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Advanced School on Scaling Laws in Geophysics: Mechanical and Thermal Processes in Geodynamics

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DEEP CONVECTION II
(Compressible Mantle Convection)

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Compressible mantle convection

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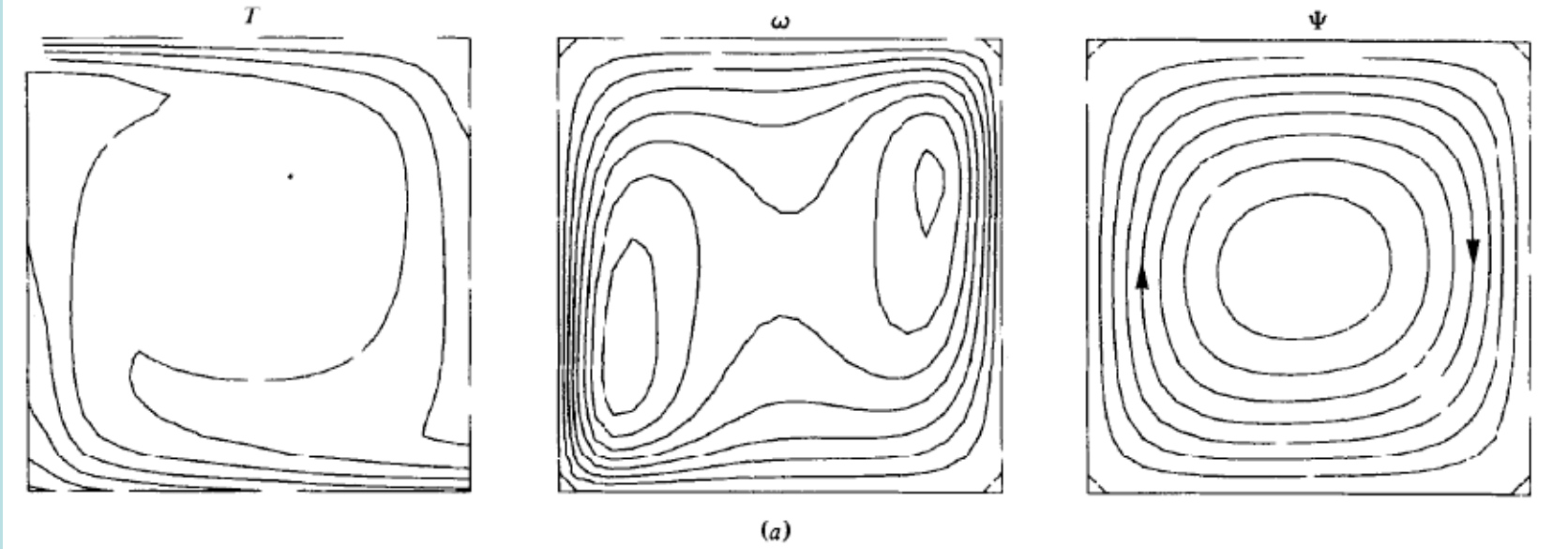
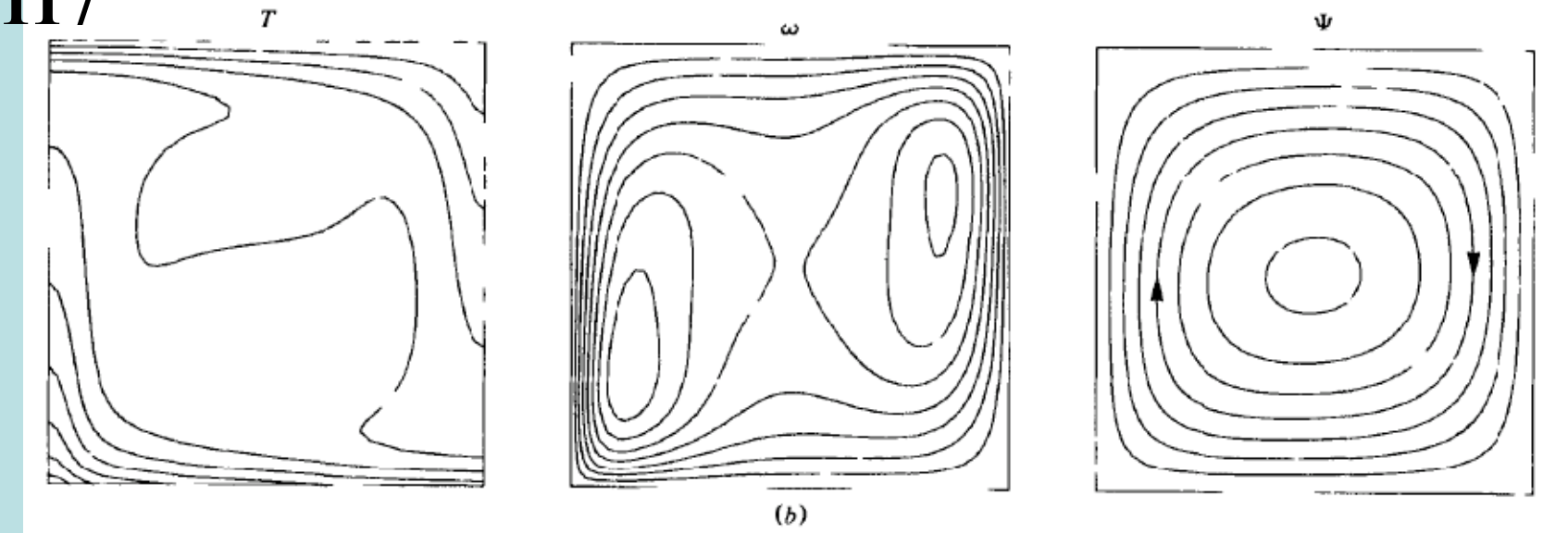
Compressible convection with different Di (Jarvis and McKenzie, 1981)

