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Hot Idea posted January 31, 2005

Recent Activity on Mars: Fire and Ice

--- New images from Mars Express show evidence of recent volcanic and glacial activity on Mars, consistent with what we know from Martian meteorites and previous evaluations of the planet's internal heat production and climate.

Perspective View of Complex Caldera of Olympus Mons

Image from ESA/DLR/FU Berlin (G. Neukum)

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Scientists combined the time-honored method of counting craters to estimate the age of planetary surfaces with brand new high-resolution, stereo images of Mars to reassess the planet's recent volcanic and glacial activity. Gerhard Neukum (Freie Universität, Berlin, Germany) and colleagues from Germany, United States, Russia, and the United Kingdom studied calderas on five major volcanoes and the shield of Olympus Mons with the High Resolution Stereo Camera (HRSC) on the European Space Agency's Mars Express Spacecraft to try to determine the duration of geologic activity more precisely than had ever been done before. Their work confirms that the Tharsis and Elysium regions were volcanically active over billions of years, that caldera eruptions were episodic but were especially numerous 100 to 200 million years ago, and that the most recent lava flows on Mars may be as young as two million years. Their findings are consistent with previous studies of Mars Global Surveyor data as well as Martian shergottite meteorites that suggest intermittent magmatism from 165 to about 500 million years ago. Neukum and coauthors also report the most recent phase of glacial activity on Olympus Mons was within the past four million years. So recent are these events in geologic time that the researchers speculate high-altitude, insulated ice deposits may be present on Olympus Mons even now and that volcanoes might still be active.

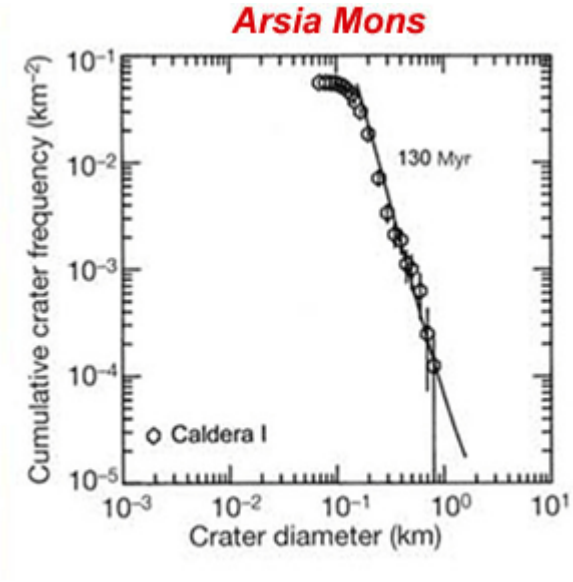
Reference:

- Neukum, G., Jaumann, R., Hoffmann, H., Hauber, E., Head J. W., Basilevsky, A. T., Ivanov, B. A., Werner, S. C., van Gasselt, S., Murray, J. B., McCord, T., and the HRSC Co-investigator team (2004) Recent and episodic volcanic and glacial activity on Mars revealed by the High Resolution Stereo Camera. *Nature,* v. 432, p. 971-979.

New Ages

The High-Resolution Stereo Camera (HRSC) co-investigator team targeted the summit calderas of five major shield volcanoes and the flanks of Olympus Mons, known sites of relatively recent volcanic activity. They defined specific terrain areas for counting craters using the 10 meters/pixel resolution images and the Super Resolution Channel's 2.5 meters/pixel resolution data along with nested Mars Orbiter Camera (MOC) images. Previous age determinations using the crater counting technique have been limited by poorer resolution or by the small areas imaged. For a short explanation of the crater counting technique visit the Planetary Science

Institute web page.

