FORMATION OF VALHALLA-LIKE MULTI-RING BASINS. B. C. Johnson[1] , T. J. Bowling[2], H. J. Melosh[1,2], [1]Department of Physics, Purdue University, 525 Northwestern Avenue, West Lafayette, IN 47907, USA (johns477@purdue.edu); [2]Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, 550 Stadium Mall Drive, West Lafayette, IN 47907, USA.

Introduction: The Valhalla basin on Callisto is the largest known impact structure in the solar system. The multi-ringed structure of the Valhalla basin extends more than 2000 km from the basin's center. The concentric rings of Valhalla are likely fault scarps that formed during the collapse of a much smaller transient crater [1]. During collapse, the warm weak asthenosphere readily flowed inward to fill the transient crater, while normal faults formed in the strong thin overlying lithosphere as it was dragged toward the basin's center [2]. The transient crater that ultimately collapsed to form Valhalla was smaller than the central high albedo region of the structure, which is ~600 km in diameter. McKinnon and Melosh (1980) estimate that the asthenosphere must have had temperatures above 240 K and the lithosphere was only 15-20 km thick at the time that Valhalla formed.

Melosh (1982) used an analytic model to estimate the stresses and strains incurred as the thin lithosphere was plastically deformed during the collapse of the transient crater. The final structure of the basin was then inferred from the calculated plastic stain. Here, we use the iSALE impact hydrodynamics code to directly model the formation of Valhalla-like basins. Our modeling focuses on directly resolving the formation of the concentric faults associated with Valhalla-like basins.

Modeling: We model a Valhalla-like basin forming event as a 50 km diameter icy projectile impacting a Callisto-like target consisting of a 300 km thick ice shell lying atop a dunite layer used to approximate the stronger ice-rock mixture underlying the outer icy shell. We use an impact velocity of 15 km/s, typical for Callisto [3]. The current day surface temperature of Callisto is ~100-130 K with estimated chondritic heat flux of 3.3-3.7 mW m^{-2} which corresponds to a thermal gradient of ~1K/km for ice with thermal conductivity ~3.3 W m^{-1} K^{-1} [4][5]. To avoid the presence of abundant, strengthless melted material deep below the basin our temperature–depth profiles switches from a conductive to a convective regime at a temperature of 240K. Using an average value for the surface temperature of 115 K, a conductive thermal gradient of 6.3-8.3 K/km is required to reproduce a 15-20 km thick lithosphere (where the lithospheric thickness is defined by the depth at which the linear thermal gradient reaches a temperature of 240K), consistent with estimates of McKinnon and Melosh (1980). Because the thermal history of Callisto is uncertain, we treat the thermal gradient as a free parameter.

Starting from a surface temperature of 115 K, we used initial thermal gradients of 2 and 7 K/km, corresponding to a lithospheric thicknesses of approximately 18 and 63 km, respectively. Hereafter we will refer to the model with the 2 K/km thermal gradient as the 'thick' lithosphere model and the model with the 7 K/km thermal gradient as the 'thin' lithosphere model.

Results: Observations of Valhalla show that in a region 200-300 km from the central bright albedo region there is a sinuous ridge zone with inward facing scarps [1]. Outside of this region is a small transitional zone and then a region with outward facing scarps [1]. Our thick lithosphere model seems inconsistent with the observations of Valhalla because in our model the region corresponding to the sinuous ridge zone has outward facing fault scarps.

Figure 1 shows that fault structure in the modeled basin is more consistent with Valhalla when a 'thin' lithosphere is used. In the region ~300-500 km away from the impact point faults extend to the base of the lithosphere and may dip towards the basin center (**figure 1 bottom**). The faults in this interior region are consistent with the observed sinuous ridge zone, and form late in the collapse process. There is a region from ~500-700 km from the basin center where there is no observable faulting. Outside of this region there are vertical faults that cut through the entire lithosphere. These faults form early in the collapse process (**figure 1 top**).

The final temperatures in our modeled basins imply that these impacts would produce a central melt pool that is ~300 km in diameter. Assuming that the size of the central melt pool corresponds to the size of the central high albedo region of Valhalla-like basins, our size estimate of 300 km in diameter is much smaller than the ~600 km diameter high albedo region of Valhalla [1]. This suggests that an impactor considerably larger than 100 km in diameter is likely responsible for creating the Valhalla basin. Alternatively, the outer portion of the high albedo region may be bright ejecta, in which case our estimated impactor size is appropriate.

Conclusions and furture work: Our initial results show that iSALE is able to resolve the faults associated with Valhalla-like multiring structures. Higher resolution simulations and additional analysis will provide insight into the processes that form these structures with precision that has never been possible before. Furthermore, we conclude that at the time of the Valhalla impact, the thermal gradient of Callisto was more similar to 7 K/km than to 2 K/km.

There are several improvements that could make our models more robust. One of these changes is to find or create an equation of state capable of approximating the ice-rock mixture believed to exist in the interior of Callisto. We must also include curvature, which is likely important because the Valhalla basin is similar in size to Callisto. Another aspect of interest is to see how the ice shell thickness changes the basin's structure. It will be interesting to see what happens when there is no dunite interior and also what happens when the ice shell is significantly thinner.

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Figure 1: Material in the thin lithosphere model, colored according to its total plastic strain at 640 s after impact (**top**) and 2850 s after impact (**bottom**). The origin is the point of impact. The black lines connect massless Lagrangian tracers. These lines were initially parallel as can be seen on the right side of the figures.