OUTFLOW CHANNELS AND ASSOCIATED FAN DELTAS: POST-NOACHIAN FLUVIAL DIVERSITY IN THE SOUTHERN HIGHLANDS OF MARS. S. Adeli[1], E. Hauber[1], L. Le Deit[2], M.G. Kleinhans[3], R. Jaumann[1], [1]Institut für Planetenforschung, DLR, Berlin, Germany (Solmaz.Adeli@dlr.de), [2]Laboratoire de Planétologie et Géodynamique, Université de Nantes, France, [3]Faculty of Geosciences, Universiteit Utrecht, Netherlands.

Introduction: Most valley networks on Mars are located in the southern highlands [1] and are thought to have formed at the boundary between the Noachian and Hesperian periods [2], about 3.8 Gyr ago [3]. Recently acquired high-resolution images, however, revealed that fluvial activity seems to have continued into the Hesperian and even into the Amazonian [e.g., 4-9]. Here we report on our observations of a series of channels in the southern highlands that display very well-preserved morphological details, including (multichannel) anabranching fluvial systems, scour marks, and depositional landforms such as bars and fan deltas.

The studied landforms are located between 35°S-45°S and ~170°E-190°E (Terra Cimmeria and Terra Sirenum). Most of the channels are situated within the extent of the hypothesized Eridania paleolake [10]. The area is characterized by ancient cratered terrain with younger geological units (e.g., plains with wrinkle ridges).

Methods: CTX images proved to be the most useful in our investigation. HRSC and THEMIS-VIS data were also used. Crater counting was performed on CTX images in order to determine the absolute model ages of surfaces which have been incised by outflow channels.

Morphological observations: Numerous channels incise different geological units (incl. Hesperian-aged terrain) and cross-cut between them. The channels display a variety of forms, from sinuous single-channel to anabranching pathways [11-13]. Scour marks as well as longitudinal bars are common (Fig. 1). Streamlined "islands" and some possible former cataracts can be identified. However, typical bifurcations, bars and other features of braided rivers are lacking. Taken together, these landforms are morphologically remarkably similar to the huge Martian outflow channels [14] and the Channeled Scabland in Washington State (USA) [15], though on a different (i.e. smaller) spatial scale. Most multichannel pathways are only a few kilometers wide, and single channels have widths of <1 km. Despite being shorter than the "typical" outflow channels, their lengths can be up to several hundred kilometers, although it is difficult to map them continuously, and neither their source area nor their terminations can be identified with certainty. A difference to the huge outflow channels is the presence of fan deltas where the channels enter topographic depressions (Fig. 2). Since these depressions are breached by outgoing channels, they seem to have hosted transient open-basin lakes. The overall paleoflow direction was south to north, as determined from the topographic gradient and from morphological details such as streamlined islands. Both the morphology of the channels and the presence of fan deltas resemble the characteristics of recently identified outflow channel systems in Ismenius Lacus [16].

Age determination: In order to determin the age of formation of the outflow channels, we performed crater counting on the surfaces, which have been incised by aqueous activity (Fig. 3-a). The estimated age of this surface is ~1.95 Ga (Fig. 2-b), which corresponds to the Early-Middle Amazonian [19]. In addition, the crater counting results (Fig. 3-b) reveal an older age of ~3.60 Ga, which corresponds to the Early-Late Hesperian [19], and may show the age of the basement, which is beneath the Amazonian surface.

Discussion: The morphology of the observed fluvial features is indicative of relatively short-term and high-energy, erosive outflow events. The formation of fan deltas in transient lakes with in- and outlets (excluding a formation of the channels by lava) is consistent with this notion, since it is known that such deposits can be formed at very short timescales [17]. The water sources are unknown so far, although heating of the subsurface by impact craters [8] may be a viable mechanism. Another way to release the water would be the breaching of ice-dammed lakes in a late-stage of the evolution of the Eridania paleolake system. No evidence for volcanic heating was detected.

The local presence of liquid water and the formation of water-related features on Mars during the late Hesperian and the Amazonian have been reported in several recent studies [e.g. 20]. The climate during Amazonian is characterized by a low atmospheric pressure and relatively dry and cold conditions [21], and therefore a local and short-lived presence of water ice would appear plausible.

Conclusions: Outflow-like events in the highlands [16] may have been more common than expected. Evidence for post-Noachian liquid water is growing. The obtained age of these flow events reveal evidence for local and limited aqueous environmental conditions during Amazonian. The identification of triggering mechanism(s) to release water with the required discharge rates will provide important insights into the climatic evolution of Mars and could increase our knowledge about Martian climate.

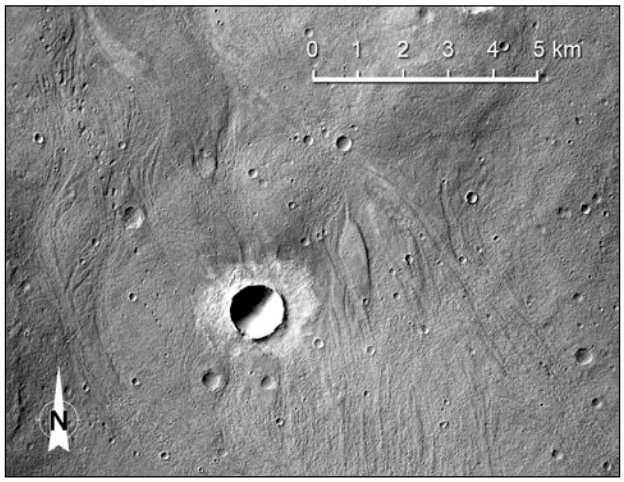


Figure 1. Example of anastomosing channels with relatively long quasi-parallel branches (detail of CTX B16_016611_1393).

