Water induced convection
and
Slab dehydration
in the
Earth's mantle transition zone

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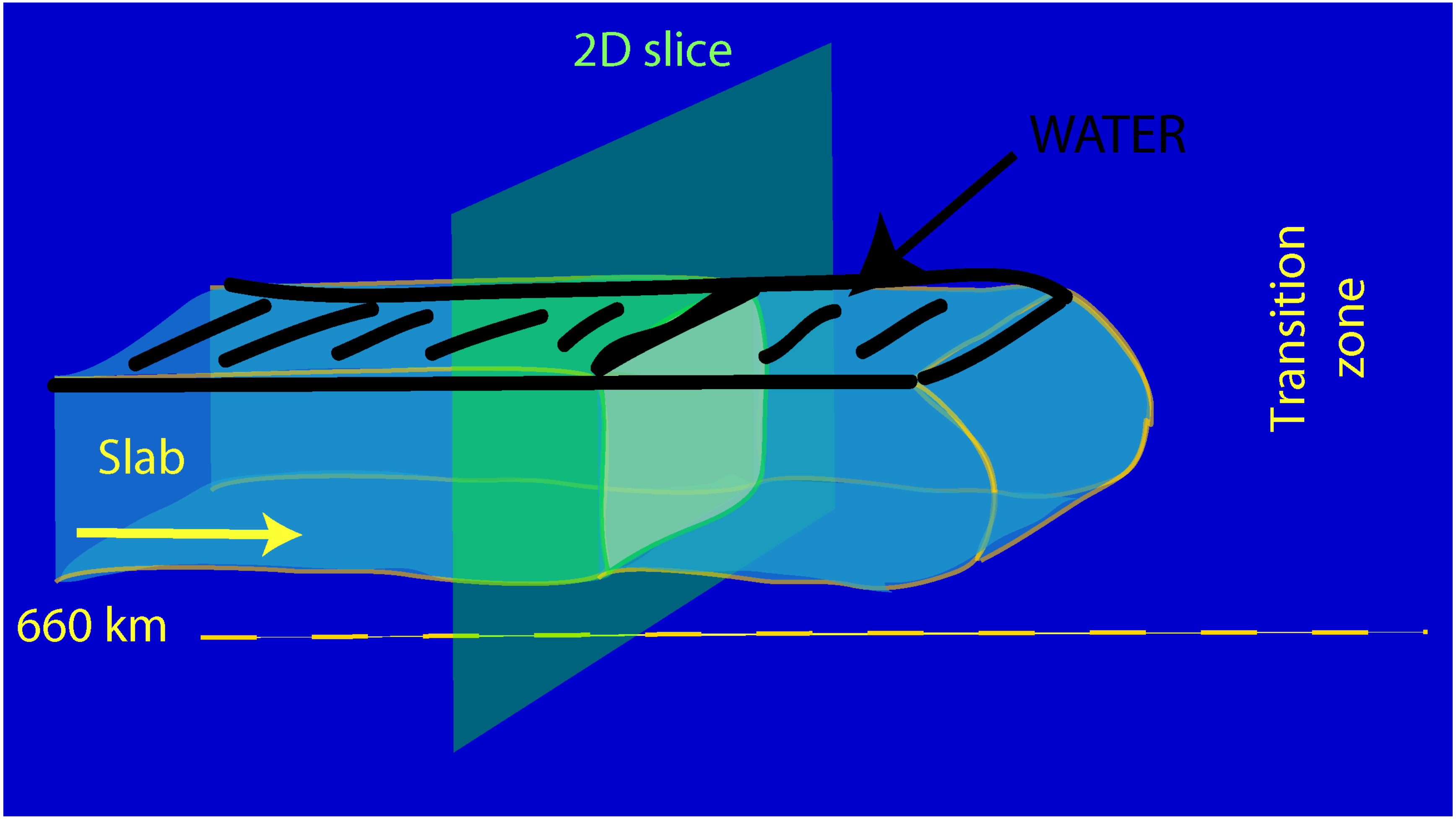
MODEL SETTINGS

- 2D lagrangian coordinate system following the slab
- Boussinesq approximation, infinite Prandtl Number
- Water and Temperature dependent density

$$\rho = \rho_0 (1 - \alpha T - \beta H)$$

- Water and Temperature dependent viscosity

$$\eta = \eta_0 H^{-r} e^{-E^* (T - T_{Slab})}$$



The essence of the model hypothesis: The lowering of density and viscosity by water triggers gravitational instabilities (small scale convection in the direction perpendicular to the slab motion)

BACKGROUND & PURPOSES

Hydrogen can be stored in the nominally anhydrous minerals composing the Earth's mantle [1-3] and has a remarkable ability to affect some of their key properties (rheology, melting [4,5]).

