The Mars Ocean Project: A Graphical Analysis of Proposed Shorelines on Mars

Richard M. Smith

Abstract: A three-dimensional model of Mars is used to test the hypothesis that certain linear features on Mars are remanent shorelines.

Introduction

In 1989, Timothy Parker and colleagues at the Jet Propulsion Laboratory began analyzing the topography of Mars' northern lowlands for evidence of shorelines that would indicate the existence of ancient oceans (Ref. 5). In 2001 Clifford and Parker published a paper (Ref. 1) that delineated their findings in a map (Figure 1) showing the locations of several proposed shorelines. Later, in 2003, Carr and Head (Ref. 2) reported their opinion that more compelling evidence for ancient large bodies of water was to be found in the deposits on the northern plains. In between and since, arguments have been presented for and against the former existence of oceans on Mars.

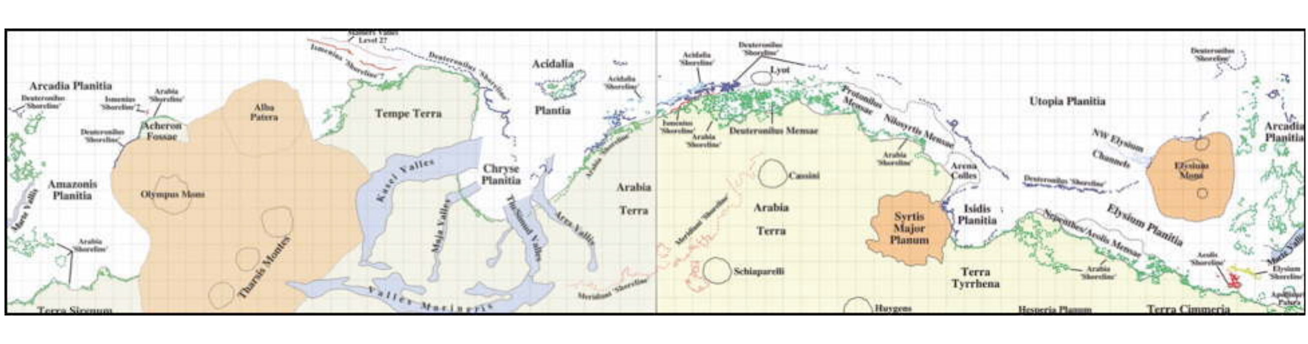


Figure 1. Cylindrical projection from Reference 1 showing many suspected shorelines including the two most prominent, Arabia and Deuteronilus. The area mapped is from 15 degrees south to 65 degrees north.

The proposed shorelines consist of discontinuous boundary contacts between land forms, thought to have been created by waves or water-related processes. However, the elevation of the contacts varies enough that they do not support a shoreline interpretation under present conditions. In addition, Carr and Head argued that some of the mapped contacts are of volcanic origin and so are not supportive of a shoreline interpretation. Of course, shorelines could have been obscured or altered by later physical processes and there is evidence to this effect.

