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What is "delamination"?

Form of convective removal

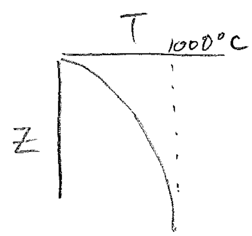
convection = advection driven by ρ contrasts
e.g. buoyancy forces (g is necessary)

$\Delta\rho$ can be compositional (chemical convection)
or thermal, e.g. $\frac{\Delta\rho}{\rho} = -\alpha\Delta T$ (thermal convection)

Magnitude of buoyancy forces

compositional
eclogite 3400 kg/m^3
peridotite 3300 kg/m^3 $\frac{\Delta\rho}{\rho} \sim 3\%$

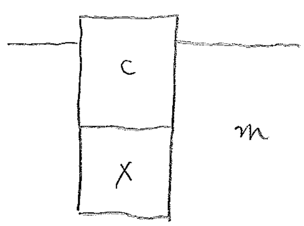
thermal
consider a TBL



$\Delta T \sim 500°C$
$\alpha = 3\times10^{-5}/°C$

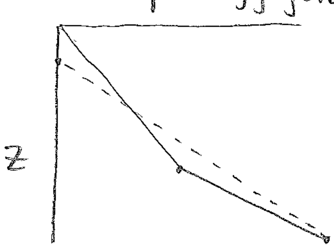
$\frac{\Delta\rho}{\rho} \sim 1.5\%$

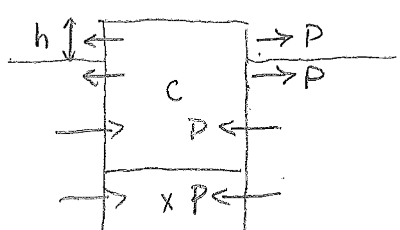
So why are ρ (hi ρ) things negatively buoyant?



consider a crustal column made of felsic crust c and eclogite crust x
with $\rho_c < \rho_m$ (mantle)
but $\rho_x > \rho_m > \rho_c$

$P = \int \rho g dz$





- note that upper part gravitationall collapses.
- lower part, P pushes in which tries to force dense root off.

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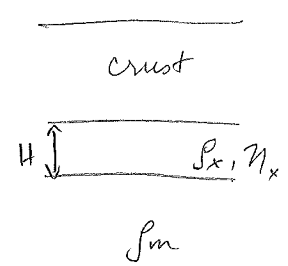
This dense root will come off if the downward buoyancy forces exceed viscous resistance.

- Lets assume that the dense layer is slightly colder than ambient mantle m. Then, the main viscous resistance comes from <u>within</u> the dense layer rather than from the surroundings

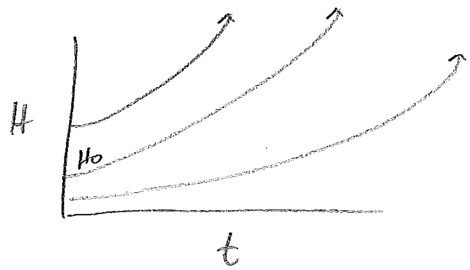


$\rho_x > \rho_m$

$$\Delta\rho = \rho_x - \rho_m$$

$$\Delta\rho g H \sim \eta \dot{\varepsilon} \sim \eta \frac{dH}{dt} \frac{1}{H_0}$$

(H_0 ↑ initial lengthscale)



$$H = H_0 \exp\left(\frac{\gamma \Delta\rho g H_0}{\eta} t\right)$$

γ is geometrical constant

$$t_{e\text{-fold}} = \frac{\eta}{\gamma \Delta\rho g H_0}$$

Rayleigh-Taylor approximation

if $\Delta\rho = 0$, $H_0 = 0$, η is high it takes too long to fall off

growth of instability aided if H_0 large
$\Delta\rho$ large
η small

NOTE: if $\Delta\rho$ is thermal, then thermal diffusion competes

$$\frac{H_0^2}{K} \sim t_{th}$$

if $t_{th} < t_{growth}$, thermal anomaly ΔT and $\Delta\rho$ erased.

This requires thickening rate to be fast.

