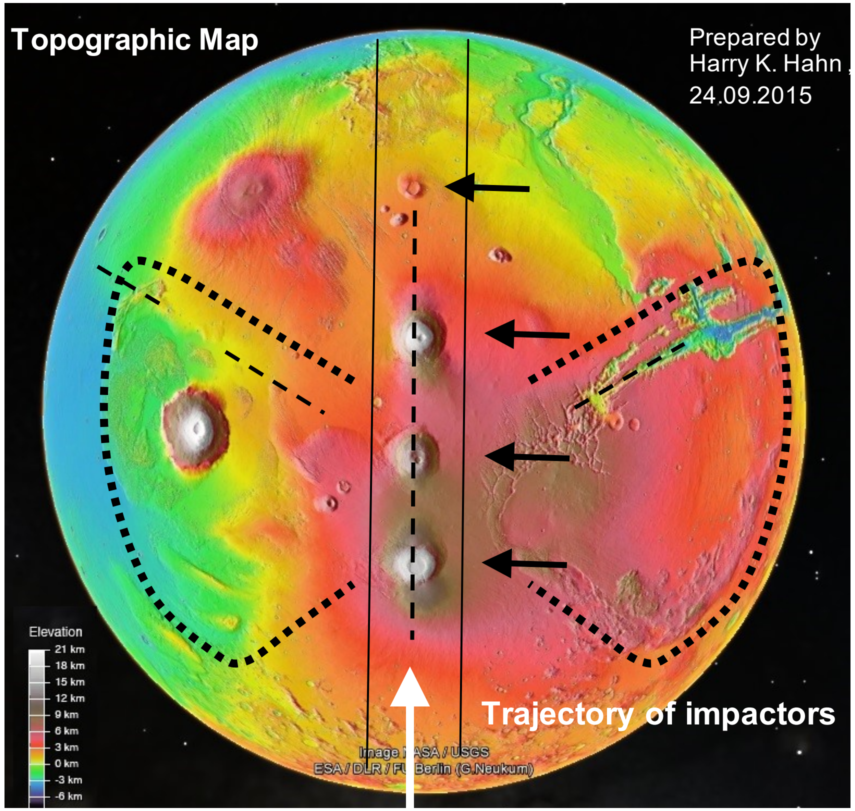
There is strong indication for a global impact event on Mars that probably happened less than 250 Ma ago

This global impact event produced at least four large impact craters of up to 600 km diameter which fractured the crust of Mars and triggered global expansion tectonics. The former oceans and ocean basins of Mars are a result of this event.

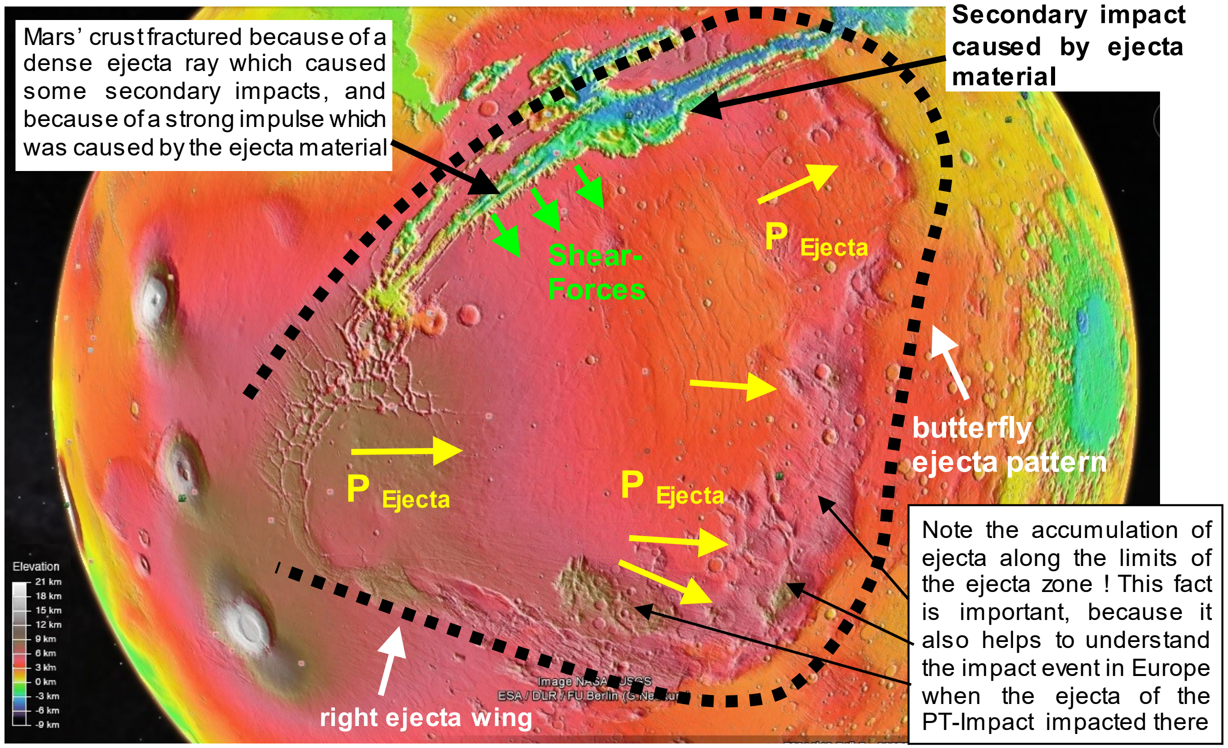
The dichotomy on Mars, extreme volcanism and the ancient oceans & water erosion on Mars are a direct result of the impact event. The water which filled the developing ocean-basins on Mars was brought to the surface in the process of global expansion tectonics started by the impact, and through the extreme volcanism that followed the impact event and that was going on for millions of years

The impactors which produced the impact craters probably had a diameter in the range of 20 to 50 km each.

The impact was an oblique impact which means that the impactors arrived in a shallow impact angle probably < 30° in regards to the surface. This is indicated by the ejecta pattern of the impact. The following images give a first explanation of the impact event :



This image clearly shows that the shield volcanos of the Tharsis Montes region are the result of a global impact event. There is fourth smaller shield volcano which lies a bit further up. All four structures lie on one precise line !
This is strong indication for an impact event, because impactors of a collapsed comet or asteroid always arrive on one straight line because they share a common orbit.



