VOLCANO FLANK TERRACES ON MARS: ARCHITECTURE.

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Introduction: Flank terraces are low-relief, laterally extensive bulge-like structures that occur on the slopes of several large Martian shield volcanoes. Terraces were first noted on the upper flanks of Olympus Mons [ ], and later on the flanks of the Tharsis Montes [ ]. Flank terraces do not readily appear to be analogous to any structures on Earth. Proposed mechanisms of formation include a.) elastic self-loading [ ]; b.) lithospheric flexure [ ]; c.) magma chamber tumescence [ ]; d.) flank relaxation [ ], [ ]; and e.) shallow gravitational slumping [ ]. Previous work on these subtle structures has been limited to analyses of 2D data; flank terraces thus remain to be fully characterized (Fig. 1 left). By understanding terrace architecture, in terms of morphology and distribution, it is possible to determine the nature and orientations of the stresses necessary for terrace formation and the role terraces play in the evolution of Martian shield volcanoes.

Methods: We use the USGS 128 pixel-per-degree gridded MOLA dataset to produce slope maps of the 22 large volcanoes on Mars [ ]. Where terraces are visible at MOLA resolution, they are delineated according to the cross-sectional terrace profile defined by [ ] (Fig. 1 right).

Fig. 1 left Sketch map of the terrace bounding edges on Olympus Mons, based on Viking data (after [2]); right Terrace sketch map of Olympus from the 128 ppd USGS gridded dataset. Note the increased number and complexity of the terraces as shown by MOLA DTM data.

Results: We characterize the architecture of recognized terraced volcanoes: Olympus, Ascraeus, Pavonis, and Arsia Montes [ ], Elysium Mons [ ] and Hecates Tholus [ ], [ ]. We also find three additional Martian edifices that have not previously been reported as terraced: Alba Patera (Fig. 2 top right), Albor Tholus (Fig. 2 middle right), and Uranius Patera. Extending our study to Earth, we observe terraces on at least five Terran volcanoes: Mauna Loa (Hawaii; Fig. 2 bottom right), Etna (Sicily), Santa Cruz (Galapagos), Alayta (Ethiopia), and Tendürek Dagi (Turkey).

Terraces occur at all flank elevations, and are not limited to the upper flanks as previously reported [ ], [ ]. The terrace profile is characterized by a broad, convex form, with a near-flat upper surface whose slope increases towards the terrace base. In plan, terraces bases are delineated by convex-outward arcuate traces, which are generally not laterally continuous. They are configured in an overlapping manner, where the outer portion of a terrace is superposed upon the inner area of the topographically lower, adjoining terrace. This imbricate arrangement forms a distinctive "fish scale" stacking pattern in plan. Terrace distribution can vary between, and across, edifices, but this fish scale pattern is systematically manifest on all terraced volcanoes. Terraces appear more prominent on steeper slopes.

Discussion: That terraces are still evident today suggests that they either are late-stage structures, or have been constantly reformed as the volcano was constructed. If the former applies, terraces develop upon some of the last units to be emplaced, towards the end of the main shield-building phase. If terraces are reactivated structures, their bounding faults may serve to accommodate shape change in the volcano throughout its lifetime.

The terrace profile is consistent with a thrust morphology, as thrusts generate similar lobate surface features. However, terrace morphology is unlike that produced by normal faulting. As terraces are present across a range of flank elevations; so, also, must be the stresses responsible for their formation. Variations in terrace distribution may be controlled by volcano geometry, internal heterogeneities, or regional slope. Terrace formation may serve to steepen volcano slopes; alternatively, terraces forming on steep flanks may develop increased basal slopes, thus appearing more prominent.

That terraces occur across such a range of volcanoes on Mars and Earth suggests that they are size-, geometry-, and age-independent structures. The presence and number of other tectonic structures, e.g. calderas and gräben, also vary between terraced volcanoes. Like these other structures, flank terraces may be a fundamental feature of Martian volcano development. Terrace formation hypotheses need to be revised accordingly.

