MAJOR EPISODES OF VOLCANIC ACTIVITY AT THE LARGE SHIELD VOLCANO TUULIKKI MONS, VENUS. M.A. Ivanov[1], J.W. Head[2], L. Wilson[3], [1]Vernadsky Institute, RAS, Moscow, Russia, mikhail_ivanov@brown.edu; [2]Brown University, Providence RI, USA; [2,3]Lancaster University, Lancaster, UK.

Introduction: Tuulikki Mons is a large shield volcano (~ 350-400 km wide) [1,2] in the eastern portion of Hinemoa Planitia, which is bordered on the north and east by the large rift zones Hecate and Devana Chasmata (Fig. 1). The Tuulikki volcano is a distinct, self-standing topographic feature [3], which is ~2 km higher than the background of the flat Hinemoa Planitia (Fig. 1). The flanks of the volcano are covered

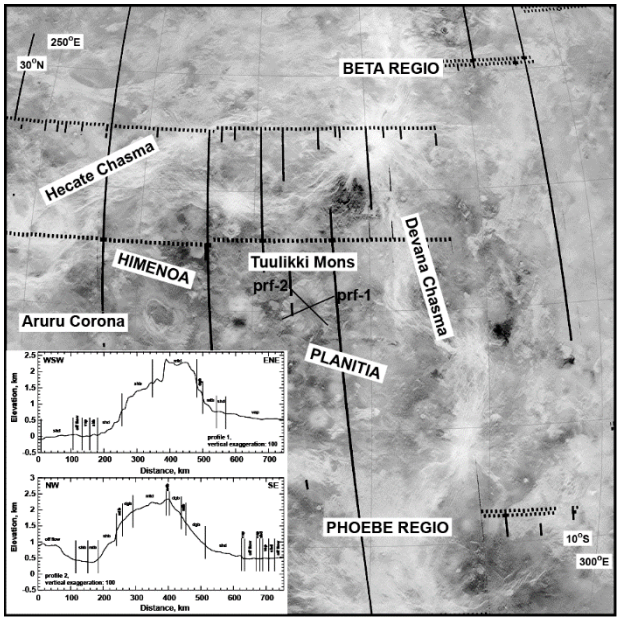

Fig. 1. Regional settings and topography of Tuulikki Mons.

by numerous and tectonically undisturbed lava flows [4] that overlie the vast plains surrounding the volcano base [5]. The lava flows of Tuulikki Mons belong to the unit of lobate plains (Bell Formation) that represent an important component of the late Network rifting-volcanism regime of resurfacing on Venus [6]. In the global geological map of Venus [5], lobate plains were mapped as a single unit. In this study, we divide them into morphologically discernible flow complexes in order to unravel the sequence of major events and eruption styles that operated during the observable evolution of the Tuulikki volcano.

Complexes of lava flows: Changes in the radar albedo patterns largely define morphologies of the lava flow complexes on the slopes of Tuulikki volcano. In our study, we used both the specific morphology and topographic position (Fig. 1) of the complexes to establish their stratigraphic relationships. Since the brightness of the radar images is mostly modulated by the meter-decameter roughness of the surface [e.g., 7], the characteristic radar albedo pattern of the flows also reflects the specific conditions of their emplacement and provides clues to the interpretation of their eruption style.

Radar-dark sheet-like flows (shd, Fig. 2a): These flows preferentially occur at the lowest topographic levels and, thus, have the lowest stratigraphic position (Fig. 3). The flows are broad (up to 30-40 km wide) and show characteristically low radar albedo. The dark flows embay the surrounding regional plains around the base of the volcano and appear to be superposed by the other types of volcano lava flows.

