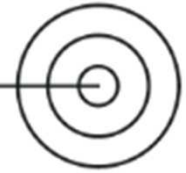




Geological Survey of
Western Australia

Centre for **EXPLORATION**
TARGETING



Numerical modelling of the west Musgrave Province

Weronika Gorczyk & Hugh Smithies

we are almost there 😊



THE UNIVERSITY OF
WESTERN AUSTRALIA



Australian Government
Australian Research Council



Numerical technique:

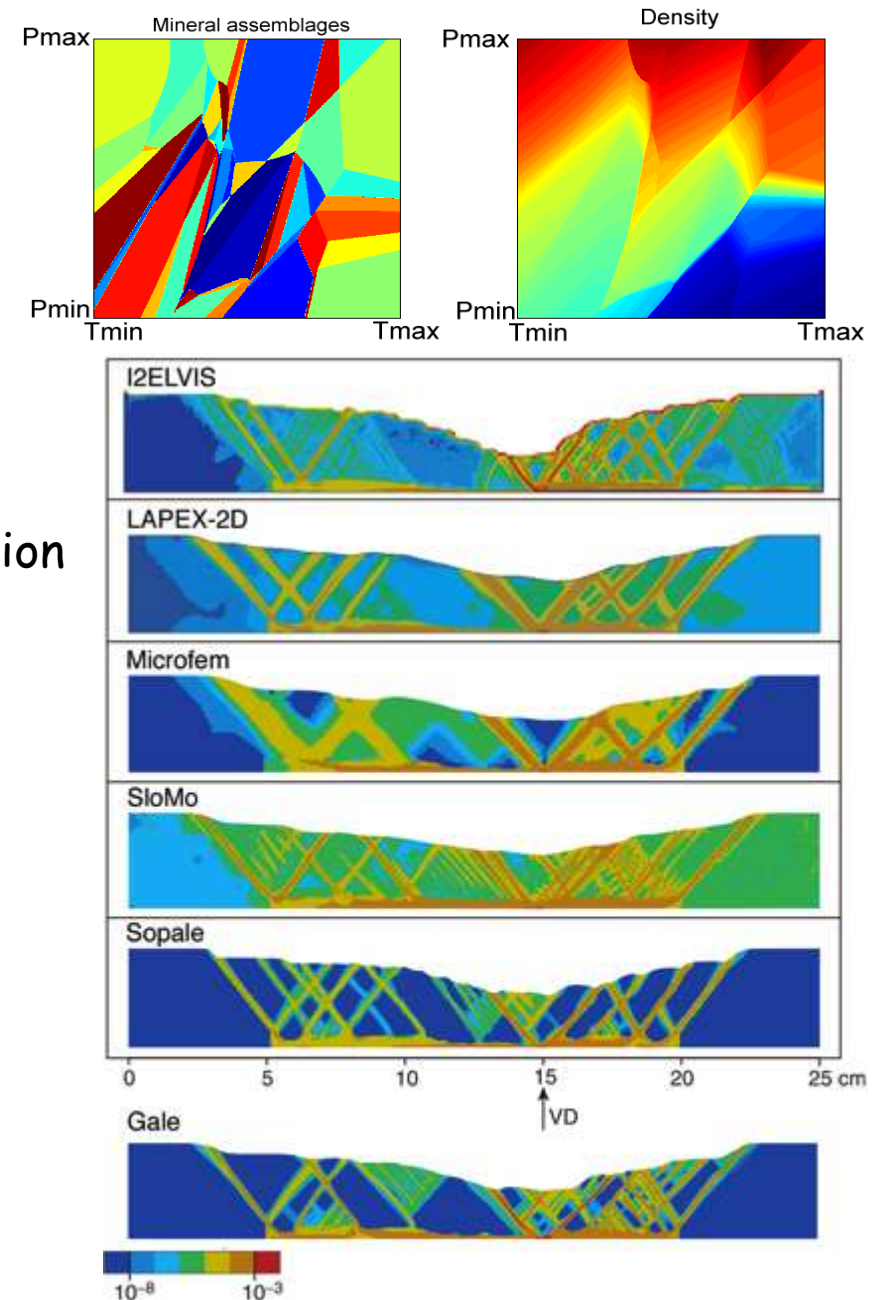
•Rheological model:

VISCO-EELASTO-PLASTIC

•**Stable mineral assemblages** are computed based on thermodynamic data and Gibbs free energy minimization (Connolly & Pettrini, 2007) as a function of P and T

•**Hydration and water migration:** Dehydration reactions and associated water release are computed based on the physico-chemical conditions and the assumption of thermodynamic equilibrium. Expelled water is stored in a newly generated water marker that moves independently

•**Changes in topography** - account for the effects of erosion and sedimentation



Numerical technique:

• **Partial melting** - For a given pressure and rock composition the volumetric degree of melting M_0 is:

$$M_0 = 0 \quad \text{when } T < T_{\text{solidus}},$$

$$M_0 = (T - T_{\text{solidus}}) / (T_{\text{liquidus}} - T_{\text{solidus}}) \quad \text{when } T_{\text{solidus}} < T < T_{\text{liquidus}},$$

$$M_0 = 1 \quad \text{when } T > T_{\text{liquidus}},$$

• effective viscosity is calculated using:

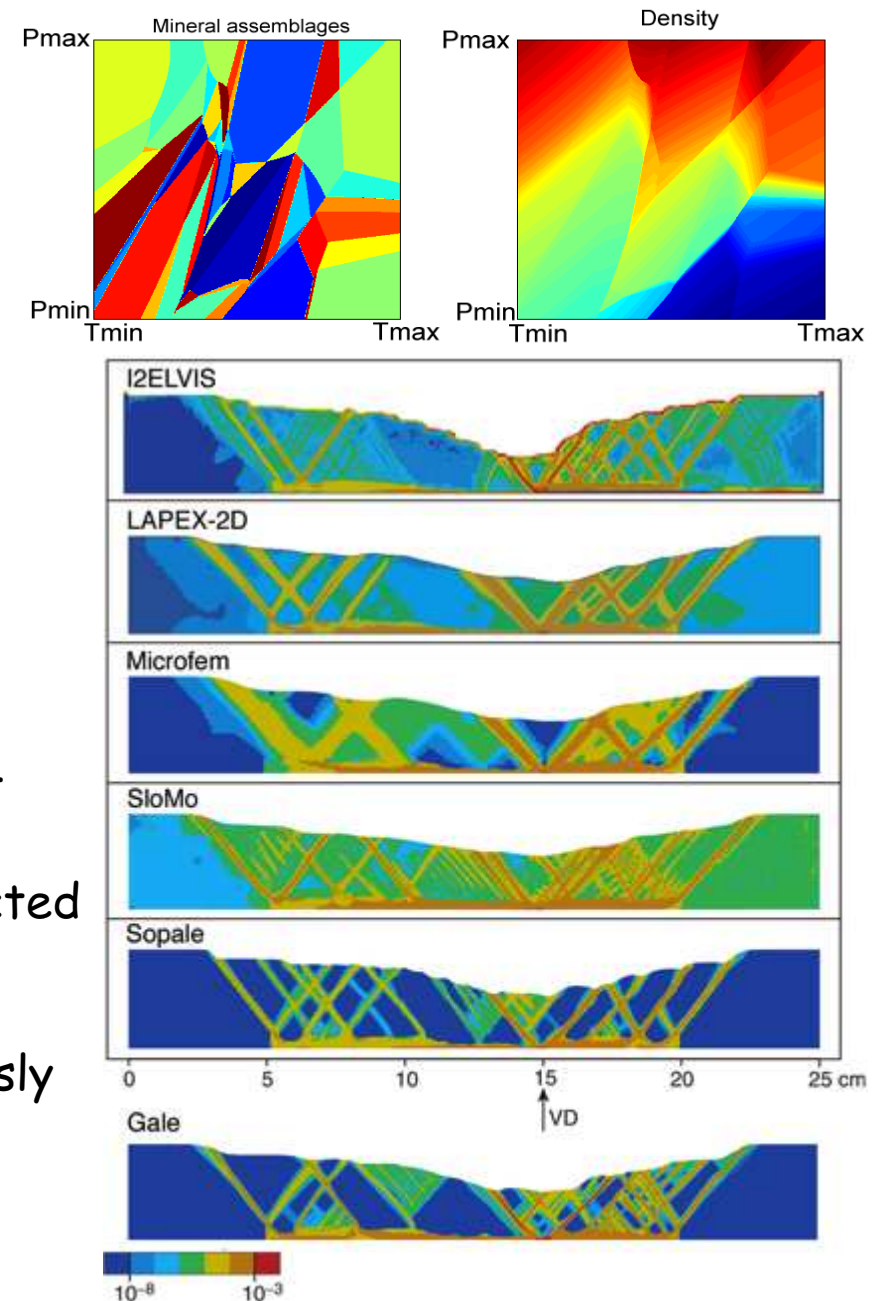
$$\eta = \eta_0 \exp\left[2.5 + (1 - M) \left(\frac{1 - M}{M}\right)^{0.48}\right]$$

$\eta_0 = 10^{13} \text{ Pa}\cdot\text{s}$ - molten mafic rocks,

$\eta_0 = 5 \times 10^{14} \text{ Pa}\cdot\text{s}$ - molten felsic rocks

• **Melt extraction and intrusion** - when melt fraction exceeds 4%, only 4% remain in the source, markers track the amount of extracted melt.

Extracted melt is transmitted instantaneously to emplacement areas:
 intrusive rocks 80% of melt
 extrusive rocks - 20 % of melt



Geological Background: Musgrave Orogeny

1345-1293Ma - *Mt West Orogeny* - *granitic magmatism*
(*Wankanki Supersuite*) + *deposition of sediments*

1220 - 1120Ma - *Musgrave Orogeny*-
UTH metamorphism + *intra-plate magmatism*

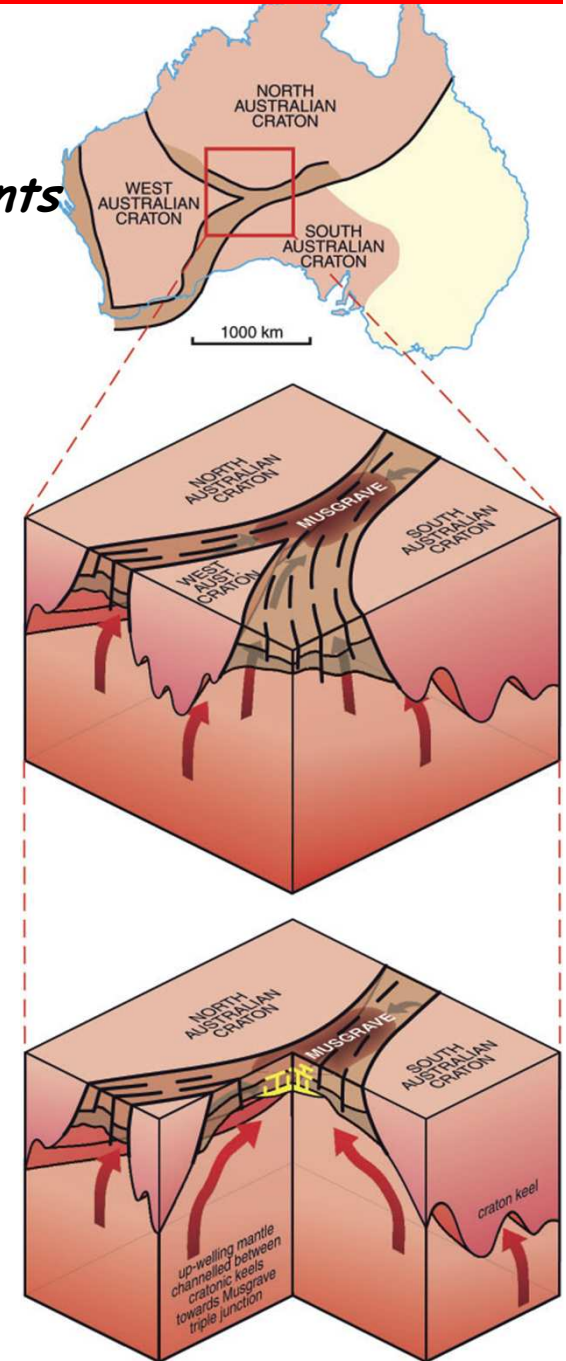
(1) A-type granites > 1000°C

(2) ~50% mantle contribution

(3) Several remobilization events (sub-groups)

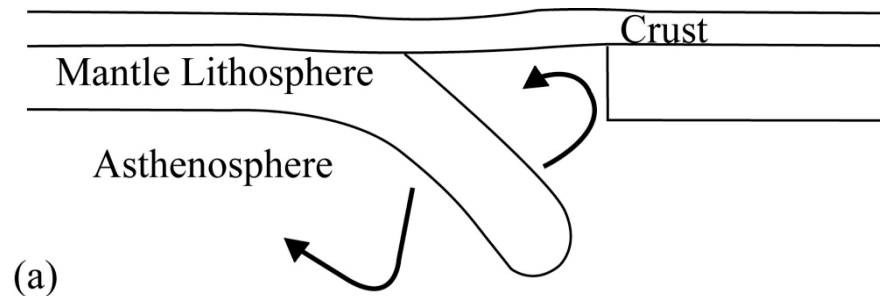
(4) 100 Ma of thin crust and extensive melting events,

1085-1040Ma - *Giles event* - extensional rifting.
Bulk mafic melting event - 60 Ma of magmatism.

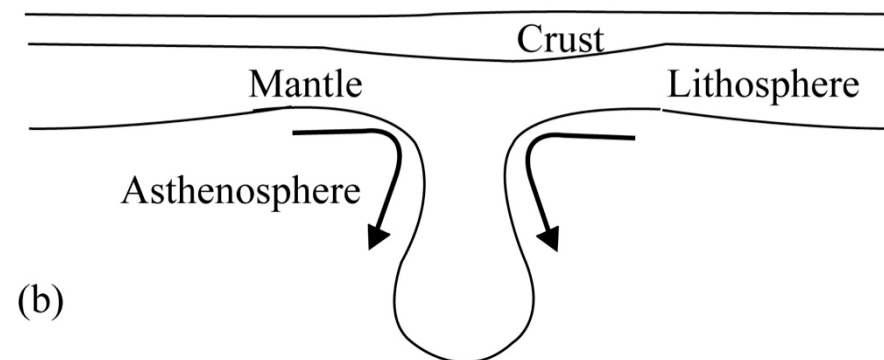


How to melt crustal material far from plate boundaries??

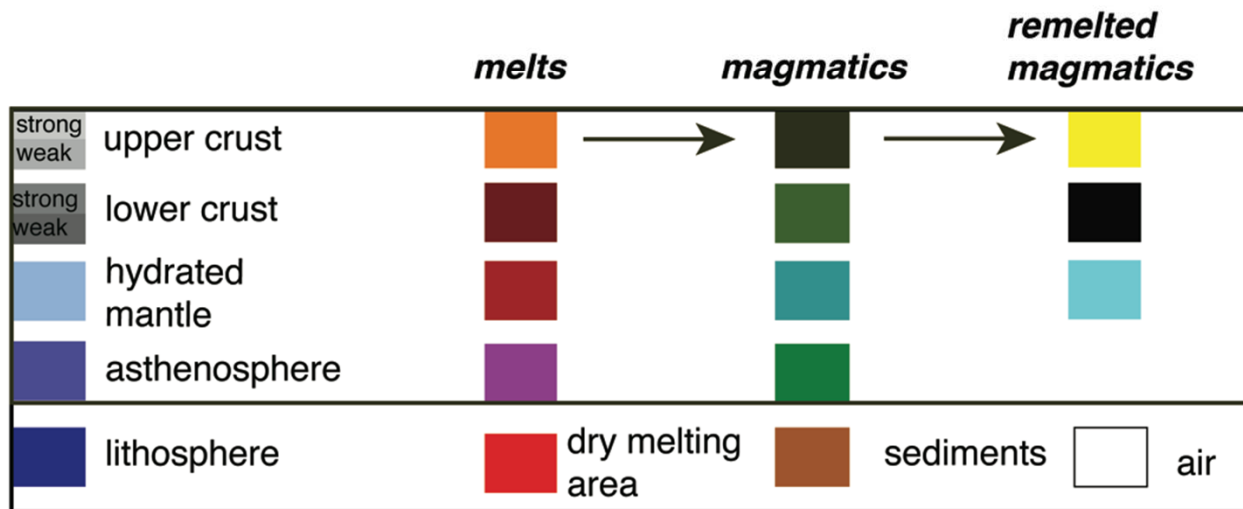
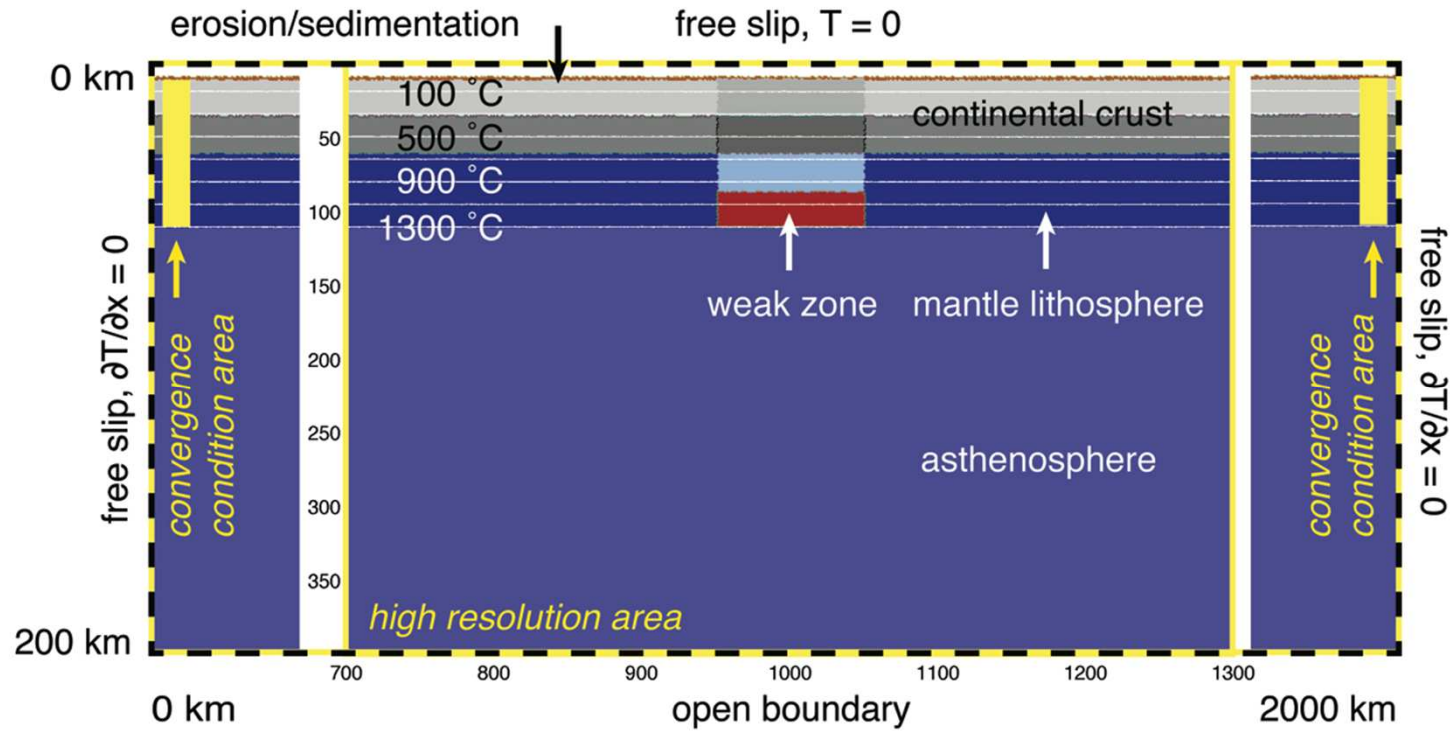
Lithospheric delamination - after Bird (1978)



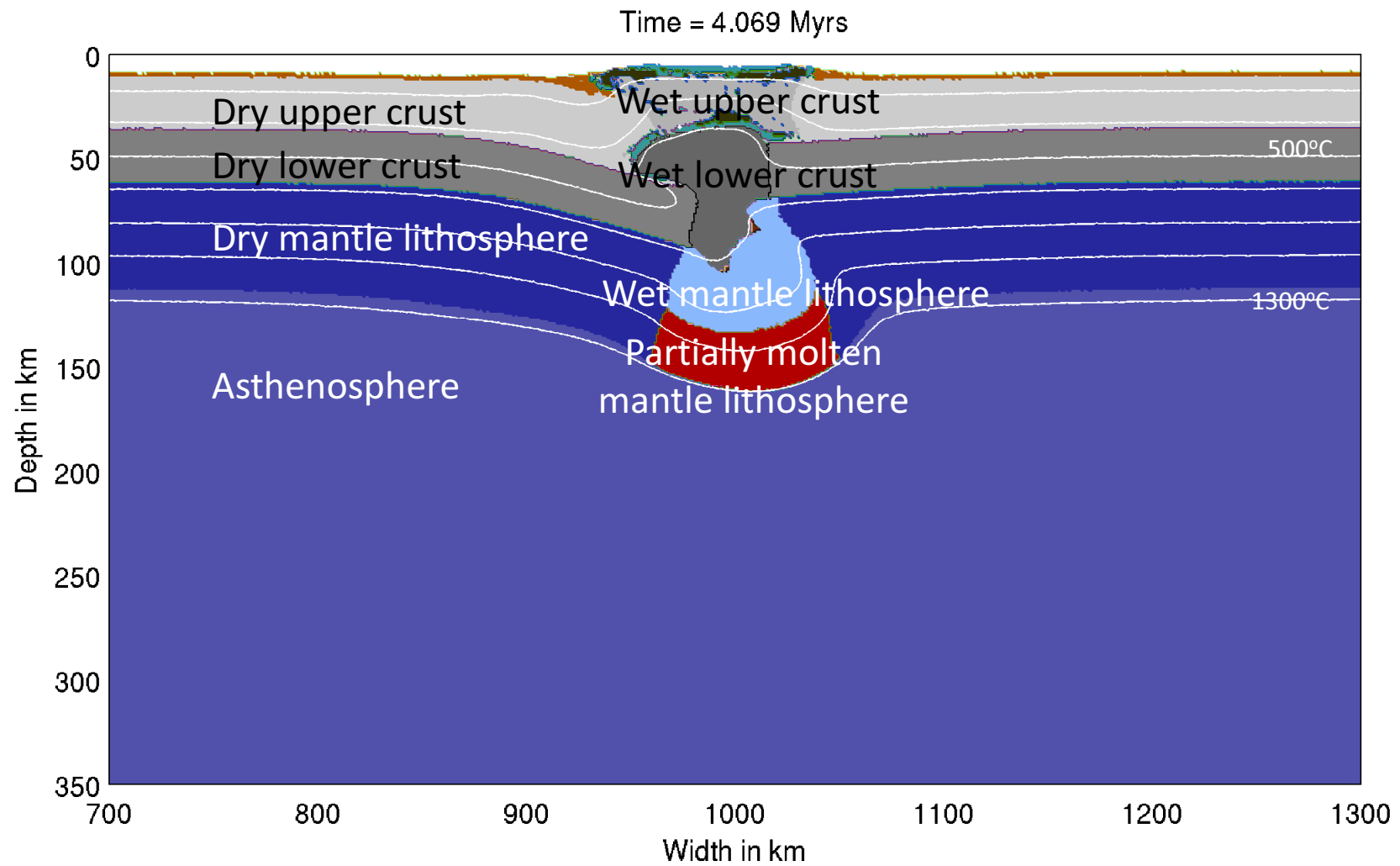
Gravitational instability - after Houseman (1981)



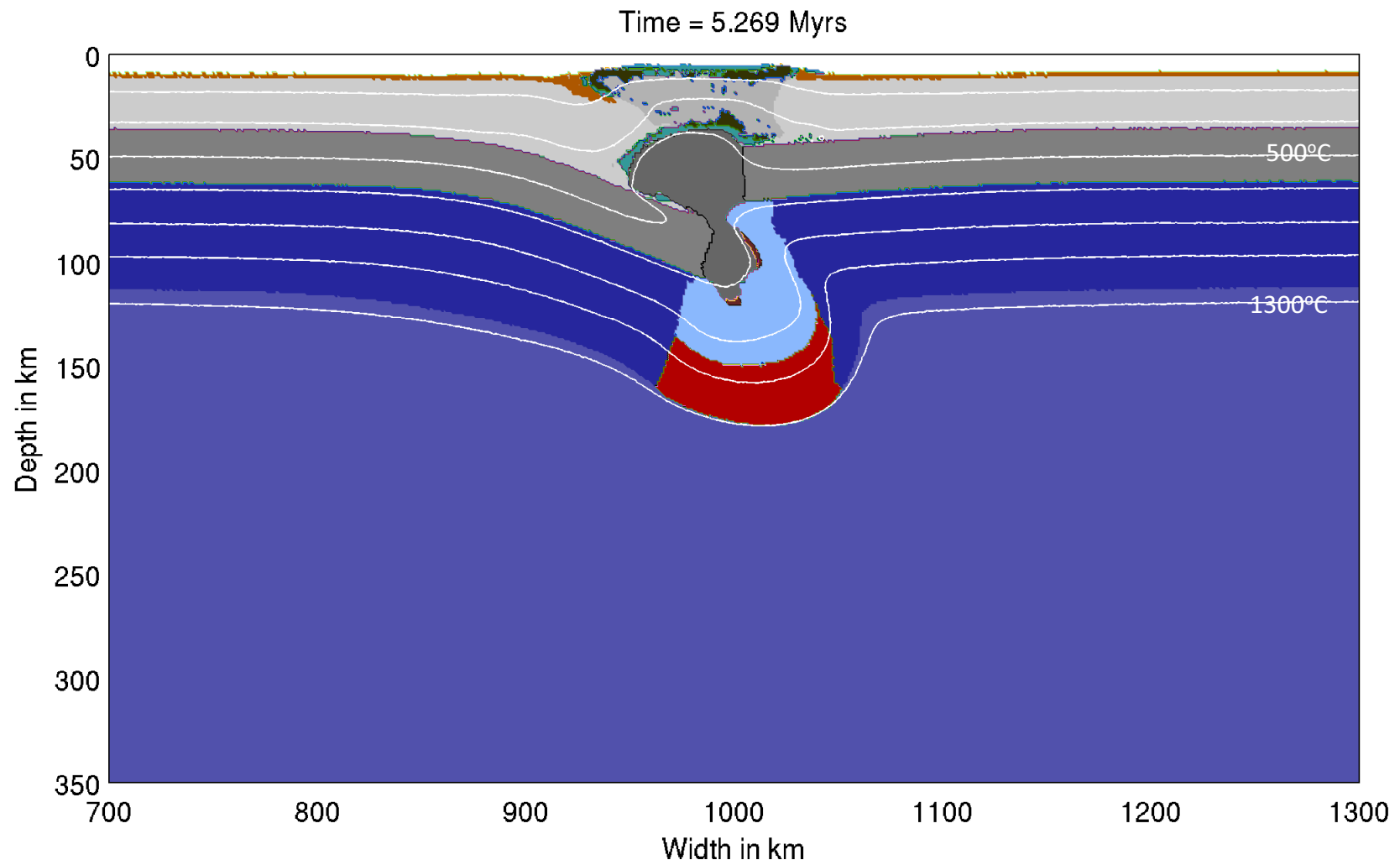
Numerical modelling: initial setup



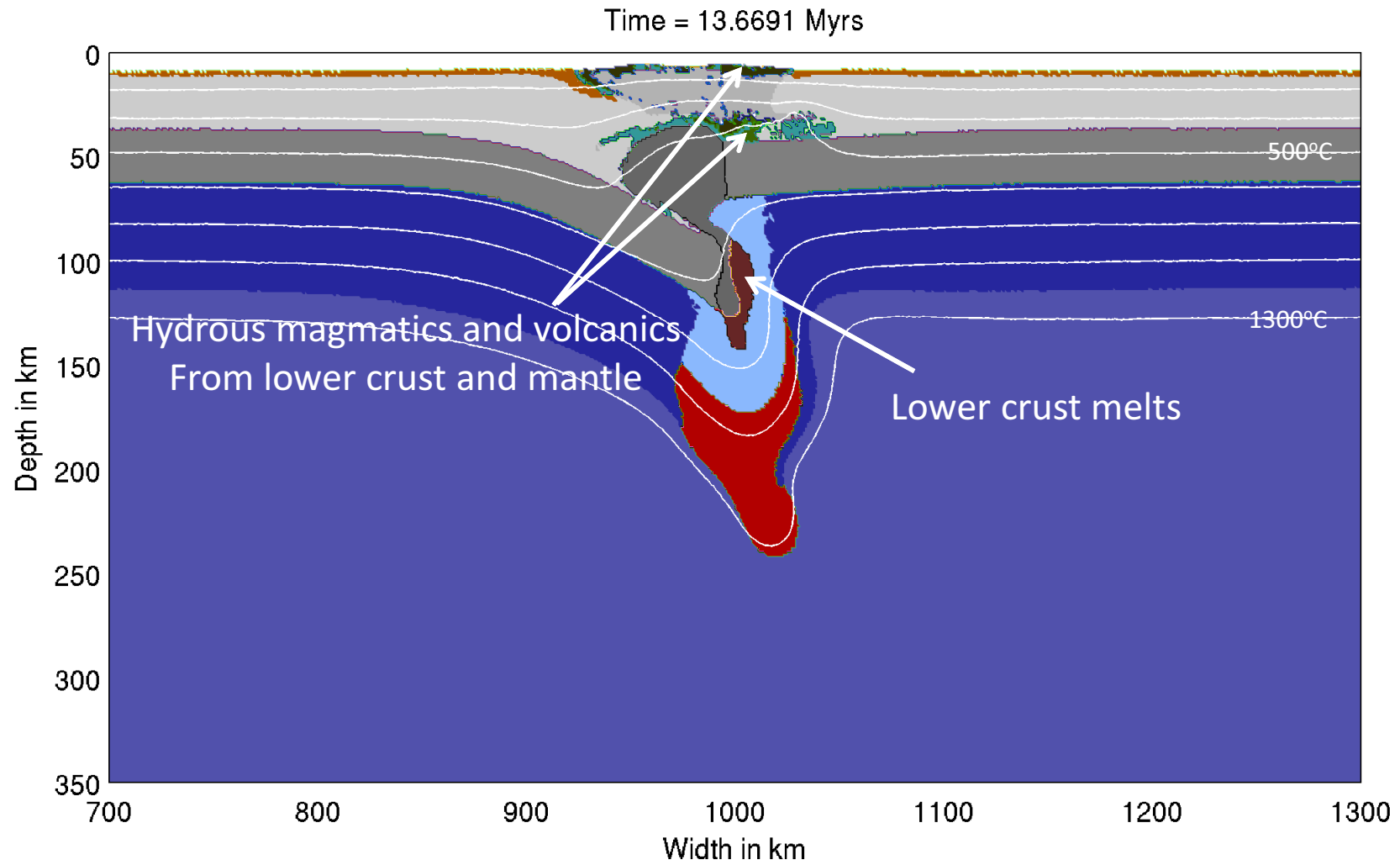
Numerical modelling: Gravitational Instability



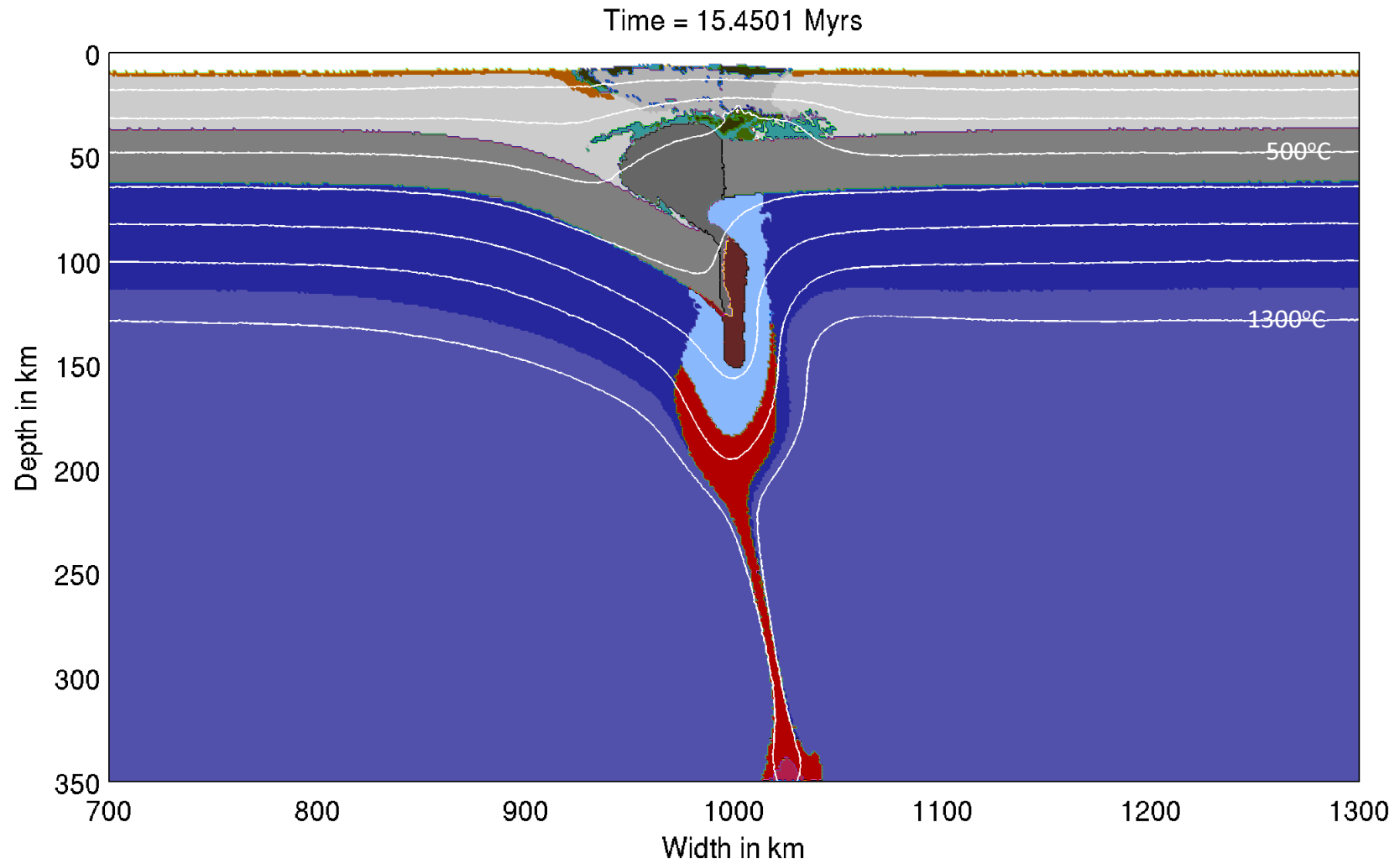
Numerical modelling: Gravitational Instability



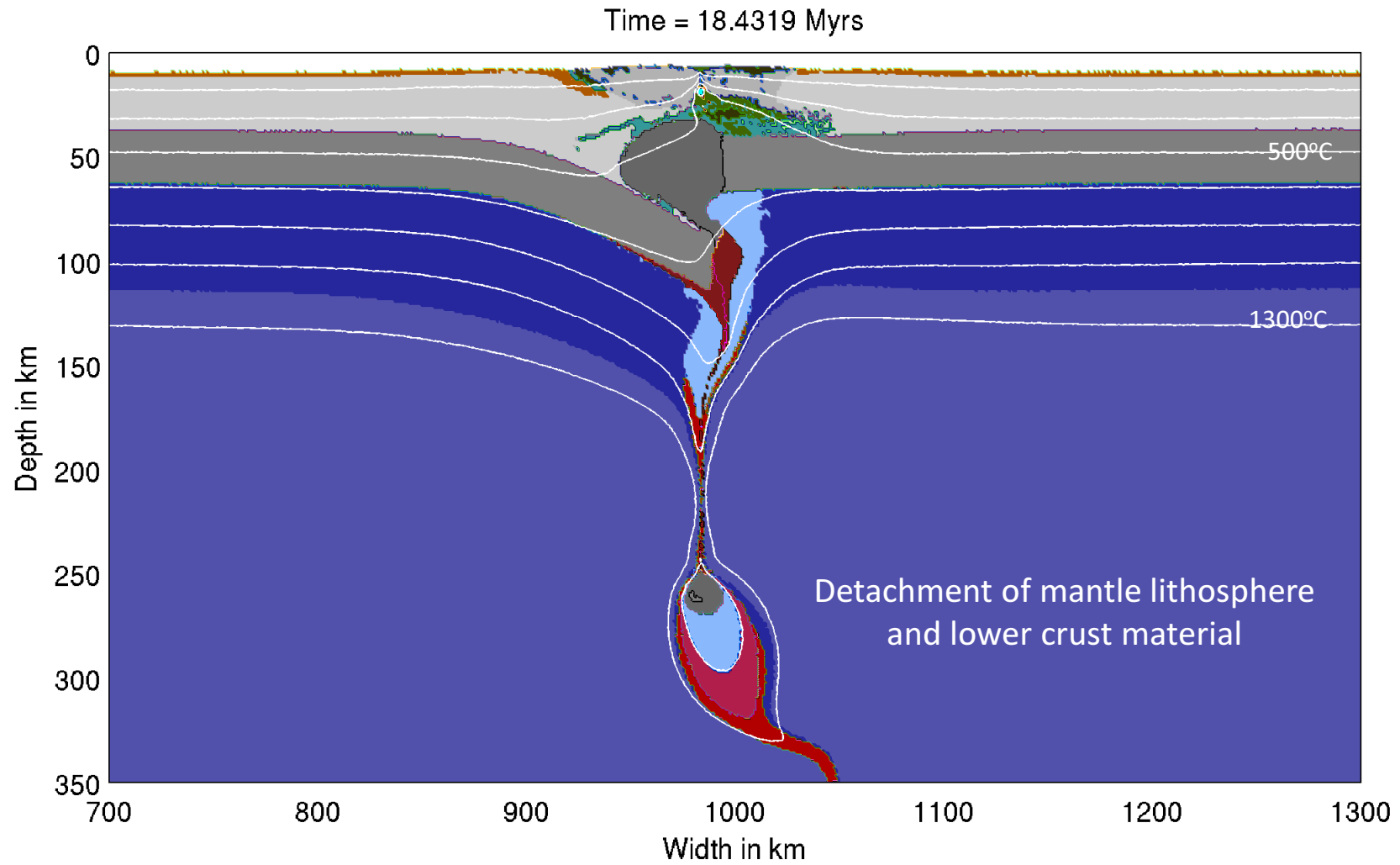
Numerical modelling: Gravitational Instability



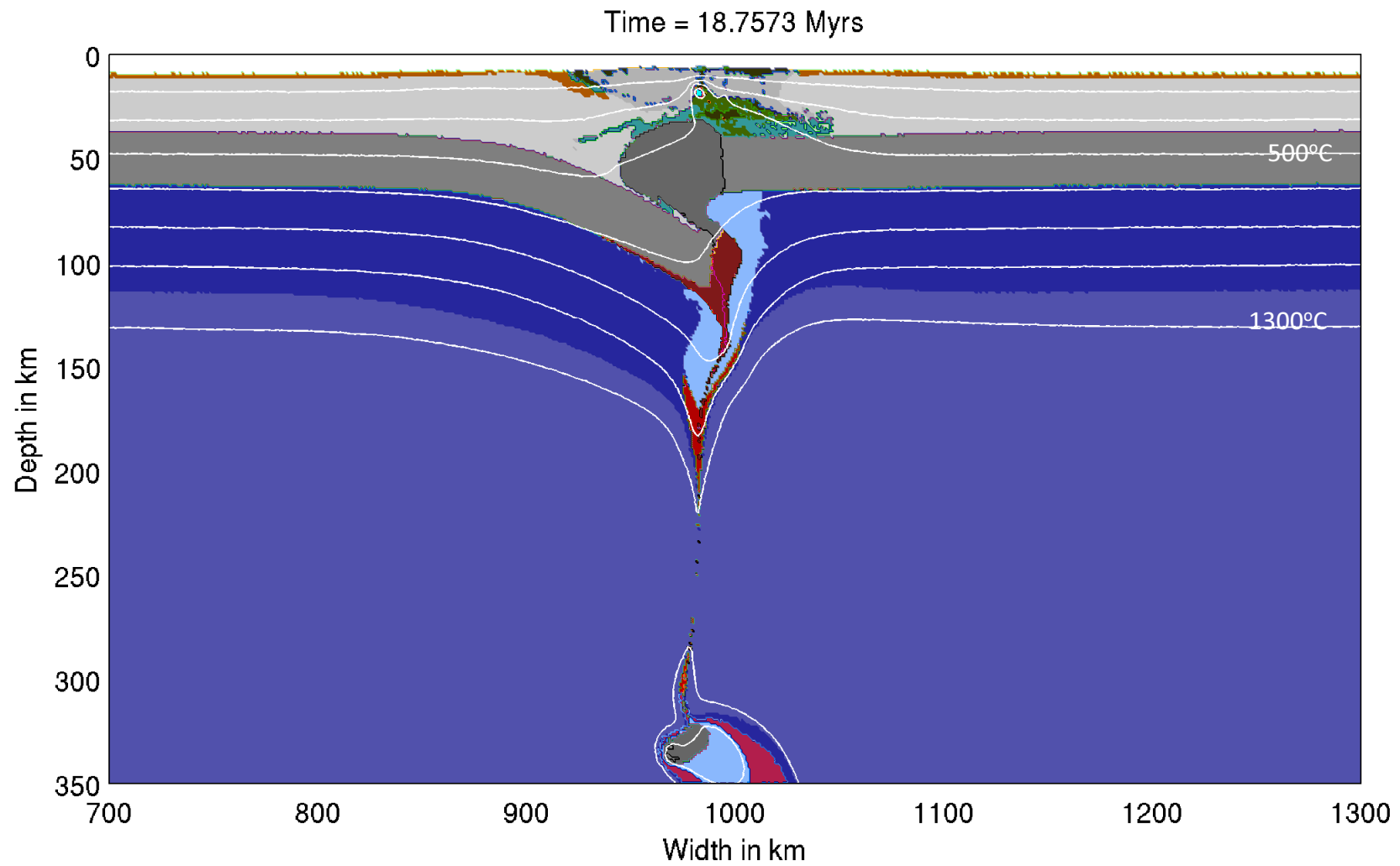
Numerical modelling: Gravitational Instability



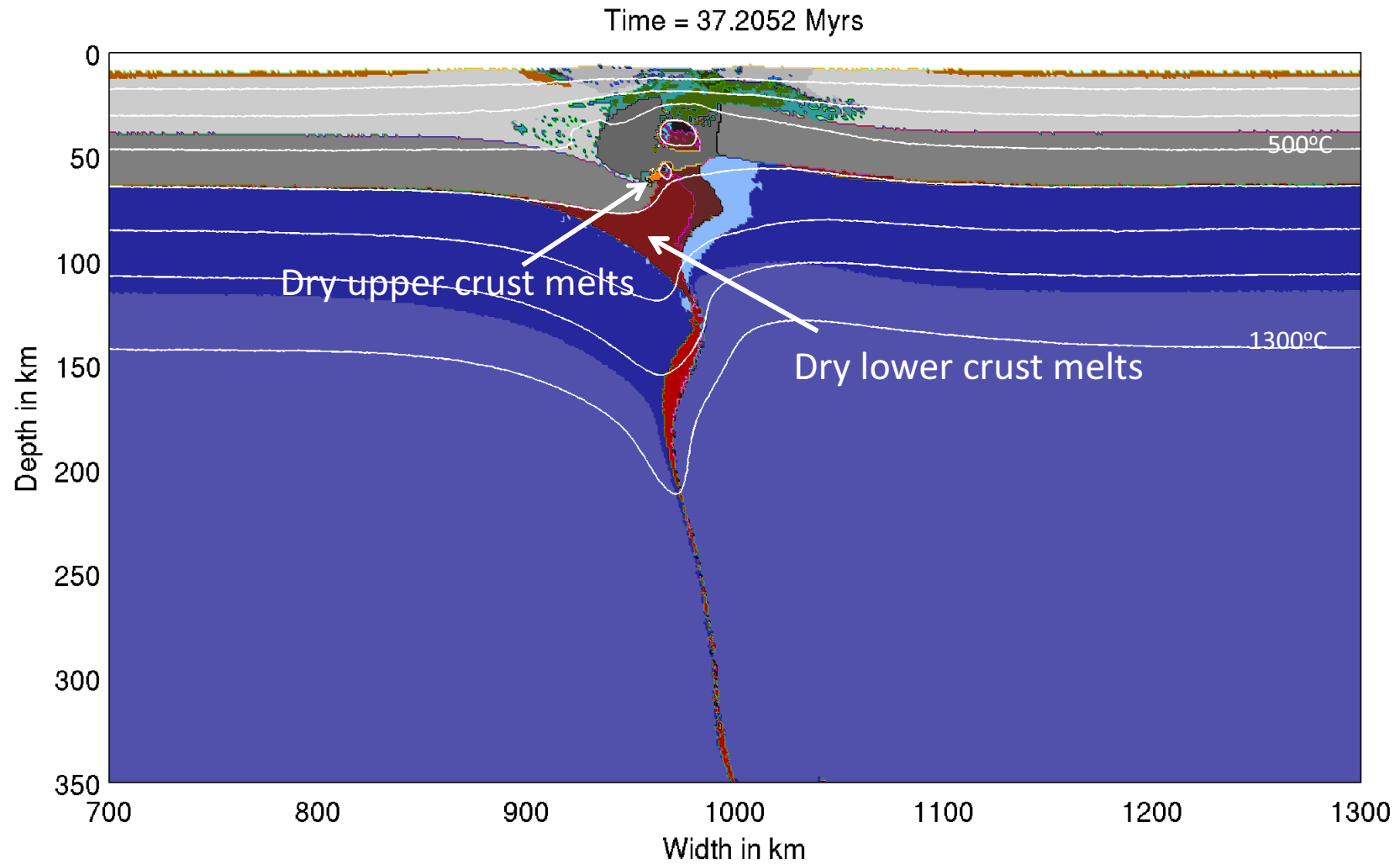
Numerical modelling: Gravitational Instability