This image shows a classical butterfly-shaped ejecta pattern on the righthand side of the impactor chain. From the shape of the ejecta pattern the trajectory of the impactors becomes obvious, because a butterfly-ejecta pattern is always wider in the direction in which the impactor(s) travelled before impact → **see introduction**

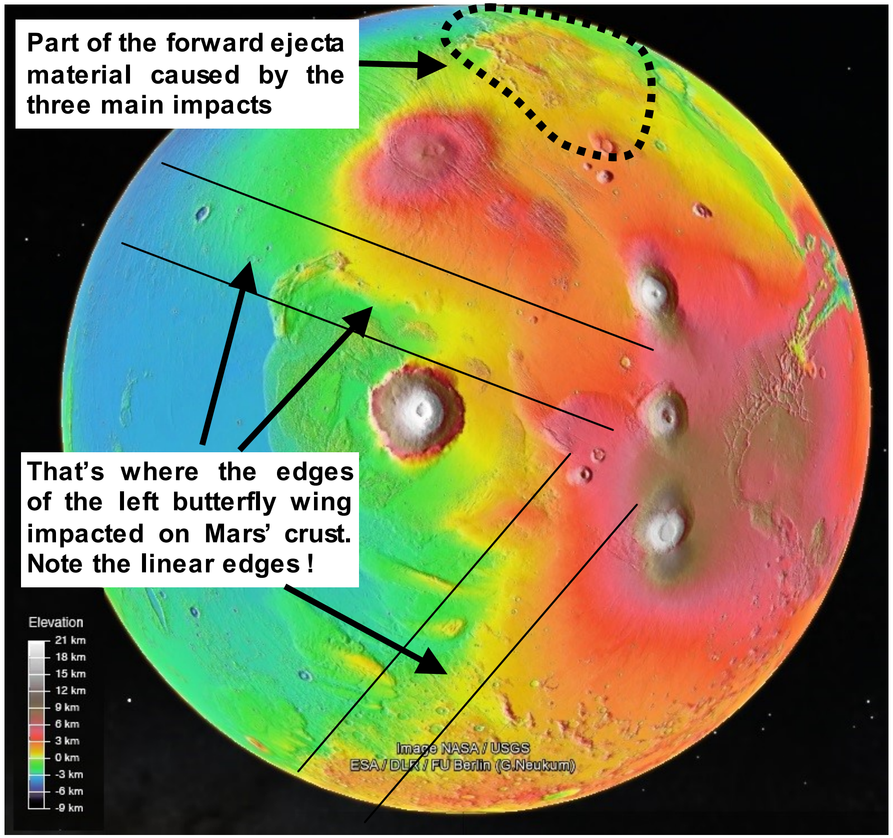
Regarding the accumulation of the ejecta material the following must be said :
Because of the nearly simultaneous impact of the three main impactors there were three spherical shock waves developing around the three craters. And along the nearly plane meeting zones of the shock waves the ejecta was forced to accumulate along straight lines. → **see Examples of double & triple impact in the Introduction !**

The dichotomy on Mars → the clear difference in the topography between the northern and southern hemisphere of Mars, and the formation of the large ocean basins Utopia Planitia & Arcadia Planitia is a direct result of this global impact event !

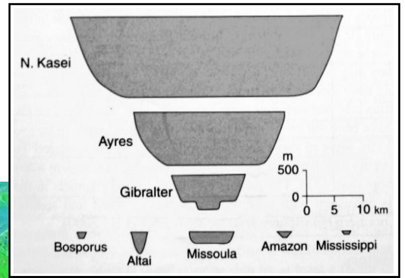
Because there was strong expansion tectonics going on, which was triggered by the global impact event, the area which is marked in blue on the map (→ deepest area !) is mainly new (additional) surface area of the planet !! Please compare this global impact event on Mars with the one on the Jupiter moon Ganymede (see study !) and with the PT-Impact Event. These impact events are very similar !

The left side of the butterfly-shaped ejecta pattern (→ the left wing) caused straight fractures in the crust of Mars, similar as it happened on the right side, caused by the right wing of the ejecta, were the impact impulse of the ejecta and secondary craters fractured the crust in a straight line and caused the gigantic Valles Marineris Canyon, which stretches over a distance of 2400 km !
But on the left side the crust completely broke apart and strong Expansion Tectonics quickly began to form the new ocean basins.

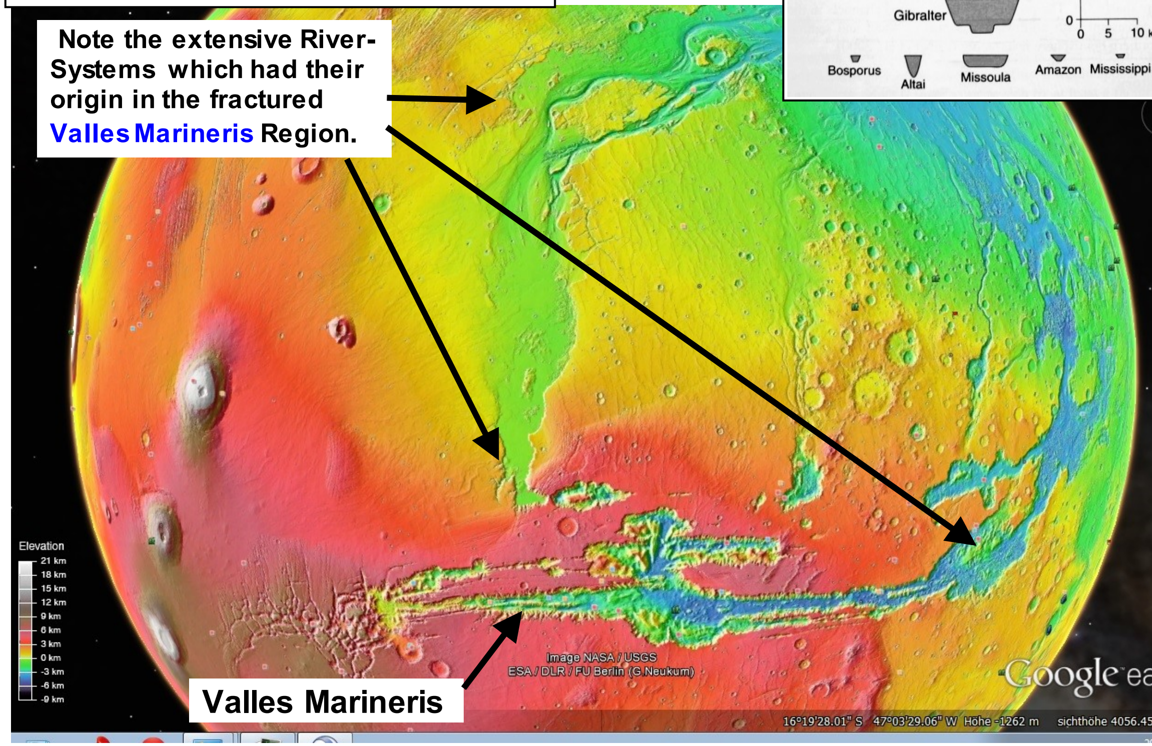
It is also easy visible that large amounts of water came from the Valles Marineris Region ! Which means that the water came from the interior of the planet ! It was water which was contained in the magma, probably in a super-saturated state. And when the planetary crust fractured it was released because of the rapid drop of pressure in the uncovered (fractured) mantle regions.
The maximum filling of the ocean basins probably happened when the expansion tectonics was in full swing.