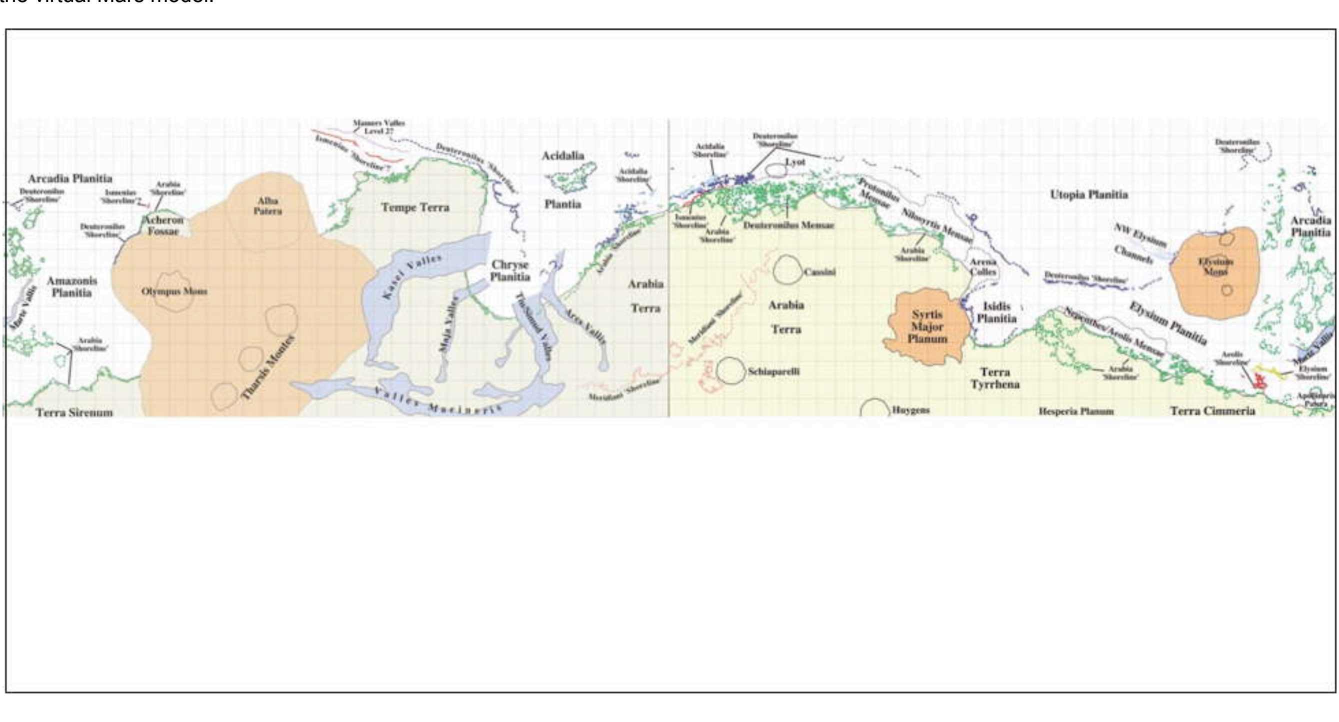
The Graphical Model

To test the idea that the proposed shorelines could have resulted from bodies of water, I needed a way to create an accurate three-dimensional model of Mars that could be manipulated and calibrated. I created a virtual three-dimensional model of Mars with a superimposed "ocean" using ray-trace rendering. I used POV-Ray (Persistence of Vision ray-trace program), a free application with powerful features available on several computer platforms.

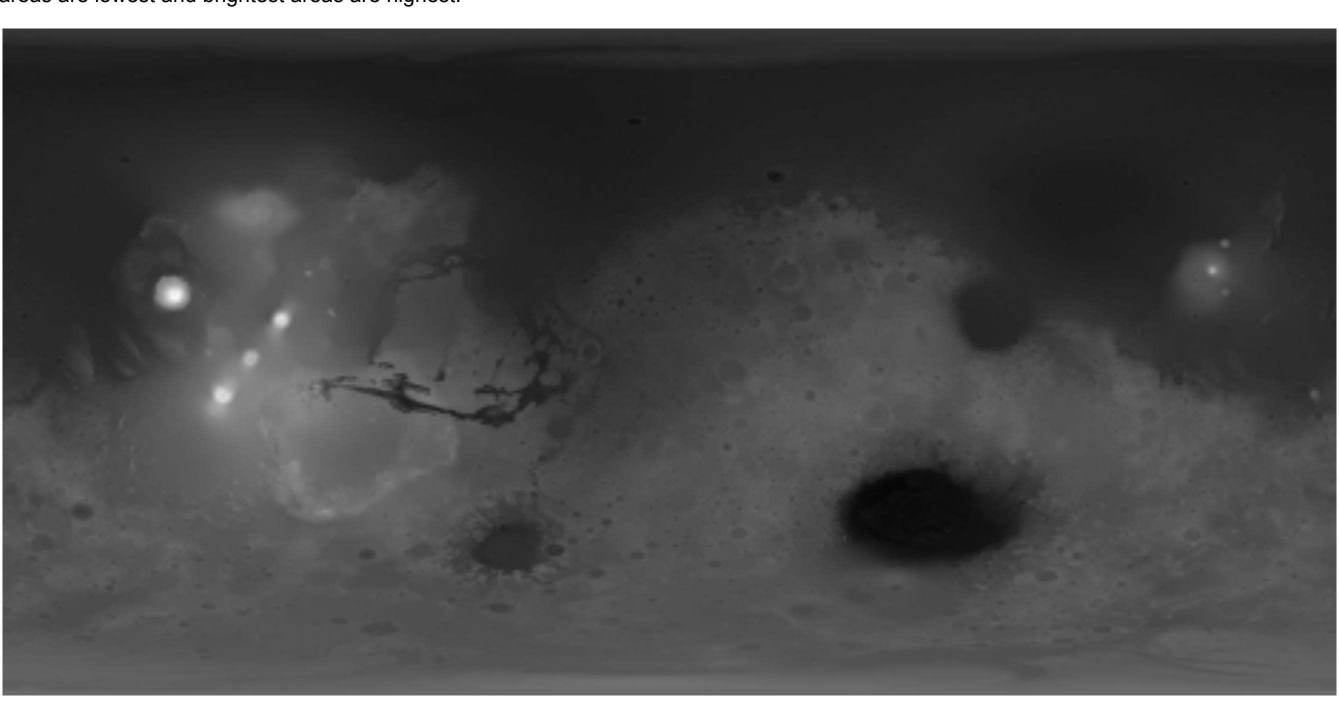
Ray-trace rendering can be used to create photorealistic scenes of virtually any object and is regularly used in many of today's motion pictures in place of physical models. A particularly useful feature of ray-trace rendering is the ability to wrap a graphical image around a virtual object. For instance, a virtual sphere can be wrapped with a flat map image of planetary terrain to create a three-dimensional image of the planet. An extension of the this feature is the ability to wrap a topographical map on the surface of a sphere to duplicate a planet's terrain elevations. This feature uses a function called an isosurface.

