THE WESTERN LIBYA MONTES VALLEY SYSTEM ON MARS: EVIDENCE FOR EPISODIC AND MULTI-GENETIC EROSION EVENTS. R. Jaumann1,2, A. Nass1,3, D. Tirsch1, and D. Reiss4; 1DLR, Inst. of Planet. Expl. Rutherfordstrasse 2, 12489 Berlin, Germany (ralf.jaumann@dlr.de); 2Dept. of Earth Sciences, Inst. of Geosciences, Remote Sensing of the Earth and Planets, Freie Universitaet Berlin, Germany; 3Dept. of Geographie, Geomatics Section, University of Potsdam, Germany; 4Inst. of Planetology, Westfälische Wilhelms-Universität, Münster.

Abstract: Martian valley networks have been cited as the best evidence that Mars maintained flow of liquid water across its surface. Although internal structures associated with a fluvial origin within valleys such as inner channels, terraces, slip-off and undercut slopes are extremely rare on Mars [1] such features can be identified in high-resolution imagery [e.g. 2,3]. However, besides internal features the source regions are an important indicator for the flow processes in Martian valleys because they define the drainage area and thus constrain the amount of available water for eroding the valley network. Furthermore, the morphology of the source regions and their topographic characteristics provide information about the origin of the water. On Mars, valley networks are thought to have been formed by retreating erosion where the water is supplied from the sub-surface. However, the mechanisms that are responsible for the release of ground water are poorly understood. The three-dimensional highly resolved data of the High Resolution Stereo Camera (HRSC) on the Mars Express Mission [4] allow the detailed examination of valley network source regions.

Introduction: Martian valley networks superficially resemble terrestrial drainage systems and thus have been taken as evidence that Mars maintained flow of liquid water across the surface [5,6]. Almost all of these valleys are concentrated in the ancient cratered Martian highlands and are considered to be very old. The valley networks have been cited as the best evidence of warm and wet conditions early in the history of Mars [e.g. 7,8,9]. An early warm and wet Mars with sustained precipitation is, however, being questioned because of the reduction of an early atmosphere due to losses of molecules by impact erosion [10], solar wind [11], significant lost of CO₂ molecules due to thermal escape [12], the theoretical difficulties to sufficiently warm Mars with a CO₂-H₂O greenhouse [13,14] during the lower sun output in the planet’s early history [15], and the lack of large weathering deposits on Noachian surfaces [16,17]. Nevertheless, the morphology of many valley networks indicates that fluvial erosion was responsible for the valley formation [e.g. 5,6,18]. Although the basic erosional process is still controversial, geologic interpretations focus on ground water sapping [6,18] or surface runoff [19,9,20] or a combination of both [21]. The morphology and dimensions of valley networks require high-energy erosional power and thus large amounts of water in order to incise valleys even into loose sediment and to move gravel and blocks. Moreover, on Mars we have to expect compact basaltic rock as the common surface material. Thus, it might not be likely that spring-driven erosion processes like groundwater exfiltrating along the base of a headwall and subsequent collapse of the head front are the dominant erosion process to incise the Martian valley networks [22]. Little is known about paleo-discharge values but the few cases where discharges of exposed and preserved interior channels have been estimated show that the amount of water within the valley systems coincide with that of dimensionally comparable terrestrial rivers valleys [23,24,3]. This indicates that the erosion of the valley networks was the result of water running on the surface at least periodically in terms of high magnitude flash floods [3]. However, the water release mechanism is still controversial. As precipitation is unlikely due to climate conditions [13,14] and seepage is equivocal [22] other possibilities might be short anomalous wet periods immediately following large impacts [25] or basal melting of large snow deposits [26]. In this paper, we explore a region in the western Libya Montes where a well-developed valley system emanates from the edge of a lava front indicating magma with ground ice or snow pack interaction as possible water release mechanism. Moreover, at least two lava streams of different ages show the same valley source features that might be due to multiple water release events. In addition, an interior channel allows the estimation of paleo-discharges and waterfall-like features at the valley heads indicate specific water release processes.

