Slab dehydration in the early Earth: insights from numerical models integrated with thermodynamic data

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1 Introduction

A large part of the **Archean continental crust** is made of a composite rock assemblage dominated by granitoids belonging to the TTG series (tonalite-trondhejmeite-granodiorite) that show a subduction signature, but their formation it is still unclear.

Here we focus our attention on the **fate of water** in a subduction zone, since it is a component that is essential to the formation of TTG series. The amount and composition of water bearing fluids in a subduction zone is controlled by slab devolatilization, and influence both the melting regime and the melt composition. Our goal is **to investigate under which conditions (i.e., pressure, temperature and paragenesis) dehydration occurs**, since this has a main influence on the composition of the fluids released during subduction and, on the trace elements composition of the continental crust that would ultimately form in the arc. We compare results from **two main different scenarios representing the present-day and the Early Earth** subduction system.

2 Model setup

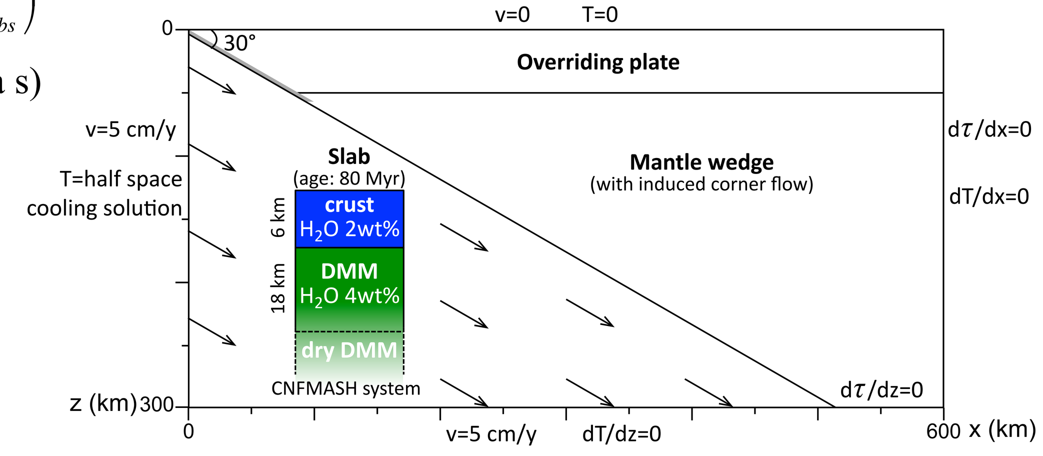
A thermal convection finite element model (Citcom; Moresi and Gurnis, 1996; Zhong et al., 2000) of a slab subducting with a constant velocity is integrated with a thermodynamic database (Perple_X package; Connolly et al. (1990, 2005,...))

- Mantle rheology: diffusion creep $\eta(T) = A \exp\left(\frac{E}{RT_{abs}}\right)$

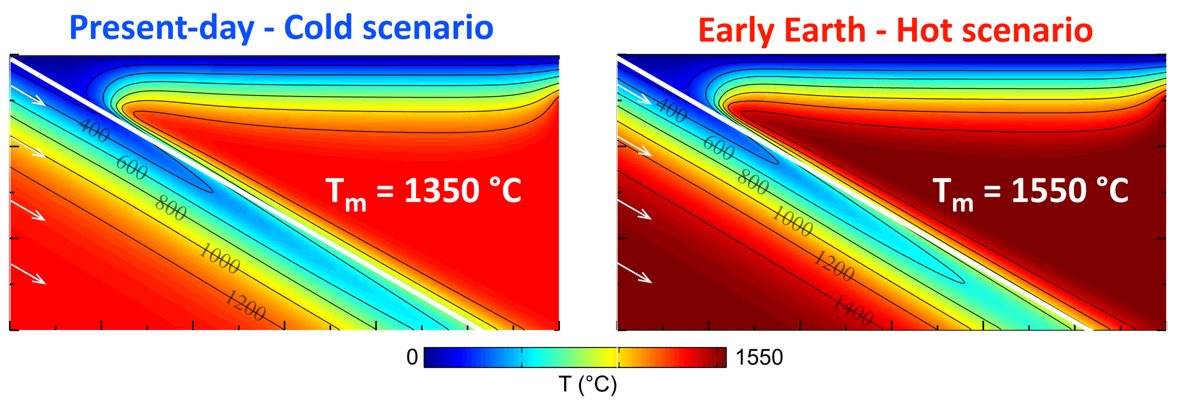
- Slab and overriding plate: constant viscosity (10^{26} Pa s)

