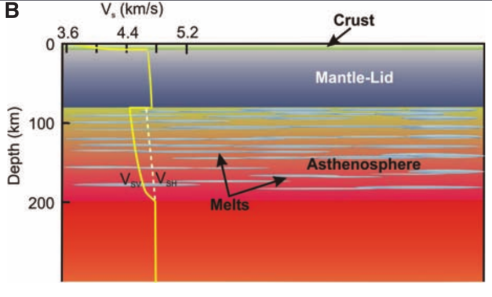
De la percolation du magma dans le manteau supérieur à la frontière Lithosphère Asthenosphère

Guillaume Richard
M. Massuyeau & F. Gaillard

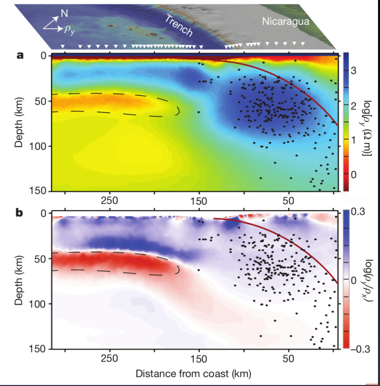
Institut des Sciences de la Terre d'Orléans (ISTO)
Observatoire de Sciences de l'Univers en région Centre (OSUC)
Université d'Orléans

Key geophysical features of the LAB

Large signals



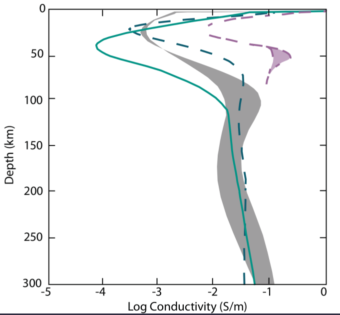
Sharp (< 20 km width) and large (5-10%) velocity drop at 70km depth, *Kawakatsu et al., Science, 2009*



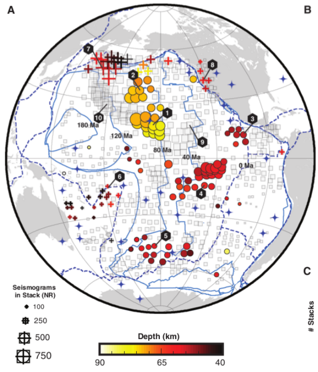
High electrical conductivities (0.02 to 0.2 S/m) under oceanic lithosphere, *Naif et al., Nature, 2013*

Key geophysical features of the LAB

Large lateral variations



Magnetotelluric models from different seafloors, *Sarafian et al., G^3, 2015*



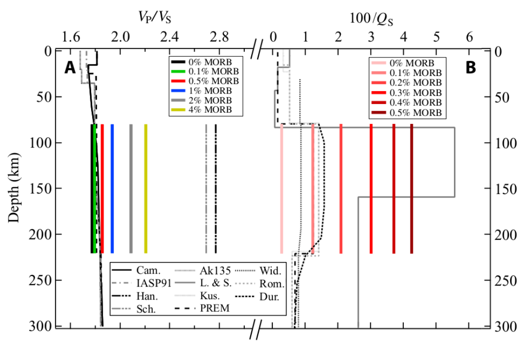
The G Discontinuity: Melt at the LAB, *Schmerr, Science, 2012*

Origin of The LAB ?

1. Large signals suggest the presence of Melt ($> 1\%$)
2. Large lateral variations suggest small scale convection

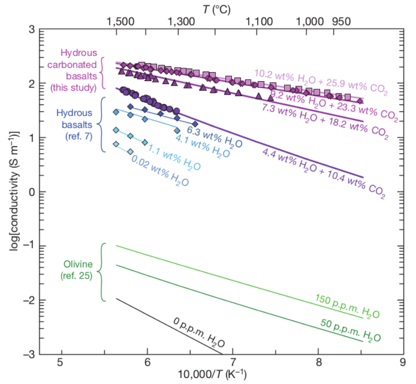
Partial melting in the asthenosphere

Experimental data suggest 0.1% of melt in a typical mantle



In situ ultrasonic velocity measurements supports mantle partial melting in the asthenosphere,

