PRELIMINARY RESULTS AND TIMING CONSTRAINTS FROM THE GEOLOGICAL MAPPING OF THE VOLCANO ATIRA MONS, BETA-ATLA-THEMIS (BAT) REGION, VENUS.
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Introduction: Atira Mons is a large volcano with an average diameter of ~600 km, a height of ~0.9 km and capped with a central caldera ~100 km across (base altitude ~0.6 km; summit altitude ~1.5 km; maximum slope ~0.35º). It is centered at 52.2°N, 272.4°E (92.4°W) in the NE portion of the Beta-Atla-Themis (BAT) region between Kawelu and Guinevere Planitiae (Fig. 1, Fig. 2). When compared to previous geological mapping [1,2], our work provides a more detailed map on a scale of 1:500,000 of the volcanic edifice region, in order to reconstruct its stratigraphy and geological history. Therefore, our results will potentially yield constraints on the relative timing and scale of the different volcanic events. This will be an important input into the time-volume release of CO_2 and SO_2 into the atmosphere from volcanism [3]. Geological units, including lava flows, grabens, fractures, fissures, wrinkle ridges, fracture belts, shield volcanoes and lava channels, are distinguished based on differences in radar brightness, topography and morphology. Relative ages of units are assessed from embayment and cross-cutting relationships.

Geological setting and relationship with other nearby features: Regional analysis shows that Atira Mons and its apron of flows occupy an area of ~300,000 km^2 (Fig. 1, Fig. 2). They partially overlie the older regional plains "**rp**" [2]; on the N and terminate against topographic barriers (fracture belts) on the E and W.

A field of small shield volcanoes is located immediately NE of the Atira Mons' flows (Fig. 2, **sh**). These small volcanoes and their associated flows appear to be younger than the regional plains, but have an uncertain age relationship with respect to Atira Mons.

On the south flank, Atira Mons flows partially cover a cluster of coronae and corona-like features, including Davies Patera (Fig. 2, **ccl**) and are covered by a dark craterless blast halo (Fig. 2, **cbh**) [4,5]. SW-trending flows (Fig. 2) can also be traced ~800 km away from the Atira Mons summit, where they partially cover older plains with wrinkle ridges (unit "**pwr**" in [2]).

Flank flow apron: Most of the mapped lava flow units extend radially downslope away from Atira Mons' summit region (**mA**, Fig. 3) until they reach a topographic barrier such as the fracture belts on the E (**fbE**, Fig. 3), W and SW sides (**fbW**, Fig. 3). The W-, NW- and N-trending flows start radially from outside the caldera rim, but eventually swing 40-50º to the W and converge towards a local bowl-shaped depression of unknown origin (labelled **bs**, Fig. 3) ~300 km NW of the summit. The E flank flows are fed from the eastern side of the caldera interior, crossing its low rim. However, the W and SW flows are not fed from the caldera interior, but more likely from buried circumferential dykes outside the caldera rim, based on their radial trend and the fact that these flows originate outside the rim. Alternatively, these W and SW flows could be fed from the caldera interior if they were emplaced before its formation. This second hypothesis would provide us with a timing constraint that would help us correlate the ages of the flows inside and outside the caldera. Radar bright landslides (yellow unit) can be seen on the W and NW flanks of the caldera (Fig. 4), partly covering and obscuring the assumed sources of the W-trending flank flows.

Central summit history: From our mapping in the summit region (Fig. 4A), we propose the following sequence of events: 1) caldera formation with greater collapse on the east side (Fig. 4B); 2) emplacement of flows on the floor of the caldera, which were later deformed by polygonal fractures and a small set of arcuate fractures [6]; 3) emplacement of younger flows covering part of the summit floor and fed from small shield volcanoes; 4) formation of a set of wrinkle ridges deforming the youngest flows.

