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Spatiotemporal development of two stepped fans in Xanthe Terra and Terra Sirenum, Mars

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INTRODUCTION

Deltas on Mars are crucial markers for reconstructing the planet's past climatic and hydrological conditions. The detailed study of Martian deltas, particularly through the interpretation of high-resolution imaging and geomorphological mapping, reveals insights into the environmental changes the planet has undergone. This study investigates stepped-fan deposits on Mars. The research utilized remote sensing techniques and landscape analysis to produce geomorphological maps of two key sites: Picardi crater in Terra Sirenum and Dukhan crater in Xanthe Terra (Fig. 1). These sites showcase extremely well-preserved stepped-fan deposits, possibly have formed during groundwater sapping events in the early Amazonian [1], [2].

Figure 1: A) Location of stepped-fan deposits in Picardi (Terra Sirenum) and Dukhan Crater (Xanthe Terra). B) Stepped-fan in Picardi crater. C) Stepped-fan deposits in Dukhan crater.

METHODS

We used data from NASA's MRO mission (HiRISE and CTX imagery and DEMs) to produced detailed geomorphological maps of the study sites. The maps were generated using a combination of two geomorphological keys. The planetary symbolization key by the Federal Geographic Data Committee of the United States (U.S.G.S., 2006) lacks the representation of small-scale features like alluvial fans, deltas, and various surface textures observed at the sites. Therefore, a synergistic mapping approach was adopted by also integrating the symbology of the cartographic standard proposed by the Italian Geological Survey and the Italian Association of Physical Geography and Geomorphology (Gruppo Nazionale Geografia Fisica e Geomorfologia CNR, 1986).

RESULTS

Picardi crater showcases an exceptionally well-developed stepped-fan deposit [3], [4]. A multitude of geomorphological features and deposits, related to impact cratering, paleochannel

activity, aeolian erosion and deposition, mass wasting and tectonism, have been identified . Most intriguing are the stepped, fan-shaped deposits in the southeastern part of Picardi crater, which have been further subdivided into individual geomorphic units, each differentiated by their specific morphometrical and sedimentological characteristics, and potential origin. The fan is connected to a small, steep-walled amphitheater-headed channel. Seven distinct fan units, originating from a single amphitheater-headed valley, were deposited radially outward from the apex (Fig. 2).

Figure 2: Detailed HiRISE images of the Picardi crater fan deposit. A) Fan Unit 1. Wrinkle ridge and smooth, sparsely cratered sediments of Fan Unit 1 distal to the main fan-geological units. B) Fan Unit 5. Finger-like extensions at the topographically low, distal part of the main fan. C) Secondary, isolated fan deposit. D) Upper part of the fan deposits with Fan Units 6 and 7 covering the highly eroded, semicircular Fan Unit 4. North is up in all panels.

Dukhan crater exhibits a diverse array of features, including plains, plateaus, tectonic structures, impact craters, and various depositional features such as fluvial, gravitational, and aeolian deposits (see figure 1c and 3). The stepped-fan deposits in Dukhan crater consist of distinct units with varied characteristics. Fan Unit 1, the most distal, has a wedge-like shape with sparse cratering and large boulders on its flat top. Fan Unit 2 is partially covered by Unit 4 and displays a slightly higher albedo with erosion on its distal side. Fan Unit 3, with a smooth surface and minor disruptions, forms the bulk of the fan. Unit 4, at the uppermost part, features asymmetrical geometry and erosion on its eastern side. The fan is connected to an amphitheater-headed inlet valley, aligned with a wrinkle ridge system on the highland plateau, suggesting underlying structural control. Along the crater walls, multiple channel-like features indicate the presence of alluvial deposits and paleochannels, gradually transitioning from rugged terrain to linear paths with changes in albedo.

Figure 3: Detailed HiRISE images of the Picardi crater deposit. A) Fan Unit 1. Wrinkle ridge and smooth, sparsely cratered sediments of Fan Unit 1 distal to the main fan-geological units. B) Fan Unit 5. Finger-like extensions at the topographically low, distal part of the main fan. C) Secondary, isolated fan deposit. D) Upper part of the fan deposits with Fan Units 6 and 7 covering the highly eroded, semicircular Fan Unit 4. North is up in all panels.

DISCUSSON

The stepped-fan deposits in Picardi crater exhibit a complex evolution, transitioning from deltaic depositional in the lower fan to alluvial dominance in the upper fan. In the middle section Unit 4 (fig. 2d), characteristics of glacial activity were recognised. The formation mechanisms of these units suggest a dynamic interplay of environmental factors, including shifts in climate and hydrological activity as well as glacial activity.

In Dukhan crater, the lowermost unit displays large boulders on its surface with diameters of >1 m and displays a massive sedimentary unit. It likely formed as a result of a landslide, and initiated the formation of the amphitheater-headed channel as a result of groundwater sapping. The upper units, resembling conical, layered deposits, have characteristics of both alluvial fans and deltaic deposits, making their differentiation challenging. While they share similarities with deltaic deposits found in other Martian regions, their lack of typical features suggests an alternative formation process, possibly through alluvial mechanisms driven by groundwater aquifers.

CONCLUSIONS

The study reveals a more complex formation history for Martian stepped-fans than previously recognized. Both Picardi and Dukhan craters show evidence of multiple processes, including deltaic, alluvial, and glacial and mass wasting processes. These findings enhance our understanding of Mars' climatic and hydrological evolution, indicating shifts from water-rich to glacial and arid conditions

over time.

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