HISTORICAL EXAMPLES OF TIDALLY SPLIT COMETS: CRATER CHAINS ON CALLISTO AND GANYMEDE; P. Schenk, Lunar and Planetary Institute, Houston, TX 77058; E. Asphaug, NASA Ames Research Center, Moffett Field, CA 94035; W. B. McKinnon and L.A.M. Benner, Washington Univ., St. Louis, MO 63130; and H.J. Melosh, Univ. of Arizona, Tucson, AZ 85721.

Linear crater chains (or catenae) on Callisto and Ganymede represent a unique record of comets split apart by tidal [1] or collisional [e.g., 2] forces during close passage of Jupiter. This knowledge has already been used to place preliminary constrains on the masses of comet fragments and their parent comets [3]. The geologic record of crater chains increases our known sample of split comets by a factor of 10. Here we explore this record and evaluate and extend model dependent conclusions regarding comet fragmentation characteristics and processes, and the properties of Jupiter-family comets.

CRATER MORPHOLOGY

A total of 8 chains have been identified on Callisto, 3 on Ganymede (from which we predict a total of 0.08 crater chains on Europa). The lack of source basins and the remarkable similarity to comet Shoemaker-Levy 9 led Melosh and Schenk to propose that these crater chains formed from the impact of similar split comets. Catena craters range from 3 to 46 km in diameter and, where resolved, have normal "complex" crater morphologies. Central peaks (or pits in larger craters), inner rimwalls, and raised rims are easily observed. Viewing conditions prevent direct depth determinations, but limited stereo coverage indicates they are as deep as typical craters on these satellites [4]. Crater size within specific catena varies by no more than a factor of 2, and there is no evidence in Voyager images of additional cratering events at small scales peripheral to or between these larger events.

CHAIN MORPHOLOGY

Spacing between craters in specific catena varies by no more than a factor of 2, and is usually between 10 and 20 km. Spacing ranges between 60 and 70 km, however, within Gipul Catena, the largest observed chain. The number of craters (and hence fragments) per chain ranges from 6 to 25, with a mean of ~11. Catena do not form great circles but form broad arcs along small circles. The catena are remarkably linear, however; crater centers deviate by no more than 1 crater radii from best-fit curves through each chain.

Catena orientations and locations on the disk are easily determined. In three cases, the fragment impact sequence can be determined from the overlap sequence of the craters. Given these observations and the requirement of close passage to Jupiter, useful constraints can be placed on the trajectories, and hence impact velocity and angle of the incoming comets. With this, McKinnon and Schenk [3] have derived fragment masses and radii from catena crater dimensions. Fragment masses range over 4 orders of magnitude (roughly 10^{12}-10^{16} g), but are more narrowly restricted to a range of only 1 order magnitude within individual catena (Fig. 1). The largest fragment in each chain generally has a mass 1/2 to 1/10th that of the total parent comet. For the 5 largest chains, crater size and derived fragment mass are largest toward the center of the chain. The other chains may also show this, but image resolution is poor in these examples. If coma brightness [and plume thermal brightness] are an indication of fragment size, and mass [e.g., 5], then the fragments of Shoemaker-Levy 9 were also larger toward the center of the fragment chain.

CONCLUSION

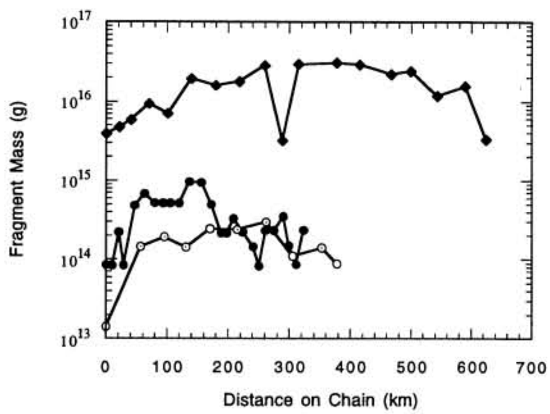
- Comets split into fragments of different mass and the number of fragments. Each individual comet splits into roughly equidimensional fragments, however, that are roughly evenly spaced. This is more consistent with with rubble-pile models, and argues against a building-block model for comets [2]. There does not appear to be any significant correlation between the number of fragments and the total mass of the parent comet (Fig. 2).
- The most massive fragments generally formed toward the center of each fragment chain (including the Shoemaker-Levy 9 fragment chain). This is consistent with tidal breakup in that smaller pieces or accumulations should form at the tidal antipodes of the precursor body.
- Crater morphology tends to favor impact of 'dense' clusters or solid fragments. Clustered (or dispersed) projectiles produce abnormally shallow and irregularly shaped craters [6], which are not seen at Voyager

