Geomorphology of Mars

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What is geomorphology?

The interaction between the topography built by internal forces with erosional action by wind, liquid water or glaciers.

=> Specific interest of Mars due to its atmosphere

=> Landforms can be used to reconstruct past climates

Lecture summary

- 1. Major geological characteristics
  - *Topography, volcanoes, tectonism, impact basins, dichotomy, Valles Marineris*

- 2. Recent erosional landforms: A cold desert
  - *Eolian activity: Dunes, wind streaks, dust devils*
  - *Water ice related features: Polar caps, permafrost features, glacial features, recent gullies, lobate ejecta craters.*

- 3. Ancient landforms: Understanding the early Mars environment
  - *Erosional features: Outflow channels, valley networks*
  - *From erosion to deposition: Oceans, lakes, deltas, layered deposits, landing sites*
  - *Exobiological implications*

Recent missions have changed the face of Mars:

1976: Viking 1 and 2 — Mapping at 100-200 m/pixel scale

1998-today:Mars GlobalSurveyor

- *MOC high resolution images* — *2-5 m/pixel*
- *MOLA topography* — *1 km resolution/1 meter vertical accuracy*
- *TES* — *Mid-IR Composition at 3 km pixel resolution*

2001-today: Mars Odyssey

- *GRS-NS: Gamma-ray and neutron composition map*
- *THEMIS: Thermal images 100 m/pixel + visible 18 m/pixel*

2004: MER rovers — *Terra Meridiani and Gusev*

2004: Mars Express

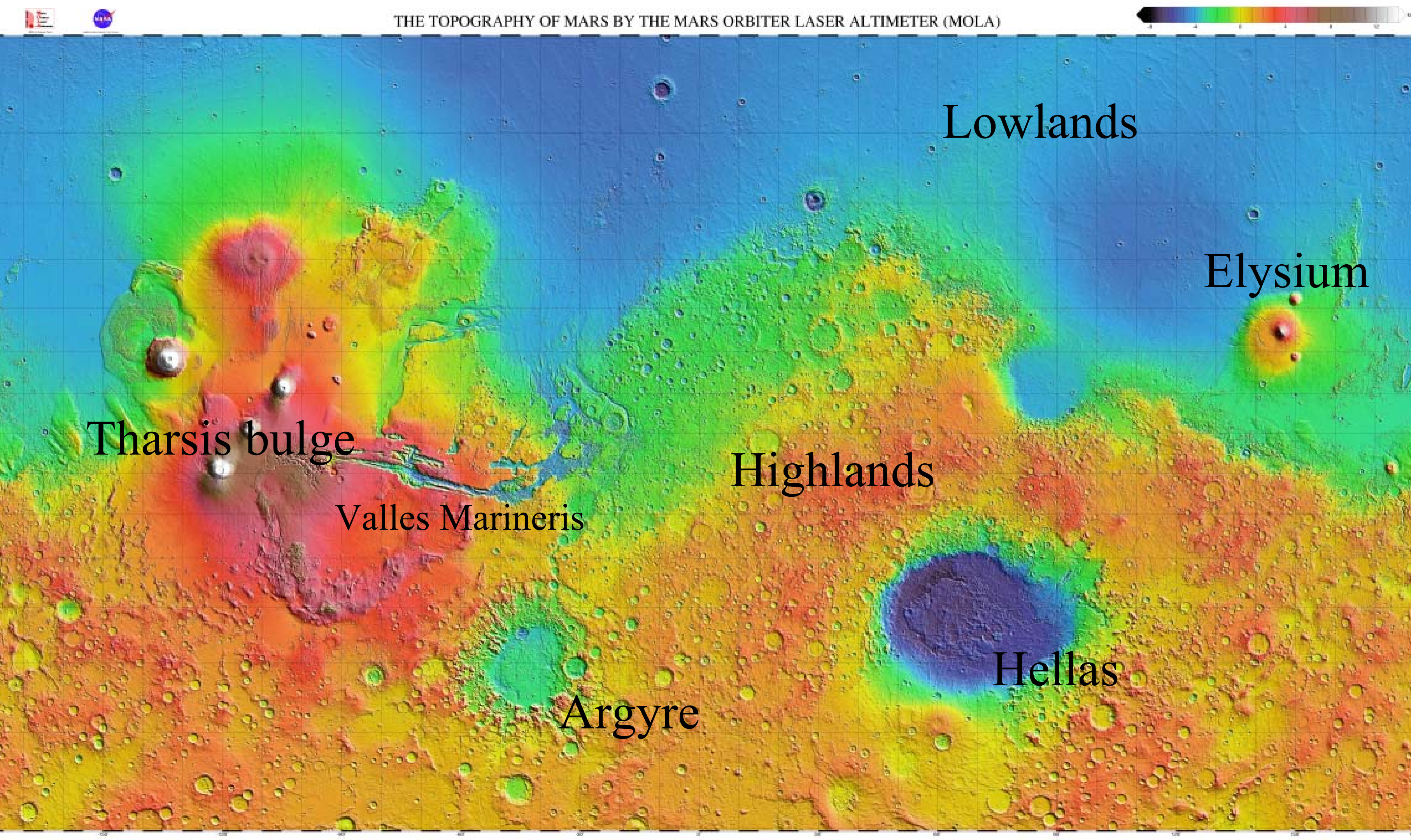
- *HRSC* — *High Resolution Stereo Camera*
- *OMEGA* — *Near-IR composition at 300 m pixel resolution*

1. Major geological characteristics

1.1 Topography and main units
- 1.1.1 Cratering and surface ages
- 1.1.2 The dichotomy
- 1.1.3 Tharsis bulge

1.2 Volcanism
- 1.2.1 Volcanoes types
- 1.2.2 Lava flows and lava plains
- 1.2.3 A recent volcanic region: Cerberus Fossae
- 1.2.4 Timing of volcanic activity

1.3 Tectonism
- 1.3.1 Tharsis deformation field
- 1.3.2 Grabens and wrinkle ridges
- 1.3.3 Plate tectonics on Mars
- 1.3.4 Valles Marineris canyons

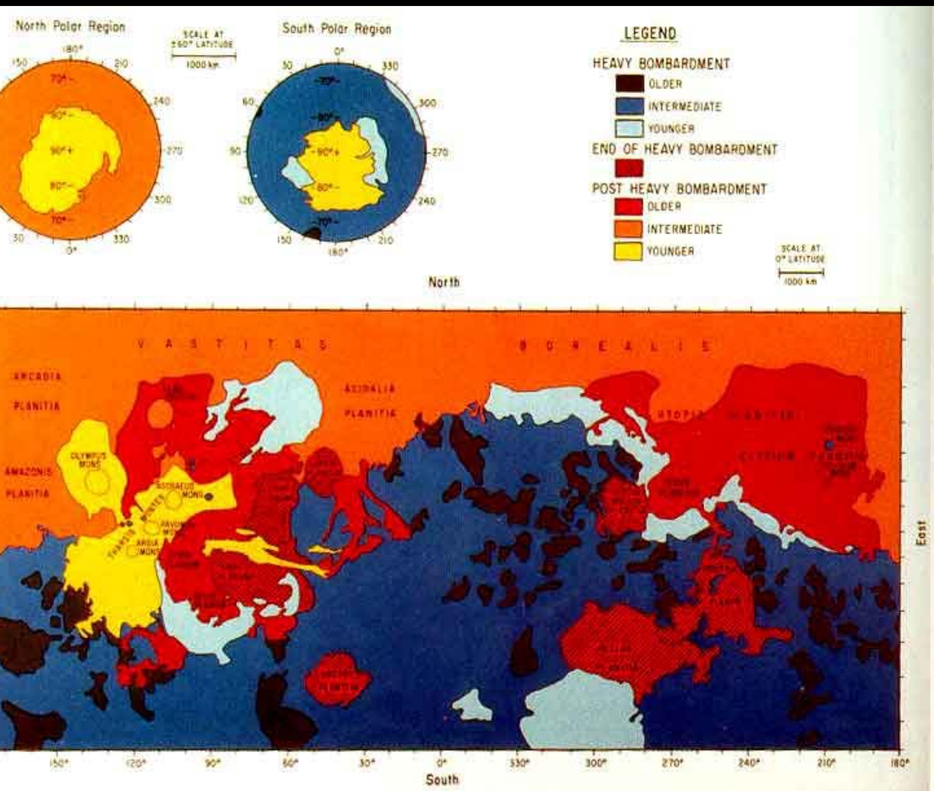


Reference: 0 km= average equatorial radius
(previous reference with Viking was 6 mbar pressure
about 2 km difference)

