THE 2014–2015 HOLUHRAUN LAVA FLOW-FIELD IN ICELAND AS AN ANALOG SITE FOR YOUNG VOLCANIC TERRAINS IN ELYSIUM PLANITIA, MARS. J.R.C. Voigt[1,2], C.W. Hamilton[2], K.M. Stack[1], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA (voigt@jpl.nasa.gov), [2]Lunar and Planetary Laboratory, University of Arizona, Tucson, Arizona, USA

Motivation: The Holuhraun eruption extended from August 2014 to February 2015 and emplaced a large (83.82 km^2) lava flow-field in the northern highlands of Iceland [1, 2]. The geologic and regional setting, as well as the produced lava morphologies show great similarities to Elysium Planitia on Mars [3, 4]. Here, we present similarities and dissimilarities between the 2014–2015 Holuhraun eruption site in Iceland and Elysium Planitia on Mars, with the aim of outlining in what perspective the terrestrial lava flow-field presents a good Mars analog and where it is lacking parallels.

Geologic Context: The high rates of volcanic activity in Iceland are related to decompression melting along the divergent Eurasian and North American plate boundary, in combination with a mantle plume upwelling below the landmass. The geologic setting in Elysium Planitia seems to be similar, even in the absence of global plate tectonics on Mars. Elysium Planitia includes the largest young fissure system on the planet, Cerberus Fossae, which indicates an extensional tectonic setting. Further, while the origin and concrete process of volcanism on Mars is still highly debated [5, 6], volcanic activity is most commonly explained by longstanding arising mantle-plumes forming hotspots [5] that might still be active [7]. An alternative hypothesis suggests that sufficient heat can be produced by thermal conductivity differences of the crust and mantle resulting in partial melting in the mantle [6]. Regardless of what magmatic processes create and concentrate melt at depth, once magma rises to the surface in Elysium Planitia, it tends to create fissure-fed eruptions forming large basaltic lava flow-fields. The dominant rock type and eruption styles within Elysium Planitia are therefore similar to Holuhraun—with lava surface morphologies that also exhibit similarities.

Lava Morphologies and Pre-emplacement Settings: Holuhraun is composed of two main lava facies making up more than 93% of the entire lava flow-field, namely the rubbly and spiny facies [3]. Rubbly is dominated by a highly disrupted lava crust whereas spiny is characterized by a smooth continuous crust. The surficial characteristics are similar to the morphologies observed in Elysium Planitia on Mars. Voigt and Hamilton (2018) [4], showed that the majority of lava facies in Eastern Elysium Planitia can be grouped into smooth and rough/disrupted facies. To illustrate the similarities between lava surfaces at Holuhraun and Elysium Planitia, Fig. 1 shows examples of two common facies for each location. Further, the spatial relationship between the two most common facies in Elysium Planitia is the same as at Holuhraun indicating that the emplacement mechanisms were similar. The smooth facies often seemed to be spatially associated with the rough/disrupted facies, implying that the smooth facies was formed as breakouts from the rough facies. Due to this observation, it is likely that true spiny lava tends to be emplaced in association with rubbly lava as the magnitude and variance of the effusion rate decreases as the eruption progresses [8].

Since the Holuhraun lava flow-field was emplaced on a glacial outwash plain, or "sandur", most of the lava was emplaced without strong topographic confinement. The best examples of spiny and rubbly facies are found at the distal part of the flow-field [3] in a region that underwent minimal overprinting by later lava flow branches. In Elysium Planitia, the topographic setting prior to lava emplacement generally included deep, but broad valley systems and flat-lying plains. Similar to the 2014–2015 Holuhraun flow-field, the best examples of smooth breakouts from rough lava can be observed in the distal parts. For example, where Marte Vallis lava debouches onto Amazonis Planitia or the southern and northern sides of the central Marte Vallis. In addition to the morphological and spatial similarities to the spiny and rubbly facies at Holuhraun, Elysium Planitia shows additional characteristics that are prominent at the Holuhraun lava flow-field, including but not limited to wakes, series of ridges and troughs, plates, and knobs, within the disrupted facies and pits, plateaus, circular plates, and drainage features in the smooth facies [3, 4]. Due to the strong morphological similarities and spatial relationships, we suggest that it is likely that the lava composing the majority of Elysium Planitia are composed of rubbly and spiny lava types instead of ʻaʻā and pāhoehoe lava types. However, as noted in [3], lava types cannot be reliably distinguished at HiRISE scale (30 cm/pixel) and thus, this hypothesis can only be confirmed with even higher resolution images or in-situ or low-altitude aerial observations.

Hydrology and Habitability: The Holuhraun lava flow-field was emplaced on a sandur with active fluvial channels associated with the Jökulsá á Fjöllum river [9, 10]. Tributaries of the Jökulsá á Fjöllum eroded into the sandur and modified the older lava flows associated with Askja volcanic system, Bárðarbunga–Veiðivötn system in the west, and the Kverkfjöll system in the east.

Elysium Planitia shows evidence of recent aqueous activity in the form of deep valley systems carved by outburst of high voluminous water, and fluvial channels formed by a more continuous water transport. Throughout Elysium Planitia we see evidence of rootless cones—constructs formed by phreatovolcanic activity and thus presents evidence of lava interaction with water or hydrated sediment during the time of emplacement [11]. Lava–water interactions are likely to create an environment suitable to extremophilic life both on Earth and Mars. Heat sources, such as lava flows, could reactivate dormant microorganisms that have former evolved in hydrothermal systems and then stored in sediments. The Holuhraun flow-field thus represents a unique site to understand the effect of volcanic eruptions and its interplay with hydrological systems on microorganisms [12] and presents an excellent analog site for Elysium Planitia and its potential habitability.

