GEOMORPHOLOGY AND MINERALOGY OF SINUOUS RIDGES TO THE EAST OF TEMPE TERRA, MARS. Zhenghao Liu[1,2], Yang Liu[1], Lu Pan[3], Jiannan Zhao[4] and Yongliao Zou[1], [1]State Key Laboratory of Space Weather, National Space Science Center, Chinese Academy of Sciences, Beijing 100190 (liuzhenghao17@mails.ucas.ac.cn), [2]University of Chinese Academy of Science, Beijing 100049, [3]Université de Lyon, Université Claude Bernard Lyon 1, ENS de Lyon, CNRS, UMR 5276 Laboratoire de Géologie de Lyon -Terre, Planètes, Environnement, 69622 Villeurbanne, France, [4]China University of Geosciences (Wuhan) 430074

Introduction: To the east of Tempe Terra, located at the northernmost highland on Mars, we found a series of sinuous ridges (SRs) (Figure 1). The SR is a distinctive morphological feature distributed on the surface of both Mars and the Earth, and most of SRs have raised and sinuous terrain, with a variety of top cross section types and a length of tens to hundreds of kilometers. This type of morphology records a complex geological history which has significant indications on the early martian environment conditions [1,2]. In this study, we will examine the geomorphology and mineralogy of SRs identified in the study area to understand their formation mechanisms.

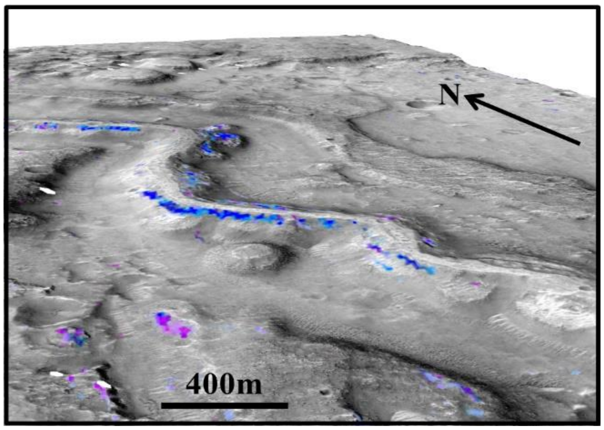

Figure 1. The HiRISE image with rendered topography based on HiRISE DTM of two paralleled ridges which are distributed to the east of Tempe Terra, the blue color on the slope highlights hydrated minerals.

Data Sets: DTM images using Mars Reconnaissance Orbiter (MRO) HiRISE datasets have been produced to investigate the physical properties of these SRs [3,4]. These images have spatial resolution of 0.3 m/pixel and vertical accuracy of ~1 m. The CTX images used to examine the geological context of ridges, which has spatial resolution of 5–6.5 m/pixel [5]. To identify the minerals, CRISM data were used which have spatial resolution of 15–19 m/pixel and spectral resolution of 6.55 nm/channel at wavelengths between 0.4-4 μm [6].

Geomorphology: The study area with two sinuous ridges is shown in the HiRISE image with rendered 3D topography based on a HiRISE. The southern ridge is about 18 km long, 50-130 m wide, and 54-61 m high relative to surrounding plain. The northern ridge is 15 km long, 200-600 m wide, and about 5-50 m high. The southern ridge has a flat surface on the top with deep slopes at both sides. The northern ridge is lower than southern ridge with an undulating top surface, which may imply that its caprock has gone through significant erosion. Several distinct features such as concentric crater fill (CCF) and inverted crater are located close to the ridges. The CCF may be related with a glacial mechanism in its formation history, which could imply the formation of the ridge due to the presence of glacier [7]. The inverted crater is a morphological feature indicating erosion and denudation. This morphological feature implies that the SRs may have undergone the erosion in its formation process.

Mineralogy: The mineralogy associated with the SRs was also investigated using the CRISM data. Consistent with an earlier study [8], we found the hydrated minerals are regularly distributed along upper part of the slope on both sides of the southern ridge, paralleled to the ridge top (Figure 2). The spectra have absorptions around 1.91 μm and 2.31 μm, mostly consistent with Mg-smectite (Figure 3) [9]. There is little information about the materials on the top of the ridge due to the dust cover.

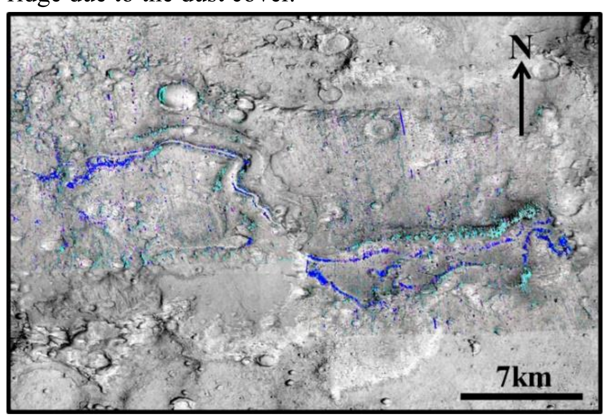

Figure 2. Mg-smectite (blue) and Low-Ca pyroxene (cyan) distributed on the ridged terrain. regularly.