Three periods:

Noachian	(heavy bombardment < 3.7 Gy)
Hesperian	(transitional cratering, 3.7-2.9 Gy)
Amazonian	(steady state cratering since 2.9 Gy)

Simplified geologic map from cratering rates



Map showing the relative ages of generalized Martian surface units referenced to the end of late heavy bombardment where the crater production size/frequency distribution changes from a differential −2 slope index to one with a −3 slope index. The bluish areas date from the period of late heavy bombardment whereas the red, orange and yellow areas formed since

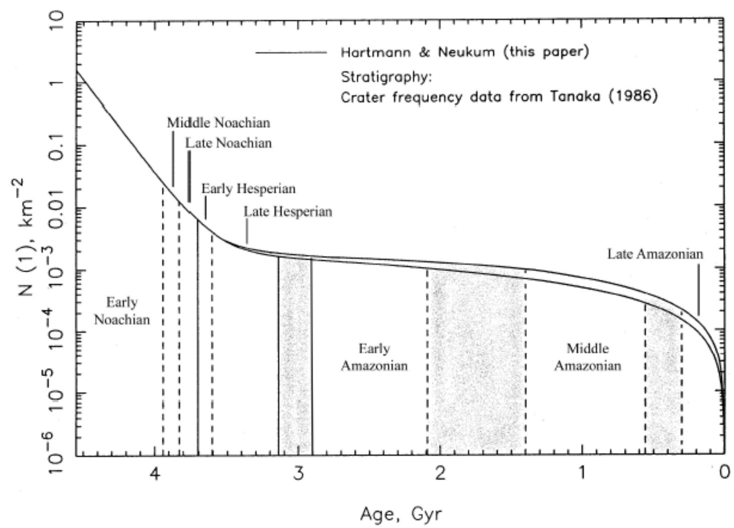


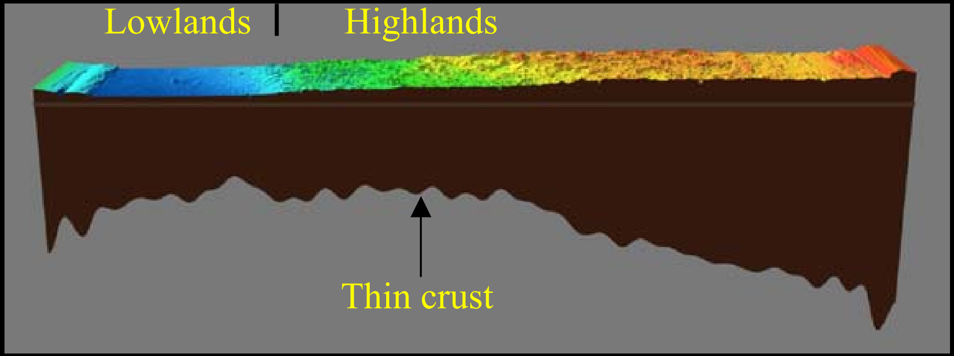
Figure 14. Mars cratering chronology model based on work in the present paper, using Tanaka (1986) definition of stratigraphy based on crater densities at $D > 1$ km (plus our rediscussion of the definition of Lower Amazonian), and Ivanov's (2001) derivation of isochrons from Neukum and Hartmann data. The solid lines give model ages based primarily on the Ivanov-Neukum isochrons combined with the Neukum equation for time dependence of cratering (with essentially constant cratering rate after 3 Gyr ago). The left curve (older ages) is from Neukum data, the right curve (younger ages) from Hartmann. The diagram shows why uncertainties are greatest in mid-Martian histories. The model ages assume $R_{\text{bolide}} = 2.0$. Model ages younger than ~3.0 Gyr are proportional to $1/R_{\text{crater}}$ (which is roughly proportional to $1/R_{\text{bolide}}$) and thus an additional uncertainty enters for those younger ages.

1.1.2 The dichotomy

* 5 km difference of elevation

* 2 end-member theories: <u>External hypothesis</u>: Huge impact on North hemisphere
Problem: The age of northern plains is >> heavy bombardment

<u>Internal hypothesis</u>: Difference in internal dynamism conduced to a thinner crust in the North (a thicker crust implies higher elevation)



Zuber et al., 1999

Problem: The dichotomy boundary does not correlate with the crustal structure

Implications: The geological manifestation of the boundary is primarily due to surfical rather than internal processes.

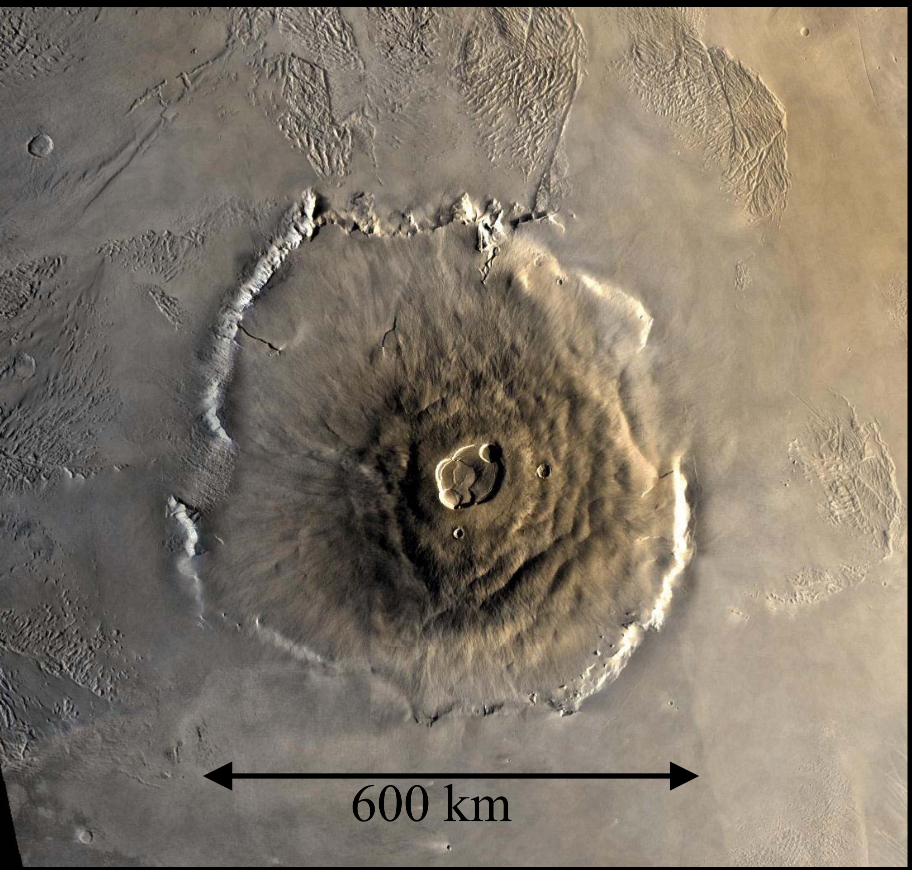
=> A combination of internal processes with geologic resurfacing probably involved to explain the dichotomy, but it is still not well understood

1.2 Volcanism

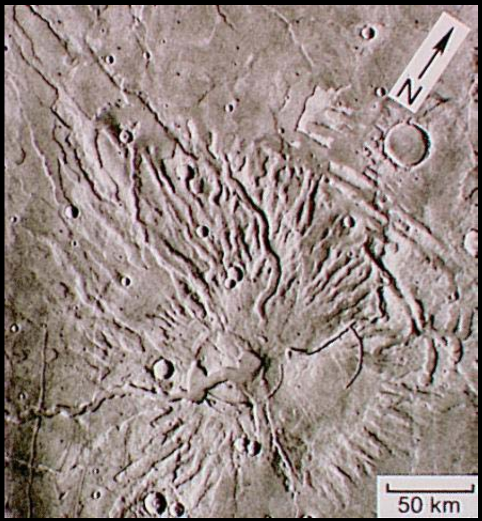
1.2.1 Volcanoes

Three types of volcanoes:

