ON THE FORMATION OF CALDERA-LIKE FEATURES ON GANYMEDE: IMPLICATIONS FROM GALILEO-G28 IMAGES.

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Introduction: During Galileo's 28th orbit (G28) around Jupiter the SSI camera has imaged a caldera-like feature (*clf*) on Ganymede to test for evidence of cryovolcanism (Fig. 1a). These data were evaluated in a previous study [1], but without utilizing their stereoscopic potential. Here we revisit this data set and include topography in the analysis to find new constraints on the formation of the feature.

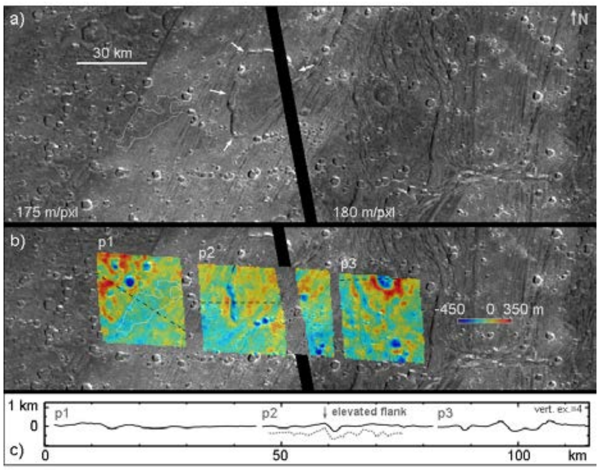

Figure 1. (a) Image mosaic composed of Galileo frames s0552445613 and s0552445600 showing a 20x40 km *clf* at 24°S/42°E (arrows) surrounded by a bright band. (b) Color-coded DEM in that region derived by stereo image analysis [2] using the top frames (set1) and frames s0552444039 (48 m/pxl), s0552444026 (47 m/pxl), s0552444013 (46 m/pxl), s0552444000 (45 m/pxl) (set2). (c) Selected DEM profiles. p2 reveals flank uplift at the western boundary of the *clf* (for comparison, the dotted profile below shows flank uplift at a rift zone boundary on Ganymede [9]). We note that the inward-facing slope of the flank is below the DEM's horizontal resolution and therefore smoothed within our method of analysis [2].

Digital Elevation Model (DEM**):** The G28 images are composed of two sets which were taken with an interval of 16 min to acquire stereo coverage. From these we derived four individual DEMs with horizontal resolution of about 1 km and vertical precision of 20-40 m (Fig. 1b). Their relative elevation levels have been adjusted such that there is no elevation offset between identical geologic units.

Observations: Termed "scalloped depression" in the previous study [1], the DEM reveals that the *clf* stands in fact higher (towards the south ~200 m) than the surrounding band. The interior is roughly planar rather than convex-shaped with relief similar to that of the band, typically 100 m at the DEM's resolution. The only exception is the western boundary region. Along that there is a ~3 km wide and up to 400 m deep trough. The trough exhibits inward- and outward facing slopes of > 29° (this slope is in shadow) and ~15°, respectively, and is associated with an elevated surrounding terrain flank (Fig. 1c, p2).

Inside the *clf* are small-scale ridges which have been heavily fractured but apart from that resemble - in dimension and strike – ridges in the band outside the *clf*. Likewise, there are fractured terrain blocks which have the same texture as terrains outside (Fig. 2a). And, there are broader but curved ridges inside the *clf* which can be traced back to the band outside (Fig. 3).

Overall the interior is pervaded with dark material (*dm*), however *dm* can also be observed outside the *clf*. In many places, it appears as lobate deposit located in shallow depressions (Fig. 1a, b, white contour) and showing embayment relationships (Fig. 2). Two 0.7x1.5 km dark patches show clear evidence of smoothness (Fig. 2; p1, p2).

Within the modelled area, dark terrain stands 100-200 m higher than the abutting bright band.

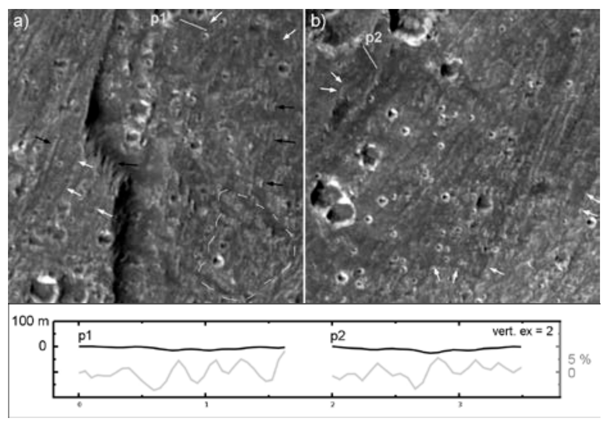

Figure 2. Cut out of s0552444026 (a) and s0552444039 (b), respectively. (a) Black arrows indicate fractured ridges inside the *clf* resembling ridges outside, and the dashed outline encircles fractured blocks with texture as can be observed in the band. (a, b) There are extended patches of *dm* and associated flow features with embayment relationships both inside and outside the *clf* (white arrows). (Bottom) Elevation profiles showing the smoothness of two dark patches at image resolution (47 m/pxl). They were derived by photoclinometry using the Lommel-Seeliger photometric function. Gray lines are image brightness relative to the mean value along the profile.

