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Strike-slip tectonics as a precursor to crustal spreading in Anshar Sulcus, Ganymede: Implications for grooved terrain formation

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Introduction

The formation of grooved terrains on the icy surface of Ganymede is still debated and it could involve extensive rifting [1, 2] or spreading [3], strike-slip tectonics [4, 5], and minor cryovolcanic resurfacing [6].

To investigate the origin and evolution of the grooved terrains, we performed a geomorphological and structural analysis of Anshar Sulcus, a grooved terrain located in the anti-Jovian hemisphere within the dark terrain of Marius Regio. In addition, we conducted a topographical analysis producing a Digital Elevation Model (DEM) of this region. We selected Anshar Sulcus because it is a terminal portion of a grooved system, and it was imaged at high resolution by the Galileo SSI. These two aspects helped us to perform a palinspastic reconstruction of the area surrounding the sulcus and, consequently, a reconstruction of the different stages of formation of this sulcus.

Methods

The geological map was produced based on SSI Galileo images having a spatial resolution of about 152 m/px, at 1:500000 scale, using the differences in tones, textures and patterns and DEM. To import these images to the Geographic Information System (GIS), we calibrated, filtered and geo-referenced them through the Integrated Software for Imagers and Spectrometers (ISIS4) [7]. The DEM was produced using the "shape-from-shading" tool (SfS) provided by the NASA Ames Stereo Pipeline tool suite [8], maintaining the same spatial resolution as the images.

Results

Our geological map (Fig. 1) shows that most of the study area is covered by the dark cratered unit (*dc*) and consists of a heavily cratered surface with several patches of hummocky material and a pervasive fracturing that we have divided into three main sets. The light grooved unit (*lg*) consists of a prominent lane that crosscuts the *dc* characterized by sets of sub-parallel linear grooves. Additionally, topographic profiles traced perpendicular to the sulcus, revealed that the elevation of the grooved terrain increases towards its central part.

From a morphological observation, we identified well preserved rims of cut craters and fractures along the boundary between the *lg* and *dc*. These structures interrupt at the boundary with *lg*, and this allowed us to reconstruct the possible original position of these structures before the formation of the light unit.

Starting from the westernmost crater along the northern boundary of the *dc* region (Fig. 2a, 2b), we observed morphological coherence and continuity between the fractures within the crater and the set of fractures in the southern region (set a), suggesting a right lateral displacement of about 15 km. Proceeding to east along the boundaries of the two *dc* regions, we noted the occurrence of two rims of a possible crater (Fig. 2c, 2d) characterized by a lateral displacement of about 13 km. Moreover, in support of morphological evidence, the topographic profiles traced within the analysed structures show a consistency between the elevations of their southern and northern portions (Figs. 3 and 4).

Discussion

Through a combination of structural and topographic analyses, we have found evidence that the formation of Anshar Sulcus grooved terrain was a result of spreading and upwelling of new material. This is supported by the presence of well-preserved structures along the boundaries between *dc* and *lg*, and by the higher topographic elevation at the centre of the sulcus, which rules out the possibility of rifting as the cause of its formation.

Our reconstruction shows that the first tectonic event was a right-lateral movement in the NW-SE direction (Fig. 5b) that divided the dark terrain of Marius Regio into two distinct regions with conservative margins. The second tectonic stage (Fig. 5c) presents the beginning of the spreading event that caused the separation of the two regions previously formed as consequence of the strike-slip event, corresponding to the formation of light grooved unit. The right lateral strike-slip tectonics continued during the spreading stage, so the separation of the two regions occurred with a transtensional movement toward a WSW- ENE direction.

