Amazonian-aged fluvial system in the southern mid-latitude regions, Mars. S. Adeli[1], E. Hauber[1], M. Kleinhans[2], L. Le Deit[3],T. Platz[4], P. Fawdon[5] and R. Jaumann[1,6], [1]Institute fuer Planetenforschung, Deutsches Zentrum fuer Luft- und Raumfahrt (DLR), Rutherfordstr. 2, 12489 Berlin, Germany (Solmaz.Adeli@dlr.de)., [2]Faculty of Geosciences, Universiteit Utrecht, PO box 80115, 3508 Utrecht, The Netherlands. [3]Laboratoire de Planétologie et Géodynamique, LPG Nantes, CNRS UMR 6112, Université de Nantes, Nantes, France. [4]Max Planck Institut für Sonnensystemforschung, Justus-von-Liebig-Weg 3, 37077 Göttingen, Germany. [5]Birkbeck, University of London, Malet St, London WC1E 7HX. [6]Freie Universität Berlin, Institute of Geological Sciences, Malteserstr. 74-100, 12249 Berlin, Germany.

Introduction: There are morphological [e.g., 1] and radar [e.g., 2] evidence showing that Mars has undergone extensive ice accumulation in non-polar areas, during Amazonian. Landforms of recent glacial origin have been observed in both mid-latitudes regions of Mars. These features, such as rock glaciers, ground ice, and latitude dependent mantle, formed during earlier epochs of the late Amazonian, tens to hundreds of millions of years ago [3]. They strongly suggest that the climate in the geological recent past have favored the accumulation of snow and ice. Global circulation models suggest that oscillations of the obliquity of the planet caused the transportation of ice from polar regions and its re-deposition at lower latitudes [4-6]. Over the past 10 Myr, Mars' obliquity has ranged from 14° to 48°. These variations caused significant changes in the seasonal cycles. Orbital variations from before 20 Myr are not very well known [7] but there is clear evidence of fluvial-related features during the earlier time, in Amazonian [8-10]. These observations and evidences show a major change in the Amazonian climate, under which the water ice was stable on the Martian surface. In this study [11] we report the presence of well-preserved fluvial features and glacial-like deposits in the Terra Cimmeria region, and we investigate their morphology, formative processes, and suggest their likely duration time frame. We believe these observations represent evidence of multiple episodes of surface run off due to snow and ice melt, which hold a crucial record of the recent Amazonian climate.

Geomorphological observation: The fluvial system is located in the mid-latitude highlands of the Terra Cimmeria region between 35° and 37° south. It terminates on the floor of the 200 km diameter Ariadnes Colles basin and it has a length of ~340 km. The first observable traces of the fluvial activity appear at an elevation of ∼1700 m north and northeast of an impact crater. The impact crater has a sharp rim and does not display traces of fluvial activity on its inner rim. The ejecta blanket of this crater is, however, partly eroded. Channels representing the head of the fluvial system appear on the outer wall and ejecta of this crater, and therefore they postdate the impact event. A ∼5 km-wide deposit is preserved adjacent to a high crater wall where a narrow channel which most likely derived from this deposit is present. This channel is linked to a wider channel traceable to the visible beginnings of the fluvial system. The link between deposit, narrow channel, and wider channel may suggest the deposit to be a preserved ice-rich residue, which had, in the past, partly melted and formed the narrow channel, and consequently fed the main stream, or the deposit is the result of a recent ice re-deposition phase. Along the main stream path, we observed more narrow channels which flow from higher elevations and join the main trench. They have a simple morphology and have no tributaries. They typically start at a local depression and end at the main channel. We have not observed any depositional features such as alluvial fans which are related to these narrow channels. The mentioned depressions are a few kilometers wide (Fig. 2 c) and have shallow and irregular shapes, and therefore do not represent old impact craters. These narrow valleys are morphologically very similar (simple morphology, narrow width, few kilometers length, and lack of fan deposits) to Amazonian-aged glaciofluvial valleys described by [12], which are interpreted to be related to ice-rich deposits in mid-latitude regions.

