GENESIS OF ANSHAR SULCUS: EVIDENCE FOR SHEAR AND EXTENSION IN MARIUS REGIO


Anshar Sulcus is a prominent groove lane situated within Marius Regio on Ganymede. The sulcus was imaged by Voyager 2 at a resolution of ~1.6 km/pixel, and at a much higher resolution of 150 m/pixel by Galileo on its G9 orbit. Two 800 x 800 pixel images were obtained of a region in which the sulcus changes from a prominent trough into a bright groove lane [1]. At ~11˚N, 191˚W. The sulcus has been suggested to represent a major fault zone cutting Ganymede’s lithosphere and showing right lateral offset [2] and this target was chosen to examine the modes of emplacement and deformation of both light and dark material.

Geology of the Anshar Sulcus target region: We have carried out detailed mapping of the mosaicked Anshar Sulcus Galileo images (Figs. 1, 2). The images were acquired at an incidence angle of 70˚ such that topographic features and structures are clearly visible, but albedo variations within the terrain are difficult to distinguish. Most of the imaged area is classified from Voyager as furrowed dark terrain [1]. In some areas the dark material is relatively smooth at this resolution, but to the north of the sulcus center, dark material has a hummocky texture at a scale of a few hundred meters (Fig. 2, A). This same texture appears elsewhere, in smaller patches. This hummocky material may correspond to ejecta from a 30 km crater, recently named Ningishzida, to the north of the imaged area. The larger craters in the imaged area are generally highly degraded by tectonism, which preferentially cuts through their centers in the same fashion noticed in other Galileo targets, such as Nicholson Regio [3]. It has been suggested [3, 4] that the craters focus the tectonism. Even craters as small as 5 km show fractures running through their floors, and this may have significant implications for the concentration of fractures and the formation of bright terrain. The largest crater in the south of the mosaic (Fig. 2, B) has been split apart by a series of fractures trending ~N30W, and is also dissected by a series of criss-crossing fine lines across what remains of its floor. This floor looks to be upbowed, and these fine-scale fractures may be the result of this upbowing, perhaps due to isostatic rebound of the floor. Some smaller craters appear relatively young, as demonstrated by their relatively crisp rims, and evidence that they have destroyed underlying fractures.

Several dark terrain furrows cross this area, oriented ~N65E. These are visible at Galileo resolution in the form of relatively low albedo troughs, with hummocky textured rim material on either side. The best resolved furrow (Fig. 2, C) has rims which appear somewhat ‘peaked’, discontinuous and very degraded, unlike the rounded,continuous furrow rims seen elsewhere on high resolution targets [5]. This furrow is particularly interesting as it has several narrow, linear fractures along its length, both inside the trough and outside of both rims. This furrow may have become degraded due to a variety of processes such as mantling by impact ejecta, mass wasting, tectonism, and sublimation [5].

Tectonism: Detailed mapping clearly shows three major trends to the tectonic fabric of this area; one trends ~N30W; a second is consistent with the trend of the furrows. Various fractures of different widths and depths are found within these two trends. The most prominent fractures, trending ~N30W, are seen close to the center of the imaged area (Fig. 2, D), and several very distinct troughs are visible, up to 3 km wide and very close together. This fracture group cuts right through the center of two distinct large (>15 km) craters, splitting them. A second, parallel set of fractures (Fig. 2, E) are observed ~30 km to the east of the main fracture set. When mapped (Fig. 2), the density and spacing of fractures within these two sets are not dissimilar to those found in the sulcus. The main set of fractures (Fig. 2, D) terminates abruptly where it meets the sulcus, suggesting it is postdated by the sulcus.

In a crater on the northern side of the sulcus (Fig. 2, F) troughs are visible of very similar proportions to those which end at the sulcus, and if these are part of the same system, it suggests that some right lateral shear has occurred (see section below).