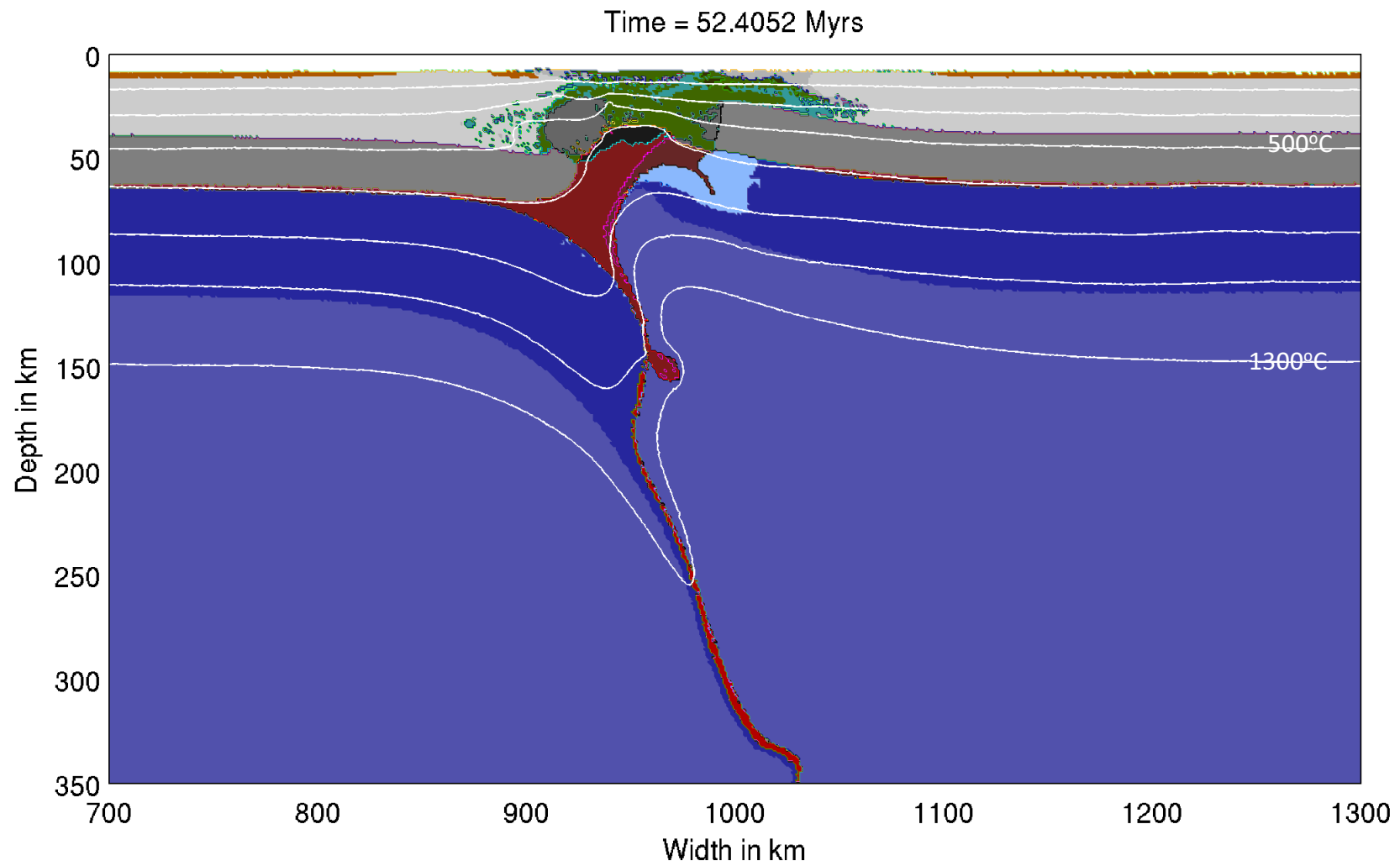
Numerical modelling: Gravitational Instability

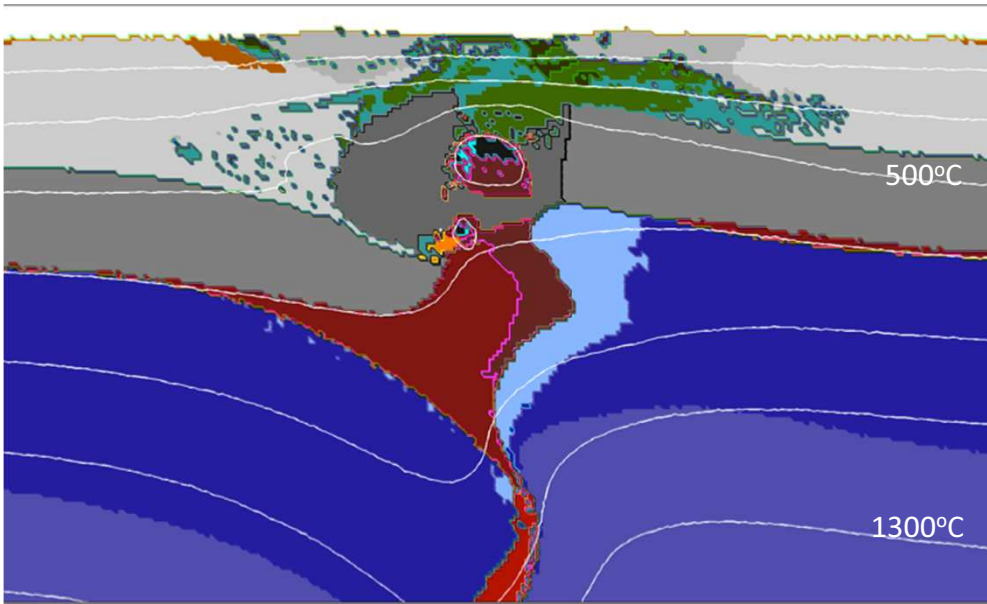


Numerical modelling: Gravitational Instability

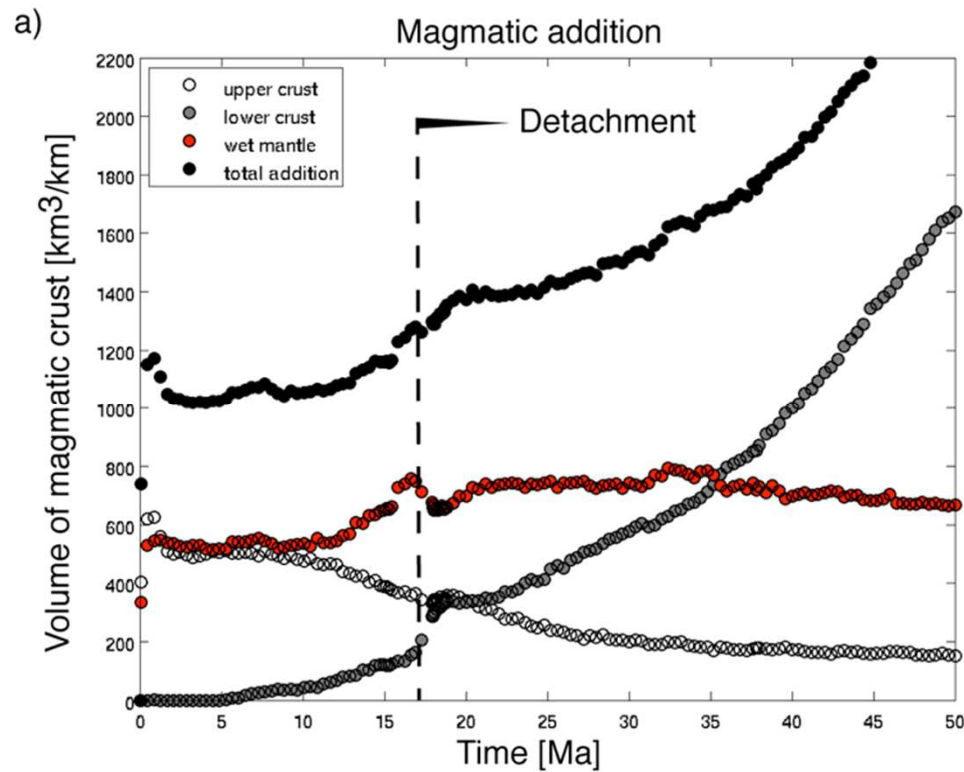


Numerical modelling: Gravitational Instability

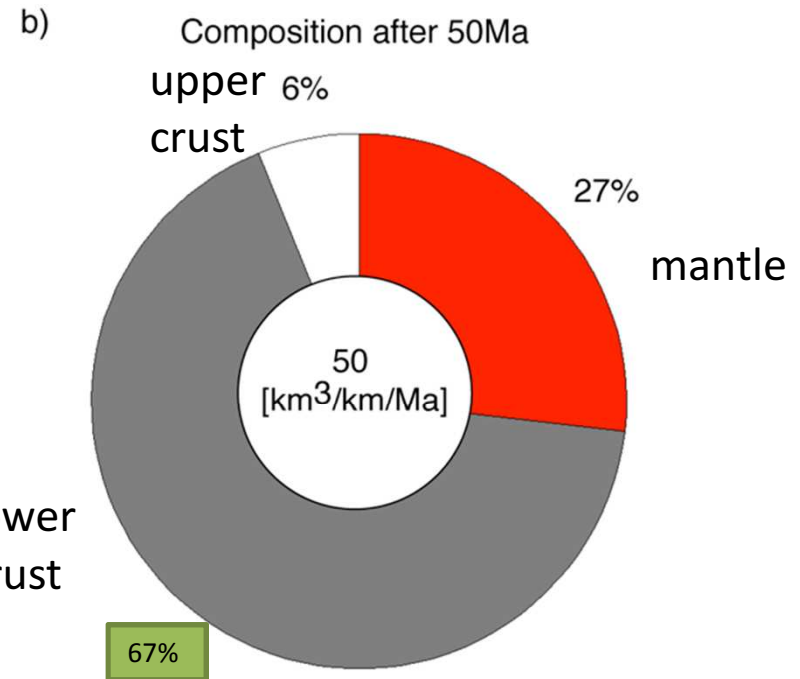


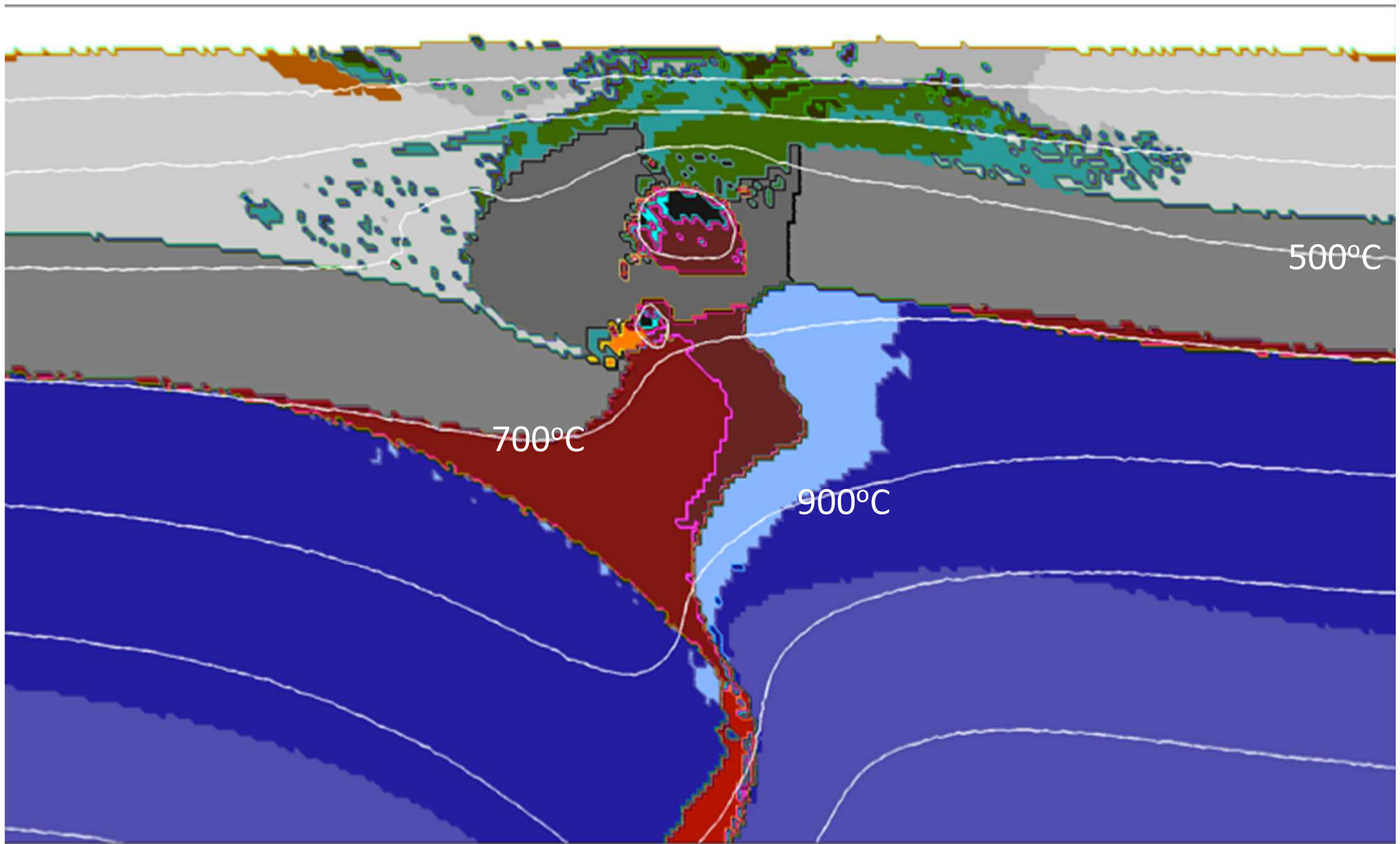


Generation of new crust happens mostly after detachment - dominated by melting of the lower crust



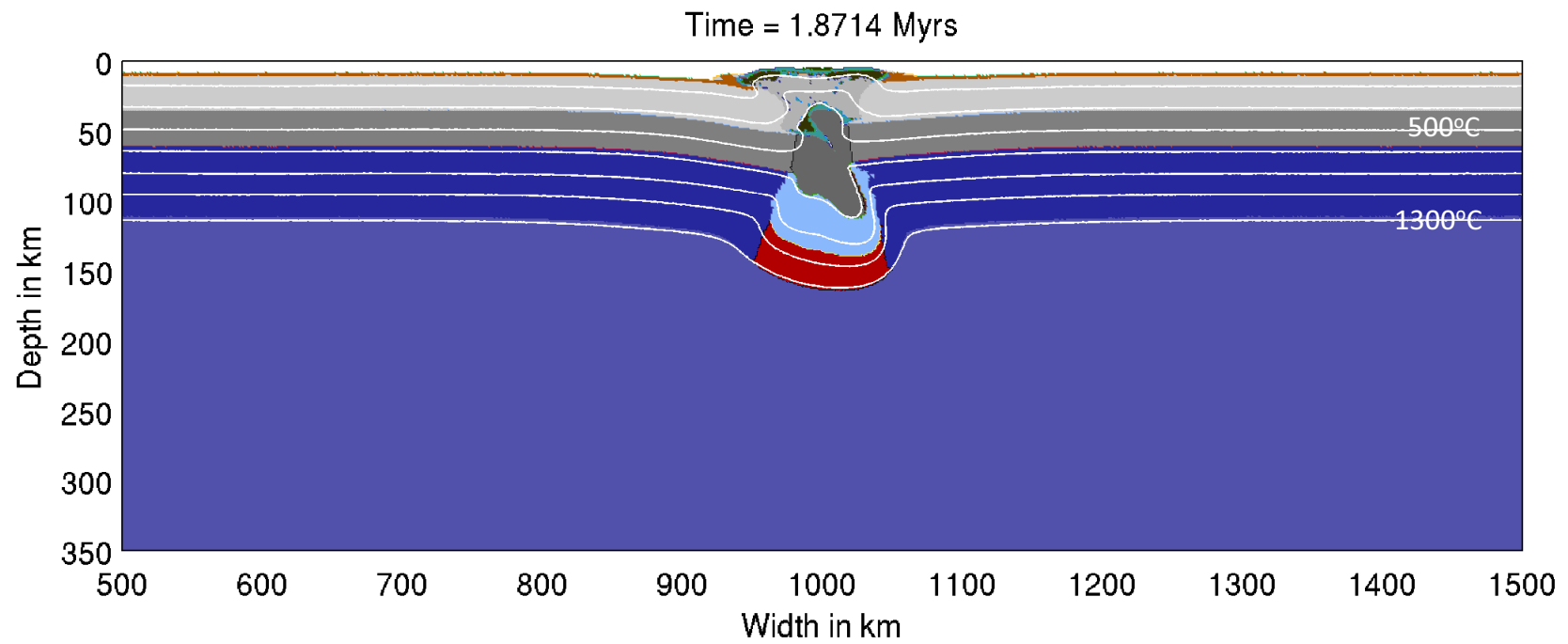
New crust



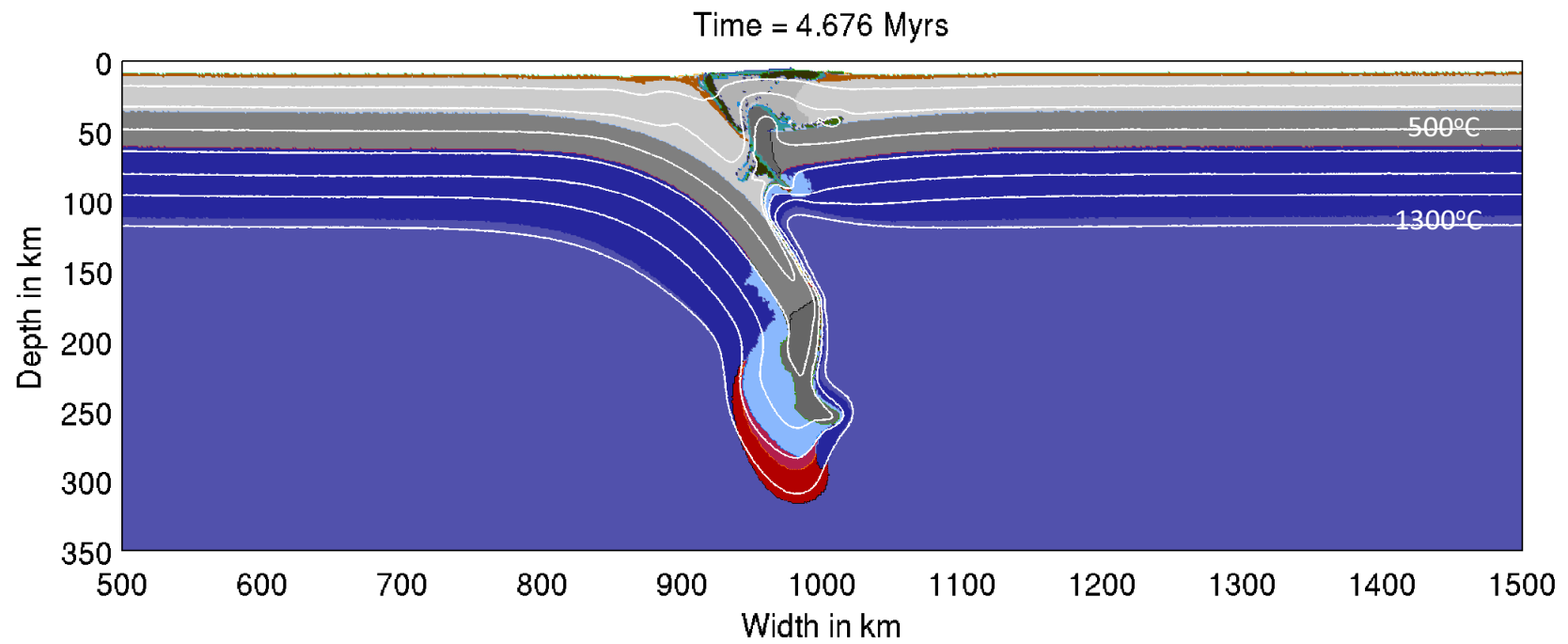


Melting of lower crust at 700 - 900°

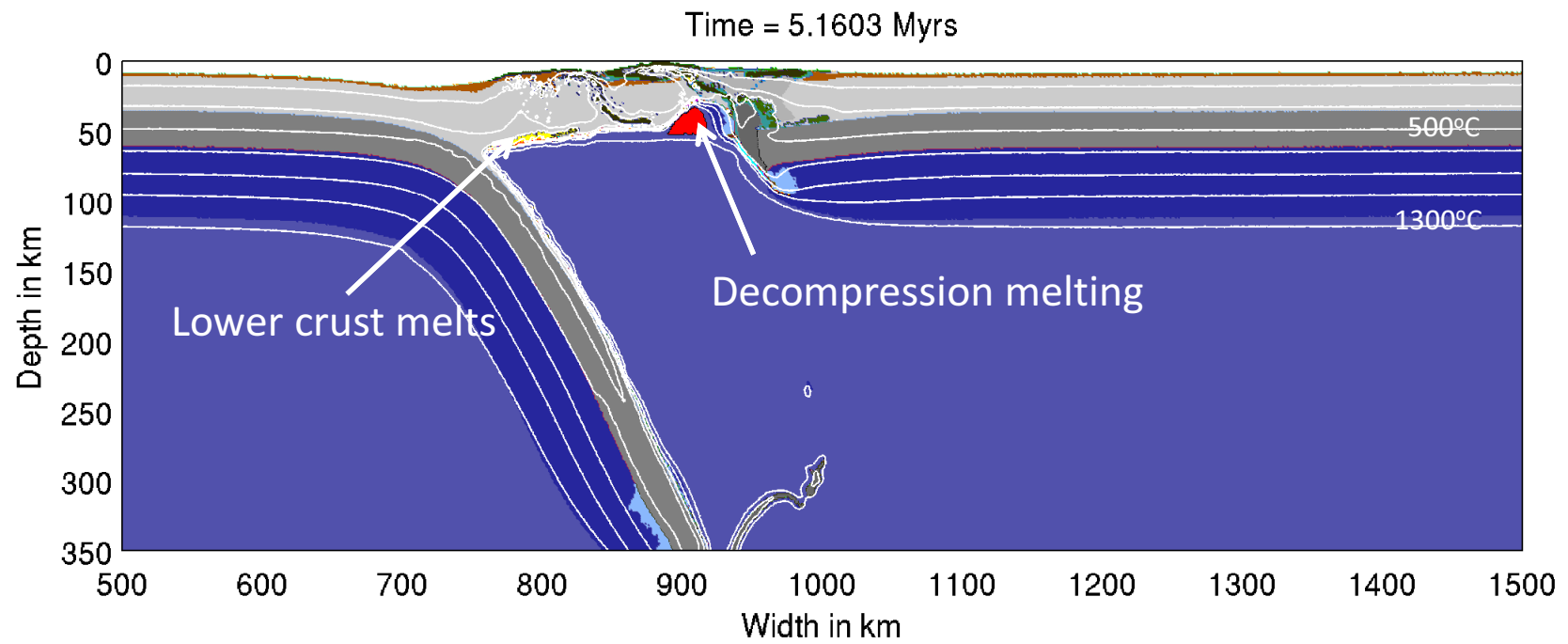
Numerical modelling: Delamination



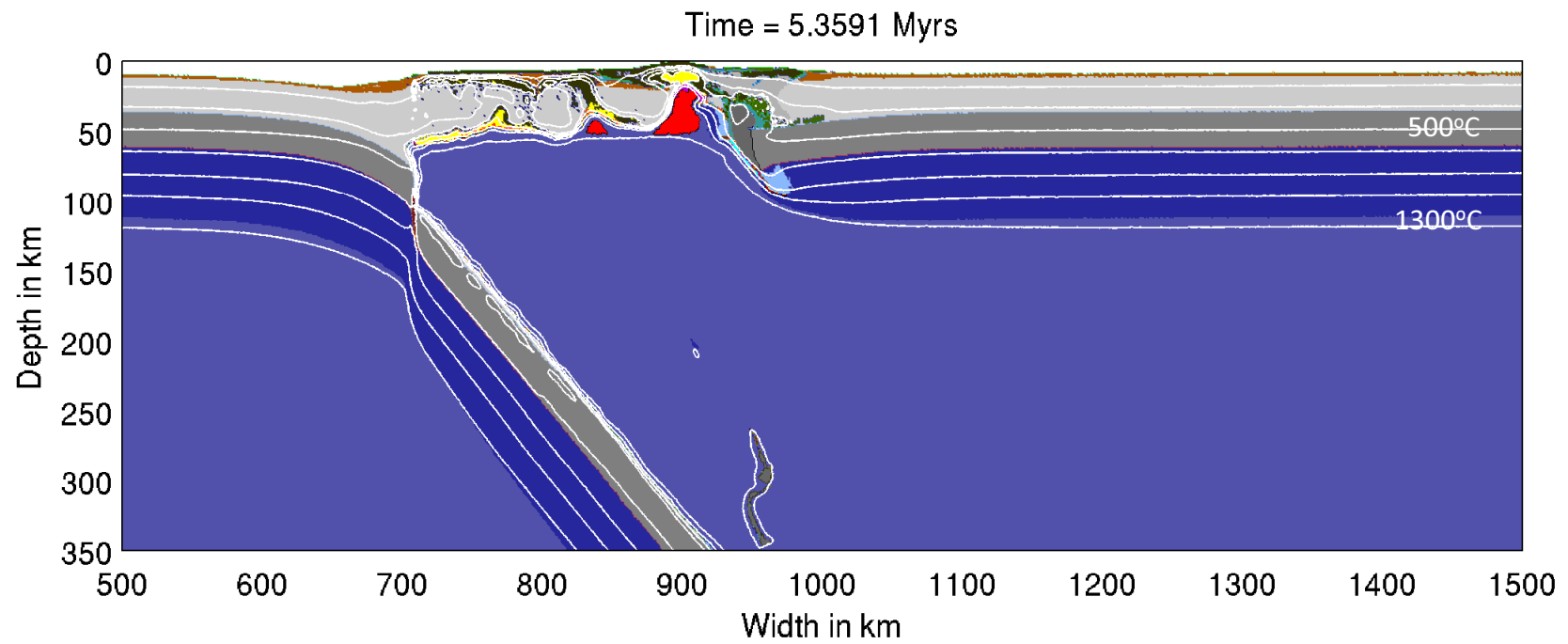
Numerical modelling: Delamination



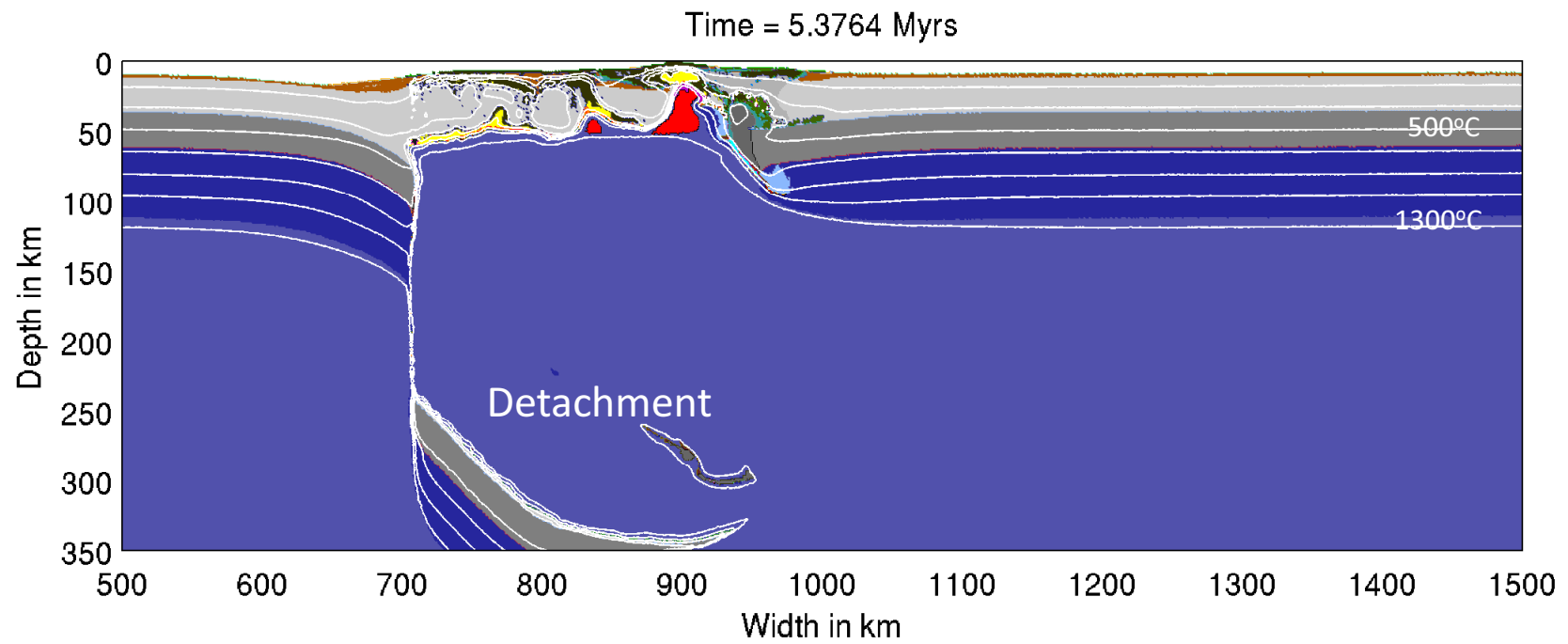
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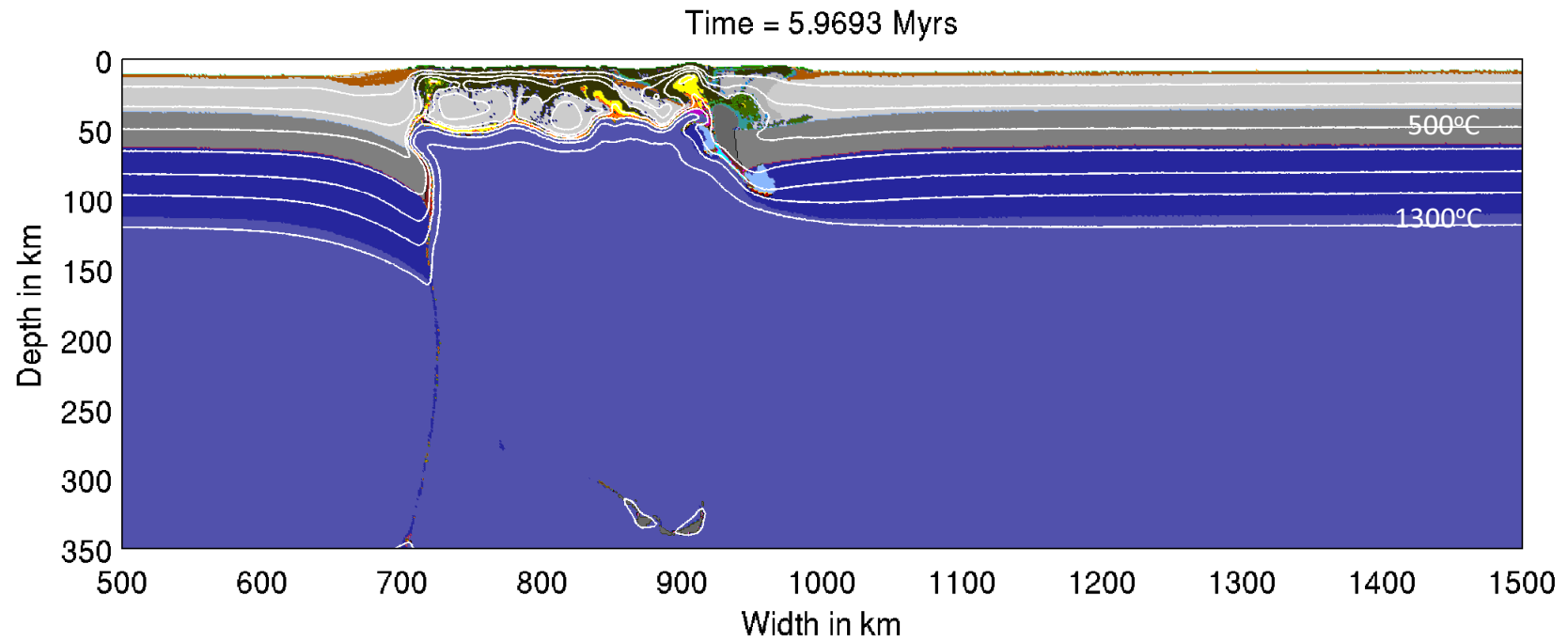
Numerical modelling: Delamination



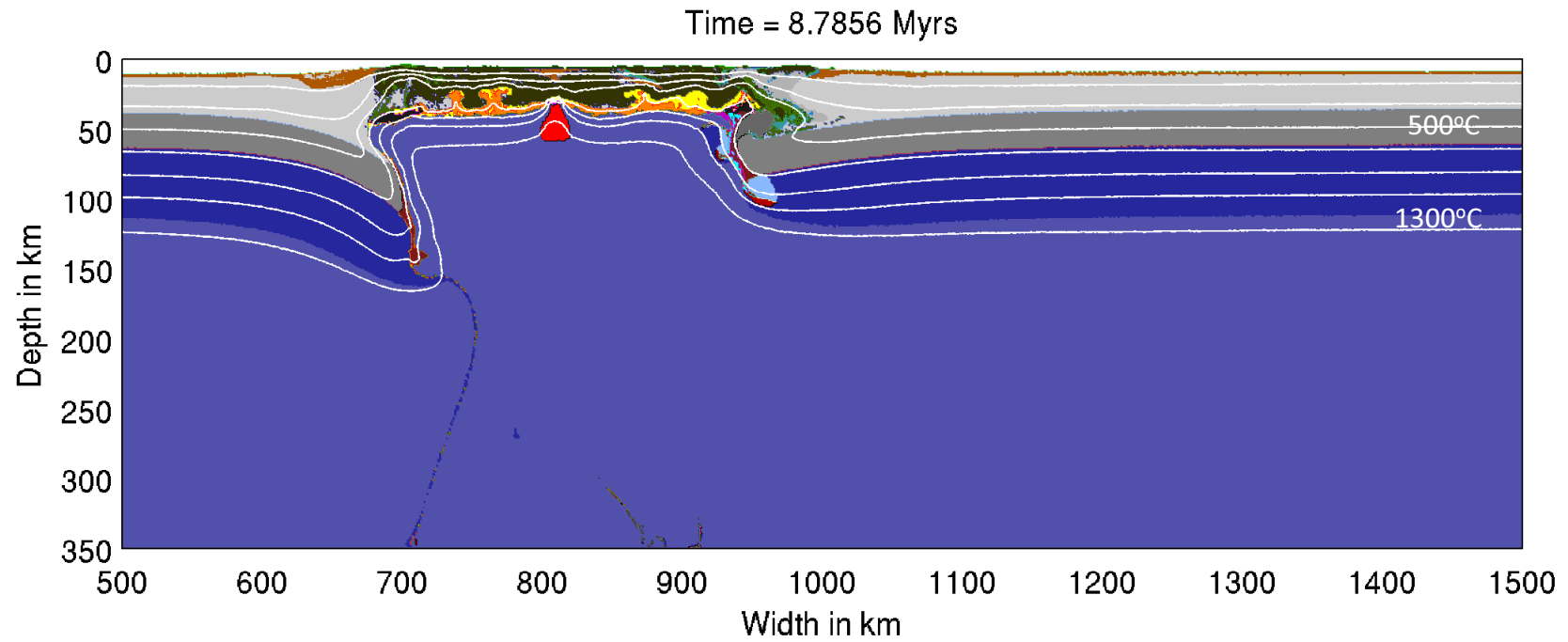
Numerical modelling: Delamination



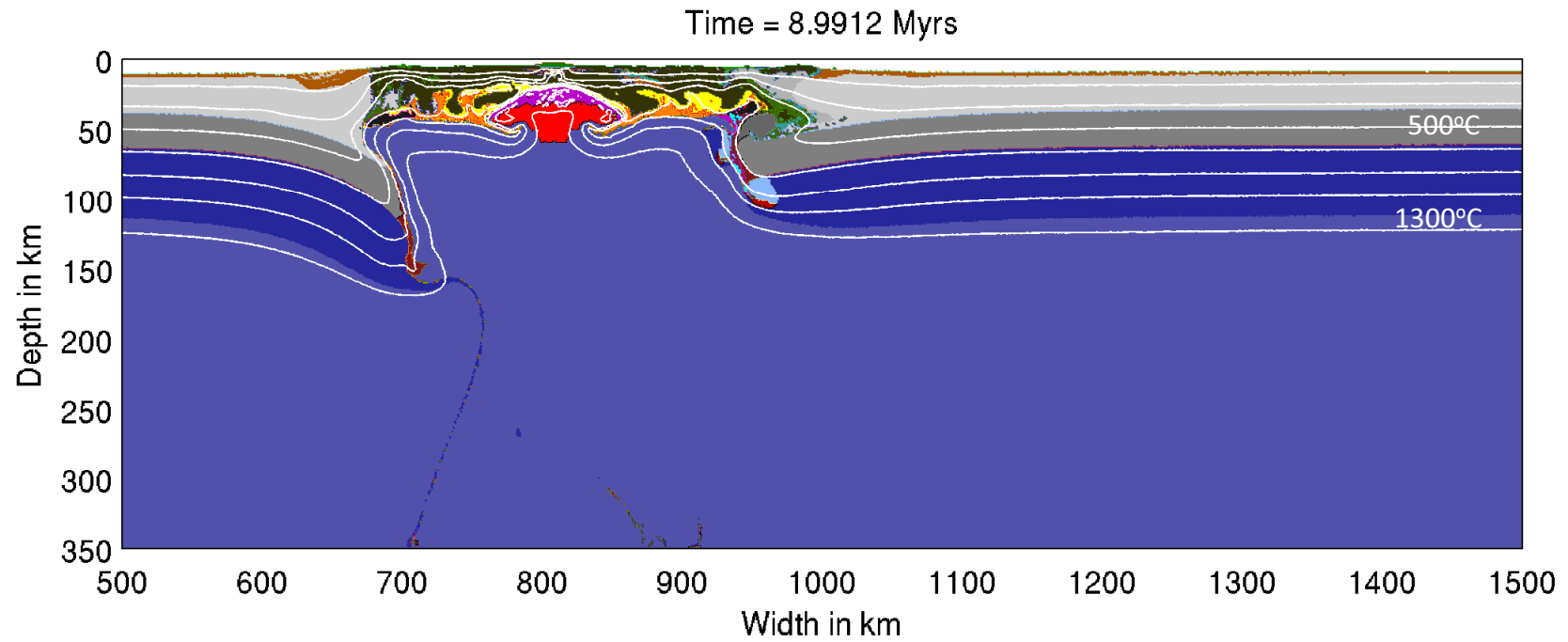
Numerical modelling: Delamination



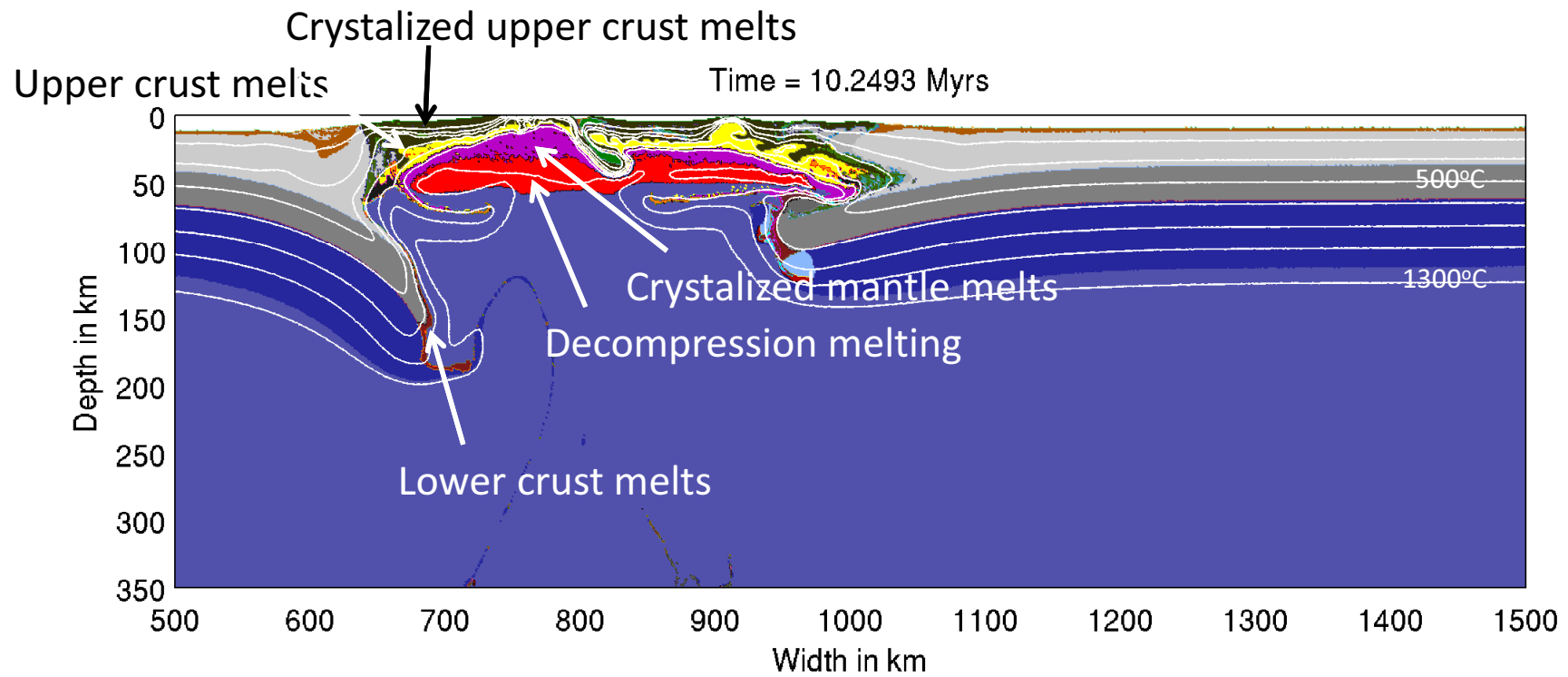
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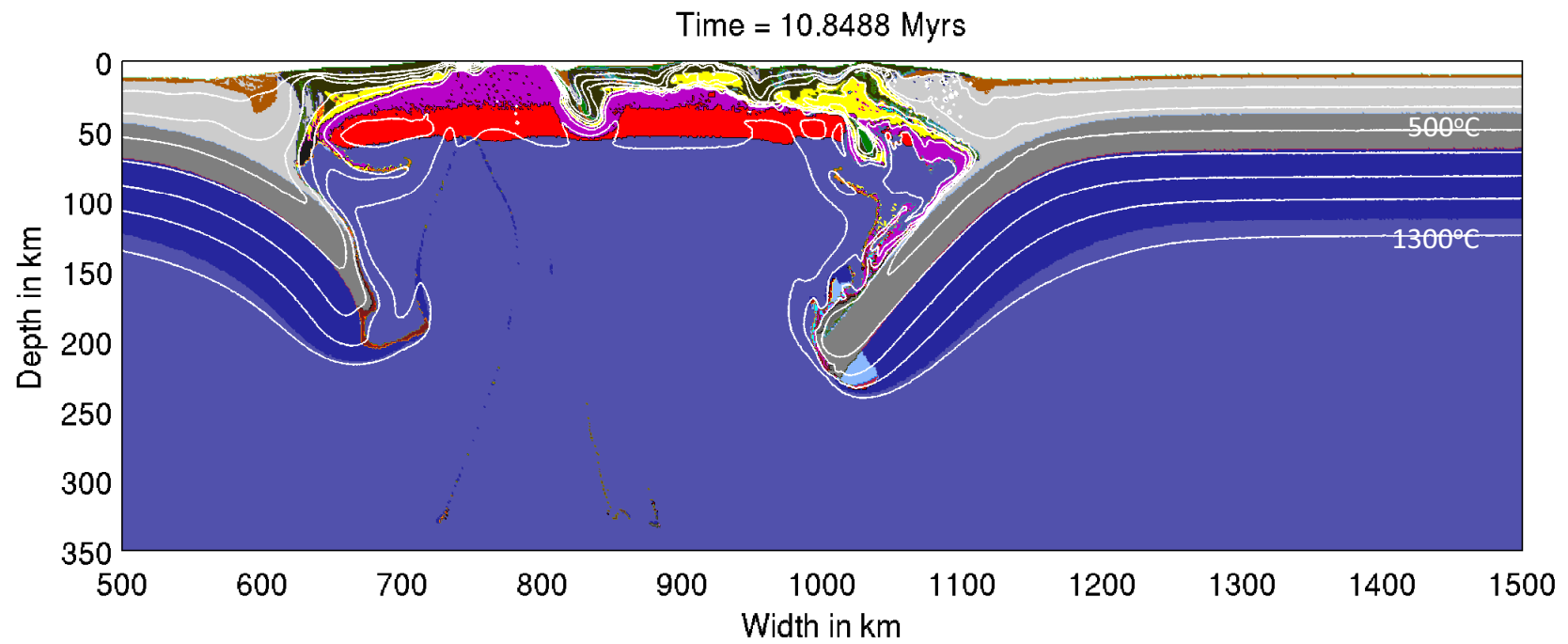
Numerical modelling: Delamination