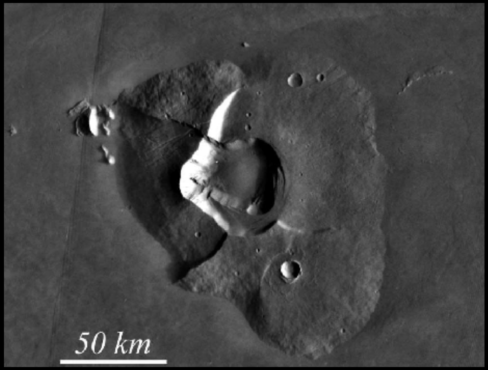
* Mons: Gigantic shield volcanoes (Olympus, Elysium, Arsia…)
* Patera: Flat-top less elevated volcanoes, often old, in highlands and eroded
* Tholus: « Small » shield volcanoes, usually Hesp-Amaz, same regions as Mons



Olympus Mons: 25 km elevation



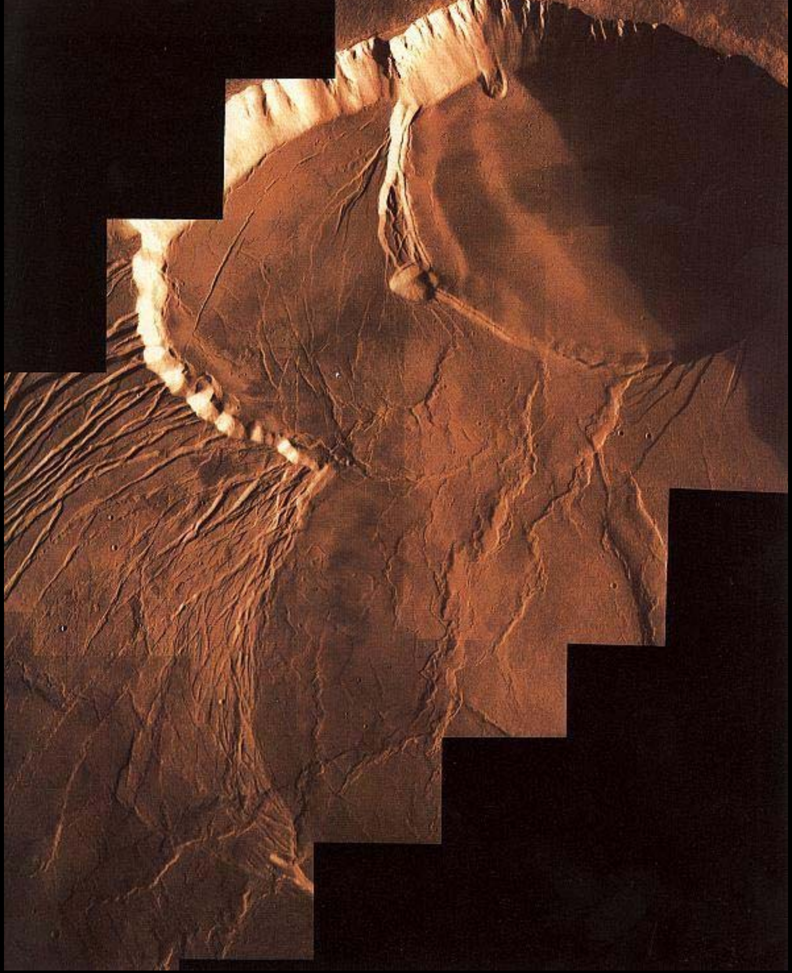
Thyrrena Patera

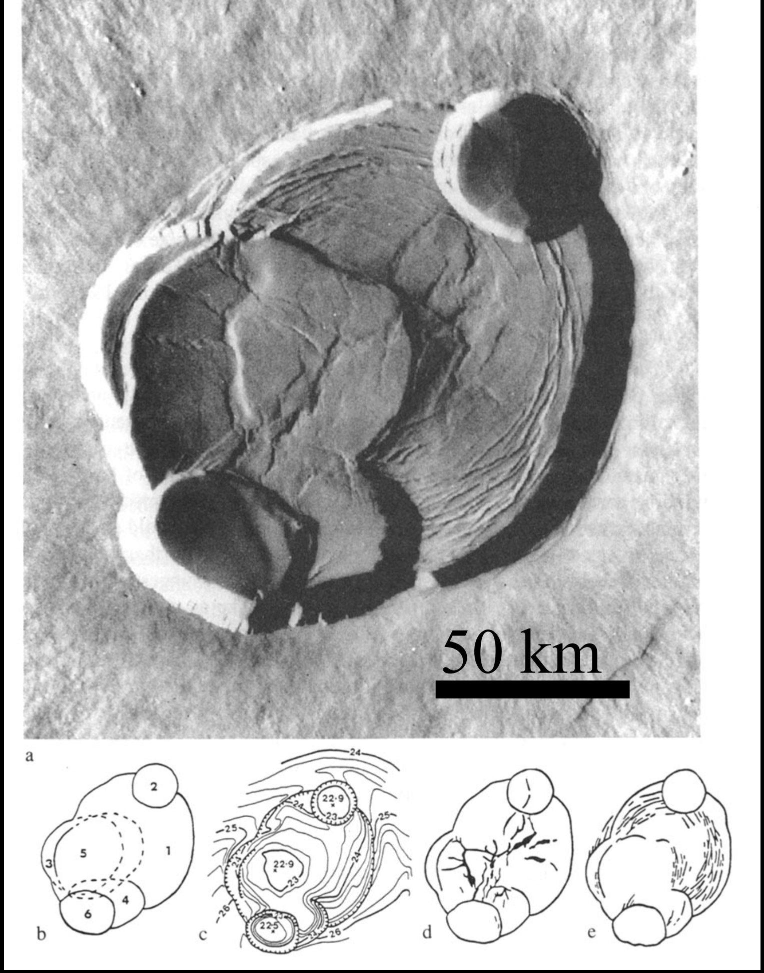


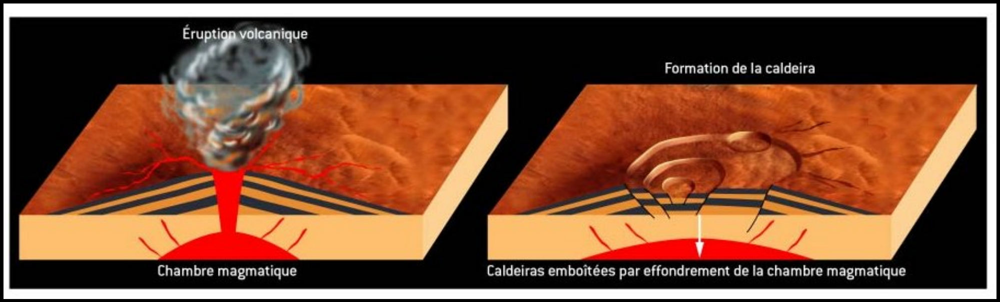
Tharsis Tholus

Typical terrestrial analogue of Olympus Mons: Mauna Loa (Hawaii island)

100 km large, 9 km elevation from ocean floor
(still 3 times less elevated and 6 times smaller than Olympus)
Basaltic shield volcanoe with caldera at top
Due to hot spots from mantellic plumes







