GEOLOGIC ANALYSIS OF DEFORMATION IN THE INTERIOR REGION OF ARTEMIS (VENUS, 34°S 132°E).
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Introduction: Artemis measures approximately 2600 km in diameter making it the largest known circular structure on a terrestrial planet. Artemis' most distinctive feature is Artemis Chasma, a ~25-200 km wide, ~1-2 km deep, ~2100 km diameter circular trough surrounding an interior topographic high. Venus' surface abounds with circular to quasi-circular features at a variety of scales including, from smallest to largest, small shield edifices, large volcanic edifices, impact craters, coronae, volcanic rises and crustal plateaus, however Artemis defies classification into any of these groups. Artemis dwarfs Venus' largest impact crater, 270 km diameter Mead, as well as the smaller volcanic edifices. Topographically Artemis resembles some coronae, however Artemis is an order of magnitude larger than the average corona and is more than twice the size of the next largest corona, Heng-O. Artemis resembles volcanic rises and crustal plateaus in planform, but differs greatly in topography. Debate during the past decade resulted in the proposal of four hypotheses for Artemis' formation. Artemis represents: 1) the surface expression of a bolide impact [1]; 2) a composite structure with the interior marking the exposure of ductily deformed deep crustal rocks analogous to a metamorphic core complex [2]; 3) a zone of northwest directed convergence and subduction [3-6]; or 4) the surface expression of a mantle plume [7-10]. We evaluate these hypotheses based on detailed geologic mapping of the interior of Artemis using NASA Magellan SAR imagery and topography data.

Observations: Artemis records a rich history of deformation and volcanic activity (figure 1). Basal terrains A and B (bta, btb), interpreted as deformed basal units, host a remarkably penetrative fabric that displays a consistent northeast trend across the interior. Radial and concentric fractures that post-date the penetrative fabric trace back to three centers of tectonic and magmatic activity, each hosting distinctive thin low-viscosity lava flows in their centers (cfm) that delicately inter-finger with the adjacent units. Composite flows that surround the centers (efb, efc) are pockmarked by shield volcanos and host numerous magmatic troughs that indicate subsurface magmatic transport. Flows along the eastern margin of the interior (efc) are both cut by and bury chasma structures, implying generally synchronus emplacement of flows and chasma formation. Artemis Chasma formed as a coherent entity, covering nearly 300 degrees of arc and narrowing and shallowing from the southeast around to the northwest where it fades out [9], suggesting that the chasma never formed a complete circle (e.g. the chasma is not buried in the northwest).

Penetrative Fabric: Penetrative fabric wavelength, measured at 19 sites (table 1, figure 1), averages 540 meters and is generally oriented NE-SW. This is a maximum wavelength given that the fabric approaches effective data resolution [11]. The short wavelength implies that a very thin layer was deformed over a huge area; presumably a subsurface layer accommodated strain homogeneously because a second, longer-wavelength fabric is not observed. Cross-cutting relationships indicate the penetrative fabric predates more-widely spaced fracture sets. Localized occurrences of the penetrative fabric near the three tectonomagmatic centers deviate from the regional NE-SW orientation by 90 degrees and parallel local fracture sets, suggesting the presence of penetrative fabric influenced the orientation of the local fracture sets and perhaps the tectonomagmatic centers' development overlapped temporally to some extent with the formation of the penetrative fabric. The penetrative fabric comprises a critical constraint that any hypothesis for forming Artemis must address.

Discussion of the four hypotheses:

Meteorite impact hypothesis: This hypothesis suggests that Artemis marks the surface expression of a bolide impact [1]. The hypothesis makes few specific predictions about Artemis, however the topographic profile of Artemis, a trough surrounding an interior high, is the inverse of that expected for a huge impact crater. Additionally, Artemis lacks the multiple ring structures expected for large impact craters. This hypothesis requires the formation of a complete rim and postulates its subsequent burial in the northwest region [1], yet Artemis Chasma and chasma structures simply fade, rather than show evidence of embayment which would be expected in the case of burial. This hypothesis also does not address the formation of the pervasive penetrative fabric, development of the tectonomagatic centers, or interior flows forming synchronously with chasma folds.

Metamorphic core complex hypothesis: This hypothesis, which predicts ~170 km of NW-SE extension in the center of Artemis that exposes deep crustal rocks [2], does not put this extension into a regional context and makes predictions that simply are not testable with the current data. Furthermore, Venus' lack of significant erosion makes exhumation of deep crustal rocks unlikely [12]. This hypothesis does not address the formation of the pervasive penetrative fabric, and the postulate extension direction is orthogonal to the penetrative fabric trend.

Subduction hypothesis: This hypothesis predicts NW-directed convergence along Artemis Chasma, the topographic expression of which is postulated as the result of flexure of the subducting slab [3-6]. Flexural modeling of the chasma met with some success for a limited portion of the trough [6] but fails to explain why the trough-like topographic expression exists where it is nearly parallel to the direction of convergence and thus where flexure should not occur. Furthermore, this hypothesis predicts strike-slip displacement in the NE and SW portions of the chasma, yet none is observed [9] and in fact, interior structures appear continuous across the NW-trending portions of the chasma. On a dry Venus we would not expect volcanism associated with subduction, meaning that all volcanic activity in the interior would occur prior to chasma formation, inconsistent with geologic relations along the eastern and southwestern interior margins. This hypothesis does not address the formation of the pervasive penetrative fabric.

