

**THE CLIMATE AND HYDROLOGY OF THE JEZERO CRATER PALEOLAKE.** D. G. Horvath<sup>1</sup>, J. C. Andrews-Hanna<sup>2</sup>, <sup>1</sup>Planetary Science Institute, Tucson, AZ (dhorvath@psi.edu), <sup>2</sup>Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ

Jezero crater, with several fan deposits [1, 2], an outlet valley [1, 3], and aqueous mineralogy [2, 4, 5] indicating the past presence of a long-lived lake within the crater, is an ideal location for a past habitable environment on Mars. The inlet and outlet valleys are enclosed by a topographic contour at -2395 m, though lake levels could have reached -2260 m prior to the initial breach based on the morphology of the rim [1]. The stratigraphy of the delta is consistent with a steady rise in the lake level, stabilized by outflow from the basin when the lake reached its crest at -2395 m [4] requiring persistent inflow to the lake without major fluctuations in lake level. While previous work has mainly focused on the surface hydrology of this system [3, 6], the fluvio-hydrologic evolution of the western Jezero delta is consistent with an integrated hydrological cycle, in which subsurface flow to the lake and/or watersheds helped maintain steady lake levels and persistent fluvial activity while surface runoff dissected the two watersheds and deposited the deltaic material. Thus, understanding the surface and subsurface hydrology and their influence over the fluctuations of a Jezero lake are important for understanding the depositional setting.

Here we present initial model results focusing on the climate of a steady-state lake at or above the outlet flow discharge elevation (between -2395 and -2260 m) and hydrological behavior associated with the different climates. Specifically, we focus on the surface and subsurface hydrology and lake metrics related to the biological potential of the past Jezero lake.

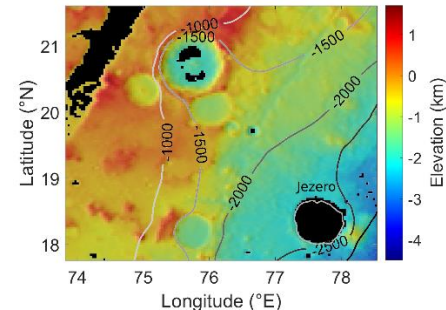
**Hydrological modeling:** The hydrological modeling was performed with a well benchmarked finite-difference model of unconfined saturated flow that incorporates an analytical solution to the overland flow equation [7]. The amount of precipitation that contributes to recharge and surface runoff are determined using an Earth-based empirical relationship (Budyko relationship) dependent on the annual potential evaporation ( $E_P$ ) and precipitation ( $P$ ) rates taken from climate data in semi-arid and arid locations on Earth [8]. We assumed that runoff discharge at the two Jezero inlets encompasses the areal extent of both delta watersheds [4], providing an upper endmember constraint on the aridity index. We focus on arid and semi-arid climates with aridity indices ( $\phi = E_P / P$ ) between 2 and 9.

The hydrological models were run on a MOLA-HRSC blended digital elevation model of Jezero crater and the surrounding region at a resolution of 2 km. We assumed a laterally homogenous aquifer with a vertically averaged permeability of  $3 \times 10^{-13} \text{ m}^2$  from the

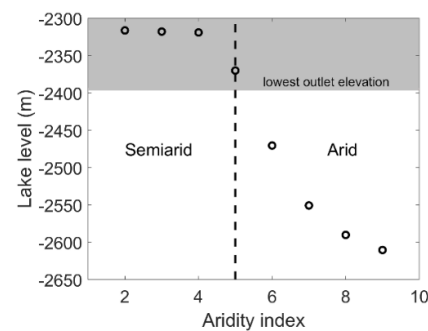
surface down with a  $100\times$  decrease down to 5 km depth [9]. Past work has shown that this assumed megaregolith aquifer is in good agreement with the cemented sulfate deposits found in Meridiani Planum [10] and the hydrologic evolution of Gale [7, 11].

From the models, we derive fluxes into and out of the Jezero lake and the relative importance of surface and subsurface inflow ( $Q_i$  and  $GW_i$ ) and outflow ( $Q_o$  and  $GW_o$ ) on the stability of the lake. We derive several hydrological parameters that correlate with biochemical conditions of lakes on Earth [12, 13]. These include the lake residence time ( $t_r = V / (GW_o + Q_o)$  where  $V$  is lake volume) and lake throughflow ( $E / I$  where  $I = GW_i + P + Q_i$ ) [12]. Finally, we compare these results to previous modeling at Gale crater [11].

**Climate dependence and hydrology:** Semiarid conditions ( $\phi \leq 5$ ) result in lake formation in Jezero above the elevation contour of the delta deposits and lowest outlet (Fig. 1, 2a) [1]. For all semiarid models, overspill occurs at the outlet above -2395 m. The semi-arid models have on average a surface to subsurface ratio of  $\sim 53:1$  with  $Q_i$  contributing 86% of the total lake inflow.  $GW_i$  contributes only 2% and  $P$  contributes 12%



**Fig. 1.** Modeled lake distribution (black) at Jezero crater for  $\phi = 4$  with hydraulic head contours in black and the -2395 m contour enclosing Jezero in gray.



