A comprehensive morphometric and mineralogical assessment of Ma’adim Vallis, Mars

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Shabana Ebrahim[1], Alok Porwal[2], and Nithya Mullassery[1]

[1]Department of PG Studies & Research in Geology, MES Ponnani College (University of Calicut), Kerala, India-679586 (shabnaebrahim@gmail.com)

[2]Centre of Studies in Resources Engineering, Indian Institute of Technology Bombay, Mumbai, India-400076

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BACKGROUND

Early Mars shared several surface processes with Earth, especially the action of liquid water. Because Mars lacks plate tectonics, many of its ancient landforms have been preserved, making it possible to study past fluvial activity in detail. Ma’adim Vallis, located at 22°S, 177.3°E in Terra Cimmeria and extending more than 900 km, is one of the most important paleofluvial systems on Mars. Its origin has been debated, with proposed mechanisms including surface runoff, paleolake overflow, and volcanic activity.

MOTIVATION

This study investigates the morphometric and mineralogical characteristics of Ma’adim Vallis to better understand how the valley formed and evolved. By examining its geomorphology and mineral signatures, the study aims to reconstruct the history of water flow in the region and access what it reveals about the past Martian climate and the planet’s potential habitability.

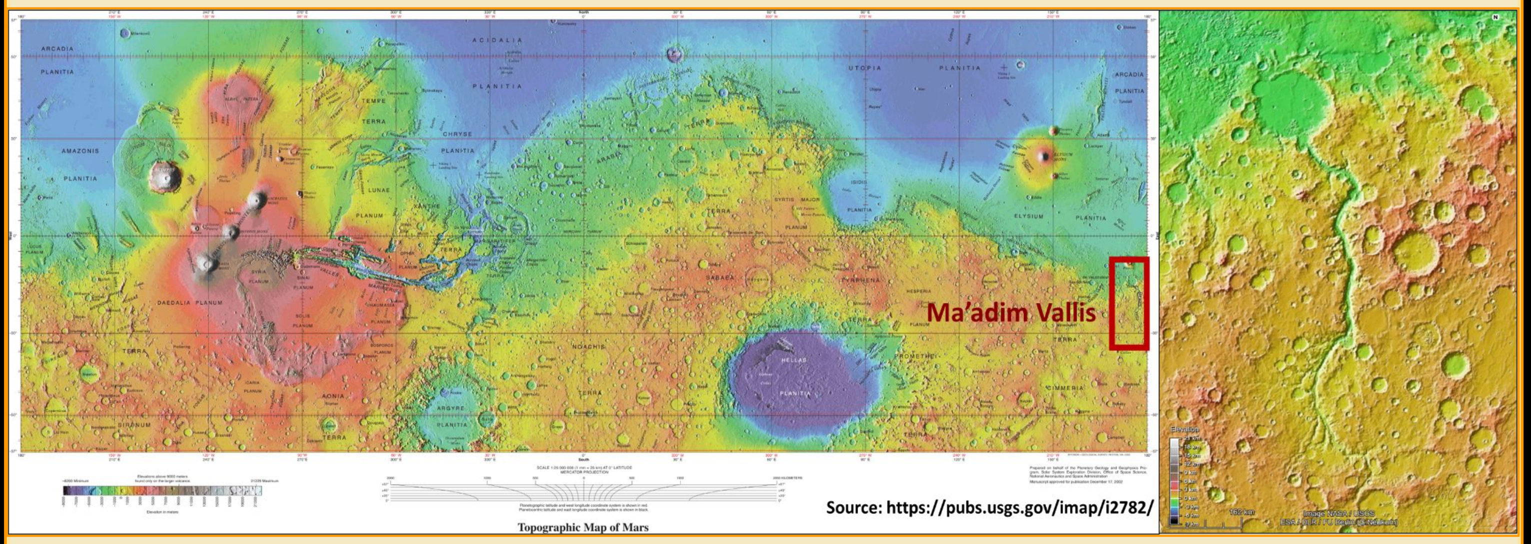

Fig 1. Topographic map of Mars (left) and Ma’adim Vallis (right)

METHODS

MARS DATASETS

- CRISM (18 m/px)
- CTX (6 m/px)
- HiRISE (0.3m/px)
- DEM (200 m/px)

