A MORPHOLOGICAL EXAMINATION OF LUGALMESLAM CRATER, GANYMEDE. C. Thomas. Planetary Science Research Group, Environmental Science Department, Lancaster University, Lancaster LA1 4YQ, United Kingdom. (constantine.thomas@lancaster.ac.uk).

Overview: Lugalmeslam is an impact crater approximately 60 km in diameter on Ganymede, located at 24°N 194°W on the southern border of Mashu Sulcus, which geographically separates Northern from Central Marius Regio. It has an unusual elliptical rim where it overlaps the bright terrain of Mashu Sulcus and it was hypothesised that extension in this terrain may have directly affected the rim (R. Pappalardo, *Pers. Comm.*). A detailed analysis of the crater's morphology is presented here which provides new insights into the processes affecting Lugalmeslam.

Datasets: Lugalmeslam was first imaged during the 1979 Voyager 2 flyby of Ganymede and was specifically targeted during the Galileo G8 flyby in May 1997. Three datasets are available for this area: a Voyager 2 low-resolution (2.5 km/pxl) colour set consisting of orange, blue, and violet filter images, a medium-resolution (1.3 km/pxl) clear filter Voyager 2 image acquired when the spacecraft was closer to Ganymede during its flyby, and a high-resolution (0.149 km/pxl) Galileo image obtained during the G8 orbit. These images were calibrated and geometrically reprojected to glean the greatest possible amount of information from them. The colour filters were combined to make a single OBV colour image with orange in the red channel, blue in the green channel, and violet in the blue channel. Finally, the colour (OBV) image, the Clear filter (CLR) image, and the G8 image were superimposed over each other as separate image layers.

Solar illumination and Albedo variation: The Galileo image was acquired at a high solar incidence angle (~ 73°), with the sun low on the eastern horizon. The Voyager images were acquired at a low incidence angle (~ 27°), with the sun high in the southern sky. Brightness variations caused by topography are therefore enhanced in the Galileo image, whereas intrinsic albedo variations in the surface are enhanced by the low incidence angle of the Voyager images. When compared with the Voyager OBV and CLR images, large-scale albedo variations in the G8 image are very hard to see - the boundary between 'Dark Terrain' and 'Bright Terrain' that is visible in the Voyager 2 images cannot be distinguished at all in the Galileo image even with extreme image manipulation.

Crater Floor Morphology: The Voyager images clearly show a dark arc just inside the western rim of the crater - if this were any kind of shadow, it would have to be cast by higher ground to its south. However, the viewing geometry is completely inappropriate for this arc to be a shadow of the rim. Furthermore, true shadow would be seen as completely black areas in the OBV colour image, and the arc is clearly a darker shade of brown than the surrounding Dark Terrain. This dark region must therefore be caused by albedo variations in the crater floor in this region. Indeed, because the sun is high in the sky and no shadows are visible in the Voyager images, only very steep slopes - steeper than 63° from horizontal - can cast shadows. It should be noted that this represents the maximum possible slope in the imaged region, and the actual slopes may not necessarily be this steep. Despite the high incidence angle however, it is possible to see small-scale albedo variations in the Galileo image. Although hard to distinguish, the darkest areas correspond to topographic lows, and also represent the smoothest terrain at this 149 m/pxl resolution. Local topographic highs and the rims of most small craters within and around Lugalmeslam are brighter than surrounding terrain. This is in agreement with the the relationship between topography and surface brightness noted by [1]. As implied by the VGR images, the crater floor in the arc just within the western part of the crater rim appears to be slightly darker than the rest of the crater floor. Examination of the image indicates that this area contains less of the small (< 1 km across, probably a few hundred metres high) bright-topped hills that give the surrounding terrain a characteristic texture. This provides a partial explanation as to why this area appears darker than the rest of the crater floor - areas in the G8 image where the density of these small bright features is lower are also darker at the lower VGR resolutions. The intrinsic photometric properties (colour, reflectivity etc.) of the material may also vary, but such small-scale variations across the floor of Lugalmeslam are impossible to determine in the single filter Galileo image. Parts of the rim wall are locally quite bright, and the floor near the southeastern wall of crater is more rugged (exposing more bright ridge tops) than the rest of the crater. The north and northeastern part of the crater contain many medium-sized craters with bright rims, so the average brightness of this region at kilometre-scale is higher than in the rest of Lugalmeslam. The central part of the crater is occupied by a convoluted ring of hummocky terrain, which apparently outlines a small arc of darker material to the east of the actual centre. The inner edge of this arc appears to be a ridge/scarp that represents the highest part of this area. This arc outlines what is generally lower ground (and darker albedo material), though the exact centre of the crater is marked by a small bright central peak structure approximately 3.5 km across that appears to approach a similar level to that of the ridge arc around it.

