Evidence of Fractures in NPLD and Their Significance to the Formation of Martian Polar Spiral Troughs.
Zuoxun Zeng[1,2], Nathaniel E. Putzig[3], Hongjie Xie[2], Stuart J. Birnbaum[2], Stephen F.Ackely[2] and Lilin Liu[1]. [1]China University of Geosciences, Wuhan, 430074, P.R.China, [2]University of Texas at San Antonio, 78249, USA, zuoxun_zeng@hotmail.com, [3]Southwest Research Institute, Boulder, CO 80302, USA

Introduction： Understanding the structure and stratigraphy of polar ice is an integral part of unraveling the history of its formation and implications for past and present climate [e.g., 1, 2]. Earlier studies of the North Polar Layered Deposits (NPLD) in Planum Boreum on Mars have provided valuable insight into the nature of these materials [3]. Radar sounding results show angular unconformities within the NPLD that are interpreted as erosional periods within climatological cycles [4]. Here, we present evidence of fractures in the NPLD based on interpretation of MOC images and radar sounding data, and we discuss the significance of these fractures to the formation of Martian polar spiral troughs.

Evidence from MOC images: We observe abundant indications of fracturing within the NPLD in MOC images. Figures 1a,b,d,e show four fracture examples at different scales. To illustrate the existance of similar cases in the South Polar Layered Deposits (SPLD), we include one image from that region (Fig. 1c). Figure 1a shows a huge en echelon fracture zone and its corresponding en echelon fault basins. The structural zone, as a whole, trends sub-north-south while the fractures and long axes of the basins trend north-north-west. The orientation of faults, fractures, and basins indicates this area experienced left-lateral shear. Figure 1b shows two sets of conjugate fractures and rhombic fault basins. One set of fractures trends north-north-west, and the other one trends west-north-west. Similarly, Fig. 1c from the SPLD shows two sets of conjugate fractures and a set of en echelon fractures. Fig 1d shows a fracture zone trending northeast. A major fault forms the northwest boundary of the zone. Conjugate fractures with one set parallel to this fault and another set trending sub-east-west are widely developed in the fracture zone. Figure 1e shows two sets of conjugate fractures and en echelon ice-dike zones trending northeast. The relative orientations of the fractures and dikes indicate a left-lateral shear sense.

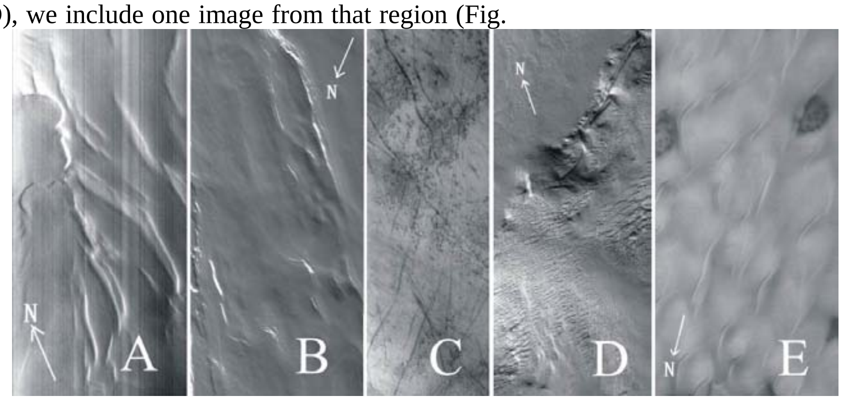

Figure 1. Fractures at different scales in the polar regions of Mars as shown by MOC imagery. (a) En echelon fractures near 84.07N, 49.01W (SP 254207). Scaled image width: 193.59 km. (b) Conjugate fractures near 84.85N, 160.96W (E1701483). Scaled image width: 3.42 km. (c) Conjugate and en echelon fractures in the SPLD near 74.41S, 137.41W (R1000676). Scaled image width: 3 km. (d) Fracture zone at the distant end of Chasma Boreale near 82.35N, 80.15W (R1801871). Scaled image width is 3.48 km. (e) Conjugate fractures and en echelon ice dikes near 80.49N, 221.16W (R1502118). Scaled image width: 3.46 km.

Fracture-controlled troughs: The origin of the large-scale spiral troughs appearing in both Martian polar ice caps has interested scientists for more than three decades [e.g., 5-13]. Different formation models have been proposed. Among them, [13] firstly related the spiral troughs to vortex fractures resulting from the differential rotation between the inner, permanently frozen part and the outer, relatively mobile part of the polar ice caps. In this paper, we show evidence from both MOC images and SHARAD/MRO radar sounding data that fractures controlled the formation of the spiral troughs. Figure 2 shows some of the evidence based on the observation of MOC images. Figures 2a-c show fractures developed in both ice-rich layers (bottom-left and top-right of Fig. 2a and Fig. 2c) and dust-rich layers in a trough. Almost all of the fractures are parallel to the trough. Both Fig. 2d and Fig. 2f show conjugate fractures. Interpretation of their development is shown in Fig. 2e and Fig. 2g, respectively. More fractures filled with ice appear on the steep vertical scarp of the trough (Fig. 2f and Fig. 2g). It is clear that both troughs initiated from one set of the conjugate fractures, respectively.

