DETERMINING VENUS' THERMAL CONDITIONS THROUGH MULTIRING BASIN FORMATION. E. Bjonnes[1] , B. C. Johnson[2], and Alexander J. Evans[1], [1]Department of Earth, Environmental, and Planetary Sciences, Brown University, 324 Brook St, Providence, RI 02912, USA, [2]Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, West Lafayette, IN, USA. (Evan_Bjonnes@brown.edu)

Introduction: The geologic and thermal evolution of Venus has long remained a mystery. The Magellan mission revealed a surface covered in lava flows and approximately 1000 pristine impact craters ranging in size from 30–300 km in diameter [1], indicating a relatively young surface of approximately 500 Ma [1-3]. However, there is an ongoing debate regarding the thickness of Venus' lithosphere and, relatedly, the frequency of volcanic activity. The four largest impact basins on Venus are classified as multiring basins [4] and, due to their large size, offer an opportunity to investigate thermal conditions in Venus' past (e. g. [5-7]).

Here we focus on the formation of Mead Basin to constrain the thermal state of Venus. Mead has a diameter of 270 km and two circumferential ring faults at approximately 194 and 270 km [4]. Currently, the crater floor is 700 m below the surrounding terrain and the crater rim is 400 m above the surrounding terrain [8], but these elevations were likely modified by subsequent viscous relaxation of the basin [9]. Fault locations, however, will not shift as the basin relaxes and their initial locations depend on the material strengths of the crust and upper mantle. By testing how different lithospheric thermal gradients affect the formation of Mead Basin and its rings, we can constrain heat flow and draw conclusions regarding whether Venus had a stagnant lid or active lid in its past.

Methods: We use the iSALE2D shock-physics code to simulate impact basin formation [10-14]. Our simulations are axisymmetric and model a spherical dunite impactor striking a flat target at 17.5 km/s and vertical incidence [15]. Our target consists of a dunite mantle underlying a 30-km-thick basaltic crust, using the same strength parameters as [16]. All models are run at a 1-km resolution with impactor diameters of 30 or 36 km. We assume a surface temperature of 723 K and vary surficial thermal gradients between 3 and 25 K/km. At a temperature of 1400 K, the temperature profile transitions to an adiabat. We evaluate our models by comparing the locations of simulated faults with the observed faults surrounding Mead Basin, which will not change as it ages.

Results: Simulations with a 30 km projectile recreate basins 230–300 km diameter with rim-to-floor depths of 8.5–2.7 km. Simulations with a 36 km projectile result in basins 250–350 km in diameter and rim-to-floor depths of 10.3–4.2 km. For both projectile sizes, simulations with lower thermal gradients produce narrower, deeper basins than those with higher thermal gradients. Although all of these rim-to-floor depths are larger than the currently observed rim-to-floor depth of 1.1 km, this is likely due to post-impact viscous relaxation of the basin (e. g. [9]). All basins contain one or two identifiable ring faults, recognized by plotting total plastic strain and identifying areas where the strain is localized. This localization of strain indicates fault displacement and correlates with bends in initially parallel tracer lines, confirming this interpretation. In the suite of simulations with a 30-km projectile, we find fault displacements of 1–3.5 km, and simulations made with a projectile 36 km show fault displacements of 1.4–4.5 km.

The thermal gradients tested affect both fault location and magnitude of displacement; for each projectile size considered, simulations with thermal gradients of 10 K/km or less produce faulting at similar locations as the faults observed at Mead. Figure 1 shows the fault locations for the range of thermal gradients tested using a 36-km projectile. The thermal gradient affects whether the developing crater deforms in a brittle or ductile manner. Increasing the thermal gradient increases the diameter of the basin, and simulations with thermal gradients higher than 16 K/km show no inner ring development because the strain occurring close to the basin center is accommodated by ductile deformation.

Discussion: The ring faults of multiring basins provide testable constraints on the geologic conditions under which they formed. Simulations with higher thermal gradients show substantially more ductile deformation during crater collapse due to the elevated temperatures preventing development of the inner ring and pushing outer ring development farther from the basin center. The presence of brittle faulting consequently depends on the interplay between the scale of the impact and the material strength of the surface of Venus. In these models we use the thermal gradient as a proxy for quantifying the material strength, but the thermal conditions have implications for possible geologic histories.

Our finding that a thermal gradient of 10 K/km or less is required to produce a Mead-like basin has implications for the regime of lid tectonics present on Venus. Higher heat flows are consistent with active lid tectonics where the rigid lithosphere is thinner and more responsive to the underlying convective mantle, and lower heat flows indicate a stagnant lid regime with a thicker lid and weak coupling between the mantle and lithosphere.

