CANDIDATE CLOSED-BASIN LAKES ON MARS: INSIGHTS INTO TIMING AND INTENSITY OF FLUVIAL ACTIVITY. T. A. Goudge[1], K. L. Aureli[1], J. W. Head[1], J. F. Mustard[1], and C. I. Fassett[2], [1]Dept. of Earth, Environmental and Planetary Sciences, Brown University, Box 1846, Providence, RI 02912, [2]Dept. of Astronomy, Mount Holyoke College, South Hadley, MA 01075. (Contact: Tim_Goudge@brown.edu)

Introduction: Martian paleolakes are commonly classified as either open-basin (i.e., hydrologically open) or closed-basin (i.e., hydrologically closed) [*1-3*]. Open-basin lake activity is hypothesized to be primarily associated with the formation of valley networks [*3,4*], a process that largely ceased by approximately the Noachian-Hesperian boundary [*4-7*]. Closed-basin lake activity on Mars is less well studied, with no global catalog of such features compiled with post-Viking data [*1,2,8*].

Analysis of closed-basin lakes can be complicated by the fact that it is difficult to state with confidence that a particular studied basin contained a standing body of water for any substantial length of time – an inlet channel flowing into a topographic basin does not require the formation of a lake. Yet the formation of these features still requires fluvial activity on the surface of Mars, and they can provide insight into the past martian hydrologic cycle. Here we present a study of >200 candidate closed-basin lakes on Mars [*8*], focusing on the timing and intensity of fluvial activity associated with these basins. Our study also provides a broader context within which Mars Science Laboratory (MSL) results on lacustrine activity [e.g., *9*] may be interpreted, as Gale crater, the site of exploration by MSL, is a candidate closed-basin lake [*4*].

Methods: We examined a catalog of 224 closed-basin lakes contained within impact craters (e.g., **Fig. 1**) [*8*]. We studied the morphologic and stratigraphic characteristics of each basin, as well as the mineralogy of all basin deposits of inferred sedimentary origin (e.g., **Figs. 2, 3**). Morphology and stratigraphy were studied using image data from the CTX (~6 m/pixel [*10*]) and HRSC (<50 m/pixel [*11*]) instruments, the ~100 m/pixel global daytime infrared mosaic from the THEMIS instrument [*12,13*], and gridded MOLA topography [*14*]. Mineralogic analyses were conducted using data from the CRISM instrument [*15*].

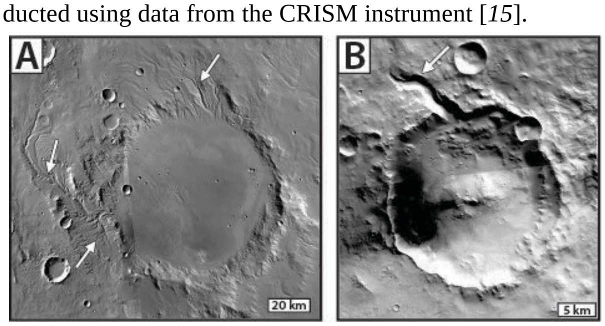

Figure 1. *Examples of the two classes of candidate closed-basin lakes. (A) Candidate closed-basin lake with long inlet channels (white arrows) at -18.8°N, 59.2°E. Mosaic of HRSC nadir images h8440_0000 and h0532_0000, and CTX images B21_017868_1583 and P16_007148_1628. North is up. (B) Candidate closed basin-lake with a short inlet channel (white arrow) at -9.6°N, 144.1°E. Mosaic of CTX images P16_007158_1703 and B02_010230_1715. North is to the right.*

Results: *Inlet Channel Morphology.* Our study revealed two major classes of closed-basin lakes, based on the morphology of the inlet channels (**Fig. 1**). The first class has inlet channels that are typically >50 km in length, are heavily degraded, show multiple branching tributaries, and are morphologically similar to typical martian valley networks [e.g., *4-6*] (**Fig. 1A**). The second class has inlet channels that are typically <10 km in length, have abrupt, amphitheater-shaped headwalls, and rarely have tributaries (**Fig. 1B**). We identified 25 closed-basin lakes with long inlet channels, and 199 with short inlet channels.

Stratigraphic Relationships. The two morphologic classes have distinct stratigraphic relationships. Closed-basin lakes with long inlet channels are often contained within heavily degraded basins (**Fig. 1A**). The inlet channel morphology is similar to typical martian valley networks [e.g., *4-6*], suggesting these basins were active prior to the Noachian-Hesperian boundary [*4-7*].

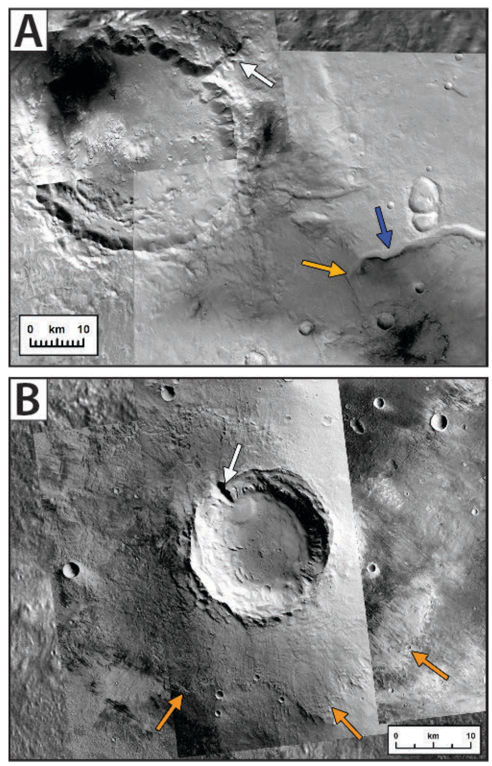

Figure 2. *Candidate closed basin lakes with short inlet channels (white arrow) and preserved continuous ejecta deposits (orange arrows). (A) Basin at 31.4°N, -13.0°E. Note that a nearby valley network (blue arrow) is superposed by the ejecta. Mosaic of CTX image B22_018055_2117 and HRSC nadir image h1498_0000 overlain on the THEMIS global daytime infrared mosaic. North is to the right. (B) Basin at 27.7°N, -124.5°E. Mosaic of CTX images P14_006693_2101, B08_012600_2072 and G19_025628_2068 overlain on the THEMIS global daytime infrared mosaic. North is down.*

