DOUBLE AND MULTIPLE CRATERS ON THE SATELLITES OF SATURN AND THEIR SIZE DISTRIBUTION.

R. J. Wagner[1], G. Neukum[2] and N. Schmedemann[2]. [1]DLR, Institute of Planetary Research, Berlin, Germany (Email: roland.wagner@dlr.de), [2]Institute of Geosciences, Freie Universitaet Berlin, Germany.

Introduction: Double and multiple craters can be identified on the terrestrial planets and on the icy satellites of Jupiter and Saturn. These crater clusters were formed by the nearly simultaneous impacts of two or more projectiles [1][2][3]. On, e.g., Earth and Venus, about 10 – 15% of the larger craters are double craters [2]. On the Galilean satellites Callisto and Ganymede, prominent crater chains were formed by the impact of cometary fragments [2, and ref's therein]. Double craters, clusters and chains can also be observed on some of the satellites of Saturn, e.g., Enceladus and Dione [4]. In this paper, we (1) discuss morphologic types of multiple impact craters, (2) determine the size distribution of craters inside and outside of these clusters, (3) use crater scaling to recalculate the sizes of craters formed by a single impactor prior to its splitting or disintegration, and (4) derive the crater distribution as if it was formed by single projectiles only.

Modes of origin of multiple craters: Doublet craters, chains and clusters can form in the following cases: (1) impacts of projectiles created by the break-up of a weak larger projectile (e.g., a "rubble pile") by tidal forces when encountering a planet [1][2][3]; (2) impacts of mutually orbiting bodies of similar sizes, or of a larger body orbited by a smaller one (e.g., an asteroid moon) [3][5]; (3) in the satellite systems of Jupiter or Saturn, *sesquinaries* can be created by material impact-ejected from one satellite and impacting on another satellite [6].

Identification: Double or multiple craters can be identified by two major properties: (1) Individual craters in a group of two or more craters have common rims, indicating they may have been formed by a cluster of projectiles. (2) Craters in a cluster are characterized by a similar morphology and degradational state. However, attributing clusters of craters to an impact of a cluster of projectiles also has a considerable degree of uncertainty: (a) double or multiple craters, even with common rims, can represent chance associations of craters formed actually in different impact events [e.g., 2]. (b) On the other hand, craters separated by tens or hundreds of kilometers may have been formed in the same impact event by a cluster of widely separated projectiles. On Earth, the most prominent examples are the associated Ries and Steinheim craters in southern Germany formed some 16 m.y. ago. On the icy satellites of Jupiter and Saturn, distant craters of similar morphology and sizes could represent similar cases (e.g., Lofn and Heimdall on Callisto, or Tiburtus and Mezentius on Dione [4]). (c) Especially at smaller sizes (< 1 km), crater clusters can represent secondary craters. To distinguish between secondary and primary clusters, the geologic context has to be taken into account (e.g., proximity of a larger impact feature which might be a source crater of secondaries).

Morphologic classes: On the icy satellites of Saturn, we identified the following morphologic classes of multiple craters in Cassini ISS images [4]: (1) classic *double craters*, representing the most abundant type of multiple craters on these bodies (*Fig. 1*). In most cases these forms have common crater rims. However, as noted above, some forms with similar morphology, degradation state and size could have been formed in different impact events but were included in this class, despite their association with the same impact event remains uncertain. (2) Linear *crater chains* contain craters of more or less similar sizes and occur in various length regimes (kilometers to hundreds of kilometers) (*Fig. 1*). In most cases they share common crater rims, but chains with individually separated members can also be observed. (3) *Multiple craters* occur less on the satellites of Saturn. Indicators for a common origin of such crater forms are common rims, similar morphology and shape inferring a similar impact angle [4].

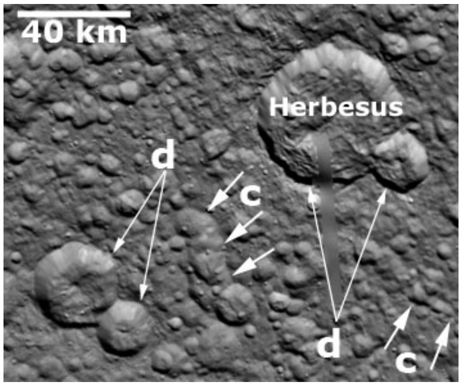

Figure 1. Type examples of double craters and linear chains on the Saturnian satellite Dione: double craters (d), linear chains (c).

