VOLCANO FLANK TERRACES ON MARS: ARCHITECTURE. P. K. Byrne1, J. B. Murray2, B. Van Wyk de Vries3, and V. R. Troll1, 1Department of Geology, Trinity College Dublin, Ireland (byrnepk@tcd.ie), 2Department of Earth Sciences, The Open University, Walton Hall, Milton Keynes, England, MK7 6AA, 3Laboratoire Magmas et Volcans, Université Blaise Pascal, Clermont-Ferrand, France.

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 [1], and later on the flanks of the Tharsis Montes [2]. Flank terraces do not readily appear to be analogous to any structures on Earth. Proposed mechanisms of formation include a.) elastic self-loading [2]; b.) lithospheric flexure [3]; c.) magma chamber tumescence [4]; d.) flank relaxation [5], [6]; and e.) shallow gravitational slumping [7]. 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 [8]. Where terraces are visible at MOLA resolution, they are delineated according to the cross-sectional terrace profile defined by [2] (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, Ascræus, Pavonis, and Arsia Montes [2], Elysium Mons [9] and Hecates Tholus [9], [10]. 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 [2], [3]. 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 volca-
noes on Mars and Earth suggests that they are size-, 
geometry-, and age-independent structures. The pre-
se and number of other tectonic structures, e.g. cal-
deras and gräben, also vary between terraced volca-
noes. Like these other structures, flank terraces may be 
a fundamental feature of Martian volcano develop-
ment. 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 ter-
race 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 un-
dergoes 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 

Conclusions: This is an ongoing study, but our 
preliminary conclusions can be summarized as fol-
lows: 1.) flank terraces occur more frequently on Mars 
than previously recognized; 2.) terraces are not re-
stricted to Martian volcanoes, but also occur on Earth; 
3.) formation of terraces occurs throughout, or after, 
the main shield-building phase; 4.) terraces are vol-
cano 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 can-
didate mechanism for flank terrace formation.

References: [1] Carr, M. H. et al. (1977) JGR, 82, 
et al. (2008b) LPS XXXIX, this volume.