Rim Morphology: For ease of reference, the rim morphology will be described here in terms of a clock face, with the 12:00 position oriented towards the north. The western rim of Lugalmeslam is very obvious, and a 410 pixel (61.09 km) diameter circle - the 'ideal circle' - can be used to approximate the shape of this portion of the rim. The rim follows this ideal circle very closely going anti-clockwise between the 12:00 and 6:00 positions. The eastern rim is much more irregular than the west, and significantly deviates from the ideal circle - in fact, the entire eastern half of the rim lies outside the ideal circle. It was traced by following inward-facing scarps of similar character and appearance, and also by using photoclinometrically derived perspective views as a rough guide. The most clearly delineated portion of the rim lies between the 10:00 and 6:00 positions. Between 10:00 and 9:00 the horizontal distance between the rim top and crater floor is between three or four kilometres. The rim wall steepens considerably between 8:00 and 6:00, where it rises from crater floor to rim top over a distance of the order of 500 metres. The rim deteriorates significantly and very suddenly beyond this point - between 6:00 and 4:00 it is a much wider, shallower slope spread over a distance of between nine and ten kilometres. A flatter area - a lower terrace - along the crater wall is evident in this area, intermediate in height between the rim top to the east and the crater floor. The 4:00 position marks a sudden downward break in slope that can be followed from the base of the crater wall out to the southeast of the crater itself. The northeastern portion of the rim between the 11:00 and 4:00 positions appears very heavily degraded. The rim appears to bifurcate at the 4:00 break - one rim follows a higher path than the other. The 'high rim' is more discontinous and is made of long, smoothly-curved arcuate ridges - this is interpreted here to be the 'true rim' of the crater. The 'low rim' lies nearer the crater floor and has a more strongly crenulated appearance, with distinct scarps casting shadows on the terrain below. Near the 1:00 position, these scarps stop abruptly and cannot be seen elsewhere along the rim. Between 12:00 and 2:00 (particularly nearer 12:00) the rim is extremely difficult to trace and in some places disappears almost completely. The slope towards the centre of the crater appears to be the shallowest in this region, though the terrain between the wall and crater centre contains many small (one to five kilometre diameter) craters. The rim appears to rise between the 11:00 and 1:00 positions, until it becomes clearly defined again near 10:00.

The BT/DT boundary: Lugalmeslam itself lies astride the border between the Dark Terrain of Central Marius Regio to its southwest and the Bright Terrain of Mashu Sulcus to its northeast - 22.7% of the crater's area lies within Mashu Sulcus, while 77.3% lies in the Dark Terrain. The rim of the crater is easy to follow in the Dark Terrain but considerably harder to distinguish in the Bright Terrain, where it blends in more with the background topography - photoclinometry was used to help locate the rim here. There is no sharply defined boundary visible in the Galileo image between the Bright Terrain and Dark Terrain - no obvious fault lines or other such features separate the two terrain types. Instead, the Bright Terrain merely seems to emerge directly from the Dark Terrain. It is interesting to note that there is little discernable difference in the Galileo image between the fine (< 1 km) textures of the actual surface of the Bright Terrain and Dark Terrain. Bright and Dark Terrain are peppered by hundreds of small craters up to 1 km in diameter, and there are only 25 larger craters up to 5 km in diameter. No craters larger than 5 km in diameter are present in the G8 image apart from Lugalmeslam itself. Crater densities on both sides of the boundary (as defined by Voyager images) are very similar - the crater density in the Bright Terrain is 0.030 craters per km², whereas the crater density in the Dark Terrain is slightly less at 0.025 craters per km². This difference is too small to be statistically significant and reveals nothing about the relative ages of the two terrains. The Bright Terrain area also contains linear, though discontinuous, ridges that cross the G8 image at a bearing (measured clockwise from north) of 120° to 130°. The axes of these ridges are separated by a distance of 16 +/- 3 km - this spacing is generally fairly regular in the imaged area. Smaller ridges (a few hundred metres in height) can be found between these major ridges, but these are much less well-defined. The major ridges are between 2 and 5 km wide from base to base across the ridge axis, though some appear less distinct than others. A major ridge in the northeastern corner of the G8 mosaic is particularly triangular in cross section, and also the base of its northeastern flank is mantled by a particularly obvious patch of smooth dark material that is visible in the CLR image. Indeed, most of these major ridges have dark material associated with their bases, again supporting the hypothesis that dark material is being deposited in topographic lows from higher ground. The width of the crater within the BT area is ~ 17 km, which is approximately the same as the wavelength of the major ridges. One ridge appears to run roughly at a tangent to the northeastern rim (intersecting at the 1:00 position). Another small ridge approaches the outside rim near the 3:00 position but does not appear to penetrate the rim. The next ridge (which marks where the Bright Terrain stops encroaching into the Dark Terrain at Voyager resolutions) does cut into the crater and extends approximately 10 km into the crater floor from the southeast (at exactly the 4:00 position), but this ridge cannot be seen to continue on the opposite side. The spacing between the first pair of ridges is ~ 21 km, while the second pair are ~ 11 km apart. No further ridges can be seen further south in the Dark Terrain. There are also at least two sets of small ridge-like lineaments that comprise a fabric oriented roughly perpendicular to the ridges that cross both the Dark and Bright Terrain areas. These are not visible in the Voyager images - the topography across them is very low. This fabric appears to be older than the BT ridges as it can be seen to be deformed by them as it crosses them. The spacing between the individual ridges of this linear fabric is 1 - 1.5 km. Just beyond the south-eastern crater rim, these lineaments are oriented tangential to the rim and one of these small ridge sets appears to intersect the rim between the 4:00 and 5:00 positions. The lineaments are not present within the crater or very close to the outside of the rim. The lineaments continue past the crater rim into the BT area where they can be seen to follow the topography of the major ridges therein, though they do curve northwards beyond the crater.

