VOLCANO-ICE INTERACTIONS RECORDED IN THE ARSIA MONS FAN-SHAPED GLACIAL DEPOSITS: SYNTHESIS AND ASTROBIOLOGICAL IMPORTANCE. K. E. Scanlon and J. W. Head, Department of Geological Sciences, Brown University, Providence, RI USA

Introduction: As outlined in [1], assessing the habitability of any region requires, at minimum, considering the availability of liquid water, its chemical characteristics, the availability of nutrients and tolerability of toxins, the presence of an energy source, temperature suitability and variability, and shelter from ultraviolet radiation and mechanical disruption. Which of these is the limiting factor varies from ecosystem to ecosystem, but moisture is uniformly important to life on Earth. In Mars's Amazonian climate regime, the melting of ice by volcanic activity may have created some of the more recent habitats on the planet's surface [1-9].

The fan-shaped deposits (FSD) on the west and northwest sides of the Tharsis Montes are interpreted as debris-covered tropical mountain glaciers [3], formed by precipitation of ice in westerly winds [10]. The presence of glaciers on the flanks of large volcanoes has given rise to an abundance of landforms that record volcano-ice interactions, as [4] and [8] documented on Pavonis Mons and Ascraeus Mons. We have mapped the glaciovolcanic features in the Arsia Mons FSD and assessed the astrobiological implications of their type and their distribution in time and space.

Features of interest: The cold-based glacial deposits on Arsia Mons are roughly 180,000 km^2 in area. They date to the late Amazonian, co-occurring with a phase of volcanism [3]. Several classes of glaciovolcanic features have already been interpreted on Arsia Mons: *(1) Dikes.* On the basis of their morphology and their exclusive association with the glacial deposits, [6] propose that the Aganippe Fossae were created by phreatomagmatic eruptions when dikes intruded and eventually breached the Arsia Mons glacier. *(2) Sills.* Lobate features in the formation have been interpreted as sill-like subglacial flows [7]. These are of special interest because of their ability to efficiently transfer heat, melting ice [5,11]. *(3) Evidence for meltwater.* [7] noted fluvial channels, esker-like features and distorted drop moraines near the northwest edge of Arsia's FSD.

These environments provide settings of potential astrobiological importance, which we explore. For example, Figure 1 depicts a lobe-shaped plateau, which extends downslope, and an adjacent crater. The plateau is ~130-150 m high and extends from the base of a ridge that is ~350 m high. We interpret the ridge, located along the strike of the linear trend, to be a sub-glacial moberg-like ridge, and the elongate plateau to be a subglacial, sill-like lava flow extending from the vent. Superposed on the lobate plateau, and extending downslope and out onto the subjacent lava flows, are two sinuous ridges that are generally continuous for ~14 km; we interpret these as eskers draining subglacial eruption-induced meltwater. Nearby and downslope from the plateau, the drop moraines bow outward for a distance of ~5-10 km. The most prominent drop moraine occurs at the distal edge of this inner set of drop moraines. Fluvial channels with a braided appearance emerge across a ~10 km segment of the edge of the glacier as it stood when they formed; they extend at least 5 km into the surrounding terrain before merging and cross-cutting the prominent moraine. These channels are shown in Figure 2 [7].

Geological factors of biological importance: Among other considerations, the suitability of the Arsia Mons glaciovolcanic features as habitats depends on the timing and longevity of volcano-ice interactions, i.e. whether they existed long enough to be colonized and for how long they provided a refuge; the presence or absence of hydrological connections between sites of meltwater generation, which would allow well-adapted microorganisms to spread and survive the freezing or draining of one site if another existed; and the water chemistry, as recorded in the sediment record.

Timing of events. [12] bracketed the lifespan of volcano-ice interactions on Arsia Mons with crater counts; [13] dated subsets of the drop moraine ridges. By coupling this information with stratigraphic relationships, we can describe the relative ages and range of absolute ages for the features mapped. The recurrence of melting events is of particular importance. For example, we interpret the multi-lobed structure of the plateau in Figure 1 to have arisen from multiple episodes of eruption, but the nearby outflow channels must be examined in the context of terrestrial analogues [e.g. 14] to assess whether this resulted in multiple meltwater discharges.

Ongoing work by colleagues addresses the relationship of Tharsis volcanism to ice loading and unloading forced by climate. From climate and glacial modeling, the boundaries of the Tharsis glaciers are expected to fluctuate with orbital variations [15]. If the retreat that left the Arsia glacial deposit's ridged facies caused eruptions on cycles of order 10 ky, organisms may have been able to survive unfavorable periods in a dormant state, but obliquity varies on longer timescales than known microbes can remain dormant. Alternatively, eruptions may have occurred whenever ice was present.