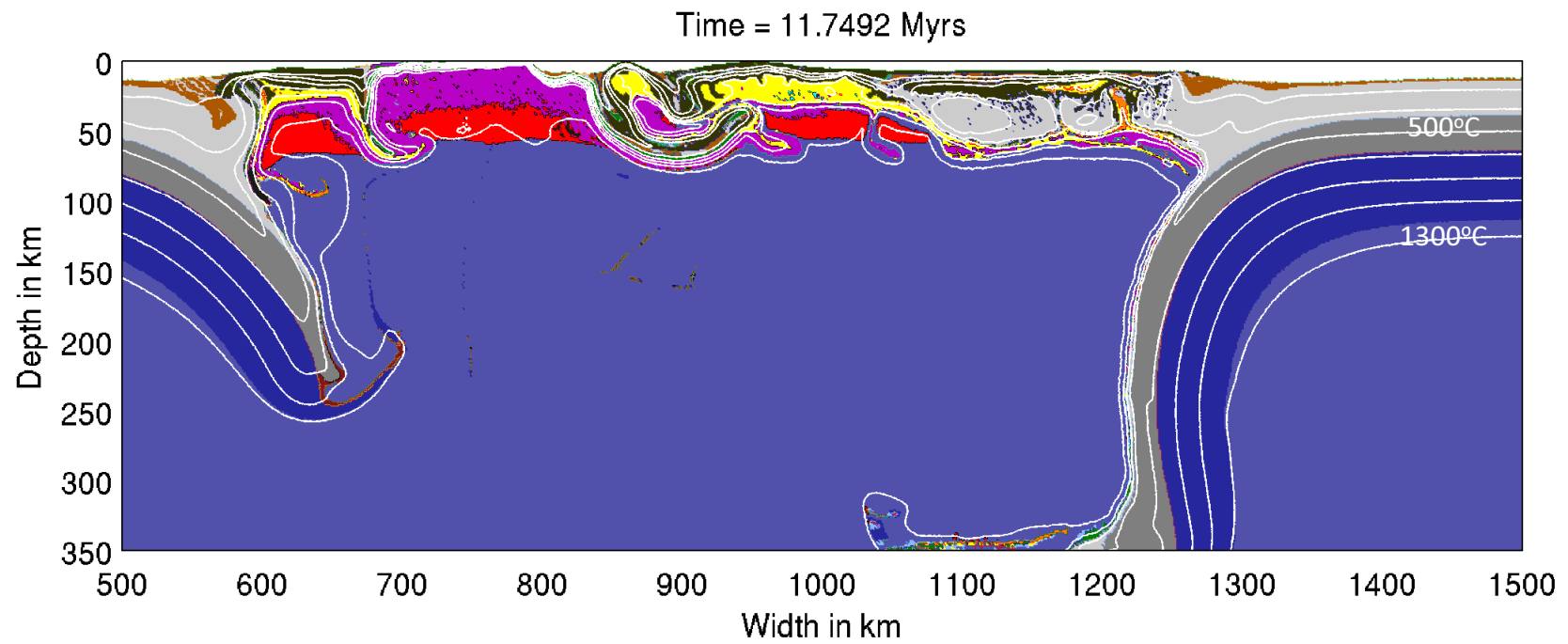
Numerical modelling: Delamination

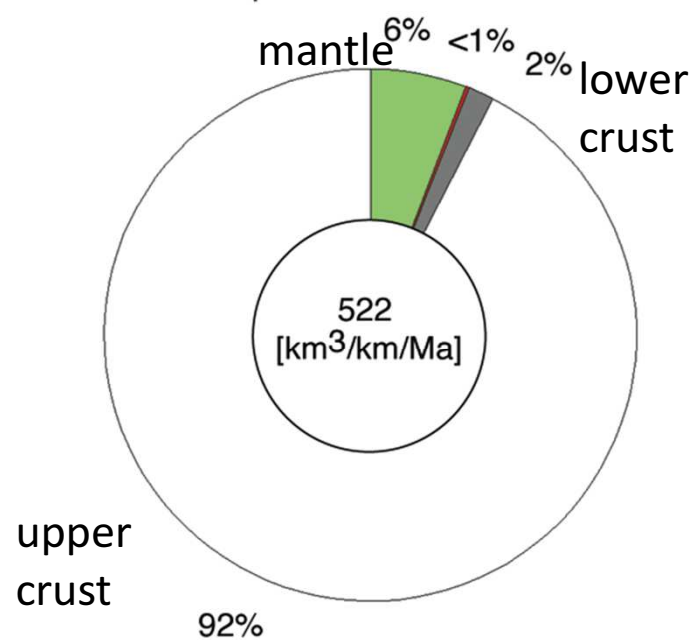
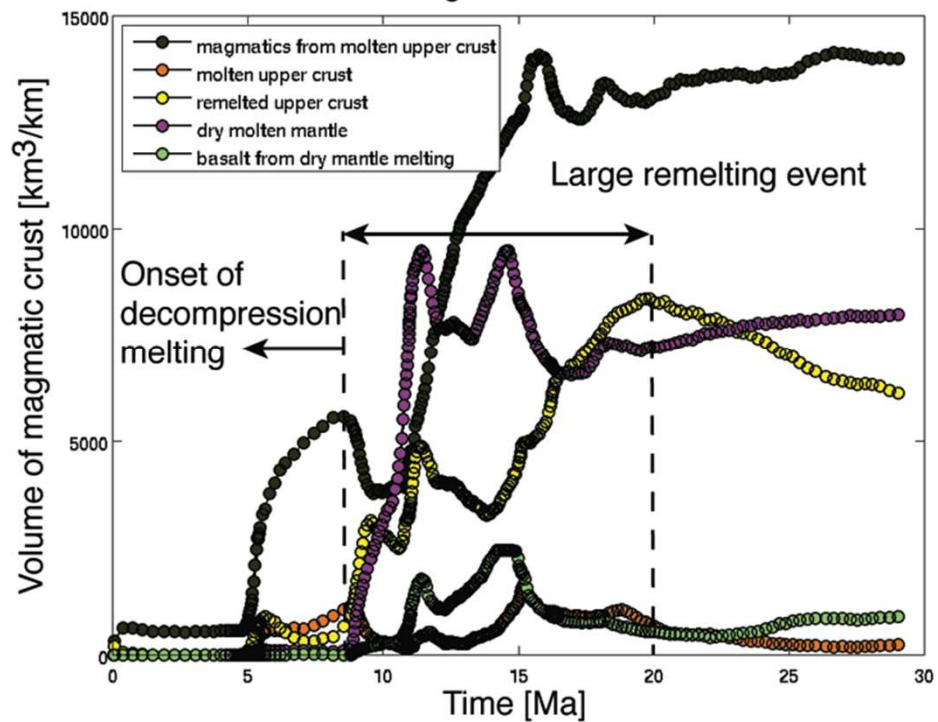
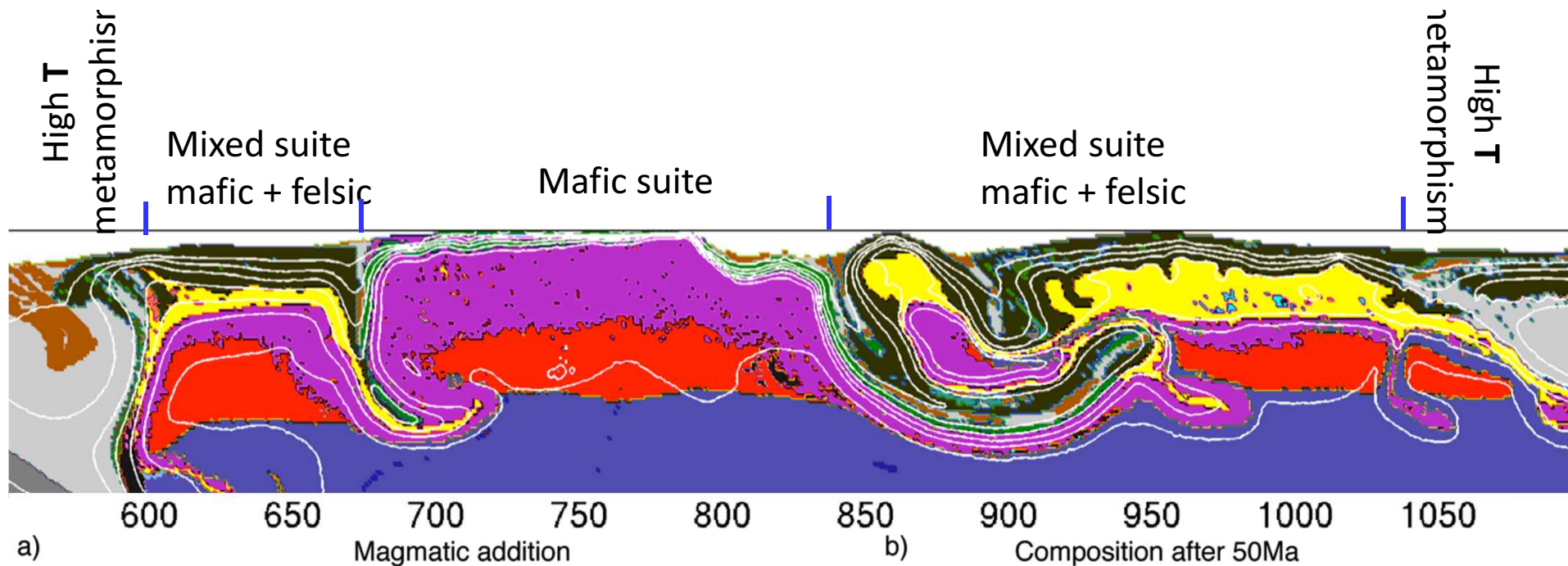


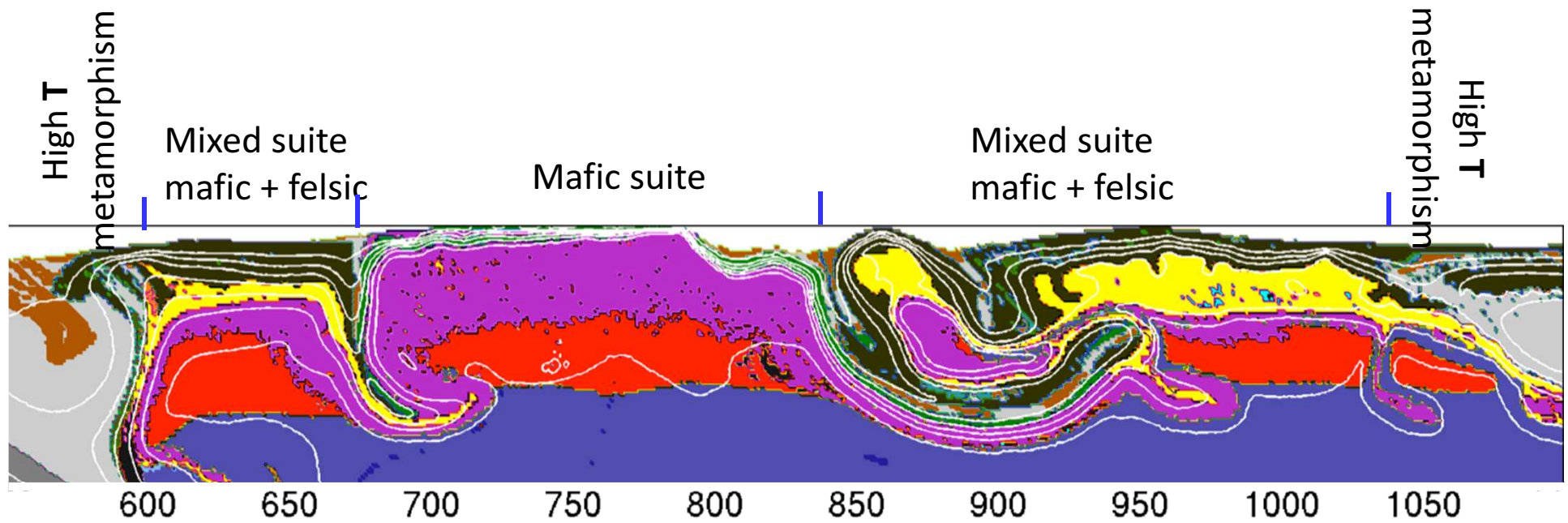
Numerical modelling: Delamination



Numerical modelling: Delamination

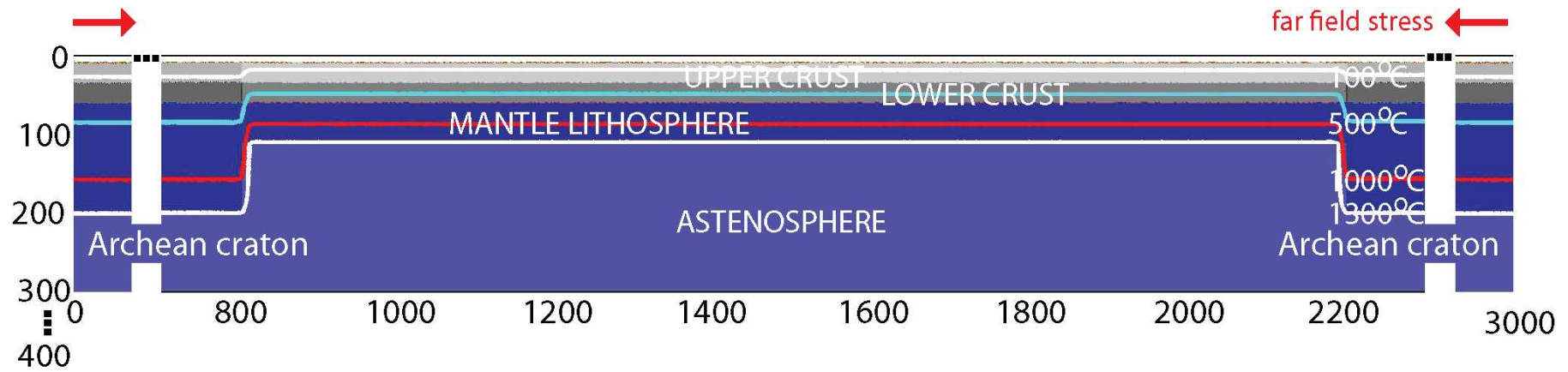




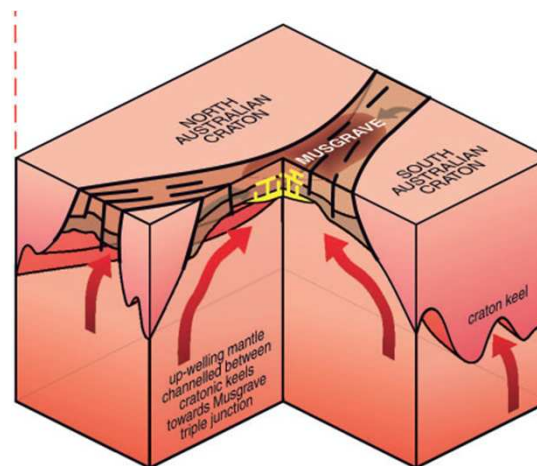


Melting of crust at $\sim 900 - 1100^{\circ}\text{C}$

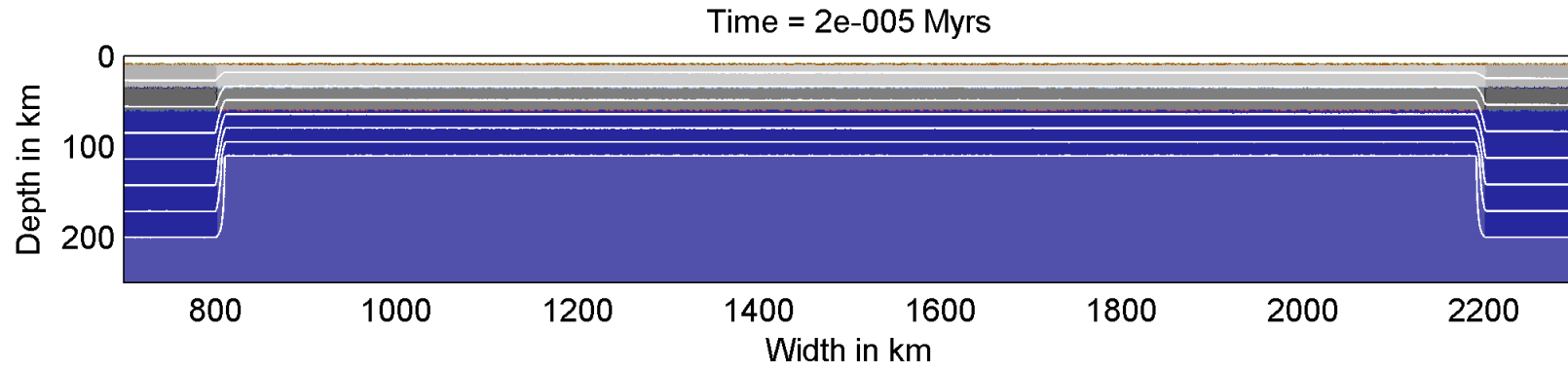
Numerical modelling: Musgrave Orogeny : initial setup



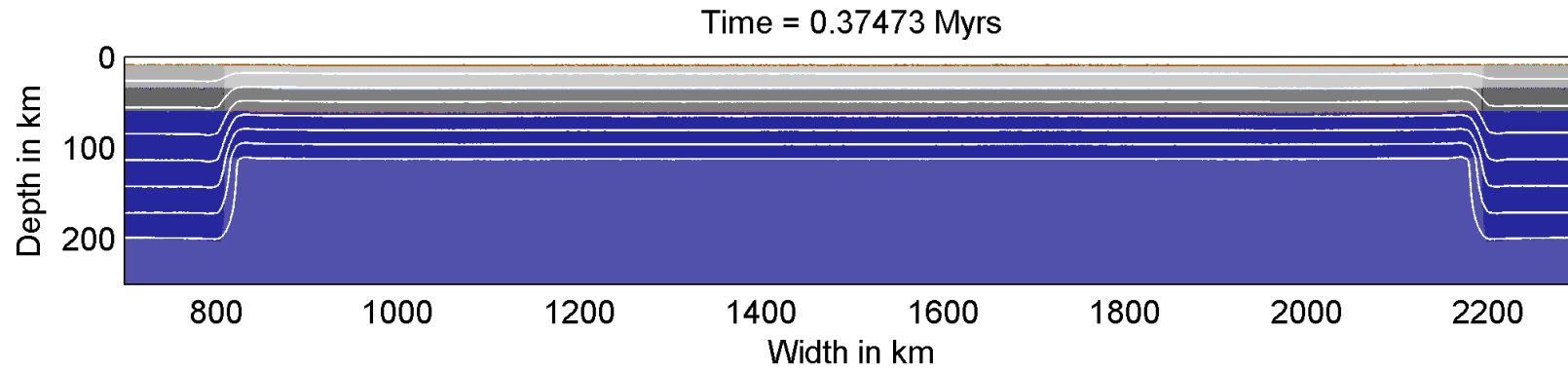
| | Solid rock | Partial melt | Magmatics | Remolten material |
|-------------|------------|--------------|-----------|-------------------|
| upper crust | | | | |
| lower crust | | | | |
| mantle | | | | |



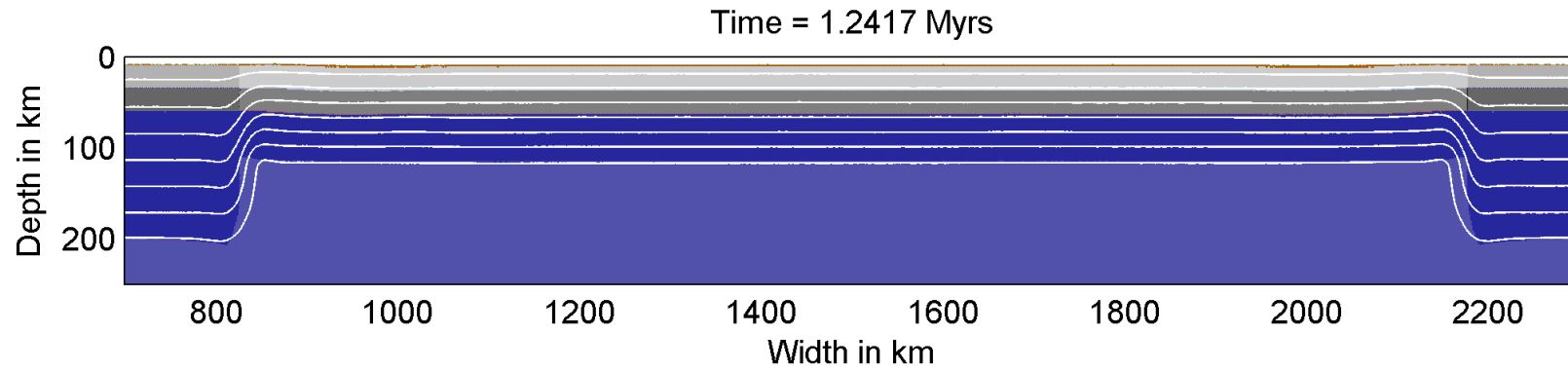
Numerical modelling: INITIAL STAGE



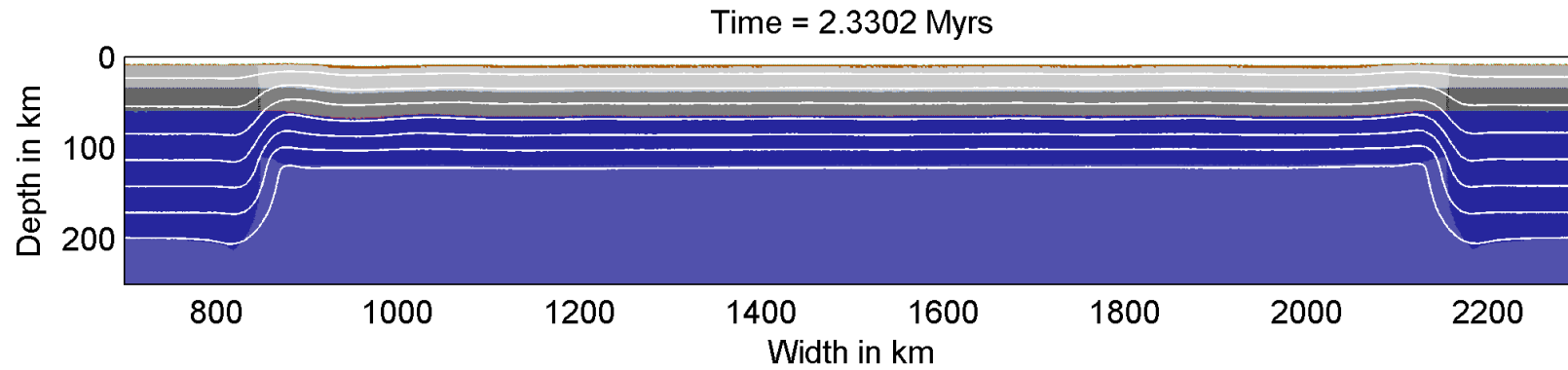
Numerical modelling: INITIAL STAGE



Numerical modelling: INITIAL STAGE

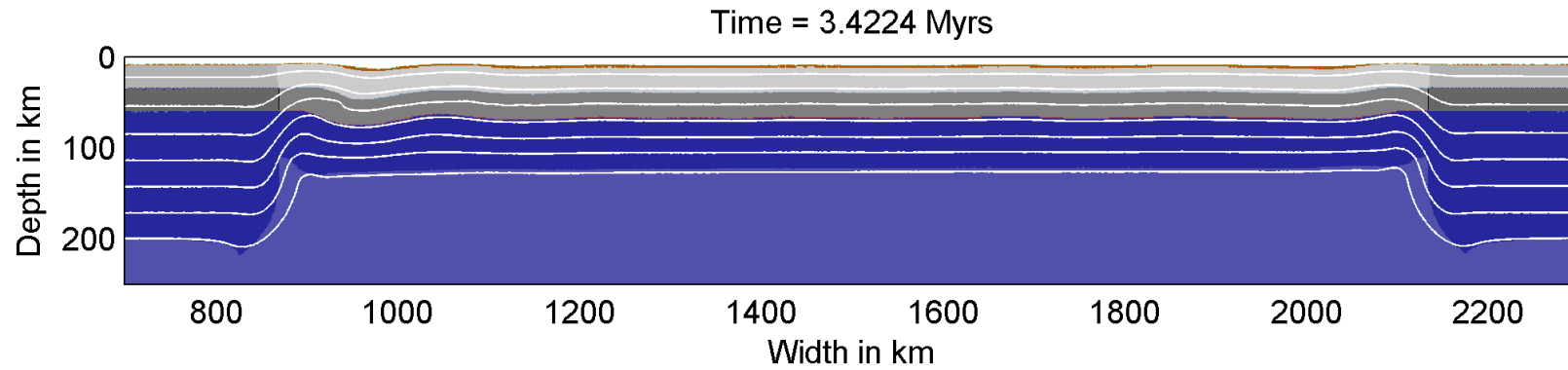


Numerical modelling: INITIAL STAGE



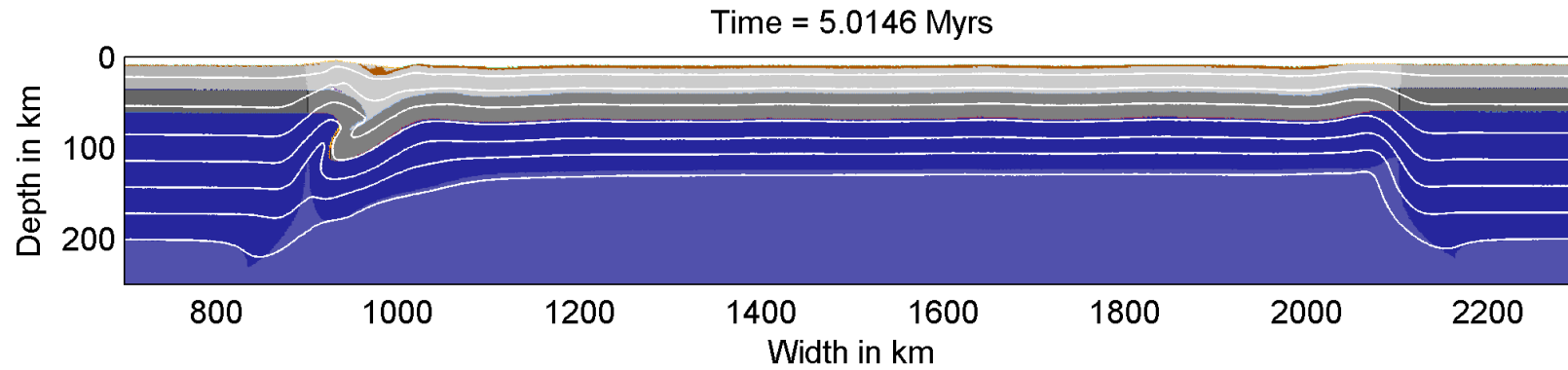
BUCKLING

Numerical modelling: INITIAL STAGE



BUCKLING

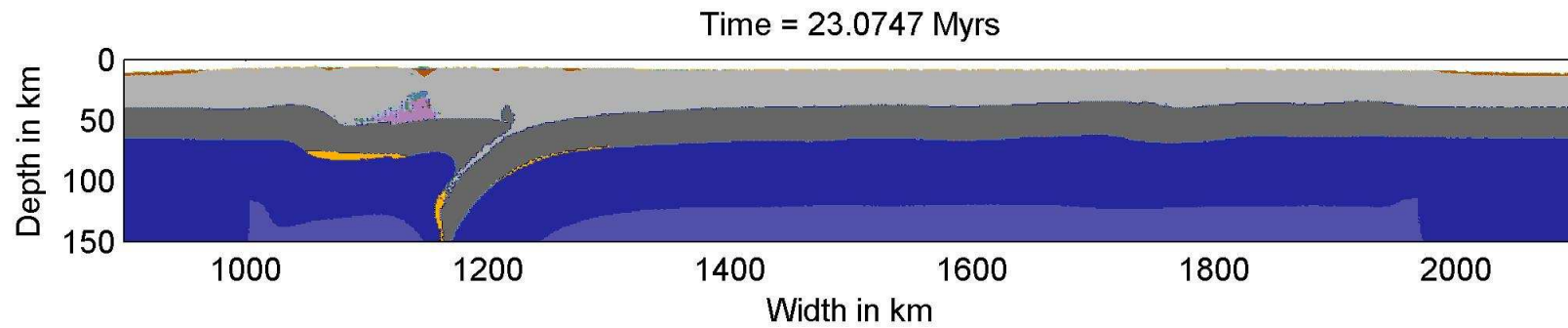
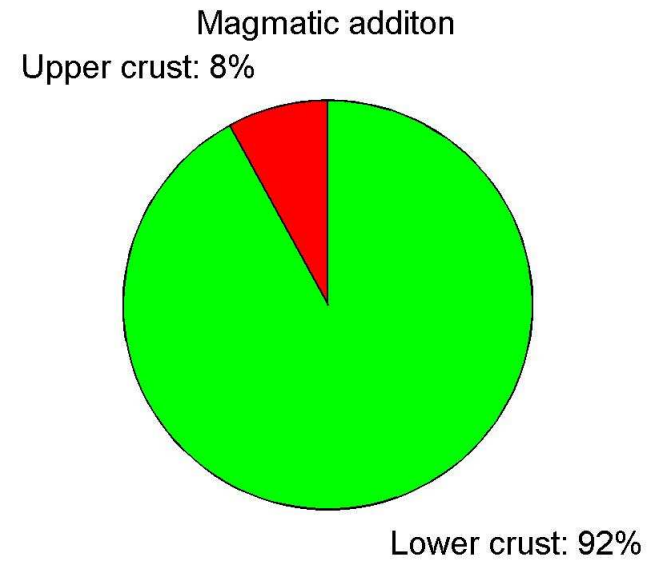
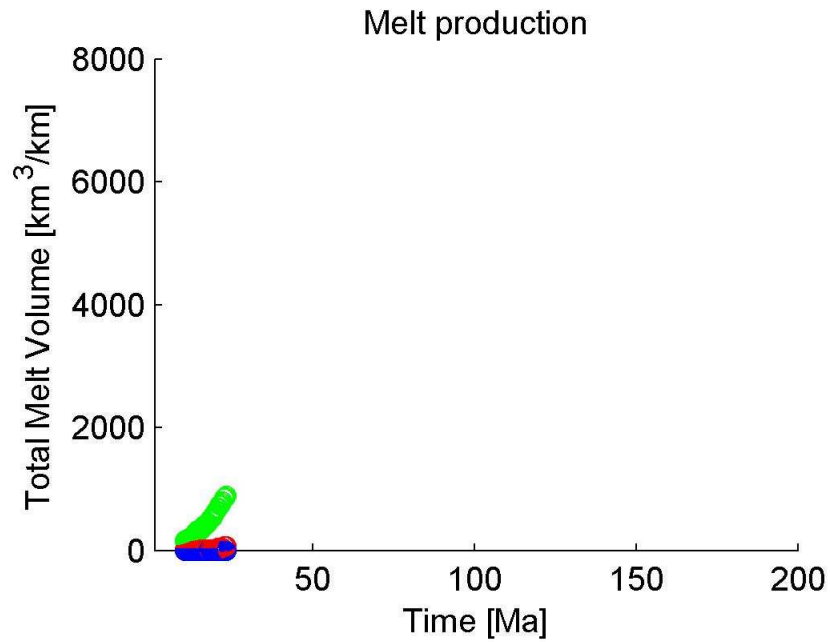
Numerical modelling: INITIAL STAGE



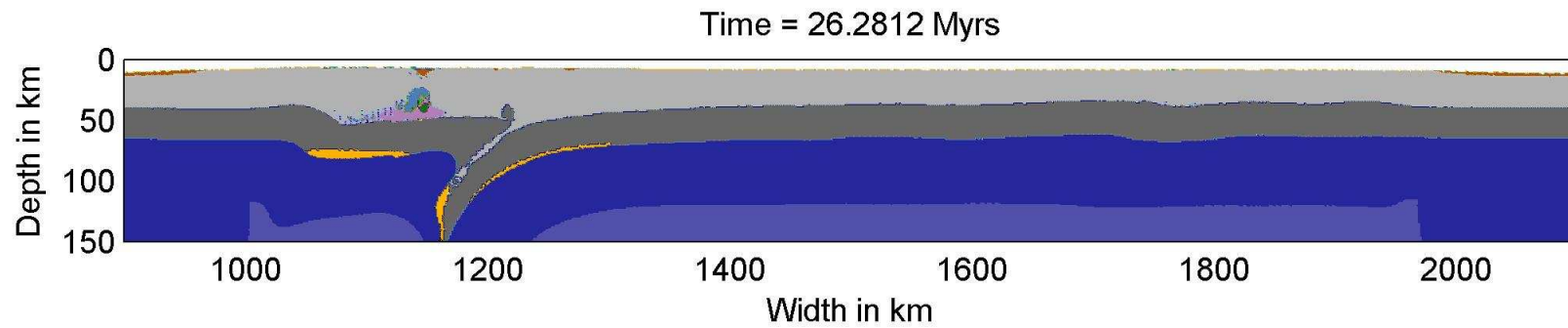
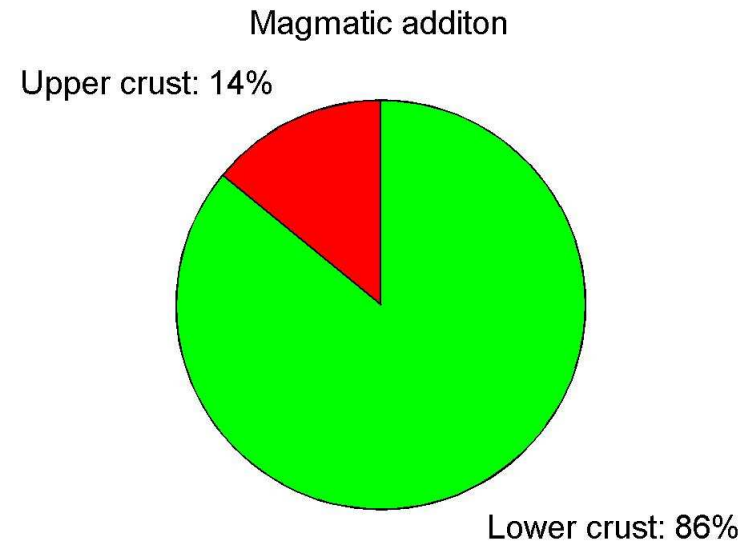
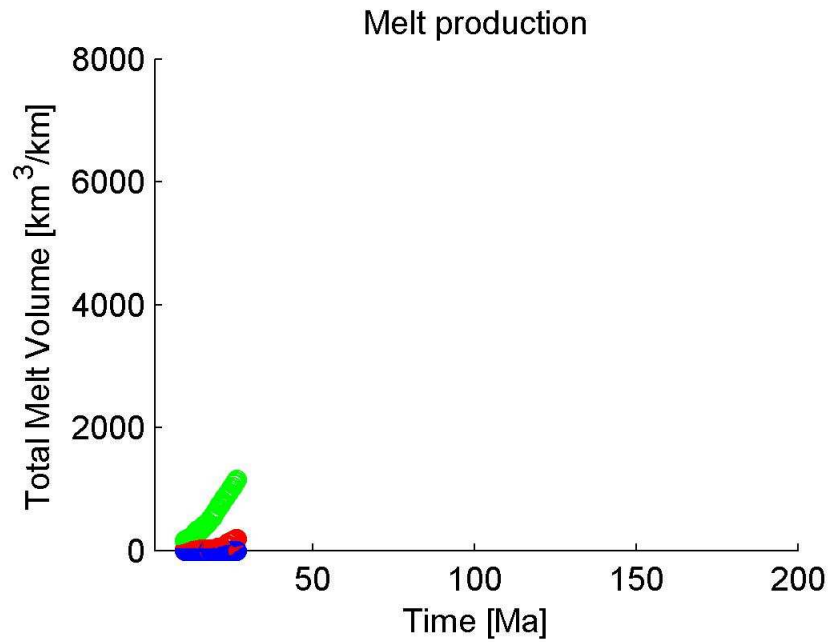
LOCALIZATION

INSUFFICIENT COMPRESSION

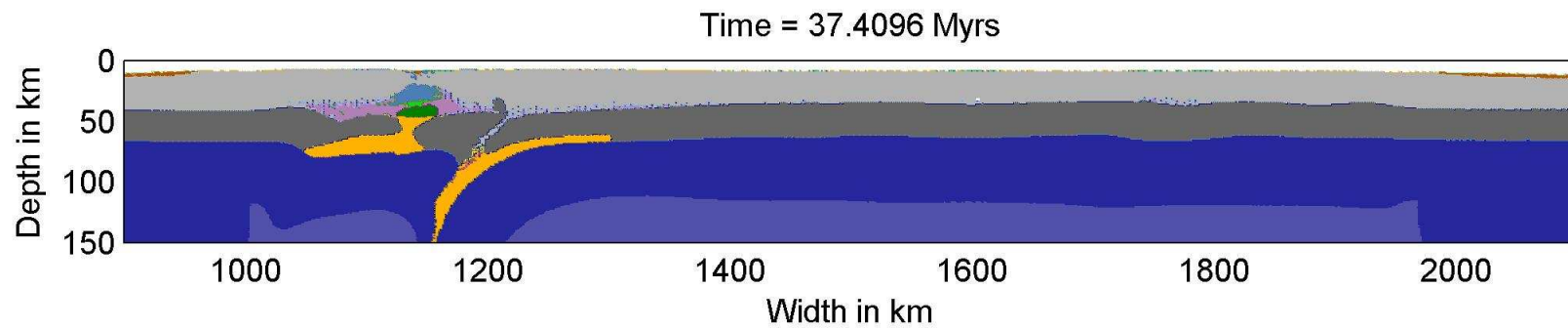
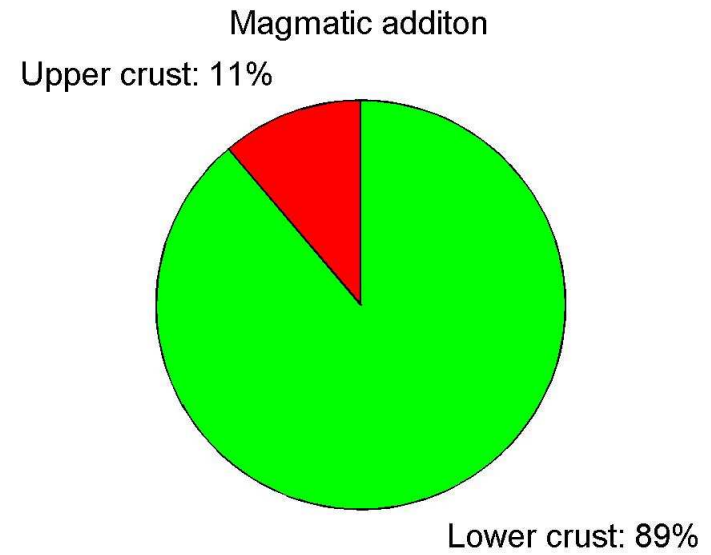
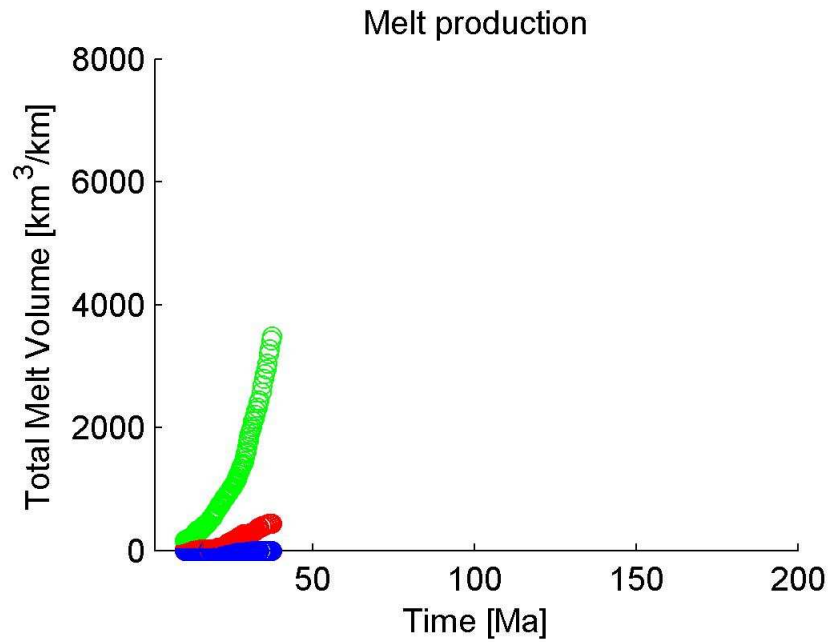
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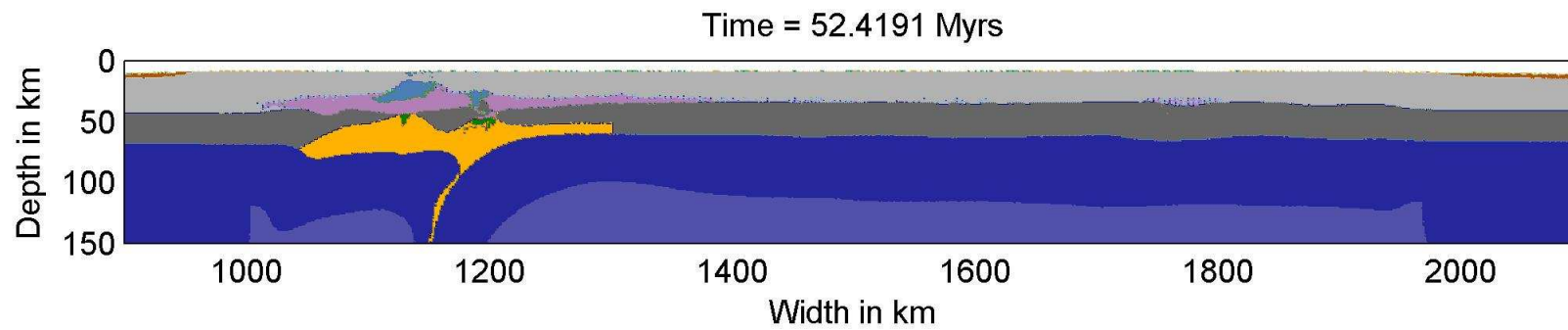
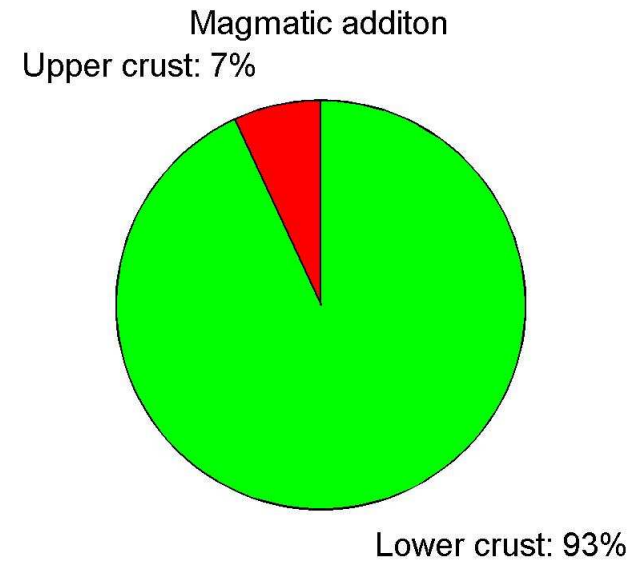
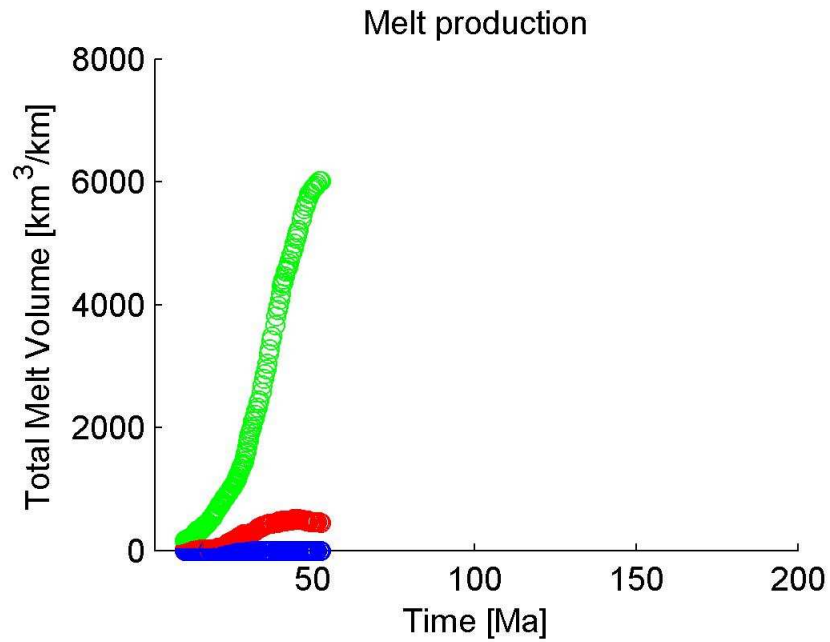
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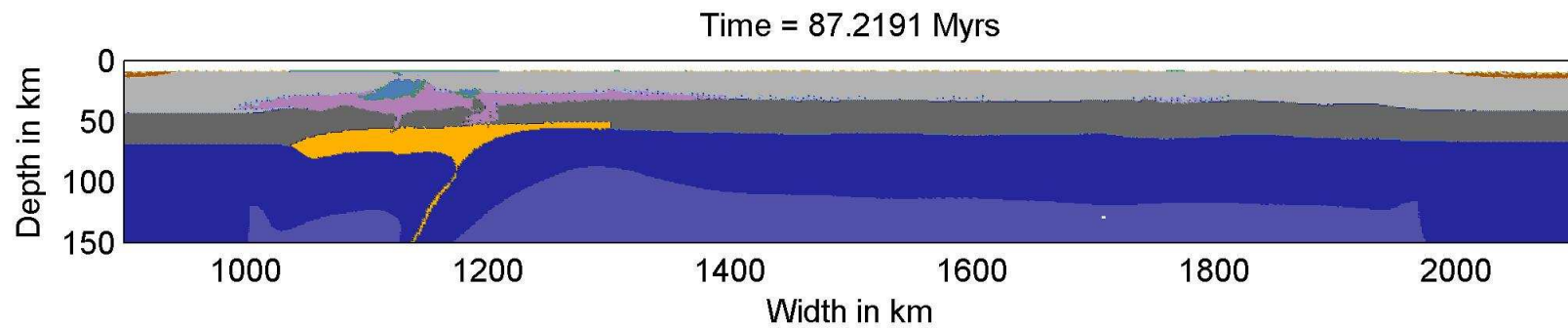
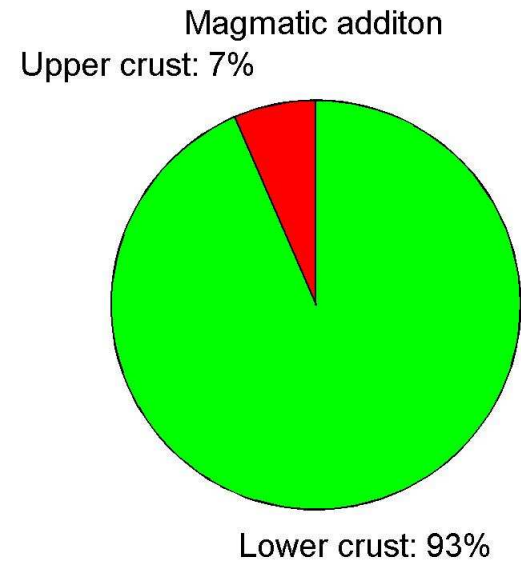
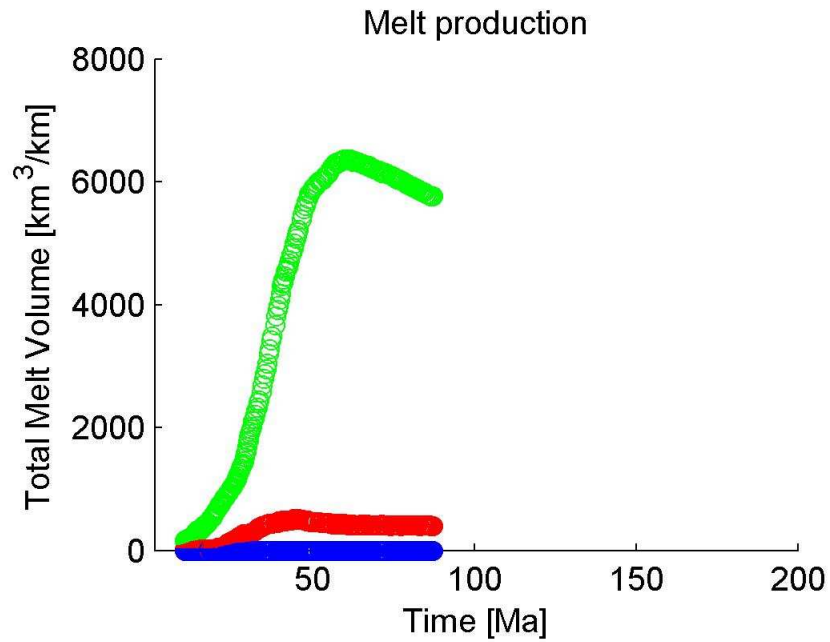
Numerical modelling: INSUFFICIENT COMPRESSION



