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Evidence for Amazonian highly viscous lavas in the southern highlands on Mars

Petr Brož [a,b,*], Ernst Hauber [c], Thomas Platz [d,e], Matt Balme [e,f]

[a] *Institute of Geophysics ASCR, v.v.i., Boční II/1401, 14131, Prague, Czech Republic*
[b] *Charles University in Prague, Faculty of Science, Institute of Petrology and Structural Geology, Albertov 6, 12800, Prague, Czech Republic*
[c] *Institute of Planetary Research, DLR, Rutherfordstr. 2, 12489, Berlin, Germany*
[d] *Institute of Geological Sciences, Freie Universität Berlin, Malteserstr. 74-100, 12249, Berlin, Germany*
[e] *Planetary Science Institute, 1700 E. Fort Lowell, Tucson, AZ 85719, United States*
[f] *CEPSAR, Open University, Milton Keynes MK7 6AA, United Kingdom*

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A B S T R A C T

We have identified small-scale volcanic edifices, two cones and three domes with associated flows, within Terra Sirenum, a region situated in the martian southern highlands. Based on thermal, morphological, and morphometrical properties, and the determination of absolute model ages, we conclude that these features were formed by volcanic activity of viscous lavas in the mid-Amazonian epoch, relatively recently in martian history. If our hypothesis is correct, this small volcanic field represents rare evidence of young volcanic activity in the martian highlands in which martian equivalents of terrestrial lava domes and coulées might be present. On Earth, such landforms are usually formed by highly viscous evolved lavas, i.e., andesitic to rhyolitic, for which observational evidence is sparse on Mars. Hence, this field might be one of only a few where martian evolved lavas might be investigated in detail.

1. Introduction

Volcanism was globally widespread on Mars in the early history of the planet, but became focused with ongoing evolution on two main volcanic provinces in the Tharsis and Elysium regions (Werner, 2009; Robbins et al., 2011; Platz and Michael, 2011; Xiao et al., 2012; Grott et al., 2013). Except for the widespread Hesperian ridged plains (Greeley and Spudis, 1981), and some isolated centres (e.g., Tyrrhenus and Hadriacus Montes, Williams et al., 2009; Robbins et al., 2011), evidence for post-Noachian (<3.7 Ga) volcanism, and in particular for individual volcanic edifices is rare in the martian highlands. It is generally thought that highland volcanism occurred early in Mars' history and stopped not later than ~1 Gyr after planet formation (Williams et al., 2009; Xiao et al., 2012).

The youngest volcanic activity in the Tharsis and Elysium volcanic provinces is characterized by the effusion of low-viscosity basaltic lavas (Vaucher et al., 2009; Hauber et al., 2011; Platz and Michael, 2011). It was long thought that more evolved (i.e., andesitic to rhyolitic) magma compositions are rare on Mars (Bandfield et al., 2004; Christensen et al., 2005), in contrast to Earth, where these lavas are common (Rogers and Hawkesworth, 2000). More recently, however, based on orbital spectroscopic observations and rover-based in situ measurements, several studies indicate that evolved magmas may have been generated on Mars (Skok et al., 2010; Wray et al., 2013; Stolper et al., 2013; Meslin et al., 2013; Sautter et al., 2014), but there are only few direct observations of kilometer-scale edifices that may be composed of evolved magmas (Rampey et al., 2007; Skok et al., 2010).

On Earth, highly viscous and evolved lavas can produce specific types of small-scale volcanic landforms such as magmatic cryptodomes or extrusive lava domes that are (qualitatively) diagnostic of rheology, and from which composition might be inferred (Fink and Griffiths, 1998). Because of their specific morphology and morphometry, these edifices may be recognized by remote sensing techniques (e.g., Rampey et al., 2007; Neish et al., 2008). The most promising martian edifices are individual hills in the western Arcadia region which may represent possible crypto- or lava domes (Rampey et al., 2007). Conversely, their spectral absorption characteristics are consistent with the presence of olivine and high-Ca pyroxene, commonly augite, suggesting a basaltic composition, but the possibility that these domes might be more silica-rich (basaltic–andesitic or andesite in composition) was not definitely ruled out (Farrand et al., 2011).

