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Morphologic and thermophysical characteristics of lava flows southwest of Arsia Mons, Mars

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ABSTRACT

The morphologic and thermophysical characteristics of part of the extensive lava flow fields southwest of Arsia Mons (22.5–27.5°S, 120–130°W) have been examined using a combination of orbital VNIR and TIR datasets. THEMIS images provide context for the regional geology and record diurnal temperature variability that is diverse and unusual for flow surfaces in such close proximity. CTX images were used to distinguish dominant flow types and assess local age relationships between individual lava flows. CTX and HiRISE images provide detailed information on flow surface textures and document aeolian effects as they reveal fine-grained deposits in many low-lying areas of the flow surfaces as well as small patches of transverse aeolian ridges. Although this region is generally dust-covered and has a lower overall thermal inertia, the THEMIS data indicate subtle spectral variations within the population of lava flows studied. These variations could be due to compositional differences among the flows or related to mixing of flow and aeolian materials. Specific results regarding flow morphology include: a) Two main lava flow types (bright, rugged and dark, smooth as observed in CTX images) dominate the southwest Arsia Mons/NE Daedalia Planum region; b) the bright, rugged flows have knobby, ridged, and/or platy surface textures, commonly have medial channel/levee systems, and may have broad distal lobes; c) the dark, smooth flows extend from distributary systems that consist of combinations of lava channels, lava tubes, and/or sinuous ridges and plateaus; and d) steep-sided, terraced margins, digitate breakout lobes, and smooth-surfaced plateaus along lava channel/tube systems are interpreted as signatures of flow inflation within the dark, smooth flow type. These flows exhibit smoother upper surfaces, are thinner, and have more numerous, smaller lobes, which, along with their the channel-/tube-fed nature, indicate a lower viscosity lava than for the bright, rugged flows. Flow patterns and local interfingering and overlapping relationships are delineated in CTX images and allow reconstruction of the complex flow field surfaces. Darker channel-/tube-fed flows are generally younger than adjacent thicker, bright, rugged flows; however, the diversity and complexity of temporal relationships observed, along with the thermophysical variability, suggests that lava sources with different eruptive styles and magnitudes and/or lavas that experienced different local emplacement conditions were active contemporaneously.

1. Introduction

The acquisition of high spatial resolution datasets with significant areal coverage provides an opportunity to explore the styles, magnitudes, and sequences of Martian volcanism in detail. The current investigation uses visible/near-infrared (VNIR) and thermal infrared (TIR) imaging to characterize lava flow fields of southern Tharsis, specifically those southwest of Arsia Mons and farther to the south in Daedalia Planum. Arsia Mons, the southernmost of the prominent Tharsis shield volcanoes, exhibits well-developed lava flow fields with a multitude of individual flows and flow lobes. Recent orbital data of the Martian surface now reveal small-scale characteristics of lava flow surfaces that provide new insights into the flow emplacement processes responsible for their formation. Our research examines flow morphology, local sequences of flow emplacement and flow field stratigraphy, degradation of flow field surfaces, and the unusual thermophysical variability of this flow field. The region includes lava flows that have been shown to exhibit some of the roughest surfaces on Mars at centimeter-to-meter-scales (Bandfield, 2009), as well as flows in close proximity showing all four types of diurnal temperature response (i.e., cool or warm in the day and cool or warm at night, as well as both kinds of day/night temperature inversions (Ramsey and Crown, 2010)). The region generally has a moderate overall dust cover and relatively low nighttime thermal inertia. Therefore, these diurnal temperature variations are likely caused by a complex combination of dust cover, albedo,

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and surface roughness. Thermal infrared datasets are also used to evaluate potential spectral differences and interpret physical properties of surface materials. Our combined morphologic and thermal characterization of this region is important both for interpreting the styles and diversity of Martian volcanism and for extending detailed thermal infrared analyses to comparable areas of the Martian surface.