Data processing and Mineral identification

Geomorphic Analysis and Landform identification

Slope Characteristics and Morphometric Analysis

Geological and Climatological Interpretation

ACKNOWLEDGEMENT

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RESULTS

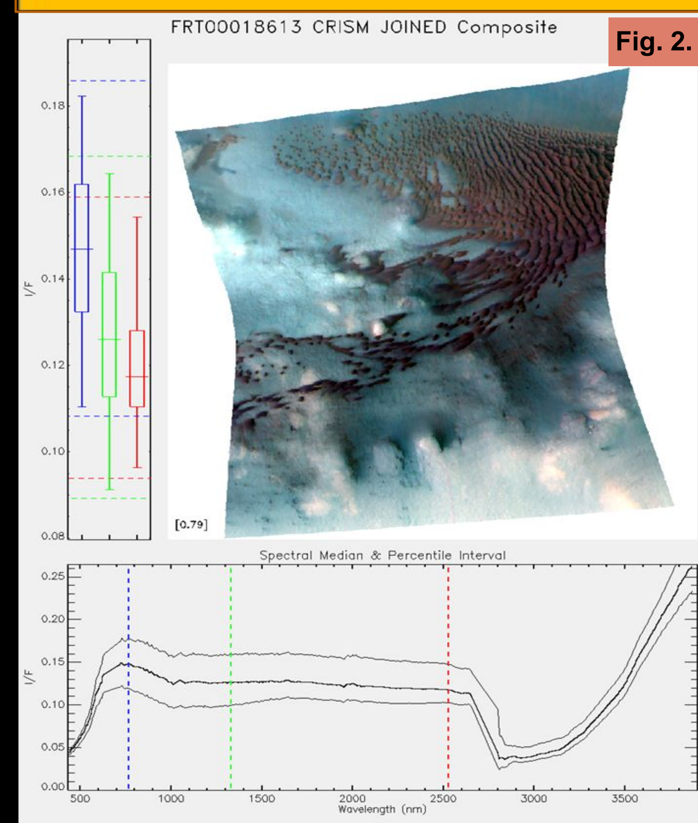
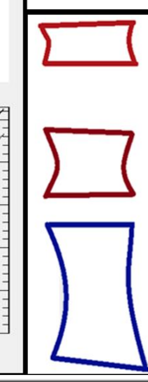


Fig. 2.

CHANNEL	MINERALS
RED	Olivine or iron/magnesium-containing Phyllosilicates
GREEN	Pyroxenes, or Aluminum Phyllosilicates, or Hydrated Silica, or Monohydrated Sulfates
BLUE	High-Calcium pyroxenes, or Hydrated minerals including Polyhydrated Sulfates, Phyllosilicates, Hydrous Carbonates, Zeolites



HRS - Half Resolution Short Targeted Observation

FRT - Full Resolution Targeted Observation

HRL - Half Resolution Long Targeted Observation

Fig. 3.