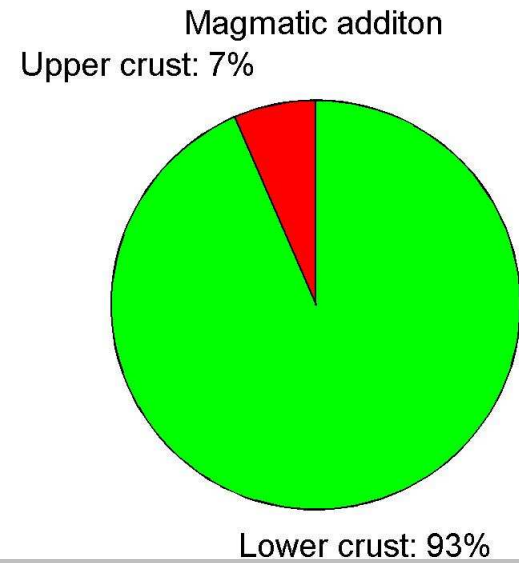
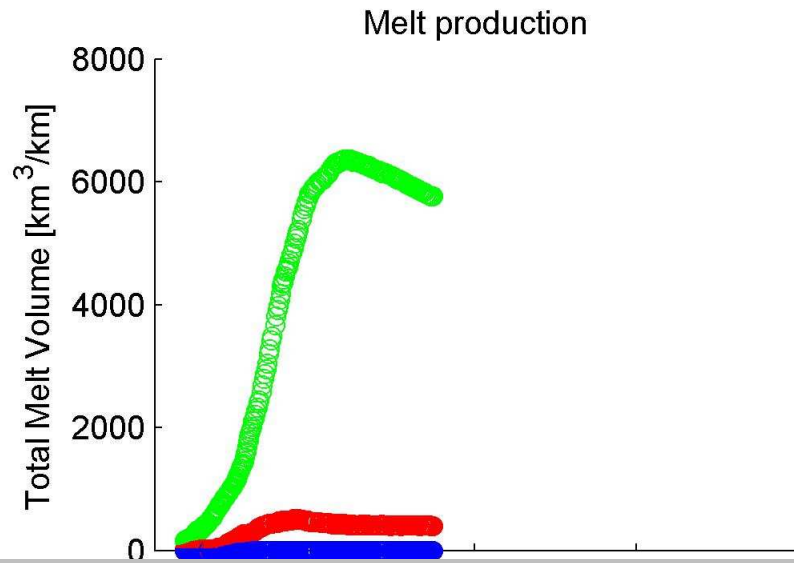
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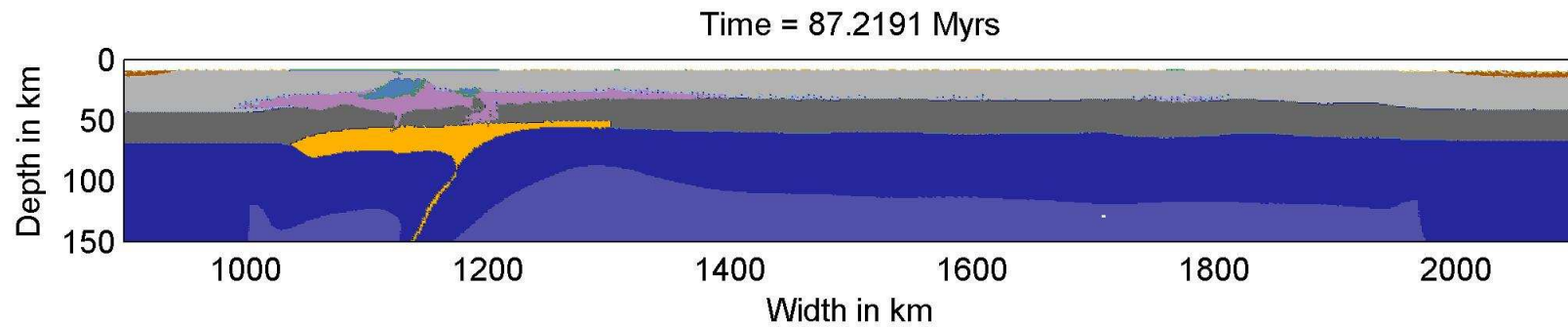
Numerical modelling: INSUFFICIENT COMPRESSION



Numerical modelling: INSUFFICIENT COMPRESSION



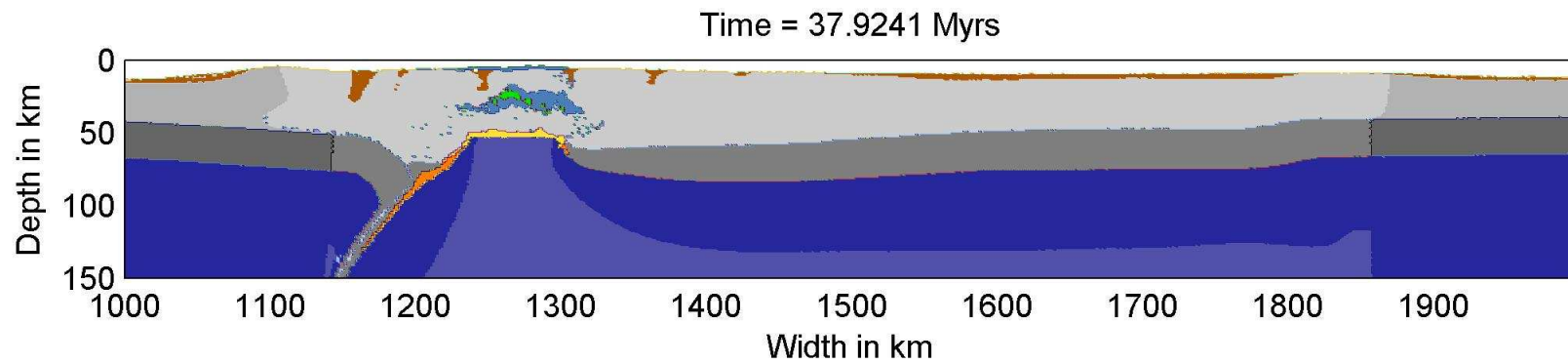
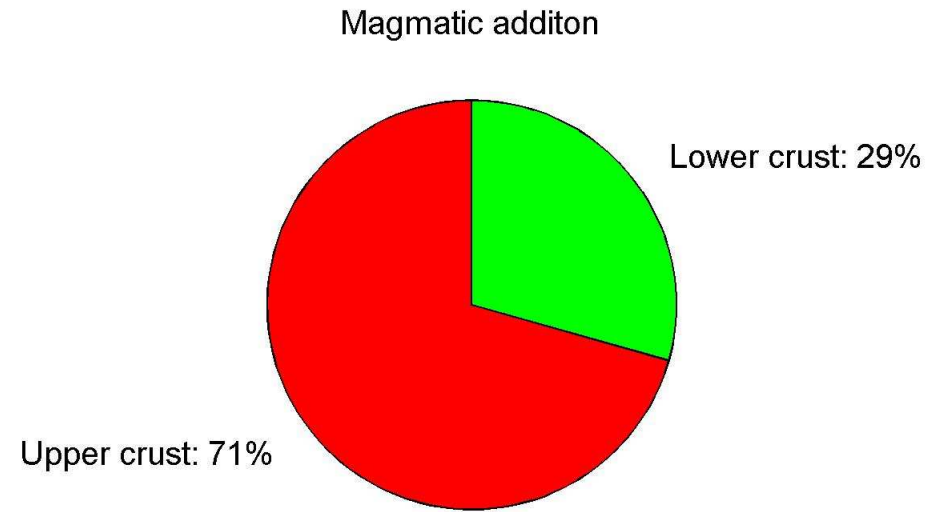
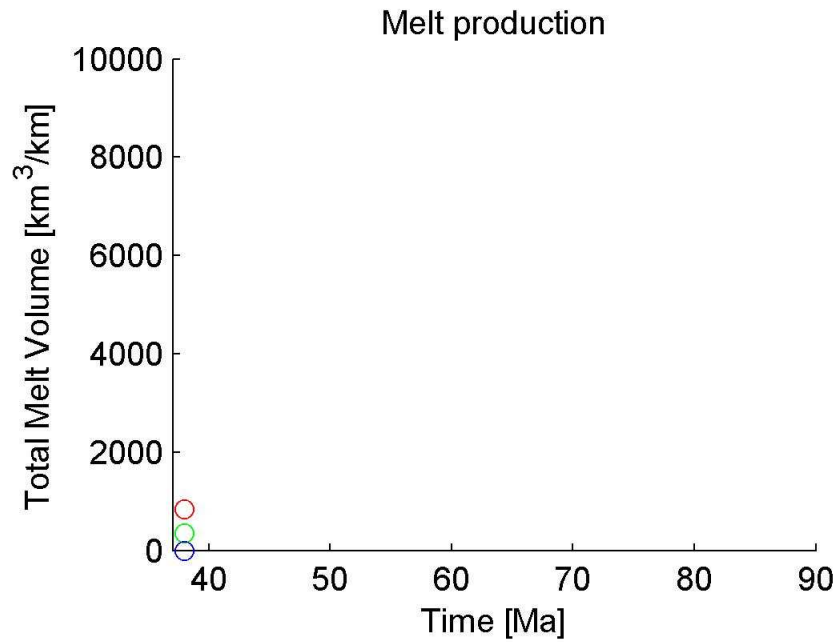
NO UHT MELTING AND MANTLE SOURCE



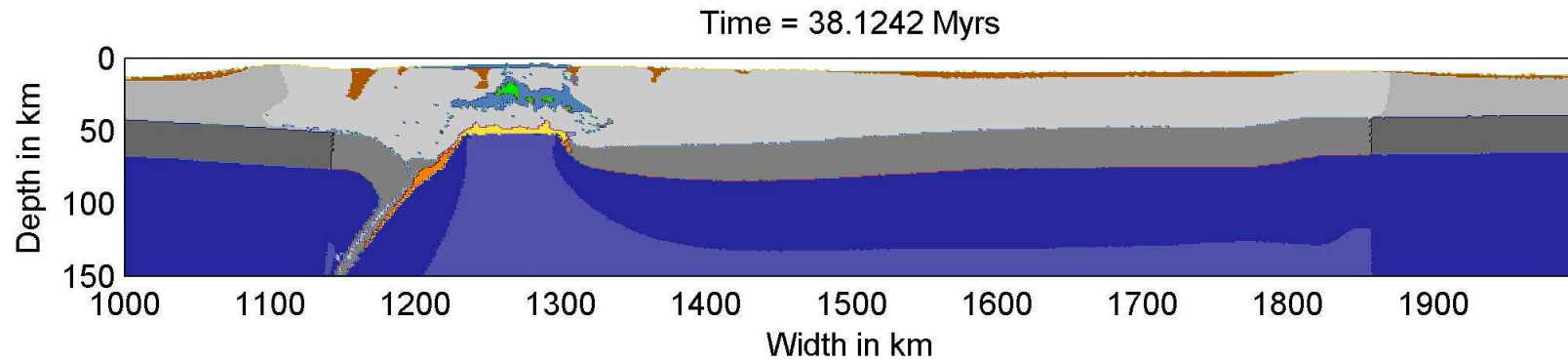
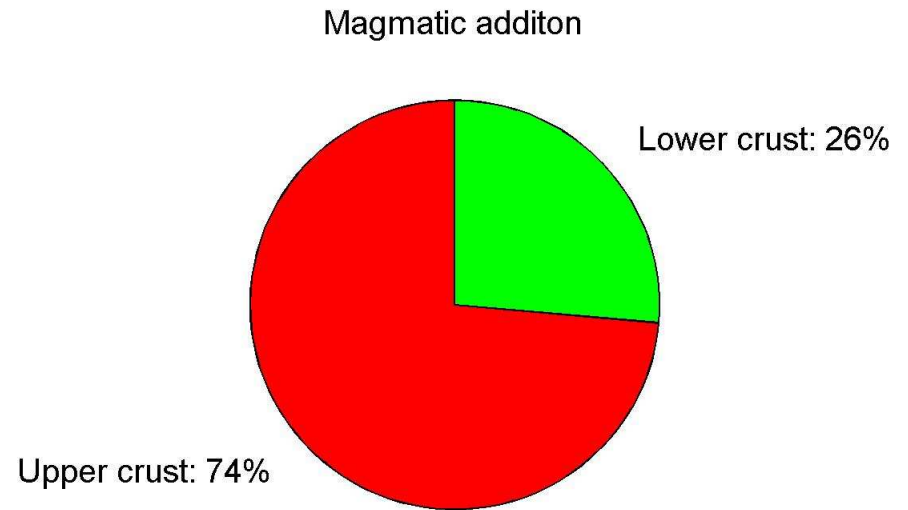
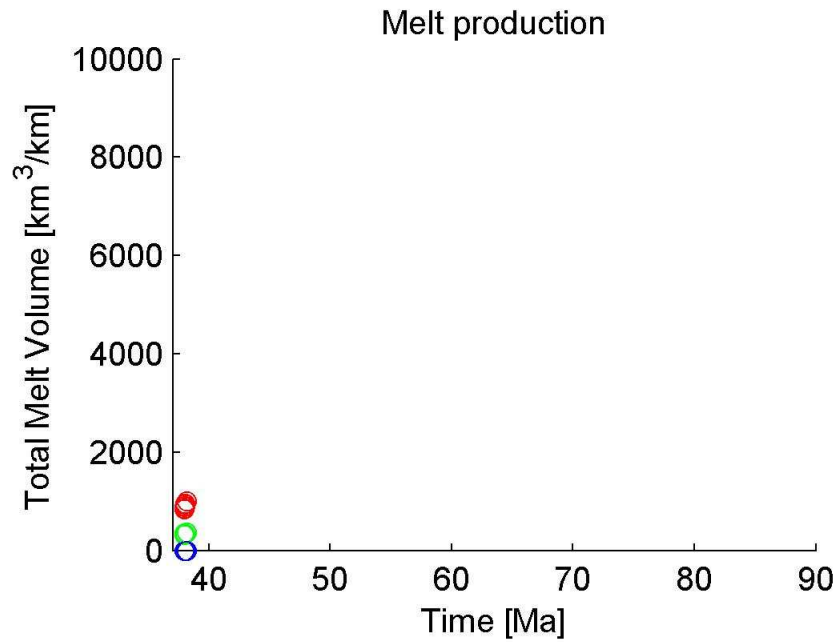
Numerical modelling: ENOUGH OF COMPRESSION

ENOUGH of COMPRESSION

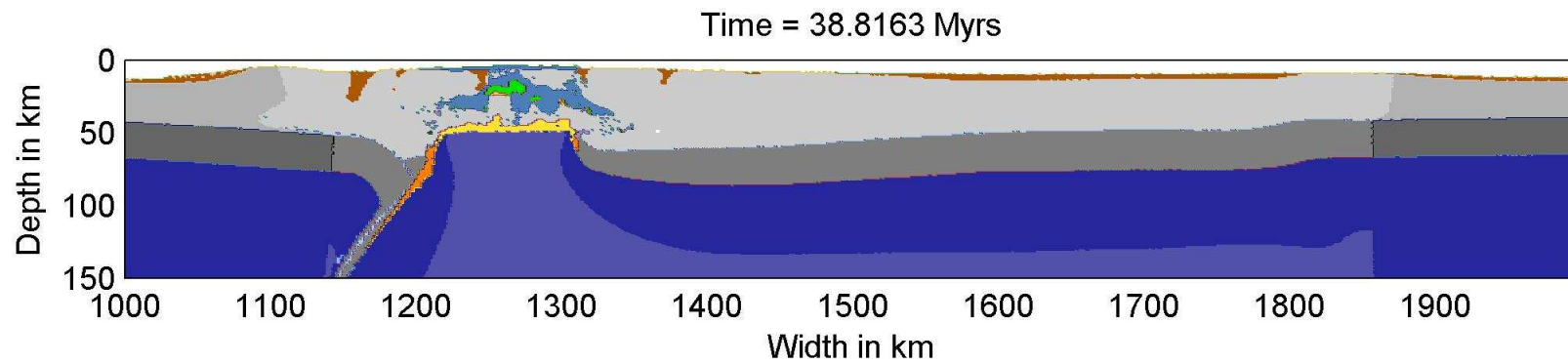
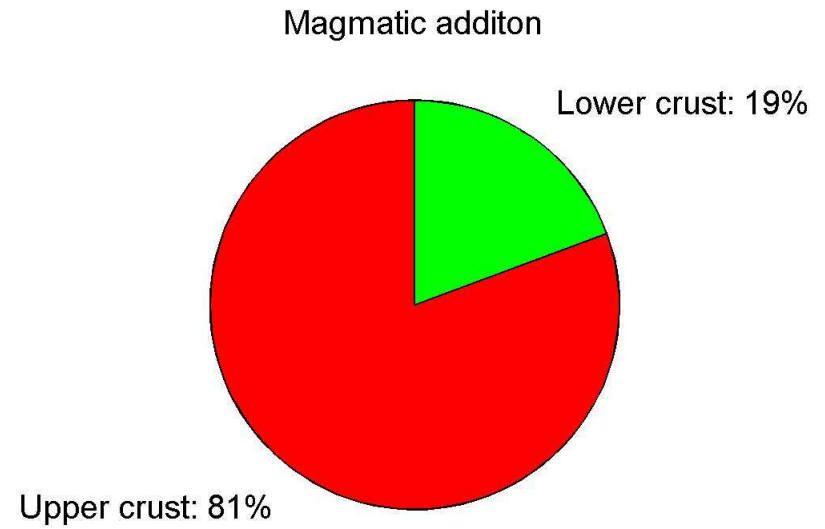
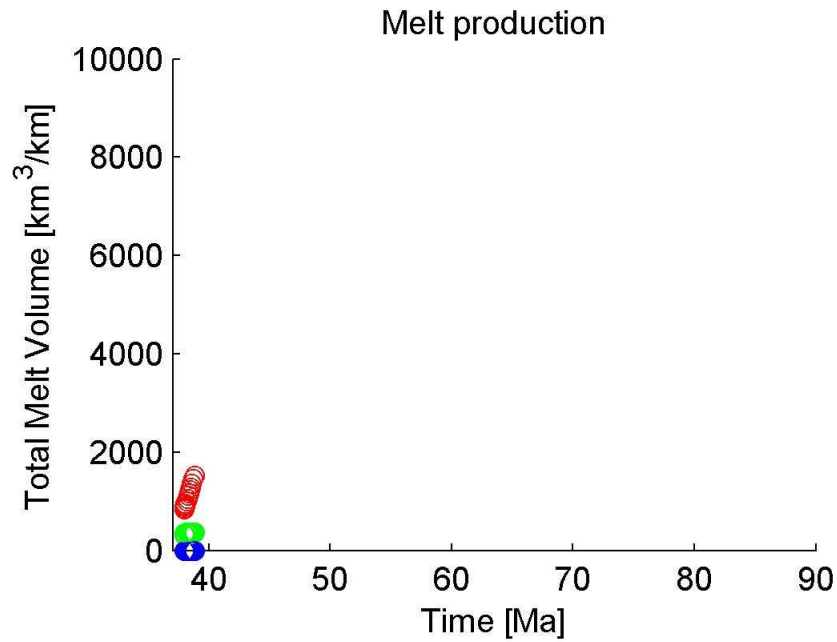
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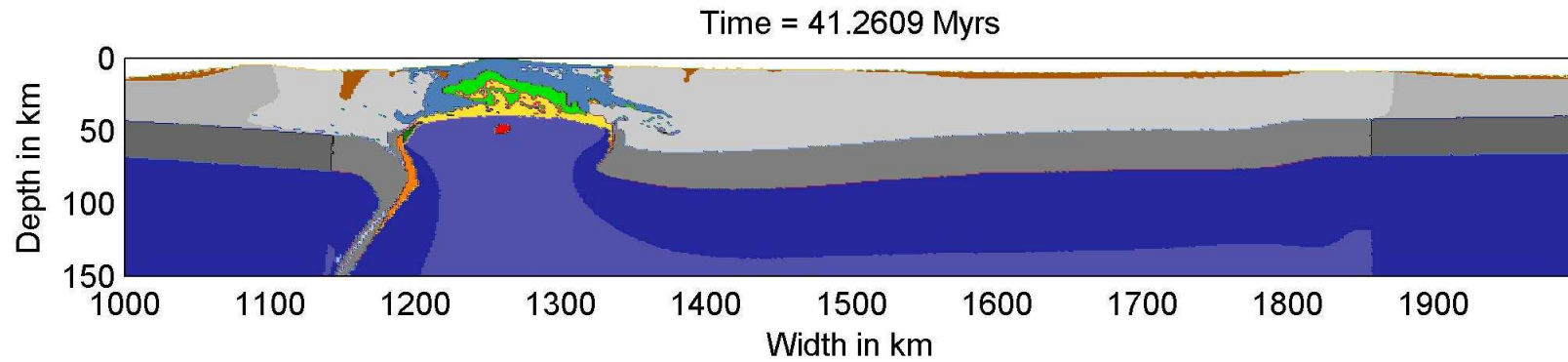
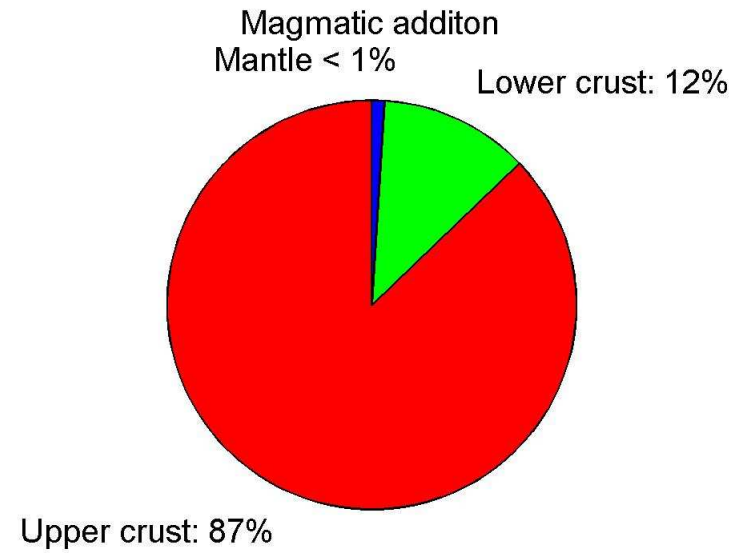
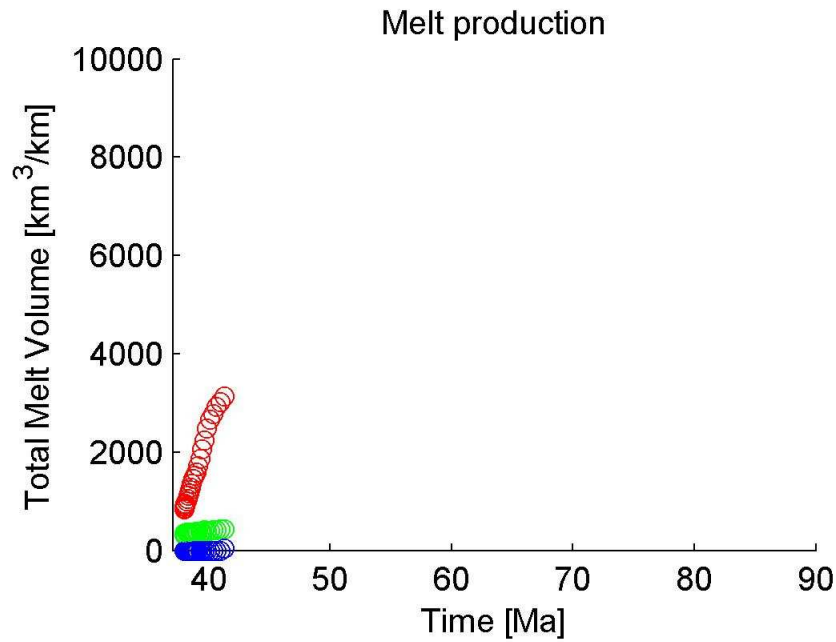
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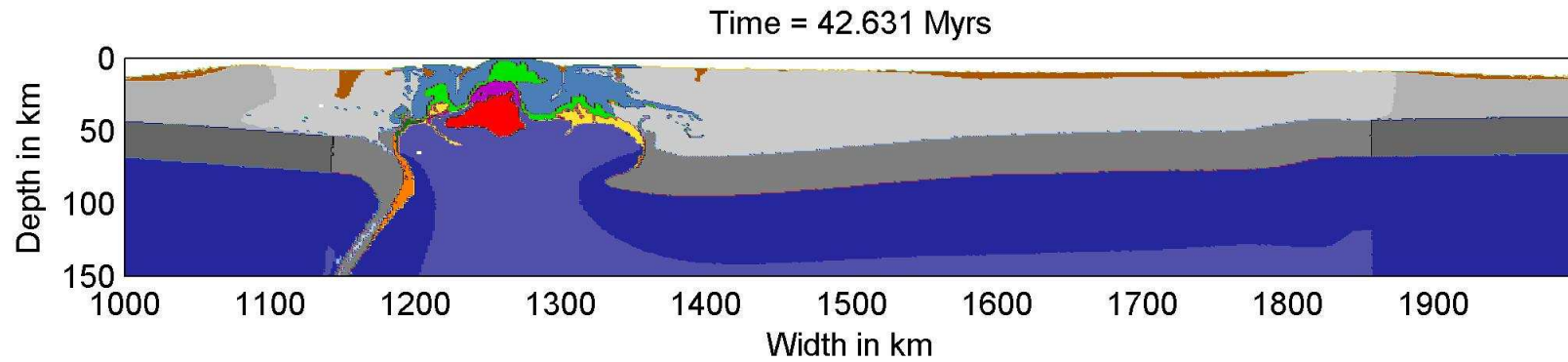
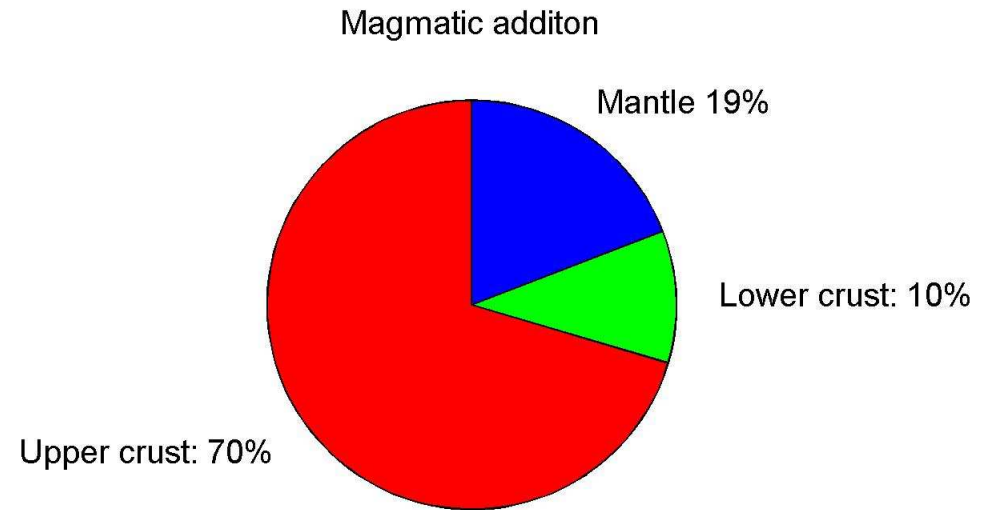
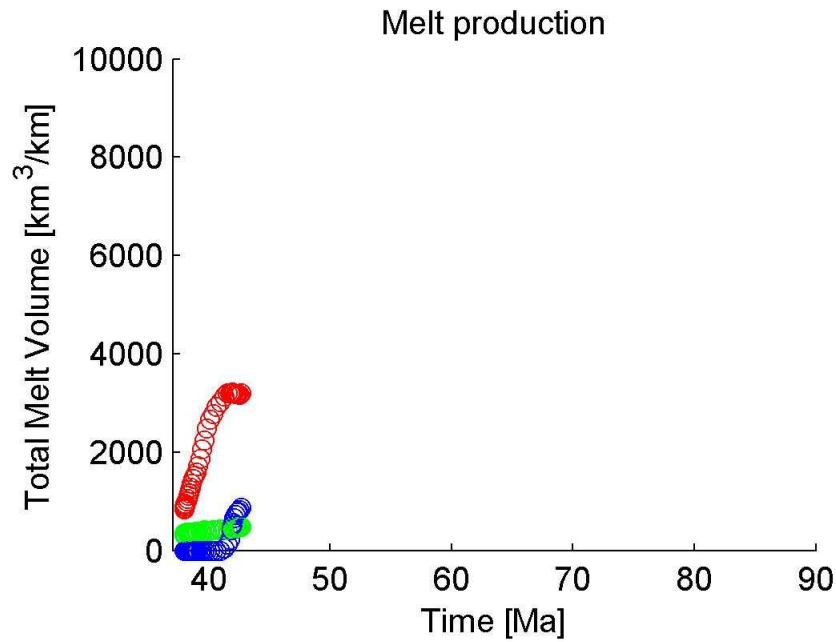
Numerical modelling: ENOUGH OF COMPRESSION



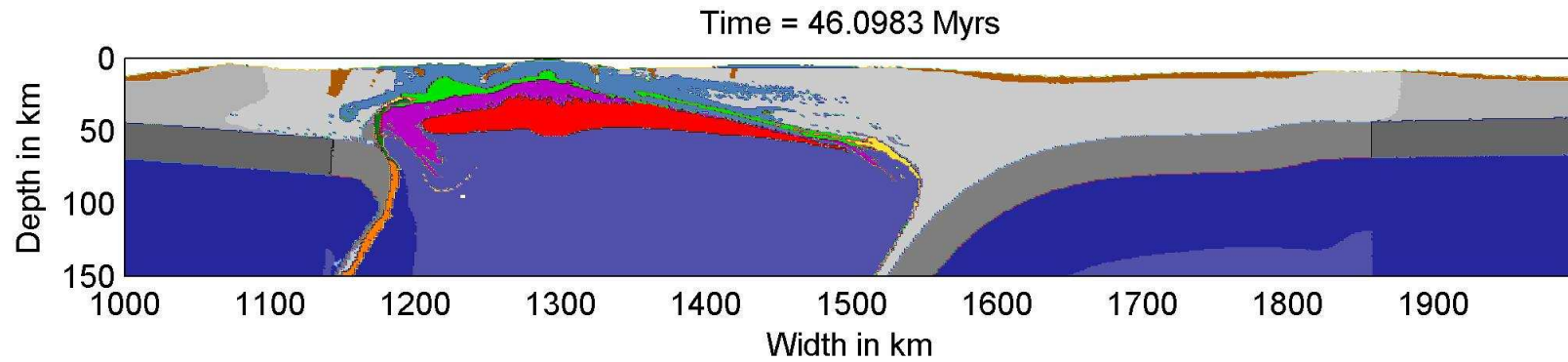
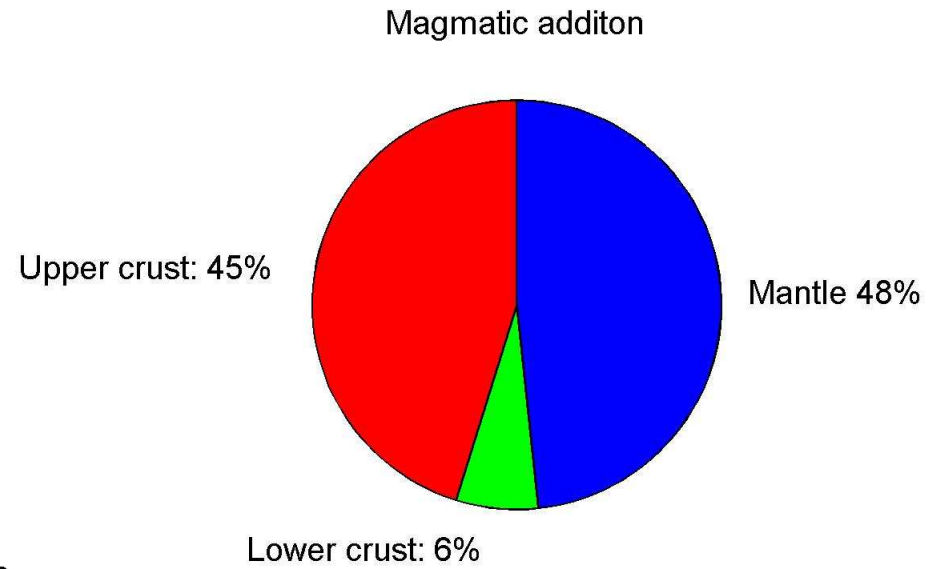
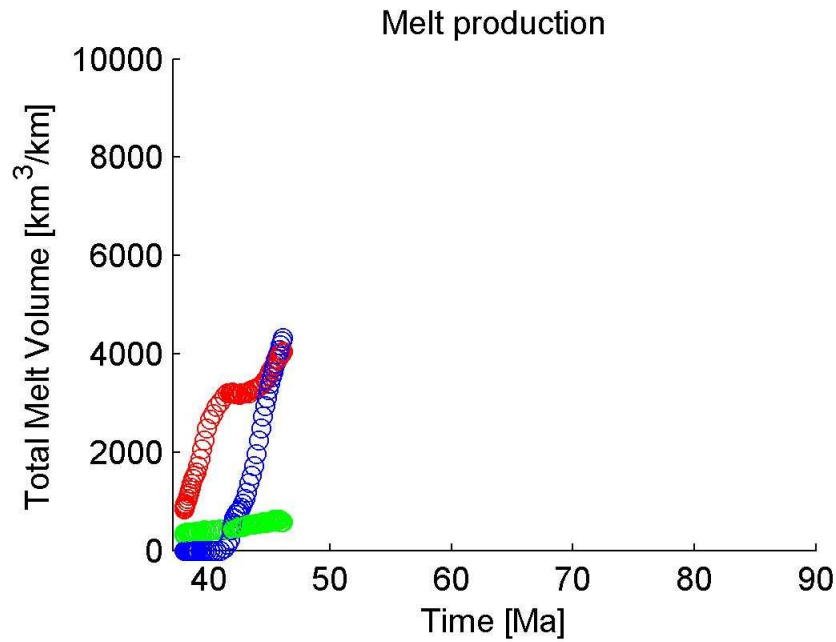
Numerical modelling: ENOUGH OF COMPRESSION



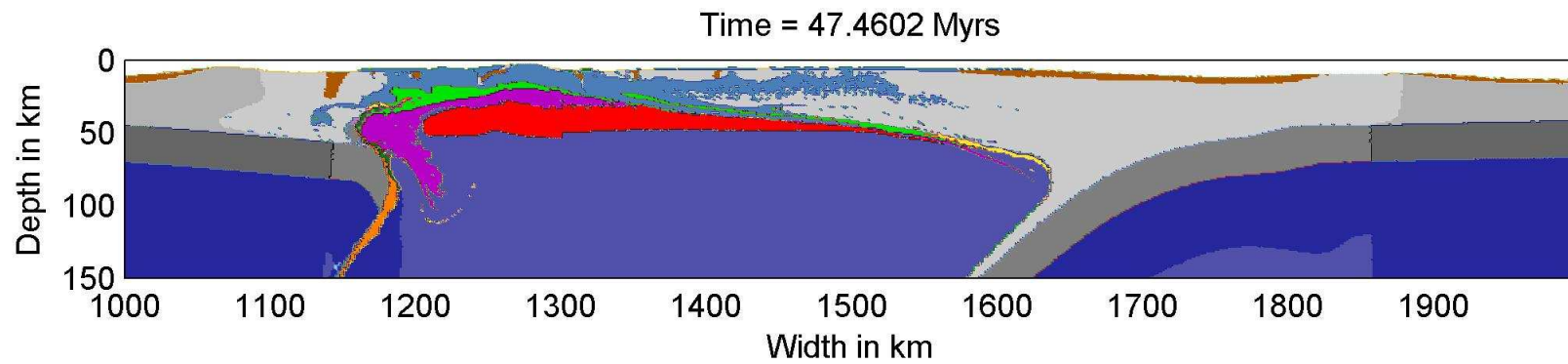
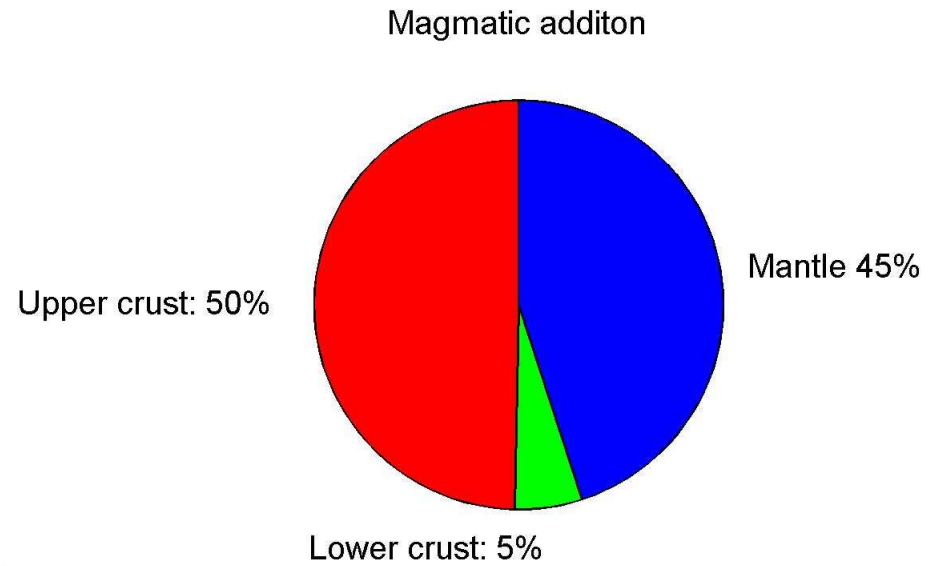
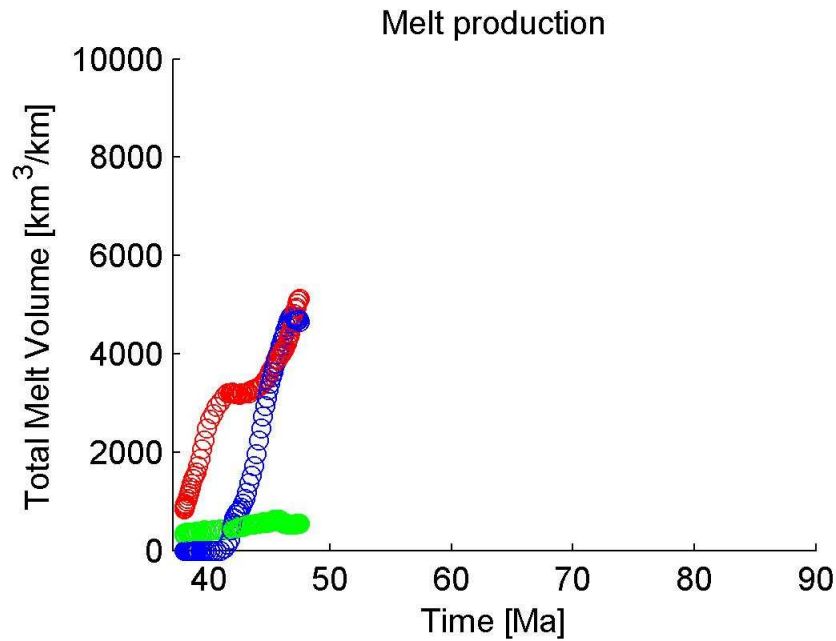
Numerical modelling: ENOUGH OF COMPRESSION



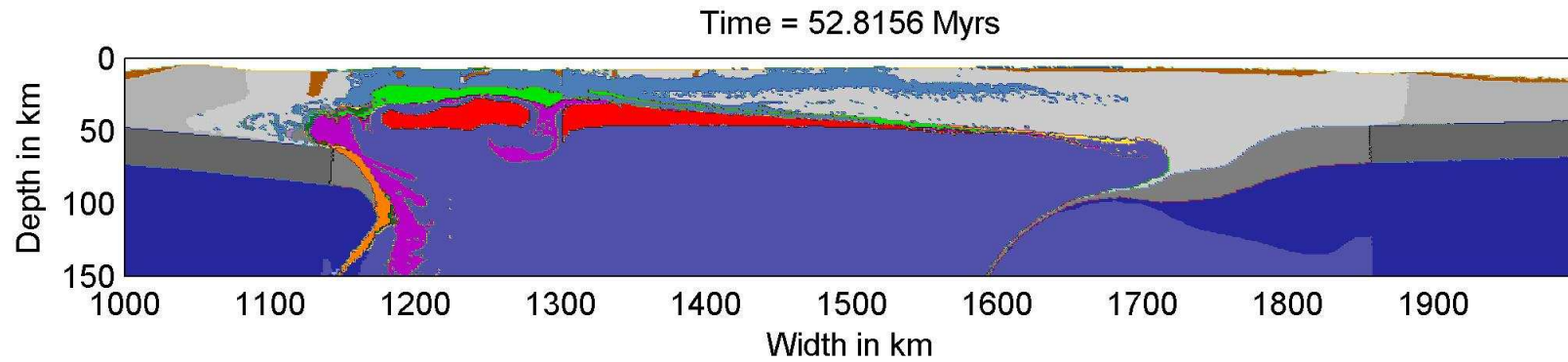
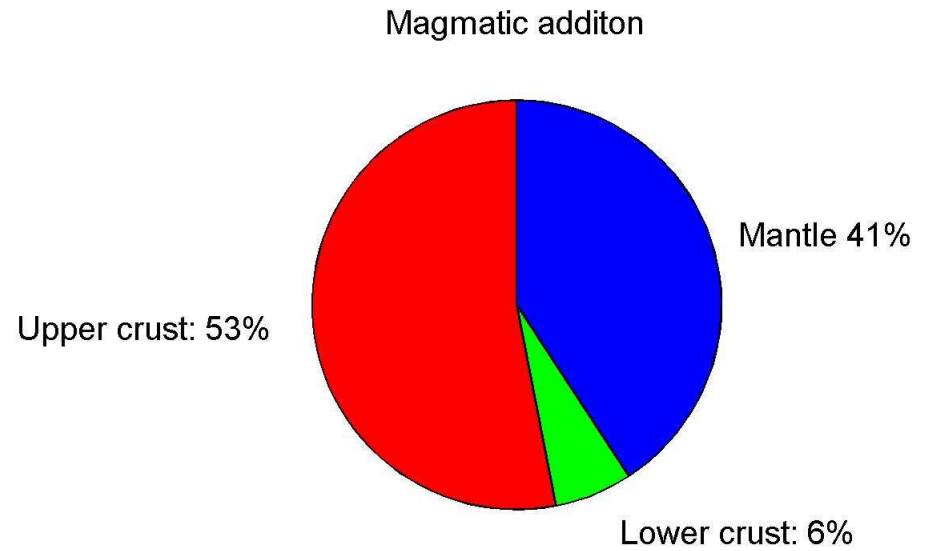
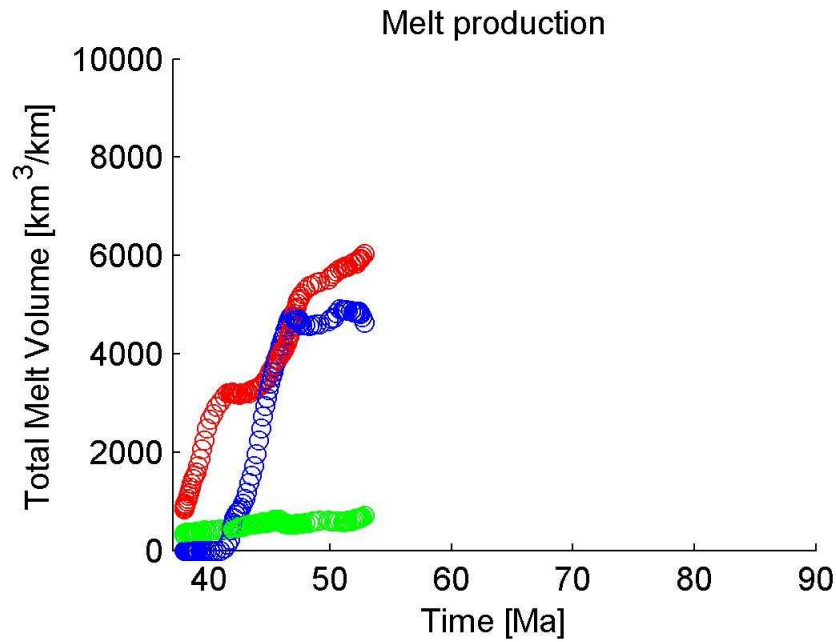
Numerical modelling: ENOUGH OF COMPRESSION



