FLUVIAL VOLUMES, TIMESCALES, AND INTERMITTENCY IN MILNA CRATER, MARS. P. B. Buhler[1], C. I. Fassett[2], J. W. Head[3], M. P. Lamb[1], [1]California Institute of Technology, Department of Geological and Planetary Science, MC 170-25, Pasadena, CA, 91126, bpeter@caltech.edu, [2]NASA-Marshall Space Flight Center, Huntsville, AL 35805, [3]Brown University, Department of Earth, Environmental and Planetary Sciences, Providence, RI, 02912

Introduction: Ancient lake deposits and valley networks on Mars provide strong evidence that its surface was once modified by liquid water [1,2,3,4,5], but the extent of that modification is still debated. Ancient lacustrine deposits in Milna Crater (23.4 S, 12.3 W; Fig. 1) provide insight into the timescale and fluid volume required to construct fluvially derived sedimentary deposits near the Noachian-Hesperian boundary. Placing the lacustrine deposits their regional context in Paraná Valles provides a quantitative measurement of the intermittency of large, water-mediated sediment transport events in that region.

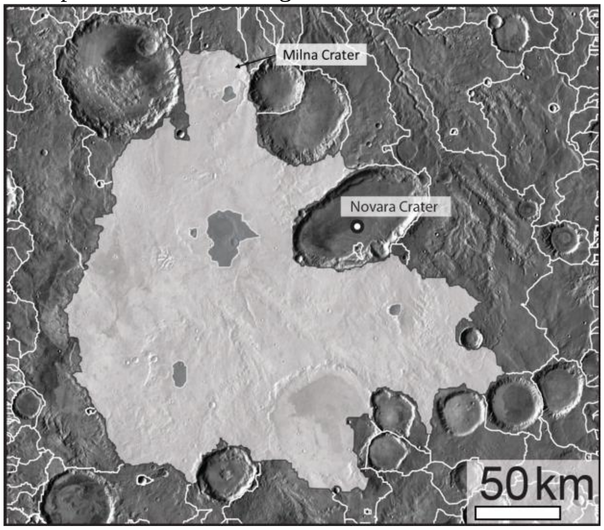

Fig 1. Context for Milna, with drainage divides (white lines). White area is drainage area source for Milna. North is up. THEMIS VIS image mosaic.

Methods: We use CTX, HiRISE, MOLA, and THEMIS data coregistered in ArcMap 10 for all measurements. Methods are more thoroughly described in [6]. We calculate the volume of the lacustrine deposits in Milna based on the current volume of the crater and the theoretical original volume of the crater [7]. We also take into account sediment porosity [8] and non-fluvially-sourced sediment by comparing the fill to that of an adjacent, similarly sized crater.

We then use a hydraulic model that takes into account bedload [9] and suspended sediment flux [10,11,12] to calculate the timescale and volume of water needed to transport the observed volume of lacustrine sediment through the inlet channel. We measure the ratio of inner channel dimensions to their host valley in the region surrounding Milna in order to constrain the dimensions of the inlet channel.We also consider a range of sediment sizes and model flow assuming various channel types (gravel, sand, and bedrock).

Results: Milna (Fig. 2) has a filled volume of 50 km^3, preserves many fans and sinuous valleys, and has an inlet and outlet valley, indicating that it was once filled with fluid. Under the assumption of continuous deposition, we find that the lacustrine fill in Milna was transported during 15-4700 terrestrial years, using the broadest possible range of model assumptions. Using the most reasonable model assumptions [see 6] we find that the range is likely to be 75-365 terrestrial years.

By placing the lacustrine deposits in Milna in regional and global context, we estimate the fraction of the time fluid flows capable of significantly transporting sediment operated (i.e. the intermittency, see [13]). Milna drains directly into the Paraná Valles system, which was fluvially active for 10^5-10^6 years during the late Noachian [14,15,16,17]. By spreading the total flux duration in Milna (i.e. ~10^2 yr) over the total length of activity in Paraná Valles, we find that the intermittency of fluvial activity of ~0.01-0.1%. We also compare the erosion rate of the drainage area sourcing Milna (Fig. 1) to average Noachian erosion rates. The average thickness of the sedimentary erosion over the entire drainage area needed to produce the fill observed in Milna is 2.2 m. Since average Noachian erosion rates were on the order of 10^{-5}-10^{-6} m/yr [18], this again yields a ~0.01-0.1% fluvial intermittency factor.

Discussion: The hydrological activity in Milna can be compared to the predictions of different climate scenarios: (i) an arid climate capable of periodic flooding events sustained over ~10^5-10^6 years [e.g. 16,19], (ii) punctuated flooding events triggered by giant impacts [e.g. 20], and (iii) a pervasively glaciated southern highlands [e.g. 21,22].

