Fluid Release and the Deformation of Subducting Crust

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Introduction

It has been suggested that the (adakitic) geochemical signatures observed in many Archean rocks are a result of melting of basaltic crust at high pressure (Fig. 1) [1,2]. Several processes can account for such geochemical signatures, one of these being the delamination and melting of subducting crust (Fig. 2).

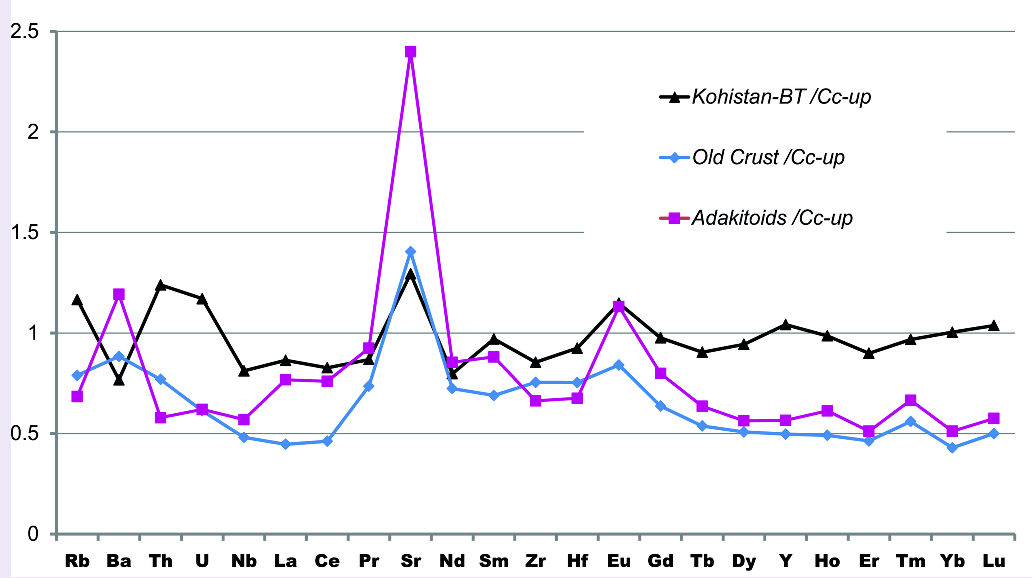


Figure 1 Trace element signatures for: crust older than 2.5Ga *(blue)*, an average adakite *(purple)* and a typical Cenozoic arc-related batholith *(black)*. Depletion of the heavy rare earth elements (towards the right of the plot) is indicative of the melting having taken place in the stability field of garnet (i.e. at >15Kbar or >50 km).

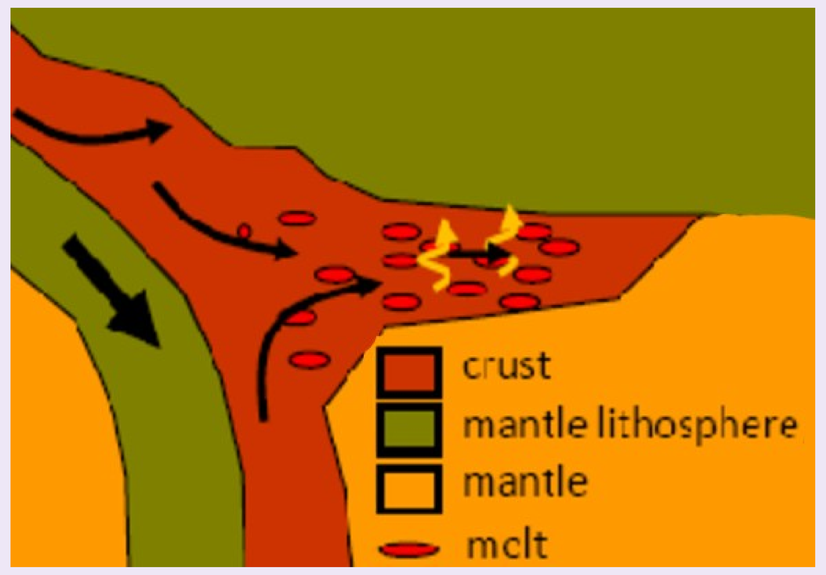


Figure 2 A sketch to illustrate how delamination can lead to high pressure melting of basaltic crust.

The aim of this study is to constrain the conditions required for significant deformation of subducting crust, in the presence of fluid, in a modern and an Archean setting, and investigate how this affects melt generation.

