**JEZERO CRATER AND THE TIMING OF AN EARLY MARTIAN OCEAN** Mark Baum[1,*] and Robin Wordsworth[1,2]. [1]Department of Earth and Planetary Sciences, Harvard University, [2]School of Engineering and Applied Sciences, Harvard University, *markbaum@g.harvard.edu.

**Introduction:** The Mars 2020 Rover will investigate Jezero Crater, the site of an ancient fluvio-lacustrine system. The crater was fed by two valley networks and hosted an open basin lake with a clear outlet channel [1,2]. Crater counting of Jezero's watershed indicates that fluvial erosion occurred before about 3.83 Ga in the Late Noachian, broadly consistent with many other large valley networks [3]. Remnants of an exceptionally well-preserved delta lie in the crater [1,2,4] and are primary targets for *in situ* investigation. Mineralogical analysis of orbital data indicates the delta is primarily composed of detritus that was aqueously altered prior to fluvial delivery [5]. Piecing together the hydrological history of the region and relating it to the global climate history is a primary objective.

Recent work has shown that removing the global topographic contribution of Tharsis corrects much of the long-wavelength topographic variation of the "Arabia shoreline" on Mars. Fitting shoreline elevation to pre-Tharsis topography implies an early ocean with sea level of -2.3 km before most of Tharsis formed. The proposed ocean is thought to have existed before 4 Ga, and perhaps quite early in the Noachian [6]. The shoreline may not be real [7], but the implications of its timing are worth examining.

**Jezero Topography:** The top two panels of Figure 1 show the global topographic contribution of Tharsis and the same contribution in the region surrounding Jezero [6,8]. Because Jezero is near the antipode of Tharsis, subtracting the modeled topographic contribution of Tharsis lowers the crater's elevation by about 2 km. As a result, the crater and its surroundings would be deep underwater in the presence of the proposed ocean. The bottom panel of Figure 1 shows areas that would be below a sea level of -2.3 km. In this scenario, the entire region is submerged. Here the outlet channel on the eastern rim of Jezero would begin at an elevation of roughly -4.4 km, or about 2 km below sea level.

**Timing of Events:** Jezero sits on the edge of the Isidis basin, which formed at about 3.96 Ga [9]. Fluvial activity at Jezero ceased at about 3.83 Ga [3]. The timing of Tharsis growth is not well understood, but it appears to have been complex, continuing into the Amazonian [10]. The proposed Arabia ocean occurred before about 4 Ga and before most of Tharsis was built [6].

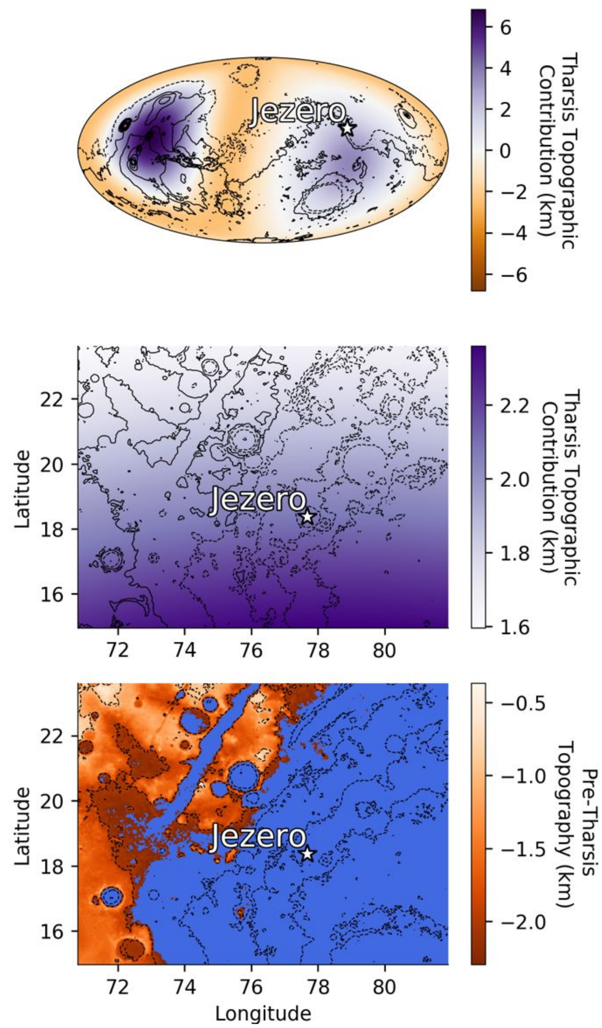


**Figure 1:** Jezero in the context of a pre-Tharsis ocean at -2.3 km. *Top:* The global topographic contribution of Tharsis [6,8] with present-day topographic contours. *Middle:* A close-up view of the Tharsis contribution in the Jezero region with present-day topographic contours. *Bottom:* Jezero topography with the Tharsis contribution removed, a uniform sea level of -2.3 km, and pre-Tharsis topographic contours.