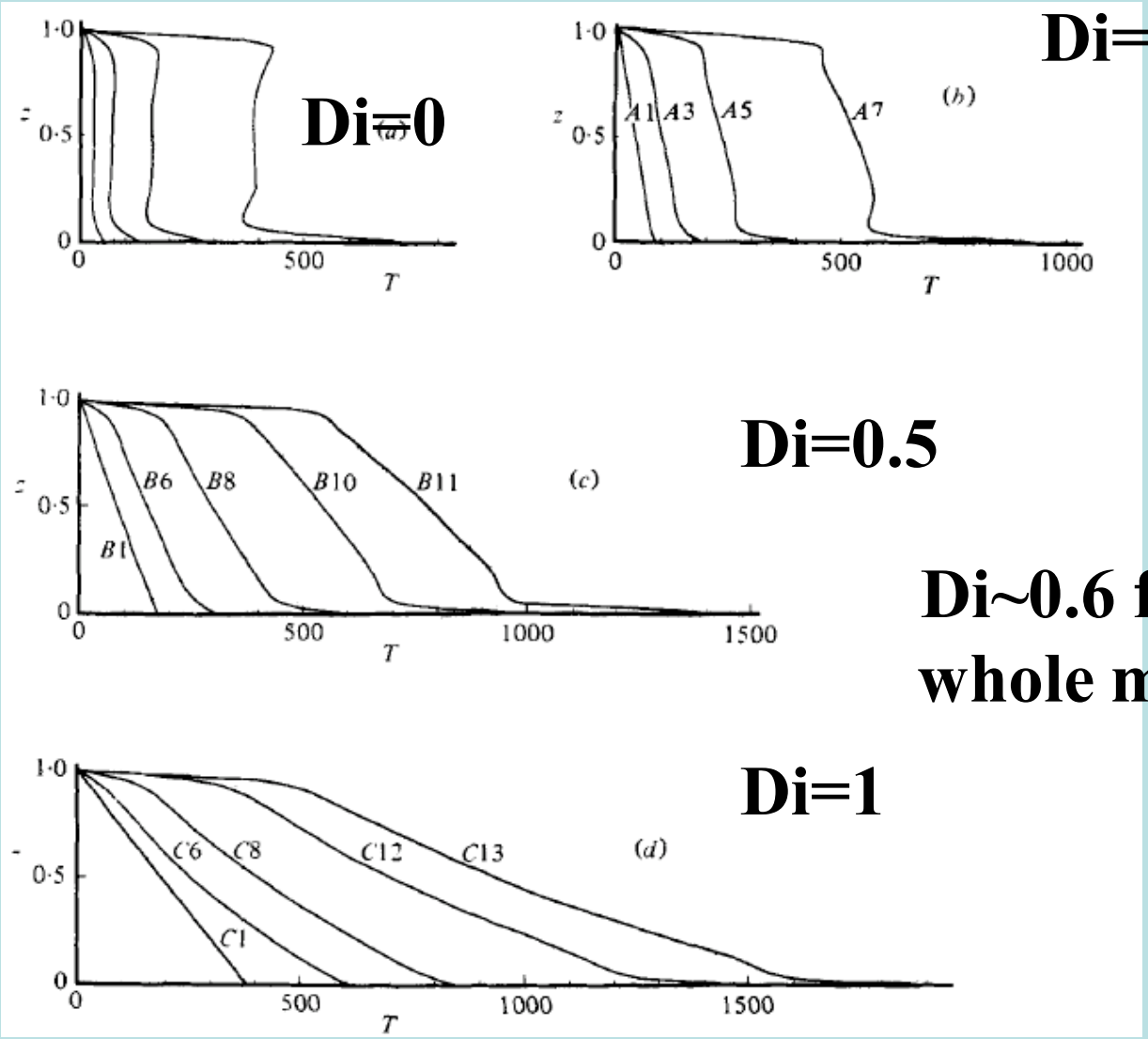
Di=0



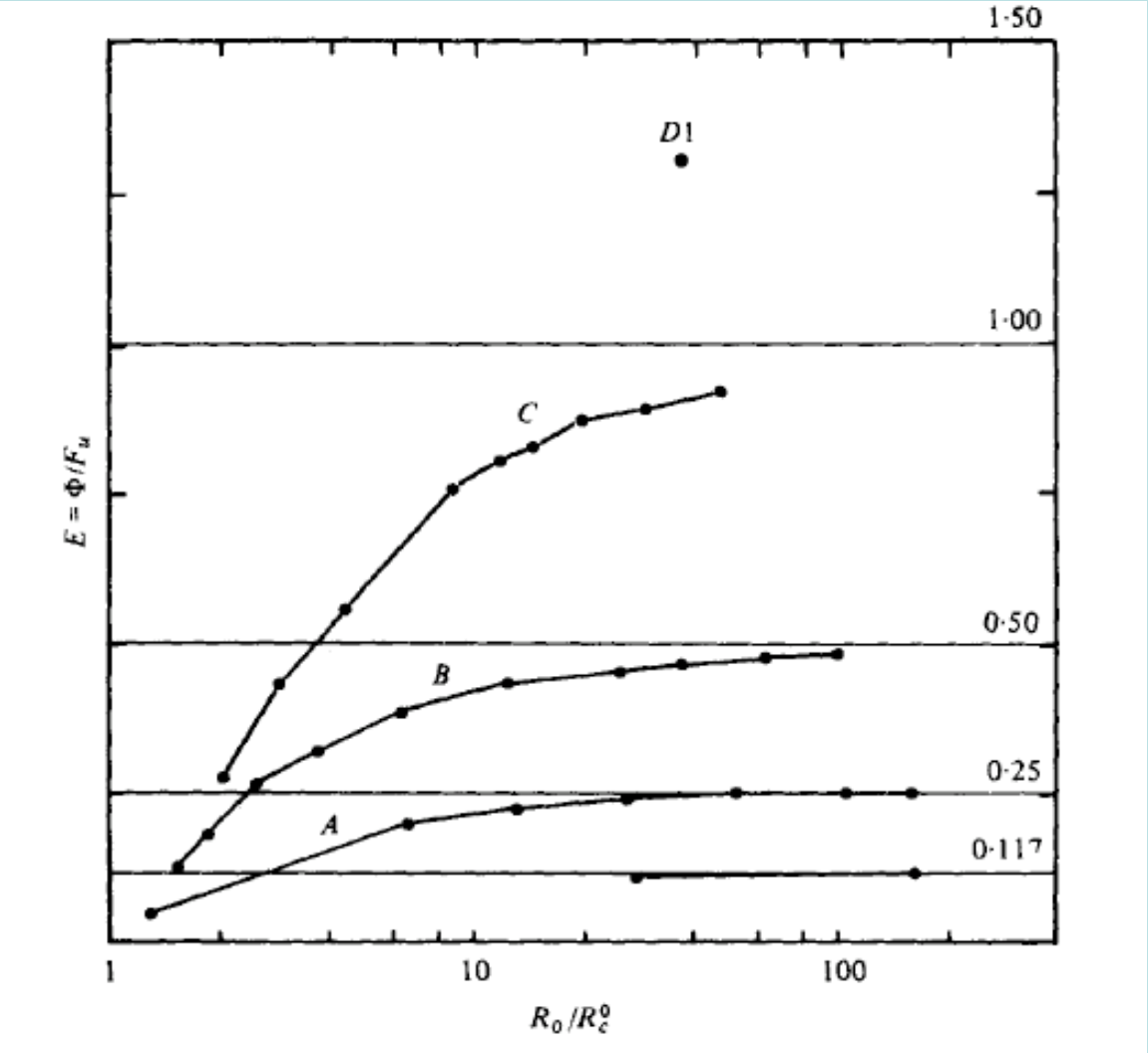
Di=0.117



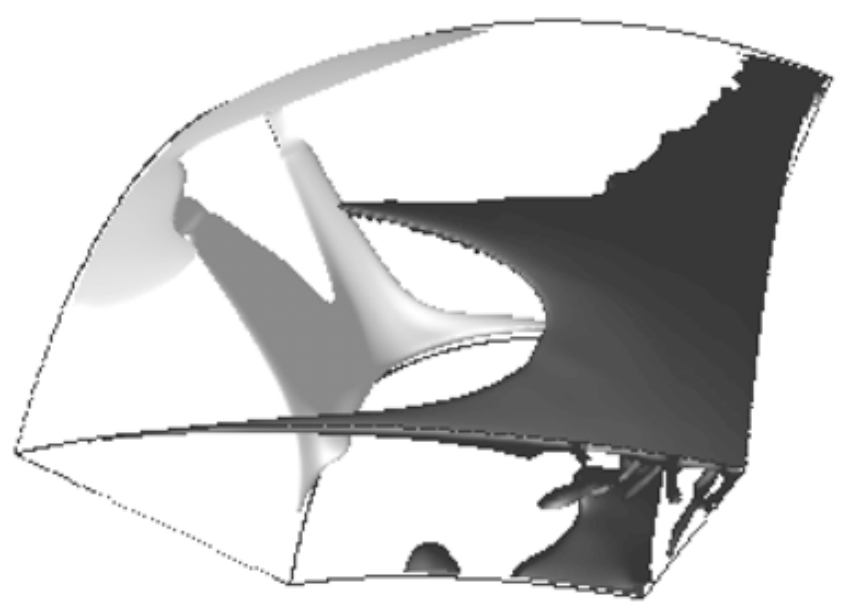
Di's effect on Tave



$\Phi/Fs = Di$ for large Ra and basal heating convection (Hewitt et al., 1975)



Effect of adiabatic heating/cooling on plume excess temperature and plume buoyancy flux



As plumes rise, they cool due to adiabatic cooling effect (expanding at smaller pressure).

How does it affect plume dynamics?

Adiabatic temperature gradient and temperature (Leng and Zhong, JGR, 2008)

$$\frac{dT_{ave}}{dr} = -\frac{\alpha g T_{ave}}{C_p},$$

$$\frac{dT_{ave}}{dr} = -\gamma D_i (T_{ave} + T_s),$$

$$D_i = \frac{\alpha_0 g d}{C_p}, \quad \gamma = R_e / d$$

$$T_{ave} + T_s = A e^{-\gamma D_i r},$$

For plumes:

$$\frac{dT_p}{dr} = -\frac{\alpha g T_p}{C_p}.$$

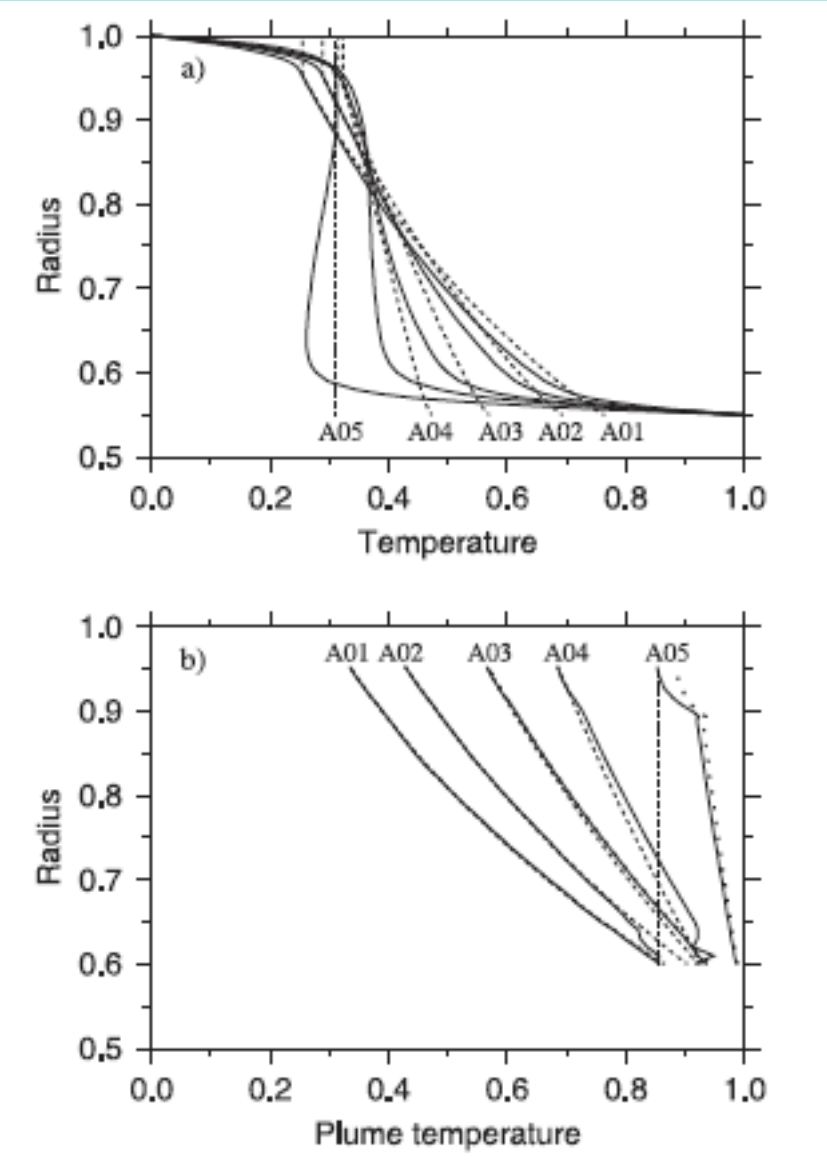
$$T_p + T_s = B e^{-\gamma D_i r},$$

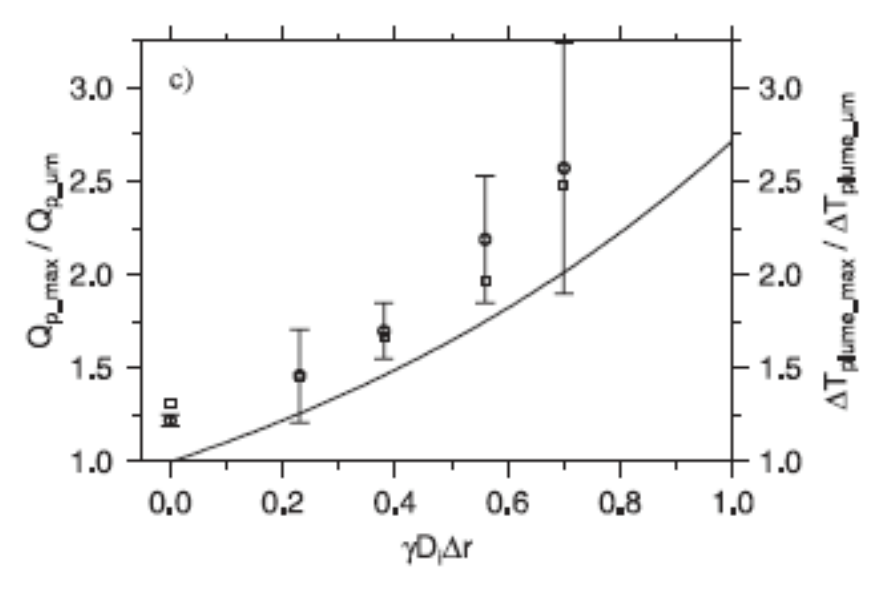
$$\Delta T_{plume} = T_p - T_{ave} = (B - A) e^{-\gamma D_i r}.$$

$$\frac{\Delta T_{plume}(r_1)}{\Delta T_{plume}(r_2)} = e^{\gamma D_i (r_2 - r_1)}.$$

