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Hot Idea Update posted July 16, 2003

Ancient Floodwaters and Seas on Mars

--- Surface deposits within the northern lowlands support the oceans hypothesis.

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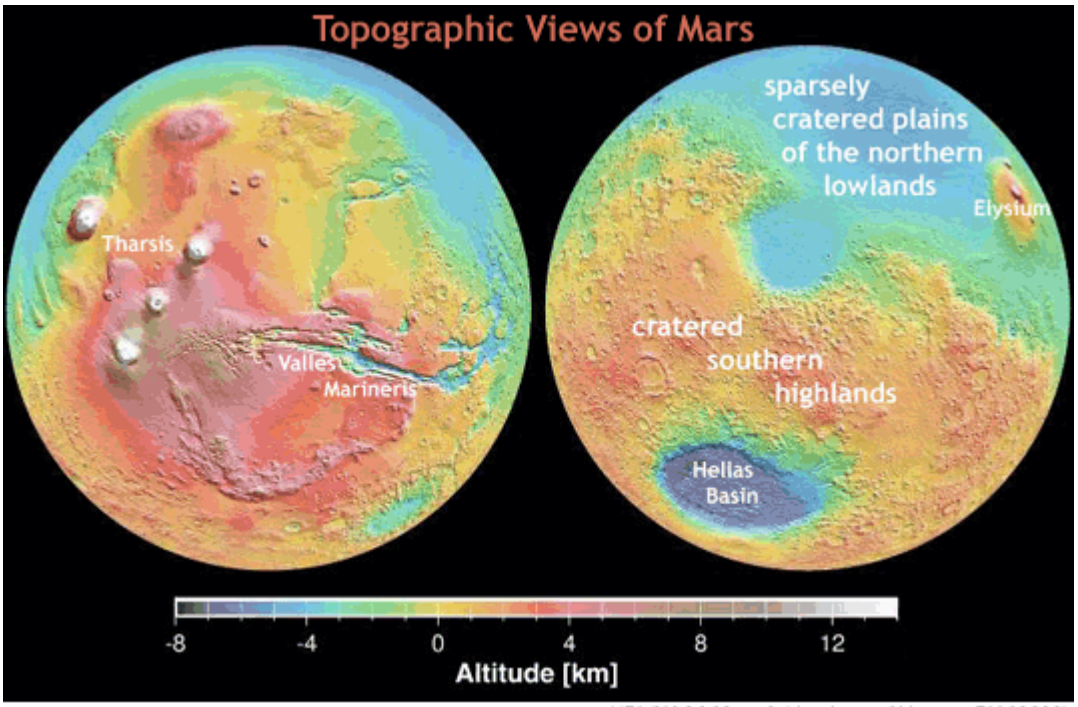
The role of water in the origin and evolution of landforms on Mars has been a main topic of planetary science research for at least the past 30 years, certainly since Mariner 9 images first showed large winding channels. The ancient immense floods that presumably formed the channels would have left behind large bodies of water at the ends of the channels. Where the bodies of water might have been, their size, or even evidence of their existence have been debated ever since. PSRD continues its coverage of water-related issues on Mars with a summary of an updated review of the evidence and possible fate of Martian oceans in the northern plains by Michael Carr (U. S. Geological Survey, Menlo Park) and James Head III (Brown University). They examined the features previously mapped as shorelines by Timothy Parker (Jet Propulsion Lab) and colleagues but found that more compelling evidence for the past presence of large bodies of water are deposits within the northern plains. They cite specifically the veneer of material of Upper Hesperian age called the Vastitas Borealis Formation (VBF). This knobby-textured surface is interpreted to be the sublimation residue from ponded flood runoff. There are multiple theories about what would have happened to the water in the northern oceans (which they predict had a volume of about 2.3×10^7 km^3). Carr and Head suggest that some of it, about 30%, could have been lost to space by sublimation, almost 20% could be in the present polar caps, and the rest could be trapped in other volatile-rich surface deposits or redistributed in the groundwater system.

