GEOMORPHIC EVIDENCE FOR FORMER LOBATE DEBRIS APRONS AT LOW LATITUDES ON MARS: INDICATORS OF THE MARTIAN PALEOCLIMATE. E. Hauber[1], S. van Gasselt[2], M. G. Chapman[3], and G. Neukum[2], [1]German Aerospace Center (DLR), Rutherfordstr. 2, 12489 Berlin, Germany (Ernst.Hauber@dlr.de), [2]Free University of Berlin, Germany, [3]U.S. Geolog. Surv., Flagstaff, AZ, USA.

Summary: Circumferential depressions enclosing mesas and plateaus in the northern Kasei Valles region of Mars are interpreted as indicators of the former extent of lobate debris aprons (LDA), thought to be mixtures of ice and clastic particles. These depressions have formed when lava flows were emplaced against former LDA about 1 Ga ago. After the LDA had been removed by sublimation and deflation, moats were left behind between the mesa or plateau scarp and the solidified lava flow front. These depressions are located equatorwards of ±30° at significantly lower latitudes than generally observed for occurrences of modern, intact LDA. This indicates that the paleoclimate at that time was different than today, probably due to a higher averaged obliquity of the planet`s rotational axis.

Background: LDA are distinctive landforms showing evidence for creep and deformation of ice-rich debris (analogous to terrestrial rock glaciers) in Martian mid-latitudes [e.g., 1-4]. The global distribution of LDA was mapped by [3] and [5], and a strong concentration in two latitudinal bands was found, each with a width of 25°, centered at 40°N and 45°S. They concluded that this latitudinal dependence implies a climatic influence on their formation. Virtually no viscous flow features were reported equatorwards of ±30° [6]. It has been shown [2,7,8] that the cross-section shape of LDA can be approximated by the flow law of polycrystalline ice [9] and the flow relation of ice [10,11]. [12] modelled flow of ice under Martian conditions and found that (a) temperatures 20 to 40 K higher than present average mid-latitude temperatures (~210 K), (b) ice contents ≥80%, and (c) net accumulation rates of ≥1 cm year-1 are required to create LDA of the observed size. LDA are young landforms. Crater counts yielded low crater densities and absolute ages of less than 100 Ma [e.g., 2, 13, 14, 8].

Geologic Setting: The focus of our study are topographic depressions or moats (Fig. 1a), which enclose mesas or run parallel to steep topographic scarps. They occur on a flat terrace north of the Kasei Valles` main channels and south of the Hesperian ridged plains of Tempe Terra. The surface of the western part of this terrace was mapped as Amazonian lava flows associated with Tharsis volcanism (unit At_5), while the eastern part was interpreted as eroded channel floor (unit *Hchh*) [15]. We performed crater counts, using the techniques described by [16,17], and obtained an absolute crater model age of unit At_5 of 1 Ga to 1.6 Ga.

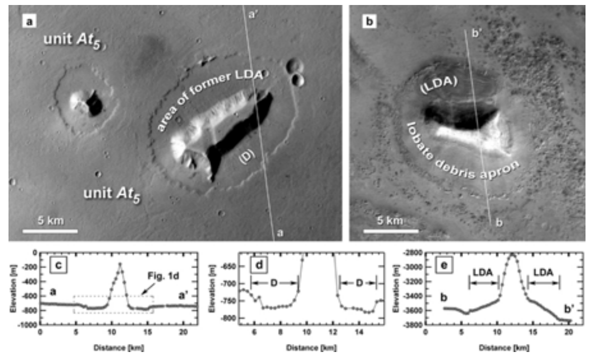

Fig. 1. Comparison between area of former LDA and modern LDA. (a) Two moats around mesas in the northern Kasei Vallis region at 28.07°N and 286.25°E (HRSC image 3217; illumination from left=west). (b) Modern LDA in Deuteronilus Mensae (centered at 46.29°N, 26.6°E; HRSC image 1461; illumination from bottom=south). (c) Single MOLA profile (track 15483) across area of former LDA, location is marked **a-a'** in Fig. 1a. (d) Detail of topographic profile **a-a'**, showing the depth of the depression and its almost flat floor. (e) Single MOLA profile (track 10306) across modern and intact LDA, location is marked **b-b'** in Fig. 1b.