Method

- The model is built on Citcom [3], a finite element code for solving thermal convection.
- A tracer method keeps track of composition.
- Stable slab geometry and temperature profile is first determined

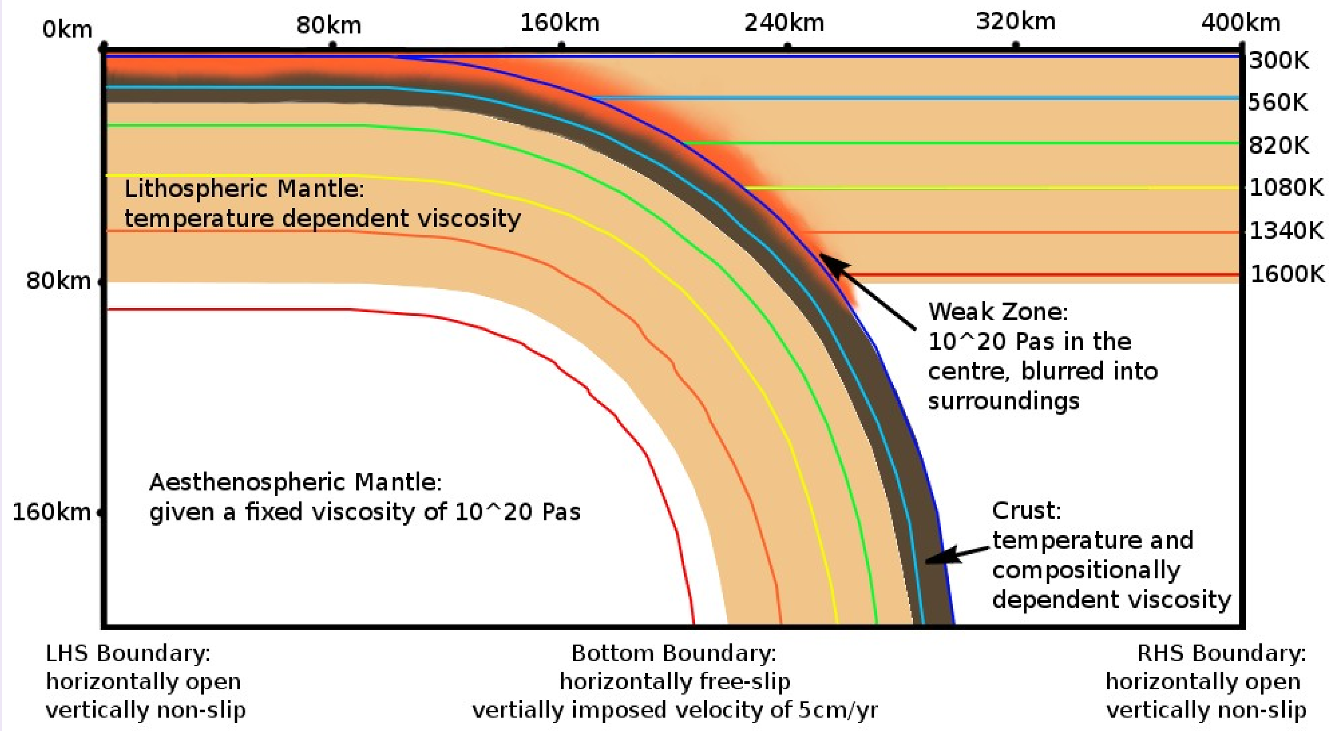


Figure 3 The basic model setup for a crustal width of 20km and a slab age of 40Ma. The weak zone decouples the two plates but material below the over-riding lithosphere is unaffected by this.
The bottom boundary condition is imposed as a first order approximation to the slab pull force which drives the subduction system.

- Incoming temperature is calculated using a half-space cooling profile.
- The effects of temperature, compositional and hydrolytic weakening on the rheology in this model is summarised as follows:

$$\eta = A_0 A_c A_m A_w \exp\left(\frac{E}{RT}\right)$$

(η=viscosity/Pas ; T=temperature/K ; R=8.31 ; see Table 1 for other definitions)

- Fluid release is handled by PerpleX [4] and any free water in the model is moved upwards (instantly) to react with the material above [5].

Future Plan

Fluid Release

The primary effect of fluid is to lower the solidus but its presence may result in extra weakening or its release may actually result in strengthening of the residual (fig. 8) [8].

