

Partial melting:

Melt Production

Partial melting impacts on the mechanical behavior of both the mantle and the continental crust. Melting changes both the density and the viscosity of partially melted rocks. Upon melt extraction, the residual depleted rock has a viscosity and density that differ from the rock before melting. Melting is therefore a fundamental process controlling the differentiation of the Earth at all scales.

In Ellipsis, melt is produced when a material passes its solidus. The solidus and liquidus are approximated by polynomial functions.

$$T_{sol}(z) = a_0 + a_1 \cdot (\rho \cdot g \cdot z) + a_2 \cdot (\rho \cdot g \cdot z)^2 + a_3 \cdot (\rho \cdot g \cdot z)^3$$

$$T_{liq}(z) = b_0 + b_1 \cdot (\rho \cdot g \cdot z) + b_2 \cdot (\rho \cdot g \cdot z)^2 + b_3 \cdot (\rho \cdot g \cdot z)^3$$

where $\rho \cdot g \cdot z$ is the pressure, a_i and b_i are polynomial coefficients.

The melt fraction F is a simple function of T_{ss} the supersolidus temperature:

$$T_{ss} = \frac{T(z) - T_{sol}(z)}{T_{liq}(z) - T_{sol}(z)} \quad \text{hence } 0 \leq T_{ss} \leq 1$$

Ellipsis uses the McKenzie and Bickle (1988) relationship as:

$$F(T_{ss}) = 0.3936 + 0.8936 \cdot T_{ss} + 0.4256 \cdot T_{ss}^2 + 2.988 \cdot T_{ss}^3$$

Density and viscosity changes

Density of the partially melted material changes with both temperature T and melt fraction F :

$$\rho(T, F) = \rho_0 \cdot (1 - \alpha \cdot \Delta T - \beta \cdot F)$$

β is Ellipsis “Material_1_depl_exp”

The viscosity changes following:

$$visc = visc + depl \cdot depl_vis_change$$

with $depl_vis_change$ is Ellipsis “Material_1_depl_visc_change”

In-situ melt also affects the behaviour of the rock in which it resides. Its primary effect is to decrease the viscosity.

However, there is only so much melt a rock can contain before it starts to migrate. The exact melt fraction at which it gets extracted varies from 2 to 35% depending whether or not deformation occurs during partial melting. Therefore, we have an upper limit on the melt present before it is considered extracted, and a lower limit on the viscosity. The melt fraction at which melt migrates out of the system is given as:

“Material_1_melt_extract “

If want to keep the melt in the system one will choose:

Material_1_melt_extract=1

The viscosity of the magma changes sharply over a relatively small range of melt fraction (the critical melt fraction) over which the magma evolve from a solid supported (viscosity of the solid matrix) to liquid supported (viscosity of the melt). The drop in viscosity can be as much as 8 order of magnitude within 10% increase on the melt fraction.

We parameterize this evolution by defining the melt fraction interval (here from 20% and 25%) over which the drop in viscosity (1000) occurs:

Material_1_Melt_frac_start_visc_change=0.20

Material_1_Melt_frac_end_visc_change=0.25

Material_1_melt_total_visc_change=1000

When melt is extracted, it also advects heat out of the system, modulating further melting. There are two approaches to this. One is to assume that when melt is extracted from the system, it leaves the temperature of the residue at the solidus. This is the simplest approach, but is perhaps a little too simplistic. A second approach is to consider the temperature as:

$$T = T_{sol} + F \cdot (T_{melt_extract} - T_{sol}) / (T_{liq} - T_{sol})$$

for a given melt fraction and temperature at which melt is extracted.

Exercise: Lower crust diapir.

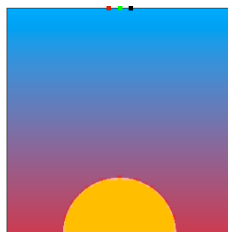
The aim of this exercise is to model a rising diapir in the continental crust which undergoes decompression melting. We build a 40km x 40 km model with a linear geotherm with: $T(z=0) = 20^\circ\text{C}$ and $T(z=\text{Moho}) = 700^\circ\text{C}$. The crust is made of a material that cannot melt whose density at atmospheric condition is 2800 kg.m^{-3} .

In the lower crust, we define a second material in the shape of a semi circle with a lower density (2500 kg.m^{-3}) and whose solidus and liquidus are (in Kelvin):

$$T_{sol}(z) = 773 + 0.005 \cdot (\rho \cdot g \cdot z)$$

$$T_{liq}(z) = 1353 + 0.005 \cdot (\rho \cdot g \cdot z)$$

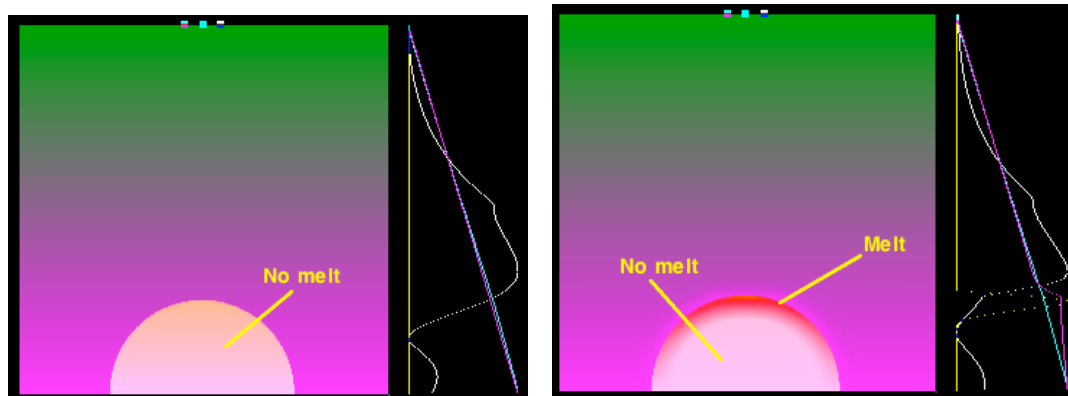
This second material is centered in $x=20\text{km}$ $z=40\text{km}$ with a of radius 10km . It has also a lower diffusivity.



We assume that the melt is not extracted from the source (...melt_extract=1), that the rheology of the crust is viscous (YIELD=off). Other relevant parameters are:

	CRUST	MAGMA
Heat capacity (Joule K ⁻¹ kg ⁻¹)	1000	1000
Diffusivity	9.48e-7	9.48e-5
Heat production (W kg ⁻¹)	0	0
Density (kg.m ⁻³)	2800	2500
Thermal expansion	-5.4e-5	3e-5
Melt expansion	-	0.20
Viscosity Drop	-	1000
...start_visc_change	-	0.2
...end_visc_change	-	0.3
...depl_visc_change	1-	10
No (Pa.s)	5.7e24	5.7e24
T1	0.011	0.011
...viscTmax (K)	-	1353
...viscTmin (K)	-	621
Entropy (full melting) (J kg ⁻¹ K ⁻¹)	-	250

In the beginning there is no melt, the buoyancy of material 2 drives upward motion. As material 2 rises, its pressure decreases triggering partial melting.



The further the rise the more melt, the more buoyant material 2...

