SUBGLACIAL DIKE EMPLACEMENT ON MARS: RADIAL RIDGES ASSOCIATED WITH THE PAVONIS MONS FAN-SHAPED DEPOSIT. L. Wilson,[1] D. E. Shean[2] and J. W. Head[2], [1]Environmental Sci. Dept., Lancaster Univ., Lancaster LA1 4YQ, UK (l.wiilson@lancaster.ac.uk), [2]Dept. Geological Sciences, Brown University, Providence, RI 02912.

Introduction: Each of the large Tharsis Montes volcanoes in the equatorial region of Mars has an unusual Amazonian-aged fan-shaped deposit on its west-northwestern flank containing three characteristic facies [1,2]: 1) a ridged facies, consisting of 10s to >100 parallel, concentric ridges around the margins of the deposit, 2) a knobby facies composed of irregular hills and hummocks, and 3) a smooth facies of broad, lobate plains located toward the volcano within the deposit. On the basis of morphology, topography, superposition relationships and close terrestrial analogs in the Dry Valleys of Antarctica [3], the fan-shaped deposits have been interpreted as the depositional remains of cold-based glaciers that formed on the northwestern flanks of the Tharsis Montes. Ridged facies are interpreted as drop moraines formed around the margins of a retreating cold-based glacier, knobby facies as a sublimation till derived from *in situ* down-wasting of cold-based glacial ice, and smooth facies as extant debris-covered glacial ice. One of the Montes, Pavonis Mons, contains radial ridges and steep lobate features interpreted to be the erosional remnants of subglacial volcanism [4]. Here we investigate the possible mode of emplacement of these radial ridges using as a basis detailed description of the features and their topography, and theoretical analyses of the emplacement of dikes and sills into terrestrial glaciers and glacial deposits [5].

Description and interpretation: We have identified six linear or curvilinear ridges in the central regions of the Pavonis fan-shaped deposit that are independent of the ridged facies and secondary ridges (Fig. 1, 2). The linear ridges are radial to the base of the shield and are ~100-200 m high, 1 km wide, and 30-60 km long (Fig. 3). All ridges are approximately linear except for one curvilinear ridge that continues beneath the main smooth facies deposit (Fig. 1). Another radial ridge appears to enlarge into an 8-km wide pancake-like feature with a small depression at its center (Fig. 1). Two other ridges originating on the northwestern flanks of Pavonis Mons appear *en echelon* in plan view while others display forking or splitting in places (Fig. 2). These ridges were previously interpreted as levees at the margins of a broad flow channel [6] or as eskers [7]. Based on their 1) radial orientations with respect to the shield (Fig. 1), 2) peaked cross sections in MOLA profiles (Fig. 3), and 3) forked or *en echelon* nature (Fig. 2), we interpret these features as radial dikes [4], which may have erupted in a subglacial environment. Analysis of high-resolution MOC images reveals that some of the radial ridges appear to have split peaks, plateaus and even elongated collapse pits along the central ridge axis (Fig. 2). These features suggest that the ridges interpreted as dikes were emplaced beneath a relatively thick glacier and may have encountered variable stresses within the ice where local pressure conditions allowed for the formation of such structures. The unusual pancake-like feature associated with one of the radial ridges may also represent a sill-like structure [e.g., 5] that formed subglacially during dike emplacement. Elsewhere in the fan-shaped deposit is evidence for additional steep-sided lobate flow-like features interpreted as subglacial sills and flows [4]. We now use theoretical treatments of dike emplacement in glacial ice [5] to test the idea that these radial ridges formed as parts of subglacial dike intrusions in which the dike overshot the rock-glacier interface and penetrated the glacial ice, subsequently to collapse into a pile of fragmental and probably altered material as the surrounding ice melted.

Analysis: Using mean values of height (~120 m) and basal width (~1000 m) for the ridges shown in Figs. 2 and 3, the cross-sectional area is typically ~60,000 m^2. If this is reconstructed into a vertical parallel-sided dike intruding a plausible ~1.5 km depth of glacial ice, the mean dike thickness is ~20 m. Given that parts of some of the ridges have split peaks or broaden into plateaus, some of the ridge volume may be magma extruded after dike collapse. Also, some of the present ridge material may be part of the rock burden of the glacier left behind after the retreat that exposed the ridges. Both these factors imply that the 20 m dike thickness may be an upper limit.

We now show that a dike width of order 20 m is consistent with the proposal that these are dikes generated as lateral intrusions from the summit magma chamber of Pavonis Mons. We assume that magma in the dike is 300 kg m^{-3} denser than the average density of the shallow parts of the edfice and 250 kg m^{-3} less dense than the deepest parts of the edifice, placing the center of the magma chamber at an ~11 km-deep neutral buoyancy level within a volcanic edifice having a plausible profile of density increasing with depth [8]. Using a model [9] of laterally propagating dikes, we calculate the implied mean dike width for a range of values of the excess pressure in the magma reservoir. We also find (Table 1) the depth below the surface to which the top of the dike could rise as a result of the limitations imposed by (i) the need for the pressure in the reservoir to support the weight of the magma in the dike and (ii) the requirement that the stress intensity be at least a few, and preferably at least many tens, of MPa m$^{1/2}$, these values representing the range of fracture toughnesses inferred for crustal rocks at depth in volcanic edifices [10,11].