Self-loading effects may lead to compression in the upper parts of an edifice, but should produce radially-oriented fractures on the lower slopes. Flank relaxation and slumping will also produce extensional features, oriented sub-radially and circumferentially to the cone, respectively. However, the characteristic convex terrace profile and fish scale arcuate pattern suggests that terraces are compressive in nature. Magma chamber tumescence will produce concentric-striking thrusts, but only above the expanding chamber; compressional structures will not form at lower flank elevations. Lithospheric flexure, however, may lead to internal compression throughout an edifice sufficient to form radially directed, circumferentially oriented thrusts. We therefore favor flexure as a causal mechanism for flank terrace formation on Mars. For this reason, we have carried out analogue modeling experiments to investigate the structures formed when an edifice undergoes flexure. We have successfully produced flank terraces, and have developed a kinematic model to describe the mechanism through which terraces are formed. This work is detailed elsewhere in this volume [11].

Conclusions: This is an ongoing study, but our preliminary conclusions can be summarized as follows: **1**.) flank terraces occur more frequently on Mars than previously recognized; **2**.) terraces are not restricted to Martian volcanoes, but also occur on Earth; **3**.) formation of terraces occurs throughout, or after, the main shield-building phase; **4**.) terraces are volcano size-, geometry-, and age-independent structures; **5**.) most proposed formation mechanisms do not agree with the observed nature, position, and occurrence of terraces; and **6**.) lithospheric flexure is a leading candidate mechanism for flank terrace formation.

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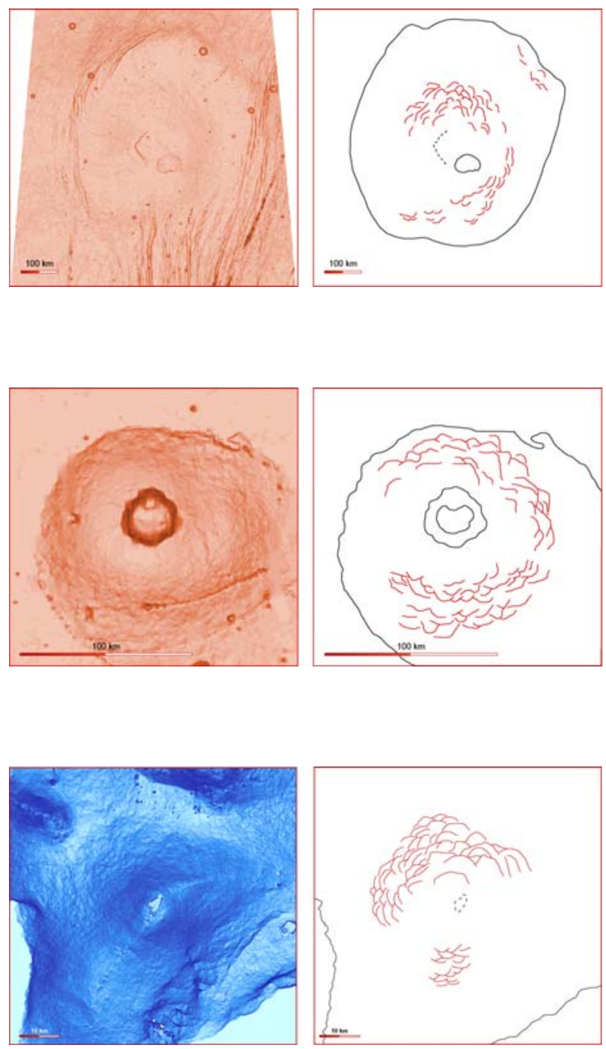

Fig. 2 top right Slope and sketch maps of terrace edges on Alba Patera, to the north of the Tharsis Montes, showing location of terraces, and the characteristic "fish scale" pattern; **middle right** Slope and sketch maps of Albor Tholus, a small shield to the south of Elysium Mons; **lower right** Slope and sketch maps of Mauna Loa, Hawaii, showing outlines of structures we contend are terrestrial flank terraces. All data is shown with a sinusoidal project, and North is up. Mars images are based on the USGS 128 ppd gridded dataset; those of Earth are from the 90m SRTM dataset.