Creating the virtual model

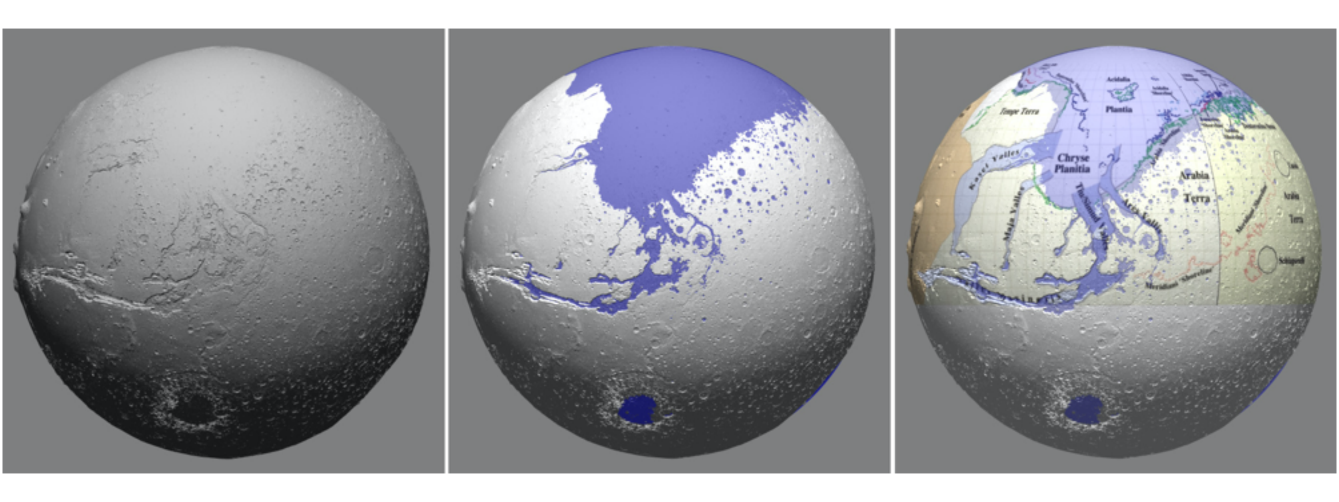
Because the shoreline map extends from 15 degrees south to 65 degrees north, it must be extended to the poles to accommodate fitting it to the virtual Mars model:



The Mars digital elevation model, or DEM, is a gray scale image that displays Mars' terrain elevations as varying shades of gray, darkest areas are lowest and brightest areas are highest:



A ray-trace function called an isosphere is used to "wrap" the DEM around a sphere and create a topographic surface matching that of Mars. Then a blue sphere is superimposed, concentric with the isosphere, and sized to intersect the isosurface terrain model to simulate an ocean. Finally, the shoreline map is wrapped around the isosphere:



Calibrating the Model

A requirement of the analysis is the ability to adjust the virtual ocean to try to fit the shorelines depicted in the shoreline map (Figure 1). Carr and Head used MOLA 64 pixel/degree data and Generic Mapping Tools to draw contour lines accurately at the elevations of the spillway between the Utopia and North Polar Basins and the spillway between Isidis Basin and the north polar depression (Reference 3). The accuracy of these two contour lines (Figure 2) provides two data points on which to base an accurate calibration of the Mars model.

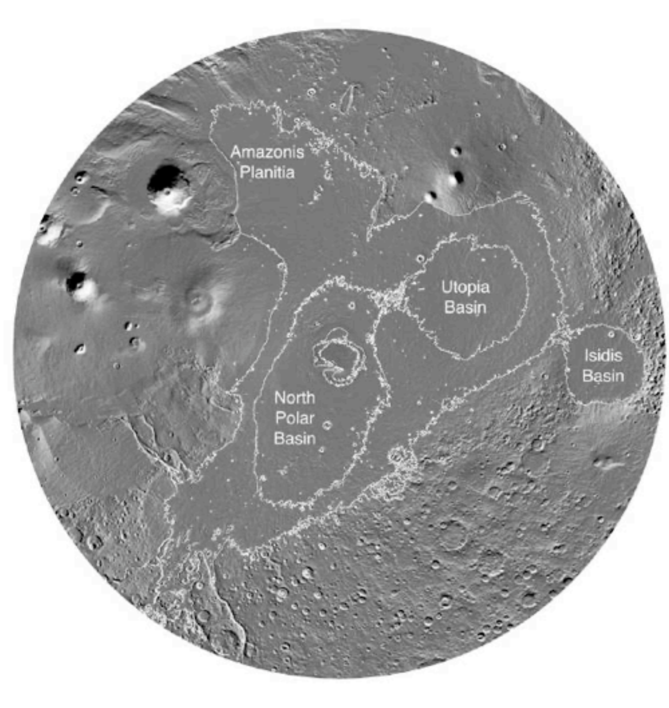


Figure 2. Polar stereographic projection map of Mars' northern hemisphere with contour lines drawn at -3.509 km and -4.350 km. From Reference 2.

Calibration is accomplished by projecting an image of the Mars model northern hemisphere onto the Carr and Head map and adjusting scale and registration until the two contour lines can be matched by setting the ocean sphere to the two values. Subsequently, the ocean sphere was set to several other known elevations to test linearity of the model.

The Mars model is sized in units equal to the equatorial radius of Mars in kilometers. Thus, by adding or subtracting values, the virtual ocean can be made to intersect the terrain at any elevation to check calibration of the model. By adjusting the scale of the isosurface until both the inner and outer basins contour lines were matched, a calibrated model was produced (Figures 3 and 4)