Volcano-tectonic Setting: Holuhraun's volcano–tectonic setting exhibits similarities to some parts of Elysium Planitia. The 2014–2015 Holuhraun eruption reactivated an older fissure segment that was feeding the 1867 Holuhraun flow-field. The new eruption produced lava that partially superimposed the older flow-fields including the 1797 and 1867 eruptions as well as the associated vents [13]. While at Elysium Planitia we do not see any evidence of spatter ramparts or cones, the source regions can be traced back to segments of the Cerberus Fossae fissure system. Specifically, in the central part of Elysium Planitia, there are indicators that different parts of the segments were active through time and some vent systems seemed to be reactivated to feed different lava flow-fields through time.

Aeolian: Even though Elysium Planitia is home to the youngest volcanic terrain on Mars and thus comparably unmodified by aeolian mantling, it is close to the largest dust source on the planet, the Medusa Fossae Formation [14]. Especially, some of the older lava flow-fields show mantling along the margins and on their interior surface but even the youngest flood basalt, Athabasca Valles, seemed to locally be gradually mantled by sediments originating from the Medusa Fossae Formation (e.g., 6 ºN, 154 ºW). Holuhraun presents a good analog site to understand the mantling evolution of young volcanic terrains. Only a few years after the eruption, sand ramps have built up along the flow margins, and dust and sand are starting to deposit on the lava crust, changing the character (specifically the roughness towards a smoother characteristics) of the lava surface and modify the flow margins.

Conclusion: The Holuhraun eruptions site provides valuable insight into the dynamics shaping planetary surfaces including a diverse spectrum of volcanic, but also aeolian and aqueous processes.

Acknowledgments: A portion of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. This work was supported by NASA's PSTAR program (Grant # 80NSSC21K0011), the Vatnajökull National Park Service, and IsViews (ID 20-8-34102-15-2012).

References: [1] Pedersen, et al. (2017) J. Volcanol. Geotherm. Res. [2] Voigt, et al. (2022) J. Volcanol. Geotherm. Res. Vol. 419, 107278. [3] Keszthelyi, et al. (2004), Geochem. Geophys. Geosyst., 5, Q11014. [4] Voigt and Hamilton (2018) Icarus, 309, 389–410. [5] Kiefer (2003) Meteorit. Planet. Sci., 38(12):1815–1832. [6] Schumacher and Breuer (2007) Geophys. Res. Lett., 34(14). [7] Broquet and Andrews-Hanna (2022) Nat. Astron. [8] Voigt et al. (2022) Geology, 50 (1): 71–75. [9] Bonnefoy, et al. (2019) J. Volcanol. Geotherm. Res. 387:106652. [10] Dundas, et al. (2020) J. Volcanol. Geotherm. Res., 408:107100. [11] Hamilton et al. (2011) JGR: Planets, 116(E3). [12] Duhamel, et al. (2022) Astrobiol., 22(10):1176–1198. [13] Hartley et al. (2013) Geochem. Geophy. Geosyst., 14(7):2286–2309. [14] Ojha et al. (2018) Nat. comm., 9(1):1–7.

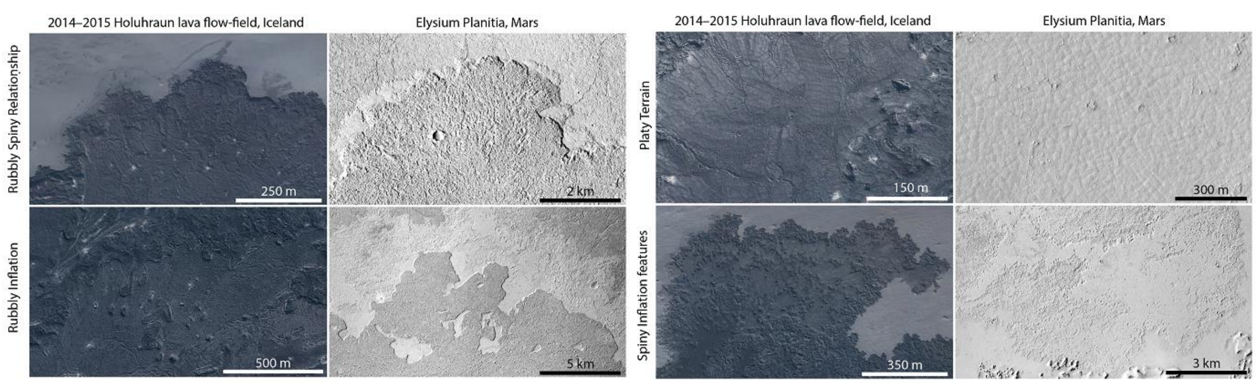

Figure 1 Examples of lava morphologies at the Holuhraun eruption site in Iceland (left panels) showing the UltraCam-Xp basemap (September 6, 2015) with a pixel scale of 20 cm/pixel and Elysium Planitia on Mars (right panels) drawn from the Context camera (CTX) and HiRISE images with 6 m/pixel resolution.