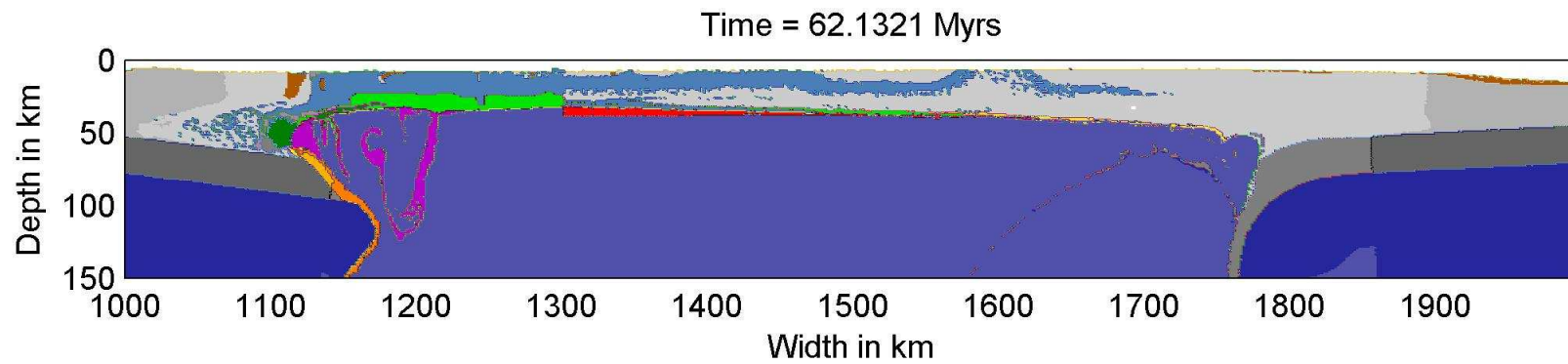
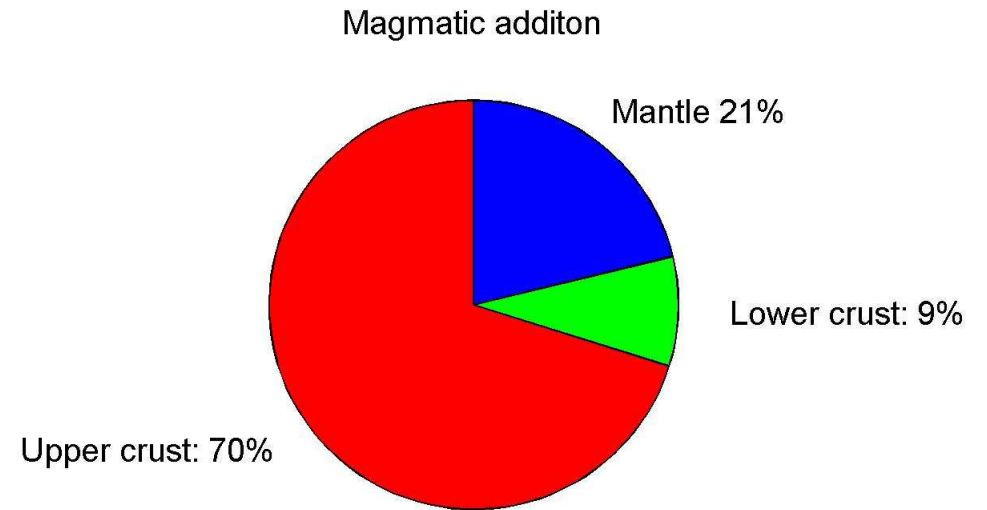
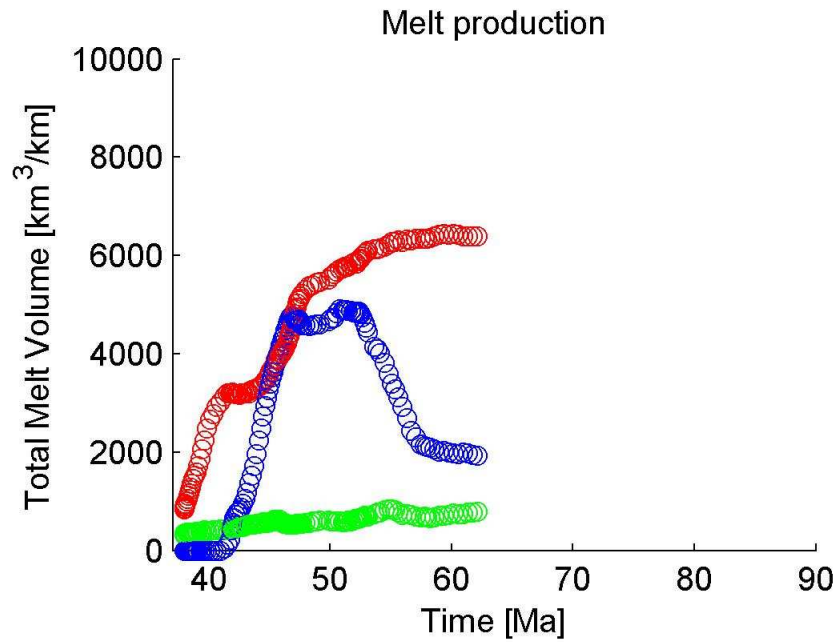
Numerical modelling: ENOUGH OF COMPRESSION



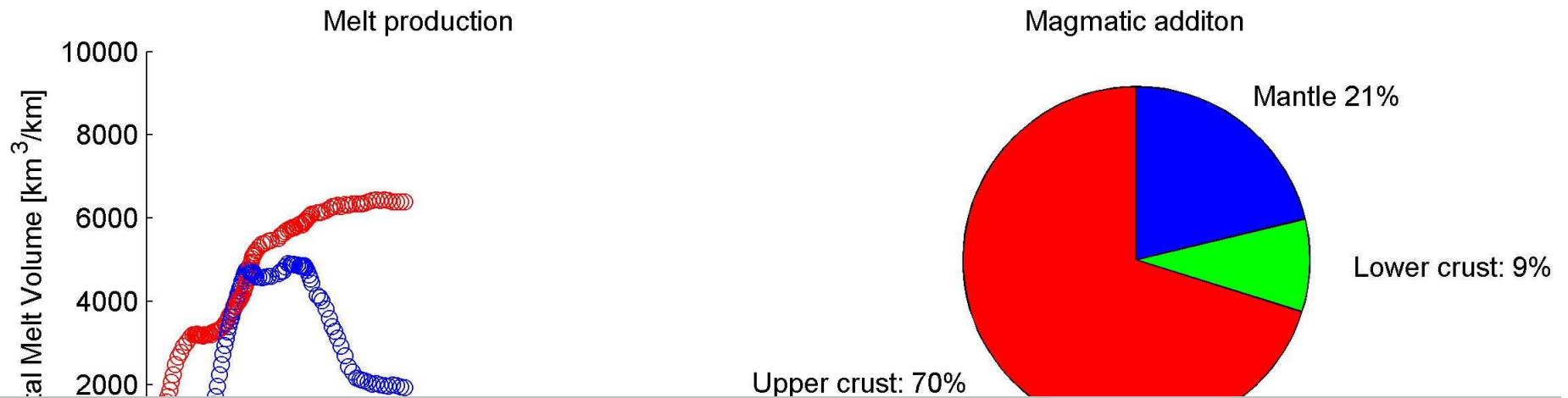
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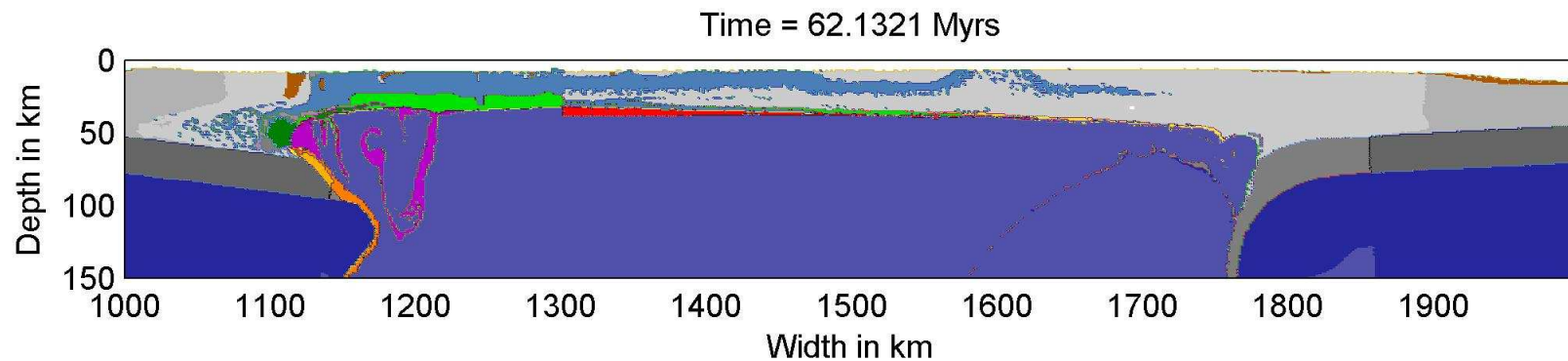
Numerical modelling: ENOUGH OF COMPRESSION



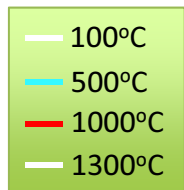
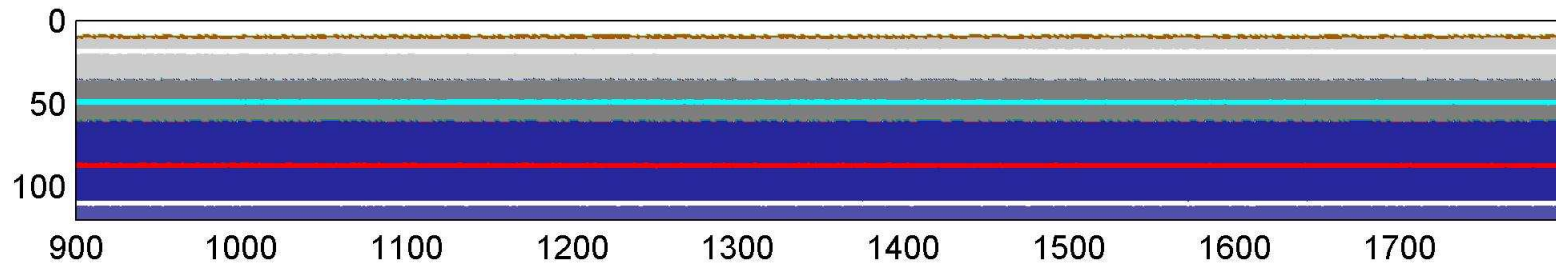
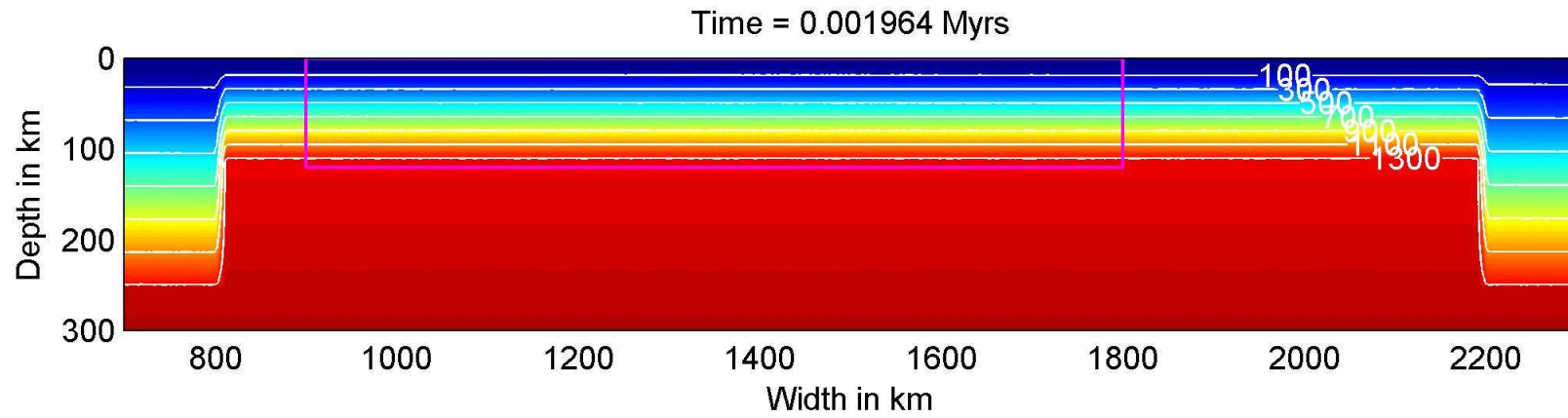
Numerical modelling: ENOUGH OF COMPRESSION



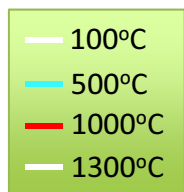
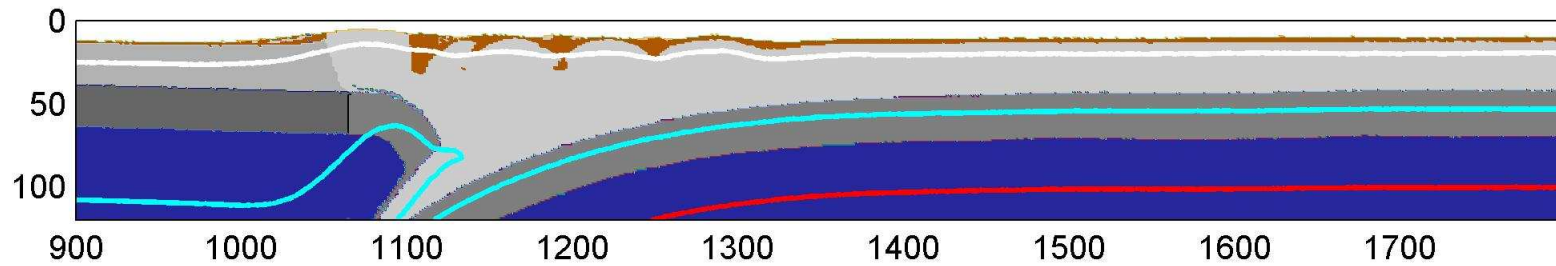
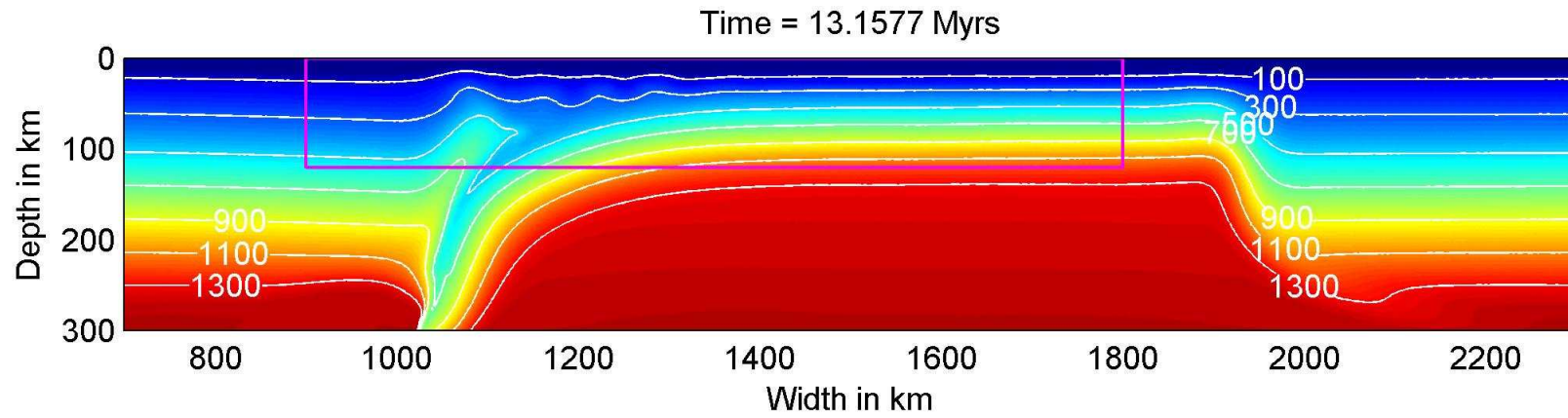
INTRODUCTION OF EXTENSIVE MELTING
AT SHALLOW LEVELS
but
TOO SHORT ACTIVE MELTING PERIOD



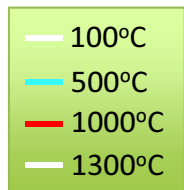
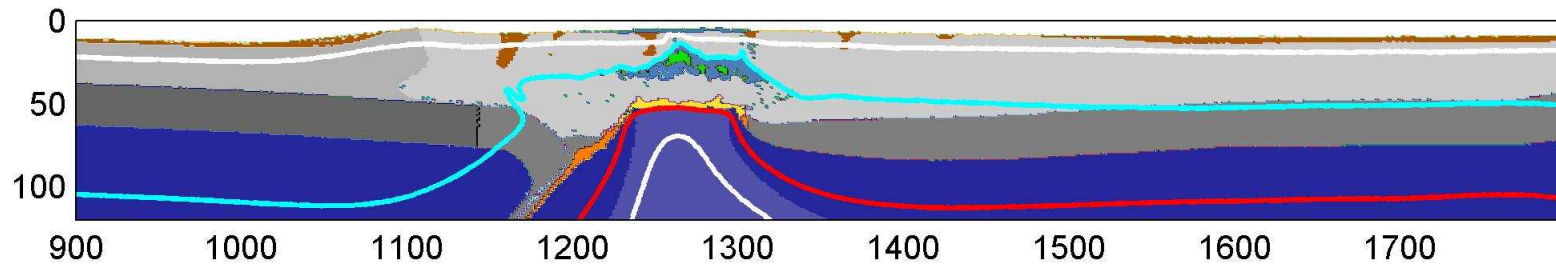
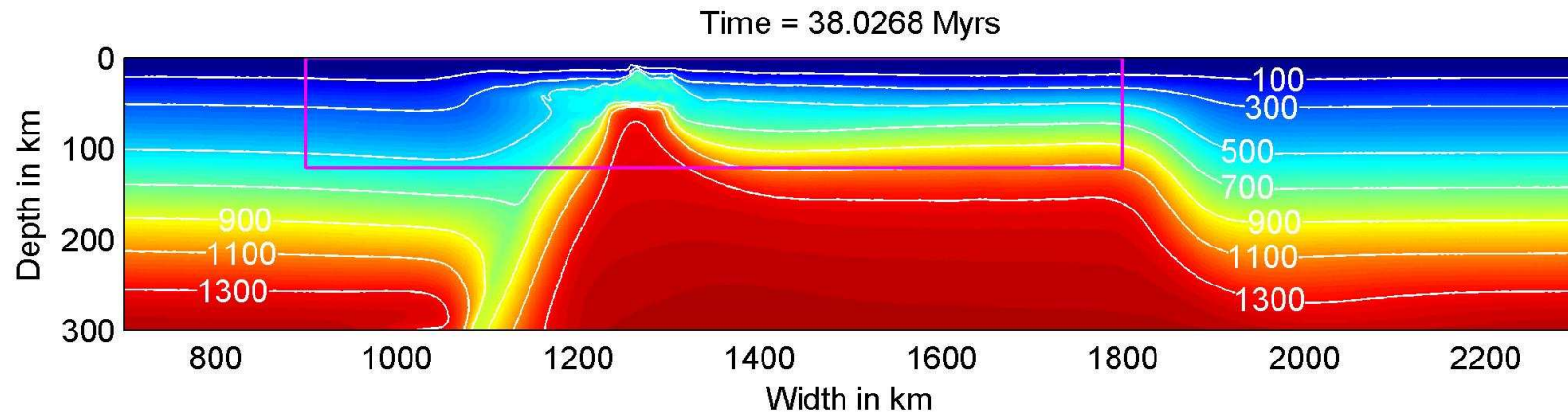
Numerical modelling: THERMAL EVOLUTION



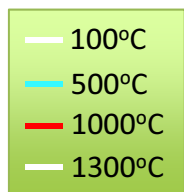
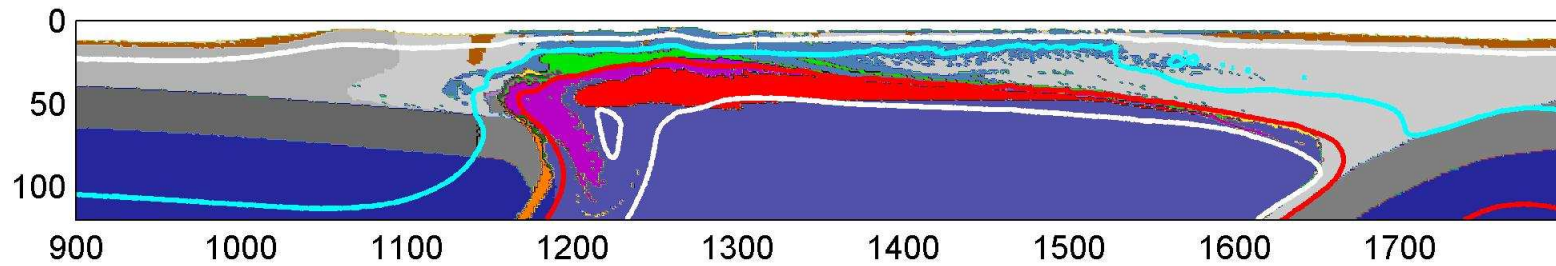
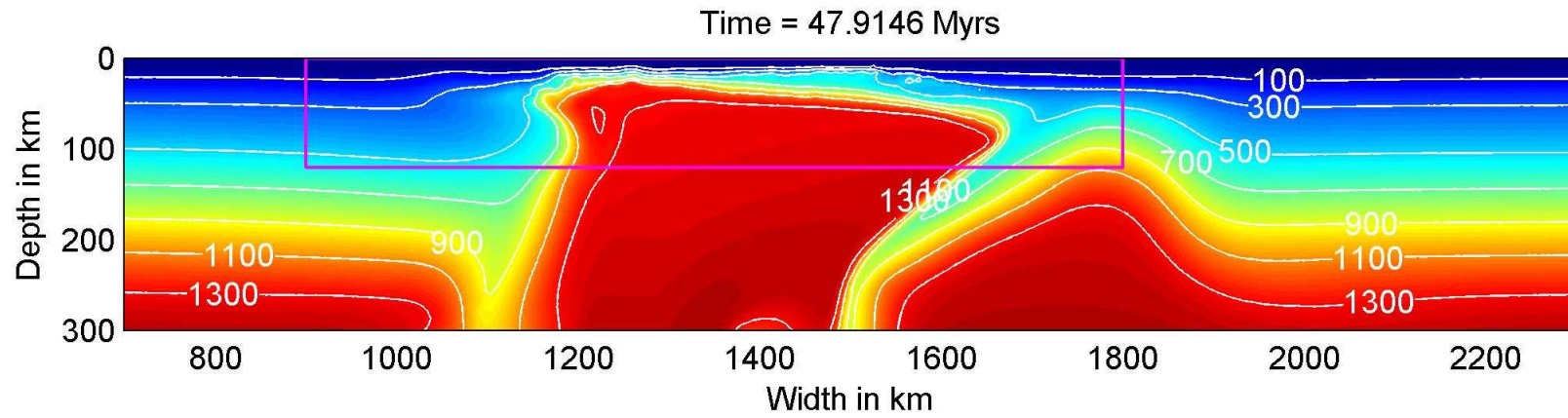
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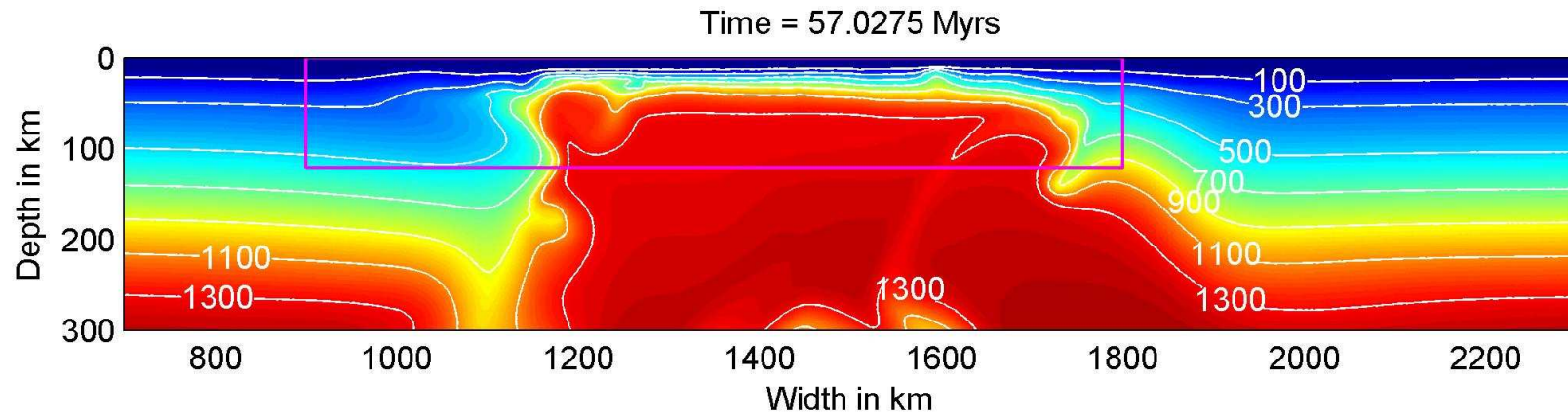
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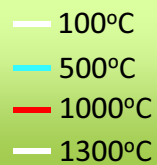
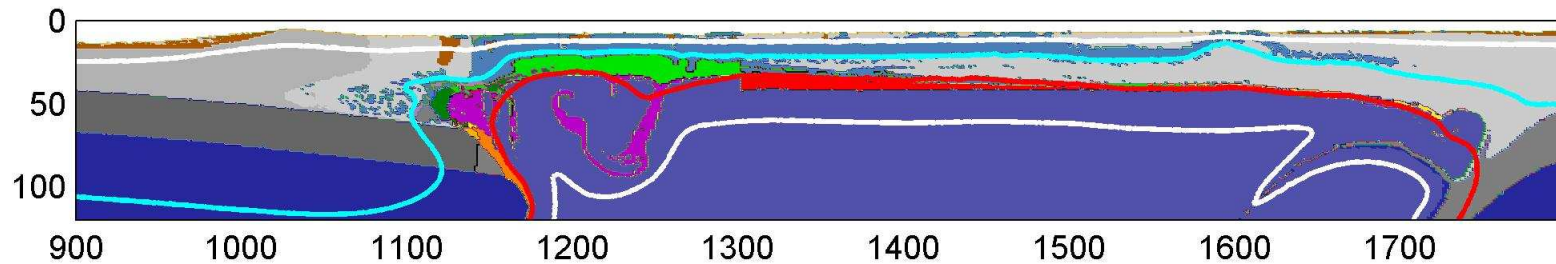
Numerical modelling: THERMAL EVOLUTION



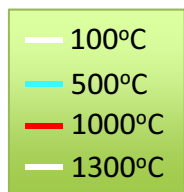
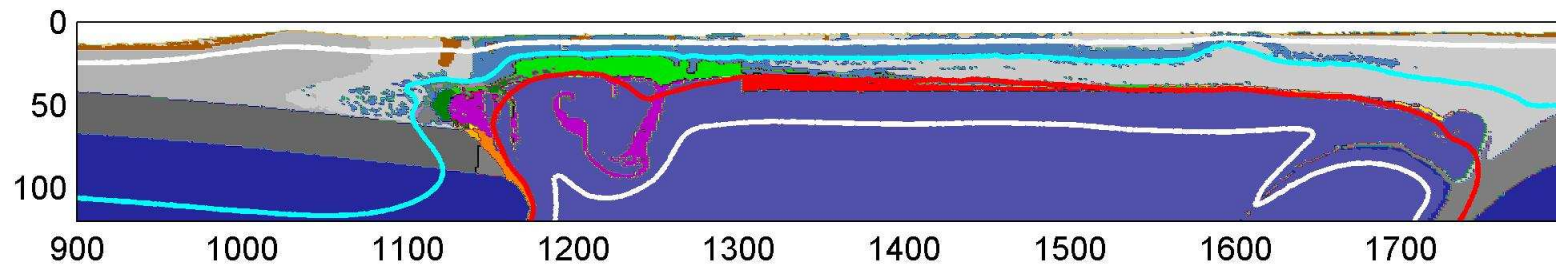
Numerical modelling: THERMAL EVOLUTION



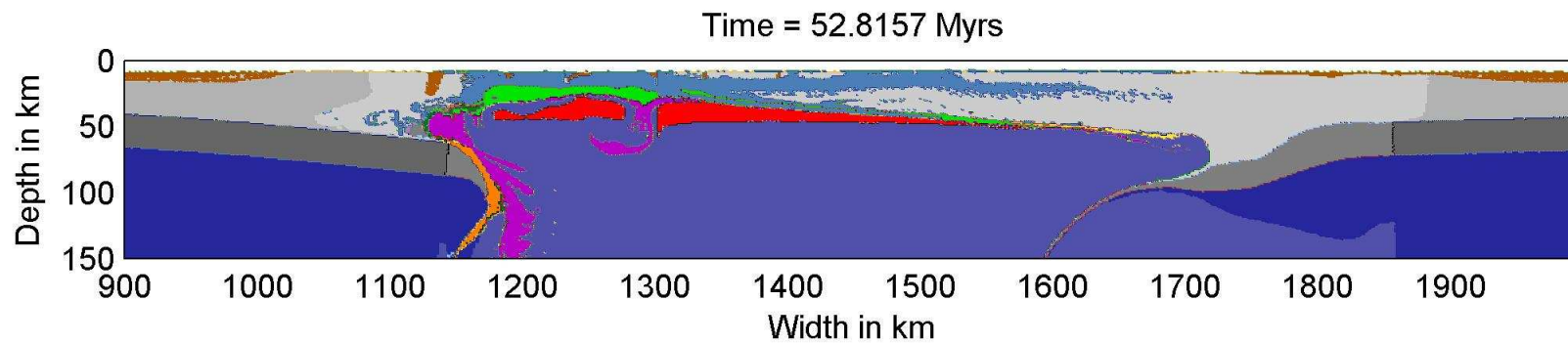
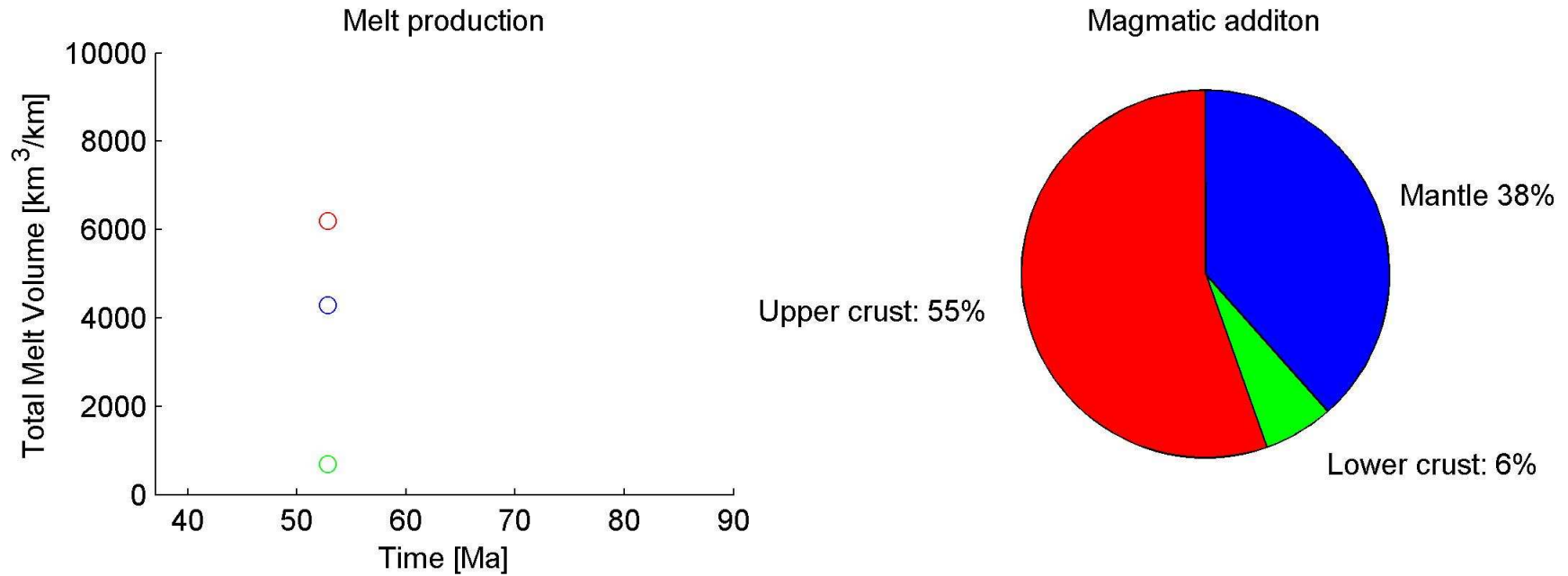
UTH MELTING AT SHALLOW LEVELS



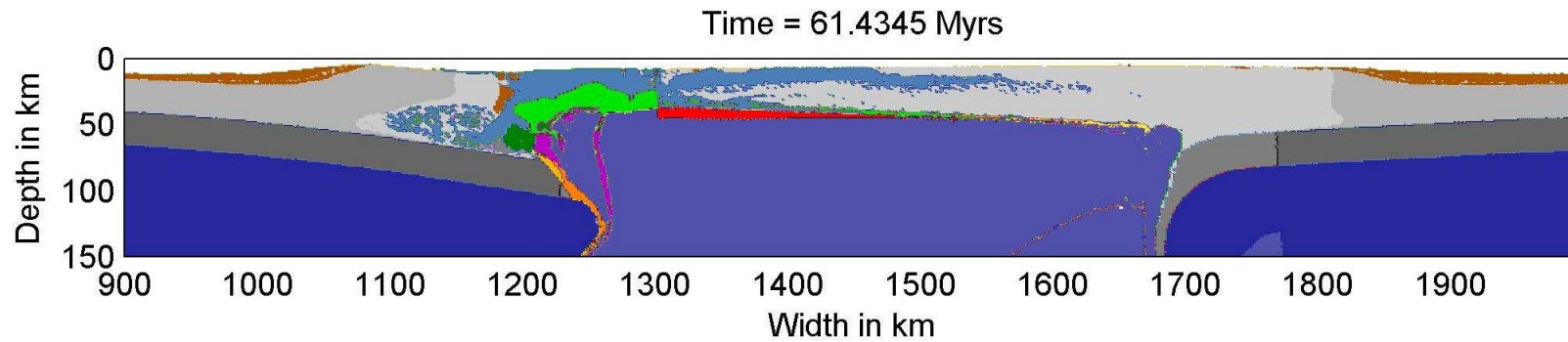
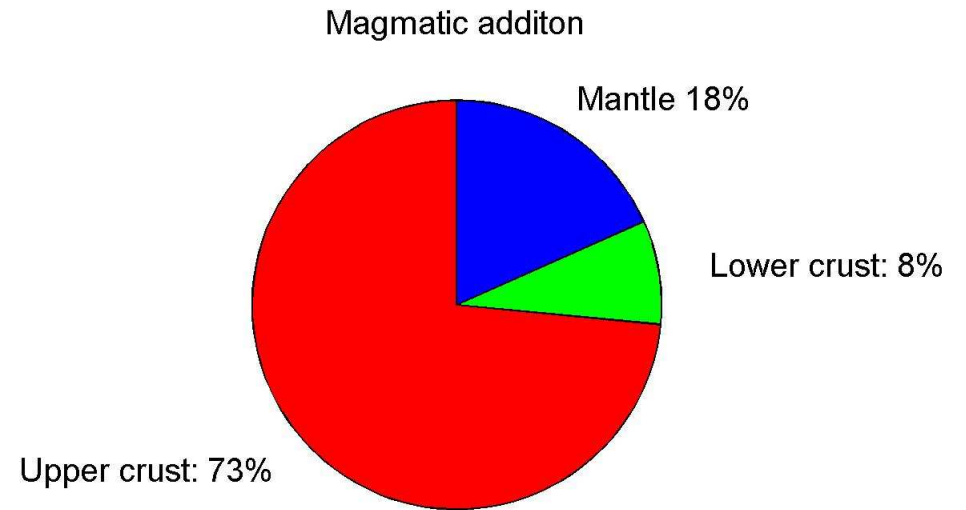
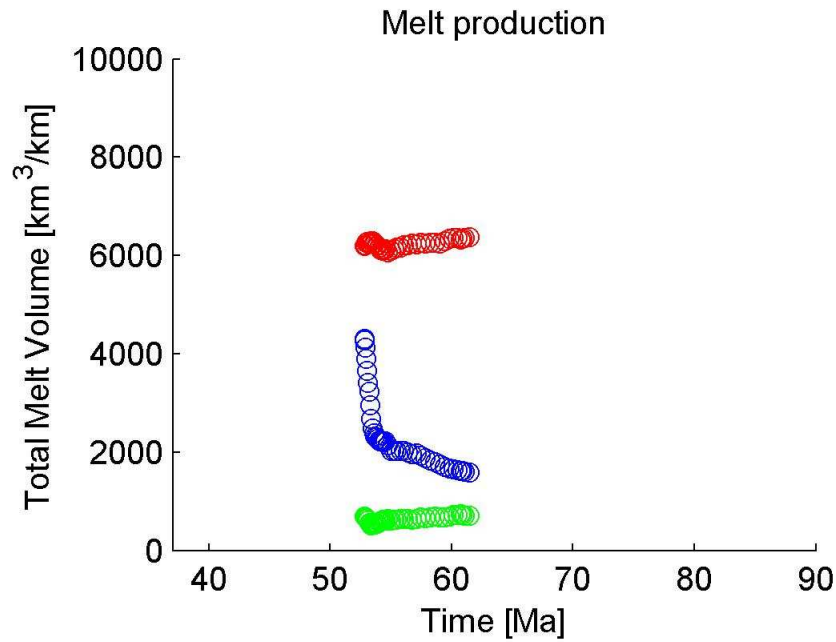
INTRODUCTION OF EXTENSIVE **UHT MELTING**
AT SHALLOW LEVELS
but
TOO SHORT ACTIVE MELTING PERIOD



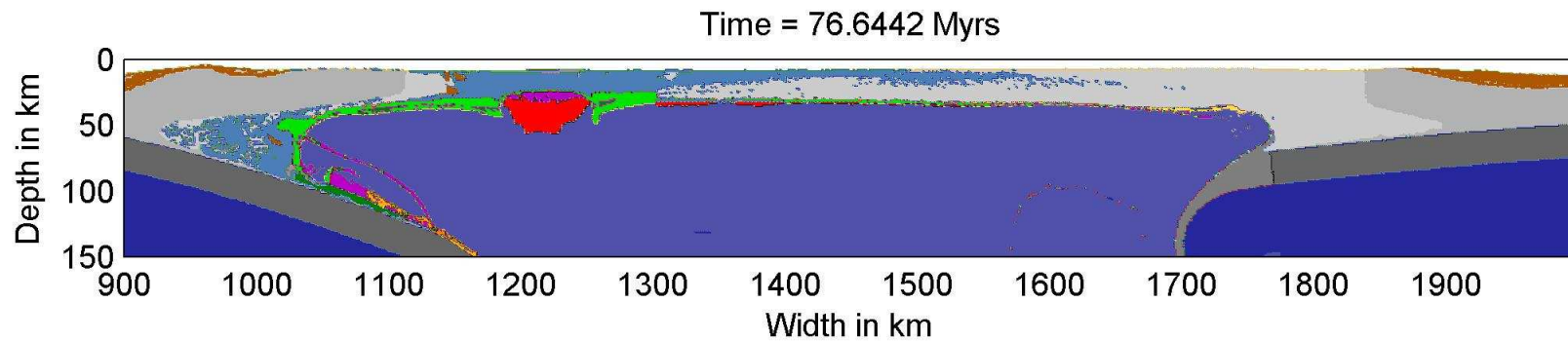
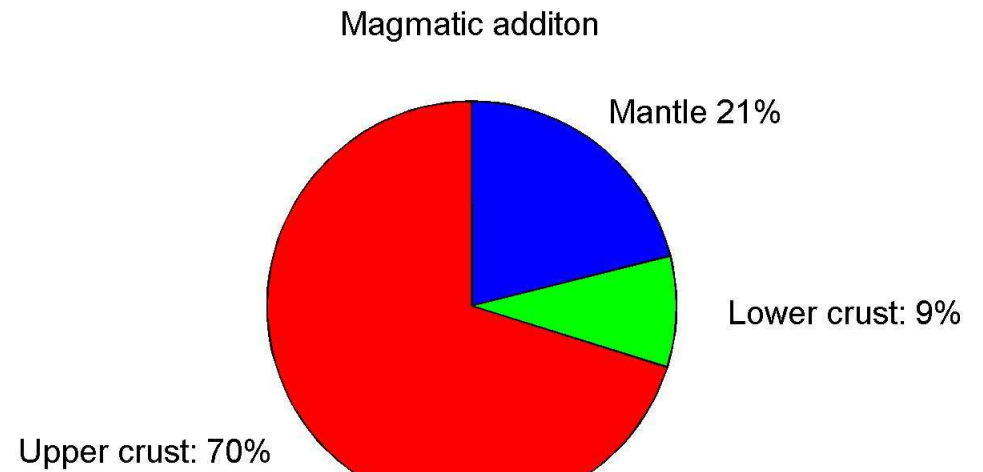
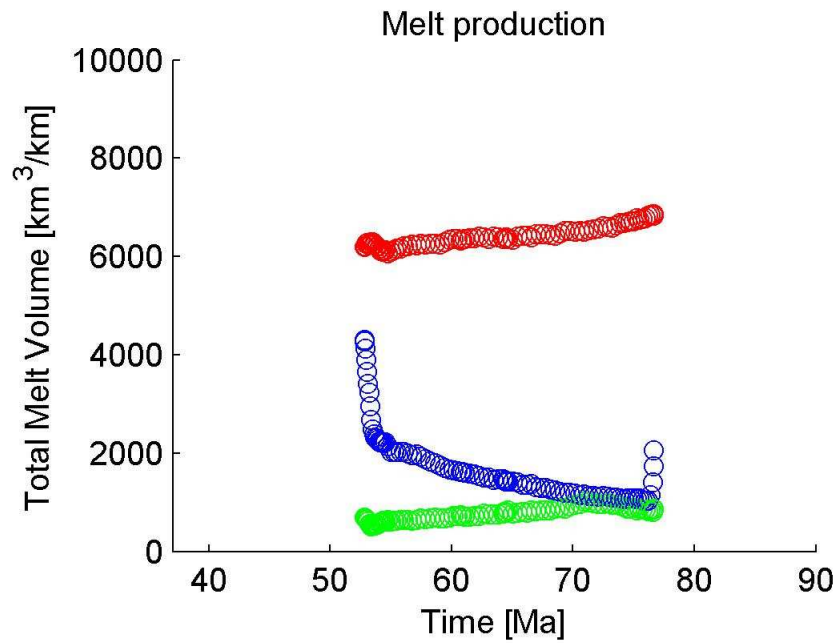
Numerical modelling: SHORT COMPRESSIONAL EPISODE