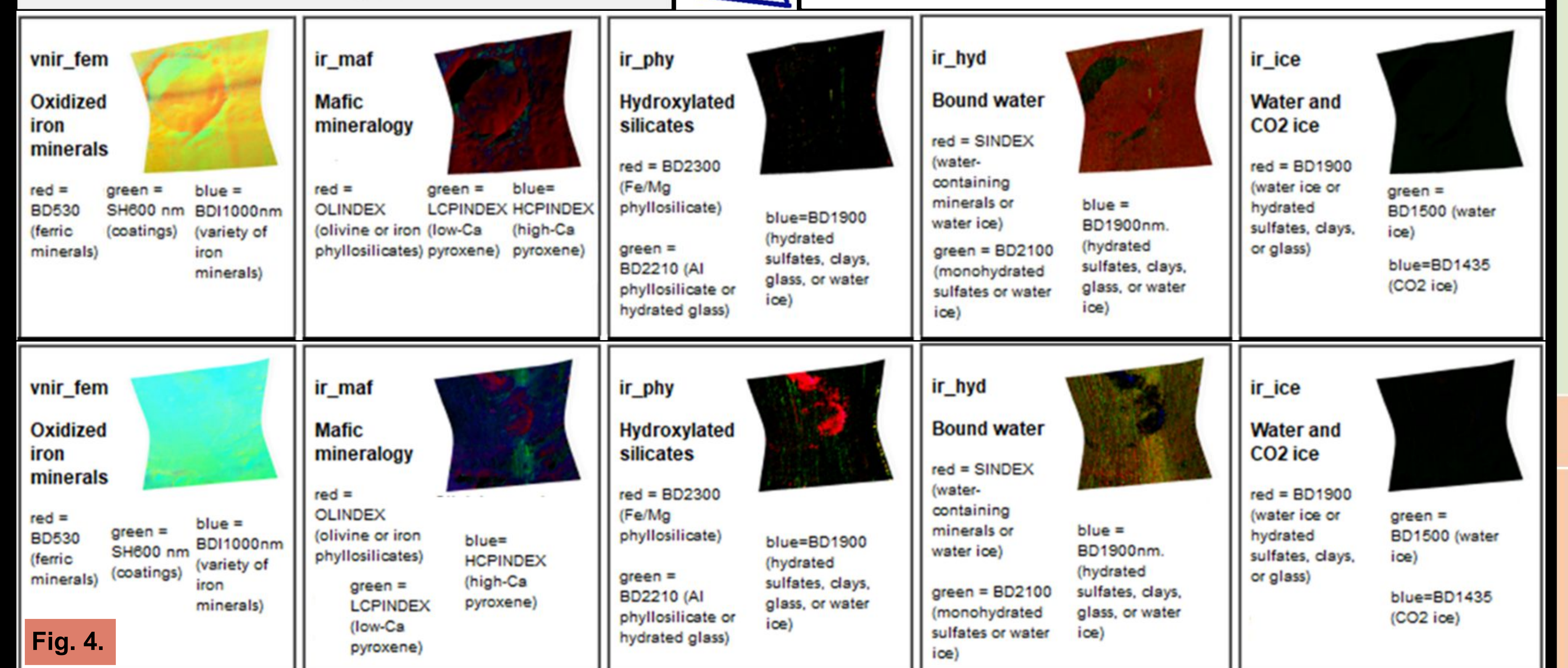


Fig. 4.

Fig. 2. The spectral profile generated by plotting wavelength (nm) in x-axis against Spectral Reflectance (I/F) in the y-axis.
Fig. 3. Three different types of hyperspectral imagery outlines of CRISM. Fig. 4. The summary parameters used to identify the Oxidized iron minerals, Mafic mineralogy, Hydroxylated silicates, Bound water, and Water and CO2 ice from the CRISM images of Ma’adim Vallis

	Morphometric parameters	Formula	Value
LINEAR	Stream Order	GIS Analysis	6
	Stream Number	GIS Analysis	559
	Total Stream Length (km)	GIS Analysis	8550.59
	Stream Length Ratio	$R_l = (L_u/L_{u-1})$	11.59
	Mean Stream Length (km)	$L_{sm} = (L_u / N_u)$	15.29
	Total Bifurcation Ratio	$R_b = (N_u/N_{u+1})$	17.71
	Mean Bifurcation Ratio	Average	3.54
	Average Rho coefficient	ρ = (Rl/Rb)	0.234
	Morphometric Parameters	**Formula**	**Value**
AREAL	Stream Frequency (km^{-2})	Fs = (ΣNu)/A	0.004
	Drainage Density (km^{-1})	Dd = (Lu/A)	0.0625
	Drainage Intensity (km^{-1})	Di = (Fs/Dd)	0.0653
	Drainage Texture (km^{-1})	Dt = (ΣNu)/P	0.195
	Form Factor	$Ff = (A/Lb^2)$	0.0707
	Infiltration number	If = (Fs × Dd)	0.000255
	Texture Ratio (km^{-1})	T = (ΣN1)/P	0.143
	Circularity Ratio	$Rc = (4\pi A/P^2)$	0.21
	Elongation Ratio	$Re = 1.128*(A^{0.5})/Lb$	0.2999
	Shape Factor	Sf = (1/Ff)	14.138
	Shape Index (km^2)	Sw = (1/ Fs)	244.49
	Constant of channel maintenance (km)	Ccm = (1/ Dd)	15.98
	Length of overland flow (km)	Lo = (1/(2Dd))	7.99
	Wandering Ratio	Rw = Lc/Lb	0.739
	Fitness Ratio	Rf = Lc/P	0.359
	Morphometric parameters	**Formula**	**Value**
RELIEF	Maximum Elevation (km)	GIS Analysis /DEM	3.337
	Minimum Elevation (km)	GIS Analysis /DEM	-1.799
	Mean Elevation	GIS Analysis /DEM	0.759
	Elevation at Source (km)	GIS Analysis /DEM	0.985
	Elevation at Mouth (km)	GIS Analysis /DEM	-1.796
	Basin Relief (km)	Bh = Z – z	1.538
	Relative Relief	Rr = Bh/P	5.14×10^{-4}
	Total Basin Relief (km)	H = Z - Em	1.541
	Relief Ratio	Rhl = H/Lb	1.108×10^{-3}
	Relative Relief Ratio (%)	Rhp = H × 100/P	0.0538
	Ruggedness Number	Rn = Dd × (H/1000)	9.64×10^{-5}
	Melton Ruggedness Number	$MRn = H/(A^{0.5})$	4.168×10^{-6}
	Gradient Ratio	Rg = (Es-Em)/Lb	-5.83×10^{-4}
	Watershed / Basin Slope	Sw = H/ Lb	1.108×10^{-3}
	Coarse Ratio	Cr = Bh * Dd	0.097
	Morphometric parameters	**Formula**	**Value**
GEOMETRY	Basin Area (km^2)	GIS Analysis	136668.38
	Basin Perimeter (km)	GIS Analysis	2861.4
	Relative Basin Perimeter (km)	Pr = A/P	47.76
	Basin Length (km)	GIS Analysis	1390.07
	Length Area relation (km^2)	$Lar = 1.4 * A^{(0.6)}$	1688.61
	Mean Basin Width (km)	Wb = A/Lb	98.32
	Lemniscate's Ratio	$K = (Lb^2 /4A)$	3.535
	Compactness co-efficient	$Cc = (P/2(\pi A)^{0.5})$	2.18
	First order stream	GIS Analysis (ΣN1)	410
	Length of Main Channel (km)	GIS Analysis	1027.79