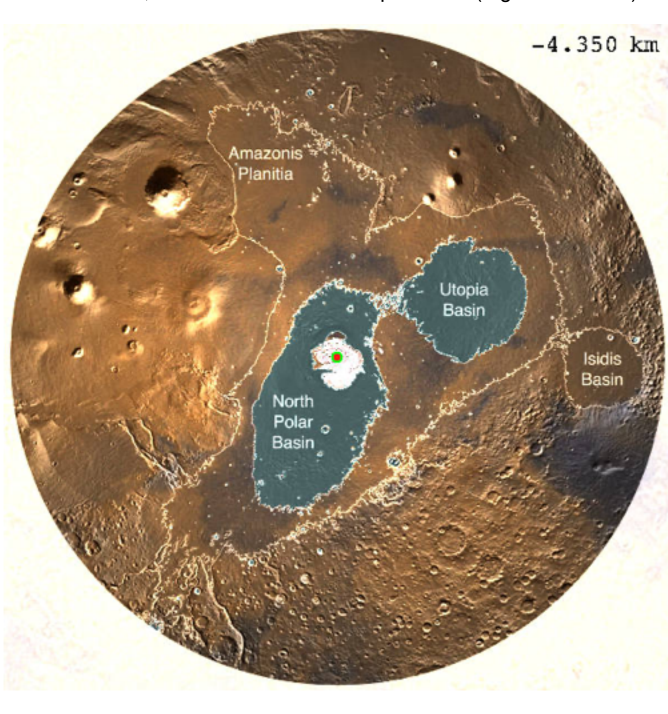


Figure 3. Inner basins 4.350 km below the Mars datum

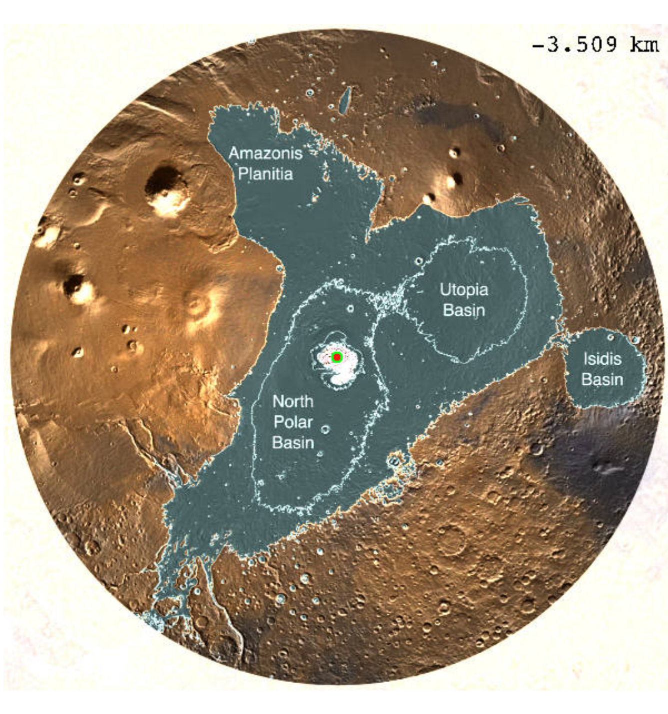


Figure 4. Outer basins 3.509 km below the Mars datum

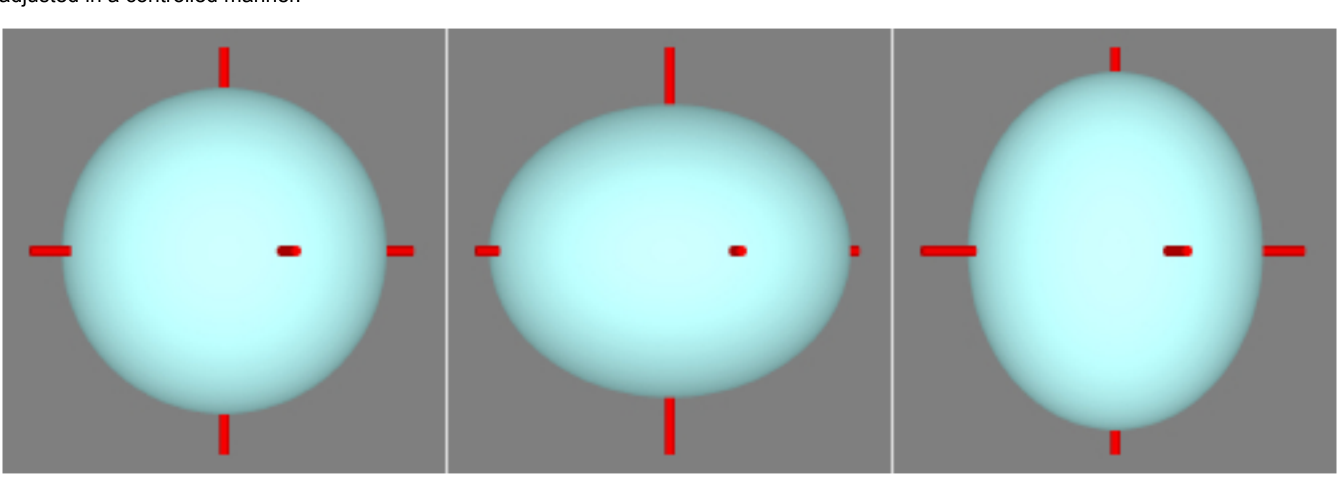
Matching the Shorelines

The ocean sphere in the model is, initially, a perfect sphere so it must be distorted to simulate a tidal bulge. I considered two types of bulge, an equatorial or oblate bulge and a polar or prolate bulge.

If Mars, orbiting the Sun as an independent planet, once had a global ocean creating the proposed shorelines, the ocean would have been distorted by planetary spin to the shape of an oblate spheroid.

If Mars, as asserted in the Saturn Myth, was one of the planets in the polar alignment configuration then the ocean shape would have been prolate.