Reference:

Carr, M. H. and Head III, J. W. (2003) Oceans of Mars: An assessment of the observational evidence and possible fate. *Journal of Geophysical Research,* v. 108(E5), 5042, doi: 10.1029/2002JE001963, 2003.

Northern Lowlands

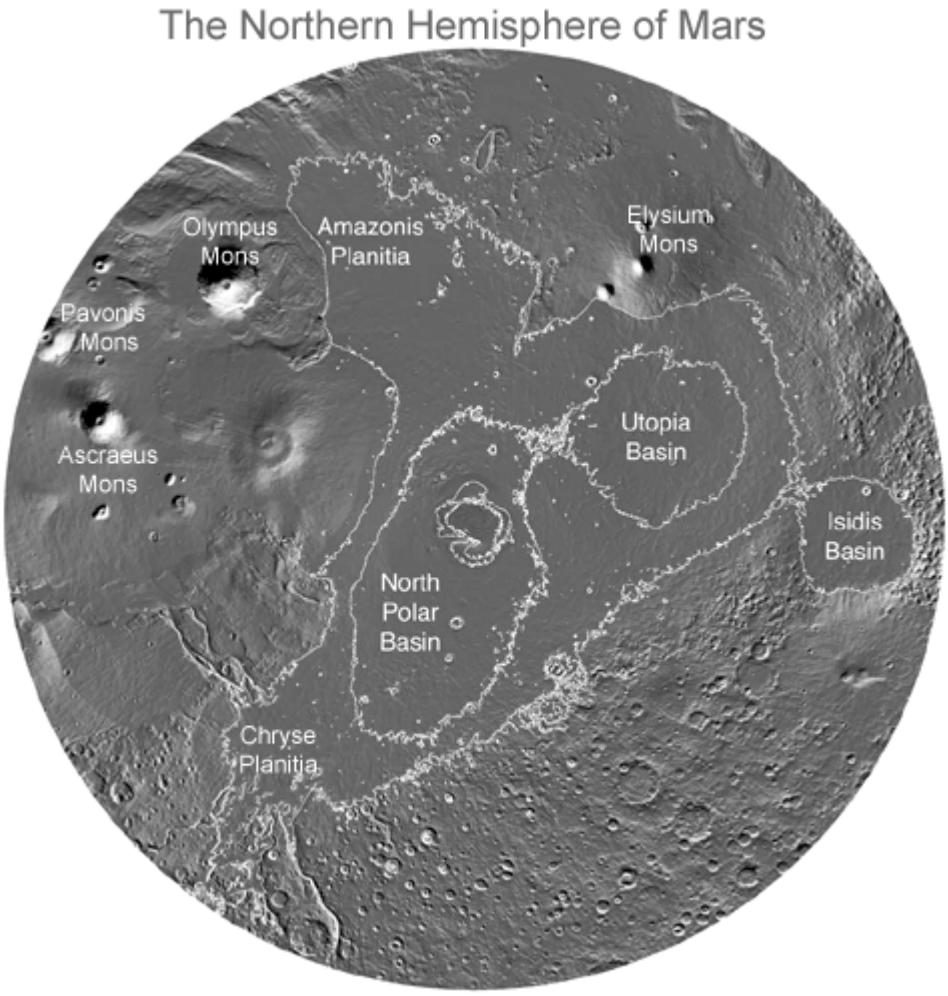
One of the most intriguing issues about Mars is the idea that oceans once filled the low, flat plains of the northern hemisphere. Today these gently sloping plains are marked by ridges, low hills, and sparsely scattered craters. They are considered to have a volcanic origin and to be Hesperian in age based on crater counts, but they are covered by layers of younger materials (described in a later section).



