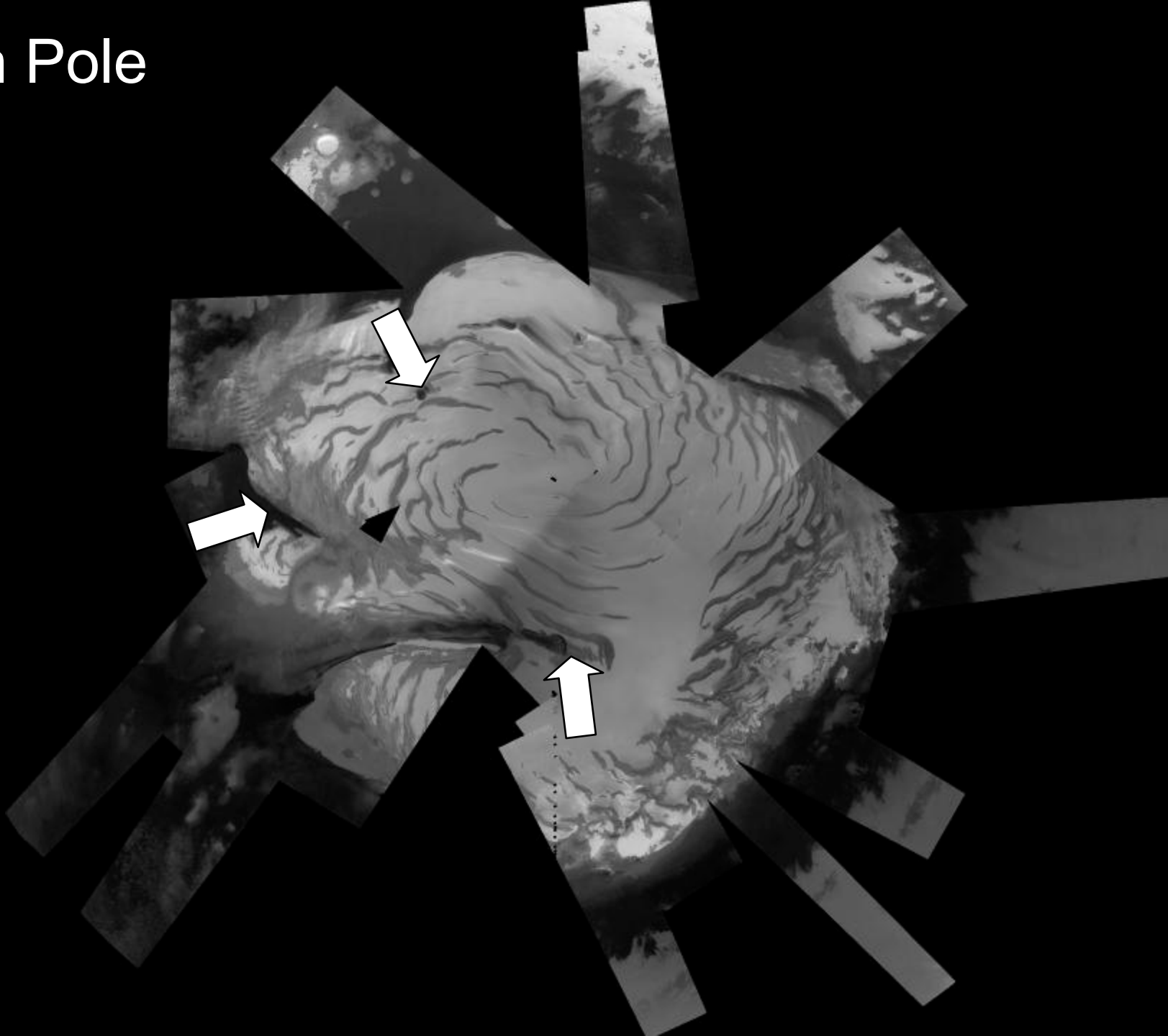
North Pole



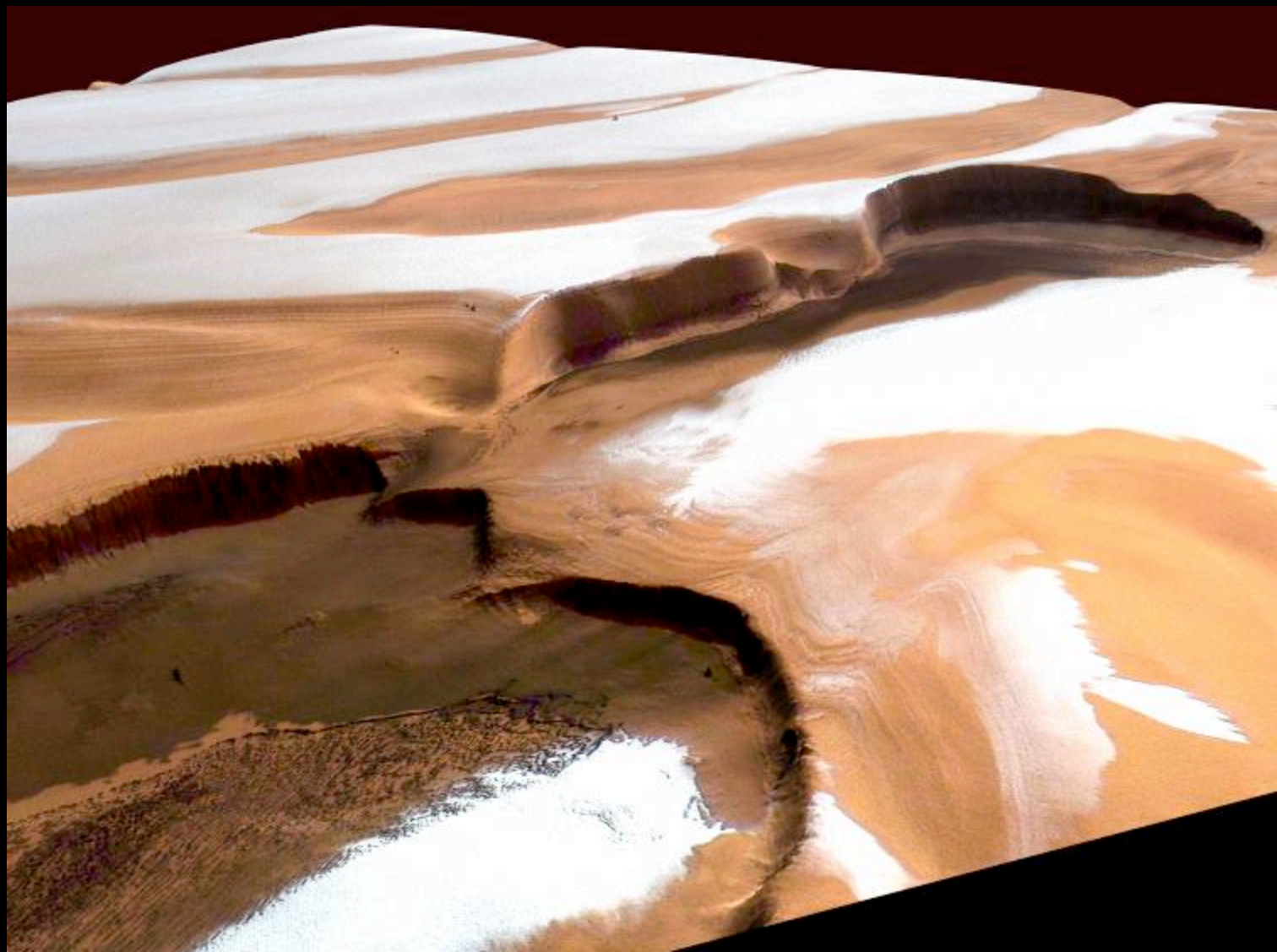

Orbit 1096

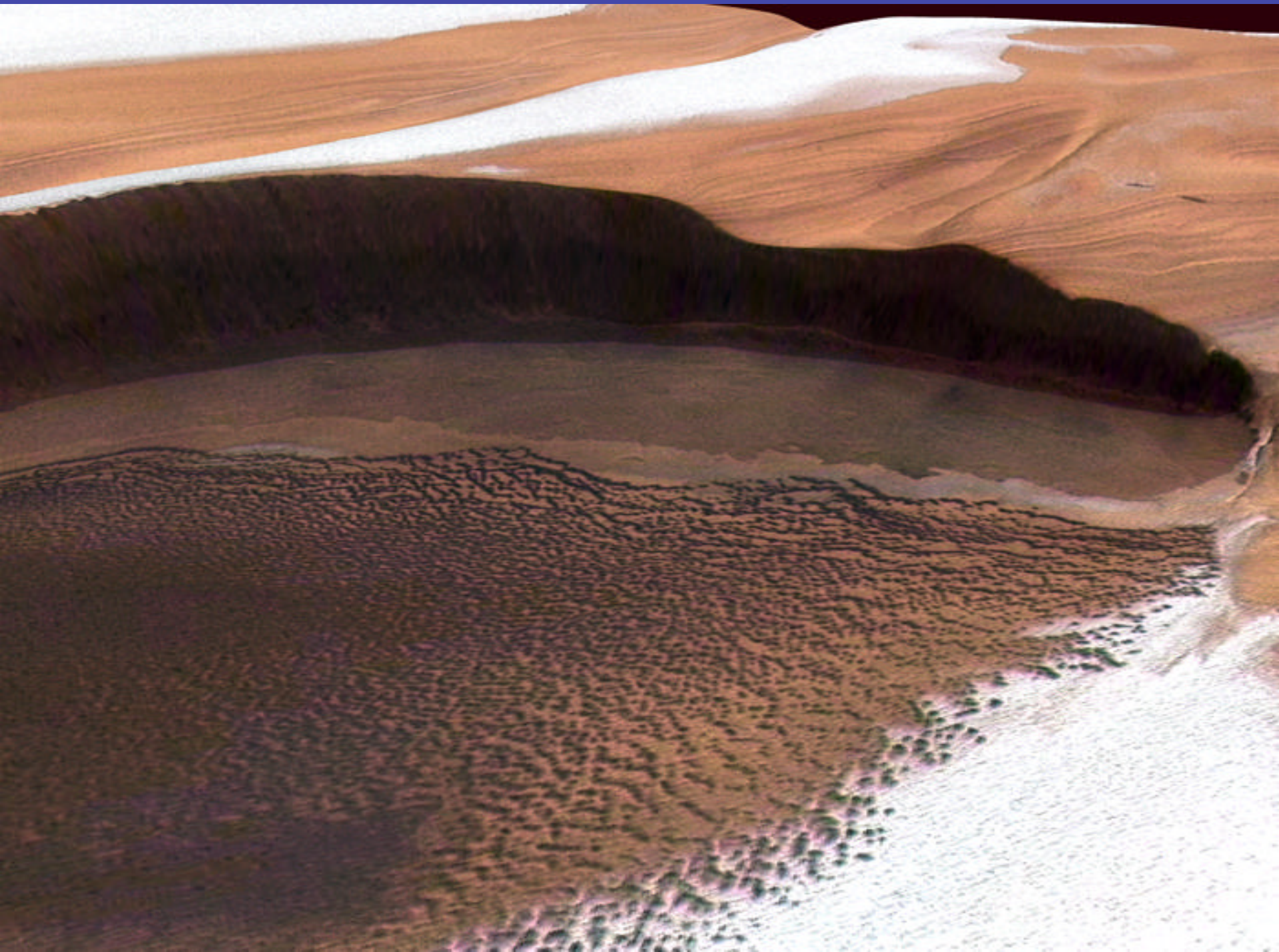
North Pole

Layers of Ice and Dust

Cliffs Almost 2 km High

Dark Material in Caldera-like Structures and Dune Fields: Volcanic Ash ?



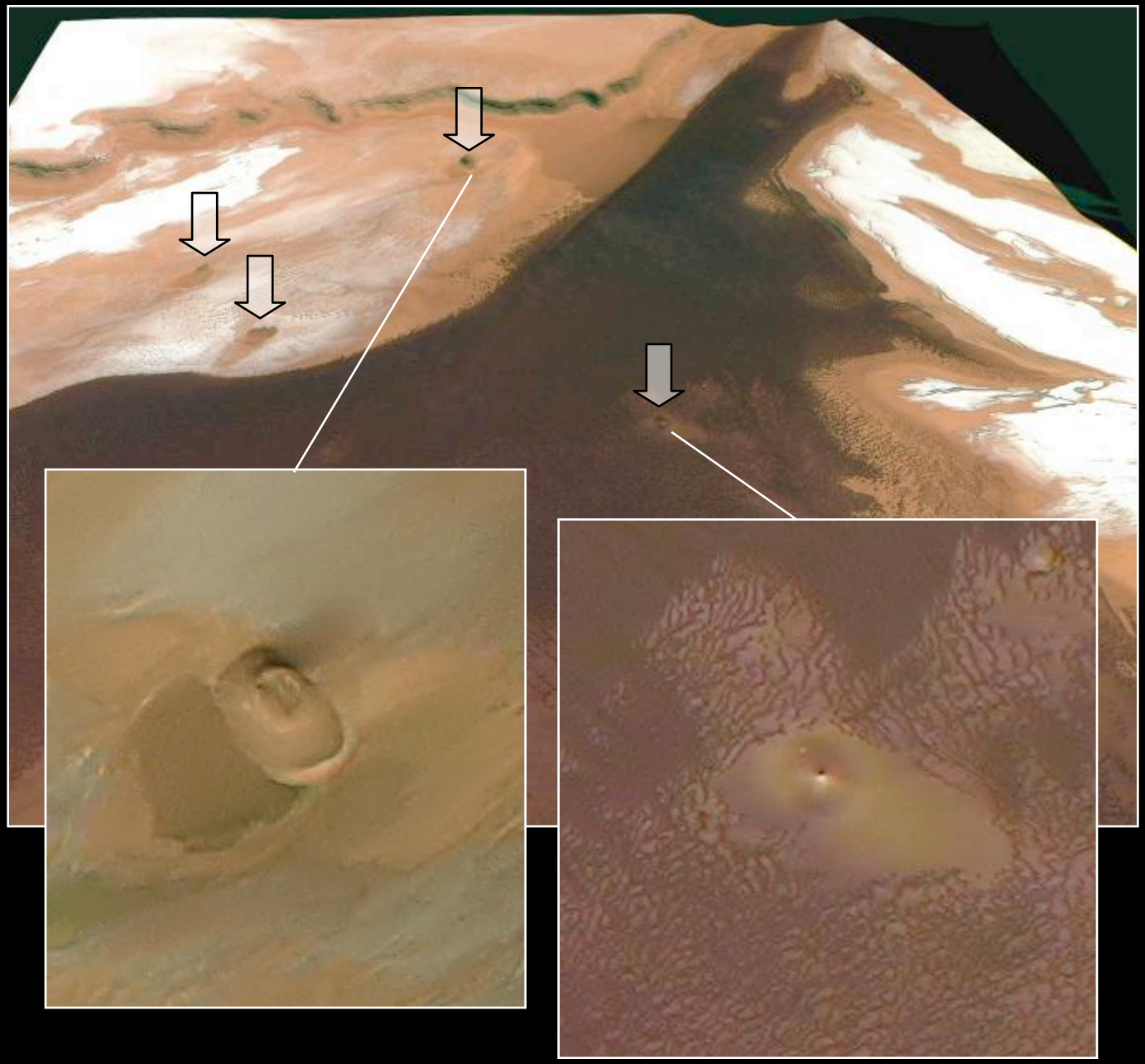


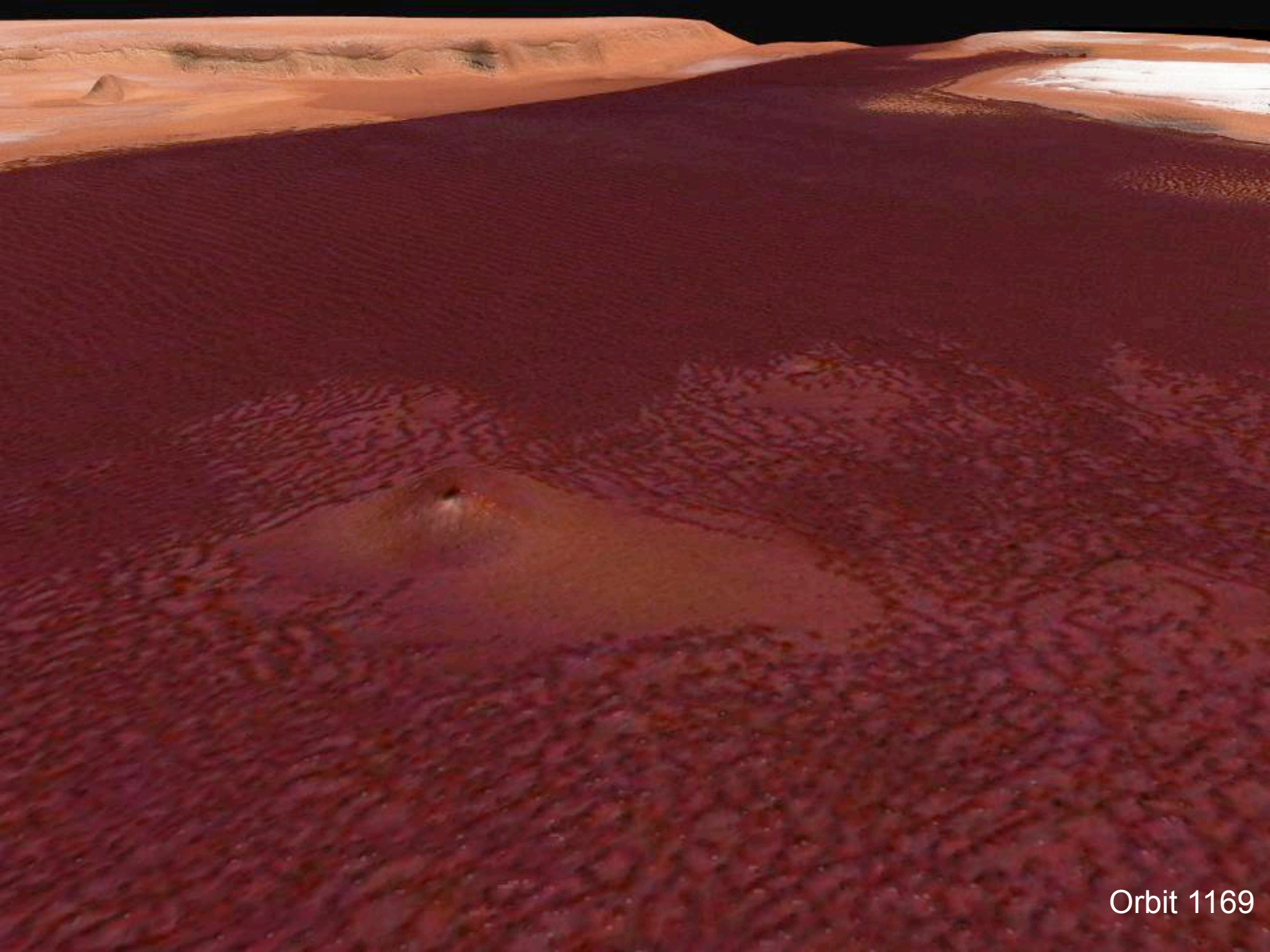
Orbit 1169

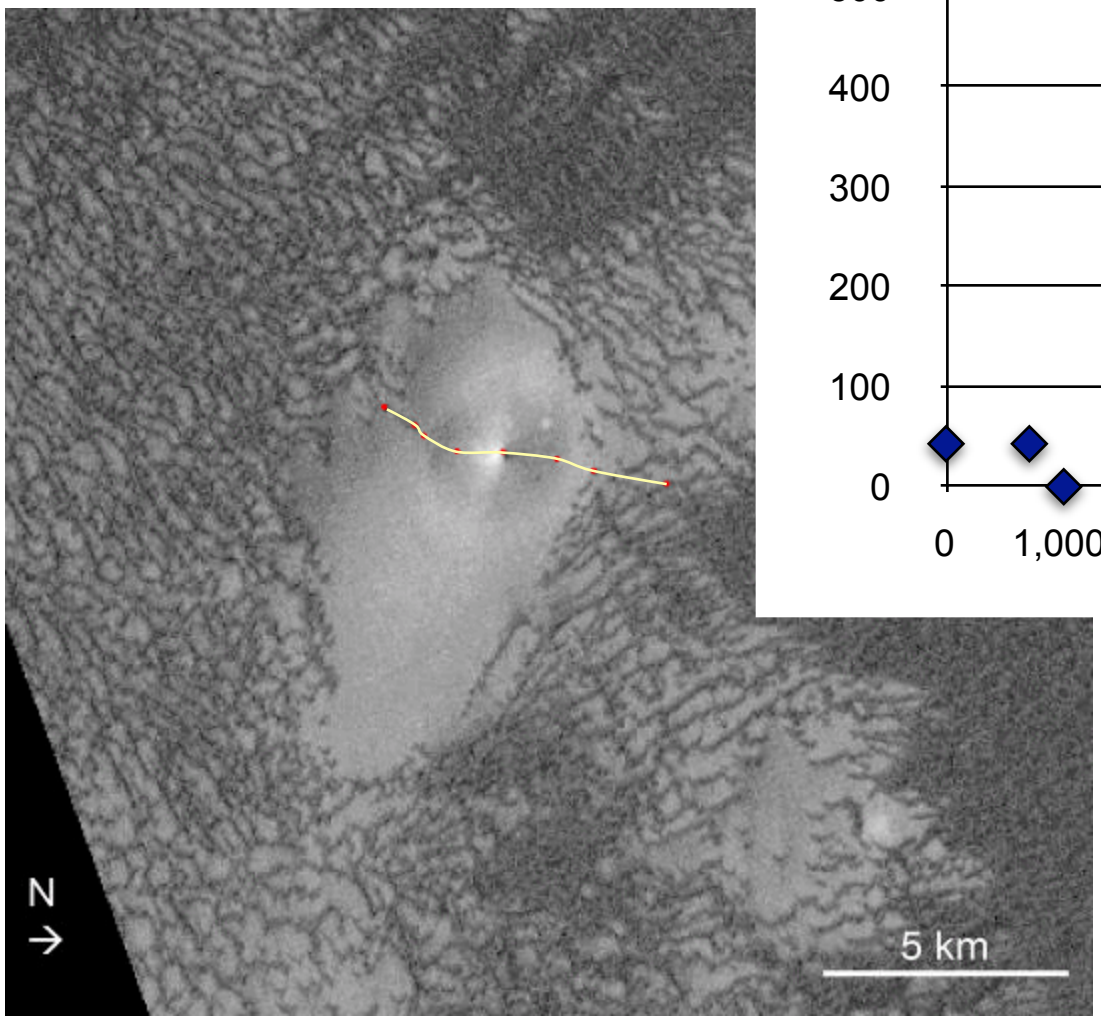
Fields of Volcanic Cones

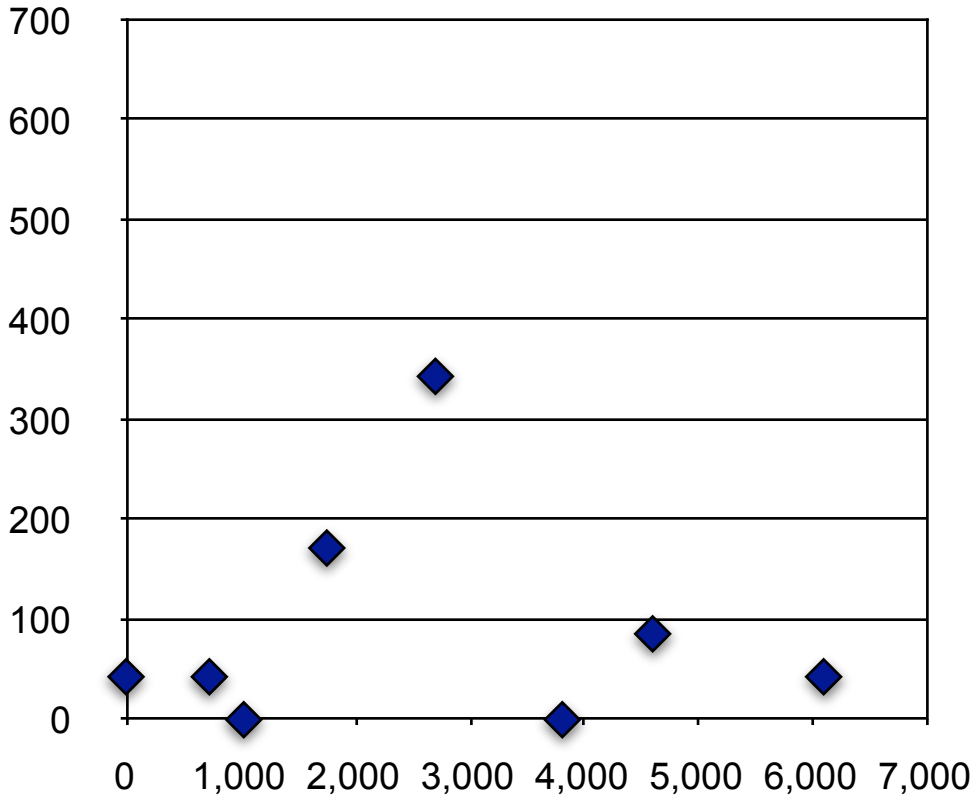
Up to 600 m high

Volcanic Activity Appears to be Very Recent, Possibly Ongoing




Orbit 1169


N
5 km


700
600
500
400
300
200
100
0
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000

North Polar

Volcanic Fields

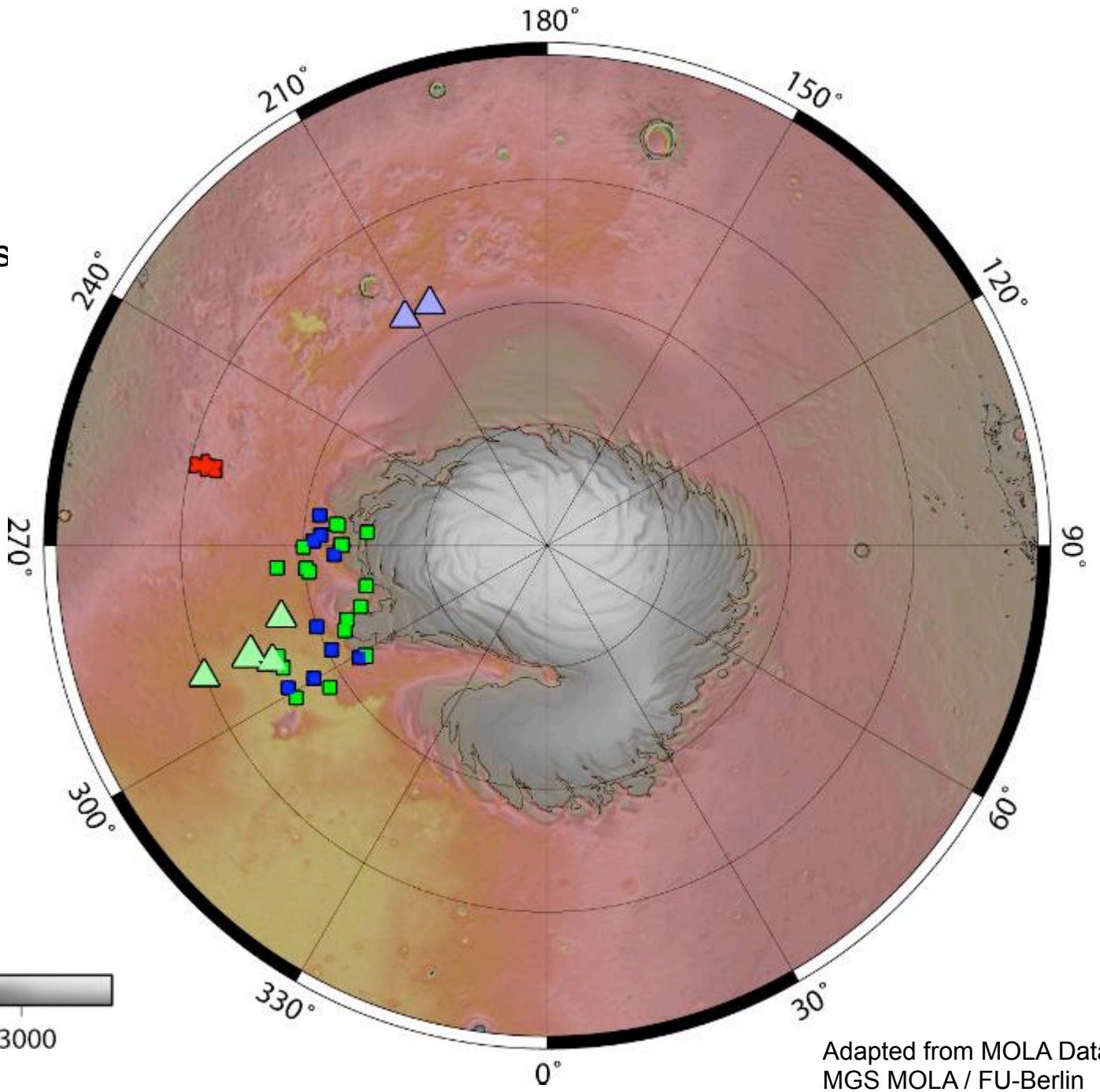
MPD
(Martian Pitted Domes

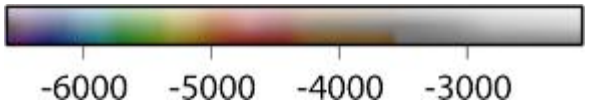
- **Garvin, 2000**
- **HRSC**

MCC
(Martian Crater Cones)

- **Garvin, 2000**
- **HRSC**

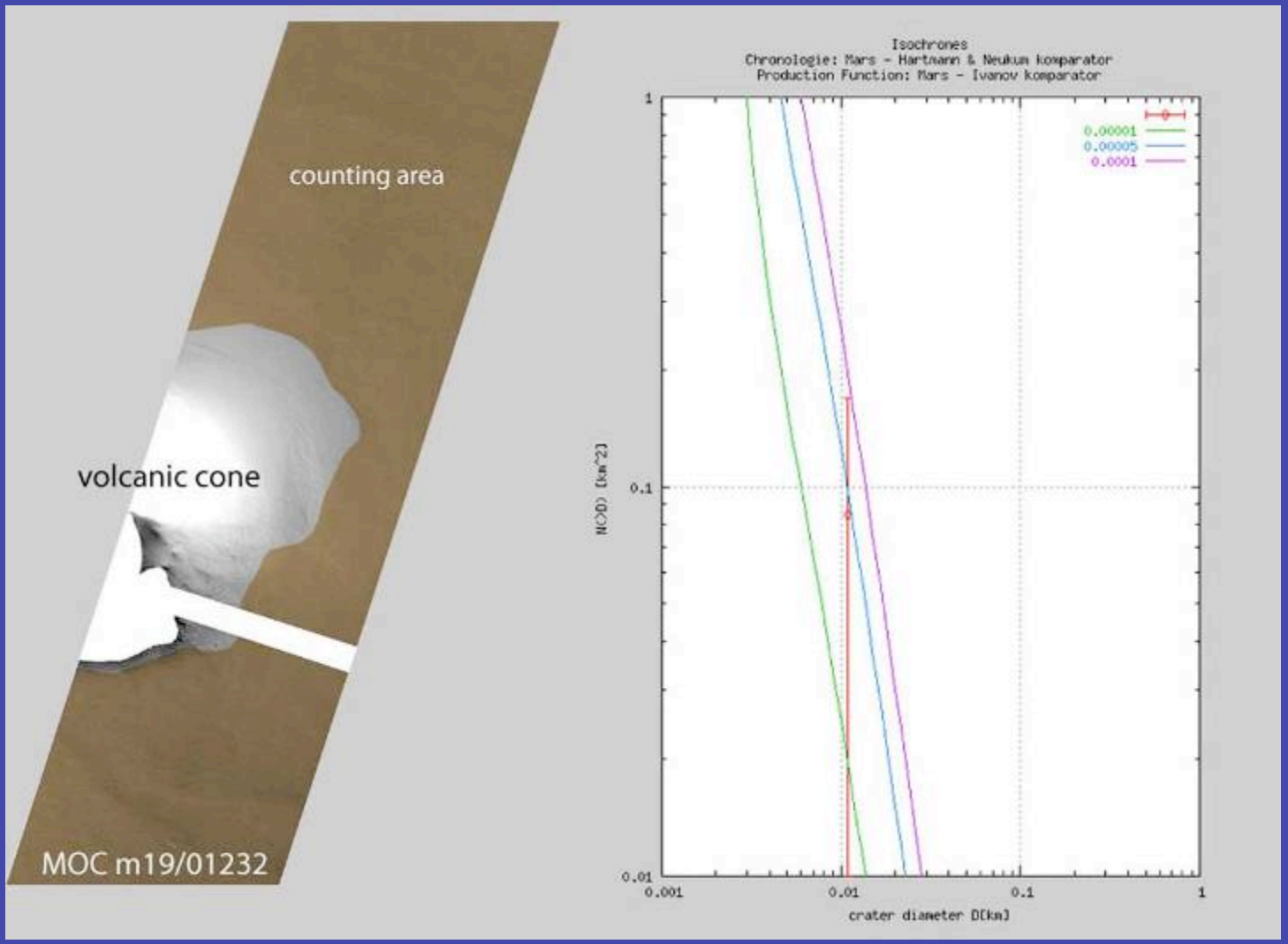
- **possible volcanic field as detected in HRSC**





Adapted from MOLA Data
MGS MOLA / FU-Berlin

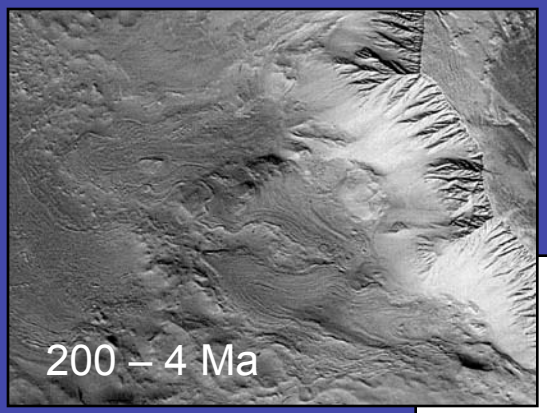
North Pole - Ages

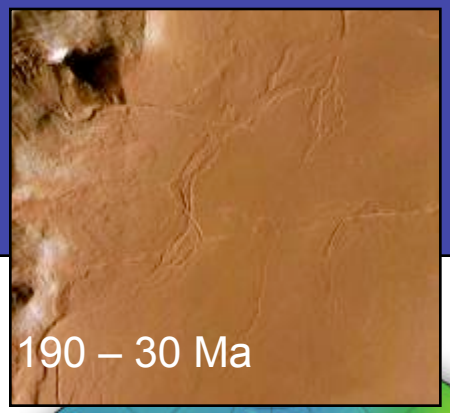


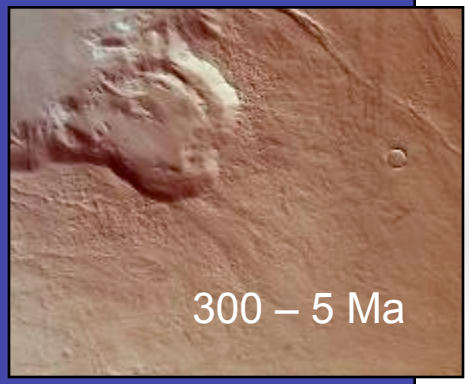
An upper limit for ages of planetary surfaces without craters can be obtained by estimating the largest crater size which could be easily recognized on a certain image basis. The area shown in the MOC image (map scale of 3.77 m/px) has been measured and the minimum crater-diameter size has been estimated to be around 3-5 times the map scale (15m to 20m).

