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Oceanus Borealis: New Facts for a Myth?

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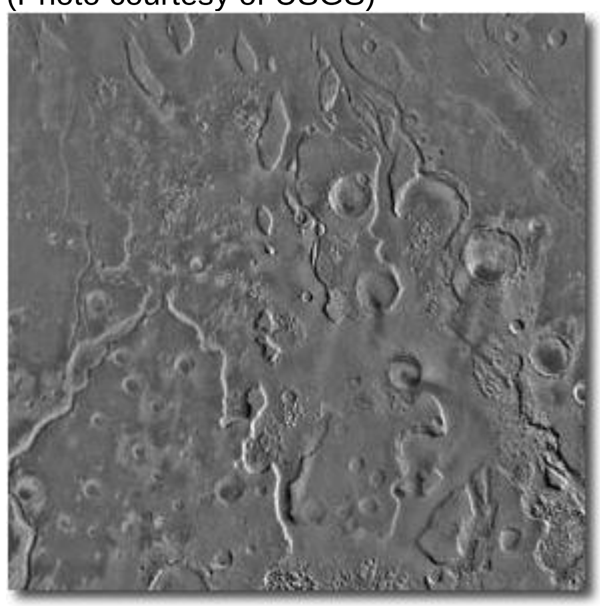
Among the most spectacular geologic features on the surface of Mars are its ancient outflow channels. The presence of these and other fluvial features scattered all over the planet indicate that during some long past epoch Mars was a far wetter place than it is today (Carr 1996). Most of the major Martian outflow channels can be found on the flanks of the Tharsis rise or adjacent to the Valles Marineris rift system. Sporadic geologic activity in these regions over billions of years episodically caused large quantities of permafrost to melt. The enormous quantities of meltwater pooled in the deep chasms of the eastern part of Valles Marineris but much was carried away by the giant outflow channels like those surrounding Chryse Planitia. This water and that from many other channels then drained northward over the relatively young northern volcanic plains (Nelson & Greeley 1999).

Ares Vallis is one of several enormous outflow channels that cut through the ancient volcanic plains that surround Chryse Planitia. Mars Pathfinder landed some distance downstream from this valley in July of 1996. Ample evidence has been found that enormous floods of water followed by water rich debris flows sculpted this region long ago (Chapman and Kargel 1999). Topographic measurements of Ares Vallis obtained by Mars Global Surveyor (MGS) using the Mars Orbiter Laser Altimeter (MOLA) in the fall of 1997 indicated that this one channel carried as much as 10 cubic kilometers each second at the peak of its largest flood (Smith et al. 1998) - a flow rate an order of magnitude larger than estimated earlier. If future MOLA measurements indicate that the other outflow channels carried more water than had been estimated, Mars was even wetter than previously suspected. But with such vast quantities of water, there is the question of where it all went after it flowed into the vast northern lowlands of Mars.

In an unpublished paper written in 1973, the late Henry Faul of the University of Pennsylvania had suggested that the northern plains was an ancient ocean basin filled by the flood waters carried by the channels clearly seen in Mariner 9 images for the first time. But his evidence at the time was meager and his suggestion went largely unnoticed for over a decade. Based on examinations of the more extensive set of higher resolution Viking images, Parker et al. (1989) suggested that many features seen across the northern lowlands looked like paleoshores. Further investigation revealed additional evidence to support the claim that these broken stretches of alleged paleoshore encircled the northern lowlands indicating that a large body of water - perhaps an ocean - covered this region on several occasions during the Hesperian and Amazonian epochs one to three billion years ago (Baker et al. 1991, Parker et al. 1993). With an ocean (possibly ice covered) occupying the northern lowlands, the Martian climate would become significantly wetter for long periods of time. Baker et al. (1991) even gave this proposed ocean a name - Oceanus Borealis or "Northern Ocean".

With twice the volume of Earth's Arctic Ocean and covering a sixth of the Martian surface, Oceanus Borealis would have been an impressive body of water indeed

Enormous outflow channels like these show that Mars once had vast quantities of running water. But where did it all go?
(Photo courtesy of USGS)



While the evidence for running water on the Martian surface is prominent and convincing, the same can not be said about the evidence for large bodies of standing water. The Viking imagery upon which claims for Oceanus Borealis were based was open to interpretation. Although the planetary science community accepted that Mars experienced large floods in the distant past, the ultimate sink for all the water was open to debate. Many believe that the flood waters would fan out over places like Chryse Planitia and northward into Acidalia Planitia where the water would be absorbed by the porous Martian surface or evaporate. While bodies of water might briefly form, they would not be long lived nor have a significant long term impact on the Martian environment. Oceanus Borealis was not needed and the alleged paleoshores were produced by some other process.