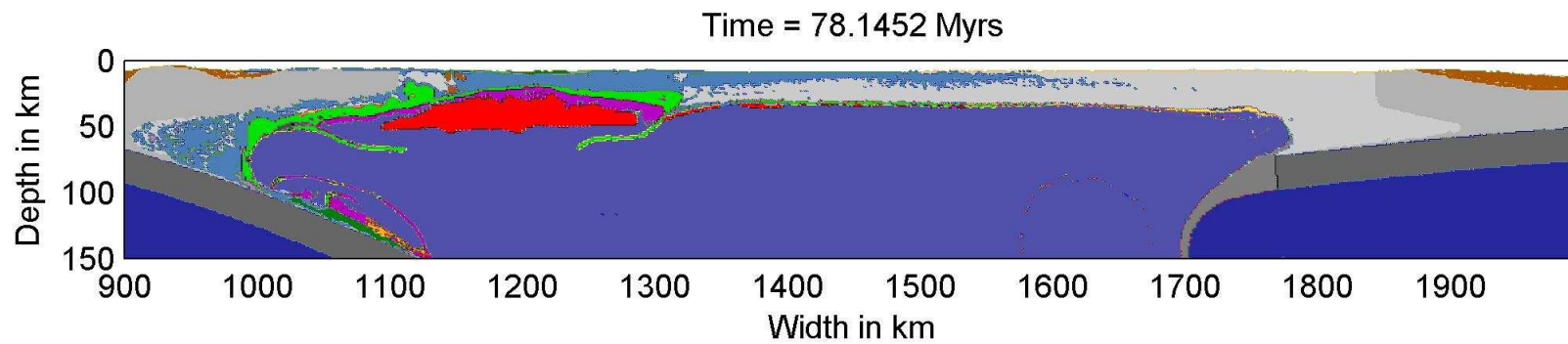
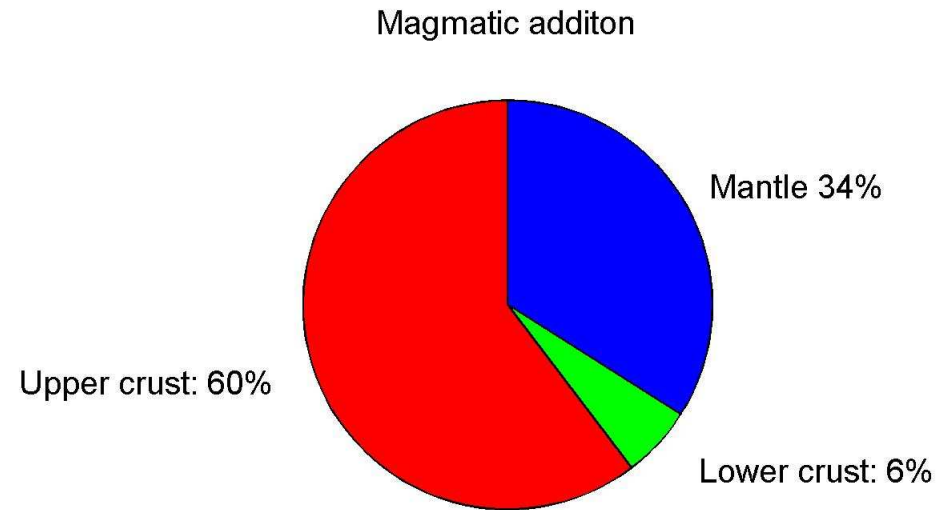
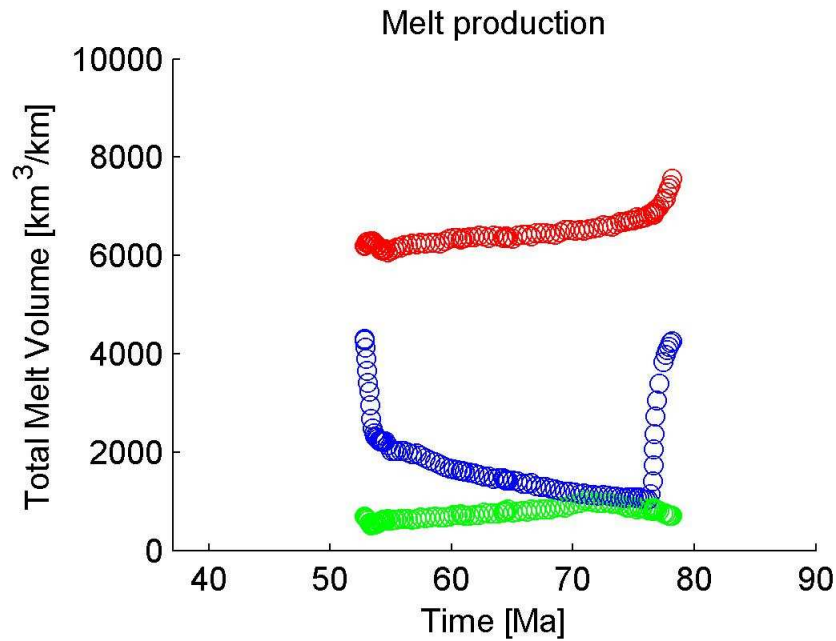
Numerical modelling: SHORT COMPRESSIONAL EPISODE



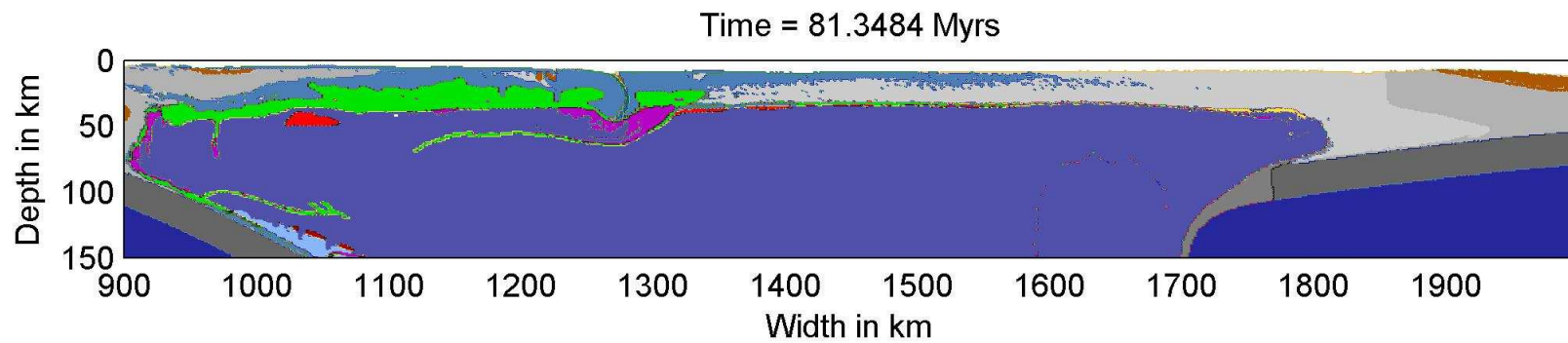
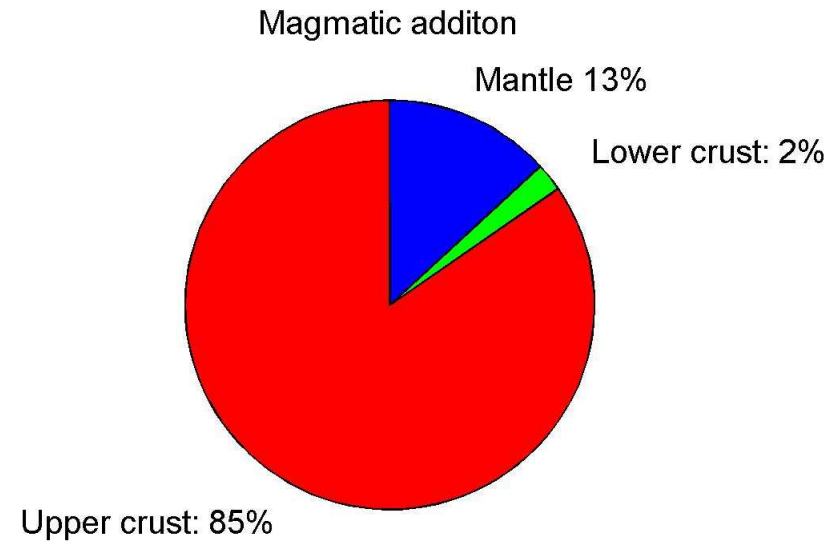
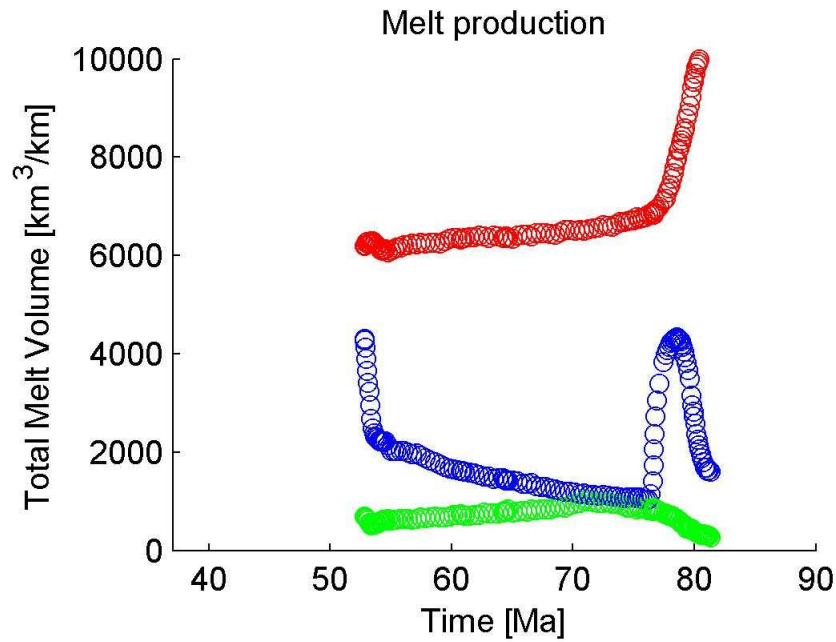
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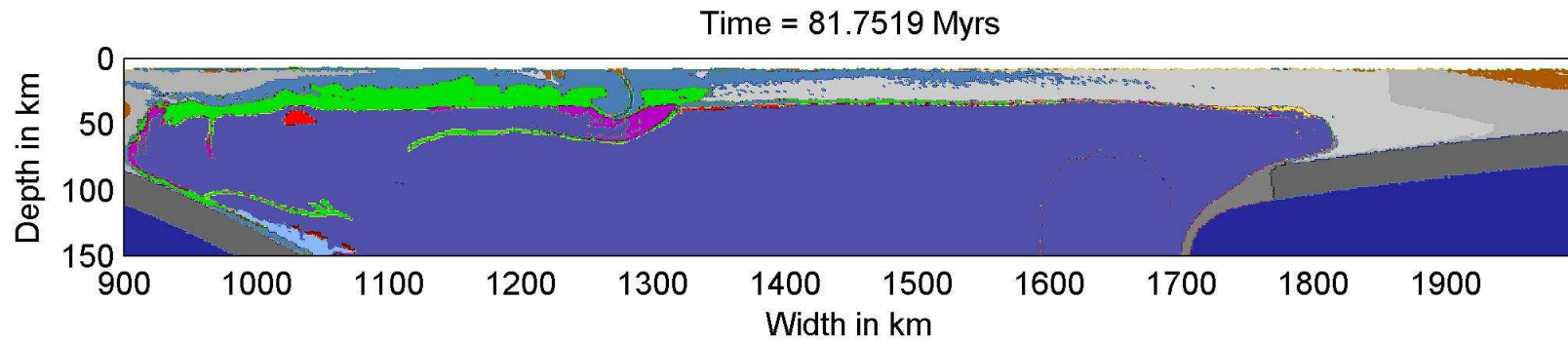
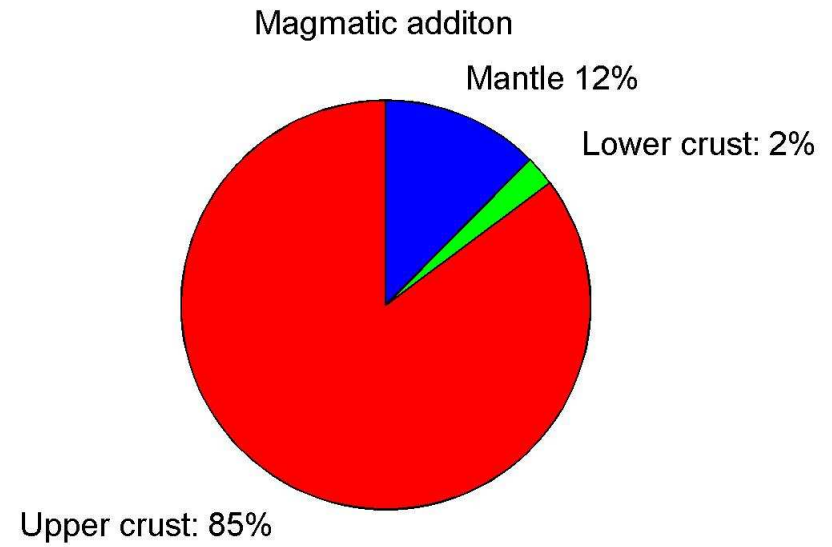
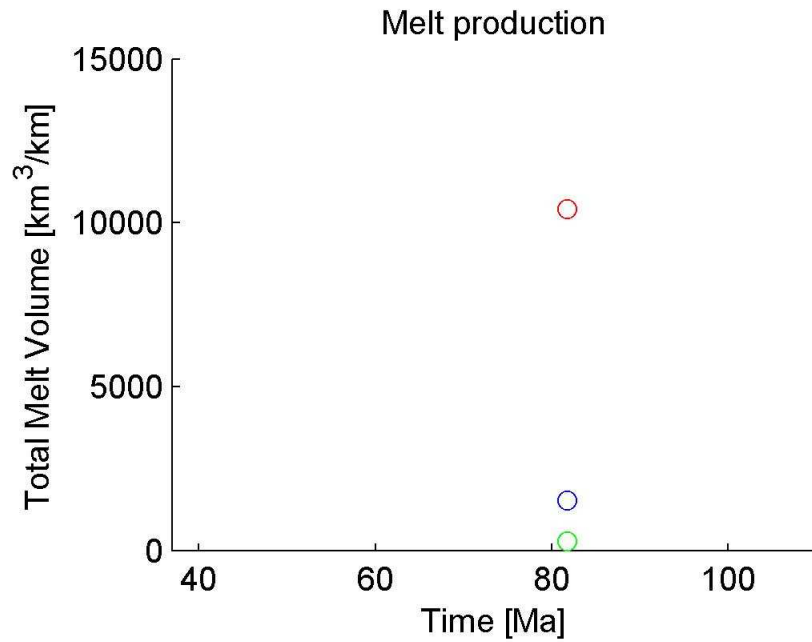
Numerical modelling: SHORT COMPRESSIONAL EPISODE



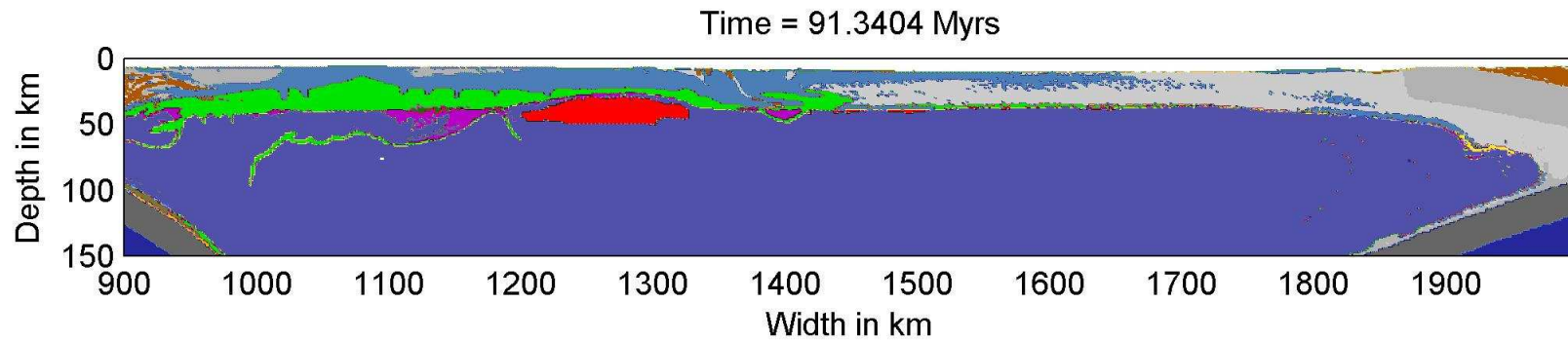
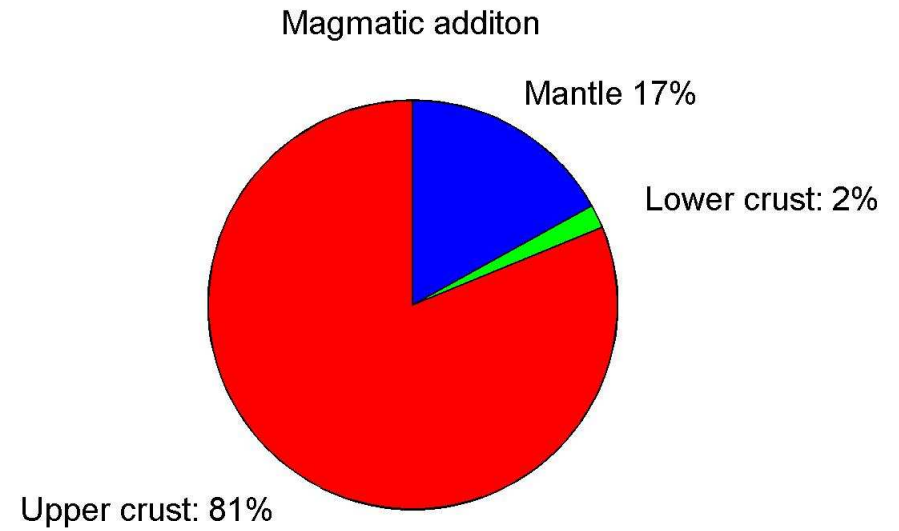
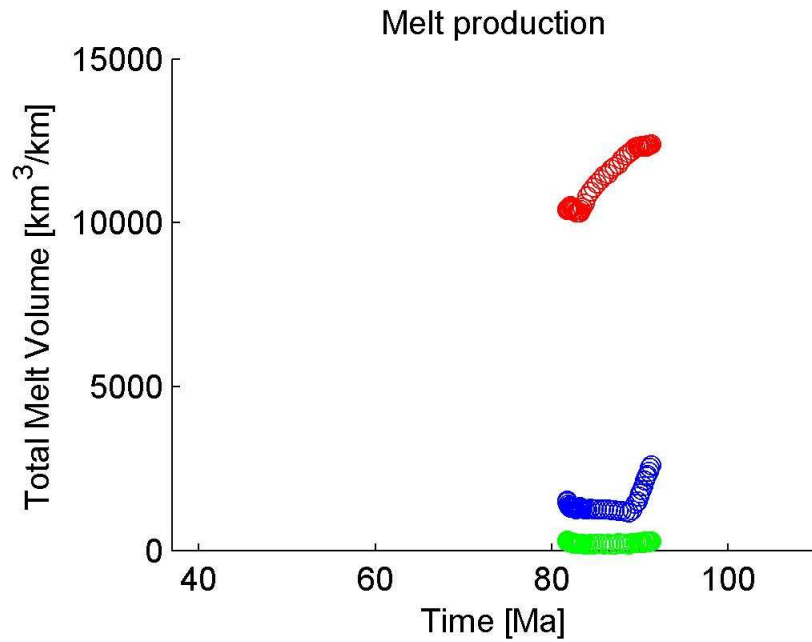
Numerical modelling: SHORT COMPRESSIONAL EPISODE



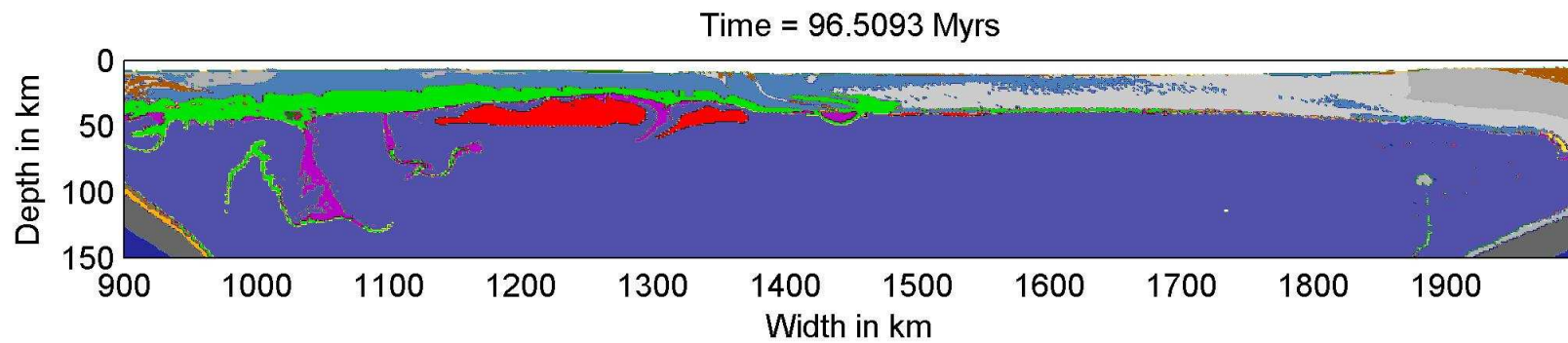
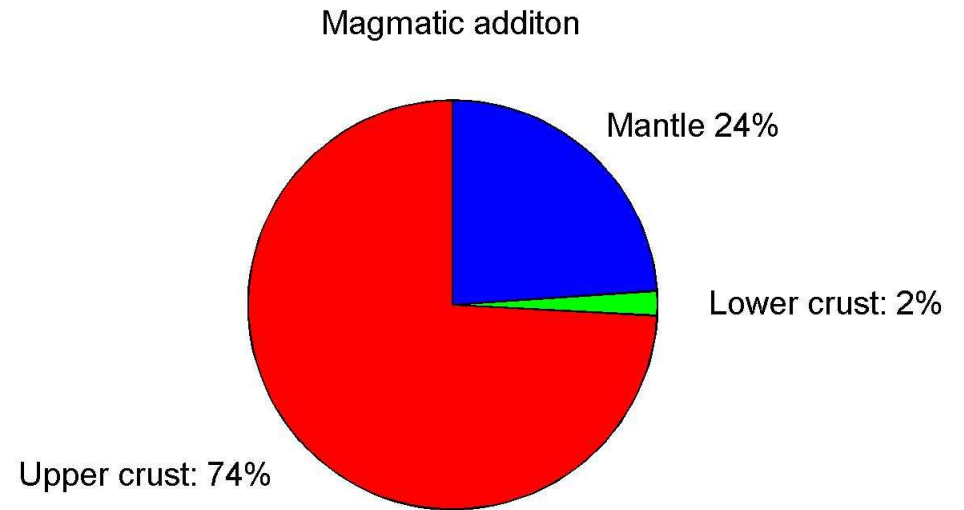
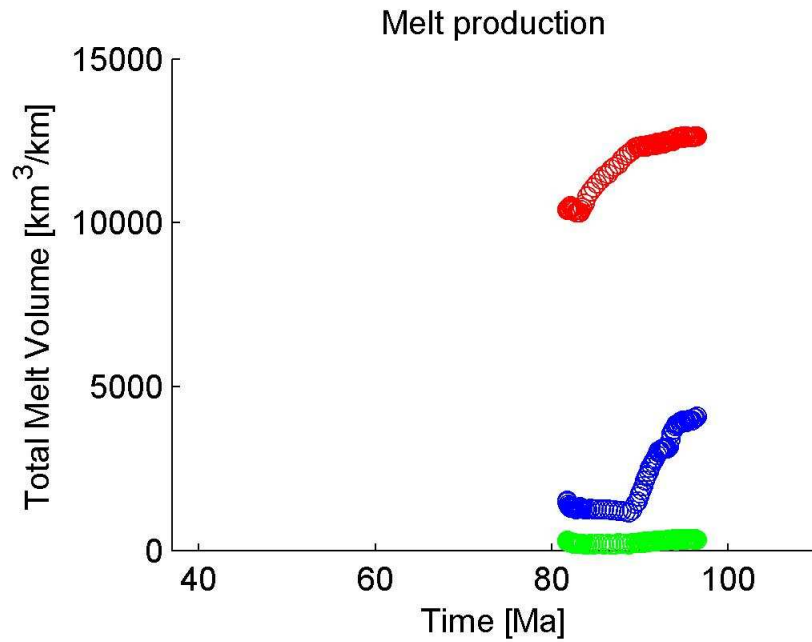
Numerical modelling: SECOND SHORT COMPRESSIONAL EPISODE



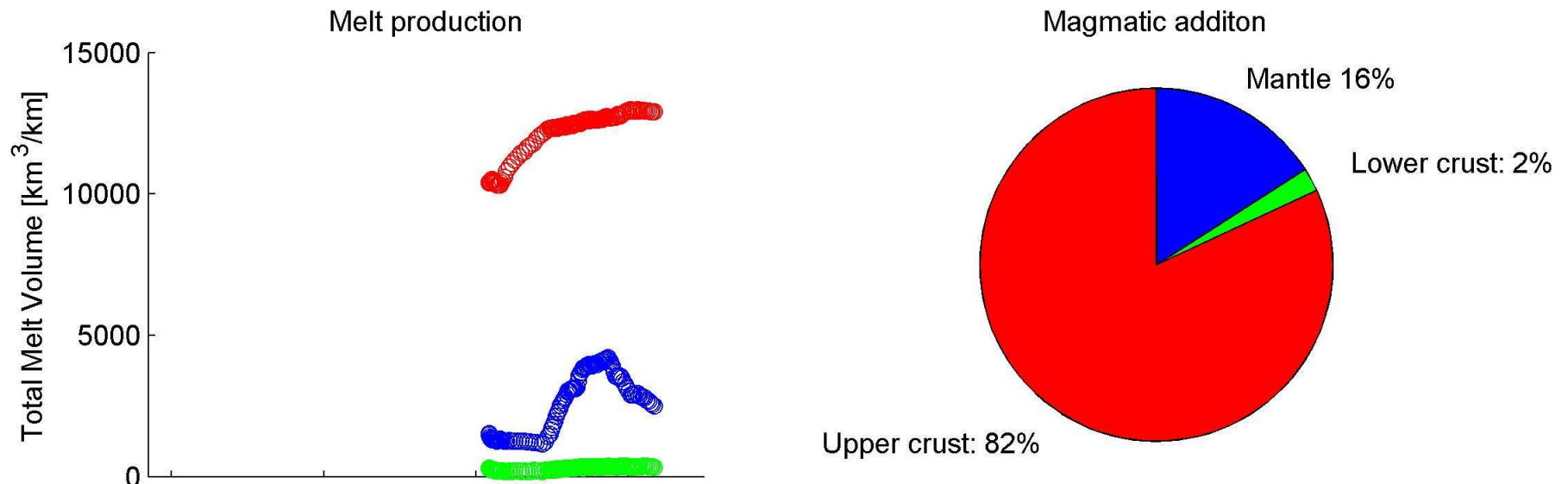
Numerical modelling: *SECOND SHORT COMPRESSIONAL EPISODE*



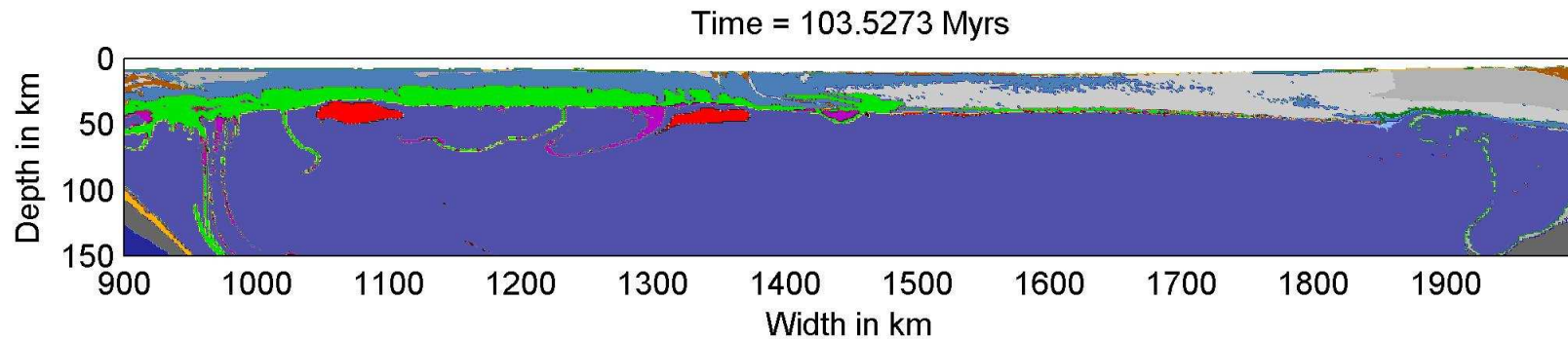
Numerical modelling: SECOND SHORT COMPRESSIONAL EPISODE



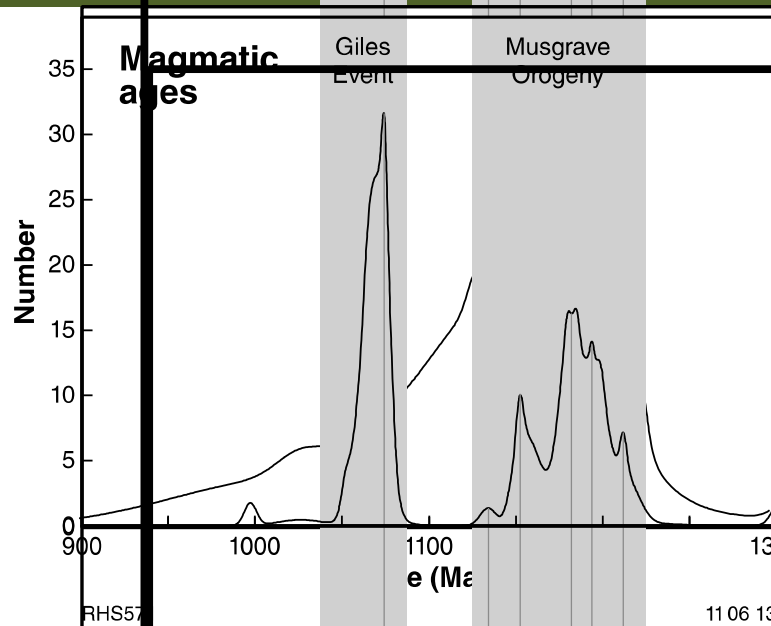
Numerical modelling: SECOND SHORT COMPRESSIONAL EPISODE



MULTIPLE REACTIVATION EVENT
but
SMALL MANTLE CONTRIBUTION

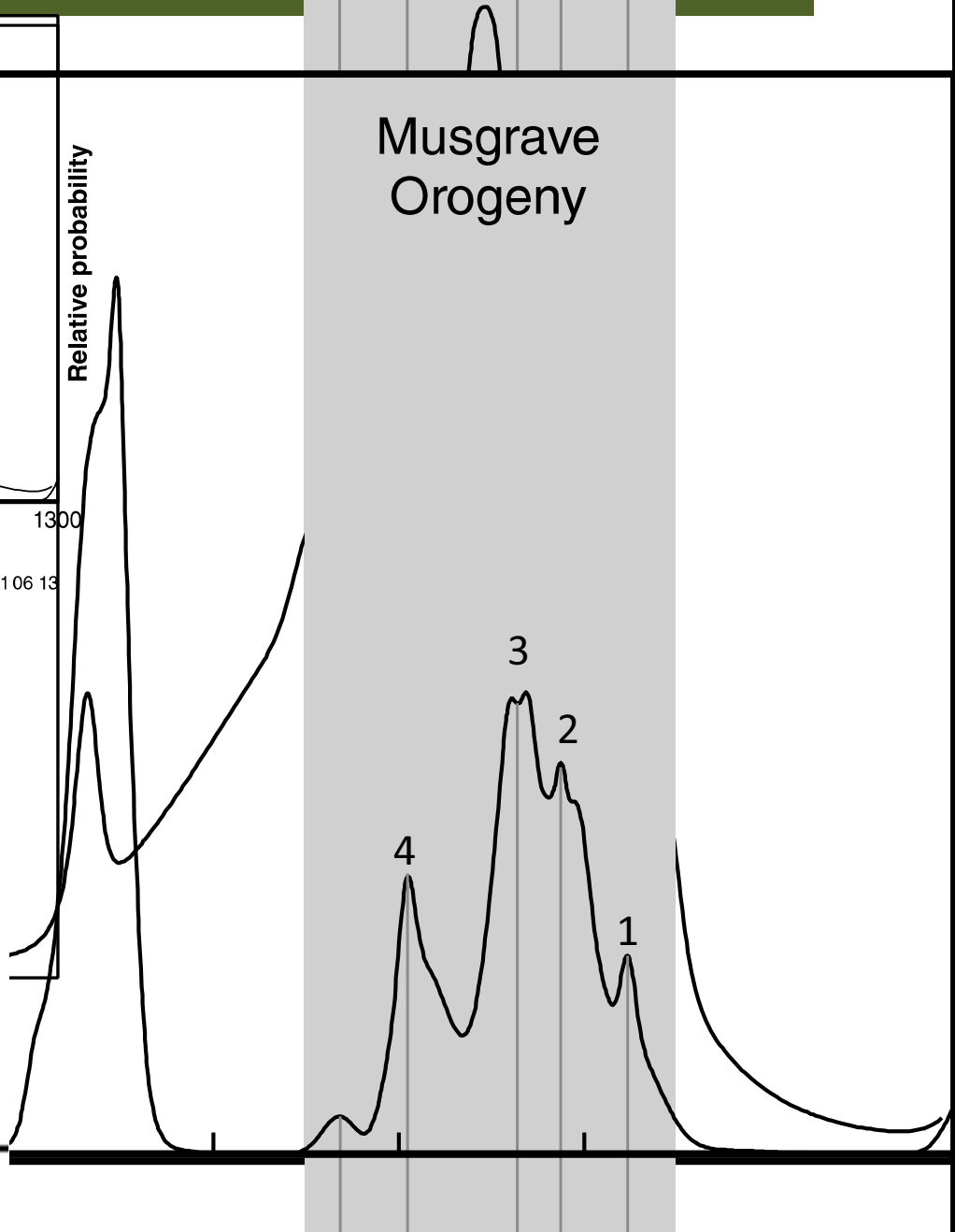
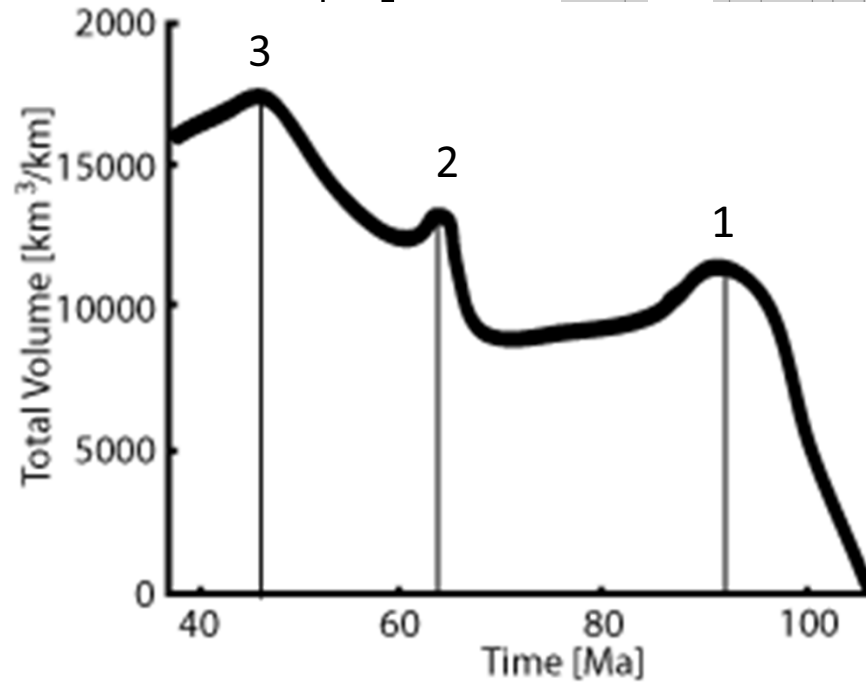


Numerical modelling *SECON* *SHO* *MPRESSIONAL E*

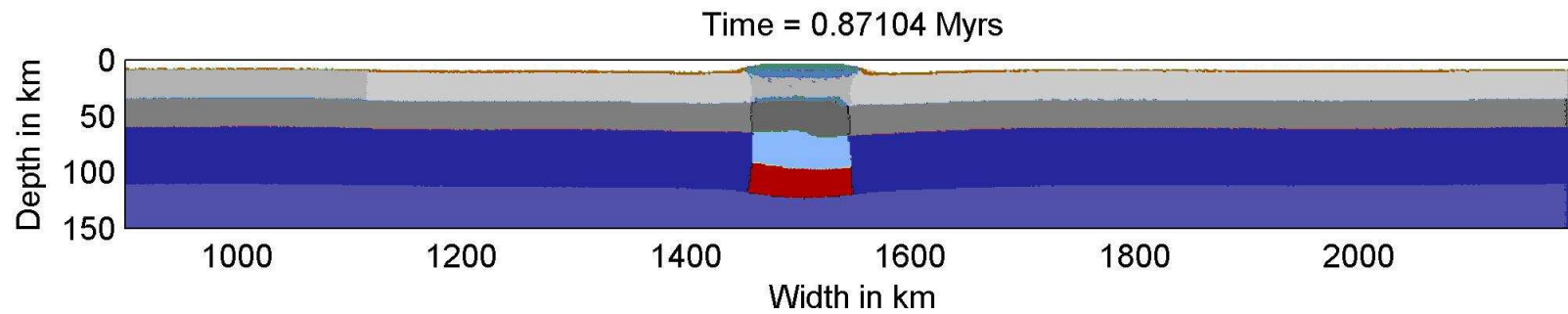
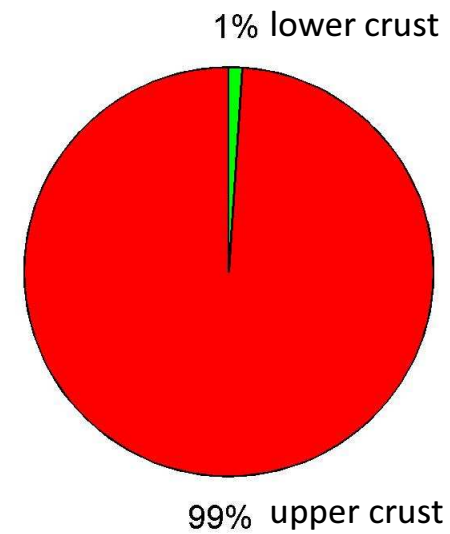
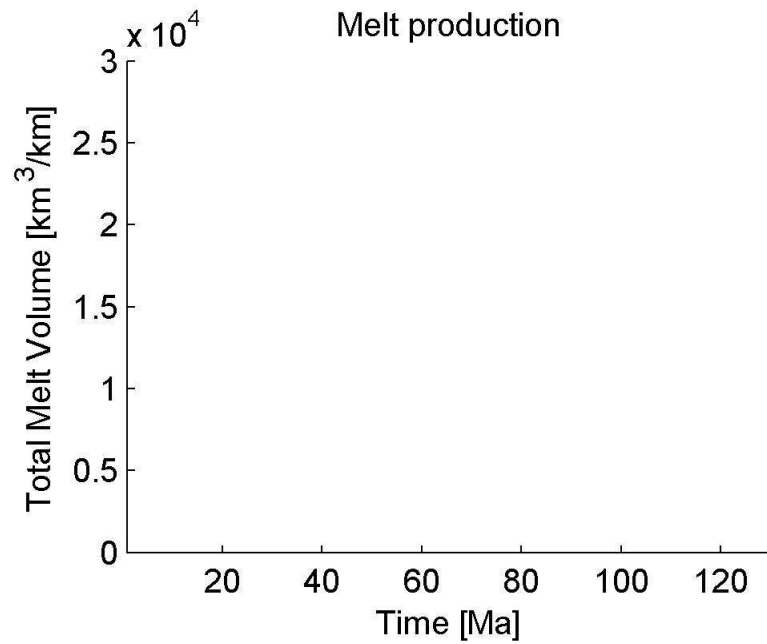


Relative probability

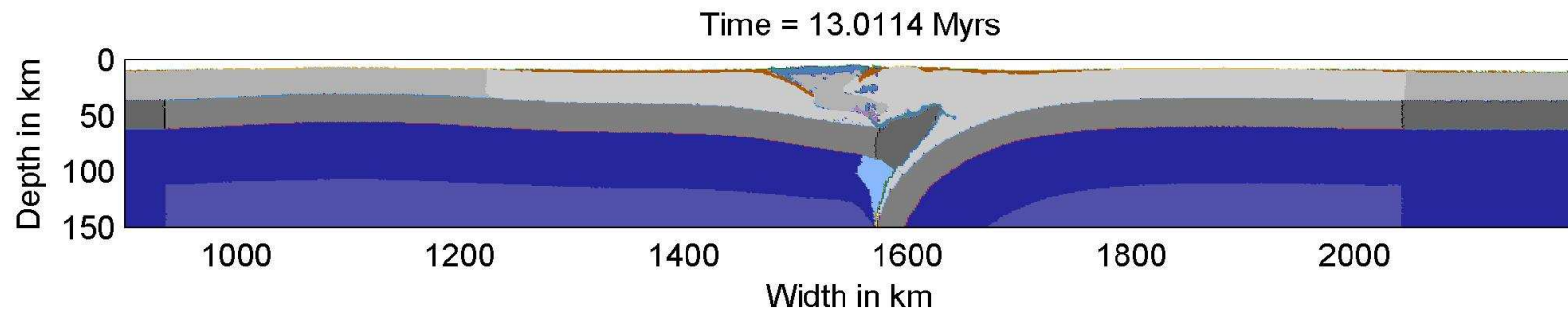
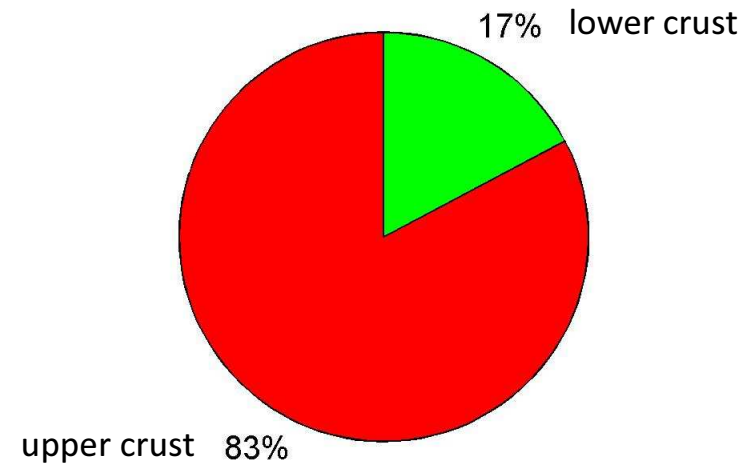
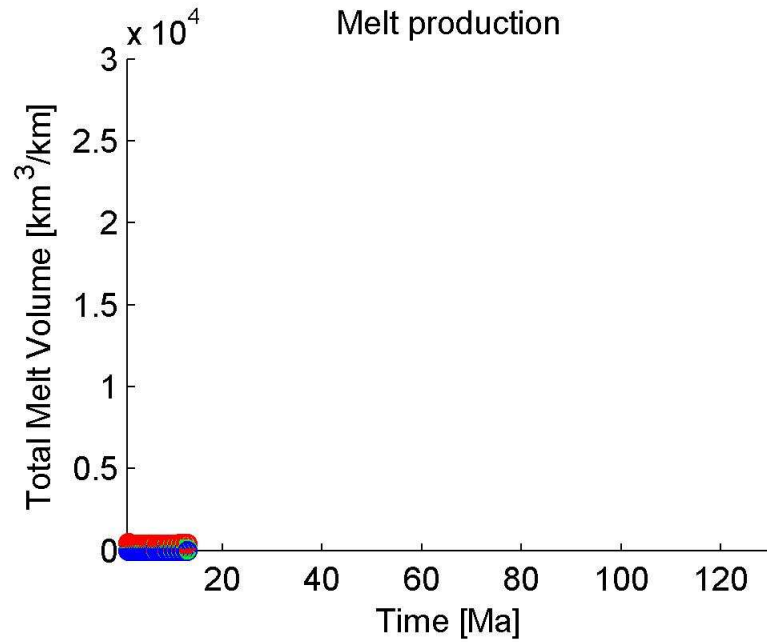
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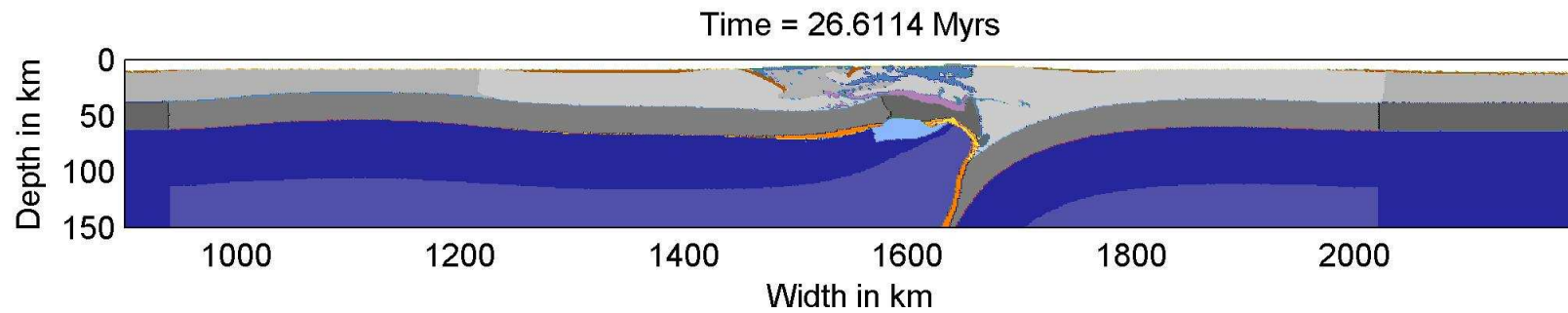
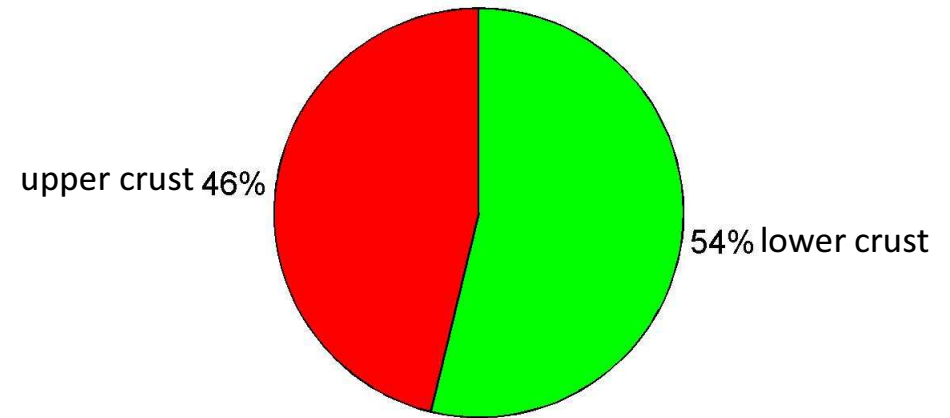
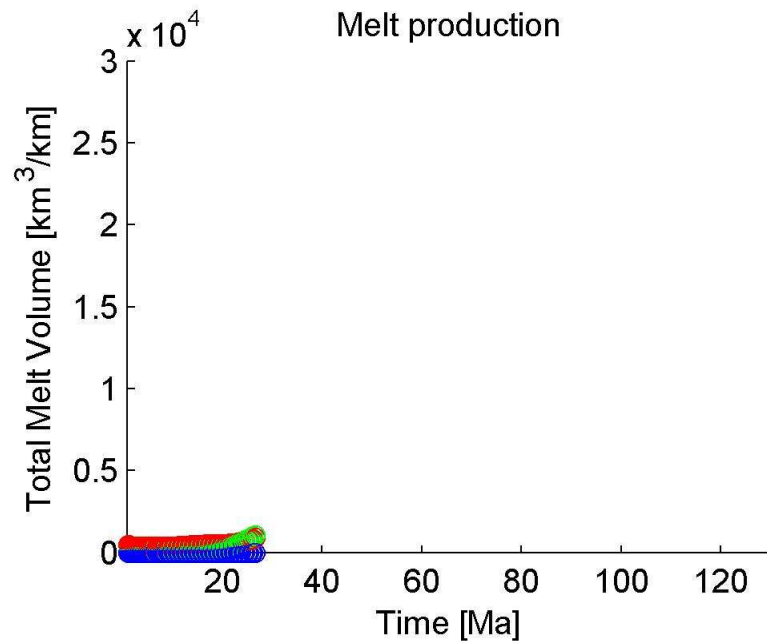
Numerical modelling: DIFFERENT INITIAL SETTING