- Weak zone between the plates to allow decoupling: 4.5 km thick, 10^{21} Pa s

- Layered slab:
  crust (nMORB composition) with 2 wt% H_2O
  depleted mantle material (DMM) with 4 wt% H_2O



- Two models with different mantle T to simulate the different temperature conditions between present-day and early Earth

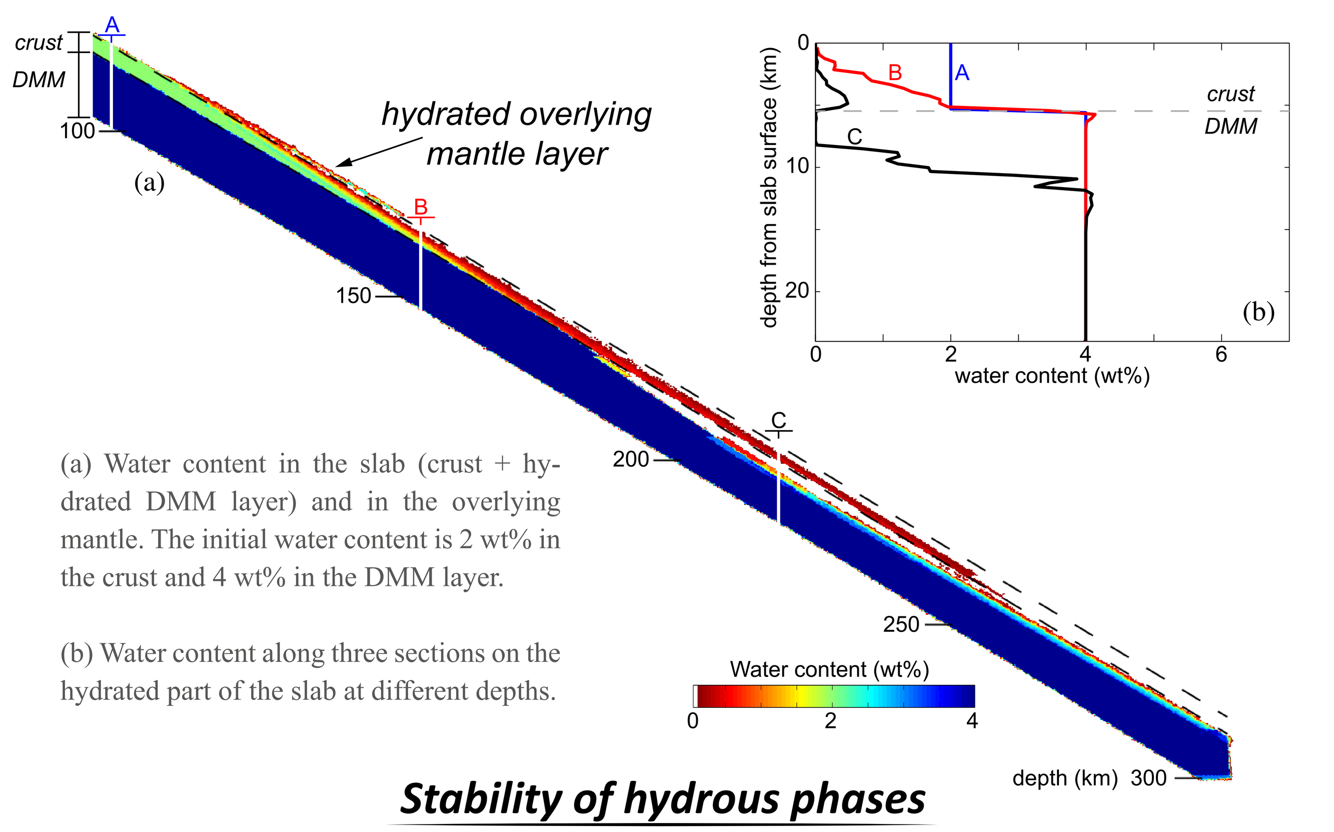


Parameters (unit)		Value
Rheological pre-exponent	A (Pa s)	1.3×10^9
Reference temperature	T_m (°C)	1350 -1550
Reference mantle viscosity	η_0 (Pa s)	10^{21}
Maximum mantle viscosity	η_{mm} (Pa s)	10^{24}
Lithosphere viscosity	η_l (Pa s)	10^{26}
Weak zone viscosity	η_w (Pa s)	10^{21}
Gas constant	R (J/mol)	8.3
Activation Energy	E (kJ/mol)	360
Plate velocity	v (cm/y)	5
Mesh resolution	km^2	1x1

