A NOACHIAN MARS OCEAN GREATER THAN 50% OF PLANET'S SURFACE AREA? T. J. Parker[1] B. G. Bills[1] and S. M. Clifford[2], [1]Jet Propulsion Laboratory, California Institute of Technology (tparker@jpl.nasa.gov, bruce.bills@jpl.nasa.gov), [2] Planetary Science Institute, 1700 East Fort Lowell, Suite 106, Tucson, AZ 85719 USA (sclifford@psi.edu).

Introduction: We continue to study the formation, evolution, timing, and ultimate fate of a potential ancient Martian ocean. To date, we have identified upwards of a dozen distinct levels, from -4000 meters to +1200 meters elevation, that might be ancient ocean shorelines. We are using the global image and topography products for Mars to improve the precision of volume estimates and history of emplacement and de-leveling over time of proposed paleoshorelines around the planetary dichotomy boundary. These results should enable an assessment of relative timing of ocean formation and loss with respect to other major events of the Late Noachian through Late Hesperian, such as Late Heavy Bombardment and major volcanism, and address the potential habitability of the paleoclimate suggested by an ocean.

Global topography and high-resolution imagery: The acquisition and analysis of a global topographic database, from the MOLA data [1] and improved gravity models [2] made testing of the ocean hypothesis much more quantitative than it had been prior to the Mars Global Surveyor mission, in that heights of possible shoreline features, relative to an equipotential surface, and their lateral position could now be determined more accurately than had been possible prior.

Model-based predictions: Many investigations have taken a modeling approach to address the plausibility and volume of an ocean and whether it could have existed for an extended period of time without freezing [3-10]. Models were also described to help determine whether wind-driven waves in a relatively warm climate could produce the observed morphologies at the proposed shorelines [11-13], or if ice-shoving in a cold climate would have been more likely [14,15]. Other investigators relied more on topographic analysis of proposed shoreline locations to test the validity of the ocean hypothesis [16-18], identify and interpret the origin of specific geomorphologies consistent with an ocean [19, Erkeling et al. 2014; Swiader 2014 Di Achille, and Hynek, 2010) or investigate post-ocean tectonic deformation based on mapped levels (Perron et al. 2007; Ivanov et al., 2017).

My mistake: We have been using the global MOLA and regional HRSC topography to correct a misidentification of a geomorphic contact along the highland margin south of Elysium Planitia as equivalent to Contact 1 (Arabia Level), in Parker et al. (1989) through Clifford and Parker (2001). The elevation difference between this contact and Contact 2 in this hemisphere is of order 2000 meters, whereas in the east Acidalia region the difference between the two contacts is about 300 meters, so it's unlikely to be the same contact. We have re-designated this contact the Ma'adim Vallis Level.

Other relevant observations: Other recent publications (Rodriguez et al. 2016; Costard et al. 2016, 2019) have extended identification and modeling of potential tsunami-related morphologies first identified in the east Acidalia/west Deuteronilus region (Parker et al. 1989; Parker 1994; Parker et al. 2010) that may have been triggered by a large impact into the ocean.

Other modes of origin for the proposed shorelines and plains surfaces within them that do not necessarily require oceans, but often include catastrophic flooding in the same region, have also been proposed (e.g., Berman and Hartmann 2002; Burr et al. 2002; Fuller and Head 2002; Plescia 2003; Werner et al. 2003; Head et al. 2002, 2003; Vaucher et al., 2009). Vaucher et al. (2009) is of particular interest with respect to the ocean hypothesis because it deals with the Elysium Planitia "platy flow" materials that seem to require flood lavas with high effusion rates and very low viscosities. These flows exhibit morphologies that are also reminiscent of sea ice floes in the terrestrial arctic (e.g., Murray et al. 2005). The basaltic surface composition, instability of surface ice at the equator, and lack of compelling evidence of near-surface ice in this region calls the Elysium sea hypothesis into question, however.

Criteria for identification of "Levels:" The best preserved, presumably younger features consist of sharp albedo and plains unit contacts, erosional terraces, lobate flow fronts, swash rills, and sediment drapes that often lie on slopes and are elevated by tens to hundreds of meters with respect to the plains interior to them. All the Levels identified in the east Acidalia and west Deuteronilus area, initially in Viking Orbiter data, are of these types. Though locally they may vary in elevation by tens of meters, regionally they do define apparent planar surfaces that have been tilted downward toward the plains interior and toward Tharsis. This tilt toward Tharsis is very small – a small fraction of a percent – so volume estimates based on simple elevation assignments for each level should be reasonable first approximations.

Higher, presumably much older Levels were identified based on apparent broad, degraded terraces in the highland margin, particularly where it is

steepest, in places like east of Gusev crater, for example. These terraces can be recognized in the MOLA topography, but are not apparent in the imagery. Terraces similar in appearance can be found in many terrestrial settings, perhaps most notably along the southern California coastline at Camp Pendleton, where the land has been uplifted in at least three stages. These uplifted terraces are easily seen in contoured topographic maps of the area, but all but the last (where the San Diego Freeway resides) are difficult to see in monoscopic imagery.