To convert from a spherical ocean in the model, a scaling factor is used. Using Cartesian coordinates, the shape of the ocean sphere can be adjusted in a controlled manner.



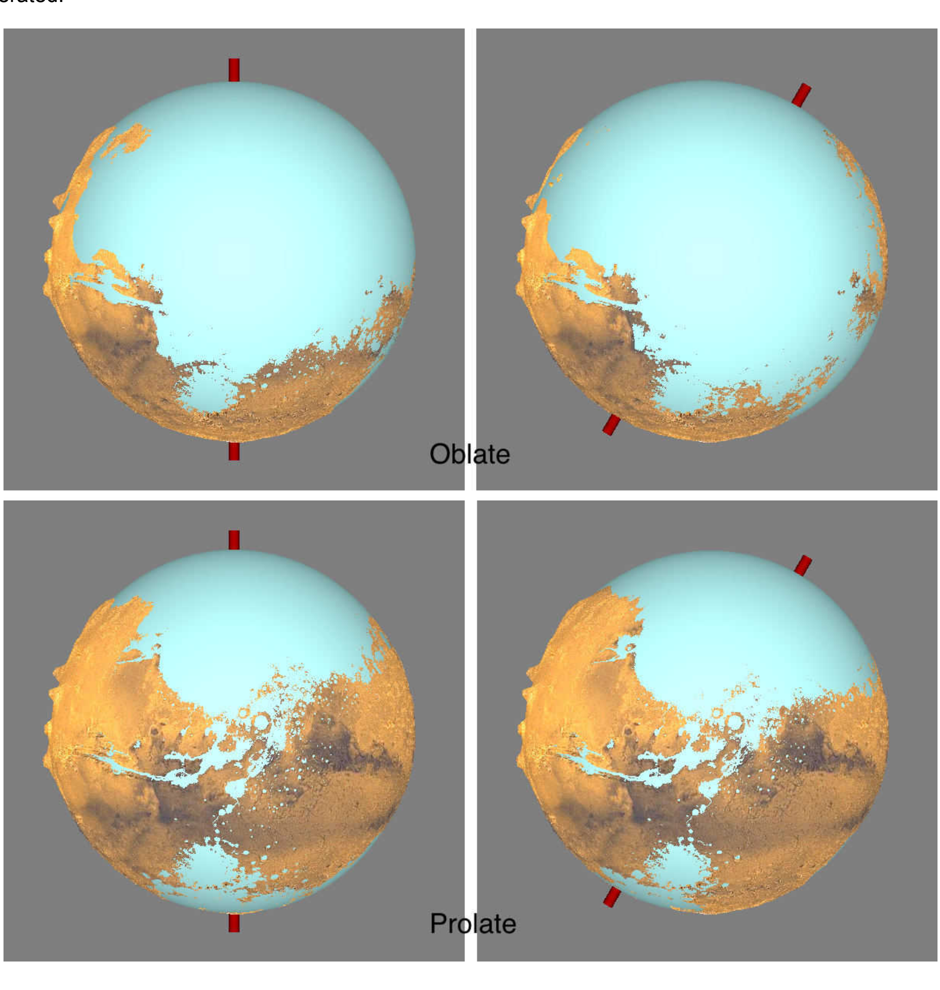
In these three images of an ocean sphere the Cartesian coordinates, x, y, z are represented by three red cylinders. The vertical cylinder is designated as the y-axis and is also the polar axis. The other two cylinders are the x and z axes. All are used for scaling. In the left image the sphere is unscaled, no tidal distortion (x, y, z = 1).

In the middle image, an oblate shape is created by scaling down the y-axis and proportionally scaling up the x and z axes (x = 1.1, y = 0.9, z = 1.1).

In the right image, a prolate shape is created by scaling up the y-axis and proportionally scaling down the x and z axes (x = 0.9, y = 1.1, z = 0.9).

All axes are scaled to allow a minimal number of manipulations when adjusting the shape of the sphere. The proportions used here are for illustration only. The proportional values used in matching shorelines are considerably smaller.

The following images show oblate and prolate oceans without (left) and with (right) latitude displacement of the pole. Topographic scale and tidal bulge are exaggerated.



Once the shape is created, the ocean pole can be displaced in latitude and longitude to place it anywhere on the planet. This distorted shape will then intersect the topography differently from the way the spherical ocean did.