3 Results

Present-day - Cold scenario

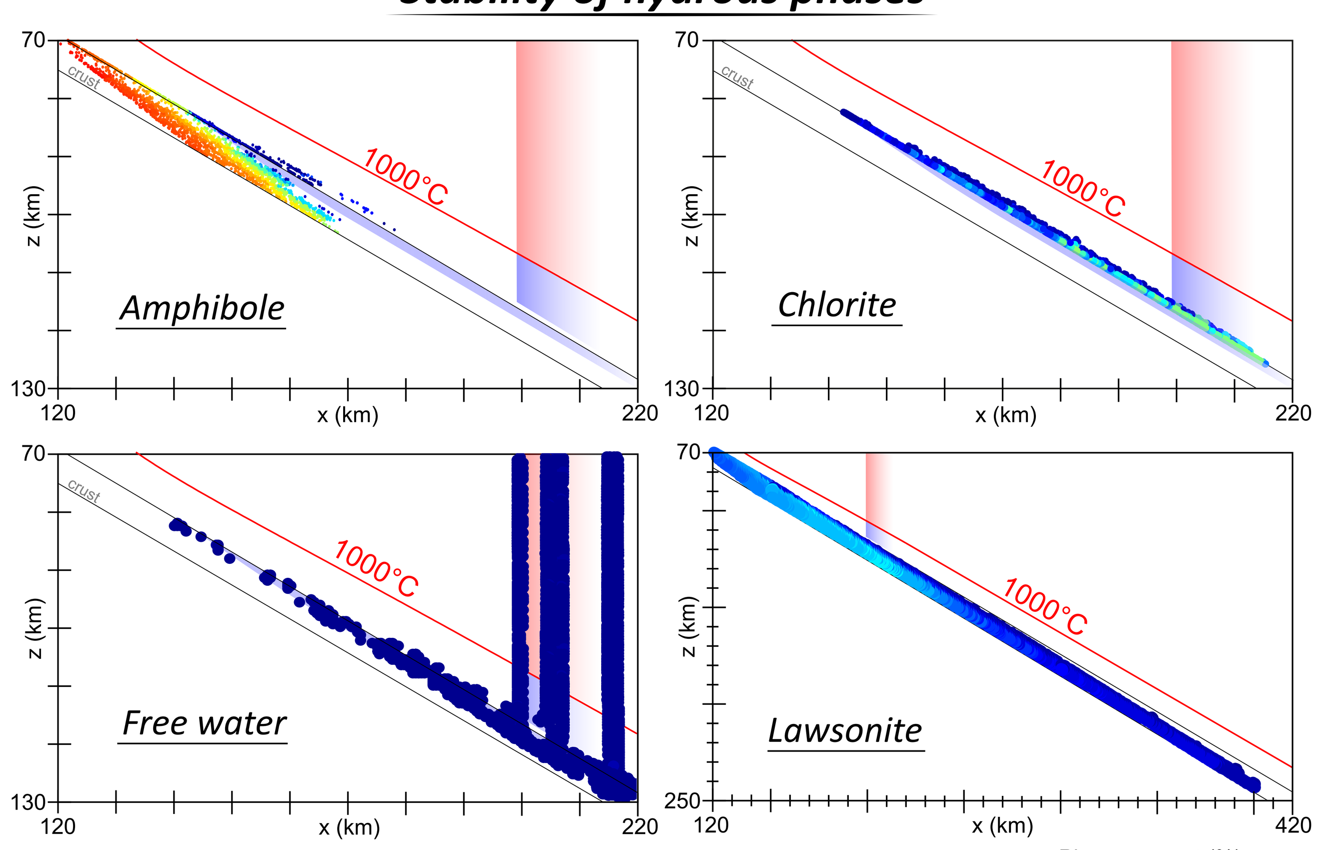
Water content



(a) Water content in the slab (crust + hydrated DMM layer) and in the overlying mantle. The initial water content is 2 wt% in the crust and 4 wt% in the DMM layer.

