Discordance Mapping of Argyre Basin: An Insight into the Fluvial and Subglacial Origin of Valley Networks in Southern Mars. R. S. Bahia[1], A. G. Galofre[2], S. Covey-Crump[1], M. Jones[1] and N. Mitchell[1], [1]Department of Earth and Environmental Sciences, The University of Manchester (rickbir.bahia@manchester.ac.uk), [2]School of Earth and Space Exploration, Arizona State University (agraugal@asu.edu)

Introduction: Martian valley networks have been noted as evidence for surface run-off and past water cycles on ancient Mars [e.g. 1–3]. There is still great uncertainty in the duration, intensity and surface conditions that led to valley formation, however, it is generally agreed that the majority formed as a result of precipitation-fed fluvial incision [4]. Many of the networks have characteristics that resemble terrestrial systems; e.g., the valleys commonly originate at or adjacent to drainage divides [5], some of which have numerous tributaries with drainage densities comparable to low-order terrestrial valley systems [3]. However, recent analysis has found that the geometries and morphological characteristics of some valley networks are more comparable to subglacial valley formation [6].

Subglacial valley systems have several morphological characteristics that make them discernable from fluvial valley systems (i.e., those formed via precipitation or sapping erosion). Subglacial valleys have large width-to-depth ratios and undulating long. profiles [e.g., 7]. Qualitative observational characteristics common for subglacial channels are stepped long. profiles, no meter scaled tributaries, an abrupt source and termination, and a semi-uniform width [e.g., 7]. Valleys fitting these characteristics have been identified across the surface of Mars [6].

Unlike fluvial valley networks, which follow the surface slope of the underlying topography [8], subglacial networks are orientated in the direction of the surface slope of the overlying ice-sheet. With this in mind, subglacial valleys may have orientations that are discordant with the underlying topography. Discordance analysis, a technique which compares the valley paleoslope direction and topographic slope direction, has previously been applied to Mars to determine areas that have undergone topographic modification since valley formation [8]. This technique could also be a tool for identify valleys with potential subglacial origins.

The Argyre Basin region of Mars (50° S, 40° W) displays an array of incisional valley networks and topography-altering features (e.g., volcanoes and craters) [10, 11]. It is hypothesized that the impact that formed Argyre Basin, ~4.04 Ga [12], initiated fluvial activity via melting of the southern ice caps, triggering valley formation [10]. Valleys within this region give insight into the complex history of fluvial and glacial activity within this area [8]. However, there are still many valleys with ambiguous formation origins. Understanding the origins (i.e., glacial or fluvial) of these valleys could reveal information about the environmental history of the Argyre Basin region.

In this study we mapped and applied discordance analysis to valley networks in and around Argyre basin. We performed detailed analysis on four valley networks (two non-discordant and two discordant) on the eastern side of Argyre Basin, to determine whether their characteristics are indicative of a fluvial or subglacial origin. Three of these systems, which are spatially distributed (> 1000 km apart from one another) along the eastern region of Argyre Basin, are likely subglacial in origin. Their occurrence indicates that an ice-sheet or multiple ice-sheets were present along the eastern region of Argyre throughout its history.

Data and Methods: Valley networks were identified in ESA Mars Express Orbiter – High/Super Resolution Stereo Colour Imager (HRSC) images (~ 25 m per pixel) and manually mapped using the polyline function within ArcMap 10.2.1, defined under analogous characteristics as those of previous studies [e.g., 3, 8]; i.e., sublinear features dividing into small branches upslope and become singular downstream whilst slightly increasing in size.

The morphology of these valleys was determined using the ArcMap 10.2.1 interpolate line feature, allowing valleys to be categorized into U-shaped and V-shaped. Due to the large area covered in this investigation, the Mars MGS MOLA - MEX HRSC Blended DEM Global 200m v2 [13] was used to obtain elevation data. In order to determine the relative ages and geological settings of the mapped valleys, the Tanaka et al. (2014) digital global map of Mars was used [14]. The ages for these surfaces are determined from crater density counts.

Drainage density was determined as the total length of valleys within a set radius of 235 km for each output raster cell (in accordance with [3]) using the ArcMap Spatial Analyst - Line Density tool.