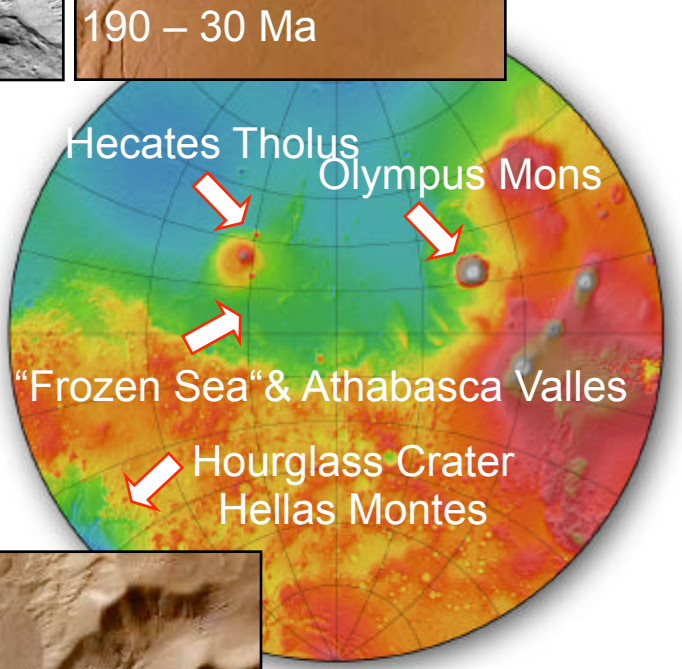
Using established chronology models the age of surrounding surface has been estimated to be in the range of **10 kyr to 100 kyr** or younger. The volcanic cones can therefore be considered to be geologically very recent features, even younger than previously estimated by Garvin et al. (2000) who derived ages on the basis of volcanic production rates.

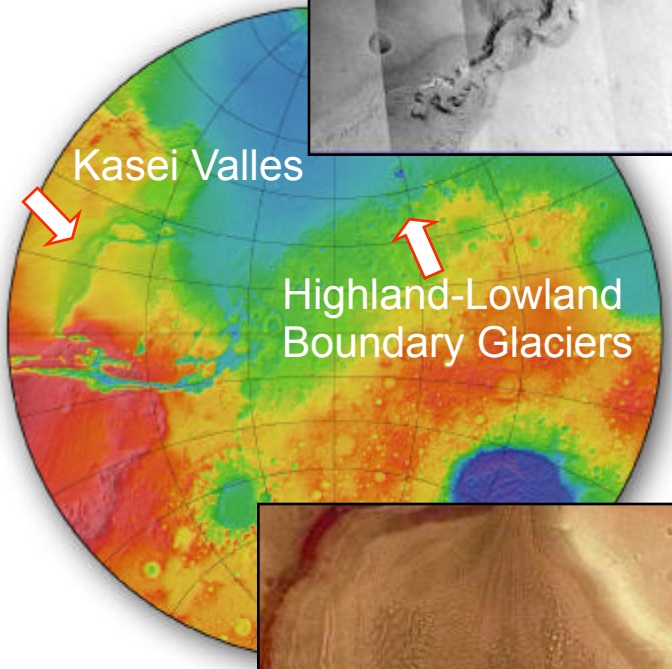
Recent Water and Ice/Glaciers

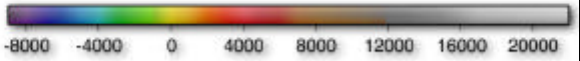


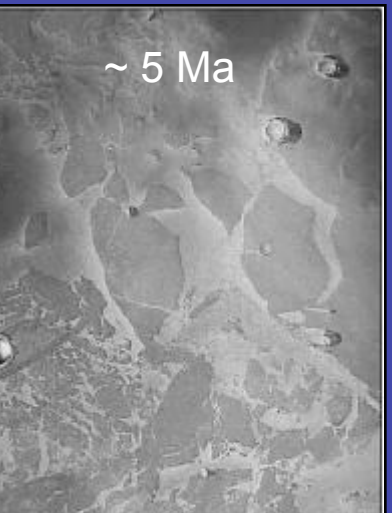


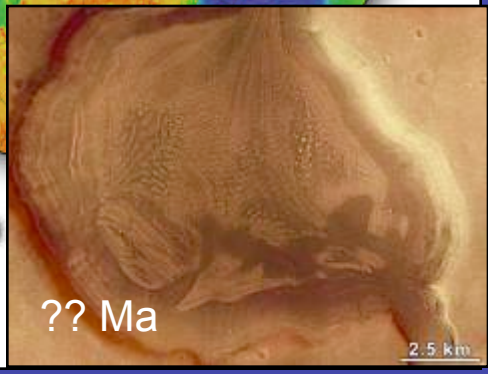








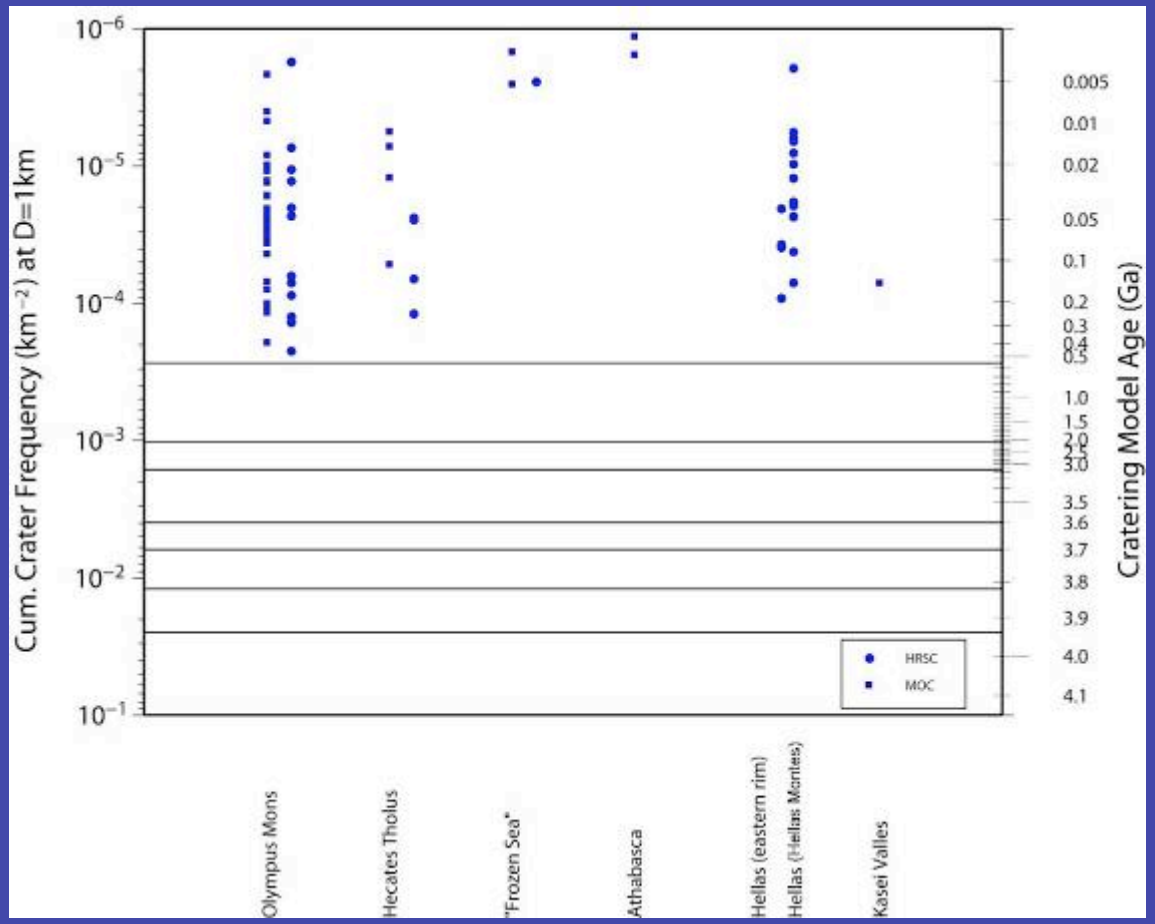




Hauber et al. .; Head et al. ; Murray et al. (2005) Nature;
Neukum et al. (2004) Nature; van Gasselt (2005) 1st MEX Sci. Conf.;
Werner et al. (2003) JGR;

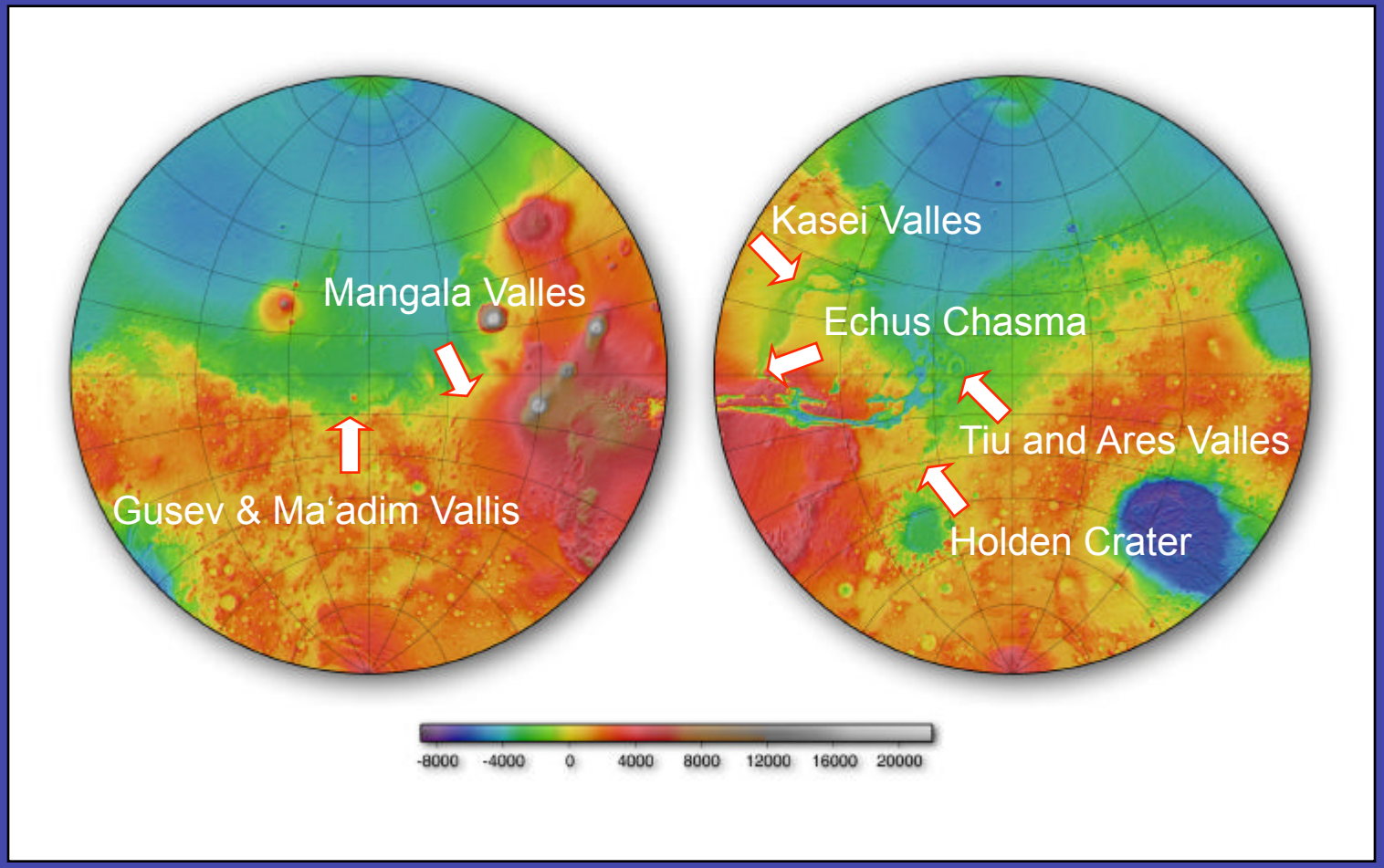
Recent Ice-Related Processes on Mars

- Landforms in the investigated areas suggest the presence of ice on the surface (under a dust cover) even now
- Recent glacial (fluvial) activity observed in the last 500 Ma
- fluvial/glacial activity often seems to have been related to volcanic/magmatic (hydrothermal) activity; episodic
- Possible relation of the activity
  - to obliquity changes
    Laskar et al. (2004) Icarus
    and/or
  - to solar flux changes
- ⇨ Periglacial/glacial morphologies observed at the highland-lowland dichotomy, flanks of the Tharsis Montes, but no ages determined yet



Hauber et al. .; Head et al. ; Murray et al. (2005) Nature; Neukum et al. (2004) Nature; van Gasselt (2005) 1st MEX Sci. Conf. ; Werner et al. (2003) JGR; Werner (2005) Dissertation

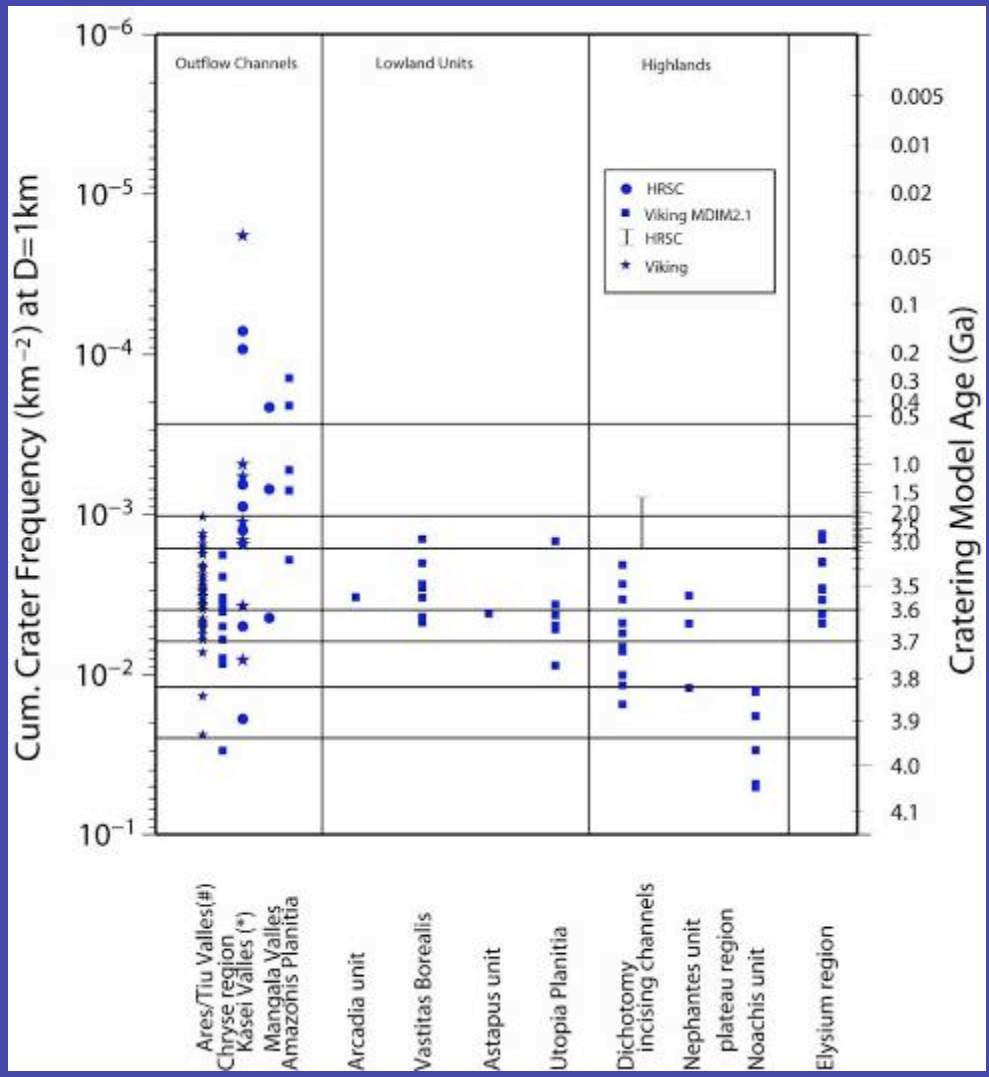
Ancient Fluvial and/or Glacial Activity



Jaumann et al. (2005) GRL; Lanz (2003) Dissertation; Marchenko et al. (1997) SSR; Werner (2005) Dissertation; Werner et al. (2005) EGU

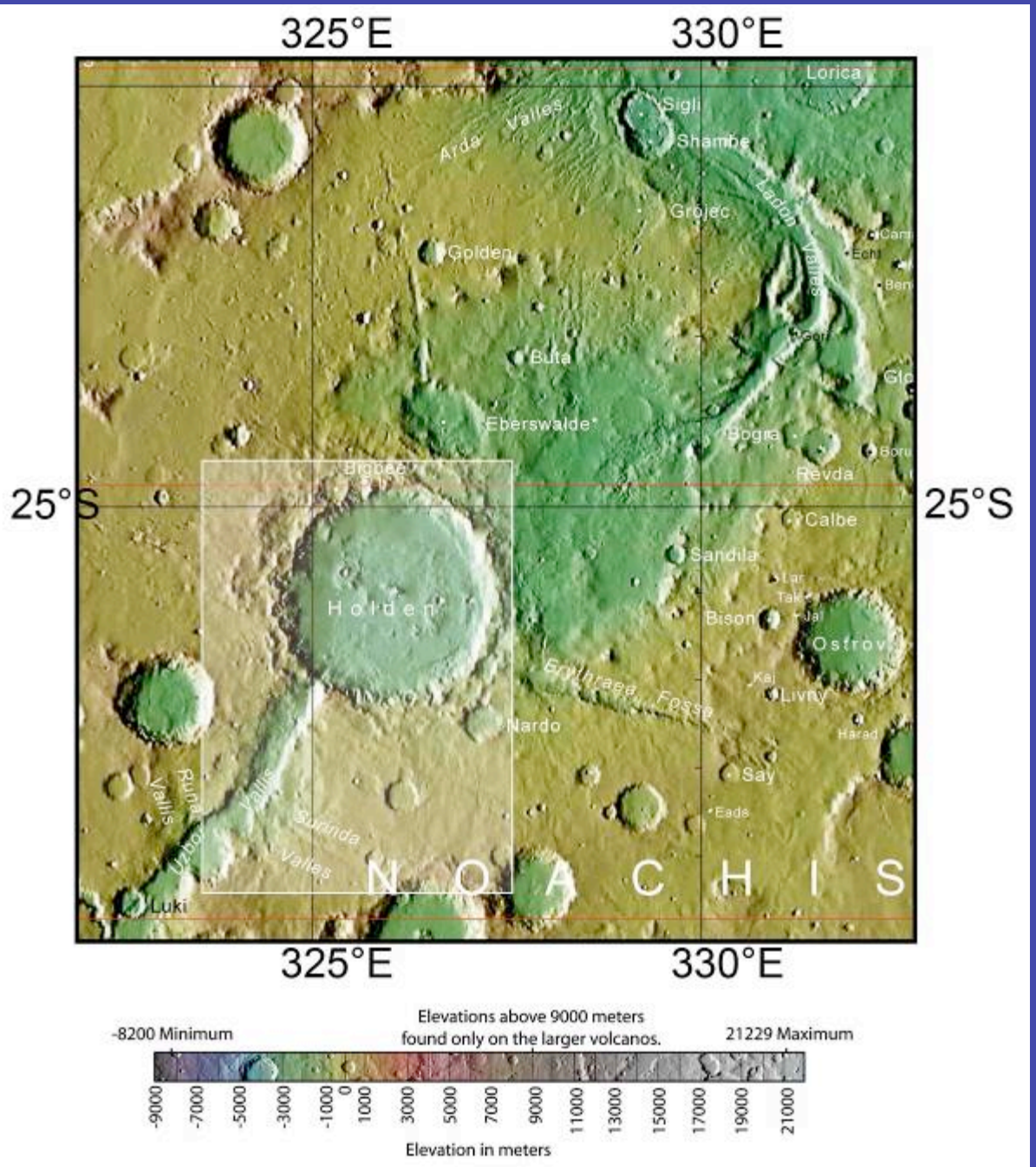
Ancient Fluvial and Ice Related Processes on Mars

- Outflow channel formation ended ~3.5 Ga ago, subsequent volcanic and water/ice related processes until recently (100s of millions of years)
- Glacial scours in Kasei, e.g. formed before ~1.3 Ga ago
- Lowland deposits formed between 3.8 and 3.4 Ga ago; locally younger correlated with topographic lows (most likely volcanic deposits)
- Highland-lowland boundary formed before 3.8 Ga ago; subsequent (regressive) erosion, possibly still ongoing (glacial)
- 400-700 Ma ago, subsurface ice-melting or water released from aquifers triggered by volcanic activity, e.g. Mangala Valles
- Sedimentation through fluvial or glacial activity in the northern lowlands ended at least before 3 Ga ago, very probably even before 3.5 Ga ago

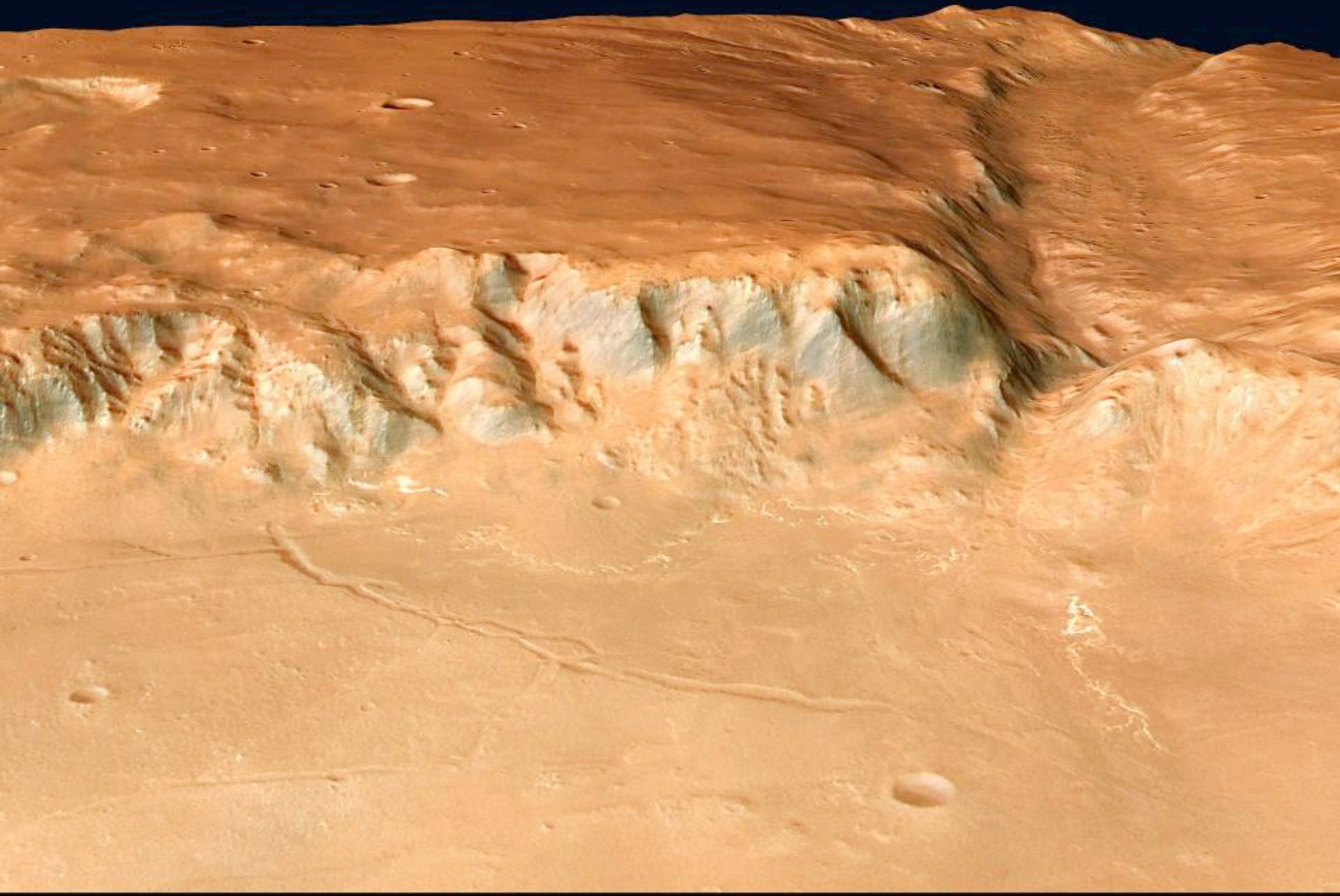


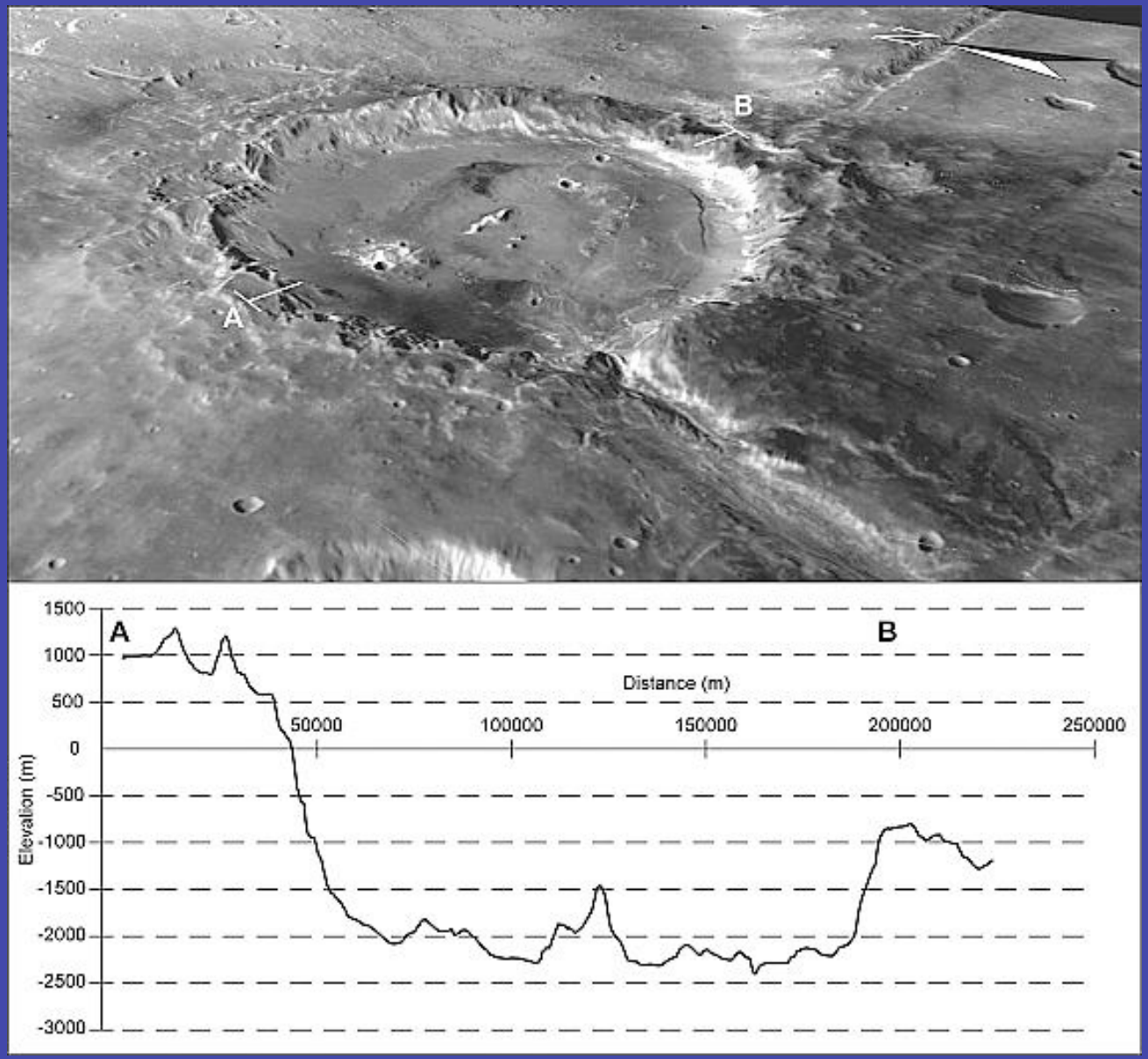
*Lanz (2003) Dissertation; # Marchenko et al. (1997) SSR;
Werner (2005) Dissertation; Werner et al. (2005) EGU