(JPL/NASA Mars Orbiter Laser Altimeter, PIA02820)

Mars Orbiter Laser Altimeter (MOLA) maps clearly show a distinction between lowlands and highlands. The northern lowlands have overall elevations about five kilometers lower than the cratered uplands of the southern hemisphere. (Click image for higher resolution options from NASA Planetary Photojournal. Will open in a new window.)

Two distinct basins are recognized within the northern lowlands: North Polar basin and Utopia basin. Carr and Head describe how floodwaters that formed channels around Chryse Planitia would have flowed into the North Polar basin. [See **PSRD** article Outflow Channels May Make a Case for a Bygone Ocean on Mars.] Water that cut the valleys northeast of Elysium would have flowed into Utopia basin. Amazonis Planitia and the smaller Isidis basin are two other smooth, flat northern regions where floodwaters could have reached.



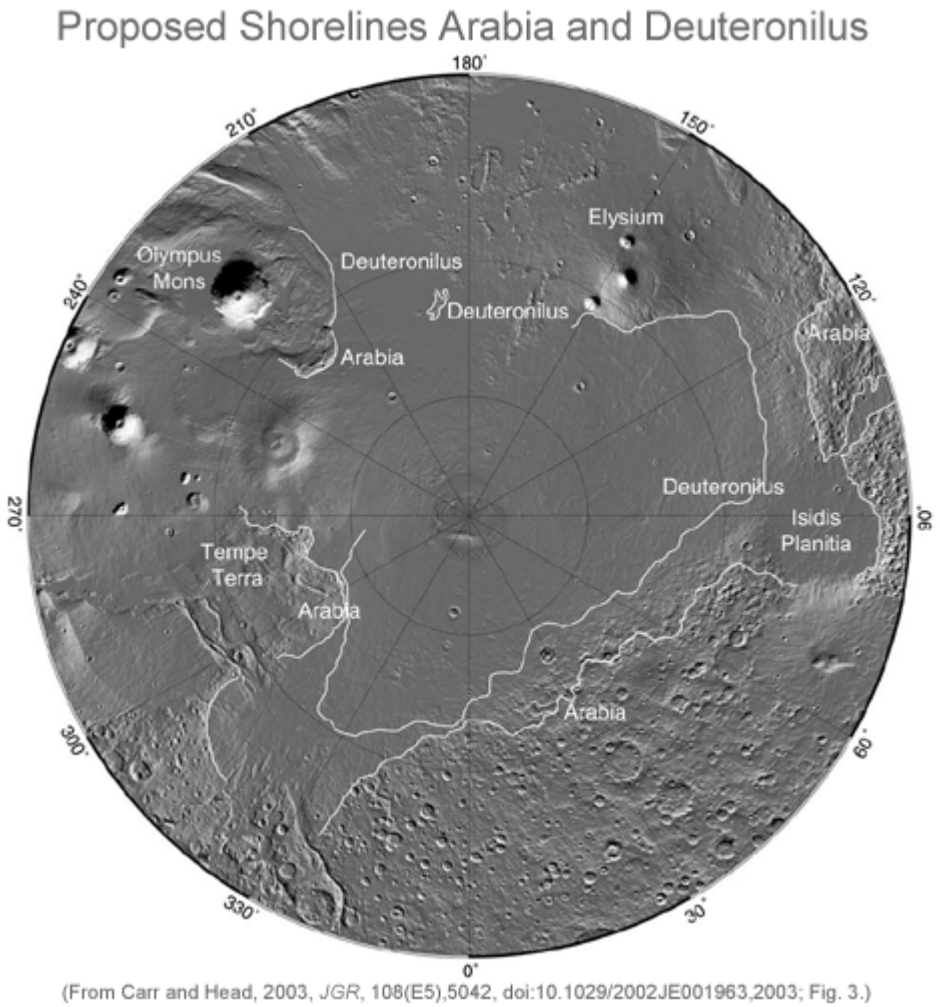
(From Carr and Head, 2003, *JGR*, 108(E5),5042, doi:10.1029/2002JE001963,2003; Fig. 2.)