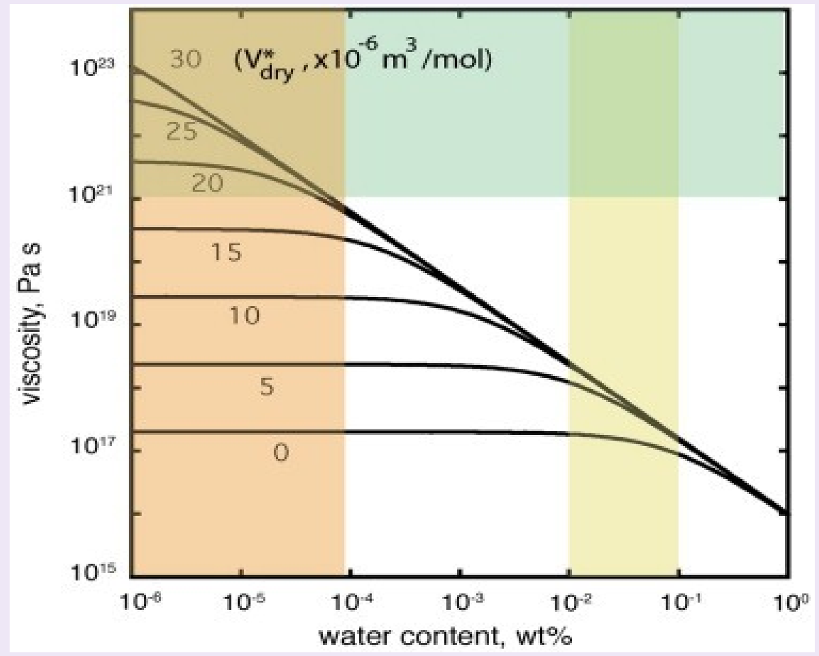


Figure 8 Sourced from [8]. Partial melting reduces the water content from the yellow to the orange region. Large increases in viscosity can occur if the activation volume (V*) is sufficiently high. Ranalli [7], for example, gives V* ≈ 5 which implies a factor of 5-10 increase.

Partial Melting

Partial melting is expected to play a large role in the dynamics of the system by weakening material exponentially [7,9].

Metamorphism

Below ~40km eclogite is the stable facies [10] which is negatively buoyant in the mantle. However, evidence from UHPM terranes suggest that the crust can remain granulitic beyond this depth and the eclogitisation reaction is strongly controlled by the presence of fluid (fig. 9) [11].

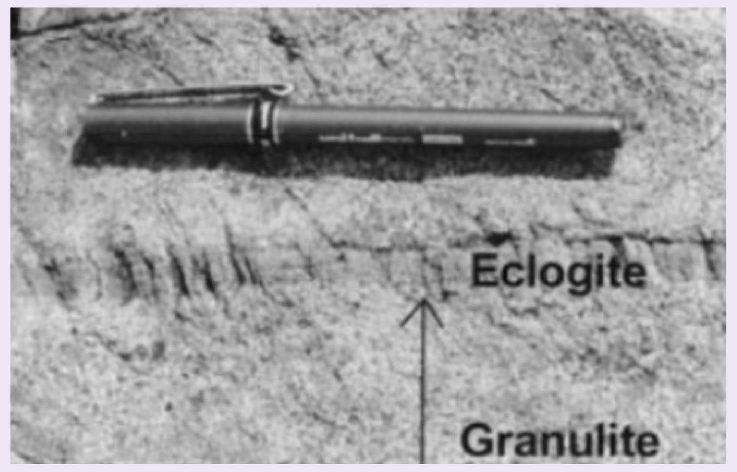


Figure 9 An example of partial eclogitisation from the western marginal zone in the Norwegian UHPM region. The degree of hydration and eclogitisation in the granulite increases towards the eclogite band. Figure is sourced from [11].

Preliminary Study

Conducted to gain insight into approximately how weak the subducting crust needs to be to deform and how it deforms. Crust is uniformly buoyant and weakened without yet considering fluid release, melting or metamorphism.

Parameter	Value / Range
slab age	10, 20, 40 Ma
Mantle temperature	1350K
slab velocity	5 cm/yr
A0 (ref. viscosity)	10^{20} Pas
Ac (crust)	1 → 0.0001
Am (melt)	1
Aw (water)	1
Eact mantle	360 KJ/mol [7]
Eact crust	260 KJ/mol [7]
thickness crust	10, 15, 20 km
Thickness ovr-rdg plate	80 km
density(ρ) crust	- 500 kg/m^3
Min / Max Viscosity	10^{19} / 10^{24} Pas

Table 1 Values of fixed parameters and the range explored for varied parameters used in the preliminary study, with references given.