Parker (1991) compared the morphology of the larger Medusae Fossae Formation mounds with that of terrestrial carbonate platforms, and suggested that, if the MFF were determined to be carbonate in composition, they might represent a sink for atmospheric CO2. Since they're not carbonates, but sulfates, the question now is whether sulfate platforms would exhibit similar morphologies in a sulfate-rich ocean. Once MOLA topography became available, it has been interesting to note that the summits of the larger mounds in southern Amazonis – Eumenides Dorsum, Amazonis Mensae, and Gordii Dorsum – as well as Aeolis Mons in Gale crater, are all at about +500 m elevation.

The highest elevation of a proposed shoreline is represented by a small non-branching channel connecting plains material to the north of Hellas with plains just interior to Isidis' south rim scarp. The topography south of this feature slopes downward into Hellas, and the topography north of it seems to connect several smooth plains surfaces among the Isidis mountains that slope eventually into the Isidis basin. If this elevation represents an ancient ocean shoreline, it suggests that greater than 50% of the planet was under water in middle Noachian times.

References:

[1] D. E. Smith et al. (1999) Science 284, 1495-1503. [2] F. G. Lemoine et al. (2001) JGR 106, E10, 23359-23376. [3] R. M. Williams et al. (2000) GRL 27, 1073-1076. [4] M. A. Kreslavsky and J. W. Head (2002) JGR 107, doi.org/10.1029/2001JE001831. [5] M. H. Carr and J. W. Head (2003) JGR 109, doi:10.1029/2002JE0001963. [6] M. H. Carr and J. W. Head (2019) Icsarus 319, 433-443. [7] W. X. Lou et al. (2017) Nature 8, No 15766. [8] R. M. Ramirez and R. A. Craddock, (2018). Nature Geoscience, doi: 10.1038/s41561-018-0093-9. [9] J. W. Head et al. (2018) LPSC 49, 2083. [10]. M. Turbet and F. Forget, (2019) Scientific Repts 9, 5717. [11] T. J. Parker, (1994) PhD, Univ. So. Cal., 200p. [12] E. R. Kraal et al. (2006) JGR 111, doi.org/10.1029/2005JE002567. [13] D. M. Banfield et al. (2015), Icarus 250, 368-383. [14] T. J. Parker and D. R. Currey (2001) Geomorphology 37, 303-328. [15] C. J. Barnhart et al. (2005) LPSC XXXVI, 1560. [16] V. E. Webb (2004). JGR 109, doi.org/10.1029/203JE002205. [17] G. J. and J. R. Zimbelman (2006) Icarus 85, 171-196. [18] S. F. Sholes et al. (2019) JGR 124, doi.org/10.1029/2018JE005837. [19] K. L. Tanaka et al. (2005) USGS map 2888. [20].

Name	Type Locality	Geomorphology	Elevation
Acidalia Level	East Acidalia	Sharp Contact	-4050 m
Deuteronilus Level	East Acidalia	Lobate Flow Fronts, Terrace	-3900 m
Mamers Vallis Level 2	East Acidalia	Terrace	-3820 m
Mamers Vallis Level 3	East Acidalia	Terrace	-3800 m
Ismenius Level	East Acidalia	Terrace, Swash Rills	-3785 m
Mamers Vallis Level 5	East Acidalia	Faint Contact	-3670 m
Arabia Level	East Acidalia	Terraces, Sediment Drapes, Albedo Contact	-3600 m
Elysium Level	Southern Elysium Planitia, ~3°S, 163°E	Platy Flow Margin	-2880 m
Mamers Vallis Level 7	East Acidalia	Faint Terrace Sediment drape?	-2800 m
Aeolis Level	Southern Elysium Planitia	Sediment Drapes, Deltas (e.g., di-Achille & Hynek)	-2540 m
Ma'adim Vallis Level	Gusev Crater Highland Slope South of Elysium Planitia	Ma'adim Vallis Delta Sharp Contact	-1640 m
Terra-Sirenum Level 1	Sloping Highland Margin East of Gusev	Degraded Erosional Terrace	-1000 m
Terra-Sirenum Level 2	Sloping Highland Margin East of Gusev	Degraded Erosional Terrace	0 m
Aeolis Mons Summit Level	Gale crater, Eumenides Dorsum, Amazonis Mensae, Gordii Dorsum	Summit Elevation of MFF and Gale Crater Mounds	+500 m
Hellas-Isidis Spillway Level	Topographic Trough Between Hellas & Isidis ~9°S, 78°E	Possible Spillway Channel Linking Hellas & Isidis, ~10.3°S, 74°E	+1200 m