AN EXPLOSIVE MUD VOLCANO ORIGIN FOR THE PITTED CONES IN SOUTHERN UTOPIA PLANITIA, MARS. L. Wang[1], J. Zhao[2], J. Huang[1], X. Xiao[1], and L. Xiao[1], [1] State Key Laboratory of Geological Processes and Mineral Resources, Planetary Science Institute, School of Earth Sciences, China University of Geosciences, Wuhan 430074, China, (lewang@cug.edu.cn), [2]Key Laboratory of Geological Survey and Evaluation of Ministry of Education, China University of Geosciences, Wuhan 430074, China.

Introduction: Zhurong, the mars rover of China's first independent Mars exploration mission Tianwen-1, successfully landed on the surface of Mars in the southern Utopia Planitia (109.925°E, 25.066°N) on May 15, 2021 [1]. There are various landforms have been identified in the Zhurong landing region, including pitted cones, polygonal troughs, ridges, mesas, and aeolian bedforms [2]. Among these landforms, pitted cones with kilometer scale basal diameters stand as the most prominent landform. Previous studies have shown that pitted cones with various morphologies and sizes are widely distributed in the northern lowlands [3-12]. The researchers also proposed various origins for the pitted cones, including rootless cones [4], tuff cones/rings [7], pingos [13], dirt cones [14], and mud volcanoes [5, 15, 16, 9, 12]. Different origin indicates different geological processes which has significance to understand the history of Mars. The purpose of this study is to determine the origin of pitted cones in the Zhurong landing region through morphological analyses.

Data: We used the latest high-resolution images (0.7 m/pixel) acquired by the High Resolution Imaging Camera (HiRIC) onboard Tianwen-1 orbiter [17] and DEMs generated from HiRIC stereo pairs [18] to conduct morphological analyses. We measured the geometric parameters of pitted cones, such as the summit pit diameters (Wco), basal diameters (Wcr), height (Hco), and their ratios (e.g., Wcr/Wco, Hco/Wco, and Hco/Wcr), and slopes.

Results: We have identified 151 pitted cones and five cone clusters in the study area. The nearest cone is ~14.5 km away from the Zhurong rover along its traveling direction. After excluding the elongated and the intensely eroded pitted cones, 96 among the 151 pitted cones were used to measure the geometric parameters.

Morphological Characteristics. We observed various degrees of preservation and morphological characteristics of these pitted cones. Some pitted cones are well preserved with sharp summit depression rims (Fig. 1a); some are degraded with small craters on the flanks and the cone shapes are ambiguous (Fig. 1b). Some pitted cones are degraded with only a portion remaining (Fig. 1c) and there are obvious impact craters on its base. In addition to quasi-circular pitted cones, there are a few well-preserved cones with elongated plan-view shapes (Fig. 1d). There are also some cones coalesced with each other and distributed in double or clusters (Fig. 1e, f). There is one pitted cone connected with a ridge (Fig. 1g) that has flow-like features (Fig. 1h) along its southwest side. The width of the ridge is about 200 m with a height of about 10 m. Among all of these pitted cones, one cone shows an obvious flow-like feature at its foot (Fig. 1i) and the floor of its summit depression shows a high abundance of boulders (Fig. 1j). It is also the nearest pitted cone to the Zhurong rover in the rover's traveling direction. We also observed that except for the cones like the one in Fig. 1b, other pitted cones almost have albedo variations on their flanks (Fig. 1k, l). The upper part of the flank is covered with relatively darker materials and the lower part has a relatively high albedo (Fig. 1k). The albedo variations are more prominent on the southern flank of the pitted cones.

Morphometric Analysis. With Tianwen-1 DEMs, we conducted morphometric analyses of the 96 pitted cones and obtained the following results: the Wco of pitted cones ranges from 317 to 1363 m, with an average diameter of 758 m; the Wcr range from 93.4 to 514 m, with an average of 258.35 m; the Hco are 13–80.46 m, with an average of 36 m; their slopes are 4–12°, with an average of 8°. The average values of Wcr/Wco, Hco/Wco, Hco/Wcr are 0.342 (0.22–0.48), 0.046 (0.025–0.077), 0.145 (0.056–0.317), respectively. We proposed to use the Wcr/Wco versus slope to plot (Fig. 2a). The cones have similar slopes with terrestrial mud volcanoes (Fig. 2b), while the Wcr/Wco of which are in the range of the terrestrial cinder cones and tuff cones/rings (Fig. 2c).