Morphology and Distribution:

Morphology. Images show a scarp, which faces steep and high topographic walls of mesas or plateau margins (Fig. 1a). The depressions have shapes and sizes in plan view that are identical to those of intact LDA (Fig. 1b). The topographic depression between the scarp and the mesa walls typically has a depth of more than 50 m (Fig. 1c,d). Its floor is almost flat, and the topographic slope raising towards the mesa walls is less than 0.4°. In contrast, the surfaces of intact LDA have slopes of around 1° to >12° [18,19] (Fig. 1e). At some places, there is a slightly raised rim at the scarp.

Distribution. Topographic depressions very similar to the examples shown in Fig. 1 exist around mesas and parallel to the southern plateau margins of Tempe Terra. They occur at latitudes between 25°N and 31°N, and between 281°E and 301°E. These locations are distinctively south of the locations of modern and intact LDA previously mapped by [3,5]. In order to find out if this phenomenon is global, we searched for comparable moats at similar or even lower latitudes, where relatively young lava or sediment has embayed mesas and topographic scarps. Several examples, though less developed than in Kasei Valles, were found around small knobs and mesas in the Tartarus Colles region. They are embayed by Early Amazonian lavas of Elysium and by Late Amazonian lava flows in Marte Vallis [20]. Their latitudes are between 24°N and 29°N.

Discussion: Based on the striking morphological similarity with modern LDA, we interpret the moats as indicators of the extent of former LDA. Lava flows (unit At_4), maybe mixed with lahars, would have flooded the terrace in northern Kasei Valles no later than 1 Ga ago. Where the lava flows terminated against LDA and solidified, they formed a steep scarp. This phenomenon is well known from the Earth, when the flow of lava is confined by glaciers [21-23]. After the LDA were removed by sublimation of ice [13] and deflation of detritus, the solidified lava front remains as a free-standing topographic cliff (Fig. 2). The almost flat floor of the moats suggests that the entire material of the original LDA has been removed. This has one or both of the following implications: Either LDA had a very high percentage of ice that sublimated away, or the clastic fraction of the LDA consisted mainly of very fine material, e.g., silt-sized particles (loess), which can be more easily removed by wind than coarser particles [e.g., 24].

A very high ice content is consistent with the modelling results of [12] and [8], because a high content of solid particles prevents flow. If modern LDA have a comparable morphology to the ancient LDA in northern Kasei Valles, the contact between modern LDA and the underlying bedrock should also be flat. This could be tested with the SHARAD radar on MRO [25].

Virtually all modern and intact LDA are located polewards of ±30°. This distribution is thought to reflect the influence of climatic conditions on the formation of features indicative of creep of ice and debris. The climate on Mars is controlled by the obliquity of the rotational axis and by orbital parameters (eccentricity and precession) [e.g., 26]. At higher obliquities than today (~25°), ground ice becomes stable even in equatorial latitudes [e.g., 27]. It was also shown by climate modelling that prolonged periods of higher obliquity lead to a mobilization of volatiles at the poles and to precipitation at low latitudes [28]. The obliquity of Mars is variable, but can not be reliably predicted backwards in time for more than about 10^7 years due to its chaotic behaviour [29]. However, recent calculations suggest that the averaged obliquity over 5 Ga was probably almost 40° [30], a value that would allow ground ice to be stable globally. Our results, which indicate the formation of LDA and the stability of ground ice equatorwards of ±30° more than 1 Ga ago, are in good agreement with models of the evolution of Mars` obliquity. Higher obliquities in the past could have lead to precipitation of snow at low latitudes, where LDA formed because ground ice would have been stable. After the embayment of LDA by lava flows, their disappearance would have been triggered by a decrease in the obliquity and the associated instability of ground ice at low latitudes. Periodic variations of the obliquity in the past might have caused the formation and entire removal by wind of LDA many times in the past, as suggested earlier [4].