Holden Crater



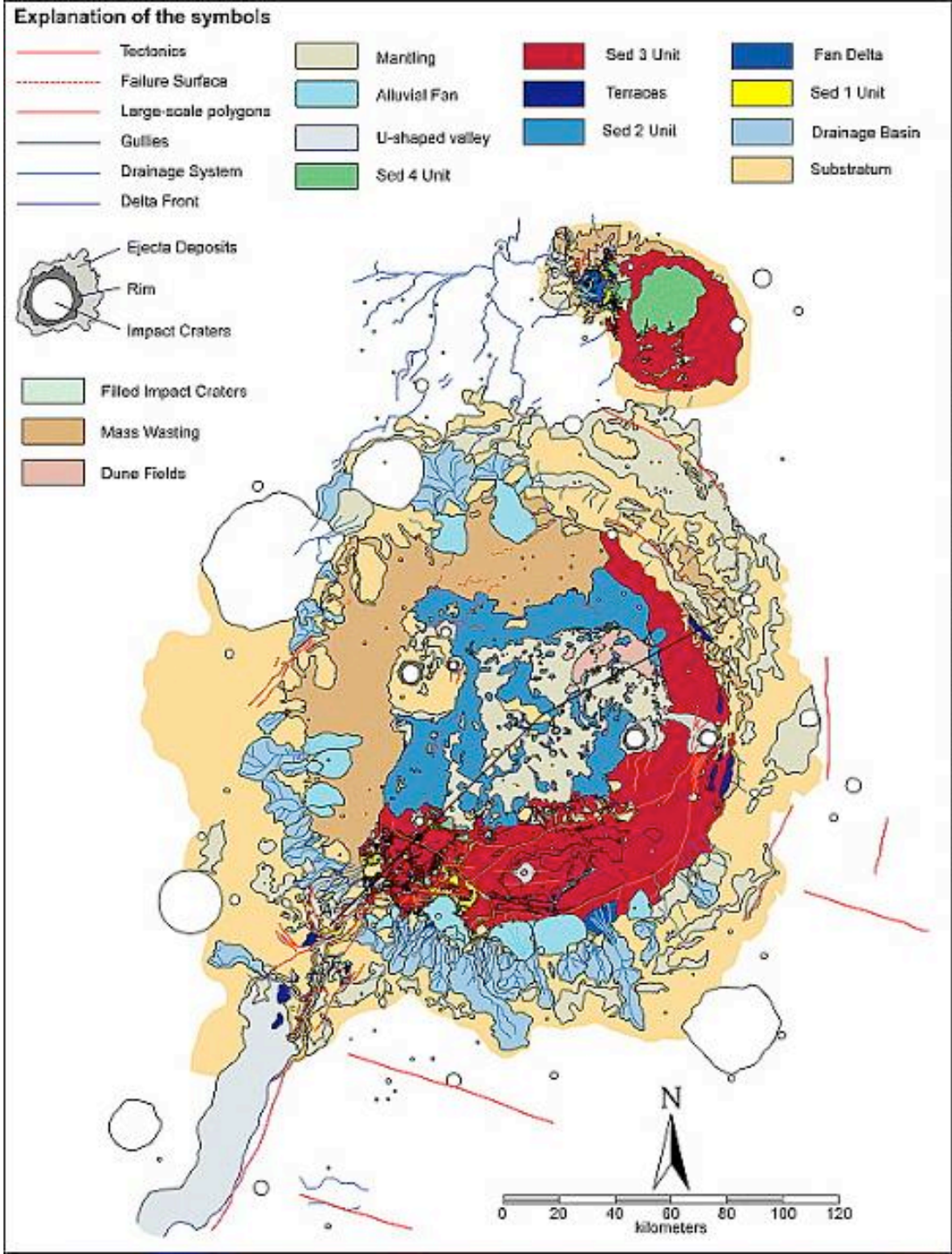
Holden Crater





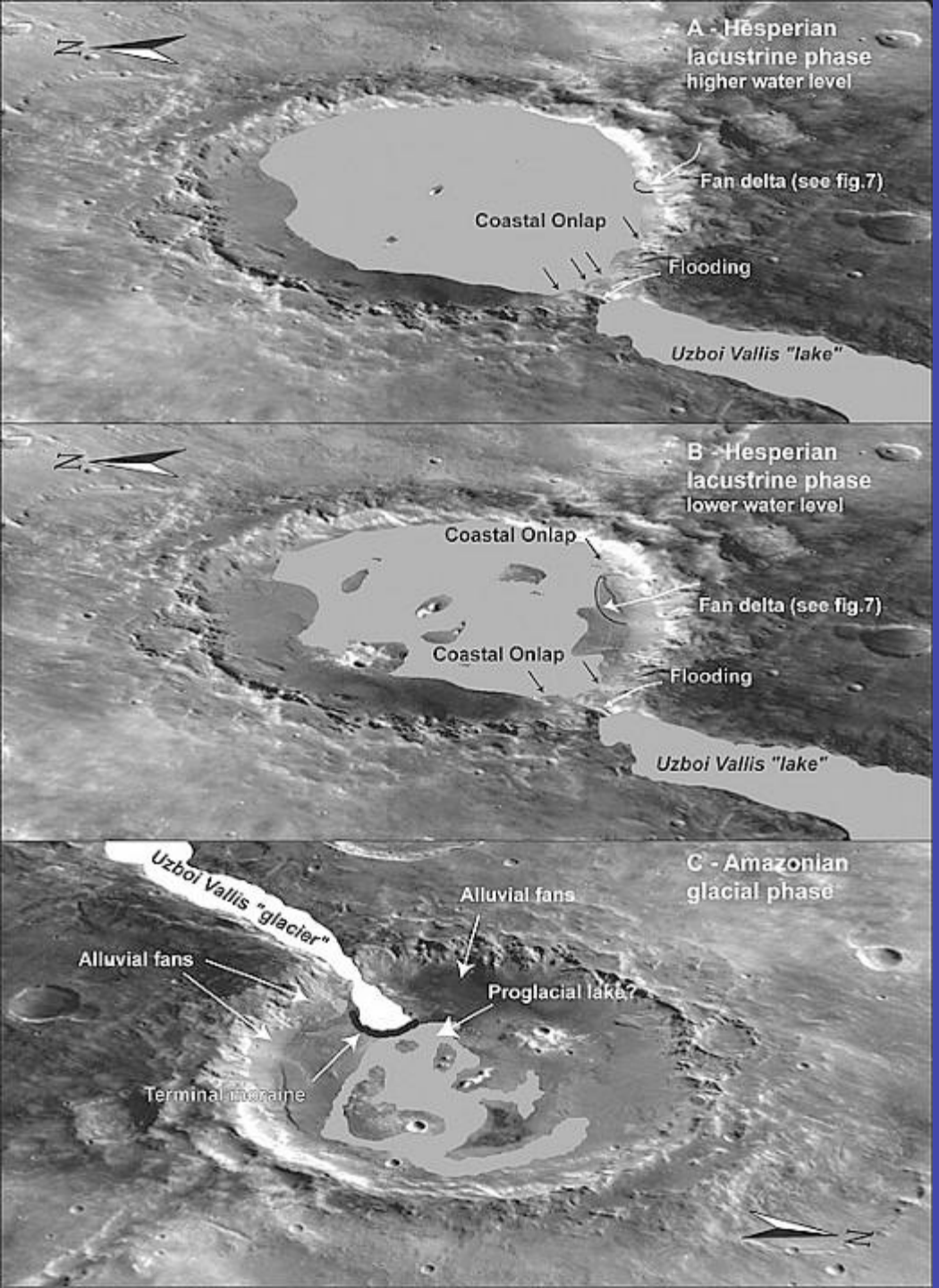
Three-dimensional view of the Holden crater obtained with MOC WA image M0102794 draped on MOLA DEM. Vertical exaggeration is 2.5. The MOLA-based altimetric profile (trace AB in the 3-D view) shows the topography of the crater.

Pondrelli et al. (2005)



Geological map of Holden crater

Pondrelli et al. (2005)

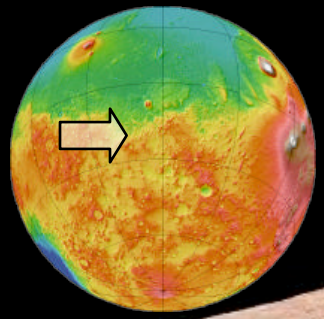


Reconstruction of evolution of the water-related environments of the Holden crater. (a) During this Hesperian “wet” phase, water level inside the crater is higher and reaches approximately −1962 m, as constrained by Sed 1 coastal onlap and by fan delta geometry. (b) During this later Hesperian “wet” phase, water level is lower (−2066 m) with incised valleys eroding the previously formed fan delta and the development of a more distal fan delta. (c) During the “icy” Amazonian phase, the Holden crater experienced a glacial phase with a glacier entering the crater via the Uzboi Vallis, eroding, and depositing a terminal moraine. A proglacial lake probably existed during this phase.

Pondrelli et al. (2005)

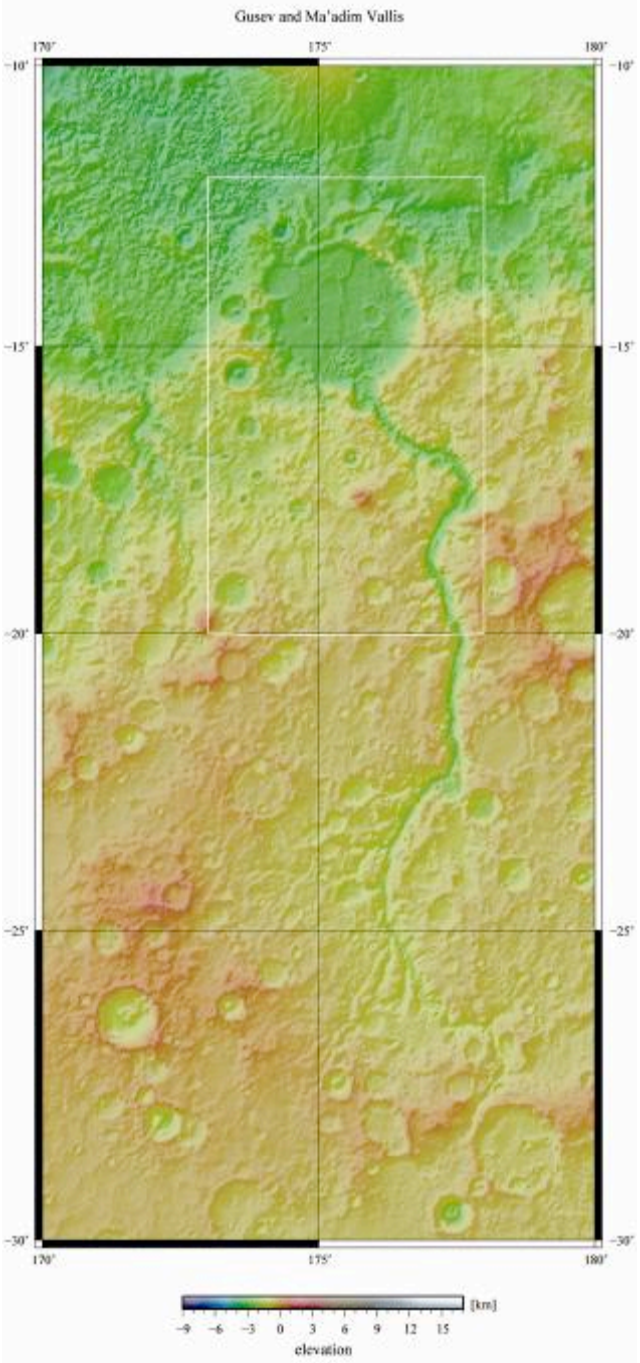
Gusev Crater and Ma’adim Vallis

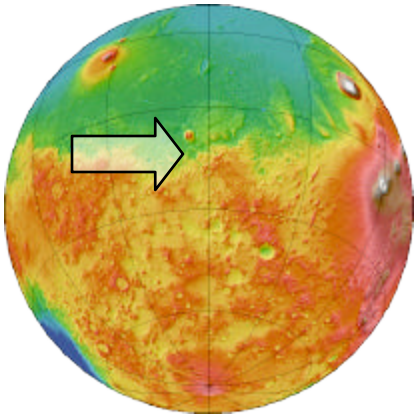
HRSC orbit 637



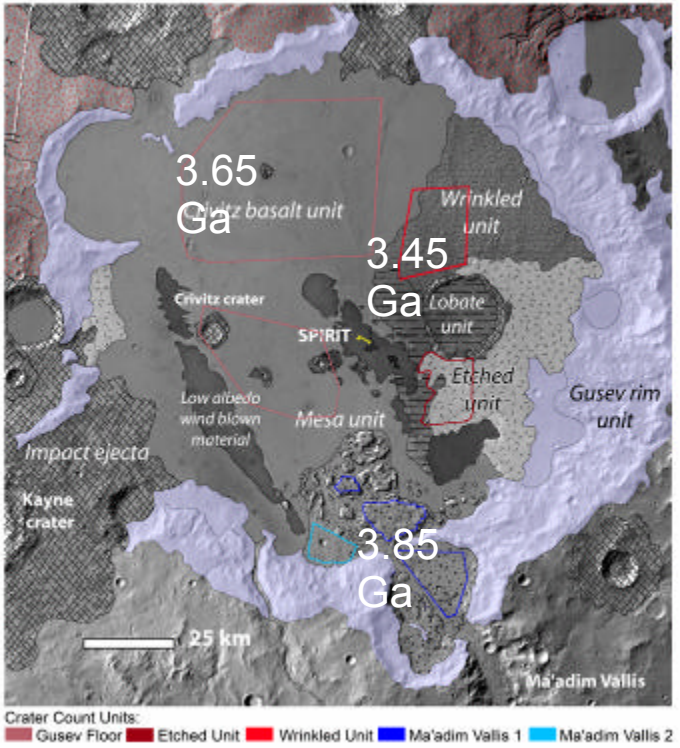
N

Ma’adim Vallis and Gusev Crater

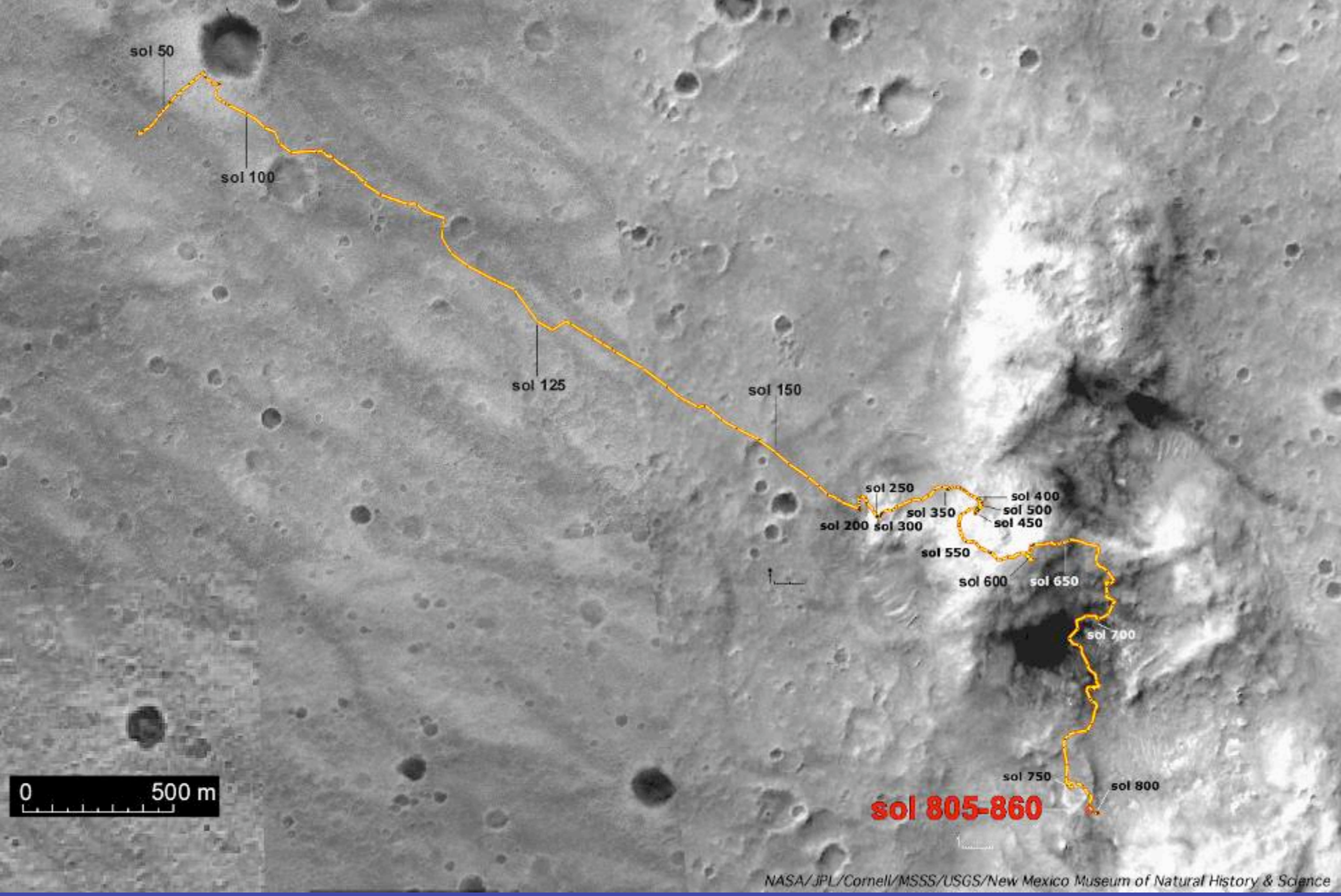




Gusev formed ~4 Ga ago; ancient fluvial activity in Ma‘adim Vallis ended between 3.85 and 3.65 Ga ago, subsequent resurfacing of Gusev‘s floor 3.45 Ga



v. Kan (2004) Diploma thesis; Zegers et al. (2005) 1st MEX Sci. Conf.; Ivanov et al (2005) 1st MEX Sci. Conf.; Werner et al. (2005) LPSC,


sol 50
sol 100
sol 125
sol 150
sol 200
sol 250
sol 300
sol 350
sol 400
sol 450
sol 500
sol 550
sol 600
sol 650
sol 700
sol 750
sol 800
sol 805-860
0
500 m
NASA/JPL/Cornell/MSSS/USGS/New Mexico Museum of Natural History & Science

Spirit

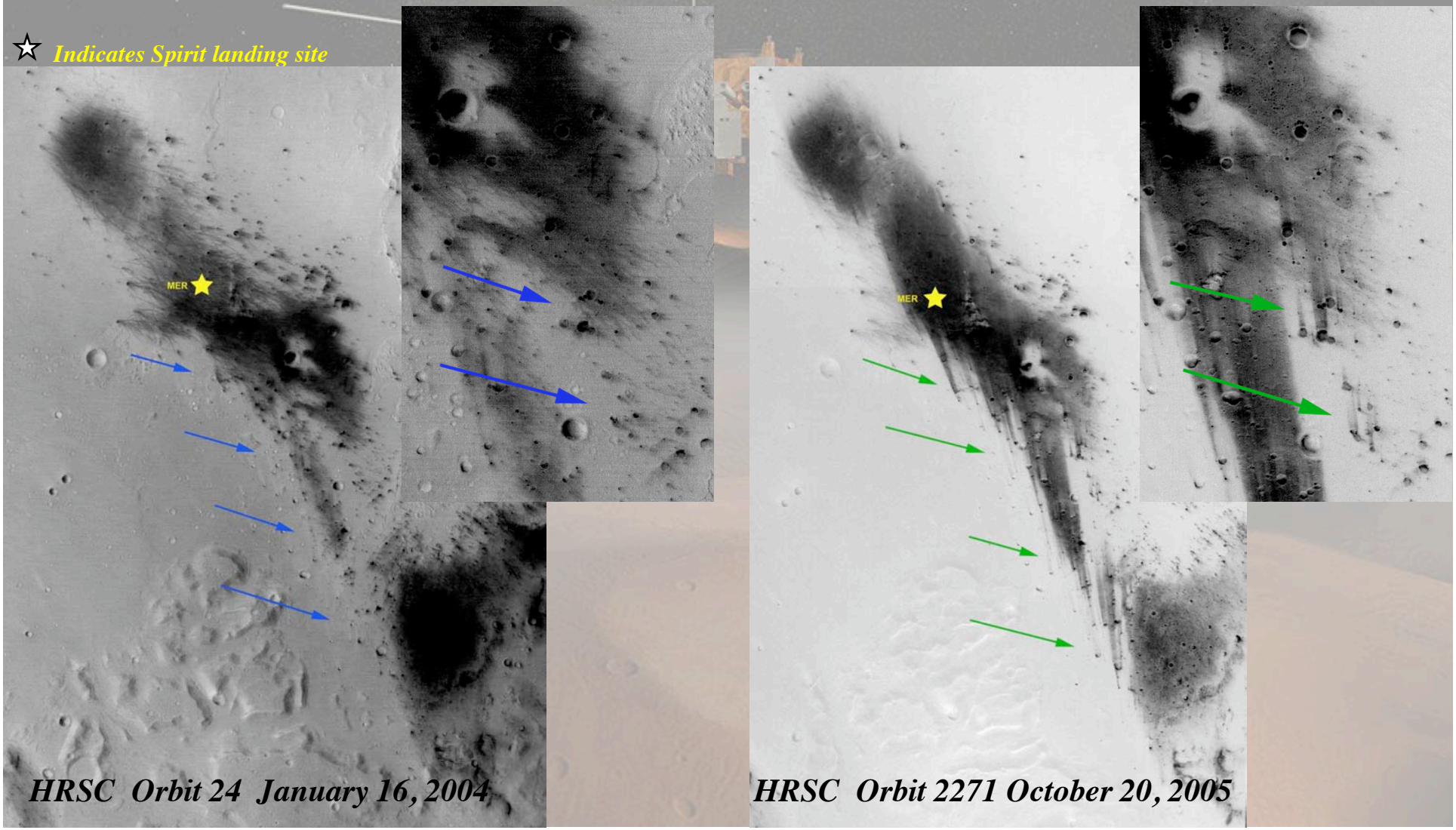
Joint MEX-MER Studies

- *Spirit* dust devil movies coordinated with MEx flyovers
  - ✦ Orbit 2249 (14 Oct 05): Movie obtained, No DD observed (HRSC did not overlap *Spirit* location)
  - ✦ Orbit 2271 (20 Oct 05): No movie obtained
- Changes in variable features (DD tracks, wind streaks)
  - ✦ Orbit 2271 shows major reorientation of wind streaks since January 2004 to a SSE direction
  - ✦ No new dust devil tracks; older wind streaks and DD tracks erased

Redirected Wind Streaks in Gusev

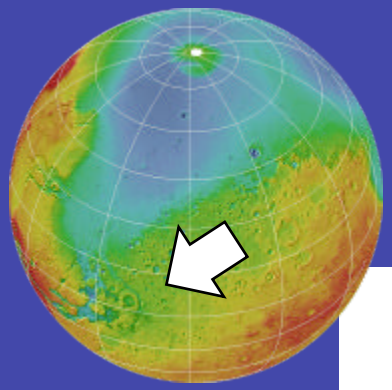
Latest HRSC data show changes in wind streak orientation, suggesting a regional change in Gusev wind patterns during the MER, MEX missions

☆ *Indicates Spirit landing site*

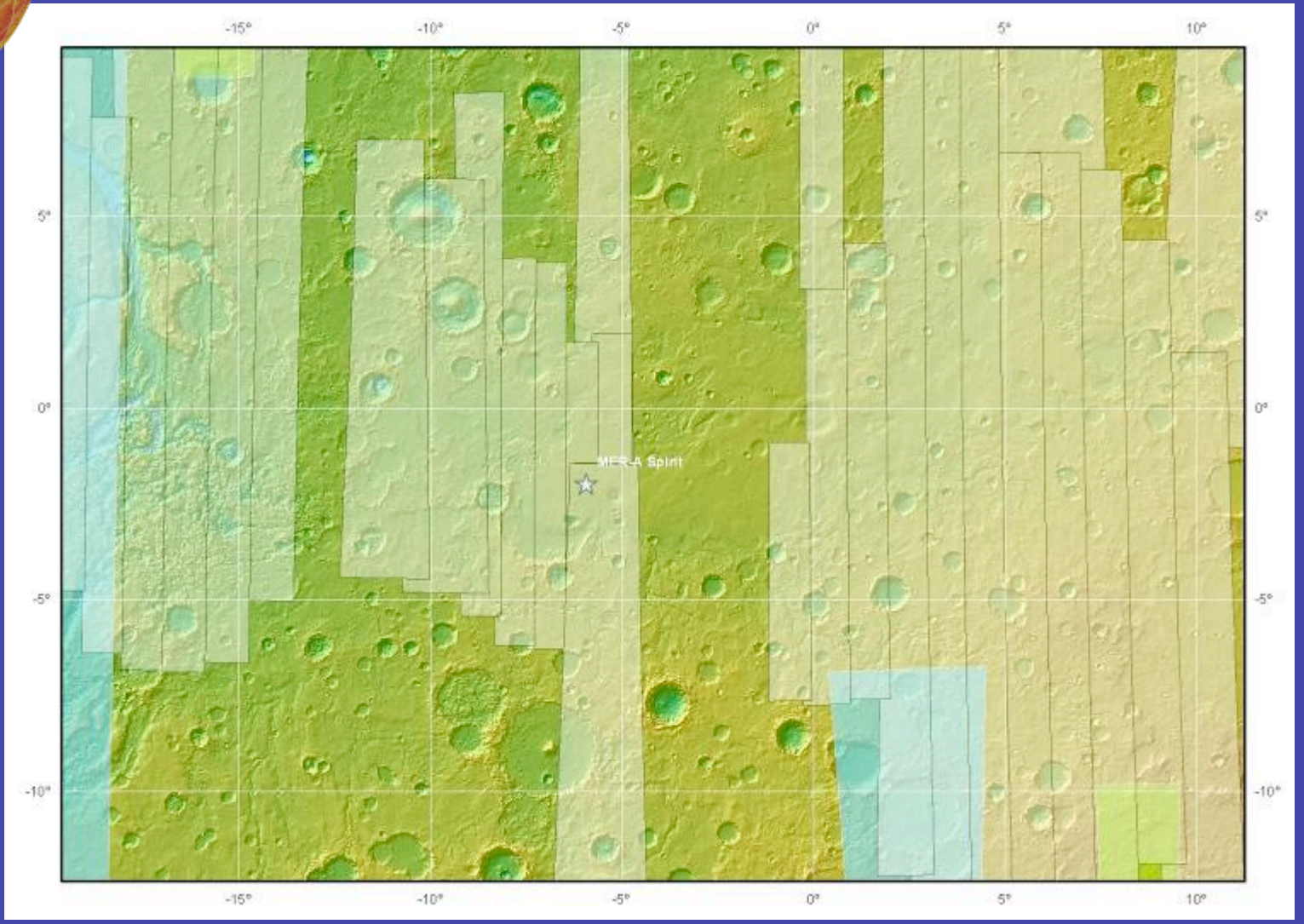


HRSC Orbit 24 January 16, 2004

HRSC Orbit 2271 October 20, 2005

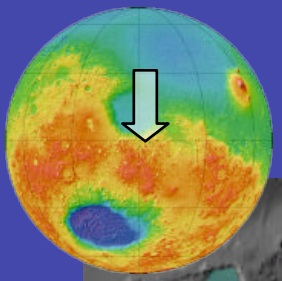


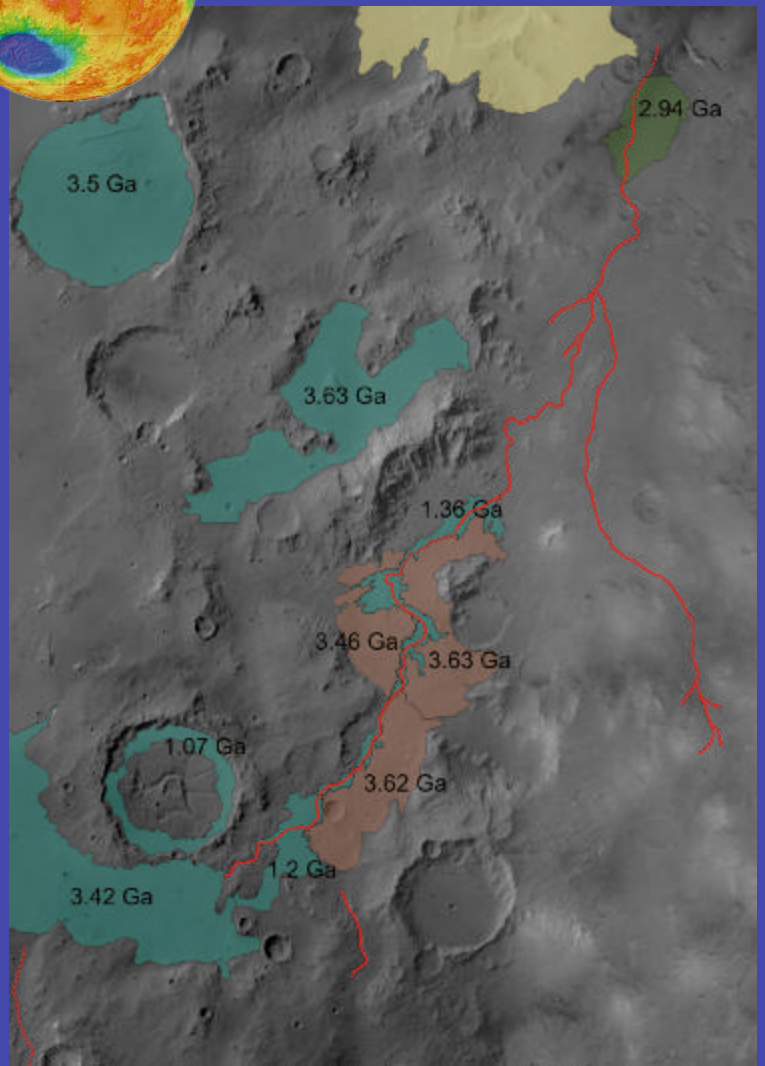
MER Opportunity Landing Site

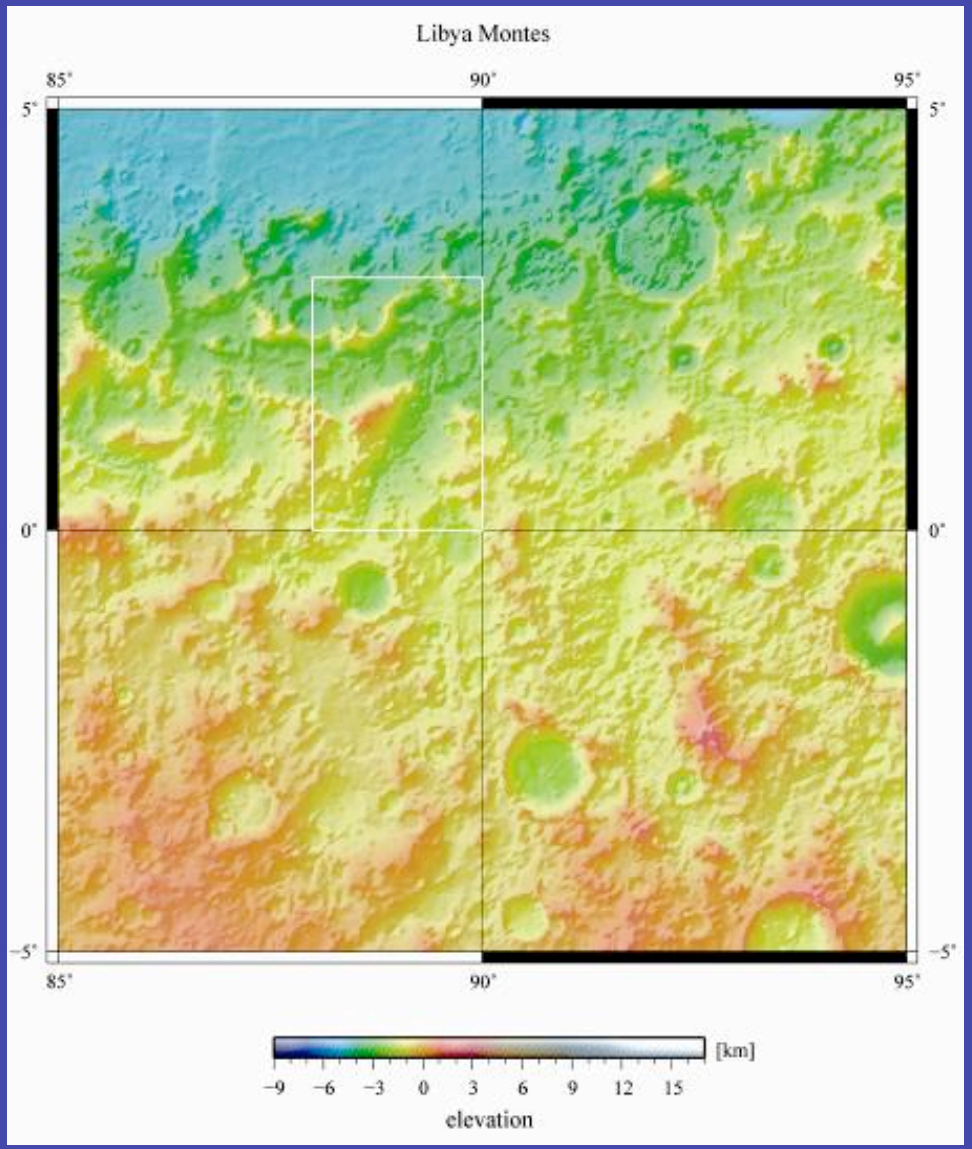


Libya Montes Channel

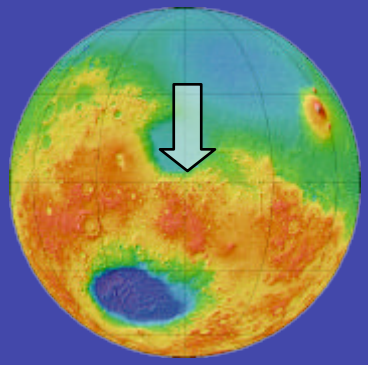
Ancient fluvial activity between ~3.7 Ga and 3.35 Ga ago and reactivation between 1.1 and 1.4 Ga ago