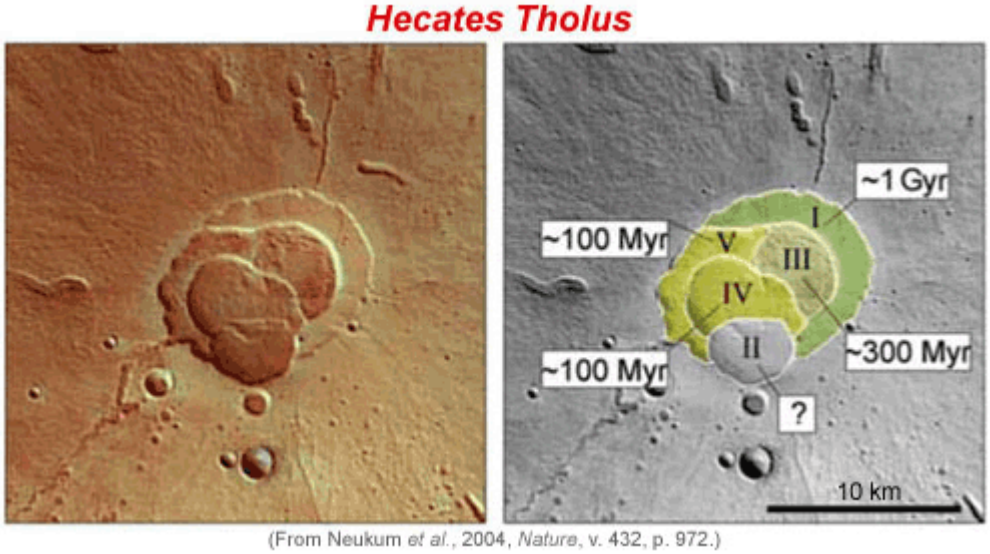


(From Neukum *et al.*, 2004, *Nature*, v. 432, p. 972.)

Crater size-frequency distribution for the caldera on Arsia Mons. Frequencies of craters per unit area were counted on the caldera floor and plotted against crater diameters to derive the absolute age of the surface at 130 million years old. Similar log-log plots were constructed for each summit caldera.

The HRSC team used the unified cratering chronology model published in 2001 by Neukum and colleagues Boris Ivanov (Russian Academy of Sciences, Moscow) and William Hartmann (Planetary Science Institute, Tucson, Arizona) that concluded craters on the Moon and Mars were created by the same family of projectiles and that the lunar cratering chronology could be transferred to Mars. The ages derived from the Martian crater counts are limited in accuracy, however. The main uncertainty is the statistical error arising from the number of craters counted (the error increases as age, hence the number of craters, decreases). There is also uncertainty in the underlying impact flux model used for Mars relative to the lunar value. In the team's study, errors are approximately 20% to 30% for derived absolute ages younger than 3 billion years and 100 to 200 million years for ages older than 3 billion years.

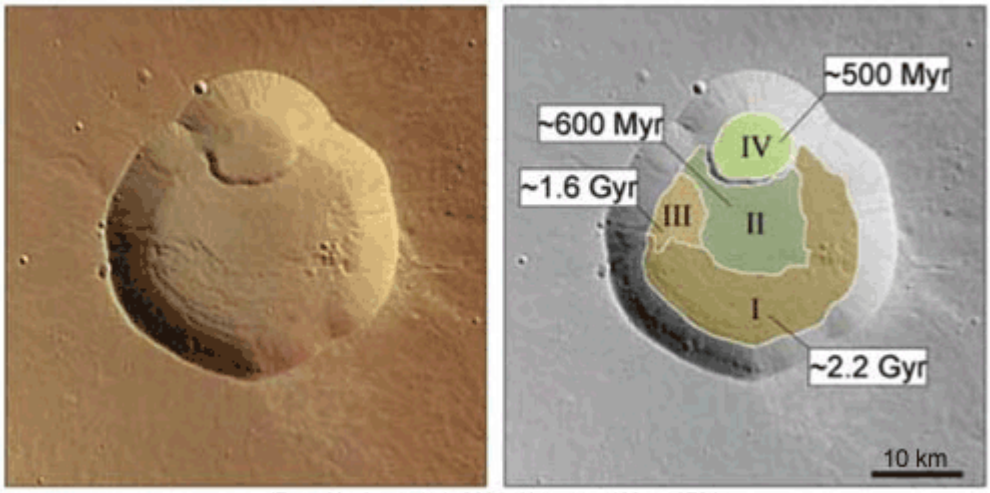
The images below show the five volcanic calderas examined in this study: Hecates Tholus, Albor Tholus, Arsia Mons, Ascraeus Mons, and Olympus Mons. In the left column are HRSC images of the five volcanic caldera complexes. They should appear as depressions (sun shining from the lower left corner). North is to the top of each image. In the right column are the crater-counting areas defined by Neukum and colleagues, which are labeled with their derived absolute ages.