The major tectonic feature present in the imaged area is the sulcus and its adjoining trough; this structure trends ~N90E at the eastern imaged portion, and ~N65W at its more northern imaged portion. In the east of the imaged area (Fig. 2, G), the uniform trough has a smooth, low albedo floor approximately 3-4 km in width, which extends for ~50 km. At the eastern end, the trough splay out into a fan-shaped series of fractures (Fig. 2, H) within a wedge of bright terrain, which appears to be a releasing bend structure on the basis of Voyager context. About halfway across the eastern part of the imaged area, the trough changes orientation (Fig. 2, J) and opens out into the groove lane. This is approximately 5 km wide, initially, and increases in width to ~18 km wide at the northern extent of the imaged area (Fig. 2, K). The change from trough to sets of fractures is consistent with a change in the orientation of the sulcus, from ~0 - 10˚ to ~30˚. The trough itself continues along the southern side of the groove for most of the rest of the imaged length of the sulcus and it appears to have one to two terraces, or tilt blocks within it at any given location. The northern portion of the center of the groove lane at this point is relatively higher albedo, heavily fractured material. These fractures are generally linear, but appear anastamosing in places throughout. The fractures separate blocks ~1 - 2 km in width. As the sulcus widens (Fig. 2, K), this fractured northern region appears to be topographically higher along the sulcus center than at its margins, although this is hard to confirm given the illumination conditions and potential albedo variations. The southern bounding fault of the sulcus is extremely well-defined, while the structure defining the northern rim is far less dramatic.

In the east of the imaged area are a series of en echelon, sigmoidal fractures (Fig. 2, L) individually trending generally within 5˚ of N50E. These faults are concentrated along the floor of one of the furrows (Fig. 2, C), and together define a zone trending N65E.

Several lines of evidence suggest that right-lateral shear of ~15 km and possibly rotation of ~5˚ has occurred along the sulcus. Reconstructing the sulcus by about ~10 km allows a much better fit to the two furrow sets which clearly
cut the sulcus, along with a fracture set which cuts through a large crater in the northern part of the western image [4]. Rather than complete separation of the lithosphere in the manner of spreading [cf. reconstruction in 4], it may be that the sulcus has extended by a lesser amount in a style of tectonic rifting.

**Interpretation:** We interpret the topography of the sulcus to be consistent with rollover of the northeastern block above a prominent northeast-dipping bounding fault [cf. 8]. The apparently topographically high center of the sulcus may result from cryovolcanism, or from isostatic rebound of thinned lithosphere. The variation in sulcus orientation at the point where it changes from a simple trough to multiple ridges (Fig. 2, J) is consistent with a strike-slip fault associated with ~N60E extension. Supporting evidence for this hypothesis is the presence of the split craters (e.g. Fig. 2, B), which exhibit extension in the N60E direction, and the triangular patch of grooved terrain (Fig. 2, H) interpreted as a releasing bend. A further piece of this tectonic puzzle comes in the series of en echelon fractures in the north-east of the imaged area (Fig. 2, L), individually oriented at approximately N50E. Observation shows that they have formed along the center of a pre-existing furrow oriented at N65E, although at a slight angle to the furrow orientation. This is evidence that deformation is concentrated along furrow floors, and is probably related to furrow tectonics. The deformation indicated by these features is of left lateral shear; this is the correct sense to correlate with the right lateral shear inferred by Anshar sulcus and the extension across the craters, but it is not quite the correct orientation expected by the inferred strain ellipse. This may be explained, however, if the deformation is influenced by the original trend of the furrow. If so, then the deformation of these three features may be contemporaneous; otherwise the deformation of the furrow probably happened at an earlier time.

**Implications for regional deformation in Marius Regio:** These results for the Anshar Sulcus target region are strikingly similar to the sense of right-lateral shear found during the most recent episode of deformation in Uruk Sulcus [6, 7] and with the local sense of shear proposed by [2]. Furthermore, preliminary studies of other targets around Marius Regio suggest that this right-lateral shear displacement may also be consistent with that seen in other Galileo images of Lagash Sulcus, Tiamat Sulcus and possibly Erech Sulcus. This implies that large areas of dark terrain have been sheared and rotated in a dextral sense during the latter stages of formation of bright terrain, although further investigation of the amounts and orientations of these deformations needs to be addressed.

**References:**


**Figure 1:** Galileo image mosaic of Anshar Sulcus

**Figure 2:** Map of Anshar Sulcus from Galileo imaging. Large arrows indicate extensional direction; half arrows indicate shear. Letters correspond to features described in the text.