PLAINS VOLCANISM ON MARS REVISITED: THE TOPOGRAPHY AND MORPHOLOGY OF LOW SHIELDS AND RELATED LANDFORMS. E. Hauber[1], [1]Institute of Planetary Research, German Aerospace Center (DLR), Rutherfordstr. 2, 12489 Berlin, Germany (Ernst.Hauber@dlr.de).

Introduction: The morphometry of Martian volcanoes provides critical input to the investigation of their tectonic setting and the rheology of their eruption products. It is also an important prerequisite for studies of comparative planetology, e.g., the comparison between terrestrial and planetary surface features. A recent study [1] used MOLA topography to measure the morphometric properties of several large Martian volcanoes. However, images of the Viking Orbiter mission showed that there are also numerous small and low shield volcanoes on Mars [2-7]. Almost all of these low shields are located within Tharsis and Elysium, the major volcanic provinces on Mars. A comprehensive description of low shields in Tempe Terra based on Viking Orbiter images is given by [5], who describes shield fields with broad, very low shields, often associated with linear fissure vents, and several steeper edifices (Fig. 1). Many of the low shields have one or more summit craters. The craters are relatively small as compared to the basal diameter, and their form may be circular or elongated along the dominant tectonic trend. Plescia [ref. 5] compared low shields in the Tempe Terra region with terrestrial volcanoes and found that they are similar in many aspects to low shields in the eastern Snake River Plains in Idaho (USA; hereafter referred to as ESRP). The characteristics of volcanic features in the ESRP are intermediate between those of flood basalts and those of large shields like Hawai´i. This led [8,9] to propose a unique style of volcanism for the ESRP, termed *plains volcanism*. Besides Tempe Terra, the Syria Planum volcanic province also contains a large number of small shields. Other clusters of low shields exist, e.g., in the Ceraunius Fossae region, southwest of Pavonis Mons, east of Olympus Mons, in the caldera of Arsia Mons, and immediately northwest of Noctis Labyrinthus. This study investigates the topography and morphology of the low shields and related landforms using MOLA, THEMIS, and MOC data.

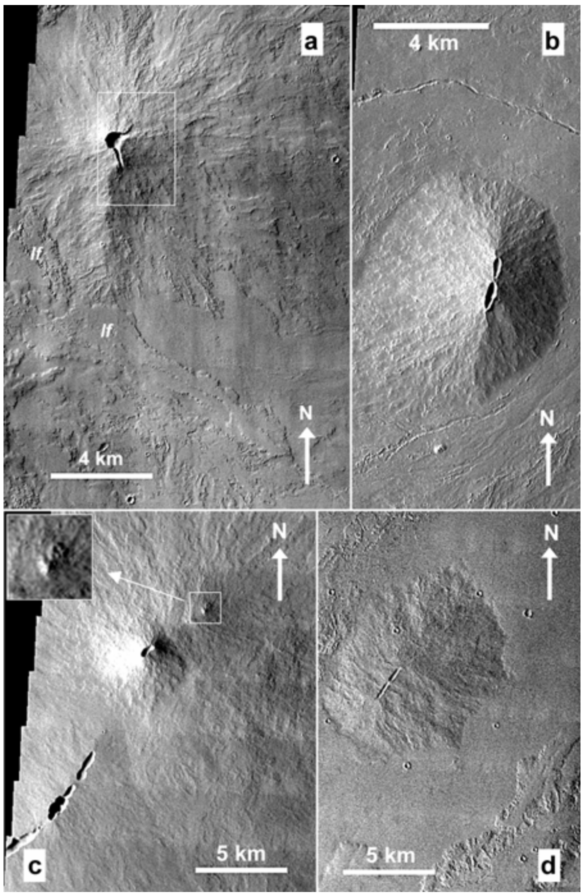

Fig. 1. Examples of low shields as observed in Themis-VIS images. (**a**) Circular shield with a clear radial texture (lava flows) and a breached summit crater. The southwestern part is embayed by younger lava flows (detail of V04124001, 18 m/pixel, near 1.59°S/251.03°E). (**b**) Slightly elliptical shield with two elliptical summit craters. The craters are offset from the center of the shield towards the east, but that may be caused by flooding of the shields by lavas coming from the east. Therefore, the diameter of the shield might have been considerably larger previous to the flooding (detail of V05596013, 18 m/pixel, near 3.24°N/253.25°E). (**c**) Shield with associated linear fissure. Note the flank vent which might be a spatter cone (white box and enlarged inset) (detail of V06658001, 36 m/pixel, near 1.74°S/254.47°E). (**d**) Low shield with two highly elliptical summit craters. The shield, marked by a rougher surface, is embayed by smooth lava flows, and perhaps only the uppermost part of the shield is now visible as kipuka (detail of V07094020, 36 m/pixel, near 0.34°N/252.19°E).

