CRATERING ON GANYMEDE & CALLISTO: COMPARISONS WITH THE TERRESTRIAL PLANETS: S. K. Croft, Lunar and Planetary Institute, 3303 NASA Road 1, Houston, TX 77058.

The suite of impact craters and basins on Ganymede and Callisto comprise a complementary data set to the suites of craters on the Moon and Mercury: crustal structures and compositions on the Moon and Mercury are similar but their gravities are different, whereas the icy compositions of Ganymede and Callisto are different from the rocky crust of the Moon but their surface gravities are about the same (1). A continuous structural sequence of morphology and morphometry of craters and basins on the terrestrial planets has been proposed (2, 3) which provides an inductive approach to the interpretation of the structures of the largest basins. Craters and basins on Ganymede can be placed in a similar continuous sequence: all craters smaller than ~5 km in diameter are bowl-shaped simple craters (SC's). Craters between ~5 km and ~35 km are either flat floored or have central peaks typical of complex impact craters (CXC's) on the Moon. Pits begin to appear in the central peaks of the complex craters at ~15 km and are universal in craters larger than ~35 km (4). Craters with pits are referred to as Pit Craters (PC's). The variation of pit diameter with rim diameter is shown in fig. 1 for fresh pit craters. Pit morphology changes with increasing rim diameters from pits in large central peaks at ~40 km, to complex crater-like structures at ~70 km to collapse caldera-like pits above ~90 km. Pit floors are generally gently domed, consisting of a bright upraised central spot and a dark annular depression. Overlapping the upper diameter end of the PC's (fig. 1) is a small group of distinctive craters called Pit Basins (PB's), whose central structures are ring-like ridges nearly twice the diameter of pits in PC's of similar rim diameter, around a bright, domed central spot. Rims and ejecta blankets of PB's and large PC's are identical. Still larger craters (>130 km) have central rings of massif-like peaks surrounding the central domed spot that are similar to the peak rings in lunar basins like Schrödinger, and are classified as Peak Ring Basins (PRB's). The ring-rim diameter relation in Ganymede PRB's parallel the relations shown in fig. 1 for basins on the terrestrial planets, but are distinctly different than the rim-pit diameter relation, implying that pits and peak rings are structurally unrelated. Another small group of distinct craters has been classified as Anomalous Pit Craters (APC's) in fig. 1. These craters resemble PB's in having a large central dome surrounded by a ring ridge or peak ring, but are much smaller than PB's in diameter. Examples of these craters range in apparent age from very old to very fresh (one on Callisto is rayed), and thus are apparently not thermally relaxed pit craters. Their dimensional relation seems to follow a downward extrapolation of the ring-peak relation.

The peak rings of Ganymedan PRB's become increasingly broad and chaotic with increasing rim diameter. As seen in fig. 2, the PRB's data are fairly dense through ~300 km in diameter. The next larger structure is the Gilgamesh basin, which consists of a circular central plain surrounded by a ring of massive peaks, a vague ring of smaller peaks, and a broad annular zone of blocky terrain. The annular zone is bounded by a scarp (diameter ~576 km) that breaks into individual peaks in some sections. This scarp forms the inner boundary of a radially textured ejecta blanket that breaks into discontinuous secondary crater chains. There are two additional weak scarp-to-graben-like rings beyond the main scarp within the ejecta blanket that can be traced completely around the sunlit portion of the basin. Extrapolation of the morphology of the PR basins to Gilgamesh's size would correlate the main bounding scarp with the main rim of the PRB's and the inner rings of peaks.
with the peak rings. The central plain is thus the central spot of Gilgamesh, not the crater proper as has been implied (5). Both the extent of the continuous ejecta blanket and the size of the largest secondary craters of Gilgamesh in comparison with the PRB's is consistent with the identification of the main scarp as the structural rim. The inferred ring-rim dimensional relations are seen in fig. 2 to follow the trend of smaller Ganymedan basins relative to basins on the terrestrial planets.