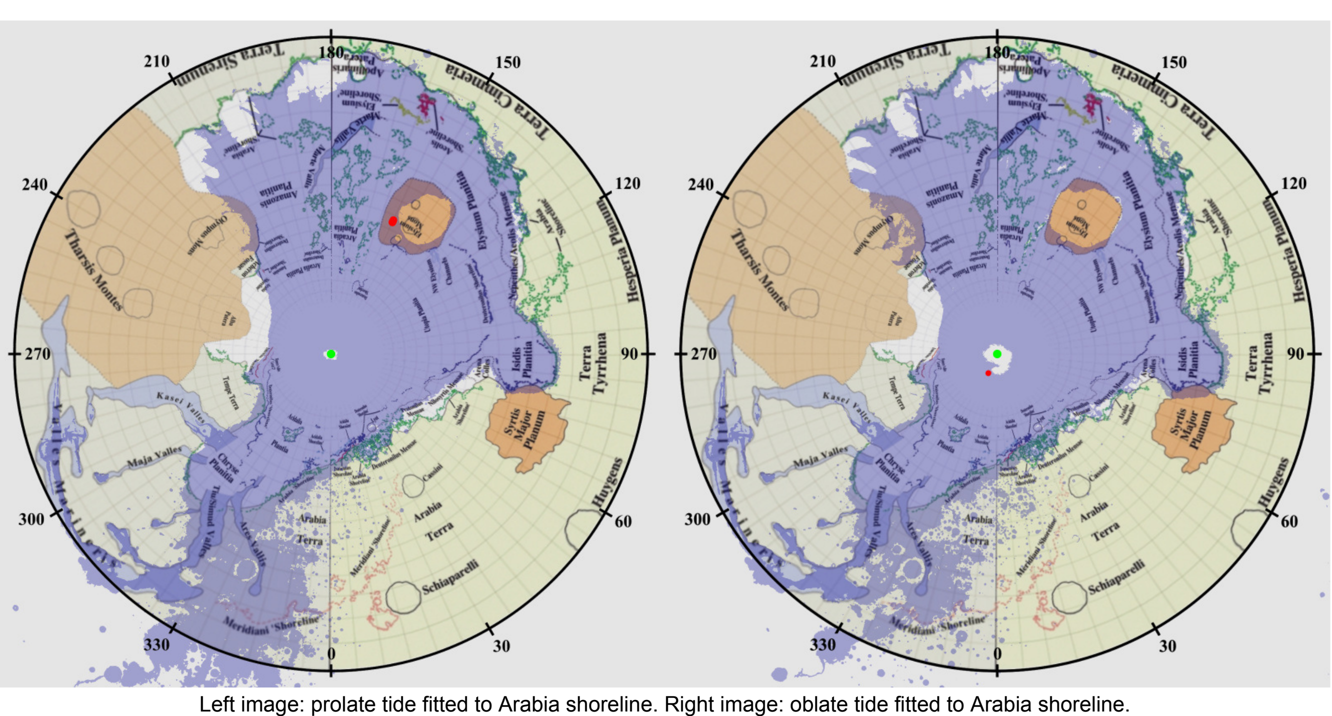
Using a polar stereographic projection of the shoreline map on the Mars isosphere, manipulation of the following ocean parameters can be used in an attempt to match the shorelines:

1. The type and magnitude of tidal bulge.

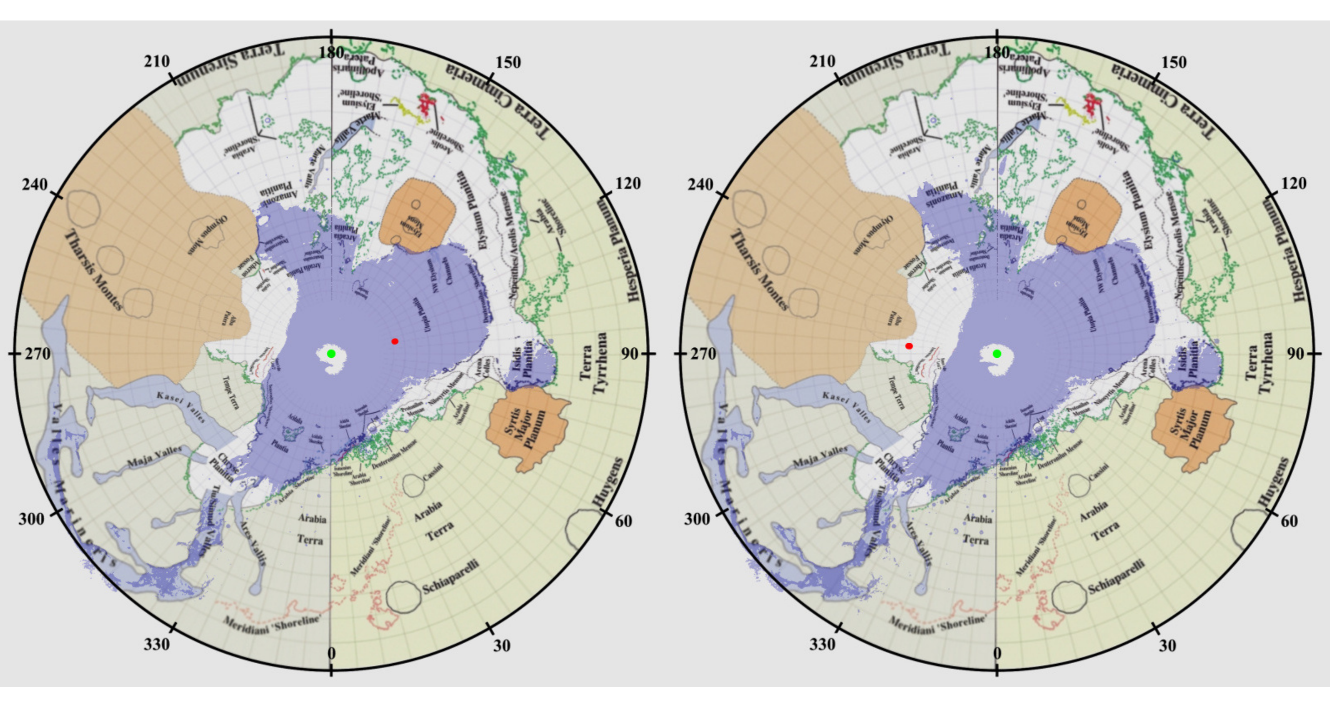
2. Displacement of the ocean pole in latitude and longitude.

