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

Introduction: Flank terraces are low-relief, laterally extensive bulge-like structures that occur on the slopes of several large Martian shield volcanoes [1], [2]. They are characterized by a broad convex form, and form a distinctive imbricate "fish scale" stacking pattern in plan view [3]. Unlike other Martian volcanotectonic structures, terraces have not previously been recognized as having any terrestrial analogue; we have recently found some probably examples, however [4]. There is currently no consensus as to the nature or mechanism of formation of Martian flank terraces.

Proposed formation hypotheses include a.) elastic self-loading [2]; b.) lithospheric flexure [5]; c.) magma chamber tumescence [6]; d.) flank relaxation [7], [8]; and e.) shallow gravitational slumping [9]. These hypotheses have been developed to explain terraces on specific volcanoes, and are based on remotely sensed orthoimages alone. Recent observations, however, indicate that flank terraces are more common, and are volcano size-, geometry-, and age-independent structures [3], when identified with 3D DTM data.

Self-loading, chamber tumescence, flank spreading, and slumping will produce structures that do not match terrace morphology or distribution. Lithospheric flexure, however, may lead to internal compression throughout an edifice sufficient to form outward-verging, circumferentially-striking 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.

Methods: The experimental setup consisted of a deep layer of 10^4 Pa.s viscous silicone gel, as an analogue to the viscoelastic crust on Mars, within a circular container to minimize edge effects. A conical load of fine quartzose sand mixed with plaster in a 10:1 ratio was added to the silicone layer, simulating a volcano. A thin layer of pure plaster was then added to the cone to preserve any subtle brittle deformation. After construction, the load was allowed to passively sink into the silicone (**Fig. 1**).

Certain key experimental parameters were varied. Slope angles of the sand cones ranged from the angle of repose of the particulate mix (~35°) to angles approaching realistic Martian volcanic slopes, e.g. 5° for Olympus Mons [10]. Various load volumes were tested to determine the relationship between the effects of flexure and edifice size. To simulate the uppermost brittle layer of the Martian crust, sand layers of varying thicknesses were included in some experiments. The thickness of the applied plaster layer was also changed, to investigate the effects of a more rigid carapace upon the cone.

Fig. 1 Photograph of the simple experimental setup used to produce flank terraces. A conical load of quartzose sand was placed upon a deep layer of viscous silicone and allowed to flex. Cone geometry is approx. 16 cm in basal diameter, and 8 cm high.

Results: Passive flexing produced convex topographic structures on the cone flanks, arranged in an imbricate, overlapping plan-view pattern about the cone. Shallow annular troughs developed at the base, and were accompanied by an outer circumferential zone of tension fracturing. The underlying silicone layer developed a shallow bowl-shaped depression beneath each cone, featuring some silicone diapirism in the centre of the depression (**Fig. 2**).

The subtle flank structures were apparent on all cone slopes between 35° and 15°; below this value surface contraction was seen to occur, but the convexities were difficult to detect visually. Cone volume changes had no patent effect upon flank structure development, whilst increasing the thicknesses of the underlying brittle layer resulted in greater spacing between structures. Increased sand layer thicknesses also increased trough wavelength and reduced trough amplitude. Increased plaster layer thicknesses suppressed, and ultimately stopped, the development of the flank convexities.

Discussion: The bowl-shaped flexural depression and silicone diapirism indicates that flexure occurred in each experiment, and that the basal surface of each cone underwent an increase in area. Each analogue volcano experienced a decrease in summit elevation, but basal diameters remained fixed. Thus volume was preserved, and a contractional surface strain was taken up, by outward verging, circumferentially striking thrusts, producing the imbricate stacking pattern. The morphology of experimental flank structures suggests an orientation of the principal stress axes as σ_1 = radial, σ_2 = concentric, and σ_3 = vertical.

Our experimental flank structures compare closely with those observed on Mars. Both sets of structures share a broad, convex profile, and our structures echo the distinctive "fish scale" pattern of Martian flank terraces. The flexural troughs that developed in our experiments mirror structures reported on Mars [11], and the annular zones of extension about each load resemble structures surrounding some of the Martian shields, e.g. Elysium Mons. Later volcanism may have obscured these structures around volcanoes where they are not apparent on Mars [12]. That terracing occurred on cones with a wide range of slopes is consistent with our observations from Mars [13], as terraces occur on a range of Martian volcano slopes: 7° on Elysium Mons to ~1° on Alba Patera [10]. The increased thicknesses of underlying brittle layers corresponded to shallower flexural bowls and greater spacing between the flank structures. This indicates that the presence of the crust tempers the degree to which a load will sink. The load experiences lower strain amounts than without the layer, and requires fewer faults to accommodate the decrease in its upper surface, thus reducing the number, and increasing the spacing between the convexities developed on the surface. This conclusion agrees with gravity/topography admittance data for Mars [14], which indicates that the thickest Martian crust lies beneath Ascraeus and Olympus Montes — the two terraced volcanoes with greatest terrace spacing of all such edifices.

Conclusions: This is an ongoing study, but our preliminary conclusions can be summarized as follows: **1**.) analogue models of lithospheric flexure produce structures with a strong architectural similarity to volcano flank terraces on Mars; **2**.) terraces form in response to the decrease in surface area of a conical load, where such decrease is accommodated by radial and concentric shortening; **3**.) the persistent development of flank terraces despite variation in load slope and volumes agrees well with the range of geometries of terraced volcanoes on Mars; **4**.) when thick brittle layers underlie a load, the spacing between terraces increases, consistent with crustal thickness estimates for those Martian volcanoes with the largest terraces; and **5**.) our experiments also show that the presence of calderas, rheological contrasts, flank spreading etc. is not necessary for the development of such structures, contrary to several previous formation hypotheses.

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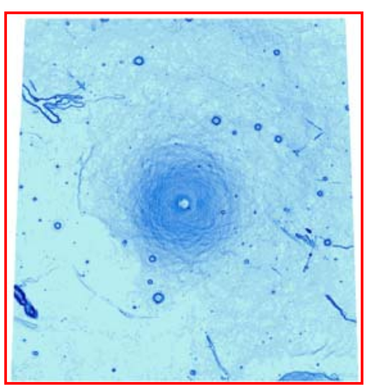

Fig. 2 far left Photograph of the conical load at experiment time = 0; **near left** sinusoidal slope map of Elysium Mons, from the USGS 128 ppd gridded dataset. Note the similarities between the two images: a circumferential zone of "fish scale" terracing about both cones, and an annular zone of extension centered on each volcano. The summit of each cone is also free of terracing, as the least surface contraction has occurred here.