The tectonic origin of Planum Boreum spiral troughs, Mars

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1 Introduction

Planum Boreum, the ice plateau at the north pole of Mars, is composed of H,O ice with smaller percentages of dust and seawater (CO) frost. At the regional scale, its surface shows complex physiography characterized by linear features with erratic outcrops disposed in spiral patterns approximately 10 to 30 km long. These are the spiral troughs whose equator-facing slopes show exposed layers, while no layering is observed in their pole-facing slopes (1). The ground penetrating radars (MARIS (Max Planck) and SHARAD (MSR)) acquired profiles that revealed the internal ice layering and the depth of Planum Boreum structures, including the spiral troughs. These cut and offset the internal ice layering from the surface down more than 1000 m of depth with a gentle slope slower than 5° towards the margin (2). Buried troughs were found in radar profiles in the late tabular extension of the plateau called Germaina Lingua. Spiral trough formation is still an open issue, and several interpretations have been proposed regarding exogenous and/or endogenous processes that affect Planum Boreum. Many suggestions attribute the spiral troughs to erosional features produced by eolian processes. Their development is influenced by the action of the katabatic winds that lead preferential erosion/ablation in the layered equator-facing slopes, followed by deposition/accumulation on the pole-facing slope due to solar ablation (2). Alternative formation hypotheses support their structural origin, suggesting that they are dynamically induced by internal/external melting flows (1).

In this contribution, we investigate the stress-related formations of the spiral troughs that show similarities with the spiral structures on Earth. Planum Boreum spiral troughs are compared with a terrestrial analog reaggregated in the Antarctica Ice Sheet (J. the glacier feeding the Cook Ice shelf) where ice covers the bedrock with approximately 1300 m of thickness and radar data show ice layering and buried structures with geometry comparable to those found in Germaina Lingua. Their formation is the effect of brittle deformation resulting from the internal dynamics and gravitational sliding typical of Earth glaciers. The trough system, revealed by the SHARAD profiles, relates to low-angle normal faults (4) with compatible slip direction. It refers to the presence of dynamic processes within the northern ice cap that leads internal large-scale brittle deformation with the consequent trough formation. This is enabled by the presence of possible deep ductile/fluid detachment at depth.

2 Data

PLANUM BOREUM

The depth data used for the investigation of the spiral trough derived from the mission Mars Reconnaissance-Orbiter (MRO). We investigated radar images of the Shikoku Radar Image (SHARAD) (3). The analyzed profile in Germaina Lingua (on the right) shows buried troughs at a depth of approximately 250 m. Image data were used to investigate the surface lineaments related to the depth features and derive from the Mars Orbiter Camera (MOC) (see Fig.6). ANTARCTICA

Antarctic analog data include the radar echo-strength profiles from the Icebridge High-Capability Radar Sounder dataset (HCA), (5) (right). Surface data have been selected from the LANDSAT-8 and Sentinel-2 imagery dataset (left).

4 Lineament domain analysis

Lineaments represent feature alignments in the topography variation enhanced by preferential erosion directions and induced by upper crustal stress/kinematic conditions (6). Their spatial distribution defines lineament systems that form coherent domains that are organized around preferential orientations and allow to infer the crustal stresses of the planetary upper crust at the regional scale. This analysis was performed in the selected satellite images that follow the tracks of the SHARAD and HCA dataset to investigate the connection between the surface and the depth structural setting. We performed a polynomial Gaussian fit by frequency to infer the astrometric trends that characterize lineament domains (6). The recognized lineament domains were compared with the katabatic wind vectors (from both Lingua Boreum and Cook Ice shelf glaciers) to investigate on their possible aero dynamic-related origin. The main lineament domain (red peak of the rose diagram), closely parallel to the wind direction, were the buried trough orientation of the investigated depth profile. This setting is compatible with the presence of an extensional regime at depth, orthogonal to the main lineament domain.

5 Structural evolution of Planum Boreum spiral troughs

HCA evolutionary model of the buried trough section in Germaina Lingua. Gravitational collapse and internal dynamics produce extensional regime that characterizes the activity of tectonic faults connected at depth with a ductile detachment located deeper than the base of the model. Faults migrate with normal propagation sequence from the oldest fault 1 (F1) to the youngest fault 4 (F4).

6 Conclusions

Tectonic processes play a key role in the formation of Planum Boreum troughs. Horizontal slip induced by a deep detachment layer (more than 1000 m deep) and glacial flow are responsible of internal dynamics. This induces extensional tectonic regime that produce brittle deformation (faulting) expressed by the troughs with brittle shape. Katabatic winds are responsible of the subsequent slip-segmentation and the trough preservation at the surface. The modelled structural setting of the martian spiral troughs through the activity of tectonic normal faults shows similarities with blind faults recognized in the Antarctica analog. The suggestion that troughs relate to fault activity provides the possibility to investigate preferential ways that connect the ice cap interior with the surface. The inferred presence of a detachment is significant for future investigation on the identification of internal ductile/fluid (H2O) layers.

References