The only global-scale, clearly endogenic tectonic and volcanic patterns in dark terrain surfaces are the radial arrangement of system II furrows (Figure 17) and the concentration of system I subradial furrows and dark smooth material toward the center of the system (Figures 13 and 16). The dimensions of the concentration of smooth material burying system I furrows suggest an underlying thermal anomaly at least 3000 km in radius; deformation of a similarly sized thermal uplift could explain the origin of furrow system II, which is ≥5000 km in radius. The radial symmetry of the furrows indicates that any uplift was very nearly circular rather than oblong [cf. *Withjack and Scheiner*, 1982].

This evidence suggests the occurrence of a single, circular thermal anomaly and uplift of at least hemispheric scale, during the formation of dark terrain. Neither diapirism, global expansion, nor any recognized type of tidal deformation could produce this organized pattern on such a large scale. However, one-celled mantle convection may be capable of producing such a thermal anomaly and uplift. A cell of order $l = 1$ would possess a single region of warm, upwelling material. *Zebib et al.* [1983] calculated that at progressively higher Rayleigh numbers, the region of warmest material would become progressively offset from the cell's center of mass and would develop into a circular warm layer underlying a portion of the sphere's surface 60°-110° of arc in radius. Thus an initially cold, uniform planetary interior that warmed and convected with a progressively higher Rayleigh number is expected to develop, over a prolonged period, a circular region of anomalously warm mantle. Thermal expansion of the warming body would place its entire surface in tension, but the greatest warming and expansion would occur in the thermally anomalous region, generating a circular, isostatic thermal uplift. Deformation of the resulting dome would be by radial extensional features [cf. *Sleep and Phillips*, 1985], but distal compressional features may not develop because of the global tensional stress. In addition, the region of anomalously warm mantle may be expected to be overlain by thinned lithosphere where volcanism and extensional tectonics could be concentrated.

Occurrence of one-celled convection in Ganymede would imply an upper limit of 700 km (η=0.27) on the radius of any convectively isolated, silicate-rich core [*Zebib et al.*, 1983]. If core-forming material formed by accretional melting was restricted to a thin upper layer of the satellite, only partial melting of an accreting ice-silicate mixture may have occurred because of the high latent heat of melting water ice. In this case, Rayleigh-Taylor unstable, core-forming material would have retained a substantial ice fraction. Accumulation of the core would leave behind a clean, differentiated upper mantle with a thickness of no more than 20 km. In other words, a 1-celled convection pattern would imply differentiation and segregation of a silicate-rich core to be probably less than 2-3% complete.

Description of Paradigm

On the basis of our observations and interpretations about dark terrain geology and the above consideration of convection in a sphere, we propose the following self-consistent model of the early geologic history of Ganymede. The surface and proposed internal structures of the satellite at the end of dark terrain formation are shown schematically in Figure 18.

1. The satellite accreted cool with little melting, resulting in less than 2-3% differentiation and segregation of silicates into a dense core.

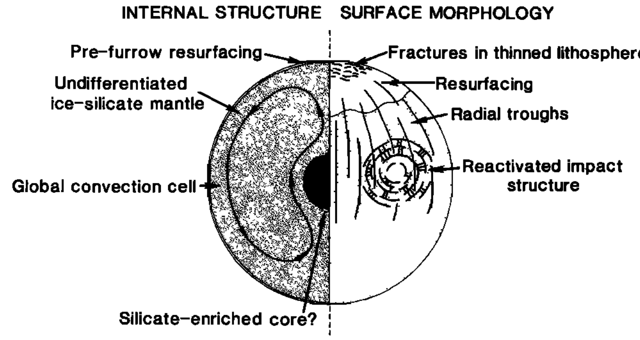

Fig. 18. Schematic representation of major elements of the model of dark terrain history and internal structure of the satellite at the end of furrow formation.

2. As Ganymede warmed internally due to radiogenic and possibly tidal heating, a prolonged period of global expansion and resurfacing began. A global layer of volcanic materials averaging perhaps 3-8 km thick accumulated and buried an ancient, Callisto-like cratered surface. Relatively younger deposits accumulated over a circular mantle thermal anomaly at least 3000 km in radius, centered south of Galileo Regio and east of Marius Regio. This anomaly is proposed to be the site of upwelling of a single, global, axisymmetric convection cell.

3. The long period of resurfacing and global expansion was preceded or punctuated by two very large impacts which created hemispheric-scale, multiringed fracture systems. The fractures served as conduits for eruption of melt and as loci for extensional deformation driven by global expansion. Extensional tectonic and volcanic reactivation of the multiringed fracture systems formed the two large systems of radial and concentric furrows, systems I and III; the most intense fracturing occurred in thinned lithosphere over the upwelling convection current.

4. By at least 3.8-4.0 Ga, a system of radial troughs (system II) at least 5000 km in radius formed by fracturing of an isostatic, thermal uplift over the convective upwelling.

5. Subsequently the tectonic and volcanic styles of Ganymede changed dramatically as the interior warmed further. The Ganymede-Callisto "dichotomy" developed as light material was emplaced and grooved terrain was deformed. Emplacement of light material began first over the convective upwelling.

Discussion of Paradigm

Some aspects of the above paradigm are similar to previously proposed models for the early geologic evolution of Ganymede, including radiogenic warming of a cool interior [*Croft*, 1985, 1986*a*,*b*], emplacement of dark terrain as volcanic flows, and formation of furrows by endogenic tectonism [*Croft and Strom*, 1985; *Croft and Duxbury*, 1987; *Croft et al.*, 1990]. However, four aspects of our paradigm are fundamentally different from other recently published models for Ganymede's internal structure and evolution [e.g., *Friedson and Stevenson*, 1983; *McKinnon and Parmentier*, 1986; *Kirk and Stevenson*, 1987]: accretion of Ganymede in a nearly undifferentiated state; maintenance of this undifferentiated state