A Structural Solution for the Formation of Dunes in the Martian Polar Region Zuoxun Zeng[1,2], Hongjie Xie[2], Stuart J. Birnbaum[2], Stephen F. Ackley[2] and Lilin Liu[1], [1]China University of Geosciences, Wuhan，430074，P.R.China, [2]University of Texas at San Antonio, Texas, 78249, USA, zuoxun_zeng@hotmail.com

Introduction: Exotic sand dunes on Mars have been known since 1972 when NASA's Mariner 9 spacecraft transmitted images of their interesting shapes. This is a common feature across the surface of Mars. Despite three decades of studying these features [e.g., 1-16], many questions remain regarding their composition，sources of sediment, morphology, age， origins, and dynamics under present and past climatic conditions. One interesting observation is that they have not moved in the past thirty years [12，15], nor, perhaps, in millions of years according to the interpretation of impact craters preserved on some dunes [16]. The most extensive dune deposits on Mars completely encircle the residual water ice deposit [10]. Research shows that dune apparent thermal inertia ranges from modest to low [4], indicating that the dunes in the polar area are made up of irregularly-shaped cemented dust and sand fragments [5] or mixtures of ice and silicate dust [6-7] that are not cemented in bulk to form a cohesive mass. Acquired visible images from MOC and HIRISE indicate that induration took place in some dunes and that niveo-aeolian deposits may be contained in some dunes [9]. [10] studied the water content of the north-polar sand dunes within Olympia Undae using Mars Odyssey Neutron Spectrometer (MONS) epithermal neutron data. Their results are consistent with a fully ice-filled pore volume at depth covered by a relatively desiccated, loose sand cover. Such a structure would then have a relatively low thermal inertia as determined using Viking Orbiter data [11], yet be relatively immobile because it would be fully cemented at depth. This suggests that frozen water (ice or snow) is present in the polar sand dunes on Mars and supports the assertion that the dunes in the north-polar region are composed of niveo-aeolian deposits [12, 13]. [14] observed the Dark Dune Spots (DDS) and their clusters on the MOC narrow angle images from the year 1998 to 2002. The shape, location, development and other features of the DDS prompted them to suggest that some fluid phase must be invoked in the explanation for the formation of the dunes, which under the given circumstances cannot be anything else but liquid water. In this case we can infer that frozen water may be the cement for the induration of the dunes. This induration may be partially responsible for the lack of movement observed in many of the larger dunes on Mars. A similar result is gained from research on dunes in cold climate regions on the Earth [17]. One question needing an answer is “what controls the spatial geometry and location of the dunes?” From the observation of more than 200 MOC images, we found that fractures in the polar region provide a possible solution. In this paper, we first show evidence of conjugate fractures and en echelon fractures developed in the polar regions of Mars. Then we suggest that the distribution of some of the dunes is controlled by these two types of fractures in these areas.

Conjugate fractures and en echelon fractures developed in the polar areas: Observations of MOC images reveal well developed fractures in the polar areas. Here we show several examples of fractures at different scales developed in both the northern and southern polar regions of Mars. Fig 1a shows two sets of conjugate fractures and rhombus fault basins. Fig 1b shows two sets of conjugate fractures and a set of en echelon fractures. Fig 1c shows two sets of conjugate fractures and en echelon ice dikes.

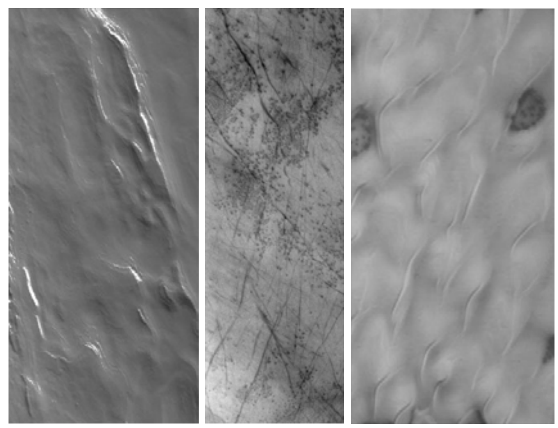

Fig.1 Fractures at different scales developed in the polar areas of Mars shown by MOC imagery. a. conjugate fractures near 84.85N, 160.96W (E1701483), scaled image width: 3.42 km b. conjugate and en echelon fractures near 74.41S, 137.41W (R1000676), scaled image width: 3 km, c. conjugate fractures and en echelon ice dikes near 80.49N, 221.16W (R1502118), scaled width: 3.46 km

Linear dunes controlled by en echelon fractures: Linear dunes appear as features with thin and long geometry (Fig 2). Compared to their width, the dunes are distant from adjacent dunes. Some of the dunes appear in a pinch-and-swell or strings-of-beads shape. Several appear as isolated barchan dunes. The most important feature is that the linear dunes show an en echelon arrangement or association. This suggests that they are controlled by en echelon fractures. Linear dunes have been observed on Earth for a long time, but lack of detailed research introduces uncertainty as to the mechanism of their formation [18]. The observation here may be helpful to the interpretation of similar dunes on Earth.