Arcuate fracture systems: A major arcuate fracture system, which is interpreted to overlie a circumferential dyke swarm [7] is located on the E flank of Atira Mons (Fig. 5). This could suggest that late in its history Atira Mons started to develop corona-like characteristics. This arcuate fracture system cuts across the majority of the E-trending radial flows (**fE**, Fig. 5), indicating that most of these fractures are younger than the flows. However, the northern end of this fracture system is completely covered by a younger set of N- and NE-trending flank flows (**fN**, Fig. 5). The presence of these arcuate fractures only on the E side could reflect formation of a partial (<360°) circumferential fracture system [8]. Two smaller arcuate fracture systems on the SW portion of Atira Mons (Fig. 5) may form part of a large elliptical system that also incorporates the eastern fracture system. We are currently assessing these patterns and their relation to caldera subsidence and similar features seen in coronae.

Eastern flank flows: Also on the eastern flank, the lobes of unit **fSE-2** have a sharp contact with the arcuate fractures and seem to originate from them (Fig. 6). This hypothesis is supported both by topography and flow morphology. Cross-cutting and embayment relationships indicate that these are some of the youngest units on Atira Mons' eastern flank. Another possibility is that these flows are actually sourced from the caldera and are, therefore, part of unit **fSE-1**.

Southwestern flank flows: On the SW flank of Atira Mons the flow unit **fSW-1** has a length of ~600 km (Fig. 7A). Its width initially is ~100 km, increasing to ~180 km and then decreasing again to ~50-100 km. This variability reflects changes in regional topography, as indicated by the profile in Fig. 7B, which could potentially be evidence for the presence of an annular depression caused by the overlying weight of the volcano: a flexural moat [9]. We are currently evaluating further evidence to assess this possibility, since most of Venus' moats are thought to be filled by lava flows from large volcano edifices [10]. This could also be related to the changing lengths of superposed phases of lava flows and a step-like structure of the edifice.

Acknowledgments: Magellan SAR images obtained from https://astrogeology.usgs.gov/search/?pmi-target=venus based on data from https://pdsimaging.jpl.nasa.gov/volumes/magellan.html#mgnFMAP.

References: [1] Dohm J. M. et al. (2011) *USGS Scientific Investigations*, Map 3158. [2] Ivanov M. A. and Head J. W. (2011) *Planet. & Space Sci*, 59, 1,559-1,600. [3] Way M. J., Del Genio A. D. (2020) *JGR*, V. 125 (5), № e2019JE006276. [4] Antropova E.G. et al. (2021) *12M-S³*. [5] Antropova E. G. et al. (2021) *AGU Fall Meeting*. [6] Smrekar S. E. et al. (2002) *JGR*, 107(E11), 8-1 to 8-17. [7] Buchan, K.L. and Ernst, R.E. (2019) In*: Srivastava et al. (eds.) Dyke Swarms of the World – A Modern Perspective*. Springer, 1-44. [8] Ernst R. E. et al. (2019) *J. of Volcan. & Geotherm. Res.*, 384, 75-84. [9] McGovern P. J. et al. (2014) *Geology*, 42, № 1, 59-62. [10] McGovern P. J. and Solomon S. C. (1997) *JGR*, 102(E7), 16,303-16,318.

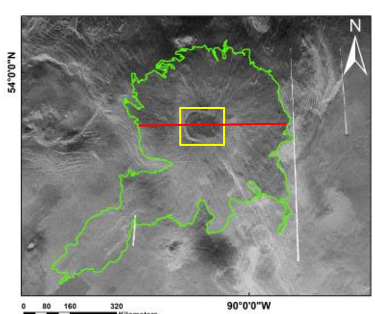


Figure 1 – General view of Atira Mons (green line). The yellow box locates Fig. 4a and the red line, Fig. 4b.

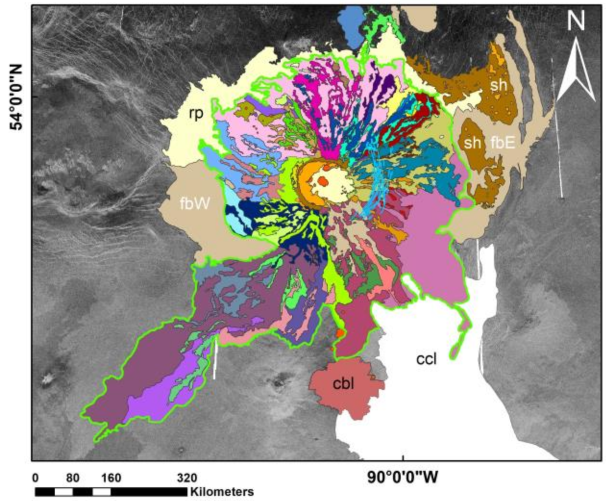


Figure 2 – Geological map of the study area. Unless indicated otherwise, colors represent different generations of lava flows and geological structures; **fbW** – western fracture belt; **fbE** – eastern fracture belt; **ccl** – cluster of coronae; **sh** – shield volcanoes; **cbh** – craterless blast halo.

