THE EFFECTS OF TARGET HETEROGENEITIES ON IMPACT SPALLATION AND FRAGMENTATION. J. R. Elliott[1] and H. J. Melosh[1], Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, 550 Stadium Mall Drive, West Lafayette, Indiana 47907, USA, (elliot26@purdue.edu).

Introduction: Impact spallation remains the most reasonable mechanism for the launch of lunar and martian meteorites [1]. Previous studies have explored the fragmentation and subsequent ejection of material, but these studies have focused on homogeneous target bodies [2–5]. Many regions on Mars and the Moon are layered with different materials. Furthermore, embedded boulders, possibly launched from other impacts, are sure to be found within the target. In this study, we combine Eulerian and Lagrangian hydrocodes to study the effect of target layers and embedded boulders on the spallation and fragmentation of impact ejecta.

A hybrid numerical model approach: Eulerian numerical models, such as iSALE [6–8], are commonly used to model impact scenarios. Eulerian meshes, in which material flows through the cell, are able to resolve extreme distortions of materials. However, they do not resolve the free surface and material boundaries well, as the position of the surface is only known to within one cell width. On the other hand, Lagrangian codes are able to precisely track the free surface and material boundaries, a necessary feature in studying spallation and fragmentation. Unfortunately, when modeling impacts, Lagrangian meshes quickly become distorted and the simulation grinds to a halt.

To remedy the issues with both types of meshes, we employ a hybrid approach, first described by [5]. The impact is initially simulated using iSALE. A vertical line of Lagrangian tracers is placed directly under the edge of the impactor (one radius away from the axis of symmetry). The velocities of these tracers are recorded. We then begin a Lagrangian simulation using SALES_2 [2], a derivative of the original Los Alamos code, SALE [6]. The cell vertex velocities along the left boundary are controlled to match those of the Lagrangian tracers from iSALE. This method allows us to avoid distortion while forming the crater with a Eulerian code, while at the same time accurately simulate the free-surface with a Lagrangian code.

All impacts in this study have similar conditions. A 1 km radius basaltic impactor collides vertically with a surface at 12 km/s. The simulation is conducted at 200 cppr, with a cell resolution of 5 m/cell. The surface is either largely basalt or dry tuff. The target structure is varied as described in the following sections. Each material is modeled using the Tillotson equation of state. The Grady-Kipp-Melosh fragmentation model [9] is used in SALES_2 to calculate a complete size frequency distribution of basalt material that is ejected above the martian escape velocity of 5 km/s. Basalt has well known Weibull parameters [10], which are $k=10^{32}$ and m=9.5. Dry tuff does not have established parameters, so we approximate it as oil shale, with $k=1.70 \times 10^{27}$ and m=8.1. The first five columns from the left-hand boundary are not considered in the cumulative size-frequency distribution calculation. We believe that these cells are subject to artificial viscosity artifacts.

Homogenous impacts: Our study begins with a target surface that is entirely basaltic. An impact is simulated with conditions described in the previous section. The simulation was run until ejection of material at above the escape velocity of Mars ceased.

Figure 1 describes the locations, mean fragment sizes, and peak pressures of all ejected cells. Only a small amount of material is ejected, with ejection ceasing at depths below 3% of the impactor radius. There is a strong negative correlation between peak pressure and mean fragment size. Near the surface, material is fragmented to a high level. Larger fragments are only found deeper into the surface, consistent with the lack of 2π cosmic ray exposure in martian meteorites [11].

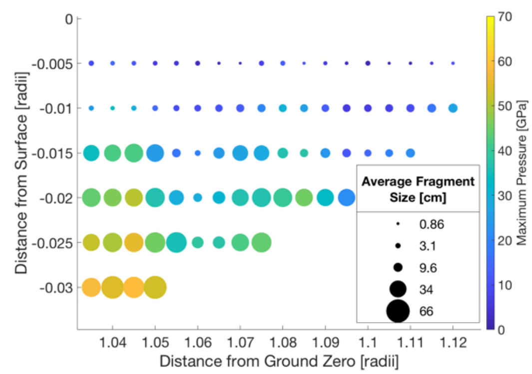

Figure 1. Locations, mean fragment sizes (size of dot), and peak pressures (colors), of all ejected cells in a homogenous impact.

