Ejecting Basaltic Achondrites from Vesta: Hydrodynamical Impact Models

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Vesta is a large (~ 570 km diameter[1]) asteroid whose crust is mostly basaltic. Spectral heterogeneity suggests a sizable olivine feature[2] which may be explained as impact excavation (exposure of sub-crustal material). The spectral data probably show a localized feature ~ 200 km in diameter or a diffuse feature ~ 400 km in diameter[3]. Lightcurve irregularities suggest heterogeneity on a similar scale[4]. This heterogeneity may represtent the crater bowl, the extent of its ejecta deposit, or indeed something unrelated to cratering. In any case drawing direct inferences about the state of Vesta's surface on the basis of these observations involves substantial speculation.

These observations lend support to the suggestion that Vesta is the Eucrite parent body[5]. But there is a dynamical problem: in order to deliver the Eucrites from Vesta to the 3:1 Jovian resonance (the most efficient route to Earth), ejection velocities of ~ 750 km/s are required. While small fragments might be ejected at such speeds from a cratering event, large fragments seemingly cannot be (on the basis of laboratory measurements and scaling relations). This is the problem of equipartition: kinetic energy tends to be roughly evenly divided between large fragments and small fragments, such that large fragments travel proportionally slowly. This issue is the same one which stands in the way of our understanding of dynamical asteroid families: how can large fragments be ejected with great velocity?

But Vesta, as Binzel and Xu have recently confirmed[6], is but the largest member of a taxonomically and dynamically distinct family of objects. The minor members of the Vesta family are basaltic achondrites between 4 and 7 km in diameter with similar e and $\sin i$. Since these objects extend in semimajor axis from Vesta to the 3:1 resonance, a trail is pointed from Vesta to a route to Earth. These asteroids are almost certainly derived from Vesta by an impact event, which may in turn be related to the observed olivine feature. And so we return to the question: how do we eject large fragments at high velocity without disrupting the target? Having such a good data base for Vesta (fragment sizes and velocities, and a possible crater diameter), it is an appropriate candidate for detailed study.

One possibility is that these large ejecta fragments are conglomerates formed by the gravitational aggregation of small debris; this implies that the small fragments are jetted along clustered trajectories. Such phenomena have been observed in the explosion of meter-sized rocks[7], and may be related to ejecta blanket rays on the moon and other planets. A second possibility is that the impactor was much larger than previously supposed, such that point-source solutions (the basis for impact scaling) are not valid. A third possibility is the existence of inhomogeneities inside the target prior to impact (the result of a previous collisional history); pre-impact fractures can greatly enhance ejection velocities by reflecting impact energy back to the surface.

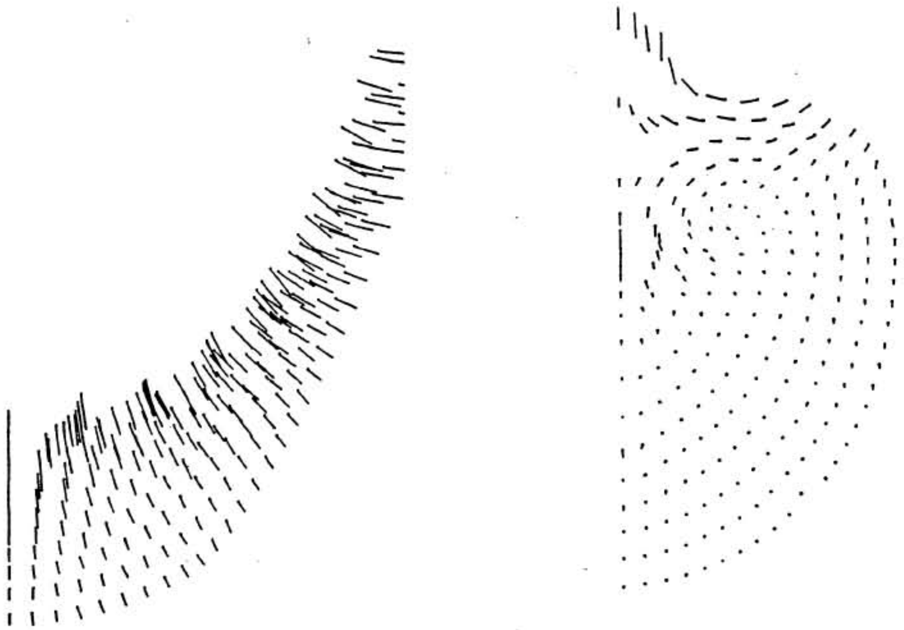
Vesta has considerable gravity and can therefore survive large impacts. Escape velocity is ~ 350 m/s, such that material ejected at 10 m/s will only stay aloft for a minute or two and rise to a height of one km. If Vesta were broken into large fragments by the impact which ejected the Eucrites, its surface might still appear (at the resolution of our spectral observations) to be an intact unit in spite of extensive fracture. Fragmentation does not imply disruption; we need look no further than Phobos (whose surface gravity is only 3% that of Vesta) with all of its fracture grooves to witness this fact. As the figures below illustrate, self-gravity can preserves the stratigraphic order of rocks in an impact even when the rocks are totally disrupted.

We are still far from understanding the boundary between cratering and catastrophic disruption, particularly on targets for which strength and self-gravity both matter. But we are now able to model the underlying physical *process* – dynamic fragmentation – accurately with fragmentation hydrocodes such as SALE 2D[8] and SPH3D[9]. We shall present several impact scenarios for Vesta; our study is similar to a previous impact model for the formation of Stickney crater on Phobos[10]. We shall illustrate the effects of impactors of different sizes and velocities, and the effect of gravity and structural inhomogeneity.

EJECTA FRAGMENTS FROM VESTA: Asphaug, Melosh and Ryan

REFERENCES: (1) L. Lebofsky *et al.*, *LPSC XXIII* 1991; (2) M. Gaffey, *LPSC XIV* 1983; (3) M. Gaffey, personal communication 1989; (4) A. Cellino *et al.*, *Icarus* **70** 1987; (5) M.J. Drake, in *Asteroids* 1979; (6) R.P. Binzel and Shui Xu, submitted to *Icarus* 1992; (7) G. Martelli *et al.* (preprint) 1992; (8) H.J. Melosh, E. Ryan and E. Asphaug, *JGR* **97** 1992; (9) W. Benz, *Comput. Phys. Comm.* **48** 1990; (10) E. Asphaug and H.J. Melosh, *Icarus* (in press) 1992.

Figure 1. The figures below show the effect of gravity alone when an impactor 40 km in radius strikes Vesta at 5 km/s. In the figure on the left, 42 minutes after impact, the target is totally dispersed and destroyed. On the right, where self-gravity is implemented, the target rebounds after 25 minutes. Note that the largest velocities (150 m/s on the right) occur in the central peak. The lines are velocity vectors; the maximum velocity is 100 m/s on the left and 150 m/s at the right for these times. The plots are in axial symmetry with the symmetry axis bounding each figure on the left; each figure was at the start of the computation a half-circle impacted from above along the axis.



Without Gravity

With Gravity