SURFACE AGES OF THE VOLCANIC DEPOSITS OF PAVONIS MONS AND IMPLICATIONS FOR THE MAGMA SUPPLY OF THARSIS. K. Gwinner[1;2], J.W. Head[2], L. Wilson[3], C. Fassett[2], S. Dissmore[2]. [1]DLR Institute of Planetary Research, Berlin, Germany (Klaus.Gwinner@dlr.de), [2]Department of Geological Sciences, Brown University, Providence, USA, [3]Lancaster Environment Centre, Lancaster University, Lancaster, United Kingdom.

Introduction: The large Martian volcanic shields represent extremely long-lived volcanism. Although absolute ages of the Mars surface from impact chronology may be uncertain to a factor of about two [1,2], the reported ages of these edifices [3,4,5] imply volcanism lasted at least one order of magnitude longer than typical for terrestrial shields. On such timescales, the magma supply available to produce even the huge volumes of the shields has been inferred to fall short of the supply rates required to sustain active reservoirs continuously [6]. Consequently, the magma supply must have been episodic. Age data from impact crater statistics is essential for better understanding the timescales and nature of this episodic activity and for establishing genetic relationships between volcanic structures and deposits. In particular, the recognition of young volcanic plains featuring clusters of low lava shields [7,8] has recently led to the idea that the episodic nature of shield-building events might also allow for significant independent magma upwelling even in close vicinity to the Tharsis shields [9].

However, the detailed geologic study of [10] reports few and only relative ages. Absolute ages in [3] are from relatively large craters and lack information on the more youthful features identified applying recent high-resolution data. [4] do not address Pavonis directly, while [5] is limited to sub-regions of the shield not systematically constrained by geological criteria.

Methods: Areas for crater counting are selected from morphological mapping [12], using HRSC DTMs and orthoimages [4,14,15], CTX imagery and HiRISE imagery [16,17]. The areas cover the entire shield and rift apron surface and large parts of the adjacent plains. In addition, the units of the existing geologic I-series map of Pavonis by Scott et al. (1998) were used after minor modifications. Craters were counted in CTX images. The high resolution (5-10 m/pixel) was found helpful to avoid misinterpretation of volcanic and tectonic depressions, distinguished from impact craters by: lack of raised rims, distinct elongation, occurrence in chains (often aligned with channels or grabens) or in nested clusters or at the head of rilles. The tools used for crater mapping and statistics [18,19] allow us to check the sensitivity of results using different binning schemes, to correct for resurfacing effects [5] and provide error bars for absolute ages. All ages are based on the impact chronology [2] in combination with the flux model [1].

Results: Our results are based on more than 3500 mapped impact craters in the diameter range of 0.2 - 4.2 km. Counting areas range from 665 to 35400 km^2. A selection of best-fit ages with 1σ-level error bars for different surface units is shown in Fig. 1.

Ages of surfaces with homogenous crater populations. A subset of the counting areas do not show distinct kinks in the cumulative frequency curves indicative of partial elimination of the cratering record by resurfacing processes. These include the younger summit caldera (Caldera II) and each of five rift aprons mapped by slope characteristics and surface texture. These surfaces likely represent depositional units thick enough to completely obliterate the pre-existing topography and formed during a rather short time period. The age for the floor of Caldera II, 81±24 Myr, agrees well with the age derived from HRSC, 82 Myr [5].

Resurfacing ages. Several of the mapped surfaces provide clear evidence of resurfacing events. This is to be expected in volcanic terrain, where many deposit types are topography-dependent and of moderate thickness. There is no unique method for identifying resurfaced intervals of frequency/diameter curves, and resurfacing might in fact take place over some extended period of time. However, the reliability of the resulting resurfacing ages is suggested by similar uncertainty as obtained for homogenous populations of similar age, and correlation with other ages, including those derived from homogeneous units. The resurfacing age for Caldera I, 361±43 Myr, agrees well with the age given in [5], 367 Myr.

Base ages of resurfaced units. Similarly, we find that the base ages of several partially resurfaced units, i.e. the best-fit age obtained for the large diameter interval not affected by resurfacing features, correlate well with other units. Note that the oldest age in the study area is obtained as the base age of the summit region, about 2.1 Gyr in agreement with [3]. However, the oldest ages found on the flanks are younger, about 0.8 Gyr, which means that the flanks must have been completely resurfaced at a more recent epoch.