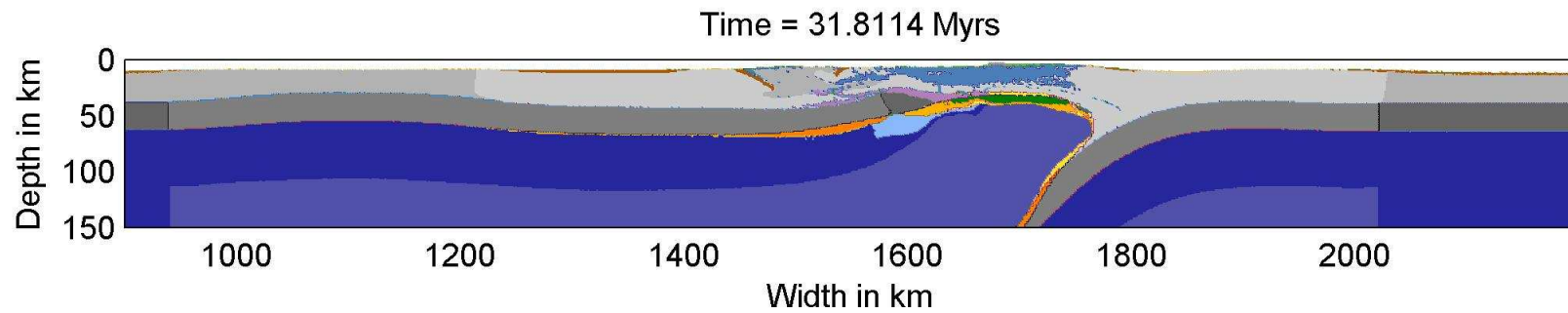
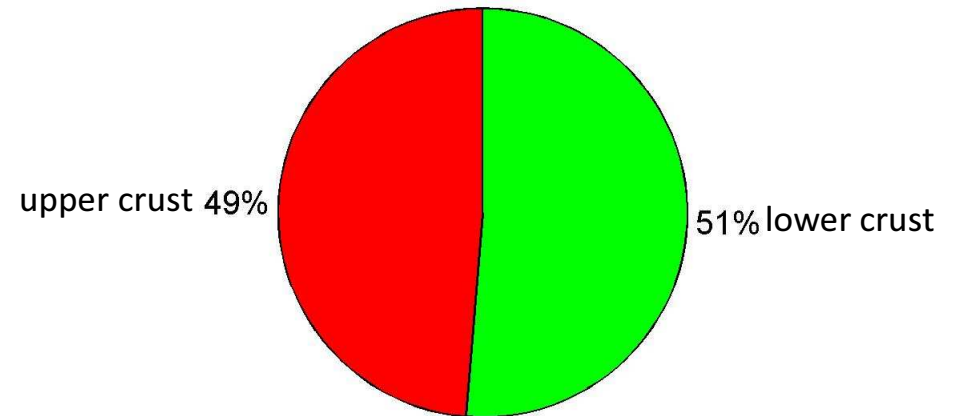
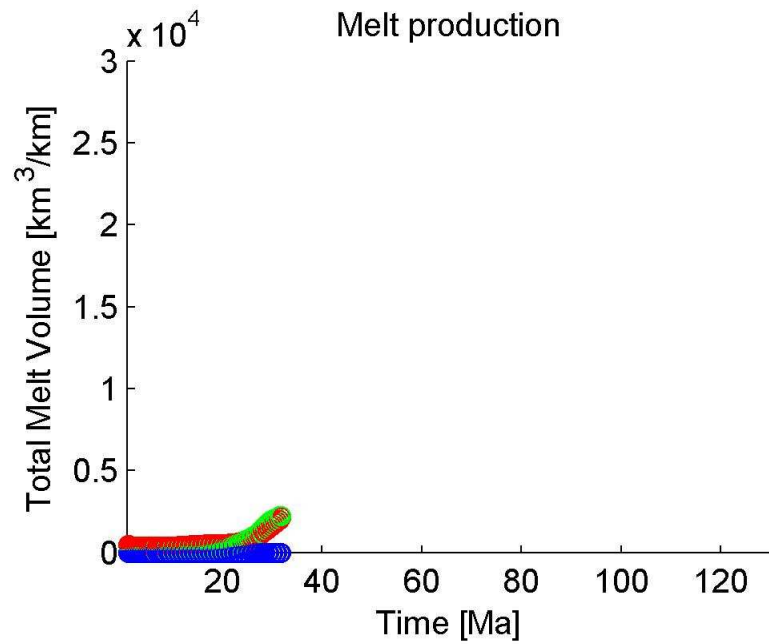
Numerical modelling: DIFFERENT INITIAL SETTING



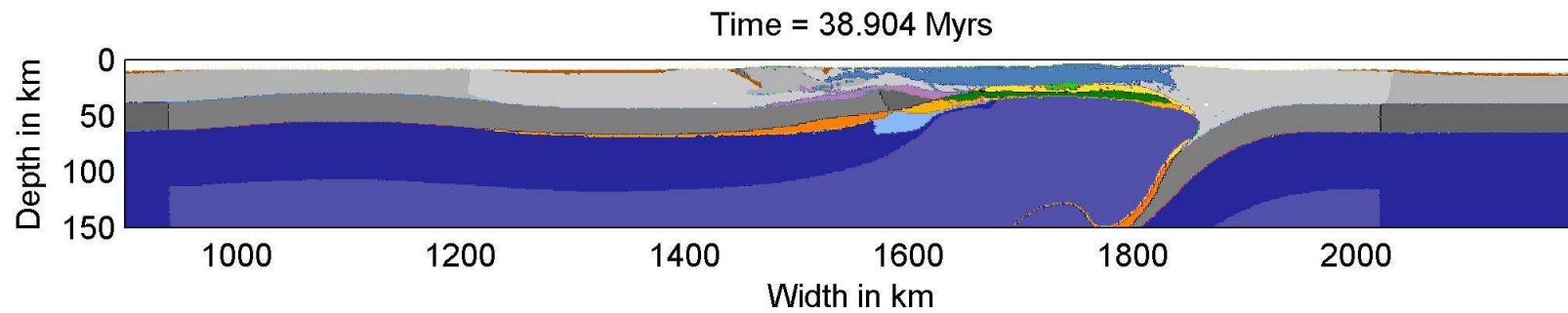
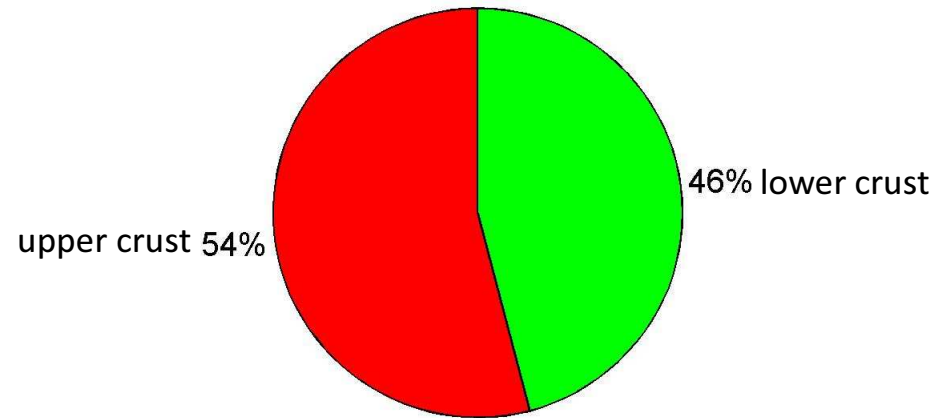
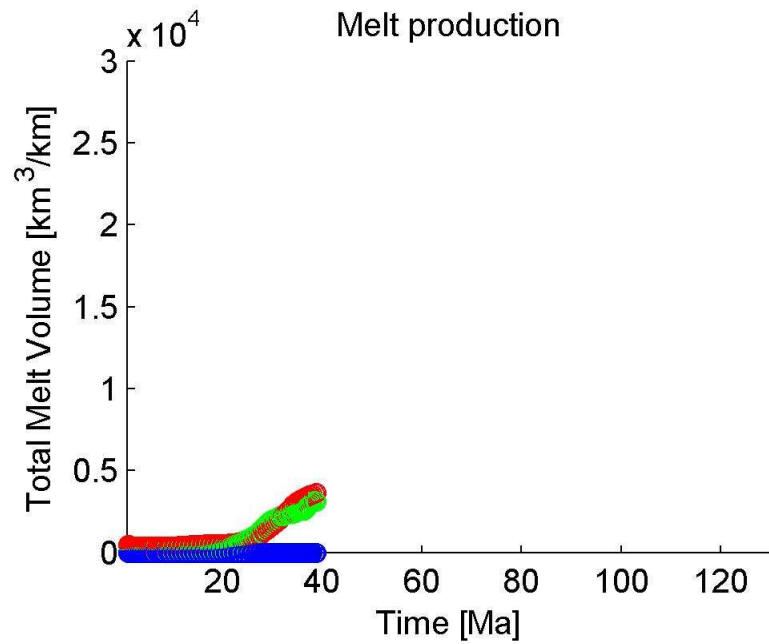
Numerical modelling: DIFFERENT INITIAL SETTING



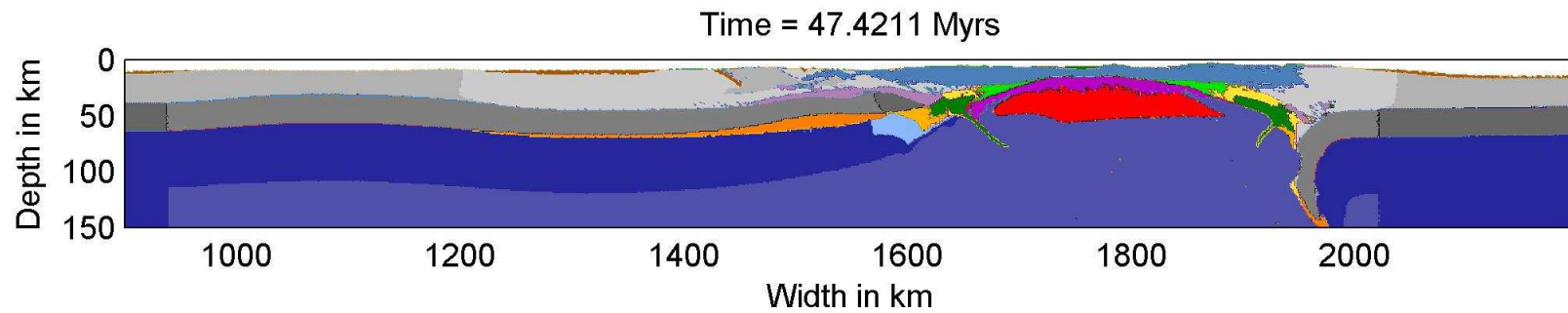
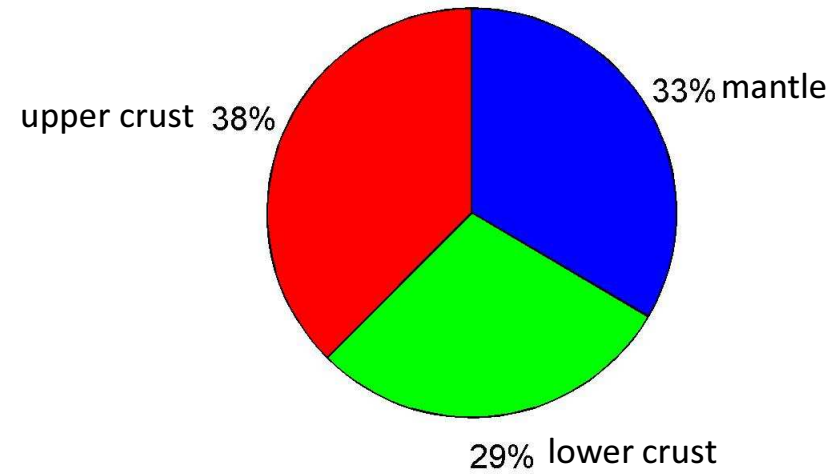
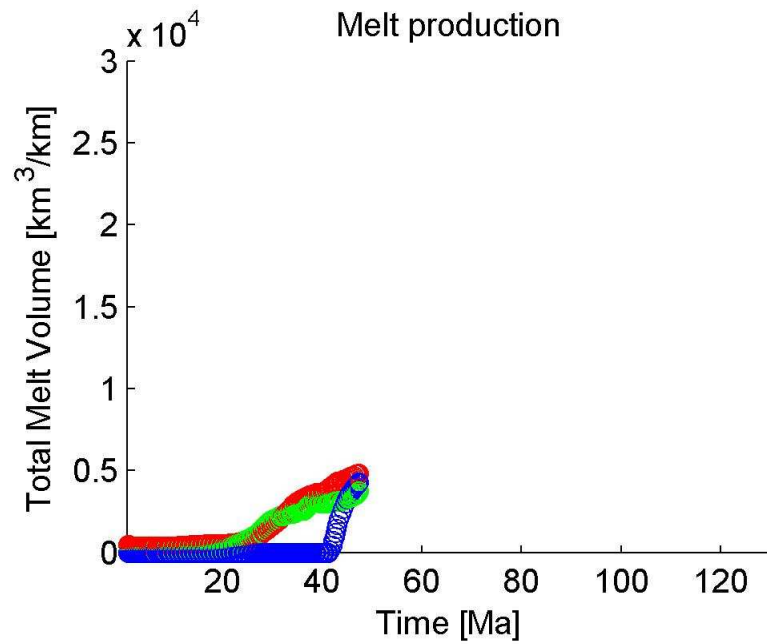
Numerical modelling: DIFFERENT INITIAL SETTING



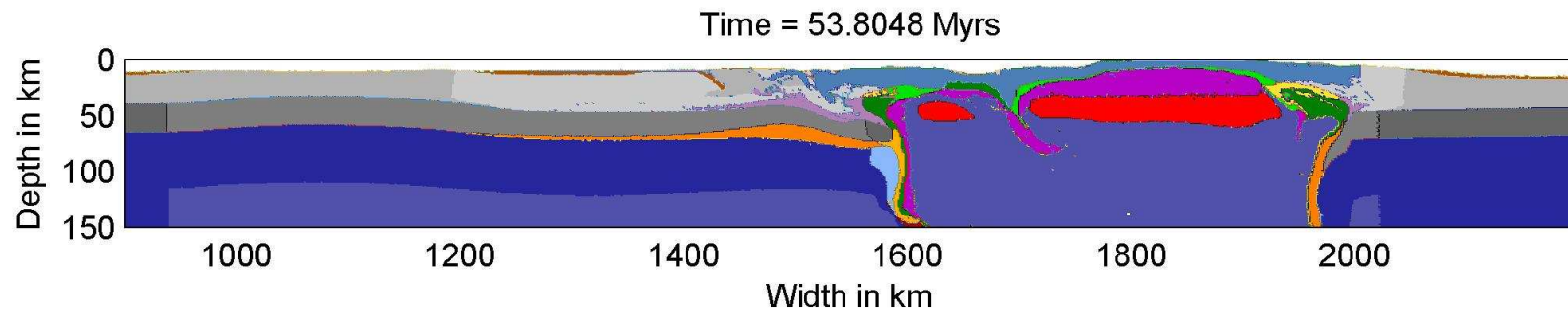
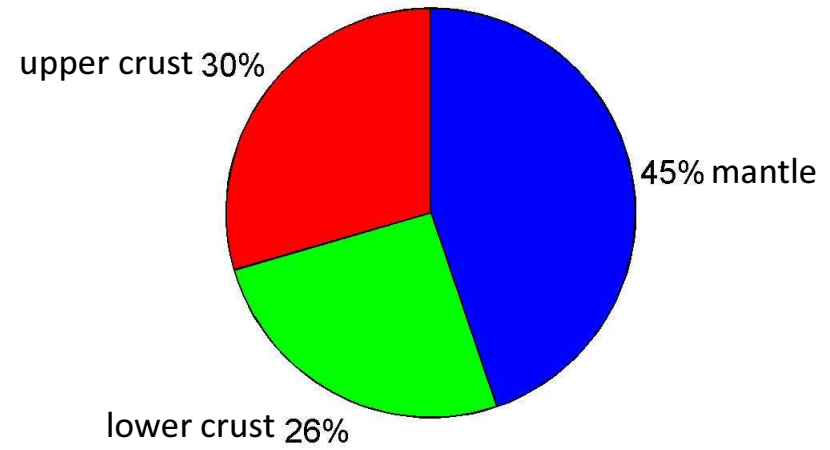
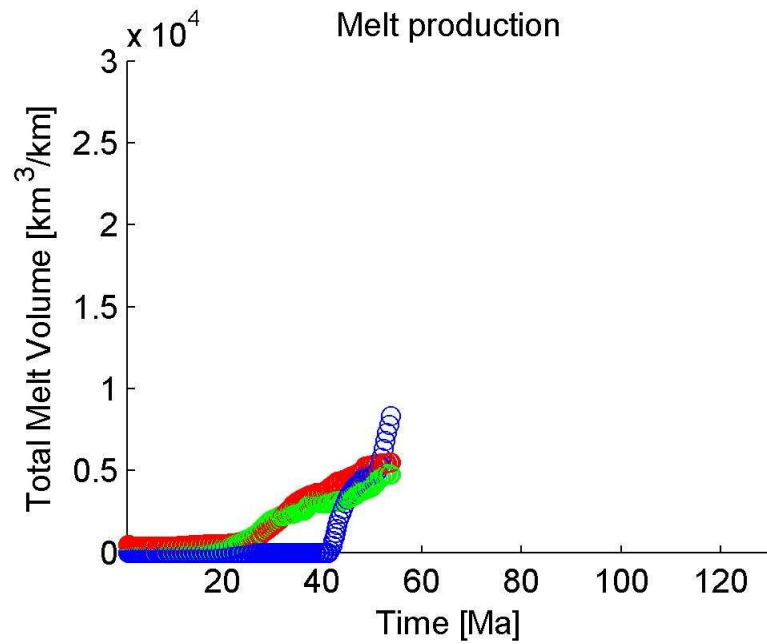
Numerical modelling: DIFFERENT INITIAL SETTING



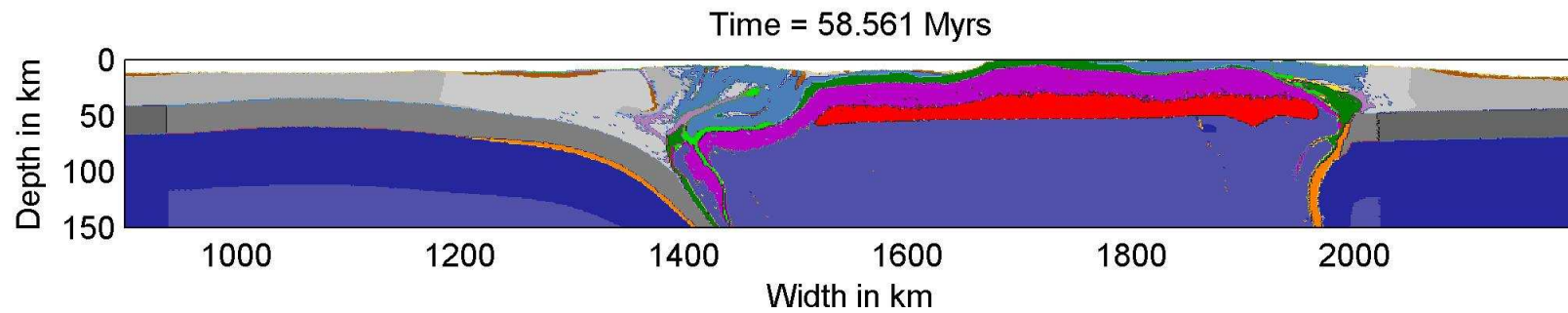
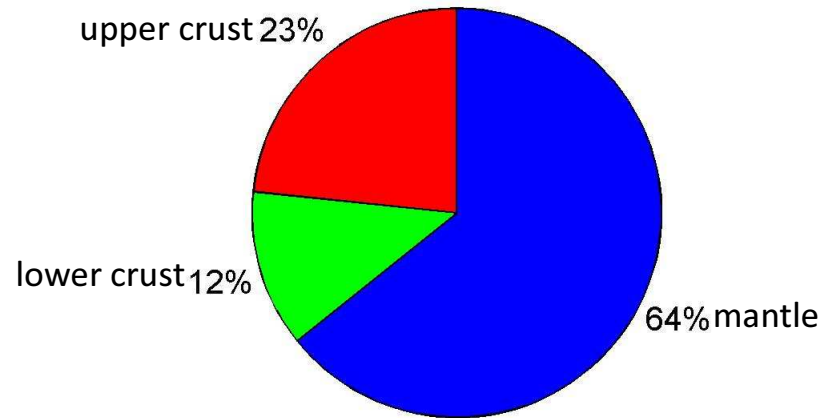
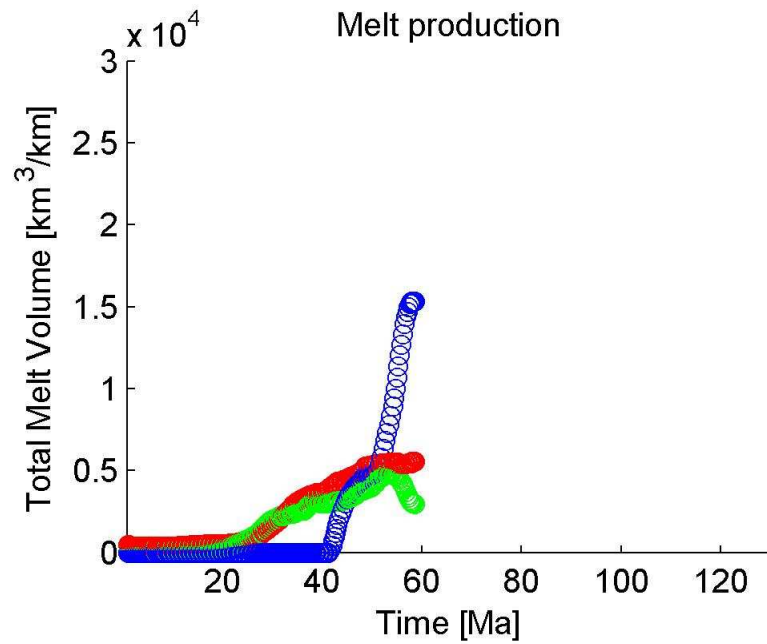
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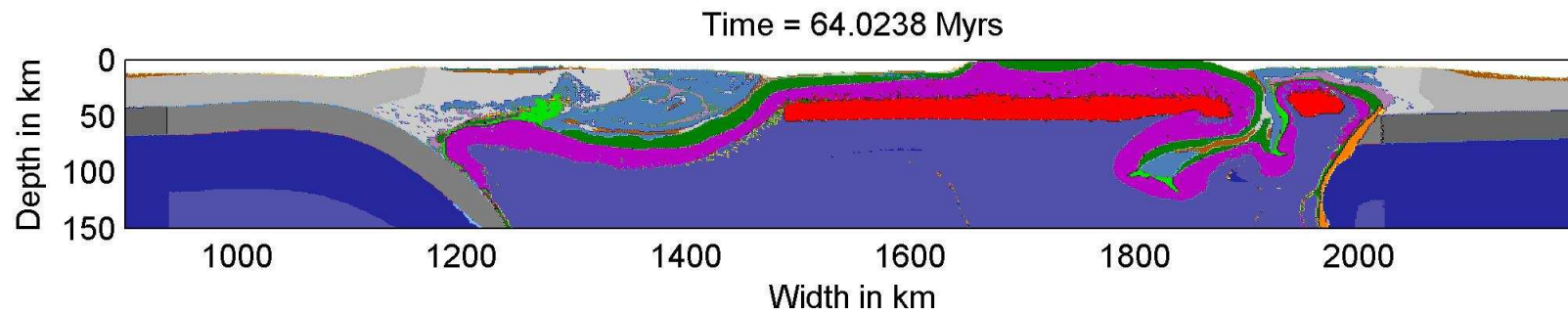
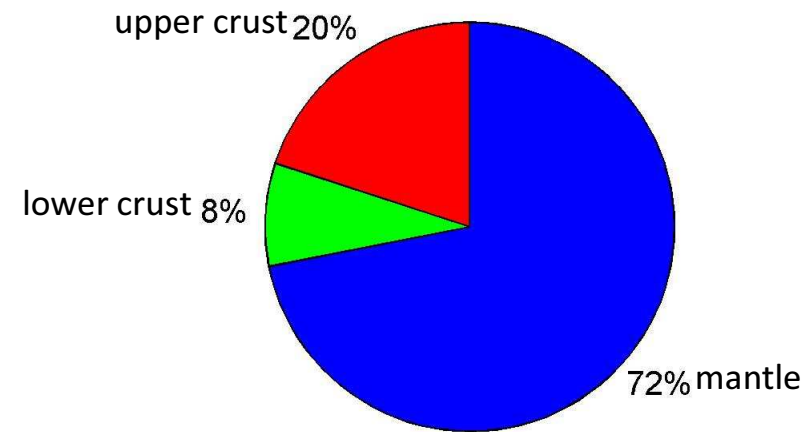
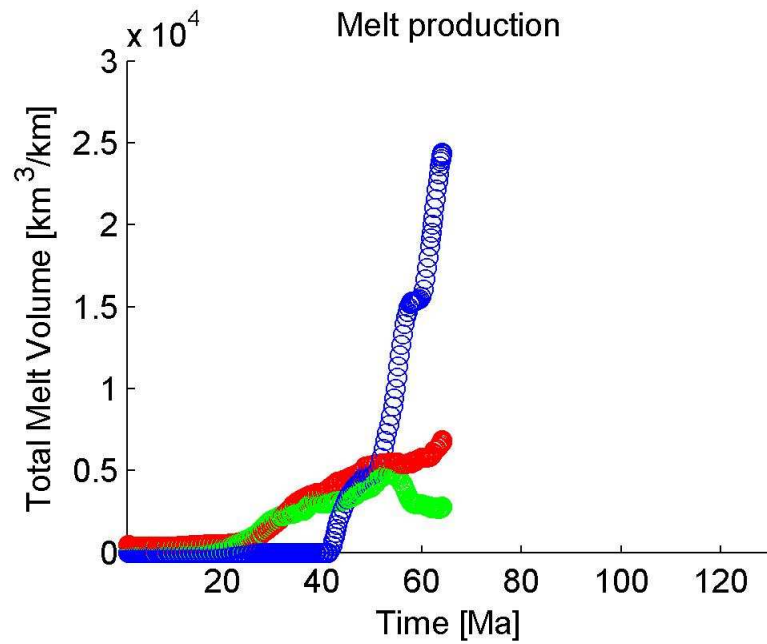
Numerical modelling: DIFFERENT INITIAL SETTING



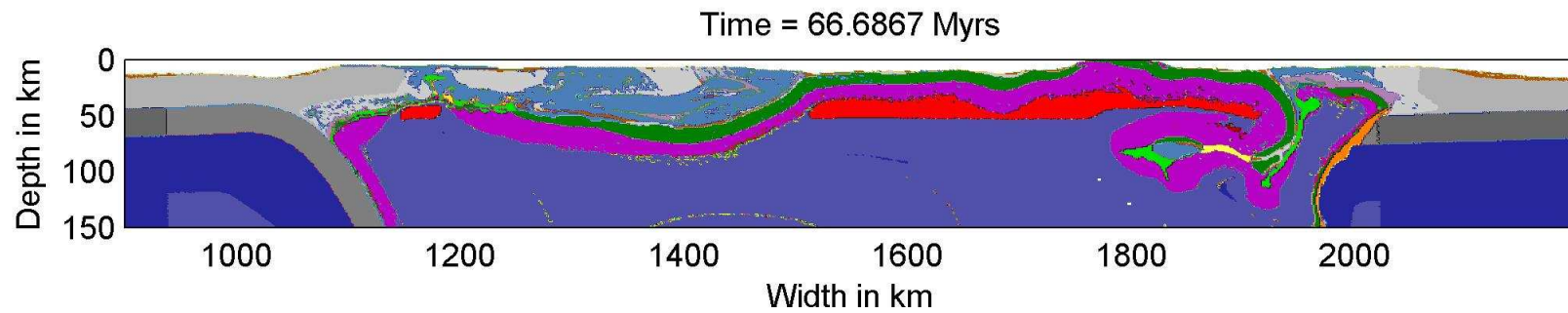
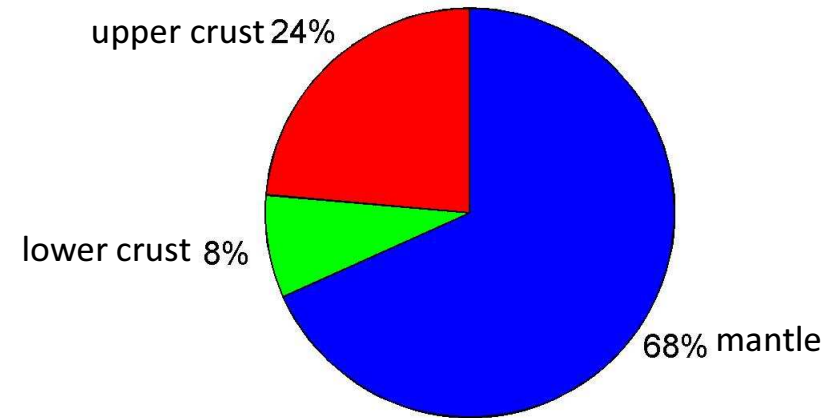
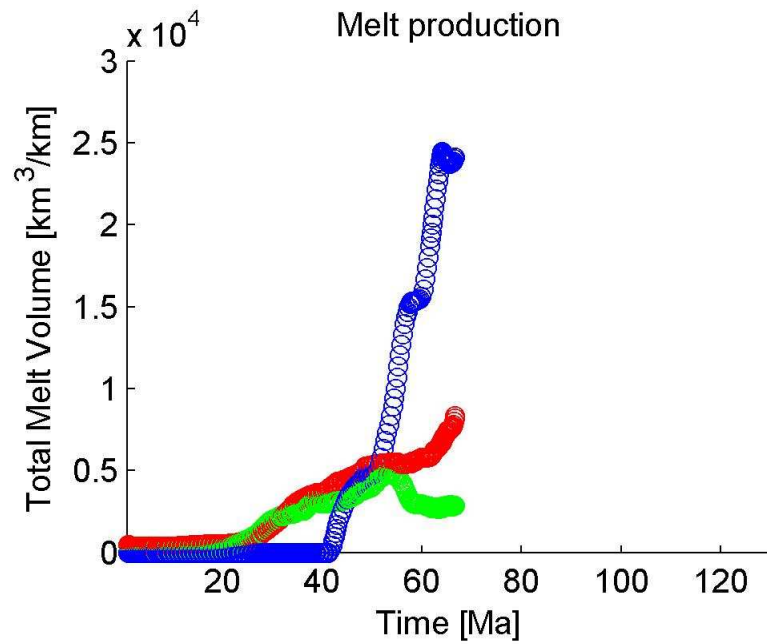
Numerical modelling: DIFFERENT INITIAL SETTING



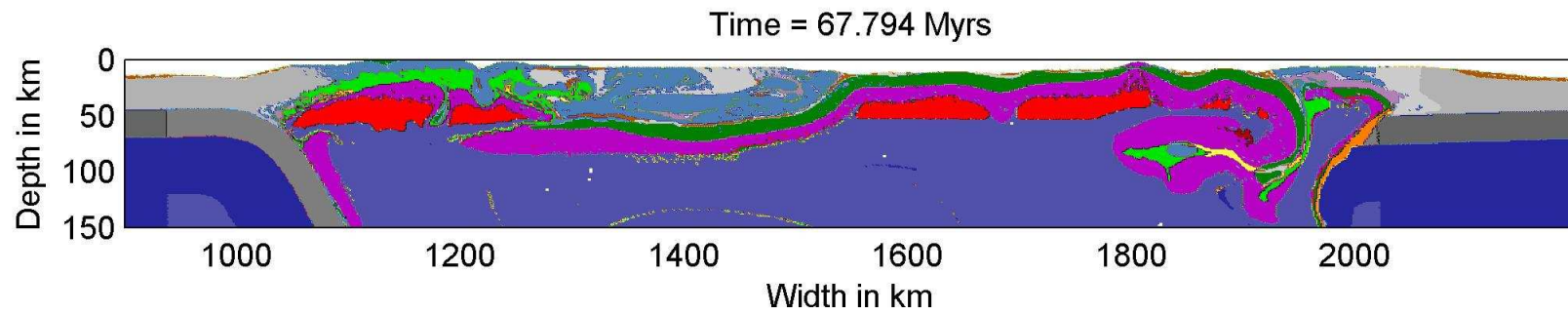
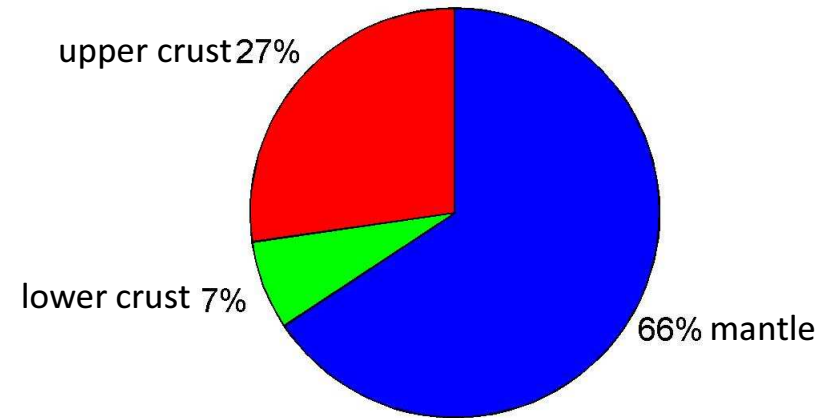
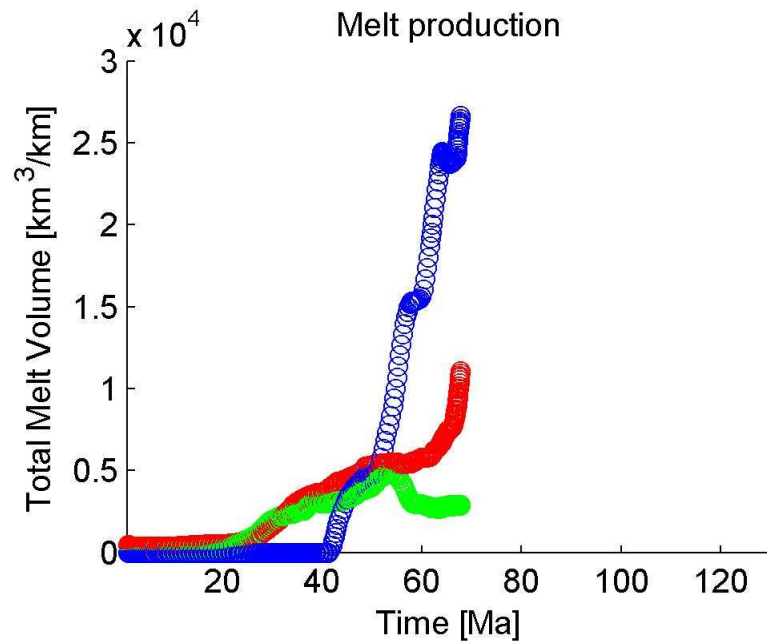
Numerical modelling: DIFFERENT INITIAL SETTING



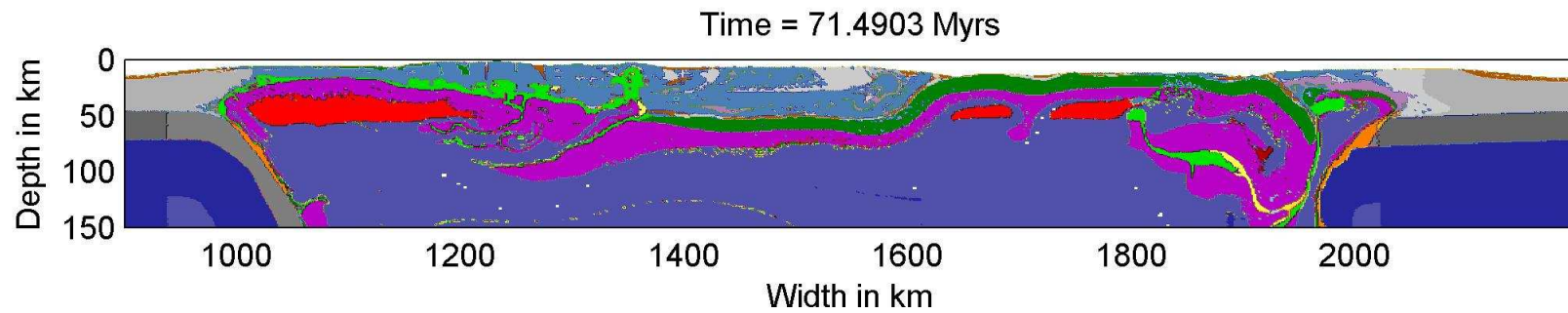
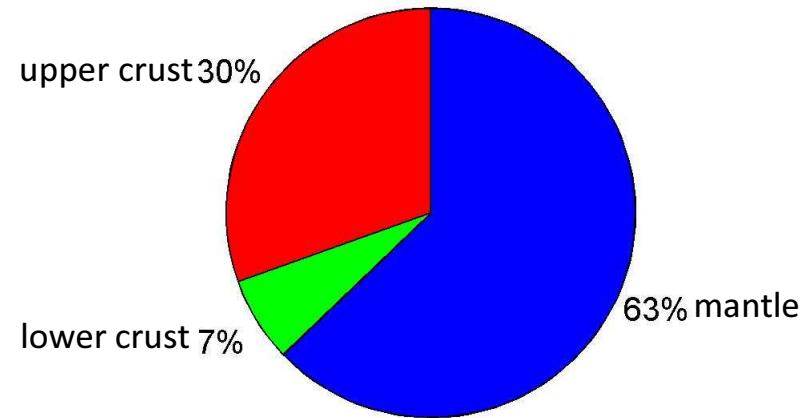
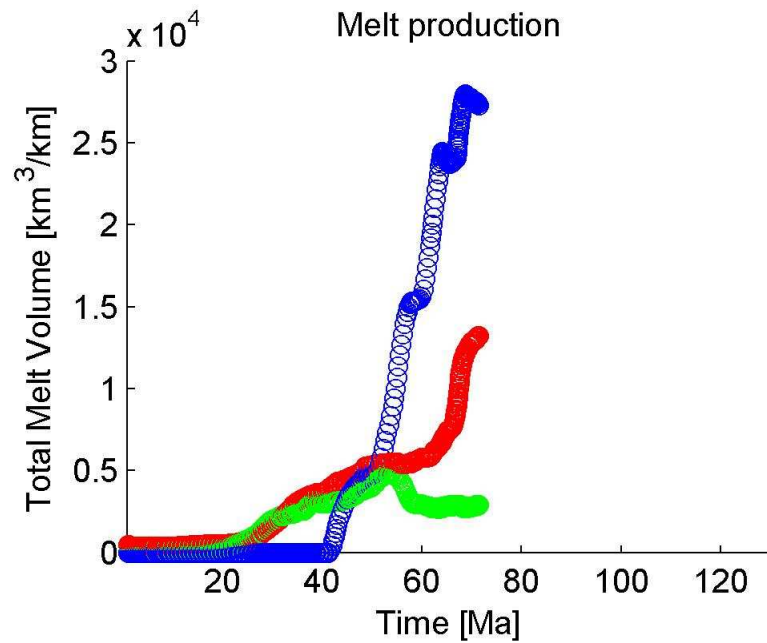
Numerical modelling: DIFFERENT INITIAL SETTING



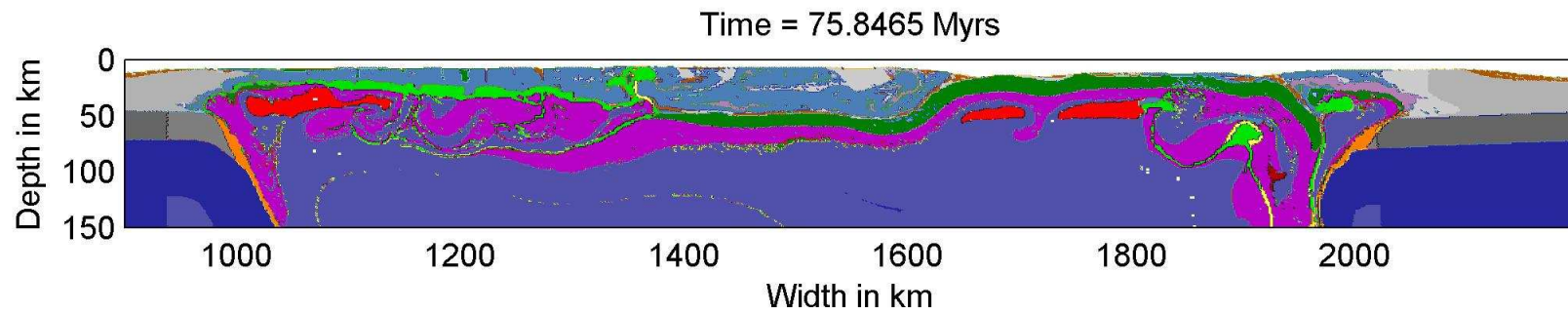
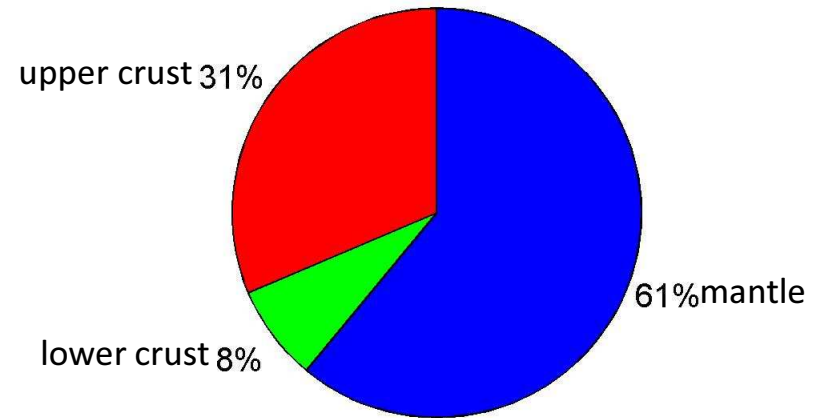
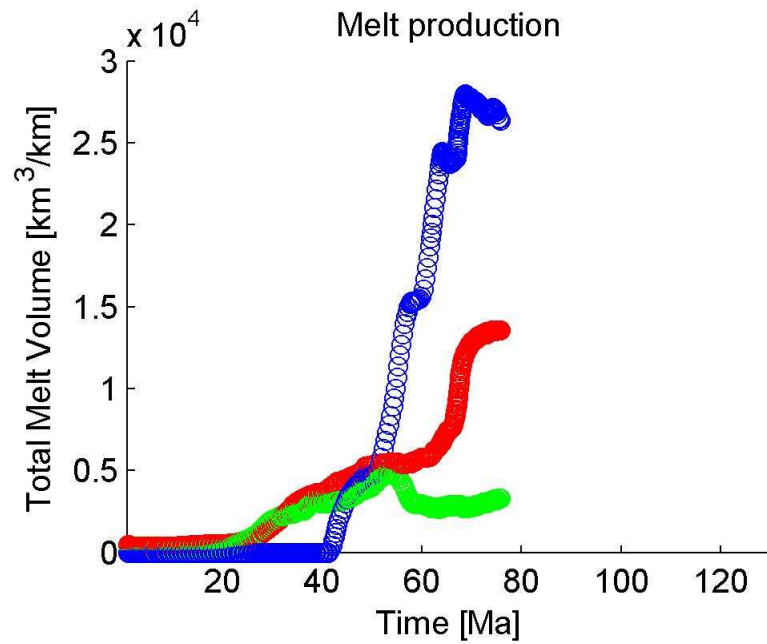
Numerical modelling: DIFFERENT INITIAL SETTING