The onset of water-related gravitational instabilities have already been proposed at shallower depths at subduction zones [6] and we address here the question of there occurrence at the top of transition zone stagnant slabs and the expected consequences on slabs dehydration process.

INSTABILITY ONSET TIME

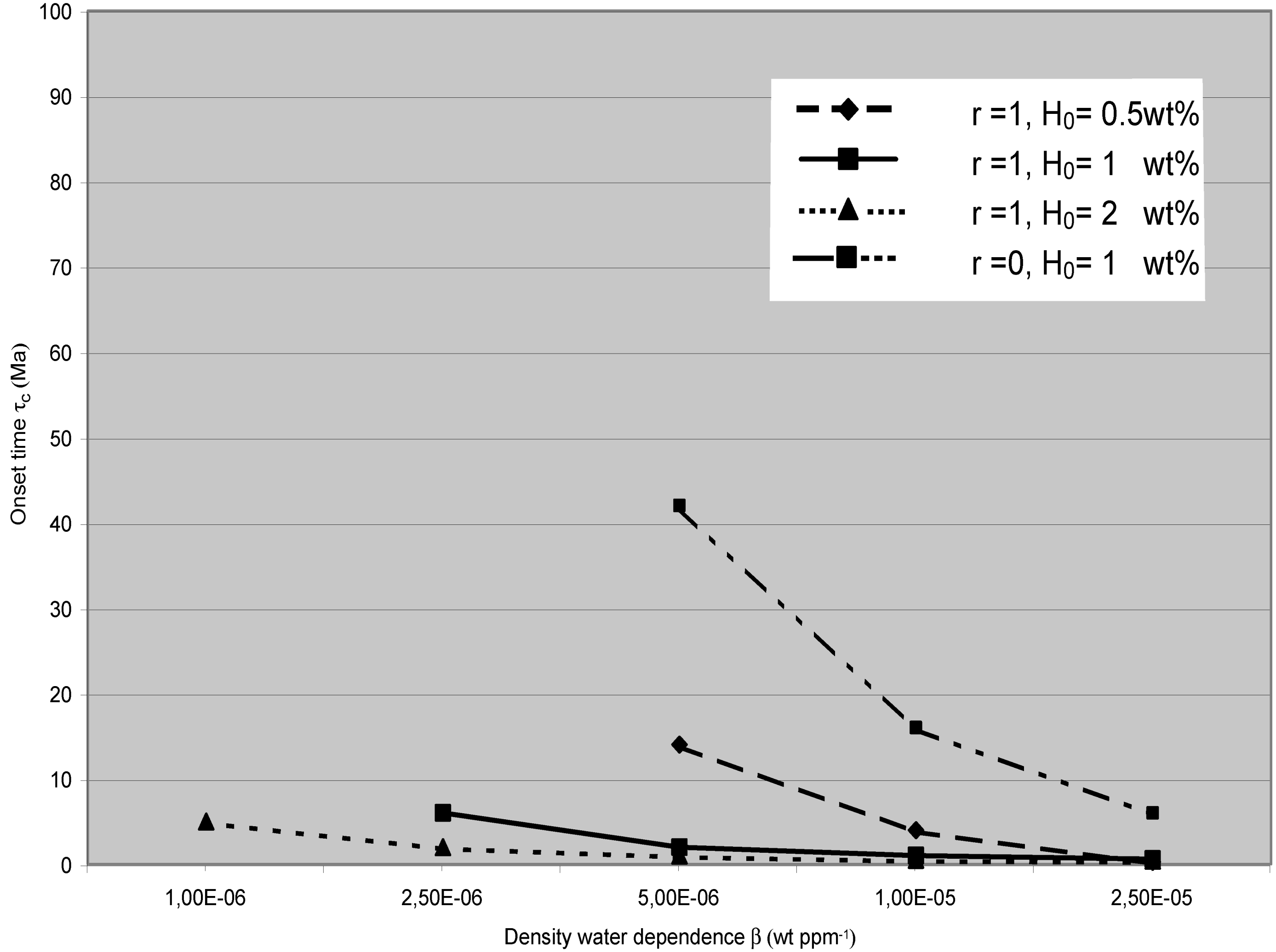
Definition of τ_c (Kinetic criterion)