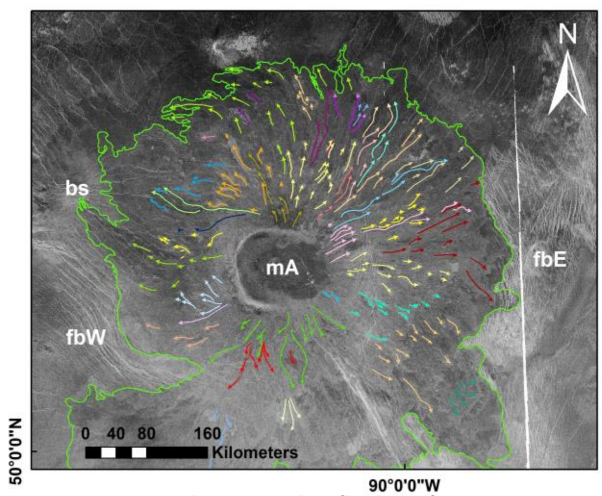


Figure 3 – Flows on the flanks of Atira Mons. Colors indicate different generations of flows mapped on the basis of embayment and cross-cutting relationships. The green line shows the full extent of the flows. **mA** – Atira Mons' summit; **fbW** – Western fracture belt; **fbE** – Eastern fracture belt; **bs** – local depression (basin).

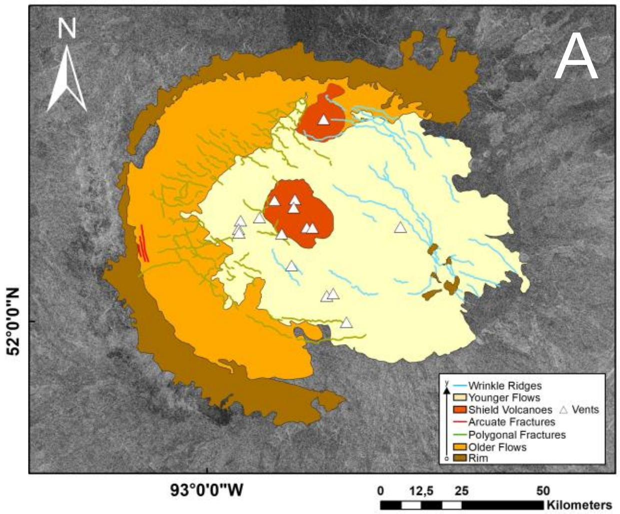


Figure 4 – A) Geological map of Atira Mons' summit (above); B) Atira Mons' W-E topographic profile (below) on the red line in Fig. 1.

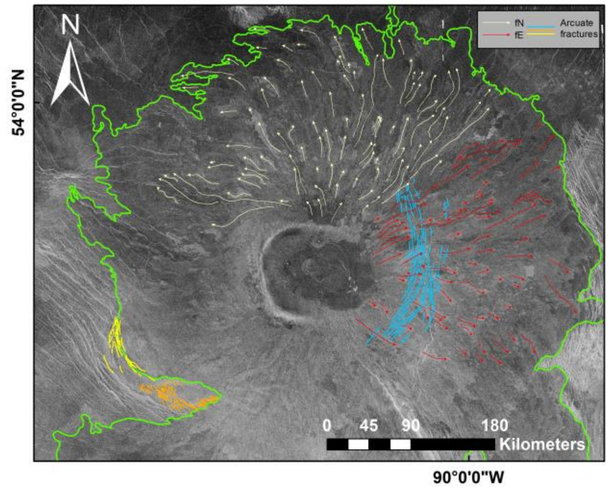
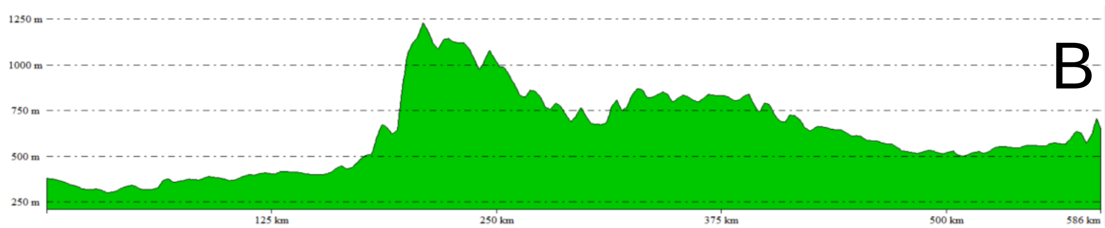


