Valleys in the Martian Libya Montes: Evidence for episodic erosion events

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Introduction: 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 (Carr and Malin, 2000) such features can be identified in high-resolution imagery (e.g. Malin and Edgett, 2001; Jaumann et al., 2005). 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. The three-dimensional highly resolved data of the High Resolution Stereo Camera (HRSC) on the Mars Express Mission (Jaumann et al., 2007) allow the detailed examination of valley network source regions.

Western Libya Montes: The Libya Montes (Fig. 1), at about 79° E to 84° E and 1.5° S to 4.5° N, border the southern margin of the Isidis Planitia rim. The Libya Montes are one of the oldest and most extremely eroded surfaces on Mars and belong to the hilly unit of the Noachian plateau sequence, which is characterized by rough hilly fractured material of moderately high relief. The massif material unit and its adjacent deposits are dissected by extended, relatively integrated broad valley systems. These valleys are characterized by floodplain-like surfaces dissected by channels. The dissected plains stratigraphically occur at the very late Noachian and extend into the late Hesperian (Crumpler and Tanaka, 2003). The dissected plain unit creates the main drainage area of the Libya Montes. All main valley systems terminate in Isidis Planitia, with clear evidence of depositional fans of relatively rocky material within the Hesperian terminal plains material that marks the transitional zone to the basin margin. The shield volcano Syrtis Major (70° E, 10° N) is located west of the Libya Montes. Distal lava flows (Greeley and Guest, 1987) of the Syrtis Major Planum volcano system invaded the western part of the Libya Montes, reaching the source regions of the Western Libya Montes Valley system that cuts the highlands between 80° E to 83.4° E and 1.2° S to 3.9° N. The Western Libya Montes Valley system consists of a western and eastern branch and drains down to Isidis Planitia over a distance of more than 300 km. The eastern branch of the Western Libya Montes Valley originates at 82.7° E, 0.2° S. The western branch of the Western Libya Montes Valley (Fig.1) originates at 80° E, 0.7° S in a region that is affected by Syrtis Major lava flows.

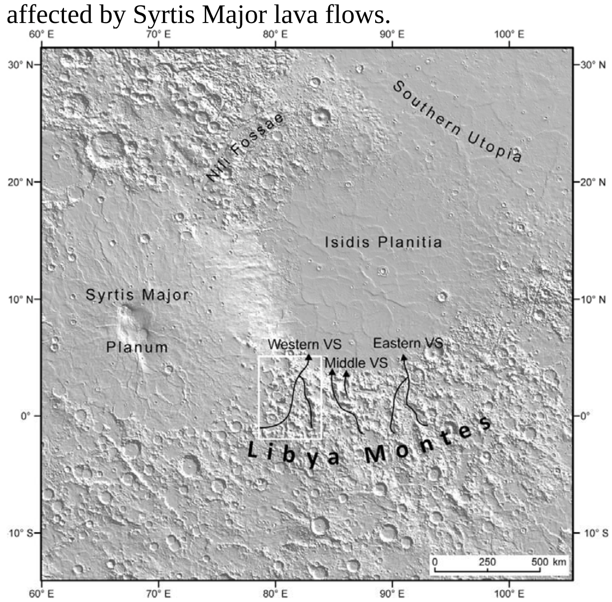

Fig. 1. Regional context of the Libya Montes Region (MOLA shaded relief). The area of investigation is marked by the white box (VS = Valley System)

Valley System: The geology of the eastern valley branch headwater region is dominated by intense erosion of the old Noachian massifs due to surface run-off, as is indicated by widespread dendritic patterns, draining from the western and eastern mountain flanks into the main valley system (Fig. 2). Volcanic activity 3.0 Ga ago, an impact event producing the crater of 11 km in diameter 2.5 Ga ago, and a second volcanic event 1.7 Ga ago modified the headwater region, cutting off the dendritic pattern at the lower slopes of the surrounding massifs and obscured the valley's source region (Fig. 2). The main fluvial activity of the eastern valley system seems to be correlated with the dendritic drainage activities in the Noachian massifs. Parts of these dendritic valleys are covered by lava and crater ejecta, especially in the lower parts of the source region. As these younger deposits do not show any modification by fluvial processes, we can be certain that no fluvial reactivation of the eastern valley branch occurred after at least the late Hesperian. Only a few dendritic patterns occur in the western branch upstream (Fig. 2) draining from Noachian massifs into the main valley. However, the dendritic drainage configuration is superimposed by lava flows that date to the early Hesperian age. These lava flows originate at the