Furthermore, we have compiled a chronostratigraphic chart (Fig. 6) that identifies three stratigraphic phases for the formation of Anshar Sulcus and surrounding area. The first phase is characterized by the formation of the dark unit due to contamination of the icy shell by impactors. The second phase is characterized by the formation of the three sets of fractures and by the start of the strike-slip event that produced the division of the dark terrain of Marius Regio. Finally, the third phase is characterized by the formation of the *lg* unit through crustal spreading. The formation of the grooves inside the light unit occurred relatively quickly, due to the brittle faulting and tilting of the new crust during the extension event that have formed the light unit, explaining the absence of deformed or displaced craters inside the sulcus.

Conclusions

Our analysis reveals a two-stage tectonic genesis of Anshar Sulcus, with a first strike-slip stage dividing the dark terrain of Marius Regio into two distinct regions, and a second stage characterized by the formation of the grooved terrain of Anshar Sulcus through crustal spreading and upwelling of new, uncontaminated material, with the simultaneous formation of grooves within it due to brittle fracturing.

Acknowledgements

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References

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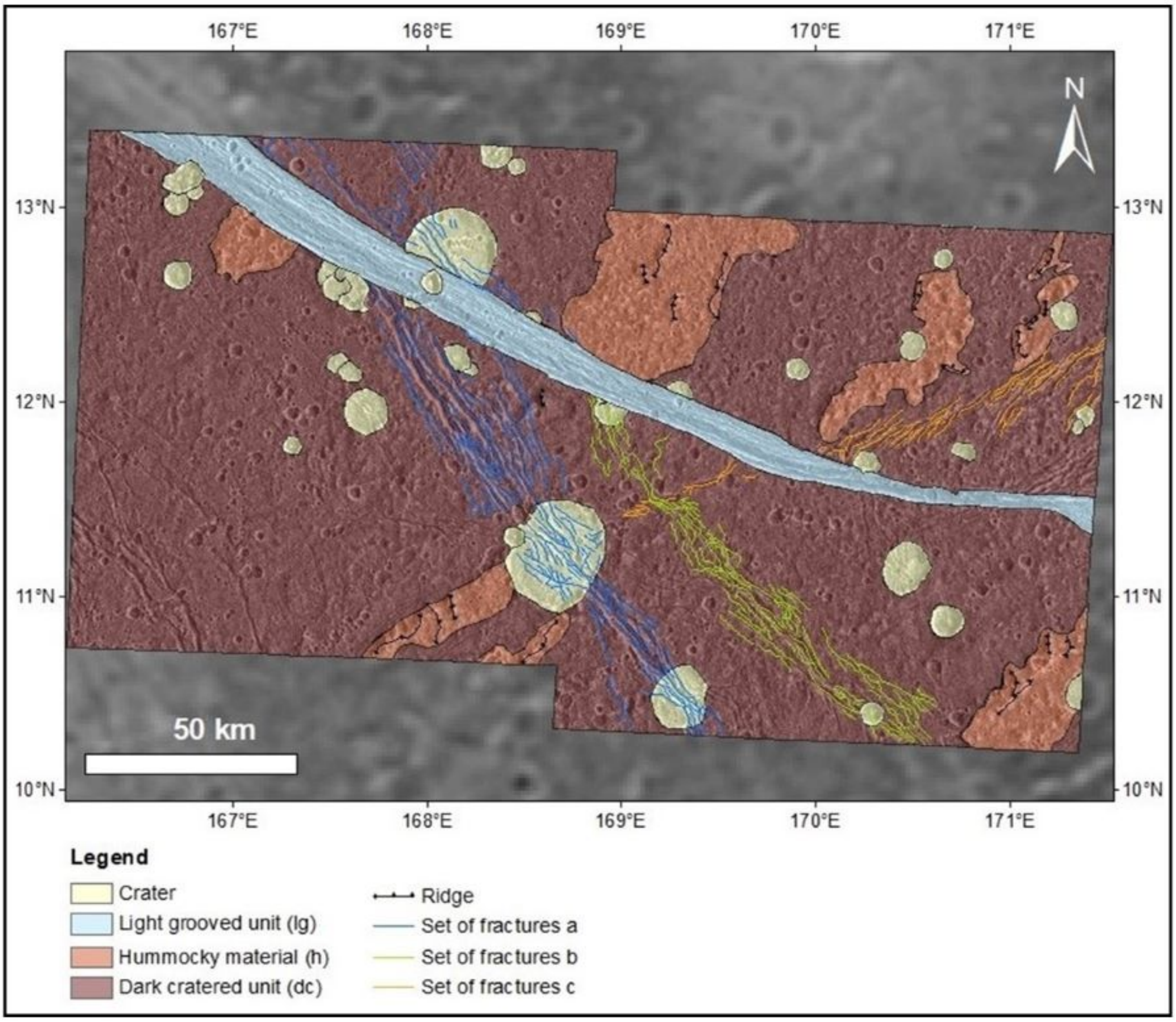