$$t = \tau_C \text{ when } |V| = \sqrt{V_x^2 + V_z^2} = V_y^{slab}/100$$

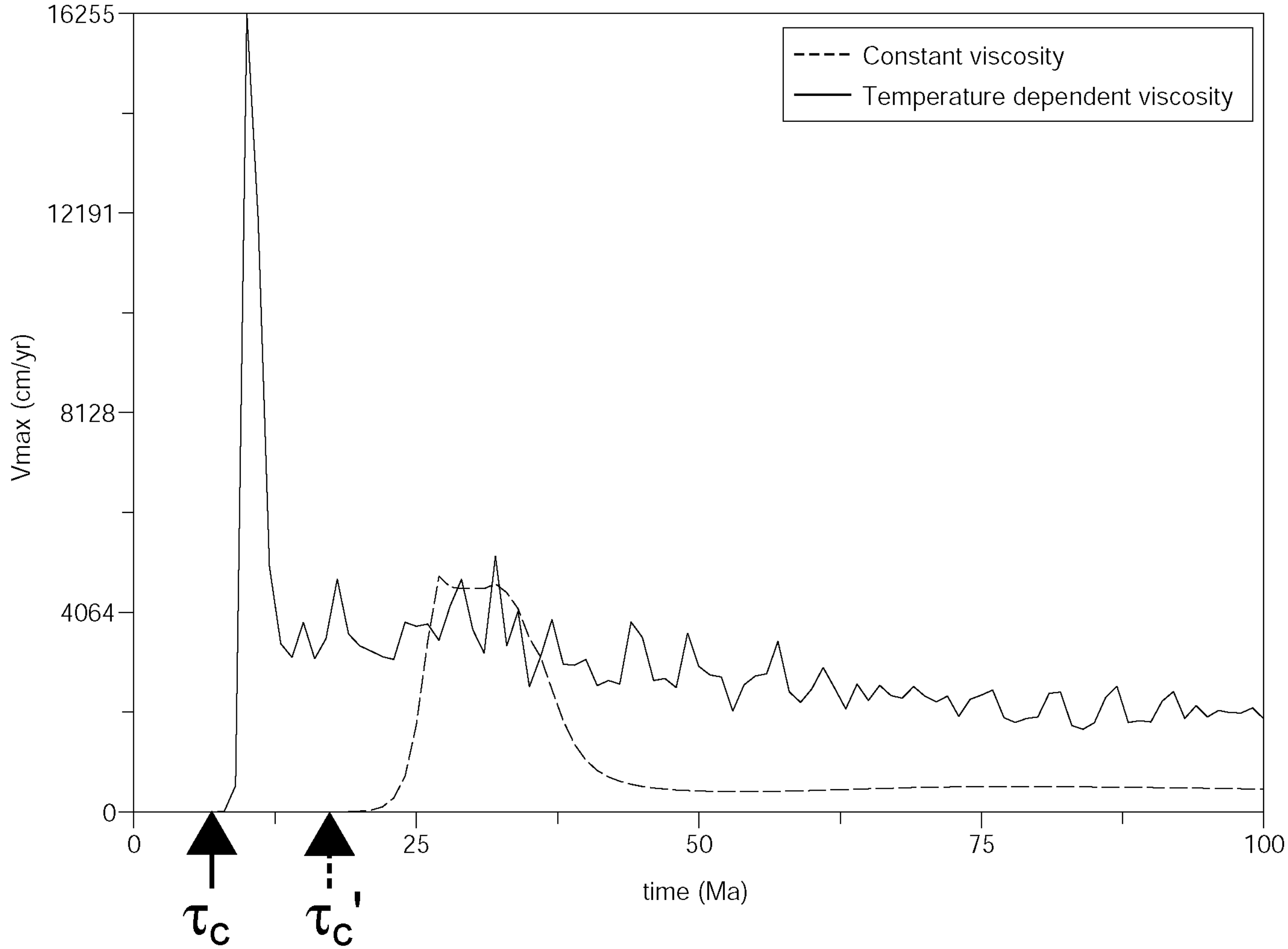
τ_c is essentially controlled by

- Water weakening (r)
- Density dependence (β)
- Initial slab water content (H_0)