Summary and Conclusions: Table 1 shows that dike widths of the correct order are predicted for excess reservoir pressures of 8-9 MPa. These values are consistent with the requirement that the pressure in the magma at the top of the reservoir should be able to support the roof against failure and caldera-subsidence. The stress at the upper dike tip easily allows fracturing of ice (or rock) to occur, and the magma is able to penetrate to within a few tens to a few hundred meters of the ice surface. Thus we conclude that the radial ridges are readily explained as residual features marking locations where dikes propagating mainly laterally under the flanks of the volcano overshot the rock-ice interface as they neared the surface and penetrated the overlying ice.

Table 1: For a series of values of the excess pressure, P_e, in a summit magma reservoir centered at 11 km depth, values are given for the mean width, W, of a laterally intruded dike, the depth, D, to the dike top, and the stress intensity, S, at the upper dike tip.

P_e (MPa)	W (m)	D (m)	S (MPa $m^{1/2}$)
7	12.5	384	21
8	18.1	268	180
9	23.6	151	340
10	29.2	34	499

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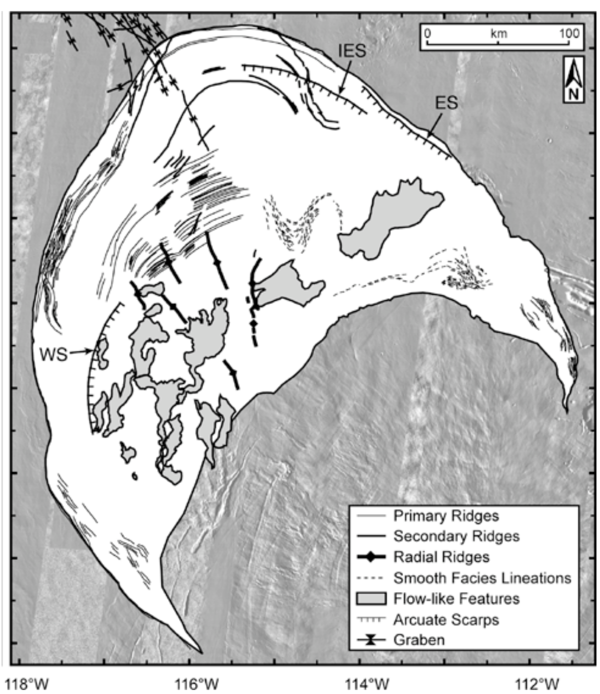

Figure 1. Geologic map of features within Pavonis Mons fan-shaped deposit [4]. Radial ridges are radial to the base of the shield and display a unique morphology similar to terrestrial dikes. Note that some radial ridges trend into graben outside the fan-shaped deposit.

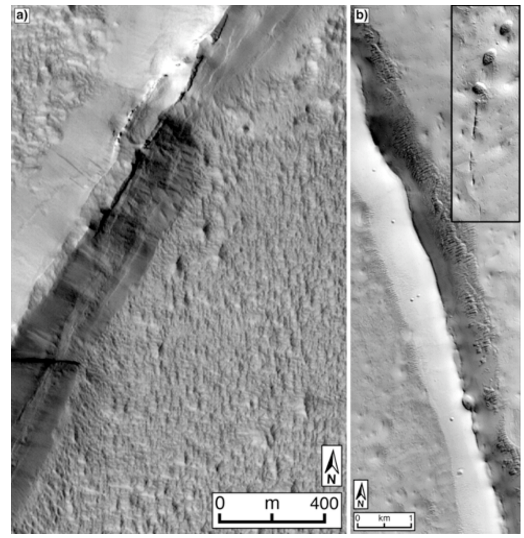

Fig. 2. MOC narrow-angle images of radial ridges interpreted as dikes erupted in a subglacial environment: (a) section of curvilinear radial ridge showing split peak and outcrop along central ridge axis (Image #M0805337); (b) radial ridge showing splitting and collapse pits along the central ridge axis (Image #E1300839). The inset image is located approximately 15 km north-northwest of the radial ridge. Features in the inset appear to represent an *en echelon* offshoot of the main dike that transitions into elongated collapse pits, suggesting an interaction with volatile-rich material during emplacement.

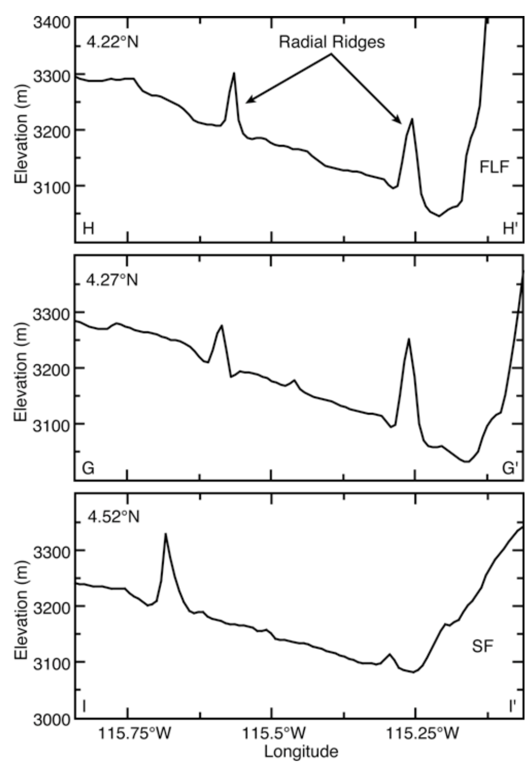

Figure 3. MOLA profiles of the two largest radial ridges at Pavonis Mons extracted from 128 pixel/degree gridded data. The radial ridges display a relief of >150 m above the surrounding terrain. Vertical exaggeration 57X.