Figure 1. Geomorphological map of Anshar Sulcus region.

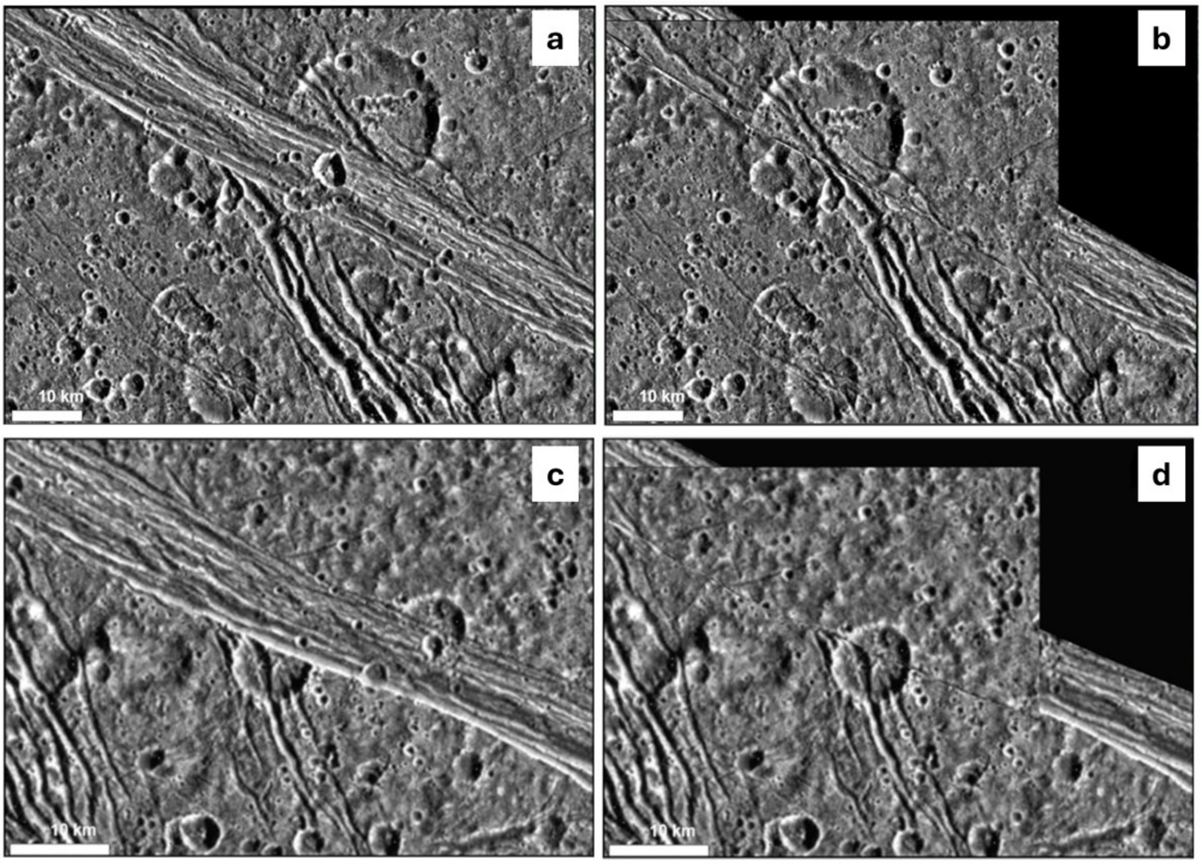

Figure 2. Current position of the westernmost crater (a) and reconstruction of its possible original position (b); Current position of the smallest crater (c) and reconstruction of its possible original position (d).

