Evolution History of Mesas in the Southern Utopia Planitia and Implications for the Ancient Oceans on Mars.

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Introduction: As one of the prominent landforms in the Zhurong landing region[1], mesas are geological features with flat tops and steep marginal cliffs. The mesas are widely distributed along the dichotomy boundary. There are various interpreted origins proposed for the mesas, such as the erosion of sedimentary layers, tuyas eruptions, or surface collapse due to the catastrophic release of groundwater. We investigate the detailed morphological characteristics of the mesas on the Late Hesperian Lowland unit[2] within the Utopia Planitia. The results indicate that the mesas in the study area are formed by the erosion of sedimentary layers and representative of the Noachian oceanic sediments. We propose an evolutionary model for the mesas. This study will provide some insights into future research of ancient ocean hypothesis of Mars and interesting targets for the exploration of the Zhurong rover.

Data: We used Context Camera (CTX; [3]) global mosaic (~6 m/pixel; [4]) to identify and carry out geomorphological analysis of the mesas in the study area with QGIS (https://qgis.org/en/site/). We applied a digital elevation model (DEM, ~200 m/pixel; [5]) obtained by blending the Mars Orbiter Laser Altimeter (MOLA; [6]) and High-Resolution Stereo Camera (HRSC; [7]) data to measure the mesas' base and top elevations. We used the data acquired by Tianwen-1 orbiter's High Resolution Imaging Camera (HiRIC, ~0.5 m/pixel; [8]) and High-Resolution Imaging Science Experiment (HiRISE, ~25-30 cm/pixel; [9]) to investigate the detailed morphological characteristics of the mesas.

Results: We identified a total of 791 mesas in the study area (Fig. 1). Most of the identified mesas in the study area are distributed along the southern margin of Utopia Planitia and within the region bounded by the -3600 m and -3900 m contours.

Classification of the mesas. Based on the morphological characteristics of mesas, we classified the mesas in the study region into four types. Type Ⅰ-Ⅳ are all characterized by flat top, while Type Ⅰ with no secondary landforms, Type Ⅱ develop secondary mesas, Type Ⅲ have top domes, and Type Ⅳ with ridges on its top surfaces. Among the mesas in the study area, there are 552 Type Ⅰ, 62 Type Ⅱ, 110 Type Ⅲ, and 67 Type Ⅳ.

Special morphological features. We observe morphological evidence for both the ice-bearing interior mesas and the sedimentary origin, including (1) small pits on the crater wall and mesa (Fig.2a-f) cliff formed by the release of volatiles like ice[10]; (2) lobate flows at the base of mesas (Fig.2g, g') formed by the melting of subsurface ice[11, 12]; (3) layered mesas indicating sedimentary origin (Fig.I, I'); (4) grooves on the top surface of mesas (Fig.h, h') formed by the volumetric compaction of sedimentary deposits[13].

Origin of the mesas: On Earth, there are various formation mechanisms for mesas that have similar morphological characteristics, such as stratigraphic erosion [14, 15] and tuyas eruption [16, 17]. Beyond the landing area of Zhurong, the mesas are also developed on the craters floor and the source depressions of the outflow channels on Mars [18]. To determine the origin of the mesas in our study region, we compared them with similar features both on Earth and other regions of Mars.

Tuyas. The volcanic eruptions underlying continental ice sheets could form lava-capped tuyas with flat tops [17, 19]. However, we did not observe any features consisting with the characteristics to identify tuyas described above. Therefore, it is unlikely that the mesas in the study area are tuyas.

Stratigraphic erosions. The original plateau can be eroded into mesas by the rivers and other weathering agents [15]. The northern plains of Mars formed many polygonal troughs under thermal contraction [20] or volumetric compaction [13], similar to the original plateaus separated by trough valleys on Earth. The subsequent erosion and expansion of polygonal troughs could generate mesas. There are no secondary mesas on the top surface of mesas formed by the erosion of sedimentary rocks covered by basalt flows. Therefore, we prefer that the mesas in the study area are erosional remnants of sedimentary rocks with different resistance.

Conclusions: The results indicate that mesas in the study area are more likely to be erosional remnants of the Noachian sedimentary strata. Based on this conclusion, we propose an evolutionary history for the mesas (Fig.3). During early and middle Noachian, the oceanic activities deposited a thick layer of sediments. Subsequently, the Martian climate changed cold [21], which caused frozen of the ocean. The water or ice of northern lowland gradually accumulated as ice and snow on the southern plateau under adiabatic cooling

[22], which resulted in decline of the groundwater table. The following erosion formed the secondary mesas units and primary mesas as two distinct groundwater loss of the northern lowland. Late Hesperian outflow channels injected catastrophic flows into the northern plains [2, 23], and leaded to the sea level rise. The features of Noachian Ocean are obscured by the Hesperian Ocean, and only leaving the mesas.

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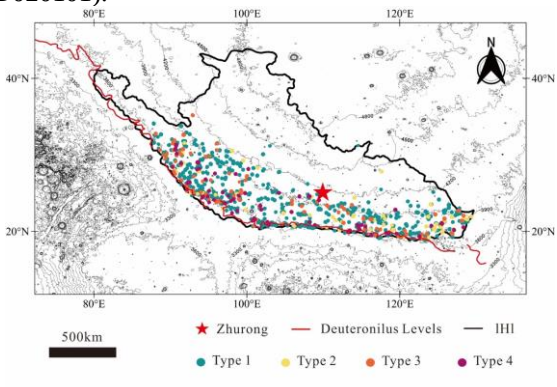

Figure 1. Distribution of identified mesas in the study area. The base map is a contour map with 300 m intervals generated from the DEM.

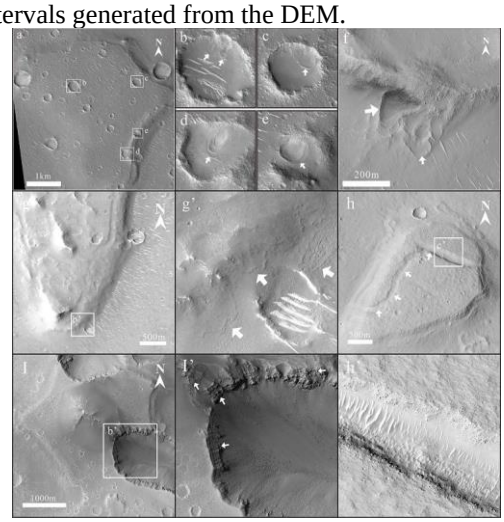

Figure 2. Special features on mesas

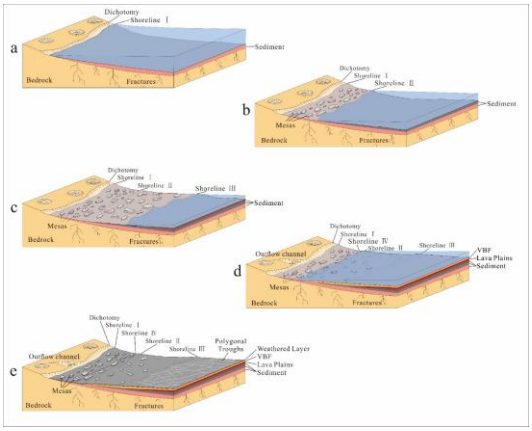

Figure 3. Diagram shows the evolutionary model for mesas in the study area.

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