Compare the biggest flood channels on Mars Kasei Valles & Ayres with the largest flood channels on Earth !!! →



MARS GEOLOGY:
Rotating Globe Geology : see → weblink



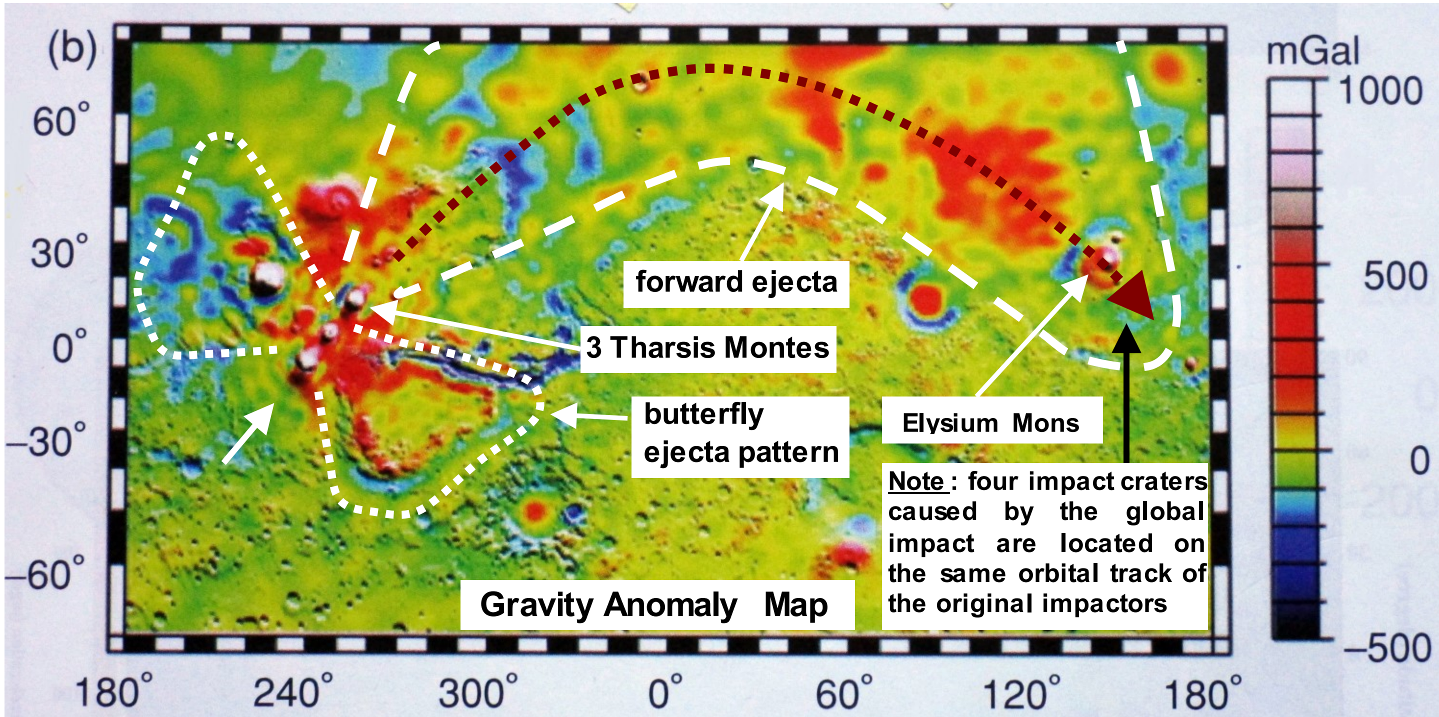
The strong concentration of the ejecta mass along the wing edges of the butterfly -ejecta pattern cut the complete crust of Mars along the edges of the ejecta blanket and formed the ocean basins Utopia Planitia & Arcadia

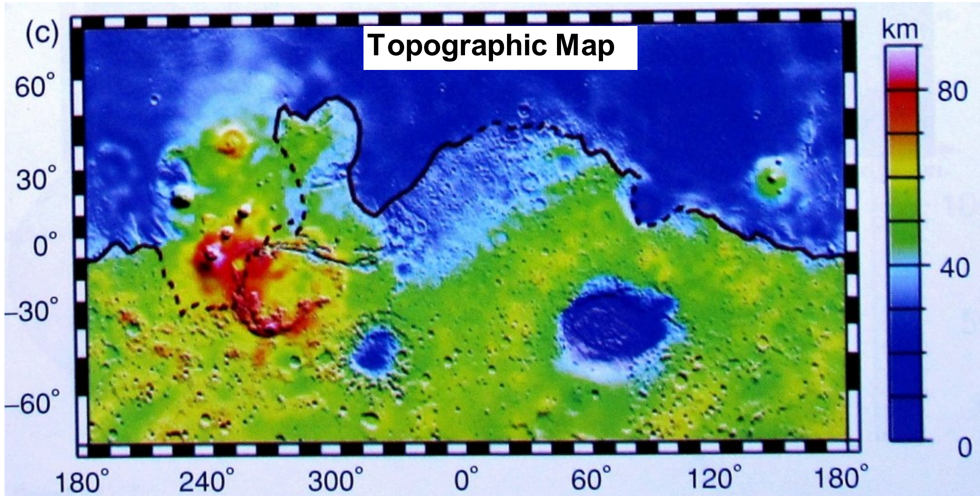
This ocean basins began to fill with water, coming out of Mars' mantle, shortly after the impact and the start of expansion tectonics