In contrast, closed-basin lakes with short inlet channels are often contained within morphologically fresh craters (**Figs. 1B, 2**). Many of these basins have preserved continuous ejecta deposits (**Fig. 2**), which may directly superpose older martian valley networks (**Fig. 2A**). This suggests that these paleolake basins were active more recently in martian history, after the Noachian-Hesperian boundary.

Basin Deposit Mineralogy. We identified 55 closed-basin lakes with depositional fans at the mouth of the mapped inlet channels (e.g., **Figs. 2, 3**). We investigated whether any alteration minerals in these deposits are detrital (transported to the basin by fluvial processes) or authigenic (formed *in situ*) in nature using CRISM data. Our results suggest that, when present, alteration minerals within these deposits are detrital [e.g., *16*] (**Fig. 3**). While there are a very small number of closed-basin lakes with evidence for authigenic alteration mineral formation [e.g., *17*], this is atypical, and we find no evidence for widespread evaporite mineral formation [e.g., *18*] in the studied basins.

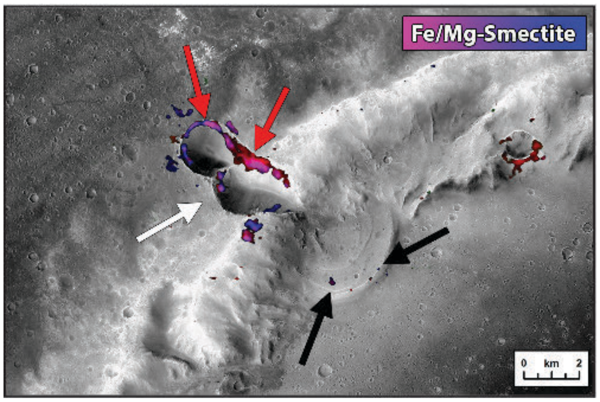

Figure 3. *Fan deposit in a candidate closed basin-lake with a short inlet channel (white arrow) at -10.0°N, -53.7°E. Note the detections of Fe/Mg-smectite in the fan (black arrows) and short inlet channel valley walls (red arrows). CRISM-derived parameter RGB (R=BD1900R, G=BD2200, B=D2300) [19,20] from image HRL000080CB overlain on CTX image P12_005583_1700. North is to the left.*

Discussion: *Timing of CBL Activity.* Based on the observed stratigraphic relationships (**Fig. 2**), we hypothesize that a substantial component of fluvial activity associated with the formation of closed-basin lakes occurred subsequent to the formation of the martian valley networks, which were primarily formed prior to the Noachian-Hesperian boundary [*4-7*]. This is supported by the observation that the majority (~89%) of the studied closed-basin lakes are fed by short inlet channels that are poorly integrated with the landscape (**Fig. 1B**), as opposed to longer inlet channels with a similar morphology to other martian valley networks (**Fig. 1A**) [e.g., *4-6*].

A post-Noachian period of fluvial activity associated with crater degradation on Mars has previously been hypothesized by [*7*]. These authors note two types of impact craters on Mars that are dissected by fluvial landforms – Type I craters, which do not show visible continuous ejecta deposits, and Type II craters, which do show visible continuous ejecta deposits [*7*]. Our results are consistent with this work. We further hypothesize, however, that Type I craters are primarily associated with open-basin lake activity, while Type II craters are primarily associated with closed-basin lake activity.

Intensity of Fluvial Activity. The small number (25; ~11%) of closed-basin lakes with long, valley network inlet channels is in stark contrast to the large number (>200) of open-basin lakes fed by valley networks [*3,4*]. We hypothesize that during the period of valley network activity, any crater initially breached by an inlet channel had a high probability of filling and breaching to form an outlet channel, as opposed to forming a stable hydrologically closed basin with a balance between inflow and evaporation/subsurface outflow. This is in contrast to the majority of (younger) closed-basin lake formation cases, in which the short, poorly integrated inlet channels suggest a substantially lower intensity of fluvial activity.

The mineralogy of deposits associated with closed-basin lakes indicates that identified alteration minerals are primarily detrital in nature (**Fig. 3**). We suggest that the lack of widespread evaporite deposits within these basins is due to the general transient nature of the candidate paleolakes. Any standing bodies of water contained within the basins were not stable for long enough to undergo sufficient evaporative concentration of input water to form major salt deposits in their interiors.

Conclusions: Stratigraphic relationships suggest that candidate closed-basin lake activity primarily occurred subsequent to the formation of martian valley networks, i.e., in the Hesperian or Amazonian [*4-7*]. During the period of valley network activity, craters breached by an input channel were instead likely to fill and breach to also form an outlet channel.

The morphology (i.e., short, poorly integrated inlet channels) and mineralogy (i.e., minimal evidence for widespread evaporite deposits) of younger closed-basin lakes also suggests these features were relatively transient and did not involve an intense period of fluvial activity. This is consistent with the hydrologic evolution of Mars where the majority of intense fluvial activity occurred prior to, and/or at, the Noachian-Hesperian boundary [*4-7*], with only minor, perhaps localized, fluvial activity subsequent to this time period [e.g., *7, 21*].

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