SIMULATED DESTRUCTION OF PUTATIVE MARTIAN SHORELINES BY CRATER POPULATIONS.

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Introduction: Visions of early oceans in the northern hemisphere of Mars capture the imagination. If such oceans existed, Mars likely hosted Earth-like and habitable environments for long periods of time. The likelihood of such oceans is an important piece of the early Martian climate puzzle.

The primary observational evidence for early martian oceans is a set of globe-circling candidate shorelines first described about 30 years ago [1]. The origin of these "levels" has been debated since then and several problems have emerged upon close inspection. Notably [2,3],

1. The features trace a wide elevation range, often with large scatter over short distances.
2. Clear location data for many mapped levels have never been available, with many different versions and derivatives appearing in the literature. Only recently have reproduced mapping coordinates appeared.
3. Re-examination of some portions of the levels with contemporary, higher-resolution images does not support a shoreline interpretation

Additionally, it has been proposed that the older "Arabia Level" is older than 3.7 Ga and possibly as old as 4 Ga [4]. This would make it one of the oldest large-scale features on the martian surface, raising the question: *Could such an old shoreline survive for so long in a recognizable and mappable form?* Crater impacts, tectonic activity, volcanism, hydrology, and other forces all have the potential to obliterate the features over billions of years. Importantly, these processes are all expected to have been most intense early in martian history.

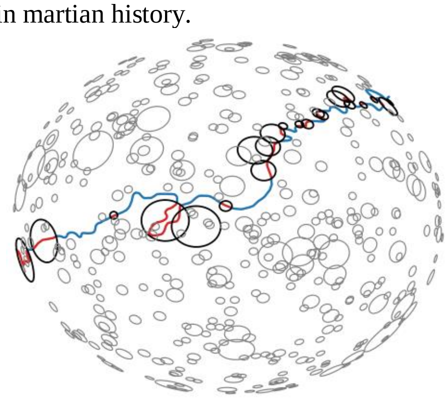

Figure 1: Example simulation with a small number of artificially large craters for visual clarity. The original Arabia Level [1] appears in blue, with impacted segments highlighted in red. Craters intersecting the shoreline are drawn in black and all other craters are drawn in gray.

Simulations: Here we estimate the effect of just one modification/destruction process on an early putative shoreline: impact cratering. With the Hartmann size-frequency bins commonly used for relative dating [5], we generate global populations of craters randomly distributed over the spherical surface of Mars and compute intersections with a putative shoreline, removing overlapping segments. Figure 1 shows an example. We include all craters larger than 100 m in radius but ignore intersections where the perpendicular overlap is less than 50 m, conservatively neglecting the smallest intersections.

For crater populations representing ages between 4 and 3 Ga, we compute 5 independent realizations with the mapped Arabia Level of [1] as reproduced by [2]. For better statistics, we also perform simulations using a hypothetical shoreline at a uniform latitude of 30º, which yield very similar results but are less computationally demanding. For all simulations, we test a set of "ejecta multiples," radially uniform fractions of each crater's radius beyond which the hypothetical shoreline is obscured by ejecta.

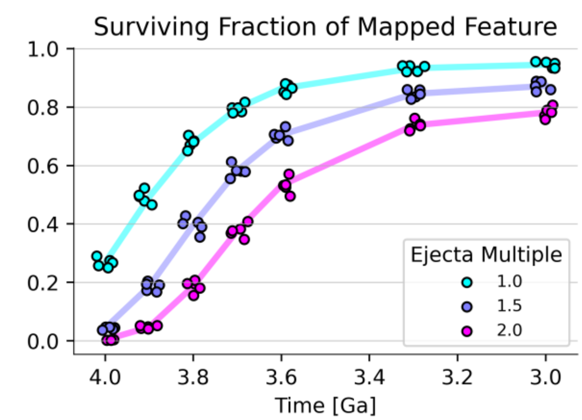

Figure 2: Fraction of the mapped putative shoreline of [1] that is not obscured by craters—the surviving fraction—for different ages, ejecta multiples, and random crater populations. Points are artificially "jittered" in the horizontal dimension for visual clarity.

Results: Figure 2 shows the surviving fraction of the mapped putative shoreline [1] after each simulation. Lines are drawn through the mean values of each group. The fractions are tightly grouped in all cases. For shoreline ages of 4 Ga, crater populations would directly impact at least 75 % of the mapped feature and >90 % of the feature for ejecta multiples of 1.5 or higher. The surviving fraction grows quickly for younger ages and is >50 % for all ejecta multiples after 3.6 Ga.