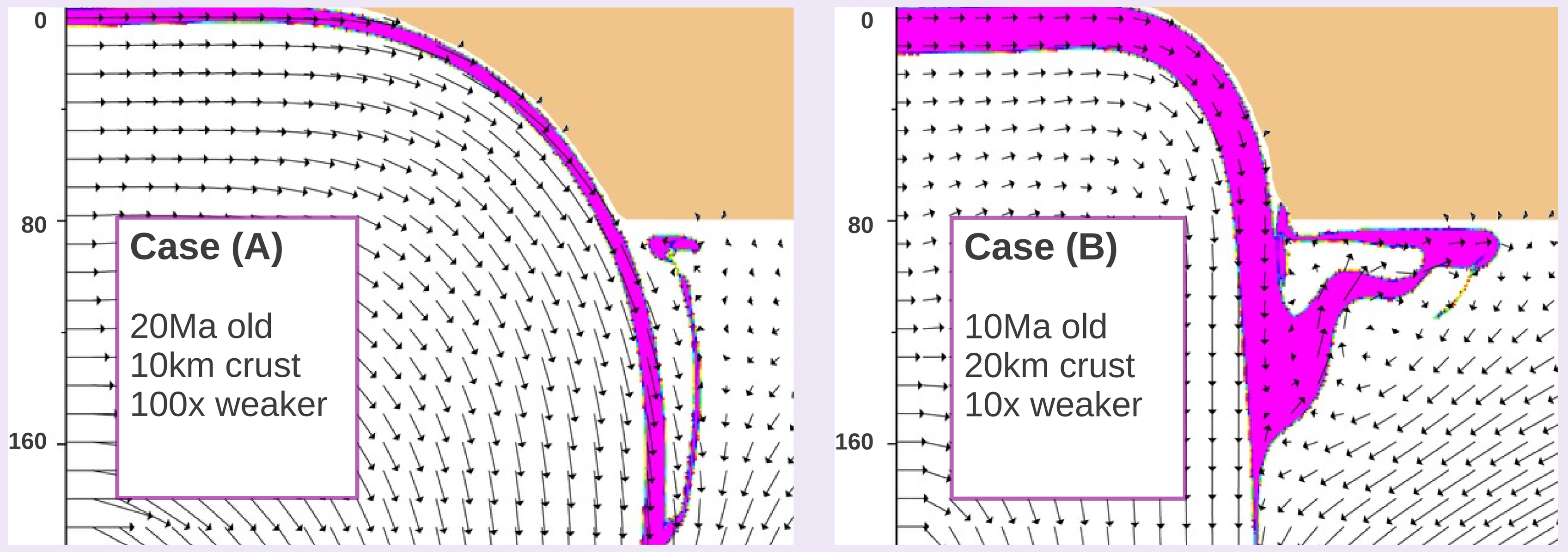


Figure 4 (above) Two examples of models where significant crustal deformation took place. The pink region is crustal material and beige is the over-riding lithosphere.