Topography: The most straightforward way to determine the morphometry of a shield is to investigate single MOLA tracks that cross its center. The results show that low shields have very shallow slopes between 0.5° and about 2°, most of them being lower than 1°. The height of the shields is limited to a few hundred meters (maximum ~400 m). Earlier studies [3] used photoclinometry to derive heights and obtained values from 200 m to 400 m, which are close to the real values. The diameter of the low shields usually does not exceed 50 km, but many low shields are considerably smaller. Although low shields on Mars are far smaller than the better-known shields like Olympus Mons, a comparison of their topographic profiles with low basaltic shields on Iceland and in the ESRP reveals that they are still major constructs (Fig. 2).

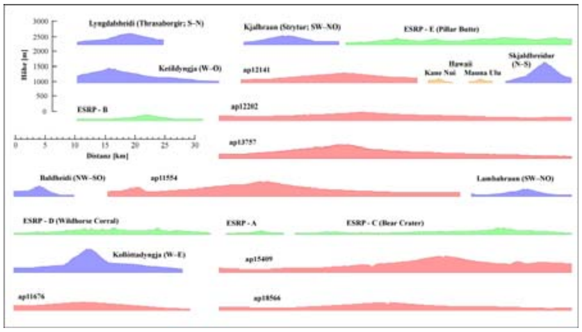

Fig. 2: Topographic profiles across low shields on Mars and Earth. Although low shields on Mars (shown in red) are much smaller than the better-known large shields like Olympus Mons or the Tharsis Montes, their dimensions are significant when compared to their terrestrial counterparts (green: Snake River Plains; blue: Iceland; orange: Hawai´i). The closest analogues are the low shields of the Snake River Plains, the type location for *plains volcanism* [9] (vertical exaggeration of all profiles 5:1).

The volumes and basal areas of low shields were determined in MOLA digital elevation models (DEM). The simplest geometrical form that models a volcanic shield is a simple cone [11]. In particular, very low terrestrial shields (e.g., Mauna Iki in Hawaii, low Icelandic shields) were explicitly referred to as lava cones [12,13]. An inspection of the entire (i.e. not only cross-sectional) topography of low shields on Mars reveals that they often are indeed almost symmetrical cones (Fig. 3 and 4). Therefore, we measure the area and the volume of shields and model the flank slopes assuming a cone as geometric shape for the edifices.

Plots of basal area vs. volume for Martian low shields are shown in Fig. 5. Basal areas of several hundred to about two thousand km^2 are common. The smallest observed shield has a basal area of only 30 km^2, but even smaller ones might have escaped the observations because of resolution limits in the MOLA DEM. Volumes range between 1 km^3 and 200 km^3. A best fit of the cone model to the measurements in the TVP yields a cone with a flank slope of 0.43°. These values agree very well with independent measurements, which also yield flank slopes of less than 1° [14-17]. For a comparison of the Martian shields with shields on Earth, we used published morphometric data of terrestrial basaltic shields [18] and derived their basal area and their volume (Fig. 5b). The low shields on Mars can clearly be distinguished from shields on Earth. While neither their basal area nor their volume are unique as compared to terrestrial shields, their flank slope is less than for all basaltic constructs listed by [18]. The same results is obtained if Martian low shields are compared to low shields in Iceland (Fig. 5c) and to other planetary shields, e.g., the large Tharsis shields and several shields on Venus (Fig. 5d). Typical terrestrial shield volcanoes have flank slopes in the range of 4° to 8° [e.g., 12,19,20]. The generally low flank slopes of the basaltic shields on Earth are controlled by the low viscosity of the lavas, the typically high effusion rates, and the relatively high ratio of flank eruptions to summit eruptions [20]. The even lower slopes of the edifices in Tharsis might indicate that one or more of these factors were particularly dominant during their formation. A high Fe-content of lavas also decreases viscosity and could be important.