Prominent basins and major landmarks in the northern hemisphere of Mars are outlined and labeled in this polar stereographic projection.

Among the early researchers to discuss possible former oceans in the northern lowlands was Baerbel Lucchitta (U. S. Geological Survey, Flagstaff) and her colleagues. Their 1986 work suggested that polygonally fractured ground downstream from outflow channels could have originated in sediments deposited in standing water. But it was the work of Timothy Parker (Jet Propulsion Lab) and colleagues beginning in 1989 that put a focus on finding evidence of a vanished ocean by looking for shorelines in the northern lowlands using Viking Orbiter images.

Proposed Shorelines

The originally proposed shorelines were two discontinuous boundary contacts between landforms thought to have formed by wave or other water-related processes. Stephen Clifford (Lunar and Planetary Institute, Houston) and Parker later refined the outlines and hypothesized that Noachian-aged bodies of water and ice covered up to one third of the surface of Mars.



(From Carr and Head, 2003, *JGR*, 108(E5),5042, doi:10.1029/2002JE001963,2003; Fig. 3.)

Shorelines proposed by Clifford and Parker (2001) in the Martian northern lowlands.

The two most continuous contacts, called the Arabia and Deuteronilus shorelines, generally parallel the southern boundary of the northern plains. The Arabia shoreline can be traced all around the planet except through the Tharsis region. The elevation of the Arabia contact varies by several kilometers, in some places by 11 kilometers. This large range in elevations does not support a shoreline interpretation. Features of the proposed shoreline that have been interpreted as formed by wave actions or other marine processes can be equally argued as being formed by mass wasting and volcanic processes.

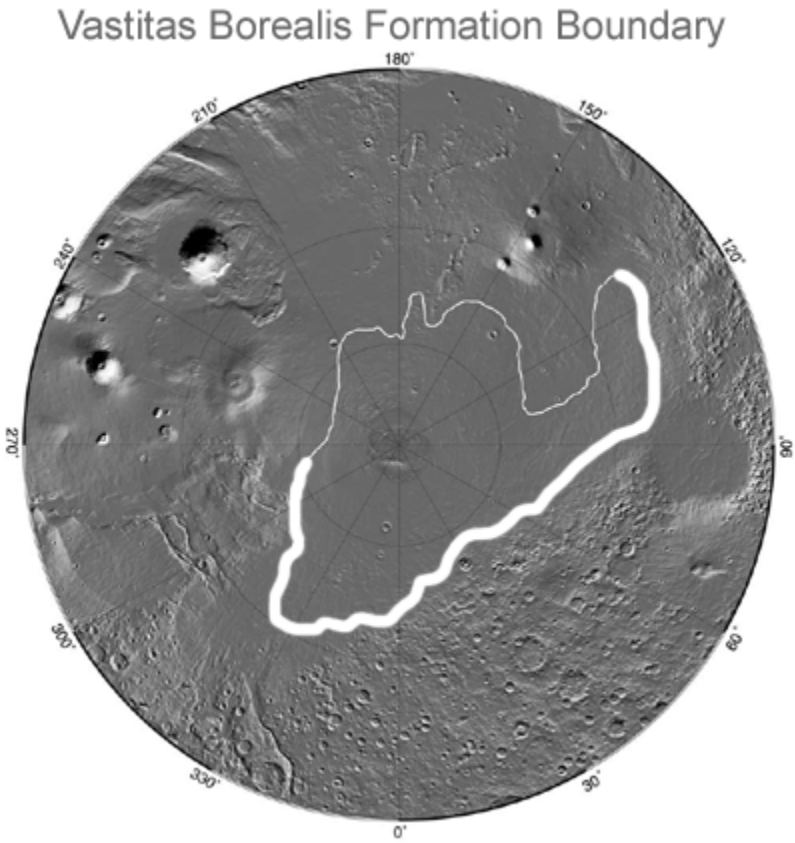
The Deuteronilus contact is more subtle than the Arabia contact but has a smaller range in elevations. For nearly half its length the Deuteronilus marks the southern extent of the geologic unit called the Vastitas Borealis Formation. For the rest of its length it is seen only intermittently around clusters of hills or across lava flows. There is sparse direct evidence that the Deuteronilus contact is a shoreline, such as inward-facing cliffs or channels that end abruptly at the contact.