For mantle like density dependence, instabilities requires high initial water content and water weakening to develop.



Onset time of the instabilities as a function of density water dependence: Slabs with low initial water content (H_0<1wt%) or not water-weakened (r=0) are unlikely to be subjected to instabilties.



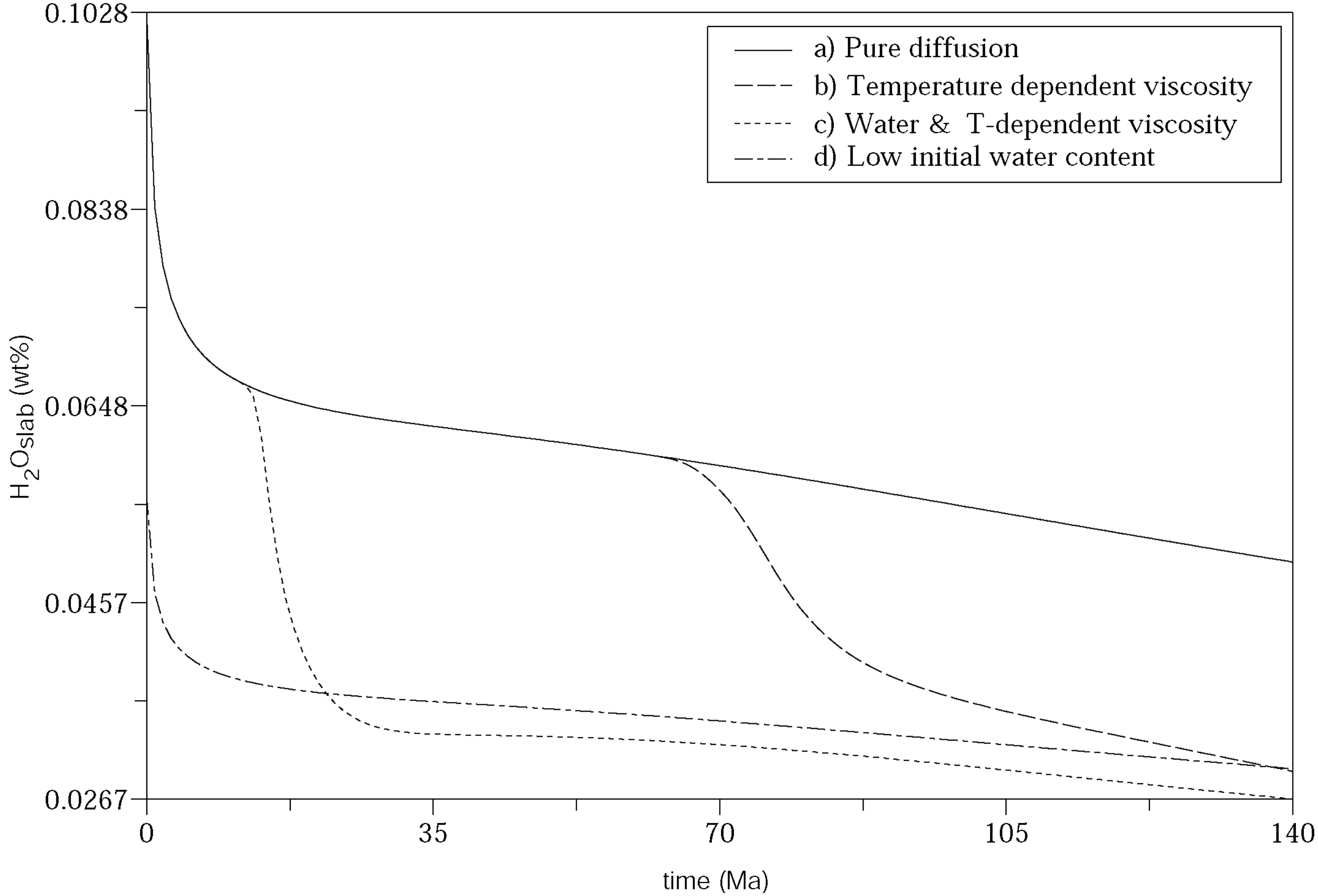
Temporal evolution of the maximum velocity of the flow *Vm* Constant viscosity case, $\eta = 10^{20}$ *(Pa.s)*, displays shorter onset time τ_c=6 *(Ma)* than temperature dependent viscosity one, $\eta' = 10^{21} e^{E^*(T-T_{slab})}$ *(Pa.s)*, τ_c' = 16 *(Ma)*.