In the following sections we modify both the fragment sizes and amount of material ejected by introducing layers and embedded boulders.

Stratigraphic layering: While most impact simulations consider large-scale layering, such as the crust and mantle, few consider small-scale, local layering of the near-surface. Much of the martian surface is heavily layered, a result of numerous volcanic eruptions or fluvial deposits [12, 13]. To simulate this, we introduce a small layer into the near-surface. The layer thickness is 3% of the impactor radius. The layer is either basalt or dry tuff.

The basalt layer, with underlying dry tuff, experiences reduced ejection velocities (Figure 2), with only 7% of the impactor radius reaching escape velocities. Fragment sizes are also quite reduced (Figure 3). The dry tuff layer experiences much higher velocities than the homogeneous impact, which causes deeper material to be ejected. Material down to 4% of the impactor radius is ejected. The basaltic fragment sizes, however, are reduced.

Embedded boulders: As evident in many Apollo and martian lander photographs, the surface is covered in large boulders, which no doubt are beneath the surface as well. These boulders may be of a different material type than the bulk of the local environment. An incoming shockwave reflects off these boulders, creating a chaotic interference region. To model this, we implemented a simple, randomized cell material assignment scheme into SALES_2. For this study, we consider targets with a 20% boulder abundance, which is a moderate rock abundance level on Mars [14].

Basaltic boulders embedded in dry tuff show a slightly higher surface velocity than a homogenous impact, but ejection ceases much closer to the edge of the impactor than in the homogenous impact. Fragment sizes are much smaller, and the number of fragments decreases as well. This is not surprising, considering the reduced amount of basalt. Dry tuff boulders result in higher ejection velocities than in a homogenous impact. The number of fragments and their sizes is quite similar to the homogenous case. It is possible that a slightly different boulder abundance may increase fragment sizes.

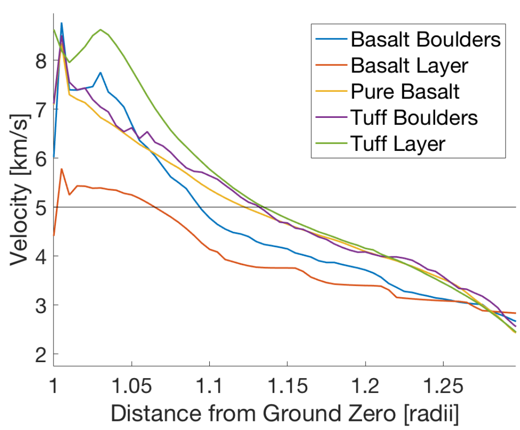

Figure 2. Peak spallation velocities along the surface.

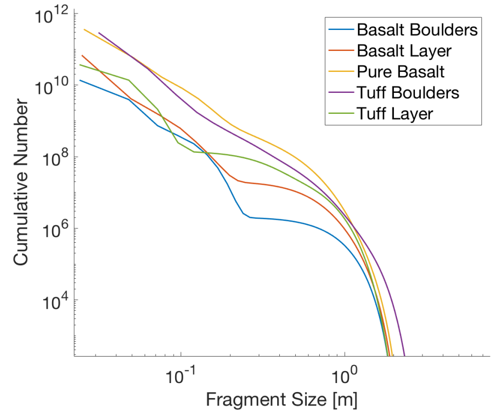

Figure 3. Cumulative size-frequency distributions of ejected basalt.

Conclusions: This work seeks to explore the trend in spall velocities and fragment size as a result of target heterogeneities. A weak overlying layer does result in deeper material being ejected, but the fragment sizes are smaller. Weak boulders embedded in basalt produce results very similar to a homogenous impact case. It seems that small-scale, local heterogeneities do not aid in explaining our martian meteorite collection.

Future work: In subsequent work we will explore more realistic target configurations that represent physical locations on both Mars and the Moon. We will implement the Grady-Kipp-Melosh fragmentation model under compression, as outlined in [4]. Experimentally derived Weibull parameters for dry tuff will increase the accuracy of future simulations.

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