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The Hypanis Valles delta: The last highstand of a sea on early Mars?

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ABSTRACT

One of the most contentious hypotheses in the geological history of Mars is whether the northern lowlands ever contained an oceanic water body. Arguably, the best evidence for an ocean comes from the presence of sedimentary fans around Mars' dichotomy boundary, which separates the northern lowlands from the southern highlands. Here we describe the palaeogeomorphology of the Hypanis Valles sediment fan, the largest sediment fan complex reported on Mars (area >970 km^2). This has an extensive catchment (4.6×10^5 km^2) incorporating Hypanis and Nanedi Valles, that we show was active during the late-Noachian/early-Hesperian period (~3.7 Ga). The fan comprises a series of lobe-shaped sediment bodies, connected by multiple bifurcating flat-topped ridges. We interpret the latter as former fluvial channel belts now preserved in inverted relief. Meter-scale-thick, sub-horizontal layers that are continuous over tens of kilometres are visible in scarps and the inverted channel margins. The inverted channel branches and lobes are observed to occur up to at least 140 km from the outlet of Hypanis Valles and descend ~500 m in elevation. The progressive basinward advance of the channellobe transition records deposition and avulsion at the margin of a retreating standing body of water, assuming the elevation of the northern plains basin floor is stable. We interpret the Hypanis sediment fan to represent an ancient delta as opposed to a fluvial fan system. At its location at the dichotomy boundary, the Hypanis Valles fan system is topographically open to Chryse Planitia – an extensive plain that opens in turn into the larger northern lowlands basin. We conclude that the observed progradation of fan bodies was due to basinward shoreline retreat of an ancient body of water which extended across at least Chryse Planitia. Given the open topography, it is plausible that the Hypanis fan system records the existence, last highstand, and retreat of a large sea in Chryse Planitia and perhaps even an ocean that filled the northern plains of Mars.

1. Introduction

Whether large seas or an ocean, which might have covered up to a third of the planet's surface, ever existed in the northern lowlands of Mars is one of the most important unanswered questions in the geological evolution of Mars. Evidence to support the ocean hypothesis has come from observations of hypothesised shoreline features in orbital images (Clifford and Parker, 2001; Parker et al., 1993), valley networks terminating at or near these shorelines (e.g., Hynek et al., 2010), and the occurrence of putative deltaic deposits at similar elevations around the dichotomy boundary (Di Achille and Hynek, 2010). Moreover, Gamma Ray Spectrometer observations (e.g., Boynton et al., 2002) suggest excess ice in the subsurface and an enrichment of the D:H ratio indicates a substantial loss of water to space (Villanueva et al., 2015). More recently, the presence of large boulders and lobe-shaped deposits have been explained as tsunami deposits caused by impacts into a martian ocean (Costard et al., 2017; Rodriguez et al., 2016). Nevertheless, identifying consistent evidence of a past standing body or bodies of water (Clifford and Parker, 2001) at a specific time or location in the northern lowlands has proved challenging (Carr and Head, 2003). Moreover it has been argued that there was not enough water to have formed a Noachian-age ocean (Carr and Head, 2015), and a colder, drier ancient Mars is implied instead (Wordsworth et al., 2015). Though this interpretation is contentious, abundant ge-