WATER TEMPORAL EVOLUTION

The total transport of water into the mantle is enhanced by the flow and its associated advective transport.

When instabilities develop the rate of dehydration is significantly boosted and the average water concentration is reduced, by at least a factor of two compared with a purely diffusive behaviour, within a short time interval (5-15 Ma).

The final stage is a return to the diffusive dehydration rate, since there is no more water to drive the gravitational flow



Slab water content temporal evolution. Average water content inside the slab is displayed for characteristic behaviors of the system. *a, b, c, d* corresponds respectively to the sets of parameters (r, β ($wt\%^{-1}$), H_0 ($wt\%$)) equals to (1, 10^6, 1), (0, 5 10^6, 1), (1, 2.5 10^6, 1), (1, 2.5 10^6, 0.5).

CONCLUSION & PROSPECT

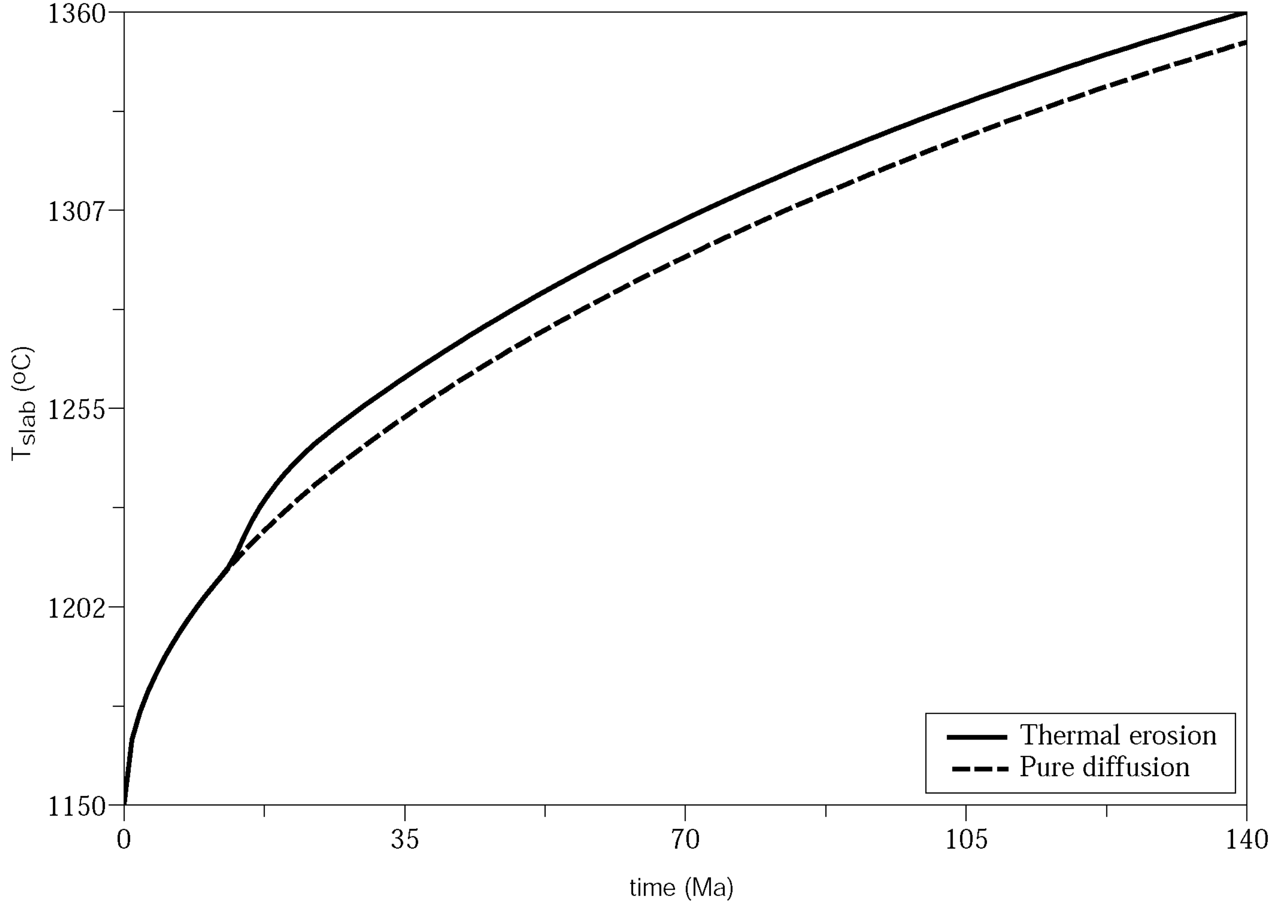
The presence of water in a stagnant slab can significantly change its dehydration history. The model demonstrates that water is likely to trigger Rayleigh-Taylor type instabilities.

