# DELTAS FORMED IN AN ANCIENT CRATER LAKE IN THE NILI FOSSAE REGION OF MARS.

C. I. Fassett and J. W. Head, Dept. of Geological Sciences, Brown University, Providence, RI. 02912 (Caleb_Fassett@brown.edu).

**Introduction:** Despite the vast amount of new information which has been learned about Mars over the past ten years, there remains substantial uncertainty about the nature of the early Martian surface environment and climate. In particular, the record of valley networks which incise the ancient highlands has led to the idea that liquid water was stable on the surface and that early Mars was warm and wet [e.g., 1], though this is disputed [e.g., 2]. In part, it has been hard to distinguish between various models for the conditions that existed when valley networks were formed, because there have been few unambiguous examples of sedimentary deposits directly associated with valleys that have been observed.

Recently, Malin and Edgett [3] and Moore et al. [4] discovered a spectacular example of fluvial deposits associated with small valley network systems around NE Holden crater, which has provisionally been renamed Eberswalde. The deposits observed in Eberswalde provide a direct record of sedimentary emplacement, though it is not obvious whether these were formed in a lacustrine environment or as alluvial fan deposits and there is continuing disagreement on this point [5, 6]. Distinguishing between subaerial and subaqueous modes of emplacement given a sedimentary fan record can be difficult in the absence of other geological constraints.

We have recently described two sedimentary fan deposits (~56 km$^2$ in areal extent) in a 40-km diameter unnamed crater (centered at 77°40’E, 18°25’N) in the Nili Fossae region of Mars (Figure 1) [7]. As we discuss in detail below, compelling geological evidence exists that these fan deposits formed as lacustrine deltas. To examine these deposits, we gathered coregistered THEMIS, HRSC, MOC, and MOLA data of the Nili Fossae region in the ArcMap GIS environment.

**Observations:** *Input Valleys.* The fan deposits we observe in the Nili Fossae region are fed by ~200-km and ~80-km long sinuous valley networks. These drain a region of 15000 km$^2$, which is substantially larger than the region drained by the valleys that feed the Eberswalde crater. The drainage density of these input valleys is between .026 and .044 km$^{-1}$, which is consistent with what is observed using new data in other Noachian regions of Mars [see, e.g., 8], which is greater than was thought to be typical based on mapping using Viking [9], though typically smaller than what is found on Earth. The large, distributed drainage area of these input valleys that deposited the fan deposits suggests that they likely formed due to precipitation and surface runoff.

*Fan Deposits.* The fan deposits at MOC scale are shown in Figure 2. We interpret inverted channel deposits, based on the presence of what we identify as cross-cutting ridges that we believe are inverted channel segments (Fig. 2a). There is also extensive layering evident (Fig. 2b) which suggests the fan was episodically active, at least in a given location.

*Geological Context and evidence for a crater lake.* As seen in Figure 1, the eastern rim of the crater is substantially incised by a large valley. The minimum elevation of this valley (~-2395 m) is above that of the fan deposits and most of the crater floor. Based on these elevations, this outlet valley appears to have formed after a substantial crater lake was formed and the eastern rim was breached. The outlet valley then incised the eastern rim by ~100 m to its present elevation.

Based on the present topography, we can estimate the volume of water that would have been required to fill the crater. If we flood the current topography to the -2320 meter level, we the volume of water would be at least ~350 km$^3$. This provides a direct estimate of the minimum amount of water that must have gone through these valley systems, though the actual volume involved could have been much greater.

**Implications**: The biggest differences between the Nili Fossae fan deposits and those found in Eberswalde crater is that the Nili Fossae deposits appear to clearly been deposited in a lacustrine environment. We also have the ability to directly estimate a strong constraint for the minimum water volume involved, given that the crater had to be filled to breach the eastern rim. With this minimum volume of ponded water and estimates of the flux of water into the crater, we can obtain estimates for the minimum length of time over which the valley networks must have been active.

*Water flux estimates*. We have used Manning’s equation scaled for Martian gravity as well as empirical relationships [10] to estimate the likely discharges of the input valleys to the crater. Although such estimates are subject to substantial uncertainty [10], we believe that the best estimate of the channel-forming flux for these valleys is ~700 m$^3$/s.

*Minimum Formation Time and Intermittency*. If flow was maintained at channel-forming conditions constantly (and water was not lost to infiltration or the atmosphere), the minimum water volume could be reached in ~16 (Earth) years. However, there are several reasons to believe that such an estimate is too small (perhaps far too small). First, maintaining channel-forming discharges for such a substantial length of time seems extremely difficult, at least if the water results from precipitation, given that such flow conditions are equivalent to ~0.5 cm/day over the entire watershed. On Earth, the percentage of time where channel-forming discharges are maintained is generally small [11].