According to the report by Carr and Head clear evidence of post-Noachian shorelines around the northern plains is ambiguous. They argue that some of the previously mapped contacts are clearly of volcanic origin, that all have significant variations in elevation, and that there is no strong support at this time for most of the proposed shorelines. But his does not mean shorelines never existed. Shorelines or other marine depositional or erosional features could have been obscured or destroyed by later geologic processes such as cratering impacts, erosion, volcanism, and tectonism. The difficulties in proving the existence of shorelines would appear to weaken the oceans hypothesis, but Carr and Head show that it gains support from other geologic evidence.

Evidence for Flooding from Within the Northern Plains

Unconvinced that the previously mapped contacts are shorelines, Carr and Head assessed the other surface features within the northern volcanic plains that could be used to support the ancient oceans hypothesis. A variety of surfaces, including polygonal ground, curvilinear ridges, highly eroded impact craters, and eroded wrinkle ridges, have been cited since the 1980s as areas formerly covered by water. What Carr and Head and other researchers have found most interesting is the question of why the northern lowlands are so much smoother than comparable plains in the south.

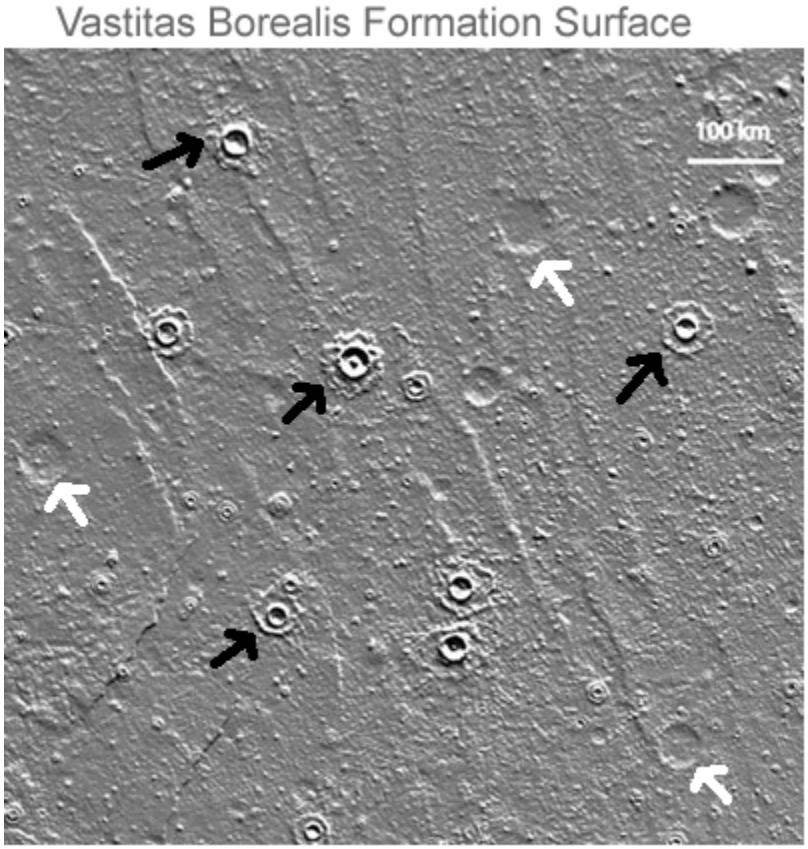
The northern plains are buried by layers of material at least 100 meters thick. Carr and Head cite as evidence the area previously mapped as the Vastitas Borealis Formation (VBF) of Upper Hesperian age.