What was needed to resolve this question was more data. NASA's Mars Global Surveyor (MGS), which entered orbit around Mars on September 12, 1997, had a variety of instruments that could shed new light on the possible existence of Oceanus Borealis. High resolution images of the alleged paleoshores would be helpful. While it would be impossible for MGS to map all of them, a sample viewed at a resolution of a few meters could be enough to confirm their origins (Parker 1998). But problems encountered during MGS's aerobraking maneuver prevented the spacecraft from attaining its final survey orbit as soon as originally scheduled. During a hiatus in a less stressful extended aerobraking phase during the fall of 1997, MGS was able to obtain science data during a number of orbits. While the paleoshores of Oceanus Borealis were not imaged during this time, MOLA did obtain 18 orbits worth of elevation measurements across Mars' northern hemisphere. An analysis of this data uncovered some highly suggestive evidence for Oceanus Borealis.

The initial analysis by Smith et al. (1998) showed that the northern hemisphere is indeed low lying and smoother on a broad range of scales than almost any other known terrain - Martian or otherwise. The only other surfaces in the solar system that were this smooth over the same distances were the abyssal plains of Earth's oceans where eons of sedimentation have softened the topography on all scales. While this was hardly proof, the gentle slopes and smoothness of the northern hemisphere were consistent with the existence of Oceanus Borealis, although the modification by later aeolian processes could also be partly responsible for the observed smoothness.

Additional analysis of the MOLA hiatus data by Aharonson et al. (1998) confirmed the earlier results. Their analysis showed that the low lying northern plains were a statistically distinct region set apart by their smoothness and low elevation. In addition, they have identified Amazonis Planitia to be the smoothest surface yet found on Mars. This same region was earlier observed to have an anomalous thermal inertia and exceptionally low radar reflectivity earning it the nickname "Stealth". Extending over 600 kilometers, the profile of Amazonis Planitia is exceptionally smooth on all scales. Based on a comparison of the roughness of several types of basins on the Moon, Earth, and Venus, it was found that this region's only analogs in the solar system are Earth's sediment-filled basins and, once again, the abyssal plains of terrestrial oceans.

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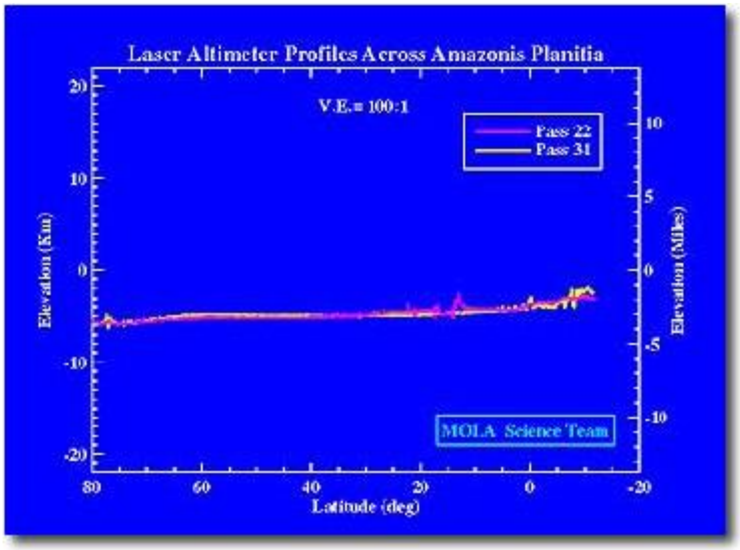

Data derived from MOLA shows that the martian northern lowlands, like Amazonis Planitia shown here, are lower and smoother than anywhere on the planet. The only other place as smooth are the abyssal plains of terrestrial oceans and Earth's sediment filled basins.
(Plot courtesy of NASA/ MGS MOLA Team)

While there are any number of mechanisms that could also explain the smoothness of Mars' northern plains, nothing in the new data disproves the existence of Oceanus Borealis and in many ways it seems to add support instead.