(From Neukum *et al.*, 2004, *Nature*, v. 432, p. 972.)

Neukum and coauthors mapped five different caldera collapse events on Hectates Tholus with floors ranging in age from approximately 2 billion years old to about 100 milliion years old. [Additional images from ESA Mars Express.]

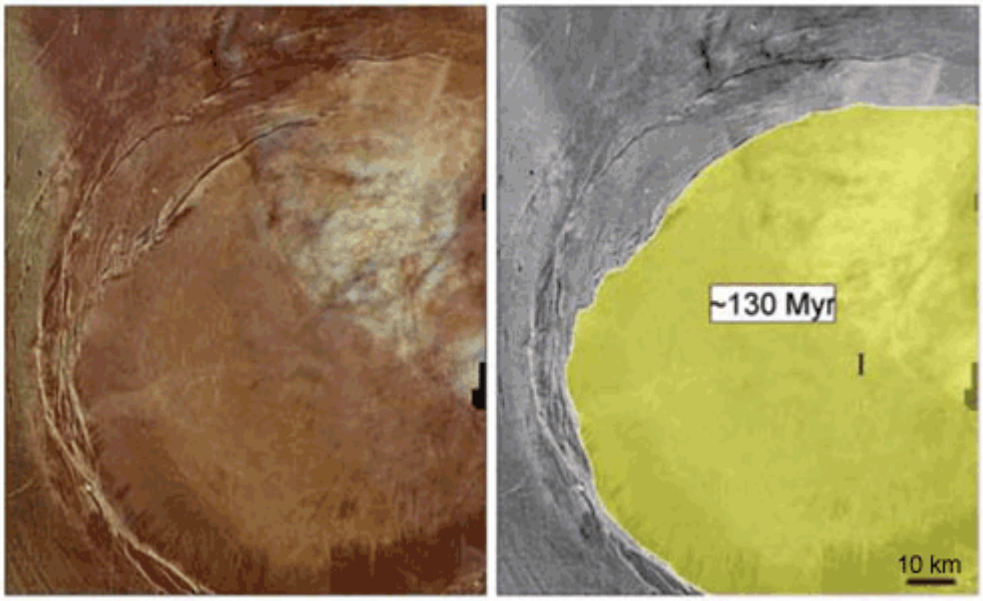
Albor Tholus



(From Neukum *et al.*, 2004, *Nature*, v. 432, p. 972.)

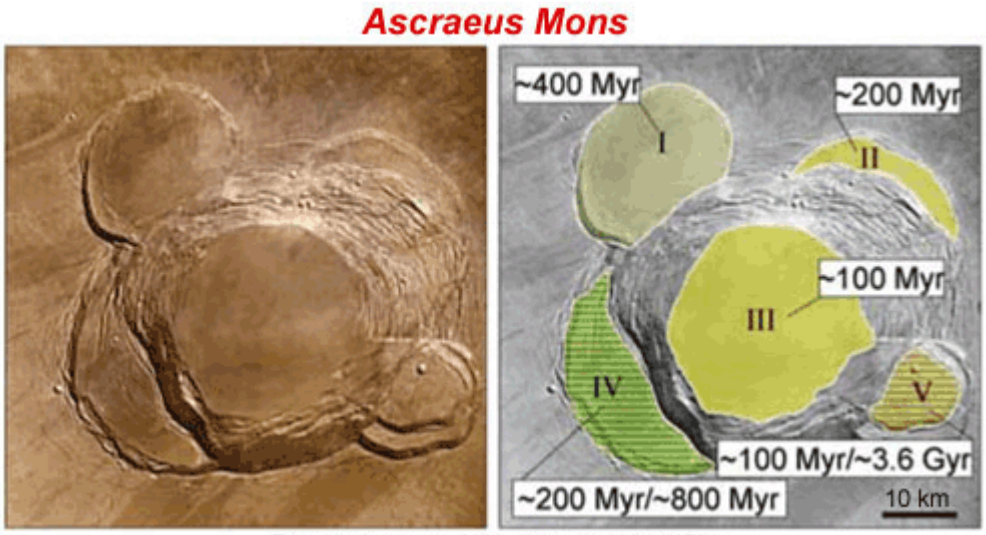
The four caldera floors mapped on Albor Tholus range in age from approximately 2.2 billion years old to about 500 million years old.

