EARLY AMAZONIAN DIKE SWARMS IN UTOPIA BASIN, MARS: NATURE OF SUBSTRATE AND ESTIMATES OF EFFUSION RATES. G. B. M. Pedersen[1], J. W. Head III [2] and L. Wilson[3]; [1]Dept. of Earth Sciences, Aarhus University, Denmark, gro.birkefeldt@geo.au.dk, [2]Dept. of Geological Sciences, Brown Univ., Providence, RI 02912, USA, [3]Environmental Science Div., Lancaster Univ., Lancaster LA1 4YQ UK.

Introduction: Hundreds of narrow, linear ridge segments are found in the transition zone between Elysium Rise and Utopia basin. Five multiple ridge systems are identified having lengths ranging from 10-45 km and widths between 1-7 km, while the lengths of single ridges are approximately 30 km and vary between 100-400 m in width. The linear ridges are interpreted to be dikes and the multiple ridge systems are interpreted to be dike swarms.

The finding of yardangs and different stages of inverted craters indicate that erosion of units has taken place in the area, making it feasible that normal dikes, emplaced into the shallow subsurface, have been exposed by erosional processes. However, evidence for möberg ridges has been reported within the area making subglacial intrusions plausible, too. The dikes are both modifying and constraining Early Amazonian flows suggesting intense dike emplacement in the transition zone between Utopia Basin and Elysium Rise in the Early Amazonian.

Background and Geologic Setting: The transition between the region of Elysium and Utopia is complex and several different landforms ranging from volcanic activity (lava flows, sills and dike emplacement [1-3]), outflow channels [2,4], glacial features such as eskers and thumbprint terrain [5], and ice-volcano interactions such as volcaniclastic flows, mega-lahars and subglacial volcanic edifices [2,6-14] have been reported in the area. Here we evaluate the geomorphic characteristics and the origin of the observed narrow ridge systems, which have not been analyzed before, and we discuss the implications for the geologic history of the transition zone between Elysium Rise and Utopia.

Morphology of linear ridges: Linear ridges occur both as single ridges in isolation and as multiple parallel features (Fig. 1). *Single ridges:* CTX images (6m/pixel) reveal that single ridges generally have a sharply defined crest, are up to 30 km long, 200 m-400 m wide and, according to single MOLA tracks, have a height varying between 5 and 30 m (Fig. 1 B-C). One of the observed single ridges is emplaced *en echelon* (Fig. 1B) and the northernmost ridge curves slightly towards the southern ridge segment in an area where a few minor ridges also are exposed. Another single ridge system penetrates a lobate flow unit and continues as a ridge on the other side (Fig. 1 C). One singular sharp-crested ridge is also associated with a rough textured mound with a central ridge, which has been interpreted to be a möberg ridge [7-8]. *Multiple Ridges:* Five occurrences of multiple ridge systems were observed within the study area having a wedge-like shape, being 10-45 km long and 1-7 km wide, broadest in the middle of the transect (Fig. 1A-1D). Fig. 1D displays a typical wedge-shaped zone of multiple ridges, being 1.2 km at the widest place and with ridges that occasionally crosscut each other, but on average the distance between the ridges is 100 m. In the westernmost part of the study area HiRISE images reveal that some of the multiple ridge systems have a distinct, symmetric fracture indicating that the ridge material is competent; moreover, short stubby flows originate from some of the ridges (Fig. 1E).

Origin of the linear ridges: Several different geologic processes can produce landforms having a ridge-like nature, such as: eskers, exhumed streams, faults, möberg ridges and dikes. Both eskers and exhumed streams are excluded due to the very uniform and linear nature of the observed ridges, the crosscutting relationship with other units and the observed flows emanating from the some of the ridges. Likewise, faults are excluded since faults usually do not exhibit symmetric ridges, and the observed flows from some of the ridges are unlikely to be related to fault activity. Thus, the ridges are most likely to be either dikes or möberg ridges, since they are very uniform, linear, crosscutting different units and sometimes being emplaced *en echelon*. The observed fractures along the crest of the ridges are not observed in hyaloclastite ridges on Earth, which probably indicates that the material is not loose hyaloclastite. This supports the conclusion that the observed ridges either are normal dikes or that they are dikes emplaced subglacially as part of an effusive eruption.