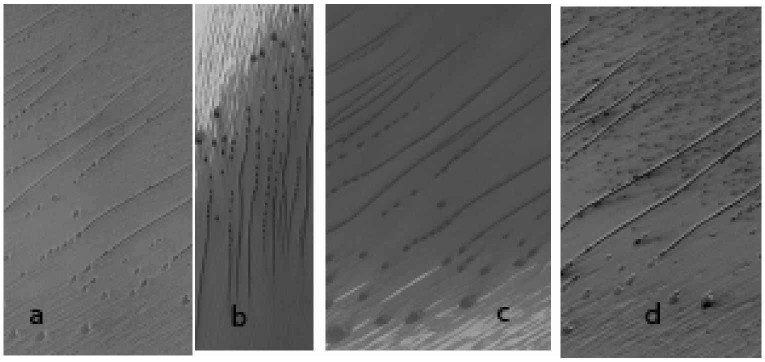

Fig. 2 Regular large spaced linear dunes with shape variation shown by MOC imagery, Chasma Boreak floor, near 84 N, 39W. a_E1500784, b_Portion of E2201561. c_ portion of S2101269, d portion of E1700584, distance across the images for a, b, c, and d are 3.44, 3.48, 3.39, 3.43 km, respectively.

Rhombus dunes controlled by conjugate fractures: Rhombus dunes are very common in the polar region and in some places their appearance is suggestive of a snake's skin (Fig. 3 b, f and g). Two sets of ice dikes in Fig 3b conjugate to each other constitute a dike net. The dark dunes occupy the white eyes of the net. Differential defrosting and/or differential erosion changed their appearance (Fig. 3 b-e) to be residual net dunes (bottom of b), linear dunes, string-of-bead dunes, isolated dunes and barchan dunes. Figures 3f and g show similar features, but the indurated dark materials (dust, soil, or sands) constitute the dike net.

Formation mechanism of the dunes: From the observation of more than 200 images of dunes on Mars, we can identify different fractures controlling the spatial geometry of dunes. Most are conjugate fractures; some are en echelon fractures. The dark materials or bright materials are different in-filled fractures. From observations and previous research (e.g. [10]), it is reasonable to suggest that the dark material could be a mixture of water ice and dust or sand, and the bright material could be water ice. Fractures create "wind traps" that initiate dune formation. Once sediment begins to accumulate, a series of processes that include induration, defrosting, isolation, and barchan formation proceed. Obviously, the different dikes changed the nature of the surface soil, sands or mixture of ice and soil, sands or dust. This provides the condition for differential melting, differential erosion, differential defrosting and differential frosting. These differences result in the formation of different dunes in the polar region on Mars.

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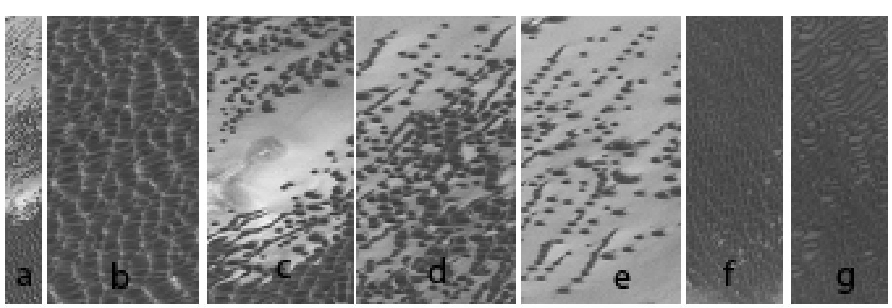

Fig.3 Rhombus dunes and their variation shown by MOC imagery, near 78.53N, 49.9W (a-e) and near 80.07N, 89.80W (f and g). a_E0102118. b-e_portions of image a. Image f and g are portions of R2001598. Scaled image width for a-e: 3.29 km. Scaled image width for f and g: 3.45 km.