3D GEOLOGIC RECONSTRUCTION AND DIGITAL FRACTURE NETWORK ANALYSIS OF URUK SULCUS REGION ON GANYMEDE. Riccardo Pozzobon[1], Costanza Rossi[1], Alice Lucchetti[1], Matteo Massironi[1, 2, 3], Maurizio Pajola[1], Luca Penasa[1], G. Munaretto[1]
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Introduction: Ganymede was first observed by both NASA Voyager missions in 1970's, when the whole satellite was imaged. Its surface was recognized to show intense tectonization. The NASA Galileo mission in 1996 improved such observations with targeted flybys, hence providing higher resolution images (up to ~70 m/pixel). Through this dataset it was discovered that the surface of Ganymede consists of a brittle icy crust which stands on top of a large liquid body, possibly a global subsurface ocean. By means of multiple Galileo flybys both geophysical and structural geology measurements constrained the average icy shell thickness to be comprised between 100 and 150 km [1,2,3,4]. From a geological perspective the surface of Ganymede can be essentially divided into dark and bright terrains depending on their relative albedo. Crater density and surface morphologies also vary within such units. In particular, bright terrains appears to be the less craterized and with a higher degree of tectonization than the dark ones. The so-called furrows and grooves are the predominant tectonic features which also represent stages of the deformation of Ganymede's icy crust.

We hereby present a structural analysis carried out with 3D geo-modelling techniques focusing on the region of Uruk sulcus (Figure 1a). This area is a NW-SE bright terrain of ~400 km by ~2500 km size located between 150W-180W and 30N-10S, and characterized by pervasive sets of parallel/sub-parallel grooves of 10s-to-100s km length. The kinematics of such structures is hypothesized to be almost entirely extensional either forming a tilt-block normal faulting [5], or crustal necking ([6], and references therein). A third hypothesis considers its overall structural framework to be the effect of a regional-scale dextral transpression [7]. Previous analyses of such structures, most of all showing dilatant to tensional behaviors, demonstrated that their spatial distribution show a fractal clustering correlation and that their length size-distribution essentially follow a power-law above a certain length threshold [1,7]. Percolation theory shows that if a structural framework follows such scaling laws, it can act as an interconnected pathway favoring fluid circulation, and, in particular case of Ganymed, enabling fluids to upraise from the ~100-150 km-deep ocean [1]. To constrain this hypothesis and to locate the possibly more interconnected areas in the icy crust, we approach this conundrum with 3D structural geomodelling.

3D geologic modelling approach: Today, 3D geomodelling is starting to be used also in planetary geology (as demonstrated by the European PLANMAP Horizon 2020 project, [8,9,10,11,12]. Such approach combines all the available information coming both from surface observations and active subsurface measurements, in addition to the ones constrained by geologic interpretation. This is done to derive a 3D geologic model of the subsurface. Such 3D outputs represent specific quantitative geologic properties of the bodies (e.g. degree of fracturing, permeability etc.) or constrain their 3D shapes and fault geometries. In this work we applied a 3D structural geologic modelling to the Uruk Sulcus region on Ganymede through the use of MOVE software.

Indeed, the Uruk sulcus model geometry has been constrained on the surface by the global Ganymede DEM from [13] textured with the controlled global mosaic from DLR of Voyager 1, 2 and Galileo images (~ 359 m/pixel). The lower model boundary – i.e. the interface between the brittle icy shell and ocean- is located at the depth value calculated using the fractal clustering analysis by [1]. An improved version of structural mapping from [7] was considered. Such mapping mainly focuses on the grooves and has been used to 3D reconstruct the Uruk sulcus structure. In particular, we slightly simplified the major regional fault geometries for GUS1 (Grooves of Uruk Sulcus 1 in red [7], figure 1) and used them as large-scale structural framework. Such assumption allows us to both isolate volumes of ice and focus on the smaller grooves within the major framework. In particular, we focused on 3 ice volumes enclosed in the white squares shown in fig. 1a, b, into three sigmoidal volumes encompassed by major GUS1 strike-slip faults [7].

Ice volumes and digital fracture network: We extracted voxel-based volumes of icy crust comprised between the surface, the lower ocean-ice interface bounded by the major fault lines of GUS1. The smaller structures (i.e. the grooves in GUS2 and GUS3) were modelled by interpreting their vergence by using high-resolution images with known illumination conditions, and/or exploiting interpretations from available literature (e.g. [7,14,15,16]) producing essentially a horst and graben setting. The dip angles were approximated to Andersonian conditions with values of ~60°. All the structures with a length below a size-distribution where a power-law scaling is not fulfilled (i.e. ~90 km [1]) were considered minor sub-vertical tensional structures. Given the overall scarcity of high-resolution data this simplified 3D model is based on direct observations and educated assumptions based on literature, aiming to provide an idealized but sufficiently realistic comprehensive model. By exploiting this geometric model, it is therefore possible to simulate a DFN (Digital Fracture Network) for each of the fractures' families (a first iteration is visible in fig. 2a) aiming to predict possible high-connectivity locations in the fractured ice volumes (figure 2b).

In conclusion, the 3D geomodelling approach, although simplified due to the lack of direct subsurface constraints, appears as a promising tool not only for scientific analysis but also to identify interesting target of future JUICE-JANUS camera observation [REF Palumbo et al. 2014], at locations where resurfacing or deep fluid expulsion could be more favored.

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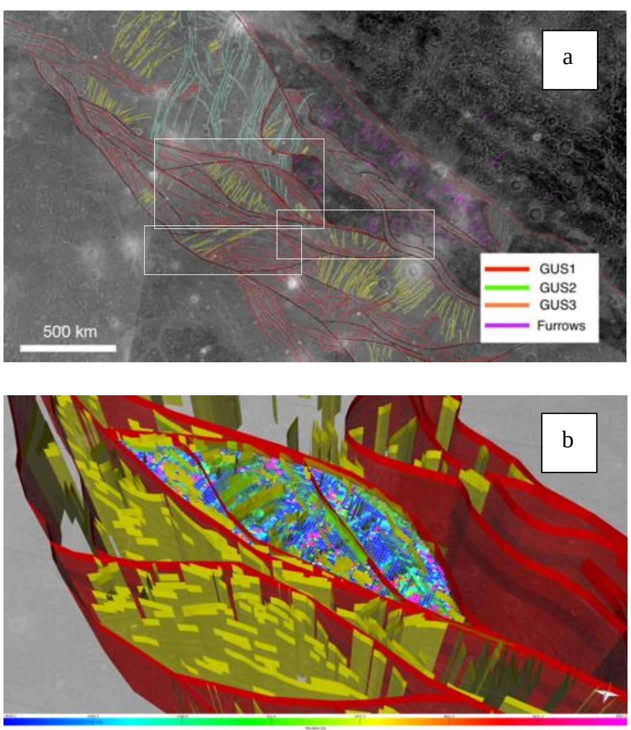

Figure 1: structural map [7] with the families of grooves (GUS) identified. The white boxes are the sigmoidal areas enclosed in the strike-slip GUS1 structures where the analysis is carried out. In b) detail of the 3D meshes modelling the structures and the voxel-based volume color coded according to connectivity values.

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