Eruption Styles: Several morphologic surface features visible in THEMIS-VIS and MOC images yield clues to infer the eruption styles associated with the formation of the low shields and related landforms of plains volcanism. Many linear fissures are found in

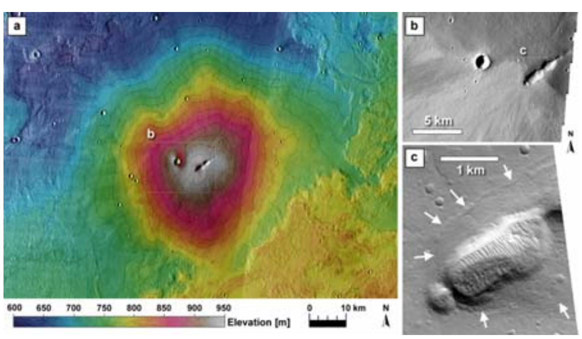

Fig. 3. (**a**) Low shield with row of summit craters in western Tempe Terra (mosaic of Themis-IR images, merged with colour-coded MOLA DEM; 1/128° per pixel, contour line interval 20 m; summit crater of larger shield at 36.34°N/265.27°E). (**b**) Detail of summit region with fractures around the elongated craters, indicating collapse due to magma removal at depth (Themis-VIS V12710004). (**c**) Detail of the westernmost summit craters. The floor of the larger crater is partly filled with eolian dunes or ripples, but the southwestern part is possibly lava. Fractures showing some possible collapse of summit region are marked with white arrows (MOC E10-03778).

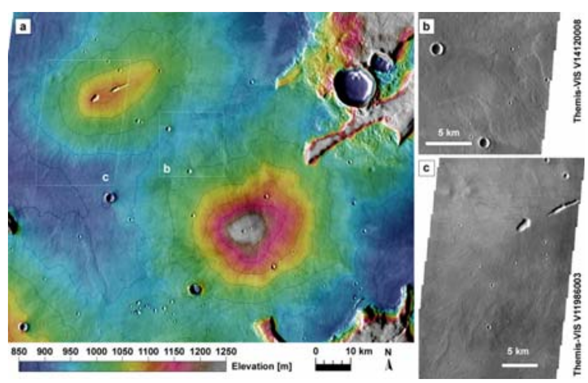

Fig. 4. (**a**) Low shields in Tempe Terra. Both shields have several summit craters, which are aligned in the direction of the regional tectonic trend (SW-NE) (mosaic of Themis-IR images in Mercator projection, merged with colour-coded MOLA DEM; 1/128° per pixel, contour line interval 50 m; summit crater of larger shield at 39.9°N/271.47°E). (**b**) Detail of shield base with multiple, overlapping lava flows (Themis-VIS V14120008). (**c**) Detail of summit region of elongated shield. Lava flows can be seen radiating outwards, and several small linear cones (upper right) might be secondary vents (V11986003).

