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OBLIQUE IMPACT JETTING OF GEOLOGICAL MATERIALS

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To understand jetting of earth materials, gabbro slabs (5 mm thick) were accelerated to 1.5-2 km/s and impacted inclined gabbro (5-10 mm thick), novaculite (10 mm thick) and porous sandstone (12 mm thick) targets at angles of 30°-60°. The ejecta were collected using a catcher box filled with styrofoam and the particles were extracted using chloroform. The mass of the ejected particles per unit area (~50 mg/cm^2) remains almost independent of impact velocity, inclination angle, thickness of the target and sample minerology and density. Based on this result, we predict that a 500 m diameter asteroid will produce only ~10^7 gm tektite material. This is negligible comparing to an estimated 2×10^{13} gm in the Ivory Coast tektite strewn field. The recovered ejecta, unlike most tektites, contains both target and impactor materials. Both of the above results suggest that the tektites are not produced by jetting.

INTRODUCTION

The detailed relation between the production of tektites which are related to large meteorite impacts is unclear [1,2]. The moldavite (Czechoslovakian) tektites were produced by the Ries impact [3-5], and the Ivory coast tektites are related to the Bosumtwi crater [6,7]. Using Nd and Sr isotopic studies of Australasian tektites, Blum et at [8] proposed that all of the Australasian tektites were derived from a single impact event in South-East Asia. Some authors suggested that tektites are produced by jetting during impact [9].

Jetting has been extensively studied for the case of oblique impact of thin metal plate materials both theoretically and experimentally [10-14]. Recently, the theory was extended to sphere vs. sphere [15], sphere vs. half space impact [16,17]. But there are virtually no experimental constraints on thick geological materials. This study provides additional results and supplements previous work [18,19] on the jetting of geological materials.

EXPERIMENTS

A series of oblique impact experiments has been conducted in the regime of jetting with a 40 mm propellant gun (Table 1). The impactors used were 5 mm thick discs of gabbro. They were accelerated to 1.5-2 km/s to impact inclined rectangular target slabs. Gabbro, novaculite and porous sandstone were used as targets. Their thickness and inclination angles were 5-12 mm and 30°-60° (Figure 1). A catch box filled with styrofoam (100 mm thick) was placed beneath the target. During the impact, the high velocity ejecta were captured by the styrofoam and a crater was formed on the styrofoam. The jetting angle was determined by measuring the relative positions of the crater and the target. The styrofoam was then dissolved in chloroform and the ejecta were recovered.

RESULTS AND DISCUSSIONS

A theoretical model [11,12,19] was employed to calculate the ejecta mass, jetting angle and the jet velocity. Figure 2 shows the flow pattern of the impactor and target in a moving frame whose origin is the collision point. In this model, three assumptions are made: (1) The materials behave as incompressible fluids; (2) the slug and jet

Table 1. Experimental Parameters

Shot No.	Flyer Plate		Target			Impact Angle	Impact Velocity
	$\rho(g/cm^3)$	t(mm)	m	$\rho(g/cm^3)$	t(mm)		(km/s)
846	2.89	5.04	gabbro	2.89	4.98	30°	1.51
852	2.9	4.99	..	2.9	4.79	30°	1.52
856	2.9	4.99	..	2.9	4.87	30°	1.53
905	2.88	5.16	novaculite	2.24	10.2	30°	1.95
906	2.87	5.13	..	2.24	10.2	45°	1.95
907	2.88	5.16	..	2.24	10.0	30°	1.52
927	2.89	5.35	sws	1.80	11.9	45°	1.49
928	2.90	4.57	sws	1.83	11.8	45°	1.83
940	2.90	4.89	gabbro	2.98	10.2	60°	1.52
941	2.90	5.42	..	2.88	10.1	60°	2.02

m=material; t=thickness; ρ=density; sws=porous sandstone.

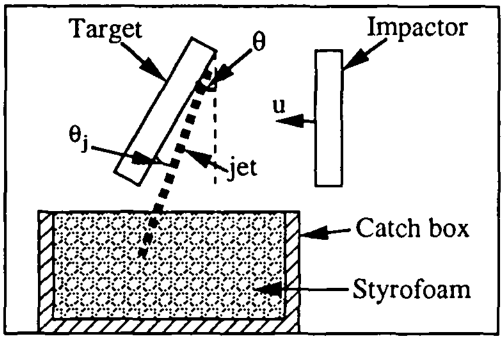

Figure1. Experimental configuration of the oblique impact experiments. u is the impact velocity, θ is the impact angle and θj is the jetting angle.