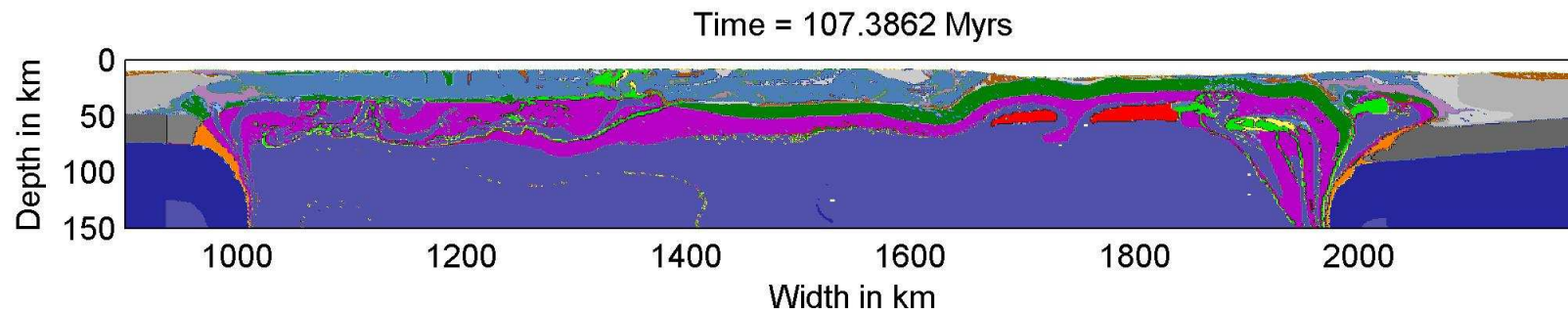
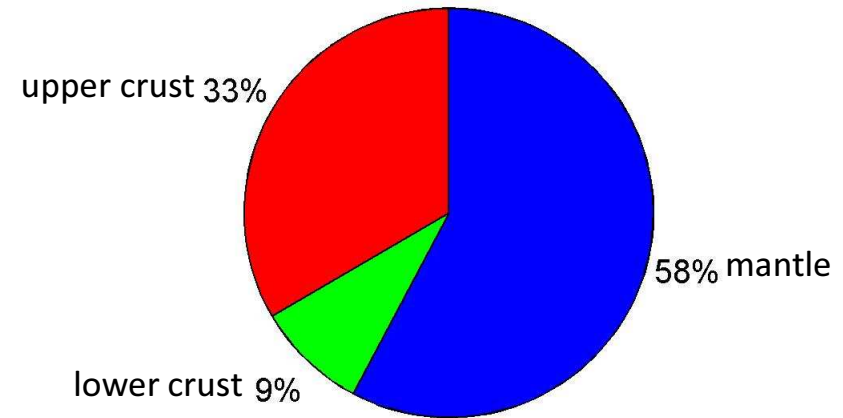
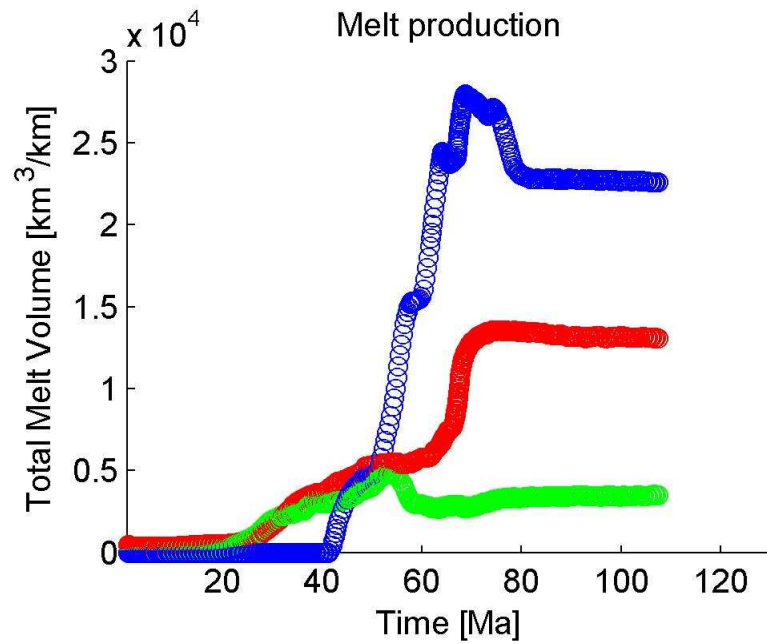
Numerical modelling: DIFFERENT INITIAL SETTING



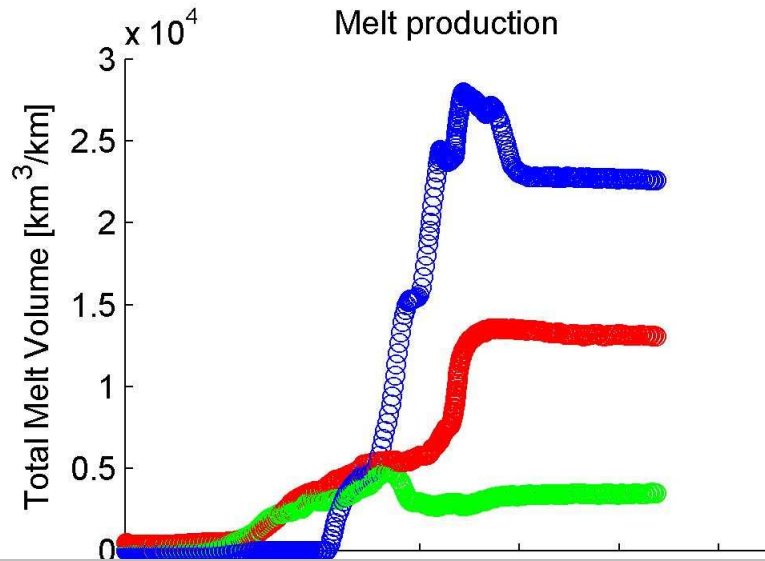
Numerical modelling: DIFFERENT INITIAL SETTING



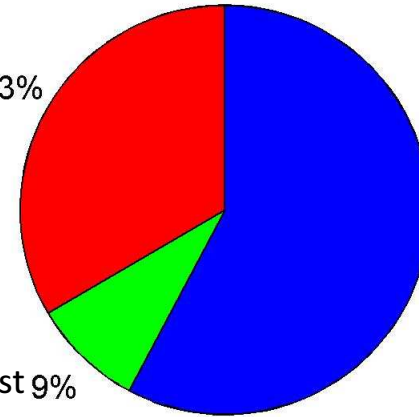
Numerical modelling: DIFFERENT INITIAL SETTING



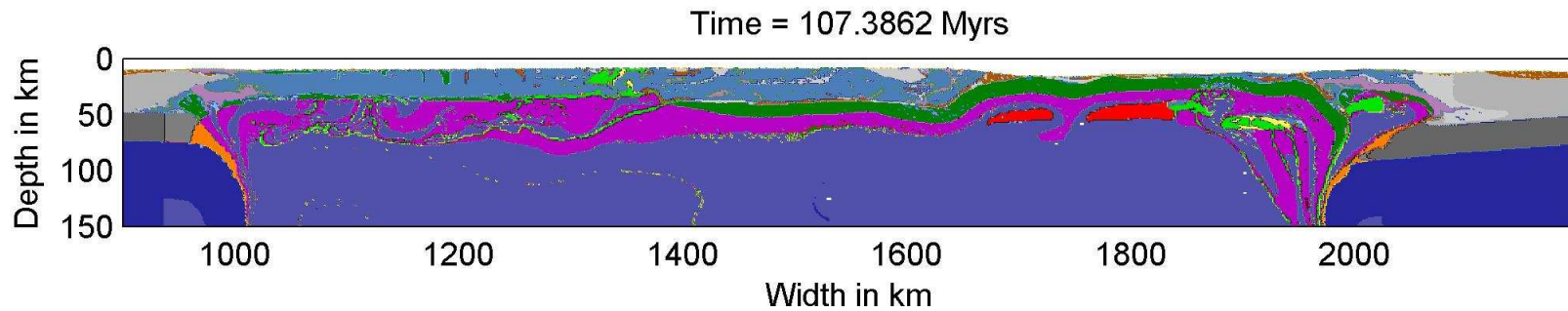
Numerical modelling: DIFFERENT INITIAL SETTING



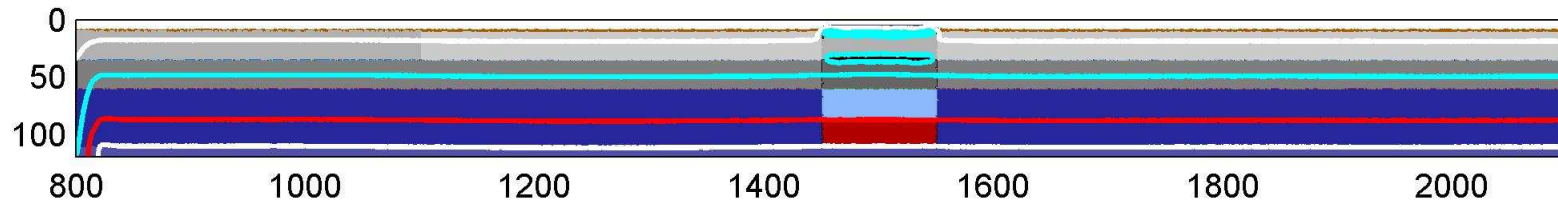
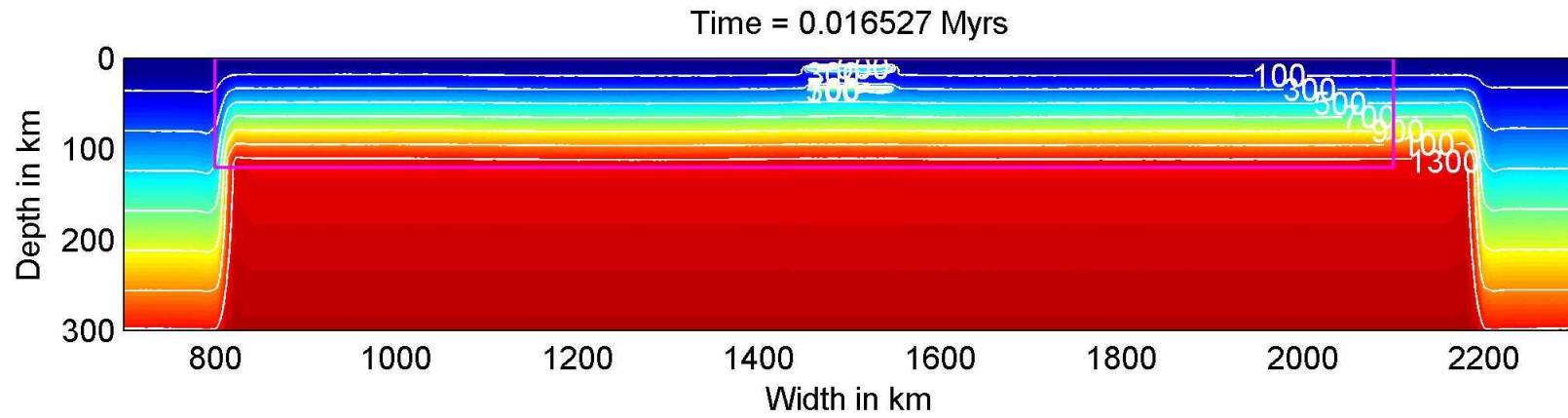
upper crust 33%



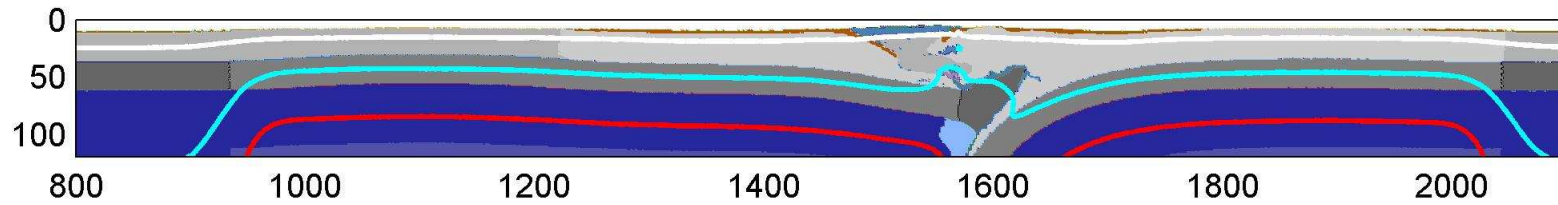
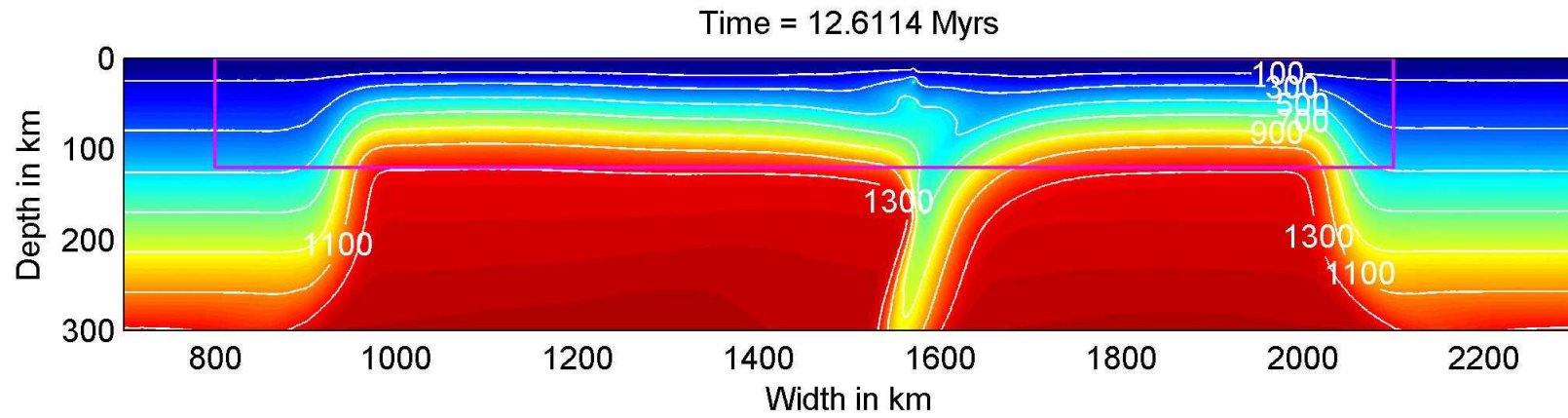
SUFFICIENT MANTLE CONTRIBUTION
but
OPENING OF THE OCEAN AT SOME STAGE



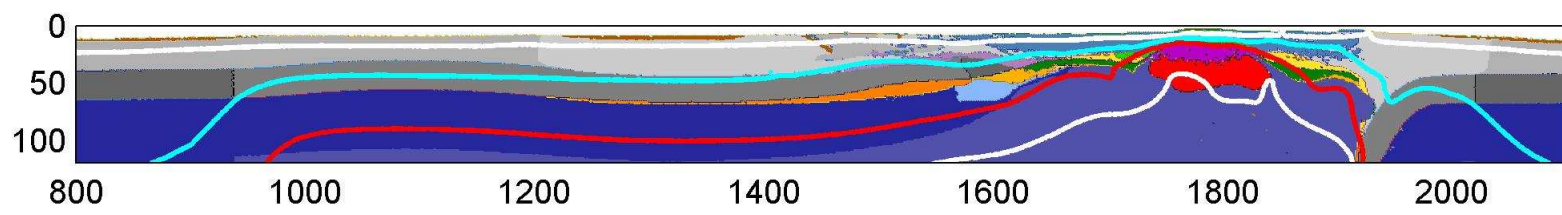
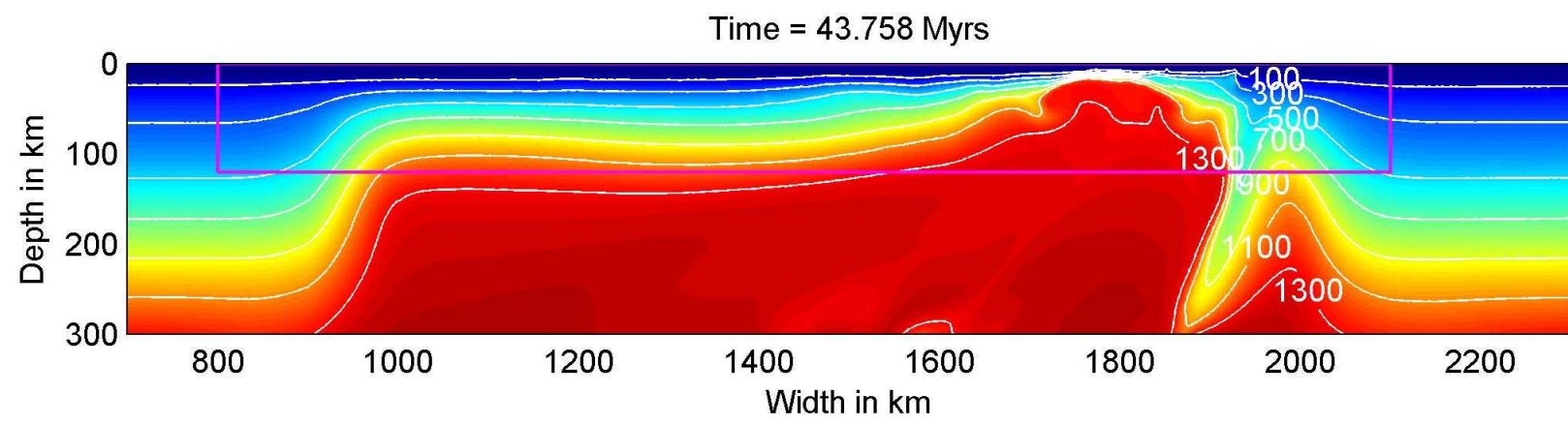
Numerical modelling: DIFFERENT INITIAL SETTING - THERMAL STUDIES



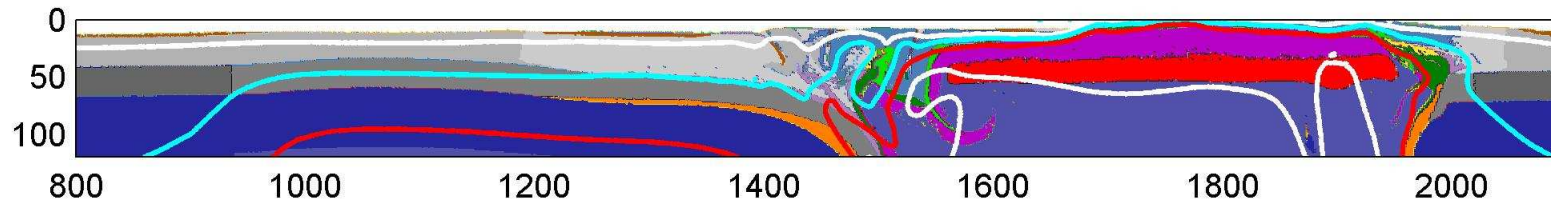
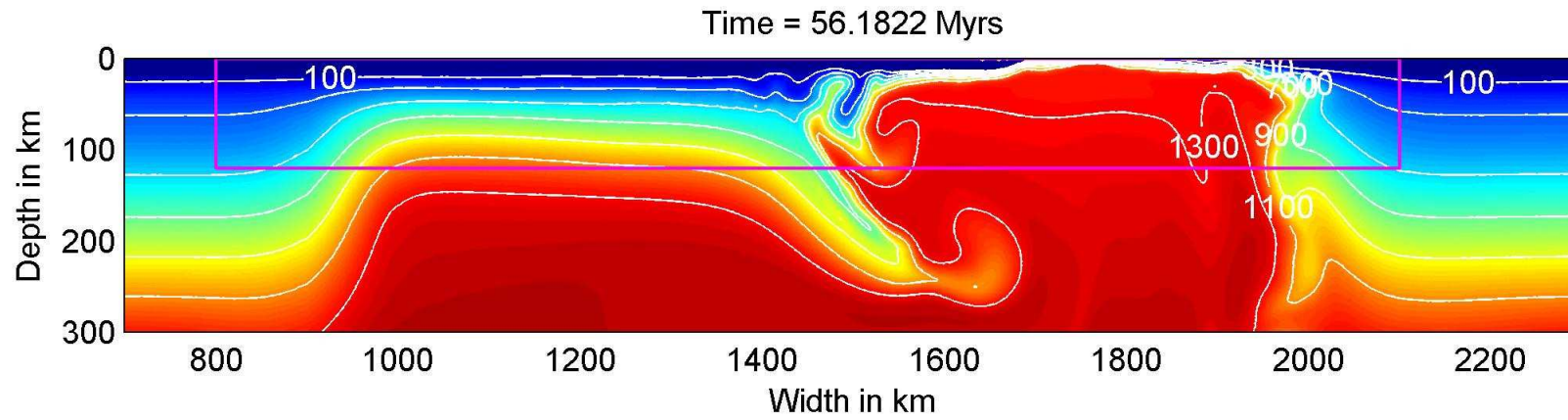
Numerical modelling: DIFFERENT INITIAL SETTING - THERMAL STUDIES



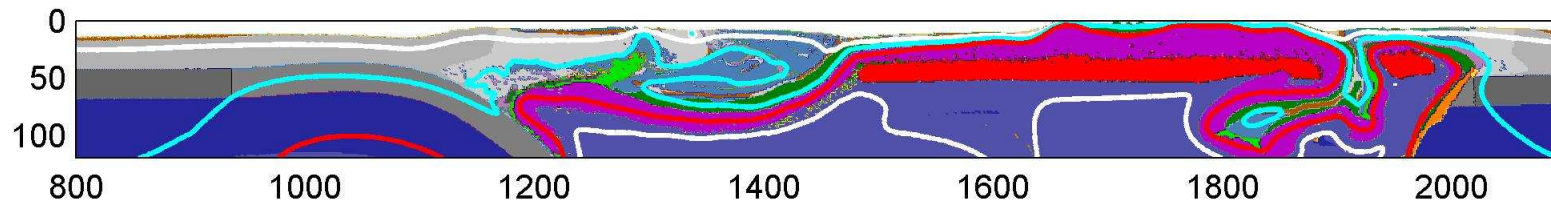
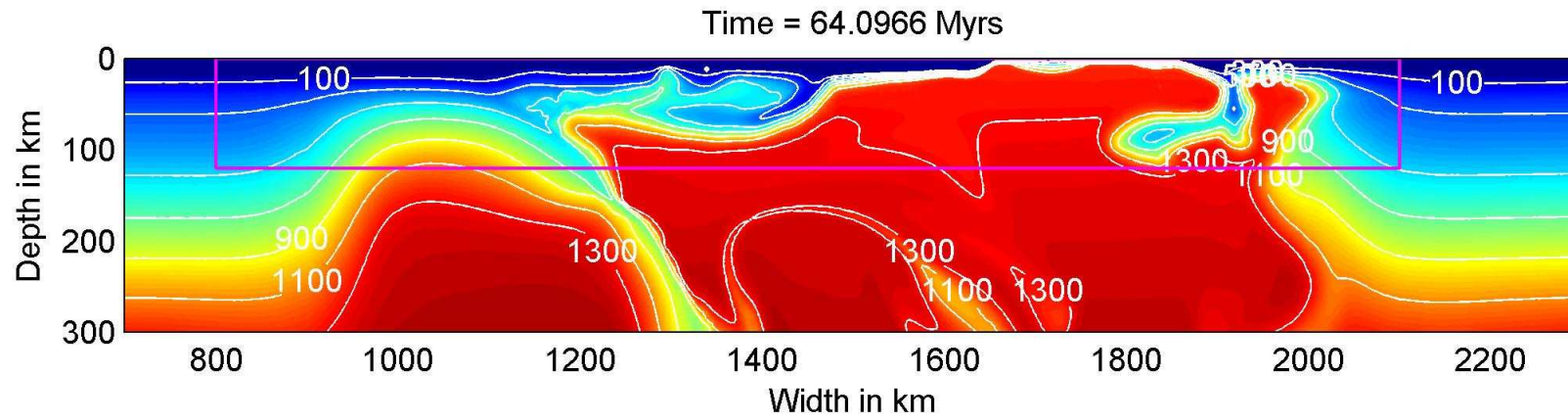
Numerical modelling: DIFFERENT INITIAL SETTING - THERMAL STUDIES



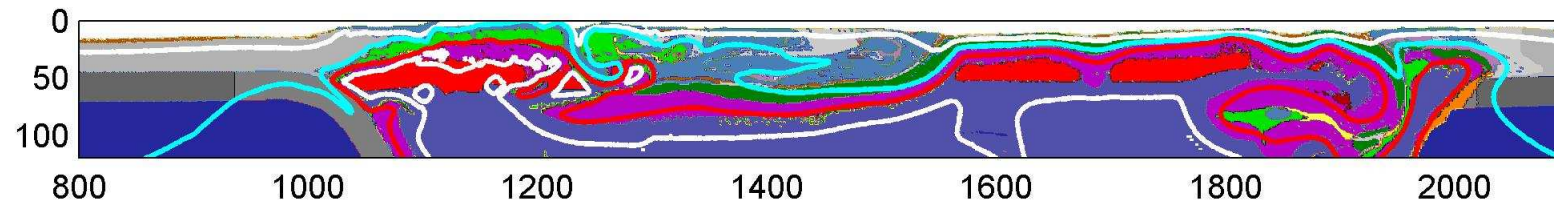
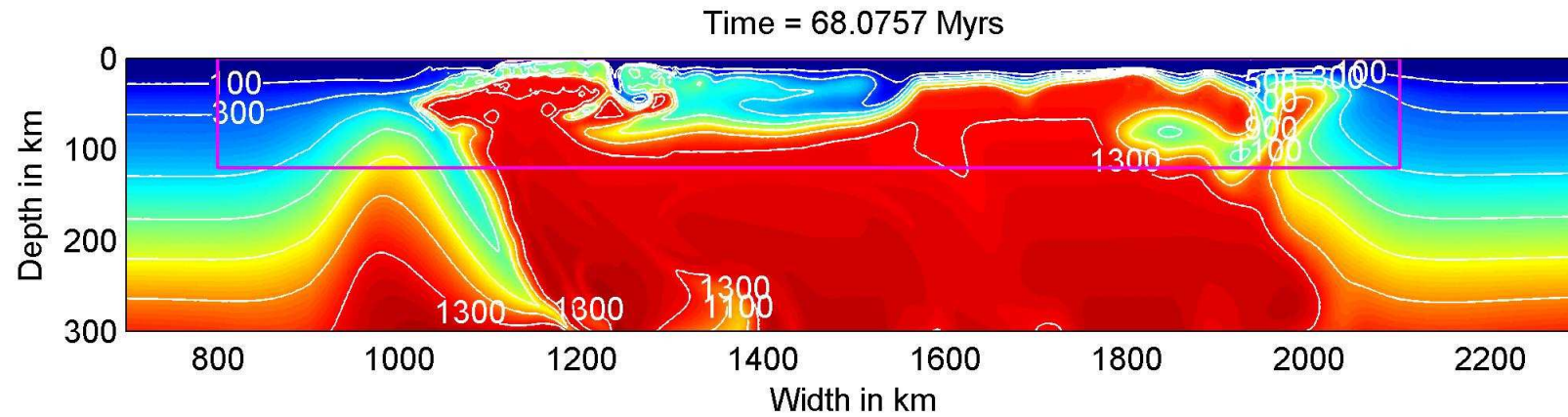
Numerical modelling: DIFFERENT INITIAL SETTING - THERMAL STUDIES



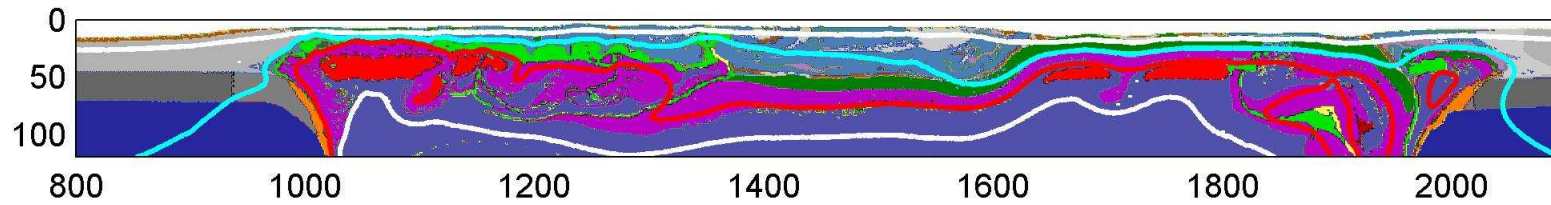
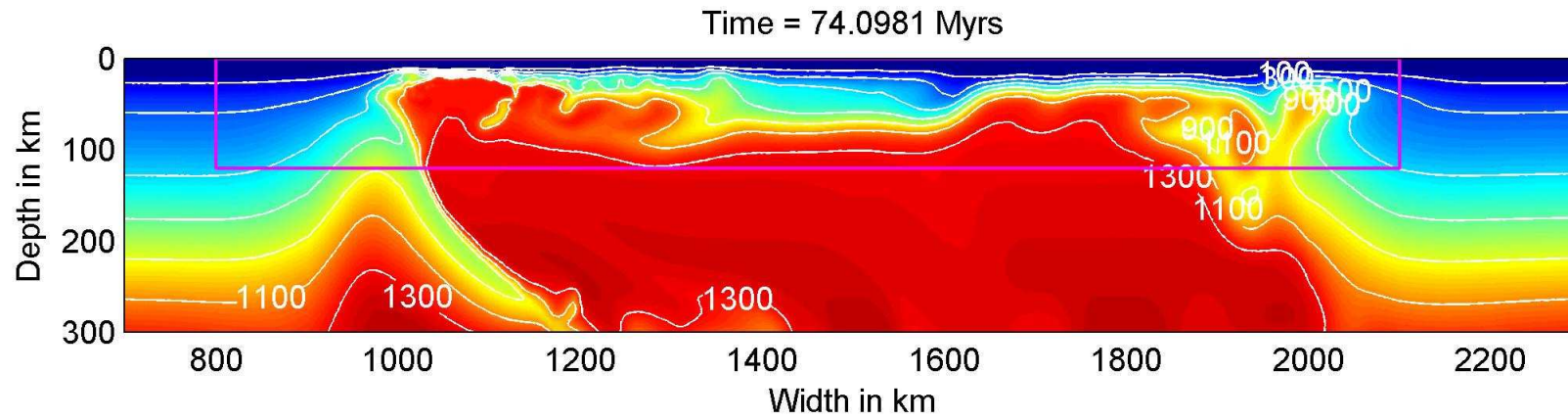
Numerical modelling: DIFFERENT INITIAL SETTING - THERMAL STUDIES



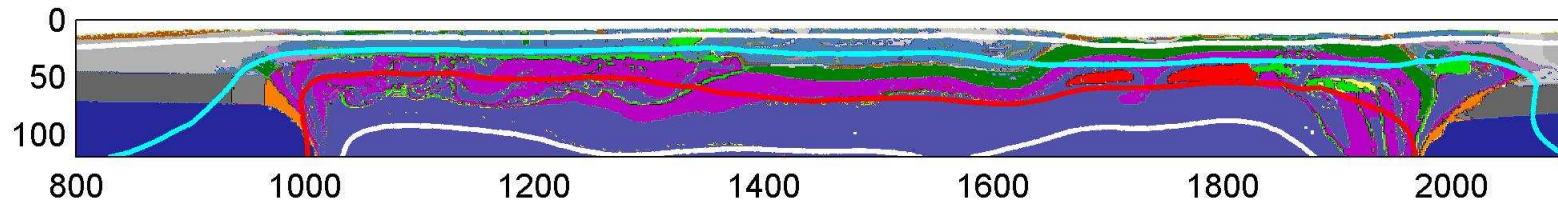
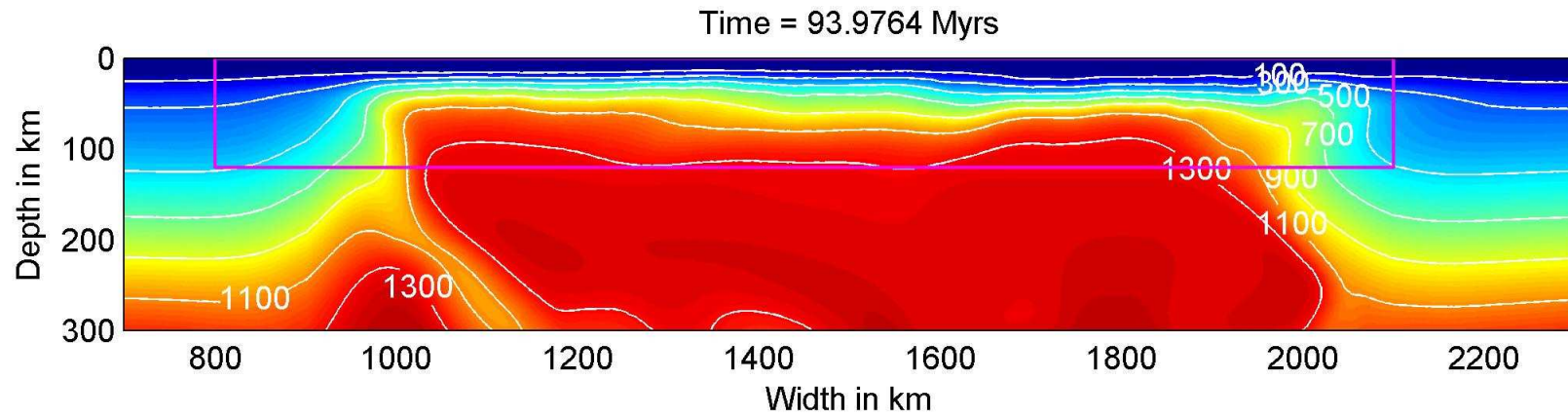
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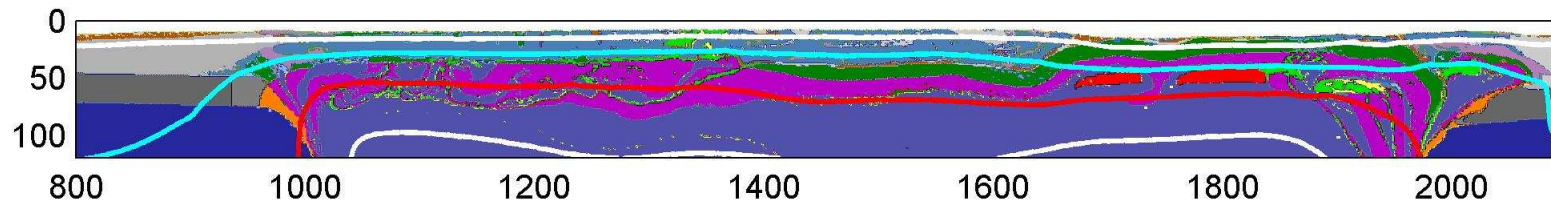
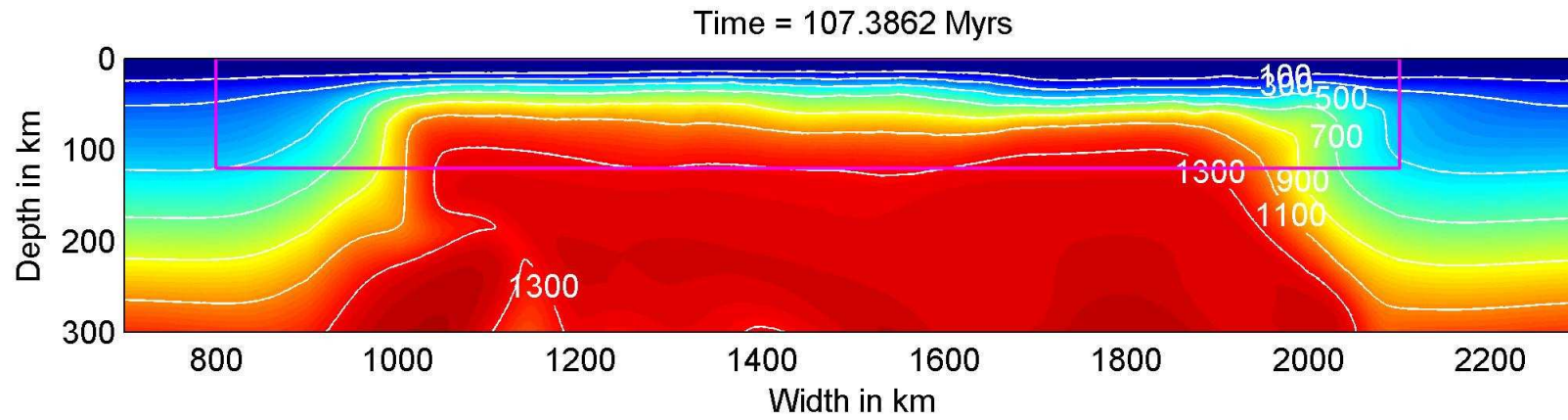
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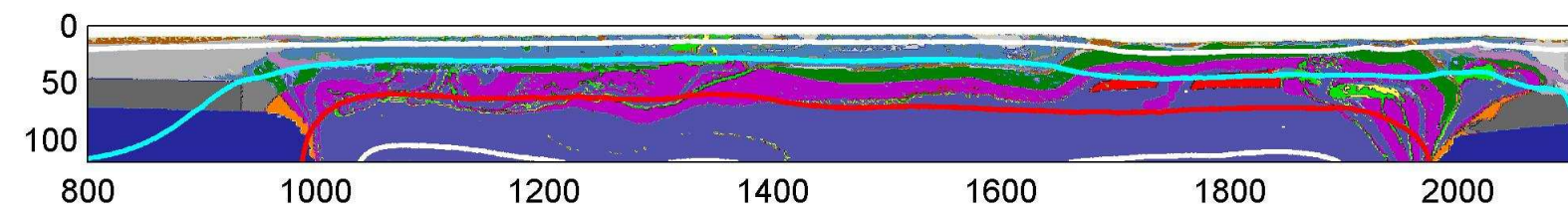
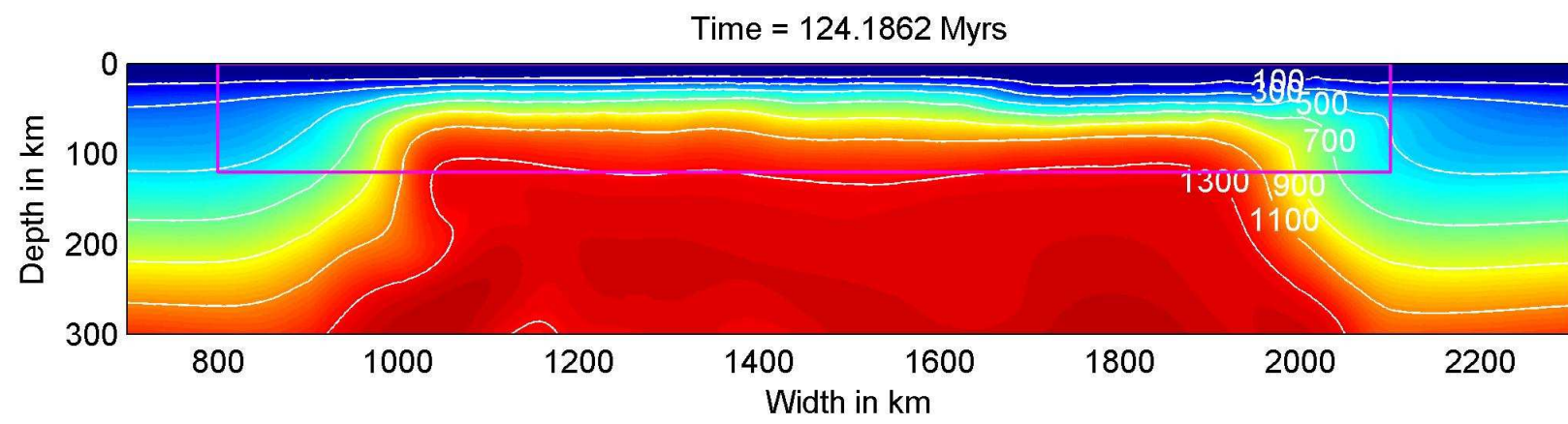
Numerical modelling: DIFFERENT INITIAL SETTING - THERMAL STUDIES

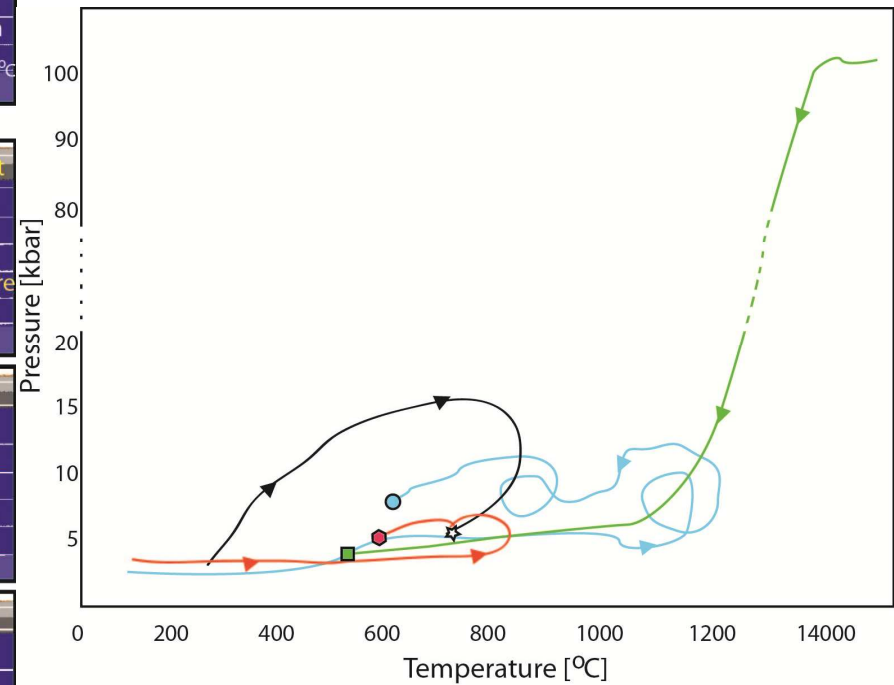
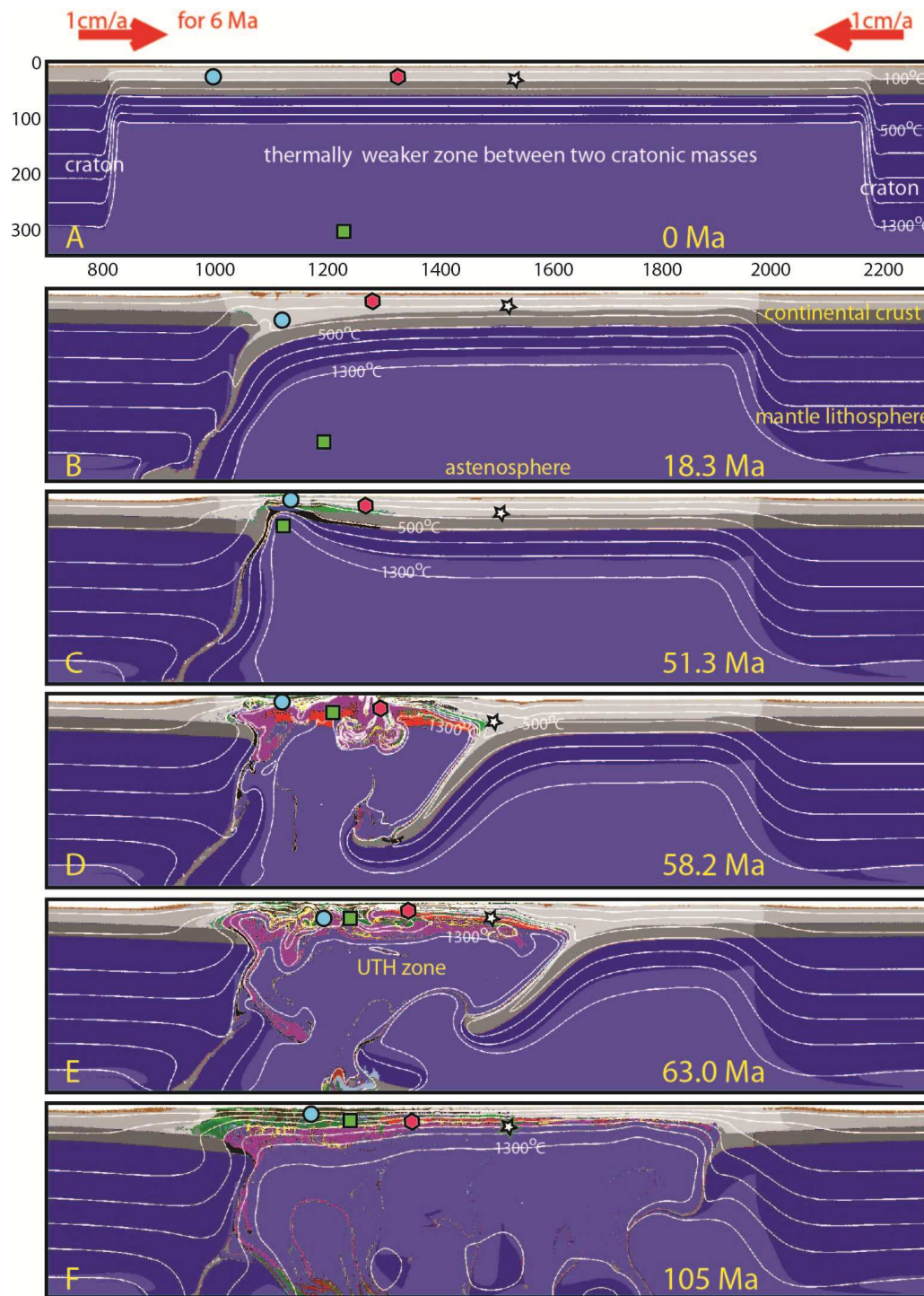


Numerical modelling: DIFFERENT INITIAL SETTING - THERMAL STUDIES



Numerical modelling: DIFFERENT INITIAL SETTING - THERMAL STUDIES





- Deeper upper mantle source
- Multiple re-melting in UTH conditions
- UHT metamorphism
- Mostly clockwise PT-paths

Maybe not YET in one single simulation

- (1) A-type granites > 1000°C ✓
- (2) ~50% mantle contribution ✓
- (3) Several remobilization events (sub-groups) ✓
- (4) 100 Ma of thin crust and extensive melting events ✓

Conclusion:

- Geometrical situation of Musgrave Province is the main trigger for UHT melting event
- Asymmetric delamination is the key to introduce UHT to the base of the Moho
- Multiple shorting events lead to prolonged melting period with refertilization events
- Multiple events best match for Musgrave Orogeny geochronology - at least 4 events
- We do not have THE PERFECT model yet ... but working on it.

