A Case Study of an Application of Fractal Theory to Gully's Alcove on Mars. Daliang. XU[1], Zuoxun. ZENG[1,2], Zongyu. YUE[3] ,Jie. Wang[1], Zhenfei.Zhang[4], Stuart.J. Birnbaum[5], Hie. Xie[5] and Dan. YAN[1]. [1]Faculty of Earth Sciences, China University of Geosciences , Wuhan, 430074 , China(xdl2003geo@163.com,zuoxun.zeng@gmail.com); [2]Huazhong Tectonomechanical Research Center , Wuhan, 430074 , China; [3]Institute of Remote Sensing Application, CAS, Beijing,100010, China. [4]Faculty of Earth Resources, China University of Geosciences , Wuhan 430074 , China, [5]University of Texas at San Antonio, Texas, 78249, USA

Introduction: Two main theories of gully formation on Mars exist depending on the source of water. One holds that water was released from the subsurface [1]. The other proposes that water is deposited as near-surface ice or snow from the atmosphere and is subsequently melted by insolation [2-4]. In this paper we applied fractal theory to study a gully's head alcove in different orientations of a small crater (~5km) within the 30°–45°S latitude band, and to support the hypothesis that gully formation within the 30°–45°S latitude band is related to snow and ice deposition and melt (mostly sublimation) due to climatic processes.

Methods: Just as with coastlines, mountain ridges, rivers, etc. on Earth, gullies on Mars take on the features of scale invariance and self-similarity, which can be analyzed from the non-linear characteristics by using fractal theory to reveal its inherent laws directly.

A box-dimension method is a simple, objective and universally-applied method. As to a gully's alcove, we can use squares with the side length of r to cover it, thus the number of the boxes required is N(r). The total number of lattices, N(r), will vary with r, the measurement scale. N(r) is a function of r. According to the definition of fractal dimension, the relation between r and N(r) can be presented as equation (1) [5]:

$$N(r) \propto r^{-D} \qquad (1)$$

where r refers to the side-length of a square lattice while N(r) represents the number of lattices covered by the gully and D is the fractal dimension. If we applied logarithm to both sides of equation (1), we get:

$$\ln N(r) \propto -D \ln r \qquad (2)$$

In the whole process of covering, we can obtain a group of (r, N(r)) data, thus we can draw a double logarithmic chart and then draw a straight line using the least squares technique on the map of lgN(r)-lgr.

$$\ln N(r) = \ln C - D \ln r \qquad (3)$$

The fractal dimension D refers to the size of the slope, which reflects the complexity of the distribution of a gully.

Data and Results: In order to reduce the control of the difference of the latitude, elevation, material and slope, a small crater with similar environments at the slopes where the gullies exist is needed, so we representatively selected the gullies at an unnamed crater (37.7°S, 192.9° E) in the Sirenum region as an example.

This crater is suborbicular, 5km in diameter, with gullies in every orientations of the crater wall which is not common on Mars (Fig 1-A). The gullies on the northern wall of the crater are more mature with the length of alcoves ranging from 200m to 350m, which may contribute to rapid upslope propagation of the landform. On the contrary, the gullies on the southern wall are less developed, with the length of alcoves only ranging from 140m to 200m.

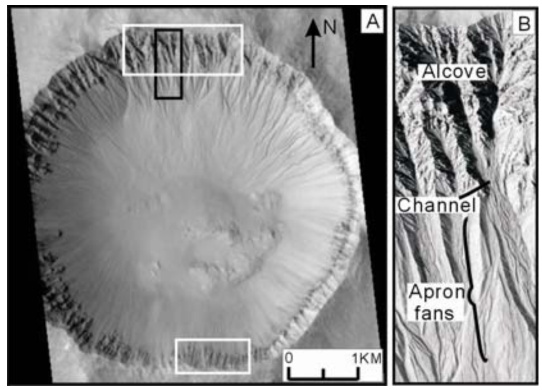

Fig.1 An unnamed crater with gullies (A) and the alcove–channel–apron morphology of gullies (B). Portion of HiRISE image PSP_003939_1420 located at 37.7°S, 192. 9°E, with N at the top of the image. Black box indicates the location of (B). Two white boxes indicate locations we used in the fractal analysis.

Choosing the alcoves from both the northern and southern walls of the crater, and drawing the secondary channel in each alcove using the ENVI software, we obtained the sketch maps as shown in fig. 2. Among them, numbers 1 to 5 are on the northern wall of the crater, and numbers 6 to 10 lay on the southern wall. In the process of covering, we use squares with the side length of r as 10m, 20m, 40m, 80m and 160m respectively. The results are all good when using the least square technique and reflect well the complexity of the distribution of the gullies..

