Consistent with the buoyancy arguments described above, their predicted dome heights are only ~5–30 m, far less than the observed heights of typical europan domes.

Although the above analytical studies are valuable, they adopted simplified prescriptions of the dynamics that potentially exclude important effects. To determine whether pit-and-dome-like surface topography can result from the full convective dynamics, *Showman and Han* (2004) performed two-dimensional numerical simulations using a diffusion creep rheology. (We note that use of a non-Newtonian rheology does not modify the fundamental buoyancy argument described above and is unlikely to, by itself, lead to convection-driven resurfacing.) *Showman and Han* (2004) found that, in stagnant-lid convection, ascending and descending plumes have essentially no surface expression — pits and uplifts do not form (see Fig. 3). This results directly from the extremely small temperature contrasts (~10 K) of the ascending and descending plumes. The simulations developed modest surface topography of ~10–30 m, which resulted from long-wavelength lateral variations in the thickness of the stagnant lid rather than from the plumes underlying the lid. *Showman and Han* (2004) found, however, that if the viscosity contrast is $\Delta\eta \sim 10^3$–10^5, then the cold ice at 1–2-km depth deforms enough to participate in the convection ($\Delta\eta$ is small enough that convection occurs in the so-called "sluggish lid" regime), leading to formation of 100–300-m-deep pits over the downwellings. However, none of the simulations produced localized uplifts. The simulated pits range in width from 5 to 100 km depending on the melting-temperature viscosity, thickness of the ice shell, and other properties. Consistent with *Nimmo and Manga* (2002), *Showman and Han* (2004) found that explaining observed pits with diameters of ~5–10 km requires melting-temperature viscosities of ~10^{12} Pa s or less, implying ice grain sizes of ≤0.04 mm. At these viscosities, the maximum heat flux transportable by convection is ~100–150 mW m^{-2}. Explaining pits less than ~4 km in diameter is extremely difficult unless the viscosities are unrealistically small.

Runaway tidal heating in hot convective plumes is sometimes invoked as a mechanism for enhancing the internal temperature contrasts, therefore increasing the amplitude of surface topography. However, *Showman and Han* (2004) pointed out that such runaways, if any (see section 5.2.1), cannot significantly enhance the thermal buoyancy in ascending hot plumes. The mean ice temperature in the convective sublayer is only ~10 K less than the temperature at the bottom of the ice shell, which for Europa is expected to be the ~260-K melting temperature. Even accounting for the pressure-dependence of the melting temperature, this puts a fundamental limit of ~10–20 K on the maximum temperature difference between ascending hot plumes and the background ice through which they rise: Plumes simply cannot be heated to temperatures exceeding the melting temperature. Once a hot plume reaches the melting temperature, any further heating will instead cause partial melting, which would increase the plume's density and therefore *decrease* its thermal buoyancy — lessening the topographic amplitude of any resulting uplifts.

Motivated by the insufficient buoyancy associated with *thermal* density contrasts, several authors have proposed that *compositional* density contrasts are important in generating the large (100–300 m) topography of typical pits and uplifts (*Nimmo et al.,* 2003; *Showman and Han,* 2004; *Pappalardo and Barr,* 2004; *Han and Showman,* 2005). The most plausible scenario for explaining uplifts is one where relatively salt-free (hence low-density) diapirs ascend through a saltier, denser environment. In this case the topography is ~$h\Delta\rho/\rho$, where $\Delta\rho$ is the plume-environment density contrast and h is the height of the plume. For a plume 10 km tall, explaining 300-m-tall uplifts would require a plume/environment density difference of ~30 kg m^{-3}, which could occur if the plume-environment salinity difference were ~5–10% (*Pappalardo and Barr,* 2004), marginally consistent with current estimates of the salinity of Europa's ocean (cf. *McKinnon and Zolensky,* 2003; *Hand and Chyba,* 2007; see also chapter by Zolotov and Kargel). However, as pointed out by *Showman and Han* (2004), it is difficult to understand how strong compositional contrasts can be maintained against mixing if the shell is convecting. Furthermore, any partial melting in the ice would tend to deplete the ice shell of salts (which percolate down into the ocean with the melt), so maintaining such compositional density contrasts over long timescales is difficult (*Showman and Han,* 2004). *Pappalardo and Barr* (2004) proposed that the compositional convection is a transient process that begins with a recent onset of thermal convection and then dies off as the ice shell becomes depleted in salts. If so, then the uplifts would be short-lived and would disappear as the shell became salt-free. However, they also suggested that diking from the base of the ice shell might replenish the shell with salts.

Han and Showman (2005) performed two-dimensional numerical simulations of thermo-compositional convection to test the qualitative scenario of *Pappalardo and Barr* (2004). Because grid-based methods can cause an artificial numerical diffusion of the salinity, *Han and Showman* (2005) treated the salinity using the particle-in-cell method, which allows advection of the salt with essentially no numerical diffusion. Following *Pappalardo and Barr* (2004), they initialized the simulations with a warm salt-poor ice layer underlying a colder, saltier, denser ice layer. In typical simulations, a Rayleigh-Taylor instability developed between the salt-poor and saltier layers, leading to compositionally driven diapirs that generated pits and uplifts with topography of ~300 m or more (see Fig. 4). Because the instability involves the relatively cold near-surface ice, it occurs over a timescale $\eta_0\chi/(g\delta\Delta\rho)$, where η_0 is the melting-temperature viscosity, χ is the assumed viscosity contrast across the ice shell, δ is the thickness of the salty layer, and $\Delta\rho$ is the density difference between the salty and salt-poor layers. This leads to pit-and-uplift formation timescales less than Europa's known surface age of 40–90 m.y. (*Zahnle et*