The craters on Callisto exhibited similar morphologies in diameter ranges similar to those on Ganymede, though the SC-CXC transition could not be accurately determined due to the poorer resolution of the Callisto images. As seen in fig. 1, the mean pit and anomalous pit diameters on Callisto are slightly smaller at a given diameter than on Ganymede. The few basins between 100 and 200 km in diameter are poorly photographed, but their rim and ring structures appear more ridge-like than their counterparts on Ganymede. A structural interpretation of the Valhalla basin is suggested by a) extrapolation of the morphologies of smaller basins on Callisto and Ganymede, b) the suggestion of a thin crust at the time of formation, c) basin formation models (3), and d) impact experiments in thin ice plates (6): the central bright spot (D≈700 km) corresponds to the cavity of excavation subsequently filled with liquid or plastic material. No peak ring structure is visible because peak ring materials originate at depth which on Callisto were liquid at the time of impact. The adjoining zone of ridges (7, 8) is a thin-crust equivalent of the zone of blocky terrain at Gilgamesh that extends to the inner edge of the remnants of the radial ejecta blanket. By analogy with Gilgamesh, the inner edge of the ejecta blanket is the tectonic crater rim (D≈1300 km). The ejecta thins with increasing range, slowly exposing the older crater population (1) and is broken by graben-like and outward facing scarps (7, 8) that formed beyond the strength crater (6). The inferred excavation crater (slightly larger than the peak ring (3)) and rim diameters are not inconsistent with extrapolation of the Main Rims curve in fig. 2.

The morphological sequence on Ganymede parallels the sequence on the terrestrial planets with a few exceptions: a) central pits are far more common (9); b) Central Peak Basins (10) do not exist on Ganymede, their sequence position being occupied by the Pit Basin; c) ring and rim structures are broader and more chaotic, and d) the central regions of icy basins are low bright domes with dark annuli. It is suggested that these differences may be explained by the low internal energy required to melt ice compared to the energy required to melt rock, and the apparently greater tendency of ice to fracture (6). The melt zone in an icy impact is large, hence materials forming central structures on rocky worlds would be melted on icy worlds, leaving central melt lakes (the pits and central spots). The similar morphologies of rims and ejecta blankets and morphometries of ring and rim structures on rocky and icy worlds suggest that impact mechanics and crater modification are the same away from the central melted region: i.e., ice simply acts as weak rock during crater formation and the presence of large amounts of melt does not significantly alter the cratering process. The correspondence is further shown by the preliminary depth/diameter data shown in fig. 3 in comparison with mean depth/diameter curves on the rocky planets. The depths of craters on Ganymede and Callisto appear intermediate between crater depths on Earth and Mars. The SC-CXC transition diameter on Ganymede is also intermediate between that of Earth and Mars. These data are consistent with a collapse stage of crater modification associated with the SC-CXC transition (3), and suggest that the shallow depths of the Ganymede craters and basins are the direct result of the modification stage and not necessarily due to thermal relaxation (4).
Thermal relaxation may be responsible for the apparent decline in crater depth at diameters above ~100 km in fig. 3, but the decline may be illusory because most of the depths indicated are the heights of the outer scarps of PR basins, and hence are lower limits on the total basin depths. Many palimpsestsb (1, 4, 5) show definite basin structure, and with vertical topography not unlike that expected for fresh terrestrial basins in rock (cf. fig. 3). In view of a) the lack of experimental data on the long-term creep properties of ice at ~1600 K, b) the unevaluated effects of crater degradation on icy crusts, and c) the possibility that the shallow depths of basins on Ganymede may be pristine, it is premature to ascribe all unusual crater statistics or crater structures (including palimpsest lacking definite basin features) to thermal relaxation.

**Figure 1:** Pit-, Peak Ring -Rim Diameter relations for crater and basin morphological classes on Ganymede & Callisto.

**Figure 2:** Comparison of Peak- and Multi-Ring morphometrical relations for basins on Ganymede & the terrestrial planets.

**Figure 3:** very preliminary depth- rim diameter relations for craters on Ganymede & Callisto compared with mean relations on the terrestrial planets.