Flows with variegated albedo pattern (vap, Fig. 2a,b): These flows show a mottled albedo pattern that consists of brighter patches on a darker background. The shape of the patches indicate that they are relatively short (5-10 km long) lava flows. The *vap*-flows predominantly occur near the southern and eastern edges of the volcano together with the dark flows (Figs. 1, 3) at lower topographic levels; where the flows occur together, there is evidence of superposition of the *vap*-flows on the *shd*-flows (Fig. 2). Both types of flows (*shd* and *vap*) form elongated features radiating away from the apparent edge of the Tuulikki Mons lava skirt (Fig. 3) and local topography of the surrounding plains seems to control the distribution of the oldest lava flows (Fig. 1). The distribution of the oldest flows does not indicate the presence of a peripheral moat around the base of the Tuulikki construct.

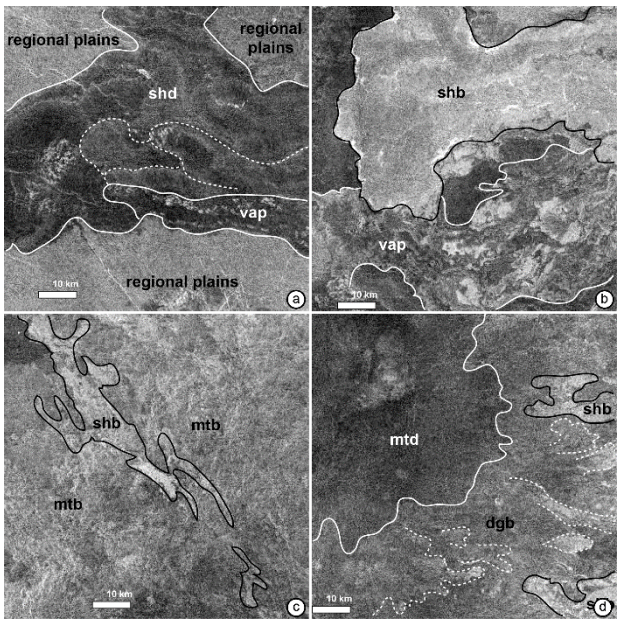

Fig. 2 Examples of lava flows that occur on Tuulikki Mons (see text for description and units).

Mottled bright materials (mtb, Fig. 2c): These consist of a great number of short and narrow (up to several km long, hundred meters wide) flows that cannot be mapped individually at the resolution of the Magellan images. Unit *mtb* covers the majority of the flanks of the volcano but does not occur either within the topographically lower lava flows or at the summit of the volcano (Figs. 1, 3). Although clear stratigraphic

relationships of *mtb* flows with *shd*- and *vap*-flows are absent, the higher topographic position of unit *mtb* (Figs. 1, 3) suggests that it also has a higher stratigraphic position.

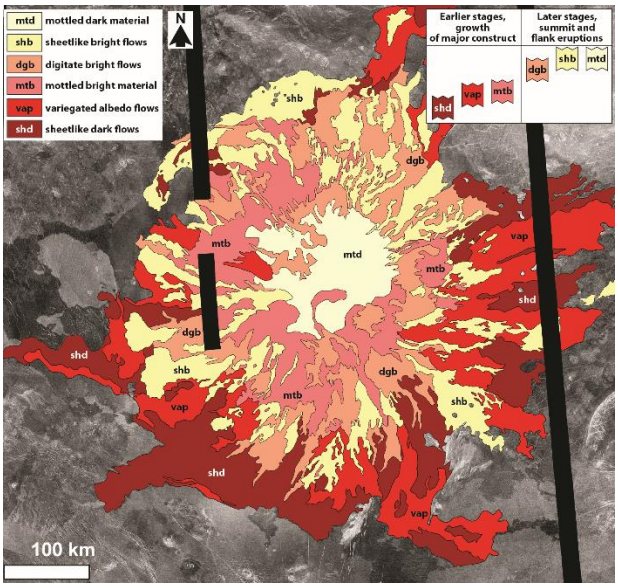

Fig. 3 Geological map and correlation chart of units that make up the surface of Tuulikki Mons.

Digitate bright flows (dgb, Fig. 2d): These form slightly elongated fields of materials with a uniform and higher radar albedo on the background of which individual and still brighter flow-like features are visible. Unit *dgb* almost exclusively occurs on the volcano flanks all around the main construct. At the topographically lower edges (Fig. 1), these flows superpose the *shd*- and *vap*-flows. In places, the brighter flows of unit *dgb* overlay unit *mtb*.