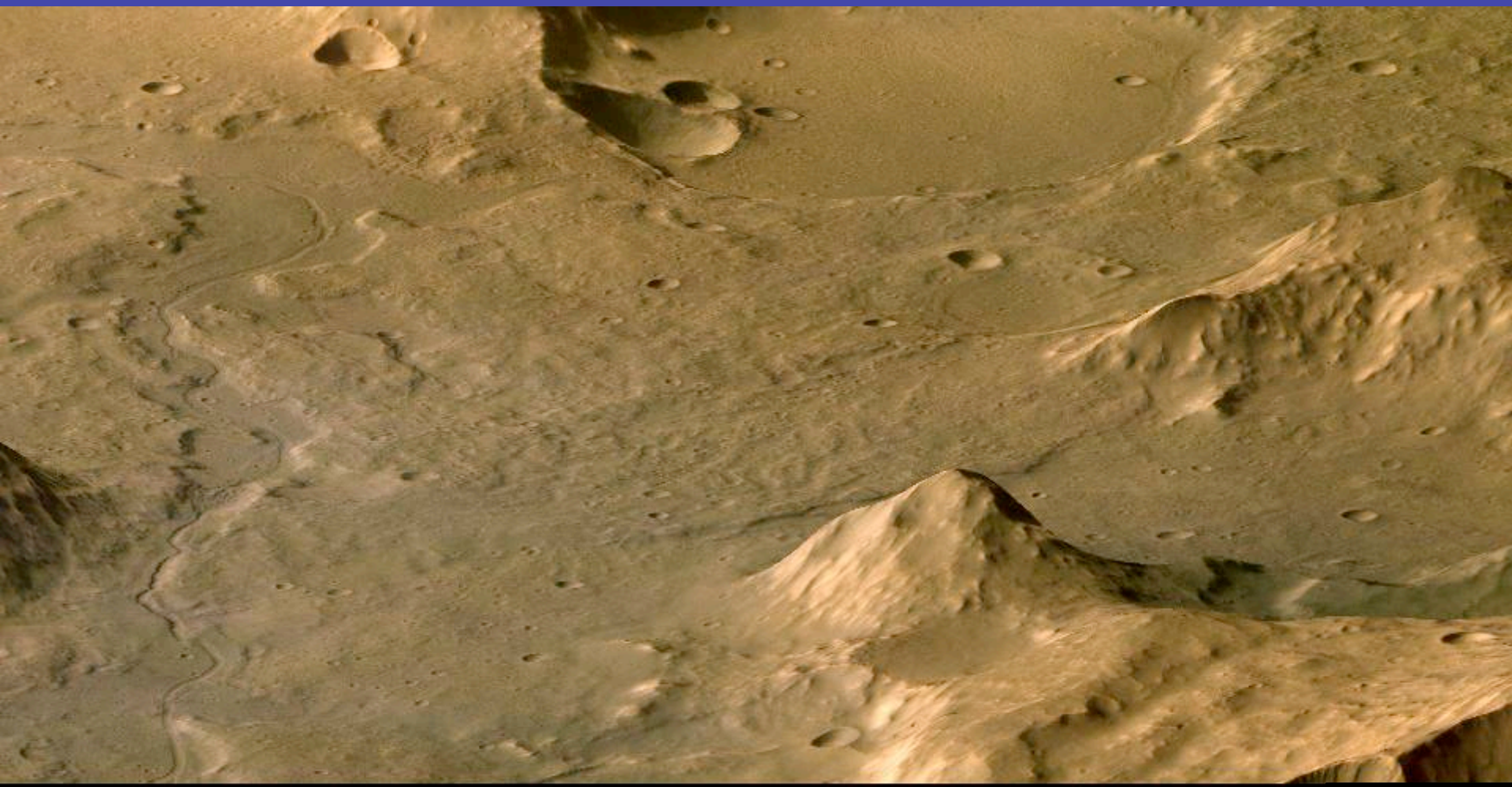




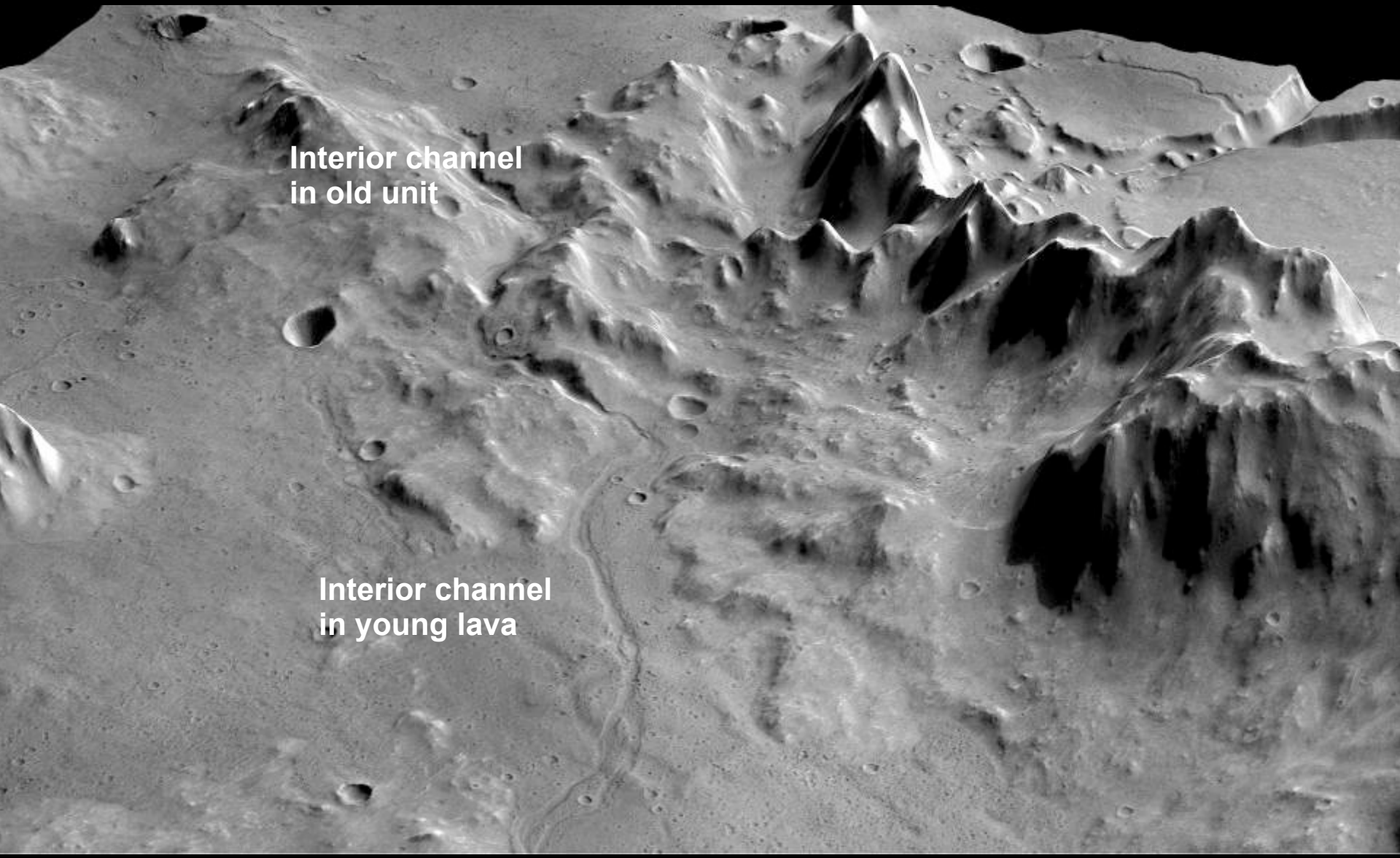
Jaumann et al. (2007) LPSC



Libya Montes

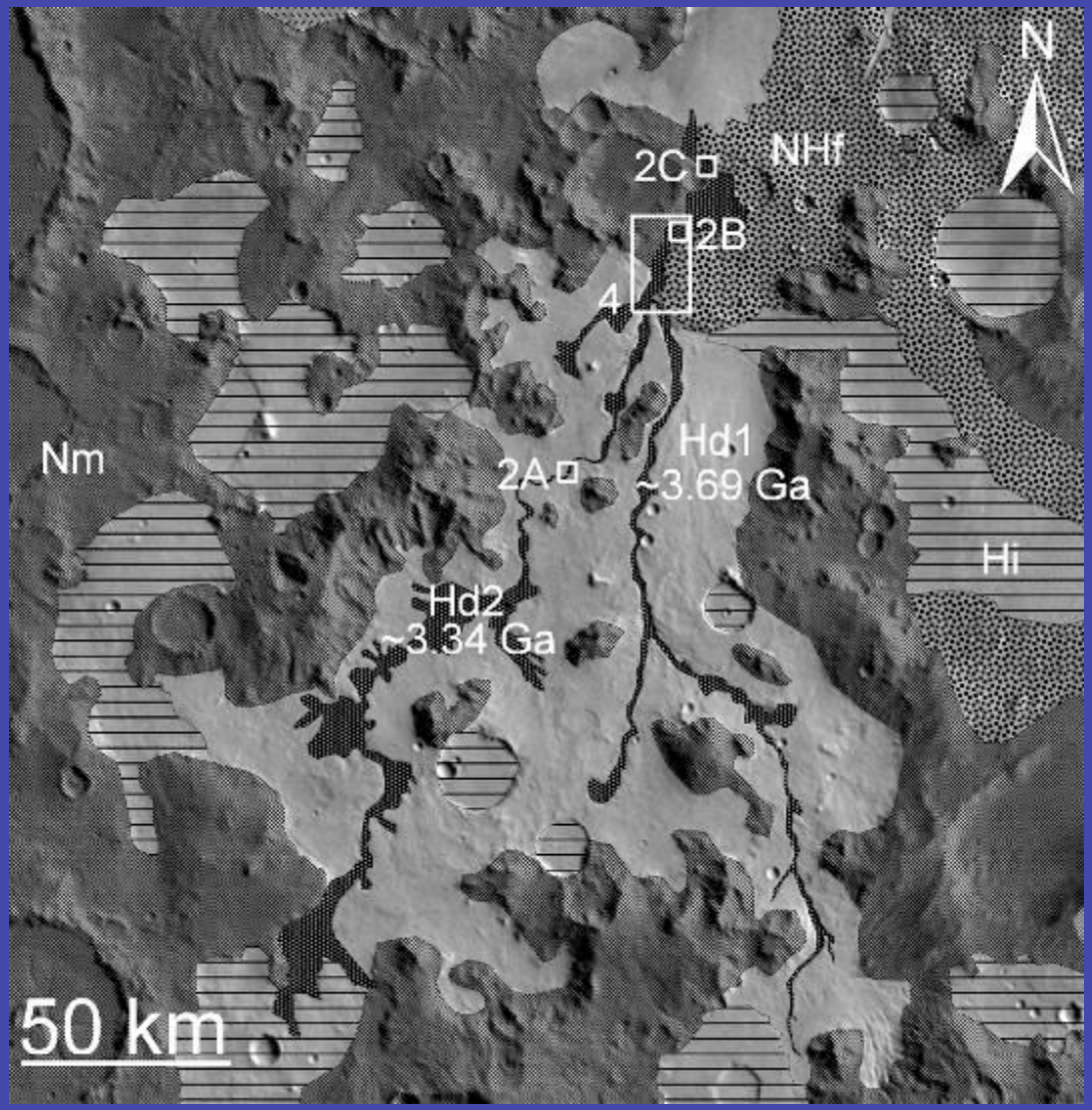


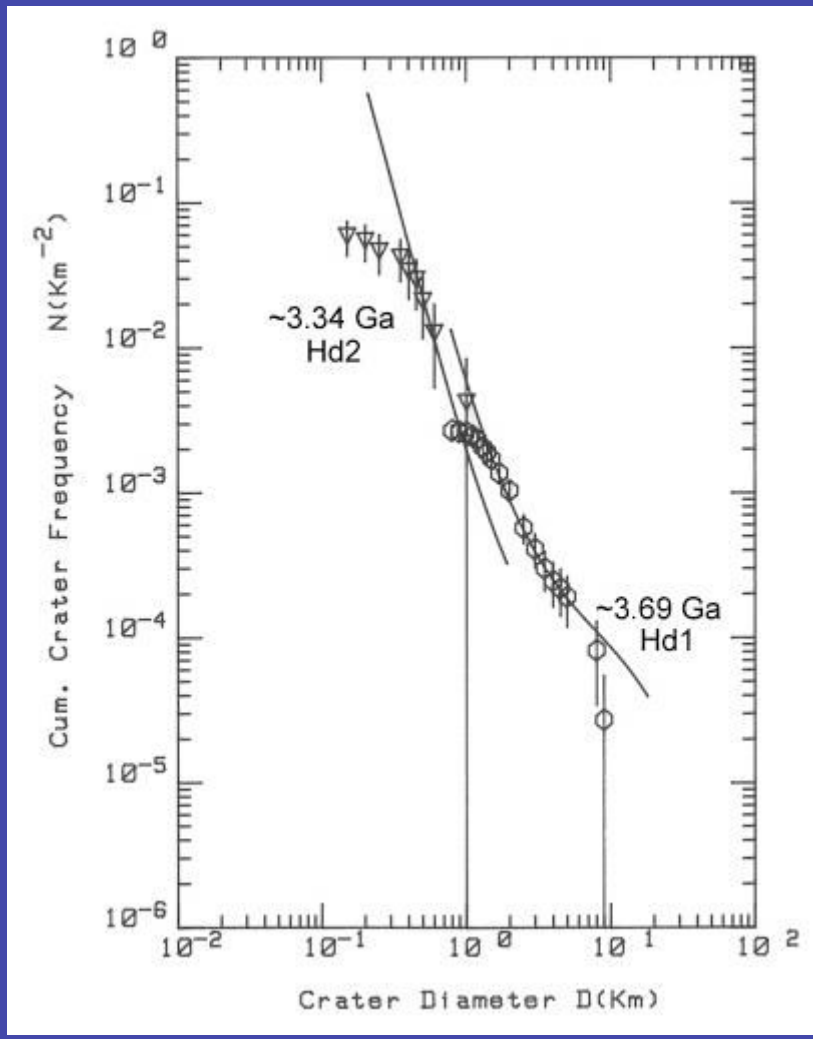
Libya Montes



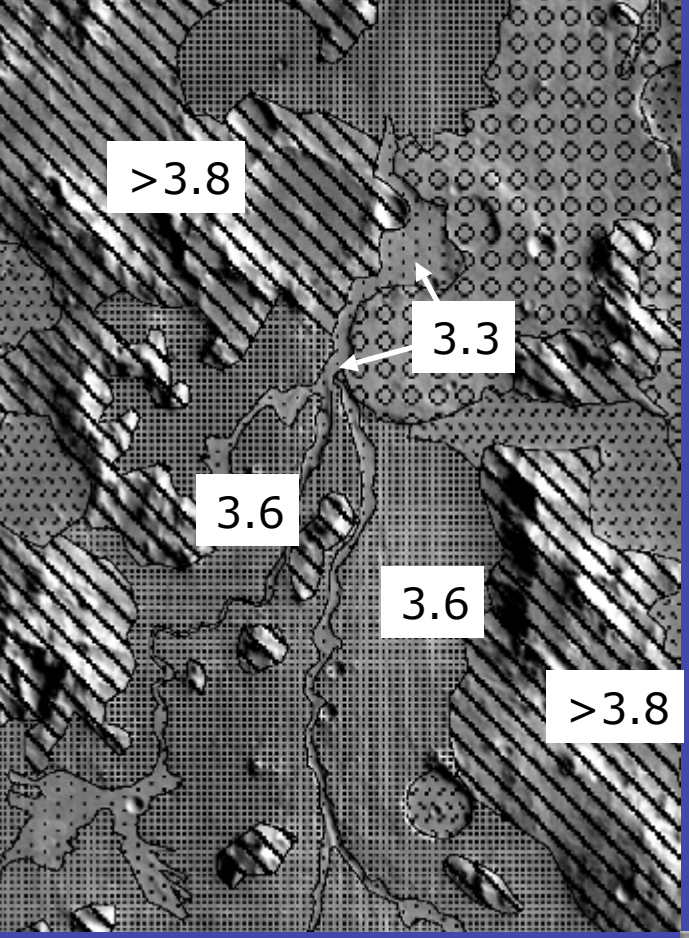
Small Channels

Libya Montes Channel: Ancient fluvial activity between ~3.7 Ga and 3.35 Ga ago





Jaumann et al. (2005) GRL



Time for valley formation: ~ 300 Ma

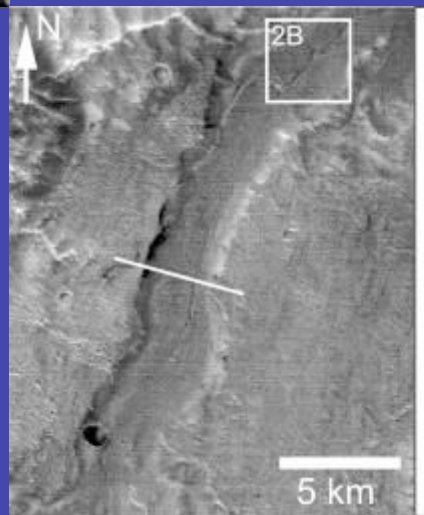
Depth of valley 280 m

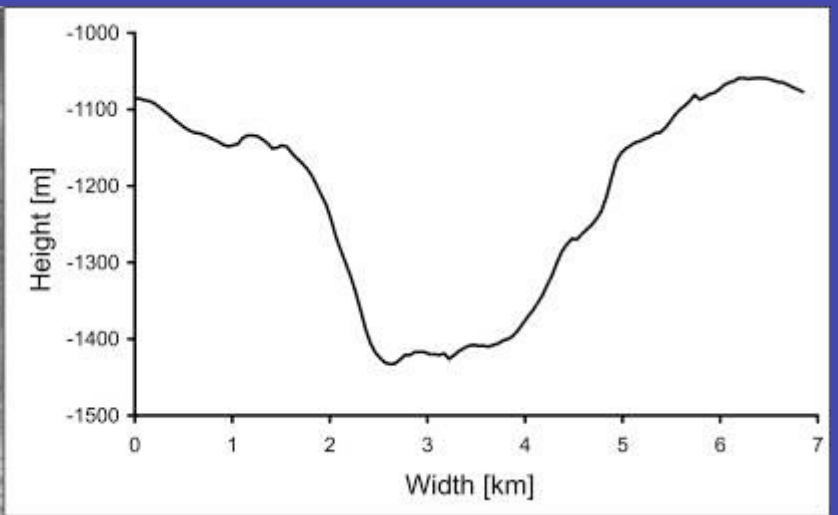
→ erosion rate = 0.9 µm/year

→ about 78400 flooding events are needed to excavate the valley Hd2

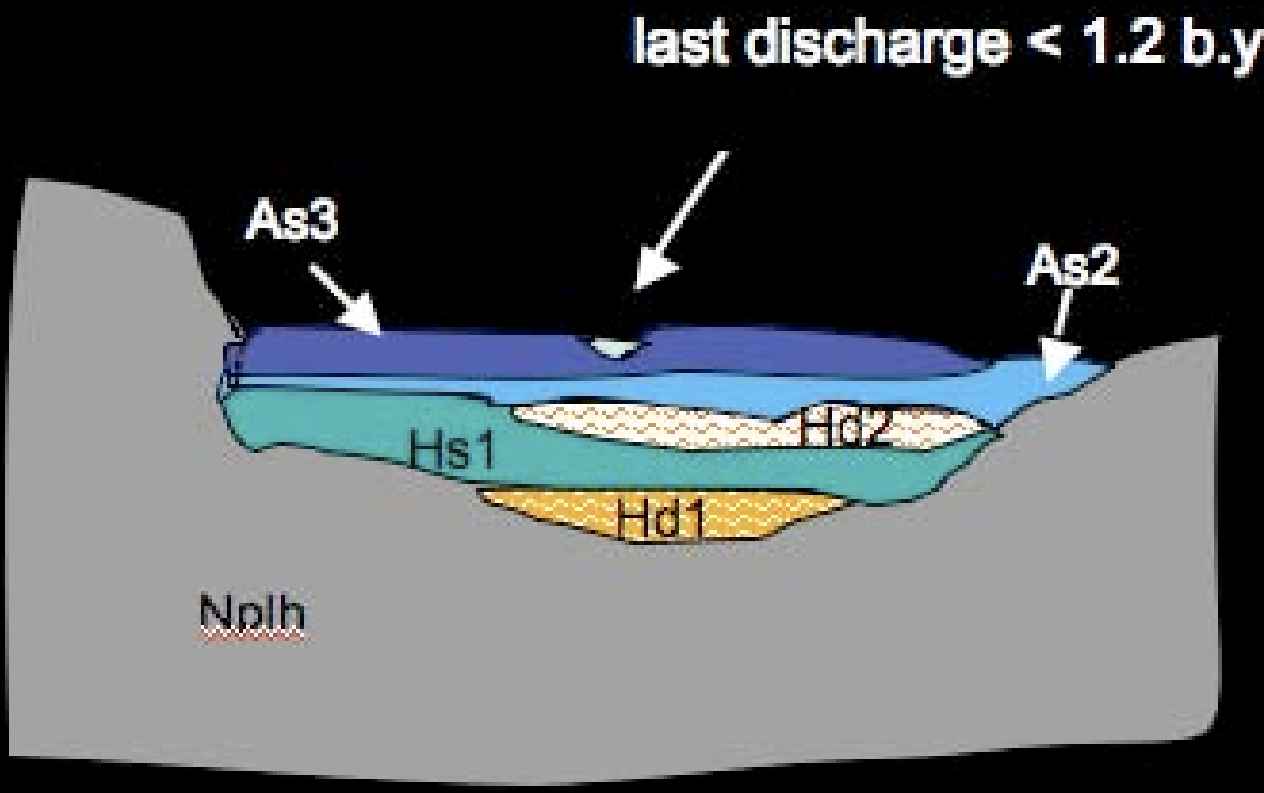
→ with reasonable assumption of bankfull flooding periods over ~ 5 days, this results statistically in a flood every ~ 3800 years between 3.6 Ga and 3.3 Ga ago

Hd2 Valley, ~3.3 Ga





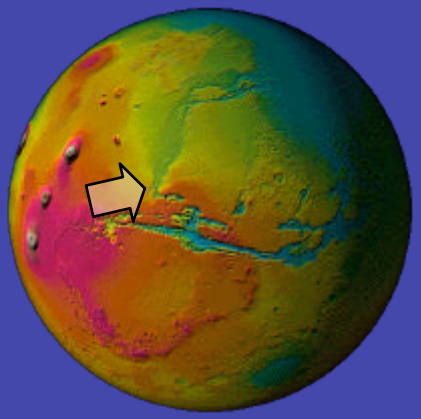
Libya Montes



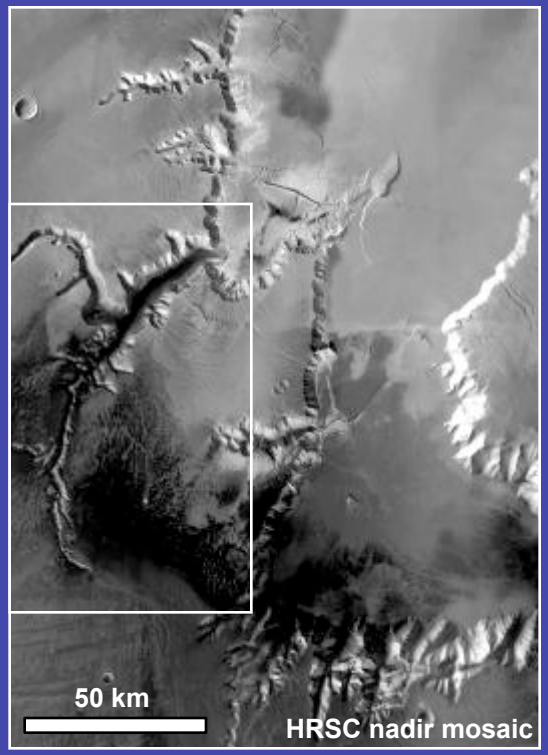
Jaumann et al. (2007) LPSC

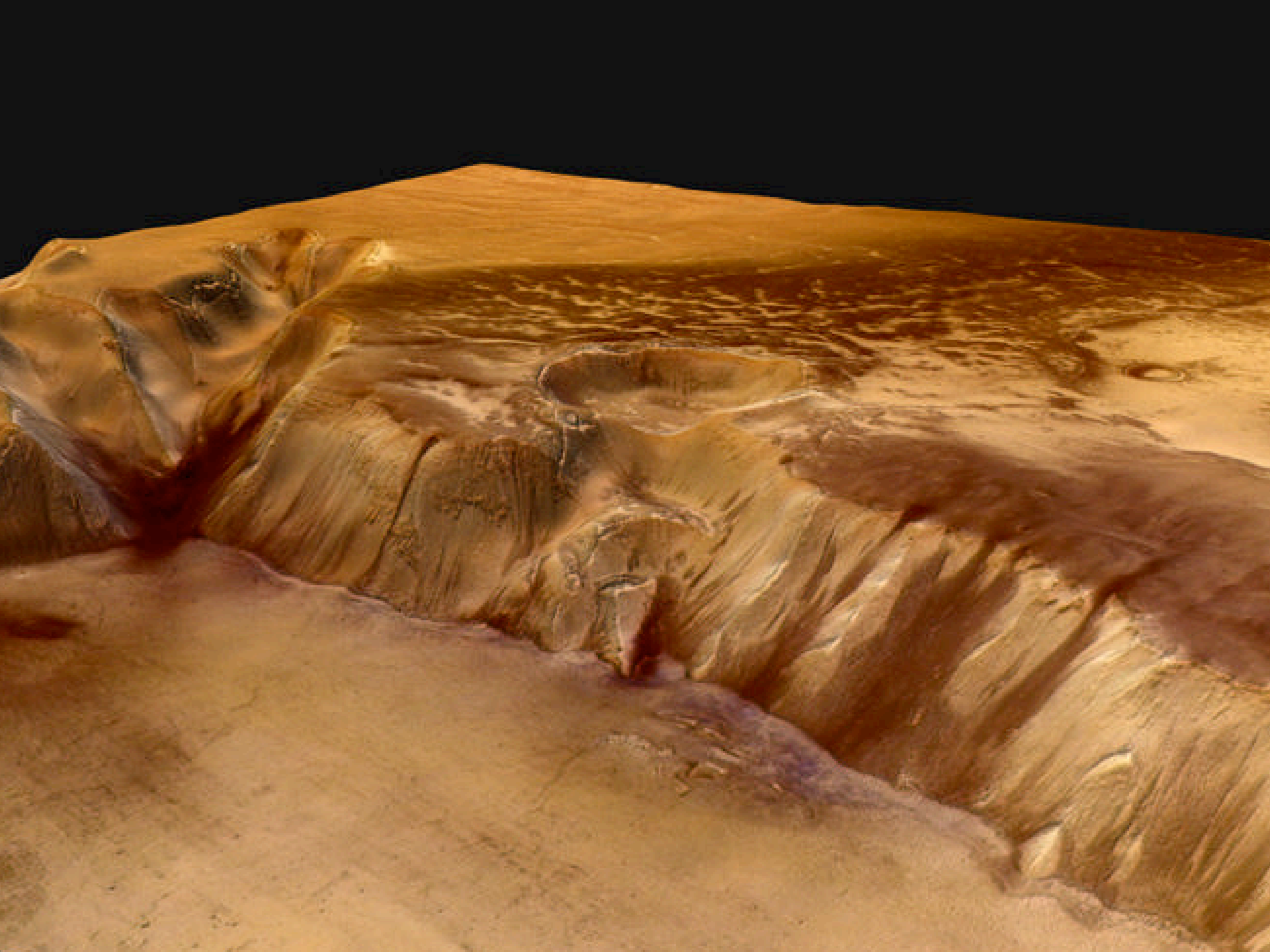
Echus Chasma

Source area of Kasei Valles

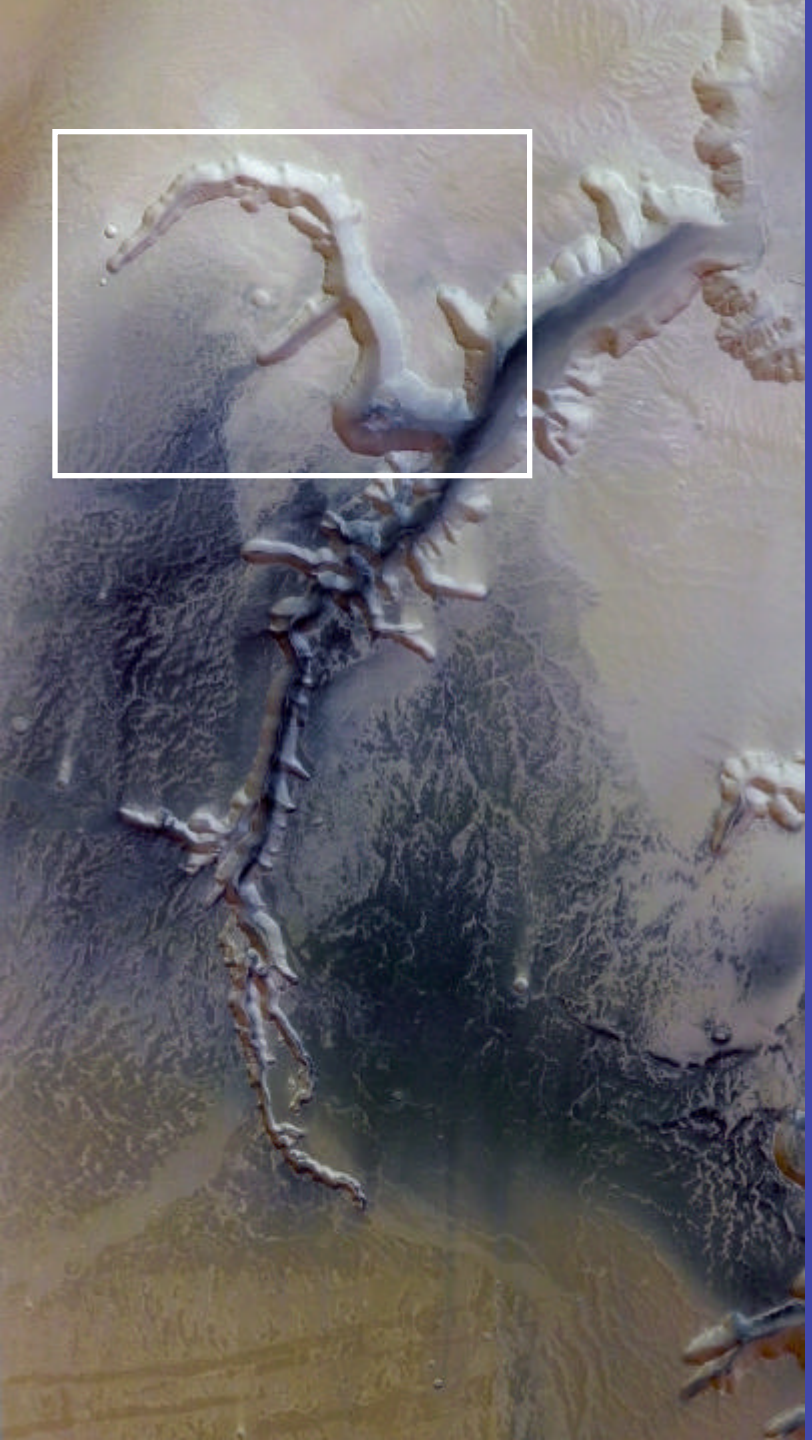


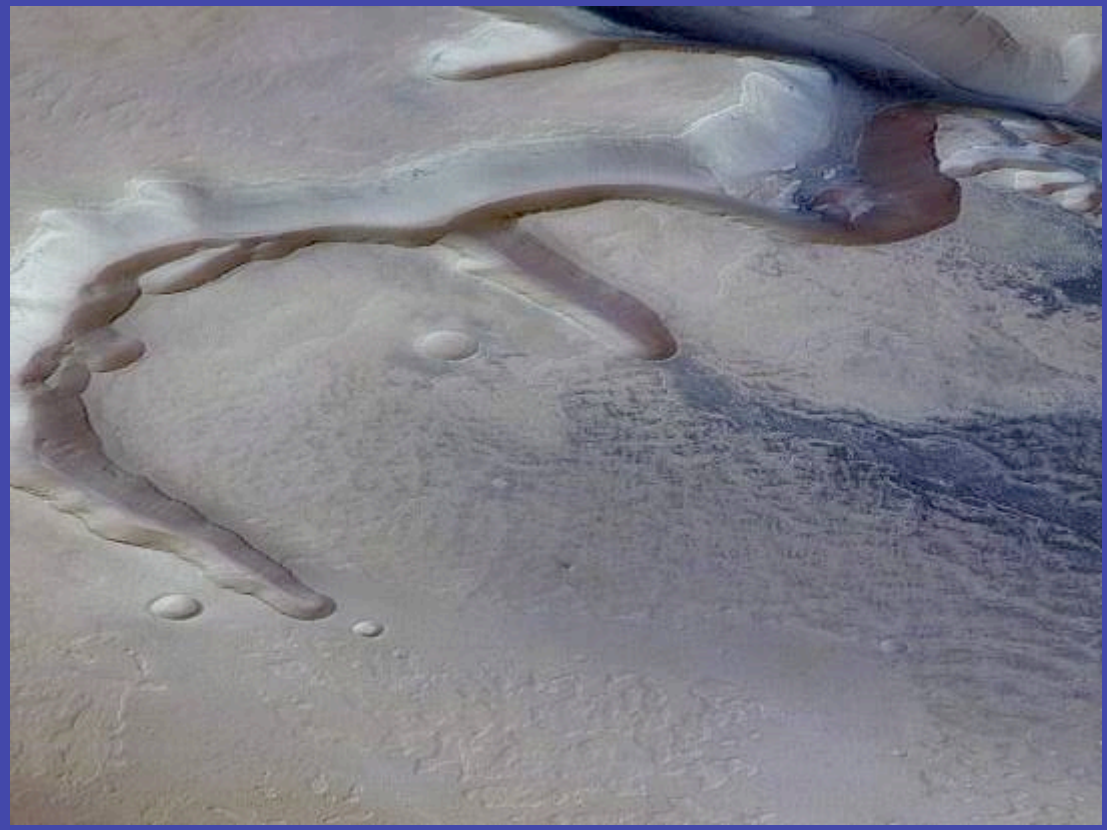
Water on the plateau surface around 1.5 billion years ago, probably a lake in the valley.

