North Pole

Layers of Ice and Dust

Cliffs Almost 2 km High

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

Up to 600 m high

Volcanic Activity Appears to be Very Recent, Possibly Ongoing
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
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.

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).
Recent Water and Ice/Glaciers

Hecates Tholus
Olympus Mons
"Frozen Sea" & Athabasca Valles
Hourglass Crater
Hellas Montes
Kasei Valles
Highland-Lowland Boundary Glaciers

200 – 4 Ma
190 – 30 Ma
300 – 5 Ma
~ 5 Ma
100 – 50 Ma
~ 20 Ma
?? Ma

Hauber et al.; Head et al.; Murray et al. (2005) Nature;
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

Ancient Fluvial and/or Glacial Activity

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

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)
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

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
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
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
Libya Montes

last discharge < 1.2 b.y.

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
Echus Chasma

**MOC E06/00116**

- **~3.3 Ga & younger**
- **~0.1 Ga**
- **~1.6 Ga**
- **~0.9 Ga**
- **3.5; ~1.6 Ga & younger**
- **~0.7 Ga**
- **~3.0 Ga**
- **~3.6 Ga & younger**
- **~0.55 Ga**
- **~1.7 Ga**
Echus Plateau
Orbit 2204

Map by M. G. Chapman
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

Lava sheet: 2.6 Gyr old

Lava sheet: 1.3 Gyr old
emplaced right after the ice was gone

Glacial grooves: 1.3 Gyr old
End of major glaciation

© ESA/DLR/FU Berlin (G. Neukum)
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

3.3 Ga
730 Ga
670 Ma (resurf.)
1.4 Ga
3.6 Ga
450 Ma

10 km
Figure: Histogram of ages extracted from measurements on HRSC and MOC imagery in the Echus Chasma/Kasei Valles and Mangala Valles.
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
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
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
Cydonia
The Face on Mars
Orbit 413 SRC Mosaic: Phobos
Caldera of the Olympus Mons volcano. Orbit 37
Perspective view of the Olympus Mons Eastern Escarpment
7000 m height difference. Orbit 1089

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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

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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