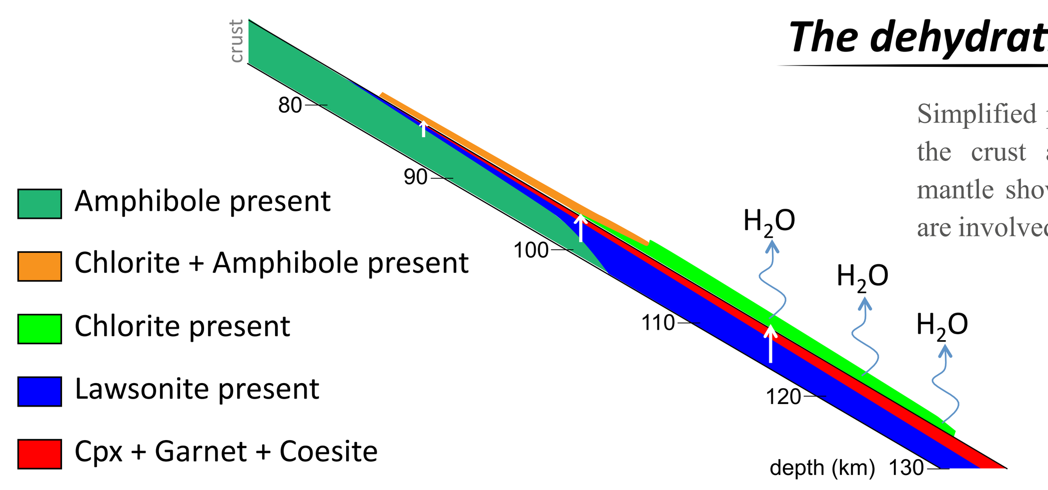
(b) Water content along three sections on the hydrated part of the slab at different depths.

Stability of hydrous phases



Plots show where important hydrous phases (and free water) involved in the dehydration process are present in the crust and in the overlying mantle. Colors show the phase amount. The shaded area outlines where water is mainly released

The dehydration process



Simplified paragenetic map of the crust and the overlying mantle showing which phases are involved in the dehydration process.

Crust slowly dehydrates until ~250 km of depth

Crust rapidly dehydrates until ~150 km of depth

Most of the water in the DMM layer remains in the slab

Most of the water in the DMM layer is released

Presence of a thin layer of hydrated mantle above the slab (mainly with chlorite)

This layer dehydrates at ~110 km of depth

Presence of a thick layer of hydrated mantle above the slab (mainly with amphibole)

This layer dehydrates (or melt) at ~90 km of depth

Water released from the crust first by amphibole and then, deeper, by lawsonite (and talc) hydrates the overlying mantle