2. Study area

Arsia Mons along with Pavonis and Ascraeus Montes form a linear chain of three large shield volcanoes that, along with Olympus Mons to the northwest, dominate the Tharsis volcanic province on Mars. Arsia Mons is 461 × 326 km across and 17.7 km high, with exposed relief of 11 + km (relative to the Tharsis plateau) and flank slopes averaging ~5° (Plescia, 2004). Daedalia Planum is an elevated plains region at the southern margin of the Tharsis province, where lava flows and plains embay remnants of highland terrain (e.g., Scott and Tanaka, 1986; Dohm et al., 2001). Typical surface slopes of the lava flow fields decrease steadily from 0 to 5° south of Arsia Mons to <0.5° at the southern margin of Daedalia Planum (Crown et al., 2012).

Arsia Mons has a well-developed summit caldera (Crumpler and Aubele, 1978; Crumpler et al., 1996; Head et al., 1998a, 1998b; Mouginis-Mark, 2002) and exhibits two large flow aprons that extend from alcoves on its northeast and southwest flanks and postdate its main shield (Plescia, 2004; Scott and Zimbelman, 1995; Bleacher et al., 2007a; Garry et al., 2014). The current investigation focuses on a zone (22.5–27.5°S, 120–130°W) (Fig. 1) within the extensive flow fields southwest of Arsia Mons and in northeast Daedalia Planum, for which high-resolution (1–15 m) VNIR and moderate-resolution (100 m) TIR data coverage is available. This work is part of broader studies of the southern Tharsis region of Mars that include geologic/flow field mapping (Crown et al., 2009, 2010, 2011, 2012, 2013, 2015, 2016, in preparation; Crown and Berman, 2012; Chuang et al., 2016; Crown, 2016, in preparation) and thermophysical mapping and modeling (Ramsey and Crown, 2010; Ramsey et al., 2012; Price et al., 2013; Simurda et al., 2015) to document the volcanic evolution of Mars' largest volcanic province.

3. Previous work

Using Viking Orbiter images, a series of sixteen 1:2 M scale lava flow maps were previously completed for the Tharsis region. Our study examines lava flows in what were defined as the Tharsis Montes and Arsia Mons flow units (Scott, 1981; Scott and Tanaka, 1981; Scott et al., 1981). Lava flows have long been recognized to the southwest of Arsia Mons, and the morphologic properties of individual flows as documented in Viking Orbiter images were used to provide some of the earliest estimates of rheologic properties of Martian lavas (Moore et al., 1978; Schaber et al., 1978). Warner and Gregg (2003) used Mars Orbiter Camera (MOC) images to document the ridged surface texture exhibited by lava flows southwest of Arsia Mons and made measurements of flow properties (e.g., flow dimensions, ridge spacing and amplitude) to estimate rheologic parameters that were consistent with basaltic or basaltic andesite compositions. More recent studies of the Tharsis region have utilized Mars Express High Resolution Stereo Camera (HRSC) images to identify small vents and their associated flow fields, to distinguish different flow morphologies, and to examine evolutionary stages in effusive volcanism (Bleacher et al., 2007a,b; see