Figure 5 – Eastern arcuate fracture system (blue lines) cutting older E trending flank flows (**fE**) but cut by younger NNE trending flank flows (**fN**). On the SW portion are located two other systems of arcuate fractures.



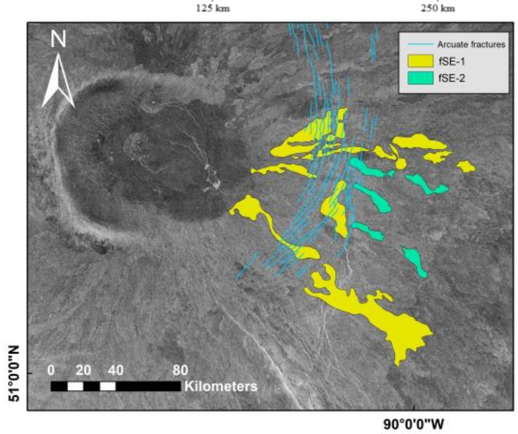
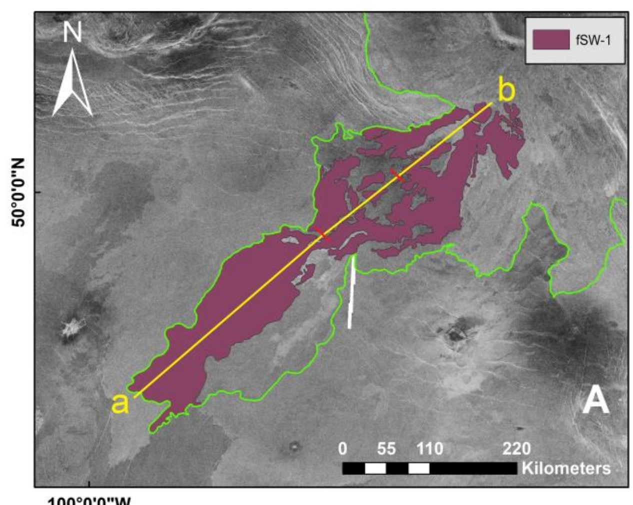


Figure 6 – Flows on the eastern flank of Atira Mons show some potential eruption sources. **fSE-1** clearly can be traced to Atira Mons' summit, while **fSE-2** could be emanating from the arcuate fractures or be a part of **fSE-1**.



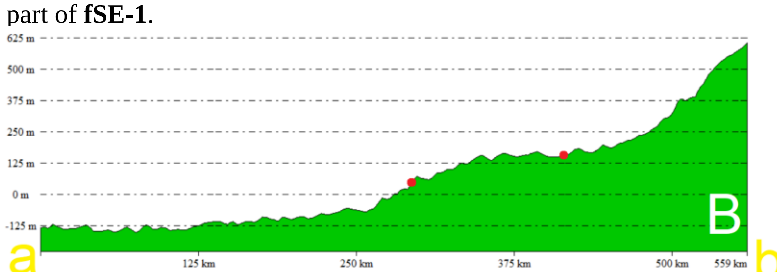


Figure 7 – A) Areal extension of unit **fSW-1** (above). The yellow line ab indicates the topographic profile shown in B, while the red lines correspond to the red dots in B; B) Topographic profile of the flow unit **fSW-1** along line ab.