LINEAR RIDGES IN ARABIA TERRA, MARS: AN ANCIENT GIANT RADIATING DYKE SWARM?

M. R. Balme[1], P. M. Grindrod[2], A. E. Jay[3], [1]School of Physical Science, The Open University, UK (matt.balme@open.ac.uk), [2]Natural History Museum, London, UK, [3]School of Environment, Earth and Ecosystems Sciences, The Open University, UK.

Introduction: The Arabia Terra region of Mars experienced multiple sedimentary deposition and erosion events during the Noachian and early Hesperian, at local to regional scale [e.g., 1–4]. Transport and deposition of sediments via fluvial [e.g., 5, 6], pyroclastic [e.g., 7, 8], groundwater [9], and aeolian processes [10], or combinations thereof [11], are all thought to have played a role in the regional evolution. Understanding the evolution of the region is complicated by the difficulty in correlating units or finding stratigraphic markers for Noachian deposits (some younger strata have been correlated [4]). However, we document here an extensive population of linear ridges (Fig. 1) in Western Arabia Terra that could provide such a stratigraphic marker. Also, although the origin of these features is unclear, their distribution and morphology suggests that a giant radiating dyke swarm is a plausible working hypothesis. If true, this suggests a mantle plume impinged on the Arabia Terra crust in the Noachian.

Morphological Overview: The linear ridges are several to a few tens of kilometers long and are generally straight. A few (< 5%) are curved by <10° along their length; even fewer (<<1%) have 'kinks' of up to ~30°. For any given location, all ridges present have remarkably similar orientations (Fig. 1). Few en-echelon patterns are seen, and there is no visible branching or other complex structure. Some ridges are continuous, but others comprise co-aligned segments or rows of knobs, or have gaps within them.

Two morphological classes occur (although the distinction is gradational): type (i) simple ridges have peaked or rounded crests, and are isolated within surrounding low-lying plains; type (ii) ridges can be flat-topped and extend from eroding plateaus or upstanding plains (Fig. 1). Some ridges closely parallel one-another to form a double ridge system; these could be a transition between the two end-member classes.

Survey Approach: We used a global mosaic [12] of 6m/pixel Context Imager [CTX; 13] data to search for the ridges, using standalone CTX images where mosaic quality was poor. Five CTX Digital Elevation Model (DEM) and ortho-image sets were created using SocetSet software to enable 3D measurements of the regions with the greatest spatial density of ridges.

We digitized the ridges as polyline objects using ArcPro GIS software, recording length and end-to-end orientation. Where co-aligned segments appeared to be the remnants of a single ridge, we digitized them as one object, but in general we recorded multiple segments as multiple polyline objects.

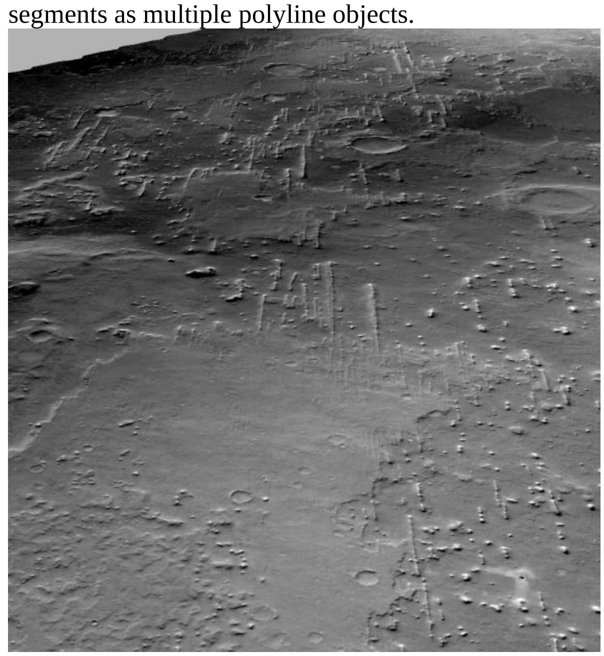

Figure 1. Northwest-looking view (CTX image and DEM mosaic) of ridges in study area 1. Note consistent ridge orientation and linearity and how some ridges appear isolated within the lower, darker plains, but others (e.g., in the middle of the image) appear to be being exposed from superposing brighter plains units. Image field of view 10 km at image bottom. Distance to image-top horizon is ~45 km. No vertical exaggeration. Credit NASA/JPL/MSSS.