Arsia Mons



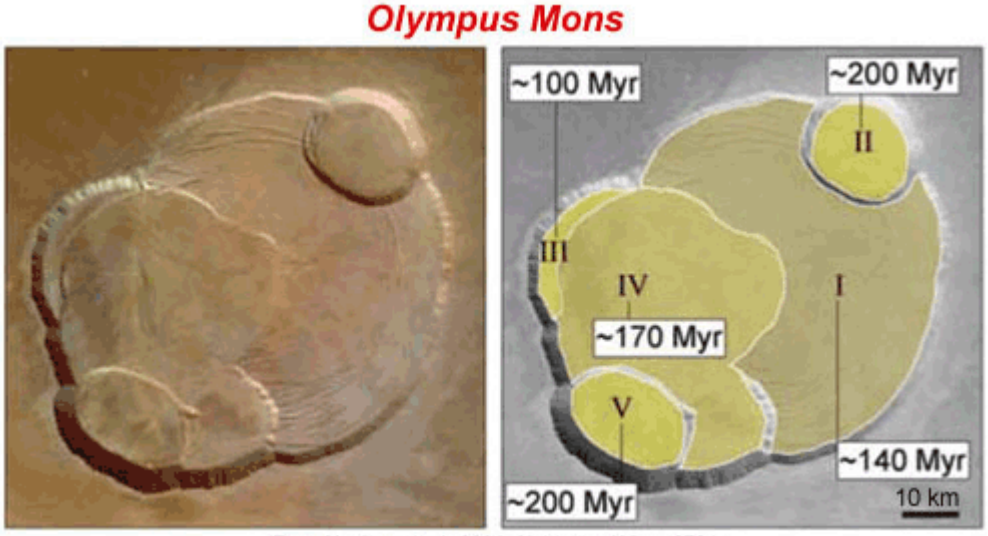
(From Neukum *et al.*, 2004, *Nature*, v. 432, p. 972.)

The summit of Arsia Mons is dominated by a single huge caldera. The floor is dated at about 130 millions years old.



(From Neukum *et al.*, 2004, *Nature*, v. 432, p. 972.)