Figure 3 shows the longest continuous shoreline segment after cratering dissects the feature, averaged across 144 realizations with a uniform latitude hypothetical shoreline at 30º. Because of the large number of craters for all ages (>2.3 billion globally for 4 Ga), the longest continuous segment is very short compared to the original length of the hypothetical shoreline (~18,000 km) and to mapped features appearing in the literature. From the minimum perpendicular overlap of 50 m and the minimum crater radius of 100 m, we know the gap between any two segments must be larger than ~170 m in these simulations.

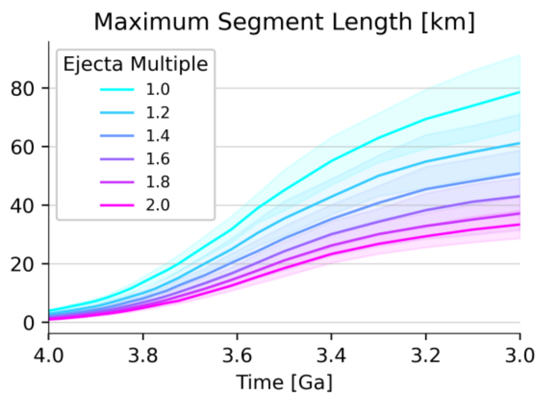

Figure 3: The maximum length of any continuous shoreline segment after cratering. Each line shows the mean value across 144 realizations with a uniform latitude shoreline. The standard deviation is shown by the bands bracketing each line.

Additionally, segments are strongly skewed toward shorter lengths. Figure 4 shows a histogram of representative segment lengths with a logarithmic vertical axis. The distribution is almost perfectly exponential. More than half of the segments are shorter than 8 km, 95% are shorter than 34 km, and the longest segment in any simulation and for any age is 136 km.

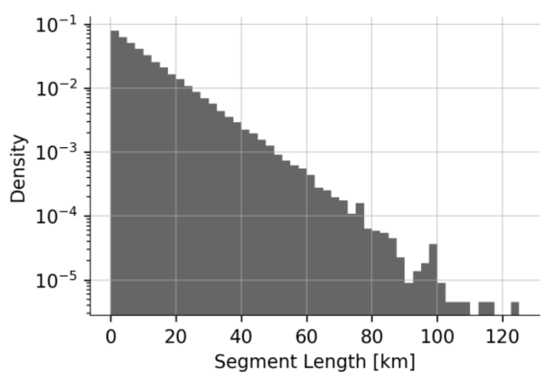

Figure 4: A histogram of segment lengths using the combined segments of 100 realizations at 4 Ga, an ejecta multiple of 1, a minimum crater radius of 500 m, and a uniform latitude shoreline at 30º.

Implications: Any very old shorelines, certainly ≥4 Ga, would be almost entirely obscured and/or destroyed by impacts. Even assuming ejecta play no role (ejecta multiple = 1), greater than 70 % of the feature would very likely be directly intersected by craters. It is extremely unlikely that shorelines with ages ~4 Ga are observable on the global scale today.

Substantial fractions of slightly younger potential shorelines, 3.7-4 Ga, would also be intersected by craters. However, this fraction is sensitive to the age and the role of ejecta. Our simulations suggest that at most 80 % of a shoreline in this age range would survive, but probably much less.

For all ages 3-4 Ga, the hypothetical shoreline is significantly disrupted and broken up into discontinuous segments. Even if most of the shoreline survives, large continuous segments are exponentially unlikely. The *largest* continuous segments are shorter than 80 km, on average, and most segments are shorter than 10 km. This is a straightforward consequence of the large number of smaller craters for any age. If the shorelines are real, any remapping efforts with high resolution imagery should expect many gaps along presently observable portions, not a globally continuous feature.

Further Discussion: We emphasize that cratering is just one mechanism by which ancient shorelines would have been modified/destroyed. Accounting for other processes will decrease the surviving fraction of features at any age, perhaps substantially.

Our simulations include impactors no smaller than 100 m in radius, but gardening by craters with diameter of 10 m or less was likely quite significant on surfaces >3.7 Ga [6]. Future work may explore the role of smaller craters in a geographically restricted domain.

Finally, we note that we have adopted general, geographically random crater distributions because there is no global crater database with craters as small as 100 m in radius. Additional simulations could be performed with different crater populations and recommendations would be welcome.

References: [1] Parker et al. (1993) *JGR, 98, 11061-11078.* [2] Sholes et al. (2019) *JGR: Planets, 124, 316-336.* [3] Sholes et al. (2021) *JGR: Planets, 126.* [4] Citron et al. (2021) *Nature, 555, 643-646.* [5] G. G. Michael (2013) *Icarus, 226, 885-890.* [6] Hartmann et al. (2001) *Icarus, 149, 37-53.*

Additional Information: All files used to produce these results are publicly available:

- `github.com/markmbaum/shoreline-survival`
- `doi.org/10.5281/zenodo.5821870`
- `doi.org/10.5281/zenodo.5821984`