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The Western Libya Montes Valley System on Mars: Evidence for episodic and multi-genetic erosion events during the Martian history

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ABSTRACT

A valley network in the Western Libya Montes region extending from 80°E to 83.4°E and 1.2°S to 3.9°N exhibits significant detail about water release processes and duration of erosional activities. The valley system originates at the southeastern offshoot of Syrtis Major and drains down to Isidis Planitia over a distance of about 300 km. Midstream, the valley network splits into a shorter eastern and a longer western part. For most of its length, the valley 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. 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 suggests 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 runoff at that time, which required atmospheric conditions that support water to be stable on the surface even late in Martian history. In summary, the Western Libya Montes Valley System demonstrates episodic and multi-genetic erosion events over most of the Martian history, with a clear change in the erosion style from precipitation to volcanic-triggered water release during the early Hesperian.

1. Introduction

Martian valley networks superficially resemble terrestrial drainage systems and thus have been taken as evidence that Mars maintained a flow of liquid water across the surface (Sharp and Malin, 1975; Pieri, 1980b). Almost all of these valleys are concentrated in the ancient cratered Martian highlands, and thus are considered to be of Noachian and early Hesperian age. Valley networks have been cited as the best evidence of warm and wet conditions early in the history of Mars (e.g. Carr, 1996; Baker, 2001; Craddock and Howard, 2002). 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 (Melosh and Vickery, 1989), solar wind (Ergun et al., 2006), significant loss of CO_2 molecules due to thermal escape, the theoretical difficulties to sufficiently warm Mars with a CO_2–H_2O greenhouse (Kasting, 1991; Haberle, 1998) during times of lower sun output in the planet's early history (Kasting, 1991), and the lack of large weathering deposits on Noachian surfaces (Christensen et al., 2001; Bibring et al., 2006). Nevertheless, the morphology of many valley networks indicates that fluvial erosion was responsible for the valley formation (Sharp and Malin, 1975; Pieri, 1980b; Carr, 1981; Baker et al., 1990). Although the basic erosional process is still controversial, geologic interpretations focus on ground water sapping (Pieri, 1980b; Carr, 1981; Baker et al., 1990), surface

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runoff (Hynek and Phillips, 2001; Craddock and Howard, 2002; Irwin and Howard, 2002) or a combination of both (Milton, 1973). The morphology and dimensions of valley networks require erosional power comparable to that of terrestrial rivers, and thus discharges of thousands of cubic meters per second are needed in order to incise valleys even into loose material 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 exfiltration along the base of a headwall and subsequent collapse of the head front, are the dominant erosion processes to incise the Martian valley networks (Lamb et al., 2006). 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 coincides with that of dimensionally comparable terrestrial rivers valleys (Irwin et al., 2005a, b; Jaumann et al., 2005). This indicates that the erosion of the valley networks was the result of water running on the surface, at least periodically, in the form of high magnitude flash floods (Jaumann et al., 2005). Precipitation is unlikely due to today's climate conditions (Haberle, 1998; Kasting, 1991) and seepage is equivocal (Lamb et al., 2006). Other possibilities might be short anomalous wet periods immediately following large impacts (Segura et al., 2002) or basal melting of large snow deposits (Carr and Head, 2003).

A region in the Western Libya Montes exhibits a well-developed valley system with an eastern branch forming dendritic patterns at its source region, and a western branch emanating from the edge of a lava front. In addition, a well-preserved interior channel within the valley resembles the former river and can be traced over most of the Western Libya Montes Valley System. The existence of this interior channel (Irwin et al., 2005b; Jaumann et al., 2005) suggests that paleo-discharges and features have formed from waterfalls at the valley head, which would be indicative of specific water release processes.

2. Regional settings

The Libya Montes, 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 (Nplh), which is characterized by rough hilly fractured material of moderately high relief. This material is interpreted to be composed of ancient brecciated highland rocks (Scott and Tanaka, 1986; Greeley and Guest, 1987). The contact between the northern plain materials of Isidis Planitia and the Libya Montes highland material at 80°E to 95°E and 2°N to 4°N is indicated in Fig. 1.