Discussion: A *clf* with high-standing interior has also been observed in Ganymede's Sippar Sulcus, though at much lower DEM resolution [3]. A high-standing interior may thus be characteristic for *clf*s. An obvious process that could account for this and which is consistent with a fractured interior as observed here would be a diapir. A diapir with radius of 40 km would be able to push up and fracture the lithosphere [4]. This may also result in a domed interior as has been observed in photoclinometry-derived profiles in one case [5]. The diapir could also have trapped water ice lavas which then were released to the surface upon touching the lithosphere and spreading of the plume. Moreover, spreading of the plume could have squeezed lavas outwards forming an annular magma chamber which after drainage leads to collapse in the overlying layers. This would explain the presence of a bounding trough in the given case and for *clf*s elsewhere on Ganymede (Fig. 4). The trough was attributed to failure above a drained melt chamber [1] consistent with the above scenario.

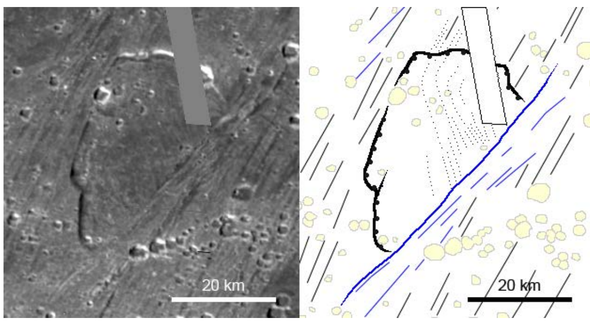

Figure 3. (Left) Cut out of mosaic s0552445613+s0552444026. (Right) Sketch map showing curved ridges (dotted lines) inside the *clf* that can be traced back to the surrounding band.

The presence of *dm* both inside and outside the *clf* may indicate that it is not intimately related to the formation of the *clf*, rather it may have been emplaced by other ways. Flow features and embayment relationships observed here and in Ganymede's Sippar Sulcus [6, 7] suggest that *dm* has been emplaced in fluid form and that it may rise to the surface because of its negative buoyancy with respect to the ice shell [8]. *dm* is thought to be a mixture of water and salts [8]. It's dark appearance is likely related to rapid vaporisation or enhanced sublimation of the H_2O portion at the time of emplacement (for sublimation and clean water ice at T=80 K a rise in temperature by just 1 K results in a 2.6 times higher rate).

The presence of curved ridges inside the *clf* suggests viscous deformation and hints at enhanced temperatures in that area at the time of formation. Whether a rising diapir can produce such deformation remains open.

The elevated flank of the bounding trough (Fig. 1c, p2) is interpreted to be the result of post formational isostatic ductile ice flows in response to unloading due to drainage of the magma chamber. As there is no indication for extension in that specific region and thus for related unloading, the elevated flank provides indirect evidence for collapse above a melt chamber.

The magma chamber must have been located at depths smaller than a critical depth d_{crit} because otherwise frictional forces would have prevented collapse. d_{crit} is approximately given by the ratio of the width of the bounding trough (3 *km*) to the coefficient of friction (0.69) which is ~4 *km*. The vertical dimension of the magma chamber is expected to be comparable to the depth of the bounding trough i.e. ~400 *m*.

As the bright band stands slightly lower than the surrounding dark terrain its density must be higher.

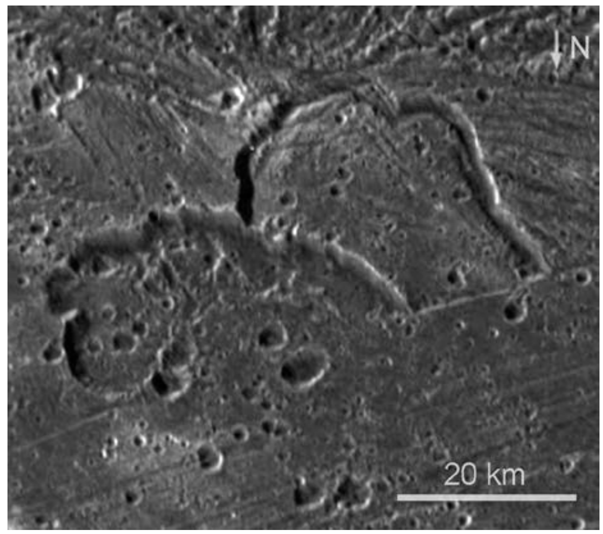

Figure 4. Image mosaic in Ganymede's Sippar Sulcus (s0394532426, s0394532452). Both *clf*s exhibit a bounding trough with pronounced flow features in the lower case.

Conclusions: Diapirism is a viable explanation for the formation of caldera-like features on Ganymede. In the here described scenario a compositionally and thermally buoyant diapir has flexed and subsequently disrupted the surface thereby flooding and displacing pre-existing surface features. Consistent with the observed topography the up-rising plume could have squeezed lavas outwards forming an annular magma chamber which after drainage leads to collapse in the overlying layers.

References: [1] Spaun N. A. et al. (2001) *LPSC XXXII*, Abstract #1448. [2] Giese B. et al. (1998) *ICARUS, 135*, 303–316. [3] Schenk P. M. et al. (2001) *Nature 410*, 57–60. [4] Kirk R. L. and Stevenson D. J. (1987) *Icarus 69*, 91-134. [5] Schenk P. M. and Moore J. M. (1995) *JGR 100, E9*, 19,009–19,022. [6] Head J. W. et al. (1998) *LPSC XXIX*, Abstract #1666. [7] Kay J. E. and Head J. W. (1999) *LPSC XXX*, Abstract #1103. [8] Wilson L. and Head J. W. (1998) *LPSC XXIX*, Abstract #1440. [9] Nimmo F. et al. (2002) *GRL, 29*, NO. 7.