Chantel et al., Sci. Adv., 2016

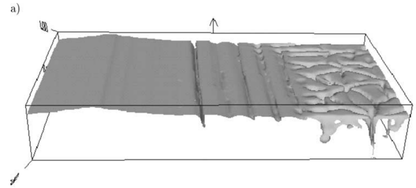


Electrical conductivity of hydrous carbonated basalts,

Sifré et al., Nature, 2014

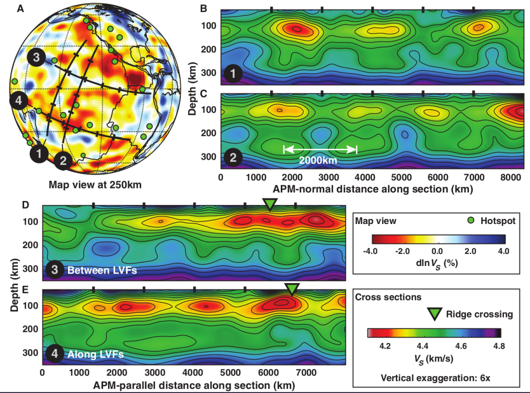
Small Scale Mantle convection

Small scale adiabatic upwellings



Mantle flow beneath mid-ocean ridges, Numerical simulation in a 1600*800*400 km box,

Morency et al., JGR, 2005

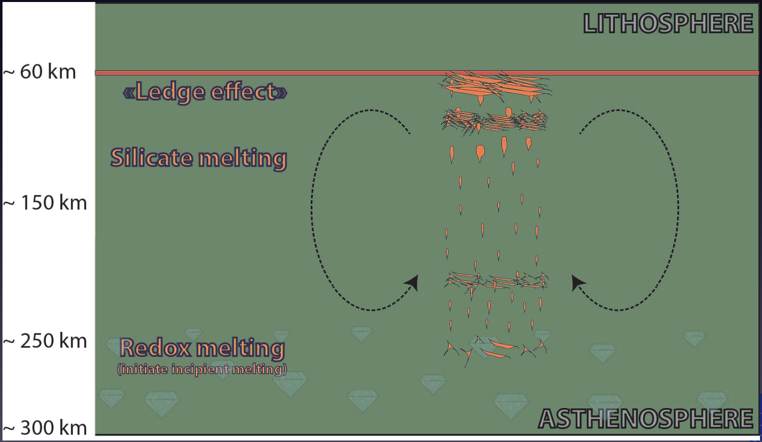


Absolute variations in isotropic shear velocity

French et al., Science, 2013

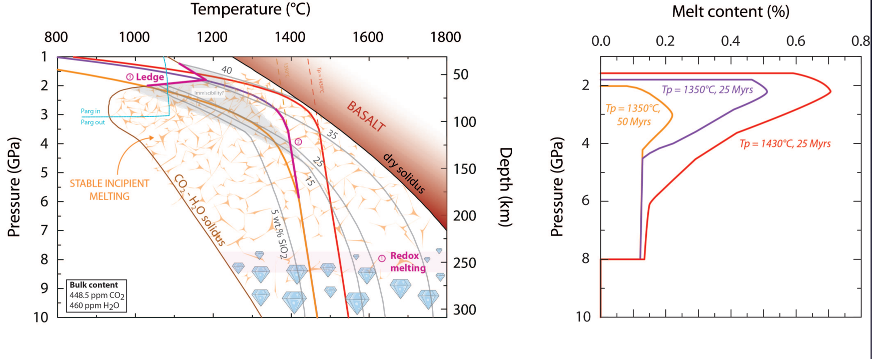
Working Hypothesis

Melt porous flow (*Havlin et al., EPSL, 2013*) associated to decompression Melting can form Melt Enriched Zone at the LAB



Thermodynamic model

Inputs :
Mantle Composition (H_2O, CO_2), Geotherms & upwelling Velocity
Ouputs :
Rate of melting $\dot{\Gamma}$, melt viscosity η_f and density ρ_f



Massuyeau et al., Chem. Geol., 2015

Two-phase Flow Model

Inputs : Upwelling Velocity, $\dot{\Gamma}$, η_f and ρ_f
Ouputs : Melt volume fraction ϕ, Effective Pressure δP

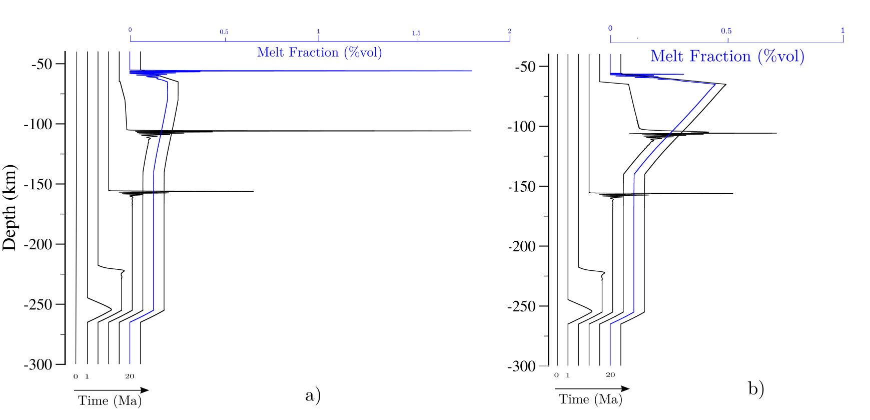
- Mass conservation
- Momentum Conservation
- Entropy conservation and positivity

