HOMOGENEOUS NUCLEATION OF SILICA DUST FOLLOWING A HYPERVELOCITY IMPACT. B. C. Johnson¹ and H. J. Melosh², ¹Purdue University, West Lafayette, IN (Johns477@purdue.edu), ²Purdue University, West Lafayette, IN

Introduction: The K-Pg boundary layer is a 65 million year old, ~3mm thick, layer of ejecta associated with the Chicxulub impact. This layer consists of closely packed spherules ~250 microns in diameter in a clay matrix [1]. Based on the size of the crater and the amount of Iridium contained in the ejecta layer, the impactor was estimated to be ~10km diameter traveling at ~20km/s [2][3]. Since this layer is globally distributed, it is generally accepted that spherules came from the material vaporized during the impact [4].

At impact velocities greater than 14km/s the release adiabat for silica goes to the liquid/vapor coexistence curve from the vapor side. This leads us to believe that homogeneous nucleation and growth are responsible for the creation of these spherules. There have been several attempts to describe the mechanism that creates these spherules, including homogeneous nucleation, all of which have predicted the spherule size within an order of magnitude [5][6][7]. All of the models use a constant value for the surface energy of silica even though the surface energy should vanish at the critical temperature. For this reason all of the models fail when the coexistence curve is intersected near the critical point. Reference [5] shows multiple nucleation events, we argue that these secondary events are unphysical. Reference [6] uses the mean properties of the vapor cloud, which is not an accurate description of the system. Reference [7] is valid only for a system that comes to the liquid/vapor coexistence curve from the liquid side, making it invalid for impact velocities less than 14km/s. For the aforementioned reasons we feel a more robust model is necessary.

We show how a careful treatment of nucleation during a vapor cloud expansion leads to more precise predictions of spherule size. We include the equations for nucleation and growth into our numerical 1-D Lagrangian hydrocode. Contrary to past models, nucleation happens during runtime on a cell-by-cell basis allowing us to obtain a spatially dependent size distribution. This helps us better understand the vapor cloud’s role in the impact process. This may explain several terrestrial, solar, and extra solar observations. The Chicxulub impact is a prime example; its estimated impact conditions and measured spherule distribution make it an ideal candidate for testing our model.

Model: In our model we assume that both the impactor and target are pure silica (SiO₂). We do this so that we can use the ANEOS equation of state for alpha quartz developed by Melosh (2007)[8]. This equation of state gives an accurate description of silica under a wide range of conditions leading to a more accurate coexistence curve than the Van der Waals Equation of state describes.

We approximate the target as an infinite plane with no atmosphere so we can safely treat the vapor cloud as a hemisphere expanding into vacuum. Finally we assume that the material in the vapor cloud comes solely from the isobaric core. The isobaric core is the most highly shocked central region of an impact with a spatially constant pressure. The pressure falls off faster than distance squared outside of the isobaric core so as a first approximation most of the vaporized material will be contained in this region. In general the isobaric core is a sphere with a radius that is about equal to the radius of the impactor [8].

Through the Hugoniot calculated by ANEOS the impact velocity uniquely determines the density and internal energy of the isobaric core. We then make the assumption that before much expansion takes place the vapor cloud is approximated by a homogeneous hemisphere at rest with a density, mass, and energy equivalent to the isobaric core. This leads to initial conditions determined only by the size and velocity of the impactor. With these simplified initial conditions, we believe a 1-D Lagrangian hydrocode is a robust way to test our nucleation model. In the future we hope to incorporate our nucleation model into a 2-D Lagrangian hydrocode allowing us to minimize approximations and assumptions.

The surface energy of silica at temperatures higher than ~2000K is not known, thus we used two expressions for surface energy in this high temperature range that we believe roughly bound the true expression. By allowing the surface tension to go to zero as temperature approaches the critical point, our calculation remains accurate close to the critical point. In addition to the basic model we also included equilibrium chemistry calculations to determine the amount of silica that has dissociated.

Results and Conclusion: As shown in figure 1 our model predicts a spherule size distribution centered around ~250 micron diameter for an impactor with 10km diameter and an impact velocity of ~20km/s, which is consistent with observations. After nucleation, growth occurs until the gas becomes too sparse and ‘quenching’ occurs. This process is illustrated in figure 2. Due to quenching there is always some fraction of vapor that does not condense. For a Chicxulub like impact ~59% of the mass condenses. If we assume that the clay matrix makes up ~50% of the mass of the impact ejecta we get a total mass of 1.6x10¹⁵ kg while an estimate using the surface area of the earth and
3mm thick layer with density of 2500 kg/m$^3$ gives a mass of 3.8x10$^{15}$ kg.

One important result of this model is the radial distribution. As described by figure 3, the spherules get smaller as the distance from point of impact increases. The velocity of the cloud follows a Hubble law $v(r)=cr$ where $c$ is a constant. This may have implications for size distributions of spherules as a function of where they are found globally. The consistency of the model’s predictions with observation leads us to believe that the model can be used to predict the nucleation products of impacts with different impact velocities and impactor sizes. This means that measurements of spherule sizes can give an independent estimate of the size and velocity of the impactor that created them. Furthermore the relationship between nucleation products, impactor size, and impact velocity could give insight into problems such as the formation of the moon and Mercury’s high density.

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**References:**

**Figure 2** (top): Typical adiabatic path followed by a cell. Both total pressure and partial pressure of silica are plotted in order to illustrate the effect of equilibrium chemistry, which changes the point at which the coexistence curve is crossed by ~200K. This has a large effect on the surface energy and thus the size of droplets created.

**Figure 1** (middle): Average droplet size by mass is plotted for the two expressions we used for surface energy of silica. The black 250 micron line acts as a guide to the eye. All data is taken 10,000s after the impact well after quenching occurs.

**Figure 3** (bottom): Average droplet size by mass is plotted as a function of distance. Each point represents the average droplet size in one of 160 cells at the average distance of that cell from the impact site. All cells have an equivalent mass. This particular curve is produced using an impact velocity of 20km/s and an expression for surface energy defined by $Tt=3000$. When averaged over the entire cloud, the average diameter of a drop by mass is ~205 micron. This data is from 10,000s after the impact well after quenching has occurred.