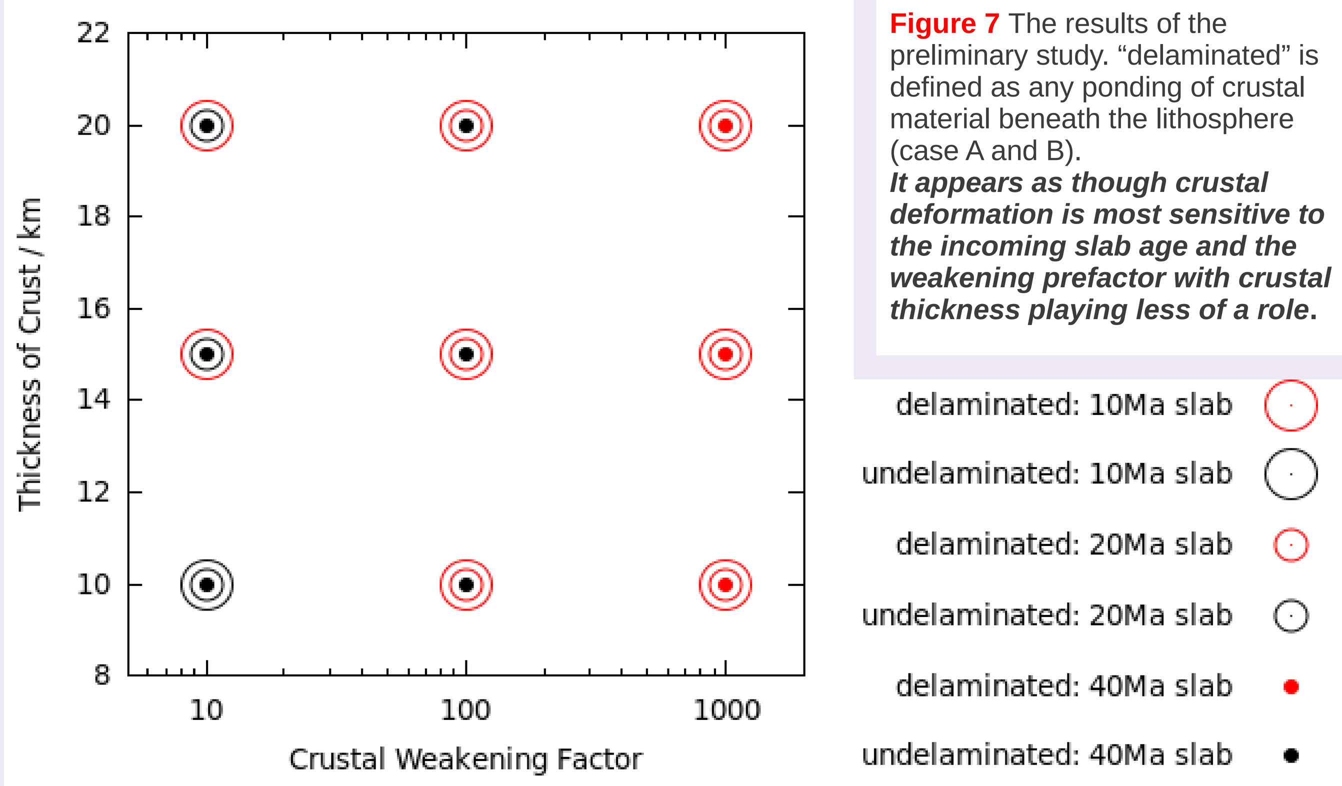
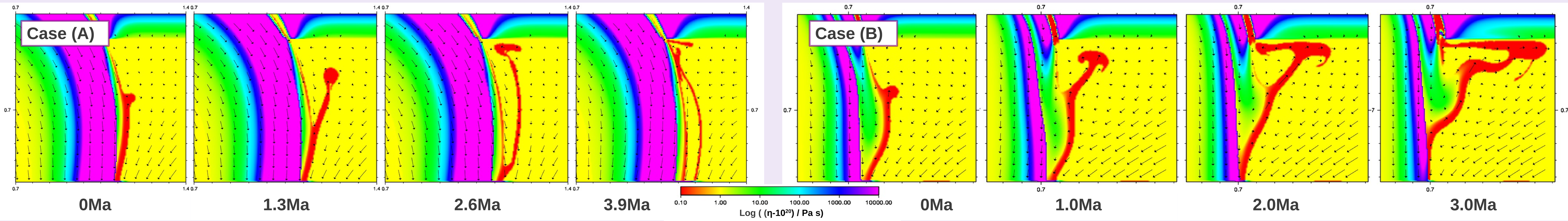


Figure 7 The results of the preliminary study. "delaminated" is defined as any ponding of crustal material beneath the lithosphere (case A and B).
It appears as though crustal deformation is most sensitive to the incoming slab age and the weakening prefactor with crustal thickness playing less of a role.

Figure 5 (below) Viscosity profile snapshots of **case (A)**. When crustal deformation occurs in 20Ma and 40Ma slabs it does so because it has been heated from above. This creates a thin weak layer which can become unstable. The resulting behaviour is similar to the "cold plumes" investigated by Gerya and Yuen (2003) **[6]** and leads to brief (~1Ma) ponding of crustal material beneath the lithosphere.

Figure 6 (below) Viscosity profile snapshots of **case (B)**. When crustal deformation occurs in 10Ma, the mantle lithosphere is thin enough for the crust to be heated from both above and below. This leads almost whole crustal delamination and extensive and more long lived ponding of crustal material beneath the lithosphere.



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