**Fig. 2.** Lake level dependence on climate at Jezero crater. The estimated elevation contour for the deltas and outlet channel above which surface outflow is possible is highlighted in gray.

of the total influx to Jezero. For arid climate ( $\phi > 5$ ), lake levels lie below the -2395 m contour with no surface discharge from the crater (Fig. 2a). However, even in these arid models ( $5 < \phi \leq 9$ ) runoff dominates with  $Q_i$ ,  $GW_i$ , and  $P$  percentages comparable to the semiarid models.

**Lake throughflow and residence time:** For all models, net subsurface flow is negative and  $E/I$  is below 1 (Fig. 3a, c), indicating that some water is being lost to processes other than evaporation. This suggests that a past Jezero lake would have existed as a throughflow lake even during dry conditions when lake levels were well below the level of the deltas and outflow channel. Therefore, Jezero would not have experienced a period in which evaporation was the only outflow from the system, though evaporation dominates the lake outflux at  $\phi \geq 4$ . Groundwater throughflow can export salts from the lakes, thereby lowering the salinity of lake, and mitigating the formation of evaporite deposits.

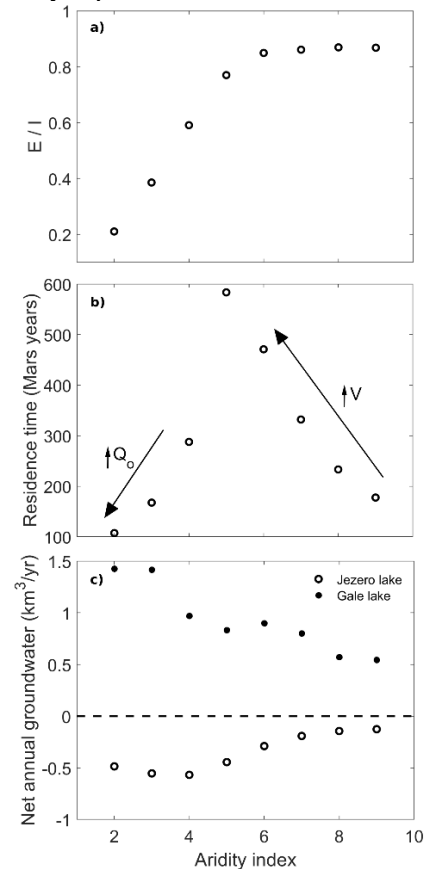
Lake residence times ( $t_r$ ) are on the order of 100s of years (Fig. 3b) and are comparable to the largest lakes on Earth [13].  $t_r$  is primarily controlled by the volume of the lake for arid models ( $\phi \geq 5$ ) and discharge to the outlet channel for semiarid models ( $\phi < 5$ ), and is sensitive to the absolute influx to the model. A  $P$  value  $3\times$  the value assumed here (near the upper limit for semiarid watersheds on Earth) would result in  $t_r \sim 30$  years, similar to 100 km<sup>2</sup> lakes on Earth [13].

**Comparison to Gale crater:** An initial comparison of these results at Jezero crater for the same conditions at Gale crater highlight the importance of crater setting on the lake hydrology. In the case of Gale, net subsurface flow for semiarid and arid climate conditions are always positive (Fig. 3c) and the  $E/I$  is 1 for all models indicating that evaporative flux is the only outflow from that system. Subsurface flux to Gale dominates the hydrology of those lakes, constituting  $>40\%$  of the total inflow [7, 11]. Under similar hydrologic conditions, a Jezero crater lake would have retained throughflow (Fig. 3c) limiting evaporite cementation as the climate shifted to more arid conditions [14].

**Conclusions:** We show that under semiarid conditions, the Jezero lake is a stable ( $<2$  m per year), seepage lake lying above the lowest inferred lake level [1]. Large  $t_r$  values [13] indicate that this lake would have been less susceptible to floods and droughts [12]. Furthermore,  $t_r$  values suggest that dissolved material and nutrients transported into the lake from the watersheds and subsurface could persist in the lake for 100s of years. Lakes on Earth with high  $t_r$  tend to have a higher biological potential [12], although this will depend on climate and other biochemical properties of the watersheds [15]. Regardless, these results suggest that although the Jezero lake was characterized by throughflow at inferred lake levels [1], material from

the watershed could have remained in the lake over periods sufficient to promote habitable conditions.

We also show that fundamental differences in the hydrologic system at Jezero and Gale crater result in different hydrologic behavior at the lakes under similar climates. This suggests that climate alone may not explain differences in morphology, mineralogy and sedimentary deposits found in martian crater lakes.



**Fig. 3. a)** The lake through flow metric and **b)** lake residence time ( $t_r$ ) dependence on climate for Jezero. **c)** Net groundwater flow for Jezero (open dots) and Gale (closed dots) crater lakes at different climates.

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