AN EVOLUTIONARY TIMESCALE FOR THE WATER ON MARS. Alberto G. Fairén, Miguel A. de Pablo. Seminar on Planetary Sciences, Universidad Complutense, 28040 Madrid, Spain. Fairen.ag@terra.es

Introduction: Starting on the idea of long-term stability of large bodies of water on the surface of Mars [1], a timescale for the water and its geomorphological associated features can be proposed. The northern landforms seem to provide independently estimates of the water budget depending on the elevations and areal extent of the basin, that indicate the standing of many water bodies, some of them in such recent times as Amazonian age. These features can be taken as evidences of correlative stages in an oceanic to lacustrine evolutionary scenario. The process would include a first Late Noachian step, portrayed by the Martian lowland/highland boundary, when a large ocean covered all Mars' septentrional third. Evidence for the Martian boundary as the ancient planet's ocean shoreline will be presented, in order to test the stability of the original great ocean, that has been historically debated [2,3]. After a dry intermediate period, a secondary, Early Hesperian ocean would have extend over the deeper areas in the lowlands. Finally, a number of lakes would have worked when Mars came through another thermal cycle, after Hesperian-age outflow channels formation. The inner ocean and the lakes shorelines are almost widely accepted. This hypothesis holds on the assumption that Mars' total water amount would have been progressively reduced in time, due to planet's low gravity, impact erosion and hydrodynamic escape.

The lowland/highland boundary as the first Martian shoreline: Since the possible oceanic inner shoreline (or Contact 2) and the paleolakes have been deeply analyzed and described in papers by Parker [2,4], Scott [5], and Head [3], evidence to support the Martian boundary (or Contact 1) as the first Mars' ocean shoreline will be addressed here, basing on:

i) The surface between Contact 1 and Contact 2 is rougher than the surface below this, but it is smoother than the surface above Contact 1, in the highlands. This points to an intermediate age for this soil crown, between the southern-highlander litosphere and the inner-last ocean.

ii) Total water capacity below Contact 1, taking its mean level of -1680 m, is 9.6×10^7 km^3 [6], volume that lies between the minimum value for the one that flowed through the outflow channels (0.6×10^7 km^3) [7] and the maximum water contain estimated for regolith (5 to 20×10^7 km^3) [8]. Subsequent to the water losing through time, following wet episodes would be also below this upper limit.

iii) Not only the unstable position of Contact 1, but Contact 2 indeed, can be explained as a result of increases and decreases in the incoming volume of water through time [9].

iv) The two major deviations from level through Contact 1, in the northwest of Elysium volcano and in the north of Alba Patera, can be explained as an identification of both Contacts 1 and 2, and as a large gap in the location of Contact 2, respectively [10].

v) Both elevation variations in Contact 1, with ranges over 11 km, and the contrast between the high Tharsis Dome and the low Arabia Terra elevations, seem to be excessive for a log-term water content, except when we take the mean level of this shoreline, -1680 m, as a plausible sea-level. The high elevation zones over this mean level would have been pre-oceanic tectonic deformations, as cliffs, in the first *Oceanus Borealis*; or even postformation elevation movements, as Tharsis Dome seems to be, since it lacks pre-Hellas (~4 Gy) magnetic anomalies. Likewise, the areas below the main level would have had many different origins, as discussed following.

vi) The own presence of the following reduced and extended in time water-masses, whose associated sedimentary deposits and water resources could alter the primitive geomorphological features of Contact 1. In this sense, it's remarkable the possibility of the infilling of the northern plains by a mud ocean, even during the Late Hesperian to Early Amazonian [11].

vii) If Contact 1 is, in fact, the remanent structure of Mars' first ocean shoreline, aged at least 4 Gy, this allows a large temporal lapse to erase its associated geological features. Postformation modification would be due to every erosion processes on a terrestrial planet's surface: volcanic, eolian, glacial and impact cratering events. But the main causes for the bad approximation of this outer shoreline to an equipotential surface would be the "Late Heavy" great impact cratering, contemporary to this first ocean disappearance, and even the cause of it; and possible vertical movements, structural changes, isostatic rebound or loading time after the original equipotential line formation, supported by the paleoplate tectonics in Mars [12], the Early Hesperian tectonic and volcanic deformation in Utopia Basin [13], and the tectonic activity throughout Hesperian and Early Amazonian ages around Tharsis [14].

