Geomorphology 207 (2014) 96–113

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Formation of Hrad Vallis (Mars) by low viscosity lava flows

Joshua P. Hopper, David W. Leverington *

Department of Geosciences, Texas Tech University, Lubbock, TX 79409, USA

ARTICLE INFO

Article history:
Received 6 July 2013
Received in revised form 26 October 2013
Accepted 28 October 2013
Available online 6 November 2013

Keywords:
Mars
Outflow channels
Volcanism
Lava

ABSTRACT

Hrad Vallis is a Martian outflow channel previously interpreted as a product of aqueous outbursts from the subsurface, possibly involving mudflows associated with lahar-like events. However, an alternative volcanic hypothesis for the development of the system is worthy of consideration on the basis of (1) the nature of landforms preserved along component channels and adjacent uplands and (2) similarities between the basic properties of this system and large volcanic channels of the inner solar system. Hrad Vallis commences on the distal flanks of the Elysium Mons shield volcano, terminates within extensive volcanic plains, is associated with landforms typical of large volcanic channels, and shows evidence for having been a conduit for large volumes of lava. The properties of this system are consistent with incision by low viscosity lava. Crude thermal estimates suggest that this system could have formed through effusion of as little as ~10,900 km^3 of magma to the surface, or ~6% of the volume of the terrestrial Columbia River Basalt Group. Incision rates of up to several meters per day are estimated for mechanical and thermal processes involving lava flows with depths of 5–20 m and dynamic viscosities of ~1 Pa s. Flow of lava within the Hrad Vallis system is predicted to have been fully turbulent and characterized by discharges as great as ~865,000 m^3/s. Predicted flow conditions are consistent with those previously determined for Athabasca Valles, which also formed as a result of the expulsion of flows from structures associated with Elysium Mons.

1. Introduction

The outflow channels of Mars predominantly originate at discrete sources marking the sites of voluminous effusion of fluids from the subsurface (McCauley et al., 1972; Masursky, 1973; Milton, 1973; Carr, 1974). The presence of anastamosing reaches, streamlined erosional residuals, and other scabland-like landforms along these systems has contributed to their widespread interpretation as the products of catastrophic aqueous floods (Milton, 1973; Baker and Milton, 1974; Carr, 1974; Masursky et al., 1977; Mars Channel Working Group, 1983). These floods are widely believed to have been generated by outbursts to the surface from enormous aquifers (e.g., Carr, 1979, 1996; Baker et al., 1991; Clifford and Parker, 2001; Andrews-Hanna and Phillips, 2007; Wilson et al., 2009; Rodriguez et al., 2012; Morgan et al., 2013), possibly augmented or even dominated by the flow of associated mudflows or glaciers (e.g., Wilson and Mouginis-Mark, 2003; Tanaka et al., 2005; Chapman et al., 2010).

Outflow channel origins are relevant to our understanding of past surface conditions and near-surface volatile contents on Mars (e.g., Carr, 1996; Head et al., 2001; Carr and Head, 2010). Outflow origins are correspondingly also relevant to basic questions regarding past prospects for development of life on Mars (e.g., Masursky et al., 1979; McKay and Stoker, 1989; Komatsu and Ori, 2000; Levy and Head, 2005) and the potential for future colonization of the planet (e.g., Risner, 1989; Graham, 2004). Importantly, recent investigations of Martian outflow systems have suggested that associated lava flows may have had substantial capacity for channel incision (e.g., Hurwitz et al., 2010; Jaeger et al., 2010; Hurwitz and Head, 2012). As a result, a need exists to revisit previous aqueous interpretations of the outflow channels of Mars and to consider alternative channel origins involving predominantly volcanic processes. Indeed, geomorphological, mineralogical, and geochemical considerations collectively suggest the past development of some or all Martian outflow channels through incision by voluminous low-viscosity lava flows (Leverington, 2004, 2007, 2009, 2011, 2012), a mechanism believed to have been responsible for development of similar but generally smaller outflow systems on the Moon, Venus, and Mercury (e.g., Greeley, 1971; Wilhelms, 1987; Baker et al., 1992; Komatsu et al., 1993; Head et al., 2011; Hurwitz et al., 2012, 2013; Byrne et al., 2013).

In order to further explore the viability of volcanic hypotheses for development of the outflow channels of Mars, this study considered the consistency of Hrad Vallis landforms with hypothesized volcanic origins and used the morphological attributes of this system as a basis for quantitative determination of the flow conditions that might have driven channel incision by lava. Elevation data used in this study were collected by the Mars Orbiter Laser Altimeter (MOLA) instrument on board Mars Global Surveyor (Smith et al., 2003a,b). Mars image data were collected by the Thermal Emission Imaging System (THEMIS) instrument on board Mars Odyssey (Christensen et al., 2004), the High Resolution Imaging Science Experiment (HiRISE) instrument on board the Mars Reconnaissance Orbiter (McEwen et al., 2007a,b), and the

* Corresponding author. Tel.: +1 806 834 5310.
E-mail address: david.leverington@ttu.edu (D.W. Leverington).