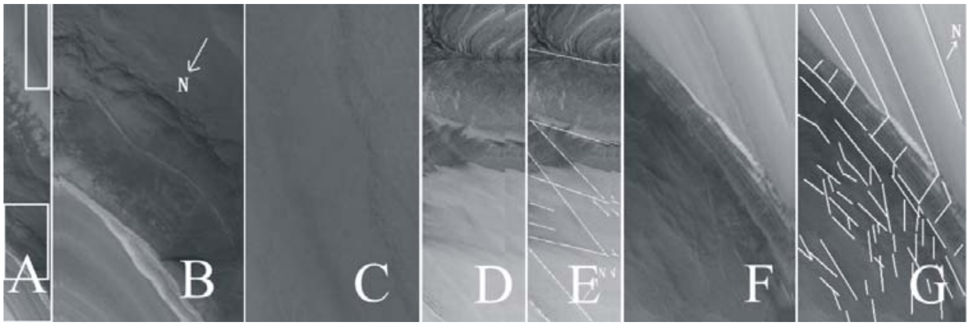

Fig. 2. Images of fracture-controlled troughs in NPLD. (a) is located near 85.03N, 208.26W (E0300270). Scaled image width: 3.29 km. White boxes show locations of (b) and (c). (d) is located near 85.75N, 60.61W, (R2201697). Scaled image width: 3.45 km. (e) shows the fracture interpretation of (d). (f) is located near 83.95N, 237.74W (R1701381). Scaled image width: 1.75 km. (g) shows the fracture interpretation of (f).

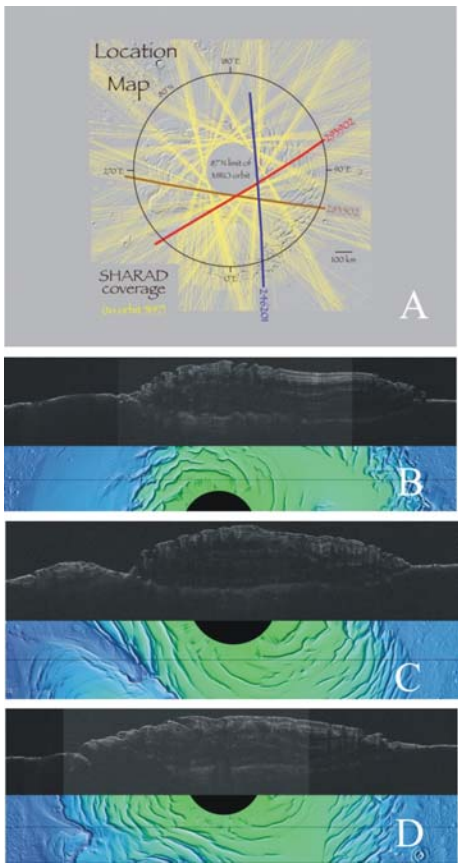

Fig.3 location map (a) and radargrams showing portions of SHARAD observations 246201 (b), 293902 (c) and 283502 (d). Horizontal scale is shown in Fig. 3a (100-km scale bar). Each radargrams shows approximately 35 microseconds of delay time, with a maximum cap thickness of ~3 km (assuming a real dielectric constant for ice of 3.15).

Evidence from radar sounding data: Figure 3 shows three selected radargrams from SHARAD/MRO and their ground track locations. The ground tracks are labeled in Fig. 3a on the end corresponding to the right side of each radargram. The grayscale radargrams are displayed in delay time (related to depth beneath the surface) and include MOLA color shaded-relief elevation maps showing the region surrounding each ground track (marked with a black line). Beneath most of the major troughs, sub-vertical fault-like structures or fractures can be seen [4], in some cases extending from the surface to depths approaching the base of the ice cap. Where the radar ground track is sub-parallel and nearly coincident with surface troughs, bright reflectors that may resemble low-angle faults are actually off-nadir surface reflections from the troughs (e.g., right of center in Figs. 3c and 3d). The fixed relationship between each surface trough and its corresponding fracture beneath implies that there is no significant poleward migration as predicated by some models.

Conclusion and Implication: From the above observations of surface and subsurface data and their interpretation, we believe that fractures are widely developed in the NPLD and are consistent with a vortex fracture model for the origin of the spiral troughs [13]. The presence of ice dikes in fractures implies that liquid water may have been one of the agents in the geological processes affecting the NPLD and the troughs therein, perhaps in a past epoch when liquid water was stable in this region.

Acknowledgments: Authors thank NASA, JPL, and Malin Space Science Systems for the use of MGS MOC images and NASA, JPL, and the Italian Space Agency (ASI) for the use of SHARAD observation data and acknowledge funding support from programs in Mars and Polar Sciences through the Laboratory for Remote Sensing and Geoinformatics at UTSA. The first author also acknowledges support from the Natural Science Foundation of China and the Chinese Scholarship Council and for the discussion with Dr. Joseph P. Skipper and Dr. Long Xiao.

References: [1] Morse et al. (1998) GRL 25(17),3383-3386. [2] Welch B. C. and Jacobel R. W. (2003) GRL, 30(8), 1444. [3] Fishbaugh K. E. and Head III J.W. (2005) Icarus 174, 444-474. [4] Putzig N. E. et al. (2007) 7th Int. Mars Con., 3295.[5] Cutts J. A. (1973), J. Geophys. Res. 78, 4231-4249 .[6]. Blasius, K.R. et al. (1982) ICARUS 50, 140-160, [7]. Howard, A.D. (1978) ICARUS 34, 581-599 [8]. Howard, A.D. et al. (1982) ICARUS 50, 161-215 [9]. Fisher, D.A. (1993) ICARUS 105, 501-511 [10]. Fisher, D.A. et al. (2000) ICARUS 144, 289-294.[11]. Ng and Zuber, 2006, Ng, F.S.L. and M.T. Zuber (2006) J. Geophys. Res., 111, E02005, doi: 10.1029/2005JE002533 .[12] Pelletier, J.D. (2004) Geology 32, 365-367 .[13] Zeng Z et al. (2007) 7th Int. Mars Con., 3368