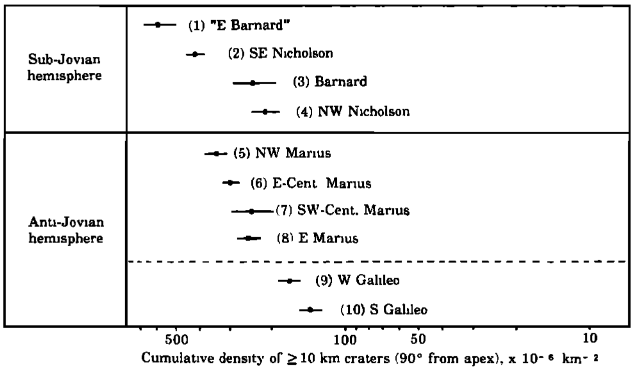

Fig. 5. Cumulative densities of craters 10 km or greater in diameter on separate dark terrain surfaces. Densities have been normalized to a corresponding density 90° from the apex of orbital motion, assuming $\delta=1.5$.

observed surface was predominantly heliocentric, as was inferred above, then it must also have affected the inner solar system due to perturbation of projectile orbits by the gravity of Jupiter [cf. *McKinnon and Parmentier*, 1986]. The lack of an apparent imprint of Ganymede-Callisto impactors in the inner solar system could be explained if it was "overprinted" by a younger bombardment largely restricted to the inner solar system. Such a distinct inner solar system population is consistent with recent analysis by *Strom* [1988, 1989] of possible orbital evolution of impactors participating in the late heavy bombardment of the inner solar system. If this analysis is correct, then the age of the heavily cratered lunar highlands (3.8-4.0 Ga) may be viewed as a lower limit to the true surface age of heavily cratered Ganymedean surfaces including dark terrain.

In addition to determination of surface ages, crater size-frequency distributions provide the basis for inferring aspects of the history of dark terrain resurfacing. Specifically, the thickness of a shallow layer of resurfacing material may be estimated from the rim height of the largest crater size class whose density was depleted by superposition of the layer (i.e., the largest crater size class that was widely buried). Two relationships of crater rim height to crater diameter may be employed for this purpose. The first is that determined by *Pike* [1981] for fresh craters on the moon, whose gravity approximates that of Ganymede. The second relationship is that determined by *Passey* [1983] for younger Ganymedean craters using the technique of photoclinometry. The latter relationship yields a rim height two-thirds smaller for a crater of a given size, consistent with the shallower depths of craters on icy than rocky bodies documented by *Croft* [1981] and *Schenk* [1989]. However, *Woronow et al.* [1982] and *Murchie et al.* [1989*b*] showed that the density of small craters in light terrain has been depleted by shallow light material resurfacing, so that many exposed craters are likely to be partly infilled. In this case, Passey's relationship probably yields minimum rim heights for fresh craters. The actual thickness of some shallow layer of resurfacing material may thus be bracketed by employing both relationships of crater rim height to crater diameter.

Testing of Models of Furrow Origin

A list was compiled of nine new and previously proposed models of furrow origin which are consistent with three basic assumptions about Ganymede's state of evolution at about 4 Ga, at the time when dark terrain is generally believed to have formed. First, the satellite was rotating synchronously long before that time [*Peale*, 1977], so that tidal despinning at that time could not directly have been the genetic mechanism of furrows. Second, accretional melt should have solidified before that time [*Reynolds and Cassen*, 1979; *Kirk and Stevenson*, 1987]. Nonsynchronous rotation of a decoupled lithosphere, as proposed for Europa by *Helfenstein and Parmentier* [1985], is therefore unlikely to have been important in furrow formation unless the satellite underwent deep melting long after accretion (a "second differentiation") [e.g., *Friedson and Stevenson*, 1983; *Mueller and McKinnon*, 1988]. Third, the thickness of the mechanical lithosphere at the time of furrow formation is interpreted to have been 6-10 km [*Golombek and Banerdt*, 1986]. With such a thin lithosphere, hemispheric-scale deformation by loading and flexure [*Banerdt et al.*, 1982] would have been unlikely. Predictions of each model about the furrows' morphology, global organization, stratigraphy, and relationship to volcanic and impact features were compared to observational constraints for each furrow system. Each of the nine models is discussed below, and the predictions of each model are illustrated as schematic maps in Figure 6.

Model 1: Impact-generated ring graben (*Figure 6a*). This model, proposed by *McKinnon and Melosh* [1980] and *Melosh* [1982], envisions development of ring graben in response to radially inward drag imposed on the base of the lithosphere by collapse of a transient impact cavity in a low-viscosity mantle. Predicted geologic features and relations include (1) abundant concentric troughs or scarps centered on a degraded impact feature, (2) fewer radial structures, (3) contemporaneous ages of all troughs, and (4) crosscutting of preexisting structures without their complete obliteration, unless trough spacing is significantly less than about two trough widths.

The pervasiveness of impact features on dark terrain suggests that even if furrows are not ring graben systems, smaller systems may be observed around identifiable impact features. One such smaller system, discussed by *Croft* [1985] and *Schenk and McKinnon* [1987], is located southeast of Marius Regio (Figure 7). Segmented, crudely concentric troughs and scarps or ridges surround a 150-km-diameter circular patch that has an albedo slightly higher than that of the surrounding terrain. Such circular albedo patches, termed "palimpsests," are common in dark terrain; they are thought to represent impact structures modified by slow viscous relaxation of their topography [e.g., *Smith et al.*, 1979*a*,*b*; *Phillips and Malin*, 1979; *Passey and Shoemaker*, 1982], prompt collapse of their topography [*Greeley et al.*, 1982], production of abundant melt due to impact heating [*Croft*, 1983; *Murchie*, 1988], or subsequent resurfacing [*Hartmann*, 1984]. In addition, several radially arranged troughs 50-100 km in length occur within the ring system. Conspicuous preexisting groove sets in the western part of the multiringed structure are crosscut by the troughs but are not degraded beyond easy recognition. This multiringed structure is consistent with predictions of the ring graben hypothesis and could serve as the type location of a ring graben system on Ganymede.

Model 2: Fractures due to an impact-generated tsunami (*Figure 6b*). This model assumes a large impact into a very low viscosity mantle capped by a thin crust [*Van Dorn*, 1968; *McKinnon and Melosh*, 1980]. Oscillations of the collapsing cavity would have created a series of outwardly propagating tsunamis, which would have caused alternating radial and concentric tensional stresses in the crust. Predictions of the model include (1) radial and concentric fractures with similar