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$$t_{e\text{-fold}} \sim \frac{\eta}{\gamma \Delta\rho g H_0} = \frac{\eta}{\gamma \rho_0 \alpha g \Delta T H_0}$$

consider thermal contrasts

ρ_0: 3×10^3 kg/m^3; α: 3×10^{-5}/°C; g: 10 m/s^2; ΔT: $\sim 10^2$ °C; γ: ?; H_0: ?

assume $H_0 \sim 10$ km

then if $\eta = 10^{19}$ Pa.s $\quad t = 1$ My

$\eta = 10^{20} \quad t \sim 10$ My

$\eta = 10^{21} \quad 100$ My

For $H_0 = 10^2$ km, $\eta = 10^{21}$ Pa.s $\quad t = 10$ My

So viscosity is very important

$$\eta = \eta_0 \exp(+E_A/RT)$$

$$\eta(1400°C) = \eta_0 \exp(+E_A/R\,1673K)$$

$$\frac{\eta(T)}{\eta(1673K)} = \exp\left(+\frac{E_A}{R}\left(+\frac{1}{T} - \frac{1}{1673}\right)\right)$$

$E_A \sim 300$ to 500 kJ/mol

$R = 8.314\times10^{-3}$ kJ/K mol

if $\eta_{1673} = 10^{18}$ Pa.s

	$E_A = 300$	$E_A = 500$
$\eta_{1200C} = \eta_{1473K}$	1.9×10^{19}	1.3×10^{20}
$\eta_{1000C} = \eta_{1273K}$	8.8×10^{20}	8×10^{22}
$\eta_{800C} = \eta_{1073K}$	1.7×10^{23}	5×10^{26}

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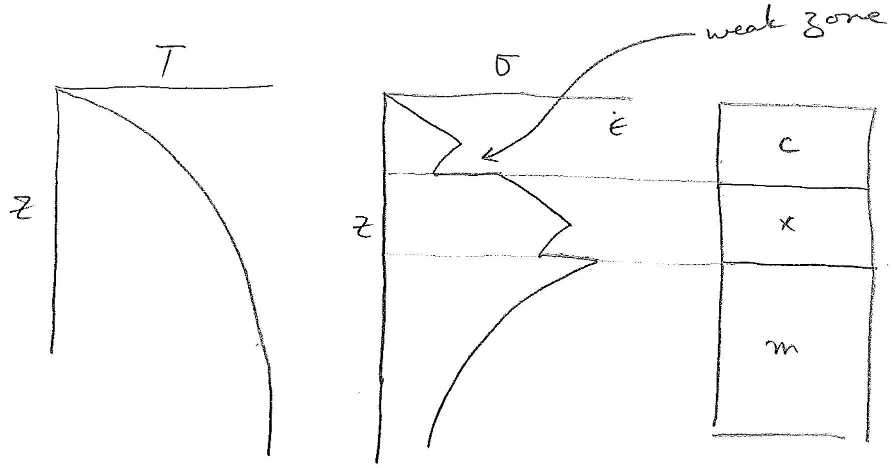
It can be seen that if the dense layer is too cold, it cannot founder viscously because η is too high.

$T < 1000°C$, no foundering!

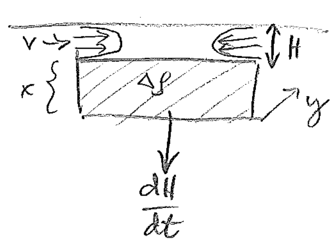
Alternative is to delaminate

- here, dense layer is strong and detaches wholesale
- facilitated by a weak zone



- delamination can initiate along weak zone -
- weak zone in crust is enhanced when crust is thick.

