THE SURFACE EXPRESSION OF THE ARSIA-MANGALA DIKE, MARS, IS CONTROLLED BY THE "SAWTOOTH" PROFILE OF SURFACE TOPOGRAPHY. Adam C. Neather, Steve Lane and Lionel Wilson. Lancaster Environment Centre, Lancaster Univ., Lancaster LA1 4YQ, UK (a.neather@lancaster.ac.uk, s.lane@lancaster.ac.uk, l.wilson@lancaster.ac.uk)

Introduction: Giant dike swarms are present on Venus, Earth, and Mars [1]. On Mars, sets of graben radiating from centres in the Tharsis volcanic region are taken as evidence for the presence of giant dike swarms [2]. The Mangala Fossa graben system and the related Mangala Valles flood valley probably have had their origins in crustal fracturing caused by the intrusion of one of these dikes [3, 4], which we call the Arsia-Mangala dike. The graben segments formed when the combination of regional extensional tectonic forces and local stresses due to dike injection caused surface subsidence along pairs of inward-facing faults [5]. In the longest graben segment, subsurface aquifer water exploited the graben faults to reach the surface, flood the graben interior, and overflow to erode the Mangala Valles flood channels [4]. Here we propose that 3 other groups of surface features are related to the emplacement of the Arsia-Mangala dike. Specifically, we infer that they are due to asymmetric changes in surface topography in the propagation direction, which the upper edge of the laterally propagating dike was unable to track vertically as the dike was being emplaced, thus leading to the dike top dynamically approaching unusually close to the surface.

Observations: The Arsia-Mangala dike is approximately radial to the Arsia Mons volcanic centre and, based on the locations of segments of the Mangala Fossa graben system, extends at least as far as 21 ºS, 156 ºW, a distance of ~2200 km (Fig. 1, upper). In addition to it having formed the main Mangala Fossa graben, we have noted that the dike has three other surface expressions. From east to west, in the direction of propagation of the dike, these are a graben-like feature near 16 ºS, 142 ºW, which we call the Eastern Crater (Fig. 1, lower right), some unusual surface deposits near 18.4 ºS, 148.5 ºW, termed the Volcanically Active Zone (Fig. 1, lower right centre), and a fractured crater floor near 19.7 ºS 152.8 ºW, termed the Shattered Floor Crater (Fig. 1, lower left). At each location the topographic profiles in Fig.1 show a slow rise from east to west along the strike of the inferred dike, and then a much more rapid decrease in elevation. These profiles were generated using the open source software package QGIS [6]. Topographic profile creation involved downloading .lbl and .img files from the MOLA data site [7] and using part of the .lbl data to generate a .vrt file required by QGIS.

At the Eastern Crater the main surface feature consists of a graben of variable width that cuts the walls and floor of an old crater. The Volcanically Active Zone marks the beginning of the main part of Mangala Fossa that acted as the source of the Mangala Valles water flood channel. Two types of deposits exist on the surface adjacent to the graben, one identified as the product of a phreatomagmatic eruption [8] and the other of muddy water fountains driven by CO_2 transferred from magma to aquifer water [9-12]. In the Shattered Floor Crater we infer that magmatic heat melted excess cryosphere ice that had invaded the brecciated zone beneath an old impact crater, leading to floor subsidence. In the cases of the Shattered Floor Crater and the Volcanically Active Zone, we can clearly see a slow rise in topography, followed by a relatively rapid descent. For the Eastern Crater, the topographic change is less obvious, but we propose that the crater was extant before the dike intrusion; the crater rim (~30 km wide) acted as the topography that triggered the graben formation. It is possible that the graben width is unusually large here due to the crustal weakness induced by the impact.

