MARTIAN PLINIAN ERUPTIONS AND PIT CHAIN CRATERS. E. D. Scott[1], L. Wilson[1] and J. W. Head[2]. [1]: Planetary Science Research Group, I. E. N. S., Lancaster University, Lancaster LA1 4YQ, U.K. [2]: Dept. Geological Sciences, Brown University, Providence RI 02912, U.S.A. E.Scott@lancaster.ac.uk.

Abstract: Alba Patera is a very large, low relief Martian shield volcano, surrounded by numerous graben, tangential to the summit caldera in the west and east, but joining the north-south trend of regional graben, found throughout Tharsis, to the north and south of the volcano. Amongst these, we identify two distinct sets of graben. One set are thought to have formed above long regional dykes emanating from a deep lower crustal reservoir located at approximately 112° W, 22° N within Tharsis [1]. They contain numerous pit craters and interact with a further set of graben formed as a response to the loading of Alba Patera on the lithosphere.

The pit craters contained within the volcanic graben are of two morphologies: small regular-shaped ones usually completely contained within a graben, but occasionally unbounded, and much larger irregular ones which appear to coalesce one into another. We argue that these two types of craters formed by different mechanisms: the smaller subsequent to a passive leakage of volatiles from the dyke surface and collapse of crustal rocks into this void space, and the larger ones during plinian eruption events.

1. Previous Ideas on the Formation of the Pit Chain Craters: Hypotheses for the mechanisms involved in the formation of the pit chain craters have been developed by various authors [2, 3, 4] who suggest that those within Valles Marineris, Noctis Labyrinthus and Tantalus Fossa, to the east of Alba Patera, are underlain by tension cracks extending the depth of the lithosphere. They argue that the graben are surface manifestations of these faults at depth [2]. Once formed these tension fractures are widened by weathering of the rock faces and erosion by fluvial, mass wasting and aeolian processes [2]. [2] and [3] argue against volcanic processes as a formation mechanism for the pits (excepting those located within the flanks of the major shields which they feel are analogous to the pits seen at Kilauea, Hawaii) because there is an absence of coeval volcanics, e.g. around the crater chains within Valles Marineris. Crater chains without an enclosing graben are taken as further evidence that the craters are formed over a tension fracture. However, the pit craters are not found throughout Valles Marineris, and where they are found they are characterised by en-echelon geometry and limited extent [5], indicating that there is an associated dyke at depth. [6].

The main reasons why the pit chain craters at Alba Patera are associated by [3] with tectonic processes are the absence of coeval volcanics and the fact that all the graben surrounding this volcano are assumed to have formed in response to the loading of this volcano on the lithosphere. However, we have argued earlier that there are two distinct sets of graben around Alba Patera; one set formed as a tectonic response to loading, and the members of the other formed over dykes which stalled below the surface [1], and therefore both types of graben cannot necessarily be treated in the same fashion.

Both the small pits that we argue are formed by a leakage of volatiles and the larger ones that we postulate formed as a consequence of a surface eruption from the top of the dyke were examined by [7]. They considered that all the pits start small, but broaden by geomorphologic processes and mass wasting events into the larger, coalescing features, and argued that the formation mechanism must be an interaction of magma and ground water at depth, because there is no evidence for the flow of lava away from these pits [7]. We argue that it is much more likely that juvenile volatiles are involved in the formation of the Alba Patera pit craters because they often occur in regular repeated cycles of sizes, from large to small. If the pit craters were phreatic, produced by the interaction of hot magma with fluids within the regolith, the craters would be disordered in their sizes, depending on the local availability of water or ice-rich permafrost. There is no evidence of channels indicating the flow of meltwater away from the craters. Neither is there evidence of the deflation of the subsurface, which if present would indicate a loss of groundwater or ice from the area.