model



assume lubrication theory

$$\Delta\rho g L x y = \eta \frac{V}{H} L y$$

buoy. force from dense slab

all viscous resistance controlled by flow in gap

conservation of mass $\quad V \cdot H = \frac{dH}{dt} L$

$$V = \frac{dH}{H\,dt} L$$

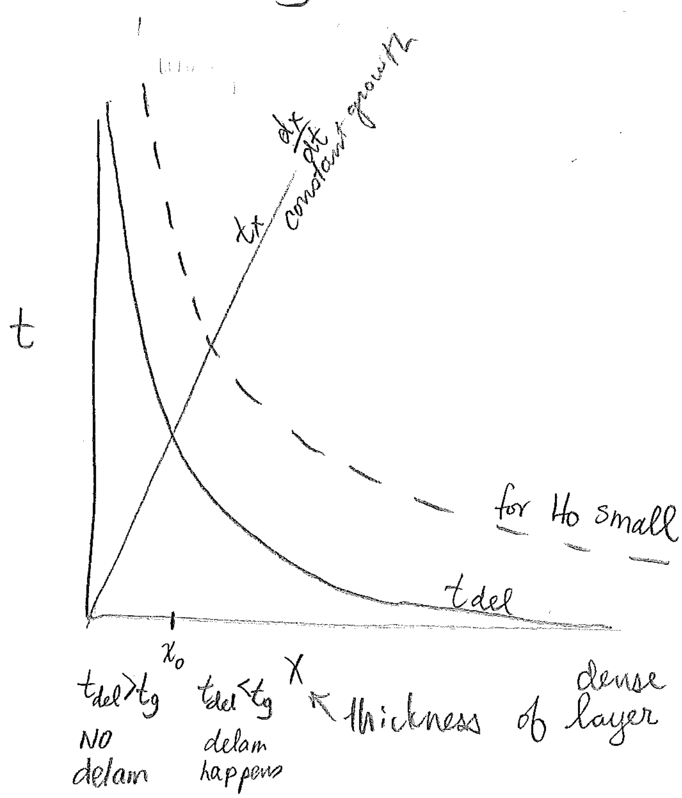
plug in $\quad \dfrac{\Delta\rho g H^2 x}{\eta L} \sim \dfrac{dH}{dt} \quad \Rightarrow \quad H = \dfrac{\eta L H_0}{\eta L - \Delta\rho g x t H_0}$

$$t_{H\infty} = \eta L / \Delta\rho g x H_0$$

rate of delamination scales with gap thickness to H^2 inversely to η

$$t_{delam} = t_{H\infty} = \frac{\eta L}{\Delta\rho g x H_0} = \frac{\eta}{\Delta\rho g x} \underbrace{\frac{L}{H_0}}_{\text{aspect ratio}}$$

- if gap is long and thin ($L >> 1$, $H_0 << 1$) then t is long
- note also that $t_{H\infty} \sim \frac{1}{X}$ which is thickness of dense layer. If dense layer grows by magmatic underplating at rate $\frac{dx}{dt}$ then initially not unstable



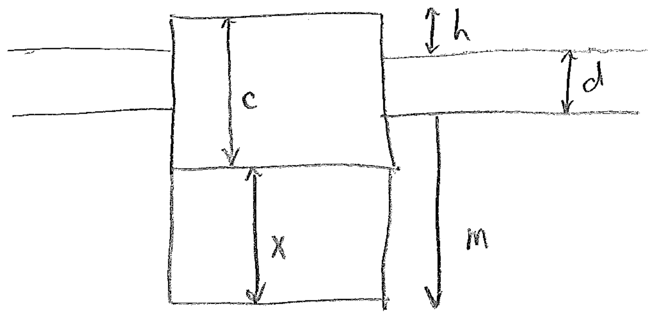
$$X_0 = \sqrt{\frac{\eta}{\Delta\rho g} \frac{L}{H_0} \frac{dx}{dt}}$$

$x > X_0$ to delaminate

$X < X_0$ no delamination

X must grow to X_0

Now, once the dense layer detaches, isostatic rebound will give rise to high elevations



$$h + d + m = c + x$$

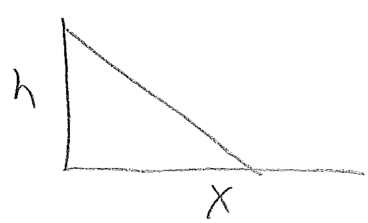
$$\rho_c c + \rho_x x = \rho_c d + \rho_m m$$

$$h = \frac{(\rho_m - \rho_c)c + (\rho_m - \rho_x)x + (\rho_c - \rho_m)d}{\rho_m}$$

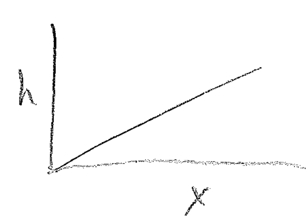
2nd term on RHS controls elevation h if everything else held constant

$$\frac{dh}{dx} = \left(\frac{\rho_m - \rho_x}{\rho_m}\right)$$ change in elevation due to change in x thickness

- if $\rho_m - \rho_x < 0$
  decrease x, increases elevation



- if $\rho_m - \rho_x > 0$
  decrease x → decrease elev.