Table 1. Linear, Areal, Relief, and Geometry parameters calculated for Ma’adim Vallis (above).
Table 2. The range of Junction Angle, Sinuosity Indices, and the Width of main channel at source and mouth regions (right side)

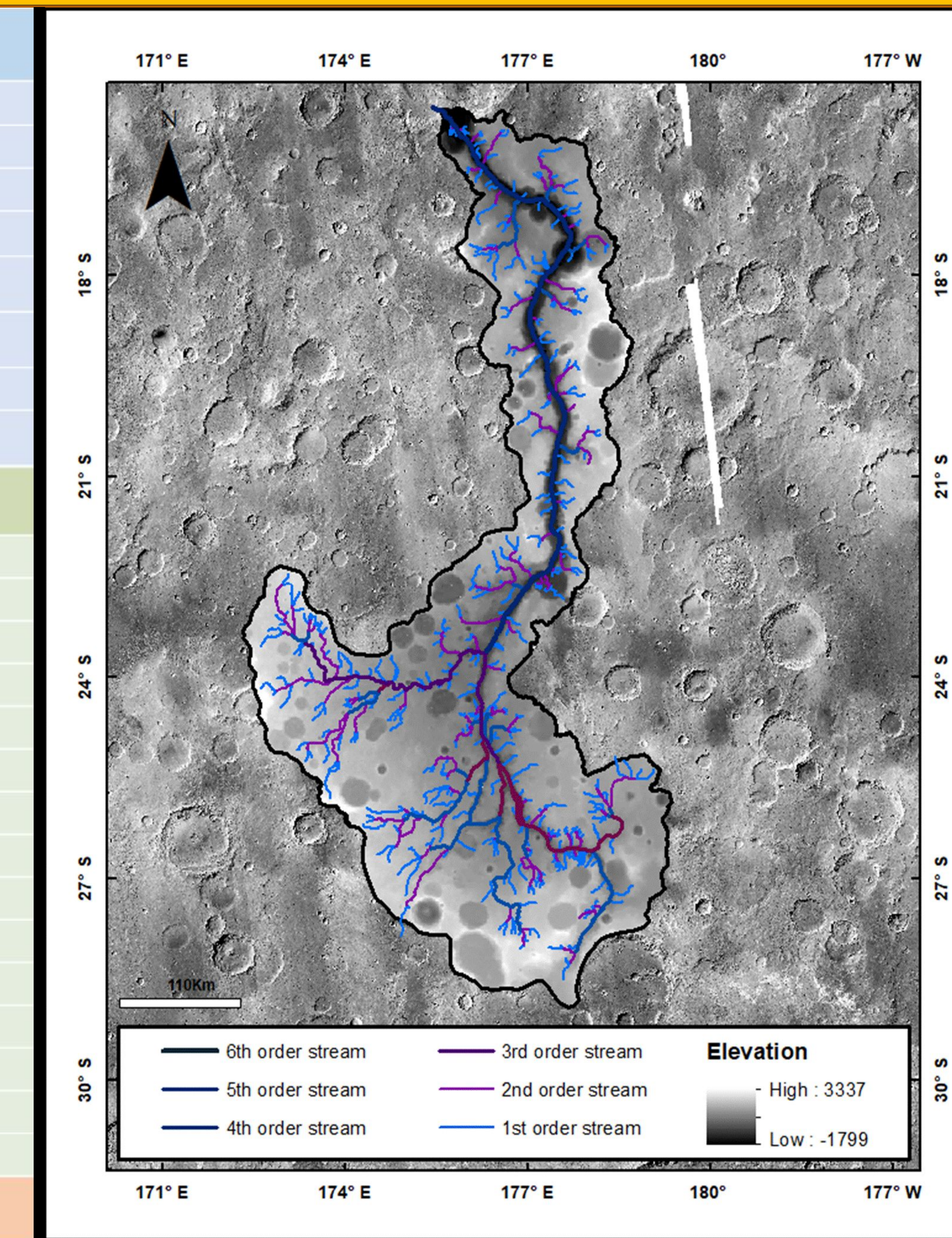


Fig. 5. Watershed Delineation map of Ma’adim Vallis indicating a 6th-order

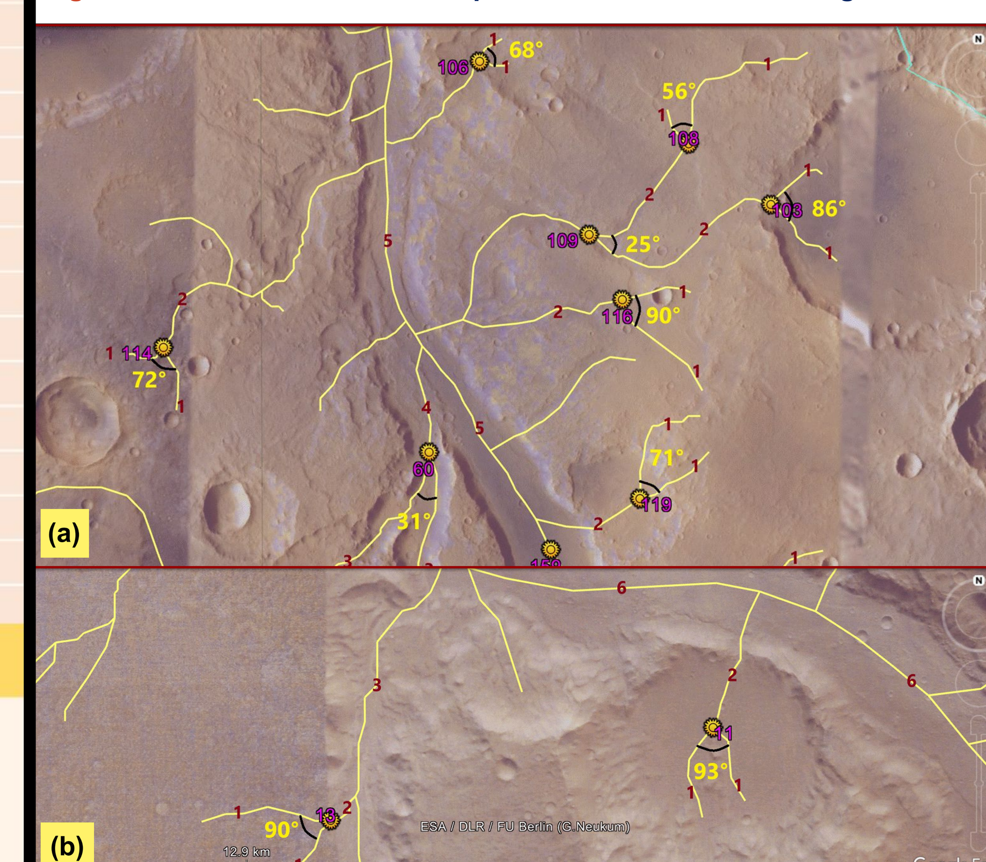


Fig. 6. The major junction angles at the (a) source and (b) mouth regions of Ma'adim Vallis

Parameters	Region	Value Range
Junction Angle	Source	40° - 90°
	Mouth	50° - 100°
Sinuosity Index	Source	~1.3
	Mouth	~1.1
Valley width of the main channel	Source	~18 km
	Mouth	~5 km

CONCLUSION

- Ma’adim Vallis records a complex fluvial evolution, not a single formation event
- Its morphometry supports catastrophic outflow, episodic flooding, groundwater seepage, and limited surface runoff
- The valley geometry also shows strong, structural control on channel development
- Mineralogical evidence such as Fe/Mg and Al-rich phyllosilicates indicate prolonged water activity and past depositional environments such as lakes, rivers, or deltas with periodic flooding
- Overall, Ma'adim Vallis preserves evidence for a warmer and wetter early Mars, followed by a shift to colder, drier conditions.

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