Hydrological connections. If the events recorded by landforms on disparate parts of the Arsia Mons FSD did not overlap perfectly in time, the extent to which they were hydrologically connected becomes important to the efficiency with which they might have been colonized. The debris left behind by the subliming glacier may have obscured the evidence for connecting channels, but possible channels have been mapped. [9] note that since geothermal heat would have been elevated beyond the location of any one interaction, ice fractures may have connected regions of subglacial eruption. The dikes that intrude the Arsia Mons FSD do not necessarily imply this type of widespread heating, but this mechanism may have connected nearby water bodies.

Mineralogy. Spectral data from these and other interpreted glaciovolcanic deposits could provide evidence of aqueous alteration and minerals with good biosignature preservation potential, and clues to metabolisms that might have been available to organisms inhabiting them [9]. Such data can be difficult to acquire in the dusty Tharsis region, but insight can be gained from altered igneous deposits elsewhere on Mars [16].

Conclusions and ongoing work: Interactions between volcanic heat and a precipitation-fed glacier would have created bodies of water that any extant martian microbial life could have colonized. Whether this ever occurred depends on the timing and duration of the interactions, metabolic pathways available to the hypothetical organisms, and the extent to which individual habitats were physically connected, as well as whether life arose on Mars, survived to the Amazonian, and evolved appropriate adaptations to successfully inhabit these environments [17]. Our goal is to produce a complete map of volcano-ice interactions in the Arsia Mons fan-shaped deposit, a detailed analysis of their suitability as habitats at the time of their formation and afterwards, and an assessment of the subglacial sediments' capacity to preserve biosignatures.

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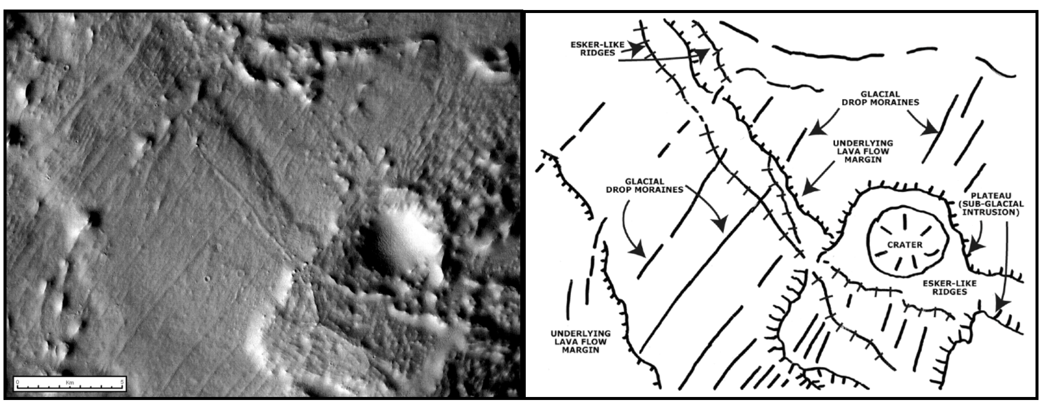

Figure 1. A formation interpreted to have resulted from subglacial eruption and meltwater production.

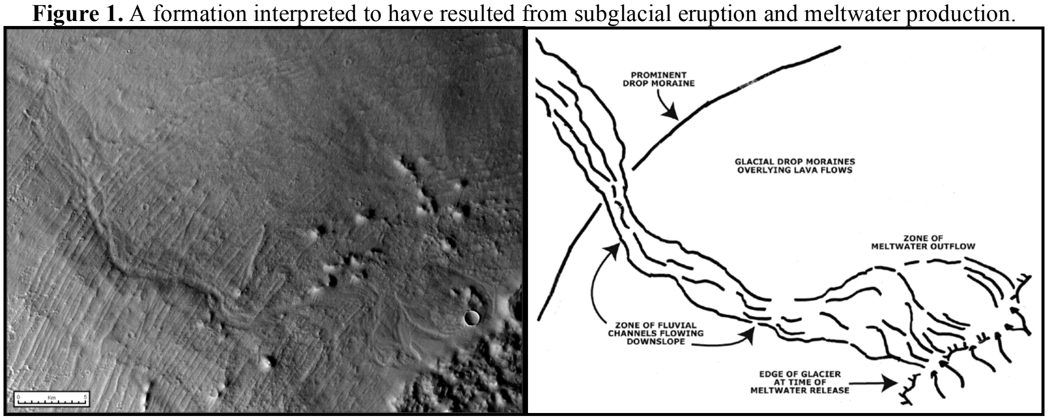

Figure 2. Outflow channels northwest of Figure 1. The scarp at southeast shows the edge of the glacier at the time of the outflow.