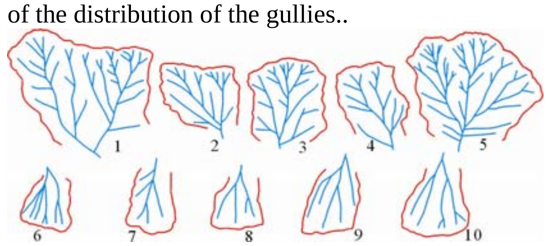

Fig.2 Sketch map showing the alcove of gullies in different orientation slopes. 1-5, northern wall of the crater；6-10, southern wall of the crater.

Discussion： Our results show that there is a significant positive correlation between the fractal characteristics of the gully and the maturity of a gully's development. The length and width of the alcove for gully numbers 1 to 5, which are on the northern wall of the crater, range from 200m to 400m, and each of the fractal values is greater than 1.4 (table 1). In contrast, gully numbers 6 to10, which occur at the southern wall, have shorter widths and lower fractal values. In addition, the fractal value of a gully's alcove has a close relationship to the slope trend of the gully with poleward facing gullies having higher fractal values than those of equator-ward facing gullies. This observation provides evidence that most gullies found were poleward [1,6-8].

The formation of gullies on Mars depends on several parameters including the source of water, the presence of steep slopes, sufficient amounts of fines/debris, and so on. So far, we can't study the material where gullies occur through in situ observation, although hyperspectral remote sensing (i.e. CRISM) has the potential to identify the materials. But the unconsolidated material determines the pattern of a gully's alcove, (e.g. dendritic or parallel, etc.), and the gullies in the study area are all dendritic which suggests that the materials where gullies occur are similar. Detailed slope measurements using HRSC-DTMs reveal that gullies in the northern and southern walls occur on slopes that are 25.3°and 23.8°, respectively, and the difference between slopes may not be a controlling parameter in the study region. The maturity of gullies is mainly controlled by the existance and amount of water.

Two main theories on the formation of gullies exist depending on the source of water: release of subsurface volatiles under pressure and accumulation/melting of surface snow packs. The results of our work show that gullies on the poleward facing slopes would require longer time and/or more erosional episodes to develop than those on the equator-ward facing slopes, and the strong orientation-dependence of gullies indeed suggests a climatic control on their formation and maturity. As previous studies have demonstrated [9], steep, shadowed crater walls in the mid/high-latitudes of Mars are effective cold traps where there is insufficient solar radiation to cause ice to sublimate as would be expected on equator-facing slopes, and as the obliquity of Mars increases, the increased solar insolations poleward facing slopes will result in melting of the accumulated ice instead of sublimation [10], thus gullies may occur more often at these locations. Our research is strongly consistent with this prediction and provides a new way to determine the maturity of gullies on Mars.

Conclusion：The results of our analysis of the aspect of the maturity of gullies at different orientations indicate that the fractal value of a gully's alcove has a close relationship to the slope trend of a gully, and that the poleward facing gullies have higher fractal values than those of equator-ward facing gullies. The formation of gullies on Mars is mainly controlled by the local climate, and the fractal value of a gully depends on the total insolation on the slopes, which provides one piece of evidence for the hypothesis that the formation of gullies within the 30°–45°S latitude band is related to snow and ice accumulation and melting due to climatic processes.

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References: [1]Malin M.C. et al. (2000) *Science, 288*, 2330- 2335. [2]Costard F. et al.(2002) *Science*, 295,110–113. [3]Hecht M.H. (2002) *Icarus,156*, 373–386. [4]Christensen P.R. (2003) *Nature, 422*,45–48. [5]Wang X.D. et al.(2005) *SGS, 25(1)*, 63-67(in Chinese). [6]Heldmann J.L. et al.(2004) *Icarus 168*, 285-304. [7]Berman D.C. et al. (2005) *Icarus, 178*,465-486. [8]Dickson J.L. et al. (2007) *Icarus, 188*, 315–323. [9]Costard F. et al. (2002) *Science*, 295, 110–113. [10]Hecht M.H.(2002) *Icarus 156*, 373–386.

Table 1 The results of fractal values of gully's head alcove

Location of gullies	Number	Width of gully's alcove（m）	Length of gully's alcove（m）	Fractal value（D）
Northern wall	1	420	310	1.57
	2	220	200	1.46
	3	210	230	1.51
	4	200	260	1.42
	5	370	340	1.58
Southern wall	6	140	160	1.31
	7	130	190	1.16
	8	150	170	1.21
	9	150	220	1.28
	10	160	210	1.24