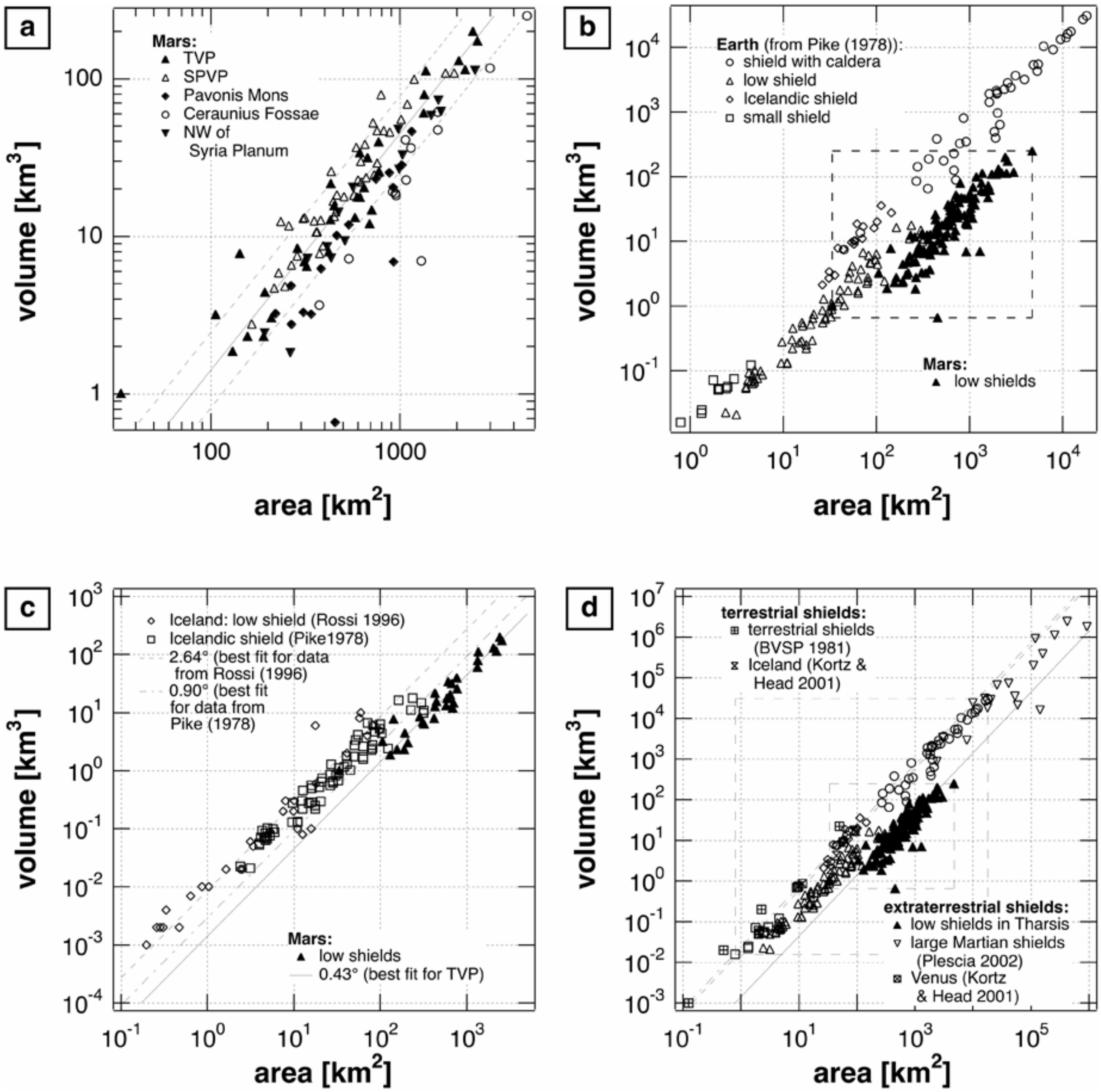

Fig. 5. Morphometric properties of low shields on Mars and comparisons to other shields. The plots show the basal area plotted vs. the volume of the shields. In this representation, the flank slope can be plotted as a diagonal line from the lower left to the upper right, assuming a cone as geometric model for a volcanic shield. For any given basal area, a lower flank slope results in a smaller volume. Consequently, lower slopes plot as diagonal lines shifted downwards. Accordingly, higher slopes. (**a**) Low shields in Tharsis. The lines results from fitting cones with various slopes to the observations. The best fit is obtained for a cone with a flank slope of 0.43°. For comparison, additional lines are plotted that represent cones with flank slopes of 0.25°and 0.75°. Almost all shields fall within this range. (**b**) Comparison between low shields in Tharsis and terrestrial basaltic shields listed by [18]. All terrestrial shields have steeper slopes than their Martian counterparts. The plot range of Fig. 5a is shown as a dashed box. (**c**) Comparison between low shields in Tharsis and Icelandic shields as given by [18] and [13]. (**d**) Comparison of low shields in Tharsis with terrestrial basaltic shields [18,21,22], Venusian shields [22], and large shields in Tharsis [23]. The plot ranges of Fig. 5a and b are shown as dashed boxes (TVP: Tempe Volcanic Province; SPVP: Syria Planum Volcanic Province; BVSP: Basaltic Volcanism Study Project).

association with low shields. These are interpreted as fissure vents leading to fissure eruptions as often observed in terrestrial basaltic environments (e.g., in Hawai´i. Small-scale positive topographic features (Fig. 6) are interpreted as spatter cones, although this can not be verified with available MGS and MO data (HiRISE images with 25 cm/pixel might be better). Well-developed sinuous channels in Tempe Terra and Syria Planum are interpreted as pathways for very low-viscous lavas (analogous to lunar sinuous rilles). In summary, the observed landforms are fully consistent with known basaltic eruptions, e.g., in Hawai´i.

