INVESTIGATING DARK IMPACTORS AS A SOURCE OF LOW-ALBEDO MATERIAL ON EUROPA

Tara C. Tomlinson[1] and Paul O. Hayne[1], [1]Laboratory for Atmospheric and Space Physics (LASP), University of Colorado Boulder, 80303; tara.tomlinson@lasp.colorado.edu, paul.hayne@lasp.colorado.edu.

Introduction: The origins of low-albedo hydrate material on the surface of Europa have been a source of great curiosity since Voyager first returned close-up images of the icy moon. At regional and local scales, hydrated salt compounds appear concentrated within chaos features, ridges, and pits, suggesting an endogenic source. [1] However, some exogenic sources are known as well, such as sulfur originating from Io which contributes dark material primarily to Europa's trailing hemisphere. [9] Many of Europa's impact craters also exhibit prominent dark ejecta, the origins of which are the focus of our study. We attempt to determine if material brought to Europa's surface by impactors could in fact be a significant source of these low-albedo materials planet-wide.

Identifying "Dark" Craters: While high-resolution imaging of the surface of Europa is limited, a global composite map has been created using Voyager 2 and Galileo flyby data, with resolutions ranging from 160,000 m/pixel down to 15 m/pixel [1][2]. This global map may prove difficult for detailed analysis of surface features, but it is sufficient for helping to identify craters with dark ejecta. Our starting criteria was simply to categorize the 43 official Europan craters [1] as having ejecta that appeared visibly darker or lighter than the background material on which it was emplaced. While this initial survey did return some interesting observations in regards to the overall crater distribution across Europa's surface, the distribution of light vs. dark craters does not, at first glance, follow any obvious geographical trends, seemingly reinforcing the hypothesis of an exogenic source for the hydrates causing the darkness in the ejecta. Once these dark craters were identified on the global map, we examined Planetary Data System files from Galileo's solid-state imager to find the best-imaged craters from our group. This enabled us to focus on an initial set of ten dark craters for detailed study.

Calculating Impactor and Ejecta Volumes: To determine the amount of dark material contributed to a crater's ejecta by a dark impactor, we first need to determine the size of the impactor. Much work on this determination process has been done by H. J. Melosh, and we used his theories of pi-scaling laws [3] and his related web-based program [4] to calculate impactor mass and volume for each of our chosen craters based on the crater's lowest estimated transient diameter [5]. In these calculations, we assumed a comet-like impactor and an icy target, accounting for Europa's gravity and negligible atmosphere [4].

We then turned to the craters themselves, calculating the volume of each crater and therefore the inferred volume of ejecta resultant from the impact. In general, we found that the mass of material removed from the crater is greater than the mass of the theorized impactor by an average three orders of magnitude, which is consistent with data from other icy bodies [6].

How Dark is "Dark"?: Once we determined the volume of ejecta surrounding a crater, we then made more detailed measurements of the amount of dark material found in the ejecta. Using known and calculated Mie parameters and a radiative transfer model [7], we created a model of bi-directional reflectance for several concentrations of dark material/pure ice mixtures. We assumed that the material from the crater and the projectile was intimately mixed. By running these same calculations for each of our craters's ratios of impactor mass/ejecta mass, we found the estimated bi-directional reflectance values matched the model for concentrations of 1-10% dark material.

Moving beyond the model, we then used computer image analysis to determine the reflectance differences between the dark ejecta and the lighter background material. This allowed us to use the same radiative transfer model to create new concentration estimates for each crater. We found that concentration values varied from 3% to almost 20% dark material content; however, this assumed a pure ice background, an unsafe assumption for most of Europa's surface.

To correct for the non-ice background, we used a low-resolution global albedo map [8] and our model to estimate dark material concentrations in the region surrounding each crater. Calibrating our ejecta concentrations based on this background reflectance gave us our final dark material concentrations for our ejecta, ranging from 0.2% to 9.5% dark material. Unsurprisingly, craters found in overall-darker areas of Europa generally showed a greater concentration of dark material in their ejecta. But this was not quite the end of the story!

The Big Reveal: A final calculation remained: comparing the mass of the dark material in the ejecta to the mass of the dark impactor. Subtracting the amount of dark material contributed by the background medium, the mass of the dark ejecta material exceeded the mass of the impactor in every case. For the two largest craters in our sample (22.34 and 14.78 km in diameter), the ratios were fairly close, 10% and 50% greater respectively. However in all other cases, the dark material in the ejecta outweighed the impactor by a factor of at least 650%, the greatest difference being over 2500%.

Conclusion: We consider these results to be consistent with the view that, while a low-albedo impactor may contribute several million kilograms of dark material to the ejecta around its newly-made crater, the mass of the impactor is hardly enough to account for all of the dark material in the ejecta. There must be other processes responsible for concentrating dark material in Europa's crater ejecta, whether endogenic or exogenic. One of the key assumptions of this model is that the dark material is intimately mixed with the excavated material; should this assumption prove incorrect, our conclusion may not hold. Work is currently being done to assess the possible effects of layering or near-surface concentration on the optical depth of the ejecta.

Further Study: There is no shortage of theories as to the source of Europa's low-albedo hydrated sulfates, and we have planned detailed examination of some of these theories for future studies. In particular, our mapping of Europa's craters on a global scale has provided enough interesting hints of geographical relations to warrant further investigation. There also seem to be considerations for the size of the crater that could affect the amount of dark ejecta material in ways other than direct emplacement. We welcome the incorporation of new data provided by Europa Clipper to further test our conclusions in the coming years.

References: [1] Doggett, T. et. al. (2009) *Europa*, 137-159. [2] Pappalardo, B et. al. (2009) *Europa*, 713-718. [3] Melosh, H.J. (1989) *Impact Cratering: A Geologic Process*, 117. [4] Collins, G.S. and Melosh, H.J., (2005) *Meteorics & Planetary Sci., 40, Nr 6*, 817-840. [5] Moore, J.M. et. al. (2001) *Icarus, 151*, 93-111. [6] McKinnon, W.B. and Schenk, P.M. (1995) *Geophysical Research Letters, 22 No.13,* 1829-1832. [7] Hapke, B. (2005) *Theory of Reflectance and Emittance Spectroscopy.* [8] Moore, J.M. et. al. (2009) *Europa*, 329-349. [9] Carlson, R.W. et. al. (2009) *Europa*, 283-327.