Mapped boundary of the Vastitas Borealis Formation. The bold line emphasizes where the VBF boundary coincides with the Deuteronilus contact.

(From Carr and Head, 2003, *JGR*, 108(E5),5042, doi:10.1029/2002JE001963,2003; Fig.11.)

The VBF appears to be layered deposits that have buried the older volcanic plains and craters, effectively smoothing the wrinkled surface and leaving behind shallow, almost rimless craters called stealth craters. The stippled, wrinkled, and cratered appearance shows clearly in MOLA images. Herbert Frey (Goddard Space Flight Center) and colleagues have shown that the northern lowlands were at one time as cratered as the southern highlands.

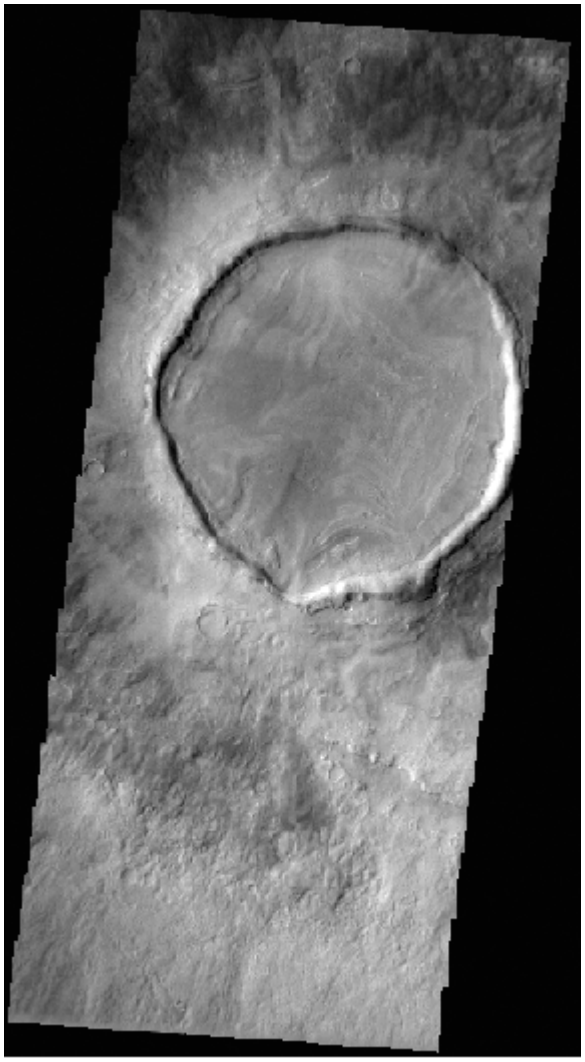


(From Carr and Head, 2003, *JGR*, 108(E5),5042, doi:10.1029/2002JE001963,2003; Fig.15.)

Typical Vastitas Borealis Formation (VBF) at 60ºN, 140ºE. Closely spaced hills create the stippled appearance. Linear patterns may be due to aligned hills or ridges. White arrows point to examples of stealth craters, interpreted to be older craters buried by the VBF. Fresher looking craters with ejecta blankets are interpreted by Carr and Head to be younger than the VBF, see examples shown by black arrows.

The Vastitas Borealis Formation is interpreted as a flood deposit left behind after a frozen ocean slowly sublimated; Carr and Head give several lines of supporting evidence: The VBF has a similar age to that of the outflow channels and it is seen in low areas at the ends of the outflow channels. There is also a similarity in the volume of the VBF (estimated at 3×10^6 km^3)and the volume of materials eroded to form the outflow channels (estimated at 4×10^6 km^3).