resolution. The clustered particle swarms proposed by Asphaug and Benz [2] may be condensed enough when they strike the satellites to produce classical craters, depending on particle properties. High resolution Galileo images may reveal morphologic details that will provide a more robust answer to how fragments are constructed.

The lack of correlation between the number of fragments formed in a given tidal encounter and the size of the precursor comet suggests that bodies of all sizes break up similarly. The tidal disruption process may be scale independent, which in turn implies that the grain sizes of comets is much smaller than the fragments which form after splitting, consistent with [2]. The number of resulting fragments may be related to the encounter distance to Jupiter [2]. If so, then it may be possible to constrain peri-Jove distance for each chain progenitor (the most important missing piece in the comet reconstruction effort). Fragment and chain characteristics may also depend on the assumed grain size in the calculations.

REFERENCES: [1] Melosh, H., and P. Schenk, *Nature*, 365, 731, 1993; [2] Asphaug, E., and W. Benz, *Nature*, 370, 120, 1994; also *LPS XXVI*, this volume, 1995; [3] McKinnon, W., and P. Schenk, submitted, *GRL*, 1995; [4] Schenk, P., *JGR*, 96, 15635, 1991; [5] Weaver et al., *Science*, 263, 787, 1994; [6] Schultz, P., and D. Gault, *JGR*, 90, 3701, 1985.

Figure 1 (*a, b*). Derived fragment mass for individual craters [3] as a function of crater location and distance along each crater chain on Callisto and Ganymede. Data are split into two figures, with different scales, for clarity. Compare with Figure 1*c*.



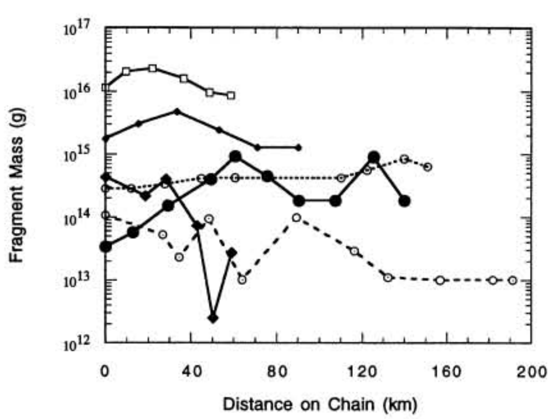


Figure 1*c*. Estimated fragment masses for most prominent nuclei of Shoemaker-Levy 9, shown in relation to their position along the fragment chain as of March, 1993. Masses estimated from derived radii of Weaver et al. [5], assuming ρ=0.6 g/cm^3.

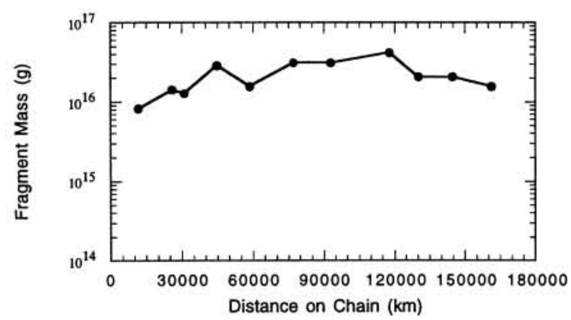


Figure 2. Derived masses of progenitor comets [3] for crater chains on Callisto and Ganymede as a function of the number of fragments in each chain.