Simulating Formation of Triton's Cantaloupe Terrain by Compositional Diapirs

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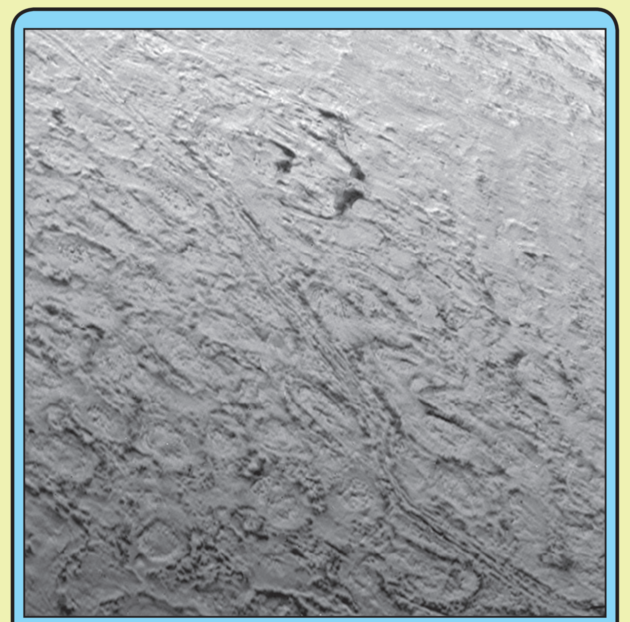
Abstract # 2089

Motivation

Cantaloupe Terrain

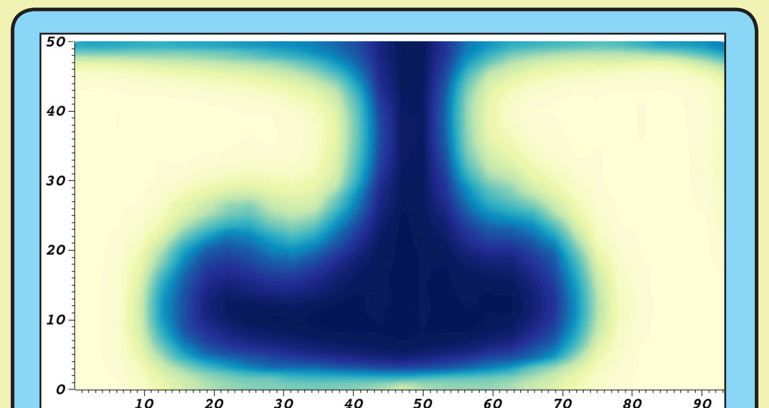
- Up to 35% of observed surface
- Irregular dimples (*cavi*) with interfering structural relationships
- 25-35 km width, smooth floors separating irregular ridges with ~800m relief
- Comparable morphology to terrestrial salt diapir canopies
- Oldest stratigraphic terrain, but almost uncratered[1]



Cantaloupe terrain on Triton from a distance of 40,000 km. Scale of individual cavi is 25-35 km across. Voyager 2 image courtesy NASA/JPL.

Diapir Hypothesis[1]

- Schenk and Jackson (1993): formed by Rayleigh-Taylor instability in a compositionally layered crust
- Overturn driven by density contrast
- Assumed low thermal gradient (<10 K/km), so little contribution from heat
- For likely surface materials, diapirs could form in ~1 Gyr



ASPECT simulation output for a model re-creating the compositional diapir model as formulated by Schenk and Jackson (1993).[1] A dense ($\Delta\rho$ = 640 kg/m^3) overlying layer, originally 20 km thick, sinks and the less dense underlying material rises in a diapir. Material rheologies are uniform.

Challenges

Timing

- Revision of Triton surface age to as low as ~10 Myr[2]

Heat

- Heating from obliquity tides may be significant [3]
- Triton's interior may have a high thermal gradient; convective motion from interior may result in surface yielding[3,4]
- Proposed surface materials have low thermal conductivities, insulating subsurface

Rheology

- Previous Rayleigh-Taylor analysis utilizes isoviscous flow
- Actual surface materials have temperature-dependent viscosities; if thermal gradient is high, surface materials may not deform in manner predicted by R-T

Can we use numerical simulations of Triton's crust to test the diapir formation hypothesis for cantaloupe terrain?