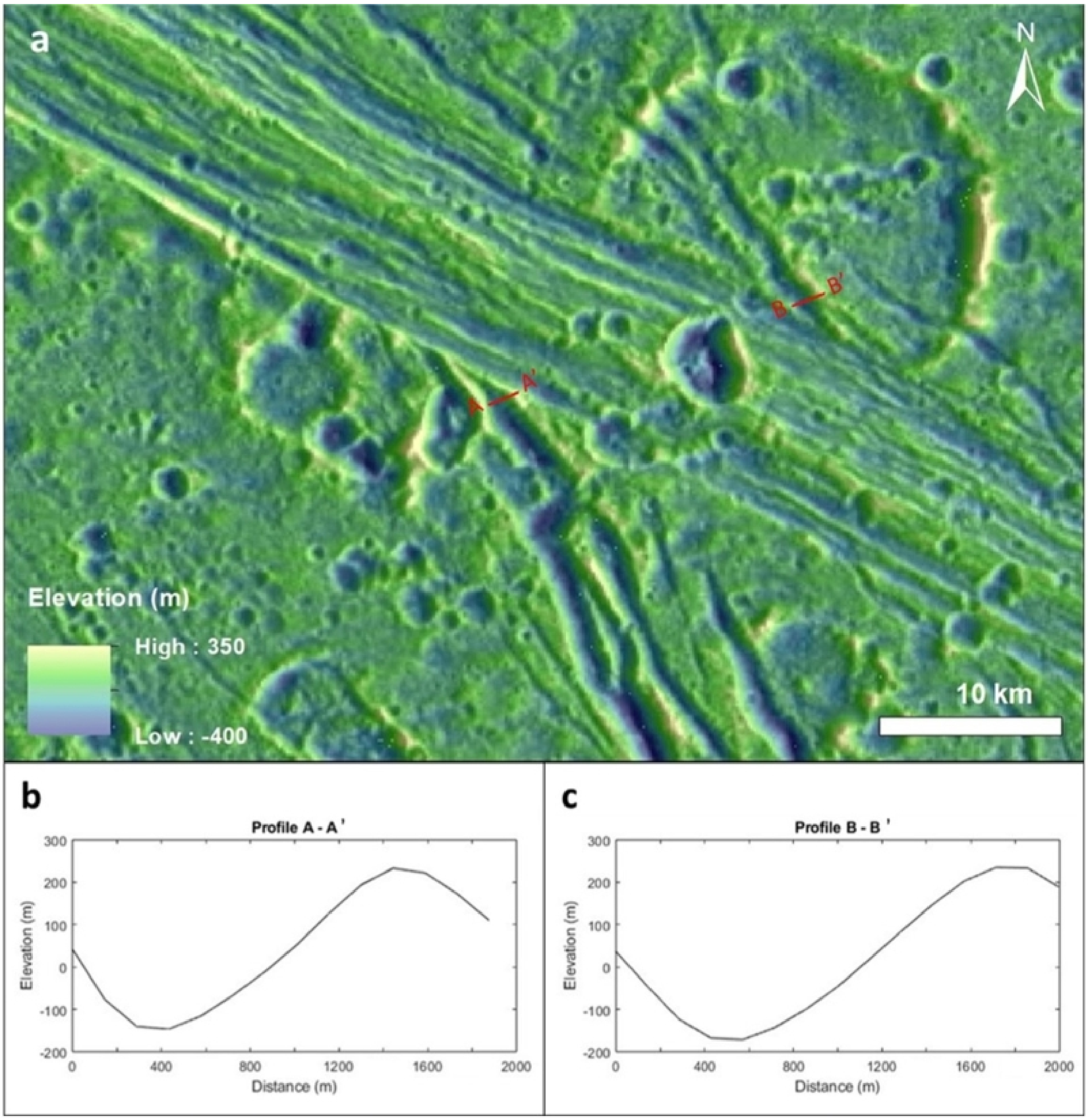

Figure 3. Digital Elevation Model of the area dissected by the fracture set "a" (panel a). Topographic profiles A-A' (panel b) and B-B′ (panel c) from the set of fractures "a".