Analysis: In giant dike swarms on Mars, laterally-propagating dikes are expected to have their centres located at a neutral buoyancy level (NBL) at the base of the crust at ~60 km depth, their tops at shallow depths below the surface, and their roots in the mantle ~120 km below the surface [2]. Changes in elevation across topographic features result in changes in the lithostatic pressure beneath the features which an underlying laterally-propagating dike will attempt to track. The dike reacts to the changes via the passage of pressure waves travelling vertically through the magma at the speed of sound, which varies from ~1 km s^{-1} in gas-free magma to ~100 m s^{-1} in magma rich in gas bubbles [13]. Assuming mafic martian mantle magmas contain similar amounts of CO_2 (~0.65 wt%, [14]) and H_2O (0.3 wt% [14]) to those on Earth, the solubility n as a mass fraction of CO_2 ($n = 5.9 \times 10^{-12}$ $(P/\text{Pa}) + 5.0 \times 10^{-6}$, [15]) dictates that martian magmas exsolve CO_2 into vapor bubbles over the entire ~120 km vertical extent of a dike with its centre at a neutral buoyancy level (NBL) at the base of the crust at 60 km depth [2]. Thus waves travelling at ~100 m s^{-1} would require ~2400 seconds for one round trip. The absolute pressure in the magma at the NBL is equal to the lithostatic pressure at that depth, ~625 MPa, plus the excess pressure due to the magma buoyancy in the mantle, ~90 MPa, i.e., ~715 MPa. The pressure P in the propagating dike tip, buffered by the above of 0.3% H_2O [14] with a solubility function [15] $n = 6.8 \times 10^{-8} (P/\mathrm{Pa})^{0.7}$, would be ~4.3 MPa. Thus the pressure difference driving the dike magma flow would be ~710 MPa and when the dike tip was approaching a travel distance of ~1500 km near East Crater the pressure gradient dP/dz would be ~470 Pa m^{-1}. In a dike of width W = ~100 m [2] with a wall friction factor of f = ~10^{-2} [16] and magma of density ρ = ~3000 kg m^{-3} this implies turbulent flow at speed $U = [(W\, dP/dz)/(f\,\rho)]^{1/2}$ = ~40 m s^{-1}. So during the ~2400 s interval that the dike shape was trying to adjust to the surface loading change the laterally propagating dike tip would have travelled ~96 km. This significantly exceeds each of the lateral distances over which the topographic change occurs [Fig. 1], and implies that the top of the dike could not adjust rapidly enough to the changing surface elevation. The asymmetric topography then encouraged the dike to approach unusually close the surface on passing the elevated terrain.

Conclusions: We identified a relationship between rapid local topography changes and various surface expressions of the Arsia-Mangala dike, caused by the inability of the upper part of the laterally-propagating dike to track surface topography changes due to the inertia induced by its rapid propagation rate. The fact that the surface features appear to be explainable by this process adds plausibility to our assumption that a single giant dike was responsible for forming both Mangala Fossa and the features studied here.

Acknowlegdements: Barry Rowlingson kindly coded a profiling tool to produce .csv files for use in spreadsheet software. Research support was from the UK Science and Technology Facilities Council.

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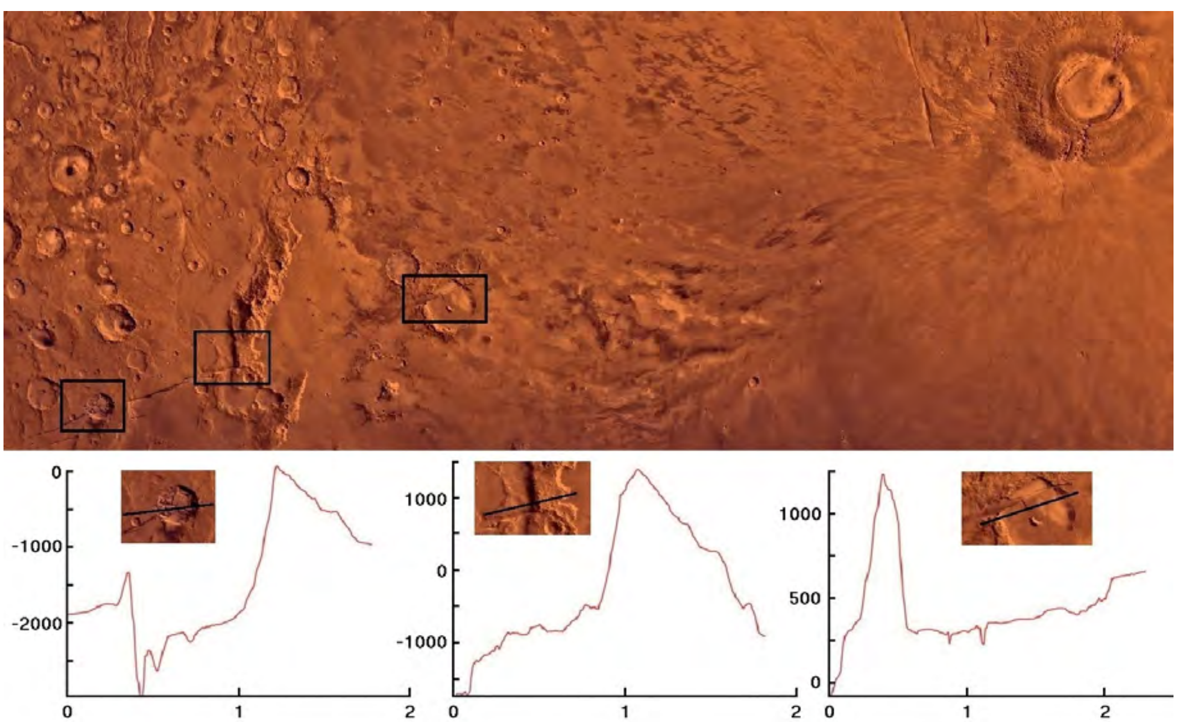

Figure 1. Region west of Arsia Mons. Outlined rectangles show locations of three places where the Arsia-Mangala dike approached unusually close to the surface forming the distinctive features described in the text. Profiles taken parallel to features show pre-formation topography: elevations in metres above MOLA datum vs. distance in km.