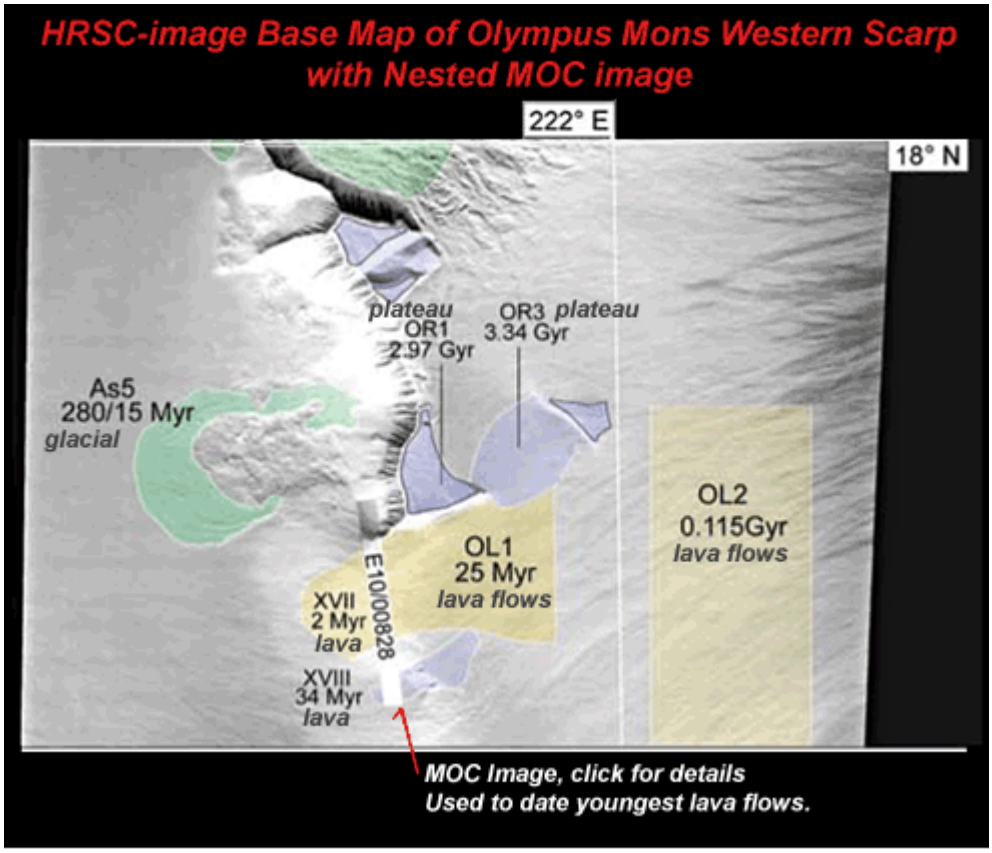
A large central caldera floor, dated at approximately 100 million years old, cuts adjacent caldera floors of various ages.



(From Neukum *et al.*, 2004, *Nature*, v. 432, p. 972.)

Olympus Mons is unusual by comparison with the other caldera complexes because the five caldera segments have ages clustering around 100 to 200 million years old. In the simplest stratigraphic sense, the top-most features are the youngest. However, the absolute ages assigned to the floors of the five calderas on Olympus Mons seem to defy this and some would argue against the validity of the assigned ages. Nevertheless, the researchers explain that since the different ages are very similar within the error limits of ± 50 million years, we must keep in mind that the formation of all the calderas on Olympus Mons could have happened in a short time span around 150 million years ago. [Additional information and high resolution images from ESA Mars Express.]

The image below shows an area of the western scarp of Olympus Mons where sparsely cratered lava flows were reexamined with the HRSC and MOC images.



(ESA/DLR/FU Berlin and MSSS and Neukum *et al.*, 2004, *Nature*, v. 4322, Fig. 3.)

Surfaces were dated using the crater size-frequency technique. The shaded areas show crater counting areas. Ages of the lava flows range from 115 million years to about two million years in the area where HRSC and MOC data were combined. [Additional information and high resolution MOC image.]

Internal heat and magma supply

The calderas on five major volcanoes have undergone repeated activity as shown by the different ages of caldera floors created by different collapse events. Based on the crater size-frequency measurements by the HRSC team in these multiple calderas, magma reservoirs were forming, solidifying, and reforming on time scales of about 20 million years. The very long activity of Martian volcanoes implies correspondingly long lifetimes of hot spots in the planet's interior. These findings by Neukum and coauthors are in agreement with theoretical analyses and geological studies that suggest subsurface magma reservoirs must cool and solidify between caldera collapse events. Magma supply to the major shield volcanoes on Mars was episodic rather than continuous. What's more, the youngest volcanic surfaces in the study areas are so geologically young (about two million years) that volcanoes must have been active within the last 2% to 4% of Martian history.

The HRSC team's conclusions for recent volcanic activity and an internally active Mars are completely consistent with what we know from other studies:

- **Martian meteorites.** Most of the Martian meteorites formed in lava flows or shallow magma bodies during Amazonian times. Shergottites are the most abundant type. All the basaltic shergottites have crystallization ages less than 500 million years, with eight of the rocks in the range of 165 to 180 million years. Although these individual rocks are far from a representative sampling of Martian lava flows, they do suggest intermittent magmatism during the past 500 million years and there is no reason to think there couldn't be even younger volcanic deposits.

