

Today I am going to discuss the preliminary results of my research on the formation of Artemis which is a unique feature on the surface of Venus

**[Next Slide] Regional Location**

Artemis is located in the Aphrodite Terra region of Venus and is surrounded by rugged highlands to the north and relatively smooth lowlands to the south. Artemis is about 2600 km across which is roughly the distance from Salt Lake City to Atlanta, Georgia.

**[Next Slide] Radar Image**

Artemis' most distinctive feature is the circular annulus of deformation known as Artemis Chasma. This chasma ranges from 25-200 km wide and completes nearly 300 degrees of arc.

**[Next Slide] Topography**

In profile you can see that the chasma boasts about 1-2 km of relief. Topographically Artemis is similar to some coronae which are a suite of quasi-circular features with an annulus of fractures plus or minus radial fractures, however the average corona is only 200 km in diameter and Artemis is more than twice the size of the largest corona. The size and plan-form shape of Artemis are similar to the broad domal uplifts of volcanic rises and the flat-topped steep-sided crustal plateaus, however Artemis is obviously dissimilar in topography.

**[Next Slide] Simplified Map**

My work has focused on detailed mapping of structures in the interior of Artemis to gain insight into its formation which I present here in a simplified form. The work from the chasma outward is schematized from published maps by Brown and Grimm in 1995 and Hansen in 2002. My mapping has revealed a rich record of deformation and volcanic activity. The blue units are interpreted as highly deformed basal units that host a remarkable penetrative fabric which I will show in the next slide that has a consistent northeast trend across the entire interior and even extends out of Artemis to the southwest though it is only shown schematically here. Radial and concentric fractures that post-date

the penetrative fabric trace back to 3 centers of tectonic and magmatic activity that are surrounded by extensive composite flows and have distinctive thin low-viscosity lava flows in their centers that delicately inter-finger with the adjacent units. The extensive flows emanating from these centers are pockmarked by shield volcanos and there are numerous magmatic troughs that indicate subsurface magmatic transport. Flow direction indicators and cross-cutting relationships indicate that the flows overlapped spatially and temporally during their development. In the east along the margin the flows are cut by chasma structures and also bury chasma structures, implying that the flows were emplaced at broadly the same time as the chasma was forming. Now let's look closer at the penetrative fabric I mentioned.

#### **[Next Slide] Penetrative Fabric**

This is a representative image of the penetrative fabric; I've inverted the image to help you see the lineaments. The fabric has a consistent northeast orientation across Artemis. I measured the fabric along 8 transects distributed across the study area noted by the yellow dots in the index map. The average wavelength is about 700 m, or about 650 m if you don't include the outlier measurement. It's important to note that this is a maximum wavelength because the fabric goes right down to the resolution of the data set making it difficult to measure. The short wavelength implies that we have a very thin layer that was deformed over a huge area with a layer beneath that accommodated strain homogeneously. One interpretation is that the brittle-ductile transition was shallow when the penetrative fabric was formed and moved deeper with time. There is also a subtle long wavelength topographic warp with a different orientation that formed after the fabric was emplaced which would be consistent with a deepening brittle-ductile transition, but again that is just one interpretation. This fabric is a critical constraint that any hypothesis for forming Artemis must address, so now I'll walk you through some of these hypotheses and see how they stand up.

#### **[Next Slide] 4 Hypotheses**

Currently there are 4 hypotheses for the formation of Artemis.

First the subduction hypothesis was proposed by various authors who looked at the chasma and noted the similarity to terrestrial subduction trenches. This hypothesis predicts northwest convergence with right lateral strike-slip motion in the southwest and left lateral strike-slip motion in the northeast portions of the chasma and the presence of chasma parallel normal faults in the subducting slab due to flexure.

The meteorite impact hypothesis is based solely on the circularity of Artemis. It predicts a ridge surrounding a basin, the obliteration of preexisting structures, and the near instantaneous formation of Artemis.

The metamorphic core complex hypothesis is based on an analysis of deformation in the center of Artemis where 170 km of extension was inferred to expose deep crustal rocks and possibly even mantle rocks.

The plume hypothesis fell out of numerical and physical modeling of the interaction of rising diapirs with a surface. There are several variations but all models agree on the formation of a circular trough with concentric fractures and varying deformation and volcanic activity in the interior.

We now have enough information to evaluate these hypotheses and at least toss a couple out right off the bat.

#### **[Next Slide] Metamorphic Core Complex**

The metamorphic core complex hypothesis doesn't put the interior deformation into a regional context and it predicts specific details that we just can't test with our current data set. This doesn't completely invalidate the hypothesis, but we just can't evaluate it right now.