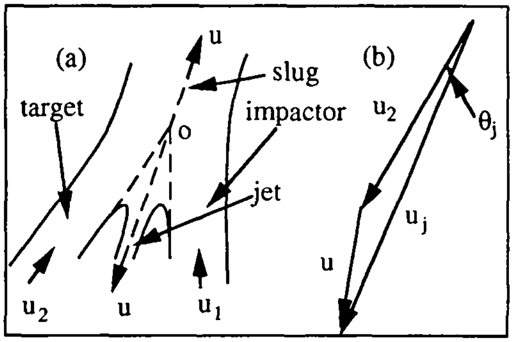

Figure 2. (a) Flow pattern of the impactor and target in a moving frame. Origin o is the collision point of the two plates; (b) Velocity vectors in the lab frame. uj and θj are the jet velocity and jetting angle, respectively.

move along a straight line although their directions are opposite; (3) The total thickness of the impactor and target material contribute to jetting process. With these assumptions, ejecta mass, jetting angle and velocity can be calculated [19]. Table 2 lists all the experimental (in parenthesis) and calculated results. It is obvious that the experimentally obtained ejecta mass does not change while the theory predicts rapidly increasing ejecta mass as target inclination angle and thickness increase (Figure 3). When the thickness of the target is ~5 mm, the experiments and theory agree well (shot 846 and 852). When target thickness increases to ~10 mm, theory predicts much more ejecta mass than found in the experiments. It seems that the effective thickness which participates in jetting process is about 5 mm. Applying this result to the situation where an asteroid impacts a planet, the jetting process is only controlled by a very thin layer of the asteroid and planet. The average ejecta mass per unit area from our experiments is ~50 mg/cm^2. Using this value, a 500 m diameter asteroid, which is able to produce the Ivory Coast crater [20], will produce only ~10^7 gm of jetted material. Compare to the tektite glass ($2x10^{13}$ gm) of Ivory Coast strewn field, this amount of jet ejecta is negligible. Note that the impact velocity change does not affect the ejecta

Table 2. Theoretical and experimental results of planar oblique impact jetting experiments

Shot No	ejecta mass (mg/cm^2)	jetting angle (degree)	ejecta velocity (km/s)
846	53 (66)*	6.7	5.78
852	52 (53)	6.8	5.82
855	52	6.8 (6.5)	5.86
905	64 (30)	5.1 (4.7)	7.43
906	153 (62)	6.1 (5.5)	4.92
907	64 (30)	5.2 (8.1)	5.79
927	155 (42)	6.6 (9.0)	3.80
928	140 (54)	5.8 (10)	4.61
940	299 (45)	3.8 (3.2)	2.76
941	323 (52)	4.3 (10)	3.70

* Experimental values are in parenthesis.

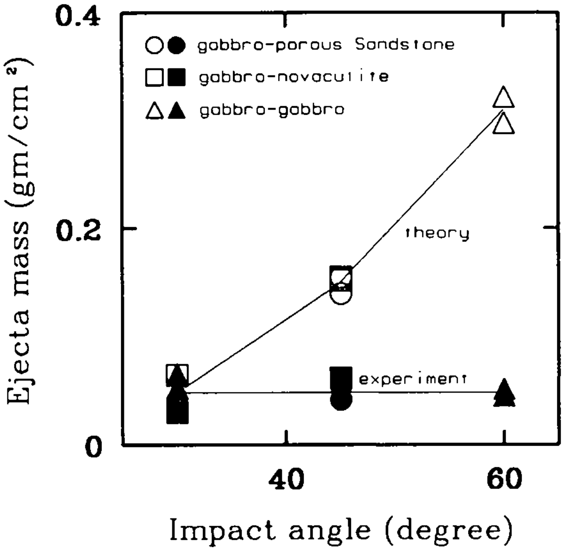

Figure 3. Ejecta mass per unit area vs. impact angle. Solid symbols are experimental results and plain symbols are theoretical predictions.

mass both theoretically and experimentally. This gives us some confidence when applying the experimental results to both large scale and hyper-velocity impact.

The recovered ejecta contains both impactor and the target materials. This is consistent with the theory. The composition of most tektites, however, show no contamination of extraterrestrial materials. The mass deficit and composition difference of the ejecta suggest that tektites are not produced by jetting. However, recently discovered tektite-like spherule beds in South Africa and Australia [22,23] apparently were contaminated with projectile material. Therefore, jetting may play a role in these events.

Shock wave and thermodynamic estimation show that both the impactor and target experienced shock pressure ~10-13 GPa and temperature ~1200 K. SEM images show that almost all the ejecta particles have a size less than 10 μm. X-ray diffraction examination shows no sign of amorphization of the orthosilicates.

CONCLUSIONS

Jetting theory developed for thin metal plates does not apply for thick geological materials. Under the experimental conditions, the effective thickness of the impactor and target is ~5 mm. Jetting cannot provide enough mass to form the observed tektite strewn fields. Unlike tektites, the recovered ejecta is always contaminated by the impactor. Tektites are not produced by jetting during impact.

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