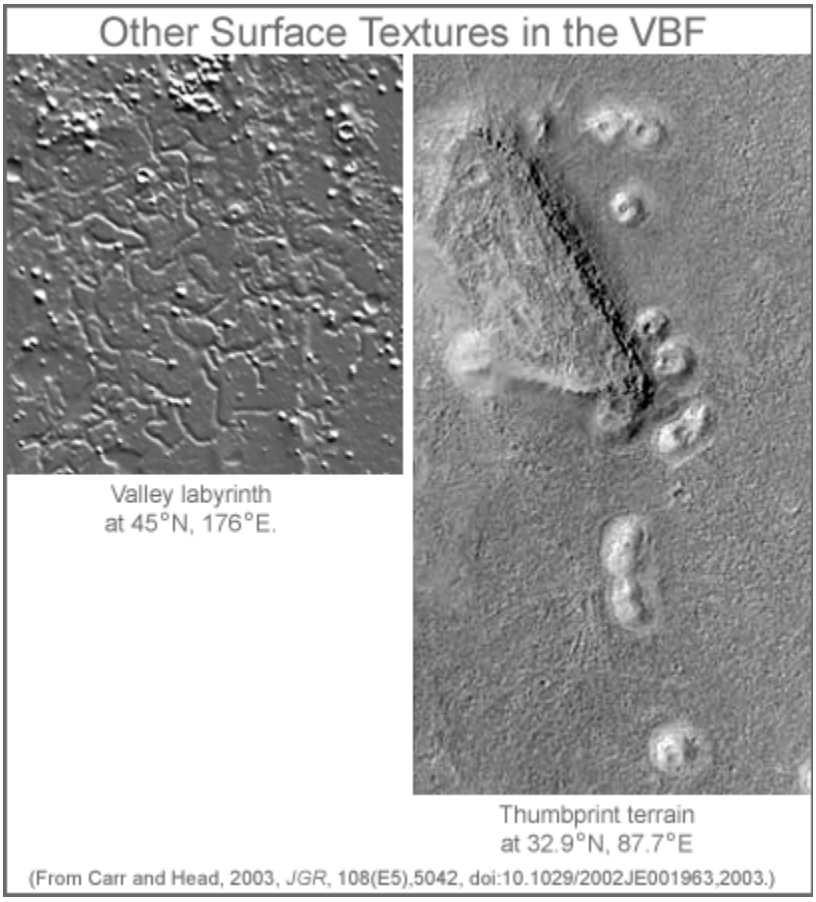
Using high resolution MOLAS, MOC, and THEMIS images, researchers can see effects of the mantle deposits in the depth/diameter relationships of craters like those with black arrows in the image above. Looking closely at the shapes of craters within Utopia basin and other northern areas, Joe Boyce and colleagues (University of Hawaii) find that commonly the crater floors are at nearly the same elevation as the surrounding plains (see image below for example). They see this relationship exclusively in the northern lowlands and interpret it as the result of deflation of layered, ice-rich, geologically young material that was deposited by the last major flooding event.



THEMIS visible image V03679003
NASA/JPL/Arizona State University

THEMIS visible image centered at 44.1 ^{o} N, 101.7 ^{o} E of a filled crater in Adamas Labyrinthus. Click on the image for higher resolution options from the THEMIS website (will open in a new window).

There are other surfaces within the VBF that have been interpreted as meltwater features associated with a stationary or retreating ice sheet. Some of these features are thumbprint terrain and labyrinthine valleys.



Each image is about 300 kilometers across. Thumbprint terrain is common around the edge of the VBF. It has been interpreted as deposits of ice or rock indicating successive positions of retreating ice. Labyrinths of curved valleys, some with central ridges, have a similar appearance to terrestrial glacial landscapes where ridges of sediment mark where the sediment-laden water once flowed in tunnels under the ice.