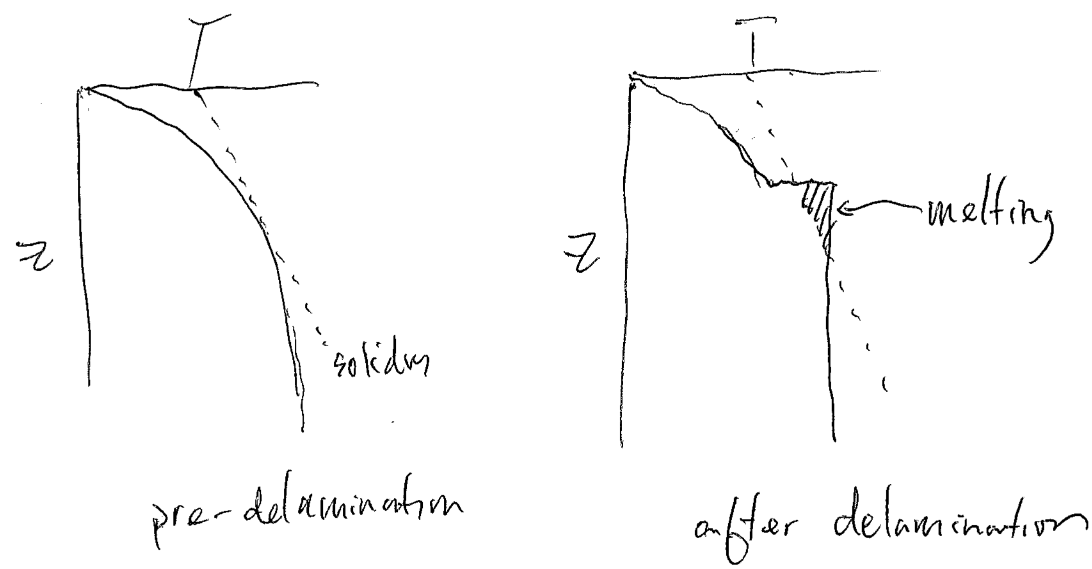


delamination of dense lower crust, if previously in isostatic balance, leads to uplift.

Note, the mantle m doesn't have to be anomalously hot.

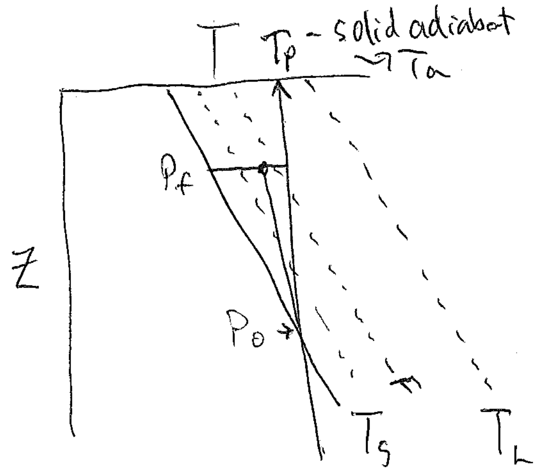
What happens after delamination in terms of melting?

- delamination is fast (once it initiates) too fast for thermal re-equilibration (by diffusion)
- asthenosphere upwells in response



What is response in terms of melting?

from Langmuir 1992



$$(P_f - P_o)\left[\frac{dT}{dP}_a - \frac{dT}{dP}_s\right] = F\left[\frac{H_f}{C_p} + \frac{dT}{dF}\right]$$

(solid adiabat) (solidus)

$$\frac{dF}{dP} = \frac{(dT/dP)_a - (dT/dP)_s}{H_f/C_p + dT/dF}$$

$$\frac{dT}{dF} = 3.5°/\% \quad \text{for } F < 0.22$$

$$\frac{dT}{dP}_a = 1°C/\text{kbar}$$

$$\frac{dT}{dP}_s = 12°/\text{kbar}$$

$$H_f = 100 \text{ cal/g}$$

$$C_p = 0.3 \text{ cal/g°K}$$

Extent of melting depends on T_p and P_f

P_f limited by point of delamination.