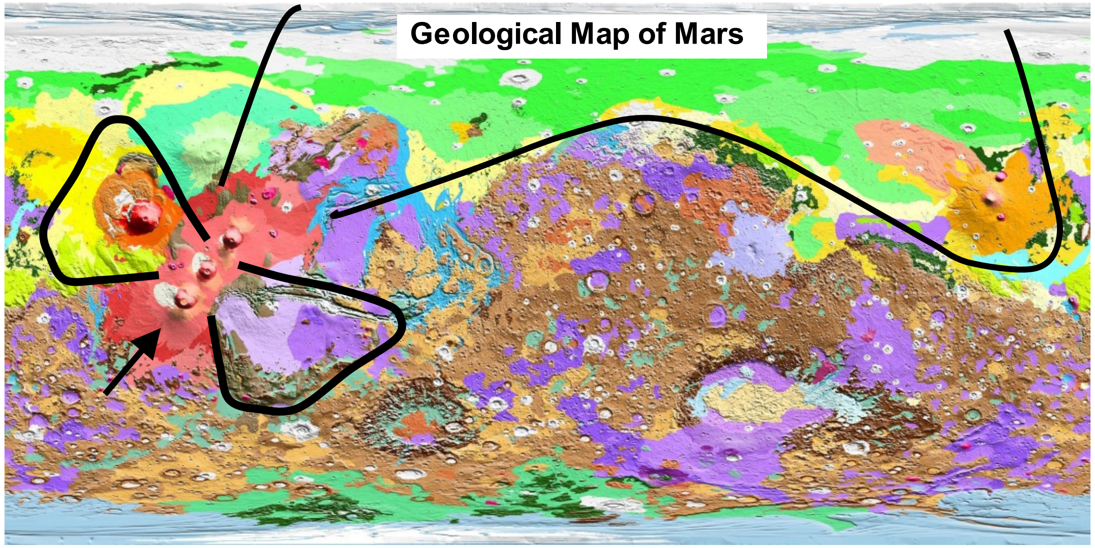
The maps on the righthand side show the full extension of the butterfly- and forward- ejecta blankets. Because there was expansion tectonics going on in the last 100-200 Ma, the forward ejecta area was probably much smaller at the time of impact. Elysium Mons was caused by the impact of the fourth Impactor from the Impactor-group (on the same orbit) !

The topographic map on the bottom shows the dichotomy border-line on Mars' crust along which the crust was cracked & cut open by the ejecta

And the geological map nicely inllustrates the massive geological changes on Mars' surface, caused by this global impact event.





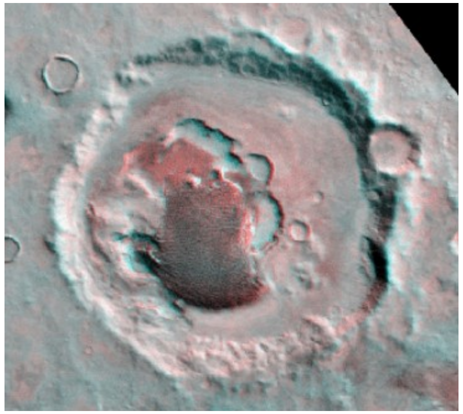


Mars’ large shield volcanos are not the result of hotspots, they are the result of large impacts !

The large shield volcanos of the Tharsis Montes region are the result of an impact event of global scale, caused by the nearly simultaneous impact of at least three large impactors ! They are not the product of so called hotspots. The three Tharsis Montes shield volcanos, and probably Elysium Mons as well, where caused by the fragments of a large asteroid or comet which probably broke apart just before impact !

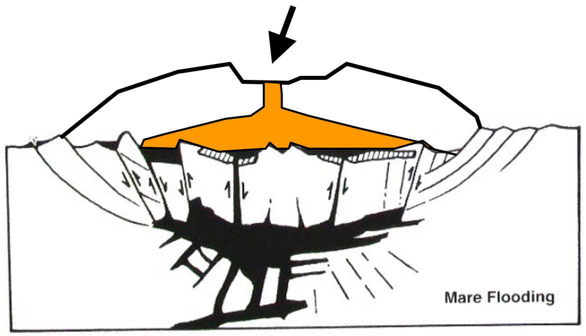
The two images below show how volcanic domes grow above large impact craters. This happens when the fractures under the crater, which result from the impact, are so extensive and deep that magma from the mantle can rise.

Then the conditions are given that shield volcanos like the large shield volcanos of the Tharsis Montes region on Mars, Ascraeus Mons, Pavonis Mons, Arsia Mons and Elysium Mons can form. Olympus Mons the largest shield volcano is probably also the direct result of an impactor or it is the result of impacting ejecta from the Tharsis Montes impacts.



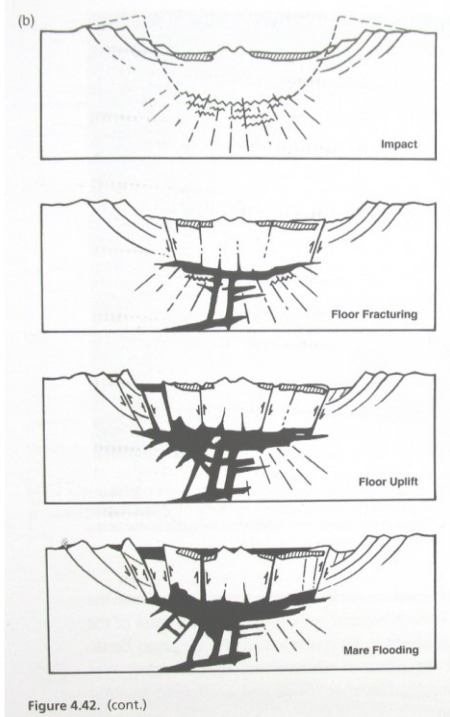
As these two examples of craters with dome structures, formed by magma outflow, clearly demonstrate, big impacts can cause large shield volcanos

Shield Volcano grown above an impact crater



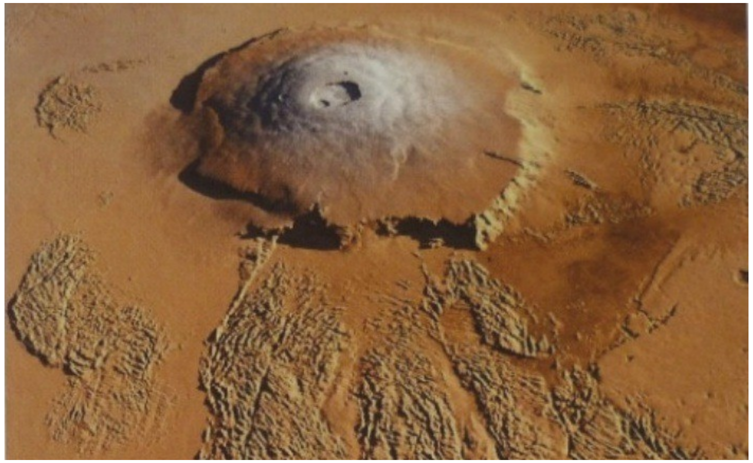
A crater with a fractured floor and massive outflow of magma can form a large shield volcano which rises high above the crater