* Formation of calderas by collapse of magmatic chambers

* Recent ages ~500 My (Viking) or < 200 My MOC

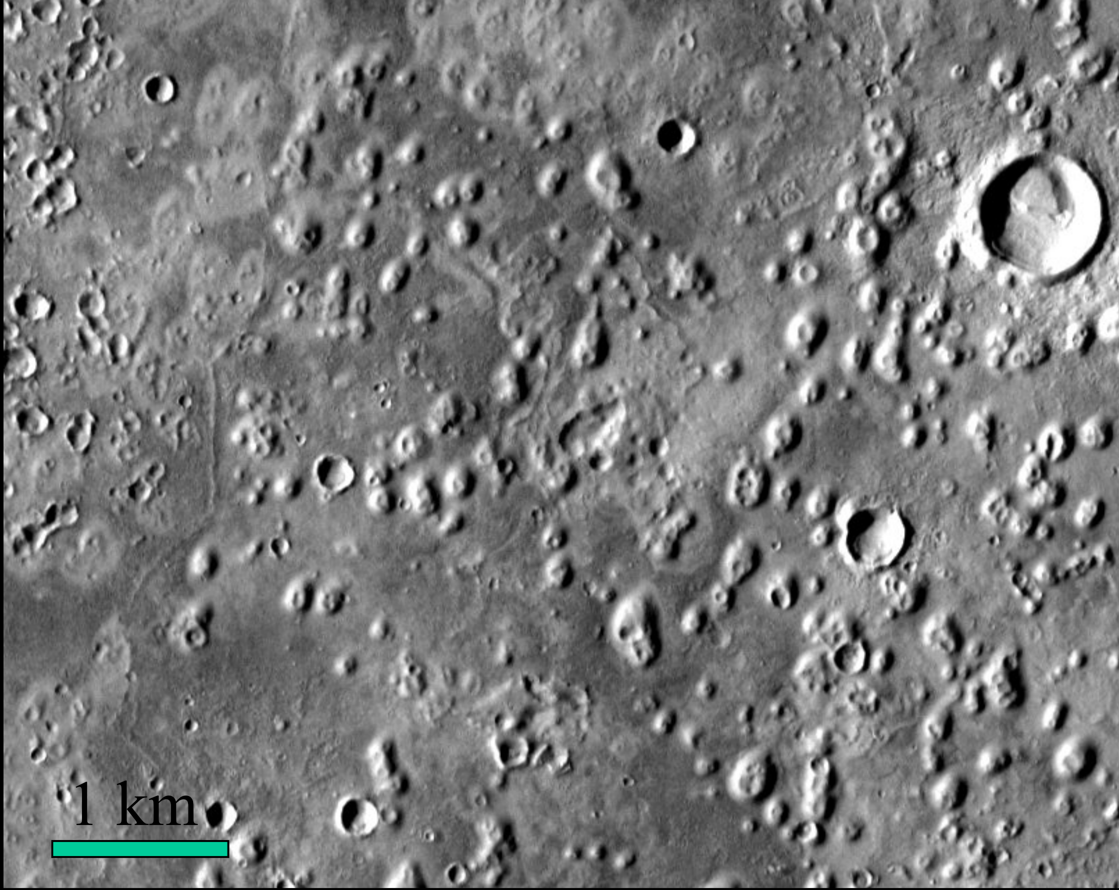
Other volcanic forms:

Small cones in Cydonia and
in Isidis region:

Small cinder cones?

Pseudocraters?
= explosive crater due to contact
of lavas with water or ice

=> could indicate water in the
ground at the time of lava flows

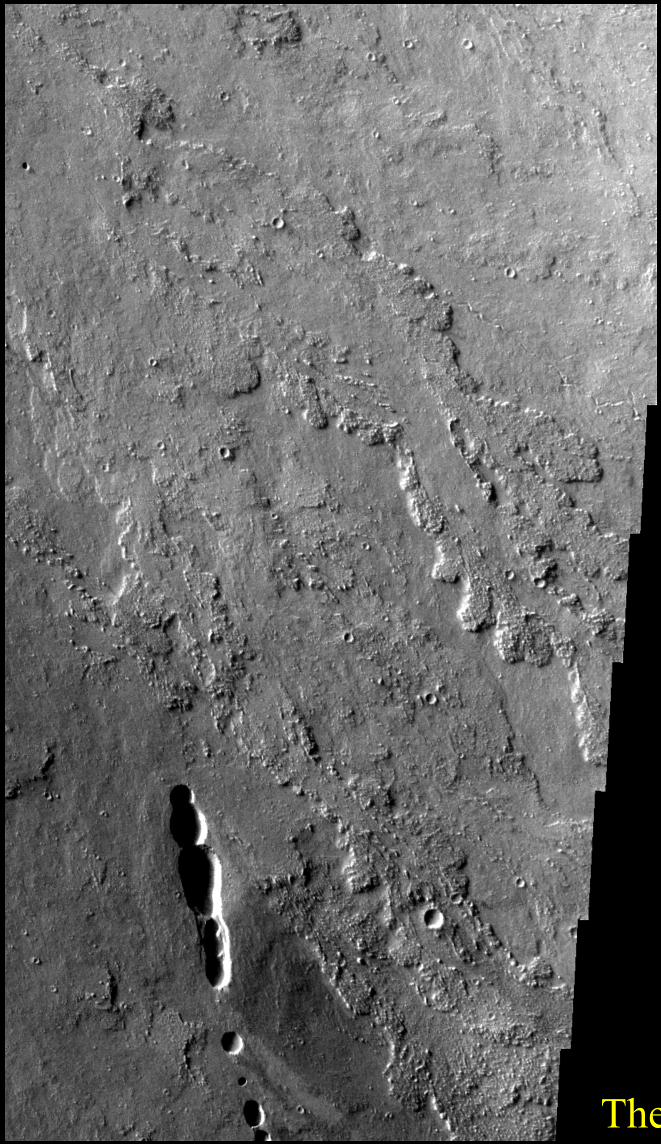


Example of
pseudocraters
in Iceland

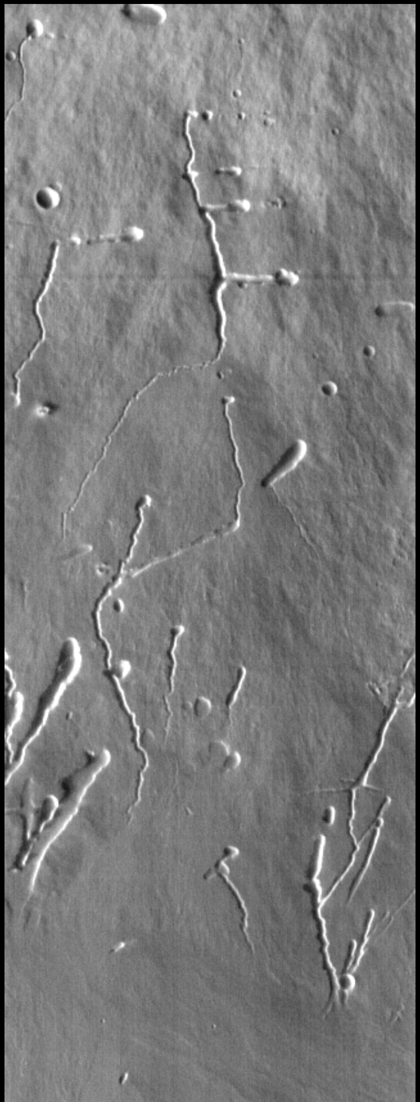
1.2.2 Lava flows and lava plains

Typical landforms over volcanoes:

* Lava flows (lobate shape, viscous flow)
* Collapse pits and lava tubes



Themis images

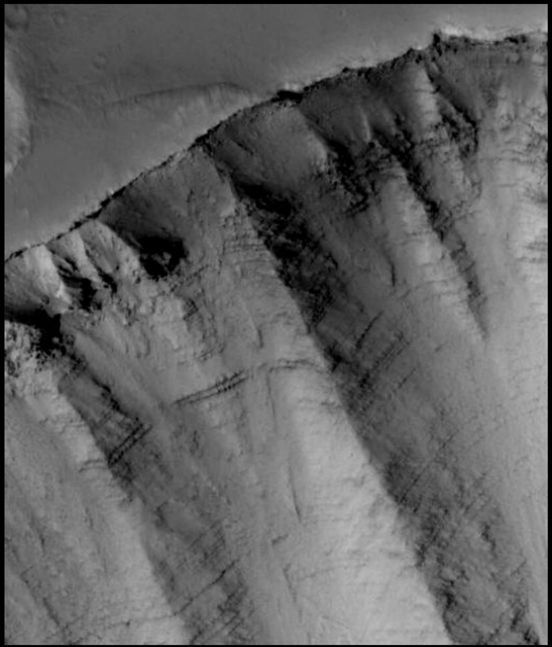


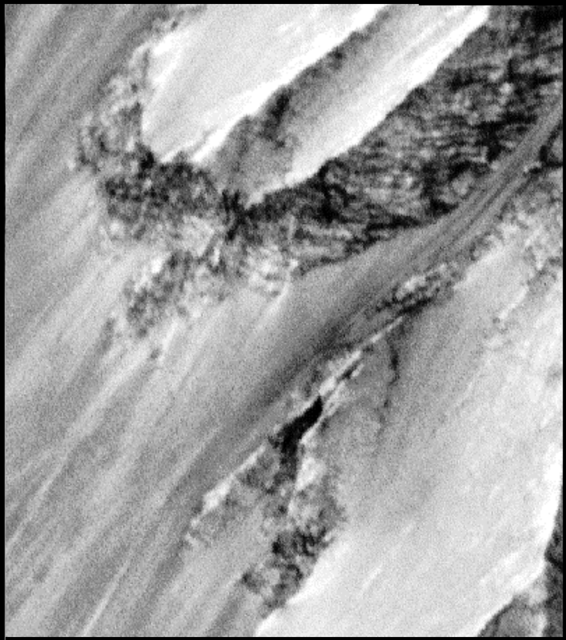
Flood lavas

Lava plains=flood basalts, very fluid lavas (10 to 1000 Pa.s)