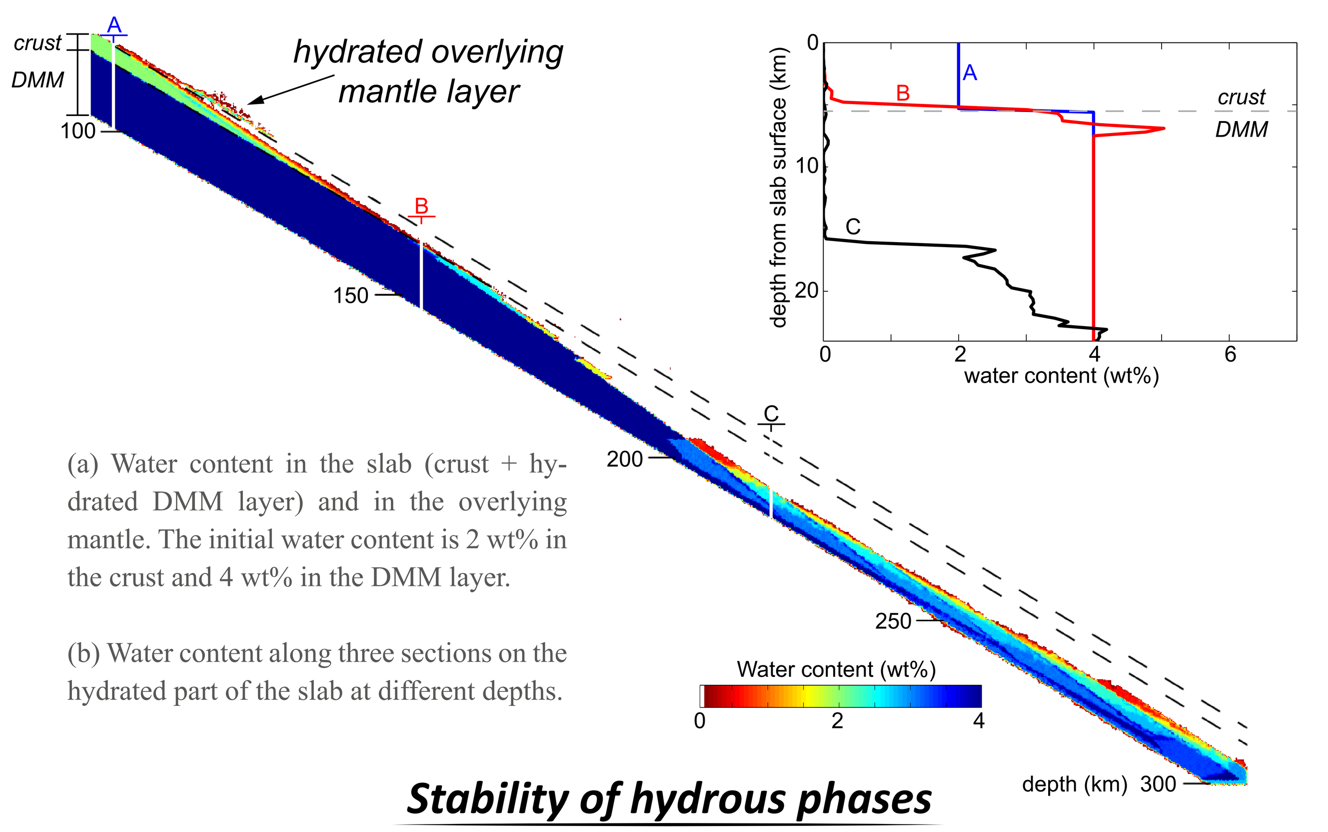
Water released from the crust by both amphibole and lawsonite hydrates the overlying mantle