Discussion: *Main phases of volcanic activity.* As seen in Fig. 1, the obtained best-fit ages tend to cluster within 4 distinct age intervals. Since these age groups also separate volcanic deposits with "homogenous" ages (presumably representing unit emplacement) that are also distinguished by stratigraphic relationships (superimposed calderas and rift aprons), and since the groups join areas within extremely different erosional environments, we conclude that they likely represent periods of high volcanic activity and emplacement of large volumes of associated deposits. During each of the 3 most recent phases, partial resurfacing of the flanks is combined with intra-caldera activity, formation of one or two rift aprons, and a pulse of flow emplacement on the adjacent plains. The only exception is the missing caldera age for the 0.16 Gyr phase; due to the close correspondence of the two most recent SW rift aprons and the very deep incision of Caldera II, it seems likely that the 0.16 Gyr-caldera has been completely destroyed by the formation of Caldera II at about 0.07 Ga. This type of episodic activity has been repeated 3 times over the last 0.38 Gyrs, i.e. after 220 and 90 Myr of relative quiescence. A fourth cycle may have taken place at about 0.55 Gyr, i.e. 170 Myr earlier, indicated by resurfacing of flank and summit, but no associated caldera structure, rift apron or plains unit has been identified thus far. A still older flank resurfacing pulse is observed only on the SE flanks. For checking possible differences between the resurfacing history of opposite flanks, we subdivide the flank area and obtain consistent resurfacing ages for the NW and SW flanks during the 3 most recent phases. The apparent textural differences between the NW and SE flanks of the shield (smoother surface appearance, stronger masking of surface structures in the NW) may thus be strongly related to local climatic conditions [20,21].

Episodicity and characteristics of the magma supply to Tharsis. Our results show that the transition from "shield-building" activity (i.e. general summit and flank activity) to rift-related activity as proposed by [10] seems to have occurred repeatedly rather than only once during the lifetime of the volcano, as originally supposed. The related cycles of volcanic activity occur on timescales of one or two in every 200 Myr. The same timescale has been estimated 1) for periods of quiescence required to sustain active reservoirs [6], 2) as the dominant mode (around 200-300 Myr) in the pulsating plume model for magma upwellings to the base of the Martian lithosphere [23], and 3) for typical age separations between calderas of other Martian shields [4,5]. Thus, it seems likely that Pavonis Mons represents a primary center for magma ascent from the mantle up to the present. Given the repetitive nature of rift-related activity, the young age of the most recent cycle (0.07 Gyr), and its spatial coincidence with the youngest SW rift apron of Pavonis, we propose that the low shield cluster located south of the shield is more likely linked to the supply system of Pavonis rather than representing an independent volcanic system, as has been recently suggested [9].

Conclusions: We present, for the first time, detailed age information on the rift apron deposits and the resurfacing history of the flanks of one of the Tharsis Montes shields. In addition, impact crater statistics provides direct evidence for episodic activity of Pavonis, linking flank resurfacing, intra-caldera activity, and deposition of large lava flow volumes at rift aprons and on adjacent plains in a repetitive pattern. Such activity pulses have occurred every 100-200 Myr and have dominated the volcanic evolution over at least ~0.5 Gyrs before present. They correlate well with theoretical predictions on magma supply rates to crustal reservoirs [6,23]. Pavonis Mons acted as primary regional center for magma ascent up to recent times, where the evolutionary scheme proposed by [10] applies to individual activity phases rather than the entire lifecycle of the shield. Since the other two large Tharsis Montes shields share the same set of depositional features it is possible that a similar evolution occurred at those edifices as well. In contrast, many of the small shield clusters of the Tharsis plains may be linked to the supply system of the large shields rather than representing independent volcanic systems.

References: [1] Ivanov B. (2001), *Space Sci. Rev. 96*. [2] Hartmann W.K. & Neukum G. (2001), *Space Sci. Rev. 96*. [3] Neukum G. & Hiller K. (1981), *JGR 86*. [4] Neukum G. et al. (2004), *Nature 432*. [5] Werner S. (2009), *Icarus 201*. [6] Wilson L. et al. (2001), *JGR 106*. [7] Hodges C. & Moore H. (1994), *USGS Prof. Pap. 1534*. [8] Hauber E. et al. (2009), *JVGR185*. [9] Bleacher J. et al. (2009), *JVGR185*. [10] Crumpler L. & Aubele J. (1978), *Icarus 34*. [12] Gwinner K. et al. (2010), *Geophys. Res. Abs. 12,* EGU2010-14554. [14] Jaumann R. et al. (2007), *PSS 55*. [15] Gwinner K. et al. (2010), *EPSL 294.* [16] Malin M.C. et al. (2007), *JGR 112*. [17] McEwen A.S. et al. (2007), *JGR 112*. [18] Kneissl T. et al. (2010), *LPS XVI*. [19] Michael, G. & Neukum G. (2010), *EPSL 294.* [20] Keszthelyi L. & Grier J. (2002), *LPS XXXIII*. [21] Shean D.E. & Head J.W. (2003), *ICM VI*. [23] Harder H. (1998), *JGR 103*.

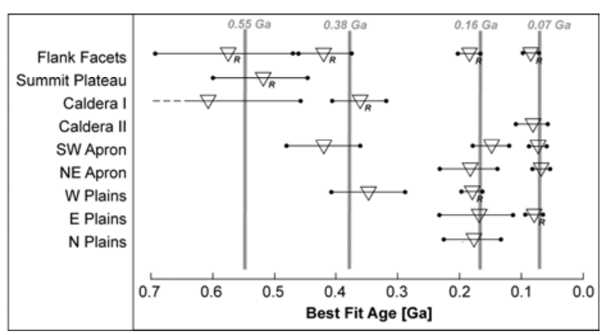

Fig. 1: Best-fit ages and resurfacing ages (R) including error bars for different morphological units. Grey vertical lines indicate average age for the observed age clusters.