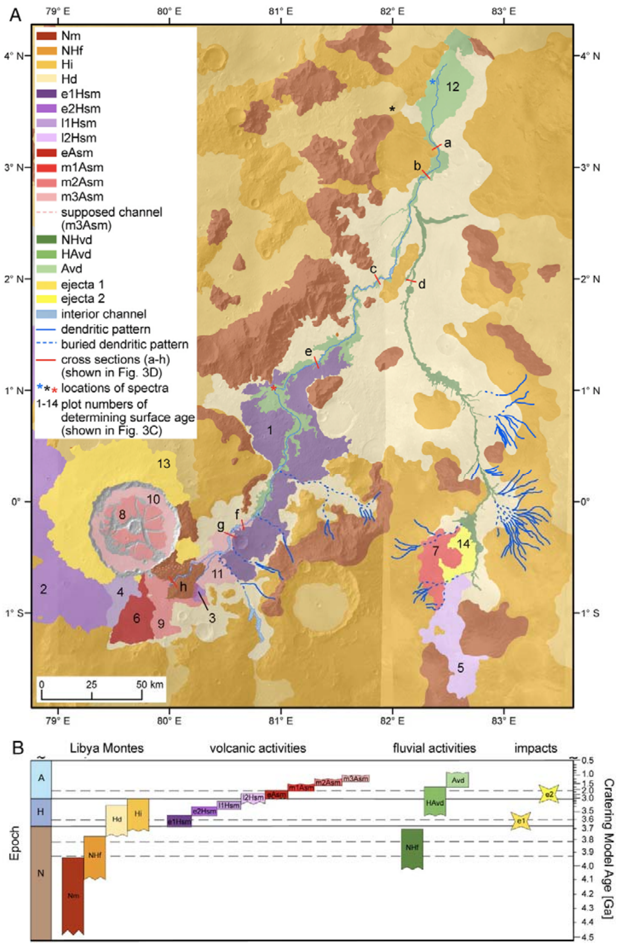

Fig. 2. A: Geologic map of the Western Libya Montes Valley System.. B: Stratigraphic correlation of map units and geological events in the Western Libya Montes ValleySystem (Jaumann et al., 2009)

south-western flank of Syrtis Major and are partly covered by ejecta of the 49 km crater at its western to southern edge and also by younger lava flows (Fig. 2). In contrast to the eastern branch, the western branch does not show any tributaries in the area where it cuts the lava. The source of the western branch at the edge of a lava plateau (Fig. 2) suggests a correlation between water release and volcanic activities. The water seems to have emanated directly from beneath the lava plateau, with no indication of amphitheatre-like hydraulic heads, which rules out a simple sapping mechanism with retreating erosion processes. A more likely explanation would be hydrothermally driven expulsion of groundwater or melting and mobilizing of ground ice due to heat induced by volcanic activity. In any case, the water release beneath the plateau is clearly correlated with volcanic events in the Hesperian and Amazonian epochs. At least 4 volcanic events originating from the eastern flank of Syrtis Major separated by about 100 to 400 Ma, and two very late events originating from the interior of the nearby impact crater separated by 100 Ma are responsible for eroding the oldest lava flows in the upstream region of the western branch. The channel within youngest basalt unit suggests that the latest erosion activity took place around 1.4 Ga ago, and a cataract-like feature at the transition between units indicates that this channel, and all previous rivers, took the same bed (Jaumann et al., 2009). HRSC digital terrain models (DTM), as derived from the stereo capability of the instrument (Jaumann, et al., 2007), were used to estimate morphometric parameters such as size, depth and slopes of fluvial features. For most of its length, the valley system exhibits an interior channel which allows constraining discharges ranging from 15,000 m^3/s to 430,000 m^3/s and yielding sediment volumes up to 250 tons/s (Jaumann et al., 2009). **Stratigraphic Sequences:** Based on stratigraphic relations, the valley system evolved during a period of about 2.8 billion years with major wet episodes in the Noachian (<4.1 Ga), the Hesperian (3.6 to 3.0 Ga) and the Amazonian (2.8 to 1.4 Ga). While precipitation dominated the fluvial activity during the Noachian era, as indicated by dendritic drainage pattern, the close correlation of lava deposits and valley source regions suggest that volcanic processes, such as ground ice melting and/or hydrothermal water release, might have played a major role during the Hesperian and Amazonian fluvial activities. In addition, multiple volcanic events in the Hesperian and Amazonian ages show that Syrtis Major was active, at least locally, until 1.4 Ga ago. Discharge estimates demonstrate a significant increase from precipitation-induced to volcanic-triggered water release. Fluvial erosion rates, discharges, sediment transport rates, and the lack of any widespread chemical alteration products, such as sulphates and phyllosilicates that are indicative for large long-lasting standing bodies of water, suggest relatively short valley formation times of only a few thousands of years. Compared with the total age of the valley system, short episodic water release events separated by long dry and inactive periods of some hundreds of millions of years, at least in the Hesperian and Amazonian, seem to be more realistic rather than a continuous flow. The youngest channel segment dates back to less than 1.4 Ga. This indicates the presence of surface run-off at that time, which required atmospheric conditions that support water to be stable on the surface even late in Martian history.

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