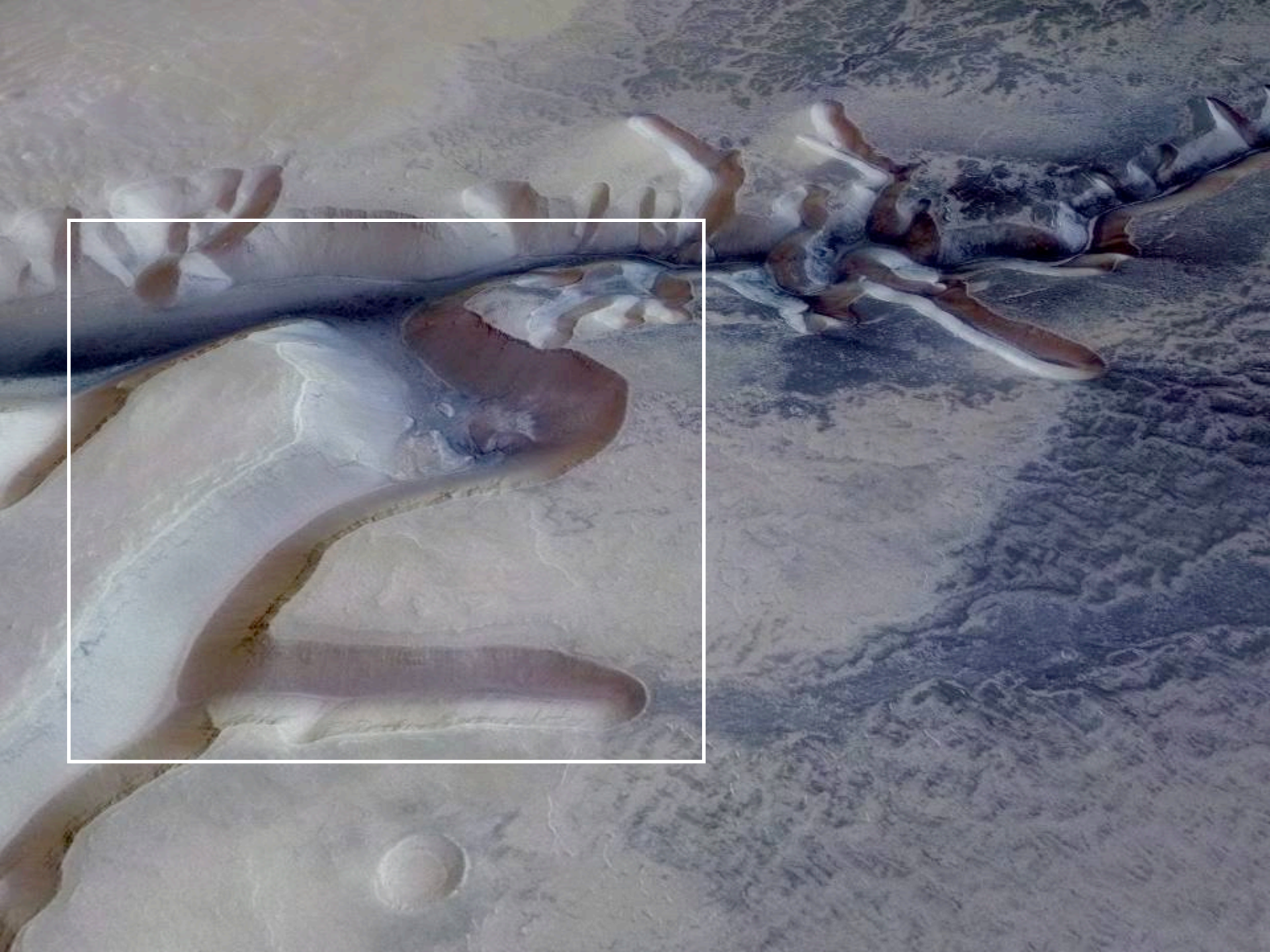




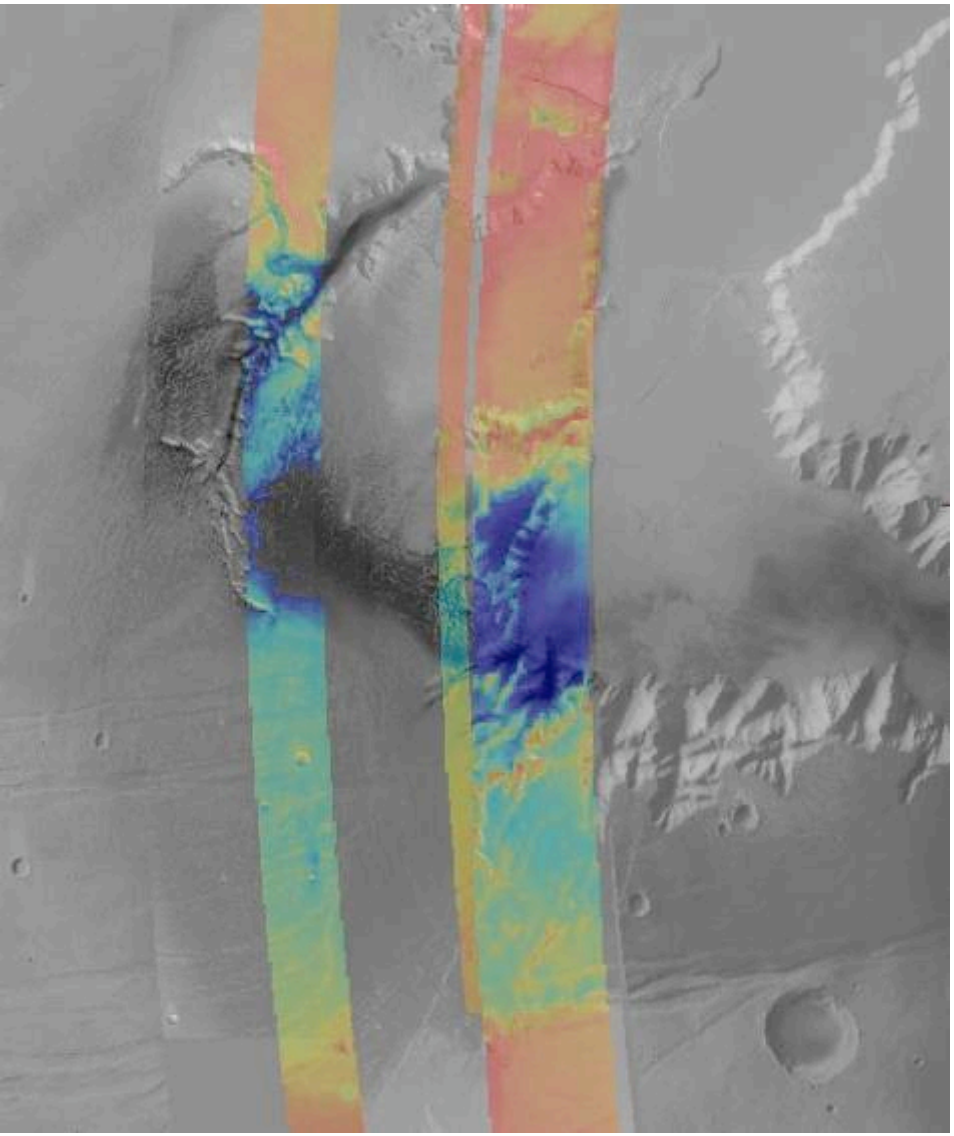
Echus Chasma



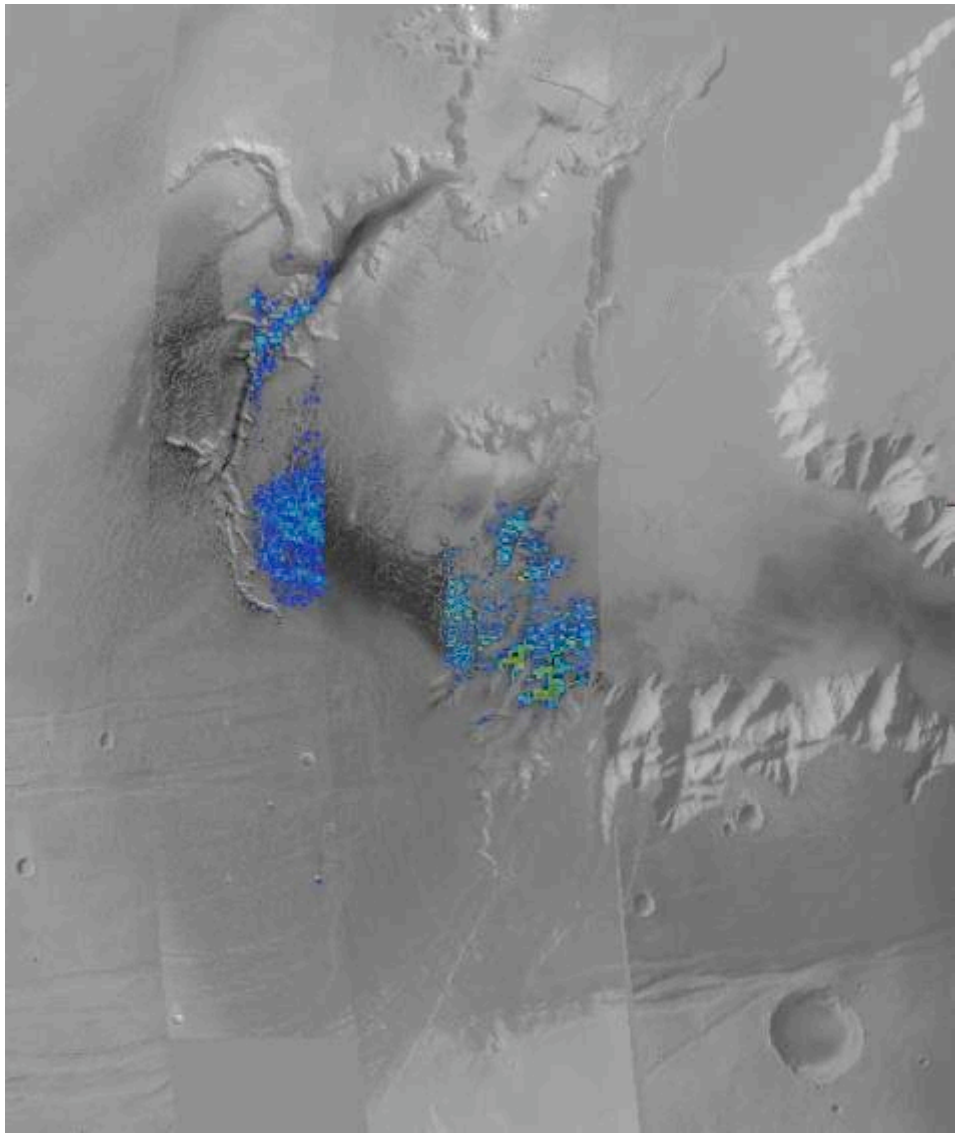




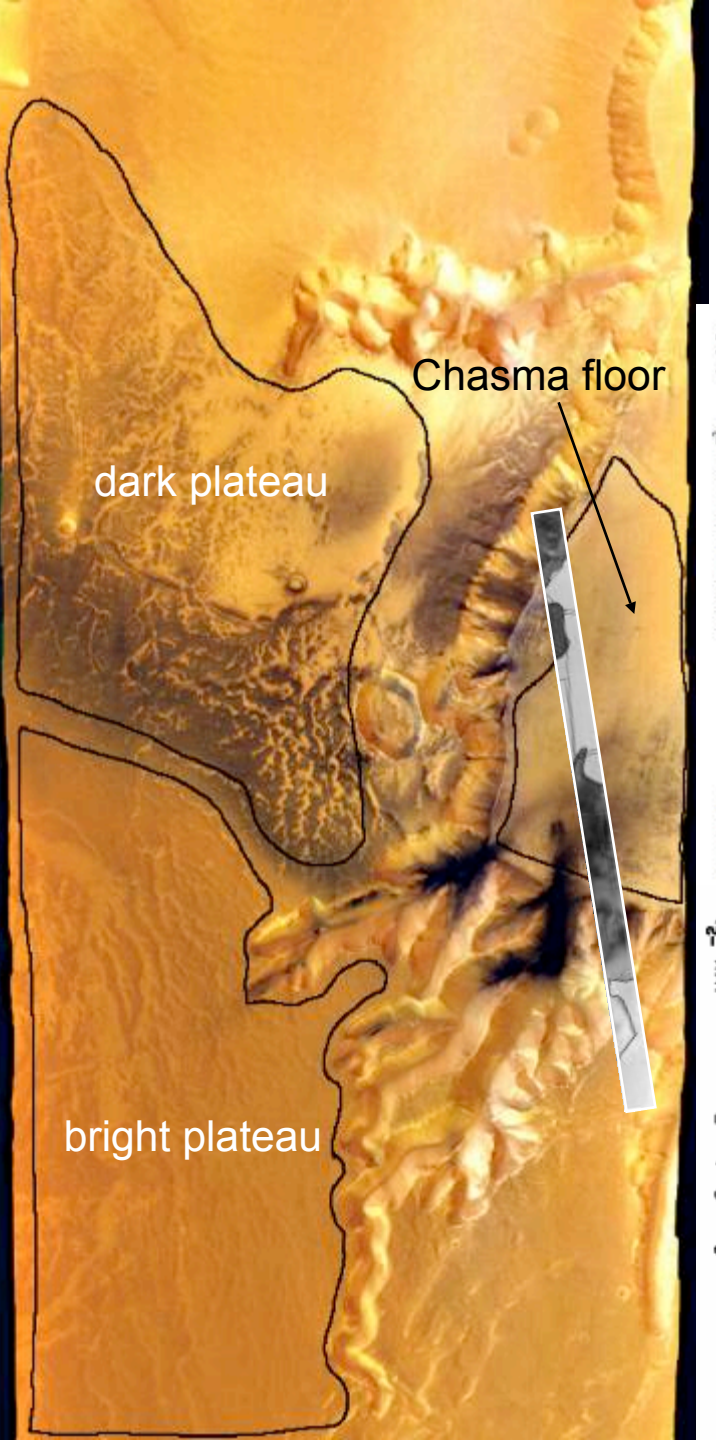
OMEGA albedo superimposed on HRSC mosaic

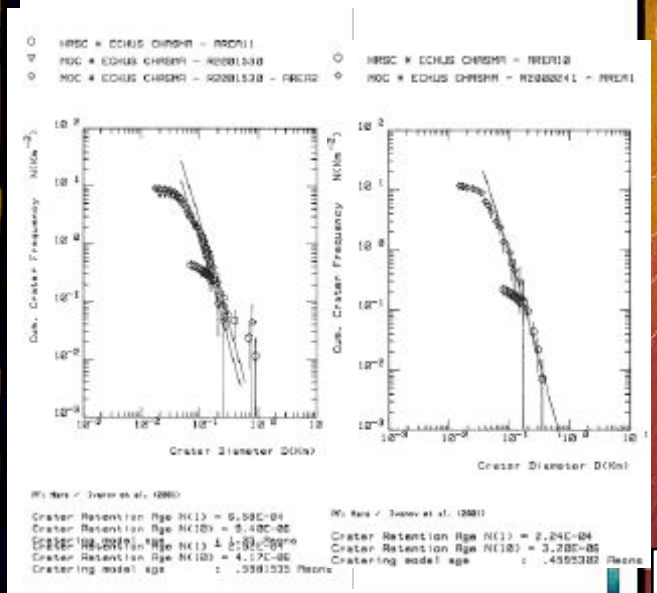


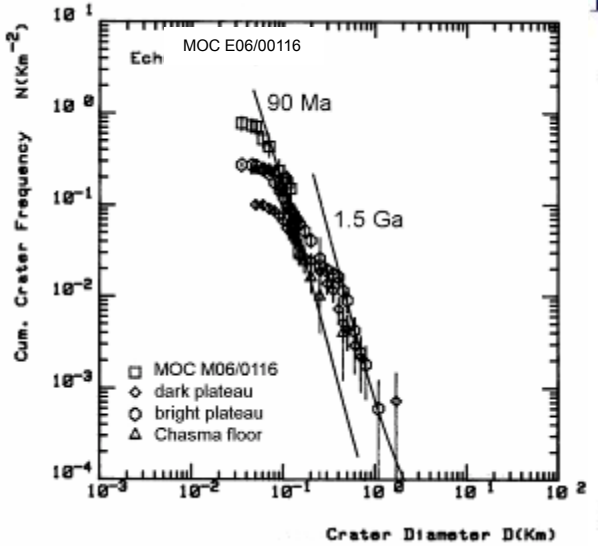
OMEGA spectral criterion for clinopyroxenes superimposed on HRSC mosaic

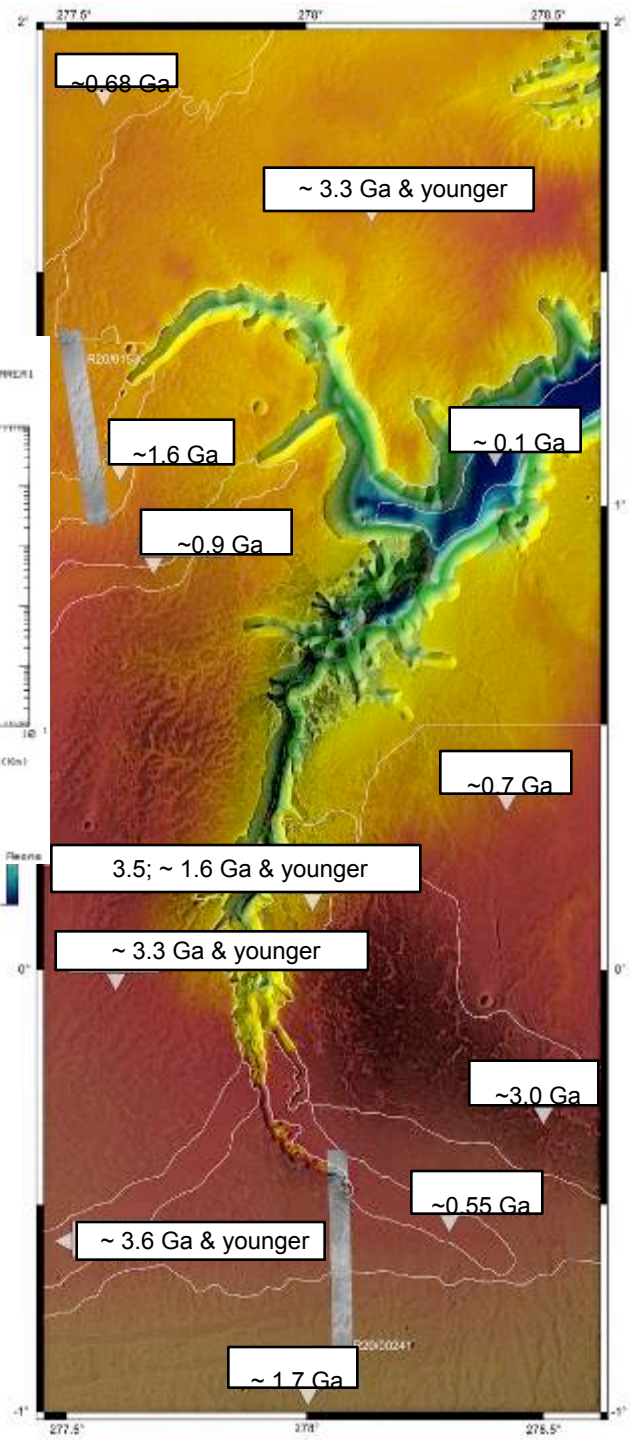


2% 4%


Chasma floor
dark plateau
bright plateau

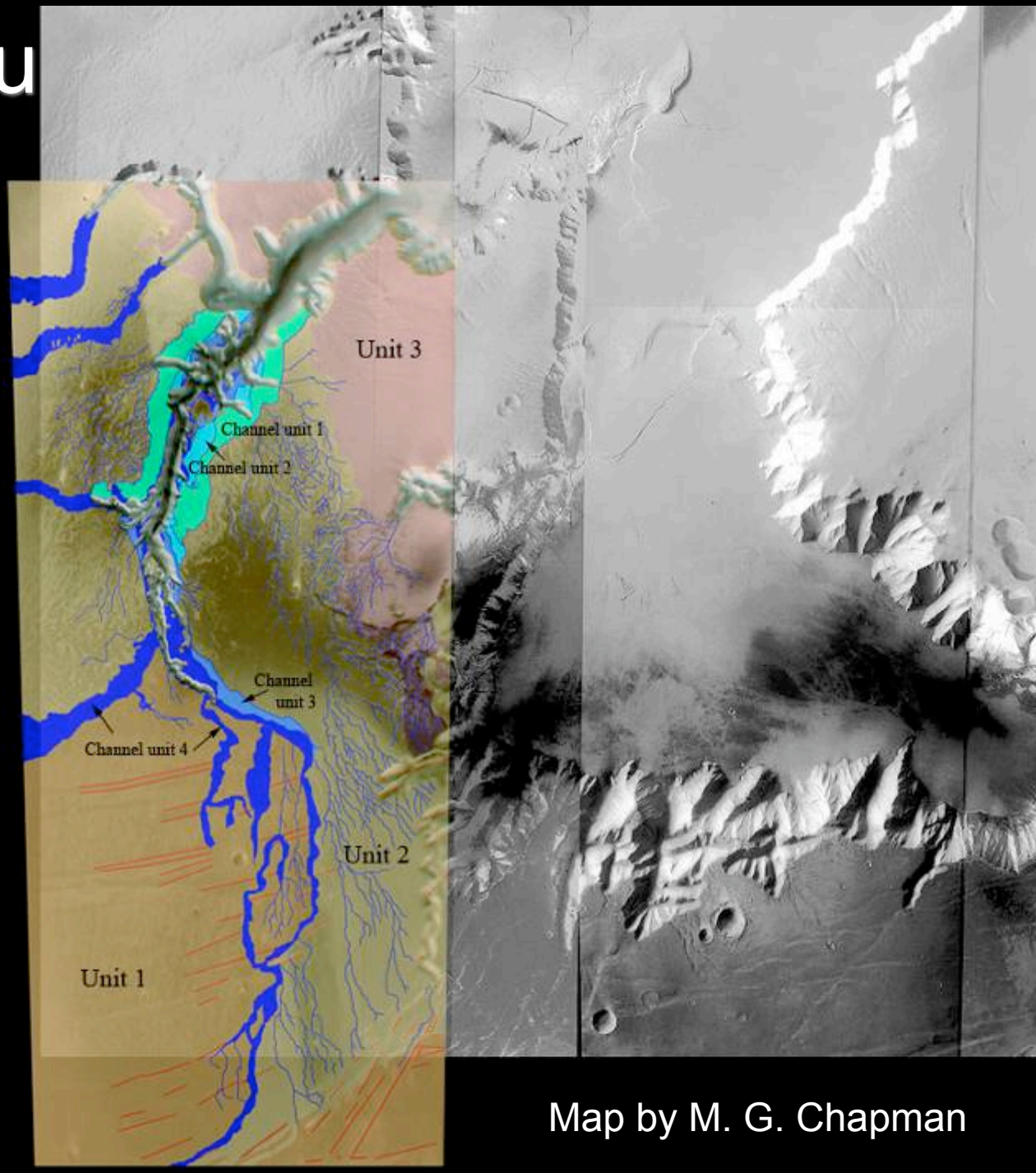



MOC E06/00116
Ech
90 Ma
1.5 Ga
MOC M06/0116
dark plateau
bright plateau
Chasma floor
Cum. Crater Frequency N(Km⁻²)
Crater Diameter D(Km)

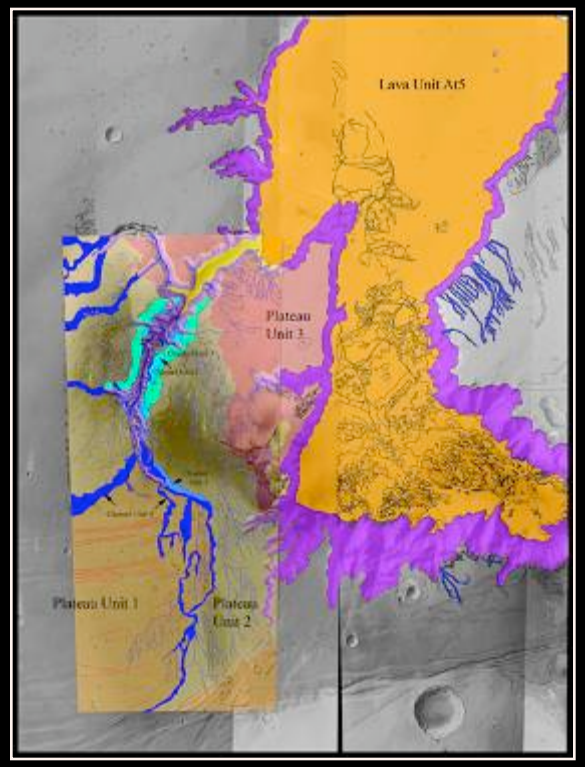

~0.68 Ga
~ 3.3 Ga & younger
~1.6 Ga
~ 0.1 Ga
~0.9 Ga
~0.7 Ga
3.5; ~ 1.6 Ga & younger
~ 3.3 Ga & younger
~3.0 Ga
~0.55 Ga
~ 3.6 Ga & younger
~ 1.7 Ga

Echus Plateau

Orbit 2204



Map by M. G. Chapman



Ancient high, plateau streamlined islands

MOLA shows continuation of plateau

High plateau grooves

Westward continuation of enigmatic ridge

MOLA topographic low

more low steamlined islands

Unit At4 pre- and post floods

MOLA low

buried ridge

chaos

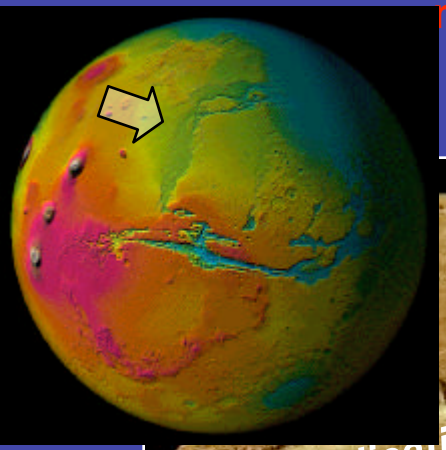
New HRSC geologic mapping indicates late surface channels and platey Echus lava flows

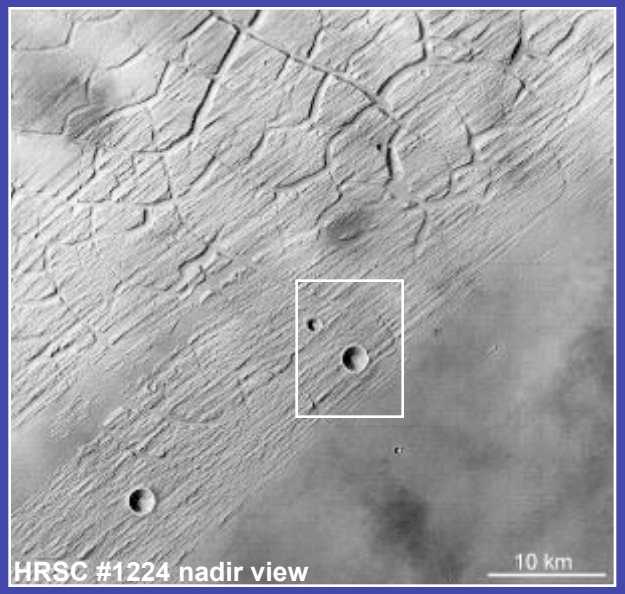
Kasei Mapping

by Mary Chapman
with contributions from
H. Hiesinger and his group

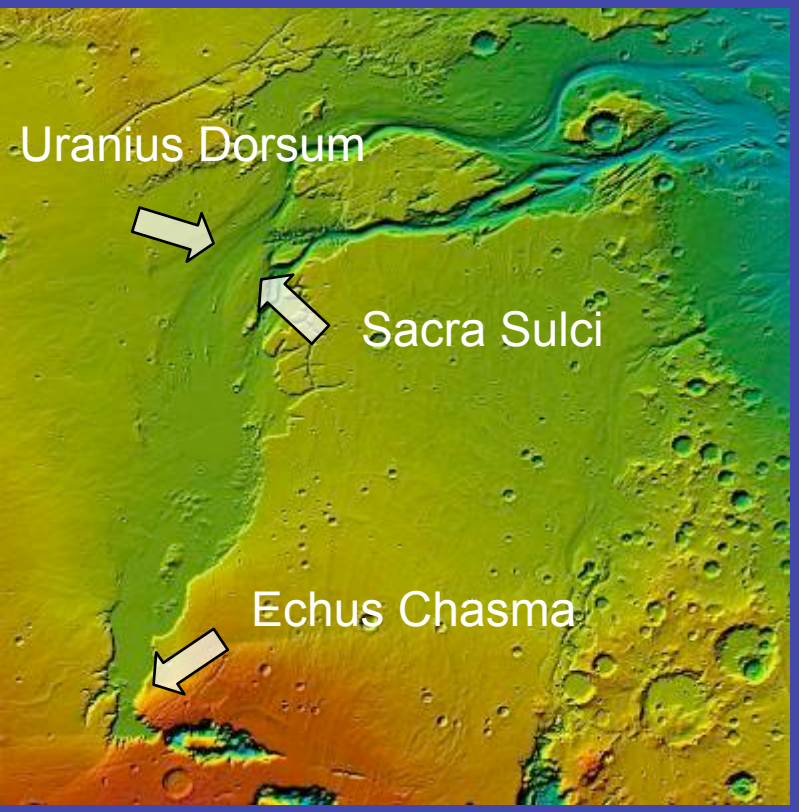
Kasei Valles

Example for volcanic, fluvial, and glacial activity over 3.5 billion years of martian history

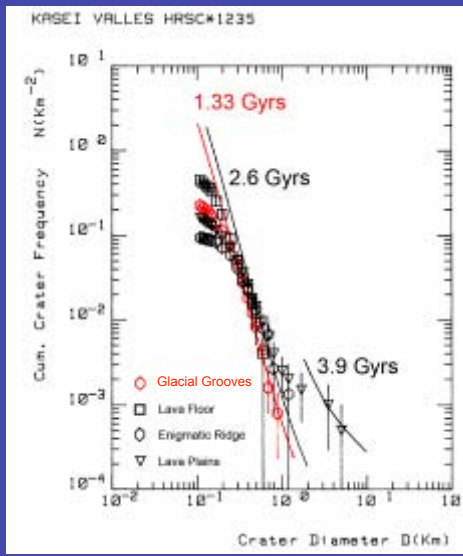


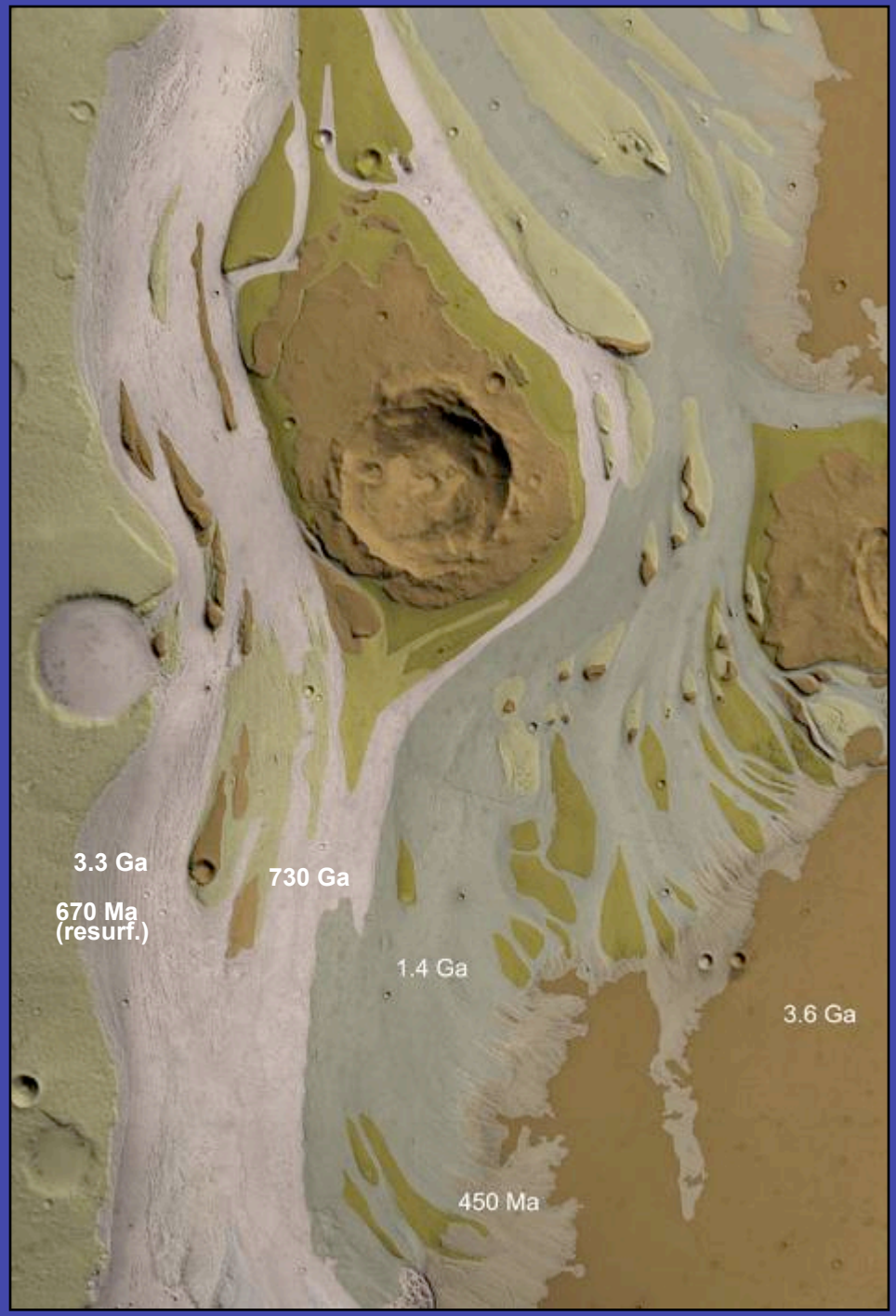


Kasei Valles Outflow Channel

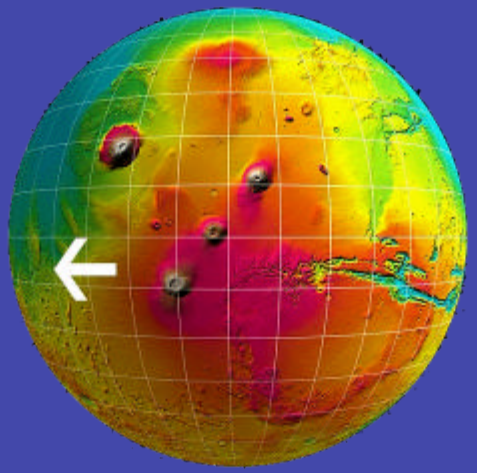


- Channel formation ~3.6 Ga ago
- Surrounding plains (volcanic) formed already at ~3.9 Ga, subsequent erosive (fluvial/ glacial) processes in the valley between 3.6 Ga and 1.3 Ga ago
- Possible glacial processes (glacial grooves, Lucchitta 1982, JGR, 2001, GRL) ended ~1.3 Ga ago
- Formation of the “enigmatic ridge“ (Uranius Dorsum) ~2.6 Ga ago (by interaction of lava with ice)
- Source region, Echus Chasma, latest fluvial activity on plateau feeding the Chasma and the glacial activity downstream ~1.5 Ga ago, volcanic blanketing ~ 90 Ma ago





