DOES MELT VOLUME GIVE THE SIGNATURE OF THE IMPACTOR?

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1. Introduction. Many analyses of impact events attempt to solve an inverse problem: Given the result, what was the impactor? One common example is the use of careful measurements of impact melt with the hope of deducing the impactor size and velocity.

The approach is as follows. Suppose the amount of impact melt is, for a given geological site and assuming a given impactor material, known (for example by code calculation) as a function of impactor mass *m,* velocity *U*. (I shall ignore complexities of oblique impacts here.) Then we have some known functional relationship

$$V_{melt} = F(m,U) \quad (1)$$

Then also we have some other known quantity, say the crater size given as

$$V_{crater} = G(m,U) \quad (2)$$

The goal is then to solve these two equations in two unknowns for the impactor mass *m* and the velocity *U*. Of course, that will fail if the two equations are not independent, and therein often lies the problem.

Equation (2) for the crater size is usually assumed to be of the form determined by the point-source approximation to impact problems, as given by the scaling relations of Holsapple, Schmidt and Housen (see, for example, the review in Holsapple 1993 [1]). The point-source approximation is expected to be valid for any measure of the cratering process that is large compared to the impactor size. Those relations have the form

$$V_{crater} = f\left(aU^{\mu}\right) \quad (3)$$

where the exponent m is assumed to be known, it is about 0.55-0.6 for non-porous materials. One must distinguish between the strength regime or the gravity regime for the function f. Assuming as a specific example a large terrestrial crater in a hard rock geology, then a specific form is given (Holsapple, 1993 [1]) as

$$V_{crater} = 0.48 m^{0.78} U^{1.3} \quad (4)$$

Thus, the measurement of the crater volume gives the numerical value for the product $mU^{1.67}$. (This is just the cube of the product aU^{μ} with some factors thrown in.)

We cannot perform laboratory experiments at impact velocities greater than 5-6 km/s, well below the minimum velocity for melt production. Therefore, code calculations must be used to determine the melt volume function of equation (1). Such calculations have been reported by O'Keefe and Ahrens [2], Orphal et al. [3] Bjorkman and Holsapple [4], Pierazzo et al. [5] and others.

O'Keefe and Ahrens [2] report that the melt volume for impact velocities greater than a threshold is proportional to the impactor kinetic energy:

$$V_{melt} = Ka^3U^2. \quad (5)$$

Later, Bjorkman and Holsapple [3] determined an importantly different result: that, for impact velocities greater than about 50 km/sec the melt volume scaled in the same way as the crater volume, namely that

$$V_{melt} = Km^{0.78}U^{1.3}. \quad (6)$$

although energy scaling does hold for lower velocities where the majority of melt is produced close to the impactor. The problem then arises for the larger velocities: if the melt and crater volumes scale in exactly the same way, both are determined by the same combination $mU^{1.67}$. Then there is no way to determine separately the mass and velocity.

Much more recently Pierazzo et al. [5] revisited the question of melt production. Their conclusion returns to that of O'Keefe and Ahrens: that the melt volume scales linearly with the energy of the impactor. They attribute the Bjorkman and Holsapple [3] result to be a consequence of insufficient grid resolution in the calculations.

I shall reevaluate the reevaluation of Pierazzo et al. Specifically, I shall show calculations and argue that, not only does energy scaling not hold for the higher velocities, it does not hold about 30 km/s. The consequence is that melt volume cannot be used to separate the effects of size and velocity for any impact velocity greater than that value.

In fact though, the different interpretations are really somewhat moot. Numerical examples will be presented that show, that even if energy scaling for melt volume is adopted down to lower velocities, the inverse problem is highly non-robust: Factors of uncertainty of only 2 in the melt or crater volume functions result in factors of uncertainty of several decades in impact velocity.

References:

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