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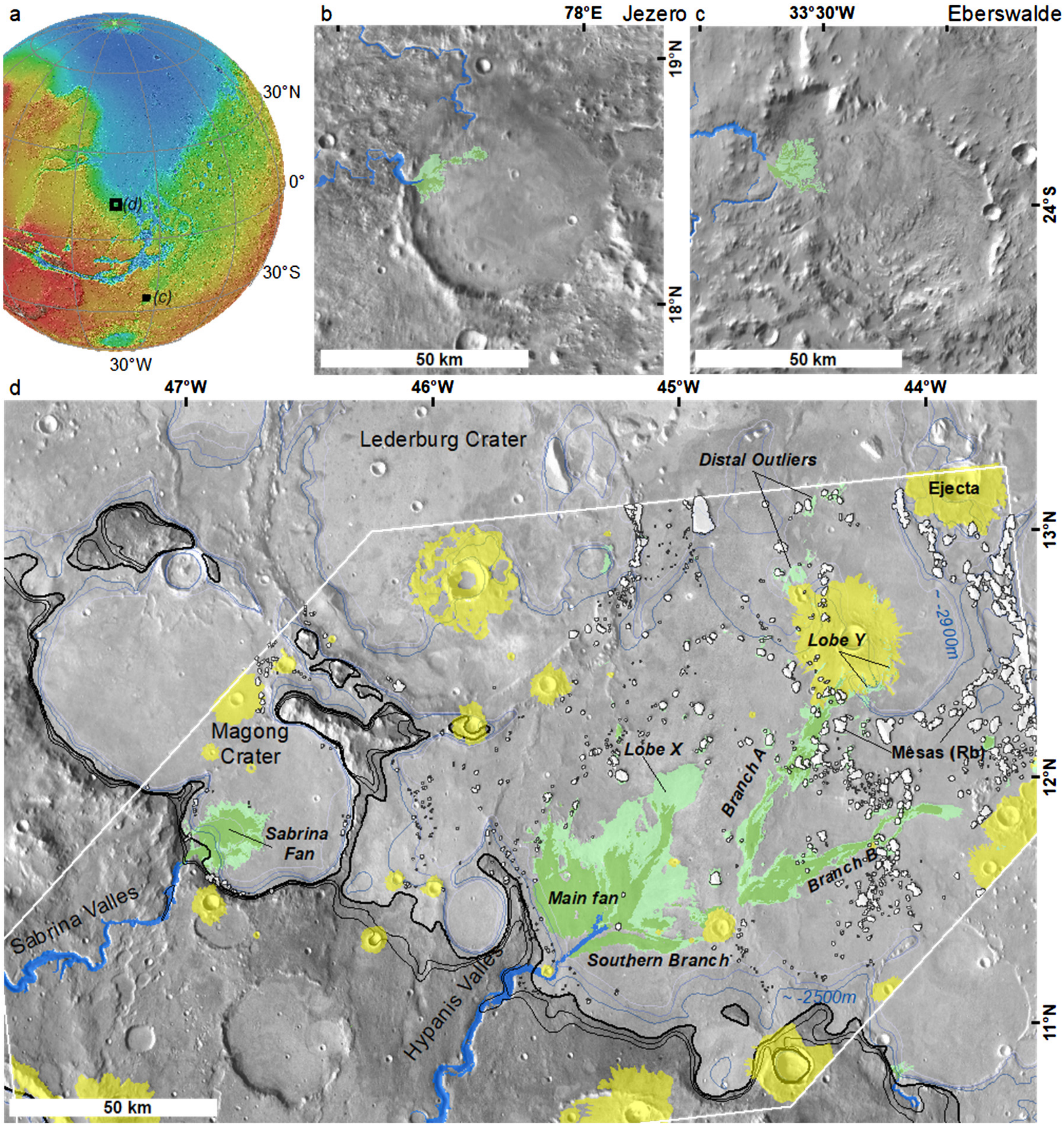

Fig. 1. (a) The location of the Hypanis Valles terminal sediment fan on Mars. Comparison between (b) Jezero (Schon et al., 2012) and (c) Eberswalde (Moore et al., 2003; Rice et al., 2013) deltas. Feeder channels are shown in blue. (d) The extent of the Hypanis and Sabrina sediment fan systems as mapped in CTX data. Here, the 'upper' and 'lower' stratal units are distinguished: Upper fan unit (Ufu), dark green; Lower fan unit (Lfu), light green. Also shown are the rounded buttes (white), impact ejecta (yellow) within the study area (white outline) along with selected MOLA topographic contours at 25 m vertical separation around −2450 m (black), and around −2500 m and −2900 m in blue. A full CTX mosaic can be found as Supplementary material. (For interpretation of the colours in the figure(s), the reader is referred to the web version of this article.)

ological evidence supports a warm and semi-arid climate (Ramirez and Craddock, 2018), however the evidence is incomplete and demands further observations.

Without being able to reliably identify fine-grained oceanic deposits or clear shorelines associated with a large open body of water, alternative evidence for standing water is required. One such piece of evidence could be the presence of sediment fans deposited where a river enters a standing body of water: i.e., delta landforms. Deltaic sedimentary bodies have been identified on Mars but usually occur where river systems enter a crater, forming a confined lake. Excellent examples have been described in Eberswalde, Terby and Jezero craters (Ansan et al., 2011; Bhattacharya et al., 2005; Goudge et al., 2017; Rice et al., 2013; Fig. 1; Wilson et al., 2007). Moreover, an *in situ* example has been described in Gale crater using observations acquired by the Curiosity rover (Grotzinger et al., 2015). Sedimentary fans have been identified around the martian crustal dichotomy along an approximate equipotential surface (Di Achille and Hynek, 2010) and interpreted as deltas, although individually these sedimentary bodies do not necessarily show convincing evidence for a deltaic origin (Kraal et al., 2008; Moore et al., 2003). Recent analysis of stratigraphy in the equatorial Aeolis Dorsa region on Mars has identified possible deltaic deposits and base-level controlled incised valleys suggesting that this region may have formed a palaeo-coastal landscape (Cardenas et al., 2018; DiBiase et al., 2013). However, to establish the possible existence of a northern hemisphere-spanning ocean, evidence is required for the regional development of deltaic sediment bodies (Barker and Bhattacharya, 2018).

Here, we describe the depositional morphology and stratigraphy of a prominent sediment fan body that is located at the