Mangala Valles Middle Reaches



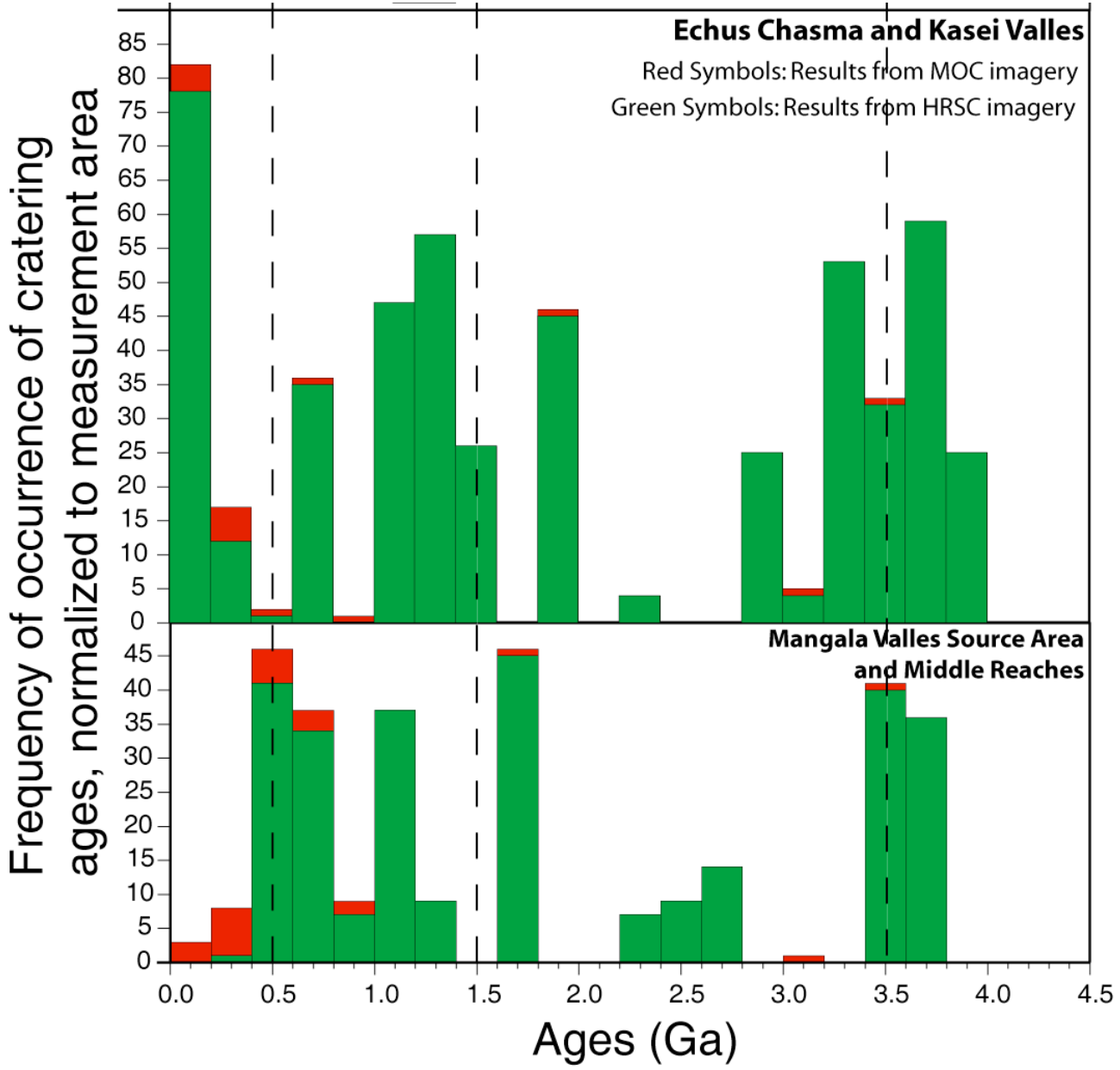
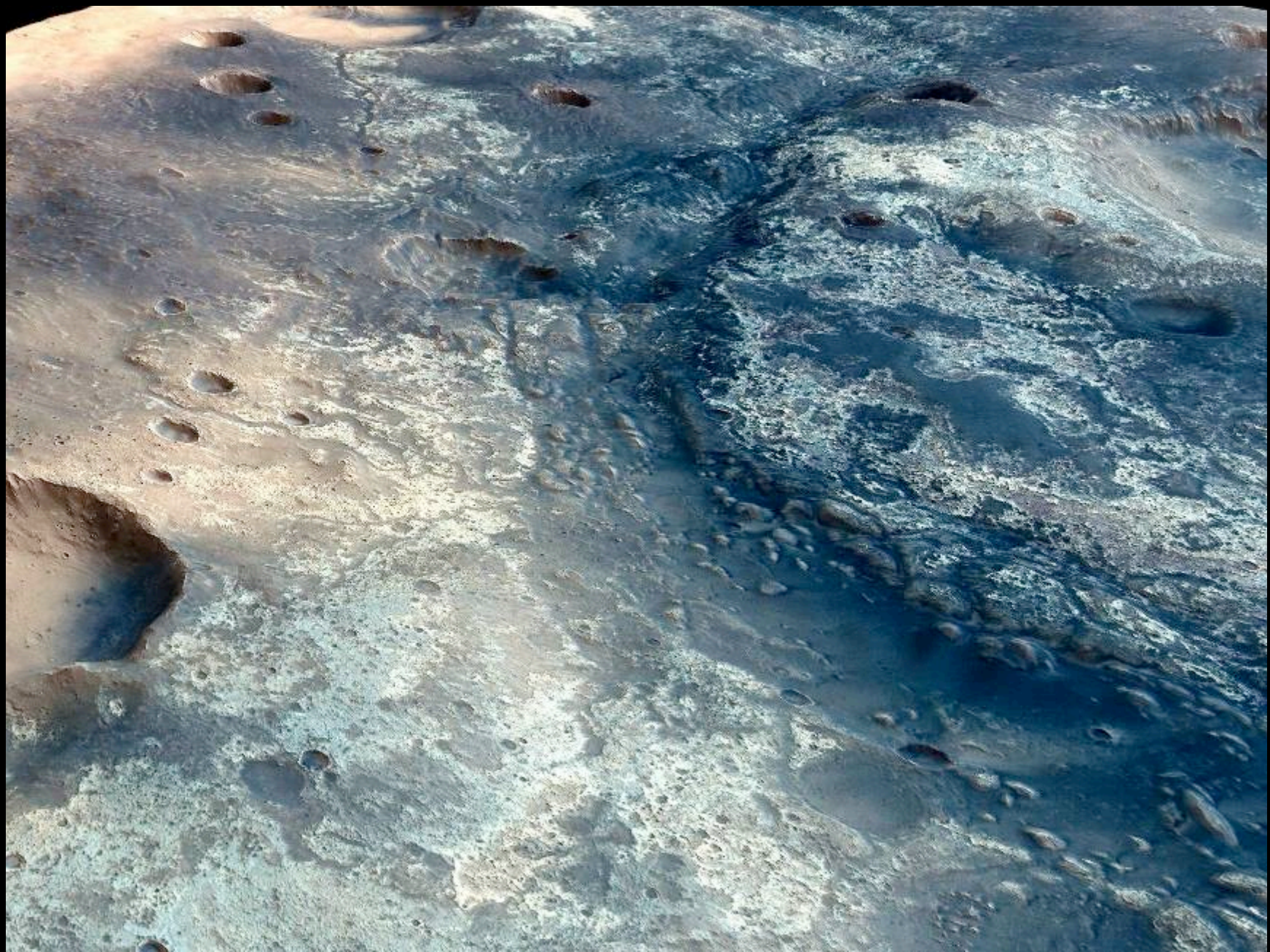
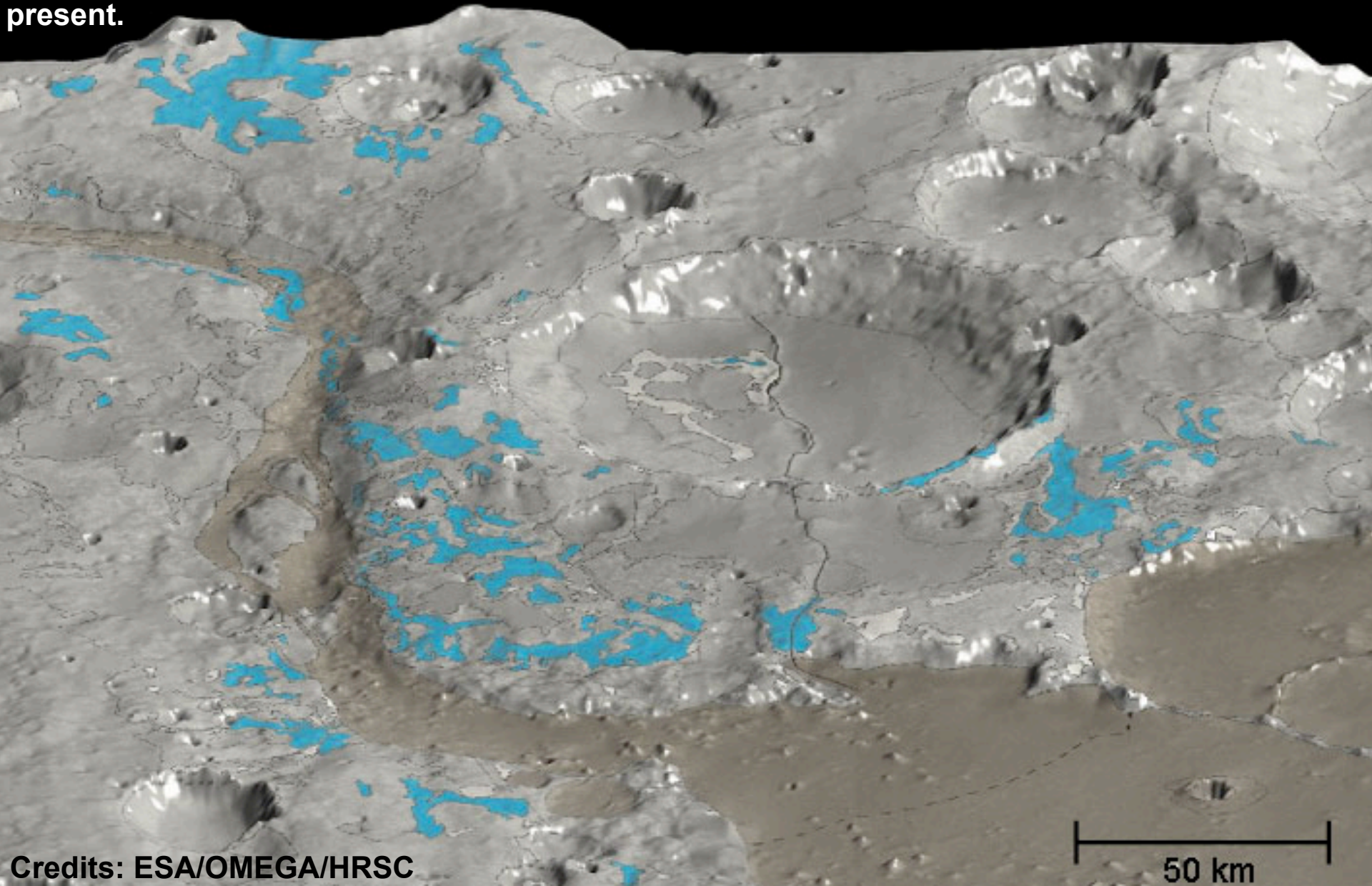


Figure: Histogram of ages extracted from measurements on HRSC and MOC imagery in the Echus Chasma/Kasei Valles and Mangala Valles.

Mawrth Vallis



In this HRSC 3-D perspective view of the Marwth Vallis area (shades of grey), OMEGA has mapped the water-rich minerals (blue). No hydrated minerals or sediments have been detected, neither in the channel nor in its opening. However, the outflow was so violent as to erode and expose ancient hydrated clay-rich minerals, tracing an early era when water was present.

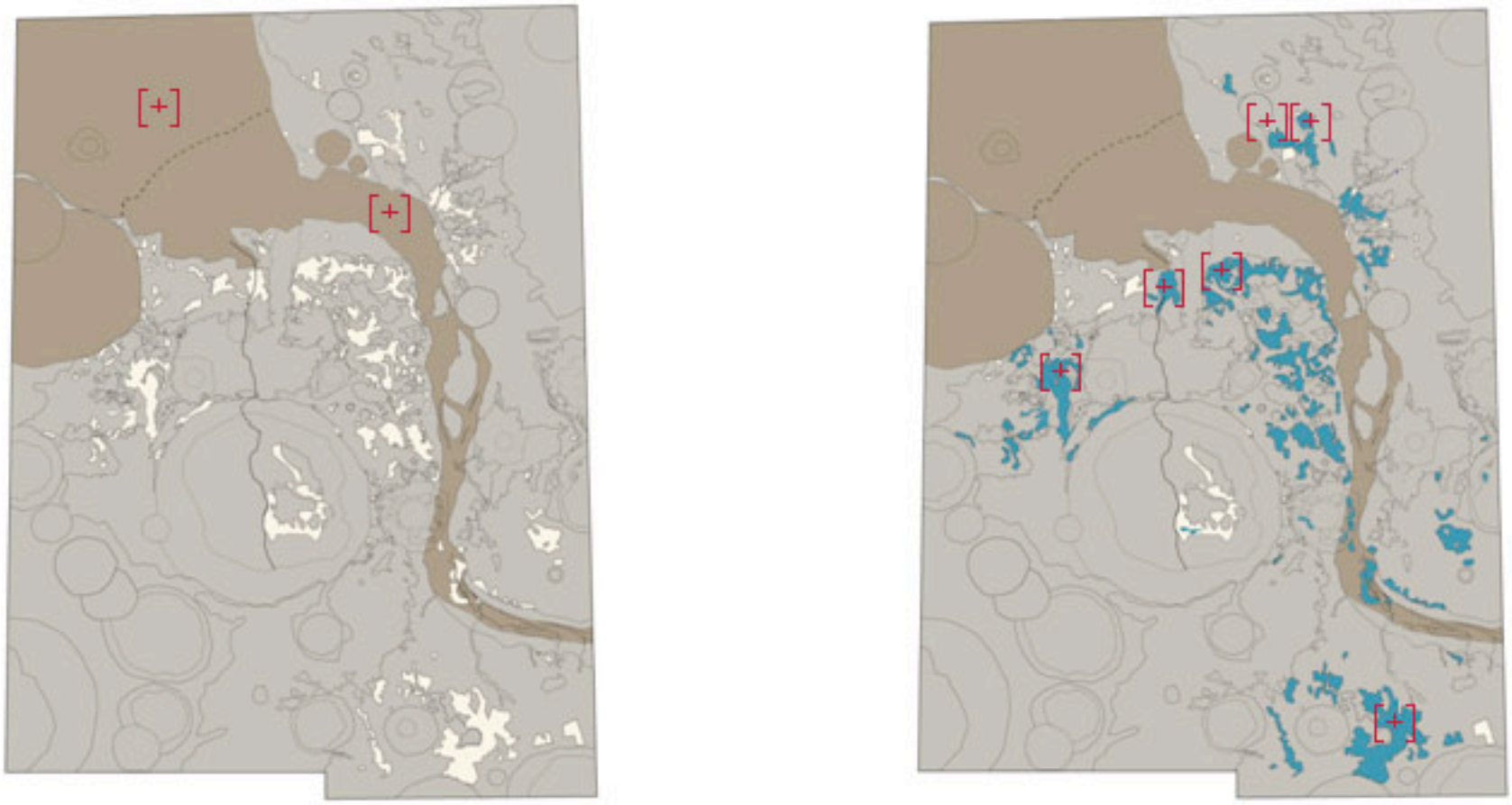


Credits: ESA/OMEGA/HRSC

A typical example: Marwth Vallis

OMEGA shows: no hydration

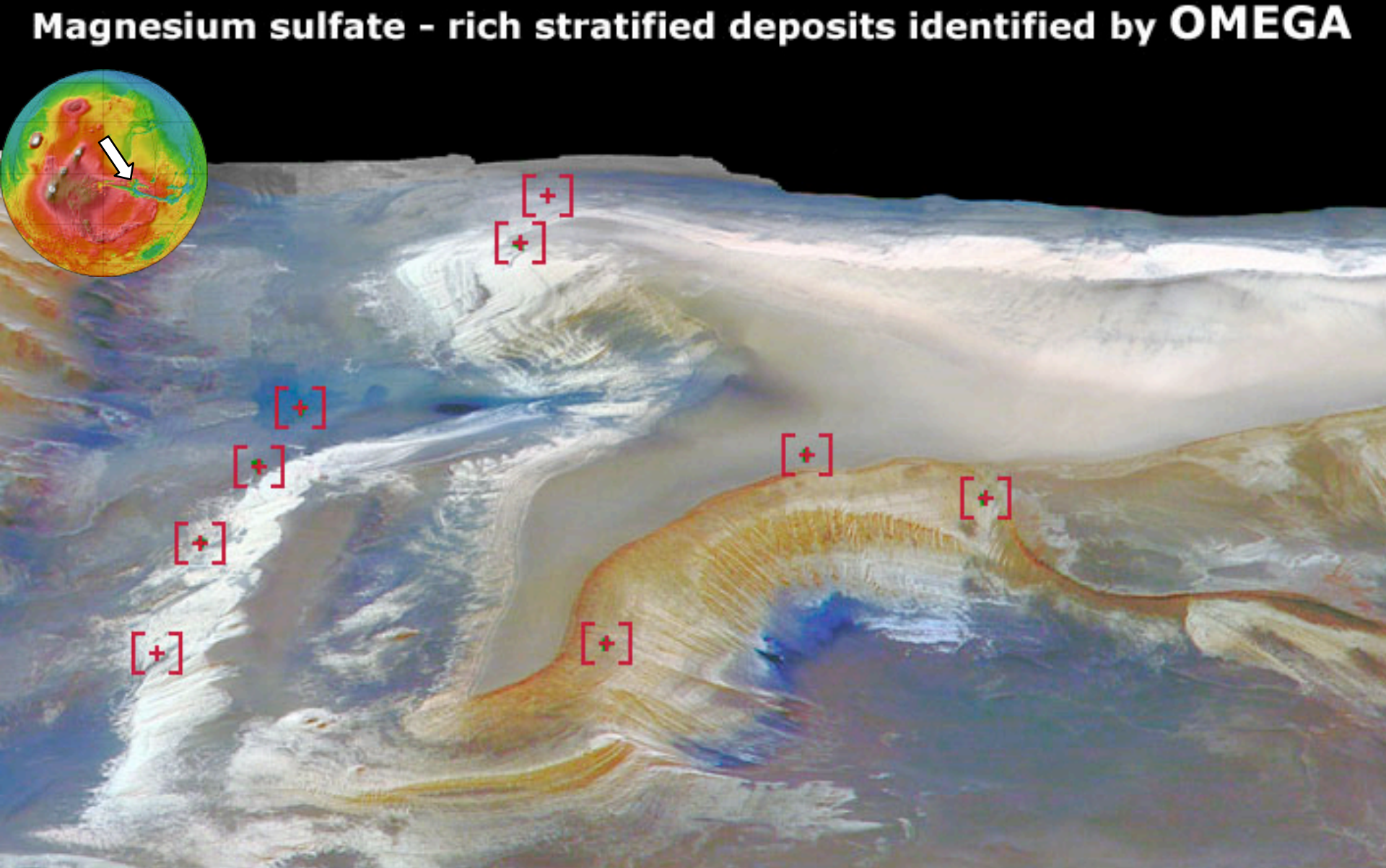
OMEGA detected: hydrated clays



The OMEGA instrument on Mars Express has shown that the violent outflows that sculpted the Marwth Vallis on Mars did not form nor flood with hydrated minerals (left). However, their erosion exposed ancient terrains in which hydrated clay minerals were detected, which trace back an early era with liquid water (right).

Credits: ESA/OMEGA/HRSC

Magnesium sulfate - rich stratified deposits identified by OMEGA

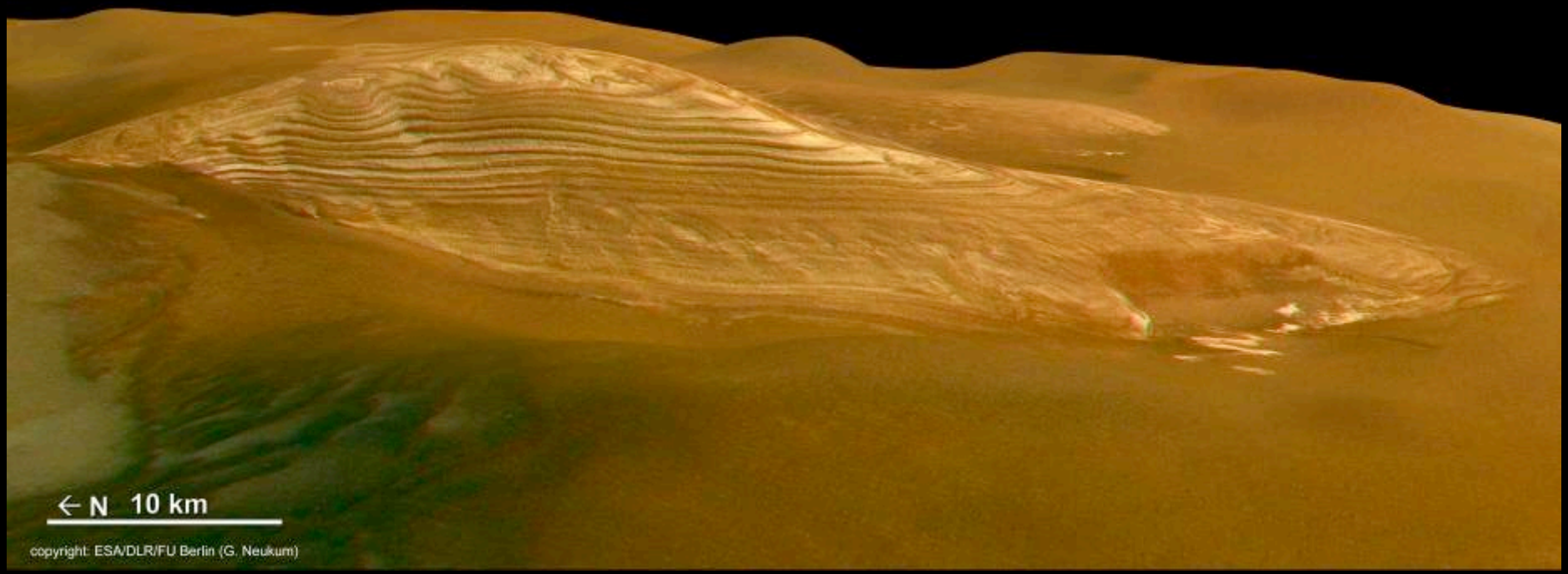


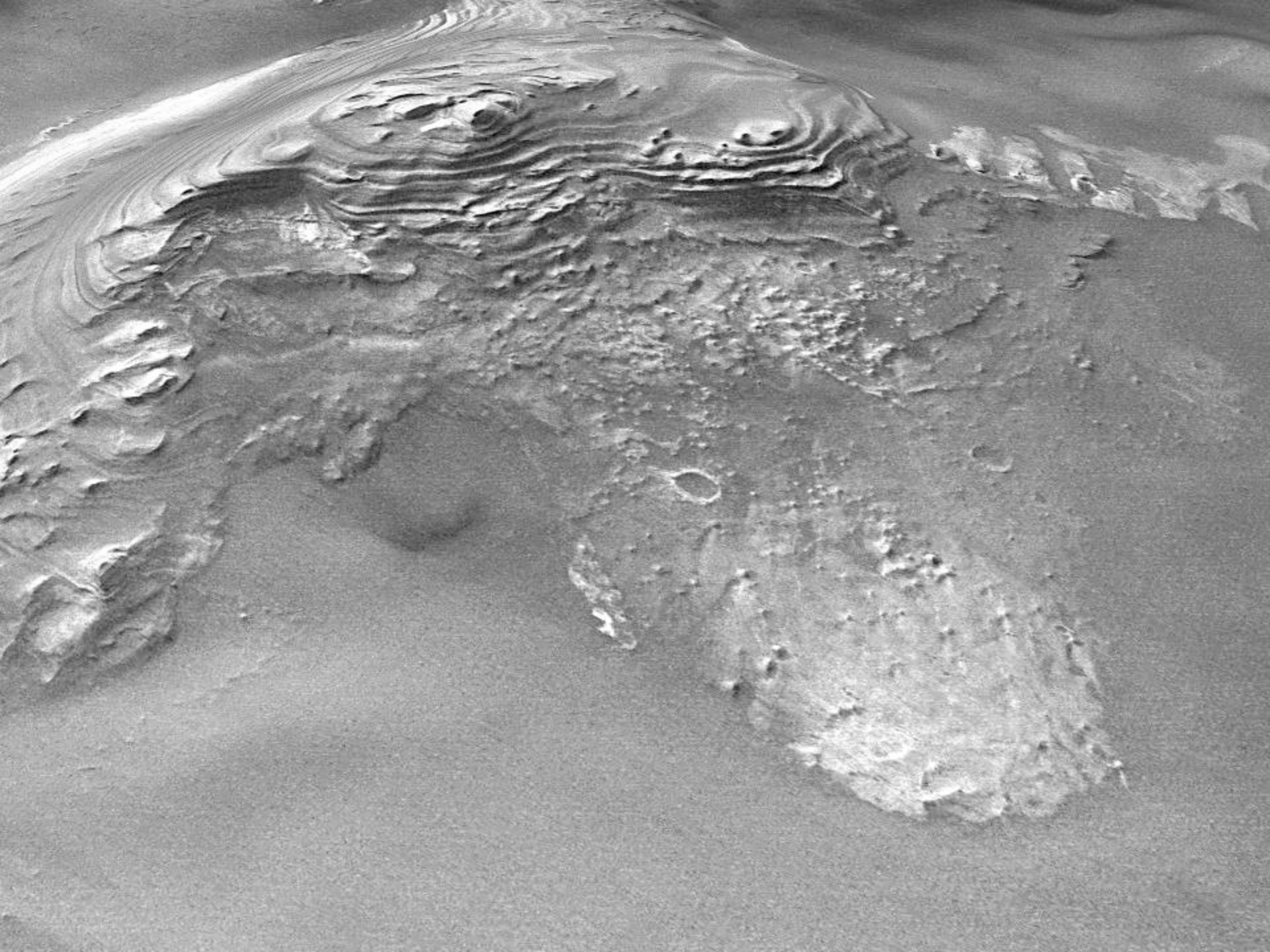
An HRSC 3-D perspective view of Candor Chasma (in false colors) characterised by the infrared images of OMEGA. It shows bright and brown deposits (red markers) that are rich in the mineral kieserite, a hydrated magnesium sulphate.

