

UPDATING THE EVIDENCE FOR OCEANS ON EARLY MARS. Alberto G. Fairén¹, James M. Dohm², Tayfun Öner³, Javier Ruiz⁴, Alexis P. Rodríguez⁵, Dirk Schulze-Makuch⁶, Jens Ormö⁷, Chris P. McKay⁸, Victor R. Baker^{2,9}, and Ricardo Amils^{1,7}

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Different-sized bodies of water have been proposed to have occurred episodically in the lowlands of Mars throughout the planet's history [1], largely related to major stages of development of Tharsis [1,2] and/or orbital obliquity [3]. These water bodies range from large oceans in the Noachian-Early Hesperian, to a minor sea in the Late Hesperian, and dispersed lakes during the Amazonian. To evaluate the more recent discoveries regarding the oceanic possibility, here we perform a comprehensive analysis of the evolution of water on Mars, including:

1. Geological assessment of proposed shorelines.

Proposed martian paleoshorelines have been mapped [1,4-9] (see Figure 1 for a comprehensive description of the shorelines). Here we disregard Arabia shoreline [5] as a true paleoshoreline, as suggested by its elevational range and geologic relations, especially with respect to the Tharsis region. In fact, elevations in the putative Meridiani shoreline [8], are roughly similar to those of the Arabia shoreline in northeast Arabia, Utopia (not taken into account the Isidis basin), Elysium, and Amazonis regions [1,9]. A paleoshoreline through these Arabia shoreline portions and the Meridiani shoreline would be a better candidate to represent a true ancient oceanic limit.

1.a. Equipotentiality. After high-resolution MOLA topography analyses, it has been suggested that the Deuteronilus shoreline is the only putative paleoshoreline which correlates to an equipotential surface [10]. However, by taking into account lithosphere rebound due to water unloading associated with the disappearance of an ocean [11,12] or different thermal isostasy histories among regions [13], especially relevant for the Tharsis and Elysium areas, it has been argued that it is not necessarily true that a paleoequipotential surface must match a present-day equipotential surface. In any case, Meridiani-extended shoreline is much more close to an equipotential surface than Arabia shoreline.

1.b. Shoreline features. The limited geological evaluation of concrete locations of the shorelines [14] merits reconsideration: the absence of shoreline features would not imply dry conditions in the Noachian, as billions of years of mainly cold and dry climate have

followed the oceanic epoch. But, in fact, some features remain there even in such reduced test, unambiguously probing the presence of oceans.

Obviously, we found no evidence for shorelines of any type north of the central volcanic structure Alba Patera and west and southwest Olympus Mons, as these are areas of relatively young lava flows whose thickness may be great enough to completely bury all relief associated with

possible pre-existing coastlines. Thus, the analysis by Malin and Edgett [14] in Lycus Sulci, on the west flank of Olympus, is in itself invalid to test the presence of ancient (i.e., pre-Amazonian) shorelines. Equally, their analysis on the Acidalia Plains [14] searching for morphologies and landforms related to temperate-climate shorelines, resulting from the action of waves, results in fact in the discovery of lines of boulders, scour marks or gravel bars, associated to the action of ice-covered oceans [1], evidencing Arctic and Antarctic-like shore morphologies, as expected in a planet with episodic milder conditions in a long-term cold and dry climate.

2. A volumetric approximation to the plains-filling proposed oceans.

Topography in regions lower than the mean elevation of the main proposed paleoshorelines has been previously used to propose preliminary estimations of water volume in these putative oceanic basins [10,15]. But, as those studies are based on present-day topography, they can only provide lower basin volume limits. Indeed, if an ocean occupied the lowlands, the weight of the water column would result in a significant load on the lithosphere in the regions inundated by water [11,16-18], sagging the sea floor, and thus increasing the total volume of the water body. We have previously considered [19] the lithosphere rebound due to water unloading associated with the disappearance of an ocean to estimate the actual volume content of the ancient martian oceans. By assuming Airy isostasy, we calculated areas and volumes below mean altitudes of the proposed Meridiani, Arabia, and Deuteronilus shorelines, by using 32 pixel/degree maps produced from MOLA data. Our results are reproduced in Table 1.

3. Geochemistry of the oceans and derived mineralogies.

The Noachian oceans, and possibly also any subsequent liquid water-mass on Mars, were enriched in iron hydroxides and magnesium sulphate salts, as revealed by the MER Opportunity after analyses on the sediments deposited at Meridiani Planum [20]. The CO₂, SO₂ and water generated from the volcanism and flood outbursts would have produced the acidic conditions to generate extensive sulfate salt emplacement on the martian surface. Aqueous thermodynamic calculations considering a CO₂-dominated atmosphere and a steady supply of iron and sulphate to seawater that respectively raised concentrations up to 0.8 mM and 13.5 mM, result in acidic oceanic waters with pH<6.2 (pH~2 when iron is in the form of ferric ion), thus suggesting paleoenvironmental surface and near-surface conditions at least moderately acidic. This precluded carbonate formation by oceanic sedimentation as a widespread global phenomena [21].