Discussion and Interpretation: The SRs are found commonly on Earth, and they are mainly located in low-lying landforms and are formed due to ice, water or lava related processes. On Mars, there are several possible processes that can form the SRs, including esker, inverted channels, deposit inversion, lava tube and leveed channel. The inverted channel is formed by river flow and subsequent weathering, and during this process the materials of riverbed are cemented to form a layer of caprock. For example, when the environmental condition in the study area became dry, the riverbed would be exposed on the martian surface and undergo weathering process. Although the surrounding materials were largely eroded away, the cemented caprock has protected the bottom materials of riverbed from denudation. So, the riverbed could be raised up to form a ridge relative to the surrounding terrain [10-12]. Some features of the southern ridge support the inverted channel hypothesis, such as Mg-smectite distributed on both sides of ridge upper slope, and layered texture on the slope. The inverted channel can form double ridges [2], which may explain the northern ridge. However, there are no hydrated minerals identified on the northern ridge, probably due to the heavier erosion of its caprock and the beneath.

Another formation hypothesis is the deposit inversion which is also related to the fluvial processes. In this case, the ridges are formed on the channel belt on the river's original flood plain, and the caprock can be formed on the channel belt through sedimentation [13]. The hydrated minerals and layered texture can be explained by sedimentation of deposit inversion. The area between the two parallel ridges may represent the original river channel. But the deposit inversion hypothesis cannot explain why the northern ridge is topographically lower.

The esker is another possible formation mechanism for these ridges. Some glacier-related features have been found around the ridges, such as concentric crater fill. The feature was formed when glacier carried the deposits to the crater inside and left a glacial landform upon the melt of the glacier. The esker is formed in subglacial streams forming tunnels, and the weathering and denudation is not the main factor in its formation [14,15]. The esker does not have an erosion-resistant caprock, which means that the process cannot form two parallel ridges. Also, the hydrated minerals are only distributed on both the sides of upper southern ridge slope, which is contradict to the esker hypothesis.

In addition, lava tube is another hypothesis for the formation of the ridges. Lava tube is formed in lava flows, and can form different types of ridge cross-section, including round-crested, double-crested, flat-crested due to the long-term weathering that the lava tube experiences [16]. Note that Alba shield volcano is right located to the west where the ridges were found, providing the possibility that these ridges could be formed from lava tube. Since lava tube hypothesis does not necessarily have water involved, it is difficult to explain the presence of hydrated minerals on the slopes of the ridge. Finally, the paralleled two ridges cannot be formed by lava tube naturally, which do not support this hypothesis either.

Finally, leveed channel is another hypothesis that we considered. Leveed channels are usually formed by lava flow, but they are less influenced by weathering but more by the dynamic process of the lava flow. In this case, the middle part of the lava flow moves faster than the two sides, and the lava at the two sides condensed due to the decreasing temperature and the low speed, forming leveed channel. As the lava in the middle of the channel moves away, leaving a double ridge [17]. Although this process can explain the double ridges reasonably, it is difficult to explain the presence of hydrated minerals on the slopes of the ridge.

In summary, the formation process of inverted channel and deposit inversion could explain many characteristics of the SRs identified in the study area well. In contrast, the eskers, lava tube, leveed channel all have some limitations in explaining the formation mechanism of the SRs observed.

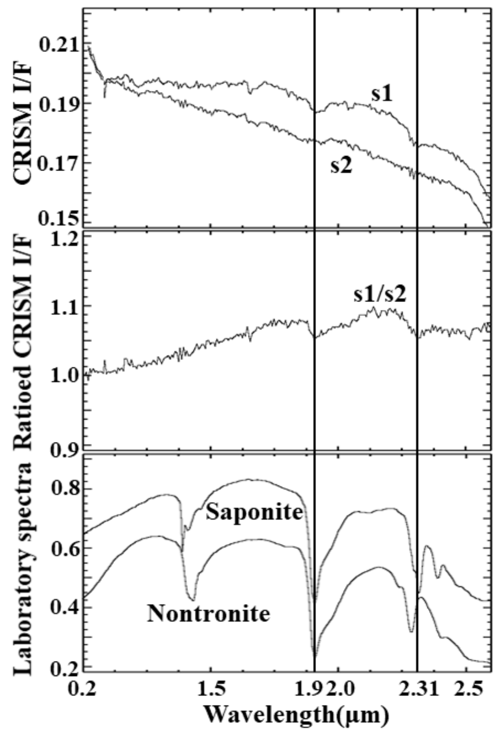

Figure 3. The spectra of Mg-smectite in CRISM image in comparison with laboratory spectra of saponite and nontronite.

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