This phenomenon provides an efficient mechanism to enhance the slab dehydration process (by a factor of two or more) and the slab heating process.

The transition zone mantle overlying stagnant slabs is probably wet as suggested by electrical conductivity data [7] and thus favourable to the presence of a predicted [8] and potentially observed [9] melt layer at the 410km discontinuity.

Water-induced temperature variations within stagnant slab may, through density variation, act upon the large scale dynamical behaviour of slabs (e.g. duration of their stay in the TZ).

The fate of slabs in the transition zone is probably highly water dependent [10].



Slab temperature temporal evolution. Average temperature inside the slab is displayed. Set of parameters (*r*, β (*wt%*$^{-1}$), H_0 (*wt%*)) used in thermal erosion and pure diffusion cases are respectively (1, 2.5 10^6, 1) and (1, 10^6, 1).

TEMPERATURE TEMPORAL EVOLUTION

The average temperature of the slab, which is slowly increasing with time when diffusion is the only transport process is seen to encounter a sudden kick when instabilities develop.

When a convective episode takes place, advective transport mainly involves the above mantle. The transport of heat out of the slab is still essentially made by diffusion but the top boundary condition is changed by the above small scale mantle convection: **the slab is thermally eroded**.

PARAMETERS

Symbols	Names	Values	Units
Parameters			
R	Gas constant	8.314	$J.mol^{-1}.K^{-1}$
κ	Thermal diffusivity	10^{-6}	$m^2.s^{-1}$
k_H	Water diffusivity	10^{-7}	$m^2.s^{-1}$
α	Thermal expansion coefficient	$3 - 3.4 10^{-5}$[a]	K^{-1}
β	Density water dependence coefficient	$10^{-6} - 2.5\ 10^{-5}$[b]	$ppm\%^{-1}$
T_0	Reference temperature (slab)	1150	^oC
δT	Temperature range (slab-mantle)	300	^oC
ρ_0	Reference mantle density (wadsleyite)	3400[b]	$kg.m^3$
η_0	Reference slab viscosity	10^{-21}	$Pa.s$
H_0	Initial water concentration	$1 - 2$	$wt\%$
μ_0	Standard-state chemical potential	-10	$kJ.mol^{-1}$
E	Activation enthalpy	~ 600[c]	$kJ.mol^{-1}$
E^*	pseudo-activation enthalpy	$23.\ 10^{-3}$	K^{-1}
r	power of the viscosity water dependence	1[c]	-
Variables			
H	Water concentration	–	$wt\%$
T	Temperature	–	^oC
τ_c	Onset time of the instability	–	Myr

[a] from [12]
[b] from [11]
[c] from [5]

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