**Implications:** As proposed, the Arabia shoreline formed in the Early Noachian, before Tharsis and perhaps before the Hellas, Isidis, and/or Argyre giant impacts. This would make the shoreline one of the oldest features on the surface of Mars and raises issues. If, however, the shoreline is younger than proposed, we might expect to see some sign of the ocean at Jezero.

*Very Old Shoreline:* Older features are more likely to be obscured and eroded by subsequent activity. Melted and vaporized ejecta from giant impacts should have covered much of the shoreline terrain. For example, the Isidis impact alone is estimated to have emplaced over 200 m of material globally [11]. Smaller impacts after the shoreline formed, which were still frequent in the Noachian, would have produced significant amounts of ejecta and could have struck the feature directly. An old shoreline must also survive longer and more intense periods of hydrological, tectonic, and volcanic activity with the potential to erode, break, and resurface it. Many forces at work on the surface of early Mars would decrease the probability of an ancient shoreline being continuously identifiable from orbit over thousands of kilometers.

*Younger Shoreline:* Contrary to the proposed sequence of events, if the shoreline is younger, its chances of survival increase. However, an Arabia ocean is not possible during the open basin lake at Jezero, as it would submerge the crater under more than a kilometer of seawater. It is also unlikely that the Arabia ocean existed after about 3.83 Ga, when fluvial activity at Jezero ceased. In this case, we might expect shoreline features about 100 km upslope of Jezero unless they were selectively obscured there, but none have been identified. We might also expect coastal or marine sediment stratigraphically above the delta deposits, but our current understanding of stratigraphy at Jezero does not include signs of this [5].

Perhaps the shoreline formed in the window of time after the giant impacts but before lacustrine activity at Jezero. Here again, we expect shoreline features upslope of Jezero, but they appear to be absent. Marine sediment might be found throughout the submerged area but below the lacustrine sediments. The "mottled terrain" is the only unit to fit this basic description [5], but its provenance is not clear. It displays curious banding, drapes underlying topography, and, as mapped in [5], is roughly confined to an area that would have been submerged. However, it appears to be part of a larger, regionally identified unit that may span areas beyond the hypothetically submerged terrain and has not been interpreted as an ancient sedimentary package [12,13,14].

**Further Investigation:** The possibility that any features in Jezero are marine in origin will be determined by *in situ* investigation of Jezero by the Mars 2020 rover and further scrutiny of orbital data. To our knowledge, the "mottled terrain" is the only stratigraphic unit that is plausibly related to an ancient ocean, although further examination of currently available data on this unit may already rule it out.

The likelihood that an early Noachian shoreline could survive giant impacts, gardening by smaller ones, and modification by other processes deserves attention. This likelihood could be assessed with some simple modeling.

Although several studies have attempted to rectify the topographic variation of shoreline features on Mars, few have sought to constrain the age of shoreline bearing terrain or even examine the features up-close [7]. More direct estimates of shoreline ages could tell us if they are as old as proposed.

**References:** [1] Fasset and Head (2005) *GRL, 32*. [2] Schon et al. (2012) *Planetary and Space Science, 67*. [3] Fasset and Head (2008) *Icarus, 195*. [4] Goudge et al. (2017) *EPSL, 458*. [5] Goudge et al. (2015) *JGR: Planets, 120*. [6] Citron et al. (2018) *Nature, 555*. [7] Sholes et al. (2019) *JGR: Planets, 124*. [8] Matsuyama and Manga (2010) *JGR, 115*. [9] Werner (2008) *Icarus, 195*. [10] Anderson et al. (2001) *JGR, 106*. [11] Toon et al. (2010) *AREPS, 38*. [12] Ehlmann et al. (2008) *Science, 322*. [13] Ehlmann et al. (2009) *JGR, 114*. [14] Mustard et al. (2009) *JGR, 114*.