- Common in the Hesperian epoch and early Amazonian epoch
- Some flood basalts can be triggered by large impacts.
- No edifice visible ~ similar to lunar plains
- Typical size 1000 km * 1000 km * 1 km thick

Terrestrial analogs = traps



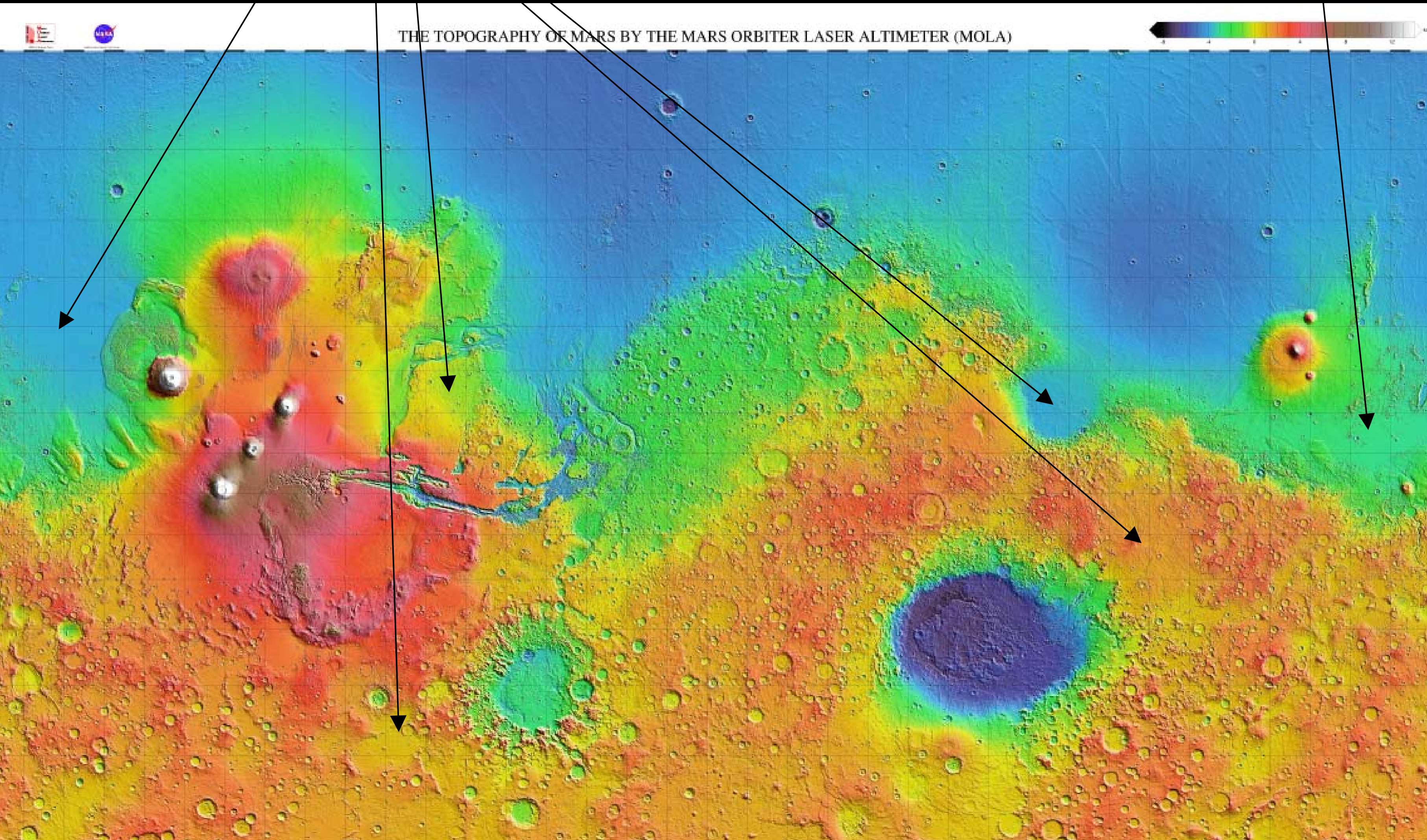


Valles Marineris scarp

Deccan traps, India
(1 Mkm^3)

Flood basalts

Cerberus Fossae

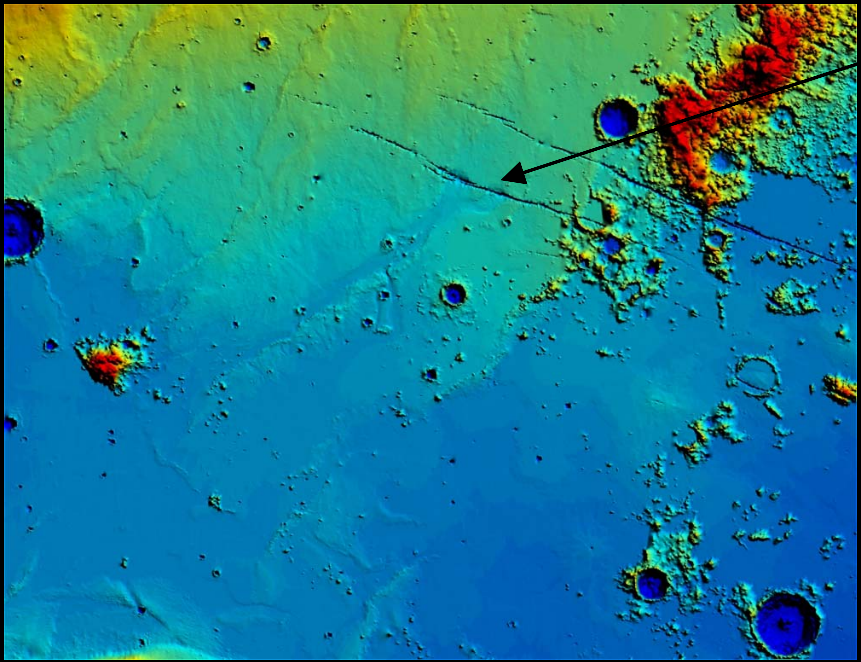


1.2.3 A recent volcanic region: Cerberus Fossae

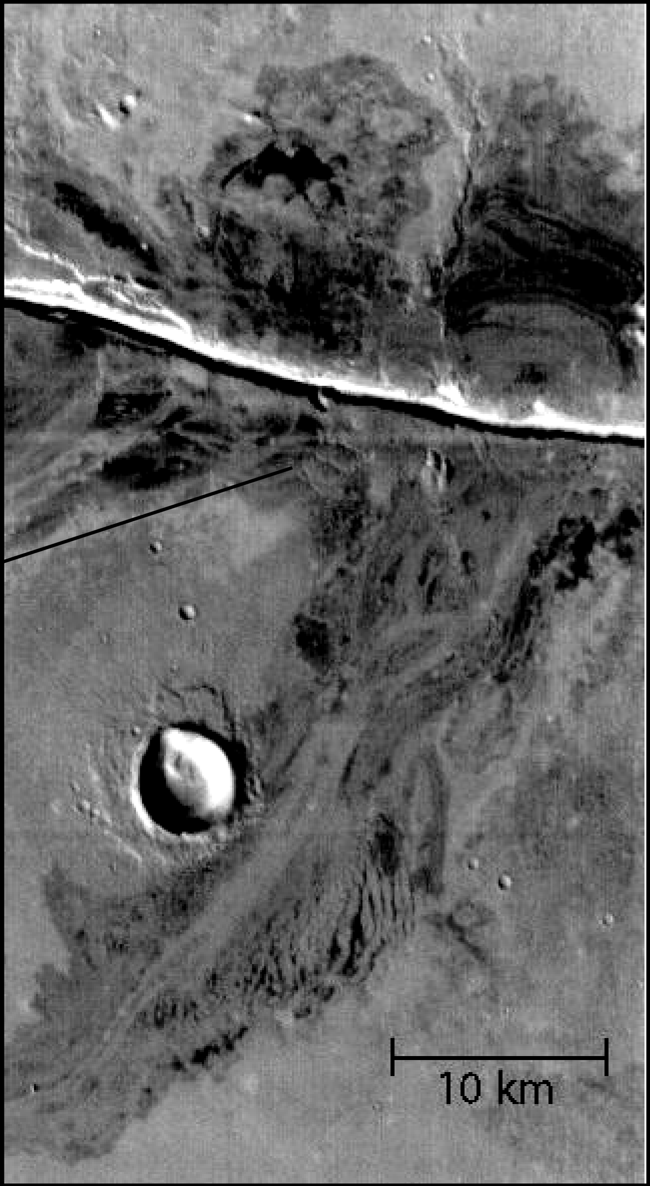
Volcanic region with 100 km long lava flows