We completed first a detailed survey of an area ~50×50 km centered on 1°E, 12°N (study area 1), digitizing all features that could be reliably identified (~ 600). However, as we expanded the study area it became clear that there are too many features to digitize individually. Our wider dataset (study area 2; ~2200 features) therefore covers much of western Arabia Terra but records only the largest or most representative examples (probably 1 in 5 to 1 in 10 of all ridges). We estimate therefore that there are 10,000-20,000 ridges in the Western Arabia Terra region.

Survey results: For study area 1 (N ~600), we found mean ridge lengths of 2 km, median 1.4 km with maximum length of 22 km. The larger study area 2 (N~2200), mean ridge length is 2.6 km, median length

1.6 km and max length 33 km. 20 ridges were analysed using CTX DEMs. Mean and median ridge height are both 41 m (max. 71 m) and mean and median ridge width are 330 m (max. 450 m). This gives mean flank slopes of ~14°. Importantly, ridge azimuth was seen to vary consistently across the region, forming a "fan shape". We grouped the ridges by location and calculated a directional mean per group. Extrapolating (Fig. 2) reveals that the ridges are orientated radially about a point at ~14°E, 1°N.

The ridges appear to be superposed by or eroding out from specific units within Arabia Terra. The superposing units are generally ~100 m thick, but often are themselves superposed by other thicker strata. Ridges form most commonly in mid-to-late Noachian $HNMe_u$ and mid-Noachian NHc_2 units (in Hynek and DiAchille's Meridiani Planum geological map [14]), but are superposed by the Hesperian Hp unit.

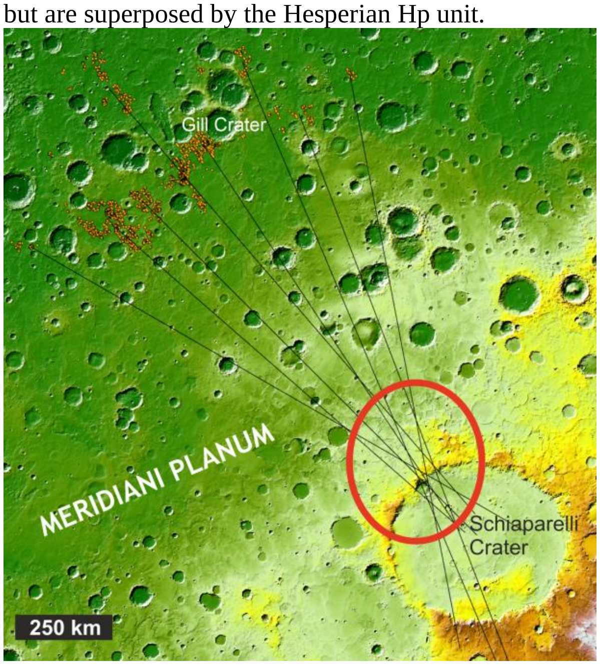

Figure 2. Extrapolated, generalized orientations (black lines) of linear ridges (orange lines). Ridge orientations converge on NW Schiaparelli Crater (red ellipse). Background is MOLA Dem and hillshade.

Discussion: The origin of the ridges is unclear, but their upstanding morphology suggests they are locally resistant materials, picked-out in positive relief by persistent erosion. Their extreme linearity, and regionally consistent orientation pattern are not well explained as responding to wind patterns, nor as ejected products of the Schiaparelli impact. They could be filled fractures created by the Schiaparelli impact, although, at 5-8 crater radii away, this seems unlikely.

The morphology orientation pattern and evidence for exposure by erosion of surrounding terrains suggest instead that the ridge might be a giant igneous dyke swarm, as seen on Earth [e.g., 15] and proposed for Mars and Venus [e.g., 16]. Individual ridges are similar in height and width to degraded dykes on Earth, e.g., Shiprock, dyke 'south' (New Mexico USA) is ~50 m high with a width of 350 m (much of this width is mass wasting; the dyke itself is ~10 m wide [17]). In addition, dykes often arrest at contacts between dissimilar horizontal layers [e.g., 18], and at depth, sometimes forming graben above [as proposed on Mars and Venus, 16]. No graben are seen here, but removal of >100 m of materials from around and above the ridges is clear, so exposure of the dyke itself at this depth seems realistic.

Conclusions: The ridges' consistent orientations and superposition relationships suggest (i) they formed simultaneously, and (ii) during the Noachian. They therefore provide a stratigraphic marker that can be used to understand the regional geological history. Furthermore, although other interpretation remain to be explored (e.g., sedimentary dykes, mineralised zones), an interpretation as an igneous dyke swarm, emplaced into sedimentary material, then further buried and later re-exposed by protracted erosion, matches most key observations. Giant radiating dyke swarms are associated with mantle plume margins on Earth [e.g., 15], so our interpretation argues for a Noachian-aged mantle plume, located in southwest Arabia Terra.

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