The floor of the channel is partly incised by scour marks, and deep grooves. Well preserved streamlined islands are observable. On the channel bed, there are several fan-shaped deposits, whose morphology points toward fan delta formation because of their flat surface with a sharp frontal scarp, in comparison with alluvial fans, which are commonly characterized by conical or concave geometry and a distal margin that grades smoothly into the adjacent plain [13]. These fan deltas are mostly deposited on the floor of what seems to be a flood plain. One fan delta has also been observed on a crater floor, which has an outlet channel as well, suggesting the presence of a temporary standing body of water in the crater (a crater lake).

The downstream part of this fluvial system is composed of a ~63 km long outflow channel, named Kārūn Valles [11] and located on the rim of the Ariadnes Colles. The Kārūn Valles extends through the ejecta blanket of an impact crater and has partly eroded the ejected material and deposited them in a wide alluvial fan, which spreads out over an area of ~$14*10^3$ km^2.

Deep grooves have been observed at the upstream part, as well as along the channel, up to the point where the deposition of the alluvial fan starts. These grooves may indicate scouring of bedrock by high pressure flow in catastrophic floods. The alluvial fan contains several bars of various sizes, which are all elongated in flow direction. The main flow was bifurcated by these bars and was divided into numerous smaller channels. On Earth the mechanism of bifurcation in a depositional environment rather than erosional, where the sediments are deposited in an alluvial fan and being shaped by the flow into the several bars, is known as braiding. Kārūn Valles, therefore, features a braided alluvial fan, which is to our knowledge a unique feature on Mars.

Hydraulic analysis: The hydraulic analysis is essential in order to better understand the channel formation mechanism and potentially the duration and/or periodicity of the flooding. In order to calculate the flow discharge rate of the Kārūn Valles, we used the method described extensively in [14] and used in [15] to calculate the flow discharge and sediment flux under Martian conditions. Our calculation is based on a high resolution stereo-based CTX DTM and is described extensively in [11]. Based on the channel dimensions, equations, and assumed grain size (sand), we obtained values for the discharge rate of Q_w=6.9 km^3/day for a channel depth of 10 m and Q_w=34 km^3/day for a channel depth of 30 m (see [11] for more detail).

In order to constrain the discharge rate with conservative error margins, we have calculated the flow discharge and sediment transport volume for three different average grain sizes. Additionally, we assumed two cases of a) full-bank condition and b) 10%-flow-depth because we cannot rule out the possibility of lower flow depth than full-bank, even though for a limited time span. Assuming that the fluvial event took place continuously in a given period of time and a bank–full condition, the alluvial fan would need 19–270 days to form, via a channel with 30 m or 10 m of depth, respectively. In case of a 10%-flow-depth condition, the alluvial fan would form in 4700–65,000 days, via flow depth of 3 m or 1 m, respectively (see [11] for more detail).

Age determination: In order to estimate the age of this fluvial activity in Terra Cimmeria, we performed the crater size–frequency distribution (CSFD) analysis on CTX images. The absolute model age of the surface, where the fluvial system was incised yields an early Amazonian age (Martian epoch boundaries from [16]) of ~1.8 (±0.2) Ga. The result from the Kārūn Valles alluvial fan surface shows a middle Amazonian age of about 510 (+0.3/-0.7) Ma, which likely refers to the latest stage of the fan formation since previous floods would have erased either by erosional or depositional mechanisms.

Discussion and conclusion: The fluvial system in Terra Cimmeria reveals a hydraulic mechanism of different erosional and depositional processes. The absolute model age of the bedrock unit shows an age of ~1.8 (±0.2) Ga, which corresponds to the early Amazonian, and indicates the maximum age of the fluvial activity.

The erosional features of incised channel floors such as groove marks, cataracts, and streamlined islands; and eroded channel banks in the main branch, as well as in Kārūn Valles, point to highly energetic fluvial activity. The morphology of the depositional features of fan deltas and alluvial fans suggests high energetic and short term events. Similar valleys and landforms of Amazonian age have been reported in other areas in mid-latitudes and been interpreted as being formed by a single and short fluvial episode [e.g., 9]. The narrow valleys originating at small depressions and remnants of ice-rich material indicate ice/snow melt as water source.

Based on our results, we conclude that fluvial activity, perhaps episodic, existed throughout the Amazonian. Liquid water was present in Terra Cimmeria in the Amazonian, and it was abundant enough, although during a short period, to carve over 340 km of fluvial channel, transport sediments and deposit them in alluvial fans and fan deltas.

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