The Libya Montes consist of massifs and hummocky terrain interbedded by local basins and dissected by flooded areas. The main drainage system of many smaller valleys throughout the Libya Montes consists of three large valleys. As these valleys are unnamed,

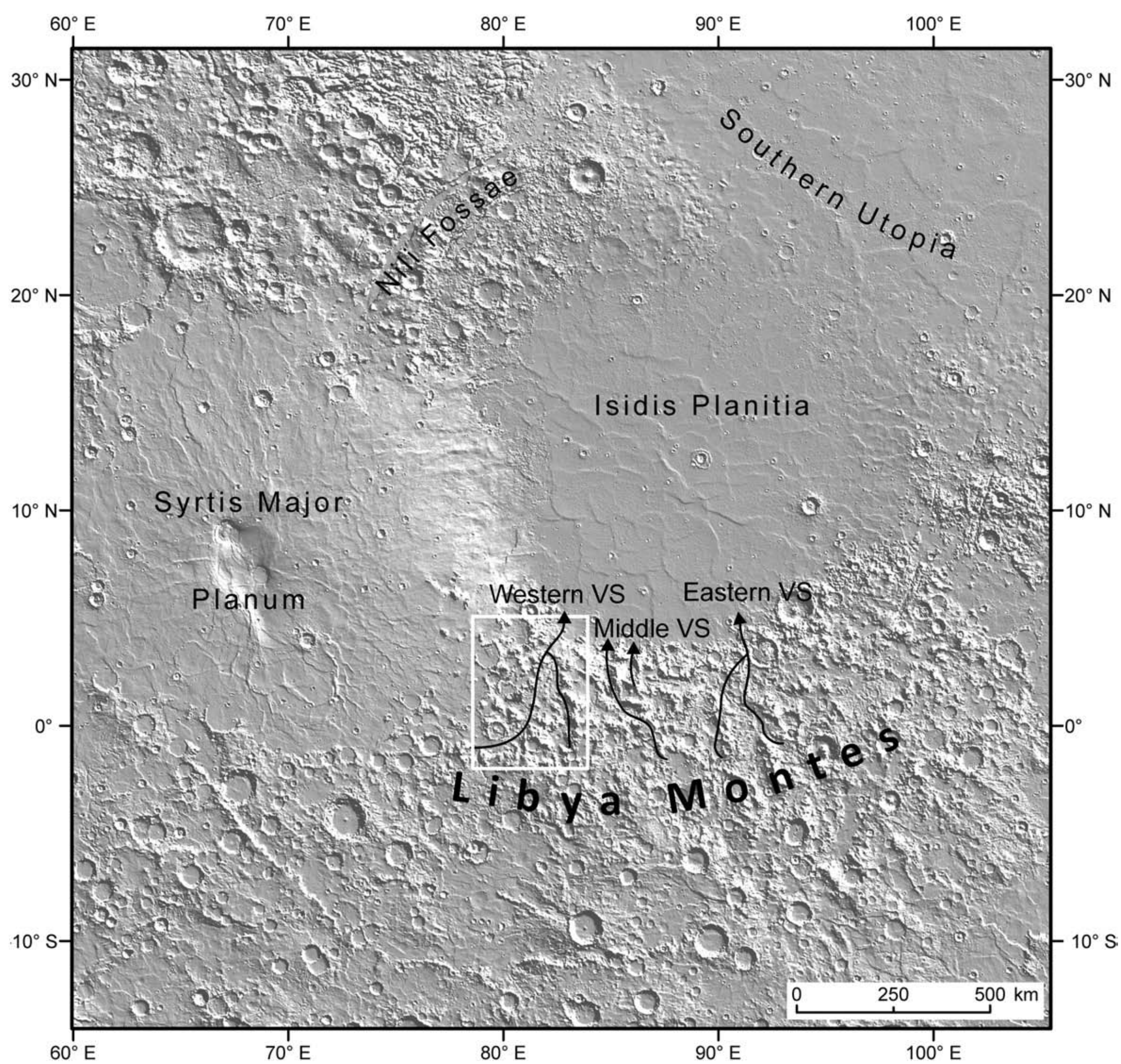

Fig. 1. Regional context of the Libya Montes Region (MOLA shaded relief). The area of investigation is marked by the white box (VS = Valley System).