We do not feel that the absence of lava flows is a contra-indication for an eruption formation scenario for these craters because of the characteristic style of Martian volcanic eruptions [8]. A plinian type eruption is the most likely candidates for events emanating from these dykes, although a hawaiian style is possible [8]. A hawaiian event occurs when the majority of magma is disrupted into clots marginally smaller than the maximum eruptable size. They decouple relatively quickly from the gas stream associated with the eruption and form a fire fountain, build cinder cones and possibly feed lava flows. Martian hawaiian-type cones are likely to be at least twice the diameter of terrestrial analogues, but no more than a quarter the height [8]. Plinian eruptions occur when the magma is disrupted into clots so small that they can be locked by drag forces into the gas stream and entrained to great heights in a convecting eruption cloud, from which they eventually descend to form a widespread fall deposit. The combination of lower Martian gravity and lower atmospheric pressure will tend to favour plinian eruptions, in which the eruption clouds can potentially attain five times the height of terrestrial ones [8], commonly more than 100 km on Mars. The greater speed of the winds means that the products will be carried for longer distances, typically 100 km for a mm sized particle and 1,000km for a 50μm clast [9]. Hence it would be difficult to connect a vent with its products, especially when the variable directions of the ambient wind is taken into account and the possibility is considered that aeolian activity has reworked the products. Lava flows are not commonly seen associated with these craters, supporting the plinian rather than hawaiian style scenario.

2. Proposed Mechanisms of Pit Chain Crater Formation: We argue that there are probably two mechanisms, an active and a passive regime, acting simultaneously within this Martian dyke system, each producing its own characteristic craters, although it is possible that the smaller craters are parasitised to produce the larger entities [6]. We argue that the smaller craters are formed passively when surface rocks collapse into the void space left behind after a leakage of volatiles from a foam layer which accumulates at the top of a stalled dyke as bubbles drift upwards through the magma [1]. Breccia bodies consisting of both dyke magma and host rock fragments observed in shallow dykes in Utah, thought by [10] to have formed during dyke emplacement, may be examples of collapse of surface rocks into a void space, as described above.

The fact that small, discrete pit craters are produced is proposed to be related to the behaviour of the foam layer from which the volatiles escape. The formation and collapse of a foam layer has been modelled experimentally [11] and it was found that once the foam layer reaches a critical thickness, the bubbles start to burst as the interstitial liquid drains and the foam layer begins to collapse. This collapse is almost instantaneous at low viscosity but, as the viscosity increases, as would be expected within the cooling magma of a stalled dyke, collapse begins at several nucleation sites [11], consistent with the observed morphology of the multiple discrete craters contained within the graben.

An alternate scenario is needed to explain the formation of the larger craters seen within some of the graben because it would be difficult to explain the assimilation of so much surface material into a dyke which has only lost volatiles. We argue that the most likely mechanism is an eruption from a dyke that approached the surface. This not only discharged magma into the atmosphere, but also formed the crater when the supply rate of magma feeding the eruption became less than the eruption rate. Stable eruptions continue only as long as the mean flux of magma from a reservoir, located at a level below that where magma fragmentation into pyroclasts takes place, is equal to the mean flux of pyroclasts and released gas above it. When a stalled dyke erupts to the surface, the dyke eventually becomes thinner as any excess pressure in the magma is released. This begins to choke the supply of magma into the eruption, so that the dynamic balance described above is disturbed. The fragmentation surface would then migrate downwards until the walls imploded and collapsed, producing a crater and probably erasing any evidence of near vent deposits.

Many authors feel that the large craters form from the smaller ones, although the mechanism described is not always the same; compare [3] with [7]. There is morphological evidence that the two processes of passive leakage and active eruption worked concurrently within the same dyke system, e.g. in Viking Orbiter image set f253s45 - f253s54. The large eruption craters can be seen with smaller pit chain crater subsets sandwiched between links of eruptive crater chains. The fact that the two types are interlinked within the same graben, and are therefore associated with the same dyke, indicates that the two processes may actually be working at approximately the same time. It is possible that the smaller gas leakage craters may form when the dyke has failed to approach close enough to the surface to produce an eruption. This is supported by the fact that, in this image set, the link of small craters is not bounded by a graben structure, whereas the larger craters either side, following exactly the same trend and are therefore produced by the same dyke. To produce a graben, a dyke must come within a critical distance of the surface. Hence it is significant that the craters proposed to have formed by the passive leakage of volatiles are frequently seen unbounded by a graben fault. To produce both a graben and a surface eruption, the dyke must closely approach the surface, explaining why the large coalescing craters are always seen enclosed within a graben structure [12].

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