#### **[Next Slide] Meteorite Impact**

A meteorite impact could possibly add enough energy to the system to create a thin layer of melt to form the penetrative fabric in, but it would not predict a preferred orientation of this fabric across this distance, nor would it explain the fabric observed outside of Artemis. More importantly the meteorite impact hypothesis predicts the inverse of the observed topography. Unless new cratering physics comes along to explain this topography we can toss this hypothesis out.

### **[Next Slide] Subduction**

As I mentioned before the subduction hypothesis came about because of the analogy to terrestrial subduction zones where we see gently sloping topography that ramps up and then dips into a trench, much like the topography observed for parts of the chasma. Flexural modeling of the chasma done by Brown and Grimm in 1996 was only able to get good results for a limited portion of the trough and had great difficulty explaining the absence of chasma parallel normal faulting in the down-going slab. There are some first order geometry problems with this hypothesis as well. First, for the chasma to cover so much arc the subduction angle would need to be very shallow, essentially putting the subducting slab on course to come out the other side of Artemis much like cutting an orange with a knife. It is also important to note that on a dry Venus we would not expect volcanism associated with subduction, we actually expect the opposite, meaning that all volcanic activity in the interior would occur prior to chasma formation, which is inconsistent with my mapping. Furthermore, in the regions where strike-slip motion is predicted it doesn't make sense for the chasma to retain its topographic expression since flexure would not occur there. Hansen's 2002 Artemis paper demonstrated the absence of strike-slip motion in the northeast so here we'll take a look at the southwest.

### **[Next Slide] No shear**

This region was previously interpreted as a shear zone based on the apparent change in trend of lineaments across this ridge. I've highlighted a few of the lineaments to help calibrate your geo-eyes. First off, I think this change in trend can be explained by foreshortening, which is a radar imaging effect where areas of high topography will be displaced towards the radar illumination source (in this case the left) which is what we see as the lineaments cross this large topographic ridge. That being said, even if you disagree and think these changes in trend are real, there are only two cases where a shear zone could produce this geometry...

### **[Next Slide] No shear 2**

...which I've highlighted here in green. If the lineaments formed and then were sheared, shown in the upper left, or if they are extensional and they formed progressively during shearing, shown in the second down on the left, a left lateral motion can produce this geometry. However this is the opposite shear sense than the subduction hypothesis predicts for this area. Note that the geometries highlighted in red don't work and especially that none of the right lateral geometries can work.

**[Next Slide] No strike-slip**

If we look at another region where strike-slip motion is predicted we see shallow troughs with the same trends on either side of the chasma. We can even see that some lineaments cut and are cut by chasma structures. I would argue that there is no evidence for horizontal displacement in this area and that cross-cutting relationships indicate that these shallow troughs were forming at roughly the same time as the chasma was forming.

**[Next Slide] Plume Hypothesis**

Moving on to the plume hypothesis, as I mentioned earlier all models predict a circular trough. Geologic mapping reveals that the simple case of a single diapir rising is unlikely, however, the onset of small scale convection in a flattening plume modeled by Griffiths and Campbell in 1992 or the spawning of secondary diapirs suggested by Hansen in 2002 can accommodate the observed tectonic and volcanic centers in the interior of Artemis. This hypothesis predicts the formation of a complete circular trough, which is not observed, but this could be explained by a crustal anisotropy or some other factor that prevented the chasma from closing the circle. A plume could bring enough heat with it to raise the brittle-ductile transition to shallow depths to form the penetrative fabric observed both inside and just outside of Artemis then allow the preservation of longer wavelength structures as the region cools and the brittle-ductile transition sinks back down, however it would predict a random fabric orientation, or perhaps a radial orientation, rather than the strong preferred fabric orientation we observe.

**[Next Slide] Conclusion**

In conclusion, of the four hypotheses that I've presented for Artemis' formation we can set aside the metamorphic core complex hypothesis for now because it makes predictions that are not testable at this time and doesn't address the big picture of Artemis' formation, the meteorite impact hypothesis predicts the inverse of the observed topography so we can toss that out, the subduction hypothesis has several geometric problems to overcome and does not accommodate an overlapping evolution of the chasma and the volcanic centers in the interior, and the simple plume scenario is not consistent with the geologic mapping. The complex plume hypothesis accommodates the volcanic centers and their spatially and temporally overlapping formation with the chasma, but it needs to be refined to explain the strong preferred orientation of the penetrative fabric. There is much more work to be done, but I think I have a good start and hopefully it will turn into a defensible master's thesis by May.

Thank you very much.