Fracturing of the crater floor of a large impact crater, and later flooding of the crater with magma flowing out of the cracks



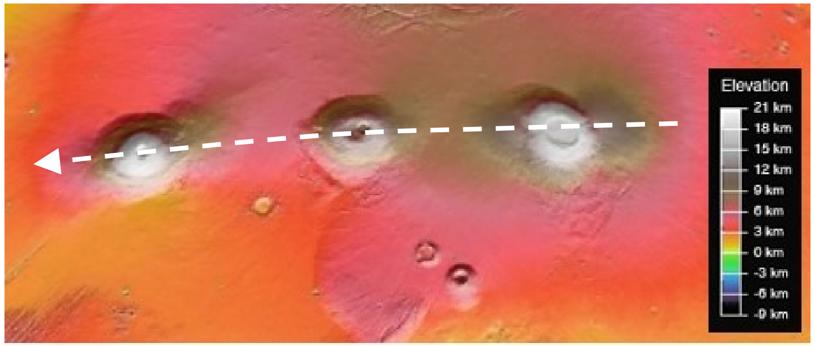
From : **Planetary Geomorphology**,

Ronald Greeley, ISBN : 978-0-521-86711-5



The shield volcano Olympus Moons is 23 km high and 600 km in diameter, and it is bordered by an escarpment up to 10 km high, at the foot, from which a series of lobate deposits (ejecta lobes ?) extend for hundreds of kilometers.

Tharsis Montes Region :

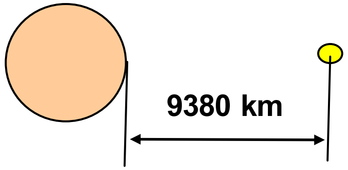


These three shield volcanos represent three major impact craters (impact sides) caused by the global impact event on Mars

Mars moon Phobos provides further evidence for the described global impact event on Mars

Mars moon Phobos is covered with parallel grooves which can only be created by a very large impact event on Mars. These grooves which were formed by parallel chains of secondary impactors are very dense on Phobos leading apex but completely missing on its trailing apex. This is strong evidence that a global impact event occured on Mars.

Note that the distance between Mars and Phobos is around 9400 km !



To give an impression of the distance which the ejecta from Mars travelled to produce the grooves : Phobos orbits Mars in an average distance of 9380 km !!

From **„Martian Geomorphology“**, M.R.Balme, A.S.Bargery, ISBN : 978-1-86239-330-1

Secondary impact chains from primary craters on Mars

The final hypothesis, that the grooves of Phobos are secondary impact crater chains from impacts on Mars, is explained in more detail in Figure 17. Unlike all of the other ideas, the pattern of grooves on Phobos almost exactly matches that predicted by theory (Fig. 12). On this hypothesis, each groove family originates from a large impact on Mars and is composed of radial (effectively parallel at the distance of Phobos) coalesced crater chains. These would, therefore, create the parallel plane intersections observed, each family having a different orientation, but the motion of Phobos would ensure that the plane passing through the leading apex of Mars would also pass through the centre of Phobos. This idea is also the only one that explains why each groove family covers only one hemisphere of Phobos, and also why the groove families are of different ages. The 'zone of avoidance' at the trailing apex of Phobos ties in exactly with what this hypothesis predicts: this is the only location that ejecta from Mars cannot reach because Phobos' forward motion in its orbit exceeds the ejecta velocity.

from Page 27 :

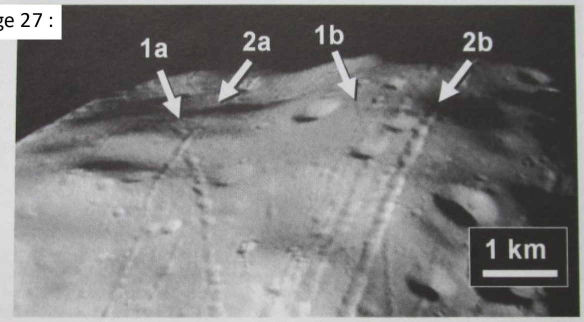


Fig. 6. The two parallel grooves 1a and 1b are cut by grooves 2a and 2b, respectively, indicating that the groove family represented by 2a and 2b is younger. From image h6906_0000.nd2. Image credit: ESA/DLR/FUB.

from Page 34 :

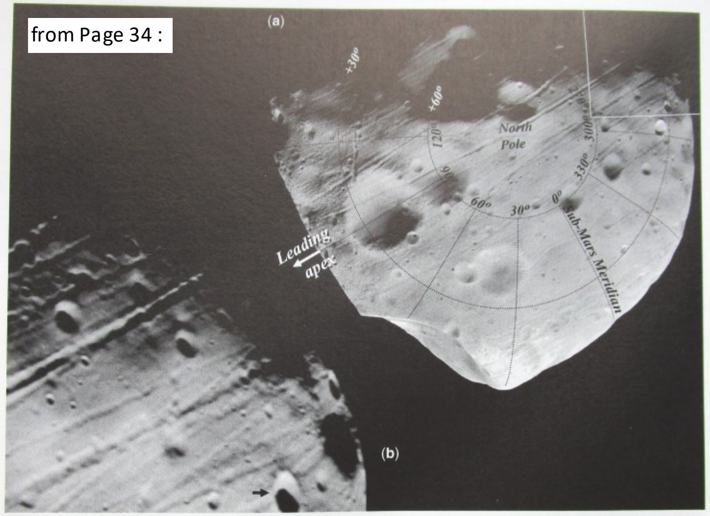


Fig. 14. (a) (Top right) Image h3310_0000.nd2 centred close to the north pole, dominated by the subparallel striations and crater chains of family A, the most complete groove family on Phobos that covers most of the northern hemisphere. Note that some individual grooves run unbroken for nearly 180° of latitude, and that the central groove of this family passes close to both the north pole and the leading apex. The tightly spaced grooves appear very straight and linear, but the super-resolution image (**b**, lower left) of the area in the box at top right shows that they comprise contiguous pits with raised rims (image h3310_sr2_0006). The top right-hand image is about 23 km left to right. Image credit: ESA/DLR/FUB.

from Page 37 :