Crater size distributions in geologic units with double and multiple craters: Under the assumption that multiple craters originated from a cluster of impactors derived from a former unsplit projectile, we investigated how measuring of craters in a cluster as if each crater was formed in a separate impact event could influence the shape of a distribution and possibly the determination of surface ages in a given geologic unit. A test area of heavily cratered terrain (unit HCT) on Enceladus west of Samarkand Sulcus (lat. 17-72° N and long. 340-35° W) was selected. A detail of this area is shown in *Fig. 2*. Areas with double or multiple craters were mapped, and the craters in each cluster were counted individually. Then, a crater scaling law used by Zahnle and others [7] was applied to each crater in a specific cluster to derive the projectile mass of the unsplit projectile and to recalculate the crater diameter created by un unsplit impactor.

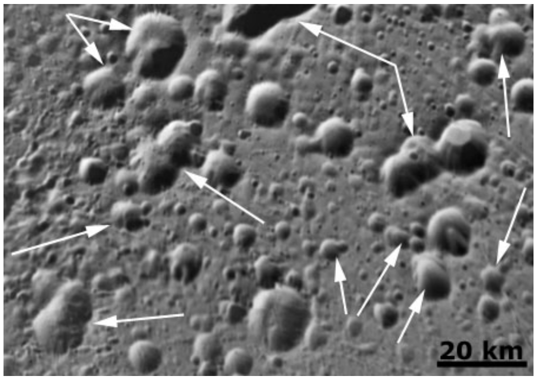

Figure 2: Detail of a test area selected on Enceladus to measure the crater size distribution with several double and multiple craters (arrows).

Results: In *Figure 3* the two cases described above are compared for the case of preferentially rocky impactors captured into planetocentric orbits about Saturn, as described by [8]. The black dots represent the distribution measured from each individual crater in a cluster and all craters outside the clusters. For the distribution shown in red dots, the crater diameters as they would have been formed by an unsplit impactor were recalculated for each cluster using a crater scaling law [7] and were then added to the distribution of the craters outside the clusters. The two distributions are identical within the error bars. Double and multiple craters should be mapped as specific units in geologic maps (as, in general, linear crater chains are) but the effect of measuring all craters outside and inside of clusters, regardless if they were formed by split projectiles, apparently has no significant effect on the shape of a distribution and on the extraction of surface ages. The procedure described here will be extended to more impact conditions and test areas on selected Saturnian satellites for further examination.

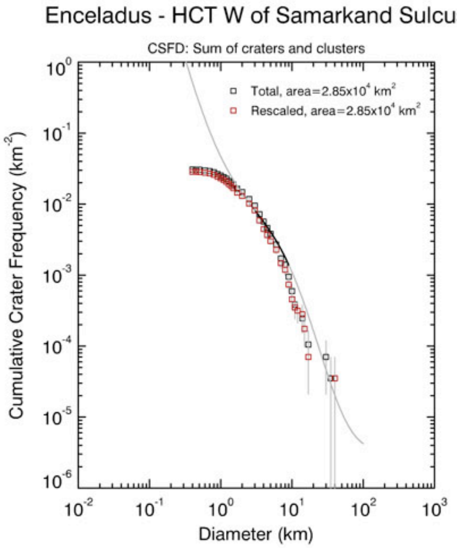

Figure 3: Comparison of the distribution of measured craters, regardless if they are part of a cluster or not (black dots), and of the distribution of craters using the crater diameters in each cluster rescaled to single (unsplit) impactors. The curve shown is the lunar production function transferred to impact conditions on Enceladus [8]. See text for details.

References: [1] Sekiguchi N. (1970) *The Moon, Vol.1, No. 4*, p. 429-439. [2] Bottke W. F. and Melosh H. J. (1996) *Icarus, 124*, 372-391. [3] Schenk P. M. et al. (2004) in: *Jupiter* (F. Bagenal, T. E. Dowling, and W. B. McKinnon, eds.), p. 427-456, Cambridge Univ. Press, U.K. [4] Wagner R. J. et al. (2010) *EPSC Abstr., Vol. 5*, abstr. No. EPSC2010-676. [5] Boehnhardt H. (2004) in: *Comets II* (M. C. Festou, H. U. Keller, and H. A. Weaver, eds.), p. 301-316, Univ. of Arizona Press, Tucson, Az. [6] Zahnle K. J. et al. (2008) *Icarus, 194*, 660-674. [7] Zahnle K. et al. (2003) *Icarus, 163,* 263-289. [8] Neukum G. et al. (2006) *EPSC Abstr., Vol. 1*, abstr. No. EPSC2010-610.

Acknowledgments: This work was financially supported by the German Space Agency (DLR) in the context of the Cassini ISS project.