Sheet-like bright flows (shb, Fig. 2b,c): These form the most pronounced lava flows that preferentially occur on the flanks of the main construct (Fig. 3) but are fewest in number. Near the northern edge of the volcano, the bright flows overlay the vast plains of the volcano surroundings. The bright sheet-like flows are large (many tens of km long and up to 15-20 km wide); they begin near the edges of the flattened volcano summit. Some of them bifurcate downslope and produce an anastomosing pattern with "islands" of the older units inside. The bright flows superpose all underlying volcanic materials described above and thus are among the youngest features of Tuulikki Mons .

Mottled dark materials (mtd, Fig. 2d): These are confined within the plateau-like summit of Tuulikki Mons (Figs. 1, 3) and show a featureless surface with relatively low radar albedo. No bright or dark elongated flow-like features cross the summit of the volcano. We also find no evidence for the presence of steep-sided domes [8] in the summit area of the volcano.

Major episodes of volcanic activity at Tuulikki Mons: The sheet-like dark flows (*shd*) and flows with variegated albedo pattern (*vap*) represent the first discernible episodes of volcanic activity at Tuulikki Mons. These broad and long flows indicate that the earlier phases of volcanism were related to voluminous eruptions. The fairly uniform and low radar albedo of the apparently oldest *shd*-flows suggests that they formed by voluminous and contiguous eruptions that caused emplacement of the smooth, pahoehoe-like lavas. The background of the following *vap*-flows is also dark but is decorated by numerous apparently sourceless bright spots and flow-like features. Such an albedo pattern suggests that the longer episodes of the formation of the *vap*-flows were punctuated by short pulses of volcanic activity during which the smaller, 'a'a-like, flows were emplaced perhaps by inflation of the older, radar-dark flows.

The emplacement of the much smaller but far more abundant flows that form unit *mtb* likely accompanied the growth of the main construct of Tuulikki volcano. The small dimensions and the great number of these flows suggest that the main construct formed by relatively weak and frequent pulses of volcanic activity. The final episodes of the formation of the volcano's main body likely were related to the emplacement of the mottled dark materials (unit *mtd*).

The later episodes of volcanism at Tuulikki Mons appear to be related to the emplacement of the large but sparse lava flows due to voluminous eruptions from localized sources. Because the flows are on the flanks of the Tuulikki construct, the episodes of emplacement of the later volcanic materials occurred when the growth of the main body of the volcano was almost completed. The most prominent bright sheet-like flows are much larger than the flow-like features composing the main volcanic construct (unit *mtb*) but distinctly smaller even than the visible portions of the earlier volcanic flows (*shd* and *vap*). This indicates a general decrease of magma supply and concentration of magmatic sources in fewer regions. Because the *shb*-flows begin at different elevations, their eruption regions probably were related to either multiple sources, or different levels of drainage of a single source, or both. The final episodes of volcanism at Tuulikki Mons resulted in the formation of the smooth, dark, and featureless summit plains, perhaps due to emplacement of a series of lava lakes within the summit region. The low radar albedo of the summit plains suggests that conditions of lava emplacement were favorable to form surfaces with low meter-decameter roughness. No evidence is seen for radial fractures, asymmetric rift zones, summit calderas/cones/domes, pyroclastic mantling deposits, or a surrounding moat due to loading and flexure.

References: [1] Crumpler and Aubele, In: Encyclopedia of Volcanoes, 727-770, 2000; [2] Stofan et al., LPSC 33, #1105, 2002; [3] Kiefer and Potter, LPSC 31, #1924, 1999; [4] Dufek and Herrick, LPSC 31, #1447, 1999; [5] Ivanov and Head, PSS, 59, 1559, 2011; [6] Ivanov and Head, PSS, 113-114, 10, 2015; [7] Campbell et al, RSE, 30, 227, 1989; [8] Basilevsky et al., LPSC 43, #1092, 2012.