3. Adjustment of the volume of water in the ocean.

The following figures show best fit results for two of Clifford and Parker's proposed shorelines, Arabia and Deuteronilus, with polar and equatorial tides.

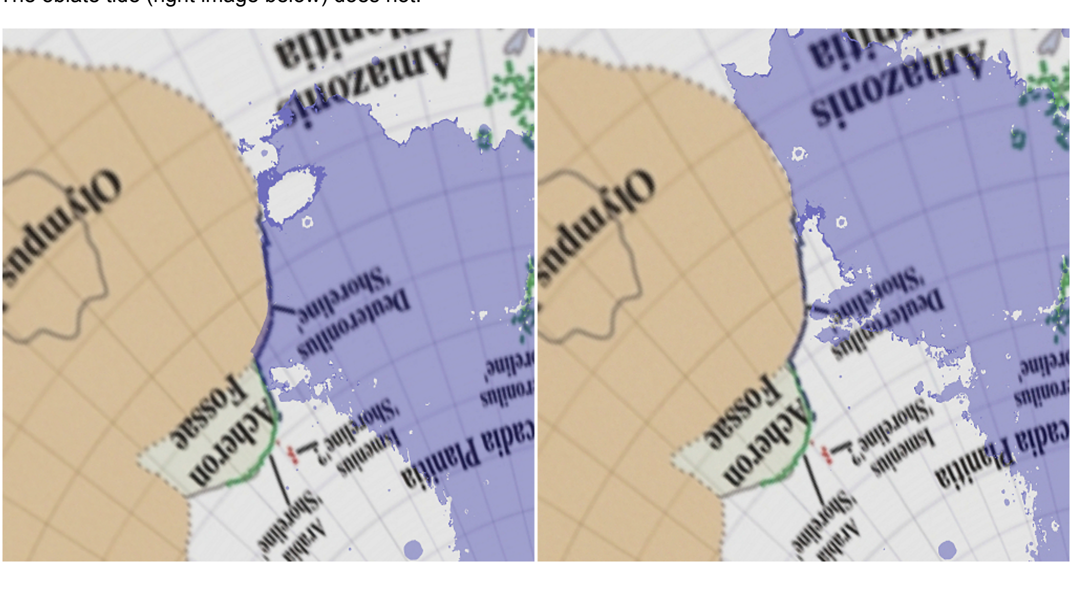


Left image: prolate tide fitted to Arabia shoreline. Right image: oblate tide fitted to Arabia shoreline.



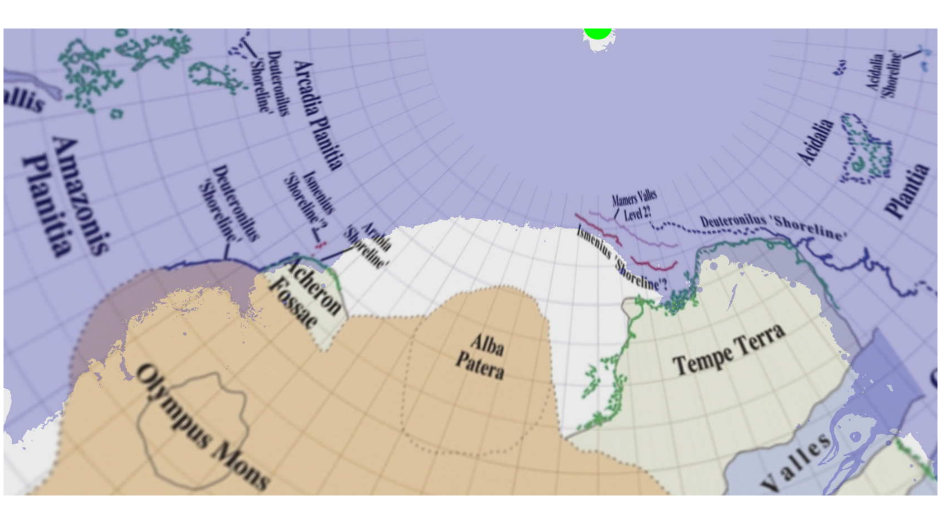
Left image: prolate tide fitted to Deuteronilus shoreline. Right image: oblate tide fitted to Deuteronilus shoreline.

At longitude 210-218, latitude 31N, there is a short section of the Deuteronilus shoreline. The prolate tide (Left image below) fits that section of the shoreline. The oblate tide (right image below) does not.



In several areas, terrain subsidence and uplift appear to have changed the elevation of the shorelines and lava flow incursions may have obliterated others.

The Arabia shoreline stops at longitude 217, interrupted by the Tharsis bulge, and picks up again at longitude 266 (see the full northern hemisphere Arabia figures). A small portion of the Arabia shoreline defines the northern edge of Acheron Fossae and is tilted upslope toward the Tharsis highland. Another portion of the Arabia shoreline, at the western edge of Tempe Terra, also is tilted upslope toward the Tharsis highland (See the following image). This implies that the Arabia ocean was emplaced prior to the highlands reaching their present elevation and extent.



The lines mapped by Clifford and Parker lie along an equipotential path as though created by a body of water shaped by gravitational forces and planetary spin. Indeed, my analysis indicates this is true. The elevation of the lines varies and can not be matched by simply placing a spherical ocean on the virtual Mars model. I believe that the variations have caused researchers to avoid trying to model a Martian ocean.