Water released from the overlying mantle layer where chlorite is present

Water released from the overlying mantle layer where amphibole is present

Early Earth - Hot scenario

Water content



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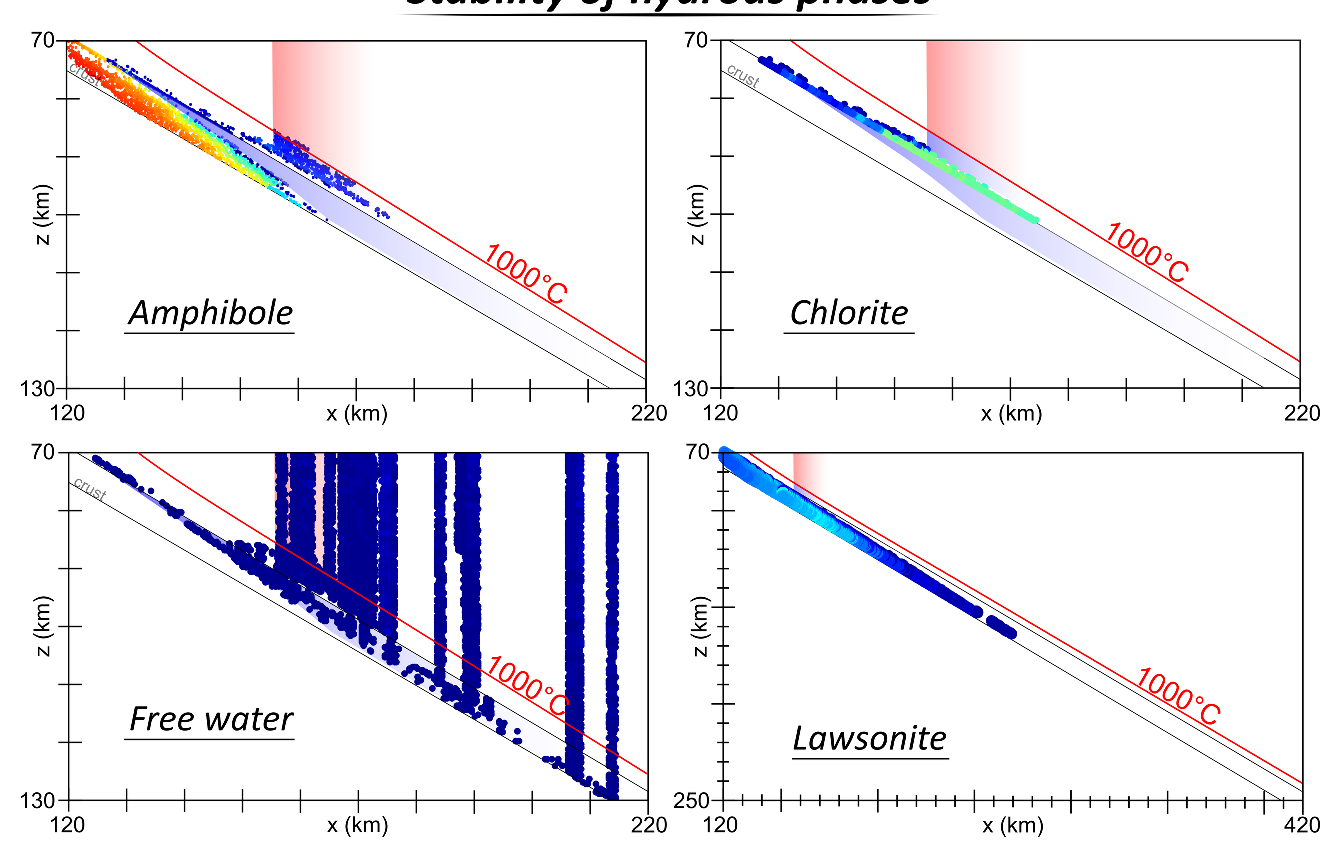

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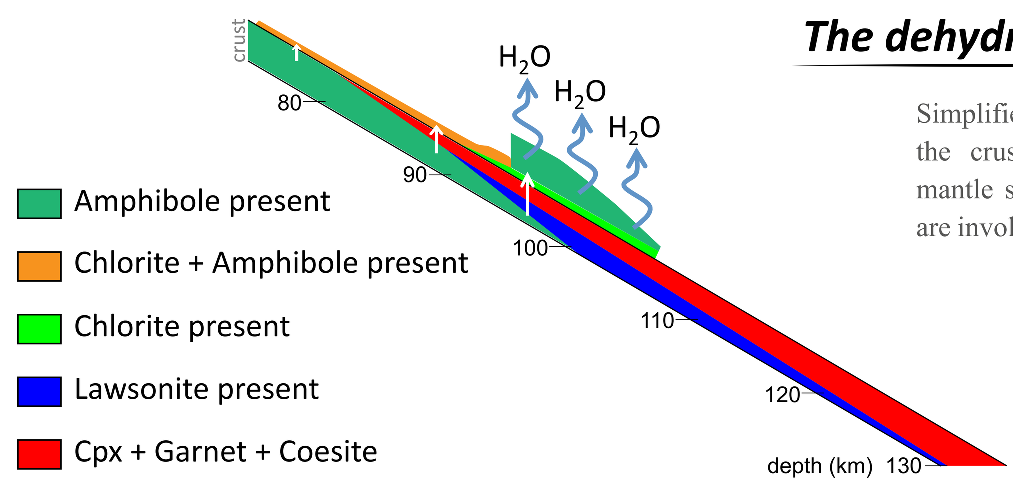

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4 Conclusions

In the hot scenario the slab starts to dehydrate shallower than in the cold scenario and with a much higher rate. In fact, the crust is totally dry at already 150 km (vs. 250 km for the cold case). Thus, the hydrated overlying mantle layer dehydrates at different PT (and H2O content) conditions and, therefore, different hydrous phases are involved in this process: amphibole + chlorite in the hot scenario; only chlorite in the cold scenario.

The early dehydration might lead to a much more enriched mantle primitive melt and this may have a strong influence on the final composition of the Early Earth continental crust.

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