New evidence to support the existence of Oceanus Borealis could come from a determination of its putative paleoshores' elevations (Banerdt & Parker 1998). All points of a shoreline should lie along the same geopotential elevation just as the shorelines of Earth's oceans all correspond with sea level. If the topography and shape of Mars have remained unchanged since the paleoshores formed, they should lie along the same elevation contour all around the Martian northern plains. Using the MOLA hiatus data, Head et al. (1998) performed an initial test of this hypothesis by measuring the elevations of some of these possible ancient shorelines.

Head et al. used a pair of paleoshore sets identified by Parker et al. (1989, 1993) to determine their positions in the MOLA data set. The older and higher set, generically labeled "Contact 1," is closely associated in many areas to the scarp separating the young northern lowlands from the older southern highlands. Contact 1 appears to have formed during Mars' Hesperian epoch two or more billion years ago. The other paleoshore, "Contact 2," is younger and lower than Contact 1. Out of the eighteen hiatus orbits with MOLA data, fourteen tracks cross Contact 1 a total of nineteen times and eleven cross Contact 2 thirteen times.

Plotting the derived paleoshore elevations as a function of longitude, Contact 1 was found to be anything but level. Measured elevations for Contact 1 ranged from -4.05 to +1.47 kilometers with a mean of about -2.16 kilometers. But the scatter in the data shows many systematic trends that can not be random. The highest elevation measurement for Contact 1 is part of a series of six data points that delineate the Tharsis bulge. This and a similar bulge seen near the Elysium Rise lie in regions that were already known to have experienced significant uplifting during Mars' geologic history. While Contact 1 may have originally been a level paleoshore, it seems to have been distorted by large-scale geologic activity since it formed. A systematic tilt near Acidalia and Chryse Planitia hint that this region has experienced large-scale tilting over the eons.

Elevation measurements for the younger Contact 2 showed it to be much less distorted. With a mean elevation of -3.73 kilometers, its measured elevations only ranged from -4.03 to -3.19 kilometers. Interestingly there seems to be a strong positive correlation between the shape of the distortions in the two contacts. Both show virtually the same systematic tilt across Acidalia and Chryse Planitia hinting that it post dates the formation of both contacts. The bulges near Tharsis and Elysium, on the other hand, are significantly smaller for Contact 2 indicating that most of the observed deformation occurred between the appearance of the two contacts. This first sample of elevation data seems to be completely consistent with the "Contacts" being paleoshores that have experienced different amounts of distortion caused by geologic activity since they formed.

Head et al. also studied the surface roughness derived from MOLA data. They confirmed that the surface inside Contact 1 was the smoothest observed on Mars. But a detailed statistical study of the surface roughness showed that the area inside Contact 2 was much smoother than the area between Contacts 1 and 2. This is perfectly consistent with the two contacts representing successive paleoshores of a shrinking Oceanus Borealis. The basin beneath Contact 2 would have been subjected to topographic softening effects of sedimentation for a longer period than the area between the contacts. While there are any number of mechanisms that could also explain the smoothness of Mars' northern plains, nothing in the new data disproves the existence of Oceanus Borealis and in many ways it seems to add support instead.

With so little distortion in the shape of Contact 2, it seems likely that the Martian geoid has changed little since Contact 2 formed allowing a reasonable estimate for its size to be calculated. According to estimates by Head et al., if Contact 2 is a paleoshore, Oceanus Borealis would have held 15 million cubic kilometers of water - enough to cover the entire Martian surface in a layer 100 meters thick. The incarnation of Oceanus Borealis that Contact 2 seems to record would have been as much as two kilometers deep and had an average depth of 620 meters.

With twice the volume of Earth's Arctic Ocean and covering a sixth of the Martian surface, Oceanus Borealis would have been an impressive body of water indeed. Contact 1 probably represents an even more voluminous incarnation for this ocean from an earlier epoch. But how the Martian geoid changed through time will have to be understood before its volume can be reliably estimated.

While 15 million cubic kilometers may seem to be a large volume of water, it lies comfortably inside the range of estimates for Martian water sources and sinks. It is larger than the lower boundary for the estimated total amount of water discharged by the flood channels (where the water came from), yet smaller than the estimated pore space in Mars' "megaregolith" (where much of the water probably went). With MGS finally in its survey orbit, the large amount of additional MOLA data combined with new images and more careful analysis of archived Viking data might finally allow us to prove the existence of Oceanus Borealis and start working out its history. A side benefit from this work would be information on the evolution of the shape and topography of Mars since the various paleoshores formed - vital geophysical information that would be difficult or impossible to get in any other way.

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