$$\frac{D\phi}{Dt} = -\frac{\phi(1-\phi)}{\eta_s}\delta P + \frac{\dot{\Gamma}}{\rho_s}$$

$$\phi\delta P - \eta_s \frac{\partial}{\partial z}\left[\frac{k(\phi)}{\eta_f}\frac{\partial \delta P}{\partial z}\right] = -\eta_s \frac{\partial}{\partial z}\left(\frac{k(\phi)}{\eta_f}\delta\rho g\right)$$

$\dot{\Gamma}$: Rate of melting
η : Viscosity
$k(\phi) = k_0\phi^n d^2$: Permeability
ρ : Density
δ = $_s - _f$: Difference operator
n = 2-3
d : Grain size

Compaction assisted Melt Focussing

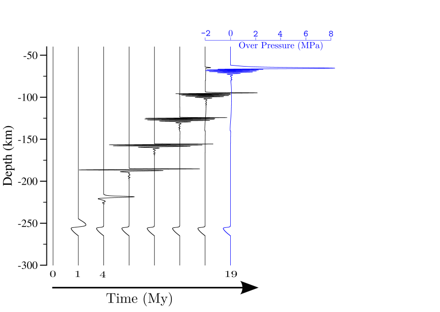


Temporal evolution of melt concentration in an hydrated upper mantle (λ = 500 m, 448 ppm CO_2, 460 ppm H_2O) under a

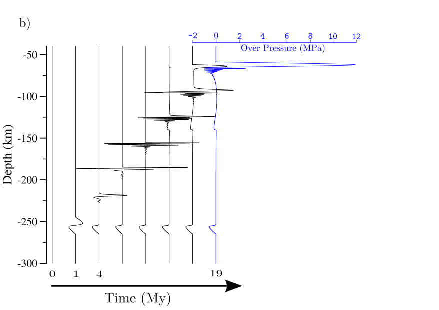
a) 50 Ma years' old lithosphere b) 25 Ma years' old lithosphere

Melt overpressure

Temporal evolution of melt overpressure in an average mantle



50 Ma years' old lithosphere



25 Ma years' old lithosphere

Main Controlling Parameters

- Ratio between **Mantle upwelling velocity** and melt Darcy velocity ($\sim$ 2 cm/year) controls MEZ formation.
  Mantle velocity < Melt Velocity favors MEZ
- Strong variations in **Melting rate** can impede MEZ formation
- **Compaction length** ($\sqrt{\frac{\eta_s k(\phi_0)}{\eta_f \phi_0}}$) controls MEZ thickness but not MEZs' amplitude
- large variation of **Melt viscosity and density variations** can trigger MEZ of small amplitude

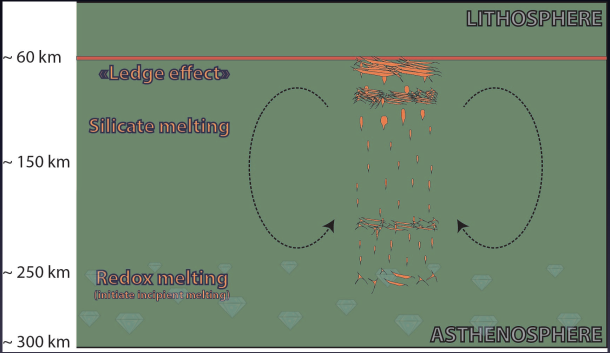
Main properties of MEZ

Melt Enriched Zones

- form in mantle slowly upwelling regions
- contain from 1 to 10$\%$ melt (maximum at the LAB)
- are around 1 km thick
- travel at a few centimetres a years
- form in the presence of volatiles (H_2O, CO_2)
- freeze at the LAB due to decarbonation

Conclusions et Perspectives

Decompression Melting and melt migration can form **episodic** Melt Enriched Zone in the upper Mantle and explain most of its geophysical signals



Consequences of mantle velocity variations deserve to be investigated to better evaluate the role of MEZ on tectonic plates formation