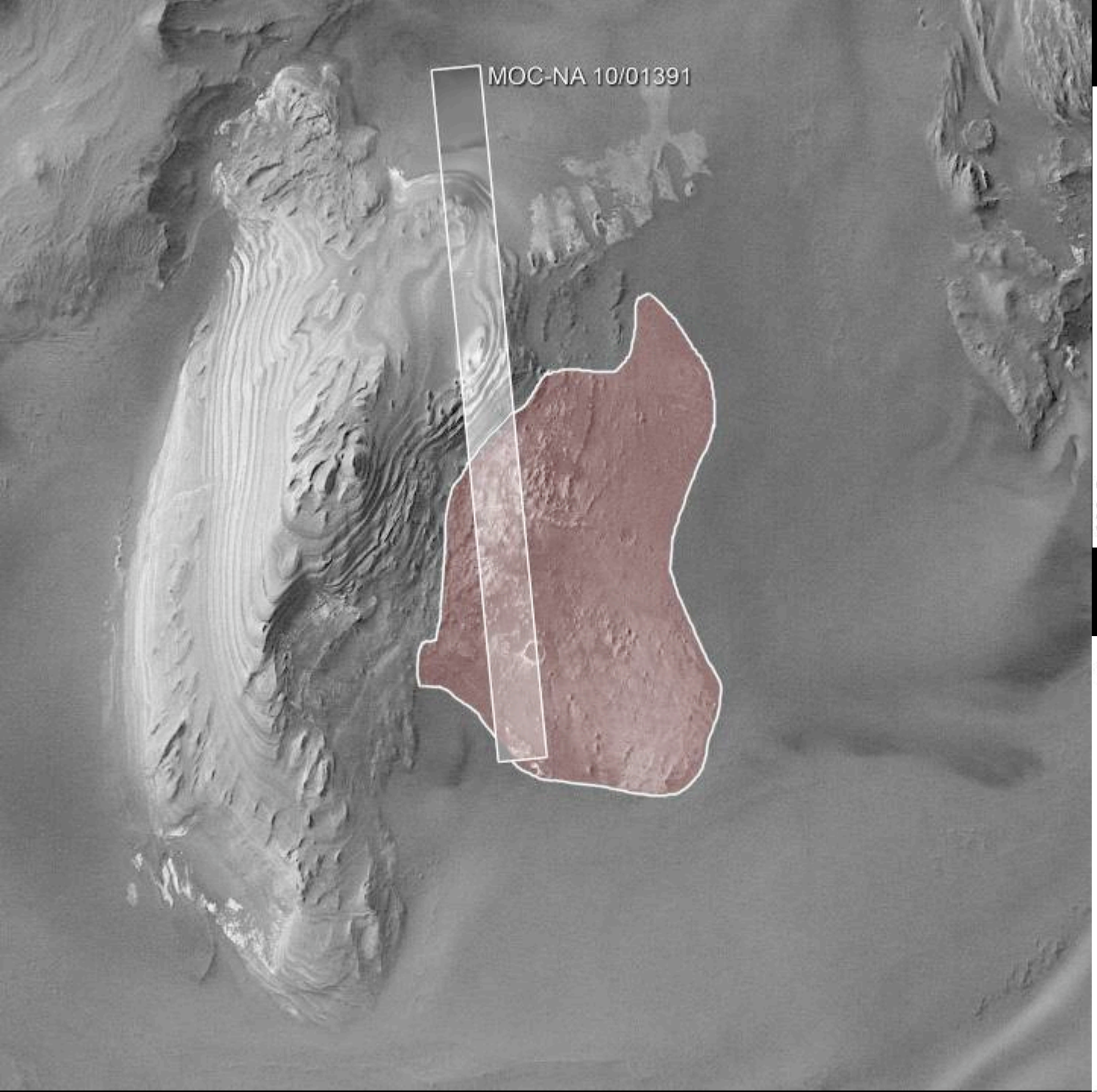
Credits: ESA/OMEGA/HRSC

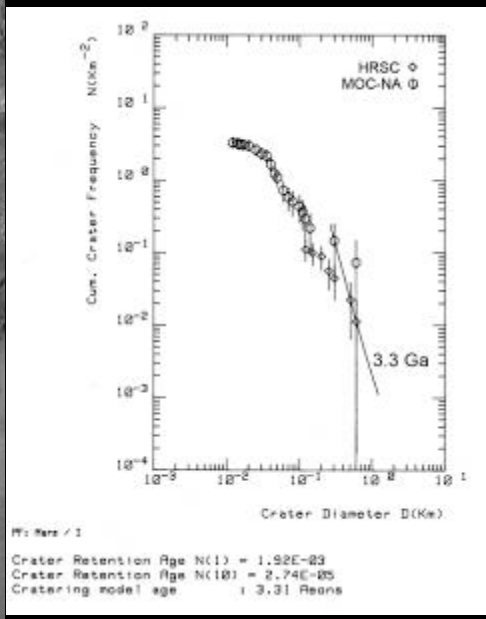
The Sulfate Mountain in Juventae Chasma

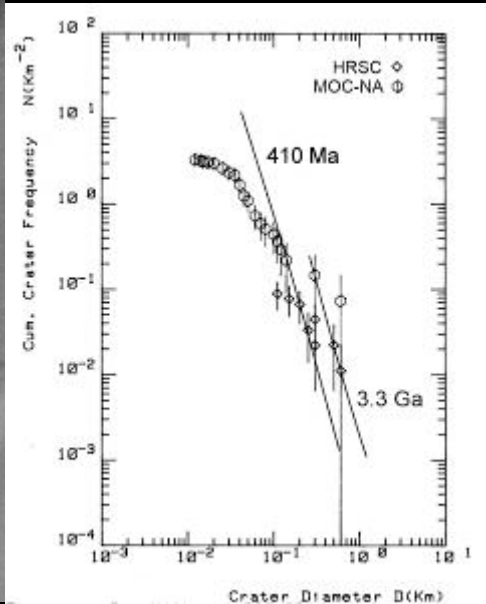
Orbit 0243 / 1070 Juventae Chasma



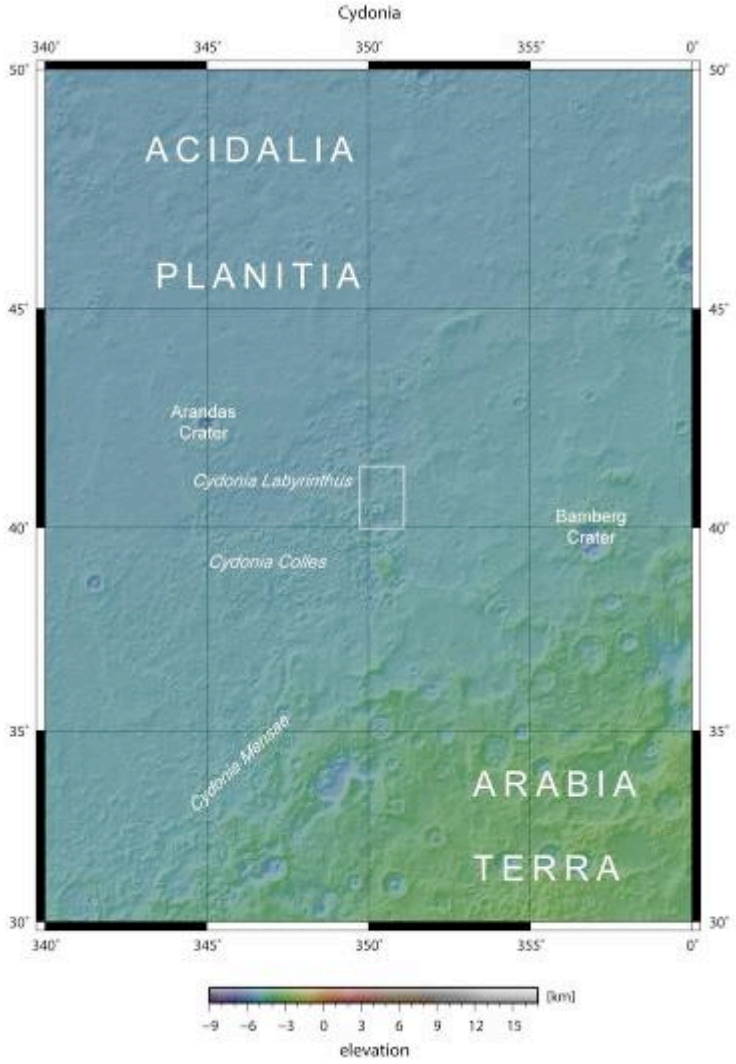


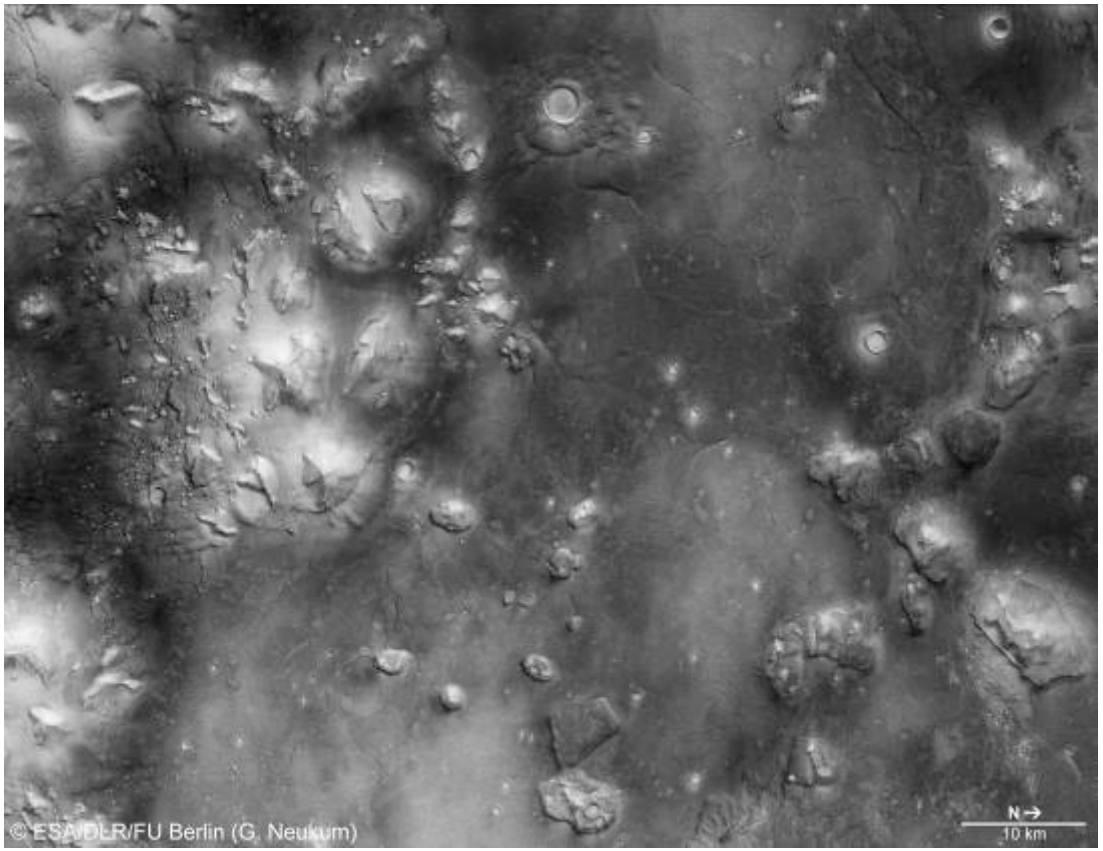

MOC-NA 10/01391

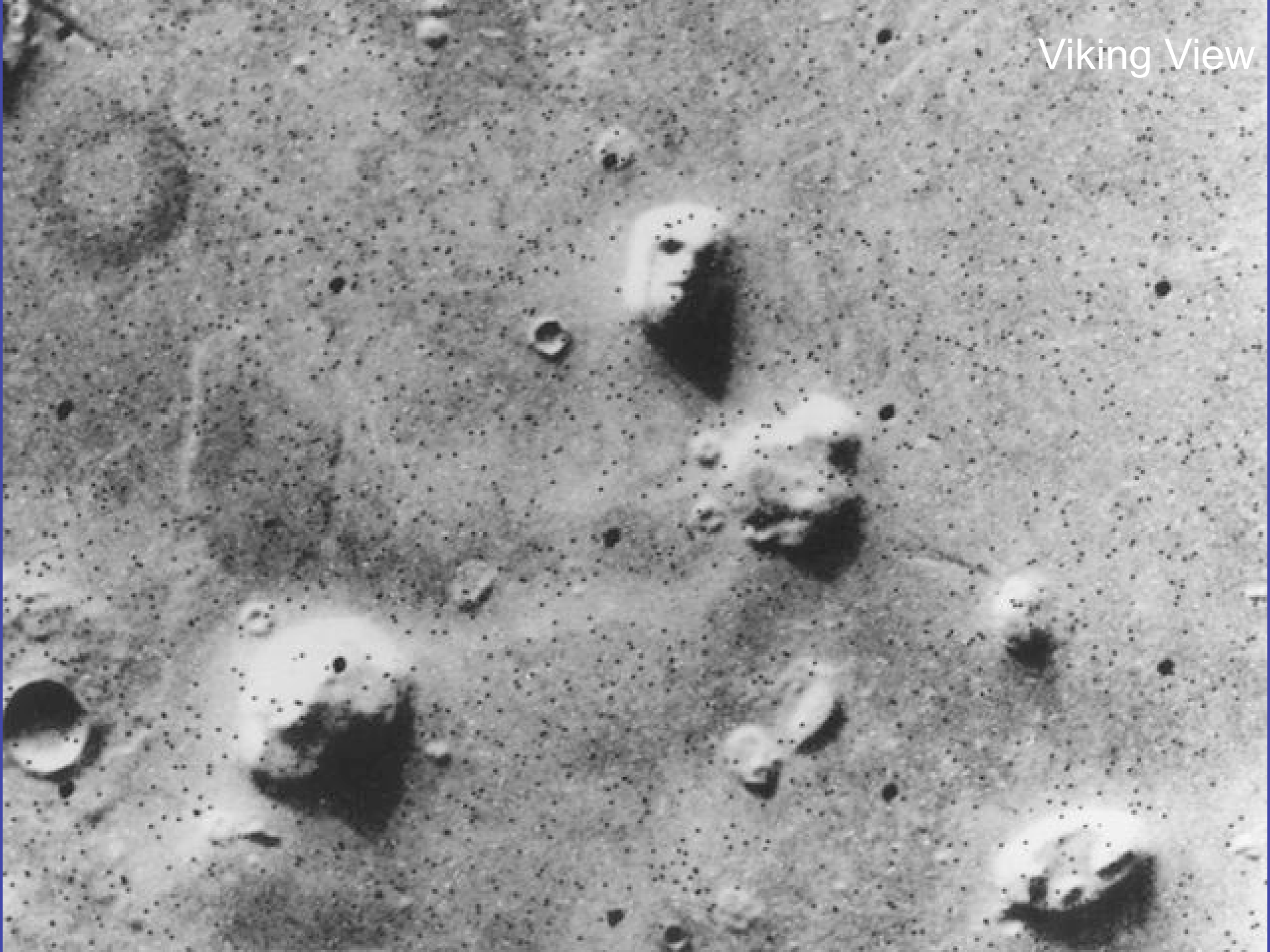

HRSC ◇
MOC-NA Φ
3.3 Ga
Cum. Crater Frequency N(Km⁻²)
Crater Diameter D(Km)
Crater Retention Age N(1) = 1.92E-03
Crater Retention Age N(10) = 2.74E-05
Cratering model age : 3.31 Aeons

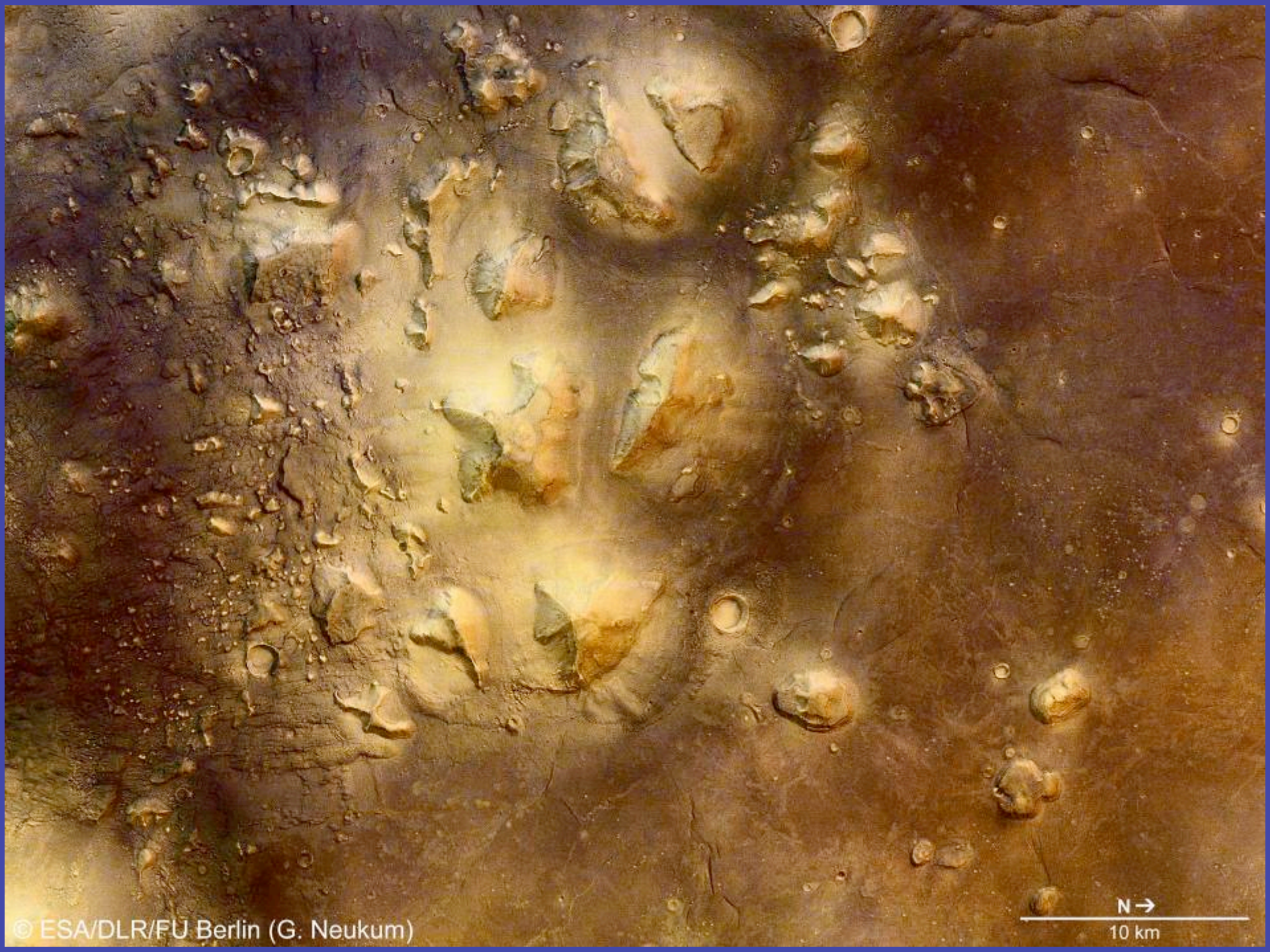

HRSC ◇
MOC-NA Φ
410 Ma
3.3 Ga
Cum. Crater Frequency N(Km⁻²)
Crater Diameter D(Km)

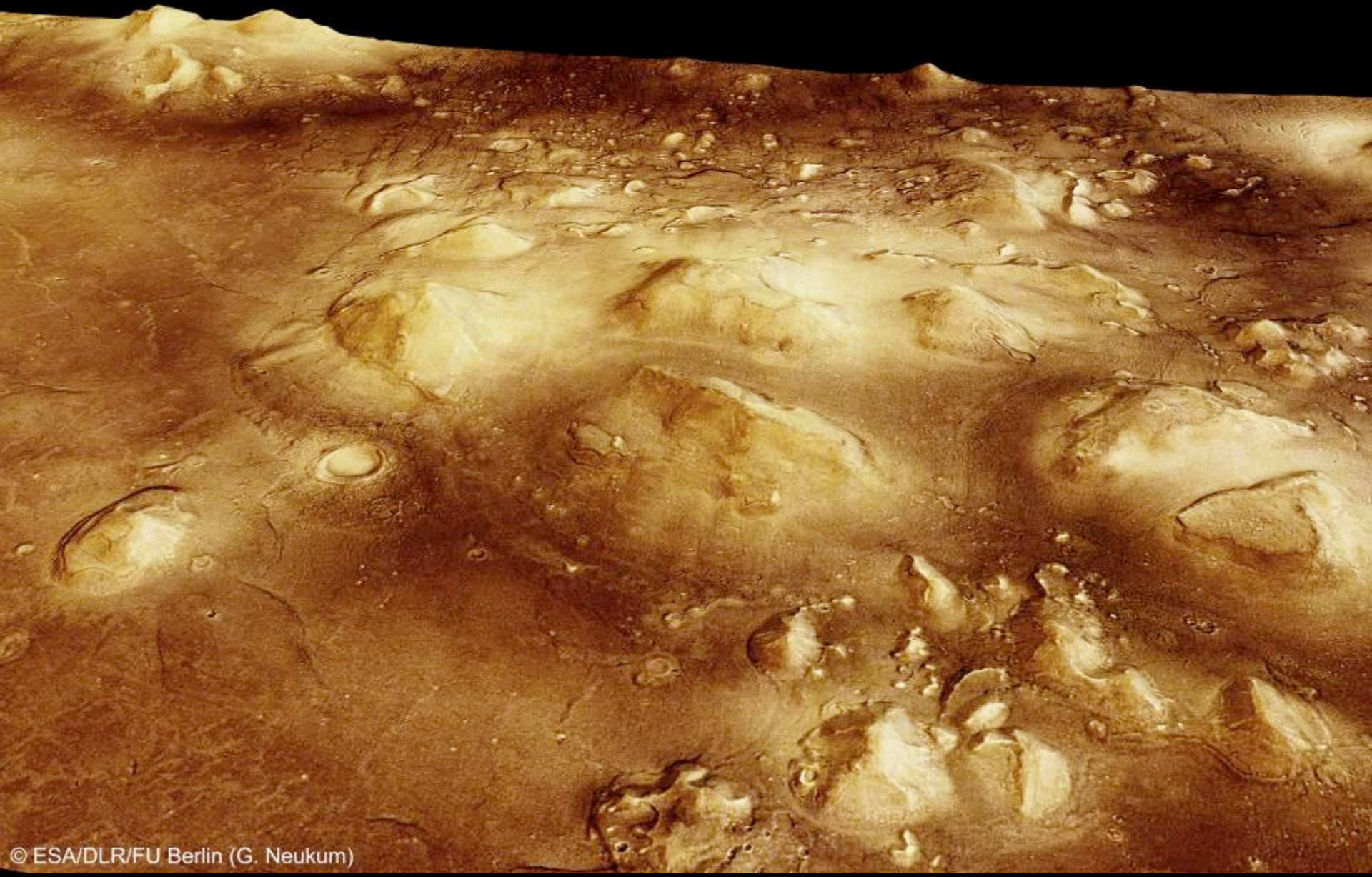
Cydonia
The Face on Mars



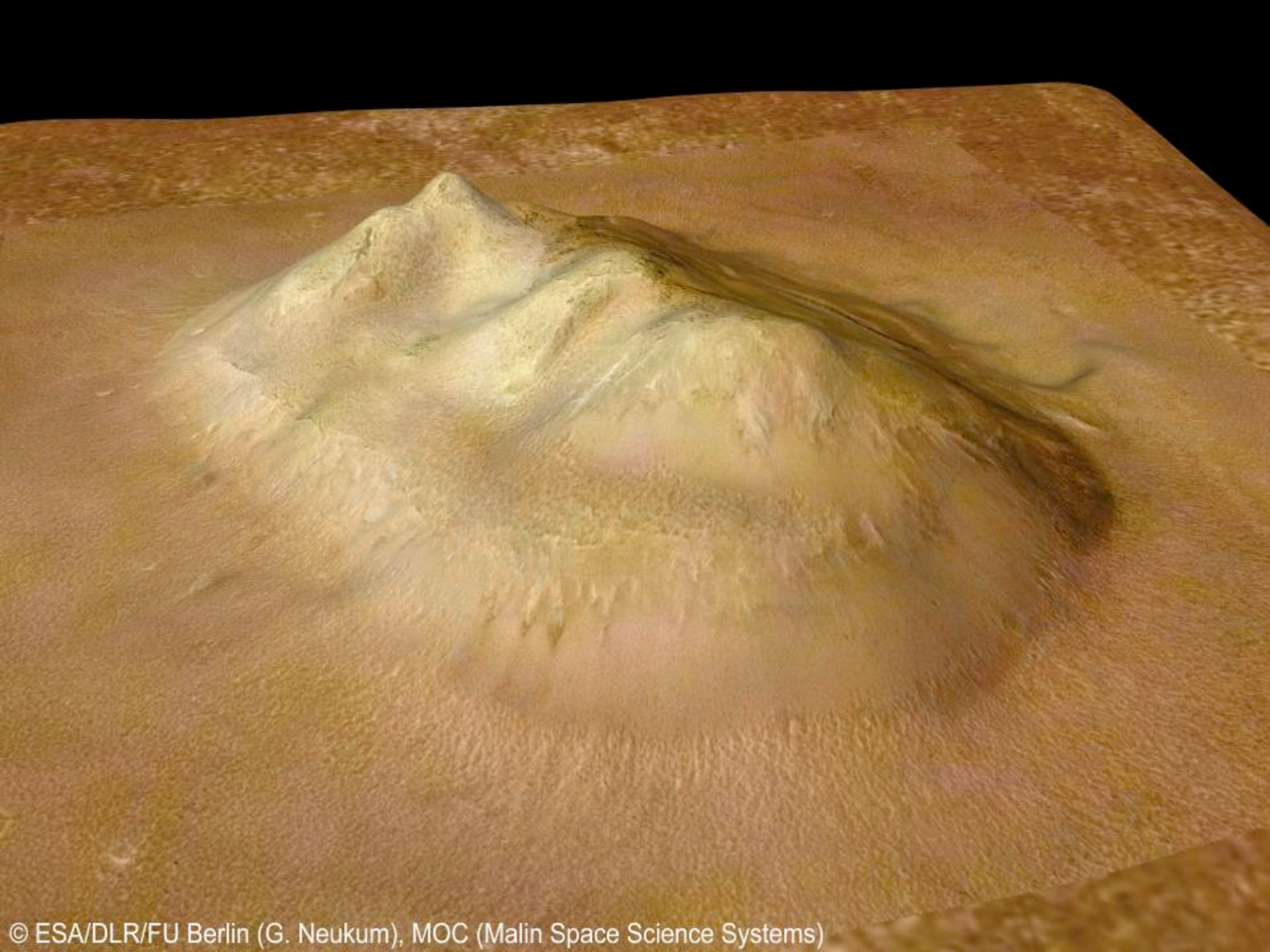


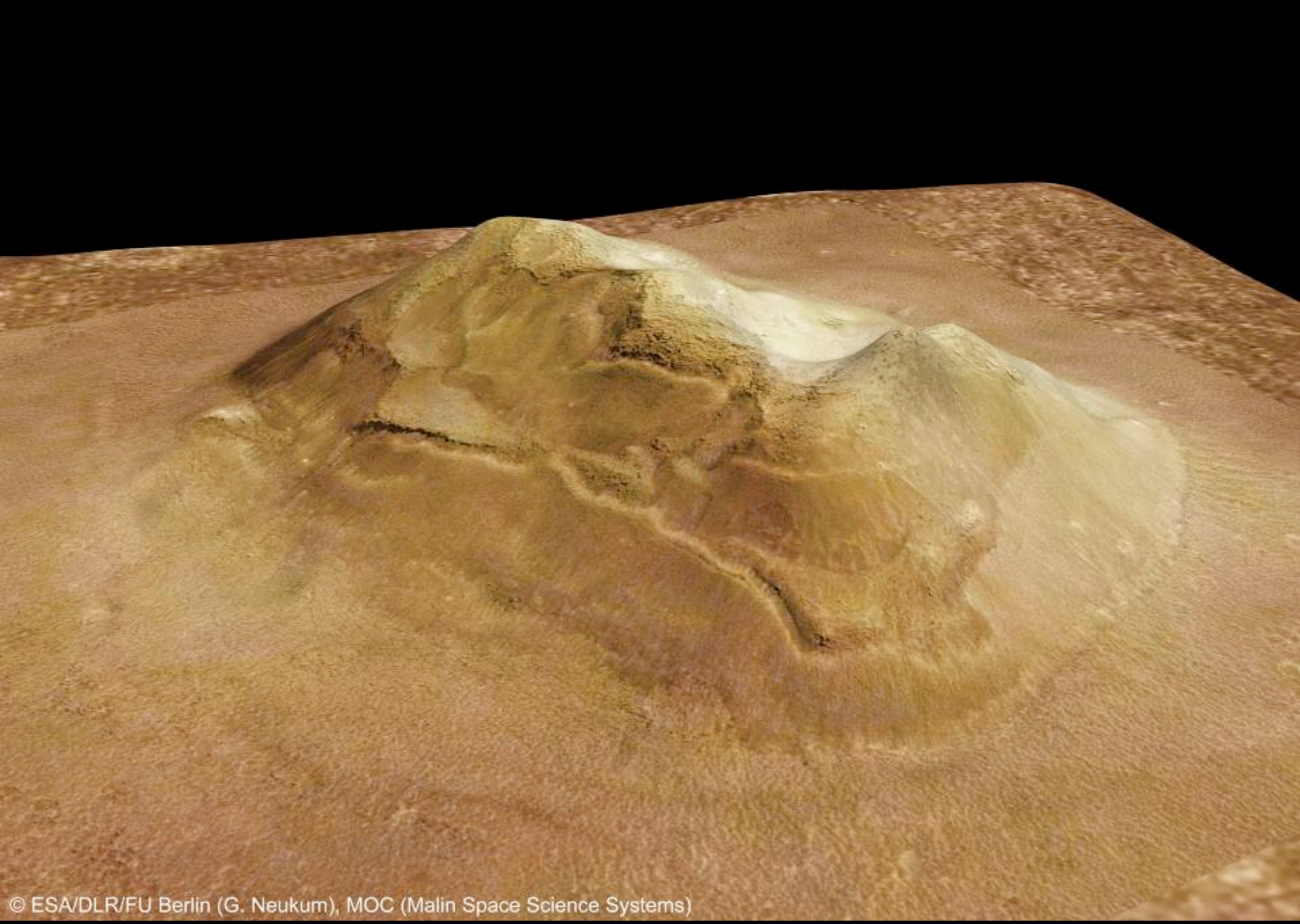

Viking View

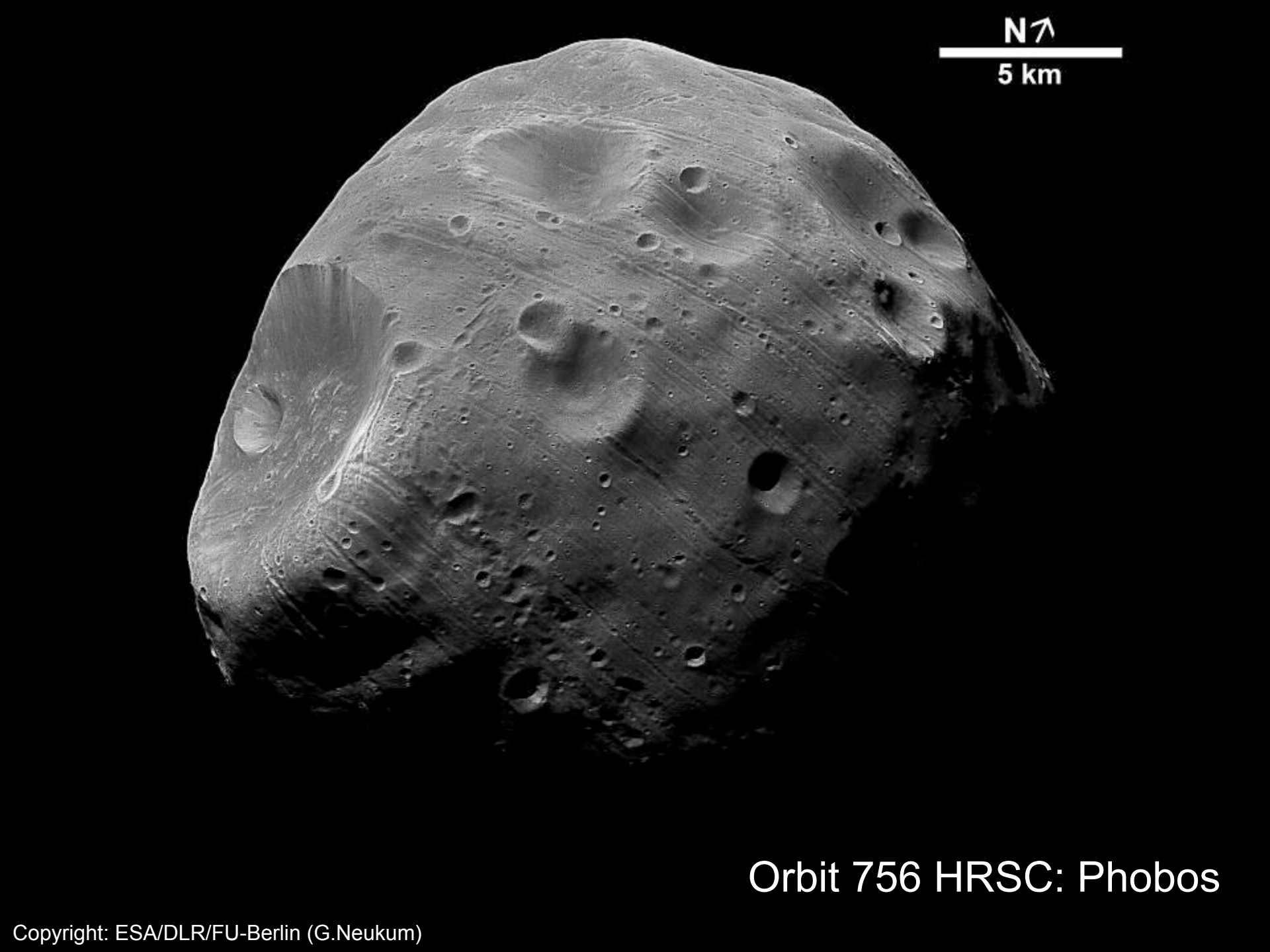



© ESA/DLR/FU Berlin (G. Neukum)


© ESA/DLR/FU Berlin (G. Neukum)

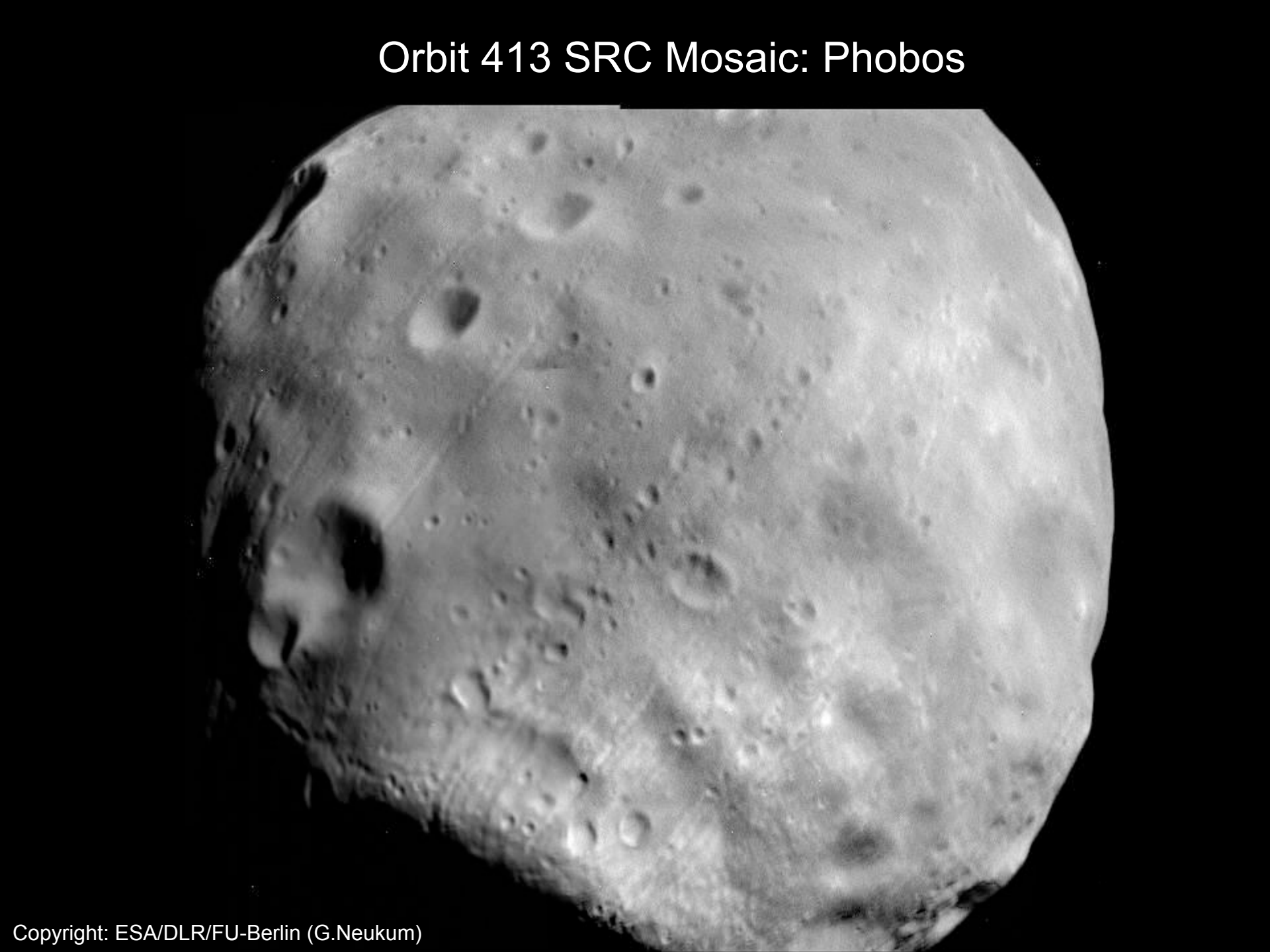

© ESA/DLR/FU Berlin (G. Neukum), MOC (Malin Space Science Systems)