Geologic relationships and preservation: The ridges crosscut different units and these relationships are helpful in constraining the timing of ridge emplacement. Some ridges clearly crosscut flows that are mapped as Early Amazonian [2,14] while other observations of the structural relationships between outflow channels and ridges indicate that the ridges have constrained Early Amazonian outflow activity [2,14]. Thus, the ridges are both modifying and constraining Early Amazonian flows suggesting intense dike emplacement in the Early Amazonian. Some of the observed ridges are also crosscutting a rough-textured knobby unit, which displays small elongated ridges, which are interpreted to be yardangs; moreover different stages of inverted craters are observed within this unit. The finding of yardangs and inverted craters indicates that erosion of geologic units has taken place, thus exposing the dikes intruded into the substrate to just below the surface [e.g., 15].

Dike Morphometry and Estimation of Effusion Rates: We use the morphometric characteristics of the linear ridges interpreted to be dike swarms to estimate effusion rates, in a manner similar to that employed in [15]. A key issue distinguishes dikes which intrude without breaking through to the surface and those that produce a significant erupted volume [16]. If eruptions took place through dikes ~200 m wide, magma flow speeds could be up to ~20 m/s and volume fluxes up to ~5000 m^3/s per meter of active fissure [15]. However, when a dike erupts to the surface, much of the excess pressure holding the dike open is relaxed as the pressure gradient driving magma flow develops [16]. Active fissures up to 20-30 km long, corresponding to the eruption of the larger lengths of single dikes observed, would correspond to the eruption of magmas with ~0.2-0.3 mass% volatiles rising at speeds in the range 1-2 m/s through dikes with sub-surface widths of ~2 m, leading to total lava volume fluxes in the range 10^4-10^5 m^3/s, readily able to produce flow units up to a few tens of km long.

Conclusions and implications: The observed linear ridges are interpreted to be single dikes and dike swarms, either emplaced as normal dikes or as subglacially emplaced dikes. The finding of yardangs and different stages of inverted craters indicate that erosion of units has taken place in the area making it feasible that normal dikes have been exposed [15]. In addition, evidence for möberg ridges [7,8] has been reported within the area making subglacial intrusions also plausible.

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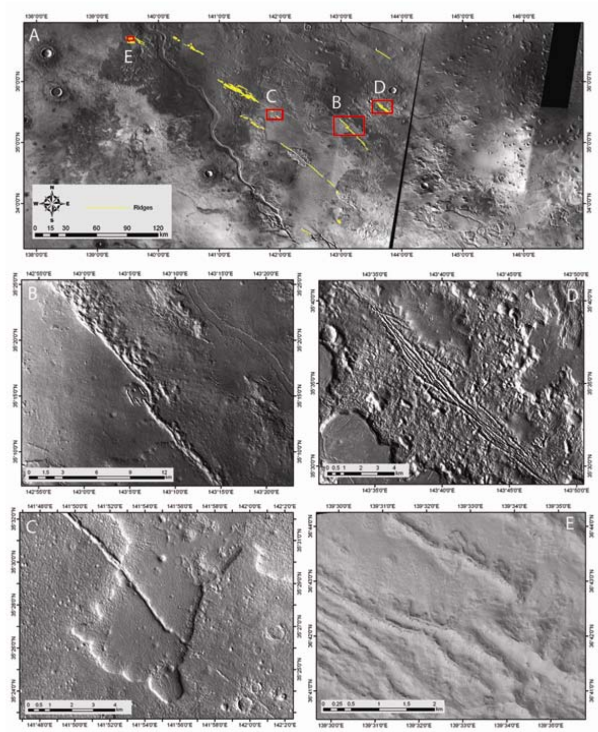

Figure 1. A) The distribution of single and multiple ridges. B) Single ridge segments emplaced en echelon emerging into eroded terrain to the north. The total length of the ridge segments is around 40 km. The northernmost ridge segment curves slightly towards the southernmost segment. P06_003268_2158. C) A single ridge penetrates a flow as a fracture and continues as a ridge on the other side of the flow. The size of the ridge segment north of the flow is 5km long and 200-250m wide, while the ridge south of flow widths 60-80m and wedges out twice 400m and 2.5 km away from the southern edge of the flow. The flow is approximately 40-50m high. P03_002345_2140. D) The easternmost multiple ridge system is a wedge shaped zone with multiple ridges being 1.2 km wide and the distance between the ridges are approximately 100m. P03_002279_2161. E) A section of HiRISE image PSP_006591_2165 displaying properties of the multiple ridges in the most western part of the research area. Some of the ridges have a very distinct, symmetric fracture on top of the ridge crest and from the northernmost ridge four stubby flows emerge.