COMPARISON OF METHODS TO DETERMINE FURROW SYSTEM CENTERS ON GANYMEDE AND CALLISTO.

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Introduction: Furrows are arcuate troughs, often with raised rims or asymmetric scarps, which are generally accepted to be the remnants of ancient multiringed impact basins on Ganymede [1]. Similar multiringed impact basins are well preserved on the surface of Callisto, but on Ganymede the process of groove formation has broken the basins into fragments found in the remnants of ancient dark terrain. If a reliable method can be found to calculate the centers of fragments of ancient impact basins, then furrow systems on Ganymede can be used as large-scale strain markers to constrain the tectonics of grooved terrain [2].

Previous researchers have investigated this issue based on Voyager data [3,4,5], but it is worth revisiting for several reasons. Moderate resolution mapping of Ganymede has now been completed by the Galileo mission, and new furrow systems have been discovered in this data. The Galileo data has also significantly improved the coordinate control network on Ganymede, resulting in significant shifts in the map location of some Voyager data. Also, different researchers have used different methods for determining the centers of furrow systems, and they have also used their own map data, so the methods have not been directly compared using the same input data. We have mapped all of the furrows on Ganymede and the multiring basins on Callisto directly from the digital mosaics into an ArcView GIS database.

Methods: Two basic methods have been used by previous researchers to determine the geometric center of furrow systems, which we will call the small circle method and the bisector method. The small circle method [3,4] finds the center of a furrow system by assuming that the furrows must lie on concentric small circles. The bisector method [5] finds the center by assuming that radial lines drawn from the central point will be perpendicular bisectors of mapped furrow segments. We have implemented both of these methods, to compare their results when given the same input data.

Our implementation of the small circle method starts with each furrow in the GIS database mapped as a series of latitude-longitude points. The program then tests a broad user-defined region of potential center points. For each potential center point, the program tests the fits of each furrow to a small circle centered on the point. All points on a small circle will lie at an equal distance from the center, so the difference between the distance from the center to any two points on the furrow should be zero. This is summarized in an unnormalized chi-squared statistic (as used by *Schenk and McKinnon* [4]):

$$\chi^2 = \sum(d_1 - d_2)^2$$

where d_1 and d_2 are distances from points on the same furrow to the center being tested. Each point on a furrow is compared to every other point on the same furrow, and the χ^2 result is summed for every point pair on every furrow in the system. The center point with the lowest χ^2 value is the best fit center, since it is the center point at which the furrows most closely match concentric small circles. Our implementation of this method differs from that of *Schenk and McKinnon* [4] in that we compare every point pair on a furrow, rather than only adjacent points.

The second method we have implemented in the GIS environment is the bisector method. Every pair of adjacent points on each furrow is a segment of the mapped line which represents the furrow. First, the great circle is found that passes through those two points, and this information is stored as the location of the pole of that great circle. Then the pole of the great circle which is the perpendicular bisector of the furrow segment is found by taking the cross product of the vectors from the center of the sphere to the pole of the furrow segment's great circle and from the center to the midpoint of the furrow segment. Finally, the cross product of any pair of bisector poles shows where those bisectors intersect. If the furrows are concentric small circles, then the perpendicular bisectors of the furrow segments should intersect each other at the center. We calculate the areal density of bisector intersection points, and locate the best fit center where the highest density of intersection points occurs.

Weighting: Though these methods work well in theory, the furrow systems on Ganymede and Callisto only approximate concentric small circles, and in detail they are inherently non-circular [3,4], especially as the distance from the center increases. To investigate this effect, and to potentially mitigate it, we are working with different weighting schemes within the two methods described above. The first testbed for these investigations is the Valhalla structure on Callisto, which is intact and has not obviously been modified since its formation. *Schenk and McKinnon* [4] also investigated Valhalla and found the most significant noncircularity in the system to be in the outer reaches of the northeastern quadrant. Figure 1 shows best fit centers for the Valhalla basin using both of the methods. Figure 2 shows how the fit of the center (as compared to the *Schenk and McKinnon* center) using the small circle method degrades with increasing furrow distance.