To identify valleys with potential sub-glacial origins, discordance analysis was performed by converting the polylines into vectors, which represent the slope direction at the time of valley formation. This slope direction was then compared to the aspect (present regional slope direction) and the difference used to determine the discordance value (slope direction discrepancy).

Two non-discordant valleys (Fento Vallis and the Darwin Crater valley system) and two discordant valleys (eastern Hale crater valley system and Nia Vallis) were studied in further detail using a combination of HRSC and CTX (Context Camera – ~5m per pixel) images, to determine their potential formation origin. In addition to morphological analysis, paleohydraulic analysis (Flint's Law [15] and Hack's Law [16, 17]) and discharge calculations (the Manning equation [18] and the Darcy-Weisbach equation [19] were performed on the non-discordant valleys.

Results: In total, 2669 V-Shaped valleys, with a total length of 36155.5 km, and 45 U-Shaped valleys, with a total length of 2683.5 km, were identified. Most V-Shaped valleys dissect the eastern and northern rim of Argyre Basin, with comparatively fewer in the south and west. This is reflected in the comparative drainage densities, with the densest northern valley networks having values up to 0.098 km^{-1}, compared to the densest in the south with values of only 0.040 km^{-1}.

The valleys present in the north generally dissect crater rims, have many tributaries and are comparatively short in length (maximum main valley length of ~ 72 km). In contrast, those in the south are much longer (e.g., Surius Vallis has a main valley length of ~ 905 km) and lack tributaries. U-Shaped valleys are prominent along the south/south-west rim, but are lacking along the northern rim of Argyre. Excluding two V-Shaped valley networks adjacent to the south-eastern rim, the centre of the basin is largely absent of valleys.

Almost half (47.8 %) of the valleys display concordance (< 45° discordance) with present slope direction, with discordant valleys scattered throughout the study area. Two dense groups of discordant valleys are present adjacent to Hale Crater and Nia Vallis. Both of these areas display features commonly associated with the presence of an ice-sheet/glacier – e.g., glacial moraines and eskers. Additionally, the morphology of these valley systems are consistent with a subglacial origin.

Fento Vallis and the Darwin Crater valley system are entirely concordant with present topographic slope, and are in relatively close proximity to one another; however, their morphologies differ greatly. Fento Vallis consists of 25 valleys with a total valley length of ~ 690 km and drainage density of 0.019 km^{-1}. The eastern rim of Darwin Crater is dissected by a dendritic valley network made up of 49 valleys, with a collective valley length of ~ 1351 km and drainage density of 0.048 km^{-1}. Fento Vallis displays a planform and surface features (e.g., inner channel eskers) indicative of a subglacial origin. Alternatively, the Darwin Crater System has a planform associated with fluvial activity and originates from cirque like depressions. Additionally, this valley system has a Hack's Law exponent characteristic for valleys formed via a precipitation-fed fluvial origin (n = 0.62). Although the Darwin Crater system appears to have a fluvial origin, less than 100 km to the east is Pallacopas Vallis, which displays inner eskers indicating that it has a subglacial origin.

Discussion: The comparative drainage densities and planforms of valleys in the north and south of Argyre Basin may indicate a different source of fluvial incision. Those in the south have planforms consistent with formation via glacial incisions and ice-melt, i.e., they lack tributaries and mainly consist of one large main valley. This is reflected in the abundance of U-Shaped valleys along the southern rim of Argyre, indicative of a glacial origin. In contrast, those in the north have dendritic planforms more consistent with valleys formed by precipitation.

The presence of glacial features (e.g., glacial moraines and/or eskers) within the Hale Crater valley region, Nia Vallis, Fento Vallis and Pallacopas Vallis, indicates that these areas were once covered by an ice-sheet. These valleys are present in surfaces spanning a range of ages (Noachian to Amazonian) and are distributed across the eastern Argyre region, indicating that an ice-sheet or multiple ice-sheets have been potentially present within this region throughout the history of Mars. In contrast to the aforementioned valley systems, the Darwin Crater valley system appears to have formed via precipitation-fed fluvial activity. The presence of cirque like depressions at the source of the valleys suggest that the fluvial activity was likely triggered by snowfall accumulation, followed by melting. This valley system dissects an Amazonian aged surface indicating snowfall has occurred within this region relatively recently, however, the valley's long. profile is convex, indicating the snowfall was short-lived as there has caused little modification to the surface.

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