Notwithstanding, the relief of the lowlands is hard to believe as originated in oceanic processes when the morphology is tested from one side of the ocean, in Utopia Basin, to the other, near Alba Patera: although both ocean sides are flat terraces, Utopia's shoreline features have its higher ridge bordering the landward side, while Alba Patera's have its raised ridge bordering the oceanward side [15]. In addition, Mars Orbiter Laser Altimeter (MOLA) has revealed a network of ridges, perpendicular to the compressive stress direction in each situation, covering the martian lowlands; in some cases, the ridges are coincident with the outer shoreline. These morphologies point to a tectonic deformation since the orientations of both shorelines are consistent with a compressive tectonic origin. So, a reasonable conclusion is that post-oceanic tectonic deformation, over 4 Gy., seems to have been the main cause for the non-clear identification of the outer contact as the first Martian ocean shoreline.

A timescale for the cyclical metastability of water on Mars: Recovering Baker's proposal of a great ocean over all Mars' septentrional third, whose shoreline would have been the boundary and that would have been almost stable repeatedly over planet's surface [1]; following with Parker's estimation of a semi-permanent and perhaps ice-covered ocean on the Martian lowlands, with two well-defined shorelines, that might have been present until as recent times as Amazonian age [4]; and taking Scott's proposal of many paleolakes instead of a single ocean on the plains [5], it can be pointed out at least three ages of long-term stability of water bodies on the planet's lowlands: a first great ocean covering the northern plains completely, during the Middle to Late Noachian; a secondary, Early Hesperian and smaller ocean over the low-altitude lands on the lowlands; and an continuous Late Hesperian to Amazonian (even contemporary) lacustrine epoch with temporary stability of small water bodies, maybe ice-covered in the later stages.

The main problem to determine a definitive timescale is the total water amount on Mars' surface throughout its history, which remains uncertain. Greeley [16] estimated that $6.6x10^6$ km^3 was released through volcanism, most of it during Early Hesperian age. But, in a parallel with the Earth and Moon, the volcanic rates may have been higher on Mars in its earliest history. So, much more water could have been present in Mars' surface along Noachian age, when the first oceans may have condensed on the lowlands. Thus, it has been proposed that the Tharsis rise at Noachian time released a total amount of ~$3x10^8$ km^3 of magmas, which volatile content would have produced the equivalent of 1.5-bar CO_2 and a global layer of water of 120 m thickness [17].

There are a large number of facts that answer for the stability of a large body of water in the Late Noachian and a secondary and reduced one in the Early Hesperian: the assessment epoch of the lowlands, at Noachian time [15], confirmed recently by the discovery of more than 550 buried impact basins, not detectable in Viking imagery, that have been revealed by MOLA data [18]; the higher expected heat flows [19] and erosion rates [20]; the valley networks [21]; and the timing of extensive denudation of the highlands, limited to an interval of 350-500 m.y. in the late Noachian [22]. In the case of the inner ocean, sedimentary deposits in Vastitas Borealis formation [23] strongly suggest the stability of a large body of water at the level of Contact 2 in the Hesperian age.

For the Hesperian to Amazonian paleolakes, Cabrol and Grin [9] found that the main lacustrine activity is placed between 3.1 and 1.8 Gy., and rises the maximum in the second half of the Late Hesperian, about 2.5 to 2.1 Gy. Activity follows through Amazonian age, especially around 0.6 and 0.4 Gy., besides Amazonian lakes are less numerous. Rice [24] presented evidence for a wide range in age aqueus sedimentary deposits in Elysium Basin, pointing to the stability of Noachian to Amazonian lacustrine environments. Besides, crater lakes associated with Ma'adim Vallis were water filled during Hesperian and Amazonian time [25], and significant volume of water in Utopia Basin during the Late Hesperian has been proposed [13], as well as subsurface outflow and surface runoff at south Elysium-north Terra Cimmeria, from Late Noachian to Early Amazonian [14].

Finally, almost contemporary [26] and abundant [9] water activity has been suggested on Mars, including very recent and short duration episodes of relatively dense atmosphere with movement of water associated [27]. In fact, some crater lakes were formed so recently [28] that the climatic conditions were then quite similar from those of today. This water stability in concrete periods over Martian history until today raises many questions about life's adaptation and survival during the extreme cold, dry ages. Recent investigations [29] on photosynthesizing cyanobacterial communities in terrestrial desert soils, which lie inactive deep in the ground for months and only rises the surface for light exposure after the rare desert rain falls, could provide an exciting scenario for life on Mars.

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