Possible Fate of Northern Oceans

The researchers have made a case for the presence of a large body, or bodies, of standing water in the northern plains over an area roughly equal to that mapped as the Vastitas Borealis Formation. Carr and Head argue that successive floods could have flowed over ice from previous floods to progressively fill the basins over a long period of time. Once flooding ceased and the ice sublimated away, layers of sublimation residues were left covering the ridged plains.

To cover all the area now mapped as the Upper Hesperian VBF would take about 2.3×10^7 km^3 of water according to Carr and Head's assessment. Spread over the surface of Mars, this volume is equal to a global layer of water (Global Equivalent Layer or GEL) about 156 meters deep.

What was the duration of the ocean and where did it go? Its fate would depend on climatic conditions. Under warm conditions, researchers such as Victor Baker (University of Arizona) argue the ocean water would have evaporated into a thick warm atmosphere, precipitated out, and returned to the ground. However, the accompanying CO_2, carbonates, and evaporite deposits expected in this scenario have not been found. Under present climatic conditions on Mars, researchers say an ocean would freeze in about 10,000 years, then sublimate away at rates strongly dependent on whether or not the icy surface was covered by rocky debris. Under such cold conditions, the sublimated ice could have been redeposited at or surrounding the polar caps. Carr and Head estimate about 30 meters GEL could be in the present polar caps. Approximately 50 meters GEL could have been lost to space and the rest, approximately 80 meters GEL could be trapped in other volatile-rich surface deposits or be redistributed in a groundwater system by polar basal melting.

A Big Job Ahead

Finding geologic evidence that everyone can agree with is crucial to test any ocean hypothesis. Right now there is no consensus on the existence of shorelines in the northern lowlands. Mike Carr and Jim Head found that more compelling

evidence lies in the deposits themselves and that the Upper Hesperian Vastitas Borealis Formation supports the ancient ocean hypothesis because it appears to be the solid remains of floodwaters from the outflow channels.

Data from the gamma ray and neutron spectrometers on Mars Odyssey show that there is considerable ice in the upper few tens of centimeters of the surface in the northern plains. In fact, north of about 60° latitude it appears that the surface is >70 vol% ice. The presence of this dirty ice would appear to be consistent with the past existence of an ocean on Mars. However, over billions of years the surface would be reworked by meteorite impacts and much of the ice would be lost by sublimation into the dry Martian atmosphere. The near-surface ice discovered by Mars Odyssey may have been deposited more recently. Much more research is needed to understand the origin of the near-surface ice on Mars and to determine if it gives us any insight into the nature of a past northern ocean.

Besides new remote sensing data from Mars, geochemists are investigating how to test the existence of an ancient ocean. Water reacts with rock to form new minerals--a process called weathering. Depending on conditions in the ocean (temperature, acidity, and concentrations of dissolved compounds), specific sets of minerals may form. We can seek out these minerals by careful interpretation of chemical data returned by Mars Odyssey (especially the concentrations of potassium, thorium, uranium, and chlorine) and in the future, by using surface rovers carrying sophisticated analytical tools or by returning samples from the northern plains. Rovers may also do geophysical surveys to search for deeply buried ice that might have been deposited in the ground beneath a freezing ocean. There is still a lot to do to understand the ancient floodwaters and seas on Mars. These and other tantalizing issues will be discussed at the Sixth International Conference on Mars July 20-25, 2003.

Additional Resources

Boyce, J. M., Mouginis-Mark, P. J., and Garbeil, H. (2003) Evidence for a thick, discontinuous mantle of volatile-rich materials in the northern high-latitudes of Mars based on crater depth/diameter measurements. *Sixth International Conference on Mars,* abstract 3193 pdf.

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Parker, T. J., R. S. Saunders, and D. M. Schneeberger (1989) Transitional Morphology in West Deuteronilus Mensae, Mars: Implications for Modification of the Lowland/Upland Boundary, *Icarus,* vol. 82, p. 111-145.

Sixth International Conference on Mars July 20-25, 2003.

2001 Mars Odyssey mission homepage.