Western Libya Montes: The Libya Montes at about 80°E to 100°E and 2°S to 6°N border the southern margin of the Isidis Planitia rim. The Libya Montes are one of the oldest and most extremely eroded surface units (Nplh) on Mars [27,28]. The contact between the northern plain materials of Isidis Planitia and the Libya Montes highlands appear at about -3.5 km altitude, between 81°E to 95°E at about 4°N. The Libya Montes consist of massifs and hummocky terrain interbedded by local basins and dissected and flooded areas. Three large valley systems build the main drainage of many smaller valleys throughout the Libya Montes. Hence these valleys are
unnamed we follow the nomenclature of [29], who called them Western, Middle and Eastern Valley. Noachian massif materials (unit Nm) form rugged mountainous features and have been categorized as the type area of “mountainous terrain” [30]. Individual massifs occur as isolated peaks or as arrays of peaks resembling the remnants of impact crater rims as well as possible remnants of the Isidis basin concentric structure. These oldest unit of the Libya Montes have mostly been formed in context with the Isidis event and pre-date the earliest recorded fluvial events. However all massifs bear evidence of extensive erosion on their flanks as indicated by small valley-and-spur relief [29] postdating their formation. The mountainous terrain are surrounded by rugged areas (unit NHf) interpreted as either pediments or bajadas cut and deposited from the adjacent massifs [29]. Short drainage networks are common in these fluted and dissected materials that postdate the massif materials unit but are still Noachian in age. The massif material unit and their adjacent deposits are dissected by extended relatively integrated broad valley systems. These valleys are characterized by floodplain-like surfaces dissected by channels. These dissected plain (unit Hd) stratigraphically occur in the late Noachian and extend into the late Hesperian [29]. Topographic lows in crater floors, between the massifs and depressions in the larger valley systems may have acted as temporary catchment basins and are filled with sedimentary intermontane plains and highland basin materials (unit Hi) [29] of similar ages as unit Hd. The dissected plain unit builds the main drainage area of the Libya Montes as the Western, Middle, and Eastern Valley. All main valley systems terminate in Isidis Planitia with clear evidence of depositional fans of relatively rocky material within the Hesperian terminal plains material (unit Ht) that marks the transitional zone of the basin margin [29]. The Syrtis Major shield volcanoes Nili Patera (8.9°E, 67°N) and Meroe Patera (6.9°N, 68.6°E) are located west to the Libya Montes. Distal lava flows (unit Hsm, [28]) of the Syrtis Major Planum volcano system invaded the western part of the Libya Montes reaching the source regions of the Western Valley system. The Western Libya Montes Valley cuts the highlands between 1.4°N to 3.5°N and 81.6°E to 82.5°E and originates in a region that is affected by the Syrtis Major lavas. The valley consists of a western and eastern branch and drains down to Isidis Planitia over a distance of 400 km (Fig. 2). Most of its distance the western branch of the valley exhibits an interior channel that allows to constraint palaeo-discharge and erosion budgets [3]. In this paper, we focus on the Western Valley system because it documents the erosion history of the Libya Montes from the mid-Noachian to the mid-Amazonian and also bear evidence for changing water release mechanisms with time.

Source Region: Whereas the source region of the eastern part of the valley is dominated by a dendritic dissected drainage area within very old geologic units (Fig. 2), the style of the western valley catchments is different. There the source region of the valley is covered by a series of lava flows. Even the upstream part of the western valley is covered by lava flows that overflow the original interior channel. Within this part of the valley a younger interior channel cuts the lava flow (Fig.3) indicating multiple flow events. Tributaries are rare, short, and not dendritically arranged in this area. The valley system emanates directly from a lava plain and cascades down over

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**Fig. 1:** Western Libya Montes valley system (left: HRSC nadir image; right: MOLA, blue to white indicates – 5000m to 3000m).

**Fig. 2:** Dendritic pattern of the eastern branch of the western Libya Montes valley system (THEMIS nighttime IR image).
old highland materials for a distance of about 20 km and a height difference of 700 m (Fig. 3). The staggered cascades have slopes of 6°. This is high compared to the overall valley slope of 0.1° but small compared with slopes of waterfalls on Earth. However if we consider slope reduction by erosional undercut and collapse, this remaining slope will coincide with former cataracts. Although we cannot exclude an early period of precipitation, as indicated by the dendritic pattern of the eastern branch, most of the western valley has been formed by retreating erosion caused by subsurface water release.

Fig. 3: Source region of the western Libya Montes valley system. The valley emanates abrupt at the end of a lava flow, cascades down the boundary of old highland materials and incises into younger lava flow (HRSC stereo image).

The close correlation of valley erosional structures and lava emplacement indicate a volcanically triggered water release mechanism either by hydrothermally driven expulsion of groundwater or more likely by melting and mobilizing ground ice due to heat induced by lava.

Stratigraphic Sequences: The analysis of stratigraphic sequences in the western branch of the valley system in terms of crater frequency measurements [31,32] indicates a series of subsequent volcano-fluvial events (Fig. 4, 5). In the Noachian < 3.7 Ga, Isidis rim material (Nm, Nplh) was initially fluvially eroded and erosional debris (Hd1) was deposited [3]. In the Hesperian (3.5 to 3.4 Ga), volcanic activity (Hs1) triggered water release followed by deposition of fluvial sediments (Hd2) 3.35 Ga ago [3]. In the Amazonian volcanic activity occurred during the period 1.4 to 1.1 Ga ago with lava flows (As2 and As3) and related fluvial activity as indicated by the interior channel in Fig. 3, which cut the lavas of unit As3.

The interior channel dissecting lava flow As3 might have been the last fluvial event in this region. According to discharge analyses discussed in [3], the amount of water released within this Amazonian aged interior channel is estimated to be about 400 m³/s. This is an order of magnitude less than the discharges measured for the early Hesperian period in the same region [3].

Fig. 4: Ages of different surface units in the western Libya Montes valley source region as derived from crater frequency measurements (see Fig. 4a, 4b, 4c for agedating plots of areas marked by asterisk).
Summary: The western Libya Montes valley was episodically active for about 2 billion years with major episodes in the Noachian (> 3.7 Ga), the Hesperian (3.5 to 3.4 Ga), and the Amazonian (1.4 to 1.1 Ga). Whereas precipitation may have dominated the fluvial activity during the Noachian as indicated by the dendritic drainage pattern in the older eastern branch, the Hesperian and Amazonian fluvial activities might have been triggered by volcanic processes such as ground ice melting or hydrothermal water release. The Hesperian discharge rate of 4800 m$^3$/s indicates fast erosion of the valley that might have been cut down within a million years [3]. This suggest rather episodic than sustained flows, which is consistent with the observation of volcanically related water release processes.