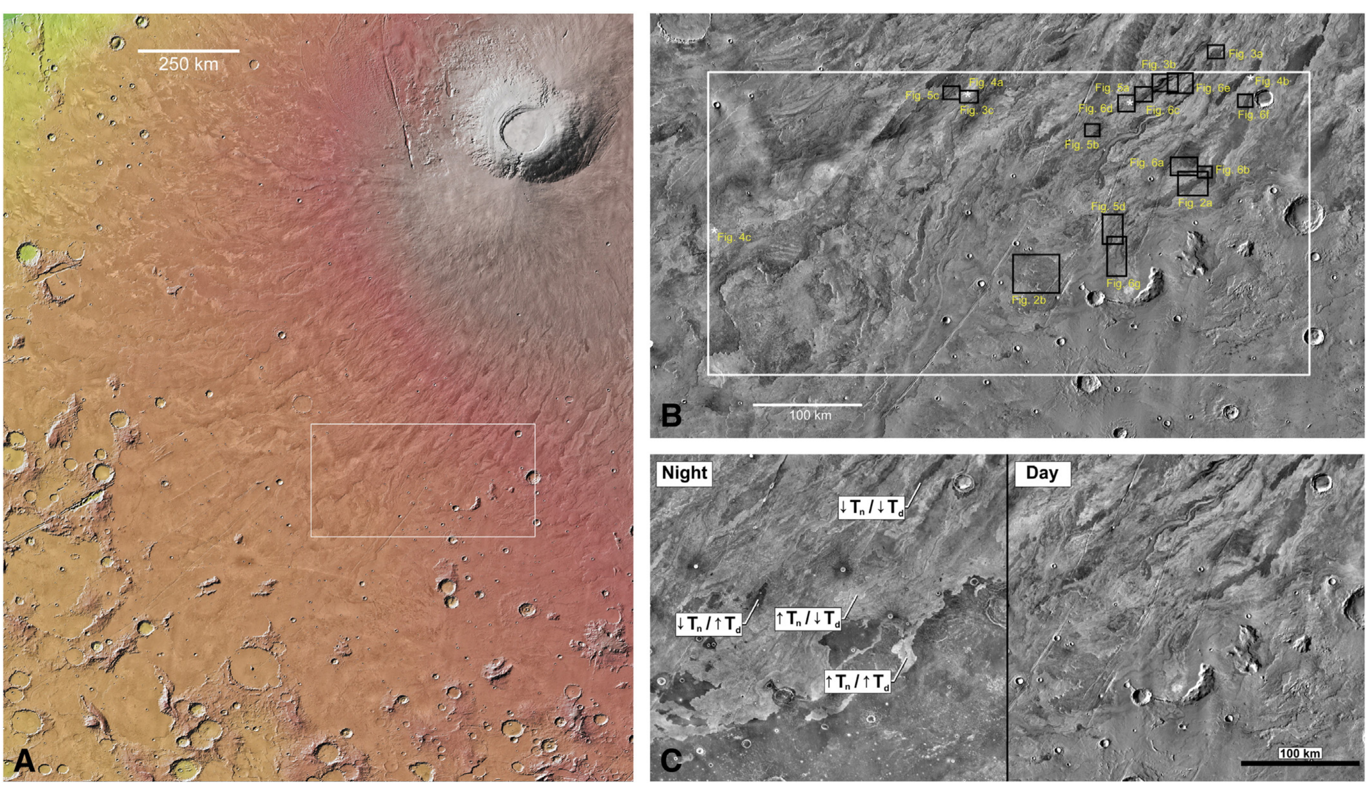

Fig. 1. A. MOLA color hill shade image (illuminated from the NW) showing location of the southwest Arsia Mons flow field study area (22.5–27.5°S, 120–130°E) outlined by white box (see Crown et al., 2015; Crown, 2016, in preparation). Note the Arsia Mons edifice (upper right) with summit caldera, southwest apron, and surrounding flow fields; remnants of ancient cratered terrain to south and southwest are embayed by southern Tharsis lava flows. North is to the top in this and all other figures. B. THEMIS TIR daytime image mosaic showing the Arsia Mons flow field study area (22.5–27.5°S, 120–130°W) outlined by white box. Locations of Figs. 2–6 are indicated by black boxes and white asterisks. C. Comparison of THEMIS TIR nighttime and daytime mosaics for the eastern part of the southwest Arsia Mons flow field, showing unusual variations in diurnal thermophysical behavior of the flows. T_n and T_d refer to the nighttime and daytime temperatures, respectively, and the arrows indicate cooler (down) and warmer (up) temperatures. Note that all possible combinations of day-night temperature variations are observed in relatively close proximity to one another.

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