© ESA/DLR/FU Berlin (G. Neukum), MOC (Malin Space Science Systems)

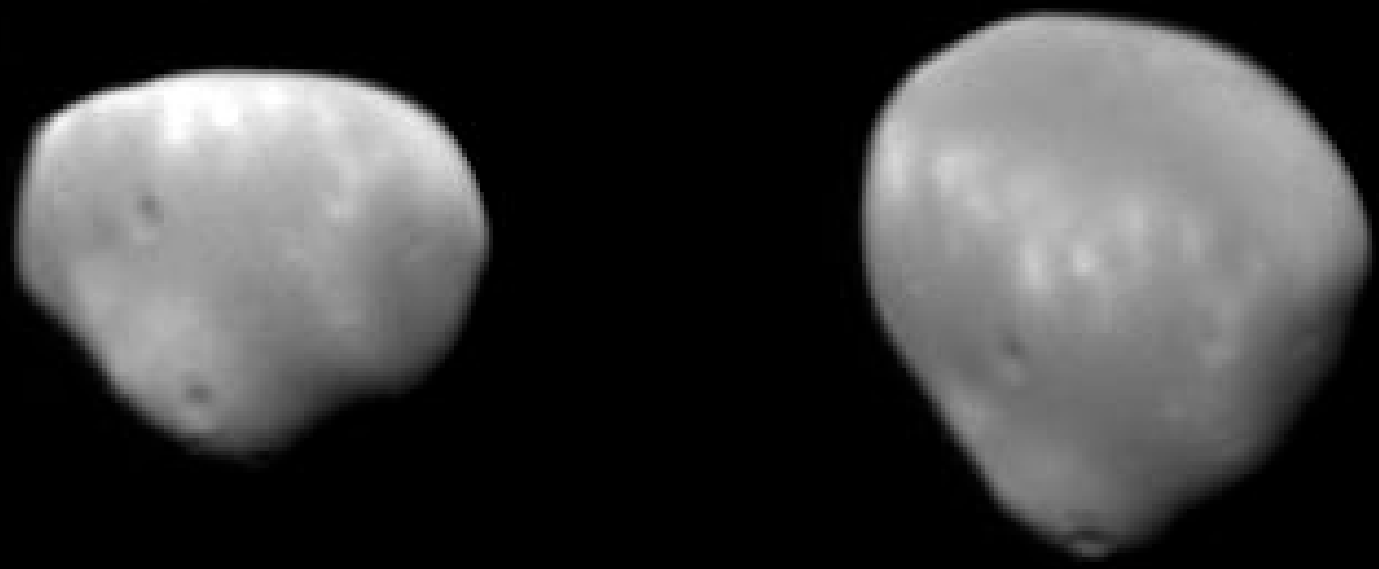


Orbit 756 HRSC: Phobos

Orbit 413 SRC Mosaic: Phobos

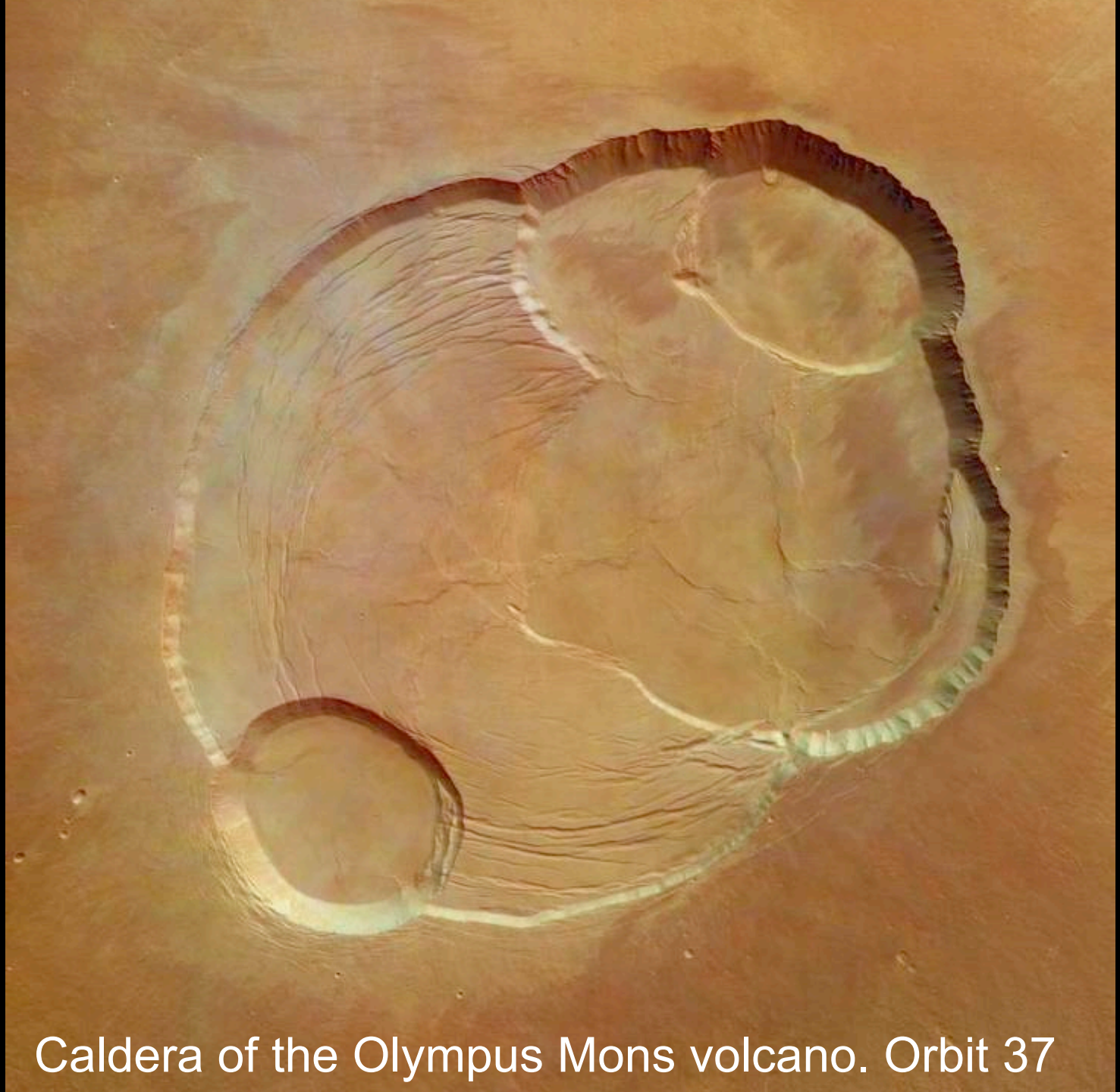


Deimos (SRC)

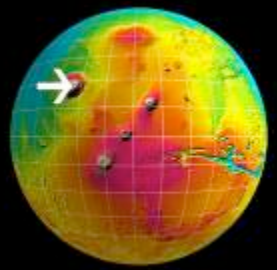


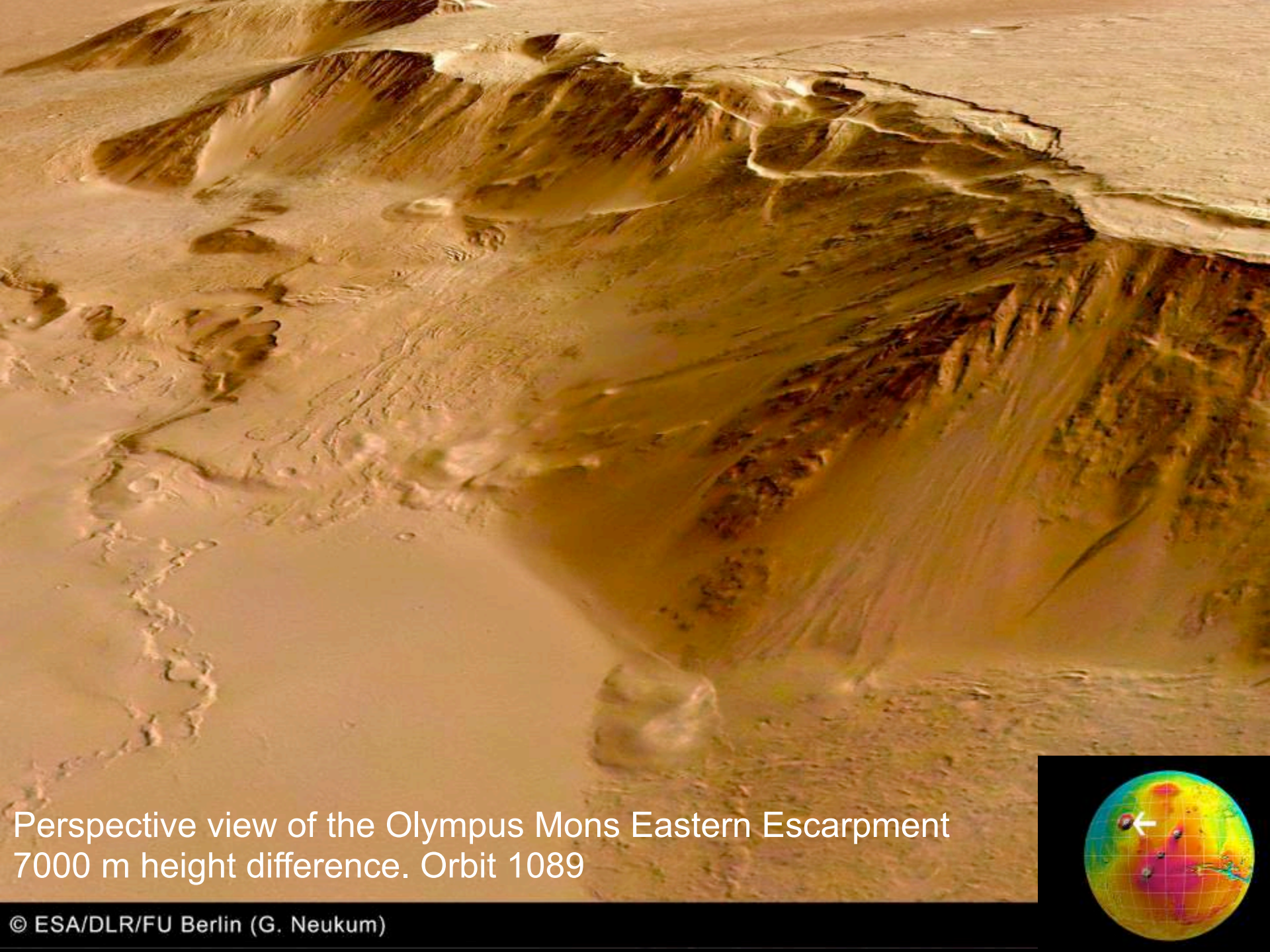
#1222

#1010

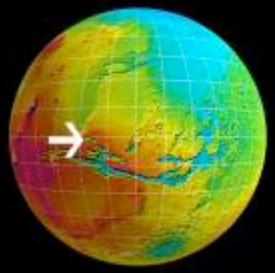


Caldera of the Olympus Mons volcano. Orbit 37

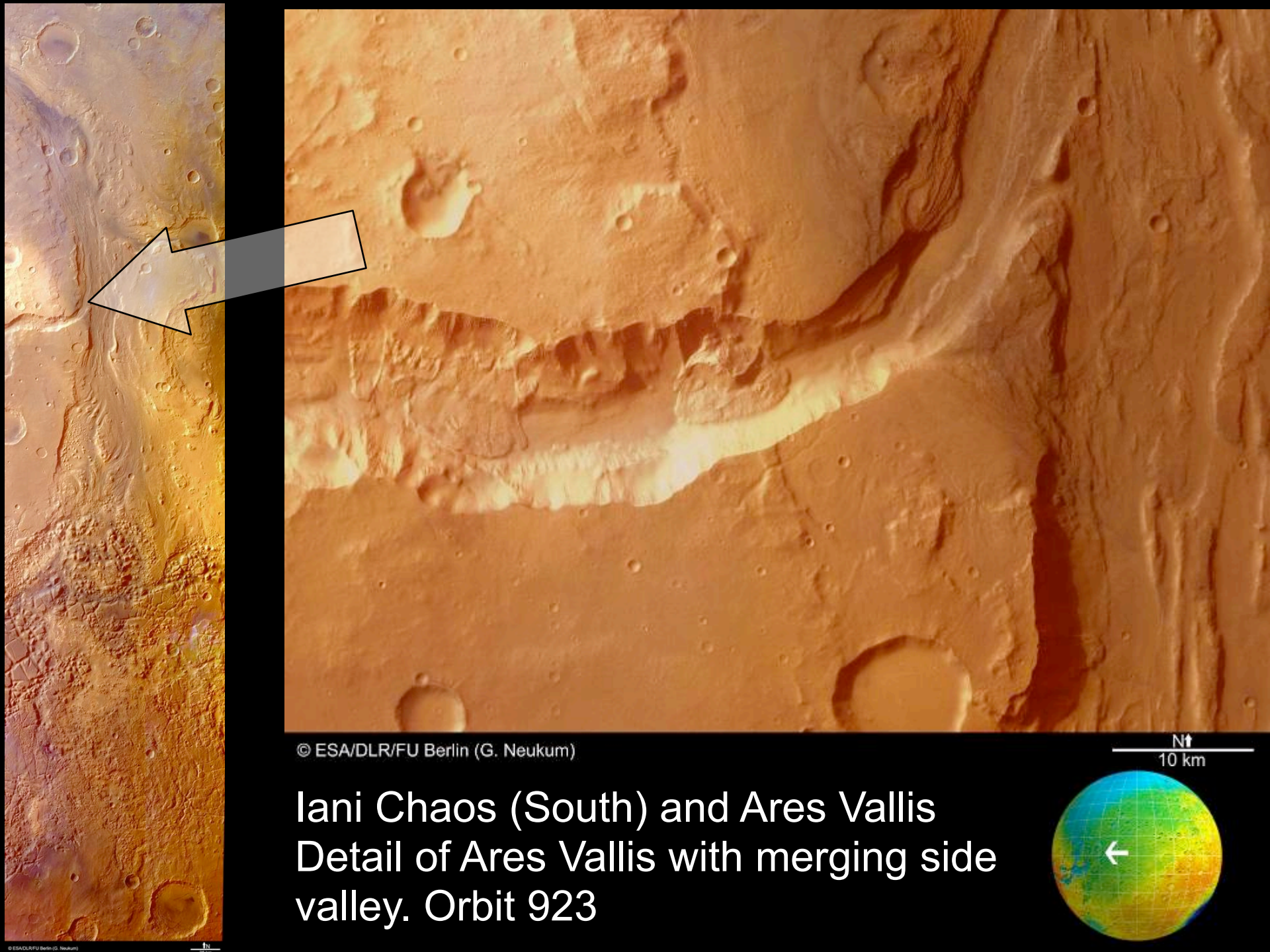




Perspective view of the Olympus Mons Eastern Escarpment
7000 m height difference. Orbit 1089

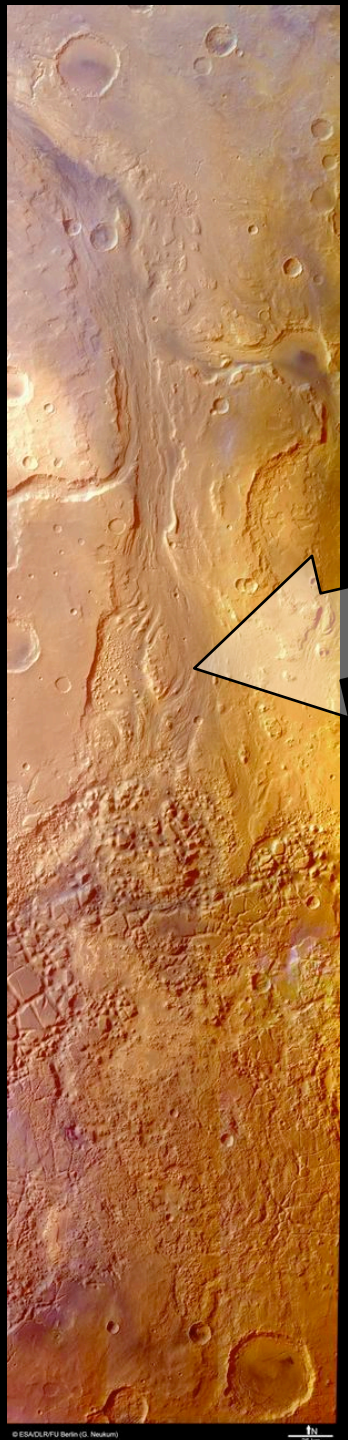


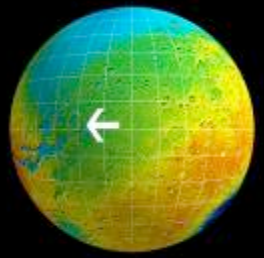
False color view of Hebes Chasma. (Detail) Orbit 2138
Image processing: E. Hauber, DLR

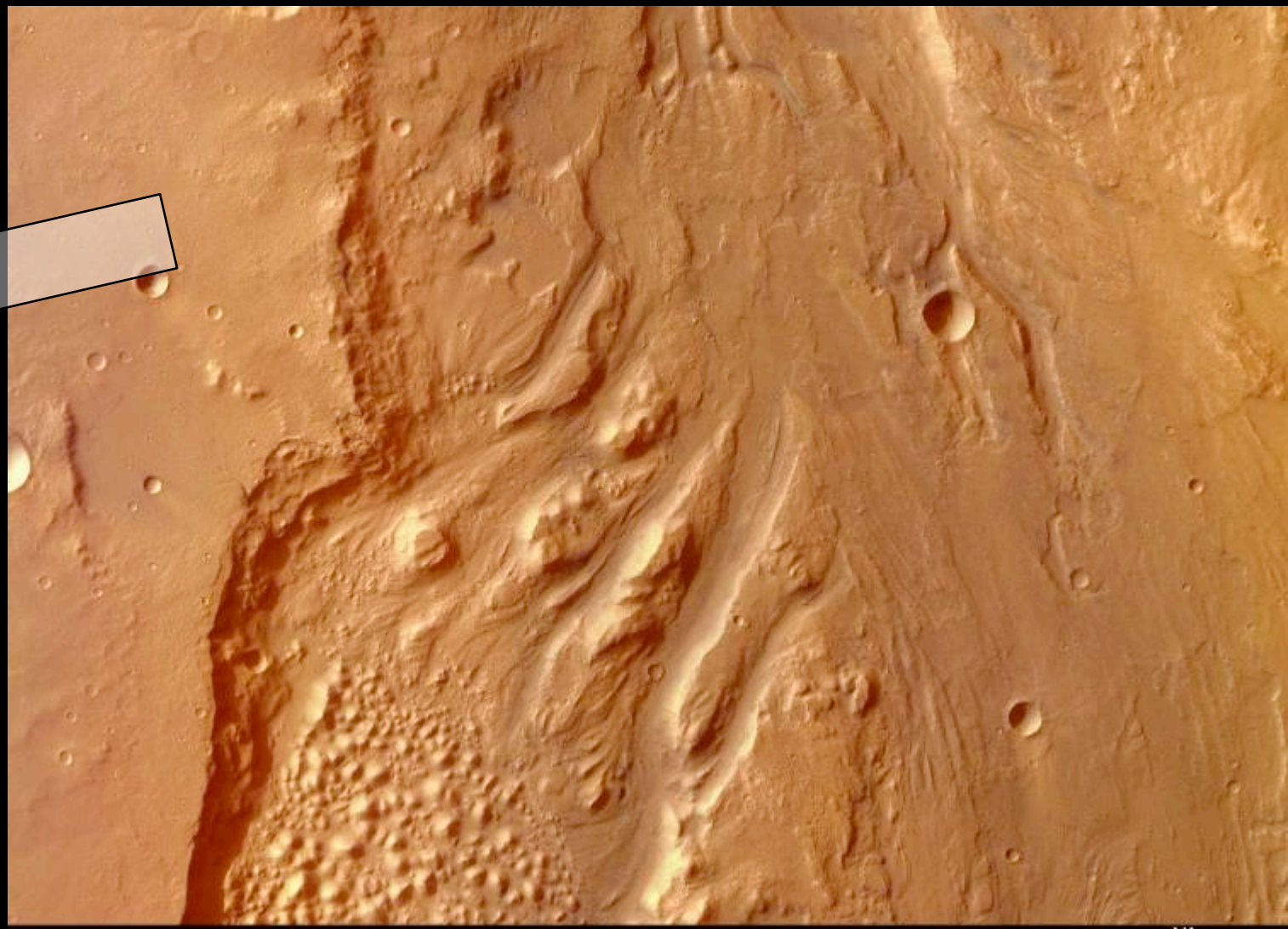


Iani Chaos (South) and Ares Vallis
Detail of Ares Vallis with merging side valley. Orbit 923

Iani Chaos (South) and Ares Vallis
Detail of Iani Chaos with erosional feature indicating massive outflow of water.
Orbit 923

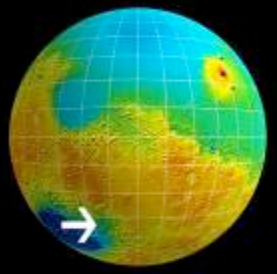




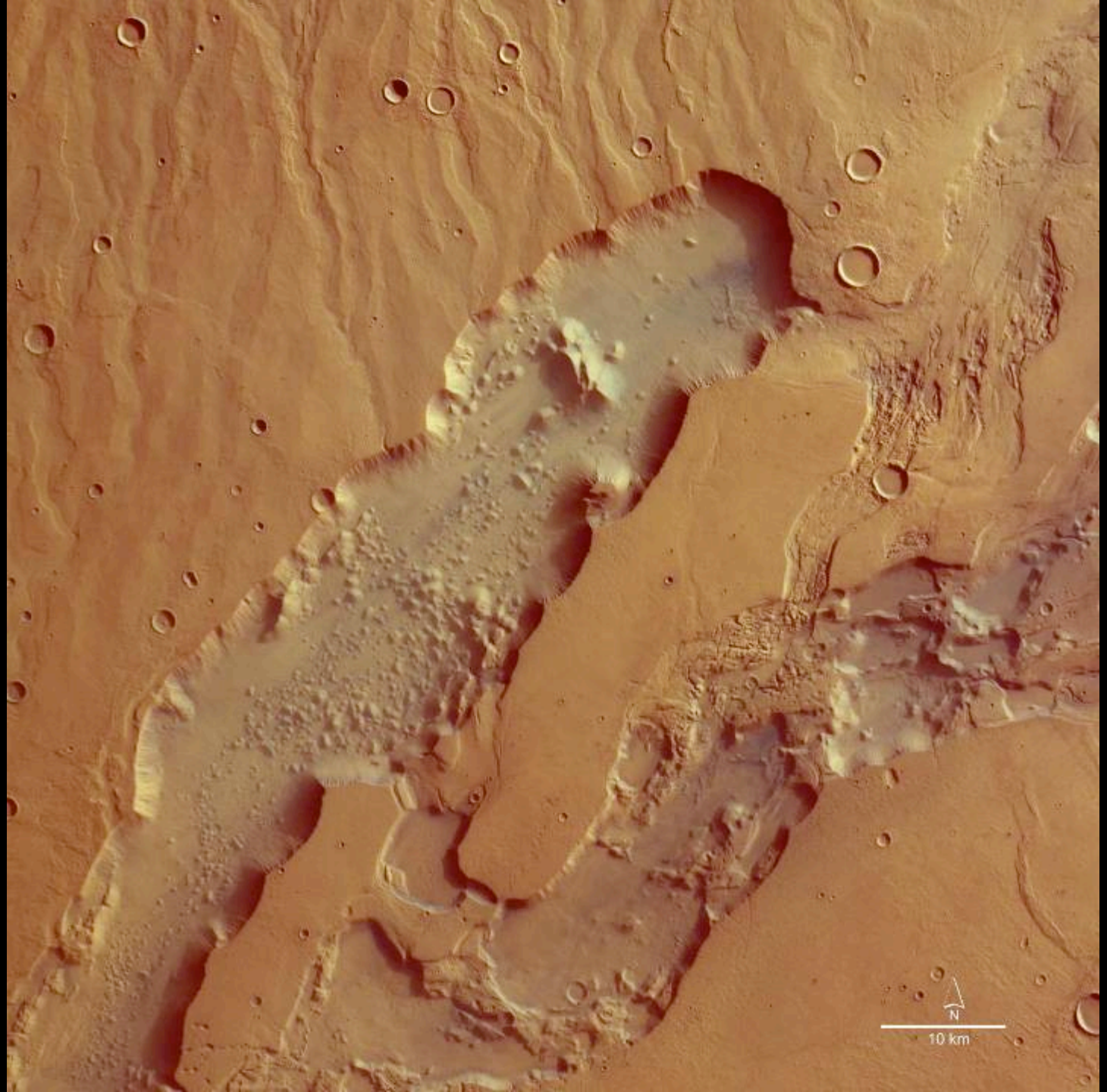


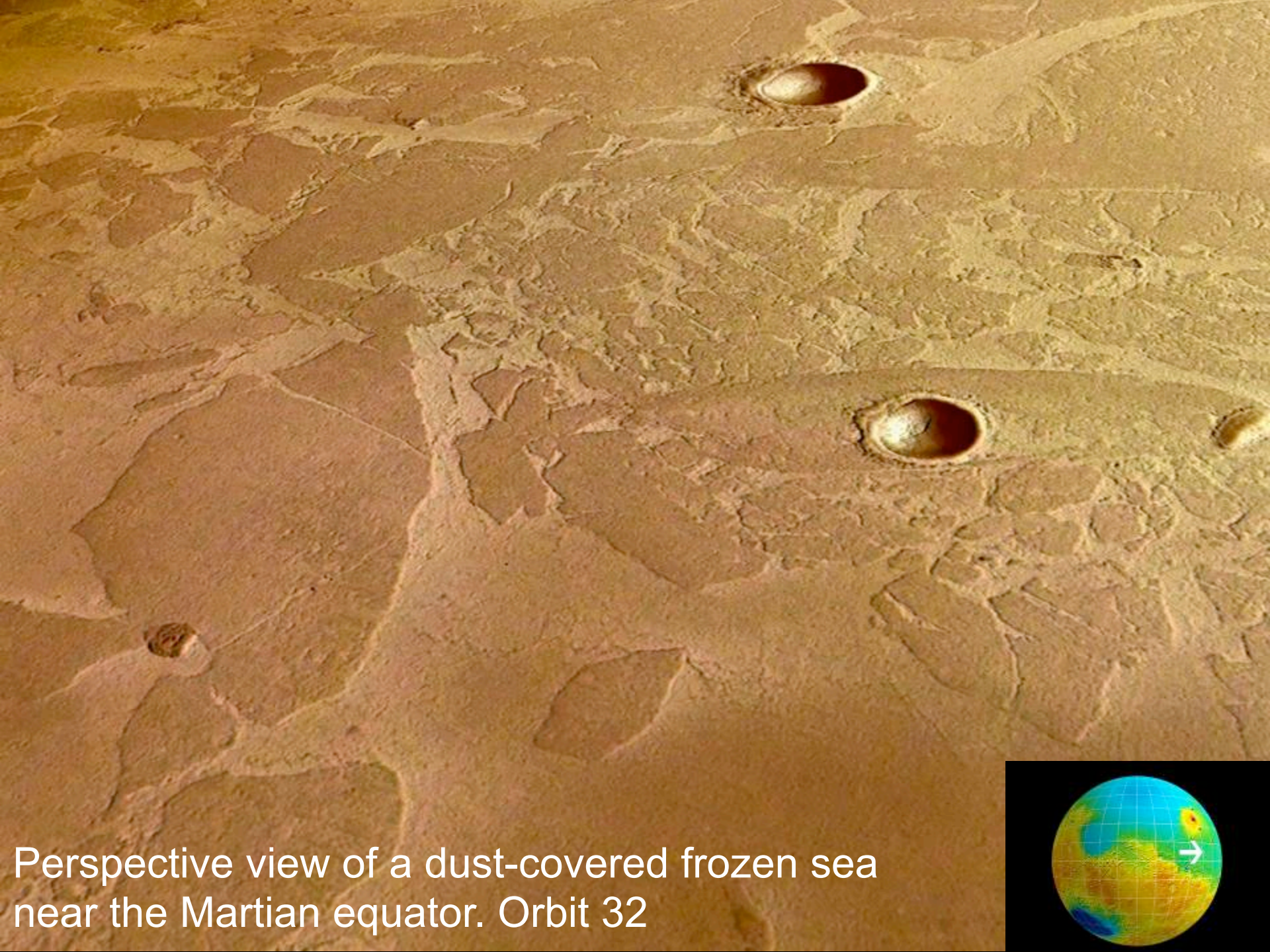
N
10 km

Perspective view of details of the outflow channel Mangala Valles. Orbit 286

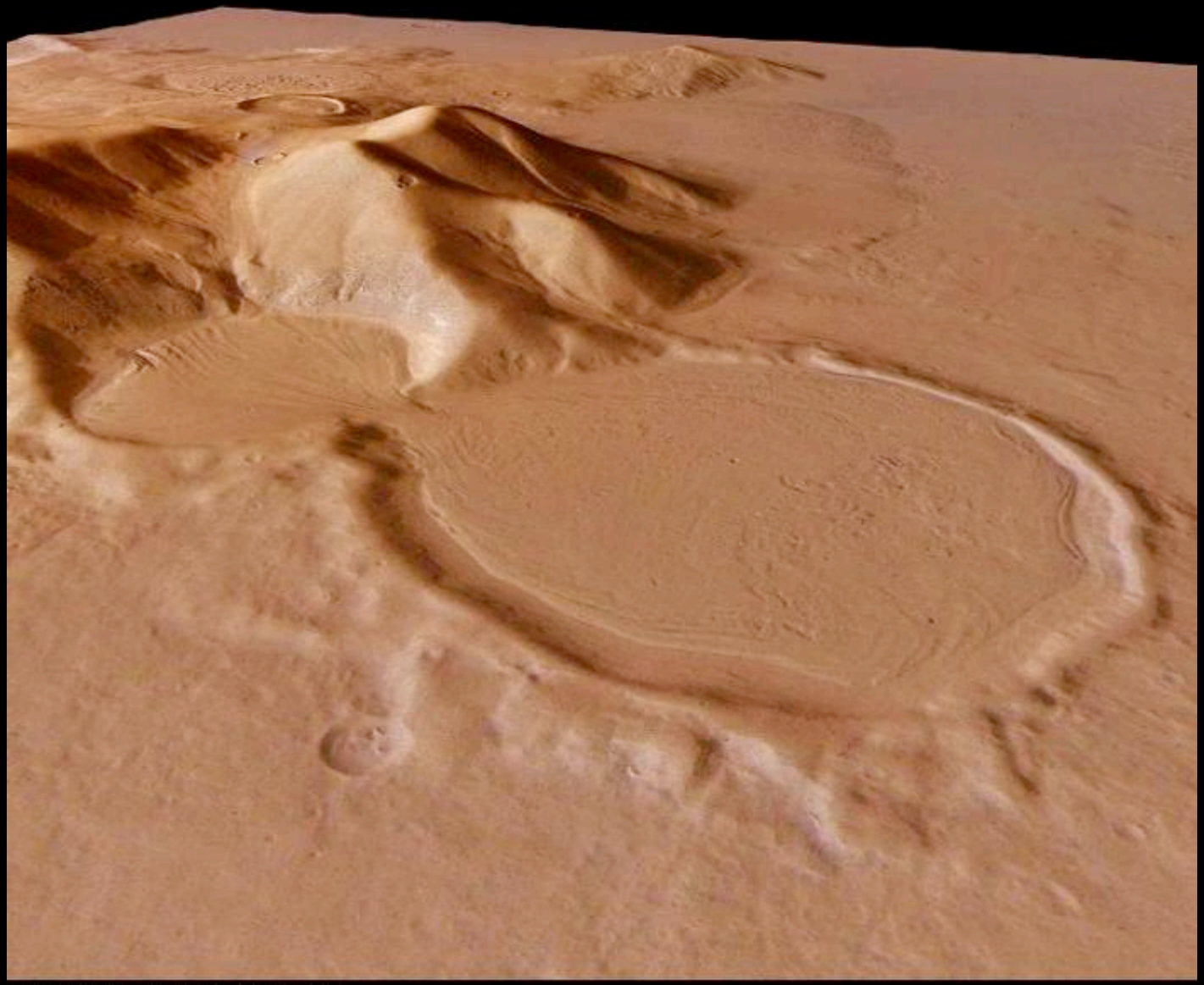


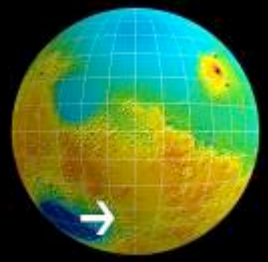
Dao and Niger Vallis outflow-channel systems located northeast of the Hellas Basin. Orbit 528



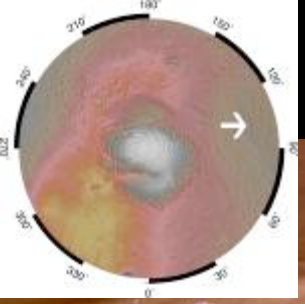


Perspective view of a dust-covered frozen sea near the Martian equator. Orbit 32





Perspective view of the "hour-glass" crater.
Orbit 451



Perspective view showing residual water ice on the floor of Vastitas Borealis Crater. Orbit 1343

Perspective view of feature at the floor of Nicholson Crater. Orbit 1106