Methods

Model Setup

- 300 km thick ice shell, 240 K NH_3-rich ocean (per Nimmo and Spencer, 2014)[3]
- Dense overlying layer composed of pure CO_2 or ammonia dihydrate (ADH), 5-20 km thick[1]
- Newtonian, temperature-dependent rheology[3,5]
- Implemented as custom material model in ASPECT (Advanced Solver for Problems in Earth's ConvecTion)[6]

Regional Simulations

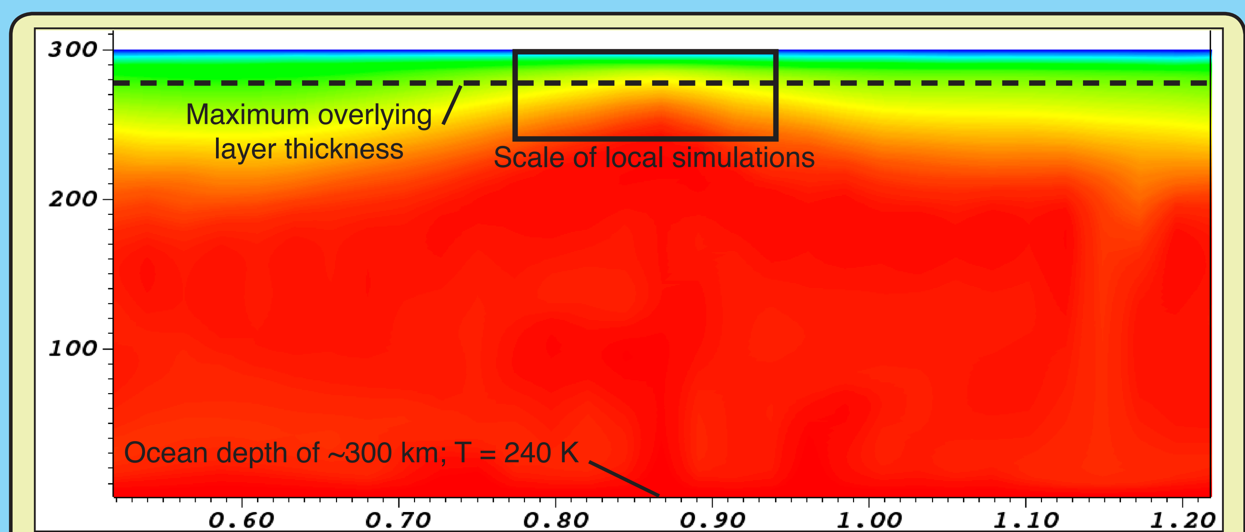
- Used to set temperature boundary conditions for near surface
- Overlying layers insulate but do not participate in flow

Variables

- Thickness and composition of overlying layer

Outputs

- Scale of crustal upwellings and temperature at ~50 km depth



Local Simulations

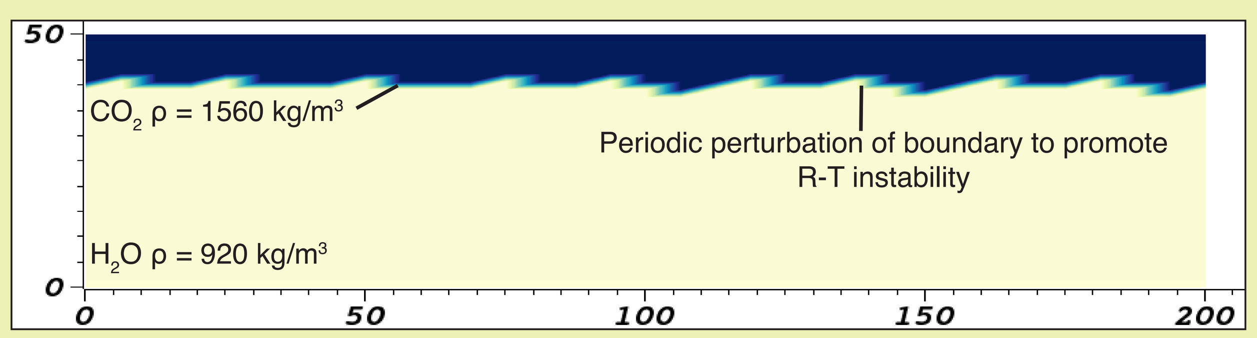
- Used to observe deformation or possible diapir formation
- Overlying layers modeled with full rheology

Variables

- Thickness and composition of overlying layer
- Temperature at bottom boundary

Outputs

- Behavior of and stress within overlying layer



Initial conditions of a representative local simulation model run. The top 10 km of the model are a compositional field with the density and rheological material parameters of CO_2; the bottom layer is water ice. The top boundary is set to 40 K, while the bottom is heated according to a range of temperatures set by the regional simulation.

References

[1] Schenk, P., and Jackson, M. (1993) *Geology, 21*, 299-392. [2] Schenk, P., and Zahnle, K. (2007) *Icarus, 192*, 135-149. [3] Nimmo, F., and Spencer, J. (2014) *Icarus, 246,* 2-10. [4] Ruiz, J. (2003) *Icarus, 166,* 436-439. [5] Durham, W., et al. (2010) *Space Science Reviews, 153,* 273-298. [6] Kronblicher, M. et al. (2012) *Geophysics J. Intl., 191,* 12-29.