* Corresponding author at: Institute of Geophysics ASCR, v.v.i., Boční II/1401, 14131, Prague, Czech Republic. Tel.: +420267103063.
E-mail address: Petr.broz@ig.cas.cz (P. Brož).

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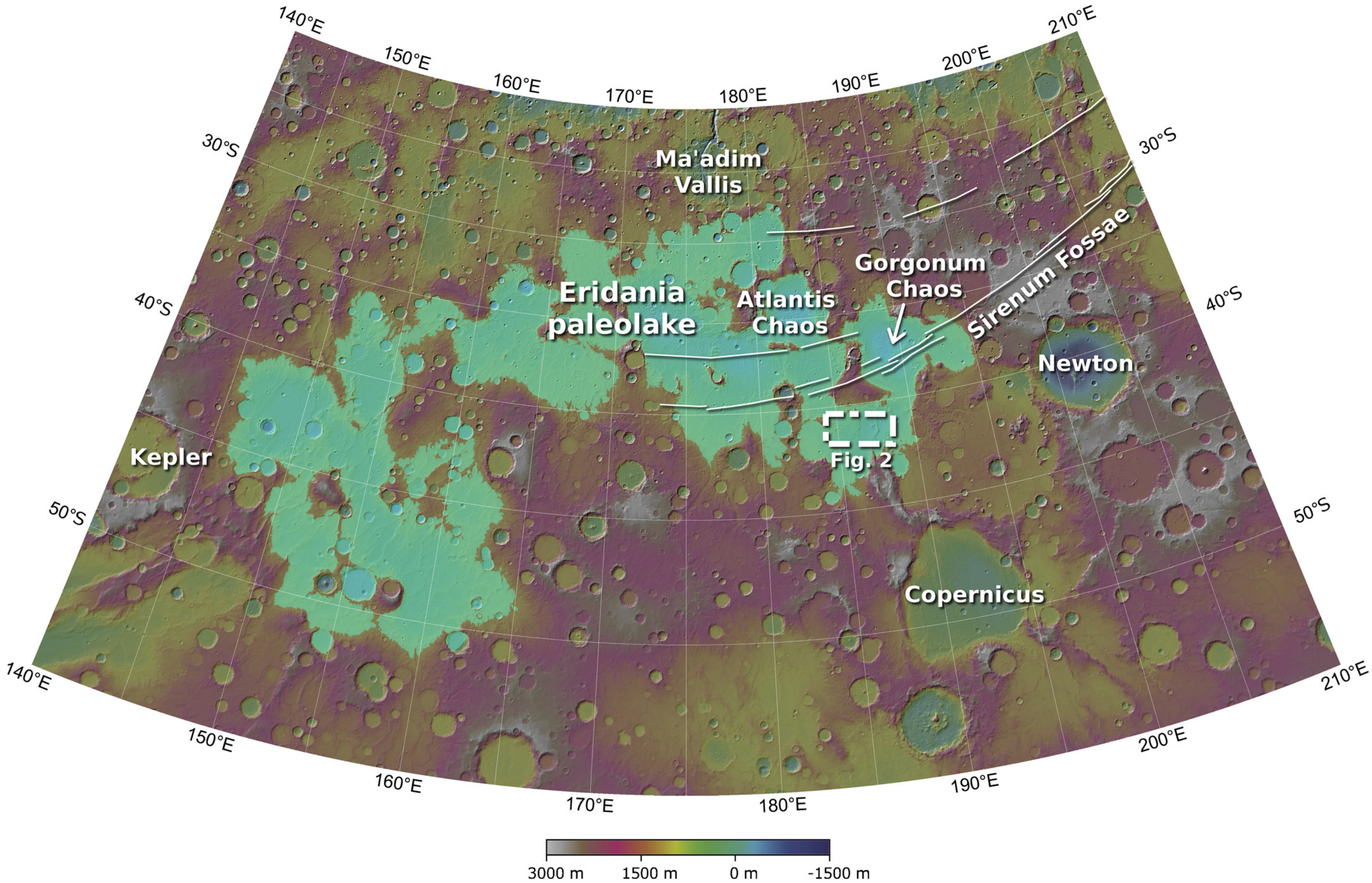