It is possible to determine the relative age of certain features on Mars; the Tharsis rise, Arabia Sea, Deuteronilus Sea, Acheron Fossae and Tempe Terra.

The Arabia Sea lines are interrupted at two places (south of Olympus Mons and east of Alba Patera) by the Tharsis rise indicating that Tharsis was created after the Arabia Sea had receded. In addition the Arabia lines at Acheron Fossae and Tempe Terra run upslope on Tharsis. The Arabia and Deuteronilus lines around Acheron Fossae are sloped as though Acheron Fossae itself was tilted by the rising of Tharsis and Alba Patera. This is illustrated in the animation.

It is apparent that the the oldest of the mentioned features is Acheron Fossae, which must have been an island in the Arabia Sea. The order then from oldest to youngest would be: Acheron Fossae and Tempe Terra formed; Arabia Sea emplaced then receded to form Deuteronilus Sea; Alba Patera-Tharsis formed, impinging upon Deuteronilus Sea just west of Acheron Fossae.

Afterword

Several issues presented themselves as I was performing this analysis.

Crustal deformation

The reader may notice that I did not model any crustal tidal deformation, although I did consider possible crustal deformation on Mars.

One scientist, assuming an equatorial tide displaced by polar wander, wrote of crustal deformation due to changes in the spin axis - but relatively little crustal deformation. He proposed pole positions ranging from 30 - 58 degrees north for Arabia and 66 - 84 degrees north for Deuteronilus. In my model the pole positions are more precisely determined. The pole location for an equatorial tide for Arabia is 80 degrees north and for Deuteronilus, 50 degrees north.

Clifford and Parker, in their paper, wrote: "assuming that the statistical distribution of Noachian elevations resembled that of today, a minimum of ~26-32% of the planet's surface would have been covered with water and ice." The graphic that accompanies this statement depicts water covering the same area as the Arabia ocean in this analysis.

Lacking a convincing argument for substantial crustal deformation, I opted to assume that the present elevations resemble those of the period when the oceans may have existed.

Ice, water and wind

Much discussion has transpired regarding the characteristics of the proposed shorelines claiming that the shorelines lack the physical evidence of wave action. Although, sometimes in the same breath, the writer admits that the final determination will require human presence on the surface.

And yet, the lines are equipotentials as though formed by a pooled fluid under the influence of gravitation and either a polar tide or an equatorial tide.

What if the "shorelines" are an artifact of large bodies of ice? Was Mars inundated by large volumes of water? If so, might that water have pooled and relatively quickly frozen before wave action could have an appreciable effect?

Alternatively, if Mars had little atmosphere at that time, there would have been little ability for wind to create waves. These questions aside, there is a surprising general correspondence between the putative shorelines and the superimposed oceans.

Calibration and accuracy

The MOLA digital elevation model (DEM) is the standard against which the other elements must be compared/calibrated. Accurate registration and scaling of the overlaid images of the Carr and Head map and the shorelines map are important in determining the degree of shorelines match.

The elevation values given in available literature for Mars' topographical features often vary from one source to another. Some are based on old information. The values given for Olympus Mons, for instance, range from 21 km to 27 km, and are not always based on the Mars datum. The MOLA DEM places the peak at 21.171 km.

The accuracy of MOLA data is given variously in available documents. Several sources allude to an accuracy of less than a meter and this is clarified in several places as "about a half meter" and "40 cm". This is ranging accuracy. The absolute accuracy of topographic elevations (radius) is +/- 10 m with a precision/resolution of 1 m. Horizontal accuracy is +/- 100 m (Reference 4). These tolerances are well below the resolution of the model.

Acknowledgement

My thanks to Dwardu Cardona and Frederic Jueneman for their constructive reviews during the preparation of this analysis.

References

(1) "The Evolution of the Martian Hydrosphere: Implications for the Fate of a Primordial Ocean and the Current State of the Northern Plains"

Icarus 154, 40-79 (2001)

Stephen M. Clifford, Lunar and Planetary Institute

Timothy Parker, Jet Propulsion Laboratory

(2) "Oceans on Mars: An assessment of the observational evidence and possible fate"

Journal of Geophysical Research, Vol. 108, No. E5, 5042 (2003)

Michael H. Carr, U.S. Geological Survey

James W. Head III, Department of Geological Sciences, Brown University

(3) Private communications from Michael Carr and James Head. (2008)

(4) "Rover Localization and Landing Site Mapping Technology for the 2003 Mars Exploration Rover Mission" (Page 9)

Submitted to *Journal of Photogrammetric Engineering and Remote Sensing* (2003)

Rongxing Li and Kaichang Di, Department of Civil and Environmental Engineering and Geodetic Science, Ohio State University

Larry H. Matthies, Jet Propulsion Laboratory

Raymond E. Arvidson, Department of Earth and Planetary Sciences, McDonnell Center for the Space Sciences, Washington University in St. Louis

William M. Folkner, Jet Propulsion Laboratory

Brent A. Archinal, U. S. Geological Survey

(5). "Coastal Geomorphology of the Martian Northern Plains"

Journal of Geophysical Research vol. 98, No. E6, 11,061-11,078 (1993)

Timothy J. Parker and Donn S. Gorsline

Department of Geological Sciences, University of Southern California, Los Angeles, CA.

R. Stephen Saunders and David C. Pieri

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA.