OUTFLOW CHANNELS AND ASSOCIATED FAN DELTAS: POST-NOACHIAN FLUVIAL DIVERSITY IN THE SOUTHERN HIGHLANDS OF MARS. E. Hauber[1], S. Adeli[1], L. Le Deit[2], M.G. Kleinhans[3], [1]Institut für Planetenforschung, DLR, Berlin, Germany (Ernst.Hauber@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 well 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 channels, scour marks, and depositional landforms such as bars and fan deltas. The landforms can be considered to be outflow channels *en miniature*, and represent a rich post-Noachian record of aqueous activity in the highlands of Mars.

Methods: Due to their high-resolution and wide coverage, CTX images proved to be most useful in our investigation. HRSC and THEMIS-VIS data were also used. HiRISE and MOC images are sparsely distributed and basically do not cover the landforms of interest.

Geologic context: The studied landforms are located between approximately 35°S and 45°S and between ~170°E and 190°E (Terra Cimmeria and Terra Sirenum). Most of the channels are situated within the extent of the hypothesized Eridania paleolake [10], but we have not searched for them yet elsewhere, so we cannot exclude that they are more widespread in the southern latitudes. The area is characterized by ancient cratered terrain, but younger geological units (e.g., plains with wrinkle ridges) are present as well.

Morphological observations: Numerous channels incise different geological units (incl. Hesperian-aged terrain) and cross contacts between them. The channels display a variety of forms, from sinuous single-channel to anabranching (multichannel) pathways [11-13]. Scour marks as well as longitudinal bars are common (Fig. 1). Streamlined "islands" (Fig. 2) and some possible former cataracts (Fig. 3) can be identified. 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 (Figs. 4 and 5). Since these depressions are breached by outgoing channels, they seem to have hosted transient open-basin lakes (Fig. 4). 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].

Discussion: The morphology of the observed fluvial features is indicative of relatively short-term and high-energy outflow events. The formation of fan deltas in transient lakes with in- and outlets (Fig. 4) (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 [ref. 17]. The water sources are unknown so far, although heating of the subsurface by impact craters ([8] and Fig. 2) 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.

Conclusions: Outflow-like events in the highlands [16] may have been more common than expected. Evidence for post-Noachian liquid water is growing, and the identification of triggering mechanism(s) to release water with the required discharge rates will provide important insights into the climatic evolution of Mars.

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.

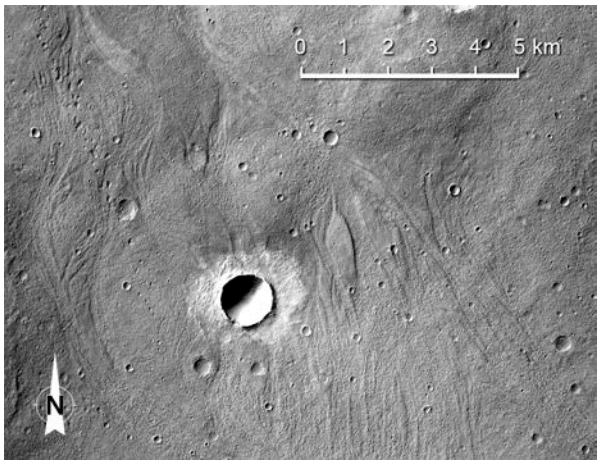

Figure 1. Example of anabranching channels with with relatively long quasi-parallel branches (detail of CTX B16_016611_1393, centered at 37.85°S/179.44°E).

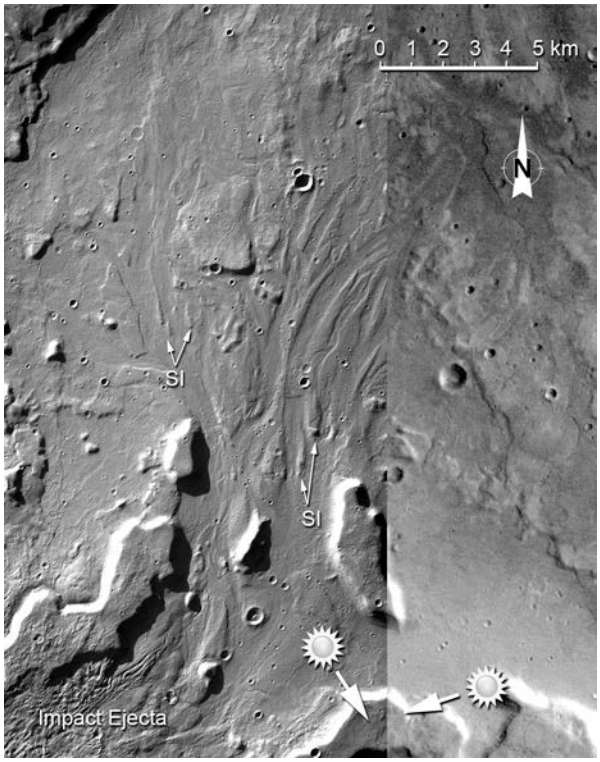

Figure 2. Anabranching channels with eroded streamlined islands (SI). This morphology is typical for the much larger circum-Chryse outflow channels. CTX (left) and HRSC (right) image mosaic centered at 41.9°S/188.9°E (note different illumination directions).

Figure 5 (right). Channel system with fan-like deposit (F) and scouring (top part). 39.2°S/180.11°E. 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].

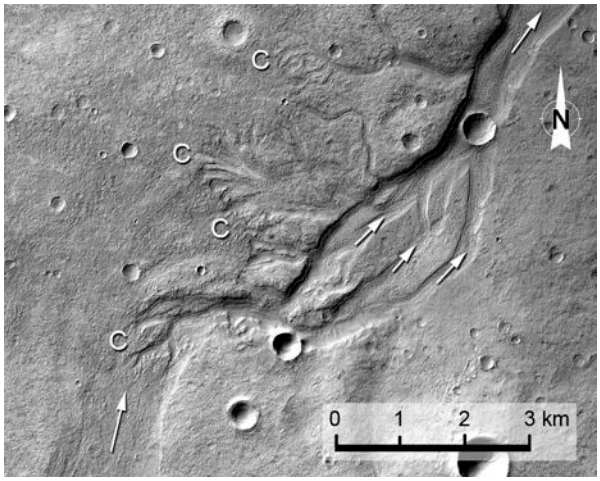

Figure 3. Diverse fluvial forms along a well-preserved channel system. A broad, possibly scoured floodplain in the SW is incised by deep alcoves (former cataracts? "C") and transitions into an anabranching system of channels. Arrows mark flow direction (detail of CTX B16_016044_1410; centered at 39.55°S/179.7°E).

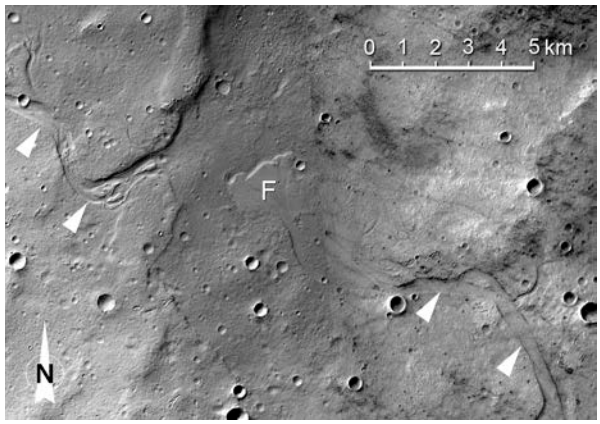

Figure 4. Channel (arrows) and fan delta (F). Flow direction was from SE to NW. CTX image mosaic centered at 39.58°S/180.4°E.