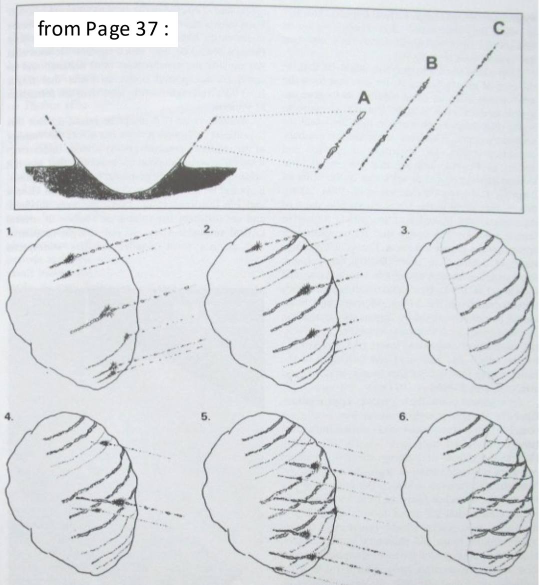


Fig. 17. Diagrams illustrating the formation of Phobos' grooves by the impact of ejecta from large impacts on Mars, from Murray *et al.* (1994). The top diagram shows a section through a large impact event on Mars, early in crater excavation. Highly shocked and melted material from both the impactor and the impacted surface is ejected at velocities of several km s^{-1} in a cone whose apex is the crater centre. The velocity of ejecta rapidly decays with time, so the leading part of each individual ejected jet of melt will steadily draw away from the following end and cause it to be stretched out into a progressively longer string of ejecta, as at A, B and C. The lower series of diagrams (1–6) shows the situation at Phobos. (1) and (2) Show radial (effectively parallel at the distance of Phobos) ejecta strings from the same impact on Mars arriving at Phobos, where Phobos' motion in its orbit (towards the lower right of the observer) causes long chains of secondary impact craters to form on its surface. (3) Shows the situation after the shower of debris has passed: nearly one half of Phobos is crossed with parallel grooves composed of contiguous secondary impact craters with raised rims. (4) and (5) Show the situation at a later time, when a different large impact on Mars results in the arrival of a second shower of ejecta, causing new parallel grooves to form at a different orientation from the earlier set. (6) Shows the final situation, with two families of parallel grooves crossing each other, each family covering only one half of Phobos.

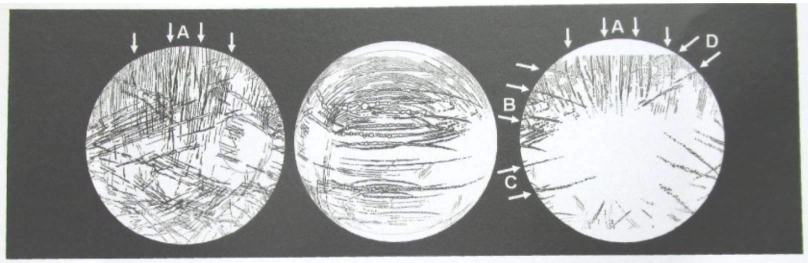


Fig. 7. (Top) Orthographic projections of groove positions on Phobos centred on (left) the leading apex (0° latitude, 90° longitude), (centre) the sub-Mars point and (right) the trailing apex. Note that grooves appear straight and in groups of parallel families when viewed from the leading and trailing apex (left and right). Four prominent families were named by Thomas *et al.* (1979); family A (the most prominent and numerous), B and D are marked. Also, note that all grooves become parallel along the sub-Mars meridian.

from Page 28 :

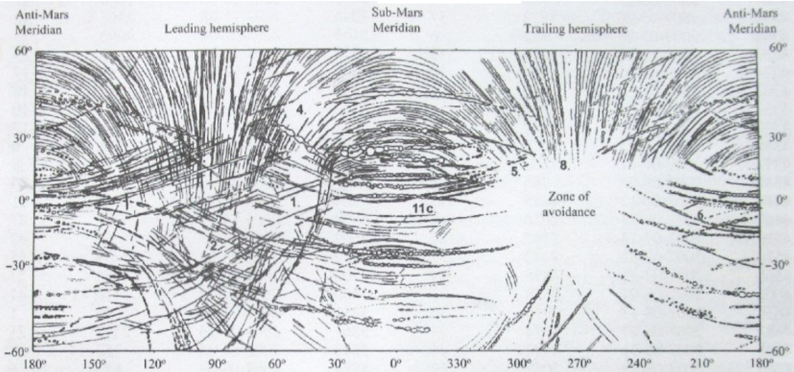
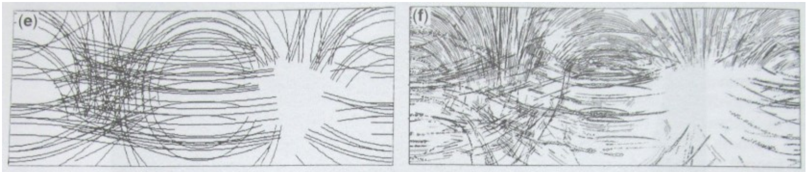


Fig. 1. Sketch map of grooves on the surface of Phobos derived from HRSC *Mars Express*, *Viking* and MGS (*Mars Global Surveyor*) images. A Mercator projection between −60° and +60° is used, and locations and orientations of features were assembled using crater positions from an existing control network (Duxbury & Callahan 1989). (1) Marks the centre of Stickney crater, the largest on Phobos; other numbers (2, 4, 5, 8 and 11c) refer to the approximate centres of figures in the text. Note that grooves become parallel along the sub-Mars and anti-Mars meridians (0° and 180°), and that there is a 'zone of avoidance' around which all grooves fade out and disappear surrounding the trailing apex (0° latitude, 270° longitude). The leading apex (0° latitude, 90° longitude) is characterized by groove families crossing each other at all orientations.

from Page 24



from Page 32

(**e**) (Lower left) Predicted secondary crater chain orientations from impacts at 12 different latitudes on Mars, chosen to match those seen on Phobos. Note the resemblance between this model and the map of grooves at the bottom. The model is simplified as a spherical Phobos, so does not fit the real situation as well as if it were modelled as a triaxial ellipsoid; nevertheless, the resemblance between theory and model illustrated in (e) is strong. (**f**) (Bottom right) Map of Phobos' grooves from HRSC images.