Interpretation: The origin of Mashu Sulcus has previously been interpreted by [2] as "tectonic blocks of dark materials, downdropped and resurfaced by light smooth material, and subsequently fractured pervasively by narrow grabens, tension fractures, or both. Sinusoidal groove cross sections due in part to mass wasting." Lugalmeslam itself is mapped as a "partly degraded crater of intermediate age", while the northeastern portion of it is mapped as "Smooth [Light] Material" interpreted as "extrusive or pyroclastic deposits of brine". Examination of the higher resolution Galileo image requires extensive modification of this interpretation. There is no evidence for cryovolcanic activity of any kind in this area and nothing to suggest that the northeastern portion of Lugalmeslam is compositionally different to its surroundings. The small-scale textural similarity between the terrain seen in Mashu Sulcus and Central Marius Regio seen in the Galileo image suggests that the only difference between the so-called Bright and Dark Terrain in this area is that the former contains large ridges and the latter does not - in other words, the only reason that Mashu Sulcus is brighter at Voyager resolution is due to averaging out of sub-pixel albedo variations brought about by the presence of the ridges and not because of any intrinsic compositional differences. It would appear that the southeastern rim of Lugalmeslam has failed along planes of weakness denoted by the small NE-SW trending lineaments and rotated downwards towards the crater floor. Debris has filled in the base of the inner rim wall and spread inwards towards the centre of the crater, thus resulting in a more gradual slope here to the surviving rim - it may be no coincidence that the crater rim between the 4:00 and 5:00 positions is straight and oriented at the same angle as the small lineaments that intersect it. The northeastern quarter of the the rim that overlaps Mashu Sulcus is the most heavily disrupted segment. It is interesting to note that the crater rim in this area is roughly parallel to the fabric of the NW-SE ridges in Mashu Sulcus. The fact that one of these major ridges actually intersects the rim in the northeastern quadrant of the crater may not be a coincidence - it is likely that the process that created the ridges disrupted the rim.

Further Work: It is obvious that some tectonic process has affected the Dark Terrain of Central Marius Regio to turn it into the 'Bright Terrain' of Mashu Sulcus - the two terrains seem identical apart from the presence of the ridges in Mashu Sulcus. It is also apparent that tectonism has affected the shape of Lugalmeslam by disrupting its rim - however, there is no evidence to support the hypothesis that Lugalmeslam has been actively extended along an axis by tectonic movement in Mashu Sulcus. The exact nature of the tectonic processes occurring in the Sulcus is unclear - however, the lack of features commonly associated with extension in this region (such as cracks and fracture belts) that are so prevalent in other areas of Ganymede (e.g. Nicholson Regio, Byblus Sulcus) hint that perhaps the ridges may not be extensional in nature. Compressional and strike-slip tectonism have been identified elsewhere on Ganymede by other authors [3, 4, 5, 6] and this form of activity may be applicable here.

The chronology of events in this area is very ambiguous. It is most likely that the Mashu Sulcus ridges and the NE-SW lineaments formed more recently than Lugalmeslam in order to disrupt the crater rim - however, the lack of lineaments in the crater floor requires explanation if this is the case. Furthermore, the lack of ejecta or secondary impacts around the crater implies that it is old and has suffered much thermal, gravitational, or micrometeorite erosion. Clearly there is more to investigate in order to determine the chronology of events in this area, and further analysis will be attempted in order to clarify the exact nature of the processes affecting Lugalmeslam.

References: [1] Spencer J., (1987) Icarus 69, 297-313. [2] Murchie and Head (1989), USGS Map JG-4. [3] Thomas C. *et al.* (1998) *LPSC XXIX* #1897. [4] Ghail R. C. and Thomas C. (2001) *LPSC XXXII*, this issue. [5] Murchie S. L. and Head J. W. (1988) *JGR*, **93**, 8795-8824. [6] Prockter L. M. *et al.* (2000) *JGR*, **105**, 22519-22540.