The first results shown for Valhalla have not had any weighting or point-editing process applied to them. As a result, more distant furrows and more sinuous furrows have a disproportionate influence on the fit of the center, because the fit in both methods is based on examining pairs of points on the furrows. More distant furrows are longer, and thus contribute more points to the solution. More sinuous furrows also contribute more points, because we have mapped the furrows as closely as possible to the base image, so every small change in azimuth in the furrow adds another point to the database.

Previous studies have countered the sinuous furrow problem by requiring each input furrow segment to be the same length, making the points equally spaced. Another way to address this issue would be to weight the contribution of each segment to the center solution by the length of that segment. To address the distant furrow issue, it is possible to weight the contribution of each furrow segment by its proximity to a preliminary center point. *Murchie and Head* [5] attempted to improve the accuracy of the bisector method by excluding bisector intersections in which the bisector poles were within 10°, since these low-angle intersections are inherently more prone to error; we are also investigating the effect of this type of constraint.

At the meeting we will further discuss the merits of the various methods and weighting schemes by comparing their results for Valhalla, Asgard, and an intact furrow system to the west of Punt on Ganymede. We will also show the results for individual sectors of these furrow systems, since the disrupted systems on Ganymede only preserve certain sectors of the original system. The goal of this evaluation is to find the best and most robust method or combination of methods for finding the center of a fragment of a furrow system, so that we can apply it to the disrupted systems on Ganymede.

References: [1] Shoemaker, E. M. et al. (1982) in *Satellites of Jupiter*, U of AZ press, 435-520.; [2] Prockter, L. M. et al. (2002) *LPSC XXXIII*, #1272; [3] Zuber, M. T., and E. M. Parmentier (1984) *Icarus* 60, 200-210; [4] Schenk, P. M., and W. B. McKinnon (1987) *Icarus* 72, 209-234; [5] Murchie, S. L., and J. W. Head (1988) *JGR* 93, 8795-8824.

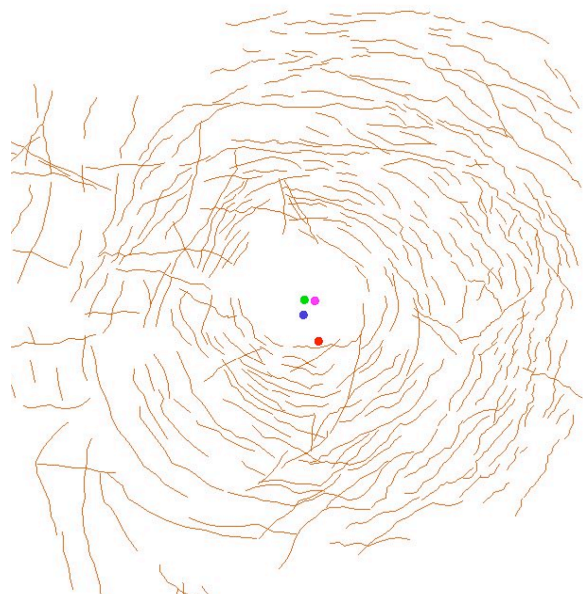

Figure 1: Map of furrows in Valhalla, with example best fit center points. Red: small circle method, all furrows; Pink: small circle method, interior furrows to 600 km radius only; Green: bisector method, all furrows; Blue: center calculated by *Schenk and McKinnon* [4] (using different input data).

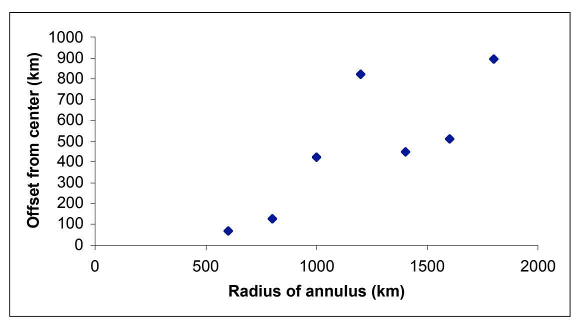

Figure 2: When the Valhalla furrows are divided into 200 km wide annuli around the calculated center point, and a new center calculated for each annulus using the small circle method, the offset of the new center point from the original point tends to increase for more distant furrows.