Fig. 1. Regional map of part of the southern hemisphere on Mars. The cyan color delineates the extent of the proposed Eridania Lake based on the 1100 m contour. Position of investigated area is marked by dashed box and clearly the area lies inside the proposed borders of the former lake. Base map is MOLA DEM and shaded relief.

In this study we focus on two cones with associated flow apron features, and three domical structures surrounded by flows, which are all located in the southern highlands. They might represent rare evidences of martian equivalents for terrestrial lava domes and coulées caused by highly viscous (i.e., andesitic to rhyolitic) lavas.

2. Methods and data

We used data sets acquired by several cameras on various orbital platforms: Context Camera (CTX; 5–6 m/pixel; Malin et al., 2007), High Resolution Stereo Camera (HRSC; 10–20 m/pixel; Jaumann et al., 2007), High Resolution Imaging Science Experiment (HiRISE; ∼30 cm/pixel, McEwen et al., 2007) and THEMIS-IR (day and night; ∼100 m/pixel; Christensen et al., 2004). CTX data were processed using the USGS Astrogeology image processing software 'ISIS 3' (Integrated System for Imagers and Spectrometers) and HRSC images using VICAR (Video Imaging Communication And Retrieval) software.

Topographic information was derived from Mars Orbiter Laser Altimeter (MOLA; Zuber et al., 1992; Smith et al., 2001) gridded Digital Elevation Models (DEMs) with 128 pixel/degree resolution (∼463 m/pixel) for regional context, and from HRSC DEMs for local scales. HRSC DEMs are interpolated from 3D points with an average intersection error of 12.6 m and most have a regular grid spacing of 50 to 100 m (Scholten et al., 2005; Gwinner et al., 2010). For detailed topographical analyses, we also used single shot data from the MOLA PEDR (Precision Experimental Data Record) data which we superposed on CTX images using ESRI ArcGIS 10 software. This software was also used to merge all available datasets. The data were projected in a sinusoidal projection with the central meridian set at 187°E to minimize geometric distortion.

Absolute model ages were determined from crater size-frequency distributions, utilizing the software tool *CraterTools* (Kneissl et al., 2011), which ensures a distortion-free measurement of crater diameters independently from map projection, and the software *Craterstats* (Michael and Neukum, 2010) applying the production function of Ivanov (2001) and the impact-cratering chronology model of Hartmann and Neukum (2001). The mapped crater population was tested for randomness to avoid the inclusion of secondary crater clusters (Michael et al., 2012). Craters were counted on CTX images.

3. Location

The study area is located in Terra Sirenum, a highland region which is crossed by approximately E–W-trending Tharsis-radial graben systems propagating from Arsia Mons over a distance of ∼3700 km. These grabens may represent the surface expression of volcanic dykes (Wilson and Head, 2002). Several wrinkle ridges, commonly interpreted as fault-propagation folds (e.g., Mercier et al., 1997; Schultz, 2000), indicate contractional deformation. The study area lies within the borders of the proposed former Eridania paleolake (Irwin et al., 2004; Fig. 1), a possible source for the formation of the Ma'adim Vallis outflow channel.

At local scale, the area is found within an unnamed depression (centred 41.40°S, 186.80°E) of unknown origin. Several conical and domical landforms (marked on Fig. 2a) are located within an area (∼150 km × ∼30 km) elongated in E–W direction. Except for one edifice (Cone T1), the remaining edifices are situated inside