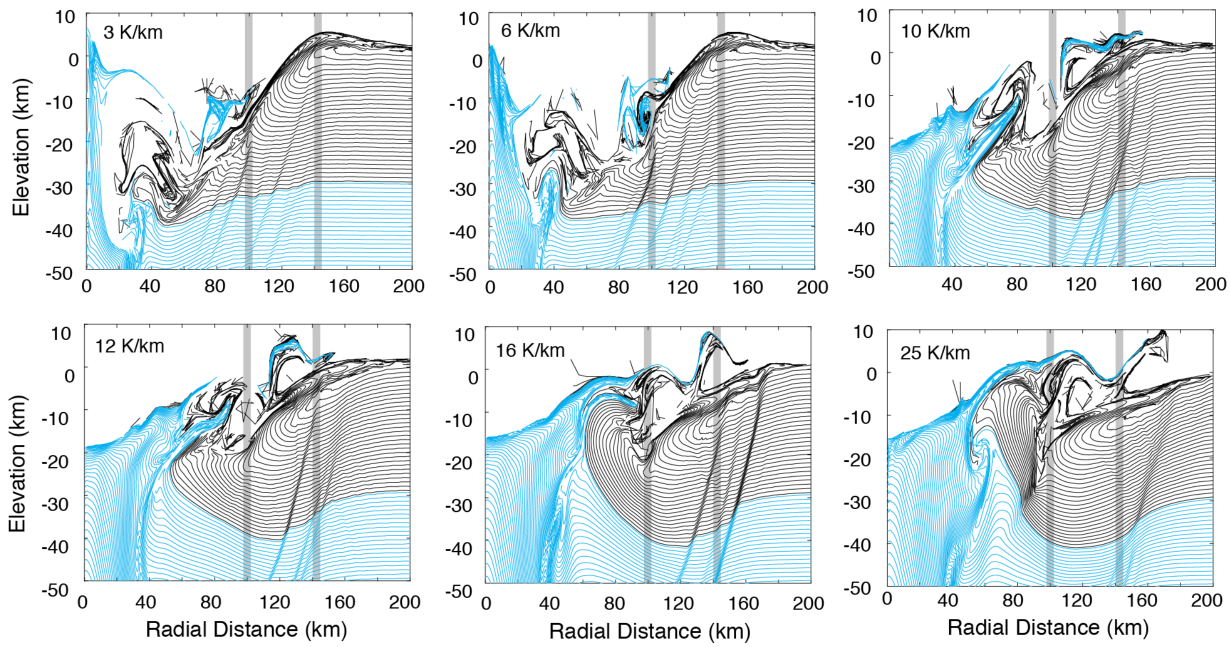

Figure 1: Plots showing basin development for a variety of tested thermal gradients 500 seconds after impact from a 36 km diameter projectile. The panels are arranged according to thermal gradient. Lines are initially horizontal tracer particles spaced 1 km apart. Tracers more than 7.5 km from the nearest horizontal neighbor are excluded for clarity. Gray bars are the current surface locations of the faults around Mead Basin. Black lines are crustal material (basalt composition) and blue lines are mantle material (dunite composition). As the thermal gradient increases, inner fault development is dominated by ductile deformation and the outer fault develops farther from the basin center.

Previous workers [17] calculated heat flows for each of the endmember lid regimes concluded that planets with thermal gradients of less than 17 K/km would be in a stagnant lid regime, higher than the thermal gradients we find here for Mead. Consequently, our simulations indicate that Venus had a relatively thick (≥ 70 km) conductive lid at the time Mead Basin formed.

Conclusions: The geologic history of Venus continues to confound researchers, specifically regarding the method and rate of resurfacing and the lack of an identifiable resurfacing mechanism. Analyzing impact basin morphologies and how they vary with thermal conditions is one way to address this issue. Here we show that faulting around Mead Basin indicates a maximum surficial thermal gradient of 10 K/km, placing Venus in a stagnant lid tectonic regime when the basin formed.

This modeling of Mead Basin is the first numerical modeling study to recreate a multiring basin on a planetary body other than the Moon and provides an independent method of testing various geologic histories of Venus. Models of crater and basin development have traditionally focused on recreating lunar basins, but this expansion of the technique onto additional terrestrial bodies will be a useful approach as we continue to strive to understand Venus and beyond.

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