* Flows are thin (<100 m) and were only partially identified with Viking

* Flows partially emerge from fissures



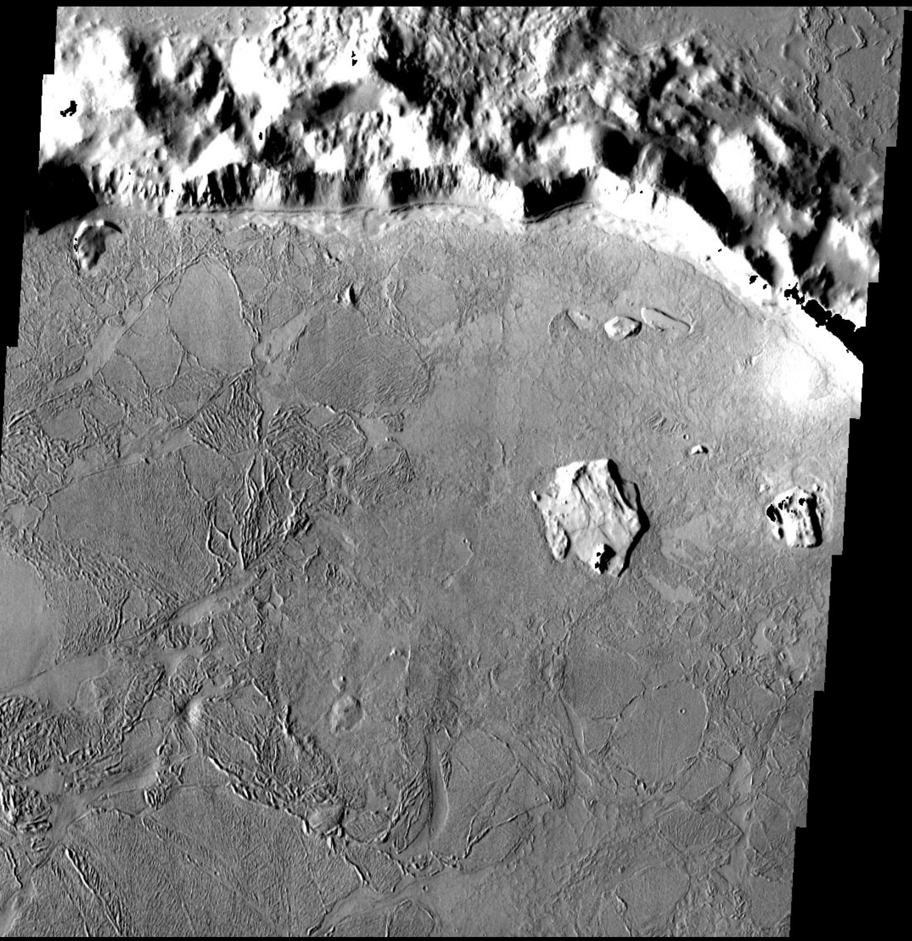
MOLA DEM



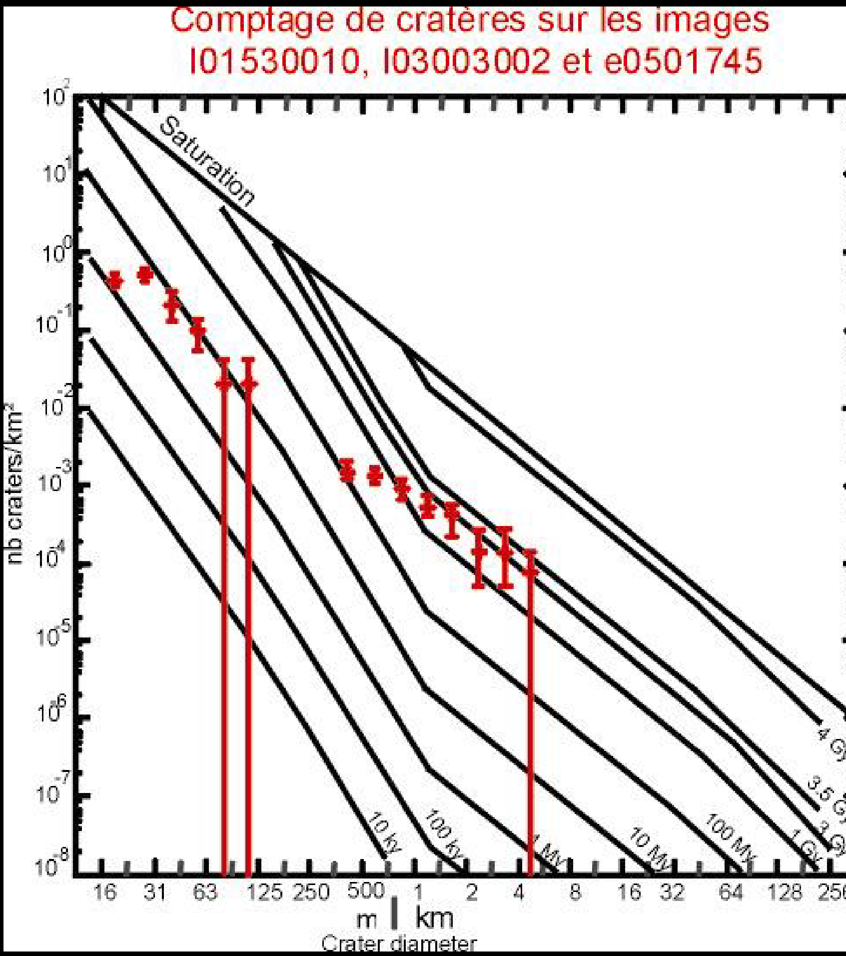
THEMIS day IR image

* Platy lava flows, very fresh morphologies
* Very recent ages: 10 My
(Burr et al., GRL, 2002, Berman and Hartmann, Icarus, 2002, Bigorne, M Th. , 2003)

=> Volcanic activity more recent than ever expected with Viking images



Themis images



Crater count over Hartmann plot

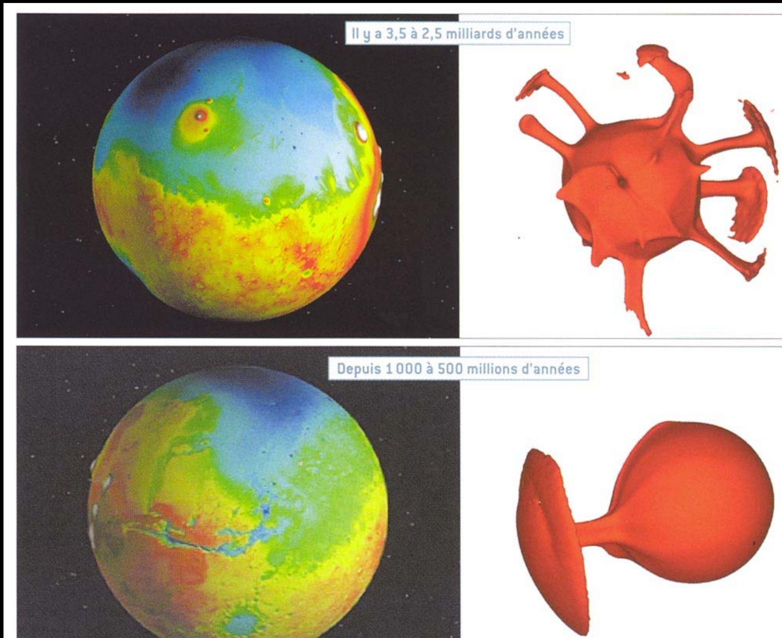
1.2.4 Timing of volcanic activity

* Mars is an intermediary body between the dynamic Earth and the dead Moon
=> smaller size=less energy