Plume hypothesis: This hypothesis arose from physical and numerical modeling of the interaction of thermal diapirs with a surface [7, 8]. Several variations exist but all models agree on the formation of a circular trough with concentric fractures and varying deformation in the interior. 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 [7] or the spawning of secondary diapirs [9] might accommodate the observed tectonomagmatic centers in Artemis' interior. A plume might transport enough heat to raise the brittle-ductile transition to shallow depths to form the penetrative fabric, then allow the preservation of longer wavelength structures as the region cools, deepening the brittle-ductile transition with time. This hypothesis does not predict the observed strong preferred orientation of the penetrative fabric, however with modification it is the most promising hypothesis avenue currently entertained.

References: [1] Hamilton, W.B., (2005) in G.R. Foulger, et al., eds., *Plates, Plumes, and Paradigms: GSA Special Paper 388*. p. 781-814. [2] Spencer, J.E., (2001) GSAB. **113**(3): p. 333-45. [3] McKenzie, D., et al., (1992) JGR. **97**(E8): p. 13533-44. [4] Brown, C.D. and Grimm, R.E., (1995) Icarus. **117**: p. 219-49. [5] Schubert, G. and Sandwell, D.T., (1995) Icarus. **117**(1): p. 173-96. [6] Brown, C.D. and Grimm, R.E., (1996) JGR. **101**(E5): p. 12697-708. [7] Griffiths, R.W. and Campbell, I.H., (1991) JGR. **96**(B11): p. 18,295-18,310. [8] Smrekar, S.E. and Stofan, E.R., (1997) Science. **277**(5330): p. 1289-94. [9] Hansen, V.L., (2002) GSAB. **114**(7): p. 839-48. [10] Ivanov, M.A. and Head, J.W., (2003) XXXIV Lunar and Planetary Science Conference,(1188.pdf). [11] Zimbelman, J.R., (2001) Geomorphology. **37**(3-4): p. 179-99. [12] Arvidson, R.E., et al., (1992) JGR. **97**(E8): p. 13303-17.

Lat	Long	λ (m)
-25.58	134.74	303
-30.35	129.70	345
-31.63	133.75	380
-34.34	132.10	402
-30.95	137.09	449
-29.59	130.09	453
-32.46	130.61	462
-30.80	134.42	468
-27.57	136.65	494
-32.15	130.93	495
-35.38	133.62	526
-30.71	130.64	572
-30.78	129.99	588
-36.21	132.48	607
-28.12	136.09	641
-35.83	132.13	657
-30.22	128.17	729
-28.68	130.33	731
-40.69	130.57	952
	Average	540

Table 1. Penetrative fabric wavelengths.

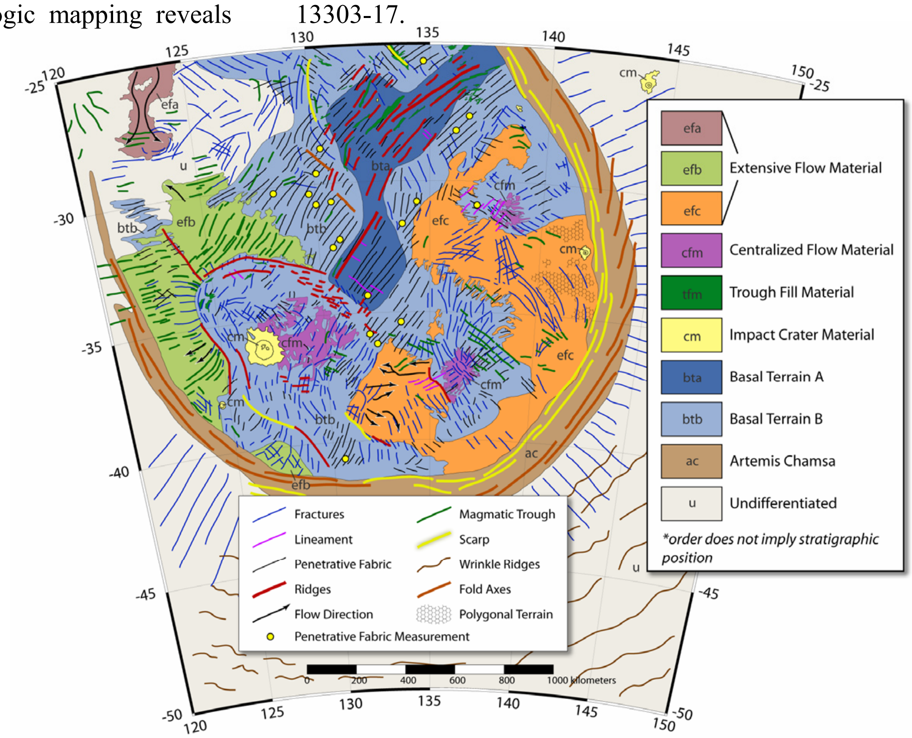

Figure 1. Simplified geologic map of the interior of Artemis.