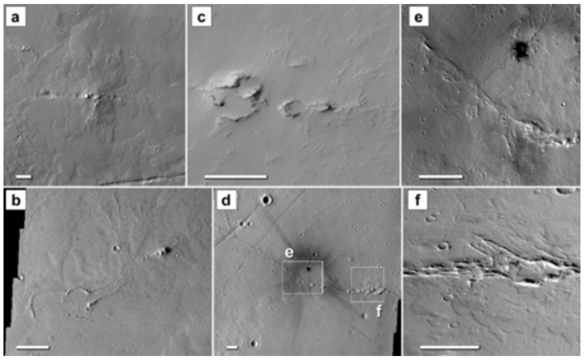

Fig. 6. Possible spatter cones as positive topographic relief features. (**a**) Cones on top of a circular shield with lava flows radiating outwards from the cones (Themis-VIS V12362002, near 8.58°S/246.6°E). (**b**) Small aligned cones (MOC R17-02743, near 8.61°S/246.12°E). (**c**) Lava pond (left) with channel and spatter cones (right; V06732018, near 0.39°N/251.9°E). (**d**) NW-SE trending dike (left) with possible spatter cones (right). The small (<100 m) crater with the very dark ejecta indicates that there might be only a very thin mantle of bright dust above relatively unweathered mafic material (V13971010, near 17.8°N/246.5°E). (**e,f**) details of Fig. 6d (e: E05-01904, f: M08-03697). Scale bar 1 km in all images, N is up.

Conclusions: Low shields and their related landforms display many morphologic and topographic similarities with terrestrial basaltic volcanic fields. They include relatively small and low shields, lava flows, which are often associated with lava channels and –tunnels, and volcanic rift zones. This study reconfirms the Viking-based conclusion [5] that *plains volcanism* [8] in the ESRP is perhaps the best terrestrial morphologic analogue for these Martian surface features. Icelandic shields and distinct structures in Hawai´i also show some similarities to Martian plains volcanism. Landforms previously not known from the low shield clusters are sinuous rilles, interpreted as evidence for high eruption rates, spatter cones, and inflation features typical for pahoehoe lava flows. The extremely shallow flank slopes suggest the eruption of lavas with very low viscosity. The reason for this low viscosity might be high eruption temperatures or a high Fe-content, which decreases the viscosity of lavas [e.g., 24,25]. The distribution of low shields in Tharsis (Fig. 7) does not show any obvious associations with large-scale tectonic features (although some spatial clustering near the rift zones of the Tharsis Montes volcanoes is visible). Further work will analyze the spatial distribution with respect to crustal thickness.

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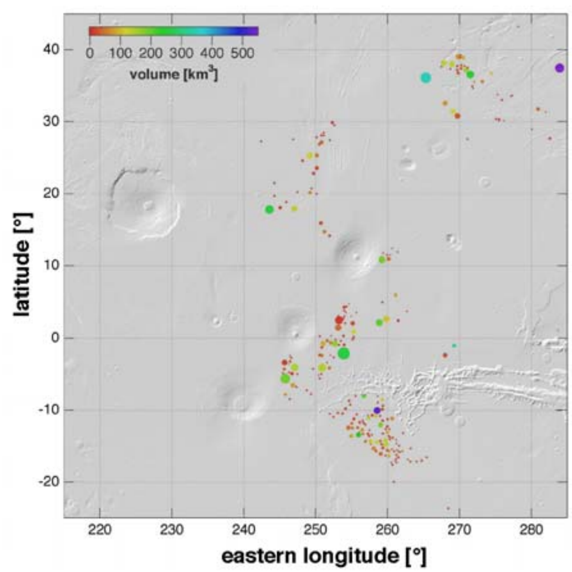

Fig. 7. Distribution of low shields in Tharsis. The size of the symbols represents the basal area of the low shields, the colour is a function of their volume. Note that some minor clusters (e.g., east of Olympus Mons and on caldera of Arsia Mons) are not shown.