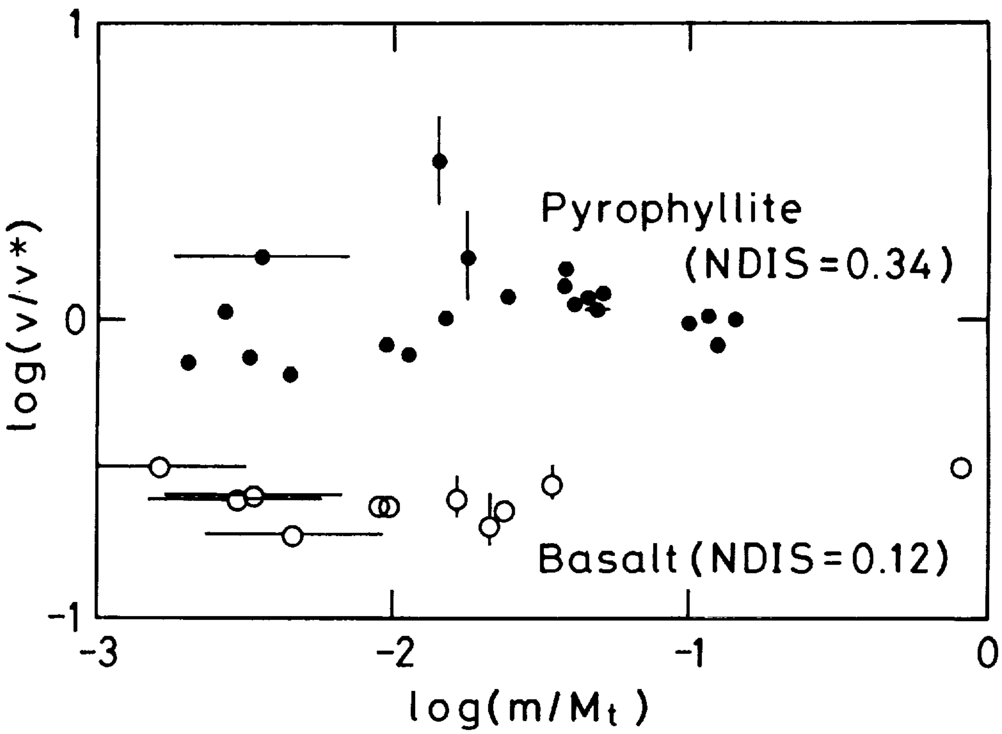

Fig. 2. Mass-velocity relations of fragments. Circles with horizontal errorbar show the data on images which were not identified with recovered fragments. The masses of these fragments were estimated from the projected areas on the film.

It is the most remarkable in Fig. 2 that the velocity range of fragments is rather narrow, at most within a factor of 3. This result is contradictory to Nakamura and Fujiwara's result, where they found the fragment velocity correlates with the mass as a manner of $v \propto m^{-1/6}$. Although we need further research to understand why we obtained different results from Nakamura and Fujiwara's result, possible sources of the difference must be sought for different experimental condition, i.e. impact velocity, size range of fragments, and others.

Figure 3 shows the average (weighted by the mass) fragment velocity normalized by the characteristic velocity, v^*. The result suggests that the v/v^*- NDIS relation is an appropriate scaling law to describe the overall fragment velocity as well as the antipodal velocity. On the other hand, this result shows that the energy partition to kinetic energy of basalt fragments is an order of magnitude larger than that of pyrophyllite fragments, because the normalizing velocity, v^*, of basalt is four times larger than that of pyrophyllite.

SUMMARY

The present results show that the fragment velocity is controlled by our scaling parameter of NDIS. The observation in turn suggests fragment velocity is not simply controlled by surface energy as discussed by Nakamura and Fujiwara (1991) but is controlled by impact shock strength and physical properties of the target (Mizutani *et al.*, 1990). At any rate, further experimental studies are necessary for better understanding impact

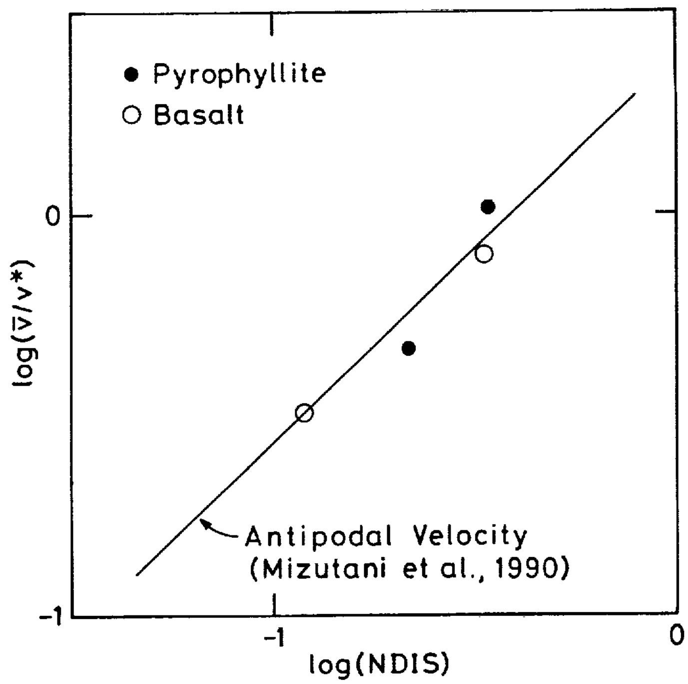

Fig. 3. Average fragment velocity normalized by v^* as a function of the nondimensional impact stress. The solid line is the antipodal velocity of the previous study (Mizutani *et al.*, 1990).

fragmentation process. The present method using a stereographic high-speed camera will provide a useful and power means for this purpose.

Acknowledgment

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