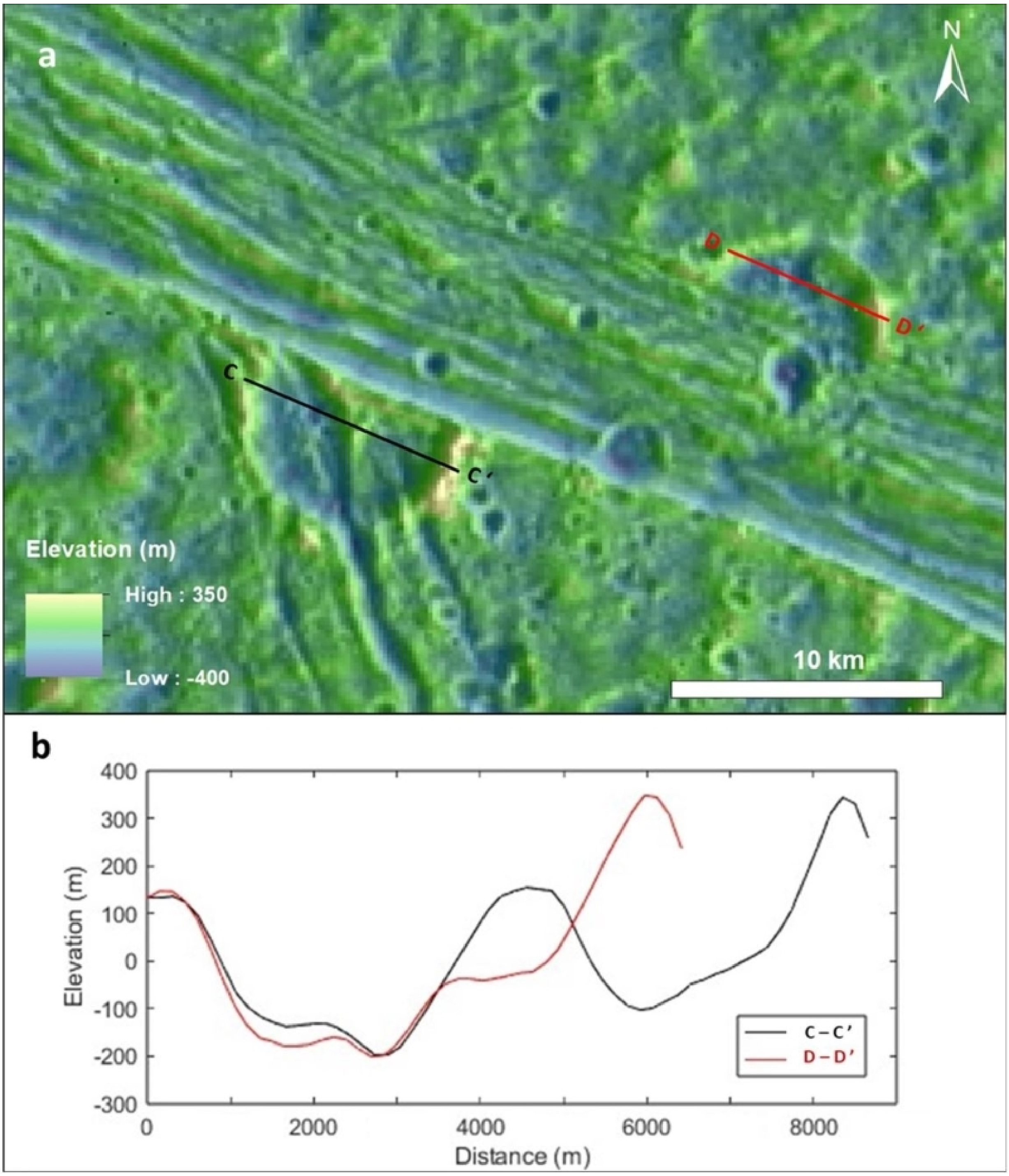

Figure 4. a) Tracks of the topographic profiles of the smallest two half craters; Topographic profiles corresponding to the tracks C-C′ and D-D′.

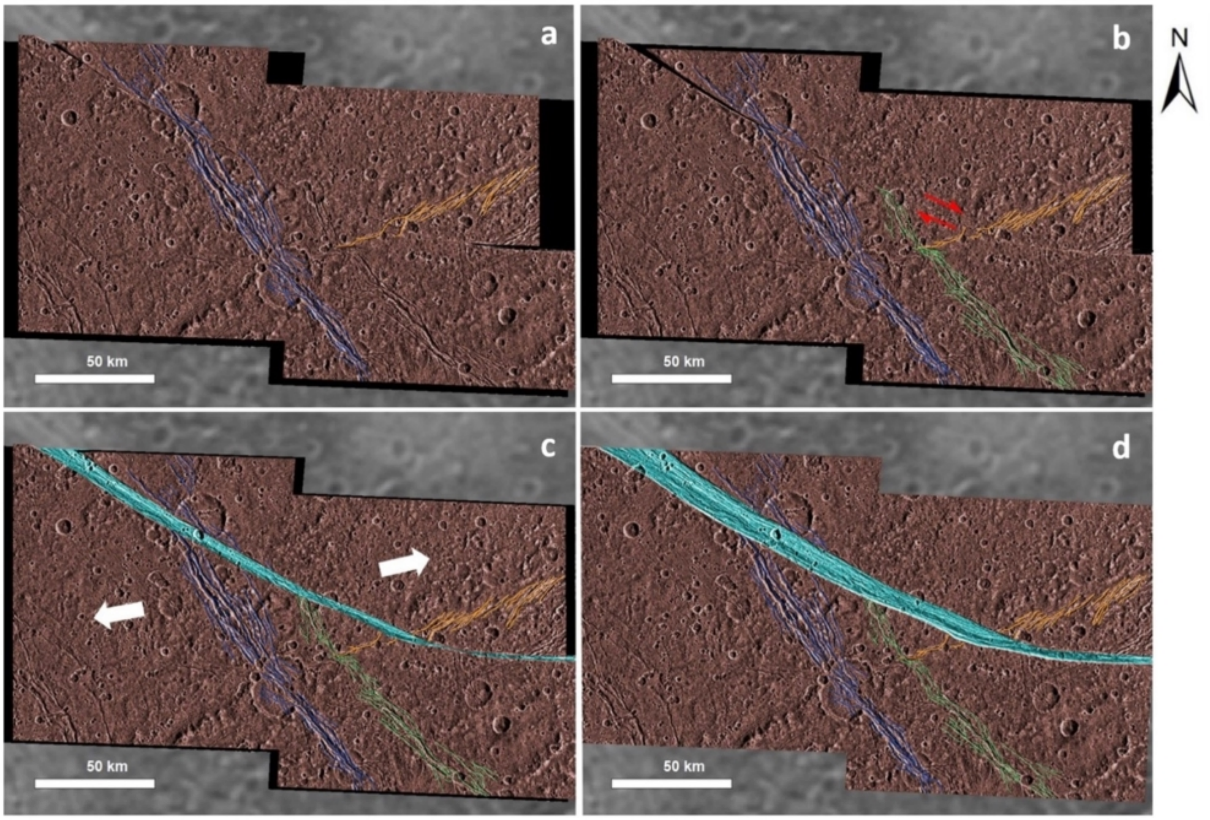

Figure 5. Reconstruction of the tectonic evolution of Anshar Sulcus area. a) Reconstruction of the dark terrain pre-deformation; b) Strike-slip right movement of the northern dark region in the NW-SE direction (red arrows); c) Opening of the sulcus through transtension in the WSW-ENE direction (bold white arrows) with upwelling of novel material.