Results

Regional Simulation Results

Temperatures @ 50 km depth

- CO_2 T range: 180-230 K
- ADH T range: 160-180 K

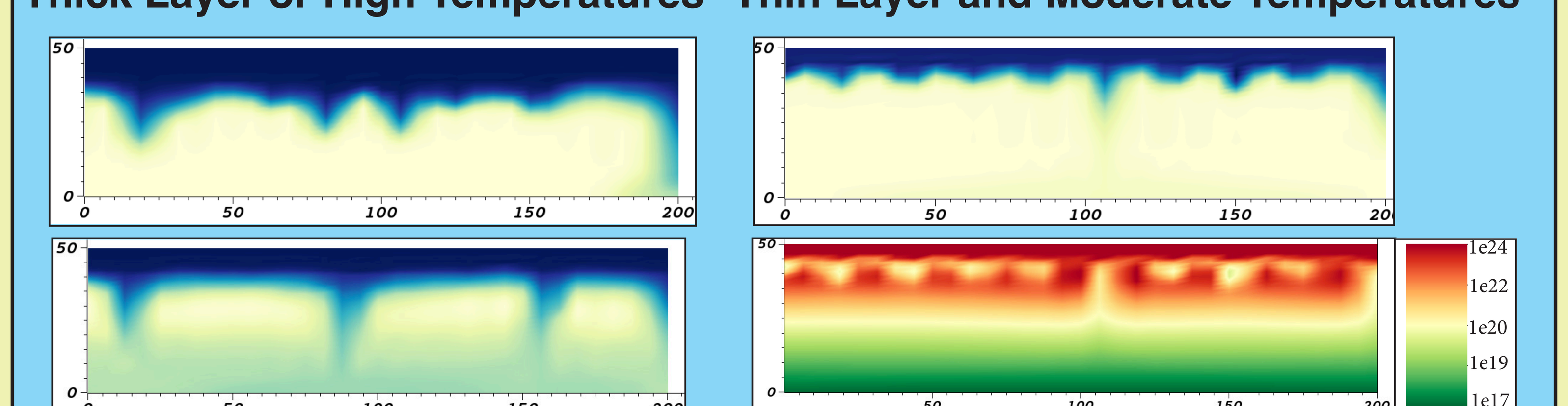
Convective behavior

- Thicker surface layers create more organized and stable convection cells
- Below ~15 km, convection cell centers begin to migrate on Myr timescales

Local Simulation Results

- **No stable diapirs form under any model setup**
- Viscosity differentials impede upward buoyant flow
- No ADH setup warm enough to deform; CO_2 deformation requires base temperatures >200 K (near center of convection cells)
- Up to 7 order of magnitude viscosity contrast across domain
- 10 K/km thermal gradient in near surface
- Above critical temperature, base of thick layers rapidly delaminate
- CO_2 downwellings concentrate differential stress up to 4 MPa

Thick Layer or High Temperatures | **Thin Layer and Moderate Temperatures**

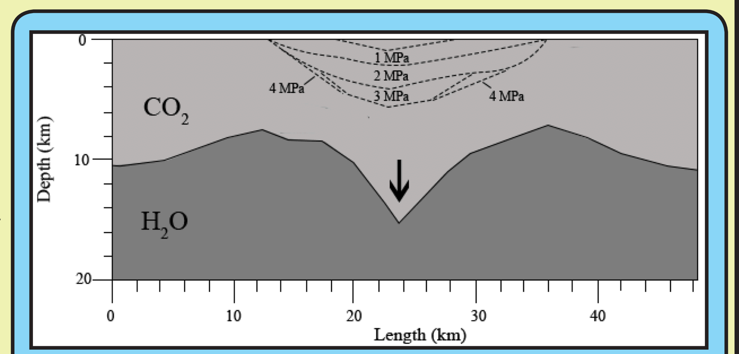


Top: 20 km thick layer of CO_2, bottom T = 210 K. *Bottom:* After ~10 Myr, layer collapses and thins.

Top: 10 km thick layer of CO_2, bottom T = 210 K. *Bottom:* Viscosity profile of above.

Takeaway Messages

- Schenk & Jackson diapir model **does not work** w/ updated heat and rheology
- No combination of plausible crustal layerings formed diapirs that can directly create cavi
- Thick (>10 km) CO_2 layers in crust may promote fracture above downwellings



Schematic diagram of differential stress magnitudes within a 10 km-thick layer of CO_2 ice above an incipient downwelling. Ice within 4 km of the surface experiences stress well above its yield strength, implying substantial fracture of surface materials above any such a feature.

- **Subsequent sublimation/scarp retreat of surface materials may form cavi and help redistribute volatiles across surface**
- **Mobile convection cells may continually modify surface if crust is rich in CO_2, resulting in low mean surface age**

This work was funded by a Graduate Student Fellowship from ILLINOIS SPACE GRANT CONSORTIUM