- **Previous interpretations of Mars Global Surveyor (MGS) camera, and Mars Orbiter Laser Altimeter (MOLA) data.** Results from 2001 studies suggested sporadic volcanic activity lasted 100 million years or longer with estimated ages of 3 to 10 million years old for the youngest surfaces. Based on these young surface ages, studies of eruption rates, and the episodic eruption style, many researchers, including Susan Sakimoto (NASA Goddard Earth Science and Technology Center) concluded that the potential for volcanic eruptions occurring during the next several tens of millions of years on Mars was not out of the question. [See Leonard David's space.com article: Mars Volcanoes Still Alive After All These Years?.]

- **Current interpretations of the Mars Odyssey Gamma Ray Spectrometer data and geophysical modeling.** Using the crustal average values for potassium and thorium from Mars Odyssey GRS data, the GRS team has calculated that half of the planet's potassium and thorium is in the crust. That leaves half in the mantle. [Mars Odyssey GRS results are about to be submitted for publication, but see Taylor, G. J. et al. (2003) Igneous and aqueous processes on Mars: Evidence from measurements of K and Th by the Mars Odyssey Gamma Ray Spectrometer. Sixth International Conference on Mars, 3207 (pdf file).] Steve Hauck and Roger Phillips (Washington University, St. Louis) and Walter Kiefer (Lunar and Planetary Institute, Houston) calculated that if approximately half of the radioactive elements such as potassium, thorium, and uranium were left in the mantle, there would be enough heat source for a small amount of volcanic activity today on Mars.

The Time Scale is Geologic not Human

If the volcanoes on the Red Planet are potentially still active, then eruptions could occur. But when? Would any of the active ESA and NASA Mars missions record the event? The most reasonable forecast for any possible future volcanic activity is in another couple to tens of millions of years...well into the future by human standards. To put it into perspective, the lava flows on Mars are akin to those that erupt from volcanoes in Hawaii. But an eruption on Oahu (where the youngest volcanic rocks are only about 100,000 to 500,000 years old) is more likely than on Mars. Is there a chance of seeing a volcanic eruption on Oahu in our lifetime? A geologist will tell you it is possible, but the odds are actually slim. The same may be said for Mars.

Glaciers on the Shield of Olympus Mons

Glacial deposits at the base of the Olympus Mons scarp look like rock glaciers or debris-covered glaciers on Earth and are interpreted as evidence for repeated phases of activity. Rock glaciers are typically covered by rocks and boulders and often have ridges, furrows, and lobes on the surface. [See Milkovich and Head (2003) Olympus Mons Fan Shaped Deposit Morphology: Evidence for Debris Glaciers. Sixth International Conference on Mars, 3149 (pdf file) for a review of glacier types.]

Neukum and coauthors found that the crater size-frequency distributions for these deposits ranged from 130 to 280 million years for the major lobes, 20 to 60 million years for some subareas, and four million years for the youngest surfaces. Snow/ice deposition on the Olympus Mons shield at elevations higher than 7000 meters may have led to episodes of glacial activity at this height. The data suggest that water ice protected by an insulating layer of dust may now exist at high altitudes at the edge of the Olympus Mons shield. Accumulations of water ice in non-polar regions are particularly hot topics of research because of their implications for hydrothermal activity and the strategy for searching for life on Mars.