* Mars had an active geodynamism 3.5 billion years ago (volcanoes scattered in highlands and flood plains)
=> Noachian and Hesperian flood plains and pateras

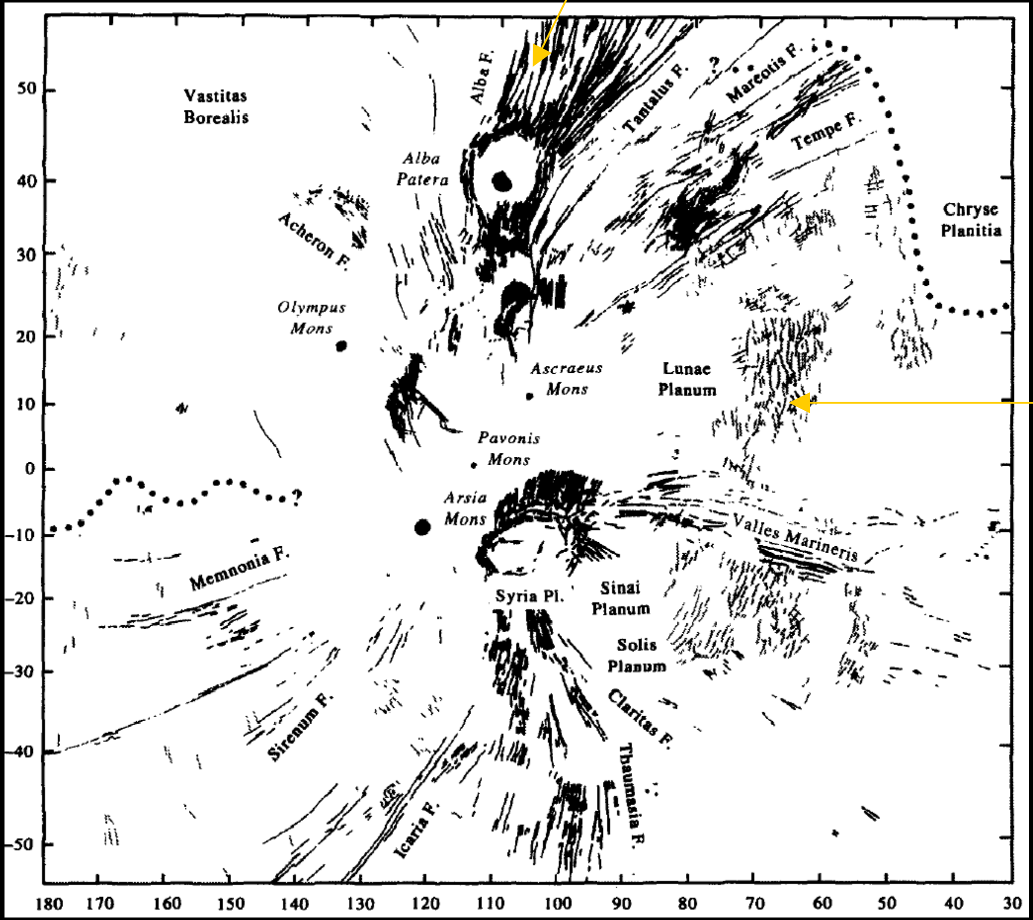
* Last 3 billion years activity are supposed to have concentrated with a hot spot under Tharsis bulge
=> Amazonian volcanoes concentrated in Tharsis and Elysium regions

* Recent volcanism in Cerberus and Amazonia region (close to Elysium), still less understood



1.3 Tectonism
1.3.1 Tharsis deformation field

Radial
normal faults



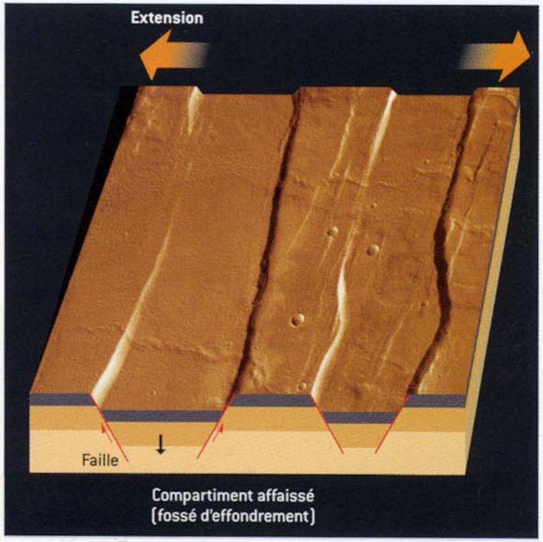
Concentric
ridges

* Radial faulting and concentric wrinkles express the deformation field around Tharsis
=> probably due to the effect of the bulge
* Faults are dates from the Noachian to the Amazonian ages=> complex history
* Noachian = main period of bulge formation, Hesperian flood plains, Amazonian volcanoes

1.3.2 Grabens and wrinkle ridges

* Radial faults are in extension :Normal faults= grabens (depressions)
Typically 2-10 km large depressions, 100 km long, 10-100 m deep

* Different models of formation:
- Pure extensional deformation (Golombek, 1998, Zuber et al., Schultz, 2000)
- Dyke swarms (Wilson and Head; 1994; Mege and Masson, 1996)
- Extension helped by subsurface properties (Tanaka, MacKinnon)

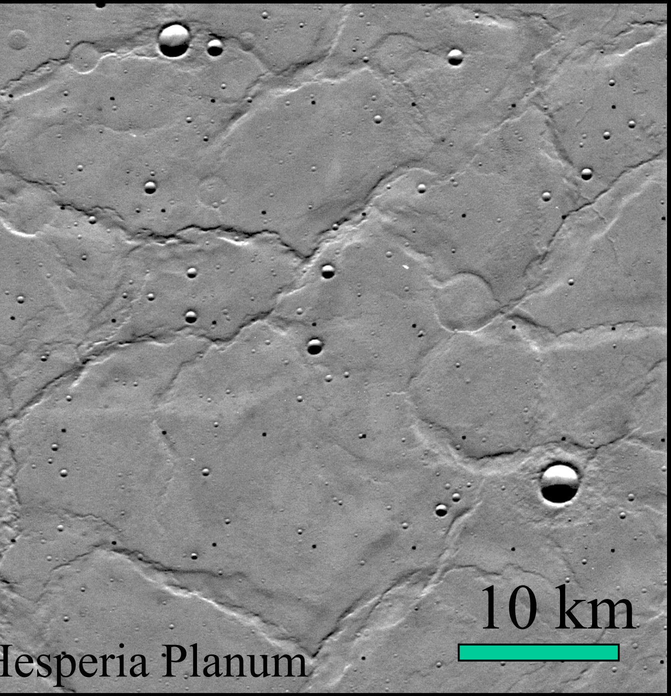


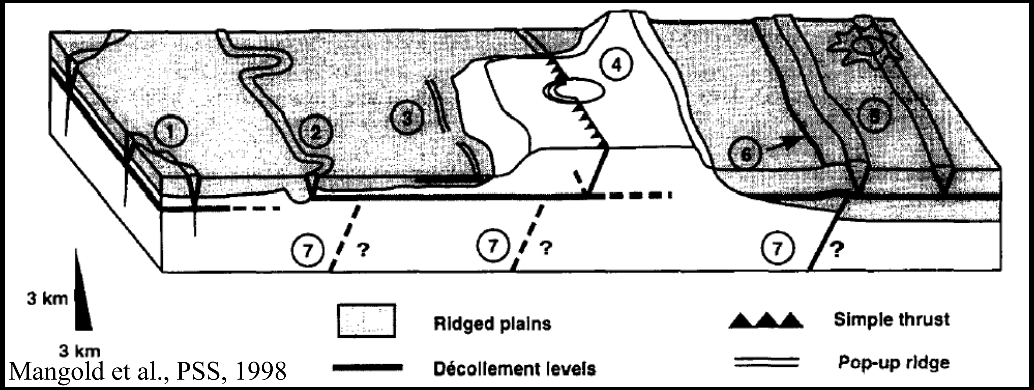
In Forget et al., book

Les fossés d'effondrement. L'image ci-contre présente des fossés d'effondrement créés par le soulèvement du volcan Alba Patera, dans la région de Tantalus Fossae située à l'est d'Alba Patera (l'éclairage vient de la gauche).