Matsubara et al. [19] use a global hydrologic routing model to assess the the ratio of precipitation to evaporation (the "X-ratio") of a lake. Matsubara et al. [19] find an "X-ratio" under which lakes are sustained over long time periods, similar to the extent of lakes in the Great Basin region in the western United States during the Last Glacial Maximum. We apply this range of the "X-ratio" to the Milna system, under the assumption of one day-long storm per martian year delivering 0.5-5 cm of rainfall (the fluid flux required to create the sediment flux required by our preferred model [6]). Under this scenario we calculate evaporation rates of

0.16-17 m per terrestrial year, which is similar to typical terrestrial evaporation rates in a wide range of climates (~meters per year [21,22]), implying that a sustained arid climate capable of periodic flooding events is compatible with the observations we make at Milna.

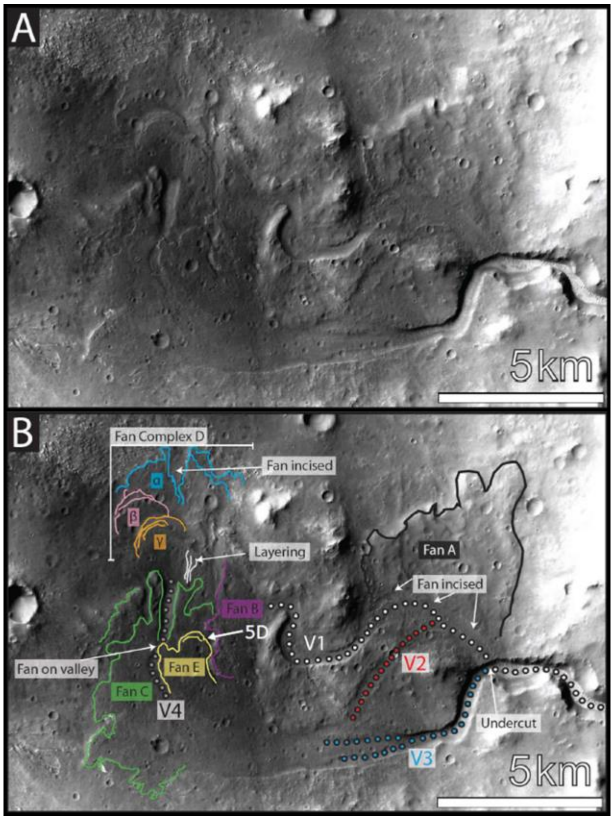

Fig 2. A. A large, multi-lobed fan that is incised by sinuous valleys in the southeast corner of Milna just below the inlet valley (lower left). **B.** Annotation. Solid lines denote scarps, dotted lines denote valleys. Note Fan E superposes a valley and that the valleys are sinuous and branched. Note also the stacked scarps visible at this (CTX) resolution in Fan Complex D, and Fans C & E. There is also layering not associated with a discrete lobe (white lines). CTX image.

Impacts may create transitory climates under which liquid water could be mobilized [20]. Using models from [20], assuming a ~100 km radius bolide under a 1 bar CO_2 atmosphere, ~3 × 10^{11} m^3 of water would be mobilized in the Milna drainage area. This is an order of magnitude less than the absolute minimum volume of water we calculate is required to transport the sediment observed in Milna (~4 × 10^{12} m^3, [6]). Thus, 10 bolides of this size would be required, which is unlikely since most of the giant impact basins were formed prior to formation of Paraná Valles [17,25]. Similar difficulties exist when considering smaller bolides [6]. Thus, flux generated by giant impacts alone is unlikely to be responsible for the morphology seen at Milna.

Periodic melting of an extensive southern ice sheet (e.g. by meteorite impacts, volcanism, or other temperature excursions [21,22]) may also provide a suitable water reservoir. Fastook and Head [22] suggest that top-down melting of such an ice sheet could produce 0.4 Mkm^3 of water across the southern highlands (enough to fill all open-basin paleolakes [26]) during an extended, moderately warm period or during a single, extremely warm summer. The observations at Milna indicate that an extended water release is more likely. We also emphasize that the required volume of water needs not only to fill the lakes, but also be capable of transporting the observed sedimentary fill.

Conclusions: We find that the total integrated fluvial activity in Milna took place over ~10^2 yr. Considering both the timescales of fluvial activity in the adjacent Paraná Valles and estimates for global Noachian erosion rates, we calculate an intermittency factor for fluvial activity of ~0.01-0.1% during 10^5-10^6 yr near the Noachian-Hesperian boundary in the Paraná Valles region. These values are comparable to arid climates on Earth where the majority of fluvial sedimentary transport takes place during floods with multi-year to decadal recurrence intervals. Our calculations of intermittency help to quantitatively reconcile the divergent estimates of the short and long timescales of fluvial activity on Mars reported in the literature. Future investigations of additional paleolakes will increase the robustness of our result.

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