4. Post-oceanic (i.e., Amazonian) evolution of the shorelines.

For the long-term evolution of the shorelines, we consider: (1) local and/or temporal changes in the effective elastic thickness of the martian lithosphere [22]; (2) possible local variations of the thermal structure of the lithosphere producing differential thermal isostasy [13,23]; (3) the emplacement of lava flows [16] and/or deposition of sediment [24] in the putative northern ocean basin region, such as recorded for the Early and the Late Hesperian, respectively; (4) water transfer between different regions [11]; (5) degradation of basins boundaries related to endogenic

or exogenic activity [7]; and (6) the influx of water into the basins throughout time [25].

5. Ultimate water evolution on Mars.

The possible fate of the ancient oceans includes escape to space and infiltration into the ground to form groundwater and permafrost. This later can be tested on future missions that follow up to the Phoenix mission. Phoenix will land in the northern hemisphere between 60 and 70 N and will dig down to ice cemented ground. A follow-up mission with a drill capable of reaching 10 meters could provide a core of ice-rich permafrost that may contain evidence of an early ocean.

References

[1] Fairén A.G. et al. (2003) *Icarus* 165, 53-67. [2] Dohm J.M. et al. (2001) *JGR* 106, 32,943-32,958. [3] Laskar J. and Robutel P. (1993) *Nature* 361, 608-612. [4] Parker T.J. et al. (1989) *Icarus* 82, 111-145. [5] Parker T.J. et al. (1993) *JGR* 98, 11,061-11,078. [6] Scott D.H. et al. (1995) *USGS Misc. Inv. Ser. Map I-2461*. [7] Clifford S.M. and Parker T.J. (2001) *Icarus* 154, 40-79. [8] Edgett K.S. and Parker, T.J. (1997) *GRL* 24, 2897-2900. [9] Ruiz et al. (2003) *LPSC XXXIV*, #1090. [10] Head J.W. et al. (1999) *Science* 286, 2134-2137. [11] Leverington, D.W. & Ghent R.R. (2004) *JGR* 109, E01005. [12] Oner T. et al. (2004) *LPSC XXXV*, #1319. [13] Ruiz J. et al. *PSS*, in press. [14] Malin M.C. and Edgett K.C. (1999) *GRL* 26, 3049-3052. [15] Carr M.H. and Head, J.W. (2003) *JGR* 108, 5042. [16] Kreslavsky M.A. & Head J.W. (2002) *JGR* 107, 5121. [17] Hiesinger H. and Head J.W. (2000) *JGR* 105, 11,999-12,022. [18] Thomson B.J. and Head J.W. (2001) *JGR* 106, 23,209-23,230. [19] Oner T. et al. (2004) *LPSC XXXV*, #1319. [20] Moore J.M. (2004) *Nature* 428, 711-712. [21] Fairén et al. (2004) in review. [22] McGovern P.J. et al. (2002) *JGR* 107, 5136. [23] Ruiz J. (2003) *JGR* 108, 5122. [24] Tanaka K.L. et al. (2001) *Geology* 29, 427-430. [25] Cabrol N.A. and Grin E.A. (2001) *Icarus* 149, 291-328.

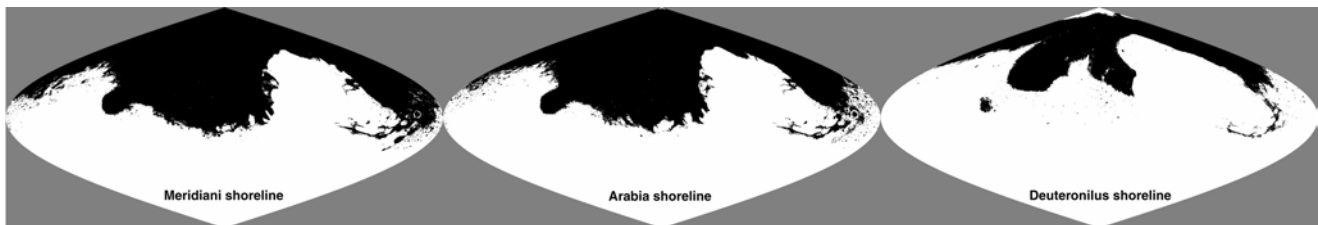


Figure 1: Main proposed martian shorelines. From left to right: Meridiani shoreline (the maximum extent of a Noachian ocean, see [1,9]), Arabia shoreline ([5], not likely a complete ancient paleoshoreline), and Deuteronilus shoreline ([5], representing the maximum extent of a Late Hesperian ocean [1]).

Shoreline enclosing basin	Mean elevation (m)	Basin area at mean elevation level (10 ⁷ km ²)	Volume (10 ⁷ km ³)	Mean depth (km)	GEL (km)
Meridiani shoreline	1500	5.35	10.66-15.46	1.99-2.89	0.74-1.07
Arabia shoreline	2090	4.67	7.67-11.12	1.64-2.38	0.53-0.77
Deuteronilus shoreline	3792	2.47	1.38-2.00	0.56-0.81	0.10-0.14

Figure 2: Basins elevations and areas for present-day topography, and lower (present-day topography) and upper (water load compensated by Airy isostasy) limits for basins volumes, mean depths and global equivalent layers (GEL). (See [19]).