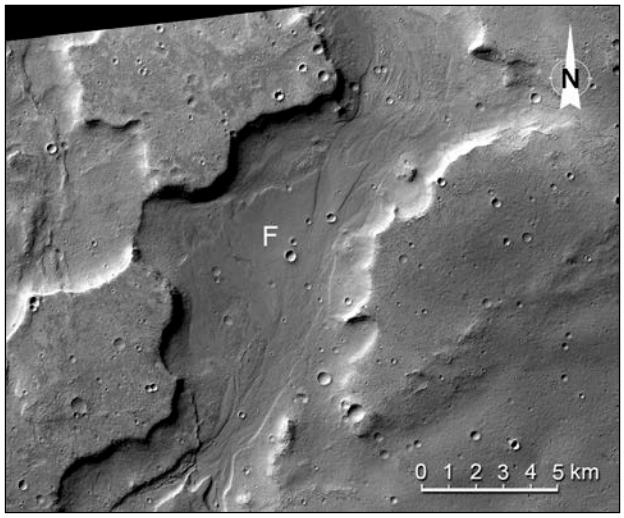
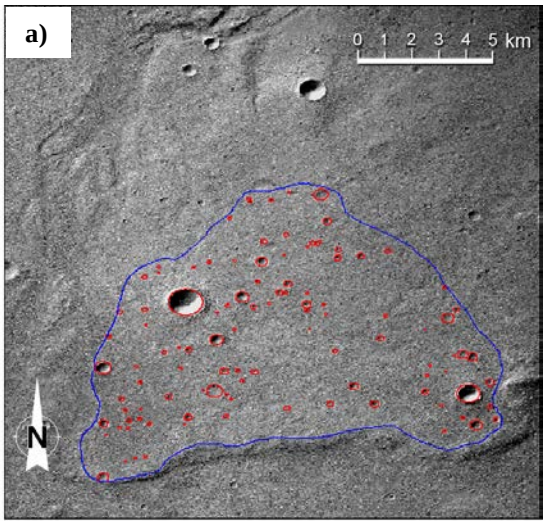


Figure 2. Channel system with fan-like deposit (F) and scouring (top part). The fan is located in an area where the channel pathway widens and where flow velocity (and transport capacity) possibly were decreased. Fan incision may indicate lowering of the base level [e.g., 18].



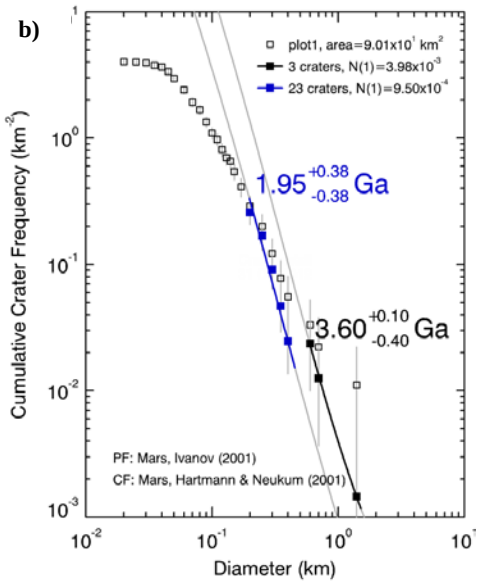


Figure 3. a) The age determination of the incised surface by an outflow channel, using crater counting method. The channel is observable at the left and upper left part of the image. **b)** The absolute model age.

References: [1] Hynek, B.M. et al. (2010) *JGR, 115,* E09008. [2] Fassett, C.I. and Head, J.W. (2008) *Icarus, 195,* 61–89. [3] Michael, G. (2013) *Icarus, 226,* 885-890. [4] Dickson, J.L. et al. (2008) *GRL, 36,* L08201. [5] Morgan, G.A. and Head, J.W. (2009) *Icarus, 202,* 39-59. [6] Fassett, C. I. et al. (2010) *Icarus, 208,* 86–100. [7] Howard, A. D. and Moore, J. M. (2011) *J. Geophys. Res., 116,* E05003. [8] Mangold, N. et al. (2012) *Icarus, 220,* 530-551. [9] Hauber, E. et al. (2013) *JGR-Planets, 118,* 1-16. [10] Irwin, R.P. et al. (2004) JGR, 109, E12009. [11] Kleinhans, M.G. (2010) *Prog. Phys. Geogr., 34,* 287-326. [12] Carling, P. et al. (2014) *Earth Surface Proc. Landforms, 39,* 26-37. [13] Makaske, B. (2001) *Earth-Sci. Rev., 53,* 149-196. [14] Baker, V.R. (2001) *Nature, 412,* 228-236. [15] Baker, V.R. (2009) *Annu. Rev. Earth Planet. Sci., 37,* 393-411. [16] Mangold, N. and Howard, A.D. (2013) *Icarus, 226,* 385-401. [17] Kleinhans M. et al. (2010) *EPSL, 294,* 378-392. [18] de Villiers, G. et al. (2013) *JGR-Planets, 118,* 651-670. [19] Michael, G.G., (2013) *Icarus, 226, 885-890.* [20] Hauber, E., et al., (2013) *J. Geophys. Res., 118, 1529-1544.* [21] Lammer, H., et al., (2013) *Space. Sci. Rev. 174, 113-154.*