0169-555X/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.geomorph.2013.10.029

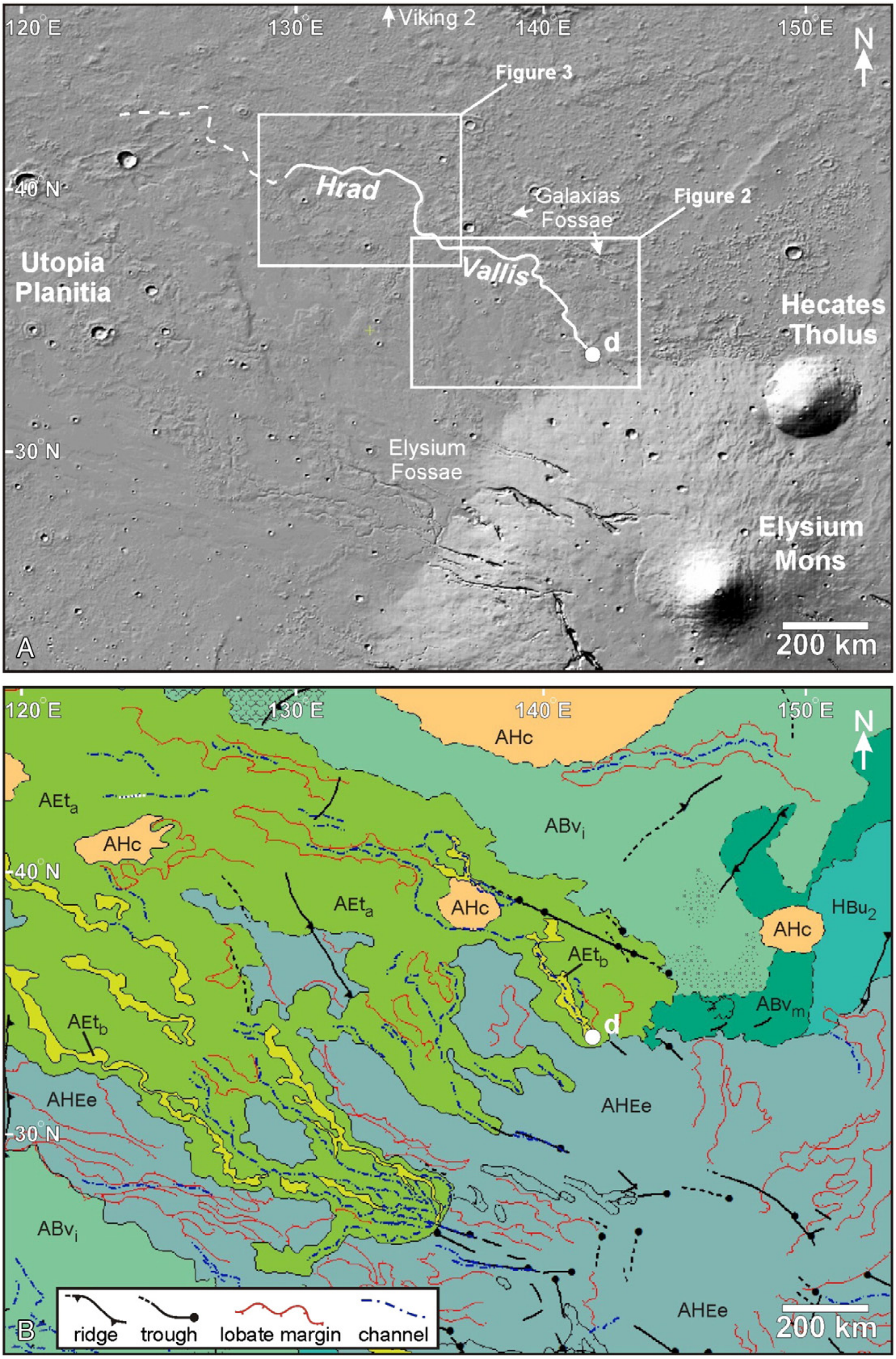

Fig. 1. (A) Map of shaded topography for the Hrad Vallis region. The channel system commences on the distal flanks of Elysium Mons, in the vicinity of several elongate depressions (the main channel commences at *d*) that are oriented approximately radially to the central caldera of this shield volcano. The Hrad Vallis system fades westward into the plains of Utopia Planitia. The white curve marking the path of Hrad Vallis is dashed for distal reaches less clearly associated with the main channel system. The Viking 2 landing site is ~32 km north of the northern limit of this map. Shaded relief data derived from Mars Orbiter Laser Altimeter (MOLA) gridded data (Smith et al., 2003a). (B) Geologic map of the region depicted in *A*, extracted and reprojected from Tanaka et al. (2005). As in (A), the main channel of Hrad Vallis commences at *d*. Map units are described in Table 1. Unit contacts are dashed where approximate or inferred. Troughs and ridges are marked by black arcs with dots and barbs, respectively; arcs are dotted where features are subdued. Lobate margins are indicated by red arcs, with hachures pointing downslope. Channels are marked by blue dashed arcs. Both maps are presented in simple cylindrical projection.