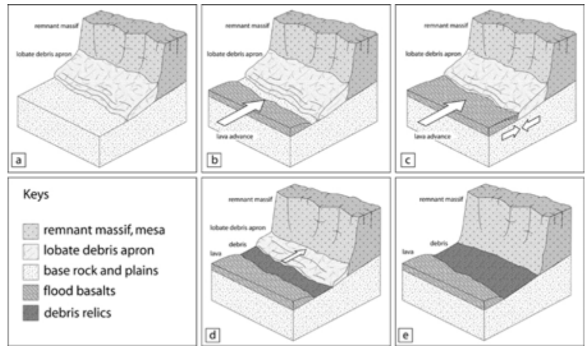

Fig. 2. Schematic model of landscape genesis. (a) LDA exists around a mesa or along a linear topographic scarp. (b) Lava flow front advances towards the LDA. (c) Lava flow terminates against LDA flow front. Lava-ice interaction causes violent steam explosions, and perhaps limited meltwater runoff. (d) LDA retreat due to climate change and beginning formation of depression. (e) Remaining depression after complete removal of LDA, present situation.

References: [1] Carr, M. H. and Schaber, G. G. (1977) *JGR, 82,* 4039-4054. [2] Squyres, S. W. (1978) *Icarus, 34,* 600-613. [3] Squyres, S. W. (1979) *JGR, 84,* 8087-8096. [4] Lucchitta, B. K. (1984) *JGR, 89,* B409-B419. [5] Squyres, S. W. and Carr, M. H. (1986) *Science, 231*, 249-252. [6] Milliken, R. E et al. (2003), *JGR, 108,* CiteID 5057, doi: 10.1029/2002JE002005. [7] Mangold, N. and Allemand, P. (2001) *GRL, 28,* 407-410. [8] Li, H. et al. (2005) *Icarus, 176,* 382-394. [9] Glen, J. W. (1955) *Proc. Royal Soc. London, Series A*, **228**, 519-538. [10] Vialov, S. S. (1958) *Int. Assoc. Hydr. Sci.*, **47**, 266–275. [11] Paterson, W. S. (1994) *The physics of glaciers*, Pergamon, Oxford. [12] Colaprete, A. and Jakosky, B. M. (1998) *JGR, 103,* 5897-5910. [13] Mangold, N. (2003) *JGR, 108,* CiteID 8021, doi: 10.1029/2002JE001885. [14] Head, J. W. et al. (2005) *Nature, 434,* 346-351. [15] Rotto, S. and Tanaka, K. L. (1995) *U.S.G.S. Misc. Inv. Ser., Map I-2441*. [16] Ivanov, B. A. (2001) *Space Sci. Rev., 96,* 87-104. [17] Hartmann, W. K. and Neukum, G. (2001) *Space Sci. Rev., 96,* 165-194. [18] Pierce, T. L. and Crown, D. A. (2003) *Icarus, 163,* 46-65. [19] Carr, M. H. (2001) *JGR, 106,* 23,571-23,594. [20] Tanaka, K. L. et al. (2005) *U.S.G.S. Sci. Inv. Map 2888*. [21] Mathews, W. H. (1952) *Amer. J. Sci., 250,* 553-565. [22] Harder, M. and Russell, J. K. (2007) *Bull. Volc., 69,* 329-340. [23] Lescinsky, D. T. and Sisson, T. W. (1998) *Geology, **26**,* 351-354. [24] Armstrong, J. C. and Leovy, C. B. (2005) *Icarus, 176,* 57-74. [25] Seu, R. et al. (2004) *Planet. Space Sci., 52,* 157-166. [26] Jakosky, B. M. et al. (1995) *JGR., 100,* 1579-1584. [27] Mellon, M. T. and Jakosky, B. M. (1995) *JGR, 100,* 11781-11799. [28] Levrard, B. et al. (2004) *Nature, 431,* 1072-1075. [29] Laskar, J. and Robutel, P. (1993) *Nature, 361,* 608-612. [30] Laskar, J. et al. (2004) *Icarus, 170,* 343-364.