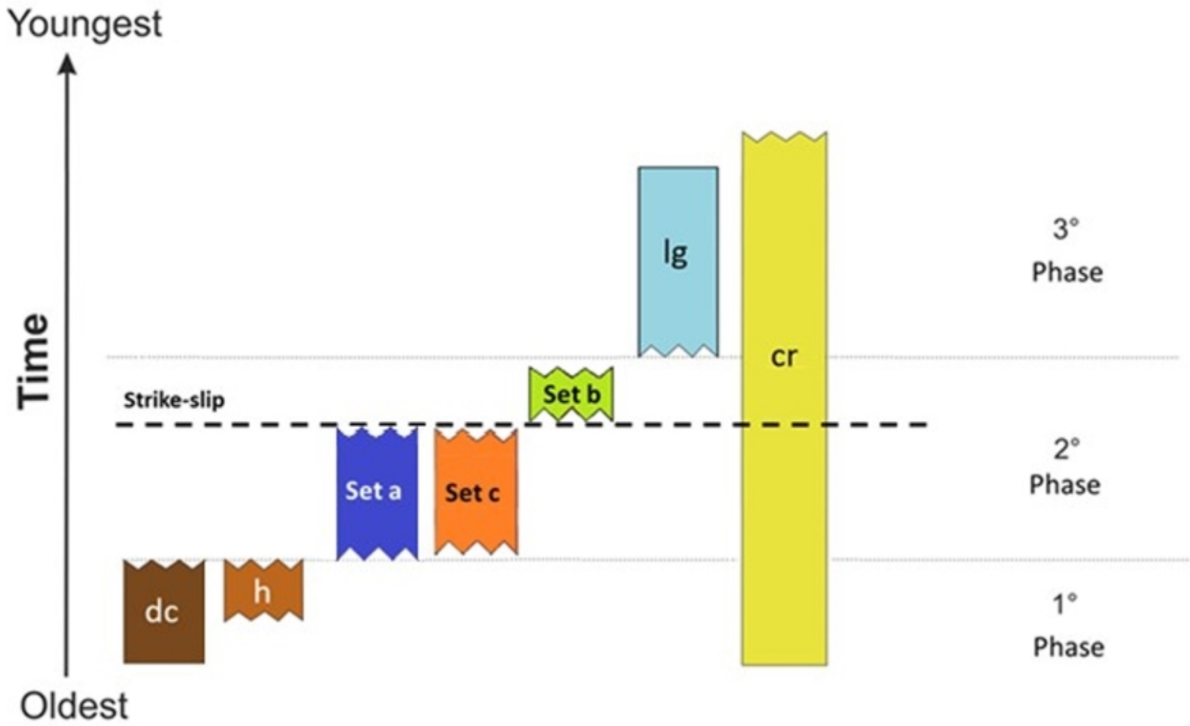

Figure 6. Stratigraphic chart showing the evolutionary temporal sequence of the Anshar Sulcus area; (dc) dark cratered unit, (h) hummocky material, (cr) crater, set of fracture a (set a), set of fracture b (set b), set of fracture c (set c), beginning of strike-slip event (black dashed line), (lg) light grooved unit. The 1◦ phase presents formation by impact events of dc and h surrounding Anshar Sulcus; the 2◦ phase presents fracturing by extensive and strike–slip tectonics, including the right-lateral strike-slip movement precursor of Anshar sulcus; the 3◦ phase presents formation of lg through spreading center mode by combination of extensive and strike-slip tectonics.