* Wrinkle ridges are positive features => compressive stress origin (reverse faulting)
Typically 100 m high, 5-10 km large, 100 km long
* Ridges not only in Tharsis region but many lava plains and highland terrains (Chicarro, 198
* Ancient hypothesis of lunar ridges due to lava flow cooling is abandoned

Usual geometry proposed:
* Rooting of faults can be deep (crustal deformation) => straight and long ridges
(Zuber et al., 1994, Golombek et al., 1996)
* Rooting can be superficial (under lava flows) => arcuate ridges initiated by craters
* Buckling hypothesis (Watters, JGR, 1991)





Mangold et al., PSS, 1998

1.3.3 Plate tectonics on Mars?

* Proposed by N. Sleep (JGR, 1994)
But no evidence from geology

* Amount of deformation by compression or extension faults is limited
=> 5% maximum, at least for Hesperian and Amazonian faults
Deformation on Earth >>5%

* No widespread rift regions, exception of Valles Marineris (but unusual rift)

* No evidence of subduction (new ideas by Baker et al., 2003 of subduction under Tharsis in the Noachian ages are speculative)

* Possibly before 4Gy with evidence from magnetised crust but no evidence from surface morphology from that period

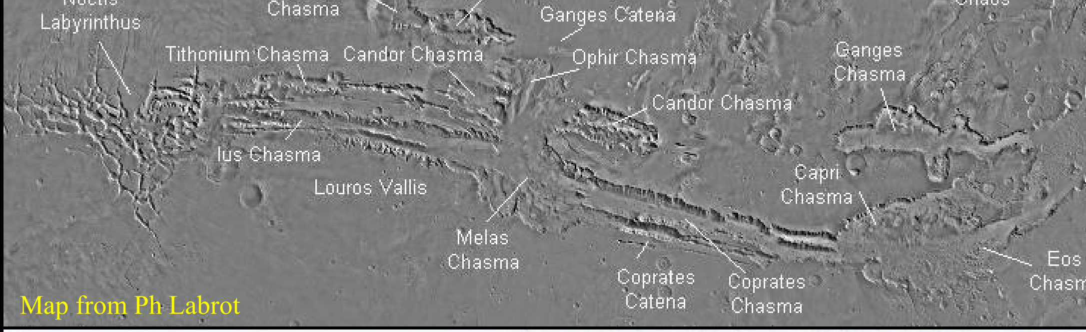
1.3.4 Valles Marineris canyons

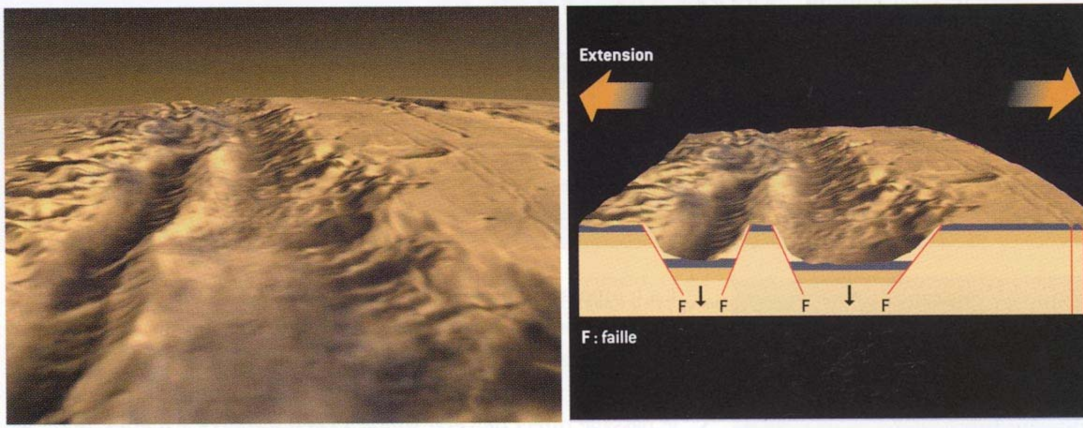
* Large canyons
(>1000 km long, 100 km wide)
* Depth: 8 km in average

* Form during Hesperian epoch
(after Early Hesperian lava plains)

* Usual theory:
-Rifting (Masson et al., 1997)
But only the first stages

- Widening due to erosional processes (Tanaka et al., Lucchita et al., Mars book, 1992, McKenzie and Nimmo, 1999)
Involved water flows, collapse, dykes-hydrovolcanic interaction, cliff recession, landslides, etc.





Vue 3D de Valles Marineris, construite à partir des données de l'altimètre MOLA. Le « plancher » de Valles Marineris s'est affaissé suivan plans de failles verticales.

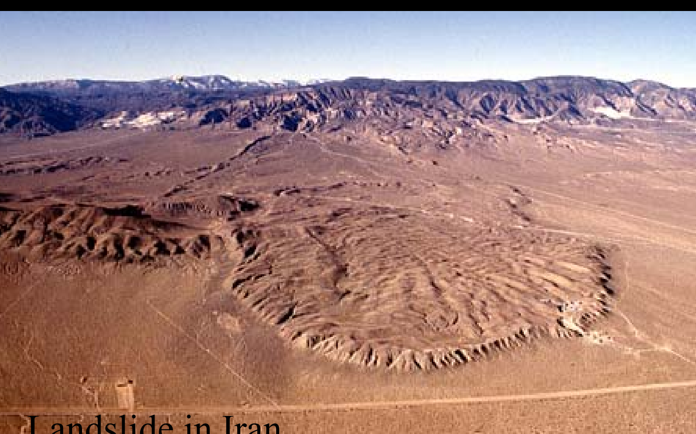
Document from Forget bo

* Huge landslides a factor of 10 larger than on Earth

* Questions remain on the influence of liquid water in their formation (Lucchita, 1987 in favor, Mac Ewen, 1992 disfavor)

* New datation by crater counts give scattered ages through the history
=> landslides triggered by marsquakes or impacts, some are very recent (<50 My)

(Quantin et al., Icarus, 2004)



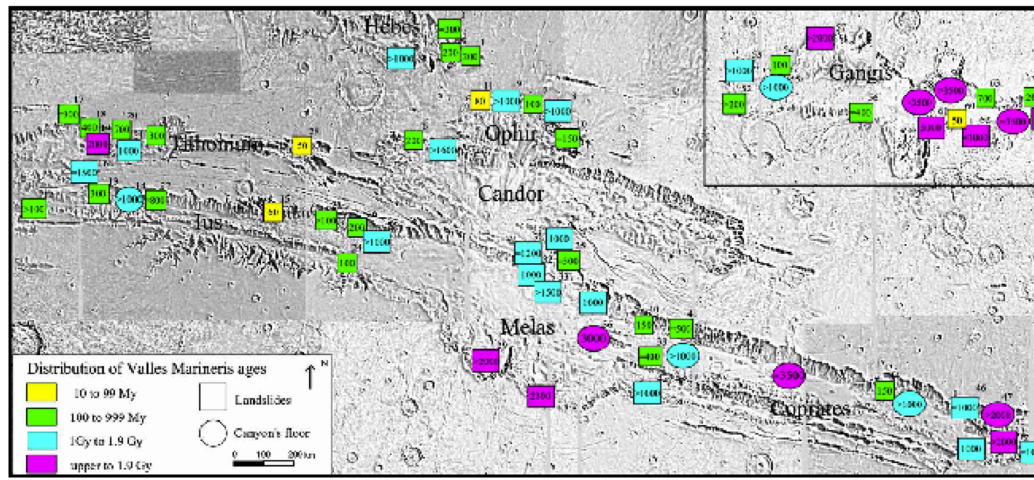


Fig. 8. Distribution of the ages within Valles Marineris. Each square corresponds to a crater date and refers to a line in Table 1 (via id). Three kinds of ages are reported on the map: the ages determined w[...] the crater distribution follows the isochrons (ex: 100 My), the ages determined when the crater distribution follows the isochrons only for the large crater diameters (ex: 100 My) and the minimum ages dete[...] when the crater distribution has a lower slope than the isochrons (ex: < 100 My).

Map by Quantin et al., Icarus, 2004