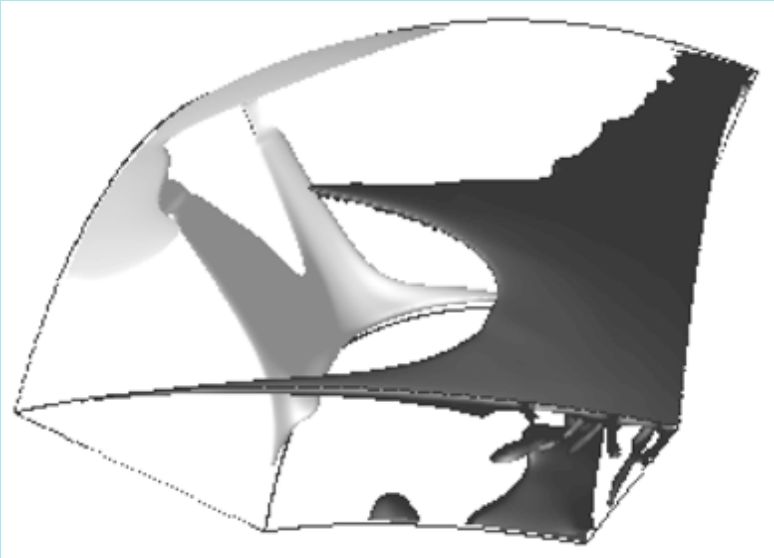
$$\frac{Q(r_1)}{Q(r_2)} = e^{\gamma D_i (r_2 - r_1)}.$$

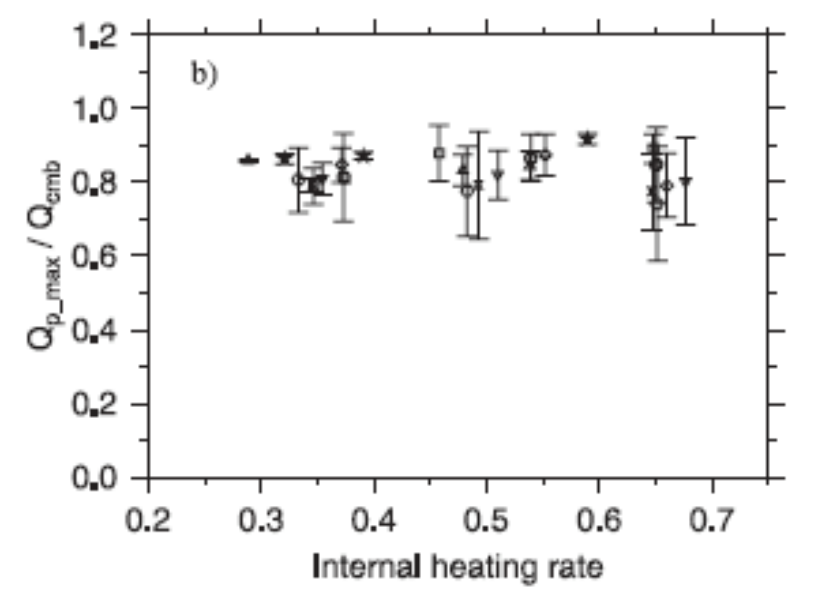
Effect of adiabatic heating/cooling on plume excess temperature and plume buoyancy flux

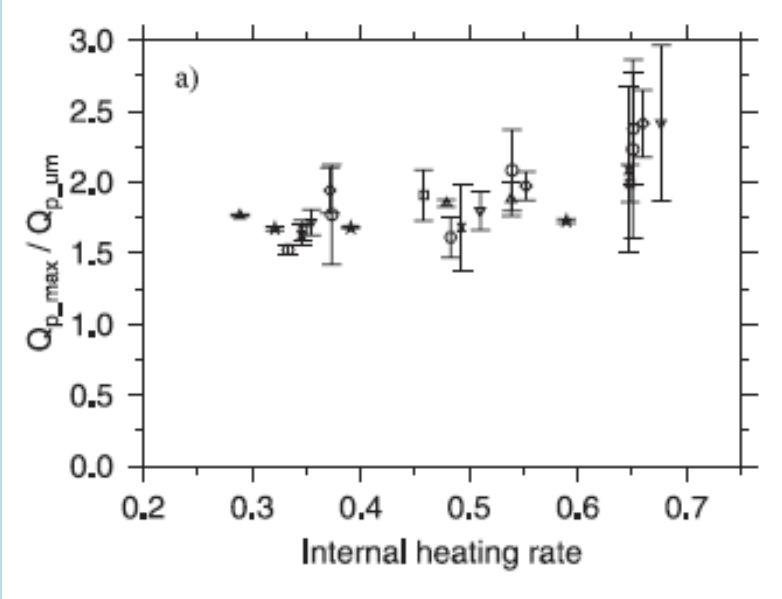




Plume buoyancy flux = CMB heat flux?







Conclusion

- Compressible mantle convection may be important for plume dynamics for the Earth.
- Pressure-dependent buoyancy is important for balancing the viscous dissipation and adiabatic heating.
- $\Phi/Fs = Di(1-1/2\xi)$ for large Ra.