Remnant massifs of the highland - lowland (dichotomy) boundary, probably are the result of a global Impact Event

The obtained absolut ages for the most recent resurfacing periods of these massifs (→ the covering of these massifs by large amounts of volcanic material) indicate that the global impact event may have happened in the range of **50 to 200 Ma** ago. It also seems that the volcanic material (the volcanic ash) which periodically covered these massifs contained large amounts of volatiles (probably mostly water), which evaporated within a certain time and caused big landslides etc., because of "volatile-activity"

The relatively smooth-appearance mantling deposit blankets most parts of the study area and overlies lowland plains and footslope aprons as well as the smoothly convex remnant massifs. It is prominent where landslide scars and small-scaled depressions, such as obliterated impact craters, form local catchment areas (Fig. 9d). At over-steepened

walls, mantling material accumulates at the foot-slope and reaches backwards uphill. Remnant crests marked by a central segmented ridge (Fig. 6a) often exhibit an overlying mantling material that terminates on both sides of the crest. This suggests the retreat of the covering material either by atmospheric loss of volatiles or by downwasting through slumping or creep at steep locations (Figs 6b, c & 7). Some of the displacement of a mantling layer occurs as glide flows, as indicated by polygonal sheets and circumferential ridges (Fig. 6b).

The mantling deposit is (a) superimposed on the remnant massif and (b) often detached from the

Remnant massifs of the highland–lowland boundary are either autochthonous, that is, they represent erosional remnants of highland material as suggested by geological mapping work (Scott & Tanaka 1986; Tanaka *et al.* 2005*a*) and earlier

discussions (Sharp 1973; Carr & Schaber 1977; Squyres 1979; Lucchitta 1984; Carr 2001), or they form uplifted crustal material as suggested for the southern hemispheric circum-Hellas and Argyre Planitiae remnants, as mapped by Greeley *et al.* (2006) (cf. question marks in Fig. 4). Alternatively, an allochthonous origin is conceivable although less likely, that is, emplacement by impact processes, similar to alternative explanations for the southern hemispheric remnant-apron features (e.g. Crown *et al.* 1992; Greeley *et al.* 2006).

Age constraints

For age determination, crater-size frequency distributions for nine lobate debris aprons were derived from undeformed impact craters. The obtained absolute ages provide proxies for the most recent resurfacing period and give some insight into the early past of apron formation or modification. Ages are in the range of 10–50 Ma, with early traces dating back to 100 Ma and up to 200 Ma ago (Table 4 & Fig. 12). Old ages for #9 are old signatures in the terrain covered by debris aprons; such older impact craters are partially filled by debris-apron material. Segmentation and stair-stepped frequency curves indicate multiple resurfacing events. Shallow branches of frequency curves strongly suggest the continuation of denudation and/or resurfacing and obliteration of older

impact craters. Individual branches indicate a clear phase at 50 Ma ago and some modification process dating back to 10–20 Ma ago. It cannot completely

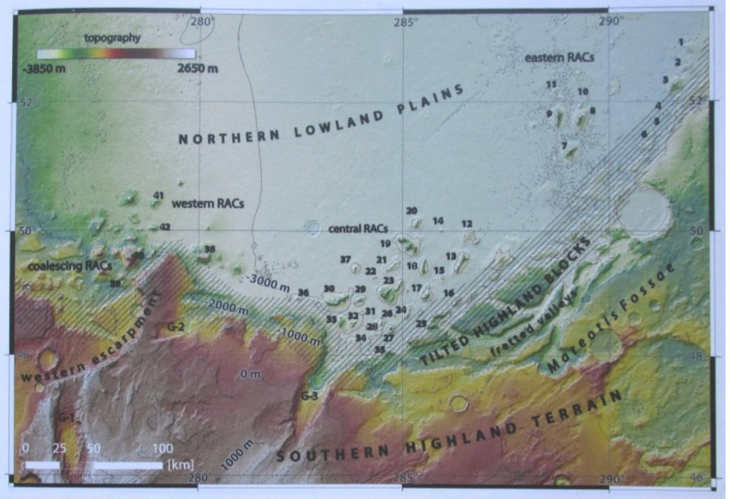


Fig. 2. Topography and general settings of the Mareotis Fossae–Tempe Terra study area; hillshade representation on colour-coded digital terrain model data as represented by a terrain model mosaic derived from bundle-block adjusted HRSC image scenes (Table 1). Labelled remnants/aprons are featured landforms referred to in the main text and used for morphometric studies. Elevations are based on the Mars areoid; the hatched area marks the escarpment transition between the southern highlands and northern lowlands. Isolines have a 500 m spacing (1 km lines are drawn solid), illumination is from upper left, map projection is Mercator. North is up. Image credit: ESA/DLR/FUB; see prelim viii for acronym definitions.

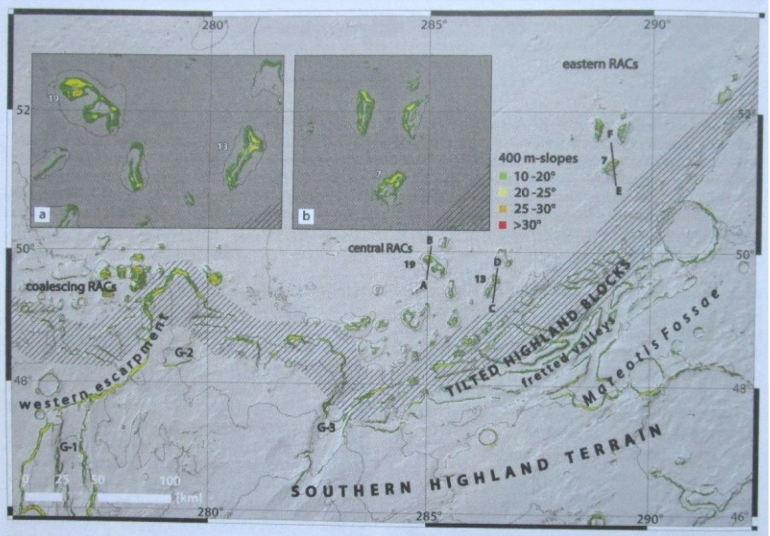


Fig. 5. Map in a hillshade-relief representation with superimposed slope data of remnant massifs and debris aprons. Slope data have been derived from 400 × 400 m digital terrain model data to avoid low-frequency noise. Locations of profiles are marked in the overview map, insets (**a**) and (**b**) show details of RAC features 7, 13 and 19 where topographical profiles are located. North is up in all images.

