late into the satellite's geologic history; endogenic extensional tectonism driven by global thermal expansion; and a stable organization of convection on the scale of a single, global, axisymmetric cell. Each of these aspects of the paradigm is now discussed.

Accretion of an undifferentiated Ganymede. Most models of Ganymede's accretion [e.g., *Schubert et al.*, 1981] assume two fundamental conditions: gas-free accretion, and accreting planetesimals of great enough size that their kinetic energy was deposited as heat at a great enough depth not simply to be radiated into space [cf. *Safronov*, 1978]. For a reasonable partitioning of kinetic energy of accreting planetesimals into heat (20-40%) [*Schubert et al.*, 1981], gas-free accretional models predict accretional temperatures that exceed the melting point of H_2O-ice and that may exceed its boiling point at 1 bar, in at least the outer several hundred kilometers of the satellite. If this accretionally heated region were able to "communicate" with the satellite's surface, gas-free accretion could generate an atmosphere with a partial pressure of H_2O of 10^{-2}-10 bars. Thus the model of gas-free accretion leading to melting and ice-silicate differentiation in the outer portion of Ganymede is probably not self-consistent, and the effects of a thin Ganymedean atmosphere on at least the later stages of accretion should be considered.

An accretionally generated atmosphere would have had a major effect on partitioning of the kinetic energy of accreting planetesimals and therefore on the extent of accretional melting. For example, much of the planetesimals' kinetic energy would have been deposited in the atmosphere; if accretion occurred rapidly, thermal disequilibrium of atmosphere and surface could have led to "cold" accretion of decelerated planetesimals [*Lunine and Stevenson*, 1982]. A Ganymedean atmosphere may also have disrupted accreting icy planetesimals into small fragments, if their material was weak and highly porous, but this possibility has not been assessed quantitatively. *Safronov* [1978] showed that if fragments of high-velocity planetesimals reached the surface of an accreting body at sizes of the order of 1 m or less, then their kinetic energy may have been deposited at shallow enough depth to be radiated into space. In this situation, accretional heating would have been minimal.

Lunine and Stevenson [1982] also modeled the effect on accretional melting of formation of Ganymede within a proto-Jovian nebula. They found that the extent of melting is dependent upon the nebular temperature gradient, which is poorly constrained. They observed that rocklike bulk densities of Io and Europa are consistent with important amounts of water ice having condensed only outside Europa's orbit. They adjusted the nebular temperature gradient so that ice condensation would have begun just inside Ganymede's orbit, and on this basis predicted a warm enough ambient temperature at Ganymede to lead to deep differentiation after accretional heating. However, a nebular temperature gradient consistent with ice condensation having begun at or just outside the orbit of Europa would have led to cool enough ambient temperatures at Ganymede to severely retard accretional melting. This latter temperature regime is not unreasonable in light of the present-day abundance of water ice on Europa as well as on Ganymede an Callisto.

In summary, two supportable statements may be made about the plausibility of accretion of an undifferentiated Ganymede. First, gas-free accretion models which predict melting and ice-silicate differentiation in Ganymede's outer portions are probably not self-consistent. Second, formation of an accretionally generated atmosphere or accretion within a cool portion of the proto-Jovian nebula would have been capable of retarding accretional melting and differentiation.

The state of differentiation of Ganymede's outer layers. Previous workers have used three main observations to support the hypothesis of differentiation of at least the outer portions of Ganymede. However, each of these three observations may be equally or better reconcilable with an undifferentiated interior.

First, the lower crater density in dark terrain than on Callisto has been interpreted to indicate viscous relaxation of ancient topography, driven by the high lithospheric thermal gradient over an initially warm, differentiated upper mantle [e.g., *Passey and Shoemaker*, 1982; *Shoemaker et al.*, 1982; *McKinnon and Parmentier*, 1986]. However, the preferential removal of small- and intermediate-sized craters is better explained by burial by dark volcanic materials.

Second, the albedo and near-infrared spectrum of Ganymede have been interpreted to indicate a >90% water-ice fraction in differentiated, near-surface materials [e.g., *Clark et al.*, 1980, 1986]. Extending an ice-rich interpretation of spectral data to the crust as a whole is unwarranted because reflectance spectroscopy samples only the upper few millimeters of surface material, which has been modified by impact gardening, magnetospheric processes, and ablation and redeposition of volatiles. Beyond this reservation, an ice-rich interpretation of spectral data assumes intimate mixing of surface ice and silicate. *Spencer* [1987*a*] has shown that ablation and redeposition of surface ice would lead to formation of a compositionally segregated surface consisting of frost patches on a silicate-rich lag, on a time scale short compared to that for impact gardening. *Murchie* [1988] observed such a patchwork of frost deposits on a darker substrate in high-resolution Voyager 2 images of the south polar region. The observed albedo and near-infrared spectrum of Ganymede could be produced by a surface possessing a 55% frost cover and 45% lag cover [*Spencer*, 1987*b*]. Additionally, *Roush* [1987] showed that Ganymede's spectral reflectance in the 3-μm wavelength region requires the presence of a substantial silicate fraction in surface materials. Therefore all surface materials may contain a larger silicate fraction than has been thought, and depletion of near-surface silicate by differentiation of at least the outer portion of Ganymede is not required to explain the satellite's observed albedo properties and spectral reflectance.

Third, the higher albedo of some dark terrain craters 50 km or more in diameter has been interpreted to indicate excavation of an upper mantle consisting of nearly clean ice [*Shoemaker et al.*, 1982; *McKinnon and Parmentier*, 1986]. The results of *Spencer* [1987*a,b*] show that the higher albedo of the crater material is not uniquely indicative of a clean-ice composition. Also, the existence of a differentiated upper mantle would imply that all deeply excavated crater ejecta should possess a high albedo. In fact, many impact features 100 km or more in diameter possess ejecta similar in albedo to nearby dark volcanic materials [*Passey and Shoemaker*, 1982; *Murchie*, 1988]. Their low albedo cannot be attributed simply to time-dependent ice darkening processes [cf. *Shoemaker et al.*, 1982], because the ejecta are in some cases superposed on younger, higher-albedo light terrain. *Croft* [1983], *Hartmann* [1984], and *Murchie* [1988] offered alternative explanations for the higher albedo of some deeply excavated ejecta, incorporation of partial melt or clean resurfacing material with