Perspective View of Western Scarp of Olympus Mons

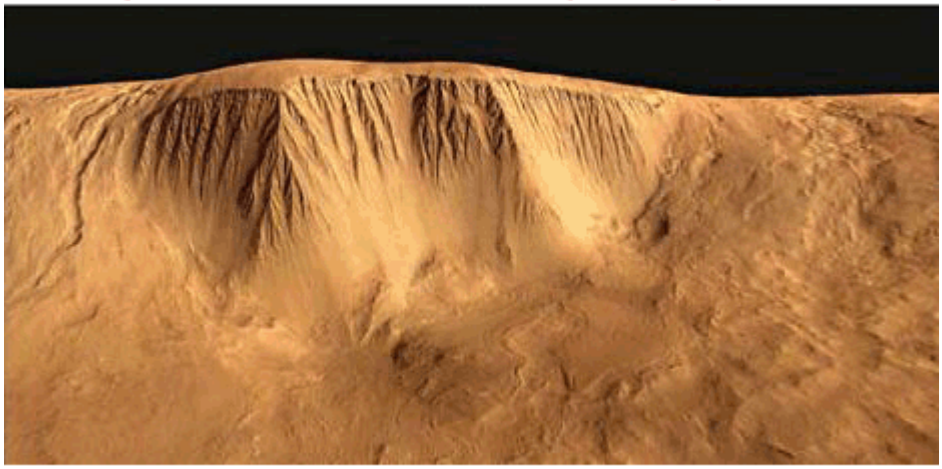


Image from ESA/DLR/FU Berlin (G. Neukum) and Neukum *et al.*, 2004, *Nature*, v. 432. Fig. 4k.

This perspective view of the western scarp of Olympus Mons shows steep gullied slopes, channels, and glacier-like flows.

More Mars Express Results

The first Mars Express Science Conference will be held February 21-25, 2005 in Noordwijk, The Netherlands. The scientific community involved in Mars Express will review the progress toward understanding Mars and put the results in the broader context of the latest scientific interpretations derived from current NASA missions: Mars Global Surveyor, Mars Odyssey, and Mars Exploration Rover.

Additional Resources

LINKS OPEN IN A NEW WINDOW.

- Borg, L. E., Nyquist, L. E., Weissman, H., Shih, C.-Y., and Reese, Y. (2003) The age of Dar al Gani 476 and the differentiation history of the Martian meteorites inferred from their radiogenic isotopic systematics. *Geochim. Cosmochim. Acta,* v. 67, p. 3519-3536.
- David, L. (2001) Mars Volcanoes: Still Alive After All These Years? space.com http://www.space.com/scienceastronomy/solarsystem/mars_volcano_011113.html.
- European Space Agency's Mars Express Mission homepage and image browser.
- Hartmann, W. K. and Neukum, G. (2001) Cratering chronology and the evolution of Mars. *Space Science Reviews,* v. 96, p. 165-194.
- Hauck, S. A. and Phillips, R. J. (2002) Thermal and crustal evolution of Mars. *Journal of Geophysical Research,* v. 107, doi 10.1029/2001JE0011801.
- Introduction to Cratering Studies and the Crater Counting Technique from the Planetary Science Institute, Tucson, Arizona.
- Kiefer, W. S. (2003) Melting in the Martian mantle: Shergottite formation and implications for present-day mantle convection on Mars. *Meteoritics and Planetary Science,* v. 38, p. 1815-1832.

- Milkovich, S M. and Head III, J. W. (2003) Olympus Mons Fan Shaped Deposit Morphology: Evidence for Debris Glaciers. Sixth International Conference on Mars, 3149 (pdf file).

- Neukum, G., Jaumann, R., Hoffmann, H., Hauber, E., Head J. W., Basilevsky, A. T., Ivanov, B. A., Werner, S. C., van Gasselt, S., Murray, J. B., McCord, T., and the HRSC Co-investigator team. (2004) Recent and episodic volcanic and glacial activity on Mars revealed by the High Resolution Stereo Camera. *Nature,* v. 432, p. 971-979.

- Neukum, G., Ivanov, B. A., and Hartmann, W. K. (2001) Cratering records in the inner solar system in relation to the lunar reference system. *Space Science Reviews,* v. 96, p. 55-86.

- Nyquist, L. E. et al, (2001) Ages and geologic histories of Martian meteorites. *Space Science Reviews,* v. 96, p. 105-164.

- Mars Odyssey GRS results are about to be submitted for publication, but see Taylor, G. J. et al. (2003) Igneous and aqueous processes on Mars: Evidence from measurements of K and Th by the Mars Odyssey Gamma Ray Spectrometer. Sixth International Conference on Mars, 3207 (pdf file).

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