*Qualitative indicators of the formation time for the fan deposits.* It is difficult to derive quantitative estimates of the intermittency on Mars in absence of the knowledge of its past climate. Nonetheless, there are qualitative indicators that the valley systems discussed here were active for longer than the minimum possible length of time. First, the input valleys show significant signs of avulsion and meander evolution. Secondly, the present maximum evolution of the fan deposits is quite consistent with the minimum breach elevation and none of the fan deposits appears to have been stranded above this minimum stand. This suggests the fan surface had enough time to adjust to the drop in lake level as the outlet valley cut down the eastern rim. Third, OMEGA data reveals the presence of clays as well as hydrated minerals in the watershed of the input valleys [12]. Though it is difficult to specify the minimum formation time for these clays without knowledge of their formation environment and the kinetics of their formation, the presence of such clays suggests water was available for a geochemically-significant amount of time.

**Conclusions:** Given the minimum formation time that we calculate and the qualitative evidence for persistent surface water in the Nili Fossae region, we believe the valley networks in this location were active for at least hundreds of years (consistent with peak flow < 20% of the time) and possibly much longer (intermittency < 1% are common in arid environments on Earth)[11]. Further work needs to be done to place more precise quantitative constraints on the valley network intermittency, as well as on the length of time over which liquid water played an important role on the early Martian surface.

**References:** [1] Craddock, R.A. & Howard, A.D. (2002) *JGR, 107,* 5111. [2] Goldspiel, J.M. & Squyres, S.W. (2000) *Icarus., 148,* 176-192. [3] Malin, M.C. & Edgett, K.S. (2003) *Science, 302,* 1931-1934. [4] Moore, J. M. et al. (2003) *GRL, 30*, 2292. [5] Jarolmack, D.J. et al. (2004) *GRL, 31,* L21701. [6] Lewis, K. & Aharonson, O. (2005) *JGR, submitted.* [7] Fassett, C.I. & Head, J.W. (2005) *GRL, 32,* L14201. [8] Hynek, B.M. & Phillips, R. J. (2003) *Geology, 31*, 757-760. [9] Carr, M.H. & Chuang, F.C. (1997), *JGR, 102*, 9145-9152. [10] Irwin, R.P. et al. (2005), *Geology, 33,* 489–492. [11] Wolman, M.G., & Miller, J.P. (1960), *Geology, 68,* 54–74. [12] Poulet, F. et al. (2005), *LPSC XXXVI,* 1819.

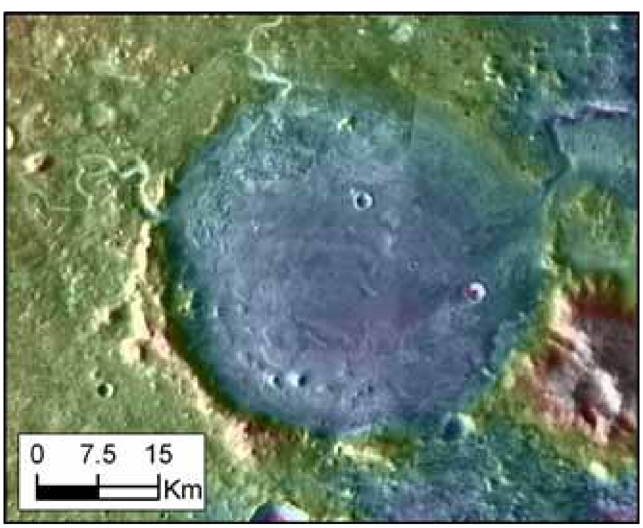


**Figure 1.** THEMIS daytime IR Mosaic of the fan deposits deposited in the 40-km crater by two input valleys. The breach in the eastern rim strongly suggests that the crater was ponded and formed a crater lake.

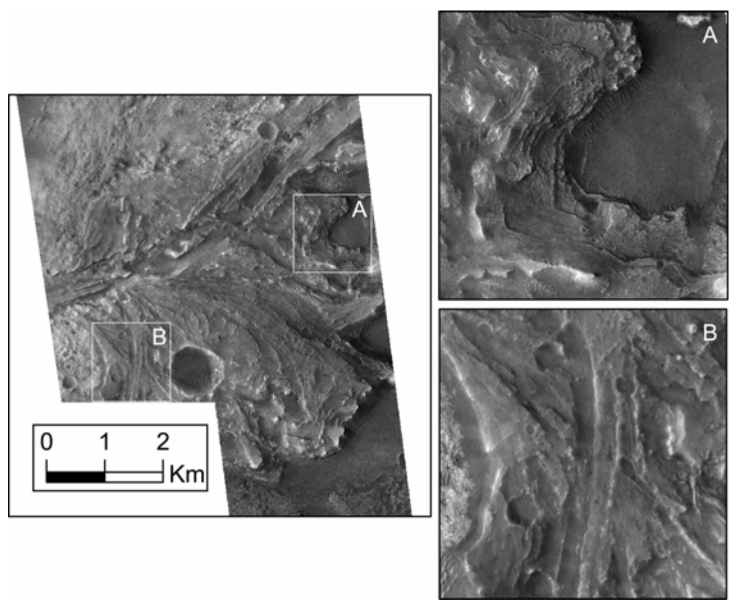


**Figure 2.** (left) Mosaic of MOC images R23-00833 and S04-00725, showing the pervasive layering (inset A) and cross-cutting inverted channel deposits (inset B) which we interpret to have been deposited in a lacustrine environment.