Discussion: *Ice related cones.* Pingos are small domical hills formed by continuous supply and freezing of pressurized groundwater and usually have an ice core [13]. Dirt cones are the remnants of glaciers formed by the debris that partially cover the glacier and protect the underlying ice from ablation [19]. These two kinds of cones have an ice-core or are composed by the cementation of ice and clastics. If the pitted cones in Zhurong landing region are ice related cones, it may be completely collapsed due to destroy of impact craters. However, there are portion remaining cones with obvious craters at its base (Fig. 2c). Therefore, pitted cones in the Zhurong landing region are inconsistent with the origin of ice related cones.

Rootless Cones. Rootless cones (pseudocraters) are formed by the deposition of ejected debris in a phreatomagmatic explosive eruption when lava flow has moved over a wet substrate [4]. There is no signal of lava flows on the subsurface structure profile derived from the low-frequency radar data of Zhurong rover [20]. The origin of rootless cones can also be excluded.

Tuff Cones/Rings. Tuff cones/rings are formed by phreatomagmatic eruptions when ascending magma interacts with groundwater [7]. The pitted cone in Zhurong landing region with an average Wcr/Wco of 0.34 (Fig. 2c), which is lower than the Wcr/Wco ratio of tuff cones/rings (0.42) in in the Nephentes-Amenthes region on Mars [7] and 0.49 on Earth [21]. Besides, the summit pit floors of the tuff cones/rings are usually lower than the preexisting surface due to the excavation of the substrate [7], which is absent for the investigated pitted cones. Thus, we excluded the origin of tuff cones/rings.

Mud Volcanoes. Mud volcanoes are usually formed as a result of the eruption of low-density argillaceous materials from a subsurface slurry chamber [22]. The slopes of pitted cones in Zhurong landing region are similar to the mud volcanoes in Azerbaijan on Earth [7] (Fig. 2b), which indicates they have similar composition. The Wcr/Wco ratio implies magnitude of explosion of eruption [23]. The investigated pitted cones have a higher Wcr/Wco than mud volcanoes on Earth, meaning they have erupted more violently than Azerbaijan mud volcanoes. In summary, we proposed the pitted cones to be explosive mud volcanoes.

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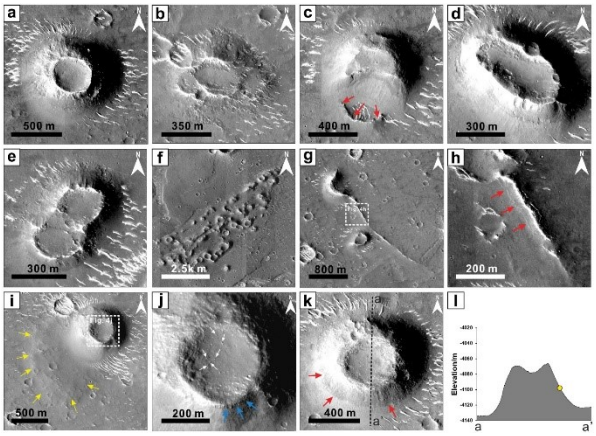

Fig. 1 The detailed characteristics of pitted cones in the vicinity of the Zhurong landing site.

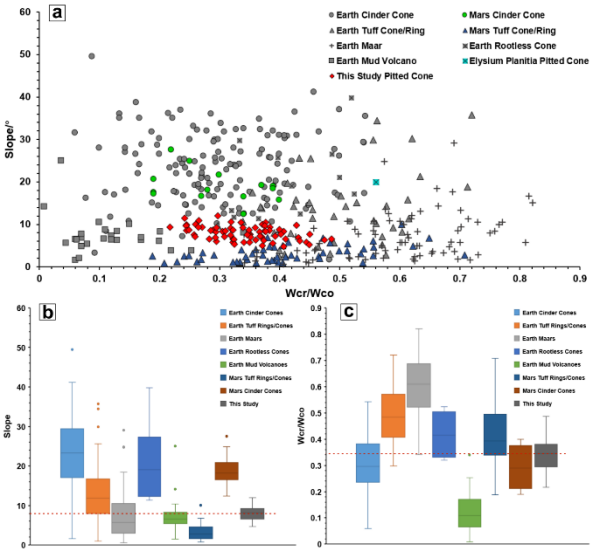

Fig. 2 Plots of geometric parameters of the pitted cones on Earth and Mars.