From **„Martian Geomorphology"**, M.R.Balme, A.S.Bargery, ISBN : 978-1-86239-330-1

from Page 49 to 60

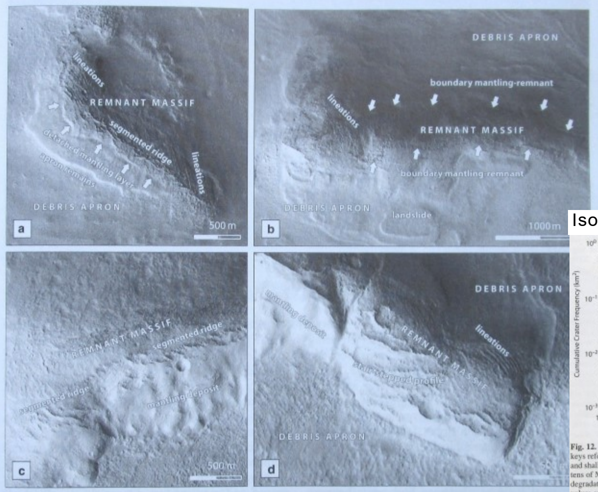


Fig. 6. Remnant massif constructs located in the western study area (278.5°E/49.5°N). (**a**) Remnant massif showing a dissected remnant surface in the detached mantling layer. The relict ridge at the crest indicates the former extent of the mantling material (CTX P19_008537_2285_XI_48N080W, complex feature #41, Fig. 2). (**b**) Remnant massif with a detached mantling layer, which is partly draped over the remnant wall rock (CTX P19_008537_2285_XI_48N080W, complex feature #41, Fig. 2). (**c**) and (**d**) remnant wall rock dissected by deeply incised gully features and stair-stepped profiles indicative of differential downslope mass movement and heavy degradation as suggested by impact-crater obliteration. Traces of remnant mantling layers are indicated at the footslope and remnant ridges on the wall rock (CTX P18_008102_2285_XI_48N081W, feature #39, Fig. 2). North is up in all images. Image credit: NASA/JPL/MSSS.

Isochrones & crater-size frequency measurements

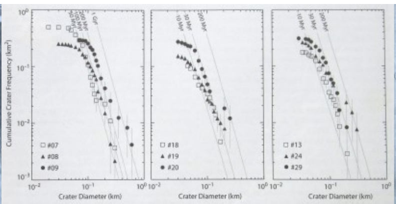


Fig. 12. Isochrones and crater-size frequency measurements for nine debris aprons in Tempe Terra. Numbers in the keys refer to the aprons labelled in Figure 2. Segmented and stair-stepped curves indicate multiple resurfacing events, and shallow segments suggest the continuation of denudation and/or resurfacing. Absolute ages are in the range of few tens of Ma, with early traces dating back to 100 Ma and up to 200 Ma ago. For all aprons, intensive thermokarst degradation with numerous subconcentric pits on the debris apron complicates the derivation of proper ages so that these values are considered as absolute minimums. For the statistics see Table 4.

Note the fluid-like appearance of the cover material of the massif !

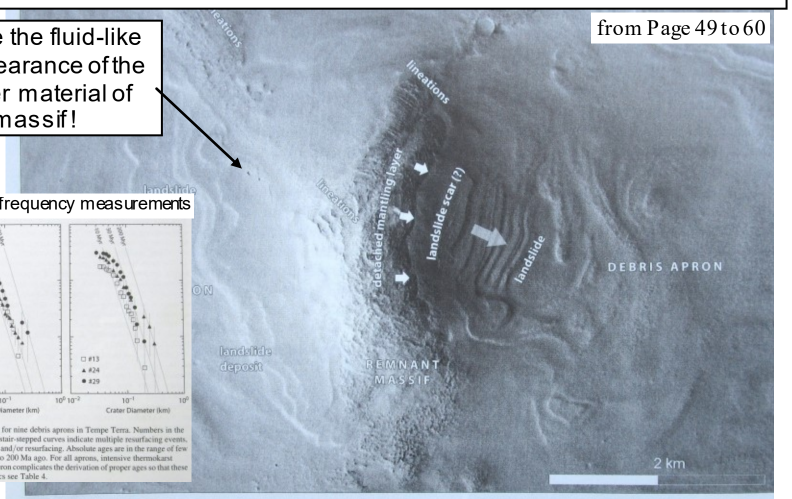


Fig. 7. Complex remnant-apron construct showing several episodes of resurfacing, as indicated by an old landslide scar, obliterated impact craters, parallel surface lineations and several younger phases of deformation of mantling deposits leading to landslides and accumulation on, as well as reworking in, lobate aprons. The mantling deposit is detached from the remnant massif (P19_008537_2285_XI 48N080W, feature #41, Fig. 2). North is up. Image credit: NASA/JPL/MSSS.

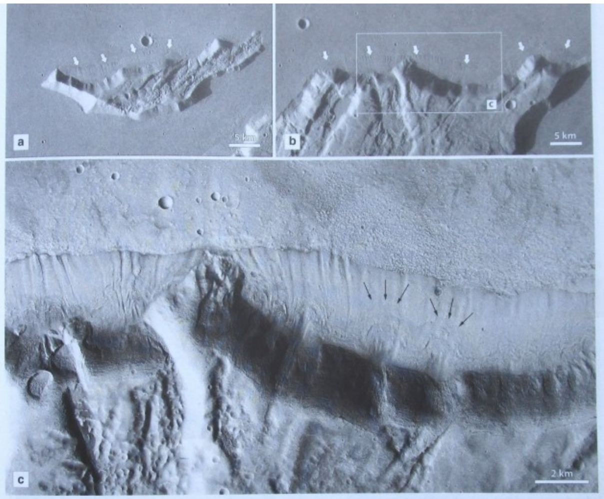


Fig. 10. Lobate debris aprons at isolated remnants in western Tempe Terra. The distribution and dimensions of lobate debris aprons in this more southern part are different from features located in more northern locations of Tempe Terra (Fig. 11). (**a**) Massif at 35.36°N with lobate debris aprons (white arrows) on the northern side, but not on the southern side (detail of HRSC image h5081 0000; centre at 35.36°N and 268.65°E; north is up, illumination is from the west/left). (**b**) Remnant highland massif with marginal lobate debris apron (white arrows). Lineations on lobate debris apron are parallel to the inferred flow direction (detail of HRSC image h5081_0000; centre at 35.0°N and 267.9°E; north is up, illumination is from the west/left). (**c**) Detailed view of lobate debris apron shown in (b); a convoluted or undulating pattern in plan view characterizes the texture of the upper (southern) parts of the apron. The position of lobes (e.g. black arrows) are controlled by indentations of the southern scarp (detail of CTX image P17_007852_2154; north is up, illumination from the SW/lower left). Image credit: ESA/DLR/FUB and NASA/JPL/MSSS.